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Technische Trendanalysen (INT)**

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EUROPEAN SPACE AGENCY
CONTRACT REPORT
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Survey of Total Ionising Dose Tolerance of Power Bipolar Transistors and Silicon Carbide Devices for JUICE

TN5.6
TID Test Report (LDR / HDR) for

Power Bipolar Transistor

BUL54A

Manufacturer:
Semelab

Date code/Lot code: KF1609Y

Report no.	Version	Date	NEO no.
019/2017	1.0	2018-12-04	NEO-14-086

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Document Approval

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Version history

Table 1: Revision history

Version	Date	Changed by	Changes
1.0	2018-12-04	Steffens	Initial release
2.0	-	-	
	-	-	

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Table of contents

List of figures

List of tables

1 Introduction

1.1 Scope

The Fraunhofer Institute for Technological Trend Analysis (INT) carried out a series of Co-60 irradiations on Power Bipolar Transistor BUL54A from Semelab for the ESA project "Survey of Total Ionizing Dose Tolerance of Power Bipolar Transistors and Silicon Carbide Devices for JUICE" (ESA-TOPSIDE, AO/1-8148/14/NL/SFe) under contract number 4000113976/15/NL/RA.

Two sets of components were tested at distinct dose rates, one within the standard rate Window 1 of ESCC 22900 [3], labelled "HDR-Test" in this report, and one at or below the low rate Window 2 of ESCC 22900, labelled "LDR-Test".

This reports documents the preparation, execution and the results of these tests.

1.2 Applicable Documents

[AD1] ITT/AO/1-8148/14/NL/SFe "Statement of work: Survey of Total Ionizing Dose Tolerance of Power Bipolar Transistors and Silicon Carbide Devices for JUICE"

[AD2] Proposal for ITT/AO/1-8148/14/NL/SFe, Fraunhofer INT

1.3 Reference Documents

[1] Website of Fraunhofer INT: http://www.int.fraunhofer.de

[2] Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, B.N. Taylor and C.E. Kuyatt, NIST Technical Note 1297, 1994, http://www.nist.gov/pml/pubs/tn1297/index.cfm.

[3] ESCC Basic Specification No. 22900, issue 5, June 2016

[4] Datasheet of Power Bipolar Transistor BUL54A, "Advanced distributed base design High voltage high speed NPN Silicon power transistor", Semelab, Prelim. 3/95

[5] TN2.6 "TID Test Plan BUL54A (HDR+LDR)", Issue 1 Revision 2, 2016-08-09

[6] MIL-STD-883K w/CHANGE 2, Method 1019.9, "Ionizing Radiation (Total Dose) Test Procedure", 2017

2 Summary

Table 2: Summary

Test Report Number	019/2017
Project (INT)	NEO-14-086
Customer	European Space Agency (ESA), contract number 4000113976/15/NL/RA
Contact	Project Coordinator: Stefan Höffgen (INT) ESA Technical Project Officer: Marc Poizat (ESA/ESTEC)
ESA project / contract number	AO/1-8148/14/NL/SFe 4000113976/15/NL/RA
Device under test	BUL54A
Family	Power Bipolar Transistor
Technology	NPN Silicon bipolar transistor
Package	TO220
Date code / Wafer lot	KF1609Y
SN	Low dose rate (LDR-Test): Biased (5x): # 2, 3, 4, 5, 6 Unbiased (5x): # 7, 8, 9, 10, 11 Reference (1x): # 1 High dose rate (HDR-Test): Biased (5x): # 14, 15, 16, 17, 18 Unbiased (5x): # 19, 20, 21, 22, 23 Reference (1x): # 13
Manufacturer	Semelab
Irradiation test house	Fraunhofer INT
Radiation source	Co-60
Irradiation facility	LDR: TK100, HDR: TK1000A
Generic specification	ESCC 22900 Iss. 5
Detail specification	ESCC 22900 Iss. 5
Test plan	TN2.6 "TID Test Plan BUL54A (HDR+LDR)", Issue 1 Revision 2, 2016-08-09
Max. test level	200 krad(Si)
Dose steps	LDR: Multiple: 9, 18, 30, 50, 97, 151, 201 krad(Si) HDR: Multiple: 10, 20, 30, 50, 100, 150, 200 krad(Si)
Dose rate	LDR: Start @ 35.4 rad(Si)/h – Stop @ 33.1 rad(Si)/h HDR: 10.9 krad(Si)/h

Start of irradiation	LDR: 2016-08-25 14:04, HDR: 2017-08-01 05:16
Stop of irradiation	LDR: 2017-05-02 14:23 HDR: 2017-08-02 11:30
Non-Homogeneity in DUT	LDR: < 2% HDR: 5.3%
Annealing	24h @RT, 168h @ 100°C
Electrical measurements/ Parameters tested	$V_{(Sus)CEO}$, $V_{(BR)CBO}$, $V_{(BR)EBO}$, I_{CBO}, I_{CEO}, I_{EBO}, $V_{CE(sat)}1$, $V_{CE(sat)}2$, $V_{CE(sat)}3$, $V_{BE(sat)}1$, $V_{BE(sat)}2$, h_{FE1}, h_{FE2}, h_{FE3}

2.1 Comments

- During the conduction of the test campaigns, several deviations from the requirements of ESCC 22900 occurred:
  - LDR test: at the transition from the 151 krad(Si) to 200 krad(Si) step, the time gap between stop of irradiation and the start of the next step was 18 minutes longer than allowed and at the transition from the 9 krad(Si) to 18 krad(Si) step even 47 minutes longer than allowed.
  - HDR test: at two steps, the time gap between stop of irradiation and the start of the next step was 1-3 minutes longer than allowed by the standard.
- .LDR test:
  - Other tests, e.g. the other bipolar power transistors of the project, were performed simultaneously to the LDR tests at the same facility TK100. Several breaks of the irradiation were necessary to conduct these tests. For the BUL54A these interruptions were approx. 11 minutes on average and max. 2h (due to maintenance).
  - The dose steps in the HDR test were within timing accuracies at the scheduled total dose levels. To avoid tests on weekends or during the night, the total dose levels in the LDR tests are different than the scheduled levels but deviate less than 10%.
- Comparison with respect to ELDRS:
  - A comparison of the tests at high and low dose rate show significant difference for several parameters.
  - Calculation of the enhancement factor showed pronounced effects for parameters $V_{(BR)CBO}$, $V_{CE(sat)}1$, $V_{CE(sat)}2$, $V_{CE(sat)}3$, h_{FE1}, and h_{FE2}..
  - We thus see that the part is susceptible to ELDRS.

2.2 Overview of results

Figure 1: LDR: Overview of results

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
V_sus_CEO	On										
	Off										
I(V_sus_CEO)	On										
	Off										
I_CEO	On										
	Off										
V_br_CBO	On						3	5	4	4	
	Off							2	3		1
I(V_br_CBO)	On							3		1	
	Off										
I_CBO	On			1	2	3	4	5	5	5	
	Off						5	5	5	5	
V_br_EBO	On										
	Off										
I(V_br_EBO)	On										
	Off										
I_EBO	On										
	Off										
V_CEsat 1	On						5	5	5	5	1
	Off					1	5	5	5	5	
V_CEsat2	On			3	5	5	5	5	5	5	5
	Off			5	5	5	5	5	5	5	5
V_CEsat3	On		5	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
V_BEsat1	On										
	Off										
V_BEsat2	On										
	Off										
HFE1	On					2	5	5	5	5	
	Off					2	5	5	5	5	
HFE2	On				4	5	5	5	5	5	5
	Off				3	5	5	5	5	5	5
HFE3	On										
	Off										

Figure 2: HDR: Overview of results

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	10	20	30	50	100	150	200	24h @RT	168h @100°C
V_sus_CEO	On										
	Off										
I(V_sus_CEO)	On										
	Off										
I_CEO	On										
	Off										
V_br_CBO	On										
	Off										
I(V_br_CBO)	On										
	Off										
I_CBO	On		1			2	5	5	5	5	
	Off						1	5	5	5	
V_br_EBO	On										
	Off										
I(V_br_EBO)	On										
	Off										
I_EBO	On										
	Off										
V_CEsat 1	On										
	Off										
V_CEsat2	On						5	5	5	5	5
	Off					2	5	5	5	5	5
V_CEsat3	On		1	4	5	5	5	5	5	5	5
	Off		4	4	5	5	5	5	5	5	5
V_BEsat1	On										
	Off										
V_BEsat2	On										
	Off										
HFE1	On							1	2	3	
	Off							1	2	3	
HFE2	On						3	5	5	5	
	Off						4	5	5	5	1
HFE3	On										
	Off										

3 Sample preparations

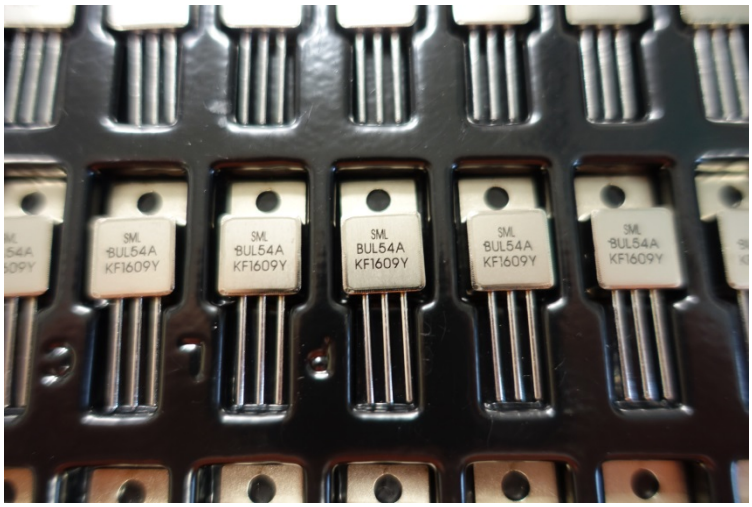
3.1 Sample shipment

A total of 30 Samples were procured by INT at a commercial supplier (Protec) for the conduction of these tests for ESA.

Table 3: Sample shipment

Samples ordered	Samples received	Samples sent back
December 2015	May 2016	still at INT

Figure 3: The ESD package with the samples



3.2 Sample identification/ marking

The samples were soldered to adapter pins, to ease the mounting to the board, exchanging, plugging and storage of the samples.

Figure 4: Sample marking. Top image: LDR-Test, bottom image: HDR-Test.

The samples were colour marked to differentiate the samples between each other and to separate the samples of the different campaigns or types.

3.3 Sample safekeeping

The samples were stored in an Electro-Static Discharge (ESD) box (Figure 4) to handle them safely during the test, the interim storage after the last measurement and the final shipment.

Table 4: Sample marking

Test	Condition	Label	S/N	Color Code
Low dose rate	Control sample	REF#1	1	
	Biased	ON#1	2	
		ON#2	3	
		ON#3	4	
		ON#4	5	
		ON#5	6	
	Unbiased	OFF#1	7	
		OFF#2	8	
		OFF#3	9	
		OFF#4	10	
		OFF#5	11	
High dose rate	Control sample	REF#1	13	
	Biased	ON#1	14	
		ON#2	15	
		ON#3	16	
		ON#4	17	
		ON#5	18	
	Unbiased	OFF#1	19	
		OFF#2	20	
		OFF#3	21	
		OFF#4	22	
		OFF#5	23	

4 Irradiation conditions

4.1 Irradiation steps

Table 5: LDR: Irradiation steps

	Step [krad(Si)]	Total [krad (Si)]	Startrate [krad(Si)/ h]	Start Irr.	Breaks [h:m:s]	Stop Irr.	Duration [d:h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0		-		-	--	24.08.2016 15:10	24.08.2016 17:36	2:26
1	9.29	9.17	0.0354	25.08.2016 14:04	00:22:24	05.09.2016 10:07	10d 20:03:44	05.09.2016 11:27	05.09.2016 12:47	1:20
2	9.12	18.3	0.0353	05.09.2016 12:54	00:24:33	16.09.2016 08:54	10d 20:00:28	16.09.2016 09:07	16.09.2016 10:31	1:24
3	11.81	30.03	0.0351	16.09.2016 10:40	00:22:39	30.09.2016 09:59	13d 23:19:17	30.09.2016 10:14	30.09.2016 11:21	1:07
4	20.78	50.03	0.0349	30.09.2016 11:51	03:05:14	25.10.2016 13:18	25d 01:27:15	25.10.2016 13:25	25.10.2016 14:53	1:28
5	46.59	96.8	0.0346	25.10.2016 14:59	02:59:14	21.12.2016 14:47	56d 23:47:27	21.12.2016 15:02	21.12.2016 16:17	1:15
6	55.18	151.17	0.0339	21.12.2016 16:30	05:37:40	27.02.2017 12:42	67d 20:11:37	27.02.2017 13:18	27.02.2017 14:49	1:31
7	49.42	201.37	0.0331	27.02.2017 15:00	01:13:41	02.05.2017 14:23	63d 23:23:43	02.05.2017 14:44	02.05.2017 15:29	0:45
8	24 h @ RT			02.05.2017 15:38		03.05.2017 15:38	1d 00:00:00	03.05.2017 15:45	03.05.2017 16:27	0:42
9	168 h @100°C			03.05.2017 16:27		10.05.2017 16:27	7d 00:00:00	10.05.2017 16:47	10.05.2017 17:22	0:35

Other tests, e.g. the other bipolar power transistors of the project, were performed simulateously to the LDR tests at the same facility TK100. Several breaks of the irradiation were necessary to conduct these tests. For the BUL54A these interruptions were approx. 11 minutes on average and max. 2h.

The dose steps in the HDR test were within timing accuracies at the scheduled total dose levels. To avoid tests on weekends or during the night, the total dose levels of the LDR tests are different than the scheduled levels but deviate less than 10%.

During the conduction of the test campaigns, several deviations from the requirements of ESCC 22900 occurred:

- LDR test: at the transition from the 151 krad(Si) to 200 krad(Si) step, the time gap between stop of irradiation and the start of the next step was 18 minutes longer than allowed and at the transition from the 9 krad(Si) to 18 krad(Si) step even 47 minutes longer than allowed.
- HDR test: at two steps, the time gap between stop of irradiation and the start of the next step was 1-3 minutes longer than allowed by the standard.

Table 6: HDR irradiatison steps

#	Step [krad(Si)]	Total [krad (Si)]	Startrate [krad(Si)/h]	Start Irr.	Stop Irr.	Duration [h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0					31.07.2017 16:09	31.07.2017 17:12	1:03
1	10.00	10	10.9	01.08.2017 05:15	01.08.2017 06:10	0d 00:55:06	01.08.2017 06:23	01.08.2017 07:32	1:09
2	10.00	20	10.9	01.08.2017 08:07	01.08.2017 09:03	0d 00:55:05	01.08.2017 09:25	01.08.2017 10:49	1:24
3	10.00	30	10.9	01.08.2017 11:04	01.08.2017 11:59	0d 00:55:05	01.08.2017 12:14	01.08.2017 13:17	1:03
4	20.00	50	10.9	01.08.2017 13:58	01.08.2017 15:48	0d 01:50:08	01.08.2017 15:58	01.08.2017 16:45	0:47
5	50.00	100	10.9	01.08.2017 17:51	01.08.2017 22:27	0d 04:35:18	01.08.2017 22:32	01.08.2017 23:18	0:46
6	50.00	150	10.9	02.08.2017 00:25	02.08.2017 05:01	0d 04:35:18	02.08.2017 05:07	02.08.2017 06:04	0:57
7	50.00	200	10.9	02.08.2017 06:55	02.08.2017 11:30	0d 04:35:18	02.08.2017 12:15	02.08.2017 12:48	0:33
8	24 h @ RT			02.08.2017 12:56	03.08.2017 14:25	01d 00:01:29	03.08.2017 14:30	03.08.2017 15:10	0:40
9	168 h @100°C			03.08.2017 15:15	10.08.2017 15:15	7d 00:00:00	10.08.2017 15:26	10.08.2017 16:11	0:45

4.2 Sample holder

A custom-build printed-circuit board (Figure 5) was manufactured to

- bias the samples according to the circuit-layout of the irradiation test plan [5] (see also chapter 4.4 Bias conditions)
- fix the samples under the radiation source (see also chapter 4.3 Geometry)
- irradiate the samples homogeneously.

In the LDR tests, the printed circuit boards were fixed to a wooden frame (Figure 6) under the radiation source at a constant distance of 60 cm. Consequently, the dose rate at the DUTs reduced over time due to the Co-60 decay (Table 5).

Figure 5: Bias board

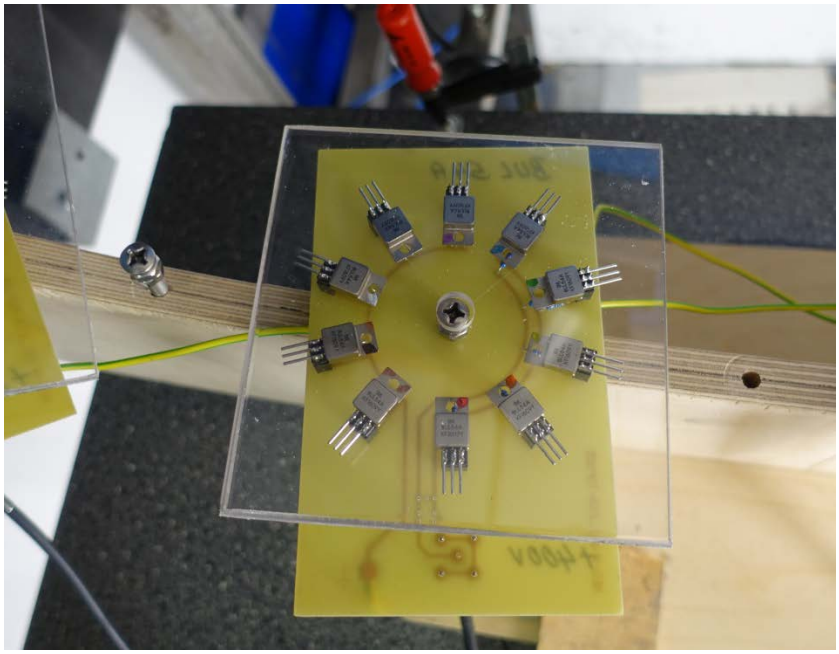


Figure 6: LDR tests: Board fixture at TK100

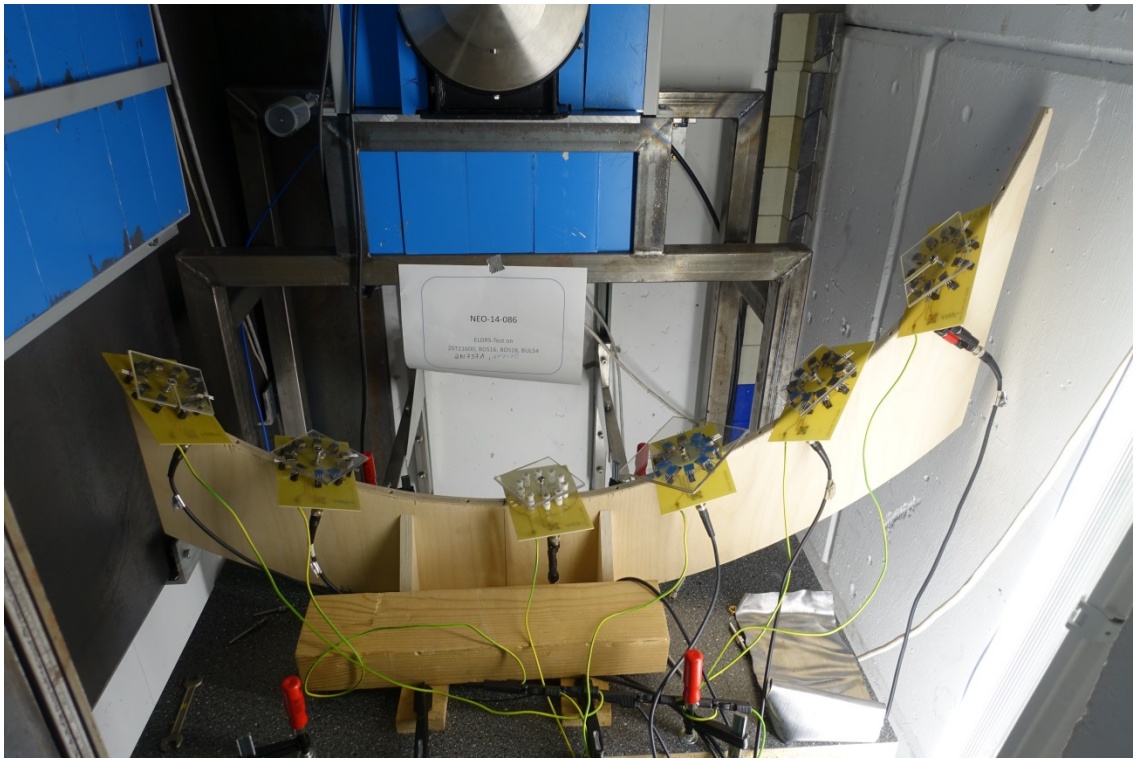
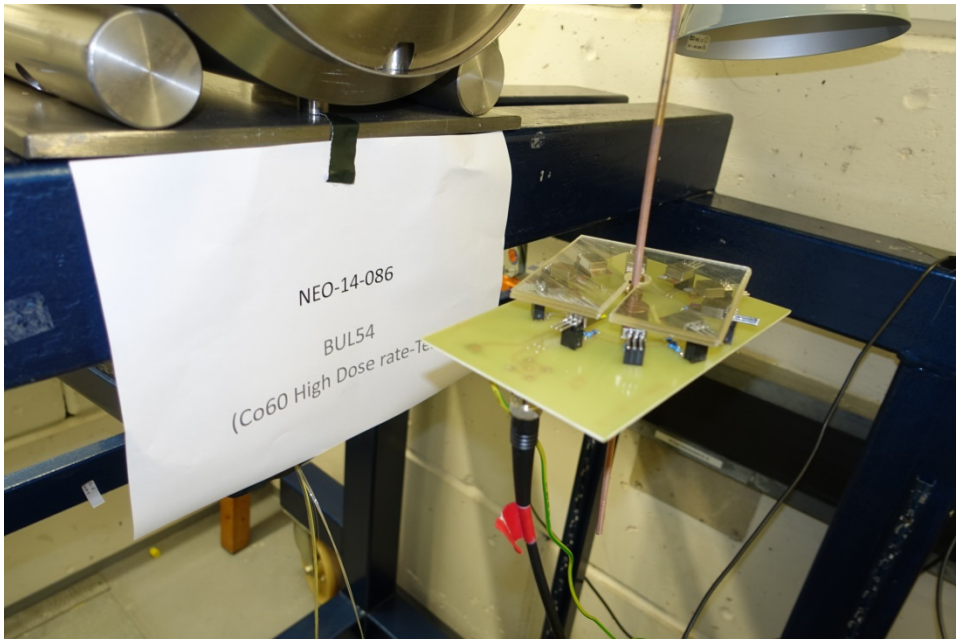


Figure 7: HDR tests: Board fixture at TK1000A



4.3 Geometry

LDR tests: The irradiation parameters correspond to a sample-distance of 60 cm from the source at TK100 (Figure 6) to the object minimum.

HDR tests: The irradiation parameters correspond to a sample-distance of 21.2 cm from the TK1000A source (Figure 7) to the object minimum.

In each test a PMMA layer of 5 mm was placed over the DUTs to achieve charge equilibrium.

4.4 Bias conditions

During the irradiation and the subsequent annealing the samples were biased or operated according to the circuit-description of the irradiation test plan [5] (see Figure 8).

A Tenelec TC952 voltage supply (no Eq.Id) was used for biasing both the low dose rate and high dose rate test.

The supply was not calibrated but the voltage was checked with a calibrated voltmeter.

During transport from the irradiation site to the electrical measurement site and back again all terminals were shorted.

Figure 8: Bias conditions

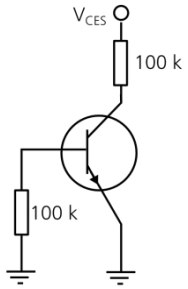
ON-Mode	OFF-Mode
 V_{CES} = 400 V (≥ 80% $V_{(BR)CEO}$)	All pins were short circuited and grounded.

Table 7: Biasing equipment

4.5 Environmental variables

All irradiation steps were done in air. The samples at TK1000A were irradiated in ambient light. The samples at TK100 were irradiated without ambient light. The parameters of the humidity and the temperature are given in the following tables and figures.

Table 8: LDR: Environmental variables during irradiation

Parameter	Value and Unit	Remarks
Humidity	30.8% ± 6.0%	Non-condensing, during irradiation and first annealing (24 h)
Temperature	25.3 °C ± 2.2 °C	During irradiation and first annealing (24 h)
Temperature	100.0 ± 3.0 °C	During second annealing and normal operation (see comments for malfunction during the HDR campaign)

Figure 9: LDR: Environment variables during irradiation. Several interrupts can be seen in the curves some of which are due to errors in the monitoring system and some due to maintenance.

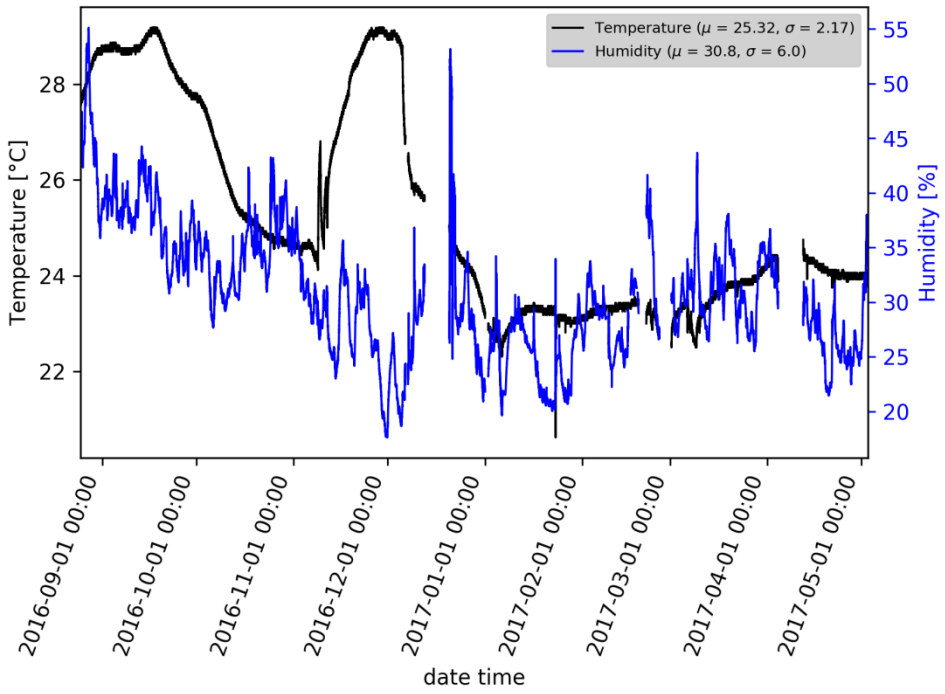
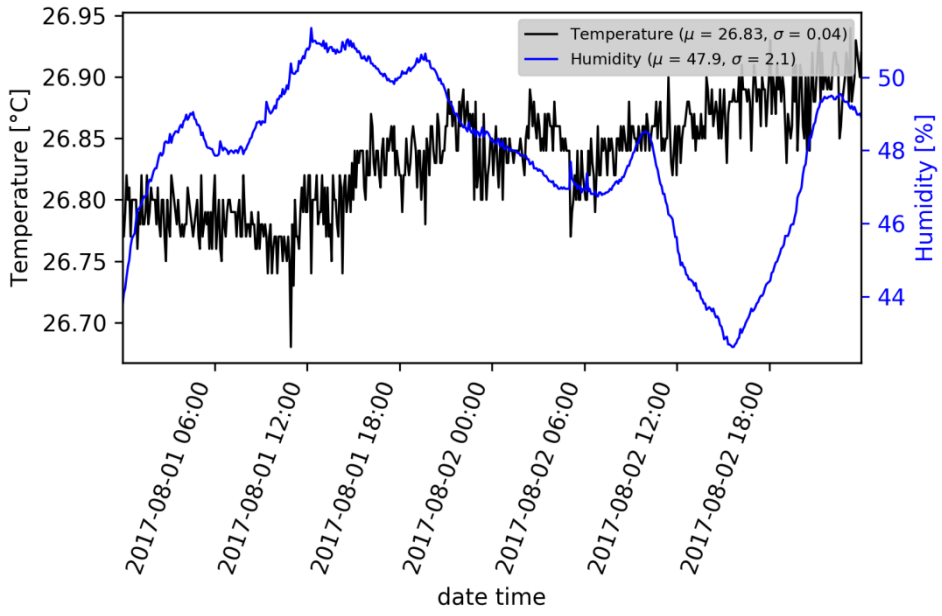


Table 9: HDR: Environmental variables during irradiation

Parameter	Value and Unit	Remarks
Humidity	47.9% ± 2.1%	Non-condensing, during irradiation and first annealing (24 h).
Temperature	26.8 °C ± 0.1 °C	During irradiation and first annealing (24 h)
Temperature	100.0 ± 3.0 °C	During second annealing (168 h)

Figure 10: HDR: Environment variables during irradiation.



5 Measurement parameters

The measurement of the electrical parameters was done by Fraunhofer INT in accordance with the measurements standards and test methods of ESA, MIL and IEC.

The test plan based on the ESA Basic Specification No. 22900 [3] in general and the irradiation test plan [5] in particular.

Parameters listed in the following Table 10 were measured before and after each irradiation step and each annealing step.

In two cases during the LDR and HDR test respectively (see Table 5 and Table 6) the ESCC22900 requirement of 2 hours between stop of radiation and the start of the next step were not fulfilled.

5.1 Measurement parameters

Table 10: Measurement parameters. Based on [4], taken from [5]

No.	Characteristics	Symbol	MIL-STD-750 Test Method	Test Conditions
1	Collector-Emitter Sustaining Voltage	$V_{(Sus)CEO}$ I_C@500V	3011, Note 2	I_C = 10 mA, Bias Condition D, Note 1
2	Collector-Base Breakdown Voltage	$V_{(BR)CBO}$ I_C@1000 V	3001	I_C = 1 mA, Bias Condition D
3	Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$ I_E@10 V	3026	I_E = 1 mA, Bias Condition D
4	Collector-Base Cut-off Current	I_{CBO}	3036	V_{CB} = 1000 V, Bias Condition D
5	Collector-Emitter Cut-off Current	I_{CEO}	3041	V_{CE} = 500 V, Bias Condition D
6	Emitter-Base Cutoff Current	I_{EBO}	3061	V_{EB} = 9 V, I_C=0 A, Bias Condition D
7	Collector-Emitter Saturation Voltage	$V_{CE(sat)1}$	3071	I_C = 100 mA, I_B = 20 mA, Notes 1
8		$V_{CE(sat)2}$		I_C = 0.5 A, I_B = 0.1 A, Notes 1
9		$V_{CE(sat)3}$		I_C = 1 A, I_B = 0.2 A, Notes 1
10	Base-Emitter Saturation Voltage	$V_{BE(sat)1}$	3066	I_C = 0.5 A, I_B = 0.1 A, Test Condition A, Notes 1
11		$V_{BE(sat)2}$		I_C = 1 A, I_B = 0.2 A, Test Condition A, Notes 1
12	Forward Current Transfer Ratio (DC Current Gain)	h_{FE1}	3076	V_{CE} = 5 V, I_C = 0.1 A, Notes 1
13		h_{FE2}		V_{CE} = 5 V, I_C = 0.5 A, Notes 1
14		h_{FE3}		V_{CE} = 1V, I_C = 1 A, Notes 1

Note 1: As discussed with the technical officer, pulse widths were increased to 1 ms while maintaining < 2% duty cycle

Note 2: The following deviation from Test method 3011 was implemented:

- V_{CE} was increased until either (whatever criteria is met first)
  a) the specified test current is achieved
  or b) the allowed max. rating of V_{CE} (identical with the min. Limit of $V_{(Br)CEO}$) is applied
- If case b) is met then the device is automatically acceptable according to the purpose and acceptance criteria of Test Method 3011, which only gives a lower limit for $V_{(sus)CEO}$.
  In this case, I_C @ V_{CE} = 500 V is recorded, which should give some information about parameter drifts.
- If case a) is met, the device fails the test, as the test current is achieved for $V_{CE}<V_{(Br)CEO\ min}$
- The same applies likewise for V_{CB} or V_{EB}

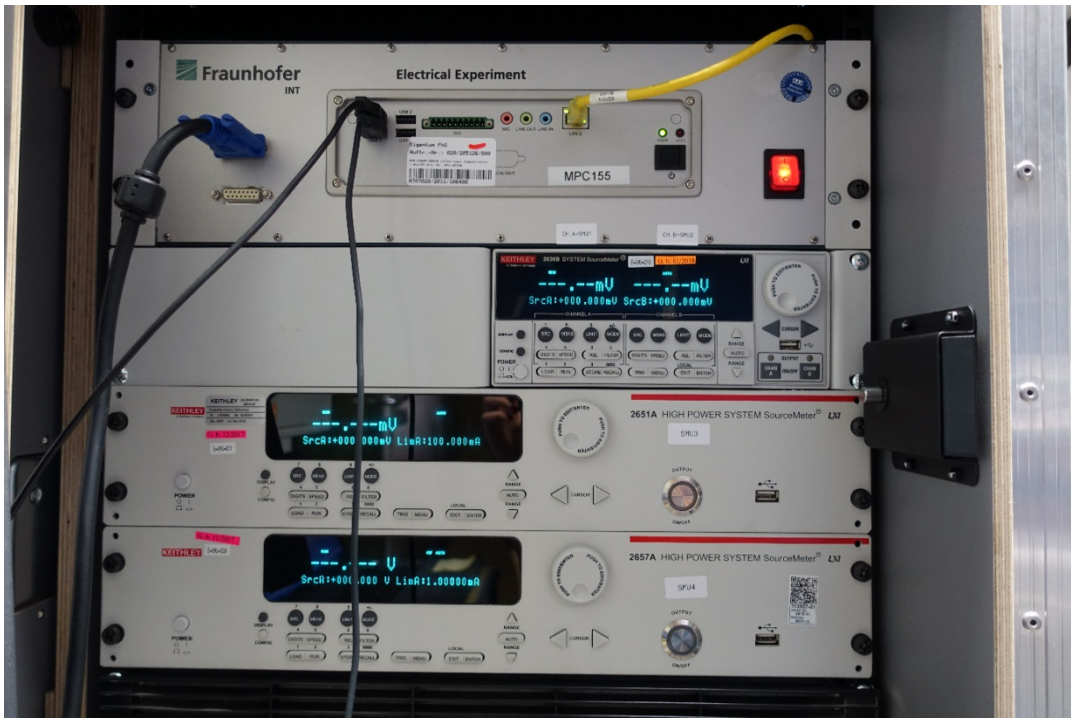
5.2 Measurement equipment

Table 11: Measurement equipment

Equipment	Manufacturer	Model	INT-Code	Calibr. due	Measurement
System Source-Meter	Keithley	2636B	E-SMU-010	01/2018	$V_{(Sus)CEO}$, $V_{(BR)CBO}$, $V_{(BR)EBO}$, I_{CBO}, I_{CEO}, I_{EBO}
High Power System Source-Meter	Keithley	2657A	E-SMU-008	11/2017	$V_{CE(sat)}1$, $V_{CE(sat)}2$, $V_{CE(sat)}3$, $V_{BE(sat)}1$, $V_{BE(sat)}2$, h_{FE1}, h_{FE2}, h_{FE3}
Test Fixture	Keithley	8010	E-SPAT-004	--	all

Figure 11: Measurement equipment/setup

Figure 12: Test setup: SMUs



5.3 Measurement procedures

Procedures according to the MIL test methods given in Table 10 and Notes 1+2.

Measurements were programmed using the software Keithley ASC Basic allowing timed operation of the SMUs during pulses (e.g. using a fixed delay between pulse rise and parameter readout times).

5.4 Environmental variables

All measurement and annealing steps were done in air. The samples are measured in a lightproof measuring-case. The parameters of the humidity and the temperature during the tests in the ESD area are given in the following table and figure.

Table 12: LDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @ 100°C
Temperature [°C]	26.0E+0	26.3E+0	27.1E+0	21.4E+0	22.9E+0	23.4E+0	22.4E+0	28.1E+0	29.3E+0	23.5E+0
Humidity [%]	60.8E+0	54.2E+0	55.1E+0	43.9E+0	55.2E+0	50.2E+0	45.5E+0	30.9E+0	36.5E+0	30.2E+0

Figure 13: LDR: Environment variables during measurements

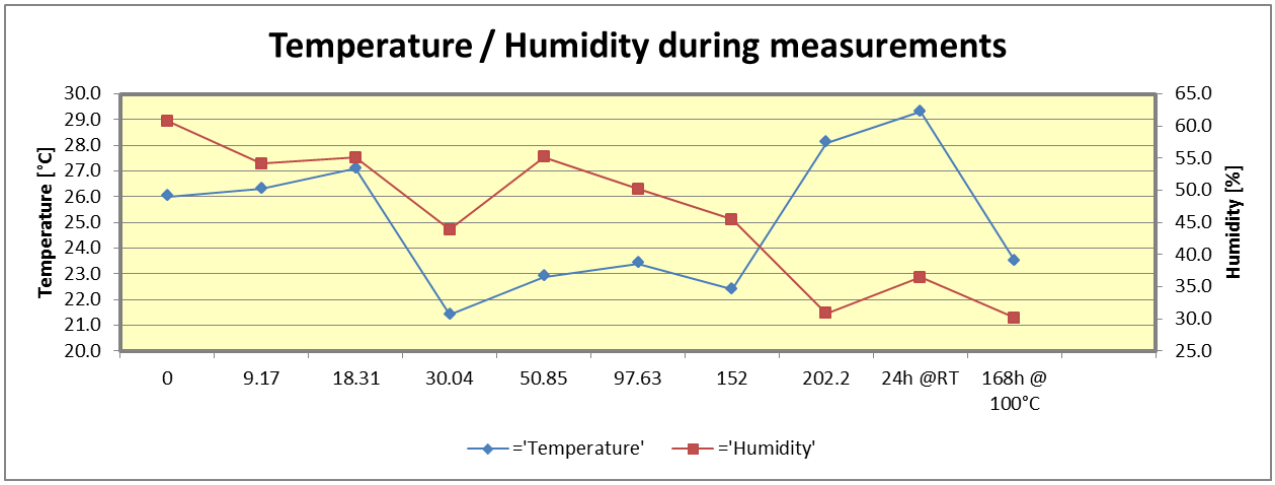
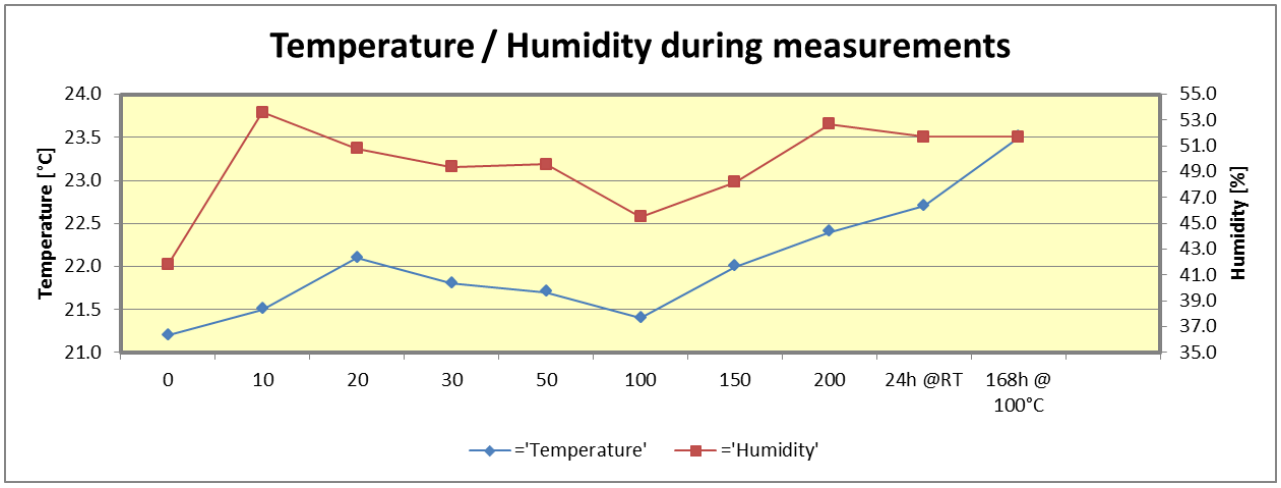


Table 13: HDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @ 100°C
Temperature [°C]	21.2E+0	21.5E+0	22.1E+0	21.8E+0	21.7E+0	21.4E+0	22.0E+0	22.4E+0	22.7E+0	23.5E+0
Humidity [%]	41.8E+0	53.6E+0	50.8E+0	49.4E+0	49.6E+0	45.5E+0	48.2E+0	52.7E+0	51.7E+0	51.7E+0

Figure 14: HDR: Environment variables during measurements



6 Enhancement Factor Calculation

The ELDRS enhancement factor is calculated as the fraction of the parameter shift at low dose rate and at high dose rate with respect to the pre-irradiation values:

$$EF(Dose) = \frac{\Delta\big(para\ (LDR, Dose)\big)}{\Delta\big(para\ (HDR, Dose)\big)}$$

with

$$\Delta(para\ (TEST, Dose)) = para(TEST, Dose) - para(TEST, 0\ krad)$$

This factor is calculated for each individual parameter, dose step and bias mode.

In the recent ESCC 22900 [3], a part is considered ELDRS sensitive if that factor is greater than 1.5 on the median value of the most sensitive measured parameter. According to test method 1019.9 from MIL-STD-883K [6], the calculation of the enhancement factor is only applicable if the respective parameter is beyond the datasheet specifications and changes are not within experimental errors.

When adapting the criteria from MIL-STD-883K, significant enhancement satisfying these criteria is found for parameters $V_{(BR)CBO}$, $V_{CE(sat)}1$, $V_{CE(sat)}2$, $V_{CE(sat)}3$, h_{FE1}, and h_{FE2}.

We thus see that the part is susceptible to ELDRS.

