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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

TN5.4
TID Test Report (LDR / HDR) for

Power Bipolar Transistor

BDS16

Manufacturer:
Semelab

Date code/Lot code: CM1438E

Report no.	Version	Date	NEO no.
017/2017	1.0	2018-12-04	NEO-14-086

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Customer	Project management
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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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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 BDS16 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 BDS16, "Silicon Planar Epitaxial NPN Transistor", Semelab, Document Number 3347, Issue 3

[5] TN2.4 "TID Test Plan BDS16 (HDR+LDR)", Issue 1, 2016-02-02

[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	017/2017
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	BDS16
Family	Power Bipolar Transistor
Technology	NPN high voltage bipolar transistor
Package	Hermetic TO220M (T0-257AB) Isolated Metal Package
Date code / Wafer lot	CM1438E
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: TK1000B
Generic specification	ESCC 22900 Iss. 5
Detail specification	ESCC 22900 Iss. 5
Test plan	TN2.4 "TID Test Plan BDS16 (HDR+LDR)", Issue 1, 2016-02-02
Max. test level	200 krad(Si)
Dose steps	LDR: Multiple: 9, 18, 30, 51, 98, 153, 202 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: 9.1 krad(Si)/h

Start of irradiation	LDR: 2016-08-25 14:04, HDR: 2017-06-06 05:02
Stop of irradiation	LDR: 2017-05-02 10:26 HDR: 2017-06-07 14:20
Non-Homogeneity in DUT	LDR: < 2% HDR: 7.4%
Annealing	24h @RT, 168h @ 100°C
Electrical measurements/ Parameters tested	$V_{CEO\ sus}$ (I_C@120V), I_{CEO}, I_{EBO},$V_{CE(sat)}1$, $V_{CE(sat)}2$,$V_{BE(on)}$, $h_{FE}1$, $h_{FE}2$

2.1 Comments

- 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 BDS16 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%.
- HDR test:
  - During the conduction of the HDR test campaign, some deviations from the requirements of ESCC 22900 occurred:
    - in two instances the time gap between stop of irradiation and the start of the next step was 3 minutes or less than 1 minute than allowed
    - The 100°C annealing phase ran more than 17 hours longer and thus ended after 185 hours at elevated temperature.
  - The tests of the BDS18 were performed simultaneously to the tests of the BDS16.
- Comparison with respect to ELDRS:
  - A comparison of the tests at high and low dose rate shows no significant difference for any parameter.
  - Calculation of the enhancement factor showed no ELDRS. Detailed analysis of the enhancement factor calculation is thus not included in this report.
  - We would argue that the part is not susceptible to ELDRS.

2.2 Overview of results

Figure 1: LDR: Overview of results

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @ 100°C
VCEO_Sus	On										
	Off										
I (VCEO_Sus)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCEsat_1	On										
	Off										
VCEsat_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On										
	Off										
HFE 2	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
VCEO_Sus	On										
	Off										
I (VCEO_Sus)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCEsat_1	On										
	Off										
VCEsat_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On										
	Off										
HFE 2	On										
	Off										

3 Sample preparations

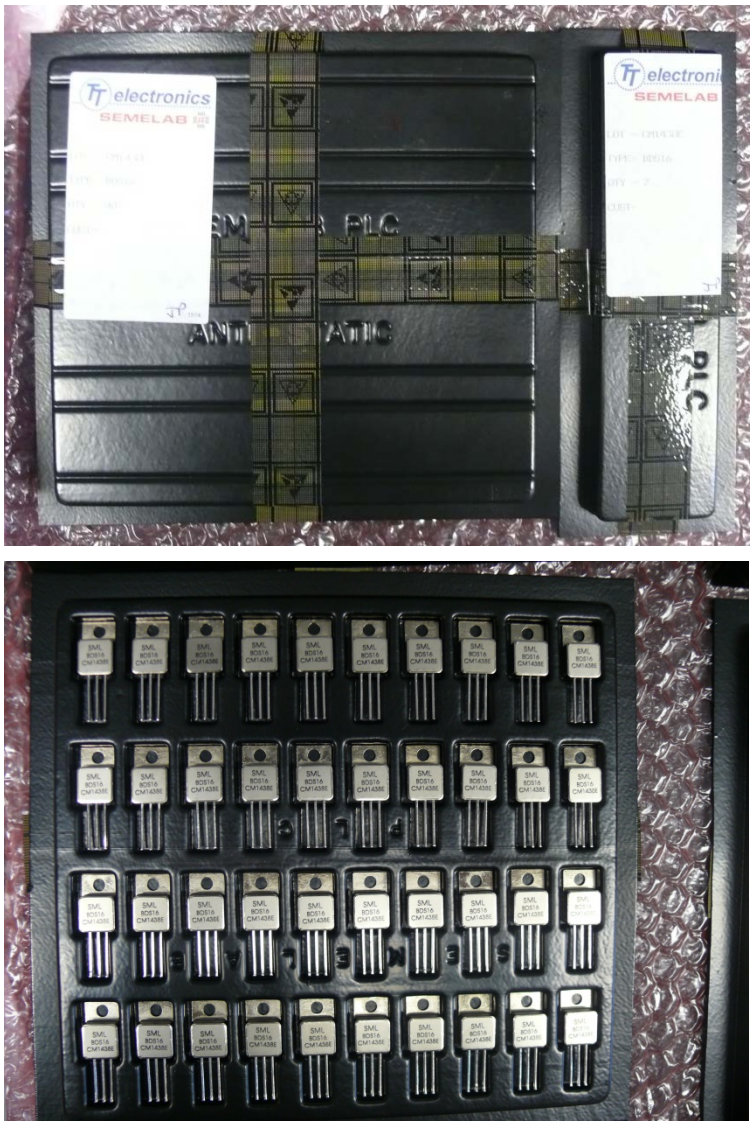
3.1 Sample shipment

A total of 47 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	January 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.

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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 13:34	24.08.2016 14:41	1:07
1	9.29	9.29	0.0354	25. 08.2016 14:04:00	00:38:09	05. 09.2016 13:46:46	10d 23:42:46	05.09.2016 14:05	05.09.2016 14:48	0:43
2	9.12	18.41	0.0353	05. 09.2016 14:53:51	00:22:56	16. 09.2016 10:35:29	10d 19:41:38	16.09.2016 10:46	16.09.2016 11:28	0:42
3	11.81	30.22	0.0351	16. 09.2016 11:37:11	00:25:50	30. 09.2016 13:07:49	14d 01:30:38	30.09.2016 13:17	30.09.2016 14:17	1:00
4	20.78	51	0.0349	30. 09.2016 14:20:42	03:02:36	25. 10.2016 14:54:57	25d 00:34:15	25.10.2016 15:03	25.10.2016 15:49	0:46
5	46.59	97.59	0.0346	25. 10.2016 15:52:42	02:49:59	21. 12.2016 09:59:05	56d 18:06:23	21.12.2016 10:05	21.12.2016 10:38	0:33
6	55.18	152.77	0.0339	21. 12.2016 10:44:44	08:49:22	28. 02.2017 10:15:55	68d 23:31:11	28.02.2017 10:27	28.02.2017 11:09	0:42
7	49.42	202.19	0.0331	28. 02.2017 11:14:00	00:49:55	02. 05.2017 10:26:39	62d 23:12:39	02.05.2017 10:40	02.05.2017 11:13	0:33
8	24 h @ RT			02. 05.2017 11:21:00		03. 05.2017 11:21:00	1d 00:00:00	03.05.2017 11:29	03.05.2017 11:54	0:25
9	168 h @100°C			03. 05.2017 12:00:00		10. 05.2017 13:00:00	7d 01:00:00	10.05.2017 13:20	10.05.2017 13:48	0:28

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 BDS16 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 HDR test campaigns, some deviations from the requirements of ESCC 22900 occurred: in two instances the time gap between stop of irradiation and the start of the next step was 3 minutes or less than 1 minute longer than allowed. The 100°C annealing phase ran more than 17 hours longer and thus ended after 185 hours at elevated temperature.

Table 6: HDR irradiatison steps

#	Step [krad(Si)]	Total [krad (Si)]	Startrate [rad(Si)/h]	Start Irr.	Stop Irr.	Duration [h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0					02.06.2017 11:05	02.06.2017 13:25	2:20
1	10.00	10	9.1000	06.06.2017 05:02.18	06.06.2017 06:08.14	0d 01:05:56	06.06.2017 06:48	06.06.2017 07:19	0:31
2	10.00	20	9.1000	06.06.2017 08:03.04	06.06.2017 09:09.01	0d 01:05:57	06.06.2017 09:31	06.06.2017 10:22	0:51
3	10.00	30	9.1000	06.06.2017 11:08.42	06.06.2017 12:14.40	0d 01:05:58	06.06.2017 12:30	06.06.2017 13:19	0:49
4	20.00	50	9.1000	06.06.2017 14:14.49	06.06.2017 16:26.44	0d 02:11:55	06.06.2017 16:39	06.06.2017 17:24	0:45
5	50.00	100	9.1000	06.06.2017 18:29.28	06.06.2017 23:59.12	0d 05:29:44	06.06.2017 00:06	06.06.2017 00:51	0:45
6	50.00	150	9.1000	07.06.2017 01:58.30	07.06.2017 07:28.14	0d 05:29:44	07.06.2017 07:45	07.06.2017 08:42	0:57
7	50.00	200	9.1000	07.06.2017 08:49.51	07.06.2017 14:19.34	0d 05:29:43	07.06.2017 14:44	07.06.2017 15:05	0:21
8	24 h @ RT			07.06.2017 15:20.00	08.06.2017 15:20.00	1d 00:00:00	08.06.2017 15:44	08.06.2017 16:26	0:42
9	168 h @100°C			08.06.2017 16:40.00	16.06.2017 10:00.00	7d 17:20:00	16.06.2017 10:20	16.06.2017 10:52	0:32

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

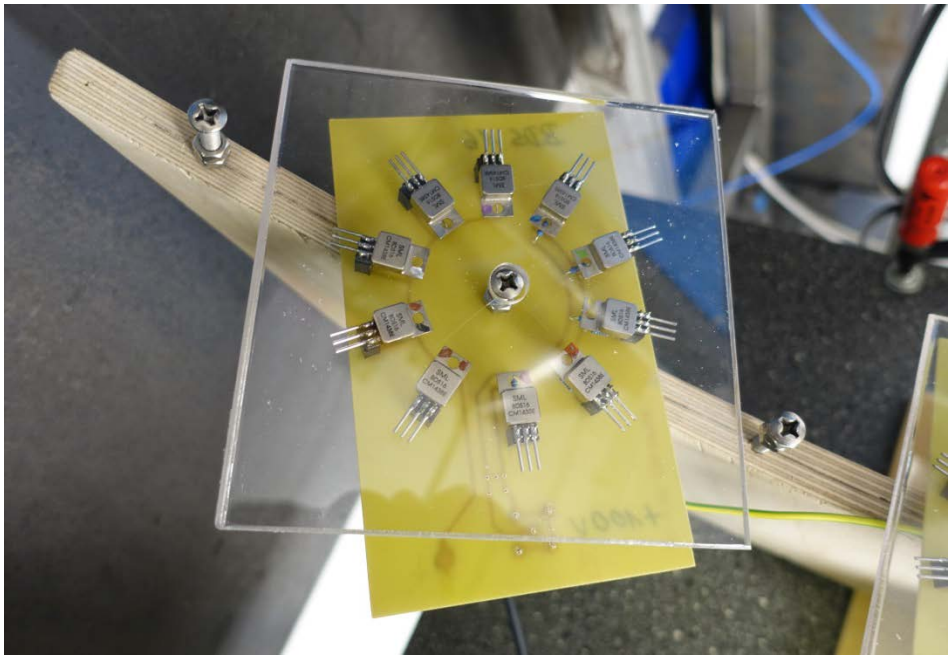


Figure 6: LDR tests: Board fixture at TK100

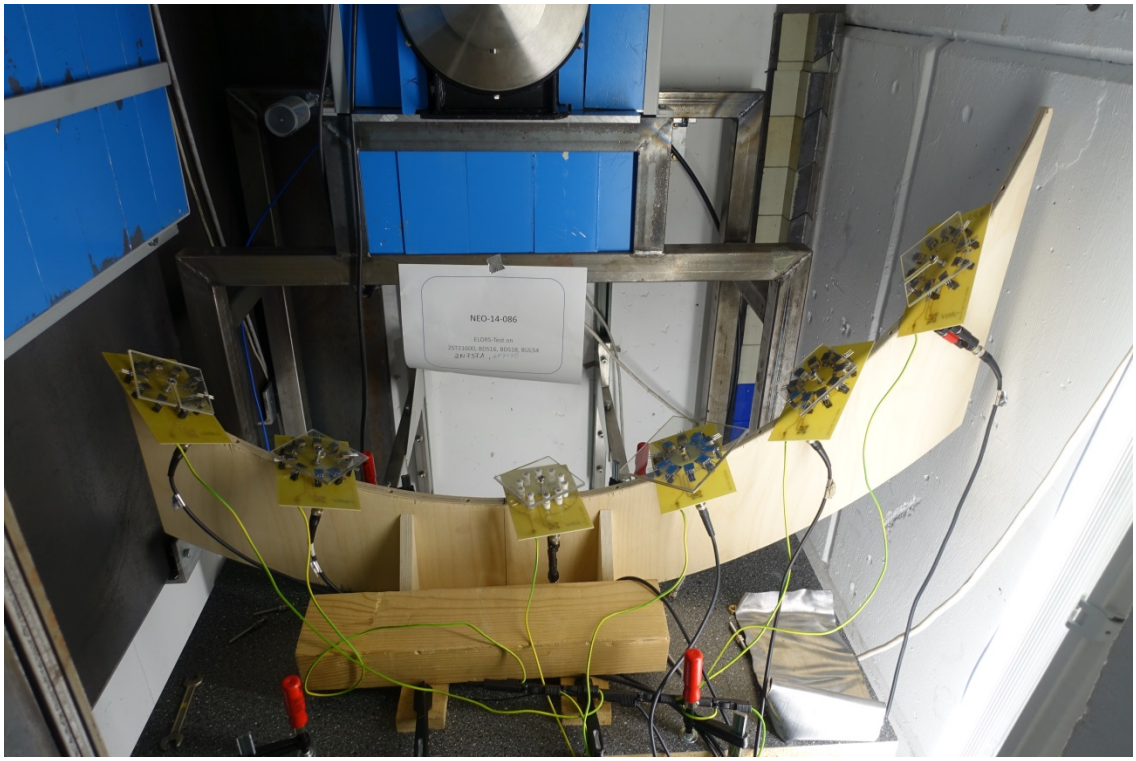
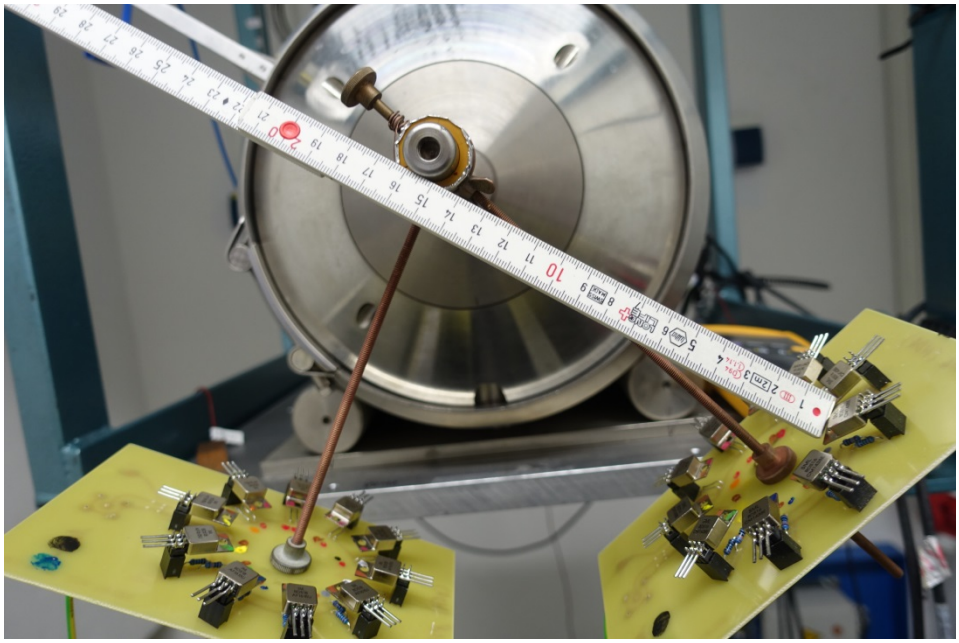


Figure 7: HDR tests: Board fixture at TK1000B



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 15.7 cm from the TK1000B 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).

LDR: An Keithley 2290E-5 voltage supply (Eq.Id E-PS1-030) was used for biasing the low dose rate test.

HDR: A fug HCE 35-125 voltage supply (Eq.Id E-PS1-044) was used for biasing the high dose rate test.

Both supplies were 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

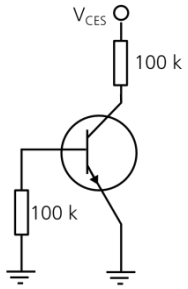
ON-Mode	OFF-Mode
 V_{CES} = 100 V (≥ 80% $V_{(BR)CEO}$)	All pins were short circuited and grounded.

Table 7: Biasing equipment. Left: LDR test (Keithley 2290E-5 in the bottom of the stack), Right: HDR test

4.5 Environmental variables

All irradiation steps were done in air. The samples at TK1000B 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.

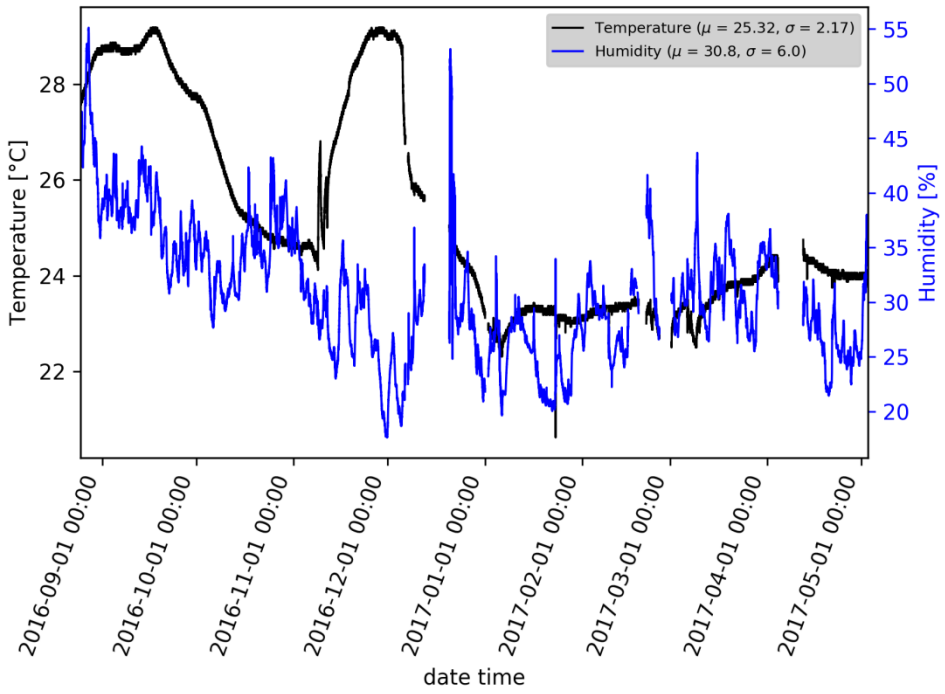
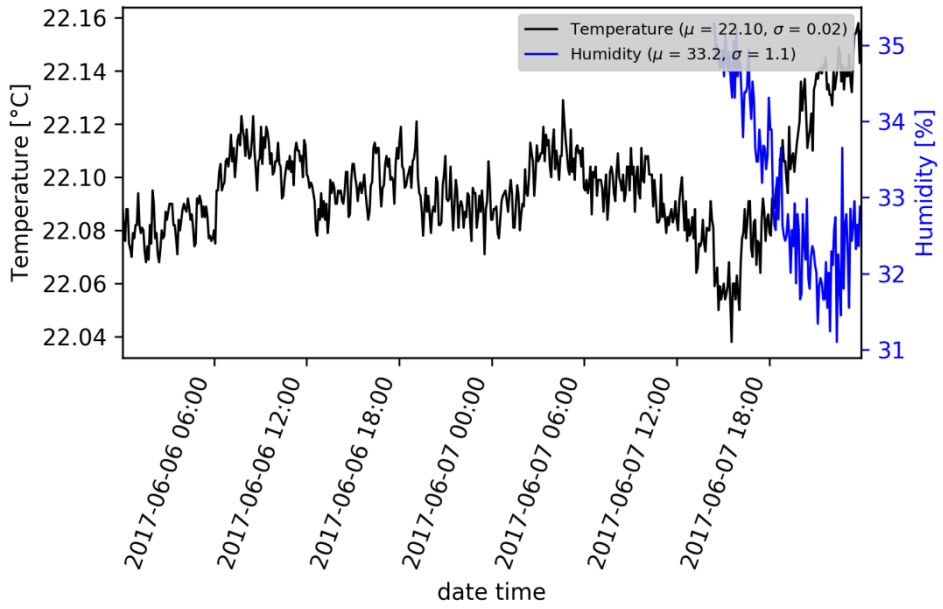


Table 9: HDR: Environmental variables during irradiation

Parameter	Value and Unit	Remarks
Humidity	(33.2% ± 1.1%)	Non-condensing, during irradiation and first annealing (24 h). Monitoring of the humidity at the source was only temporary running during the tests.
Temperature	22.1 °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. Monitoring of the humidity at the source was only temporary running during the tests.



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 HDR test (see 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	$V_{CEO(sus)}$ I_C@120V	3011, Note 2	I_C = 100 mA, Bias Condition D, Note 1
2	Collector-Emitter Cut-off Current	I_{CEO}	3041	V_{CE} = 60 V, Bias Condition D
3	Emitter-Base Cutoff Current	I_{EBO}	3061	V_{EB} = 5 V, Bias Condition D
4	Collector-Emitter Saturation Voltage	$V_{CE(sat)1}$	3071	I_C = 4A, I_B = 400 mA, Note 1
5		$V_{CE(sat)2}$		I_C = 0.5 A, I_B = 50 mA, Note 1
6	Base-Emitter Voltage	$V_{BE(on)}$	3066	I_C = 1.0 A, V_{CE} = 2.0 V, Test Condition B, Note 1
7	Forward Current Transfer Ratio	h_{FE1}	3076	V_{CE} = 2V, I_C = 0.5 A, Note 1
8		h_{FE2}		V_{CE} = 2V, I_C = 4 A, Note 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 $V_{(BR)CEO}$.

In this case, I_C @ V_{CE} = 120 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 $V_{BR(CBO)}$ or $V_{BR(EBO)}$

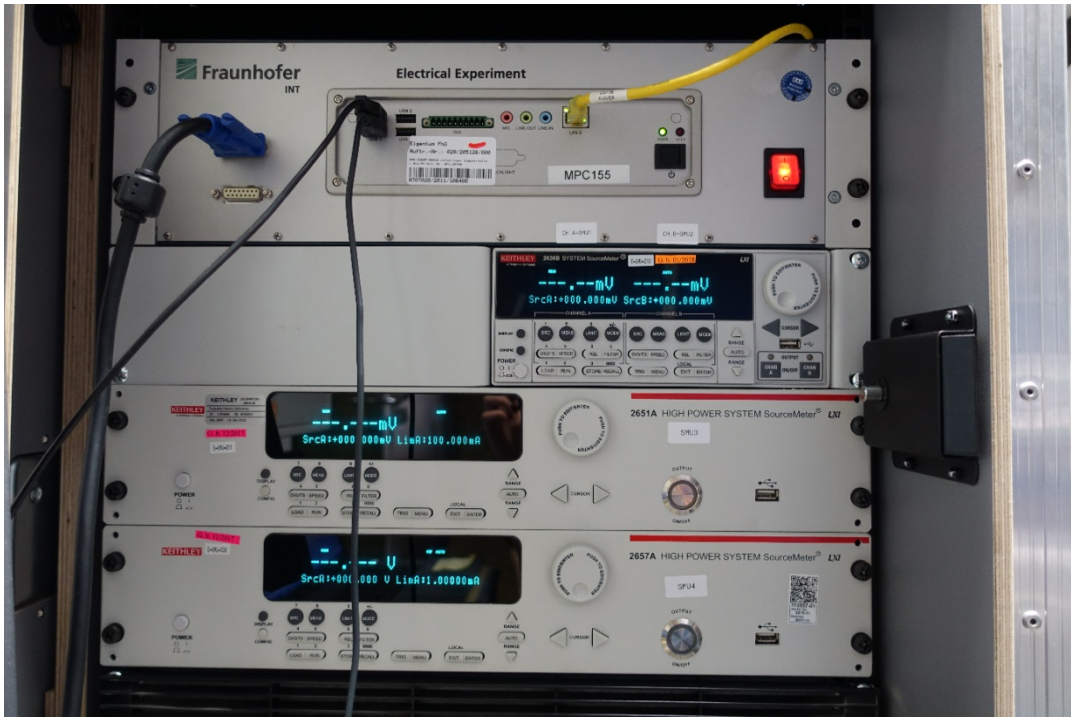
5.2 Measurement equipment

Table 11: Measurement equipment

Equipment	Manufacturer	Model	INT-Code	Calibr. due	Measurement
System Source-Meter	Keithley	2636B	E-SMU-010	01/2018	$V_{CEO\ sus}$ (I_C@120V), I_{CEO}, I_{EBO}
High Power System Source-Meter	Keithley	2657A	E-SMU-008	11/2017	$V_{CE(sat)}1$, $V_{CE(sat)}2$,$V_{BE(on)}$, $h_{FE}1$, $h_{FE}2$
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	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @ 100°C
Temperature [°C]	25.8E+0	26.2E+0	27.5E+0	21.2E+0	23.3E+0	23.1E+0	22.6E+0	26.8E+0	28.5E+0	25.3E+0
Humidity [%]	59.2E+0	56.5E+0	57.3E+0	43.5E+0	54.0E+0	45.2E+0	38.2E+0	32.9E+0	32.2E+0	31.8E+0

Figure 13: LDR: Environment variables during measurements

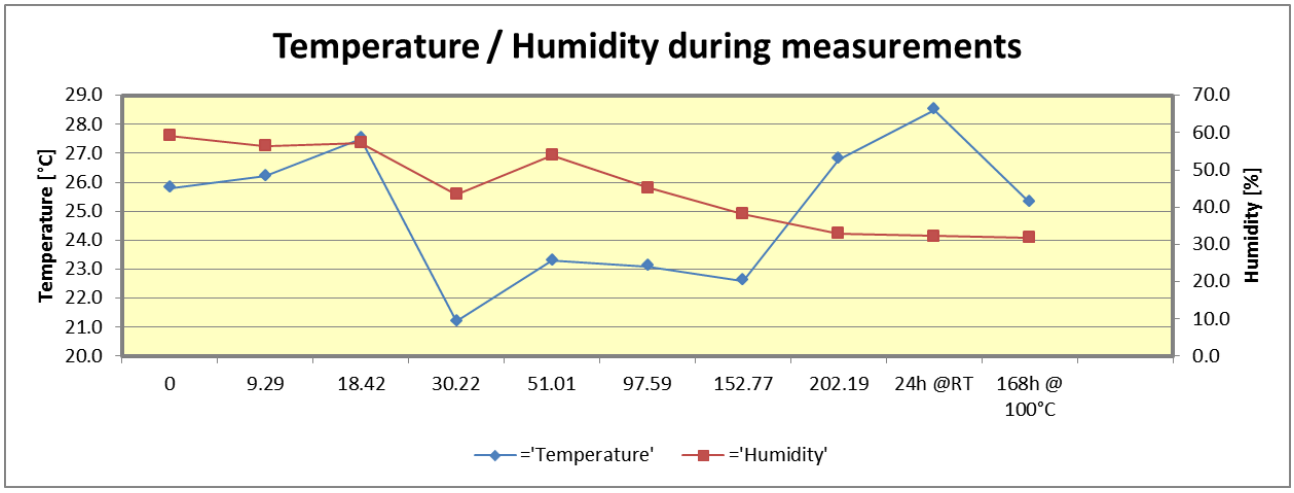
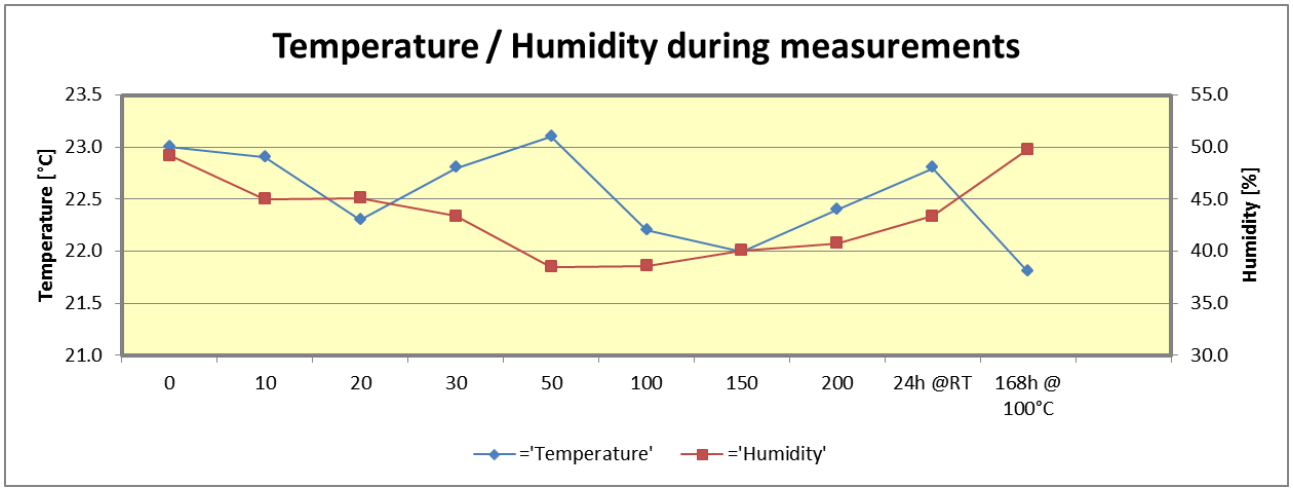


Table 13: HDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @ 100°C
Temperature [°C]	23.0E+0	22.9E+0	22.3E+0	22.8E+0	23.1E+0	22.2E+0	22.0E+0	22.4E+0	22.8E+0	21.8E+0
Humidity [%]	49.2E+0	45.0E+0	45.1E+0	43.4E+0	38.5E+0	38.6E+0	40.1E+0	40.8E+0	43.4E+0	49.8E+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, no enhancement satisfying these criteria is found, mostly due to all parameters being within specification.