7 Results LDR

7.1 Overview: Pass/Fail

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
V_sus_CEO	On										
	Off										
I(V_sus_CEO)	On										
	Off										
I_CEO	On										
	Off										
V_br_CBO	On						3	5	4	4	
	Off							2	3		1
I(V_br_CBO)	On							3		1	
	Off										
I_CBO	On			1	2	3	4	5	5	5	
	Off						5	5	5	5	
V_br_EBO	On										
	Off										
I(V_br_EBO)	On										
	Off										
I_EBO	On										
	Off										
V_CEsat 1	On						5	5	5	5	1
	Off					1	5	5	5	5	
V_CEsat2	On			3	5	5	5	5	5	5	5
	Off			5	5	5	5	5	5	5	5
V_CEsat3	On		5	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
V_BEsat1	On										
	Off										
V_BEsat2	On										
	Off										
HFE1	On					2	5	5	5	5	
	Off					2	5	5	5	5	
HFE2	On				4	5	5	5	5	5	5
	Off				3	5	5	5	5	5	5
HFE3	On										
	Off										

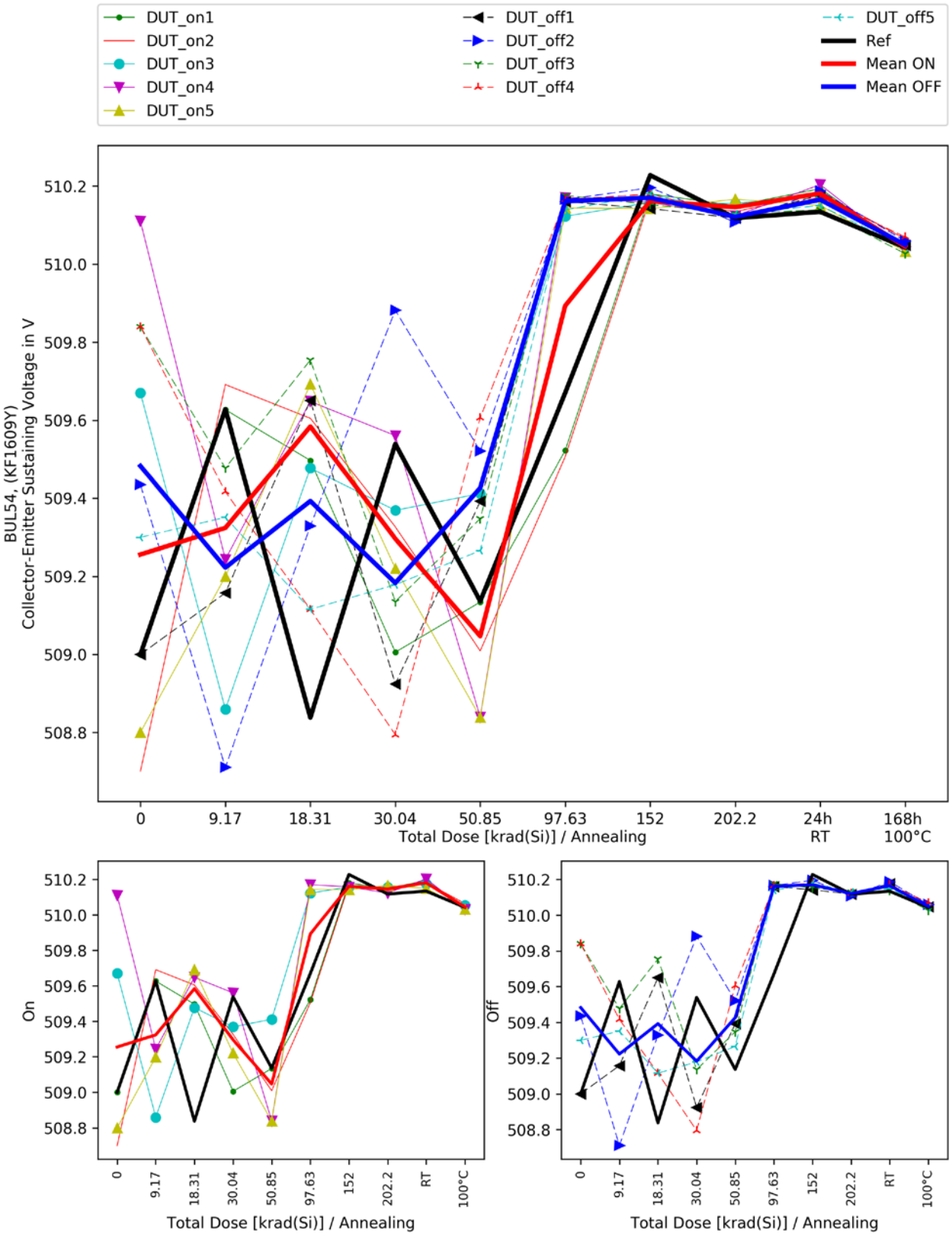
7.2 Collector-Emitter Sustaining Voltage

Collector-Emitter Sustaining Voltage **BUL54**
V_sus_CEO in V Date-/Lotcode: KF1609Y
Limit: 500.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	509.0E+0	509.6E+0	509.5E+0	509.0E+0	509.1E+0	509.5E+0	510.2E+0	510.2E+0	510.2E+0	510.0E+0
DUT_on2	508.7E+0	509.7E+0	509.6E+0	509.3E+0	509.0E+0	509.5E+0	510.2E+0	510.1E+0	510.2E+0	510.1E+0
DUT_on3	509.7E+0	508.9E+0	509.5E+0	509.4E+0	509.4E+0	510.1E+0	510.2E+0	510.2E+0	510.2E+0	510.1E+0
DUT_on4	510.1E+0	509.2E+0	509.6E+0	509.6E+0	508.8E+0	510.2E+0	510.2E+0	510.1E+0	510.2E+0	510.0E+0
DUT_on5	508.8E+0	509.2E+0	509.7E+0	509.2E+0	508.8E+0	510.1E+0	510.1E+0	510.2E+0	510.2E+0	510.0E+0
Radiation-Mean ON	509.3E+0	509.3E+0	509.6E+0	509.3E+0	509.0E+0	509.9E+0	510.2E+0	510.1E+0	510.2E+0	510.0E+0
Standarddeviation	609.0E-3	340.6E-3	93.8E-3	203.9E-3	239.1E-3	346.0E-3	14.0E-3	17.1E-3	20.2E-3	14.0E-3
Mean + kσ	510.9E+0	510.3E+0	509.8E+0	509.9E+0	509.7E+0	510.8E+0	510.2E+0	510.2E+0	510.2E+0	510.1E+0
Mean - kσ	507.6E+0	508.4E+0	509.3E+0	508.7E+0	508.4E+0	508.9E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	509.0E+0	509.2E+0	509.7E+0	508.9E+0	509.4E+0	510.2E+0	510.1E+0	510.1E+0	510.2E+0	510.0E+0
DUT_off2	509.4E+0	508.7E+0	509.3E+0	509.9E+0	509.5E+0	510.2E+0	510.2E+0	510.1E+0	510.2E+0	510.1E+0
DUT_off3	509.8E+0	509.5E+0	509.8E+0	509.1E+0	509.3E+0	510.2E+0	510.2E+0	510.1E+0	510.1E+0	510.0E+0
DUT_off4	509.8E+0	509.4E+0	509.1E+0	508.8E+0	509.6E+0	510.2E+0	510.2E+0	510.1E+0	510.2E+0	510.1E+0
DUT_off5	509.3E+0	509.4E+0	509.1E+0	509.2E+0	509.3E+0	510.1E+0	510.2E+0	510.1E+0	510.2E+0	510.0E+0
Radiation-Mean OFF	509.5E+0	509.2E+0	509.4E+0	509.2E+0	509.4E+0	510.2E+0	510.2E+0	510.1E+0	510.2E+0	510.0E+0
Standarddeviation	361.9E-3	310.6E-3	297.9E-3	421.0E-3	136.2E-3	13.9E-3	21.9E-3	9.0E-3	19.8E-3	16.2E-3
Mean + kσ	510.5E+0	510.1E+0	510.2E+0	510.3E+0	509.8E+0	510.2E+0	510.2E+0	510.1E+0	510.2E+0	510.1E+0
Mean - kσ	508.5E+0	508.4E+0	508.6E+0	508.0E+0	509.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	509.0E+0	509.6E+0	508.8E+0	509.5E+0	509.1E+0	509.7E+0	510.2E+0	510.1E+0	510.1E+0	510.0E+0
Min. Value	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Collector-Emitter Sustaining Voltage in V
510.2
510.0
509.8
509.6
509.4
509.2
509.0
508.8
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.3 ICE @ 500 V

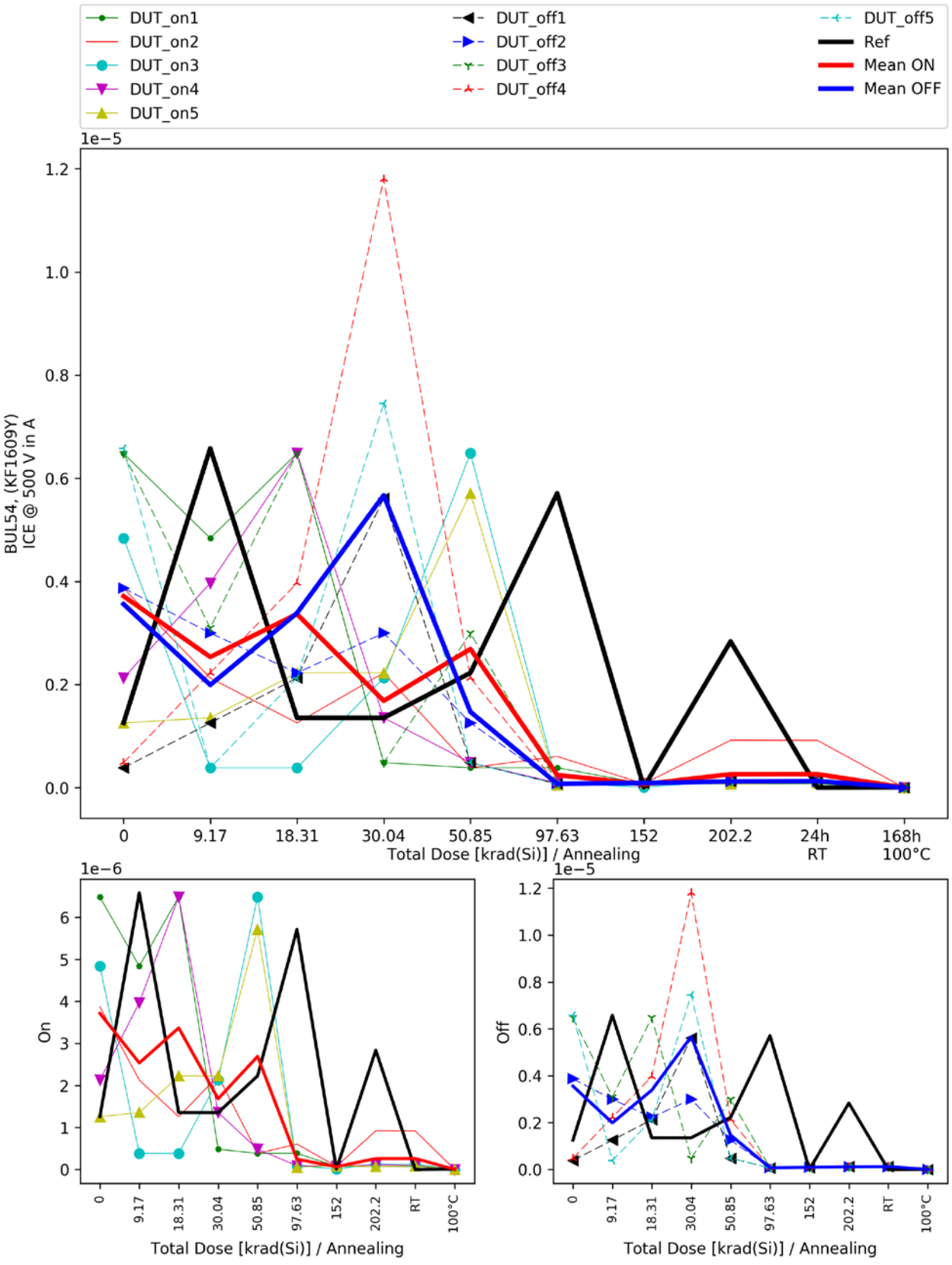
ICE @ 500 V
I(V_sus_CEO) in A
Limit: x < 0.01

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	6.5E-6	4.8E-6	6.5E-6	484.4E-9	386.2E-9	387.3E-9	77.2E-9	71.5E-9	76.7E-9	3.2E-9
DUT_on2	3.9E-6	2.1E-6	1.3E-6	2.2E-6	385.6E-9	605.1E-9	77.4E-9	920.7E-9	918.2E-9	560.4E-12
DUT_on3	4.8E-6	385.6E-9	385.4E-9	2.1E-6	6.5E-6	91.0E-9	11.3E-9	133.8E-9	131.0E-9	4.3E-9
DUT_on4	2.1E-6	4.0E-6	6.5E-6	1.4E-6	485.0E-9	92.7E-9	81.4E-9	113.8E-9	101.5E-9	88.2E-12
DUT_on5	1.3E-6	1.4E-6	2.2E-6	2.2E-6	5.7E-6	55.2E-9	90.9E-9	71.2E-9	90.0E-9	4.4E-9
Radiation-Mean ON	3.7E-6	2.5E-6	3.4E-6	1.7E-6	2.7E-6	246.3E-9	67.7E-9	262.2E-9	263.5E-9	2.5E-9
Standarddeviation	2.1E-6	1.8E-6	2.9E-6	763.7E-9	3.1E-6	241.3E-9	32.0E-9	369.1E-9	366.5E-9	2.1E-9
Mean + kσ	9.4E-6	7.6E-6	11.4E-6	3.8E-6	11.2E-6	907.9E-9	155.3E-9	1.3E-6	1.3E-6	8.1E-9
Mean - kσ	-2.0E-6	-2.5E-6	-4.6E-6	-409.9E-9	-5.9E-6	-415.3E-9	-20.0E-9	-749.9E-9	-741.6E-9	-3.1E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	385.2E-9	1.3E-6	2.1E-6	5.6E-6	485.3E-9	72.4E-9	86.5E-9	123.0E-9	133.1E-9	820.2E-12
DUT_off2	3.9E-6	3.0E-6	2.2E-6	3.0E-6	1.3E-6	78.1E-9	99.0E-9	115.5E-9	117.1E-9	2.9E-9
DUT_off3	6.5E-6	3.1E-6	6.5E-6	484.8E-9	3.0E-6	89.5E-9	95.4E-9	127.6E-9	129.6E-9	1.2E-9
DUT_off4	484.7E-9	2.2E-6	4.0E-6	11.8E-6	2.1E-6	69.4E-9	95.7E-9	112.6E-9	142.7E-9	3.8E-9
DUT_off5	6.6E-6	385.1E-9	2.1E-6	7.4E-6	484.9E-9	69.3E-9	87.4E-9	119.7E-9	124.2E-9	4.1E-9
Radiation-Mean OFF	3.6E-6	2.0E-6	3.4E-6	5.7E-6	1.5E-6	75.7E-9	92.8E-9	119.7E-9	129.3E-9	2.6E-9
Standarddeviation	3.1E-6	1.2E-6	1.9E-6	4.3E-6	1.1E-6	8.5E-9	5.5E-9	6.0E-9	9.6E-9	1.5E-9
Mean + kσ	11.9E-6	5.2E-6	8.6E-6	17.5E-6	4.5E-6	99.0E-9	107.9E-9	136.1E-9	155.7E-9	6.6E-9
Mean - kσ	-4.8E-6	-1.2E-6	-1.8E-6	-6.2E-6	-1.5E-6	52.4E-9	77.6E-9	103.3E-9	103.0E-9	-1.5E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	1.3E-6	6.6E-6	1.4E-6	1.4E-6	2.2E-6	5.7E-6	11.6E-9	2.8E-6	2.6E-9	9.3E-9
Max. Value	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−5
BUL54, (KF1609Y)
ICE @ 500 V in A
Total Dose [krad(Si)] / Annealing
1e−6
On
1e−5
Off
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C

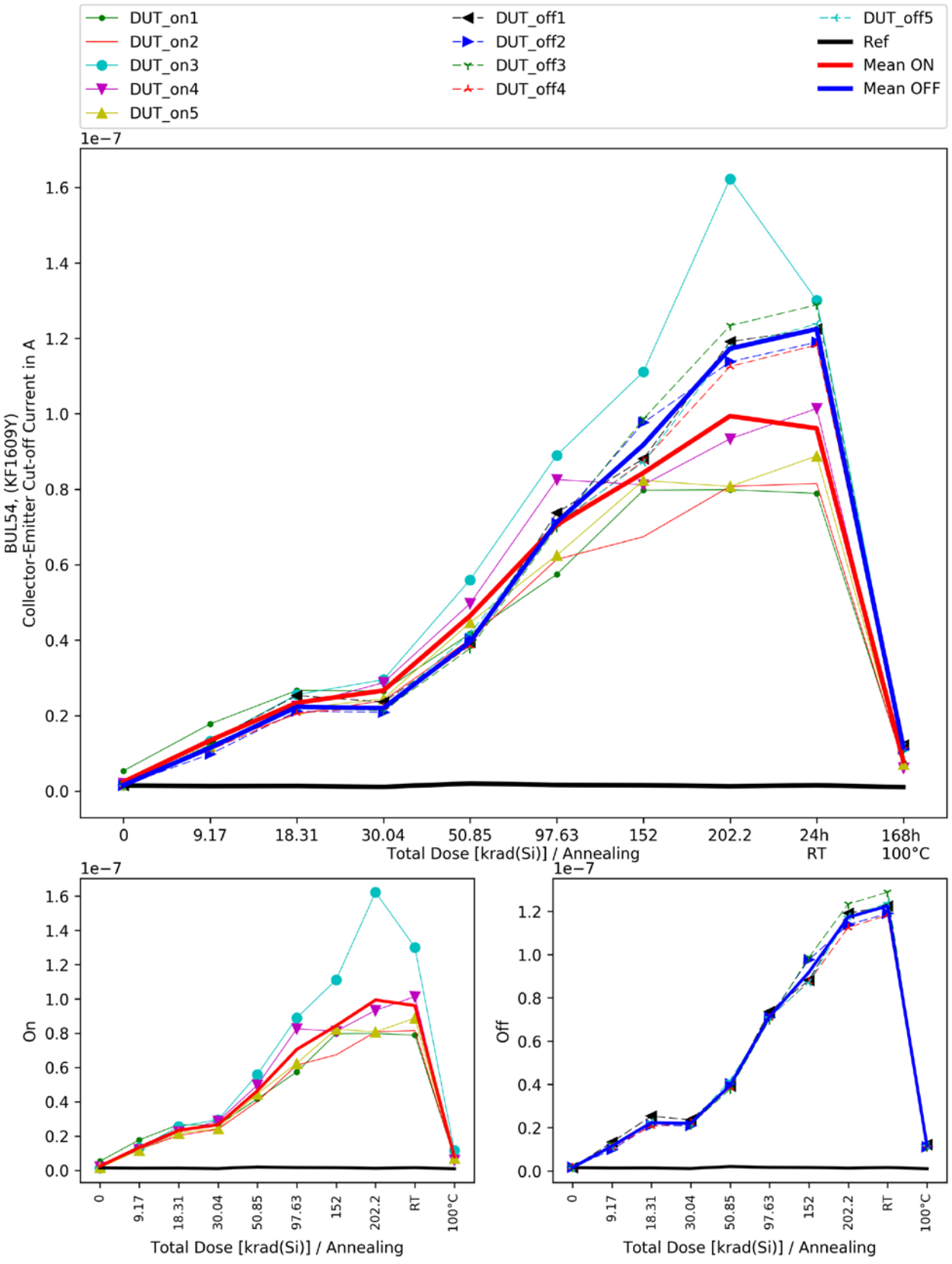
7.4 Collector-Emitter Cut-off Current

Collector-Emitter Cut-off Current **BUL54**
I_CEO in A Date-/Lotcode: KF1609Y
Limit: x < 0.0001

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	5.4E-9	17.8E-9	26.7E-9	26.5E-9	41.7E-9	57.4E-9	79.7E-9	79.9E-9	78.9E-9	7.6E-9
DUT_on2	1.5E-9	12.2E-9	20.4E-9	24.0E-9	40.2E-9	61.4E-9	67.4E-9	80.8E-9	81.5E-9	7.2E-9
DUT_on3	1.6E-9	13.2E-9	25.6E-9	29.5E-9	56.0E-9	89.0E-9	111.1E-9	162.3E-9	130.1E-9	11.7E-9
DUT_on4	2.0E-9	12.1E-9	22.6E-9	28.7E-9	49.7E-9	82.6E-9	81.2E-9	93.4E-9	101.4E-9	6.1E-9
DUT_on5	1.6E-9	11.8E-9	21.8E-9	24.4E-9	44.7E-9	62.5E-9	82.3E-9	80.7E-9	88.8E-9	7.1E-9
Radiation-Mean ON	2.4E-9	13.4E-9	23.4E-9	26.6E-9	46.5E-9	70.6E-9	84.4E-9	99.4E-9	96.1E-9	7.9E-9
Standarddeviation	1.7E-9	2.5E-9	2.6E-9	2.5E-9	6.4E-9	14.2E-9	16.1E-9	35.6E-9	20.9E-9	2.2E-9
Mean + kσ	7.0E-9	20.3E-9	30.6E-9	33.4E-9	64.1E-9	109.5E-9	128.5E-9	197.0E-9	153.4E-9	13.9E-9
Mean - kσ	-2.1E-9	6.6E-9	16.2E-9	19.9E-9	28.8E-9	31.7E-9	40.2E-9	1.8E-9	38.9E-9	2.0E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	1.6E-9	13.3E-9	25.3E-9	23.6E-9	39.4E-9	73.7E-9	88.1E-9	119.1E-9	122.5E-9	12.2E-9
DUT_off2	1.5E-9	9.8E-9	21.1E-9	20.9E-9	40.2E-9	70.9E-9	97.6E-9	113.8E-9	119.0E-9	11.1E-9
DUT_off3	1.7E-9	12.3E-9	21.9E-9	21.3E-9	37.8E-9	69.9E-9	98.6E-9	123.3E-9	128.9E-9	11.1E-9
DUT_off4	1.5E-9	10.9E-9	20.7E-9	22.2E-9	38.5E-9	70.7E-9	87.4E-9	112.5E-9	118.2E-9	12.0E-9
DUT_off5	1.5E-9	11.1E-9	22.6E-9	22.0E-9	41.8E-9	71.1E-9	87.1E-9	117.6E-9	123.8E-9	11.7E-9
Radiation-Mean OFF	1.6E-9	11.5E-9	22.3E-9	22.0E-9	39.5E-9	71.3E-9	91.8E-9	117.3E-9	122.5E-9	11.6E-9
Standarddeviation	109.7E-12	1.3E-9	1.8E-9	1.0E-9	1.5E-9	1.4E-9	5.8E-9	4.3E-9	4.3E-9	509.6E-12
Mean + kσ	1.9E-9	15.2E-9	27.3E-9	24.9E-9	43.8E-9	75.2E-9	107.7E-9	129.1E-9	134.2E-9	13.0E-9
Mean - kσ	1.3E-9	7.8E-9	17.3E-9	19.2E-9	35.3E-9	67.3E-9	75.9E-9	105.4E-9	110.8E-9	10.2E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	1.4E-9	1.3E-9	1.3E-9	1.1E-9	2.0E-9	1.6E-9	1.5E-9	1.3E-9	1.5E-9	1.1E-9
Max. Value	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−7
BUL54, (KF1609Y)
Collector-Emitter Cut-off Current in A
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

7.5 Collector-Base Breakdown Voltage

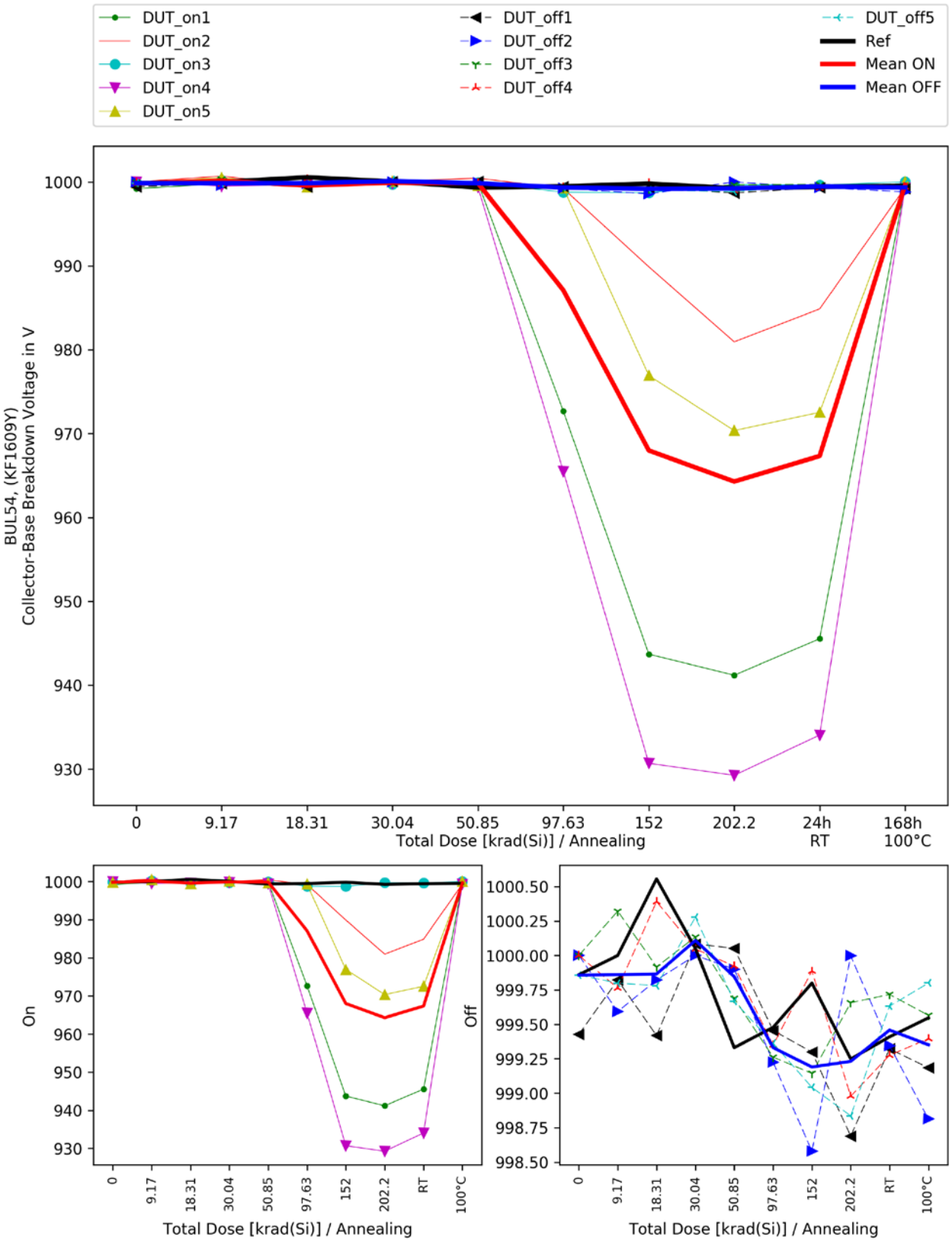
Collector-Base Breakdown Voltage
V_br_CBO in V
Limit: 999.1<x

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	999.2E+0	999.8E+0	999.6E+0	999.9E+0	999.9E+0	972.7E+0	943.7E+0	941.2E+0	945.5E+0	999.6E+0
DUT_on2	1.0E+3	1.0E+3	999.6E+0	1.0E+3	1.0E+3	999.2E+0	989.9E+0	980.9E+0	984.9E+0	999.3E+0
DUT_on3	999.9E+0	1.0E+3	999.6E+0	999.7E+0	999.9E+0	998.8E+0	998.7E+0	999.7E+0	999.6E+0	1.0E+3
DUT_on4	1.0E+3	999.5E+0	999.7E+0	999.8E+0	999.4E+0	965.5E+0	930.7E+0	929.3E+0	934.1E+0	999.3E+0
DUT_on5	999.9E+0	1.0E+3	999.4E+0	1.0E+3	999.6E+0	999.3E+0	976.9E+0	970.4E+0	972.5E+0	1.0E+3
Radiation-Mean ON	999.8E+0	1.0E+3	999.6E+0	999.9E+0	999.9E+0	987.1E+0	968.0E+0	964.3E+0	967.3E+0	999.7E+0
Standarddeviation	348.5E-3	495.9E-3	92.2E-3	158.2E-3	405.4E-3	16.6E+0	29.5E+0	28.8E+0	27.2E+0	334.9E-3
Mean + kσ	1.0E+3	1.0E+3	999.8E+0	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Mean - kσ	998.8E+0	998.8E+0	999.3E+0	999.5E+0	998.7E+0	941.5E+0	887.1E+0	885.2E+0	892.8E+0	998.7E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	999.4E+0	999.8E+0	999.4E+0	1.0E+3	1.0E+3	999.5E+0	999.3E+0	998.7E+0	999.3E+0	999.2E+0
DUT_off2	1.0E+3	999.6E+0	999.8E+0	1.0E+3	999.9E+0	999.2E+0	998.6E+0	1.0E+3	999.3E+0	998.8E+0
DUT_off3	1.0E+3	1.0E+3	999.9E+0	1.0E+3	999.7E+0	999.3E+0	999.1E+0	999.7E+0	999.7E+0	999.6E+0
DUT_off4	1.0E+3	999.8E+0	1.0E+3	1.0E+3	999.9E+0	999.3E+0	999.9E+0	999.0E+0	999.3E+0	999.4E+0
DUT_off5	999.9E+0	999.8E+0	999.8E+0	1.0E+3	999.7E+0	999.4E+0	999.0E+0	998.8E+0	999.6E+0	999.8E+0
Radiation-Mean OFF	999.9E+0	999.9E+0	999.9E+0	1.0E+3	999.8E+0	999.3E+0	999.2E+0	999.2E+0	999.5E+0	999.4E+0
Standarddeviation	248.0E-3	273.7E-3	349.3E-3	106.0E-3	164.2E-3	90.3E-3	473.0E-3	566.1E-3	201.0E-3	376.4E-3
Mean + kσ	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	999.6E+0	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Mean - kσ	999.2E+0	999.1E+0	998.9E+0	999.8E+0	999.4E+0	999.1E+0	997.9E+0	997.7E+0	998.9E+0	998.3E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	999.9E+0	1.0E+3	1.0E+3	1.0E+3	999.3E+0	999.5E+0	999.8E+0	999.2E+0	999.4E+0	999.5E+0
Min. Value	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0	999.1E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Collector-Base Breakdown Voltage in V
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

7.6 ICB @ 1000 V

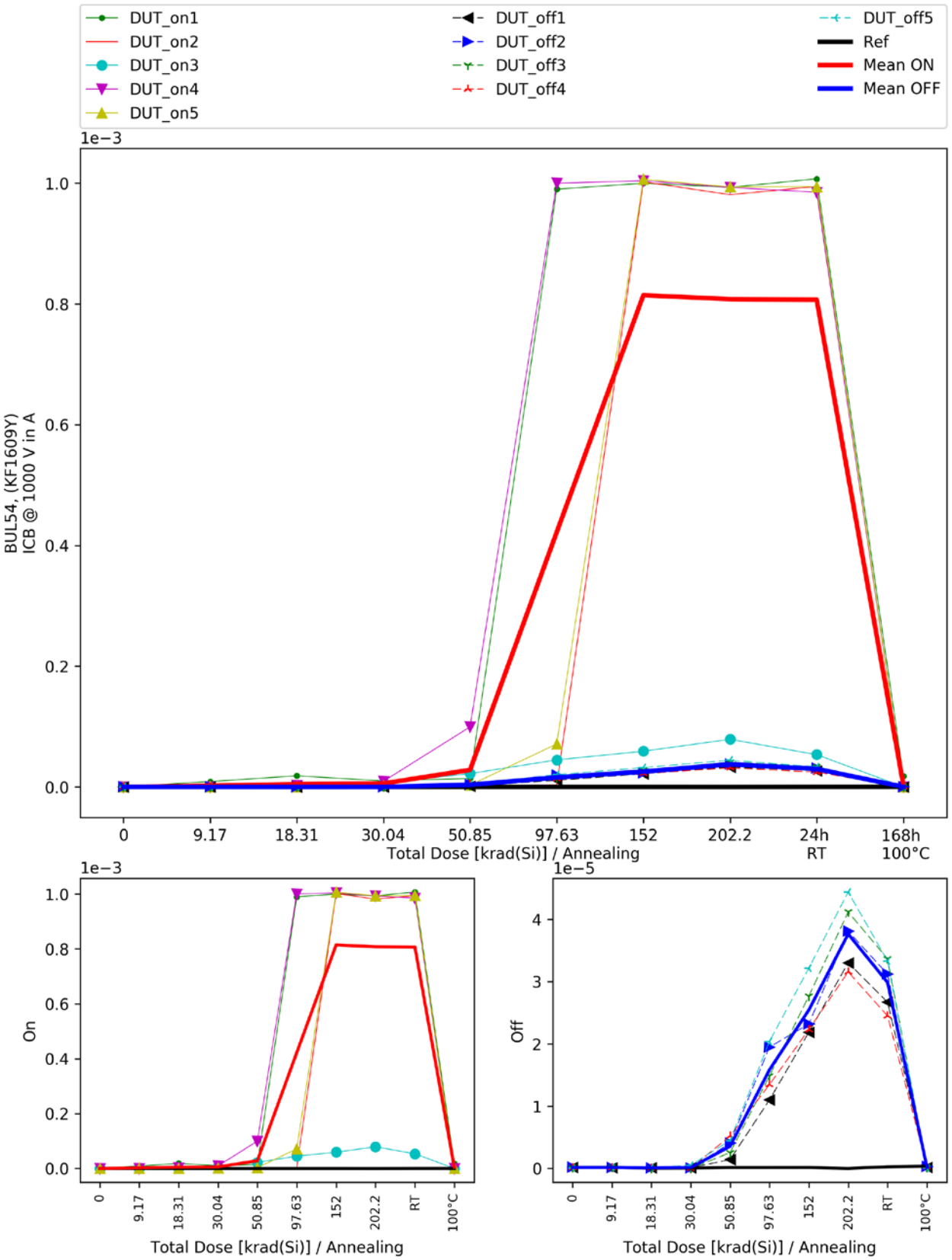
ICB @ 1000 V
I(V_br_CBO) in A
Limit: x < 0.001

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	166.2E-9	9.0E-6	18.5E-6	10.1E-6	14.1E-6	990.1E-6	1.0E-3	993.2E-6	1.0E-3	18.3E-6
DUT_on2	149.0E-9	149.1E-9	359.8E-9	1.3E-6	2.3E-6	3.7E-6	1.0E-3	980.9E-6	994.7E-6	4.5E-9
DUT_on3	166.2E-9	45.4E-9	1.6E-6	6.3E-6	22.1E-6	44.8E-6	59.2E-6	78.9E-6	53.6E-6	183.3E-9
DUT_on4	152.7E-9	198.5E-9	2.4E-6	9.4E-6	99.5E-6	1.0E-3	1.0E-3	993.0E-6	985.1E-6	84.9E-9
DUT_on5	139.9E-9	188.7E-9	103.2E-9	1.8E-6	3.0E-6	71.2E-6	1.0E-3	993.8E-6	994.3E-6	49.2E-9
Radiation-Mean ON	154.8E-9	1.9E-6	4.6E-6	5.7E-6	28.2E-6	422.0E-6	814.4E-6	808.0E-6	807.0E-6	3.7E-6
Standarddeviation	11.4E-9	4.0E-6	7.8E-6	4.1E-6	40.7E-6	523.7E-6	422.2E-6	407.6E-6	421.2E-6	8.2E-6
Mean + kσ	186.1E-9	12.8E-6	26.0E-6	17.0E-6	139.8E-6	1.9E-3	2.0E-3	1.9E-3	2.0E-3	26.1E-6
Mean - kσ	123.6E-9	-8.9E-6	-16.8E-6	-5.5E-6	-83.4E-6	-1.0E-3	-343.2E-6	-309.6E-6	-348.1E-6	-18.6E-6

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	157.2E-9	121.9E-9	149.0E-9	126.6E-9	1.4E-6	11.0E-6	21.8E-6	33.0E-6	26.7E-6	183.3E-9
DUT_off2	180.5E-9	113.0E-9	72.4E-9	67.1E-9	4.0E-6	19.5E-6	23.2E-6	38.1E-6	31.2E-6	272.6E-9
DUT_off3	144.5E-9	179.7E-9	4.1E-9	430.2E-12	2.5E-6	14.8E-6	27.7E-6	41.1E-6	33.6E-6	129.6E-9
DUT_off4	98.7E-9	95.0E-9	45.4E-9	18.4E-9	5.2E-6	13.4E-6	22.3E-6	31.5E-6	24.5E-6	227.9E-9
DUT_off5	86.0E-9	166.2E-9	157.2E-9	504.1E-9	4.5E-6	20.4E-6	32.1E-6	44.4E-6	33.3E-6	40.2E-9
Radiation-Mean OFF	133.4E-9	135.2E-9	85.6E-9	143.3E-9	3.5E-6	15.8E-6	25.4E-6	37.6E-6	29.9E-6	170.7E-9
Standarddeviation	39.9E-9	36.2E-9	66.3E-9	207.5E-9	1.5E-6	4.0E-6	4.4E-6	5.4E-6	4.1E-6	90.2E-9
Mean + kσ	242.7E-9	234.3E-9	267.4E-9	712.3E-9	7.8E-6	26.8E-6	37.5E-6	52.4E-6	41.1E-6	417.9E-9
Mean - kσ	24.1E-9	36.0E-9	-96.1E-9	-425.7E-9	-676.0E-9	4.8E-6	13.3E-6	22.8E-6	18.6E-6	-76.5E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	149.0E-9	166.7E-9	35.6E-9	58.9E-9	131.0E-9	130.8E-9	138.5E-9	4.5E-9	263.6E-9	353.0E-9
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−3
BUL54, (KF1609Y)
ICB @ 1000 V in A
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
1e−3
On
1e−5
Off

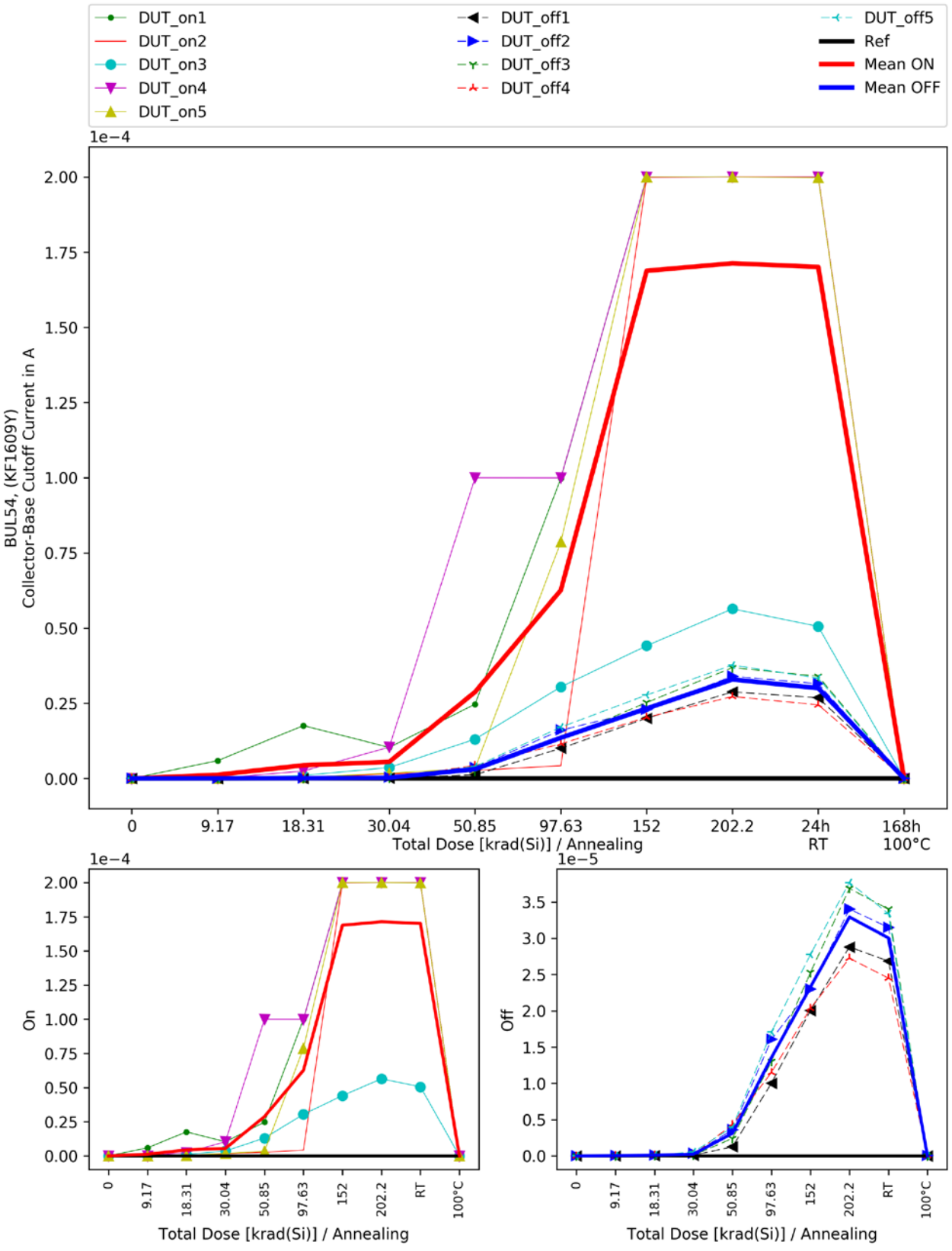
7.7 Collector-Base Cutoff Current

Collector-Base Cutoff Current **BUL54**
I_CBO in A Date-/Lotcode: KF1609Y
Limit: x < 1e-05

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	22.2E-9	5.9E-6	17.6E-6	10.3E-6	24.7E-6	99.8E-6	200.0E-6	200.0E-6	199.9E-6	23.2E-9
DUT_on2	2.8E-9	75.1E-9	497.6E-9	1.5E-6	2.7E-6	4.3E-6	199.8E-6	200.0E-6	200.0E-6	19.4E-9
DUT_on3	2.1E-9	95.3E-9	1.0E-6	3.7E-6	13.1E-6	30.5E-6	44.1E-6	56.4E-6	50.6E-6	44.8E-9
DUT_on4	2.0E-9	51.5E-9	2.5E-6	10.4E-6	100.0E-6	99.9E-6	199.9E-6	200.0E-6	200.0E-6	22.9E-9
DUT_on5	1.8E-9	44.1E-9	383.8E-9	1.8E-6	3.4E-6	78.6E-6	200.0E-6	200.0E-6	199.8E-6	19.2E-9
Radiation-Mean ON	6.2E-9	1.2E-6	4.4E-6	5.5E-6	28.8E-6	62.6E-6	168.8E-6	171.3E-6	170.1E-6	25.9E-9
Standarddeviation	9.0E-9	2.6E-6	7.4E-6	4.5E-6	40.8E-6	43.2E-6	69.7E-6	64.2E-6	66.8E-6	10.7E-9
Mean + kσ	30.8E-9	8.4E-6	24.8E-6	17.8E-6	140.6E-6	181.1E-6	359.8E-6	347.3E-6	353.2E-6	55.4E-9
Mean - kσ	-18.5E-9	-6.0E-6	-16.0E-6	-6.8E-6	-83.1E-6	-55.9E-6	-22.3E-6	-4.8E-6	-13.1E-6	-3.5E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	1.5E-9	22.7E-9	50.2E-9	93.2E-9	1.3E-6	10.0E-6	20.0E-6	28.8E-6	26.8E-6	22.9E-9
DUT_off2	6.8E-9	60.5E-9	107.8E-9	334.7E-9	3.6E-6	16.1E-6	23.0E-6	34.0E-6	31.5E-6	33.5E-9
DUT_off3	1.6E-9	21.0E-9	47.6E-9	93.4E-9	2.4E-6	13.0E-6	25.3E-6	36.9E-6	34.0E-6	25.2E-9
DUT_off4	3.2E-9	38.7E-9	82.9E-9	186.7E-9	4.3E-6	11.5E-6	20.3E-6	27.2E-6	24.5E-6	31.8E-9
DUT_off5	4.7E-9	59.3E-9	129.7E-9	541.6E-9	4.0E-6	17.1E-6	27.8E-6	37.7E-6	33.4E-6	35.9E-9
Radiation-Mean OFF	3.6E-9	40.4E-9	83.6E-9	249.9E-9	3.1E-6	13.5E-6	23.3E-6	32.9E-6	30.0E-6	29.8E-9
Standarddeviation	2.2E-9	19.1E-9	35.8E-9	190.6E-9	1.3E-6	3.0E-6	3.3E-6	4.7E-6	4.2E-6	5.6E-9
Mean + kσ	9.7E-9	92.7E-9	181.7E-9	772.5E-9	6.6E-6	21.7E-6	32.3E-6	45.8E-6	41.5E-6	45.1E-9
Mean - kσ	-2.6E-9	-11.9E-9	-14.5E-9	-272.7E-9	-349.5E-9	5.4E-6	14.3E-6	20.0E-6	18.6E-6	14.6E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	1.6E-9	1.5E-9	25.4E-9	2.0E-9	6.5E-9	2.5E-9	2.5E-9	1.7E-9	2.2E-9	1.3E-9
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−4
BUL54, (KF1609Y)
Collector-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off
1e−5