7 Results LDR

7.1 Overview: Pass/Fail

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @ 100°C
VCEO_Sus	On										
	Off										
I (VCEO_Sus)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCEsat_1	On										
	Off										
VCEsat_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On										
	Off										
HFE 2	On										
	Off										

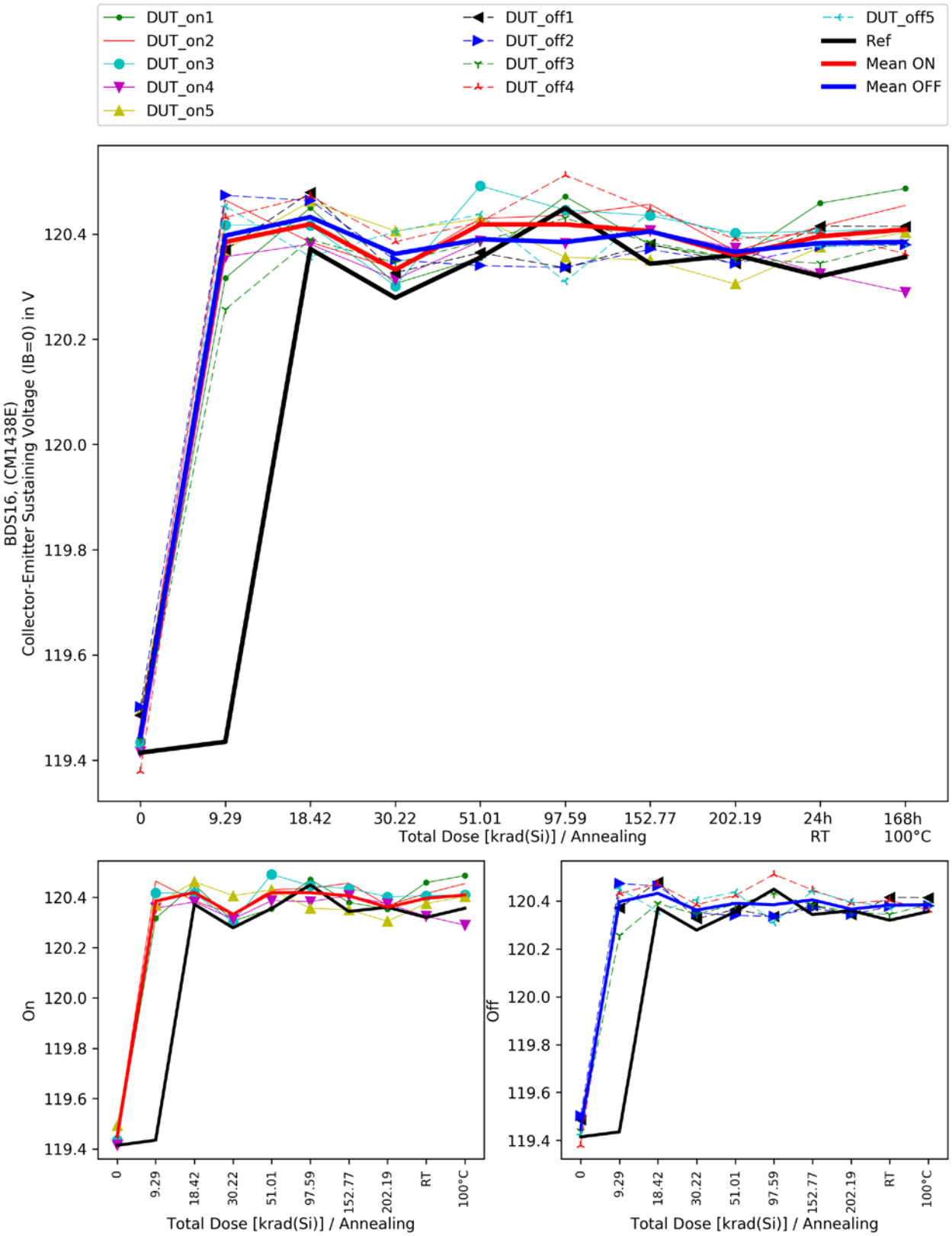
7.2 Collector-Emitter Sustaining Voltage (IB=0)

Collector-Emitter Sustaining Voltage (IB=0) **BDS16**
VCEO_Sus in V Date-/Lotcode: CM1438E
Limit: 119.3<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	119.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.5E+0	120.4E+0	120.4E+0	120.5E+0	120.5E+0
DUT_on2	119.5E+0	120.5E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.5E+0	120.4E+0	120.4E+0	120.5E+0
DUT_on3	119.4E+0	120.4E+0	120.4E+0	120.3E+0	120.5E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
DUT_on4	119.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.3E+0
DUT_on5	119.5E+0	120.4E+0	120.5E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0
Radiation-Mean ON	119.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
Standarddeviation	31.2E-3	57.1E-3	36.9E-3	43.1E-3	51.5E-3	47.5E-3	42.3E-3	35.5E-3	49.6E-3	74.8E-3
Mean + kσ	119.5E+0	120.5E+0	120.5E+0	120.5E+0	120.6E+0	120.5E+0	120.5E+0	120.5E+0	120.5E+0	120.6E+0
Mean - kσ	119.4E+0	120.2E+0	120.3E+0	120.2E+0	120.3E+0	120.3E+0	120.3E+0	120.3E+0	120.3E+0	120.2E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	119.5E+0	120.4E+0	120.5E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0
DUT_off2	119.5E+0	120.5E+0	120.5E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0
DUT_off3	119.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0
DUT_off4	119.4E+0	120.4E+0	120.5E+0	120.4E+0	120.4E+0	120.5E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
DUT_off5	119.4E+0	120.5E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
Radiation-Mean OFF	119.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
Standarddeviation	48.9E-3	87.4E-3	55.4E-3	31.7E-3	40.3E-3	84.5E-3	36.1E-3	26.0E-3	27.6E-3	18.8E-3
Mean + kσ	119.6E+0	120.6E+0	120.6E+0	120.4E+0	120.5E+0	120.6E+0	120.5E+0	120.4E+0	120.5E+0	120.4E+0
Mean - kσ	119.3E+0	120.2E+0	120.3E+0	120.3E+0	120.3E+0	120.2E+0	120.3E+0	120.3E+0	120.3E+0	120.3E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	119.4E+0	119.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0
Min. Value	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+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
BDS16, (CM1438E)
Collector-Emitter Sustaining Voltage (IB=0) in V
120.4
120.2
120.0
119.8
119.6
119.4
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.3 ICE @ VCEsus

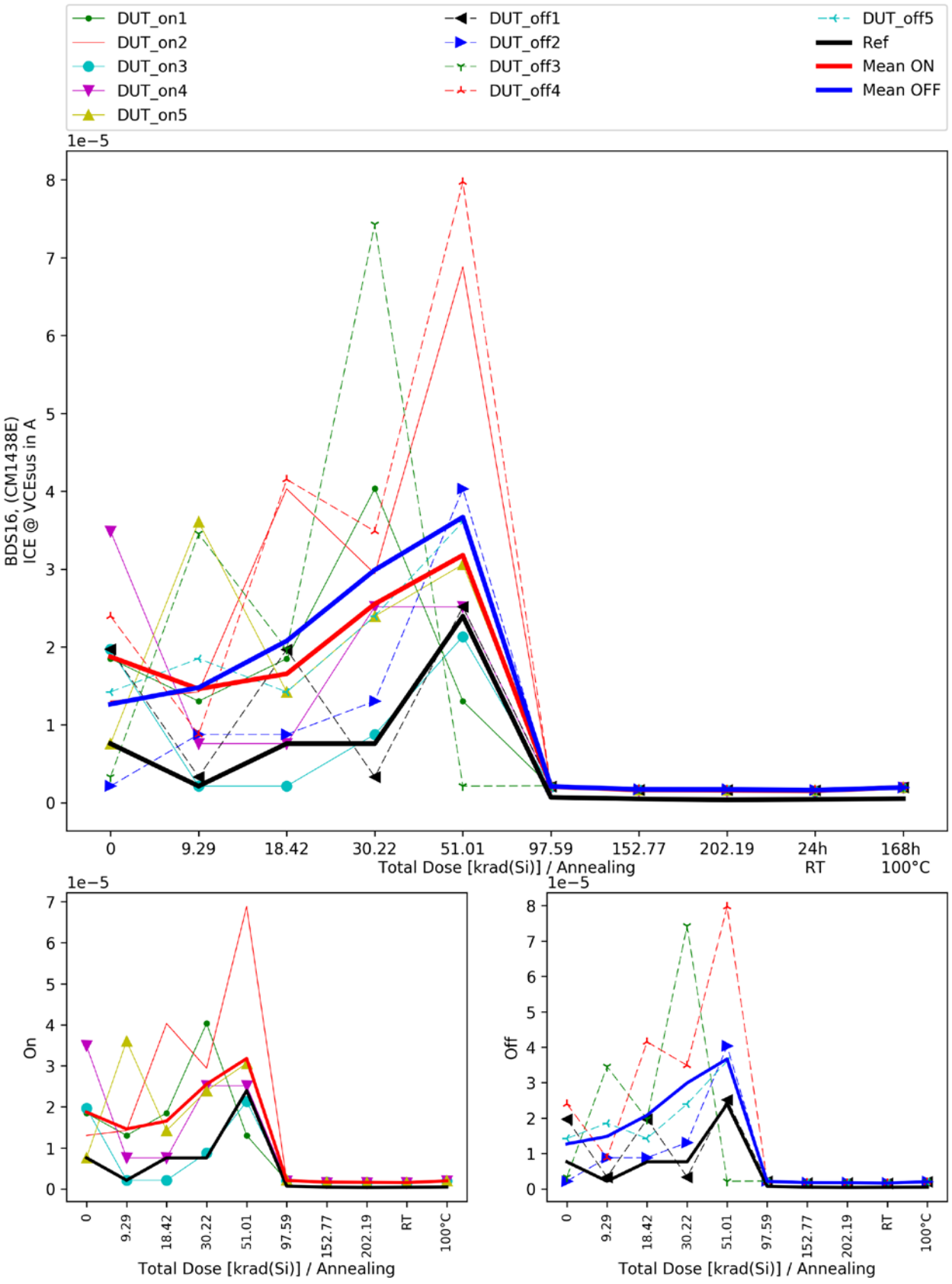
ICE @VCEsus
I (VCEO_Sus) in A
Limit: x<0.1

BDS16
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	18.5E-6	13.0E-6	18.5E-6	40.3E-6	13.0E-6	2.0E-6	1.7E-6	1.7E-6	1.6E-6	2.0E-6
DUT_on2	13.0E-6	14.2E-6	40.3E-6	29.4E-6	68.8E-6	2.1E-6	1.8E-6	1.7E-6	1.6E-6	2.0E-6
DUT_on3	19.7E-6	2.1E-6	2.1E-6	8.8E-6	21.3E-6	2.0E-6	1.6E-6	1.5E-6	1.5E-6	1.9E-6
DUT_on4	34.9E-6	7.6E-6	7.6E-6	25.2E-6	25.1E-6	2.0E-6	1.5E-6	1.5E-6	1.4E-6	1.9E-6
DUT_on5	7.6E-6	36.1E-6	14.2E-6	24.0E-6	30.6E-6	2.2E-6	1.7E-6	1.6E-6	1.6E-6	2.0E-6
Radiation-Mean ON	18.7E-6	14.6E-6	16.6E-6	25.5E-6	31.8E-6	2.1E-6	1.7E-6	1.6E-6	1.5E-6	2.0E-6
Standarddeviation	10.2E-6	12.9E-6	14.7E-6	11.4E-6	21.7E-6	106.1E-9	93.7E-9	69.3E-9	91.8E-9	41.8E-9
Mean + kσ	46.8E-6	50.0E-6	56.8E-6	56.7E-6	91.2E-6	2.4E-6	1.9E-6	1.8E-6	1.8E-6	2.1E-6
Mean - kσ	-9.3E-6	-20.8E-6	-23.7E-6	-5.7E-6	-27.6E-6	1.8E-6	1.4E-6	1.4E-6	1.3E-6	1.9E-6

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	19.7E-6	3.3E-6	19.7E-6	3.3E-6	25.1E-6	2.1E-6	1.6E-6	1.7E-6	1.6E-6	2.0E-6
DUT_off2	2.1E-6	8.8E-6	8.8E-6	13.0E-6	40.3E-6	2.2E-6	1.7E-6	1.7E-6	1.6E-6	1.9E-6
DUT_off3	3.3E-6	34.5E-6	19.7E-6	74.3E-6	2.1E-6	2.2E-6	1.8E-6	1.7E-6	1.6E-6	2.0E-6
DUT_off4	24.0E-6	8.8E-6	41.5E-6	34.9E-6	79.7E-6	2.0E-6	1.7E-6	1.7E-6	1.6E-6	1.9E-6
DUT_off5	14.2E-6	18.5E-6	14.2E-6	24.0E-6	36.1E-6	2.0E-6	1.8E-6	1.7E-6	1.6E-6	2.0E-6
Radiation-Mean OFF	12.7E-6	14.8E-6	20.8E-6	29.9E-6	36.7E-6	2.1E-6	1.7E-6	1.7E-6	1.6E-6	2.0E-6
Standarddeviation	9.7E-6	12.3E-6	12.4E-6	27.5E-6	28.3E-6	78.2E-9	49.1E-9	28.2E-9	25.2E-9	40.6E-9
Mean + kσ	39.3E-6	48.6E-6	54.9E-6	105.2E-6	114.2E-6	2.3E-6	1.9E-6	1.8E-6	1.7E-6	2.1E-6
Mean - kσ	-14.0E-6	-19.0E-6	-13.3E-6	-45.4E-6	-40.8E-6	1.9E-6	1.6E-6	1.6E-6	1.5E-6	1.8E-6

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	7.6E-6	2.1E-6	7.6E-6	7.6E-6	23.9E-6	698.4E-9	490.2E-9	376.6E-9	442.7E-9	516.2E-9
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
1e−5
BDS16, (CM1438E)
ICE @ VCEsus in A
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

Version 1.0

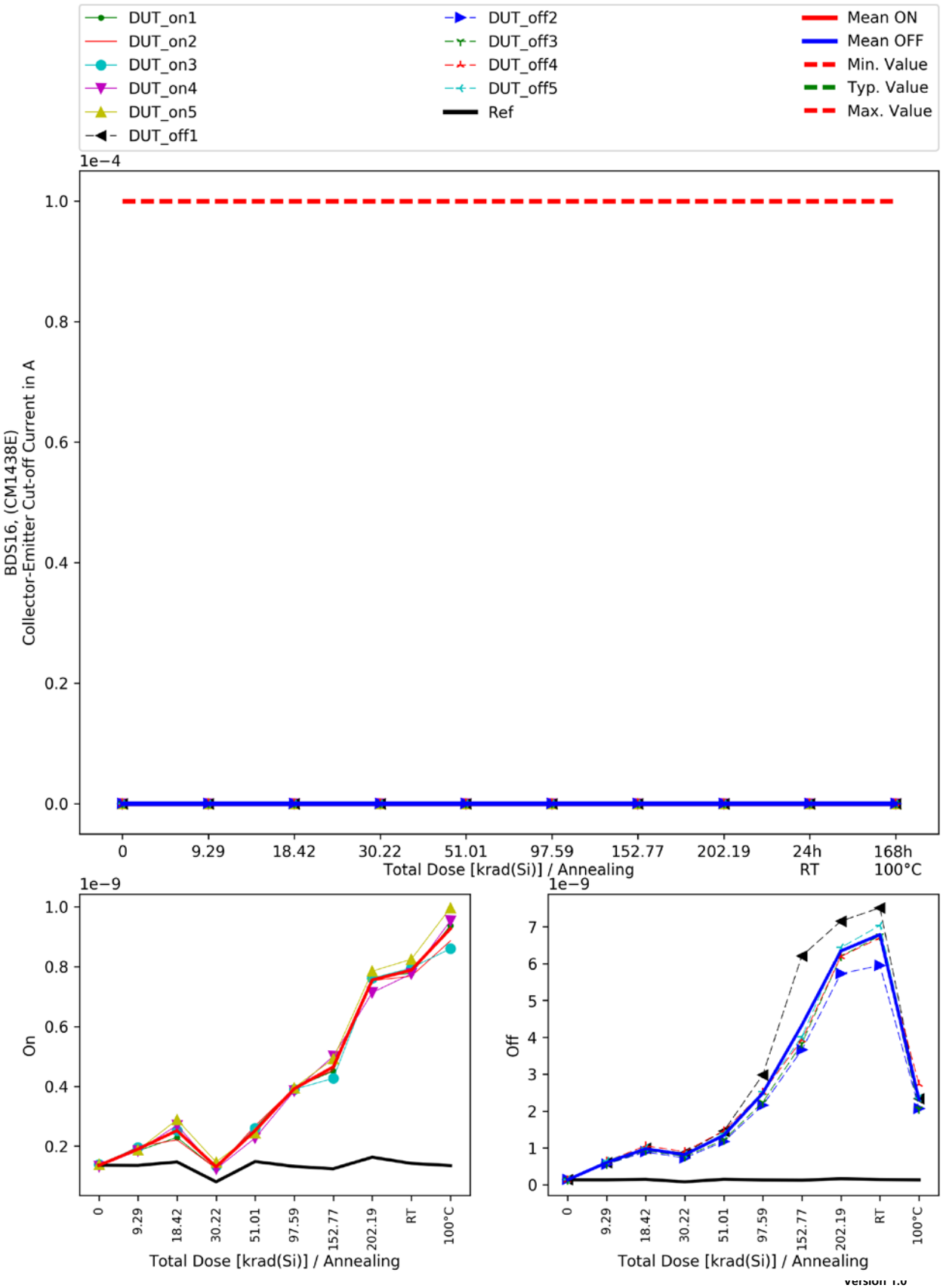
7.4 Collector-Emitter Cut-off Current

Collector-Emitter Cut-off Current **BDS16**
ICEO in A Date-/Lotcode: CM1438E
Limit: x < 0.0001

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	135.1E-12	184.2E-12	228.8E-12	123.8E-12	261.0E-12	394.8E-12	450.3E-12	764.9E-12	777.5E-12	937.2E-12
DUT_on2	132.3E-12	198.2E-12	220.7E-12	125.1E-12	267.8E-12	393.7E-12	454.0E-12	753.1E-12	768.0E-12	886.2E-12
DUT_on3	138.6E-12	195.5E-12	252.1E-12	133.9E-12	259.1E-12	389.6E-12	426.3E-12	761.1E-12	795.7E-12	860.0E-12
DUT_on4	131.9E-12	184.7E-12	269.3E-12	123.7E-12	227.0E-12	384.0E-12	500.6E-12	713.2E-12	775.9E-12	953.1E-12
DUT_on5	138.6E-12	186.4E-12	288.3E-12	146.5E-12	243.7E-12	395.0E-12	491.7E-12	784.8E-12	824.5E-12	996.7E-12
Radiation-Mean ON	135.3E-12	189.8E-12	251.8E-12	130.6E-12	251.7E-12	391.4E-12	464.6E-12	755.4E-12	788.3E-12	926.6E-12
Standarddeviation	3.2E-12	6.5E-12	28.0E-12	9.9E-12	16.4E-12	4.7E-12	30.9E-12	26.3E-12	22.6E-12	54.3E-12
Mean + kσ	144.2E-12	207.7E-12	328.5E-12	157.6E-12	296.7E-12	404.2E-12	549.2E-12	827.6E-12	850.3E-12	1.1E-9
Mean - kσ	126.4E-12	171.9E-12	175.1E-12	103.6E-12	206.8E-12	378.6E-12	379.9E-12	683.3E-12	726.3E-12	777.7E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	142.4E-12	600.2E-12	994.4E-12	863.5E-12	1.5E-9	3.0E-9	6.2E-9	7.2E-9	7.5E-9	2.3E-9
DUT_off2	136.1E-12	557.0E-12	892.9E-12	725.5E-12	1.2E-9	2.2E-9	3.7E-9	5.7E-9	5.9E-9	2.1E-9
DUT_off3	130.0E-12	560.4E-12	928.5E-12	766.0E-12	1.2E-9	2.2E-9	3.8E-9	6.2E-9	6.8E-9	2.1E-9
DUT_off4	130.7E-12	640.1E-12	1.1E-9	900.8E-12	1.5E-9	2.5E-9	3.9E-9	6.2E-9	6.7E-9	2.7E-9
DUT_off5	135.9E-12	647.8E-12	1.0E-9	825.0E-12	1.4E-9	2.5E-9	4.0E-9	6.4E-9	7.0E-9	2.4E-9
Radiation-Mean OFF	135.0E-12	601.1E-12	976.1E-12	816.2E-12	1.3E-9	2.5E-9	4.3E-9	6.3E-9	6.8E-9	2.3E-9
Standarddeviation	5.0E-12	42.7E-12	65.2E-12	71.1E-12	137.9E-12	322.7E-12	1.1E-9	520.9E-12	571.0E-12	273.6E-12
Mean + kσ	148.8E-12	718.2E-12	1.2E-9	1.0E-9	1.7E-9	3.4E-9	7.2E-9	7.8E-9	8.4E-9	3.1E-9
Mean - kσ	121.2E-12	484.0E-12	797.4E-12	621.2E-12	961.0E-12	1.6E-9	1.4E-9	4.9E-9	5.2E-9	1.6E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	135.9E-12	135.3E-12	146.9E-12	80.4E-12	148.2E-12	131.8E-12	124.1E-12	162.8E-12	141.9E-12	134.8E-12
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
Min. Value
Typ. Value
Max. Value
1e−4
BDS16, (CM1438E)
Collector-Emitter Cut-off Current in A
Total Dose [krad(Si)] / Annealing
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
1e−9
On
Off
Total Dose [krad(Si)] / Annealing

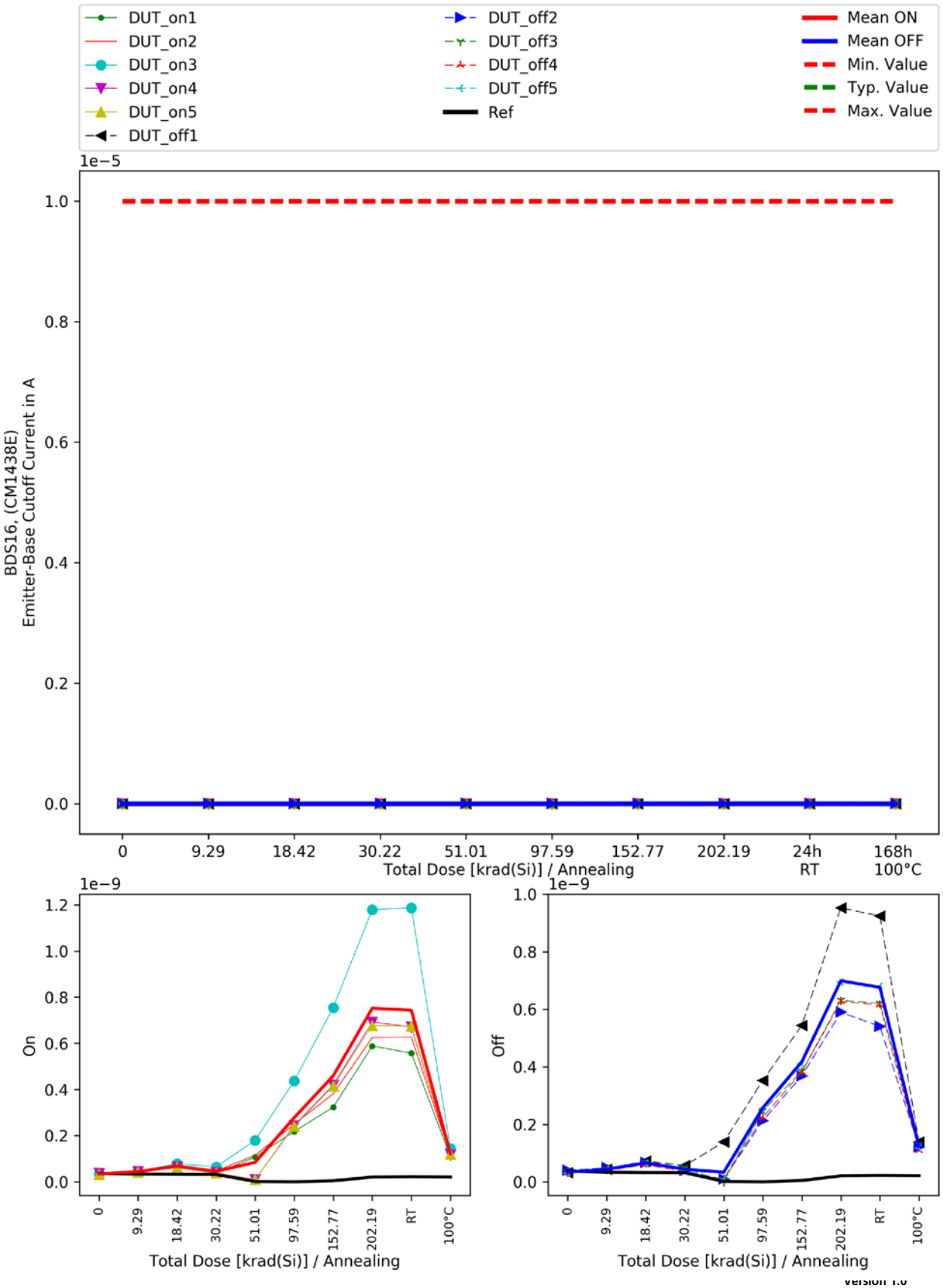
7.5 Emitter-Base Cutoff Current

Emitter-Base Cutoff Current **BDS16**
IEBO in A Date-/Lotcode: CM1438E
Limit: x < 1e-05

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	33.8E-12	41.7E-12	61.8E-12	37.2E-12	107.5E-12	218.4E-12	323.1E-12	588.4E-12	557.7E-12	109.7E-12
DUT_on2	34.5E-12	47.4E-12	74.1E-12	46.9E-12	115.2E-12	249.3E-12	381.2E-12	624.7E-12	627.2E-12	117.3E-12
DUT_on3	35.0E-12	47.0E-12	78.0E-12	65.0E-12	179.5E-12	437.2E-12	755.1E-12	1.2E-9	1.2E-9	144.1E-12
DUT_on4	36.5E-12	45.0E-12	63.8E-12	39.6E-12	9.9E-12	244.0E-12	419.7E-12	692.0E-12	670.8E-12	117.3E-12
DUT_on5	32.5E-12	41.4E-12	62.4E-12	38.4E-12	9.4E-12	240.4E-12	415.4E-12	676.6E-12	675.1E-12	120.9E-12
Radiation-Mean ON	34.4E-12	44.5E-12	68.0E-12	45.4E-12	84.3E-12	277.9E-12	458.9E-12	752.1E-12	743.5E-12	121.9E-12
Standarddeviation	1.5E-12	2.9E-12	7.5E-12	11.6E-12	73.6E-12	89.9E-12	170.1E-12	242.0E-12	252.3E-12	13.1E-12
Mean + kσ	38.4E-12	52.4E-12	88.6E-12	77.2E-12	286.2E-12	524.3E-12	925.2E-12	1.4E-9	1.4E-9	157.8E-12
Mean - kσ	30.5E-12	36.6E-12	47.4E-12	13.7E-12	-117.6E-12	31.5E-12	-7.4E-12	88.5E-12	51.8E-12	86.0E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	32.6E-12	44.3E-12	72.4E-12	56.2E-12	138.6E-12	352.7E-12	543.4E-12	952.6E-12	923.9E-12	139.0E-12
DUT_off2	40.3E-12	48.6E-12	67.5E-12	39.1E-12	8.9E-12	212.6E-12	368.0E-12	589.5E-12	540.5E-12	121.2E-12
DUT_off3	33.5E-12	43.4E-12	67.3E-12	49.9E-12	1.1E-12	247.0E-12	383.9E-12	631.2E-12	620.9E-12	130.4E-12
DUT_off4	31.1E-12	39.9E-12	59.4E-12	35.9E-12	9.0E-12	224.1E-12	381.4E-12	627.1E-12	615.2E-12	109.9E-12
DUT_off5	31.7E-12	42.3E-12	64.1E-12	39.5E-12	10.0E-12	249.5E-12	410.0E-12	694.0E-12	680.4E-12	117.1E-12
Radiation-Mean OFF	33.8E-12	43.7E-12	66.1E-12	44.1E-12	33.5E-12	257.2E-12	417.3E-12	698.9E-12	676.2E-12	123.5E-12
Standarddeviation	3.7E-12	3.2E-12	4.8E-12	8.6E-12	58.8E-12	55.6E-12	72.1E-12	146.7E-12	147.1E-12	11.4E-12
Mean + kσ	44.0E-12	52.5E-12	79.3E-12	67.6E-12	194.9E-12	409.7E-12	615.0E-12	1.1E-9	1.1E-9	154.7E-12
Mean - kσ	23.7E-12	34.9E-12	53.0E-12	20.6E-12	-127.8E-12	104.7E-12	219.7E-12	296.6E-12	272.8E-12	92.3E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	37.1E-12	33.9E-12	32.3E-12	31.9E-12	1.8E-12	247.3E-15	4.6E-12	20.8E-12	22.7E-12	21.2E-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
Min. Value
Typ. Value
Max. Value
1e−5
BDS16, (CM1438E)
Emitter-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
1e−9
On
Off
Total Dose [krad(Si)] / Annealing