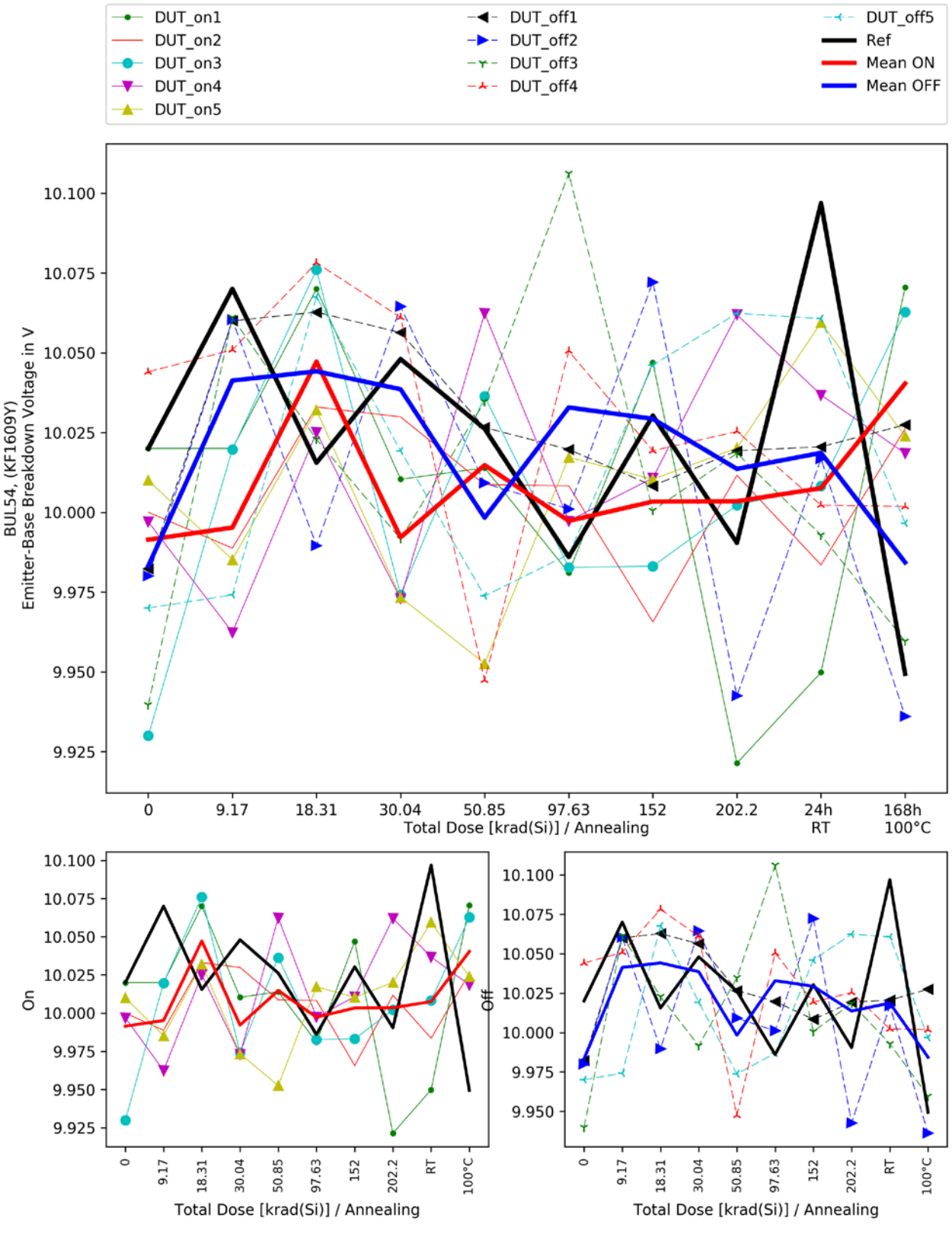
7.8 Emitter-Base Breakdown Voltage

Emitter-Base Breakdown Voltage **BUL54**
V_br_EBO in V Date-/Lotcode: KF1609Y
Limit: 9.9<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	10.0E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	9.9E+0	9.9E+0	10.1E+0
DUT_on2	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0
DUT_on3	9.9E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0
DUT_on4	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0
DUT_on5	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0	10.0E+0
Radiation-Mean ON	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**
Standarddeviation	35.5E-3	24.7E-3	23.8E-3	26.5E-3	40.7E-3	15.8E-3	31.0E-3	51.2E-3	43.2E-3	24.3E-3
Mean + kσ	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.0E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**
Mean - kσ	**9.9E+0**	**9.9E+0**	**10.0E+0**	**9.9E+0**	**9.9E+0**	**10.0E+0**	**9.9E+0**	**9.9E+0**	**9.9E+0**	**10.0E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	10.0E+0	10.1E+0	10.1E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0
DUT_off2	10.0E+0	10.1E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.1E+0	9.9E+0	10.0E+0	9.9E+0
DUT_off3	9.9E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0
DUT_off4	10.0E+0	10.1E+0	10.1E+0	10.1E+0	9.9E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0
DUT_off5	10.0E+0	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0	10.1E+0	10.0E+0
Radiation-Mean OFF	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**
Standarddeviation	38.0E-3	37.8E-3	37.0E-3	31.9E-3	36.9E-3	47.4E-3	29.5E-3	43.6E-3	26.0E-3	36.2E-3
Mean + kσ	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.2E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**
Mean - kσ	**9.9E+0**	**9.9E+0**	**9.9E+0**	**10.0E+0**	**9.9E+0**	**9.9E+0**	**9.9E+0**	**9.9E+0**	**9.9E+0**	**9.9E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	10.0E+0	10.1E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.0E+0	10.1E+0	9.9E+0
Min. Value	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Emitter-Base Breakdown Voltage in V
10.100
10.075
10.050
10.025
10.000
9.975
9.950
9.925
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.9 IEB @ 10 V

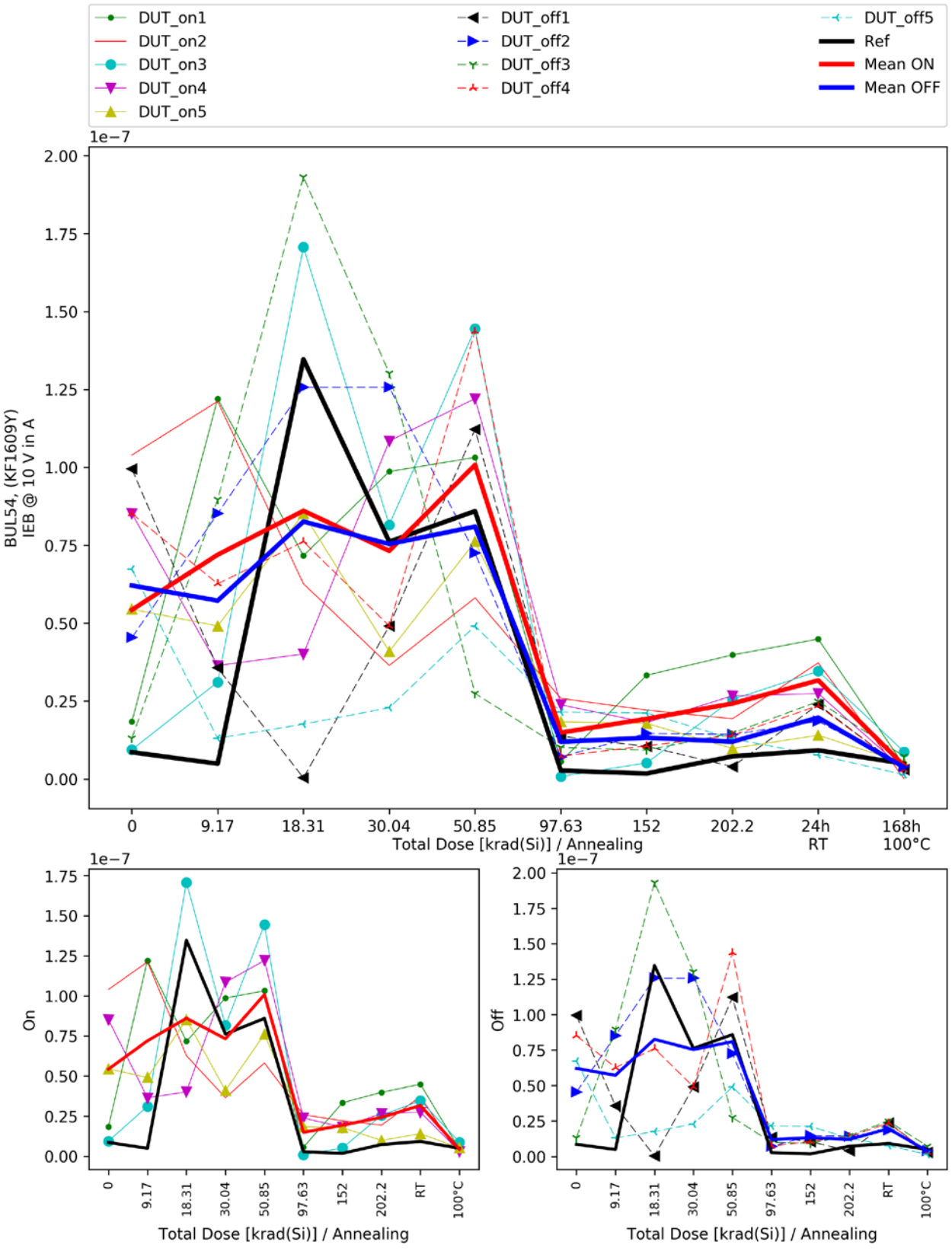
IEB@10V
I(V_br_EBO) in A
Limit: x<0.001

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	18.4E-9	122.0E-9	71.7E-9	98.7E-9	103.2E-9	5.6E-9	33.3E-9	39.8E-9	44.9E-9	4.3E-9
DUT_on2	104.0E-9	121.2E-9	62.6E-9	36.5E-9	58.1E-9	25.9E-9	22.1E-9	19.4E-9	37.3E-9	172.8E-12
DUT_on3	9.4E-9	31.1E-9	170.7E-9	81.5E-9	144.5E-9	831.1E-12	5.2E-9	25.5E-9	34.6E-9	8.8E-9
DUT_on4	85.2E-9	36.4E-9	40.1E-9	108.4E-9	122.1E-9	23.8E-9	18.1E-9	26.7E-9	27.4E-9	3.0E-9
DUT_on5	54.5E-9	49.1E-9	85.2E-9	41.0E-9	76.2E-9	18.4E-9	17.9E-9	9.8E-9	14.0E-9	5.1E-9
Radiation-Mean ON	54.3E-9	72.0E-9	86.1E-9	73.2E-9	100.8E-9	14.9E-9	19.3E-9	24.2E-9	31.6E-9	4.3E-9
Standarddeviation	41.0E-9	45.8E-9	50.1E-9	33.0E-9	34.6E-9	11.1E-9	10.1E-9	11.0E-9	11.7E-9	3.1E-9
Mean + kσ	166.7E-9	197.5E-9	223.4E-9	163.6E-9	195.7E-9	45.5E-9	47.0E-9	54.3E-9	63.6E-9	12.9E-9
Mean - kσ	-58.1E-9	-53.6E-9	-51.3E-9	-17.2E-9	5.9E-9	-15.6E-9	-8.3E-9	-5.8E-9	-316.6E-12	-4.3E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	99.5E-9	35.7E-9	393.0E-12	49.1E-9	112.2E-9	13.7E-9	10.5E-9	4.0E-9	23.9E-9	3.1E-9
DUT_off2	45.4E-9	85.2E-9	125.7E-9	125.7E-9	72.5E-9	7.1E-9	14.7E-9	14.3E-9	18.5E-9	4.0E-9
DUT_off3	13.1E-9	89.7E-9	193.2E-9	130.2E-9	27.5E-9	10.1E-9	9.3E-9	14.7E-9	24.9E-9	7.3E-9
DUT_off4	85.2E-9	62.7E-9	76.2E-9	49.1E-9	143.7E-9	7.3E-9	10.7E-9	14.0E-9	23.6E-9	3.1E-9
DUT_off5	67.3E-9	13.1E-9	17.6E-9	22.9E-9	49.1E-9	21.5E-9	21.2E-9	12.9E-9	7.7E-9	1.4E-9
Radiation-Mean OFF	62.1E-9	57.2E-9	82.6E-9	75.4E-9	81.0E-9	12.0E-9	13.2E-9	12.0E-9	19.7E-9	3.8E-9
Standarddeviation	34.0E-9	32.7E-9	79.2E-9	49.2E-9	47.1E-9	6.0E-9	4.9E-9	4.5E-9	7.1E-9	2.2E-9
Mean + kσ	155.4E-9	146.9E-9	299.9E-9	210.2E-9	210.0E-9	28.3E-9	26.6E-9	24.4E-9	39.3E-9	9.7E-9
Mean - kσ	-31.2E-9	-32.4E-9	-134.7E-9	-59.4E-9	-48.1E-9	-4.4E-9	-134.7E-12	-417.4E-12	124.5E-12	-2.2E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	8.6E-9	4.9E-9	134.7E-9	76.2E-9	86.0E-9	2.7E-9	1.8E-9	7.3E-9	9.2E-9	5.0E-9
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−7
BUL54, (KF1609Y)
IEB @ 10 V in A
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

7.10 Emitter-Base Cutoff Current

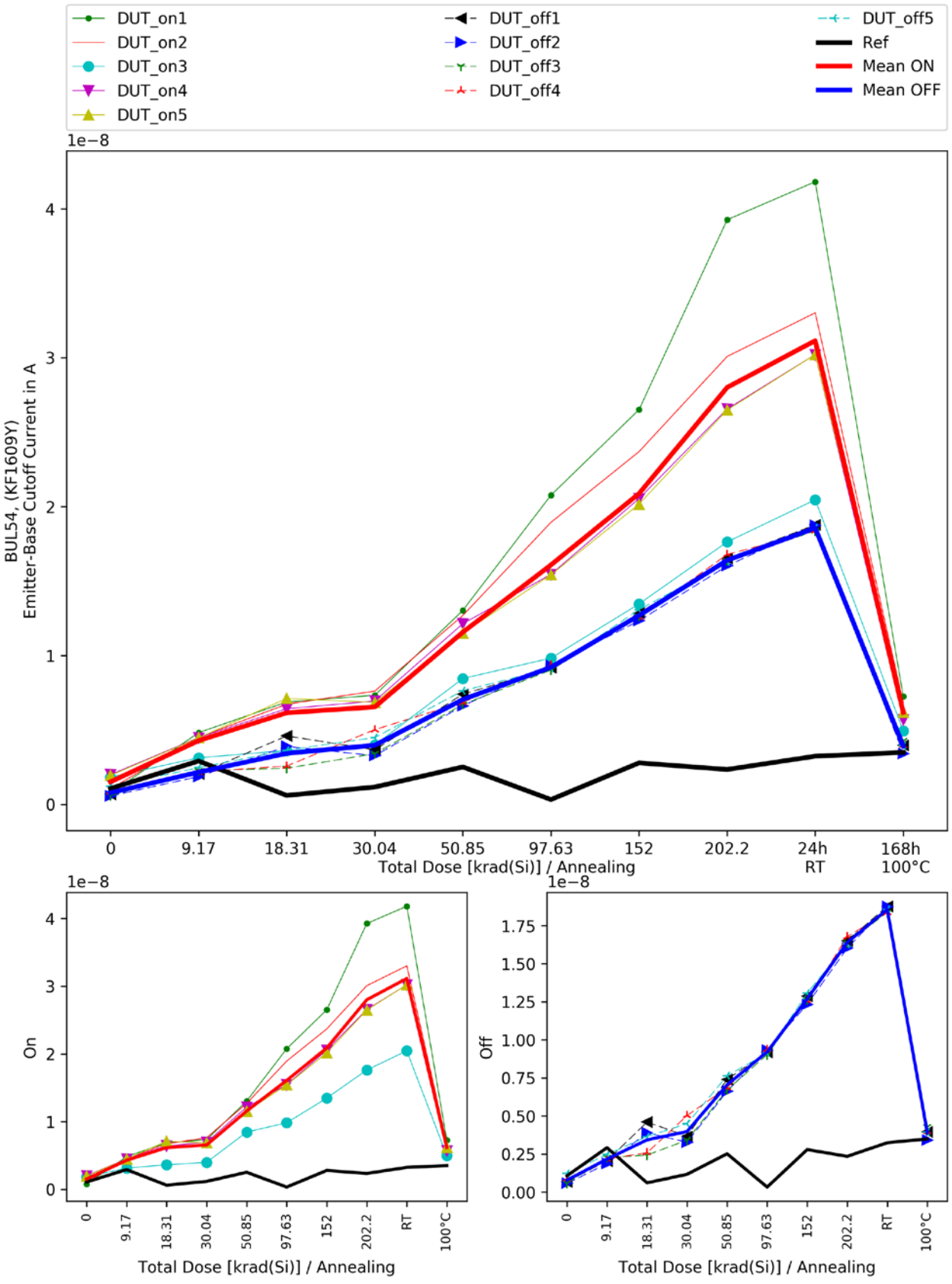
Emitter-Base Cutoff Current **BUL54**
I_EBO in A Date-/Lotcode: KF1609Y
Limit: x < 1e-05

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	748.3E-12	4.8E-9	6.9E-9	7.3E-9	13.0E-9	20.8E-9	26.5E-9	39.3E-9	41.8E-9	7.2E-9
DUT_on2	1.0E-9	4.5E-9	6.7E-9	7.6E-9	12.7E-9	18.9E-9	23.7E-9	30.1E-9	33.0E-9	6.8E-9
DUT_on3	1.8E-9	3.1E-9	3.6E-9	4.0E-9	8.5E-9	9.8E-9	13.5E-9	17.6E-9	20.5E-9	4.9E-9
DUT_on4	2.0E-9	4.5E-9	6.4E-9	6.9E-9	12.1E-9	15.5E-9	20.5E-9	26.6E-9	30.2E-9	5.7E-9
DUT_on5	1.9E-9	4.5E-9	7.1E-9	6.9E-9	11.5E-9	15.4E-9	20.2E-9	26.5E-9	30.2E-9	6.2E-9
Radiation-Mean ON	1.5E-9	4.3E-9	6.2E-9	6.5E-9	11.6E-9	16.1E-9	20.9E-9	28.0E-9	31.1E-9	6.2E-9
Standarddeviation	577.2E-12	658.8E-12	1.4E-9	1.5E-9	1.8E-9	4.2E-9	4.9E-9	7.8E-9	7.6E-9	909.6E-12
Mean + kσ	3.1E-9	6.1E-9	10.1E-9	10.6E-9	16.6E-9	27.6E-9	34.2E-9	49.4E-9	52.1E-9	8.7E-9
Mean - kσ	-66.0E-12	2.5E-9	2.2E-9	2.5E-9	6.5E-9	4.6E-9	7.5E-9	6.6E-9	10.2E-9	3.7E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	676.0E-12	2.1E-9	4.6E-9	3.7E-9	7.4E-9	9.2E-9	12.9E-9	16.5E-9	18.8E-9	4.0E-9
DUT_off2	565.2E-12	1.9E-9	3.9E-9	3.3E-9	6.6E-9	9.3E-9	12.3E-9	16.0E-9	18.7E-9	3.4E-9
DUT_off3	578.7E-12	2.3E-9	2.4E-9	3.4E-9	6.7E-9	9.0E-9	12.6E-9	16.4E-9	18.4E-9	4.3E-9
DUT_off4	871.7E-12	2.2E-9	2.6E-9	5.0E-9	6.9E-9	9.4E-9	12.6E-9	16.8E-9	18.4E-9	4.0E-9
DUT_off5	1.2E-9	2.5E-9	3.6E-9	4.5E-9	7.6E-9	9.1E-9	13.1E-9	16.3E-9	18.6E-9	3.9E-9
Radiation-Mean OFF	782.7E-12	2.2E-9	3.4E-9	4.0E-9	7.0E-9	9.2E-9	12.7E-9	16.4E-9	18.6E-9	3.9E-9
Standarddeviation	274.4E-12	223.3E-12	915.0E-12	751.4E-12	446.7E-12	140.4E-12	285.1E-12	281.1E-12	195.5E-12	314.7E-12
Mean + kσ	1.5E-9	2.8E-9	5.9E-9	6.0E-9	8.3E-9	9.6E-9	13.5E-9	17.2E-9	19.1E-9	4.8E-9
Mean - kσ	30.2E-12	1.6E-9	919.8E-12	1.9E-9	5.8E-9	8.8E-9	11.9E-9	15.6E-9	18.0E-9	3.1E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	1.1E-9	2.9E-9	605.0E-12	1.2E-9	2.5E-9	327.0E-12	2.8E-9	2.3E-9	3.2E-9	3.5E-9
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6

Fraunhofer
INT



Version 1.0

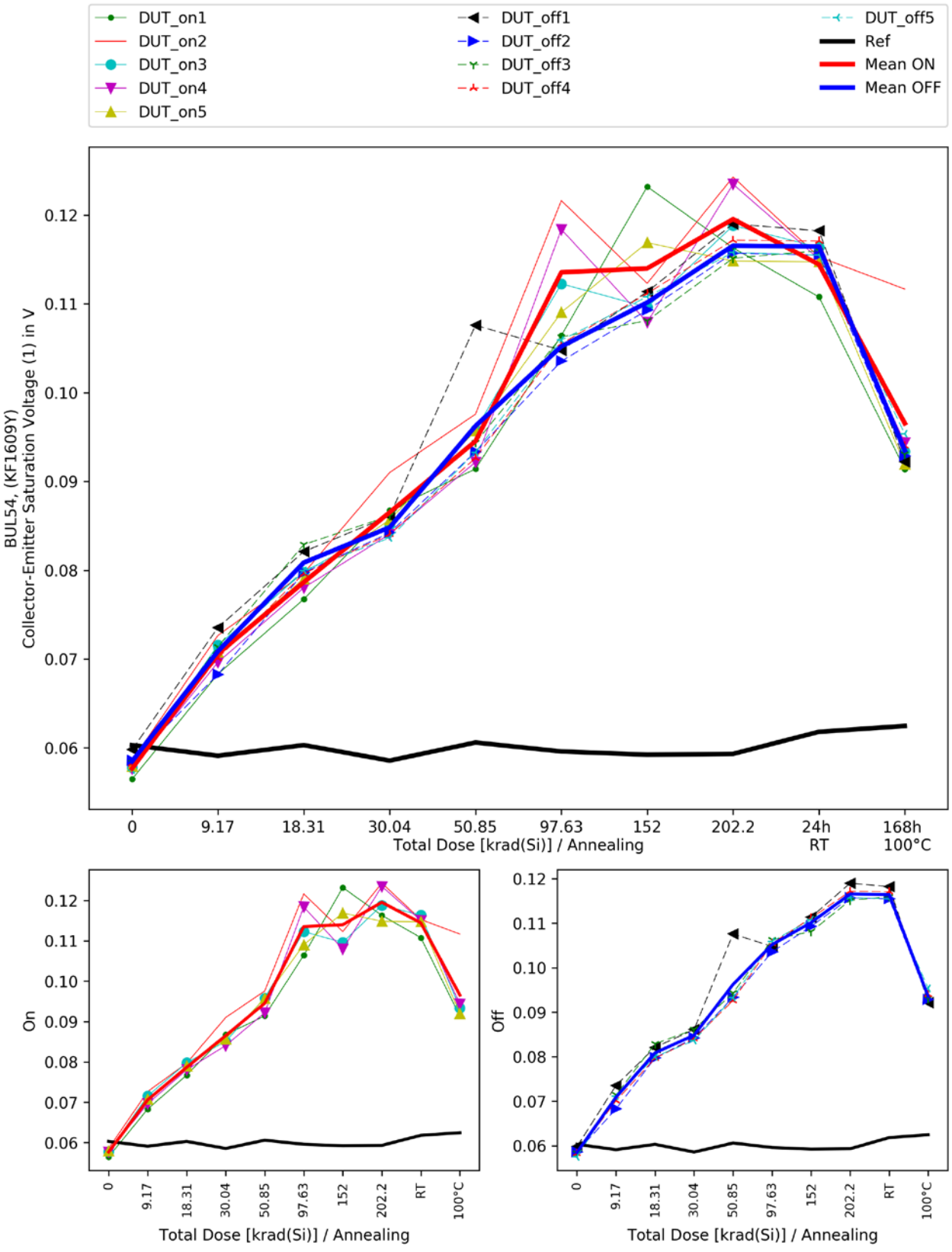
7.11 Collector-Emitter Saturation Voltage (1)

Collector-Emitter Saturation Voltage (1) **BUL54**
V_CEsat 1 in V Date-/Lotcode: KF1609Y
Limit: x<0.1

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	56.5E-3	68.3E-3	76.7E-3	86.8E-3	91.4E-3	106.4E-3	123.2E-3	116.3E-3	110.8E-3	91.4E-3
DUT_on2	58.6E-3	72.7E-3	79.7E-3	91.0E-3	97.6E-3	121.6E-3	112.3E-3	124.3E-3	115.3E-3	111.7E-3
DUT_on3	57.8E-3	71.6E-3	79.8E-3	85.1E-3	95.8E-3	112.3E-3	109.6E-3	118.8E-3	116.4E-3	93.4E-3
DUT_on4	57.7E-3	69.6E-3	78.0E-3	84.1E-3	92.2E-3	118.4E-3	107.9E-3	123.5E-3	115.0E-3	94.4E-3
DUT_on5	57.9E-3	70.8E-3	79.0E-3	85.7E-3	95.7E-3	109.0E-3	116.9E-3	114.8E-3	114.7E-3	91.9E-3
Radiation-Mean ON	57.7E-3	70.6E-3	78.6E-3	86.5E-3	94.5E-3	113.5E-3	114.0E-3	119.5E-3	114.4E-3	96.5E-3
Standarddeviation	756.9E-6	1.7E-3	1.3E-3	2.7E-3	2.6E-3	6.3E-3	6.2E-3	4.2E-3	2.1E-3	8.5E-3
Mean + kσ	59.8E-3	75.2E-3	82.1E-3	93.9E-3	101.7E-3	131.0E-3	130.9E-3	131.1E-3	120.3E-3	119.9E-3
Mean - kσ	55.6E-3	66.0E-3	75.1E-3	79.1E-3	87.3E-3	96.1E-3	97.1E-3	108.0E-3	108.6E-3	73.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	59.8E-3	73.5E-3	82.1E-3	86.1E-3	107.6E-3	104.8E-3	111.4E-3	119.0E-3	118.2E-3	92.2E-3
DUT_off2	58.6E-3	68.3E-3	79.7E-3	84.2E-3	93.3E-3	103.5E-3	109.3E-3	115.7E-3	115.5E-3	92.9E-3
DUT_off3	58.3E-3	71.4E-3	82.9E-3	86.1E-3	94.4E-3	106.3E-3	108.1E-3	115.1E-3	116.0E-3	93.1E-3
DUT_off4	58.3E-3	70.1E-3	79.6E-3	84.1E-3	92.6E-3	105.5E-3	111.2E-3	117.2E-3	117.1E-3	94.0E-3
DUT_off5	57.5E-3	71.1E-3	80.0E-3	83.6E-3	93.3E-3	105.9E-3	110.8E-3	115.8E-3	115.5E-3	95.4E-3
Radiation-Mean OFF	58.5E-3	70.9E-3	80.9E-3	84.8E-3	96.2E-3	105.2E-3	110.1E-3	116.6E-3	116.4E-3	93.5E-3
Standarddeviation	836.4E-6	1.9E-3	1.5E-3	1.2E-3	6.4E-3	1.1E-3	1.4E-3	1.6E-3	1.2E-3	1.2E-3
Mean + kσ	60.8E-3	76.2E-3	85.0E-3	88.1E-3	113.7E-3	108.2E-3	114.0E-3	120.8E-3	119.7E-3	96.8E-3
Mean - kσ	56.2E-3	65.6E-3	76.7E-3	81.6E-3	78.7E-3	102.2E-3	106.3E-3	112.3E-3	113.2E-3	90.2E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	60.3E-3	59.1E-3	60.3E-3	58.6E-3	60.6E-3	59.6E-3	59.2E-3	59.3E-3	61.8E-3	62.5E-3
Typ. Value	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3
Max. Value	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Collector-Emitter Saturation Voltage (1) in V
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.12 Collector-Emitter Saturation Voltage (2)

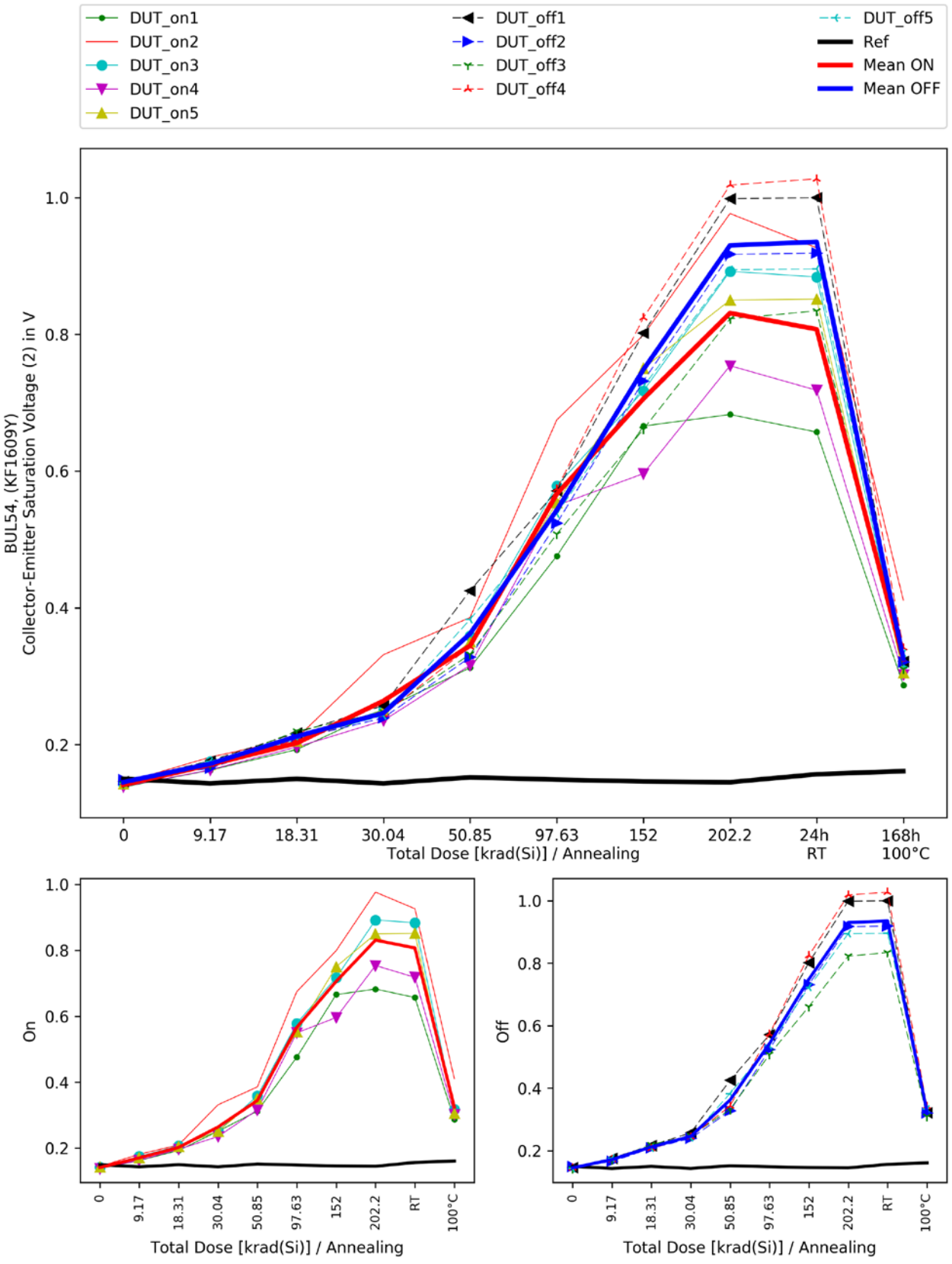
Collector-Emitter Saturation Voltage (2)
V_CEsat2 in V
Limit: x<0.2

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	137.8E-3	162.6E-3	192.7E-3	251.1E-3	312.3E-3	475.7E-3	665.7E-3	682.6E-3	656.9E-3	286.9E-3
DUT_on2	144.3E-3	181.4E-3	209.5E-3	331.4E-3	385.7E-3	674.6E-3	798.8E-3	976.5E-3	926.3E-3	411.0E-3
DUT_on3	142.5E-3	174.8E-3	206.8E-3	251.1E-3	358.6E-3	578.2E-3	717.2E-3	892.0E-3	883.8E-3	318.0E-3
DUT_on4	138.4E-3	163.0E-3	196.4E-3	235.0E-3	316.0E-3	549.6E-3	596.1E-3	754.0E-3	718.1E-3	301.8E-3
DUT_on5	142.3E-3	170.7E-3	205.0E-3	250.8E-3	350.0E-3	553.5E-3	750.1E-3	849.9E-3	851.3E-3	305.1E-3
Radiation-Mean ON	141.0E-3	170.5E-3	202.1E-3	263.9E-3	344.5E-3	566.3E-3	705.6E-3	831.0E-3	807.3E-3	324.6E-3
Standarddeviation	2.8E-3	8.0E-3	7.2E-3	38.4E-3	30.7E-3	71.6E-3	78.1E-3	115.3E-3	114.6E-3	49.6E-3
Mean + kσ	148.8E-3	192.5E-3	221.8E-3	369.1E-3	428.8E-3	762.7E-3	919.7E-3	1.1E+0	1.1E+0	460.5E-3
Mean - kσ	133.3E-3	148.5E-3	182.4E-3	158.7E-3	260.2E-3	369.9E-3	491.5E-3	514.7E-3	493.1E-3	188.6E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	146.0E-3	176.2E-3	217.2E-3	257.0E-3	425.1E-3	570.9E-3	801.6E-3	998.3E-3	999.7E-3	321.5E-3
DUT_off2	148.5E-3	165.2E-3	208.0E-3	239.0E-3	327.6E-3	523.4E-3	731.6E-3	916.7E-3	918.6E-3	320.6E-3
DUT_off3	142.7E-3	170.5E-3	219.5E-3	247.7E-3	331.8E-3	507.9E-3	661.0E-3	822.4E-3	834.2E-3	310.3E-3
DUT_off4	144.8E-3	171.3E-3	207.0E-3	243.7E-3	343.2E-3	573.5E-3	823.9E-3	1.0E+0	1.0E+0	341.5E-3
DUT_off5	143.3E-3	175.8E-3	208.7E-3	242.4E-3	382.9E-3	537.0E-3	723.2E-3	894.3E-3	895.6E-3	333.8E-3
Radiation-Mean OFF	145.1E-3	171.8E-3	212.1E-3	246.0E-3	362.1E-3	542.5E-3	748.3E-3	930.0E-3	935.1E-3	325.6E-3
Standarddeviation	2.3E-3	4.5E-3	5.8E-3	6.9E-3	41.4E-3	29.0E-3	65.4E-3	79.8E-3	78.5E-3	12.2E-3
Mean + kσ	151.4E-3	184.1E-3	228.0E-3	264.9E-3	475.7E-3	622.0E-3	927.5E-3	1.1E+0	1.2E+0	359.0E-3
Mean - kσ	138.8E-3	159.5E-3	196.2E-3	227.1E-3	248.5E-3	463.1E-3	569.1E-3	711.2E-3	719.7E-3	292.1E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	149.7E-3	143.2E-3	149.7E-3	143.2E-3	152.0E-3	148.7E-3	146.0E-3	144.9E-3	156.6E-3	161.1E-3
Typ. Value	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3
Max. Value	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Collector-Emitter Saturation Voltage (2) in V
1.0
0.8
0.6
0.4
0.2
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

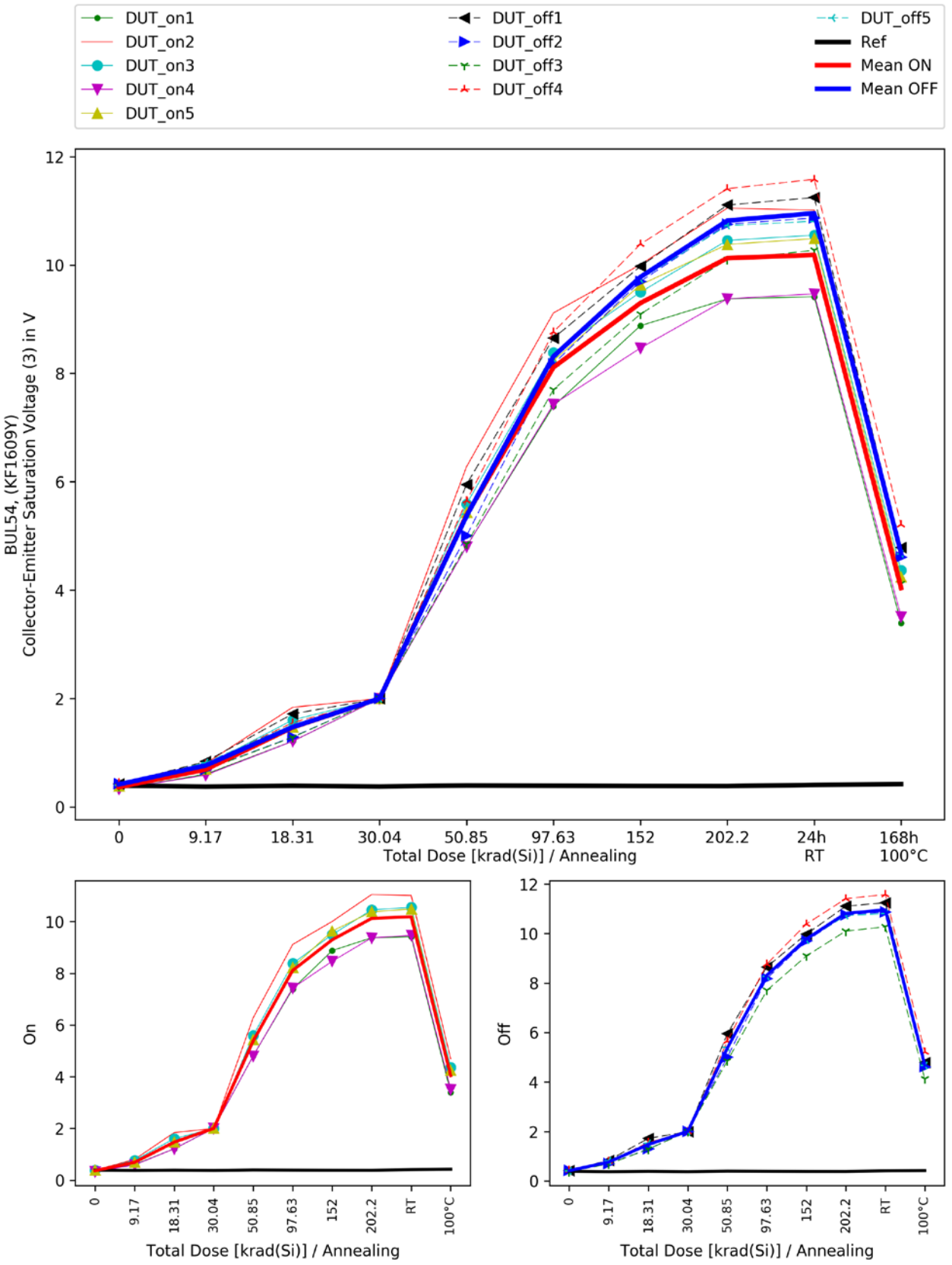
7.13 Collector-Emitter Saturation Voltage (3)

Collector-Emitter Saturation Voltage (3) **BUL54**
V_CEsat3 in V Date-/Lotcode: KF1609Y
Limit: x<0.5

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	328.8E-3	603.9E-3	1.2E+0	2.0E+0	4.8E+0	7.4E+0	8.9E+0	9.4E+0	9.4E+0	3.4E+0
DUT_on2	391.4E-3	802.8E-3	1.8E+0	2.0E+0	6.3E+0	9.1E+0	10.0E+0	11.0E+0	11.0E+0	4.7E+0
DUT_on3	390.2E-3	767.8E-3	1.6E+0	2.0E+0	5.6E+0	8.4E+0	9.5E+0	10.5E+0	10.5E+0	4.4E+0
DUT_on4	332.1E-3	587.4E-3	1.2E+0	2.0E+0	4.8E+0	7.4E+0	8.5E+0	9.4E+0	9.5E+0	3.5E+0
DUT_on5	385.5E-3	692.9E-3	1.5E+0	2.0E+0	5.4E+0	8.2E+0	9.6E+0	10.4E+0	10.5E+0	4.2E+0
Radiation-Mean ON	365.6E-3	691.0E-3	1.5E+0	2.0E+0	5.4E+0	8.1E+0	9.3E+0	10.1E+0	10.2E+0	4.0E+0
Standarddeviation	32.2E-3	95.9E-3	267.8E-3	152.3E-6	614.5E-3	719.4E-3	616.5E-3	734.2E-3	709.6E-3	562.1E-3
Mean + kσ	453.9E-3	953.8E-3	2.2E+0	2.0E+0	7.1E+0	10.1E+0	11.0E+0	12.1E+0	12.1E+0	5.6E+0
Mean - kσ	277.4E-3	428.1E-3	734.6E-3	2.0E+0	3.7E+0	6.1E+0	7.6E+0	8.1E+0	8.2E+0	2.5E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	424.3E-3	837.8E-3	1.7E+0	2.0E+0	5.9E+0	8.6E+0	10.0E+0	11.1E+0	11.2E+0	4.8E+0
DUT_off2	424.7E-3	690.4E-3	1.3E+0	2.0E+0	5.0E+0	8.2E+0	9.7E+0	10.8E+0	10.9E+0	4.6E+0
DUT_off3	384.3E-3	686.5E-3	1.3E+0	2.0E+0	4.8E+0	7.7E+0	9.1E+0	10.1E+0	10.3E+0	4.1E+0
DUT_off4	444.6E-3	793.5E-3	1.6E+0	2.0E+0	5.6E+0	8.8E+0	10.4E+0	11.4E+0	11.6E+0	5.2E+0
DUT_off5	402.6E-3	820.2E-3	1.5E+0	2.0E+0	5.4E+0	8.3E+0	9.7E+0	10.7E+0	10.8E+0	4.7E+0
Radiation-Mean OFF	416.1E-3	765.7E-3	1.5E+0	2.0E+0	5.4E+0	8.3E+0	9.8E+0	10.8E+0	11.0E+0	4.7E+0
Standarddeviation	23.2E-3	72.3E-3	184.2E-3	244.9E-6	453.5E-3	421.6E-3	469.6E-3	489.1E-3	493.1E-3	390.2E-3
Mean + kσ	479.7E-3	963.8E-3	2.0E+0	2.0E+0	6.6E+0	9.5E+0	11.1E+0	12.2E+0	12.3E+0	5.7E+0
Mean - kσ	352.5E-3	567.6E-3	968.5E-3	2.0E+0	4.1E+0	7.2E+0	8.5E+0	9.5E+0	9.6E+0	3.6E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	392.0E-3	377.0E-3	389.6E-3	378.0E-3	396.5E-3	390.8E-3	386.4E-3	385.1E-3	408.1E-3	419.7E-3
Typ. Value	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3
Max. Value	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Collector-Emitter Saturation Voltage (3) in V
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