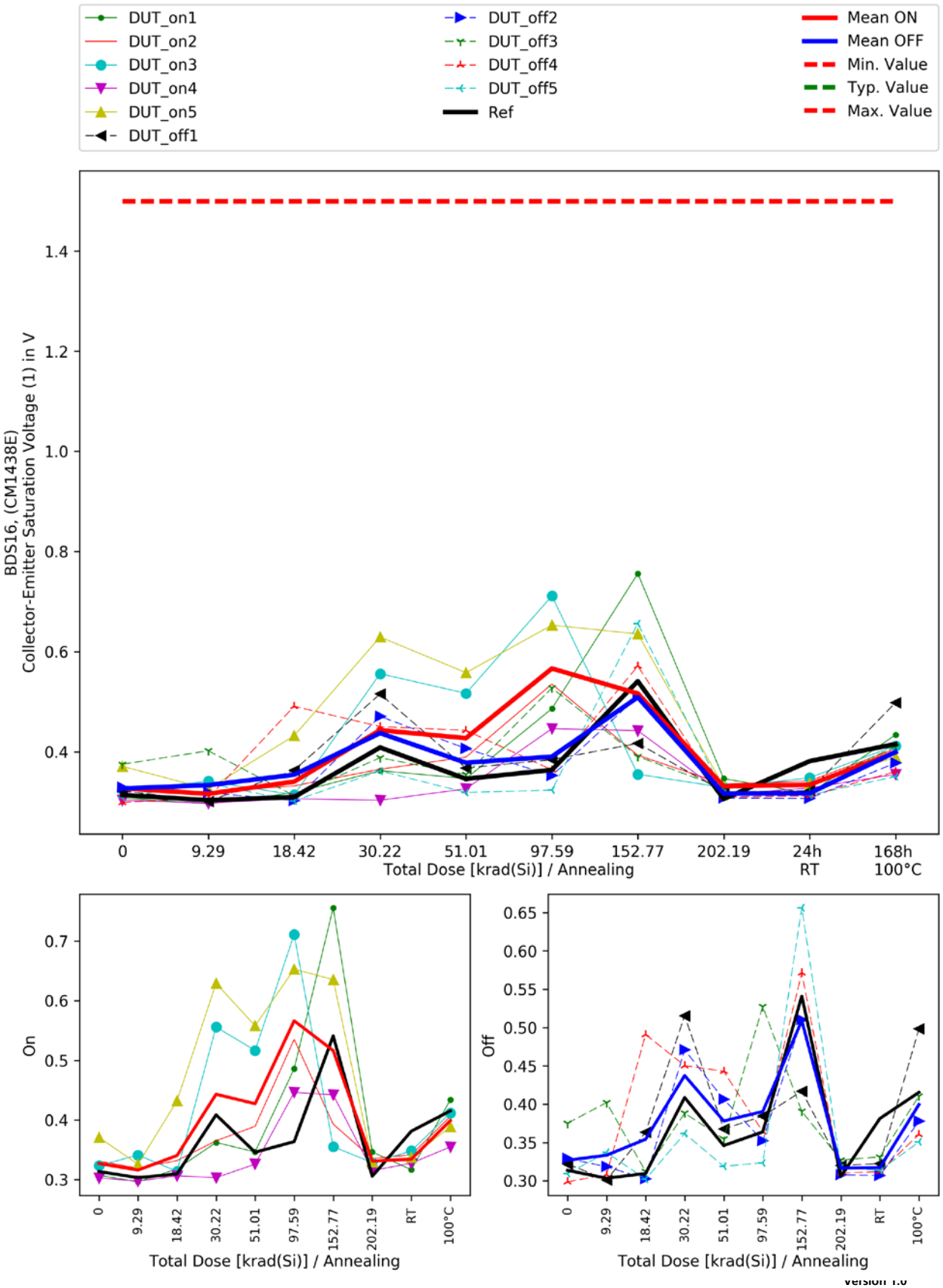
7.6 Collector-Emitter Saturation Voltage (1)

Collector-Emitter Saturation Voltage (1) **BDS16**
VCEsat_1 in V Date-/Lotcode: CM1438E
Limit: x<1.5

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	307.3E-3	296.4E-3	318.0E-3	362.3E-3	346.6E-3	486.1E-3	755.8E-3	346.4E-3	316.7E-3	433.9E-3
DUT_on2	331.1E-3	319.1E-3	332.0E-3	365.2E-3	389.5E-3	535.3E-3	393.1E-3	335.4E-3	341.7E-3	406.0E-3
DUT_on3	323.6E-3	341.3E-3	314.0E-3	555.9E-3	516.7E-3	711.1E-3	355.2E-3	328.7E-3	348.2E-3	411.9E-3
DUT_on4	302.9E-3	297.6E-3	306.3E-3	303.4E-3	326.0E-3	446.3E-3	442.2E-3	315.1E-3	327.7E-3	355.0E-3
DUT_on5	370.9E-3	325.8E-3	432.1E-3	629.2E-3	558.0E-3	662.9E-3	635.4E-3	330.2E-3	337.3E-3	388.9E-3
Radiation-Mean ON	327.2E-3	316.0E-3	340.5E-3	443.2E-3	427.4E-3	566.3E-3	516.4E-3	331.2E-3	334.3E-3	399.1E-3
Standarddeviation	27.0E-3	19.1E-3	52.1E-3	140.9E-3	104.0E-3	112.1E-3	171.9E-3	11.3E-3	12.4E-3	29.5E-3
Mean + kσ	401.3E-3	368.5E-3	483.2E-3	829.6E-3	712.6E-3	873.7E-3	987.7E-3	362.3E-3	368.2E-3	480.0E-3
Mean - kσ	253.0E-3	263.6E-3	197.8E-3	56.7E-3	142.1E-3	258.9E-3	45.0E-3	300.1E-3	300.4E-3	318.3E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	322.0E-3	301.3E-3	363.3E-3	515.4E-3	367.6E-3	384.3E-3	416.9E-3	319.9E-3	322.4E-3	498.2E-3
DUT_off2	329.0E-3	318.4E-3	302.7E-3	470.8E-3	406.4E-3	352.4E-3	510.2E-3	307.8E-3	306.9E-3	377.8E-3
DUT_off3	375.1E-3	402.1E-3	312.2E-3	388.2E-3	354.7E-3	527.5E-3	390.6E-3	327.1E-3	331.2E-3	410.4E-3
DUT_off4	298.7E-3	308.0E-3	490.9E-3	450.4E-3	442.8E-3	364.0E-3	571.1E-3	310.0E-3	312.0E-3	360.4E-3
DUT_off5	309.3E-3	337.1E-3	302.0E-3	361.8E-3	318.9E-3	323.5E-3	656.2E-3	317.1E-3	313.6E-3	350.6E-3
Radiation-Mean OFF	326.8E-3	333.4E-3	354.2E-3	437.3E-3	378.1E-3	390.4E-3	509.0E-3	316.4E-3	317.2E-3	399.5E-3
Standarddeviation	29.4E-3	40.7E-3	80.5E-3	62.3E-3	47.8E-3	79.8E-3	109.6E-3	7.8E-3	9.6E-3	59.7E-3
Mean + kσ	407.5E-3	445.0E-3	574.9E-3	608.1E-3	509.2E-3	609.1E-3	809.5E-3	337.7E-3	343.6E-3	563.1E-3
Mean - kσ	246.1E-3	221.7E-3	133.5E-3	266.5E-3	247.0E-3	171.6E-3	208.5E-3	295.1E-3	290.9E-3	235.9E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	313.7E-3	303.3E-3	309.6E-3	408.6E-3	346.0E-3	363.8E-3	540.9E-3	305.7E-3	381.3E-3	415.4E-3
Max. Value	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+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
BDS16, (CM1438E)
Collector-Emitter Saturation Voltage (1) in V
1.4
1.2
1.0
0.8
0.6
0.4
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
0.7
0.6
0.5
0.4
0.3
Total Dose [krad(Si)] / Annealing
Off
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
Total Dose [krad(Si)] / Annealing

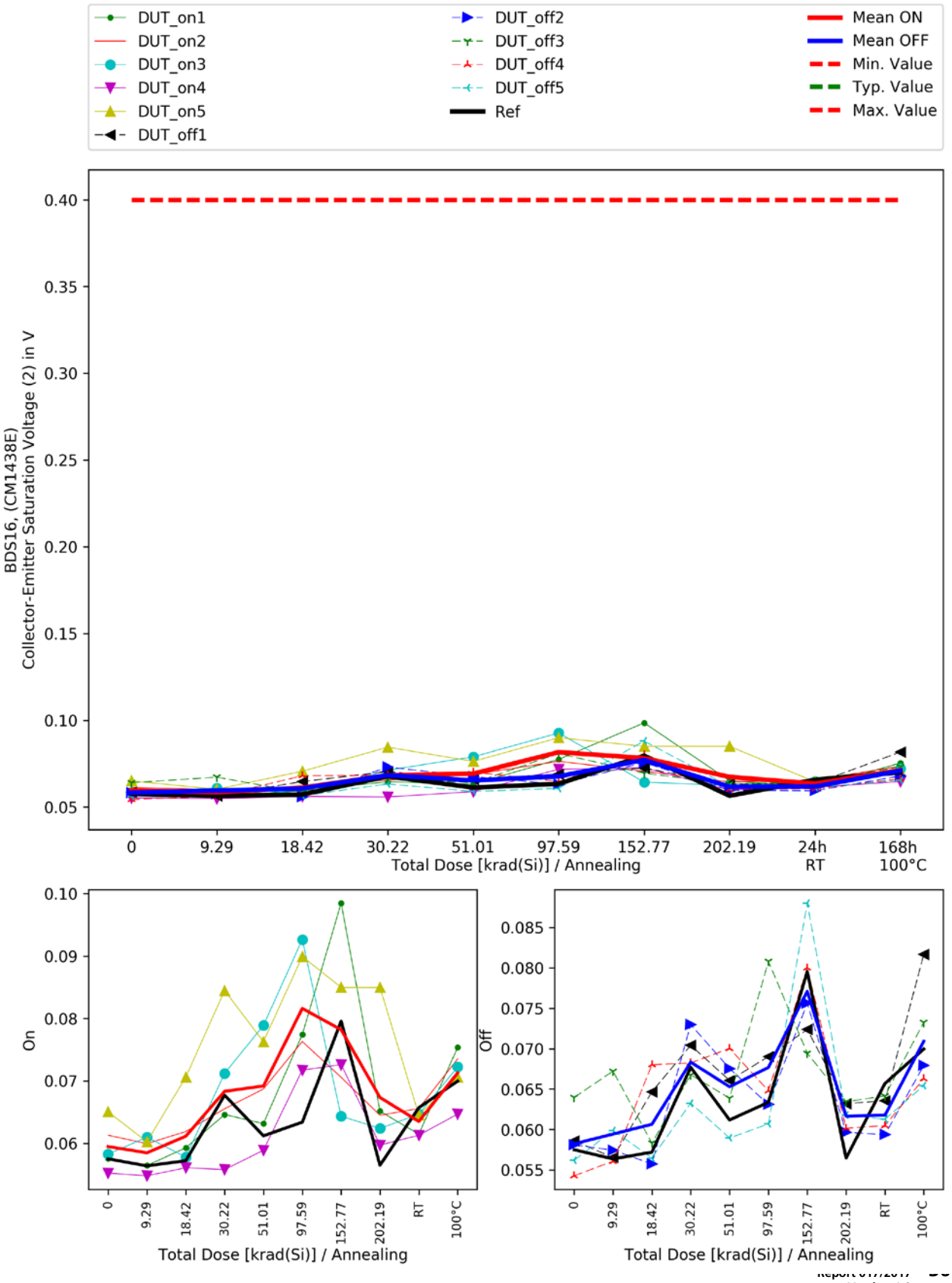
7.7 Collector-Emitter Saturation Voltage (2)

Collector-Emitter Saturation Voltage (2) **BDS16**
VCEsat_2 in V Date-/Lotcode: CM1438E
Limit: x<0.4

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	57.5E-3	56.4E-3	59.3E-3	64.6E-3	63.1E-3	77.4E-3	98.5E-3	65.1E-3	61.4E-3	75.4E-3
DUT_on2	61.3E-3	59.9E-3	61.9E-3	65.5E-3	68.7E-3	76.3E-3	70.6E-3	64.5E-3	65.6E-3	73.5E-3
DUT_on3	58.3E-3	61.0E-3	57.8E-3	71.2E-3	78.9E-3	92.7E-3	64.3E-3	62.4E-3	64.7E-3	72.2E-3
DUT_on4	55.2E-3	54.8E-3	56.1E-3	55.8E-3	58.9E-3	71.7E-3	72.6E-3	59.7E-3	61.3E-3	64.7E-3
DUT_on5	65.0E-3	60.2E-3	70.6E-3	84.5E-3	76.3E-3	89.9E-3	85.0E-3	85.0E-3	64.5E-3	70.6E-3
Radiation-Mean ON	59.5E-3	58.5E-3	61.1E-3	68.3E-3	69.2E-3	81.6E-3	78.2E-3	67.3E-3	63.5E-3	71.3E-3
Standarddeviation	3.8E-3	2.7E-3	5.7E-3	10.6E-3	8.5E-3	9.2E-3	13.6E-3	10.1E-3	2.0E-3	4.1E-3
Mean + kσ	69.9E-3	65.9E-3	76.8E-3	97.3E-3	92.4E-3	106.7E-3	115.5E-3	95.0E-3	68.9E-3	82.5E-3
Mean - kσ	49.1E-3	51.0E-3	45.5E-3	39.3E-3	45.9E-3	56.5E-3	40.9E-3	39.7E-3	58.0E-3	60.1E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	58.6E-3	56.5E-3	64.7E-3	70.4E-3	66.1E-3	69.0E-3	72.4E-3	63.2E-3	63.5E-3	81.7E-3
DUT_off2	58.1E-3	57.4E-3	55.8E-3	73.0E-3	67.5E-3	63.1E-3	75.6E-3	59.7E-3	59.4E-3	67.9E-3
DUT_off3	64.0E-3	67.2E-3	58.3E-3	66.8E-3	63.9E-3	80.8E-3	69.5E-3	63.4E-3	64.2E-3	73.3E-3
DUT_off4	54.3E-3	56.1E-3	68.0E-3	68.2E-3	70.0E-3	64.8E-3	80.0E-3	60.2E-3	60.5E-3	66.3E-3
DUT_off5	56.2E-3	59.9E-3	56.5E-3	63.3E-3	59.0E-3	60.7E-3	88.0E-3	61.8E-3	61.3E-3	65.4E-3
Radiation-Mean OFF	58.2E-3	59.4E-3	60.6E-3	68.3E-3	65.3E-3	67.7E-3	77.1E-3	61.7E-3	61.8E-3	70.9E-3
Standarddeviation	3.6E-3	4.6E-3	5.4E-3	3.7E-3	4.2E-3	7.9E-3	7.3E-3	1.7E-3	2.0E-3	6.7E-3
Mean + kσ	68.2E-3	72.0E-3	75.5E-3	78.4E-3	76.8E-3	89.5E-3	97.0E-3	66.4E-3	67.4E-3	89.4E-3
Mean - kσ	48.2E-3	46.8E-3	45.8E-3	58.3E-3	53.8E-3	45.9E-3	57.2E-3	56.9E-3	56.2E-3	52.4E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	57.5E-3	56.4E-3	57.2E-3	67.7E-3	61.2E-3	63.4E-3	79.6E-3	56.5E-3	65.7E-3	70.0E-3
Max. Value	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-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
Min. Value
Typ. Value
Max. Value
BDS16, (CM1438E)
Collector-Emitter Saturation Voltage (2) in V
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
0.10
0.09
0.08
0.07
0.06
Off
0.085
0.080
0.075
0.070
0.065
0.060
0.055
Total Dose [krad(Si)] / Annealing

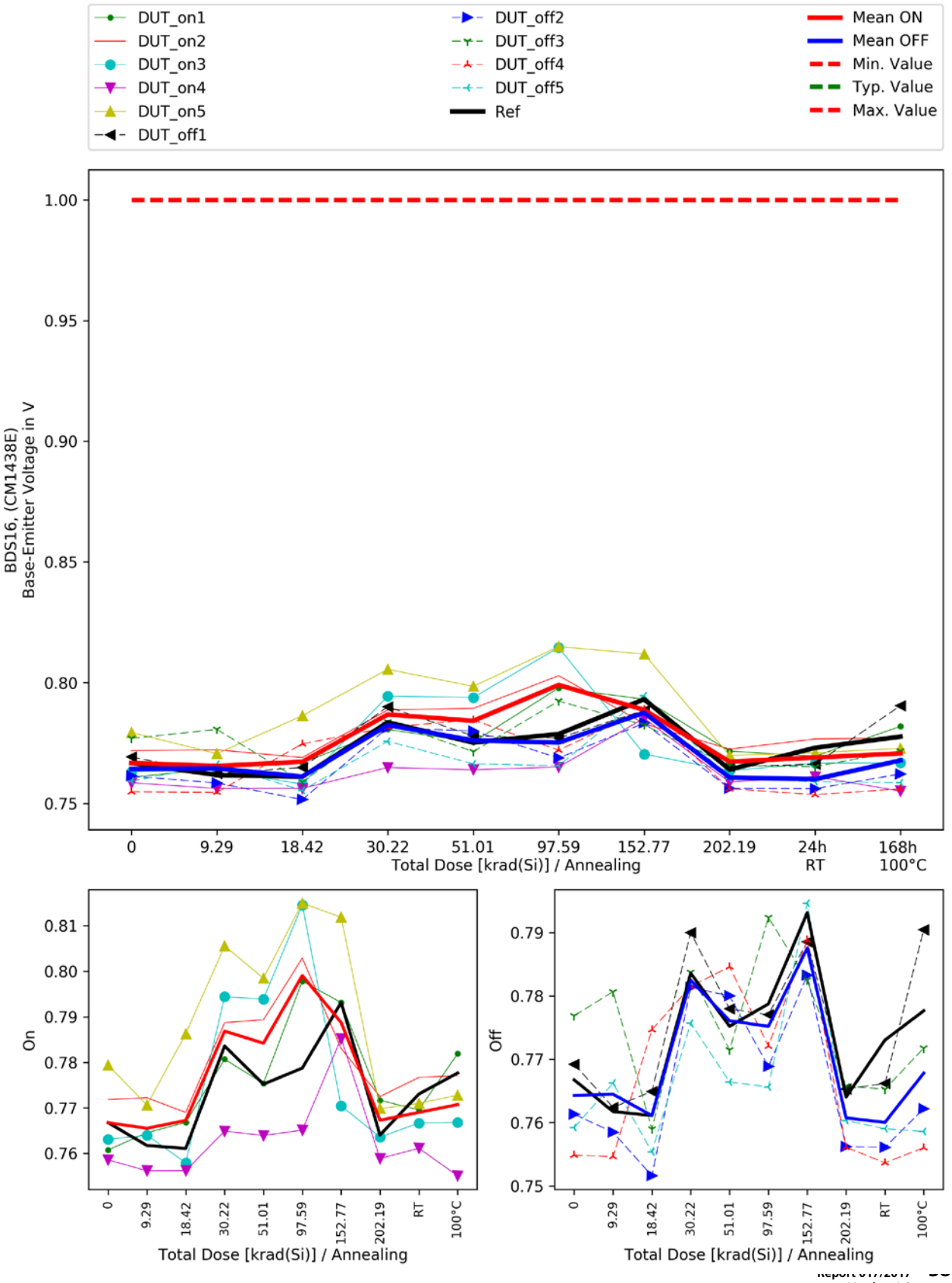
7.8 Base-Emitter Voltage

Base-Emitter Voltage **BDS16**
VBEon in V Date-/Lotcode: CM1438E
Limit: x<1.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	760.8E-3	764.5E-3	766.8E-3	780.7E-3	775.4E-3	797.8E-3	793.1E-3	771.7E-3	769.6E-3	781.9E-3
DUT_on2	771.8E-3	772.2E-3	769.0E-3	788.7E-3	789.3E-3	802.9E-3	783.0E-3	772.5E-3	776.7E-3	777.1E-3
DUT_on3	763.1E-3	764.0E-3	757.9E-3	794.4E-3	793.9E-3	814.6E-3	770.4E-3	763.6E-3	766.6E-3	766.8E-3
DUT_on4	758.6E-3	756.2E-3	756.2E-3	764.9E-3	763.9E-3	765.1E-3	785.2E-3	758.8E-3	761.1E-3	755.1E-3
DUT_on5	779.4E-3	770.6E-3	786.3E-3	805.5E-3	798.5E-3	815.0E-3	811.9E-3	769.8E-3	771.0E-3	772.8E-3
Radiation-Mean ON	766.7E-3	765.5E-3	767.2E-3	786.8E-3	784.2E-3	799.1E-3	788.7E-3	767.3E-3	769.0E-3	770.7E-3
Standarddeviation	8.7E-3	6.3E-3	12.0E-3	15.2E-3	14.3E-3	20.4E-3	15.3E-3	5.9E-3	5.7E-3	10.4E-3
Mean + kσ	790.5E-3	782.9E-3	800.1E-3	828.7E-3	823.3E-3	855.0E-3	830.6E-3	783.4E-3	784.7E-3	799.1E-3
Mean - kσ	742.9E-3	748.1E-3	734.4E-3	745.0E-3	745.1E-3	743.2E-3	746.8E-3	751.2E-3	753.3E-3	742.3E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	769.2E-3	762.4E-3	764.9E-3	790.0E-3	777.9E-3	777.0E-3	788.6E-3	765.3E-3	766.2E-3	790.5E-3
DUT_off2	761.3E-3	758.5E-3	751.6E-3	781.4E-3	780.0E-3	768.8E-3	783.3E-3	756.2E-3	756.1E-3	762.2E-3
DUT_off3	776.9E-3	780.7E-3	759.0E-3	783.7E-3	771.5E-3	792.4E-3	782.5E-3	765.8E-3	765.3E-3	771.8E-3
DUT_off4	754.8E-3	754.6E-3	774.7E-3	781.5E-3	784.6E-3	772.1E-3	788.8E-3	756.1E-3	753.6E-3	756.0E-3
DUT_off5	759.2E-3	766.2E-3	755.4E-3	775.7E-3	766.4E-3	765.6E-3	794.7E-3	760.3E-3	759.0E-3	758.6E-3
Radiation-Mean OFF	764.3E-3	764.5E-3	761.1E-3	782.5E-3	776.1E-3	775.2E-3	787.6E-3	760.7E-3	760.0E-3	767.8E-3
Standarddeviation	8.8E-3	10.0E-3	9.0E-3	5.1E-3	7.2E-3	10.5E-3	4.9E-3	4.7E-3	5.5E-3	14.0E-3
Mean + kσ	788.3E-3	792.0E-3	785.9E-3	796.6E-3	795.8E-3	804.0E-3	801.1E-3	773.6E-3	775.2E-3	806.2E-3
Mean - kσ	740.3E-3	736.9E-3	736.4E-3	768.3E-3	756.4E-3	746.4E-3	774.0E-3	747.8E-3	744.9E-3	729.4E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	766.7E-3	761.7E-3	761.1E-3	783.6E-3	775.2E-3	778.7E-3	793.1E-3	764.0E-3	773.0E-3	777.7E-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
Min. Value
Typ. Value
Max. Value
BDS16, (CM1438E)
Base-Emitter Voltage in V
1.00
0.95
0.90
0.85
0.80
0.75
0
9.29
18.42
30.22
51.01
97.59
152.77
202.19
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
0.81
0.80
0.79
0.78
0.77
0.76
RT
Total Dose [krad(Si)] / Annealing
Off
0.79
0.78
0.77
0.76
0.75
Total Dose [krad(Si)] / Annealing

7.9 Forward Current Transfer Ratio (1)

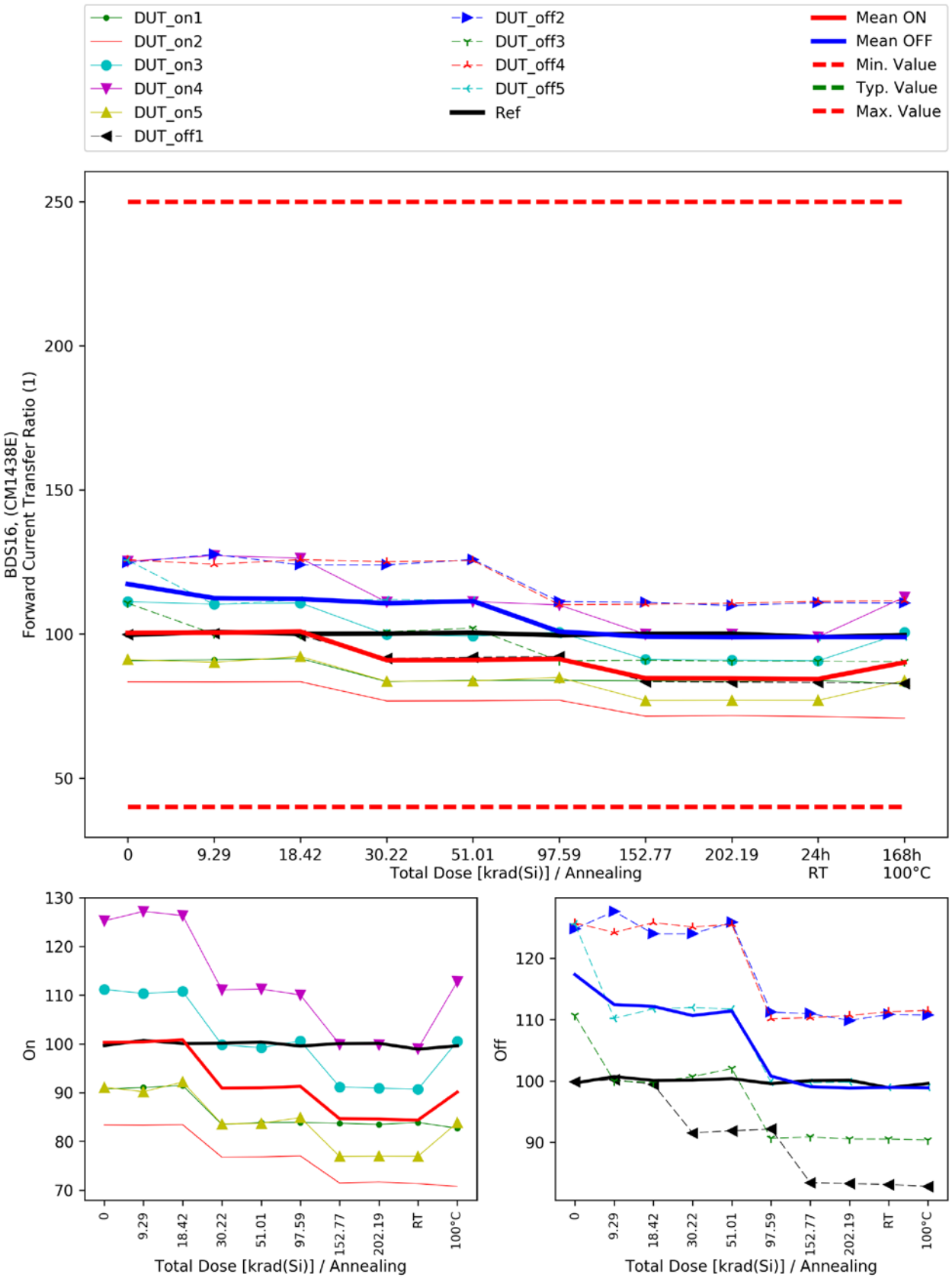
Forward Current Transfer Ratio (1) **BDS16**
HFE 1 Date-/Lotcode: CM1438E
Limit: 40.0<x<250.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	90.7E+0	91.0E+0	91.5E+0	83.5E+0	83.9E+0	83.9E+0	83.7E+0	83.5E+0	83.9E+0	82.7E+0
DUT_on2	83.4E+0	83.3E+0	83.4E+0	76.8E+0	76.8E+0	77.0E+0	71.5E+0	71.7E+0	71.3E+0	70.7E+0
DUT_on3	111.2E+0	110.3E+0	110.8E+0	99.8E+0	99.2E+0	100.6E+0	91.2E+0	90.9E+0	90.7E+0	100.5E+0
DUT_on4	125.2E+0	127.2E+0	126.3E+0	111.1E+0	111.2E+0	110.0E+0	99.9E+0	99.9E+0	99.0E+0	112.7E+0
DUT_on5	91.1E+0	90.2E+0	92.2E+0	83.6E+0	83.7E+0	84.9E+0	76.9E+0	77.0E+0	77.0E+0	83.8E+0
Radiation-Mean ON	**100.3E+0**	**100.4E+0**	**100.8E+0**	**90.9E+0**	**91.0E+0**	**91.3E+0**	**84.6E+0**	**84.6E+0**	**84.4E+0**	**90.1E+0**
Standarddeviation	**17.3E+0**	**18.0E+0**	**17.4E+0**	**14.1E+0**	**14.0E+0**	**13.6E+0**	**11.3E+0**	**11.2E+0**	**10.9E+0**	**16.5E+0**
Mean + kσ	**147.9E+0**	**149.8E+0**	**148.6E+0**	**129.6E+0**	**129.3E+0**	**128.5E+0**	**115.6E+0**	**115.2E+0**	**114.4E+0**	**135.4E+0**
Mean - kσ	**52.8E+0**	**51.0E+0**	**53.1E+0**	**52.3E+0**	**52.6E+0**	**54.0E+0**	**53.7E+0**	**53.9E+0**	**54.4E+0**	**44.8E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	99.8E+0	100.2E+0	99.4E+0	91.6E+0	91.9E+0	92.2E+0	83.4E+0	83.3E+0	83.2E+0	82.8E+0
DUT_off2	124.8E+0	127.6E+0	124.0E+0	124.0E+0	125.8E+0	111.2E+0	111.0E+0	109.9E+0	110.8E+0	110.7E+0
DUT_off3	110.7E+0	100.0E+0	99.8E+0	100.7E+0	102.0E+0	90.7E+0	90.9E+0	90.6E+0	90.5E+0	90.4E+0
DUT_off4	125.8E+0	124.2E+0	125.8E+0	125.1E+0	125.5E+0	110.1E+0	110.3E+0	110.7E+0	111.3E+0	111.5E+0
DUT_off5	125.6E+0	110.2E+0	111.7E+0	111.9E+0	111.7E+0	99.8E+0	99.7E+0	99.8E+0	98.9E+0	99.0E+0
Radiation-Mean OFF	**117.3E+0**	**112.4E+0**	**112.1E+0**	**110.7E+0**	**111.4E+0**	**100.8E+0**	**99.1E+0**	**98.8E+0**	**99.0E+0**	**98.9E+0**
Standarddeviation	**11.7E+0**	**13.0E+0**	**12.7E+0**	**14.6E+0**	**14.8E+0**	**9.7E+0**	**12.0E+0**	**12.0E+0**	**12.4E+0**	**12.5E+0**
Mean + kσ	**149.3E+0**	**148.1E+0**	**146.8E+0**	**150.6E+0**	**152.0E+0**	**127.3E+0**	**132.1E+0**	**131.6E+0**	**132.9E+0**	**133.3E+0**
Mean - kσ	**85.3E+0**	**76.8E+0**	**77.4E+0**	**70.7E+0**	**70.8E+0**	**74.3E+0**	**66.1E+0**	**66.0E+0**	**65.0E+0**	**64.5E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	99.7E+0	100.7E+0	100.1E+0	100.1E+0	100.4E+0	99.6E+0	100.1E+0	100.1E+0	98.9E+0	99.6E+0
Min. 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
Max. Value	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0