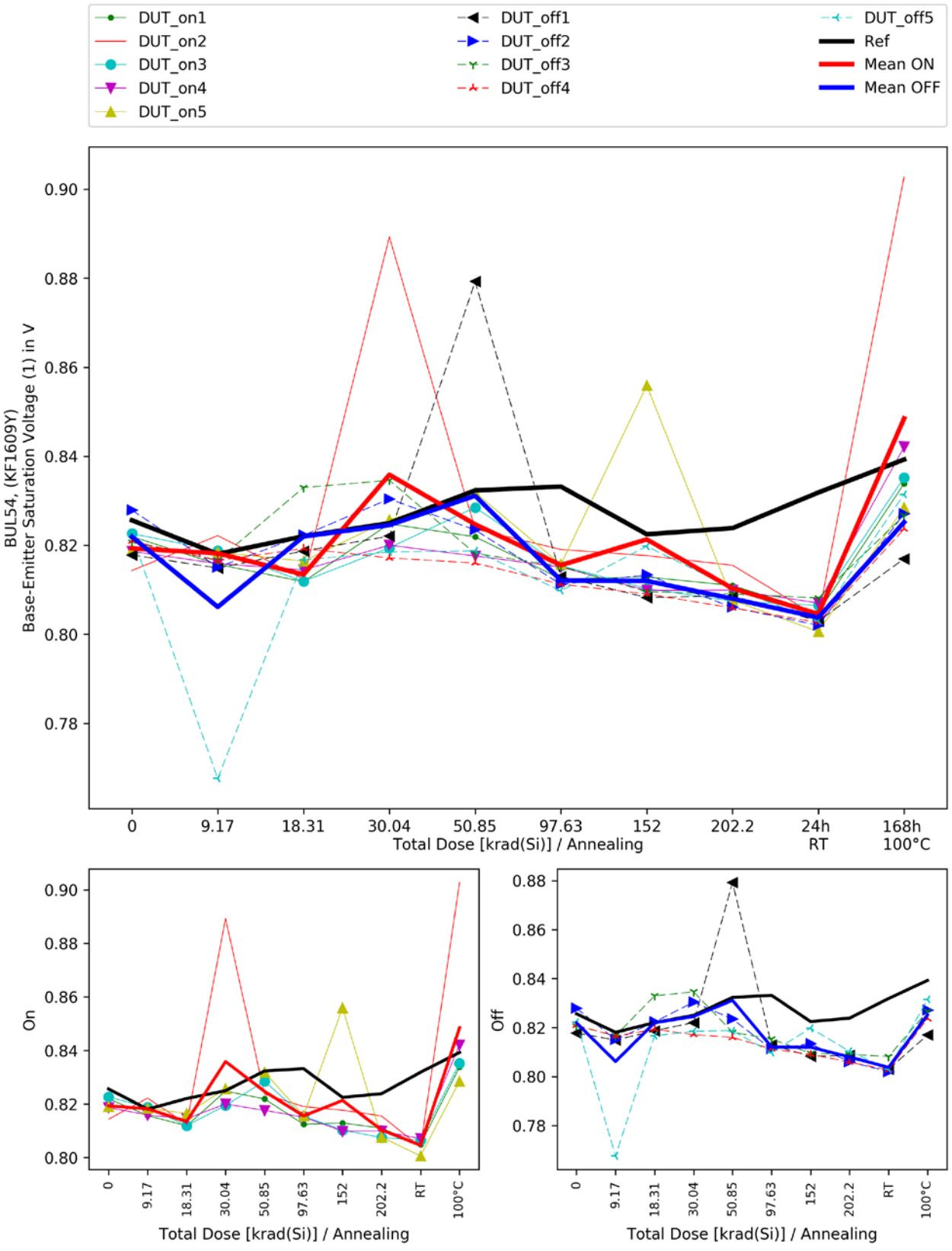
7.14 Base-Emitter Saturation Voltage (1)

Base-Emitter Saturation Voltage (1) **BUL54**
V_BEsat1 in V Date-/Lotcode: KF1609Y
Limit: x<1.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	822.0E-3	815.7E-3	811.8E-3	824.8E-3	821.9E-3	812.4E-3	812.9E-3	811.0E-3	804.9E-3	833.8E-3
DUT_on2	814.3E-3	822.2E-3	812.5E-3	889.3E-3	823.7E-3	819.1E-3	817.7E-3	815.5E-3	803.8E-3	902.8E-3
DUT_on3	822.6E-3	818.7E-3	811.9E-3	819.4E-3	828.5E-3	815.4E-3	810.3E-3	807.4E-3	806.5E-3	835.2E-3
DUT_on4	818.6E-3	815.9E-3	814.5E-3	820.0E-3	817.6E-3	815.1E-3	809.9E-3	809.9E-3	807.0E-3	842.1E-3
DUT_on5	819.0E-3	818.4E-3	816.4E-3	825.7E-3	831.9E-3	815.7E-3	855.9E-3	807.7E-3	800.6E-3	828.5E-3
Radiation-Mean ON	819.3E-3	818.2E-3	813.4E-3	835.8E-3	824.7E-3	815.5E-3	821.3E-3	810.3E-3	804.6E-3	848.5E-3
Standarddeviation	3.3E-3	2.6E-3	2.0E-3	30.0E-3	5.6E-3	2.4E-3	19.6E-3	3.3E-3	2.6E-3	30.7E-3
Mean + kσ	828.3E-3	825.4E-3	818.9E-3	918.1E-3	840.0E-3	822.0E-3	875.0E-3	819.3E-3	811.6E-3	932.8E-3
Mean - kσ	810.3E-3	811.0E-3	808.0E-3	753.6E-3	809.4E-3	809.1E-3	767.7E-3	801.3E-3	797.5E-3	764.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	817.8E-3	814.9E-3	818.7E-3	822.0E-3	879.3E-3	813.0E-3	808.3E-3	808.7E-3	802.9E-3	817.0E-3
DUT_off2	827.9E-3	815.1E-3	822.2E-3	830.4E-3	823.5E-3	811.2E-3	813.3E-3	806.0E-3	802.0E-3	827.1E-3
DUT_off3	820.7E-3	816.7E-3	833.0E-3	834.6E-3	818.1E-3	815.3E-3	809.5E-3	809.1E-3	808.2E-3	826.7E-3
DUT_off4	820.9E-3	816.5E-3	819.3E-3	817.1E-3	816.0E-3	811.3E-3	809.1E-3	805.9E-3	802.7E-3	823.6E-3
DUT_off5	822.2E-3	767.6E-3	816.7E-3	818.5E-3	818.7E-3	809.8E-3	819.8E-3	810.3E-3	803.0E-3	831.5E-3
Radiation-Mean OFF	821.9E-3	806.2E-3	822.0E-3	824.5E-3	831.1E-3	812.1E-3	812.0E-3	808.0E-3	803.8E-3	825.2E-3
Standarddeviation	3.7E-3	21.6E-3	6.5E-3	7.6E-3	27.0E-3	2.1E-3	4.8E-3	1.9E-3	2.5E-3	5.4E-3
Mean + kσ	832.1E-3	865.3E-3	839.7E-3	845.5E-3	905.3E-3	817.9E-3	825.1E-3	813.3E-3	810.6E-3	839.9E-3
Mean - kσ	811.7E-3	747.0E-3	804.3E-3	803.6E-3	757.0E-3	806.3E-3	798.9E-3	802.7E-3	796.9E-3	810.5E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	825.6E-3	818.1E-3	822.0E-3	825.0E-3	832.3E-3	833.2E-3	822.5E-3	823.8E-3	831.9E-3	839.3E-3
Typ. Value	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3
Max. Value	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Base-Emitter Saturation Voltage (1) in V
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.15 Base-Emitter Saturation Voltage (2)

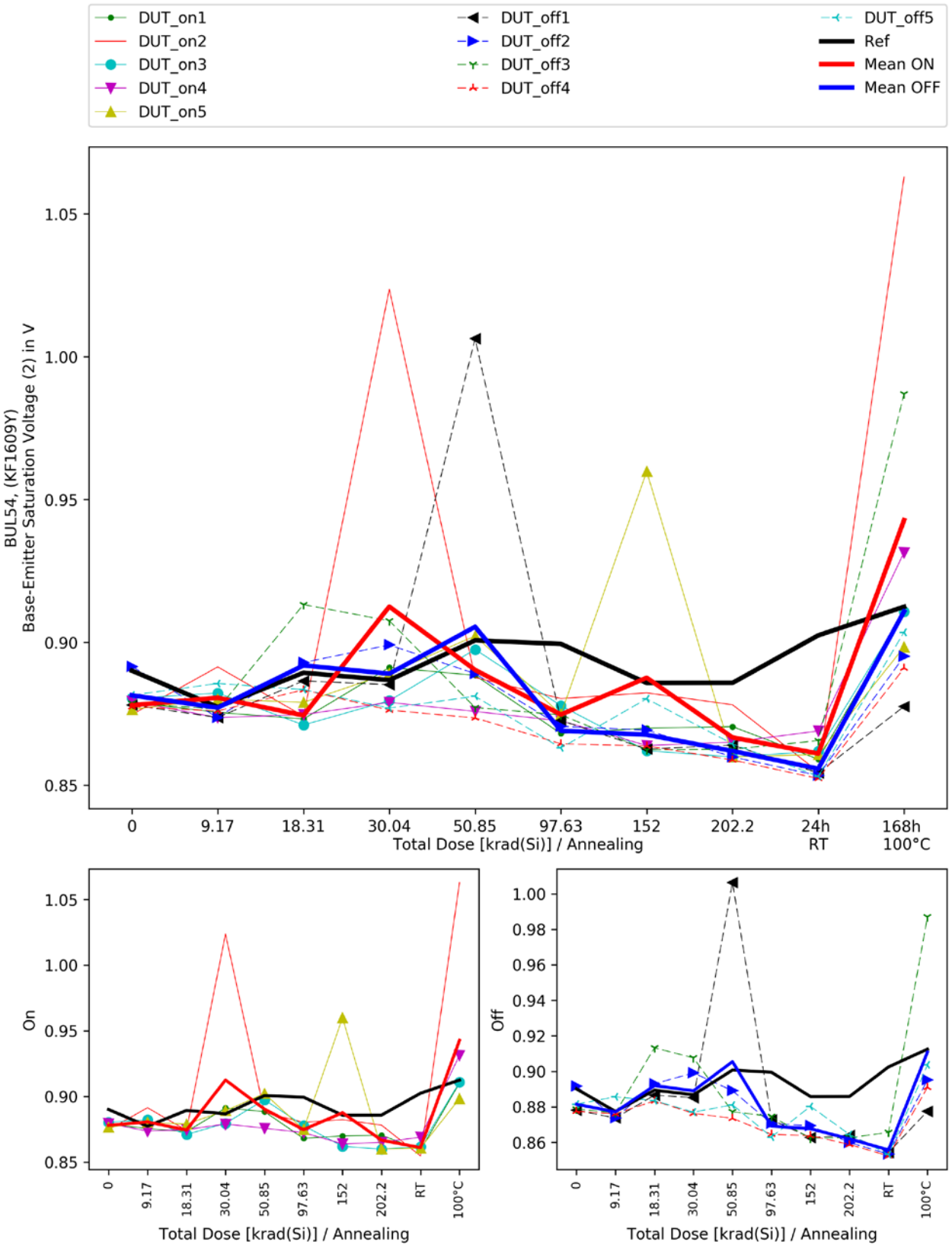
Base-Emitter Saturation Voltage (2)
V_BEsat2 in V
Limit: x<1.1

BUL54
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	879.0E-3	875.5E-3	873.2E-3	891.2E-3	888.5E-3	868.1E-3	870.0E-3	870.5E-3	859.1E-3	910.3E-3
DUT_on2	874.7E-3	891.4E-3	874.2E-3	1.0E+0	887.7E-3	880.3E-3	882.3E-3	878.2E-3	854.7E-3	1.1E+0
DUT_on3	880.4E-3	882.2E-3	871.1E-3	879.6E-3	897.5E-3	877.8E-3	862.1E-3	859.9E-3	861.9E-3	910.8E-3
DUT_on4	879.3E-3	873.7E-3	874.7E-3	879.0E-3	875.8E-3	872.5E-3	863.9E-3	865.1E-3	869.0E-3	931.5E-3
DUT_on5	876.5E-3	880.2E-3	879.0E-3	889.2E-3	902.2E-3	874.9E-3	959.8E-3	859.9E-3	860.7E-3	898.4E-3
Radiation-Mean ON	878.0E-3	880.6E-3	874.4E-3	912.5E-3	890.3E-3	874.7E-3	887.6E-3	866.7E-3	861.1E-3	942.8E-3
Standarddeviation	2.3E-3	7.0E-3	2.9E-3	62.4E-3	10.2E-3	4.7E-3	41.1E-3	7.8E-3	5.2E-3	68.3E-3
Mean + kσ	884.3E-3	899.7E-3	882.4E-3	1.1E+0	918.2E-3	887.7E-3	1.0E+0	888.0E-3	875.3E-3	1.1E+0
Mean - kσ	871.6E-3	861.5E-3	866.5E-3	741.5E-3	862.4E-3	861.7E-3	774.8E-3	845.4E-3	846.8E-3	755.7E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	878.0E-3	873.7E-3	886.5E-3	885.2E-3	1.0E+0	872.7E-3	862.7E-3	864.0E-3	854.3E-3	877.6E-3
DUT_off2	891.6E-3	873.7E-3	893.0E-3	899.1E-3	889.0E-3	870.6E-3	869.3E-3	859.9E-3	853.4E-3	895.1E-3
DUT_off3	878.7E-3	876.6E-3	913.2E-3	907.6E-3	877.2E-3	874.6E-3	862.3E-3	862.6E-3	865.6E-3	987.0E-3
DUT_off4	877.5E-3	876.0E-3	883.4E-3	876.3E-3	873.5E-3	864.5E-3	863.7E-3	858.8E-3	852.3E-3	890.9E-3
DUT_off5	881.5E-3	885.6E-3	883.5E-3	877.0E-3	881.1E-3	863.0E-3	880.3E-3	864.4E-3	853.2E-3	903.6E-3
Radiation-Mean OFF	881.5E-3	877.1E-3	891.9E-3	889.0E-3	905.5E-3	869.1E-3	867.7E-3	862.0E-3	855.7E-3	910.8E-3
Standarddeviation	5.9E-3	4.9E-3	12.5E-3	13.8E-3	56.7E-3	5.1E-3	7.6E-3	2.5E-3	5.5E-3	43.6E-3
Mean + kσ	897.5E-3	890.6E-3	926.3E-3	927.0E-3	1.1E+0	883.0E-3	888.4E-3	868.8E-3	871.0E-3	1.0E+0
Mean - kσ	865.4E-3	863.6E-3	857.5E-3	851.0E-3	749.9E-3	855.2E-3	846.9E-3	855.1E-3	840.5E-3	791.3E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	890.1E-3	877.4E-3	889.4E-3	886.8E-3	900.7E-3	899.5E-3	885.8E-3	885.8E-3	902.5E-3	912.5E-3
Typ. Value	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3
Max. Value	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54, (KF1609Y)
Base-Emitter Saturation Voltage (2) in V
1.05
1.00
0.95
0.90
0.85
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
1.05
1.00
0.95
0.90
0.85
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0
9.17
18.31
30.04
50.85
97.63
152
202.2
RT
100°C
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

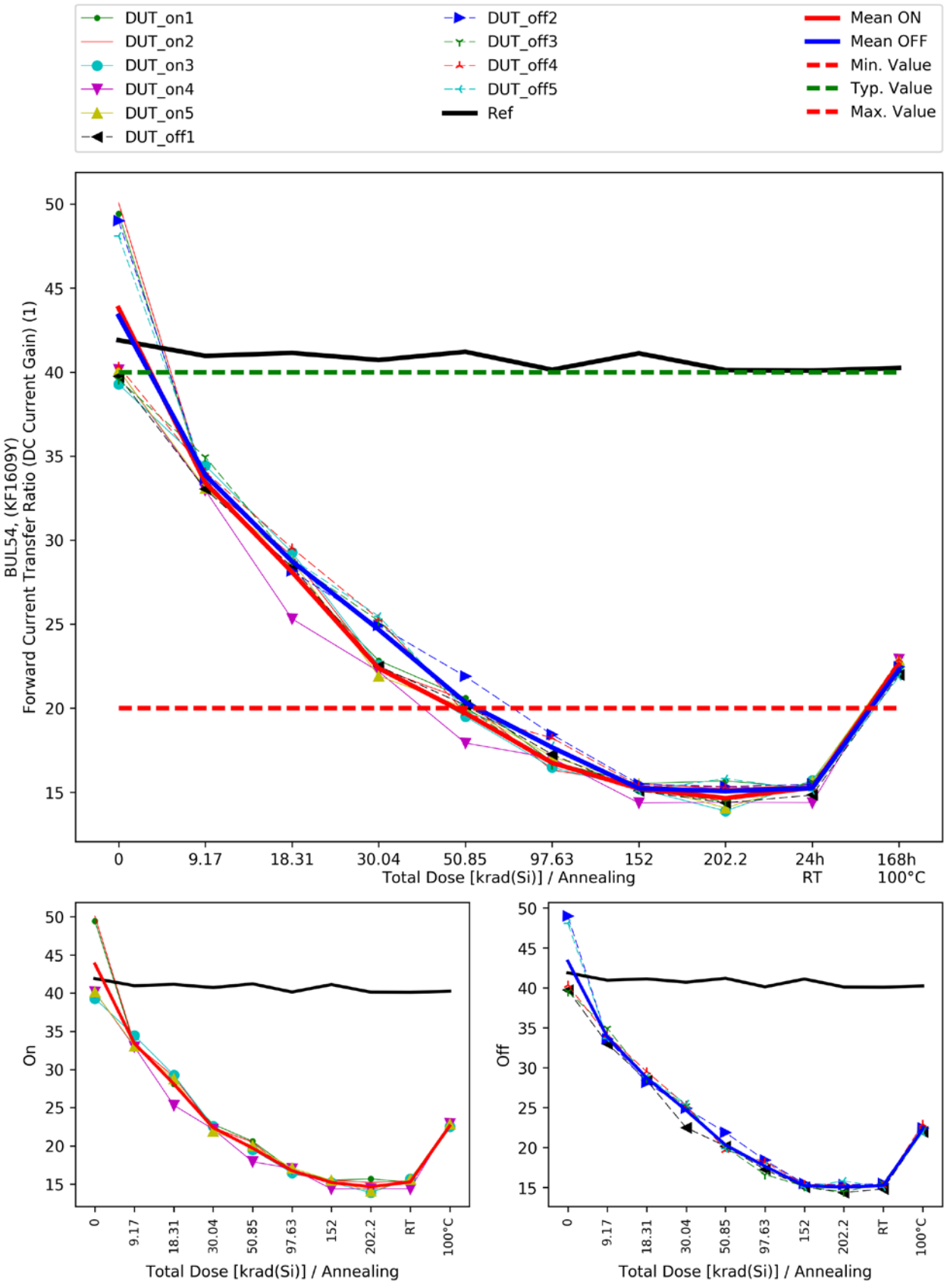
7.16 Forward Current Transfer Ratio (DC Current Gain) (1)

Forward Current Transfer Ratio (DC Current Gain) (1) **BUL54**
HFE1 Date-/Lotcode: KF1609Y
Limit: 20.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	49.4E+0	33.2E+0	28.1E+0	22.8E+0	20.6E+0	16.8E+0	15.5E+0	15.7E+0	15.2E+0	22.3E+0
DUT_on2	50.1E+0	33.4E+0	29.1E+0	22.4E+0	20.5E+0	16.3E+0	15.5E+0	15.2E+0	15.4E+0	22.5E+0
DUT_on3	39.3E+0	34.4E+0	29.3E+0	22.6E+0	19.5E+0	16.5E+0	15.2E+0	13.9E+0	15.7E+0	22.5E+0
DUT_on4	40.1E+0	33.0E+0	25.3E+0	22.2E+0	17.9E+0	17.0E+0	14.4E+0	14.4E+0	14.4E+0	22.9E+0
DUT_on5	40.1E+0	33.1E+0	28.8E+0	21.9E+0	20.0E+0	17.1E+0	15.5E+0	14.1E+0	15.6E+0	22.8E+0
Radiation-Mean ON	43.8E+0	33.4E+0	28.1E+0	22.4E+0	19.7E+0	16.7E+0	15.2E+0	14.6E+0	15.3E+0	22.6E+0
Standarddeviation	5.4E+0	591.4E-3	1.6E+0	351.6E-3	1.1E+0	345.6E-3	490.0E-3	767.8E-3	531.5E-3	256.5E-3
Mean + kσ	58.7E+0	35.0E+0	32.5E+0	23.3E+0	22.7E+0	17.7E+0	16.5E+0	16.7E+0	16.7E+0	23.3E+0
Mean - kσ	28.9E+0	31.8E+0	23.7E+0	21.4E+0	16.7E+0	15.8E+0	13.9E+0	12.5E+0	13.8E+0	21.9E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	39.7E+0	33.0E+0	28.4E+0	22.5E+0	20.2E+0	17.3E+0	15.1E+0	14.4E+0	14.8E+0	22.0E+0
DUT_off2	49.0E+0	33.6E+0	28.2E+0	24.9E+0	21.9E+0	18.4E+0	15.5E+0	15.3E+0	15.5E+0	22.4E+0
DUT_off3	39.6E+0	34.9E+0	28.7E+0	25.2E+0	20.1E+0	16.6E+0	15.1E+0	14.4E+0	15.6E+0	22.3E+0
DUT_off4	40.4E+0	34.1E+0	29.5E+0	25.3E+0	19.7E+0	18.2E+0	15.4E+0	15.3E+0	15.3E+0	22.9E+0
DUT_off5	48.1E+0	33.7E+0	28.9E+0	25.5E+0	19.9E+0	17.8E+0	15.1E+0	15.8E+0	15.1E+0	21.9E+0
Radiation-Mean OFF	43.3E+0	33.9E+0	28.7E+0	24.7E+0	20.3E+0	17.7E+0	15.2E+0	15.1E+0	15.2E+0	22.3E+0
Standarddeviation	4.8E+0	706.8E-3	520.6E-3	1.2E+0	883.2E-3	732.0E-3	191.7E-3	626.7E-3	304.7E-3	404.6E-3
Mean + kσ	56.4E+0	35.8E+0	30.2E+0	28.1E+0	22.8E+0	19.7E+0	15.8E+0	16.8E+0	16.1E+0	23.4E+0
Mean - kσ	30.3E+0	31.9E+0	27.3E+0	21.3E+0	17.9E+0	15.7E+0	14.7E+0	13.3E+0	14.4E+0	21.2E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	41.9E+0	41.0E+0	41.1E+0	40.7E+0	41.2E+0	40.1E+0	41.1E+0	40.1E+0	40.1E+0	40.2E+0
Min. Value	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0
Typ. Value	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
Min. Value
Typ. Value
Max. Value
BUL54, (KF1609Y)
Forward Current Transfer Ratio (DC Current Gain) (1)
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

7.17 Forward Current Transfer Ratio (DC Current Gain) (2)

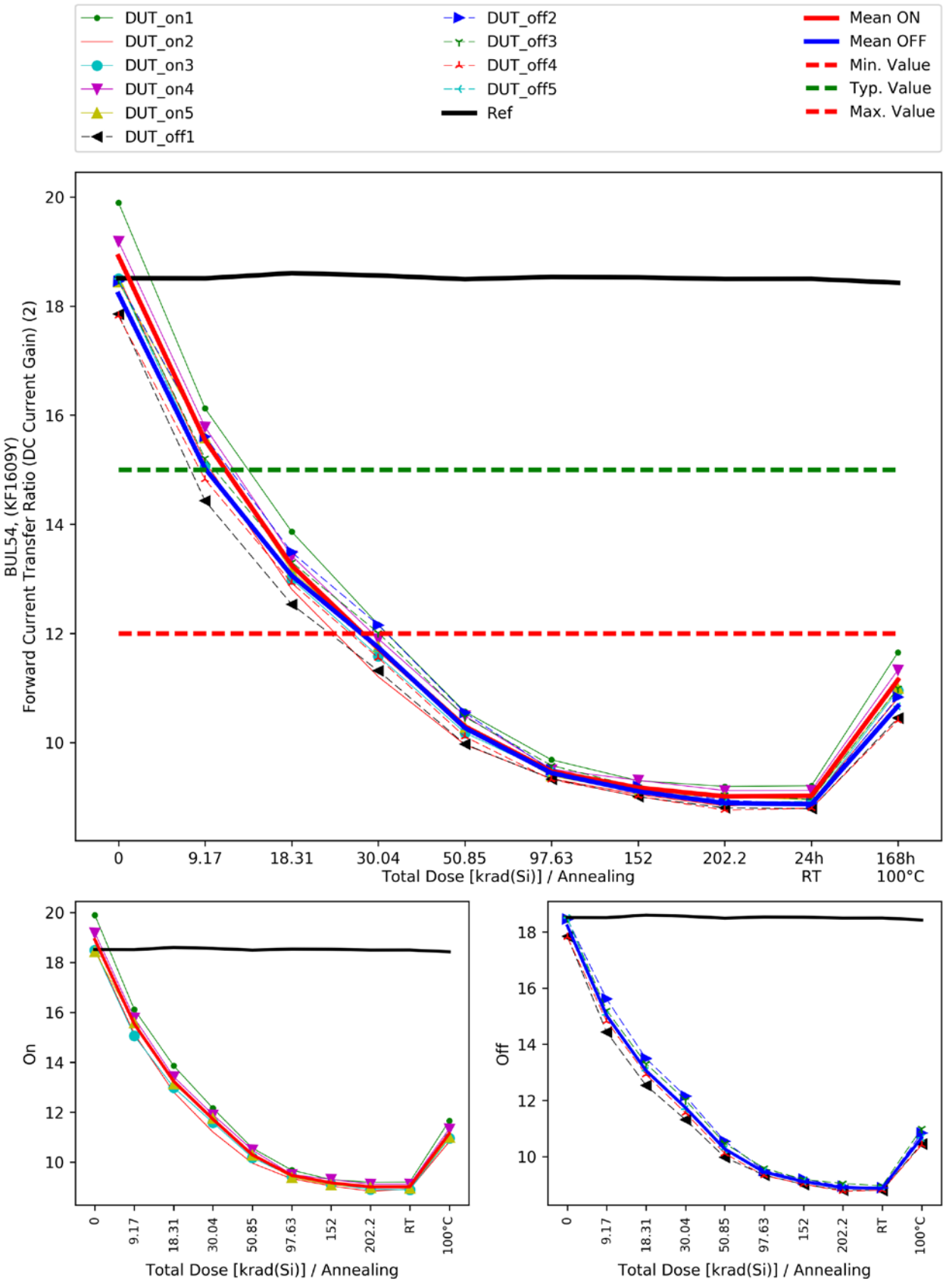
Forward Current Transfer Ratio (DC Current Gain) (2) **BUL54**
HFE2 Date-/Lotcode: KF1609Y
Limit: 12.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	19.9E+0	16.1E+0	13.9E+0	12.2E+0	10.6E+0	9.7E+0	9.3E+0	9.2E+0	9.2E+0	11.7E+0
DUT_on2	18.5E+0	15.1E+0	12.8E+0	11.2E+0	10.0E+0	9.3E+0	9.0E+0	8.8E+0	8.9E+0	10.8E+0
DUT_on3	18.5E+0	15.1E+0	13.0E+0	11.6E+0	10.2E+0	9.4E+0	9.1E+0	8.9E+0	8.9E+0	11.0E+0
DUT_on4	19.2E+0	15.8E+0	13.4E+0	11.9E+0	10.5E+0	9.5E+0	9.3E+0	9.1E+0	9.1E+0	11.3E+0
DUT_on5	18.4E+0	15.6E+0	13.1E+0	11.8E+0	10.3E+0	9.4E+0	9.1E+0	9.0E+0	9.0E+0	11.0E+0
Radiation-Mean ON	18.9E+0	15.5E+0	13.2E+0	11.7E+0	10.3E+0	9.5E+0	9.2E+0	9.0E+0	9.0E+0	11.1E+0
Standarddeviation	629.0E-3	442.6E-3	412.6E-3	357.6E-3	242.9E-3	134.7E-3	122.7E-3	146.9E-3	137.5E-3	338.8E-3
Mean + kσ	20.6E+0	16.8E+0	14.4E+0	12.7E+0	11.0E+0	9.8E+0	9.5E+0	9.4E+0	9.4E+0	12.1E+0
Mean - kσ	17.2E+0	14.3E+0	12.1E+0	10.7E+0	9.6E+0	9.1E+0	8.8E+0	8.6E+0	8.6E+0	10.2E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	17.9E+0	14.4E+0	12.5E+0	11.3E+0	10.0E+0	9.3E+0	9.0E+0	8.8E+0	8.8E+0	10.5E+0
DUT_off2	18.5E+0	15.6E+0	13.5E+0	12.2E+0	10.5E+0	9.5E+0	9.2E+0	8.9E+0	8.9E+0	10.8E+0
DUT_off3	18.5E+0	15.2E+0	13.3E+0	12.0E+0	10.5E+0	9.6E+0	9.2E+0	9.0E+0	9.0E+0	11.0E+0
DUT_off4	17.8E+0	14.8E+0	12.9E+0	11.6E+0	10.1E+0	9.3E+0	9.0E+0	8.8E+0	8.8E+0	10.4E+0
DUT_off5	18.5E+0	15.0E+0	13.1E+0	11.7E+0	10.2E+0	9.5E+0	9.1E+0	8.9E+0	8.9E+0	10.7E+0
Radiation-Mean OFF	18.2E+0	15.0E+0	13.1E+0	11.7E+0	10.3E+0	9.4E+0	9.1E+0	8.9E+0	8.9E+0	10.7E+0
Standarddeviation	354.8E-3	438.5E-3	367.6E-3	340.0E-3	240.9E-3	112.4E-3	89.7E-3	110.7E-3	75.0E-3	250.5E-3
Mean + kσ	19.2E+0	16.2E+0	14.1E+0	12.7E+0	10.9E+0	9.7E+0	9.3E+0	9.2E+0	9.1E+0	11.4E+0
Mean - kσ	17.2E+0	13.8E+0	12.1E+0	10.8E+0	9.6E+0	9.1E+0	8.9E+0	8.6E+0	8.7E+0	10.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	18.5E+0	18.5E+0	18.6E+0	18.6E+0	18.5E+0	18.5E+0	18.5E+0	18.5E+0	18.5E+0	18.4E+0
Min. Value	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0
Typ. Value	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0

Fraunhofer
INT



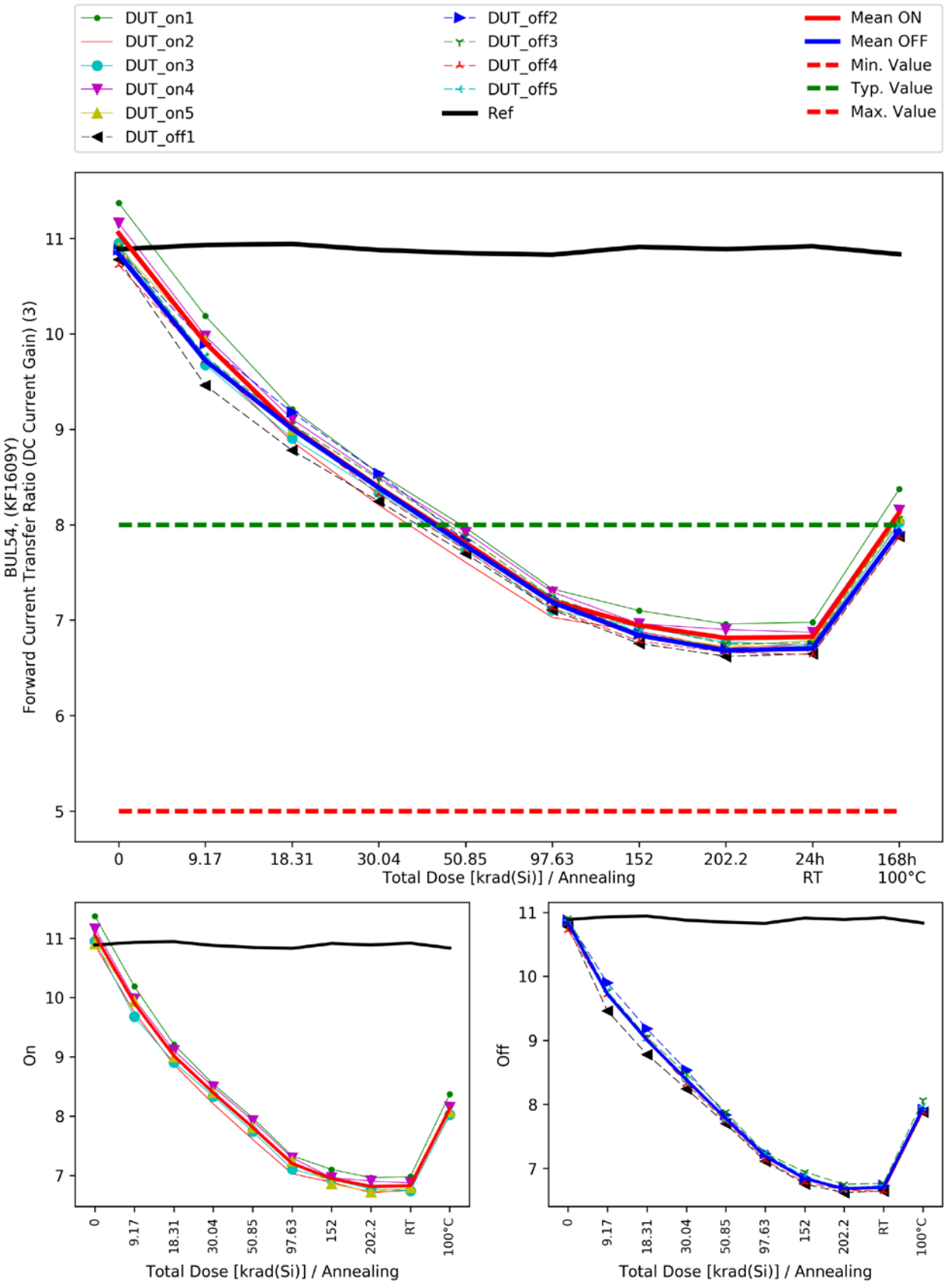
7.18 Forward Current Transfer Ratio (DC Current Gain) (3)

Forward Current Transfer Ratio (DC Current Gain) (3) **BUL54**
HFE3 Date-/Lotcode: KF1609Y
Limit: 5.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_on1	11.4E+0	10.2E+0	9.2E+0	8.5E+0	8.0E+0	7.3E+0	7.1E+0	7.0E+0	7.0E+0	8.4E+0
DUT_on2	10.9E+0	9.7E+0	8.9E+0	8.2E+0	7.6E+0	7.0E+0	6.9E+0	6.7E+0	6.7E+0	8.0E+0
DUT_on3	11.0E+0	9.7E+0	8.9E+0	8.3E+0	7.7E+0	7.1E+0	6.9E+0	6.8E+0	6.7E+0	8.0E+0
DUT_on4	11.2E+0	10.0E+0	9.1E+0	8.5E+0	7.9E+0	7.3E+0	7.0E+0	6.9E+0	6.9E+0	8.2E+0
DUT_on5	10.9E+0	9.9E+0	9.0E+0	8.4E+0	7.8E+0	7.2E+0	6.9E+0	6.7E+0	6.8E+0	8.1E+0
Radiation-Mean ON	**11.1E+0**	**9.9E+0**	**9.0E+0**	**8.4E+0**	**7.8E+0**	**7.2E+0**	**6.9E+0**	**6.8E+0**	**6.8E+0**	**8.1E+0**
Standarddeviation	**209.6E-3**	**201.5E-3**	**140.4E-3**	**132.2E-3**	**145.1E-3**	**127.7E-3**	**94.8E-3**	**111.9E-3**	**100.2E-3**	**147.2E-3**
Mean + kσ	**11.6E+0**	**10.5E+0**	**9.4E+0**	**8.8E+0**	**8.2E+0**	**7.5E+0**	**7.2E+0**	**7.1E+0**	**7.1E+0**	**8.5E+0**
Mean - kσ	**10.5E+0**	**9.4E+0**	**8.6E+0**	**8.0E+0**	**7.4E+0**	**6.8E+0**	**6.7E+0**	**6.5E+0**	**6.6E+0**	**7.7E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
DUT_off1	10.8E+0	9.5E+0	8.8E+0	8.2E+0	7.7E+0	7.1E+0	6.8E+0	6.6E+0	6.6E+0	7.9E+0
DUT_off2	10.9E+0	9.9E+0	9.2E+0	8.5E+0	7.8E+0	7.2E+0	6.9E+0	6.7E+0	6.7E+0	7.9E+0
DUT_off3	10.9E+0	9.8E+0	9.0E+0	8.5E+0	7.9E+0	7.2E+0	6.9E+0	6.8E+0	6.8E+0	8.1E+0
DUT_off4	10.7E+0	9.7E+0	9.0E+0	8.3E+0	7.7E+0	7.1E+0	6.8E+0	6.7E+0	6.6E+0	7.9E+0
DUT_off5	10.9E+0	9.8E+0	9.0E+0	8.4E+0	7.8E+0	7.2E+0	6.9E+0	6.7E+0	6.7E+0	8.0E+0
Radiation-Mean OFF	**10.8E+0**	**9.7E+0**	**9.0E+0**	**8.4E+0**	**7.8E+0**	**7.2E+0**	**6.8E+0**	**6.7E+0**	**6.7E+0**	**7.9E+0**
Standarddeviation	**80.3E-3**	**160.3E-3**	**144.2E-3**	**118.6E-3**	**74.5E-3**	**63.3E-3**	**75.4E-3**	**47.6E-3**	**57.0E-3**	**79.3E-3**
Mean + kσ	**11.1E+0**	**10.2E+0**	**9.4E+0**	**8.7E+0**	**8.0E+0**	**7.4E+0**	**7.0E+0**	**6.8E+0**	**6.9E+0**	**8.2E+0**
Mean - kσ	**10.6E+0**	**9.3E+0**	**8.6E+0**	**8.1E+0**	**7.6E+0**	**7.0E+0**	**6.6E+0**	**6.6E+0**	**6.5E+0**	**7.7E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.31	30.04	50.85	97.63	152	202.2	24h @RT	168h @100°C
Ref1	10.9E+0	10.9E+0	10.9E+0	10.9E+0	10.8E+0	10.8E+0	10.9E+0	10.9E+0	10.9E+0	10.8E+0
Min. Value	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0
Typ. Value	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
Min. Value
Typ. Value
Max. Value
BUL54, (KF1609Y)
Forward Current Transfer Ratio (DC Current Gain) (3)
Total Dose [krad(Si)] / Annealing
0
9.17
18.31
30.04
50.85
97.63
152
202.2
24h
RT
168h
100°C
On
Off

8 Results HDR

8.1 Overview: Pass/Fail

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	10	20	30	50	100	150	200	24h @RT	168h @100°C
V_sus_CEO	On										
	Off										
I(V_sus_CEO)	On										
	Off										
I_CEO	On										
	Off										
V_br_CBO	On										
	Off										
I(V_br_CBO)	On										
	Off										
I_CBO	On		1			2	5	5	5	5	
	Off						1	5	5	5	
V_br_EBO	On										
	Off										
I(V_br_EBO)	On										
	Off										
I_EBO	On										
	Off										
V_CEsat 1	On										
	Off										
V_CEsat2	On						5	5	5	5	5
	Off					2	5	5	5	5	5
V_CEsat3	On		1	4	5	5	5	5	5	5	5
	Off		4	4	5	5	5	5	5	5	5
V_BEsat1	On										
	Off										
V_BEsat2	On										
	Off										
HFE1	On							1	2	3	
	Off							1	2	3	
HFE2	On						3	5	5	5	
	Off						4	5	5	5	1
HFE3	On										
	Off										

8.2 Collector-Emitter Sustaining Voltage

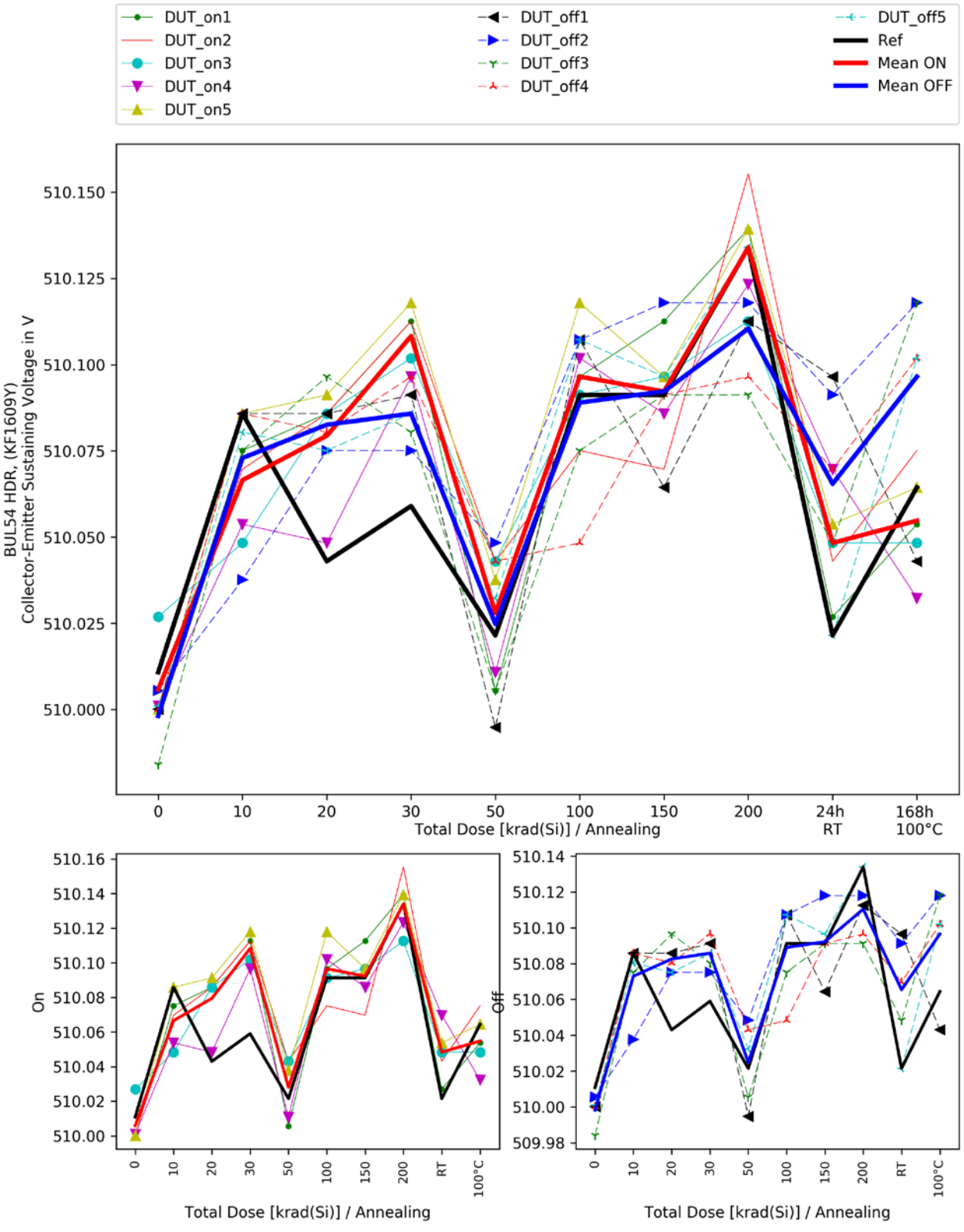
Collector-Emitter Sustaining Voltage
V_sus_CEO in V
Limit: 500.0<x

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0
DUT_on2	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.2E+0	510.0E+0	510.1E+0
DUT_on3	510.0E+0	510.0E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.0E+0
DUT_on4	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0
DUT_on5	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0
Radiation-Mean ON	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0
Standarddeviation	11.8E-3	15.4E-3	17.5E-3	8.8E-3	18.3E-3	15.6E-3	15.8E-3	16.5E-3	15.6E-3	16.2E-3
Mean + kσ	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.2E+0	510.1E+0	510.1E+0
Mean - kσ	510.0E+0	510.0E+0	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.0E+0	510.0E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0
DUT_off2	510.0E+0	510.0E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0
DUT_off3	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0
DUT_off4	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0
DUT_off5	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0
Radiation-Mean OFF	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0
Standarddeviation	8.2E-3	20.2E-3	9.0E-3	8.5E-3	23.5E-3	26.7E-3	19.1E-3	17.2E-3	31.1E-3	31.0E-3
Mean + kσ	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.1E+0	510.2E+0	510.1E+0	510.2E+0	510.2E+0	510.2E+0
Mean - kσ	510.0E+0	510.0E+0	510.1E+0	510.1E+0	510.0E+0	510.0E+0	510.0E+0	510.1E+0	510.0E+0	510.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.0E+0	510.1E+0	510.1E+0	510.1E+0	510.0E+0	510.1E+0
Min. Value	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0	500.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Collector-Emitter Sustaining Voltage in V
510.150
510.125
510.100
510.075
510.050
510.025
510.000
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
510.16
510.14
510.12
510.10
510.08
510.06
510.04
510.02
510.00
509.98
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.3 ICE @ 500 V

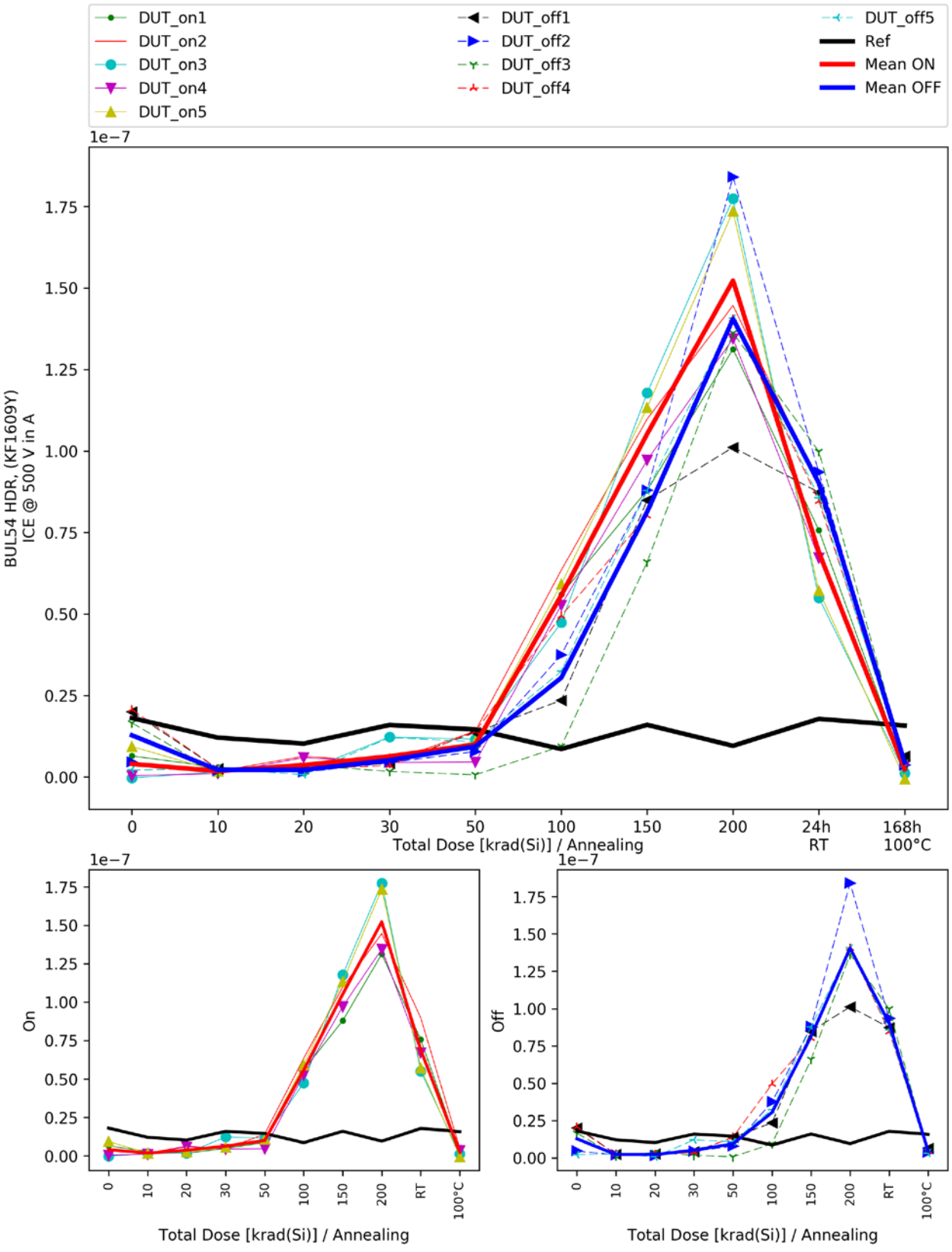
ICE @ 500 V
I(V_sus_CEO) in A
Limit: x < 0.01

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	6.5E-9	3.0E-9	1.7E-9	4.8E-9	8.7E-9	56.0E-9	87.9E-9	131.2E-9	75.7E-9	2.7E-9
DUT_on2	4.1E-9	1.7E-9	6.4E-9	4.6E-9	14.1E-9	63.5E-9	109.8E-9	144.6E-9	89.7E-9	4.9E-9
DUT_on3	-284.8E-12	1.6E-9	1.8E-9	12.2E-9	11.6E-9	47.4E-9	117.8E-9	177.4E-9	55.0E-9	1.2E-9
DUT_on4	428.7E-12	1.1E-9	5.9E-9	4.4E-9	4.6E-9	52.8E-9	97.2E-9	134.5E-9	67.2E-9	3.7E-9
DUT_on5	9.3E-9	1.7E-9	2.5E-9	5.5E-9	10.9E-9	59.1E-9	113.3E-9	173.5E-9	57.1E-9	-654.3E-12
Radiation-Mean ON	**4.0E-9**	**1.8E-9**	**3.7E-9**	**6.3E-9**	**10.0E-9**	**55.7E-9**	**105.2E-9**	**152.3E-9**	**68.9E-9**	**2.4E-9**
Standarddeviation	**4.1E-9**	**697.4E-12**	**2.3E-9**	**3.3E-9**	**3.6E-9**	**6.1E-9**	**12.3E-9**	**21.8E-9**	**14.3E-9**	**2.2E-9**
Mean + kσ	**15.1E-9**	**3.7E-9**	**10.0E-9**	**15.4E-9**	**19.8E-9**	**72.5E-9**	**139.0E-9**	**212.0E-9**	**108.0E-9**	**8.4E-9**
Mean - kσ	**-7.1E-9**	**-97.0E-12**	**-2.7E-9**	**-2.8E-9**	**167.7E-12**	**38.9E-9**	**71.4E-9**	**92.5E-9**	**29.8E-9**	**-3.6E-9**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	20.0E-9	2.5E-9	2.7E-9	4.1E-9	13.7E-9	23.5E-9	84.9E-9	101.1E-9	87.3E-9	6.4E-9
DUT_off2	4.5E-9	2.0E-9	1.5E-9	4.4E-9	7.8E-9	37.4E-9	87.9E-9	184.0E-9	93.5E-9	3.7E-9
DUT_off3	16.6E-9	1.2E-9	3.6E-9	1.7E-9	677.5E-12	9.4E-9	65.9E-9	136.2E-9	99.8E-9	4.7E-9
DUT_off4	20.7E-9	2.5E-9	2.3E-9	3.5E-9	14.0E-9	49.4E-9	80.1E-9	140.5E-9	84.6E-9	4.3E-9
DUT_off5	2.1E-9	2.6E-9	706.8E-12	12.1E-9	10.8E-9	32.4E-9	87.8E-9	140.7E-9	85.7E-9	3.1E-9
Radiation-Mean OFF	**12.8E-9**	**2.2E-9**	**2.2E-9**	**5.2E-9**	**9.4E-9**	**30.5E-9**	**81.3E-9**	**140.5E-9**	**90.2E-9**	**4.5E-9**
Standarddeviation	**8.8E-9**	**584.3E-12**	**1.1E-9**	**4.0E-9**	**5.5E-9**	**15.0E-9**	**9.2E-9**	**29.4E-9**	**6.4E-9**	**1.2E-9**
Mean + kσ	**36.9E-9**	**3.8E-9**	**5.3E-9**	**16.1E-9**	**24.4E-9**	**71.7E-9**	**106.5E-9**	**221.2E-9**	**107.7E-9**	**7.9E-9**
Mean - kσ	**-11.4E-9**	**581.9E-12**	**-904.2E-12**	**-5.8E-9**	**-5.6E-9**	**-10.8E-9**	**56.2E-9**	**59.8E-9**	**72.6E-9**	**1.0E-9**

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	18.1E-9	12.1E-9	10.2E-9	16.0E-9	14.6E-9	8.6E-9	16.0E-9	9.6E-9	17.8E-9	15.8E-9
Max. Value	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−7
BUL54 HDR, (KF1609Y)
ICE @ 500 V in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.4 Collector-Emitter Cut-off Current

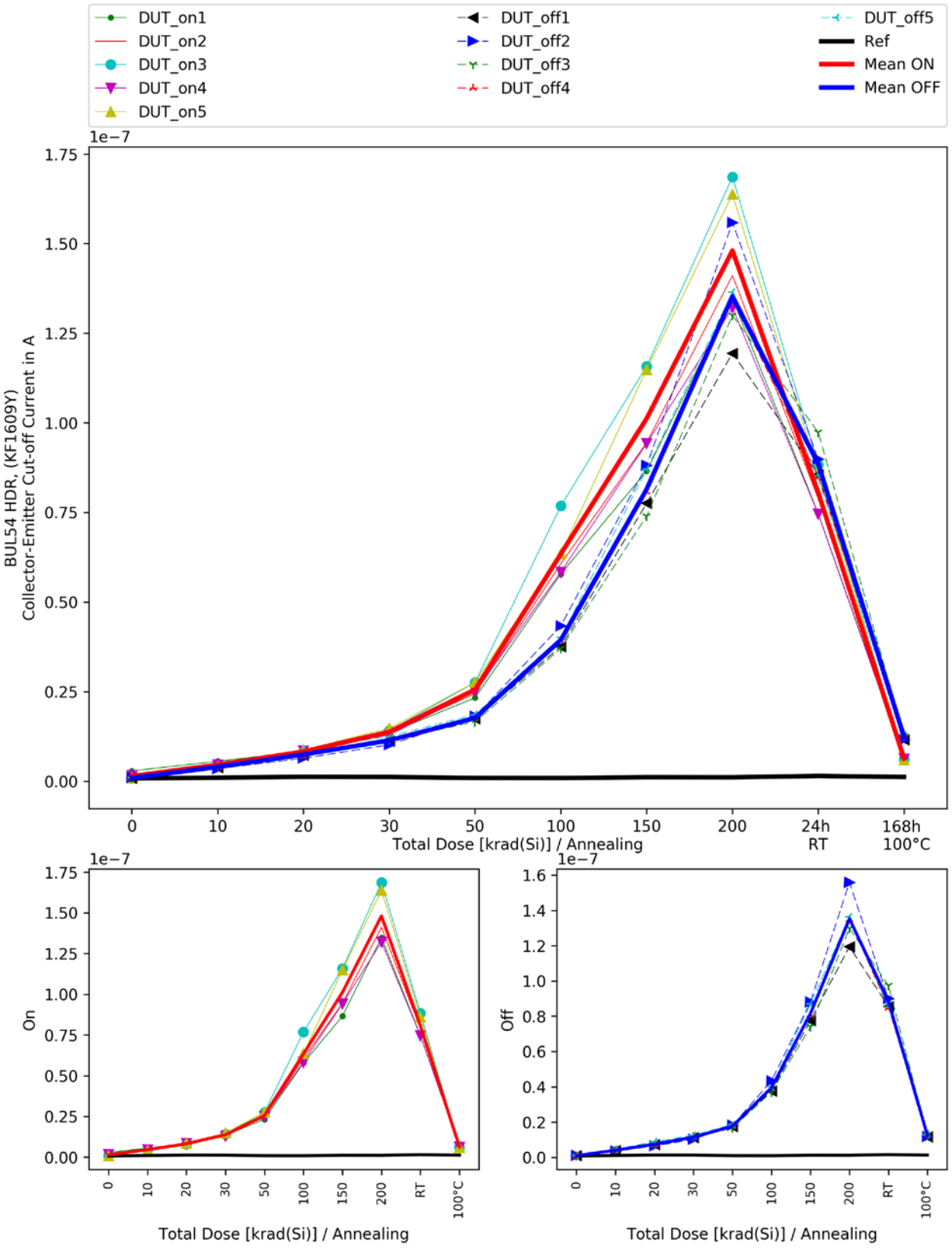
Collector-Emitter Cut-off Current
I_CEO in A
Limit: x < 0.0001

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	2.9E-9	5.6E-9	8.4E-9	13.5E-9	23.3E-9	57.8E-9	86.6E-9	134.7E-9	74.7E-9	6.7E-9
DUT_on2	816.1E-12	3.9E-9	7.6E-9	13.6E-9	24.5E-9	60.7E-9	94.5E-9	141.1E-9	78.8E-9	6.8E-9
DUT_on3	1.0E-9	4.7E-9	8.1E-9	14.1E-9	27.6E-9	76.8E-9	115.8E-9	168.6E-9	88.3E-9	6.1E-9
DUT_on4	1.6E-9	4.6E-9	8.5E-9	12.9E-9	25.0E-9	58.4E-9	94.2E-9	132.1E-9	74.6E-9	6.3E-9
DUT_on5	876.6E-12	4.2E-9	8.8E-9	14.8E-9	27.6E-9	63.4E-9	114.9E-9	163.7E-9	86.1E-9	5.9E-9
Radiation-Mean ON	1.4E-9	4.6E-9	8.3E-9	13.8E-9	25.6E-9	63.4E-9	101.2E-9	148.0E-9	80.5E-9	6.4E-9
Standarddeviation	873.1E-12	635.7E-12	458.4E-12	698.8E-12	1.9E-9	7.8E-9	13.3E-9	16.9E-9	6.4E-9	373.4E-12
Mean + kσ	3.8E-9	6.4E-9	9.5E-9	15.7E-9	30.9E-9	84.8E-9	137.6E-9	194.5E-9	98.1E-9	7.4E-9
Mean - kσ	-948.9E-12	2.9E-9	7.0E-9	11.9E-9	20.3E-9	42.0E-9	64.7E-9	101.6E-9	62.9E-9	5.3E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	893.1E-12	3.9E-9	7.3E-9	11.2E-9	17.4E-9	37.6E-9	77.6E-9	119.4E-9	85.5E-9	11.6E-9
DUT_off2	977.4E-12	3.5E-9	6.4E-9	10.2E-9	18.1E-9	43.4E-9	88.0E-9	155.8E-9	89.8E-9	11.6E-9
DUT_off3	927.0E-12	4.3E-9	7.6E-9	11.5E-9	16.6E-9	37.0E-9	74.0E-9	129.9E-9	97.4E-9	12.8E-9
DUT_off4	880.4E-12	3.9E-9	7.1E-9	11.6E-9	17.6E-9	39.1E-9	80.7E-9	134.8E-9	84.8E-9	13.0E-9
DUT_off5	959.4E-12	4.5E-9	8.9E-9	12.5E-9	18.6E-9	40.1E-9	87.0E-9	136.4E-9	85.3E-9	12.9E-9
Radiation-Mean OFF	927.5E-12	4.0E-9	7.5E-9	11.4E-9	17.7E-9	39.4E-9	81.5E-9	135.3E-9	88.5E-9	12.4E-9
Standarddeviation	41.6E-12	395.8E-12	902.3E-12	846.1E-12	749.7E-12	2.5E-9	6.0E-9	13.3E-9	5.3E-9	701.8E-12
Mean + kσ	1.0E-9	5.1E-9	9.9E-9	13.7E-9	19.7E-9	46.3E-9	98.0E-9	171.7E-9	103.2E-9	14.3E-9
Mean - kσ	813.4E-12	2.9E-9	5.0E-9	9.1E-9	15.6E-9	32.5E-9	64.9E-9	98.9E-9	73.9E-9	10.5E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	777.8E-12	1.0E-9	1.2E-9	1.2E-9	943.9E-12	920.5E-12	1.1E-9	1.1E-9	1.5E-9	1.2E-9
Max. Value	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6	100.0E-6


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−7
BUL54 HDR, (KF1609Y)
Collector-Emitter Cut-off Current in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.5 Collector-Base Breakdown Voltage

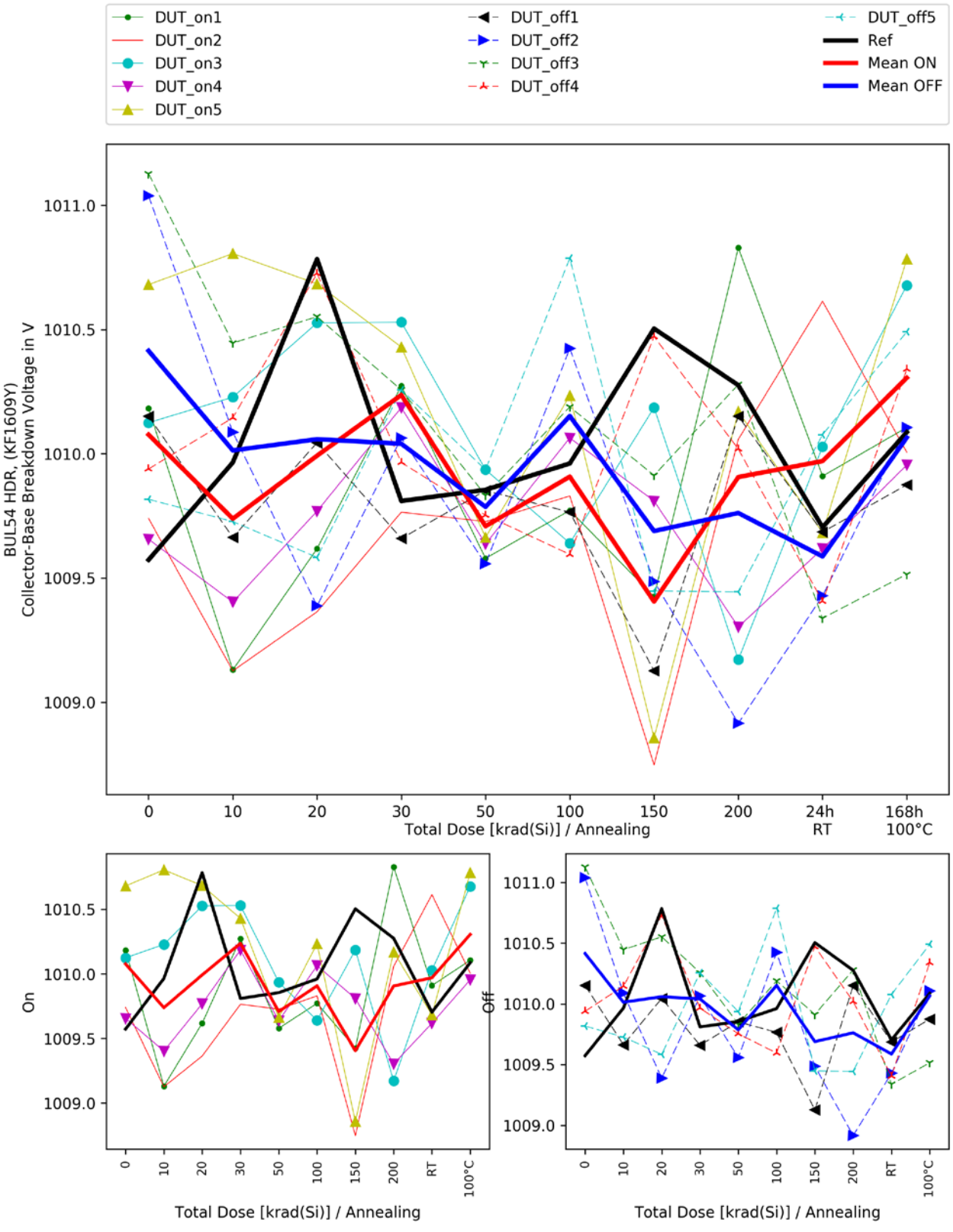
Collector-Base Breakdown Voltage
V_br_CBO in V
Limit: 1000.0<x

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_on2	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_on3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_on4	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_on5	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Radiation-Mean ON	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Standarddeviation	409.0E-3	747.9E-3	580.7E-3	295.7E-3	137.9E-3	238.2E-3	613.7E-3	679.8E-3	396.4E-3	393.7E-3
Mean + kσ	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Mean - kσ	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_off2	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_off3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_off4	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
DUT_off5	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Radiation-Mean OFF	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Standarddeviation	622.6E-3	322.0E-3	584.4E-3	247.8E-3	143.7E-3	484.4E-3	519.5E-3	570.8E-3	304.0E-3	386.5E-3
Mean + kσ	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Mean - kσ	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3
Min. Value	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3	1.0E+3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Collector-Base Breakdown Voltage in V
1011.0
1010.5
1010.0
1009.5
1009.0
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

8.6 ICB @ 1000 V

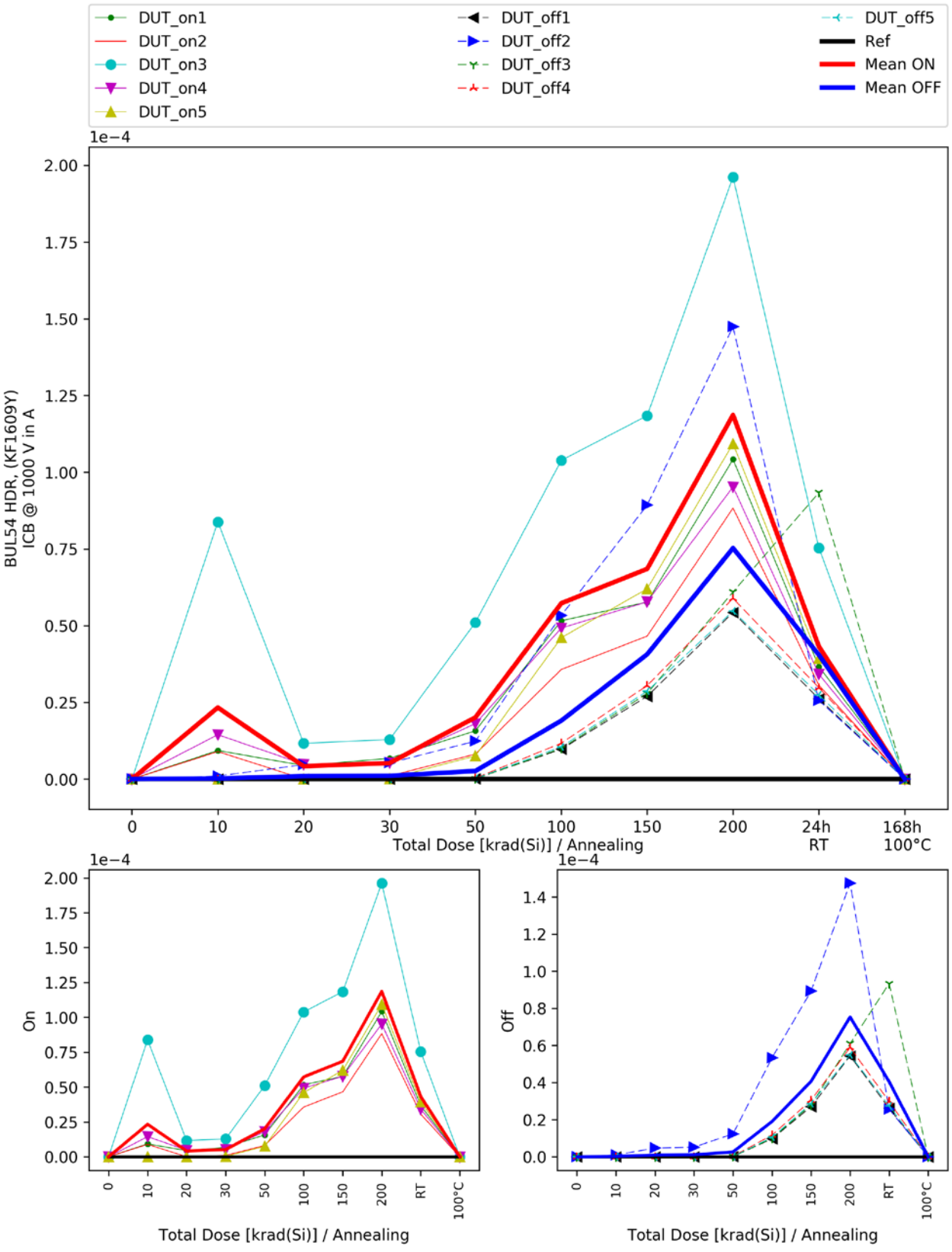
ICB @ 1000 V
I(V_br_CBO) in A
Limit: x < 0.001

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	28.5E-9	9.3E-6	4.4E-6	6.8E-6	15.7E-6	51.6E-6	57.7E-6	104.2E-6	36.7E-6	42.7E-9
DUT_on2	16.5E-9	9.0E-6	43.1E-9	1.0E-6	8.2E-6	35.7E-6	46.6E-6	88.3E-6	30.6E-6	37.9E-9
DUT_on3	27.5E-9	83.8E-6	11.7E-6	12.9E-6	51.1E-6	103.9E-6	118.4E-6	196.2E-6	75.3E-6	43.3E-9
DUT_on4	26.0E-9	14.5E-6	4.8E-6	5.3E-6	18.1E-6	49.2E-6	57.8E-6	95.2E-6	34.2E-6	39.2E-9
DUT_on5	14.1E-9	48.1E-9	58.3E-9	203.1E-9	7.6E-6	46.1E-6	62.0E-6	109.3E-6	39.3E-6	31.8E-9
Radiation-Mean ON	22.5E-9	23.3E-6	4.2E-6	5.2E-6	20.1E-6	57.3E-6	68.5E-6	118.7E-6	43.2E-6	39.0E-9
Standarddeviation	6.7E-9	34.2E-6	4.8E-6	5.1E-6	17.9E-6	26.7E-6	28.5E-6	44.1E-6	18.2E-6	4.6E-9
Mean + kσ	40.8E-9	117.1E-6	17.3E-6	19.2E-6	69.2E-6	130.6E-6	146.6E-6	239.6E-6	93.2E-6	51.7E-9
Mean - kσ	4.2E-9	-70.5E-6	-8.9E-6	-8.7E-6	-28.9E-6	-16.0E-6	-9.6E-6	-2.3E-6	-6.8E-6	26.3E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	10.7E-9	5.5E-9	27.1E-9	45.9E-9	182.3E-9	9.7E-6	27.0E-6	54.3E-6	26.2E-6	40.7E-9
DUT_off2	17.3E-9	1.0E-6	4.7E-6	5.3E-6	12.4E-6	53.3E-6	89.3E-6	147.4E-6	25.6E-6	59.8E-9
DUT_off3	10.3E-9	4.3E-9	29.1E-9	39.5E-9	131.7E-9	10.0E-6	27.9E-6	61.0E-6	93.3E-6	38.6E-9
DUT_off4	13.1E-9	6.2E-9	31.0E-9	53.9E-9	350.1E-9	11.7E-6	30.5E-6	58.9E-6	29.8E-6	39.9E-9
DUT_off5	10.7E-9	6.4E-9	32.8E-9	44.0E-9	222.1E-9	10.5E-6	28.7E-6	54.8E-6	27.5E-6	37.2E-9
Radiation-Mean OFF	12.4E-9	209.6E-9	967.6E-9	1.1E-6	2.7E-6	19.1E-6	40.7E-6	75.3E-6	40.5E-6	43.3E-9
Standarddeviation	2.9E-9	456.3E-9	2.1E-6	2.3E-6	5.4E-6	19.2E-6	27.2E-6	40.4E-6	29.6E-6	9.4E-9
Mean + kσ	20.4E-9	1.5E-6	6.7E-6	7.5E-6	17.6E-6	71.7E-6	115.2E-6	186.1E-6	121.6E-6	68.9E-9
Mean - kσ	4.4E-9	-1.0E-6	-4.8E-6	-5.3E-6	-12.3E-6	-33.5E-6	-33.9E-6	-35.5E-6	-40.7E-6	17.6E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	13.4E-9	13.4E-9	1.1E-9	1.5E-9	1.0E-9	1.2E-9	2.3E-9	1.1E-9	3.3E-9	1.2E-9
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−4
BUL54 HDR, (KF1609Y)
ICB @ 1000 V in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.7 Collector-Base Cutoff Current

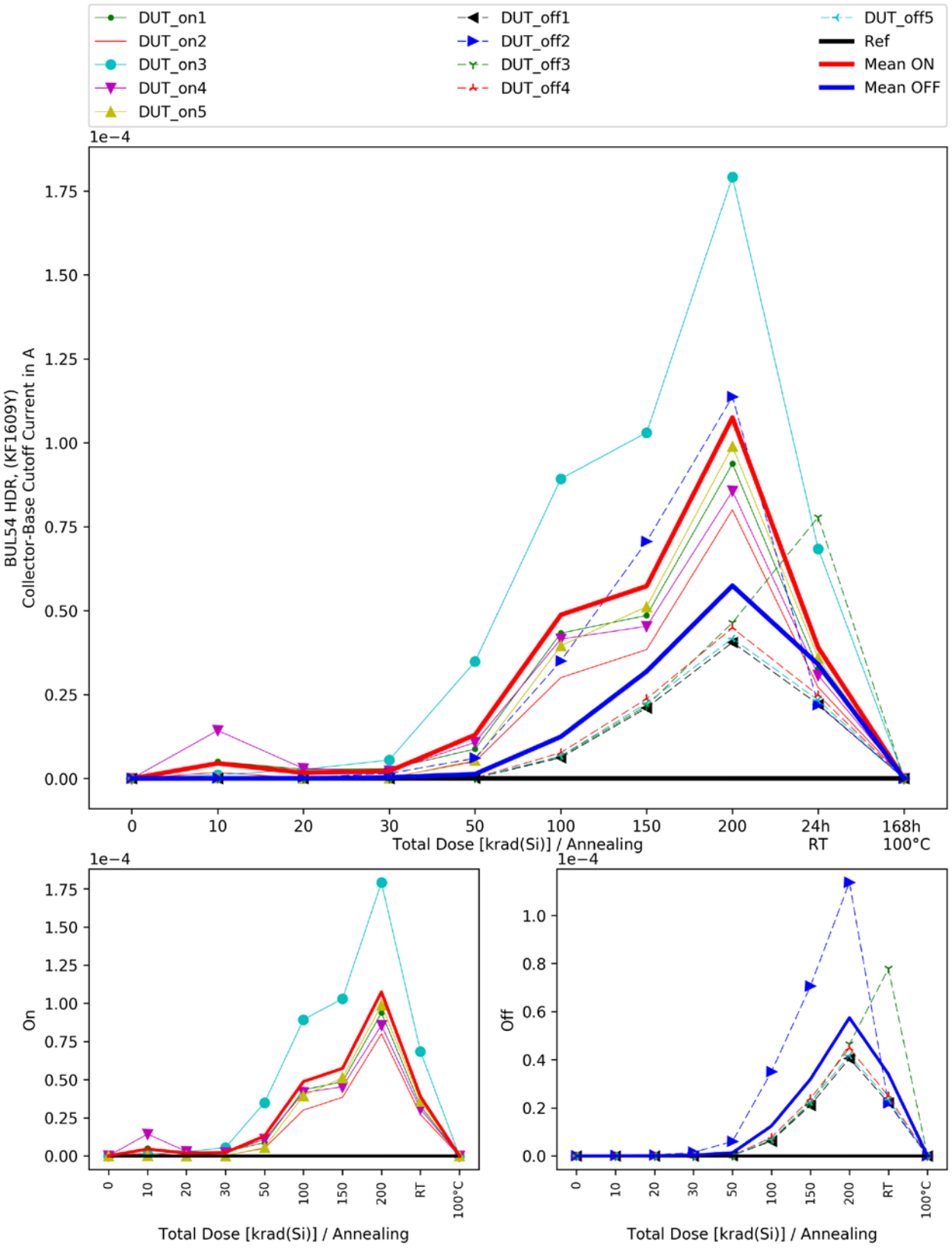
Collector-Base Cutoff Current
I_CBO in A
Limit: x < 1e-05

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	15.1E-9	5.1E-6	2.7E-6	2.9E-6	8.8E-6	43.3E-6	48.6E-6	93.8E-6	32.7E-6	28.9E-9
DUT_on2	3.8E-9	1.8E-6	108.3E-9	260.7E-9	5.1E-6	30.1E-6	38.4E-6	80.0E-6	27.1E-6	24.3E-9
DUT_on3	11.6E-9	1.1E-6	2.7E-6	5.5E-6	34.8E-6	89.3E-6	103.0E-6	179.2E-6	68.4E-6	27.6E-9
DUT_on4	14.3E-9	14.3E-6	3.0E-6	2.2E-6	10.8E-6	41.5E-6	45.3E-6	85.6E-6	30.7E-6	27.8E-9
DUT_on5	1.7E-9	209.6E-9	33.5E-9	110.4E-9	5.5E-6	39.5E-6	51.2E-6	98.9E-6	35.9E-6	18.4E-9
Radiation-Mean ON	9.3E-9	4.5E-6	1.7E-6	2.2E-6	13.0E-6	48.7E-6	57.3E-6	107.5E-6	39.0E-6	25.4E-9
Standarddeviation	6.2E-9	5.8E-6	1.5E-6	2.2E-6	12.4E-6	23.2E-6	26.0E-6	40.7E-6	16.8E-6	4.3E-9
Mean + kσ	26.2E-9	20.4E-6	5.8E-6	8.2E-6	47.1E-6	112.4E-6	128.6E-6	219.2E-6	85.0E-6	37.1E-9
Mean - kσ	-7.6E-9	-11.3E-6	-2.4E-6	-3.9E-6	-21.1E-6	-15.0E-6	-14.0E-6	-4.2E-6	-7.0E-6	13.7E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	1.2E-9	5.8E-9	15.7E-9	29.7E-9	119.0E-9	6.2E-6	21.1E-6	40.5E-6	22.1E-6	25.7E-9
DUT_off2	2.6E-9	115.2E-9	360.6E-9	1.5E-6	6.0E-6	35.0E-6	70.6E-6	113.7E-6	21.9E-6	44.0E-9
DUT_off3	1.4E-9	5.3E-9	13.7E-9	25.4E-9	101.4E-9	6.6E-6	21.7E-6	46.4E-6	77.9E-6	25.8E-9
DUT_off4	1.6E-9	6.5E-9	18.5E-9	33.5E-9	188.4E-9	7.7E-6	23.7E-6	44.8E-6	24.8E-6	27.5E-9
DUT_off5	1.5E-9	6.7E-9	17.4E-9	29.6E-9	124.8E-9	6.7E-6	22.4E-6	41.7E-6	23.3E-6	24.4E-9
Radiation-Mean OFF	1.7E-9	27.9E-9	85.2E-9	322.2E-9	1.3E-6	12.4E-6	31.9E-6	57.4E-6	34.0E-6	29.5E-9
Standarddeviation	553.9E-12	48.8E-9	154.0E-9	654.3E-9	2.6E-6	12.6E-6	21.7E-6	31.5E-6	24.6E-6	8.2E-9
Mean + kσ	3.2E-9	161.8E-9	507.4E-9	2.1E-6	8.5E-6	47.0E-6	91.3E-6	143.9E-6	101.3E-6	52.0E-9
Mean - kσ	144.0E-12	-106.0E-9	-337.0E-9	-1.5E-6	-5.9E-6	-22.2E-6	-27.5E-6	-29.0E-6	-33.3E-6	7.0E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	1.8E-9	1.1E-9	1.6E-9	1.8E-9	1.6E-9	1.8E-9	1.7E-9	1.7E-9	2.2E-9	1.7E-9
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−4
BUL54 HDR, (KF1609Y)
Collector-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.8 Emitter-Base Breakdown Voltage

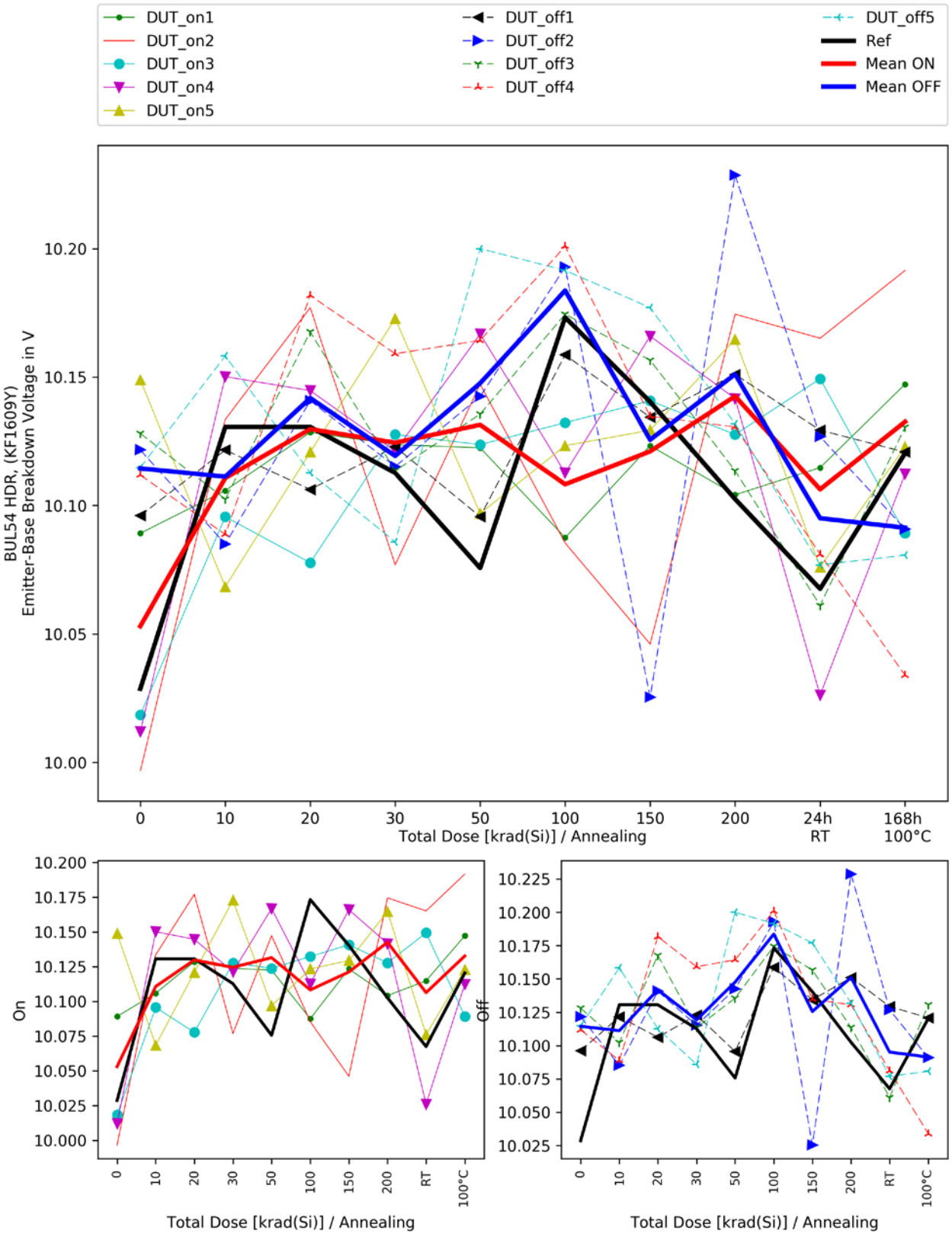
Emitter-Base Breakdown Voltage
V_br_EBO in V
Limit: 9.9<x

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0
DUT_on2	10.0E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0	10.0E+0	10.2E+0	10.2E+0	10.2E+0
DUT_on3	10.0E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0
DUT_on4	10.0E+0	10.2E+0	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.2E+0	10.1E+0	10.0E+0	10.1E+0
DUT_on5	10.1E+0	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0
Radiation-Mean ON	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**
Standarddeviation	64.3E-3	32.1E-3	36.2E-3	34.0E-3	26.6E-3	21.1E-3	45.0E-3	28.3E-3	56.4E-3	39.0E-3
Mean + kσ	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.3E+0**	**10.2E+0**
Mean - kσ	**9.9E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.1E+0**	**10.1E+0**	**10.0E+0**	**10.1E+0**	**10.0E+0**	**10.0E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0
DUT_off2	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.2E+0	10.0E+0	10.2E+0	10.1E+0	10.1E+0
DUT_off3	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0	10.2E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0
DUT_off4	10.1E+0	10.1E+0	10.2E+0	10.2E+0	10.2E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0	10.0E+0
DUT_off5	10.1E+0	10.2E+0	10.1E+0	10.1E+0	10.2E+0	10.2E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0
Radiation-Mean OFF	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.1E+0**	**10.2E+0**	**10.1E+0**	**10.2E+0**	**10.1E+0**	**10.1E+0**
Standarddeviation	12.1E-3	30.0E-3	33.1E-3	26.3E-3	38.4E-3	17.0E-3	58.8E-3	45.3E-3	31.1E-3	38.2E-3
Mean + kσ	**10.1E+0**	**10.2E+0**	**10.2E+0**	**10.2E+0**	**10.3E+0**	**10.2E+0**	**10.3E+0**	**10.3E+0**	**10.2E+0**	**10.2E+0**
Mean - kσ	**10.1E+0**	**10.0E+0**	**10.1E+0**	**10.0E+0**	**10.0E+0**	**10.1E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**	**10.0E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	10.0E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0	10.2E+0	10.1E+0	10.1E+0	10.1E+0	10.1E+0
Min. Value	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0	9.9E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Emitter-Base Breakdown Voltage in V
10.20
10.15
10.10
10.05
10.00
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
10.200
10.175
10.150
10.125
10.100
10.075
10.050
10.025
10.000
10.225
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.9 IEB @ 10 V