Fraunhofer
INT



Version 1.0

7.10 Forward Current Transfer Ratio (2)

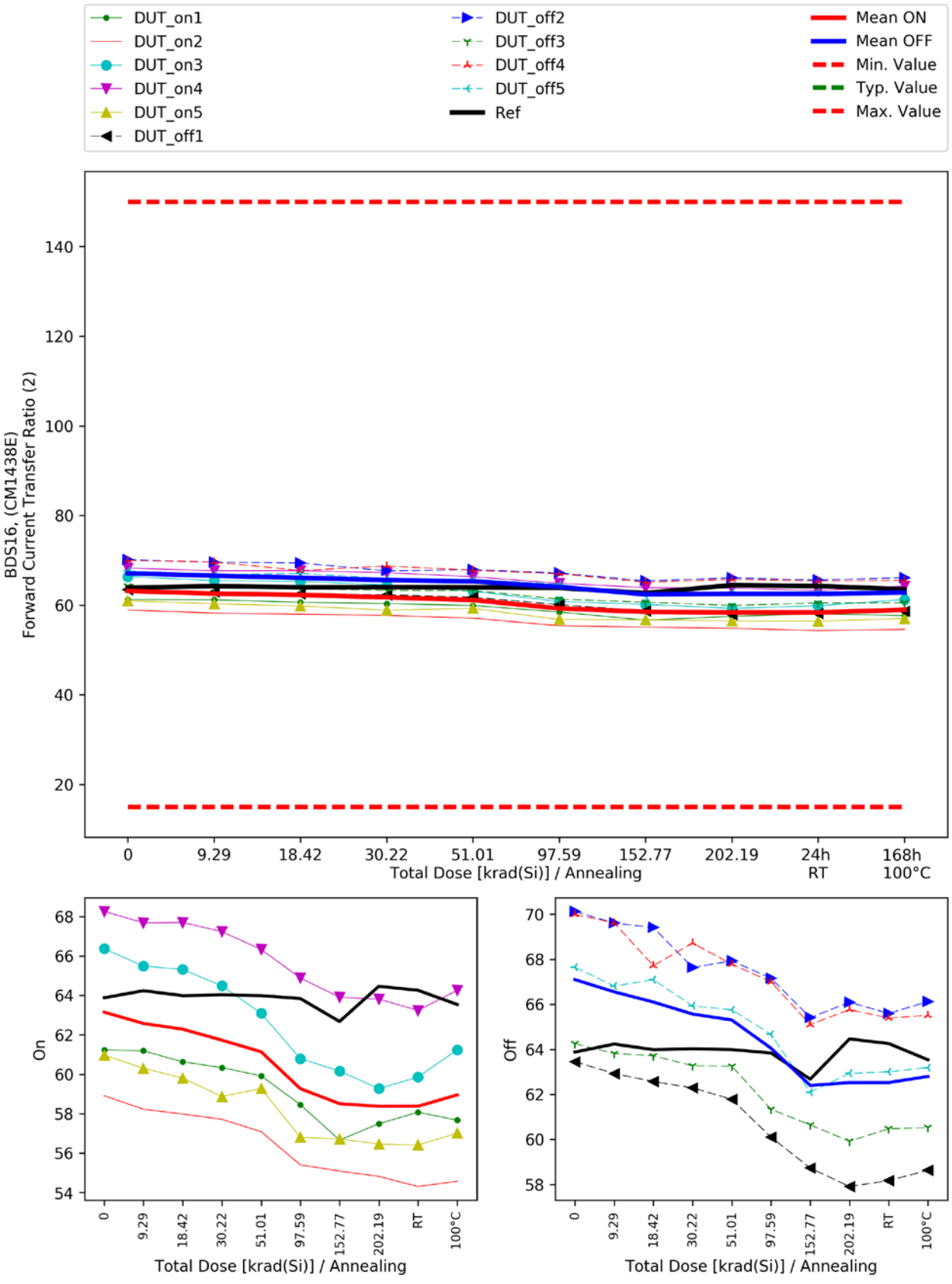
Forward Current Transfer Ratio (2) **BDS16**
HFE 2 Date-/Lotcode: CM1438E
Limit: 15.0<x<150.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_on1	61.2E+0	61.2E+0	60.6E+0	60.3E+0	59.9E+0	58.5E+0	56.7E+0	57.5E+0	58.1E+0	57.7E+0
DUT_on2	58.9E+0	58.2E+0	58.0E+0	57.7E+0	57.1E+0	55.4E+0	55.1E+0	54.8E+0	54.3E+0	54.6E+0
DUT_on3	66.4E+0	65.5E+0	65.3E+0	64.5E+0	63.1E+0	60.8E+0	60.2E+0	59.3E+0	59.9E+0	61.2E+0
DUT_on4	68.3E+0	67.7E+0	67.7E+0	67.2E+0	66.3E+0	64.9E+0	63.9E+0	63.8E+0	63.2E+0	64.3E+0
DUT_on5	61.0E+0	60.3E+0	59.8E+0	58.9E+0	59.3E+0	56.8E+0	56.7E+0	56.5E+0	56.4E+0	57.0E+0
Radiation-Mean ON	63.1E+0	62.6E+0	62.3E+0	61.7E+0	61.1E+0	59.3E+0	58.5E+0	58.4E+0	58.4E+0	59.0E+0
Standarddeviation	4.0E+0	3.9E+0	4.1E+0	4.0E+0	3.6E+0	3.7E+0	3.5E+0	3.4E+0	3.4E+0	3.8E+0
Mean + kσ	74.0E+0	73.2E+0	73.4E+0	72.7E+0	71.0E+0	69.5E+0	68.2E+0	67.8E+0	67.7E+0	69.4E+0
Mean - kσ	52.3E+0	51.9E+0	51.2E+0	50.7E+0	51.2E+0	49.1E+0	48.8E+0	48.9E+0	49.0E+0	48.5E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
DUT_off1	63.5E+0	62.9E+0	62.6E+0	62.3E+0	61.8E+0	60.1E+0	58.7E+0	57.9E+0	58.2E+0	58.6E+0
DUT_off2	70.1E+0	69.6E+0	69.4E+0	67.6E+0	67.9E+0	67.2E+0	65.4E+0	66.1E+0	65.6E+0	66.1E+0
DUT_off3	64.3E+0	63.8E+0	63.7E+0	63.3E+0	63.3E+0	61.3E+0	60.6E+0	59.9E+0	60.5E+0	60.5E+0
DUT_off4	70.0E+0	69.6E+0	67.7E+0	68.7E+0	67.8E+0	67.0E+0	65.1E+0	65.8E+0	65.4E+0	65.5E+0
DUT_off5	67.7E+0	66.8E+0	67.1E+0	65.9E+0	65.8E+0	64.7E+0	62.1E+0	62.9E+0	63.0E+0	63.2E+0
Radiation-Mean OFF	67.1E+0	66.6E+0	66.1E+0	65.6E+0	65.3E+0	64.1E+0	62.4E+0	62.5E+0	62.5E+0	62.8E+0
Standarddeviation	3.1E+0	3.1E+0	2.9E+0	2.8E+0	2.7E+0	3.2E+0	2.9E+0	3.6E+0	3.2E+0	3.2E+0
Mean + kσ	75.7E+0	75.2E+0	73.9E+0	73.1E+0	72.8E+0	72.9E+0	70.3E+0	72.4E+0	71.3E+0	71.6E+0
Mean - kσ	58.5E+0	57.9E+0	58.3E+0	58.0E+0	57.8E+0	55.2E+0	54.5E+0	52.7E+0	53.7E+0	54.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.29	18.42	30.22	51.01	97.59	152.77	202.19	24h @RT	168h @100°C
Ref1	63.9E+0	64.2E+0	64.0E+0	64.0E+0	64.0E+0	63.8E+0	62.7E+0	64.5E+0	64.3E+0	63.5E+0
Min. 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
Max. Value	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0

Fraunhofer
INT



Version 1.0

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
VCEO_Sus	On										
	Off										
I (VCEO_Sus)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCEsat_1	On										
	Off										
VCEsat_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On										
	Off										
HFE 2	On										
	Off										

8.2 Collector-Emitter Sustaining Voltage (IB=0)

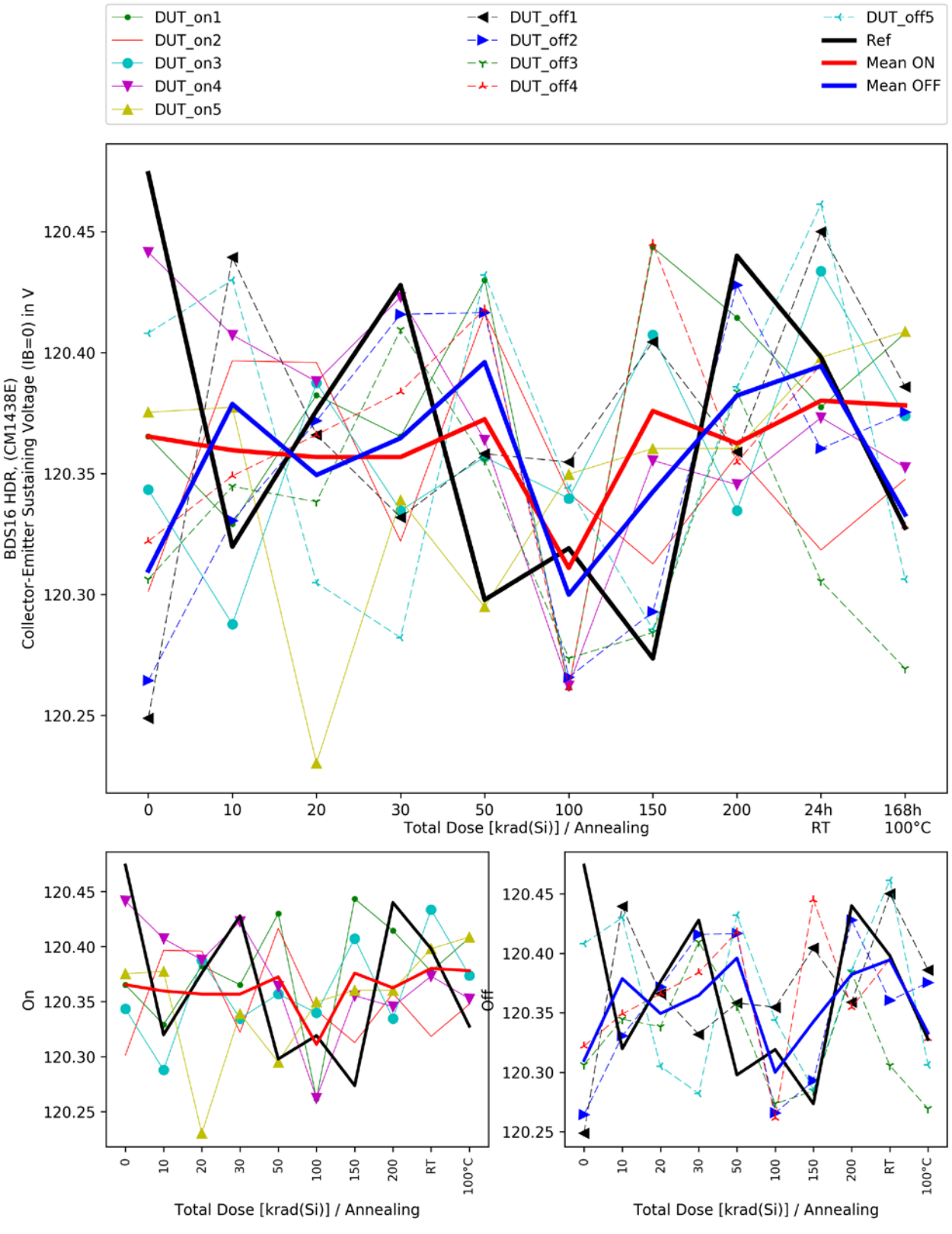
Collector-Emitter Sustaining Voltage (IB=0)
VCEO_Sus in V
Limit: 120.0<x

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
DUT_on2	120.3E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.3E+0	120.3E+0
DUT_on3	120.3E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0
DUT_on4	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0
DUT_on5	120.4E+0	120.4E+0	120.2E+0	120.3E+0	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
Radiation-Mean ON	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
Standarddeviation	51.2E-3	50.1E-3	70.9E-3	40.2E-3	53.8E-3	45.0E-3	50.5E-3	30.8E-3	42.0E-3	29.3E-3
Mean + kσ	120.5E+0	120.5E+0	120.6E+0	120.5E+0	120.5E+0	120.4E+0	120.5E+0	120.4E+0	120.5E+0	120.5E+0
Mean - kσ	120.2E+0	120.2E+0	120.2E+0	120.2E+0	120.2E+0	120.2E+0	120.2E+0	120.3E+0	120.3E+0	120.3E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	120.2E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0	120.4E+0
DUT_off2	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0
DUT_off3	120.3E+0	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.3E+0	120.3E+0
DUT_off4	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.4E+0	120.3E+0
DUT_off5	120.4E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.5E+0	120.3E+0
Radiation-Mean OFF	120.3E+0	120.4E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0
Standarddeviation	62.4E-3	51.6E-3	28.1E-3	56.7E-3	36.3E-3	45.5E-3	76.5E-3	29.2E-3	64.4E-3	48.4E-3
Mean + kσ	120.5E+0	120.5E+0	120.4E+0	120.5E+0	120.5E+0	120.4E+0	120.6E+0	120.5E+0	120.6E+0	120.5E+0
Mean - kσ	120.1E+0	120.2E+0	120.3E+0	120.2E+0	120.3E+0	120.2E+0	120.1E+0	120.3E+0	120.2E+0	120.2E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	120.5E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0	120.3E+0	120.3E+0	120.4E+0	120.4E+0	120.3E+0
Min. Value	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+0	120.0E+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
BDS16 HDR, (CM1438E)
Collector-Emitter Sustaining Voltage (IB=0) in V
120.45
120.40
120.35
120.30
120.25
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