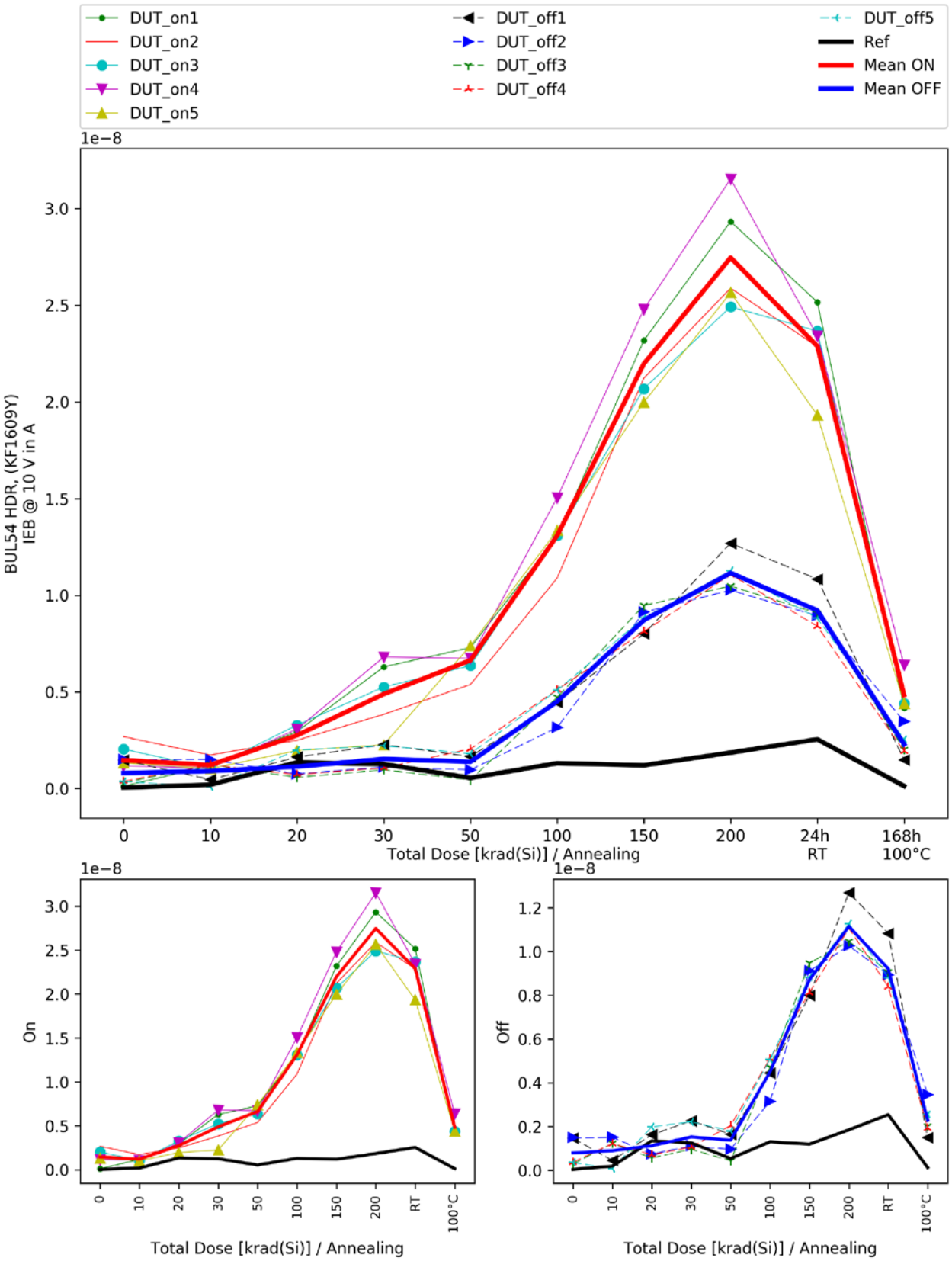
IEB@10V
I(V_br_EBO) in A
Limit: x<0.001

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	113.4E-12	1.2E-9	2.9E-9	6.3E-9	7.3E-9	13.1E-9	23.2E-9	29.3E-9	25.2E-9	4.2E-9
DUT_on2	2.7E-9	1.7E-9	2.5E-9	3.8E-9	5.4E-9	10.9E-9	21.2E-9	25.9E-9	22.9E-9	4.8E-9
DUT_on3	2.0E-9	1.0E-9	3.3E-9	5.2E-9	6.4E-9	13.1E-9	20.7E-9	24.9E-9	23.7E-9	4.4E-9
DUT_on4	1.2E-9	1.1E-9	3.1E-9	6.8E-9	6.7E-9	15.0E-9	24.8E-9	31.5E-9	23.4E-9	6.4E-9
DUT_on5	1.3E-9	1.0E-9	2.0E-9	2.3E-9	7.4E-9	13.3E-9	20.0E-9	25.7E-9	19.3E-9	4.4E-9
Radiation-Mean ON	1.5E-9	1.2E-9	2.7E-9	4.9E-9	6.6E-9	13.1E-9	22.0E-9	27.5E-9	22.9E-9	4.8E-9
Standarddeviation	967.3E-12	296.7E-12	525.6E-12	1.9E-9	816.3E-12	1.5E-9	2.0E-9	2.8E-9	2.2E-9	896.9E-12
Mean + kσ	4.1E-9	2.0E-9	4.2E-9	10.0E-9	8.9E-9	17.1E-9	27.4E-9	35.3E-9	28.8E-9	7.3E-9
Mean - kσ	-1.2E-9	395.7E-12	1.3E-9	-202.2E-12	4.4E-9	9.0E-9	16.6E-9	19.7E-9	16.9E-9	2.4E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	1.5E-9	452.8E-12	1.6E-9	2.3E-9	1.6E-9	4.4E-9	8.0E-9	12.7E-9	10.8E-9	1.5E-9
DUT_off2	1.5E-9	1.5E-9	748.8E-12	1.1E-9	960.6E-12	3.2E-9	9.1E-9	10.3E-9	8.9E-9	3.5E-9
DUT_off3	285.8E-12	1.2E-9	569.0E-12	965.2E-12	438.1E-12	4.7E-9	9.5E-9	10.5E-9	9.1E-9	2.0E-9
DUT_off4	366.6E-12	1.2E-9	714.5E-12	1.1E-9	2.0E-9	5.1E-9	8.1E-9	11.1E-9	8.4E-9	1.9E-9
DUT_off5	360.1E-12	76.2E-12	2.0E-9	2.2E-9	1.8E-9	5.1E-9	8.8E-9	11.3E-9	8.8E-9	2.5E-9
Radiation-Mean OFF	793.5E-12	897.9E-12	1.1E-9	1.5E-9	1.4E-9	4.5E-9	8.7E-9	11.1E-9	9.2E-9	2.3E-9
Standarddeviation	625.3E-12	603.9E-12	632.3E-12	654.8E-12	661.2E-12	801.9E-12	635.8E-12	954.8E-12	942.1E-12	757.8E-12
Mean + kσ	2.5E-9	2.6E-9	2.9E-9	3.3E-9	3.2E-9	6.7E-9	10.4E-9	13.8E-9	11.8E-9	4.4E-9
Mean - kσ	-921.0E-12	-757.9E-12	-606.6E-12	-272.8E-12	-435.5E-12	2.3E-9	7.0E-9	8.5E-9	6.6E-9	207.2E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	42.2E-12	191.0E-12	1.3E-9	1.3E-9	542.6E-12	1.3E-9	1.2E-9	1.9E-9	2.5E-9	123.5E-12
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−8
BUL54 HDR, (KF1609Y)
IEB @ 10 V in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.10 Emitter-Base Cutoff Current

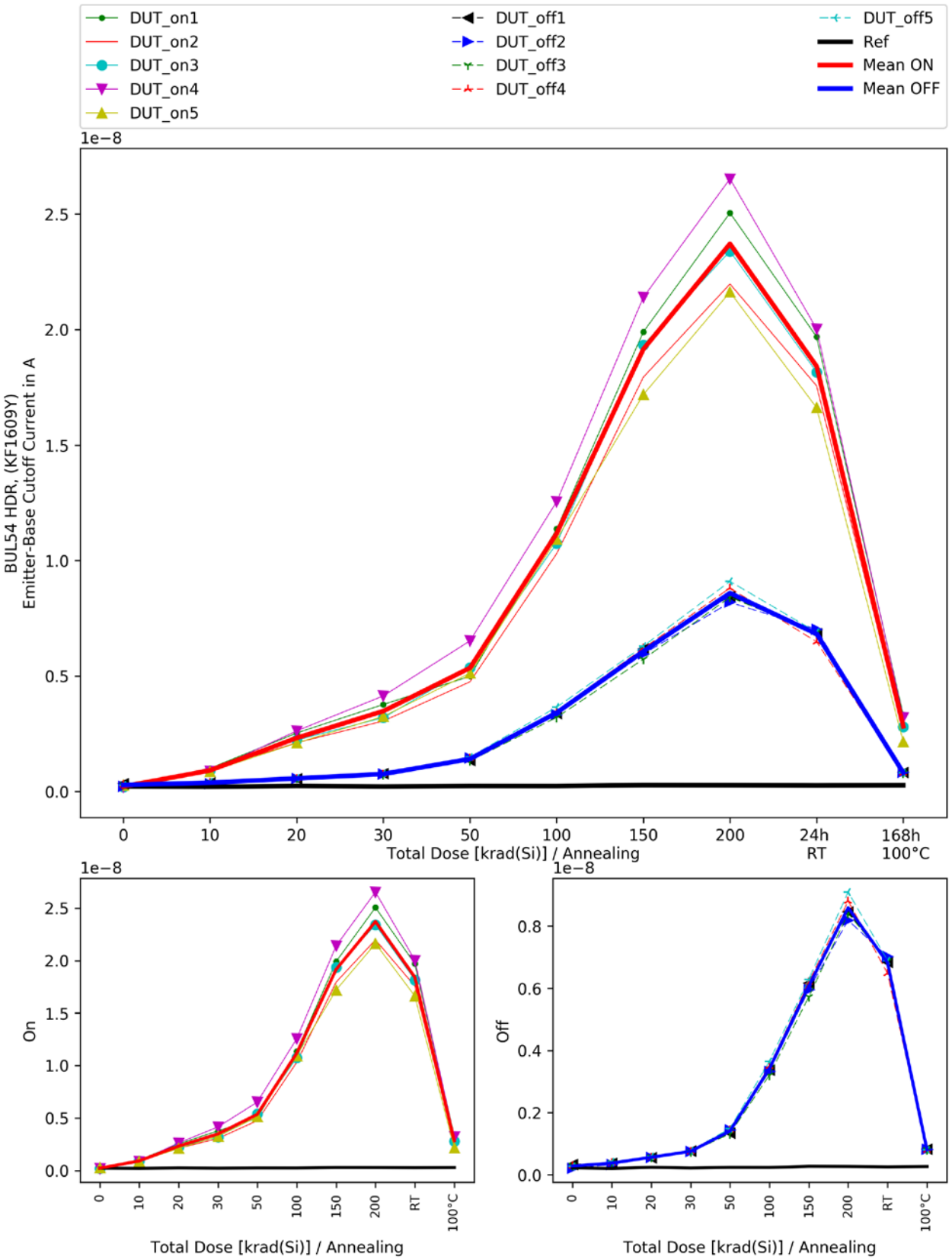
Emitter-Base Cutoff Current
I_EBO in A
Limit: x < 1e-05

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	223.8E-12	1.0E-9	2.5E-9	3.8E-9	5.0E-9	11.4E-9	19.9E-9	25.1E-9	19.7E-9	3.3E-9
DUT_on2	197.4E-12	928.3E-12	2.1E-9	3.0E-9	4.7E-9	10.3E-9	17.9E-9	22.0E-9	17.6E-9	2.6E-9
DUT_on3	195.3E-12	889.2E-12	2.2E-9	3.2E-9	5.4E-9	10.7E-9	19.3E-9	23.4E-9	18.2E-9	2.8E-9
DUT_on4	199.4E-12	881.9E-12	2.6E-9	4.1E-9	6.5E-9	12.6E-9	21.4E-9	26.5E-9	20.0E-9	3.2E-9
DUT_on5	274.1E-12	865.2E-12	2.1E-9	3.2E-9	5.1E-9	10.9E-9	17.2E-9	21.6E-9	16.6E-9	2.2E-9
Radiation-Mean ON	218.0E-12	911.7E-12	2.3E-9	3.5E-9	5.4E-9	11.2E-9	19.2E-9	23.7E-9	18.4E-9	2.8E-9
Standarddeviation	33.4E-12	57.9E-12	243.0E-12	457.8E-12	692.9E-12	859.5E-12	1.7E-9	2.1E-9	1.4E-9	467.3E-12
Mean + kσ	309.6E-12	1.1E-9	3.0E-9	4.7E-9	7.3E-9	13.5E-9	23.7E-9	29.4E-9	22.3E-9	4.1E-9
Mean - kσ	126.4E-12	753.0E-12	1.7E-9	2.2E-9	3.5E-9	8.8E-9	14.6E-9	18.0E-9	14.5E-9	1.5E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	339.4E-12	374.8E-12	556.7E-12	774.9E-12	1.3E-9	3.4E-9	6.2E-9	8.5E-9	6.8E-9	825.3E-12
DUT_off2	208.0E-12	327.5E-12	556.4E-12	748.2E-12	1.4E-9	3.3E-9	6.0E-9	8.2E-9	7.0E-9	820.6E-12
DUT_off3	303.3E-12	389.0E-12	562.0E-12	734.4E-12	1.3E-9	3.2E-9	5.7E-9	8.4E-9	6.9E-9	802.6E-12
DUT_off4	288.2E-12	385.9E-12	560.9E-12	748.4E-12	1.4E-9	3.5E-9	6.2E-9	8.8E-9	6.5E-9	799.2E-12
DUT_off5	278.6E-12	416.7E-12	592.5E-12	775.1E-12	1.5E-9	3.7E-9	6.3E-9	9.1E-9	6.9E-9	806.9E-12
Radiation-Mean OFF	283.5E-12	378.8E-12	565.7E-12	756.2E-12	1.4E-9	3.4E-9	6.1E-9	8.6E-9	6.8E-9	810.9E-12
Standarddeviation	48.1E-12	32.6E-12	15.2E-12	18.1E-12	72.2E-12	169.1E-12	227.0E-12	360.0E-12	202.8E-12	11.4E-12
Mean + kσ	415.5E-12	468.0E-12	607.4E-12	805.8E-12	1.6E-9	3.9E-9	6.7E-9	9.6E-9	7.4E-9	842.3E-12
Mean - kσ	151.5E-12	289.5E-12	524.0E-12	706.6E-12	1.2E-9	2.9E-9	5.4E-9	7.6E-9	6.3E-9	779.6E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	224.0E-12	205.4E-12	239.5E-12	218.7E-12	237.0E-12	235.1E-12	273.1E-12	268.9E-12	257.2E-12	267.3E-12
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−8
BUL54 HDR, (KF1609Y)
Emitter-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
On
Off
0
10
20
30
50
100
150
200
24h
RT
168h
100°C

8.11 Collector-Emitter Saturation Voltage (1)

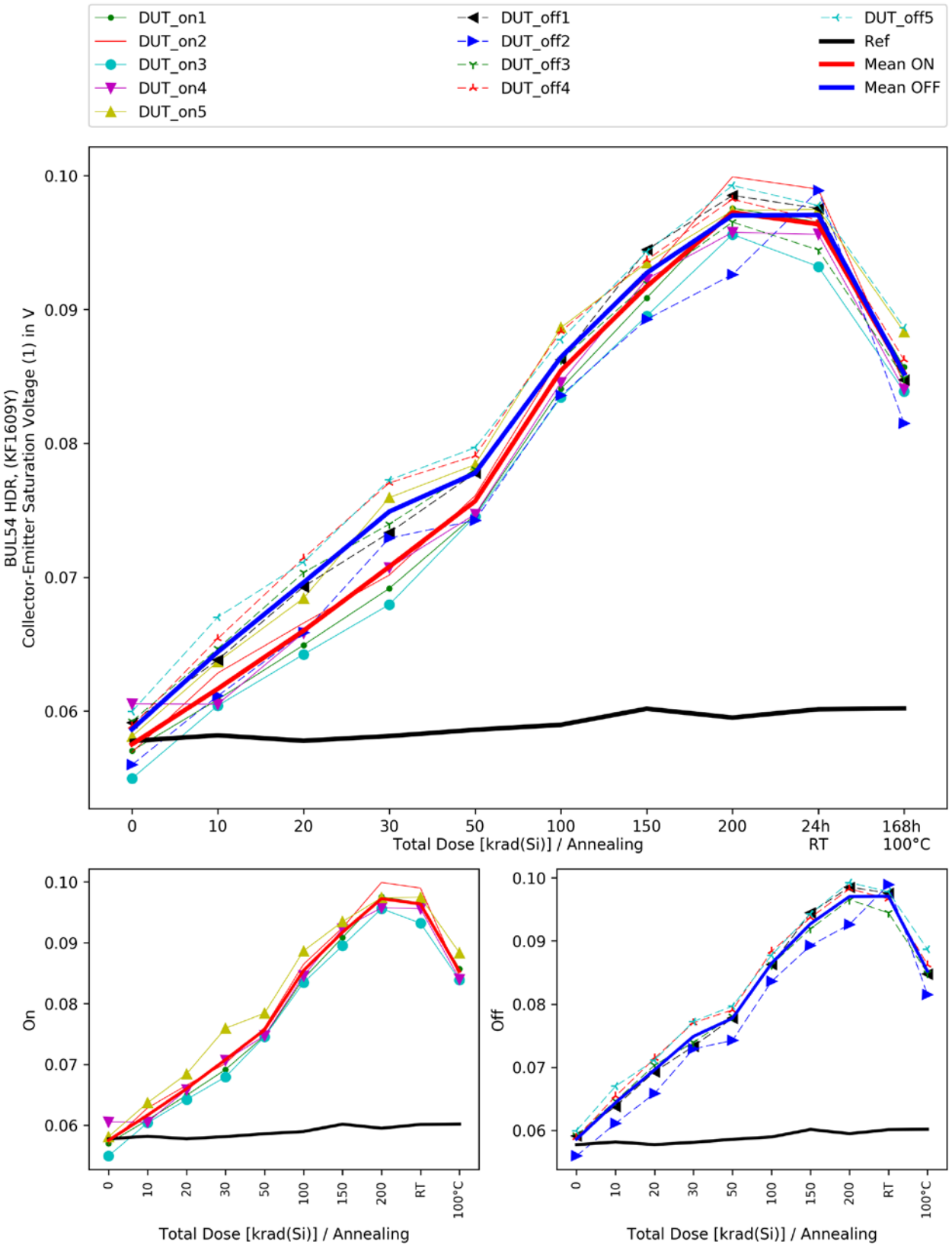
Collector-Emitter Saturation Voltage (1)
V_CEsat 1 in V
Limit: x<0.1

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	57.0E-3	60.9E-3	64.9E-3	69.2E-3	74.7E-3	84.1E-3	90.9E-3	97.6E-3	96.5E-3	85.7E-3
DUT_on2	56.9E-3	62.8E-3	66.6E-3	70.2E-3	76.1E-3	86.5E-3	92.5E-3	99.9E-3	99.0E-3	84.5E-3
DUT_on3	55.0E-3	60.4E-3	64.2E-3	67.9E-3	74.5E-3	83.4E-3	89.5E-3	95.6E-3	93.2E-3	83.9E-3
DUT_on4	60.5E-3	60.5E-3	65.8E-3	70.7E-3	74.7E-3	84.5E-3	92.3E-3	95.8E-3	95.6E-3	84.0E-3
DUT_on5	58.1E-3	63.7E-3	68.4E-3	75.9E-3	78.4E-3	88.6E-3	93.5E-3	97.4E-3	97.5E-3	88.3E-3
Radiation-Mean ON	57.5E-3	61.7E-3	66.0E-3	70.8E-3	75.7E-3	85.4E-3	91.7E-3	97.2E-3	96.4E-3	85.3E-3
Standarddeviation	2.0E-3	1.5E-3	1.6E-3	3.1E-3	1.7E-3	2.1E-3	1.5E-3	1.7E-3	2.2E-3	1.8E-3
Mean + kσ	63.1E-3	65.8E-3	70.4E-3	79.2E-3	80.2E-3	91.2E-3	96.0E-3	102.0E-3	102.3E-3	90.4E-3
Mean - kσ	51.9E-3	57.5E-3	61.5E-3	62.4E-3	71.2E-3	79.6E-3	87.5E-3	92.5E-3	90.4E-3	80.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	59.1E-3	63.8E-3	69.3E-3	73.3E-3	77.8E-3	86.3E-3	94.5E-3	98.5E-3	97.6E-3	84.7E-3
DUT_off2	56.0E-3	61.1E-3	65.8E-3	72.9E-3	74.2E-3	83.6E-3	89.3E-3	92.6E-3	98.9E-3	81.5E-3
DUT_off3	59.2E-3	64.7E-3	70.3E-3	74.0E-3	78.1E-3	86.2E-3	91.9E-3	96.5E-3	94.4E-3	84.9E-3
DUT_off4	58.9E-3	65.4E-3	71.4E-3	77.0E-3	79.1E-3	88.4E-3	93.7E-3	98.2E-3	96.7E-3	86.3E-3
DUT_off5	60.0E-3	67.0E-3	71.1E-3	77.3E-3	79.7E-3	87.7E-3	94.3E-3	99.3E-3	97.8E-3	88.7E-3
Radiation-Mean OFF	58.6E-3	64.4E-3	69.6E-3	74.9E-3	77.8E-3	86.4E-3	92.7E-3	97.0E-3	97.1E-3	85.2E-3
Standarddeviation	1.5E-3	2.2E-3	2.3E-3	2.1E-3	2.1E-3	1.8E-3	2.2E-3	2.7E-3	1.7E-3	2.6E-3
Mean + kσ	62.8E-3	70.4E-3	75.8E-3	80.6E-3	83.6E-3	91.5E-3	98.7E-3	104.4E-3	101.6E-3	92.3E-3
Mean - kσ	54.4E-3	58.4E-3	63.4E-3	69.2E-3	72.0E-3	81.4E-3	86.7E-3	89.7E-3	92.5E-3	78.1E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	57.8E-3	58.2E-3	57.8E-3	58.1E-3	58.6E-3	59.0E-3	60.2E-3	59.5E-3	60.1E-3	60.2E-3
Typ. Value	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3	50.0E-3
Max. Value	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3	100.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Collector-Emitter Saturation Voltage (1) in V
0.10
0.09
0.08
0.07
0.06
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

8.12 Collector-Emitter Saturation Voltage (2)

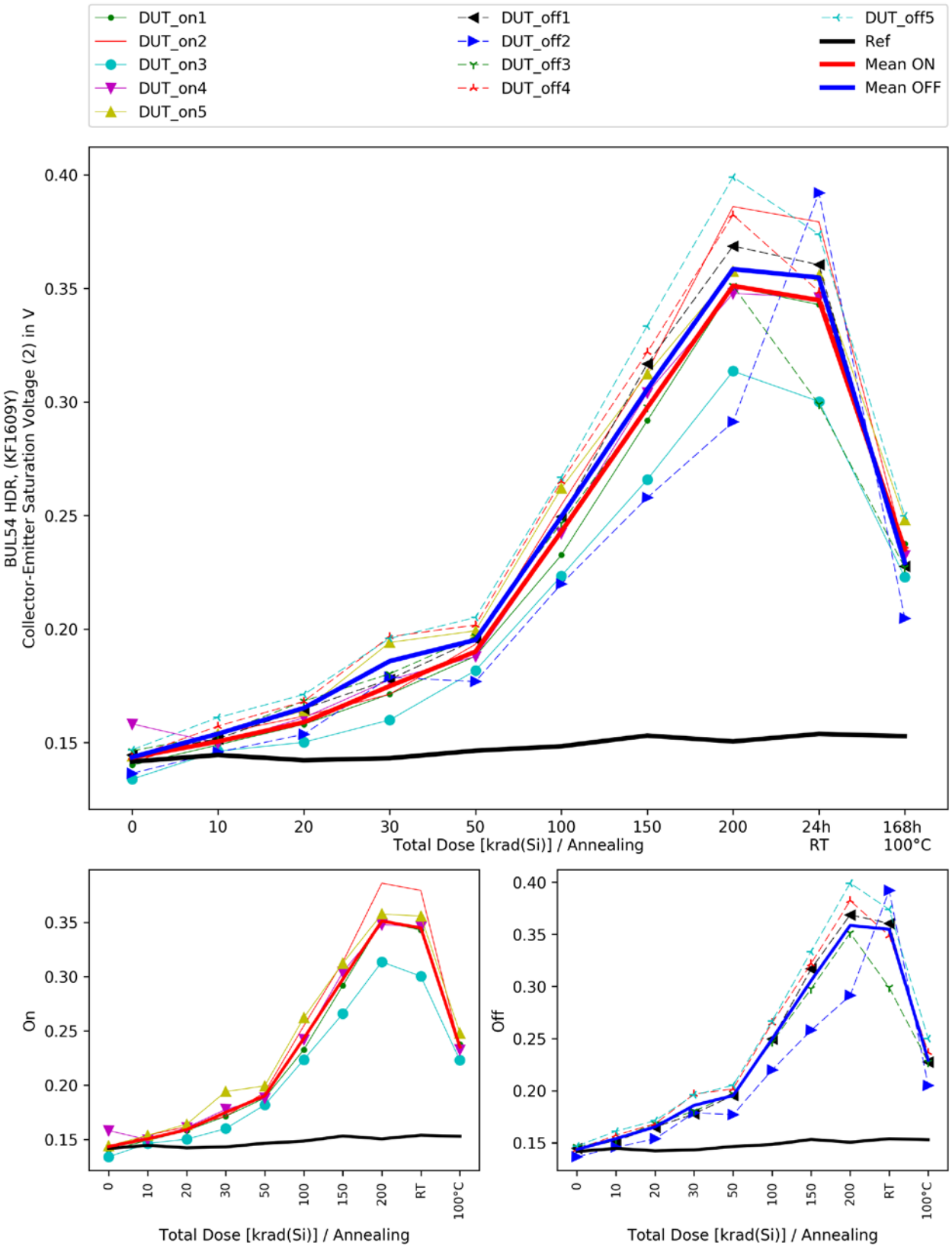
Collector-Emitter Saturation Voltage (2)
V_CEsat2 in V
Limit: x<0.2

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	140.0E-3	149.0E-3	158.0E-3	171.4E-3	188.1E-3	232.6E-3	291.8E-3	350.7E-3	342.9E-3	237.6E-3
DUT_on2	141.1E-3	153.8E-3	161.6E-3	171.3E-3	193.3E-3	254.6E-3	313.4E-3	386.1E-3	379.3E-3	234.7E-3
DUT_on3	133.9E-3	146.2E-3	150.1E-3	160.0E-3	181.8E-3	223.4E-3	265.8E-3	313.6E-3	300.2E-3	222.9E-3
DUT_on4	158.2E-3	149.7E-3	160.9E-3	177.7E-3	187.9E-3	242.2E-3	304.0E-3	347.8E-3	345.9E-3	232.5E-3
DUT_on5	144.0E-3	153.7E-3	164.0E-3	194.1E-3	199.2E-3	262.0E-3	312.3E-3	357.6E-3	355.7E-3	248.1E-3
Radiation-Mean ON	143.5E-3	150.5E-3	158.9E-3	174.9E-3	190.1E-3	243.0E-3	297.5E-3	351.1E-3	344.8E-3	235.1E-3
Standarddeviation	9.0E-3	3.3E-3	5.4E-3	12.5E-3	6.6E-3	15.7E-3	19.7E-3	25.9E-3	28.7E-3	9.1E-3
Mean + kσ	168.2E-3	159.4E-3	173.6E-3	209.1E-3	208.0E-3	286.1E-3	351.5E-3	422.2E-3	423.6E-3	260.0E-3
Mean - kσ	118.7E-3	141.5E-3	144.3E-3	140.6E-3	172.1E-3	199.8E-3	243.4E-3	280.1E-3	266.0E-3	210.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	144.6E-3	151.7E-3	164.9E-3	177.8E-3	195.3E-3	249.3E-3	316.7E-3	368.7E-3	360.4E-3	227.6E-3
DUT_off2	136.5E-3	145.8E-3	153.7E-3	178.8E-3	176.9E-3	219.9E-3	257.8E-3	291.2E-3	392.1E-3	204.8E-3
DUT_off3	146.3E-3	153.6E-3	168.3E-3	180.3E-3	196.9E-3	246.7E-3	297.7E-3	351.2E-3	298.9E-3	227.1E-3
DUT_off4	143.6E-3	157.2E-3	168.1E-3	196.6E-3	201.8E-3	265.0E-3	321.9E-3	382.3E-3	348.6E-3	236.6E-3
DUT_off5	146.8E-3	161.0E-3	171.2E-3	195.8E-3	205.1E-3	266.7E-3	333.5E-3	399.1E-3	373.8E-3	249.9E-3
Radiation-Mean OFF	143.6E-3	153.9E-3	165.2E-3	185.9E-3	195.2E-3	249.5E-3	305.5E-3	358.5E-3	354.8E-3	229.2E-3
Standarddeviation	4.2E-3	5.8E-3	6.8E-3	9.5E-3	11.0E-3	18.9E-3	29.6E-3	41.5E-3	35.1E-3	16.5E-3
Mean + kσ	155.0E-3	169.7E-3	183.9E-3	212.0E-3	225.2E-3	301.2E-3	386.8E-3	472.4E-3	451.1E-3	274.4E-3
Mean - kσ	132.1E-3	138.1E-3	146.5E-3	159.8E-3	165.1E-3	197.8E-3	224.3E-3	244.6E-3	258.4E-3	184.0E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	141.6E-3	144.5E-3	142.3E-3	143.1E-3	146.4E-3	148.4E-3	153.1E-3	150.5E-3	153.8E-3	152.8E-3
Typ. Value	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3	150.0E-3
Max. Value	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3	200.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Collector-Emitter Saturation Voltage (2) in V
0.40
0.35
0.30
0.25
0.20
0.15
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.13 Collector-Emitter Saturation Voltage (3)

Collector-Emitter Saturation Voltage (3)
V_CEsat3 in V
Limit: x<0.5

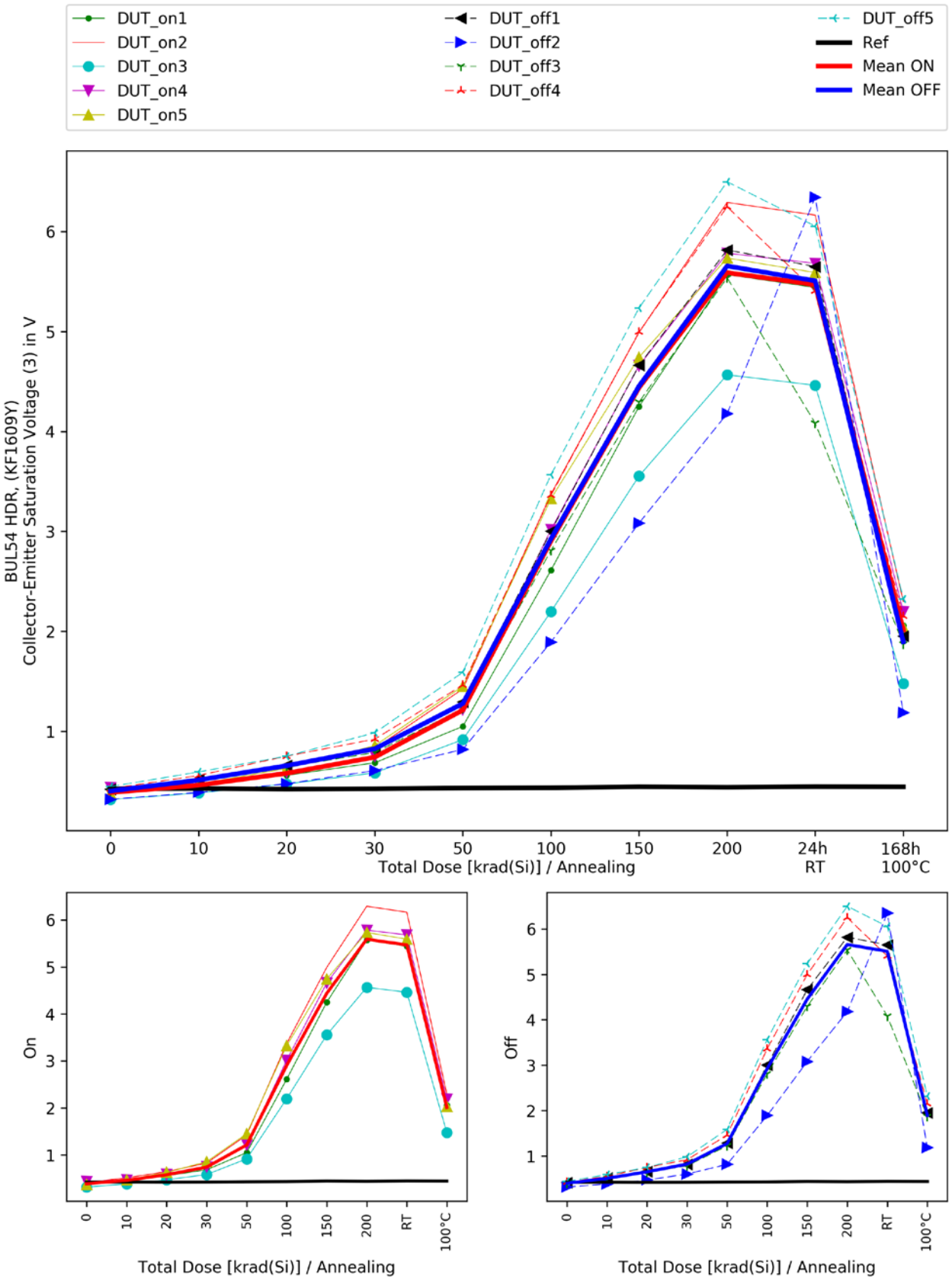
BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	389.4E-3	458.7E-3	558.7E-3	684.3E-3	1.0E+0	2.6E+0	4.2E+0	5.6E+0	5.4E+0	2.1E+0
DUT_on2	413.4E-3	513.6E-3	644.9E-3	826.7E-3	1.4E+0	3.4E+0	5.0E+0	6.3E+0	6.2E+0	2.3E+0
DUT_on3	316.4E-3	382.9E-3	472.5E-3	583.4E-3	916.2E-3	2.2E+0	3.6E+0	4.6E+0	4.5E+0	1.5E+0
DUT_on4	440.0E-3	472.0E-3	593.3E-3	754.1E-3	1.2E+0	3.0E+0	4.7E+0	5.8E+0	5.7E+0	2.2E+0
DUT_on5	376.7E-3	472.5E-3	627.2E-3	855.6E-3	1.5E+0	3.3E+0	4.7E+0	5.7E+0	5.6E+0	2.0E+0
Radiation-Mean ON	387.2E-3	459.9E-3	579.3E-3	740.8E-3	1.2E+0	2.9E+0	4.4E+0	5.6E+0	5.5E+0	2.0E+0
Standarddeviation	46.4E-3	47.8E-3	68.2E-3	110.4E-3	232.3E-3	499.1E-3	562.1E-3	632.0E-3	624.5E-3	318.4E-3
Mean + kσ	514.4E-3	590.9E-3	766.4E-3	1.0E+0	1.8E+0	4.3E+0	6.0E+0	7.3E+0	7.2E+0	2.9E+0
Mean - kσ	260.0E-3	329.0E-3	392.2E-3	438.2E-3	574.5E-3	1.5E+0	2.9E+0	3.9E+0	3.8E+0	1.1E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	418.9E-3	519.7E-3	657.7E-3	822.2E-3	1.3E+0	3.0E+0	4.7E+0	5.8E+0	5.6E+0	2.0E+0
DUT_off2	318.8E-3	387.7E-3	474.2E-3	606.4E-3	818.7E-3	1.9E+0	3.1E+0	4.2E+0	6.3E+0	1.2E+0
DUT_off3	402.2E-3	501.9E-3	641.3E-3	786.8E-3	1.2E+0	2.8E+0	4.3E+0	5.5E+0	4.1E+0	1.9E+0
DUT_off4	425.1E-3	556.5E-3	751.1E-3	920.8E-3	1.5E+0	3.4E+0	5.0E+0	6.2E+0	5.4E+0	2.2E+0
DUT_off5	446.0E-3	592.4E-3	751.1E-3	984.7E-3	1.6E+0	3.6E+0	5.2E+0	6.5E+0	6.1E+0	2.3E+0
Radiation-Mean OFF	402.2E-3	511.6E-3	655.1E-3	824.2E-3	1.3E+0	2.9E+0	4.5E+0	5.7E+0	5.5E+0	1.9E+0
Standarddeviation	49.2E-3	77.5E-3	113.3E-3	144.8E-3	293.5E-3	649.2E-3	844.2E-3	906.2E-3	874.0E-3	434.8E-3
Mean + kσ	537.0E-3	724.2E-3	965.8E-3	1.2E+0	2.1E+0	4.7E+0	6.8E+0	8.1E+0	7.9E+0	3.1E+0
Mean - kσ	267.4E-3	299.0E-3	344.4E-3	427.0E-3	472.2E-3	1.1E+0	2.1E+0	3.2E+0	3.1E+0	703.9E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	423.2E-3	426.7E-3	421.3E-3	424.2E-3	431.4E-3	434.9E-3	444.1E-3	439.7E-3	445.3E-3	443.4E-3
Typ. Value	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3	300.0E-3
Max. Value	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3

Fraunhofer
INT



Version 1.0

8.14 Base-Emitter Saturation Voltage (1)

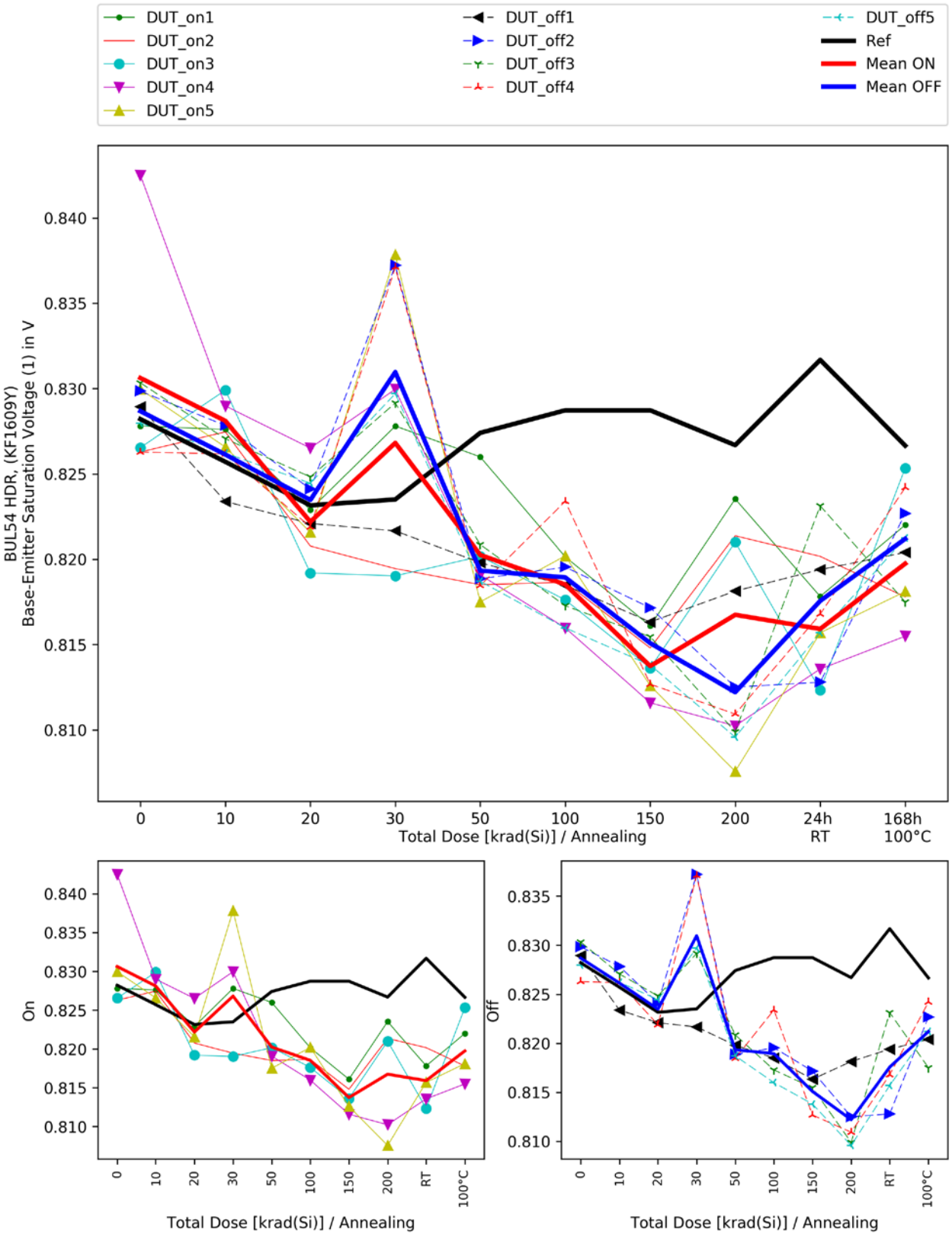
Base-Emitter Saturation Voltage (1)
V_BEsat1 in V
Limit: x<1.0

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	827.8E-3	827.6E-3	822.9E-3	827.8E-3	826.0E-3	820.1E-3	816.1E-3	823.5E-3	817.8E-3	822.0E-3
DUT_on2	826.3E-3	827.5E-3	820.8E-3	819.5E-3	818.5E-3	818.6E-3	814.8E-3	821.4E-3	820.2E-3	817.8E-3
DUT_on3	826.5E-3	829.9E-3	819.2E-3	819.0E-3	820.2E-3	817.6E-3	813.6E-3	821.0E-3	812.3E-3	825.3E-3
DUT_on4	842.5E-3	829.0E-3	826.5E-3	830.0E-3	819.1E-3	816.0E-3	811.6E-3	810.2E-3	813.6E-3	815.5E-3
DUT_on5	830.0E-3	826.6E-3	821.6E-3	837.9E-3	817.5E-3	820.2E-3	812.6E-3	807.6E-3	815.7E-3	818.1E-3
Radiation-Mean ON	830.6E-3	828.1E-3	822.2E-3	826.8E-3	820.2E-3	818.5E-3	813.7E-3	816.7E-3	815.9E-3	819.7E-3
Standarddeviation	6.8E-3	1.3E-3	2.8E-3	7.9E-3	3.4E-3	1.8E-3	1.8E-3	7.3E-3	3.2E-3	3.9E-3
Mean + kσ	849.3E-3	831.7E-3	829.8E-3	848.4E-3	829.5E-3	823.4E-3	818.6E-3	836.7E-3	824.6E-3	830.5E-3
Mean - kσ	812.0E-3	824.5E-3	814.6E-3	805.2E-3	811.0E-3	813.6E-3	808.9E-3	796.8E-3	807.2E-3	809.0E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	828.9E-3	823.4E-3	822.1E-3	821.7E-3	819.8E-3	818.5E-3	816.3E-3	818.1E-3	819.4E-3	820.4E-3
DUT_off2	829.8E-3	827.8E-3	824.1E-3	837.2E-3	818.8E-3	819.5E-3	817.2E-3	812.5E-3	812.8E-3	822.7E-3
DUT_off3	830.3E-3	827.1E-3	824.8E-3	829.2E-3	820.9E-3	817.3E-3	815.5E-3	809.9E-3	823.1E-3	817.5E-3
DUT_off4	826.3E-3	826.2E-3	821.9E-3	837.1E-3	818.4E-3	823.4E-3	812.7E-3	810.9E-3	816.8E-3	824.2E-3
DUT_off5	828.0E-3	826.2E-3	824.4E-3	829.7E-3	818.7E-3	816.0E-3	813.8E-3	809.6E-3	815.7E-3	821.2E-3
Radiation-Mean OFF	828.7E-3	826.1E-3	823.5E-3	831.0E-3	819.3E-3	818.9E-3	815.1E-3	812.2E-3	817.6E-3	821.2E-3
Standarddeviation	1.6E-3	1.7E-3	1.4E-3	6.5E-3	994.4E-6	2.8E-3	1.8E-3	3.5E-3	3.9E-3	2.5E-3
Mean + kσ	833.1E-3	830.7E-3	827.2E-3	848.8E-3	822.1E-3	826.7E-3	820.1E-3	821.8E-3	828.3E-3	828.1E-3
Mean - kσ	824.3E-3	821.5E-3	819.7E-3	813.2E-3	816.6E-3	811.2E-3	810.1E-3	802.6E-3	806.8E-3	814.3E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	828.2E-3	825.7E-3	823.2E-3	823.5E-3	827.4E-3	828.7E-3	828.7E-3	826.7E-3	831.7E-3	826.7E-3
Typ. Value	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3	800.0E-3
Max. Value	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Base-Emitter Saturation Voltage (1) in V
0.840
0.835
0.830
0.825
0.820
0.815
0.810
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.15 Base-Emitter Saturation Voltage (2)

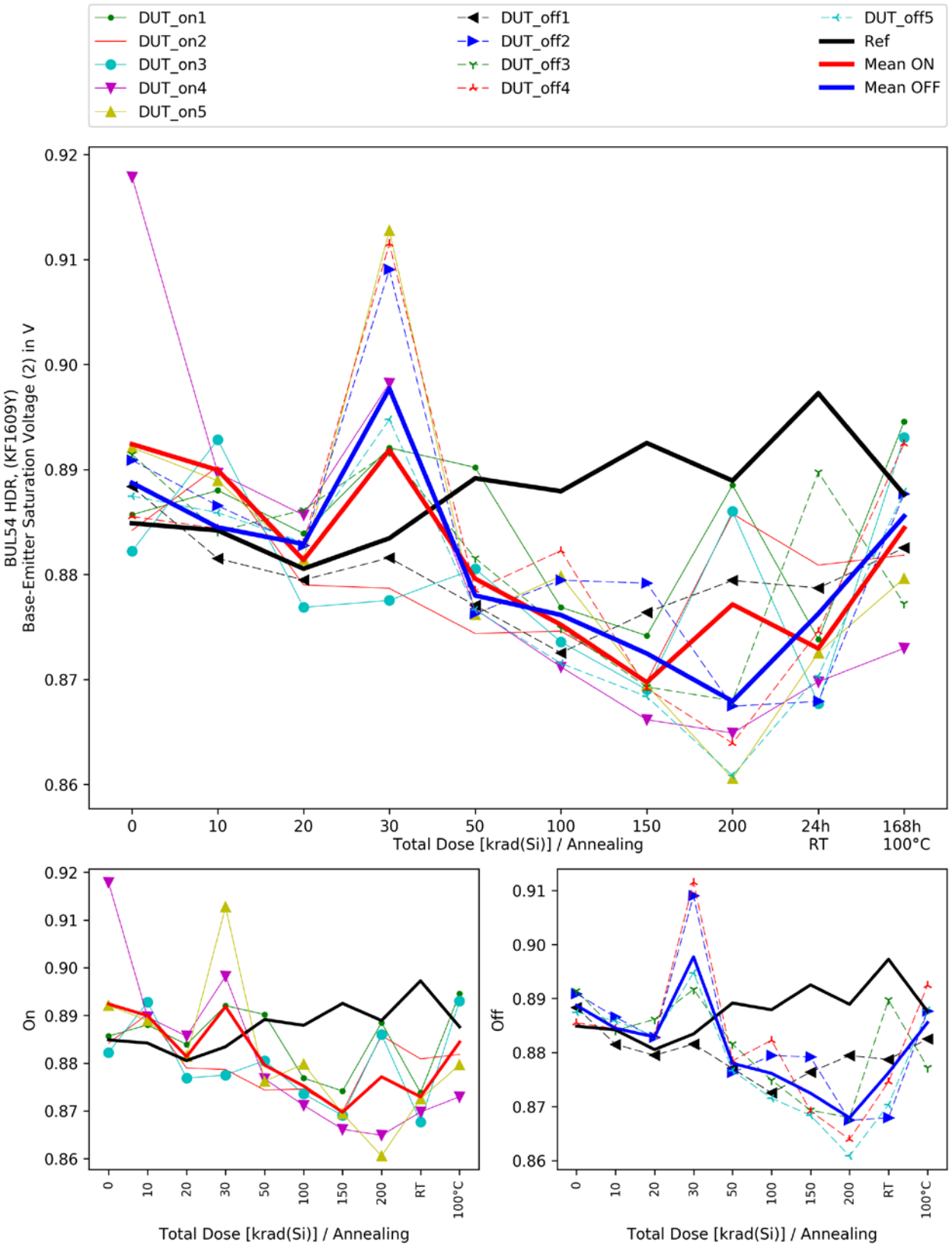
Base-Emitter Saturation Voltage (2)
V_BEsat2 in V
Limit: x<1.1

BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	885.7E-3	888.0E-3	883.9E-3	892.1E-3	890.2E-3	876.9E-3	874.2E-3	888.5E-3	873.8E-3	894.6E-3
DUT_on2	884.2E-3	890.3E-3	879.0E-3	878.7E-3	874.4E-3	874.6E-3	869.8E-3	885.8E-3	880.9E-3	881.8E-3
DUT_on3	882.2E-3	892.8E-3	876.9E-3	877.5E-3	880.5E-3	873.6E-3	869.0E-3	886.0E-3	867.7E-3	893.0E-3
DUT_on4	917.9E-3	889.7E-3	885.7E-3	898.2E-3	876.7E-3	871.2E-3	866.2E-3	864.9E-3	869.8E-3	873.0E-3
DUT_on5	892.1E-3	888.9E-3	881.4E-3	912.8E-3	876.2E-3	879.8E-3	869.5E-3	860.6E-3	872.5E-3	879.6E-3
Radiation-Mean ON	892.4E-3	890.0E-3	881.4E-3	891.9E-3	879.6E-3	875.2E-3	869.7E-3	877.2E-3	873.0E-3	884.4E-3
Standarddeviation	14.7E-3	1.8E-3	3.6E-3	14.6E-3	6.3E-3	3.3E-3	2.9E-3	13.3E-3	5.0E-3	9.2E-3
Mean + kσ	932.7E-3	895.0E-3	891.1E-3	932.0E-3	897.0E-3	884.2E-3	877.6E-3	913.6E-3	886.8E-3	909.6E-3
Mean - kσ	852.1E-3	884.9E-3	871.6E-3	851.7E-3	862.2E-3	866.2E-3	861.9E-3	840.7E-3	859.1E-3	859.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	888.4E-3	881.5E-3	879.5E-3	881.6E-3	877.0E-3	872.5E-3	876.4E-3	879.4E-3	878.7E-3	882.5E-3
DUT_off2	890.9E-3	886.6E-3	882.8E-3	909.0E-3	876.3E-3	879.5E-3	879.2E-3	867.5E-3	867.9E-3	887.7E-3
DUT_off3	891.4E-3	884.1E-3	886.1E-3	891.7E-3	881.6E-3	874.9E-3	869.3E-3	868.0E-3	889.7E-3	877.2E-3
DUT_off4	885.5E-3	884.4E-3	883.0E-3	911.5E-3	878.5E-3	882.3E-3	869.2E-3	863.9E-3	874.6E-3	892.4E-3
DUT_off5	887.5E-3	885.9E-3	883.0E-3	894.8E-3	876.6E-3	871.5E-3	868.4E-3	860.9E-3	870.4E-3	887.9E-3
Radiation-Mean OFF	888.7E-3	884.5E-3	882.9E-3	897.7E-3	878.0E-3	876.1E-3	872.5E-3	867.9E-3	876.3E-3	885.5E-3
Standarddeviation	2.4E-3	1.9E-3	2.4E-3	12.5E-3	2.2E-3	4.6E-3	5.0E-3	7.0E-3	8.6E-3	5.8E-3
Mean + kσ	895.4E-3	889.8E-3	889.4E-3	931.9E-3	883.9E-3	888.7E-3	886.1E-3	887.2E-3	899.8E-3	901.5E-3
Mean - kσ	882.0E-3	879.1E-3	876.4E-3	863.5E-3	872.1E-3	863.5E-3	858.9E-3	848.6E-3	852.7E-3	869.6E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	884.9E-3	884.2E-3	880.5E-3	883.4E-3	889.2E-3	887.9E-3	892.5E-3	888.9E-3	897.3E-3	887.6E-3
Typ. Value	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3	900.0E-3
Max. Value	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0	1.1E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
BUL54 HDR, (KF1609Y)
Base-Emitter Saturation Voltage (2) in V
0.92
0.91
0.90
0.89
0.88
0.87
0.86
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

8.16 Forward Current Transfer Ratio (DC Current Gain) (1)

Forward Current Transfer Ratio (DC Current Gain) (1)
HFE1
Limit: 20.0<x

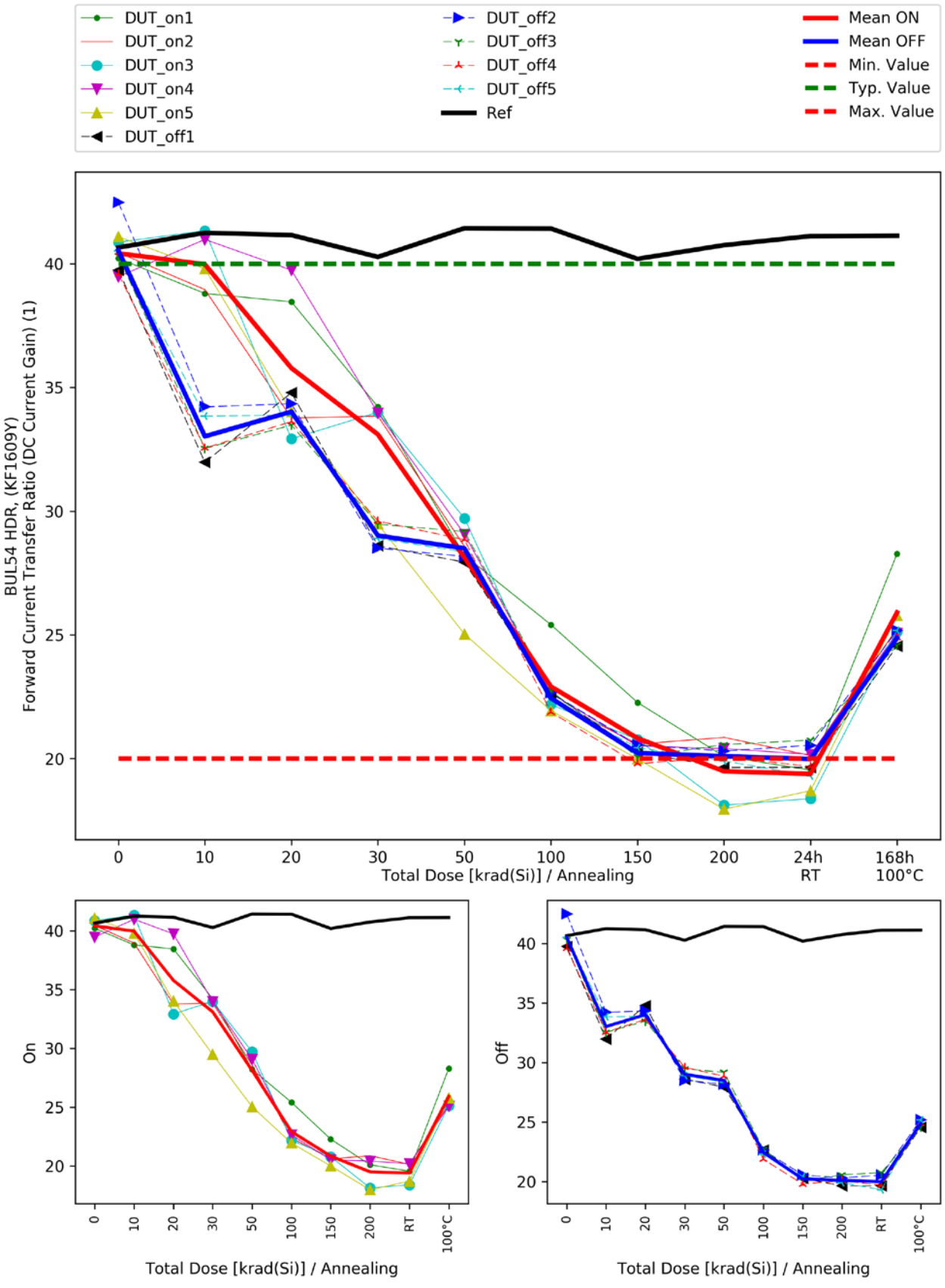
BUL54 HDR
Date-/Lotcode: KF1609Y

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	40.2E+0	38.8E+0	38.5E+0	34.2E+0	28.2E+0	25.4E+0	22.3E+0	20.1E+0	19.5E+0	28.3E+0
DUT_on2	40.5E+0	39.0E+0	33.8E+0	33.8E+0	28.6E+0	22.4E+0	20.6E+0	20.9E+0	20.1E+0	25.3E+0
DUT_on3	40.9E+0	41.3E+0	32.9E+0	34.0E+0	29.7E+0	22.2E+0	20.8E+0	18.1E+0	18.4E+0	25.1E+0
DUT_on4	39.5E+0	41.0E+0	39.7E+0	34.0E+0	29.1E+0	22.6E+0	20.5E+0	20.4E+0	20.2E+0	25.1E+0
DUT_on5	41.1E+0	39.8E+0	34.0E+0	29.5E+0	25.0E+0	21.9E+0	20.0E+0	18.0E+0	18.7E+0	25.8E+0
Radiation-Mean ON	40.4E+0	40.0E+0	35.8E+0	33.1E+0	28.1E+0	22.9E+0	20.8E+0	19.5E+0	19.4E+0	25.9E+0
Standarddeviation	629.8E-3	1.2E+0	3.1E+0	2.0E+0	1.8E+0	1.4E+0	857.8E-3	1.4E+0	815.8E-3	1.4E+0
Mean + kσ	42.1E+0	43.1E+0	44.3E+0	38.7E+0	33.1E+0	26.8E+0	23.2E+0	23.2E+0	21.6E+0	29.6E+0
Mean - kσ	38.7E+0	36.8E+0	27.3E+0	27.5E+0	23.1E+0	19.0E+0	18.5E+0	15.8E+0	17.1E+0	22.2E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	39.7E+0	32.0E+0	34.8E+0	28.6E+0	27.9E+0	22.7E+0	20.3E+0	19.6E+0	19.6E+0	24.5E+0
DUT_off2	42.5E+0	34.2E+0	34.3E+0	28.5E+0	28.2E+0	22.6E+0	20.6E+0	20.3E+0	20.5E+0	25.2E+0
DUT_off3	40.3E+0	32.5E+0	33.5E+0	29.5E+0	29.2E+0	22.7E+0	20.1E+0	20.6E+0	20.7E+0	24.6E+0
DUT_off4	39.6E+0	32.5E+0	33.6E+0	29.6E+0	28.8E+0	21.9E+0	19.8E+0	20.1E+0	19.7E+0	24.9E+0
DUT_off5	40.5E+0	33.8E+0	33.9E+0	28.9E+0	28.4E+0	22.3E+0	20.4E+0	19.9E+0	19.3E+0	25.2E+0
Radiation-Mean OFF	40.5E+0	33.0E+0	34.0E+0	29.0E+0	28.5E+0	22.4E+0	20.2E+0	20.1E+0	20.0E+0	24.9E+0
Standarddeviation	1.2E+0	954.2E-3	539.4E-3	499.7E-3	506.1E-3	360.6E-3	304.2E-3	356.7E-3	624.6E-3	304.5E-3
Mean + kσ	43.7E+0	35.6E+0	35.5E+0	30.4E+0	29.9E+0	23.4E+0	21.1E+0	21.1E+0	21.7E+0	25.7E+0
Mean - kσ	37.4E+0	30.4E+0	32.5E+0	27.6E+0	27.1E+0	21.5E+0	19.4E+0	19.1E+0	18.3E+0	24.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	40.7E+0	41.2E+0	41.2E+0	40.3E+0	41.4E+0	41.4E+0	40.2E+0	40.8E+0	41.1E+0	41.1E+0
Min. Value	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0	20.0E+0
Typ. Value	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0	40.0E+0

Fraunhofer
INT



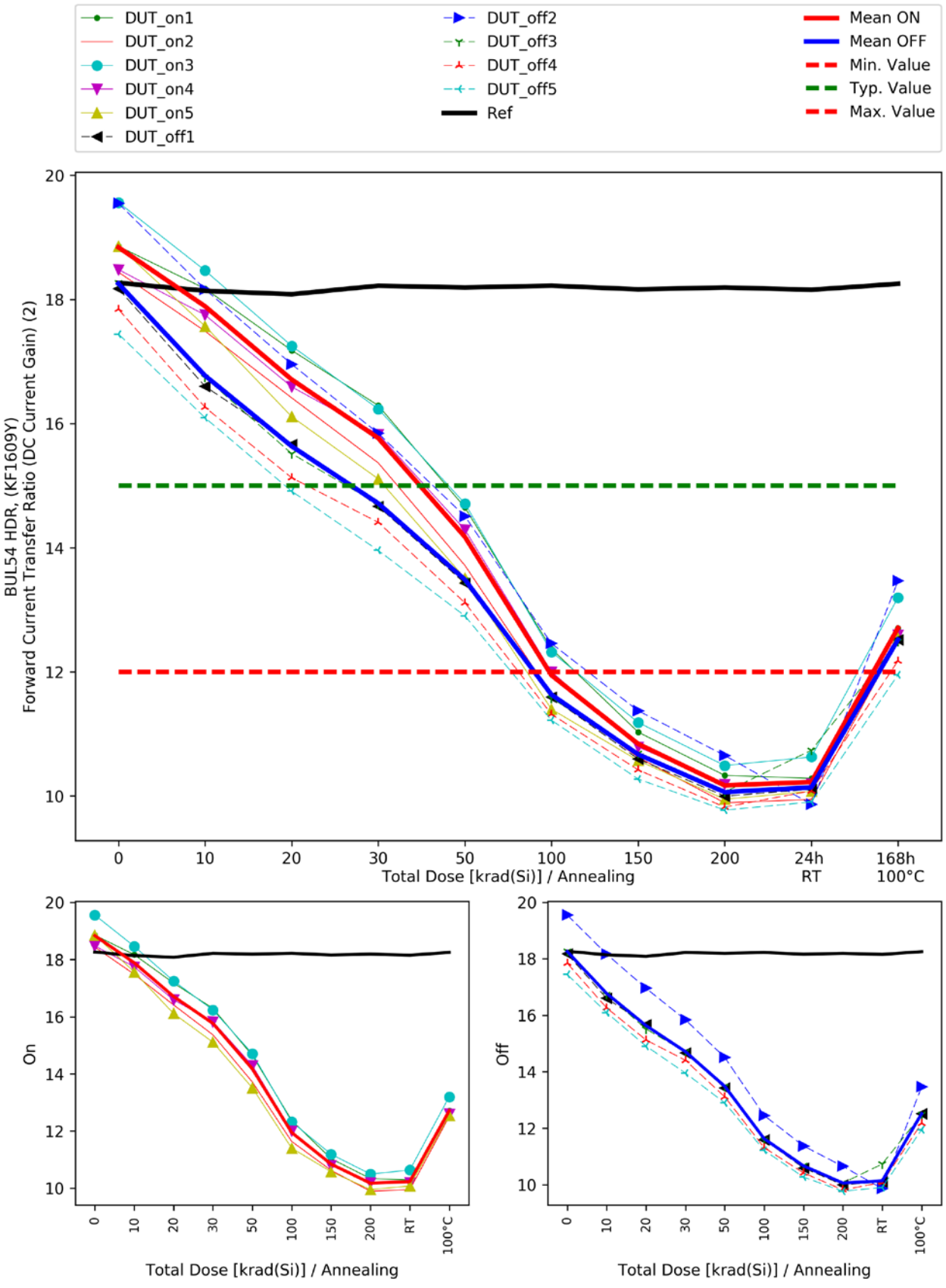
8.17 Forward Current Transfer Ratio (DC Current Gain) (2)

Forward Current Transfer Ratio (DC Current Gain) (2) **BUL54 HDR**
HFE2 Date-/Lotcode: KF1609Y
Limit: 12.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	18.9E+0	18.2E+0	17.2E+0	16.3E+0	14.6E+0	12.4E+0	11.0E+0	10.3E+0	10.3E+0	12.7E+0
DUT_on2	18.4E+0	17.5E+0	16.4E+0	15.4E+0	13.7E+0	11.6E+0	10.6E+0	9.9E+0	9.9E+0	12.5E+0
DUT_on3	19.6E+0	18.5E+0	17.2E+0	16.2E+0	14.7E+0	12.3E+0	11.2E+0	10.5E+0	10.6E+0	13.2E+0
DUT_on4	18.5E+0	17.7E+0	16.6E+0	15.8E+0	14.3E+0	12.0E+0	10.8E+0	10.2E+0	10.2E+0	12.6E+0
DUT_on5	18.9E+0	17.6E+0	16.1E+0	15.1E+0	13.5E+0	11.4E+0	10.6E+0	9.9E+0	10.1E+0	12.5E+0
Radiation-Mean ON	18.8E+0	17.9E+0	16.7E+0	15.8E+0	14.2E+0	11.9E+0	10.8E+0	10.2E+0	10.2E+0	12.7E+0
Standarddeviation	450.3E-3	417.1E-3	492.7E-3	522.9E-3	543.1E-3	425.1E-3	262.9E-3	253.6E-3	259.2E-3	283.8E-3
Mean + kσ	20.1E+0	19.0E+0	18.1E+0	17.2E+0	15.7E+0	13.1E+0	11.6E+0	10.9E+0	10.9E+0	13.5E+0
Mean - kσ	17.6E+0	16.7E+0	15.4E+0	14.3E+0	12.7E+0	10.8E+0	10.1E+0	9.5E+0	9.5E+0	11.9E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	18.2E+0	16.6E+0	15.7E+0	14.7E+0	13.4E+0	11.6E+0	10.6E+0	10.0E+0	10.1E+0	12.5E+0
DUT_off2	19.5E+0	18.2E+0	17.0E+0	15.8E+0	14.5E+0	12.5E+0	11.4E+0	10.7E+0	9.9E+0	13.5E+0
DUT_off3	18.3E+0	16.7E+0	15.5E+0	14.7E+0	13.5E+0	11.6E+0	10.7E+0	10.1E+0	10.7E+0	12.5E+0
DUT_off4	17.8E+0	16.3E+0	15.1E+0	14.4E+0	13.1E+0	11.3E+0	10.4E+0	9.8E+0	10.1E+0	12.2E+0
DUT_off5	17.4E+0	16.1E+0	14.9E+0	14.0E+0	12.9E+0	11.2E+0	10.3E+0	9.8E+0	9.9E+0	12.0E+0
Radiation-Mean OFF	18.3E+0	16.8E+0	15.6E+0	14.7E+0	13.5E+0	11.6E+0	10.7E+0	10.1E+0	10.1E+0	12.5E+0
Standarddeviation	792.3E-3	819.6E-3	797.2E-3	697.1E-3	617.9E-3	488.0E-3	424.3E-3	351.8E-3	350.2E-3	577.2E-3
Mean + kσ	20.4E+0	19.0E+0	17.8E+0	16.6E+0	15.2E+0	13.0E+0	11.8E+0	11.0E+0	11.1E+0	14.1E+0
Mean - kσ	16.1E+0	14.5E+0	13.4E+0	12.8E+0	11.8E+0	10.3E+0	9.5E+0	9.1E+0	9.2E+0	10.9E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	18.3E+0	18.1E+0	18.1E+0	18.2E+0	18.2E+0	18.2E+0	18.2E+0	18.2E+0	18.2E+0	18.3E+0
Min. Value	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0	12.0E+0
Typ. Value	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0	15.0E+0


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
Min. Value
Typ. Value
Max. Value
BUL54 HDR, (KF1609Y)
Forward Current Transfer Ratio (DC Current Gain) (2)
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
On
Off

8.18 Forward Current Transfer Ratio (DC Current Gain) (3)

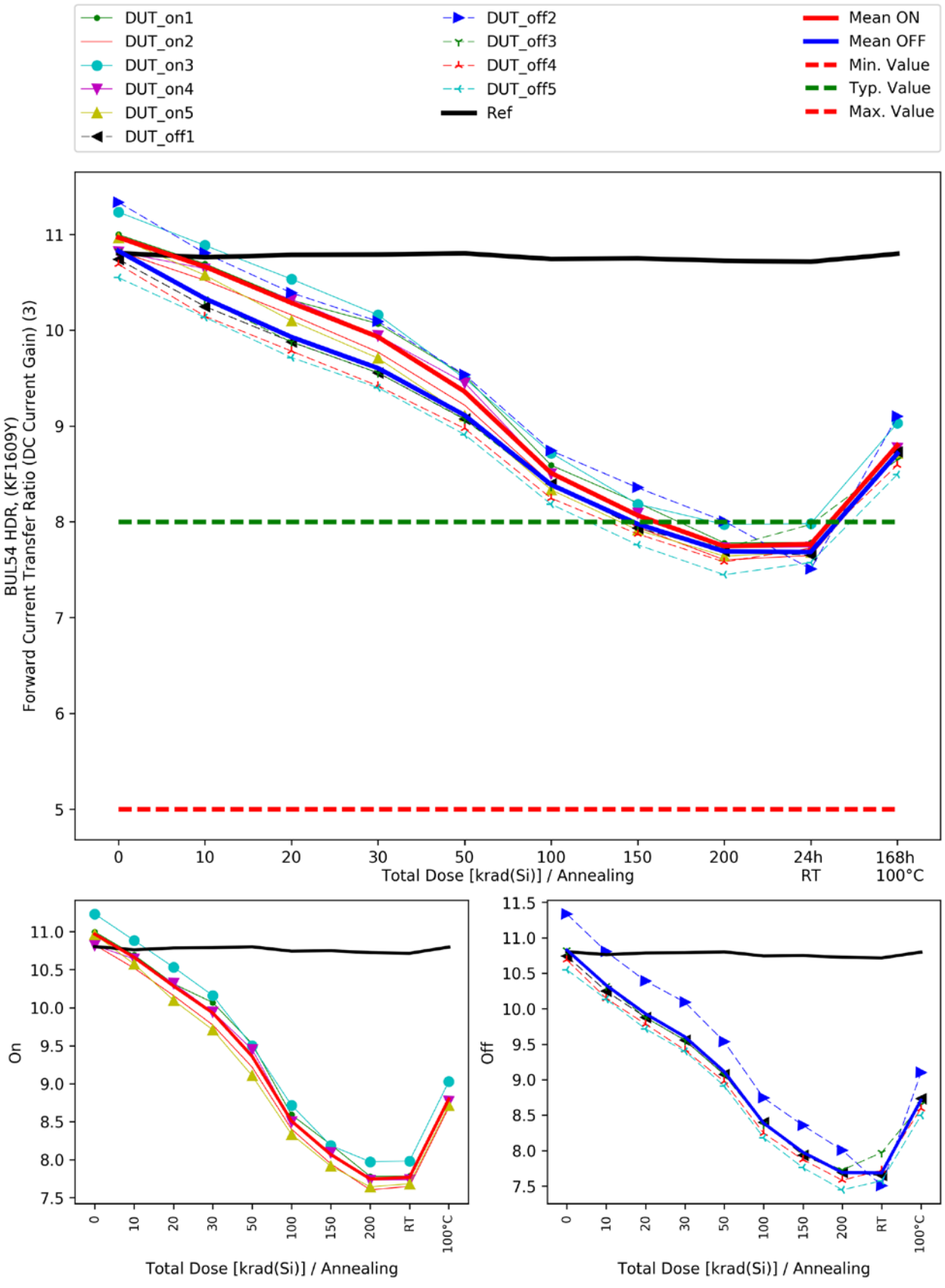
Forward Current Transfer Ratio (DC Current Gain) (3) **BUL54 HDR**
HFE3 Date-/Lotcode: KF1609Y
Limit: 5.0<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	11.0E+0	10.7E+0	10.3E+0	10.1E+0	9.5E+0	8.6E+0	8.2E+0	7.8E+0	7.8E+0	8.8E+0
DUT_on2	10.8E+0	10.5E+0	10.2E+0	9.8E+0	9.2E+0	8.4E+0	7.9E+0	7.6E+0	7.6E+0	8.7E+0
DUT_on3	11.2E+0	10.9E+0	10.5E+0	10.2E+0	9.5E+0	8.7E+0	8.2E+0	8.0E+0	8.0E+0	9.0E+0
DUT_on4	10.8E+0	10.6E+0	10.3E+0	9.9E+0	9.5E+0	8.5E+0	8.1E+0	7.7E+0	7.7E+0	8.8E+0
DUT_on5	11.0E+0	10.6E+0	10.1E+0	9.7E+0	9.1E+0	8.3E+0	7.9E+0	7.6E+0	7.7E+0	8.7E+0
Radiation-Mean ON	**11.0E+0**	**10.7E+0**	**10.3E+0**	**9.9E+0**	**9.4E+0**	**8.5E+0**	**8.1E+0**	**7.7E+0**	**7.8E+0**	**8.8E+0**
Standarddeviation	**168.8E-3**	**140.4E-3**	**169.1E-3**	**191.1E-3**	**187.0E-3**	**151.5E-3**	**132.1E-3**	**145.0E-3**	**130.7E-3**	**135.0E-3**
Mean + kσ	**11.4E+0**	**11.0E+0**	**10.7E+0**	**10.5E+0**	**9.9E+0**	**8.9E+0**	**8.4E+0**	**8.1E+0**	**8.1E+0**	**9.2E+0**
Mean - kσ	**10.5E+0**	**10.3E+0**	**9.8E+0**	**9.4E+0**	**8.8E+0**	**8.1E+0**	**7.7E+0**	**7.3E+0**	**7.4E+0**	**8.4E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	10.7E+0	10.2E+0	9.9E+0	9.6E+0	9.1E+0	8.4E+0	7.9E+0	7.7E+0	7.6E+0	8.7E+0
DUT_off2	11.3E+0	10.8E+0	10.4E+0	10.1E+0	9.5E+0	8.7E+0	8.4E+0	8.0E+0	7.5E+0	9.1E+0
DUT_off3	10.8E+0	10.3E+0	9.9E+0	9.6E+0	9.1E+0	8.4E+0	8.0E+0	7.7E+0	8.0E+0	8.6E+0
DUT_off4	10.7E+0	10.1E+0	9.8E+0	9.4E+0	9.0E+0	8.2E+0	7.9E+0	7.6E+0	7.7E+0	8.6E+0
DUT_off5	10.5E+0	10.1E+0	9.7E+0	9.4E+0	8.9E+0	8.2E+0	7.8E+0	7.4E+0	7.6E+0	8.5E+0
Radiation-Mean OFF	**10.8E+0**	**10.3E+0**	**9.9E+0**	**9.6E+0**	**9.1E+0**	**8.4E+0**	**8.0E+0**	**7.7E+0**	**7.7E+0**	**8.7E+0**
Standarddeviation	**301.2E-3**	**275.5E-3**	**267.1E-3**	**282.5E-3**	**245.8E-3**	**216.8E-3**	**225.8E-3**	**207.1E-3**	**180.0E-3**	**232.1E-3**
Mean + kσ	**11.7E+0**	**11.1E+0**	**10.7E+0**	**10.4E+0**	**9.8E+0**	**9.0E+0**	**8.6E+0**	**8.3E+0**	**8.2E+0**	**9.3E+0**
Mean - kσ	**10.0E+0**	**9.6E+0**	**9.2E+0**	**8.8E+0**	**8.4E+0**	**7.8E+0**	**7.4E+0**	**7.1E+0**	**7.2E+0**	**8.1E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	10.8E+0	10.8E+0	10.8E+0	10.8E+0	10.8E+0	10.7E+0	10.7E+0	10.7E+0	10.7E+0	10.8E+0
Min. Value	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0	5.0E+0
Typ. Value	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0

Fraunhofer
INT



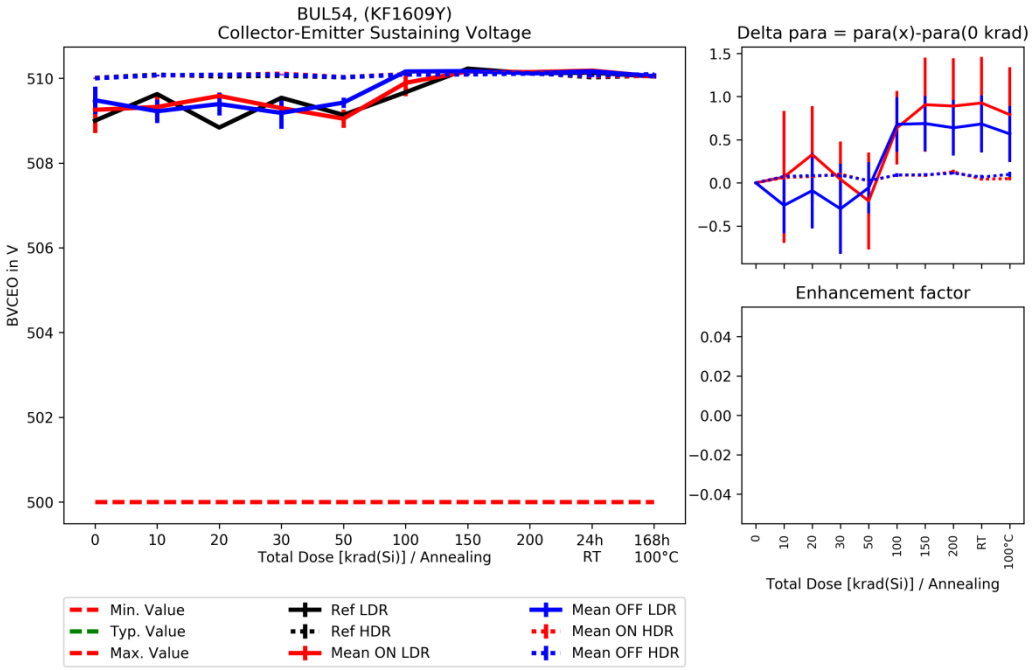
9 Results of Enhancement Calculation

9.1 Overview of Enhanced low dose rate sensitivity

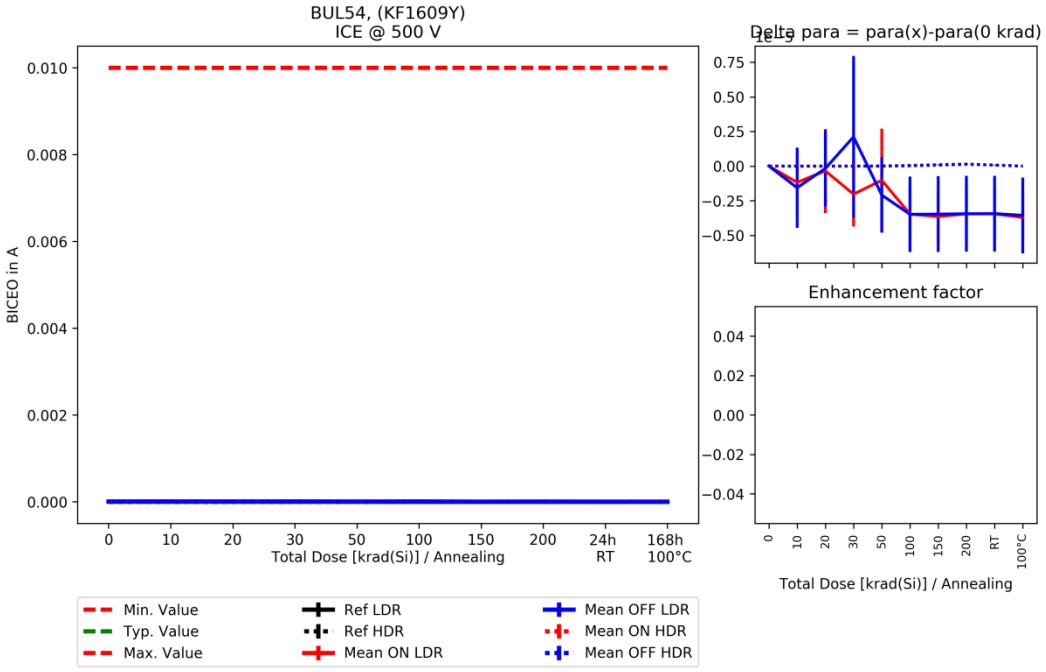
#	Characteristics	Symbol	Values out of specs during irradiation?	Enhancement factor applicable (ELDRS?)	max. Calculated enhancement factor	Comment
1	Collector-Emitter Sustaining Voltage	$V_{(Sus)CEO}$ I_C@500V	no	no	--	--
2	Collector-Base Breakdown Voltage	$V_{(BR)CBO}$ I_C@1000 V	**yes**	**yes**	**On: >200 Off: 2 12 for I_C@1000 V**	no degradation found at HDR (see remark below)
3	Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$ I_E@10 V	no	no	--	--
4	Collector-Base Cutoff Current	I_{CBO}	**yes**	**yes**	**2.9**	--
5	Collector-Emitter Cut-off Current	I_{CEO}	no	no	no	
6	Emitter-Base Cutoff Current	I_{EBO}	no	no	no	--
7	Collector-Emitter Saturation Voltage	$V_{CE(sat)1}$	**yes**	**yes**	**2.0**	--
8		$V_{CE(sat)2}$	**yes**	**yes**	**4.4**	
9		$V_{CE(sat)3}$	**yes**	**yes**	**6.1**	
10	Base-Emitter Saturation Voltage	$V_{BE(sat)1}$	no	no	no	
11		$V_{BE(sat)2}$	no	no	no	
12	Forward Current Transfer Ratio (DC Current Gain)	h_{FE1}	**yes**	**yes**	**2.0**	
13		h_{FE2}	**yes**	**yes**	**2.3**	
14		h_{FE3}	no	no	no	

Remark: The large enhancement factors found in parameters $V_{(BR)CBO}$ could be considered artifacts of the test procedure. As the voltage sweep was stopped at the rated voltage instead (see Note 2 in Section 5.1, the HDR value was nearly constant. Thus applying the formula in Section 6 leads to division by a near-zero value.

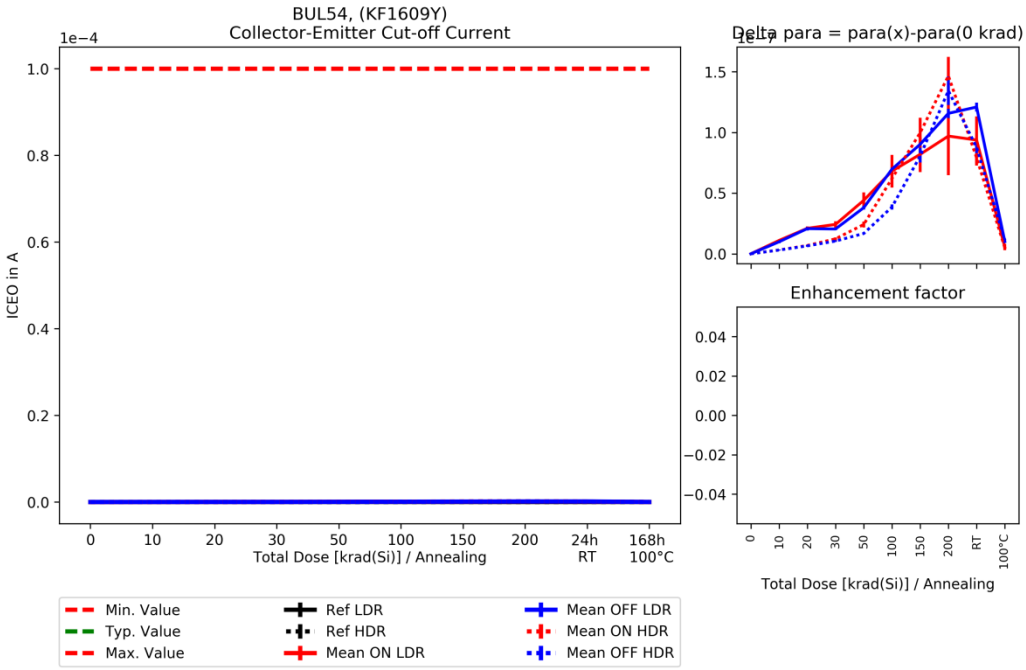
9.2 Collector-Emitter Sustaining Voltage



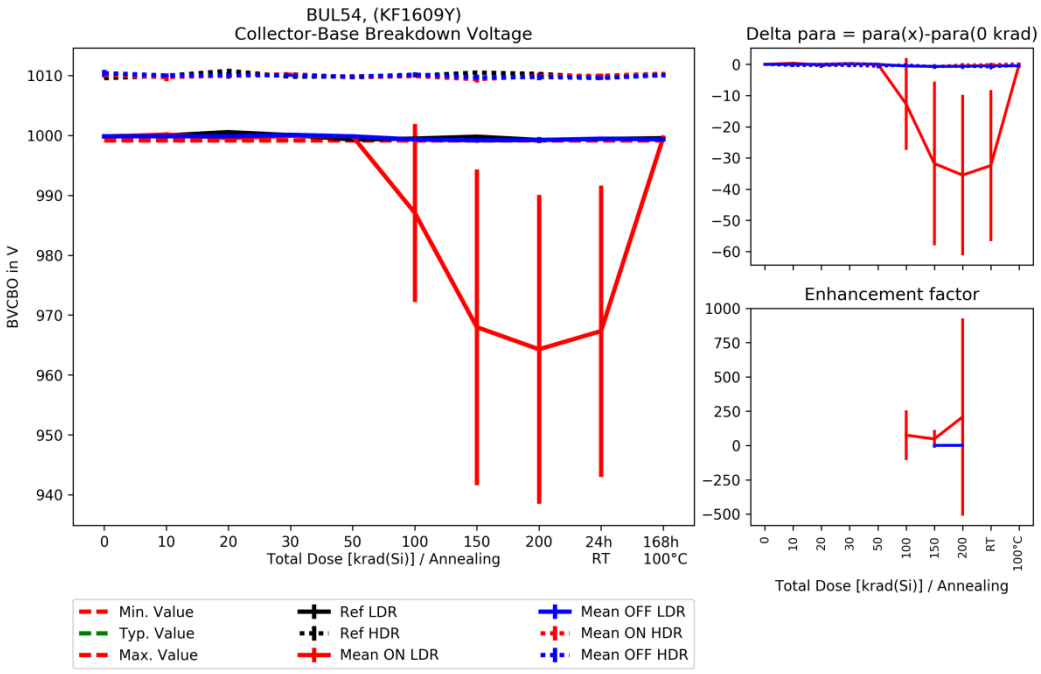
9.3 ICE @ 500 V



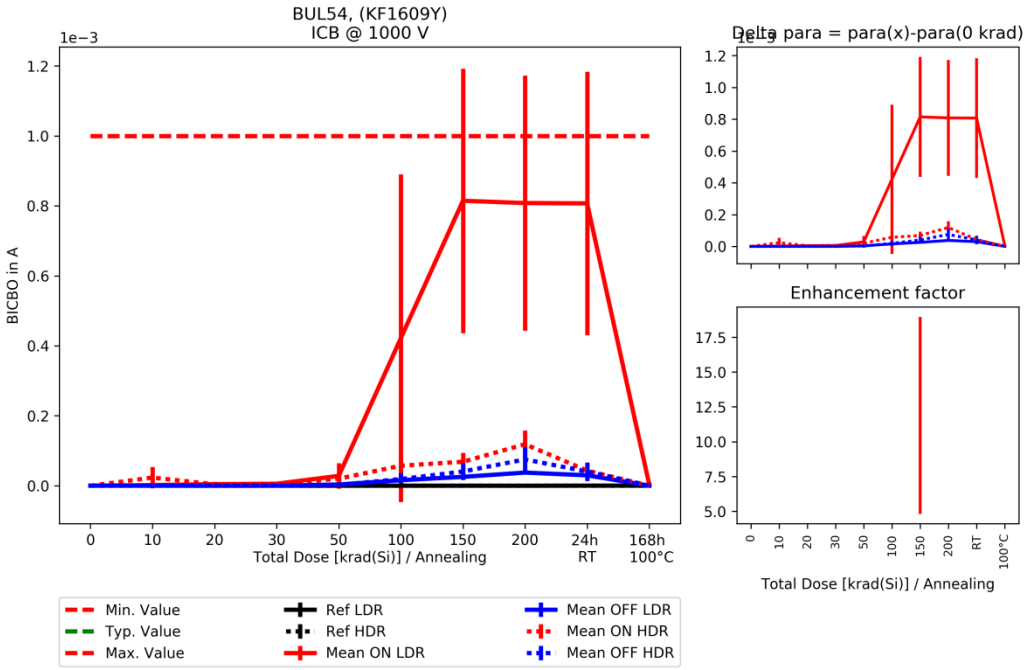
9.4 Collector-Emitter Cut-off Current



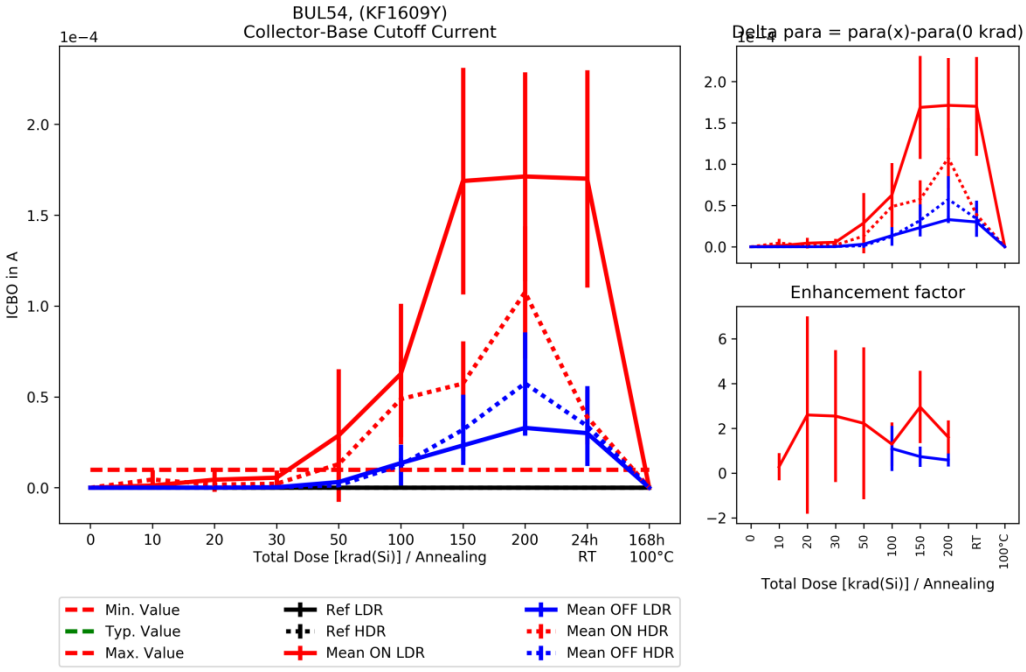
9.5 Collector-Base Breakdown Voltage



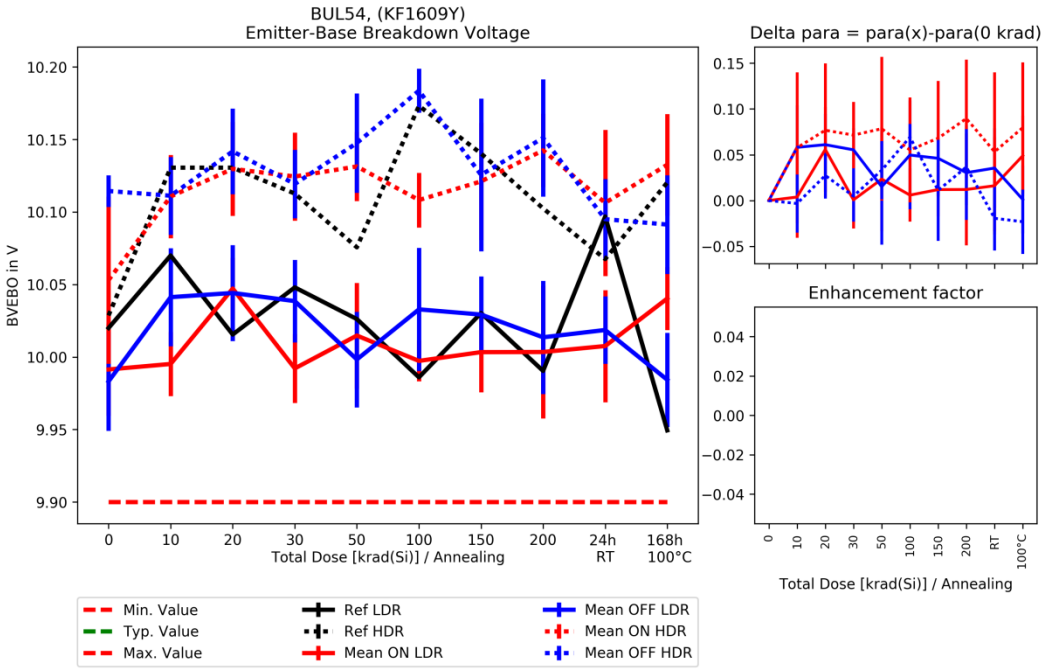
9.6 ICB @ 1000 V



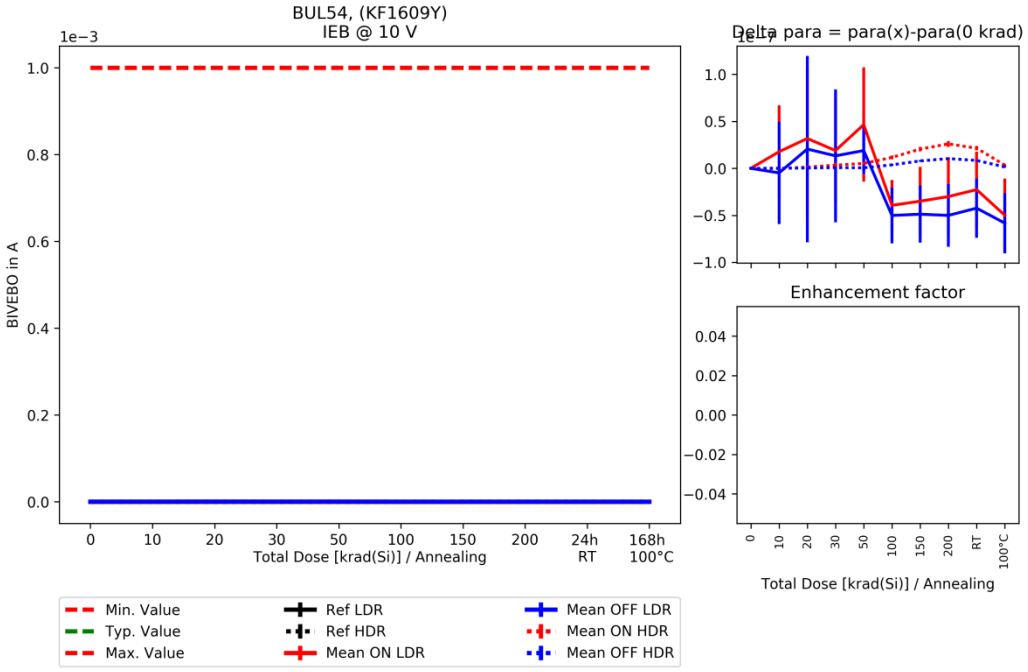
9.7 Collector-Base Cutoff Current



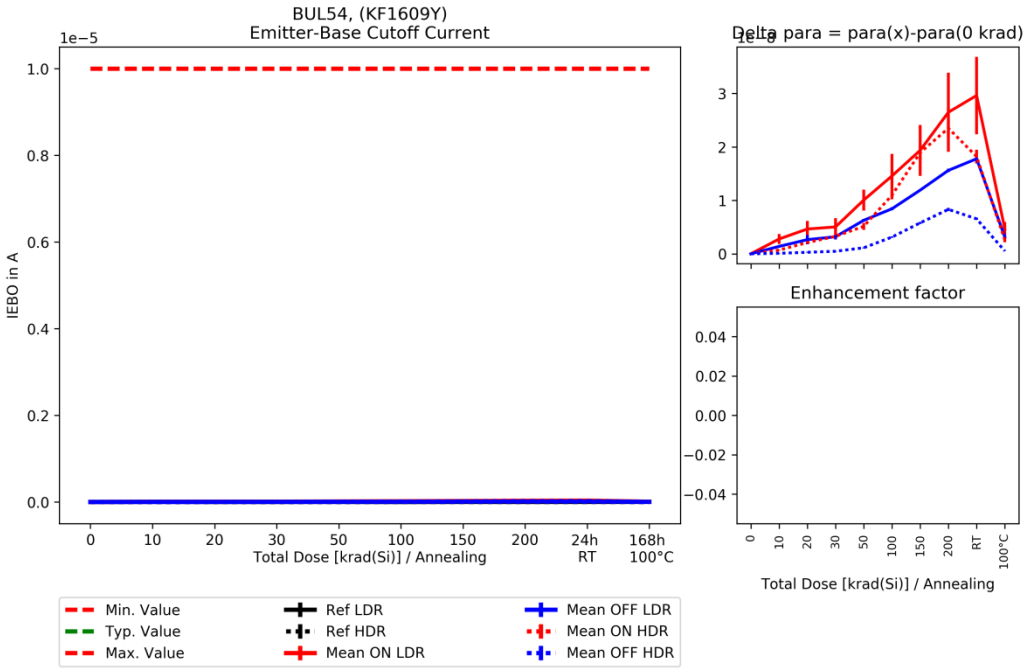
9.8 Emitter-Base Breakdown Voltage



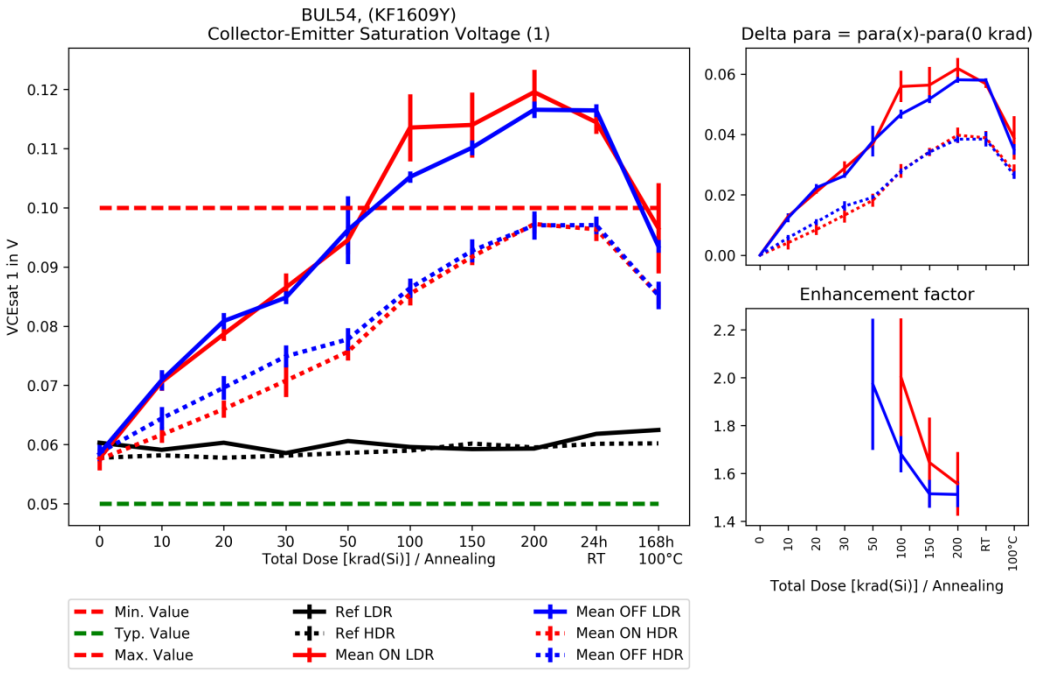
9.9 IEB @ 10 V



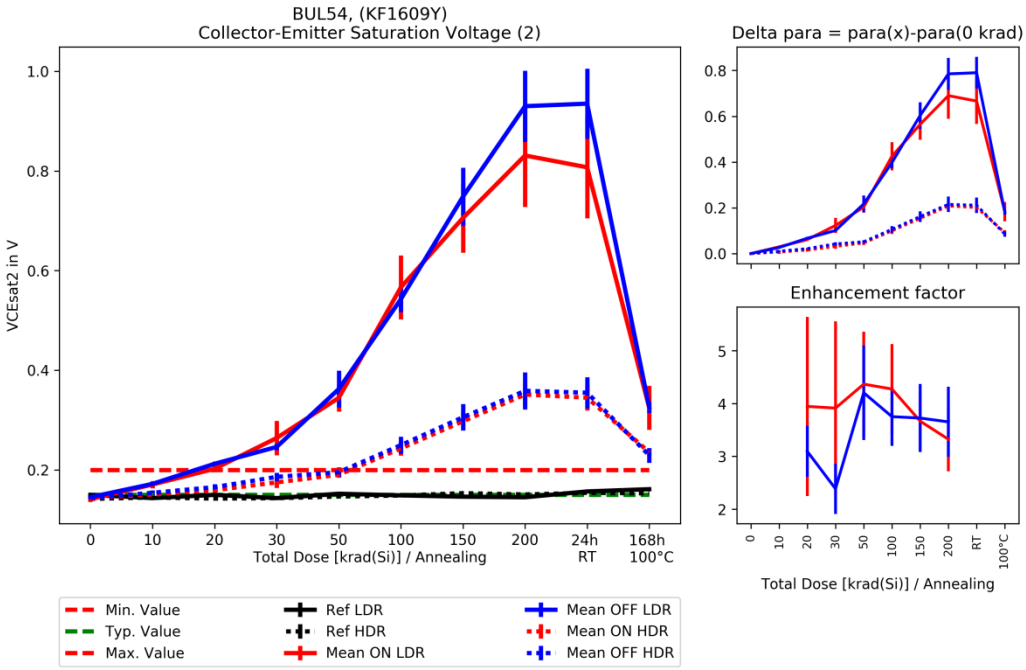
9.10 Emitter-Base Cutoff Current



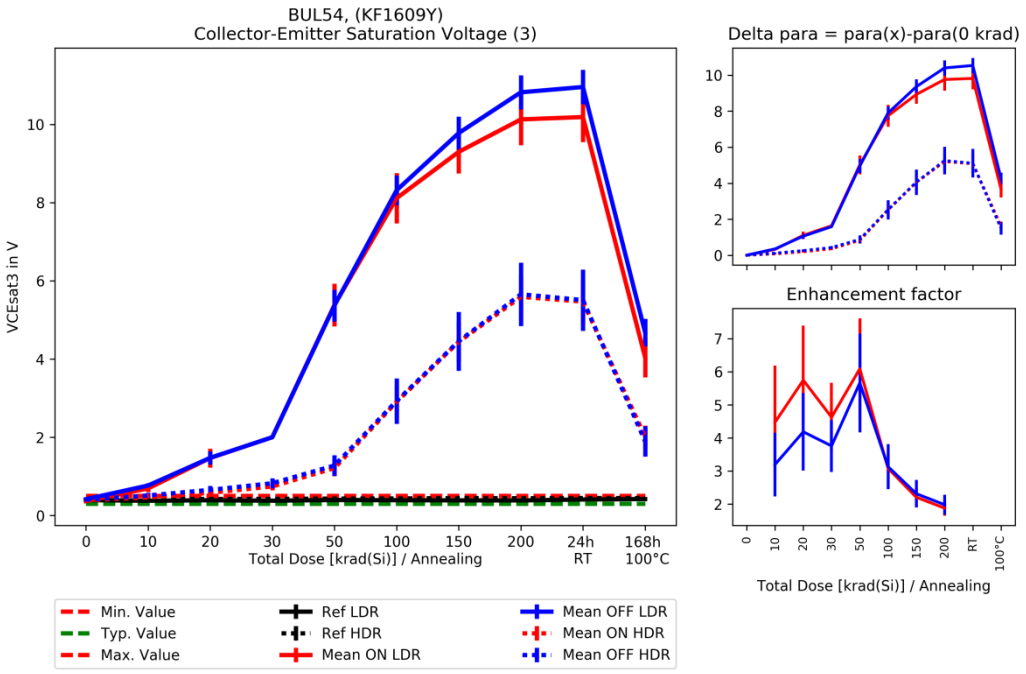
9.11 Collector-Emitter Saturation Voltage (1)



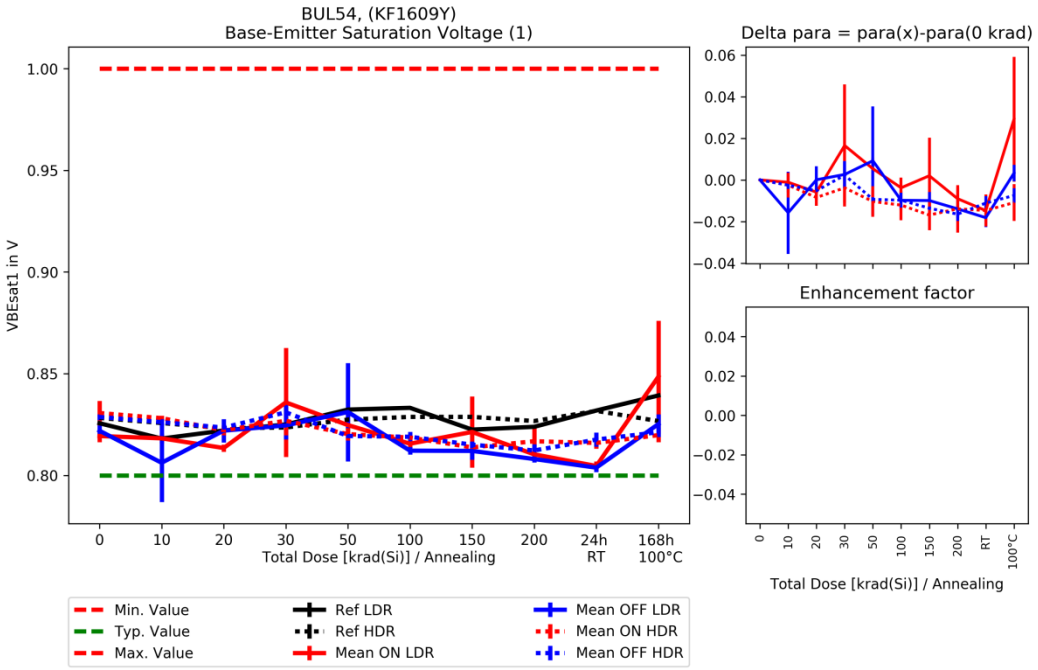
9.12 Collector-Emitter Saturation Voltage (2)



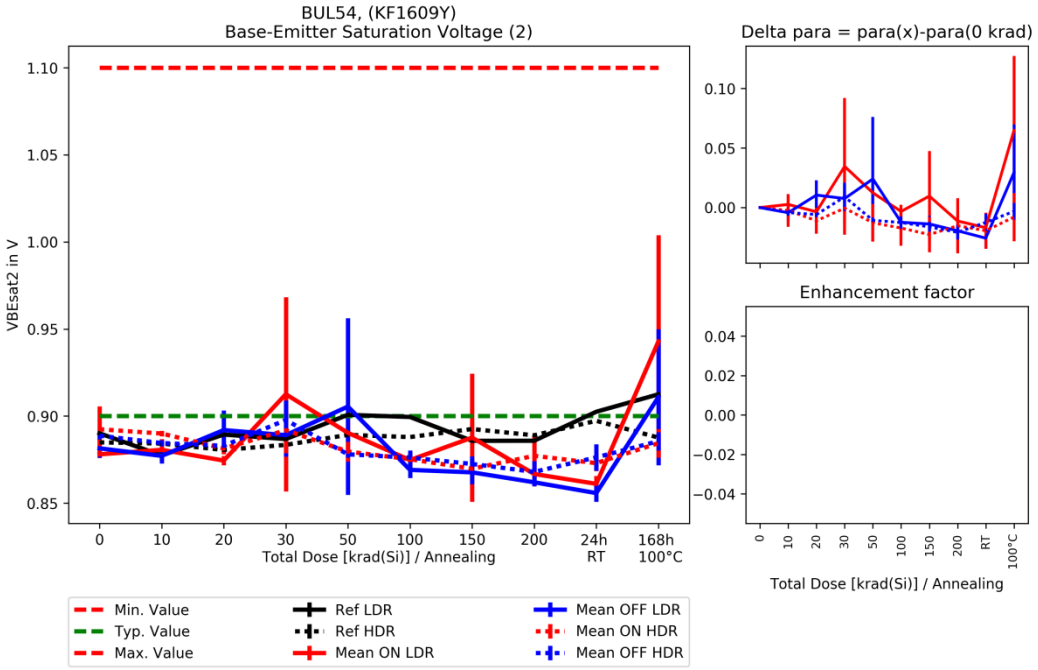
9.13 Collector-Emitter Saturation Voltage (3)



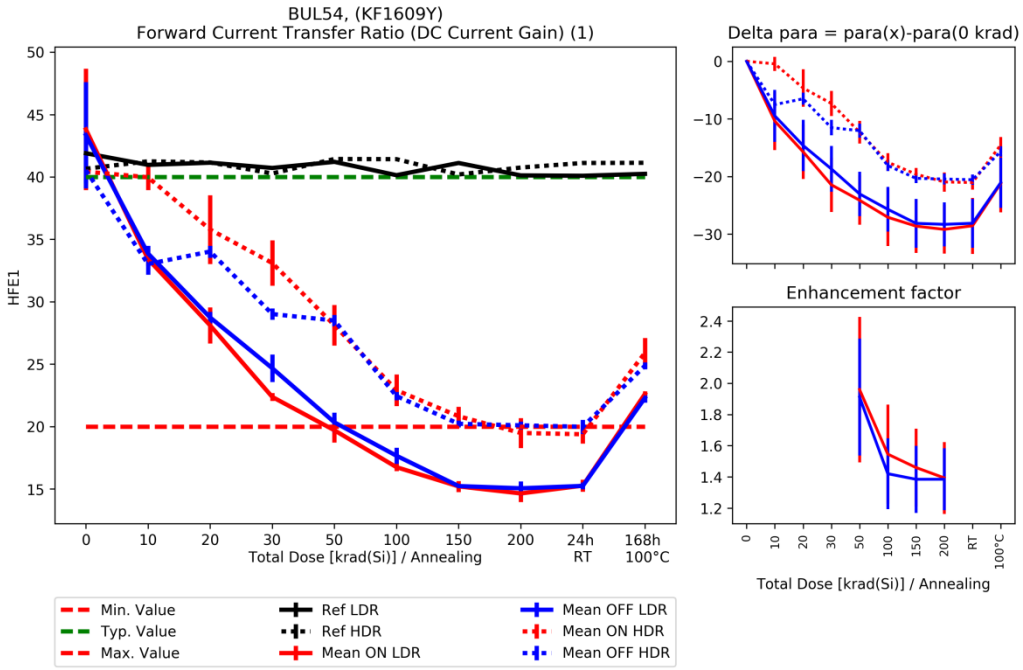
9.14 Base-Emitter Saturation Voltage (1)



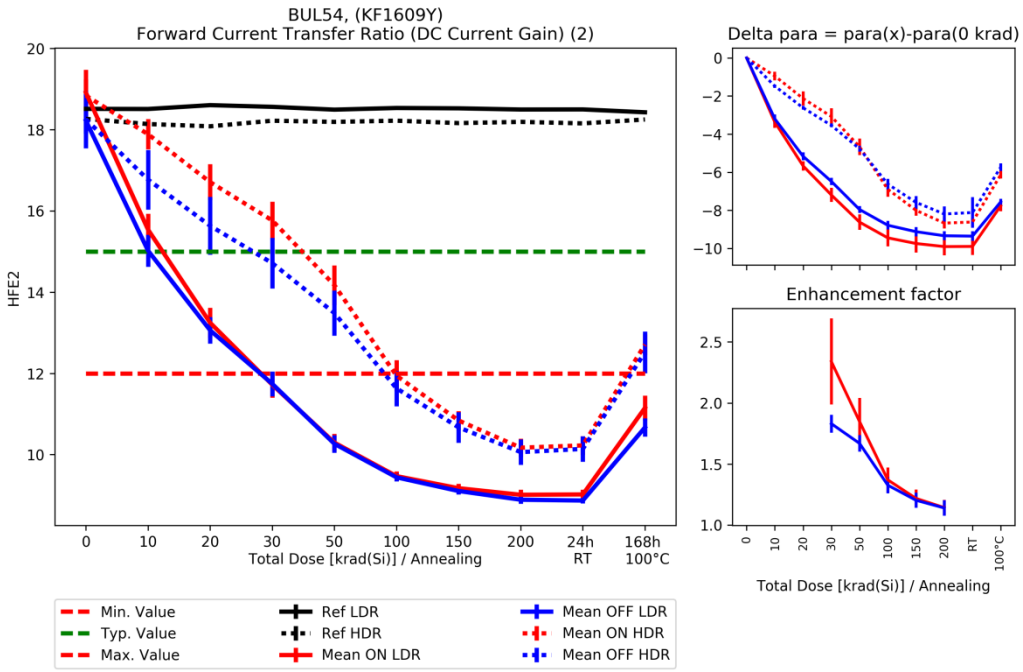
9.15 Base-Emitter Saturation Voltage (2)



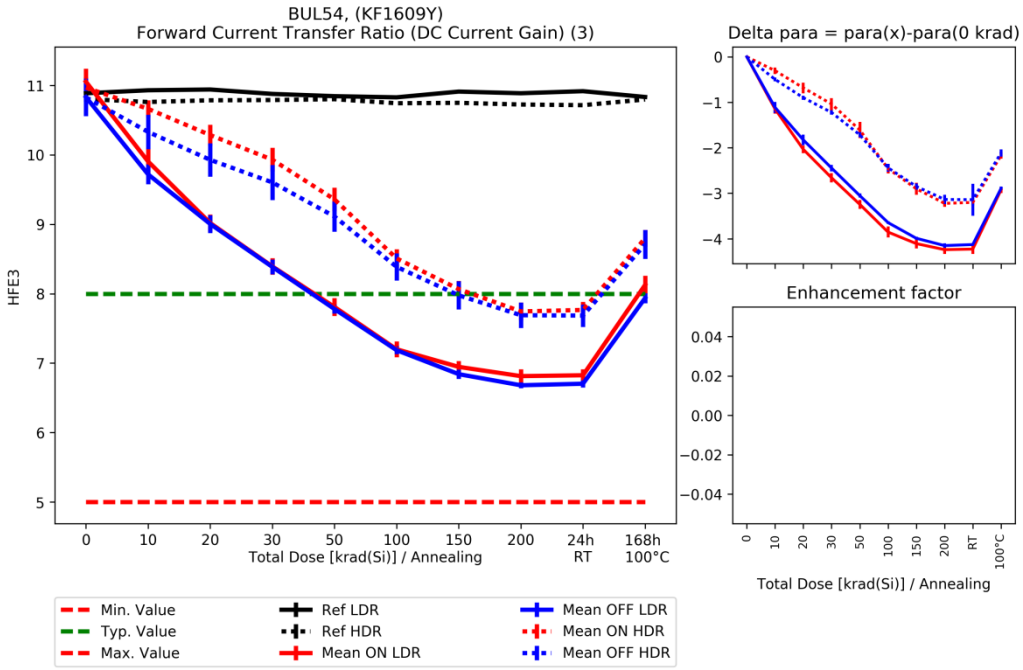
9.16 Forward Current Transfer Ratio (DC Current Gain) (1)



9.17 Forward Current Transfer Ratio (DC Current Gain) (2)



9.18 Forward Current Transfer Ratio (DC Current Gain) (3)



A Fraunhofer INT

A.1. About the institute

The Fraunhofer Institute for Technological Trend Analysis INT provides scientifically sound assessments and counselling on the entire spectrum of technological developments. On this basis, the Institute conducts Technology Forecasting, making possible a long-term approach to strategic research planning. Fraunhofer INT constantly applies this competence in projects tailor-made for our clients.

Over and above these skills, we run our own experimental and theoretical research on the effects of ionizing and electromagnetic radiation on electronic components, as well as on radiation detection systems. To this end, INT is equipped with the latest measurement technology. Our main laboratory and large-scale appliances are radiation sources, electromagnetic simulation facilities and detector systems that cannot be found in this combination in any other civilian body in Germany.

For more than 40 years, INT has been a reliable partner for the Federal German Ministry of Defence, which it advises in close cooperation and for which it carries out research in technology analysis and strategic planning as well as radiation effects. INT also successfully advises and conducts research for domestic and international civilian clients: both public bodies and industry, from SMEs to DAX 30 companies.

Further information can be found on the website [1].

A.2. Business unit Nuclear Effects in Electronics and Optics

The Business Unit „Nuclear Effects in Electronic and Optics (NEO)“ at Fraunhofer INT investigates the effects of ionizing radiation on electronic, optoelectronic, and photonic components and systems. Its work is based on more than 40 years of experience in that field.

NEO performs irradiation tests based on international standards and advises companies regarding radiation qualification and hardening of components and systems. The knowledge obtained in years of radiation testing is also used for the development of new radiation sensor systems. These activities are performed either at irradiation facilities installed at INT or at partner institutions to which our scientists have regular access.

A multitude of modern equipment to measure electrical and optical parameters is available. Furthermore our institute runs a precision mechanical workshop and an electronic laboratory. This enables us to conduct most of the irradiation tests without help or equipment of the customer.

The activities within NEO are:

- Investigations of the effects in all kinds of radiation environments
- Performance, analysis, and evaluation of irradiation tests done at Fraunhofer INT and external facilities

- Ensuring the operability of components and systems in typical radiation environments, such as space, nuclear facilities, medicine, or accelerators
- Consulting users and manufacturers on the use of products in radiation environments by selecting, optimizing and hardening
- Measurement of the radiation effects on optical fibers and fiber Bragg gratings (FBG)
- Development of radiation sensors based on optical fibers, FBGs, oscillating crystals, UV-EPROMs, and SRAMs
- Participation in the development of international test procedures for IEC, IEEE, NATO, and IAEA
- Since 2013 all services of the business unit are certified according to ISO 9001

A.3. Irradiation facilities

Fraunhofer INT operates several irradiation facilities on site that are dedicated to perform irradiation tests. For that purpose the design and operation characteristics are highly optimised from many decades of experience and to comply with all relevant standards and test procedures.

Furthermore Fraunhofer INT accesses regularly external facilities, partly with dedicated irradiation spots for exclusive use to Fraunhofer INT.

These irradiation facilities are:

- Co-60 irradiation sources on site to simulate the effect of total dose
- Neutron generators on site to simulate the displacement damage of heavy particles
- 450 keV X-ray irradiation facility on site
- Laser induced single event test system on site
- Dedicated proton irradiation spot at the injector cyclotron of FZ Jülich to simulate the effects of solar and trapped protons
- External Co-60 irradiation sources for high dose and high dose rate irradiations

The facilities used in the context of this work will be described in detail in the following sections.

A.4. QM-Certificate

DNV·GL

MANAGEMENT SYSTEM CERTIFICATE

Certificate No: 126306-2012-AQ-GER-DAkkS
Initial certification date: 13. February 2013
Valid: 29. March 2018 - 12. February 2019

This is to certify that the management system of

Fraunhofer INT

Fraunhofer-Institut für Naturwissenschaftlich-Technische Trendanalysen INT
Appelsgarten 2, 53879 Euskirchen, Germany

has been found to conform to the Quality Management System standard:

ISO 9001:2015

This certificate is valid for the following scope:

Scientific research on the effects of nuclear and electromagnetic radiation as well as application and development of methods for their characterization

Place and date:
Essen, 29. March 2018

DAkkS Deutsche Akkreditierungsstelle D-ZM-18453-01-00

For the issuing office:
DNV GL - Business Assurance
Schnieringshof 14, 45329 Essen, Germany

Thomas Beck
Technical Manager

Lack of fulfilment of conditions as set out in the Certification Agreement may render this Certificate invalid.
ACCREDITED UNIT: DNV GL Business Assurance Zertifizierung und Umweltgutachter GmbH, Schnieringshof 14, 45329 Essen, Germany.
TEL: +49 201 7296-222. www.dnvgl.de/assurance

B Irradiation details LDR

B.1. Irradiation facility TK100

The TK100 is a Co-60 gamma irradiator manufactured by Sauerwein Isotopentechnik, Germany. Inside the shielding container is a small radioactive pellet with a diameter of 2 mm and a length of 3 mm. The activity decreases with a physical half-life of 5.27 years. The current used radioactive pellet was installed in the irradiator at 2015-12-17. The activity at that time was 485 GBq.

In deactivated state the radioactive pellet is stored inside the shielding container allowing the operator to install the samples and conduct measurements without getting exposed to ionizing radiation. On activation, the radioactive source is pushed into the source guiding tube in less than a second irradiating the surrounding volume.

The certificate of the radioactive source can be found in Appendix B.4.

Figure 15: TK100 irradiation facility

B.2. Radiation properties of TK100

The samples are irradiated with Co-60 gamma radiation. The radioactive Co 60 isotope decays by emitting beta radiation (i.e. electrons) into a highly excited Ni-60 isotope which emits two gamma photons to reach the stable ground state. The gamma radiation has two energy levels of 1.172 MeV and 1.332 MeV.

The gamma radiation of around 1 MeV is a penetrating radiation, so the samples are irradiated completely. The shielding of the sample holder and other surrounding material between the source and the sample is negligible.

The radiation is emitted from a point-like source. Thus the dose rate $\dot{D}$ falls off with $1/r^2$ where r is the distance from the source.

$$\dot{D}(r) = \dot{D}_0 \cdot \frac{r_0^2}{r^2}$$

B.3. Dosimetry at TK100

The dosimetry is done regularly with calibrated and ionization chambers manufactured by IBA, Germany, and PTW Freiburg, Germany.

The dose rates obtained at varying distances between 2 cm and 50 cm and in different directions relative to the source are used to develop a model of the dose rate distribution around the source as a function of distance and direction. The dose rate of an individual measurement is scaled to a reference date taking the half-life of the radioactive isotope into account. This model is constantly checked and improved with each additional measurement of dose rates.

As a result a reliable description of the dose rates inside a specific volume arranged in a given geometry in the vicinity of the irradiation source is available.

The uncertainties of the reported dose rates are given by an uncertainty evaluation according to [2] and mainly result from the uncertainties of the dosimetry and positioning of the samples.

The uncertainty evaluation for this irradiation can be found in Appendix C.

B.4. Certificate of TK100 irradiation source

IT-Service Leipzig

Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik

Qualitätszertifikat

für umschlossene Strahlenquelle

Prüfungszeugnis - Nr.:	15805
Kunde:	Fraunhofer Institut
Strahler/HRQ Ident. Nr.:	**RU002**
Kapsel Typ:	G6
ISO Code:	ISO/99/C 64545
AFNOR Code:	NF/99/C 64545 ic (i:Feuertest, c:Korrosionstest)
Zertifikat Nr.:	B/012/S-96 (Rev. 10)
Radionuklid:	**Co-60**
Physikalische Form:	**fest, umschlossen**
Chemische Form:	**Element, metallisch**
Brennfleck in mm x mm:	4,2x2,6 mm
Herstellungsaktivität:	1563,99 GBq (42,27 Ci)
Herstellungsdatum:	19.01.2007

Dichtheitsbescheinigung

Oberflächenkontaminationstest:		ohne Beanstandung
Datum:	19.01.2007	Ergebnis: < 185 Bq
Lecktest:		ohne Beanstandung
Datum:	19.01.2007	Ergebnis: dicht

Die Qualitätskontrolle wurde vom Hersteller in unserem Namen durchgeführt.
Es wird bescheinigt, daß die umschlossene radioaktive Strahlenquelle den Anforderungen nach NF / ISO 9978 (1992), ISO 2919 (1999) und NF M61002 (1984) entspricht.

Der oben genannte Strahler wurde in einem neuen bzw. entsprechend DIN 54115 Teil 6 überprüften und zugelassenen Strahlerhalter Nr.: **7221** eingebaut.

Datum: 17.12.2015 Signum IT-Service:

IT-Service Leipzig GmbH, BS Haan, Bergische Straße 16, 42781 Haan Tel.: 02129 / 377595 Fax: 02129 / 378794

C Irradiation Documentation LDR

Irradiation Test Documentation

Fraunhofer INT

Irradiation Source	TK100 (2015)	Date	13.05.2016
Responsible Employee	MS		
Project Description	ESA-PowerBipolar ELDRS		

Reference Data for Dose Rate Calculation

Reference Activity	0.44 TBq ± *10.0%*	Standard uncertainty[1)]
Reference Dose Rate	0.1187 Gy/s ± *2.5%*	Standard uncertainty[1)]
Reference Distance	10 cm ± *0.5%*	Standard uncertainty[1)]
Reference Date	01.01.1990	

Geometry of Irradiated Object (As defined or measured):

Inner Diameter	4.50 cm ± *0.05* cm	Standard uncertainty[1)]
Outer Diameter	5.50 cm ± *0.05* cm	Standard uncertainty[1)]
Height	0.50 cm ± *0.05* cm	Standard uncertainty[1)]

Distances of Point Source:

Surface of Object	60.00 cm ± *0.05* cm	Standard uncertainty[1)]
Object Minimum	60.04 cm ± 0.05 cm	Standard uncertainty[2)]
Object Maximum	60.56 cm ± 0.07 cm	Standard uncertainty[2)]
Mean Distance	**60.30 cm ± 0.11 cm**	*Expanded uncertainty*[3)]

Dose Rates in Object

Minimum	0.0001 Gy/s ± 2.7%	Standard uncertainty[2)]
Mean	**0.0001 Gy/s ± 2.7%**	Standard uncertainty[2)]
Maximum	0.0001 Gy/s ± 2.7%	Standard uncertainty[2)]

Irradiation Time	**20342698 s ± *1* s**	Standard uncertainty[1)]
in MM DD HH:MM:SS	08 22 10:44:58 ± *1* s	Standard uncertainty[1)]

Dose in Object

Minimum	1983 Gy ± 2.7%	Standard uncertainty[2)]
Maximum	2017 Gy ± 2.7%	Standard uncertainty[2)]
Mean	**2000 Gy ± 5.4%**	*Expanded uncertainty*[3)]
Homogeneity	1.7%	

[1)] Experience or statistics based estimation of standard uncertainty with a coverage factor k=1
[2)] Combined standard uncertainty with a coverage factor k=1
[3)] Determined from a combined standard uncertainty (i.e., estimated standard deviations of values above) and a coverage factor k = 2. Since it can be assumed that the possible estimated values of the dose are approximately normally distributed with approximate standard deviation, the unknown value of the dose is believed to lie in the interval given with a level of confidence of approximately 95 %.

Standard Irradiation Test Documentation Sheet, 2015-12-18

For the LDR campaign this only serves to document the geometry and field homogeneity. Timing calculation does not account for Co60 decay.

D Irradiation Details HDR

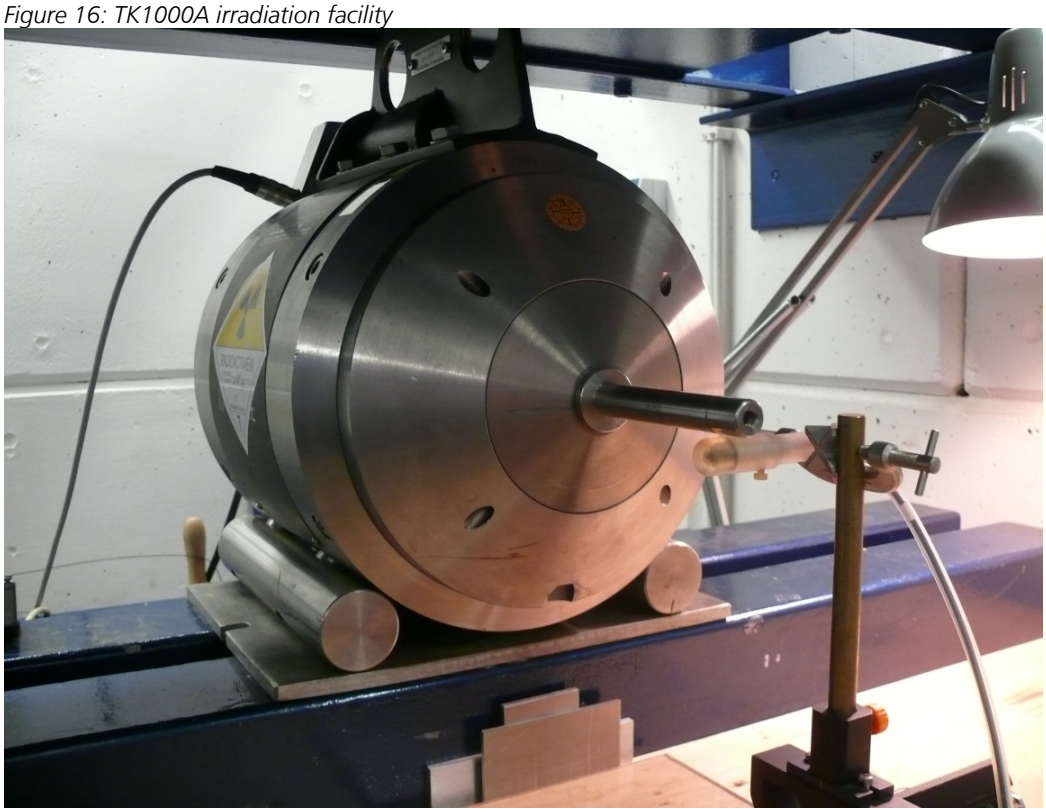
D.1. Irradiation facility TK1000A

The TK1000A is a Co-60 gamma irradiator manufactured by Sauerwein Isotopentechnik, Germany. Inside the shielding container is a small radioactive pellet with a diameter of 7 mm and a length of 10.4 mm. The activity decreases with a physical half-life of 5.27 years. The current radioactive pellet was installed in the irradiator at 2015-11-23. The activity at that time was 21773 GBq.

In deactivated state the radioactive pellet is stored inside the shielding container allowing the operator to install the samples and conduct measurements without getting exposed to ionizing radiation. On activation, the radioactive source is pushed into the source guiding tube in less than a second irradiating the surrounding volume.

The certificate of the radioactive source can be found in Appendix B.4.

Figure 16: TK1000A irradiation facility



D.2. Radiation properties of TK1000A

The samples are irradiated with Co-60 gamma radiation. The radioactive Co 60 isotope decays by emitting beta radiation (i.e. electrons) into a highly excited Ni-60 isotope which emits two gamma

photons to reach the stable ground state. The gamma radiation has two energy levels of 1.172 MeV and 1.332 MeV.

The gamma radiation of around 1 MeV is a penetrating radiation, so the samples are irradiated completely. The shielding of the sample holder and other surrounding material between the source and the sample is negligible.

The radiation is emitted from a point-like source. Thus the dose rate $\dot{D}$ falls off with $1/r^2$ where r is the distance from the source.

$$\dot{D}(r) = \dot{D}_0 \cdot \frac{r_0^2}{r^2}$$

D.3. Dosimetry at TK1000A

The dosimetry is done regularly with calibrated ionization chambers manufactured by IBA, Germany, and PTW Freiburg, Germany.

The dose rates obtained at varying distances between 2 cm and 50 cm and in different directions relative to the source are used to develop a model of the dose rate distribution around the source as a function of distance and direction. The dose rate of an individual measurement is scaled to a reference date taking the half-life of the radioactive isotope into account. This model is constantly checked and improved with each additional measurement of dose rates.

As a result a reliable description of the dose rates inside a specific volume arranged in a given geometry in the vicinity of the irradiation source is available.

The uncertainties of the reported dose rates are given by an uncertainty evaluation according to [2] and mainly result from the uncertainties of the dosimetry and positioning of the samples.

The uncertainty evaluation for this irradiation can be found in Appendix E.

D.4. Certificate of TK1000A irradiation source

IT-Service Leipzig

Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik

Qualitätszertifikat

für umschlossene Strahlenquelle

Prüfungszeugnis - Nr.:	15754
Kunde:	Fraunhofer Institut
Strahler/HRQ Ident. Nr.:	**002(GK60R01)**
Kapsel Typ:	GK60R01
ISO Code:	ISO/99/C 65546
AFNOR Code:	NF/99/C 65546
Zertifikat Nr.:	RUS/5614/S-96 (Rev. 1)
Radionuklid:	**Co-60**
Physikalische Form:	**fest, umschlossen**
Chemische Form:	**Element, metallisch**
Brennfleck in mm x mm:	7,0x10,4 mm
Herstellungsaktivität:	22192,6 GBq (599,8 Ci)
Herstellungsdatum:	01.10.2015

Dichtheitsbescheinigung

Oberflächenkontaminationstest:		ohne Beanstandung
Datum:	01.10.2015	Ergebnis: < 185 Bq
Lecktest:		ohne Beanstandung
Datum:	01.10.2015	Ergebnis: dicht

Die Qualitätskontrolle wurde vom Hersteller in unserem Namen durchgeführt.
Es wird bescheinigt, daß die umschlossene radioaktive Strahlenquelle den Anforderungen nach NF / ISO 9978 (1992), ISO 2919 (1999) und NF M61002 (1984) entspricht.

Der oben genannte Strahler wurde in einem neuen bzw. entsprechend DIN 54115 Teil 6 überprüften und zugelassenen Strahlerhalter Nr.: **21** eingebaut.

Datum: 23.11.2015 Signum IT-Service:

IT-Service Leipzig GmbH, BS Haan, Bergische Straße 16, 42781 Haan Tel.: 02129 / 377595 Fax: 02129 / 378794

E Irradiation documentation HDR

Irradiation Test Documentation

Irradiation Source	TK1000A (2015)	Date	13.05.2016
Responsible Employee	MS		
Project Description	NEO-14-086 HDR(1)		

Reference Data for Dose Rate Calculation

Reference Activity	17.48 TBq ± *10.0%*	Standard uncertainty[1]
Reference Dose Rate	5.2345 Gy/s ± *2.5%*	Standard uncertainty[1]
Reference Distance	10 cm ± *0.5%*	Standard uncertainty[1]
Reference Date	01.01.1990	

Geometry of Irradiated Object (As defined or measured):

Inner Diameter	4.50 cm ± *0.05* cm	Standard uncertainty[1]
Outer Diameter	5.50 cm ± *0.05* cm	Standard uncertainty[1]
Height	0.50 cm ± *0.05* cm	Standard uncertainty[1]

Distances of Point Source:

Surface of Object	21.10 cm ± *0.05* cm	Standard uncertainty[1]
Object Minimum	21.21 cm ± 0.05 cm	Standard uncertainty[2]
Object Maximum	21.78 cm ± 0.07 cm	Standard uncertainty[2]
Mean Distance	**21.50 cm ± 0.11 cm**	*Expanded uncertainty*[3]

Dose Rates in Object

Minimum	0.0296 Gy/s ± 2.8%	Standard uncertainty[2]
Mean	**0.0304 Gy/s ± 2.7%**	Standard uncertainty[2]
Maximum	0.0312 Gy/s ± 2.7%	Standard uncertainty[2]

Irradiation Time	**65844 s ± *1* s**	Standard uncertainty[1]
in DD HH:MM:SS	00 18:17:24 ± *1* s	Standard uncertainty[1]

Dose in Object

Minimum	1948 Gy ± 2.8%	Standard uncertainty[2]
Maximum	2054 Gy ± 2.7%	Standard uncertainty[2]
Mean	**2000 Gy ± 5.5%**	*Expanded uncertainty*[3]
Homogeneity	5.3%	

[1] Experience or statistics based estimation of standard uncertainty with a coverage factor k=1
[2] Combined standard uncertainty with a coverage factor k=1
[3] Determined from a combined standard uncertainty (i.e., estimated standard deviations of values above) and a coverage factor k = 2. Since it can be assumed that the possible estimated values of the dose are approximately normally distributed with approximate standard deviation, the unknown value of the dose is believed to lie in the interval given with a level of confidence of approximately 95 %.

Standard Irradiation Test Documentation Sheet, 2015-12-18