8.3 ICE @ VCEsus

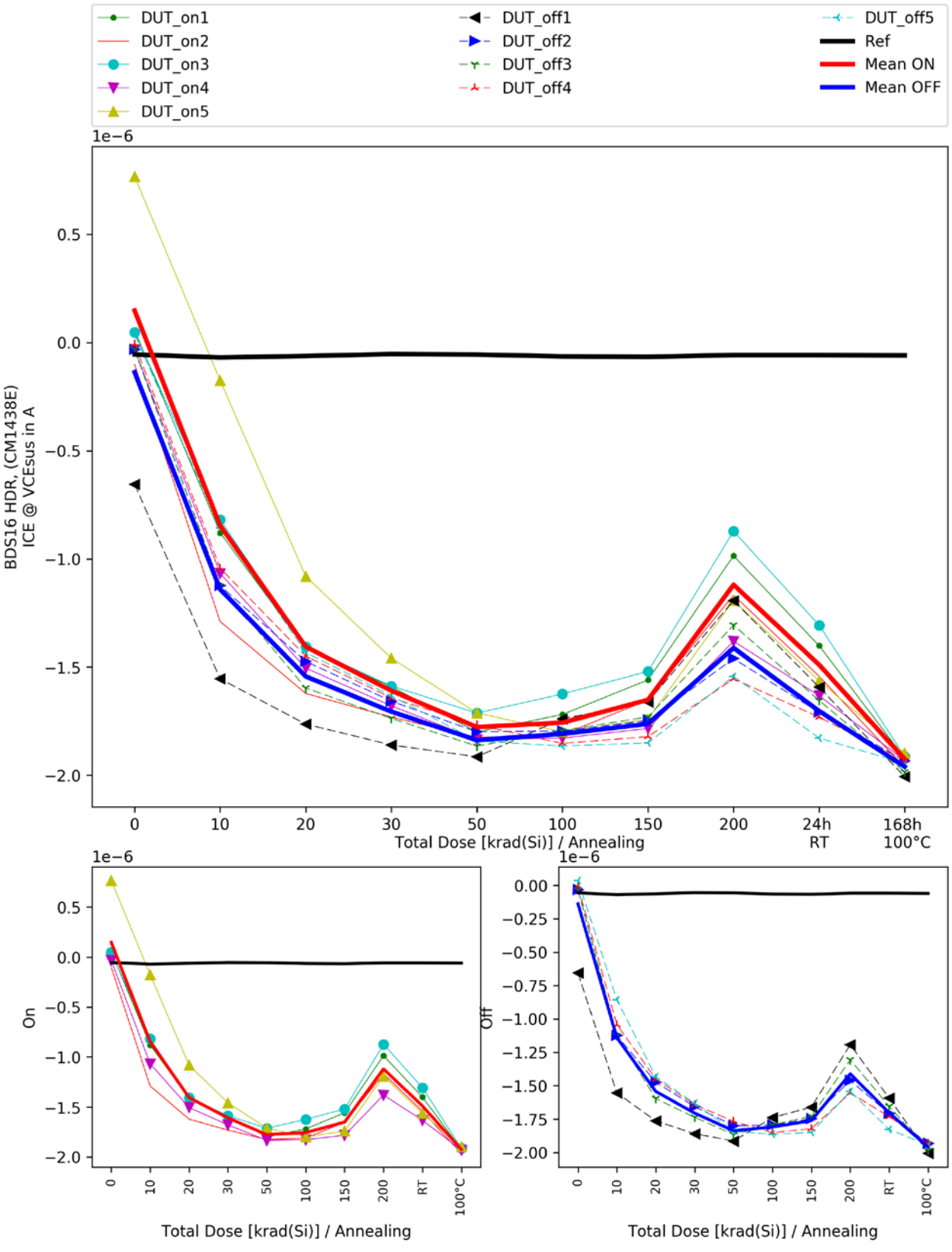
ICE @VCEsus
I (VCEO_Sus) in A
Limit: x<0.1

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	56.6E-9	-879.3E-9	-1.4E-6	-1.6E-6	-1.8E-6	-1.7E-6	-1.6E-6	-985.8E-9	-1.4E-6	-1.9E-6
DUT_on2	-101.9E-9	-1.3E-6	-1.6E-6	-1.7E-6	-1.8E-6	-1.8E-6	-1.7E-6	-1.2E-6	-1.5E-6	-2.0E-6
DUT_on3	47.4E-9	-818.7E-9	-1.4E-6	-1.6E-6	-1.7E-6	-1.6E-6	-1.5E-6	-871.9E-9	-1.3E-6	-1.9E-6
DUT_on4	-32.2E-9	-1.1E-6	-1.5E-6	-1.7E-6	-1.8E-6	-1.8E-6	-1.8E-6	-1.4E-6	-1.6E-6	-1.9E-6
DUT_on5	767.5E-9	-175.5E-9	-1.1E-6	-1.5E-6	-1.7E-6	-1.8E-6	-1.7E-6	-1.2E-6	-1.6E-6	-1.9E-6
Radiation-Mean ON	147.5E-9	-845.9E-9	-1.4E-6	-1.6E-6	-1.8E-6	-1.8E-6	-1.7E-6	-1.1E-6	-1.5E-6	-1.9E-6
Standarddeviation	352.6E-9	417.3E-9	201.5E-9	103.9E-9	60.4E-9	85.1E-9	113.2E-9	196.7E-9	132.3E-9	25.1E-9
Mean + kσ	1.1E-6	298.4E-9	-852.9E-9	-1.3E-6	-1.6E-6	-1.5E-6	-1.3E-6	-580.0E-9	-1.1E-6	-1.9E-6
Mean - kσ	-819.2E-9	-2.0E-6	-2.0E-6	-1.9E-6	-1.9E-6	-2.0E-6	-2.0E-6	-1.7E-6	-1.9E-6	-2.0E-6

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-654.6E-9	-1.6E-6	-1.8E-6	-1.9E-6	-1.9E-6	-1.7E-6	-1.7E-6	-1.2E-6	-1.6E-6	-2.0E-6
DUT_off2	-32.2E-9	-1.1E-6	-1.5E-6	-1.7E-6	-1.8E-6	-1.8E-6	-1.7E-6	-1.5E-6	-1.7E-6	-1.9E-6
DUT_off3	-30.9E-9	-1.1E-6	-1.6E-6	-1.7E-6	-1.9E-6	-1.8E-6	-1.7E-6	-1.3E-6	-1.7E-6	-2.0E-6
DUT_off4	-7.0E-9	-1.0E-6	-1.4E-6	-1.6E-6	-1.8E-6	-1.9E-6	-1.8E-6	-1.6E-6	-1.7E-6	-1.9E-6
DUT_off5	37.4E-9	-856.4E-9	-1.4E-6	-1.6E-6	-1.8E-6	-1.9E-6	-1.9E-6	-1.5E-6	-1.8E-6	-1.9E-6
Radiation-Mean OFF	-137.5E-9	-1.1E-6	-1.5E-6	-1.7E-6	-1.8E-6	-1.8E-6	-1.8E-6	-1.4E-6	-1.7E-6	-2.0E-6
Standarddeviation	290.4E-9	255.8E-9	139.1E-9	95.5E-9	57.3E-9	50.7E-9	75.6E-9	157.5E-9	87.8E-9	33.5E-9
Mean + kσ	658.9E-9	-438.9E-9	-1.2E-6	-1.4E-6	-1.7E-6	-1.7E-6	-1.6E-6	-979.2E-9	-1.5E-6	-1.9E-6
Mean - kσ	-933.9E-9	-1.8E-6	-1.9E-6	-2.0E-6	-2.0E-6	-1.9E-6	-2.0E-6	-1.8E-6	-1.9E-6	-2.1E-6

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-55.3E-9	-69.2E-9	-62.3E-9	-53.6E-9	-55.8E-9	-64.0E-9	-66.2E-9	-57.9E-9	-57.9E-9	-59.7E-9
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
1e−6
BDS16 HDR, (CM1438E)
ICE @ VCEsus in A
Total Dose [krad(Si)] / Annealing
On
Off
0
10
20
30
50
100
150
200
24h
RT
168h
100°C

8.4 Collector-Emitter Cut-off Current

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

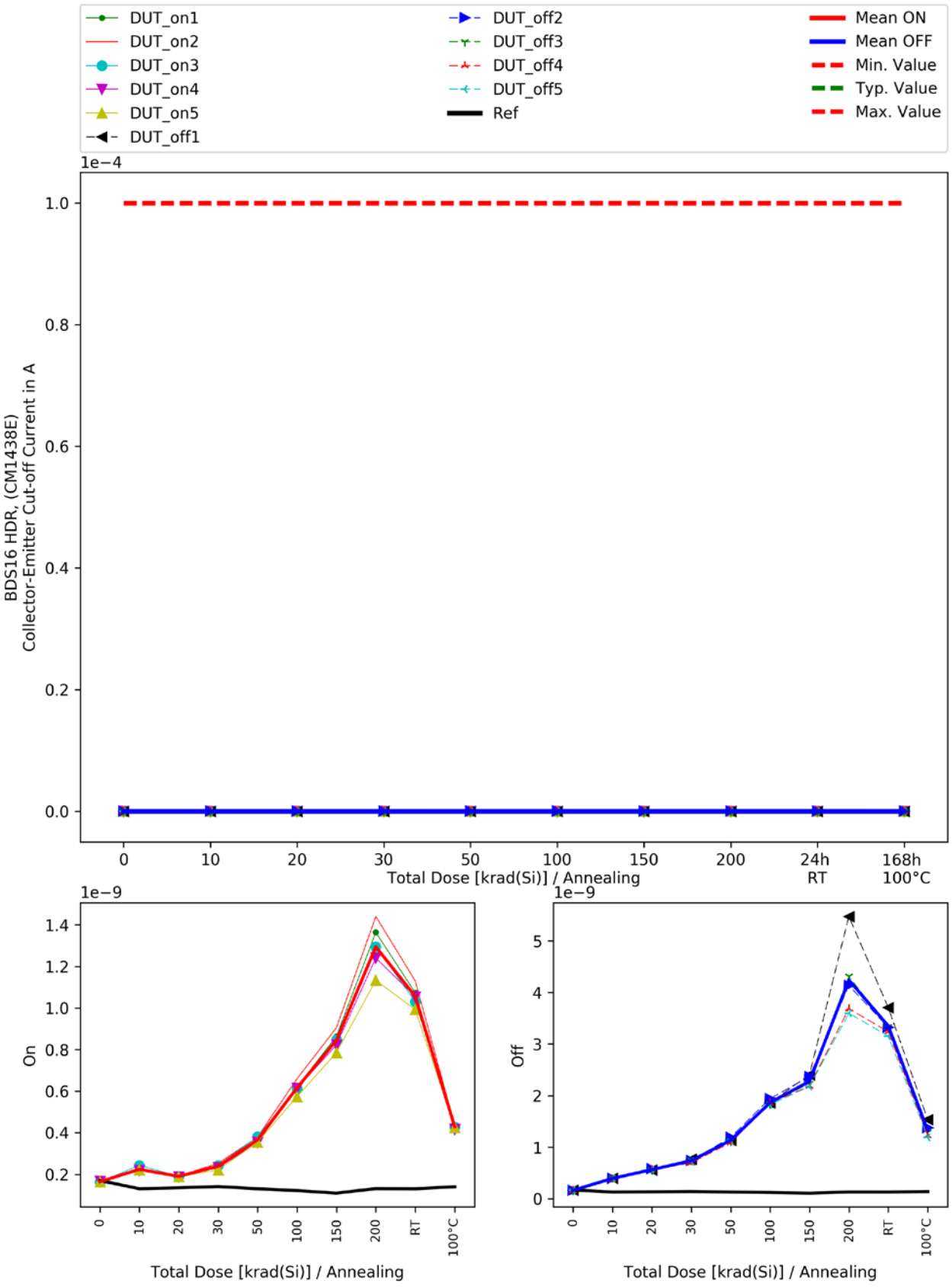
BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	166.6E-12	217.4E-12	188.8E-12	245.8E-12	361.2E-12	619.7E-12	863.4E-12	1.4E-9	1.1E-9	437.2E-12
DUT_on2	160.5E-12	219.4E-12	192.2E-12	252.5E-12	379.4E-12	659.4E-12	904.8E-12	1.4E-9	1.1E-9	436.8E-12
DUT_on3	162.9E-12	243.3E-12	190.5E-12	243.3E-12	381.1E-12	613.1E-12	846.7E-12	1.3E-9	1.0E-9	427.1E-12
DUT_on4	167.3E-12	219.6E-12	189.3E-12	231.2E-12	353.1E-12	613.5E-12	822.2E-12	1.2E-9	1.1E-9	416.5E-12
DUT_on5	163.9E-12	220.1E-12	189.0E-12	221.2E-12	354.5E-12	573.2E-12	785.3E-12	1.1E-9	992.5E-12	426.1E-12
Radiation-Mean ON	164.2E-12	224.0E-12	190.0E-12	238.8E-12	365.9E-12	615.8E-12	844.5E-12	1.3E-9	1.1E-9	428.8E-12
Standarddeviation	2.8E-12	10.9E-12	1.4E-12	12.5E-12	13.5E-12	30.6E-12	44.7E-12	117.3E-12	51.2E-12	8.6E-12
Mean + kσ	171.9E-12	253.8E-12	193.9E-12	273.0E-12	402.9E-12	699.7E-12	967.1E-12	1.6E-9	1.2E-9	452.3E-12
Mean - kσ	156.6E-12	194.1E-12	186.1E-12	204.6E-12	328.8E-12	531.9E-12	721.9E-12	972.6E-12	915.7E-12	405.2E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	165.8E-12	398.0E-12	559.7E-12	768.9E-12	1.1E-9	1.9E-9	2.4E-9	5.5E-9	3.7E-9	1.5E-9
DUT_off2	159.6E-12	389.4E-12	577.4E-12	739.7E-12	1.2E-9	1.9E-9	2.4E-9	4.1E-9	3.3E-9	1.4E-9
DUT_off3	163.6E-12	409.2E-12	558.4E-12	749.5E-12	1.1E-9	1.8E-9	2.2E-9	4.3E-9	3.3E-9	1.3E-9
DUT_off4	160.6E-12	374.2E-12	562.4E-12	696.2E-12	1.1E-9	1.9E-9	2.2E-9	3.7E-9	3.2E-9	1.2E-9
DUT_off5	166.6E-12	397.0E-12	563.8E-12	724.5E-12	1.1E-9	1.8E-9	2.2E-9	3.6E-9	3.2E-9	1.2E-9
Radiation-Mean OFF	163.2E-12	393.6E-12	564.3E-12	735.8E-12	1.1E-9	1.9E-9	2.3E-9	4.2E-9	3.3E-9	1.3E-9
Standarddeviation	3.1E-12	13.0E-12	7.6E-12	27.4E-12	36.5E-12	46.1E-12	106.1E-12	750.8E-12	211.5E-12	139.0E-12
Mean + kσ	171.7E-12	429.1E-12	585.2E-12	810.9E-12	1.2E-9	2.0E-9	2.6E-9	6.3E-9	3.9E-9	1.7E-9
Mean - kσ	154.8E-12	358.0E-12	543.5E-12	660.7E-12	1.0E-9	1.7E-9	2.0E-9	2.2E-9	2.8E-9	940.7E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	170.1E-12	130.7E-12	135.2E-12	141.2E-12	130.4E-12	121.7E-12	109.6E-12	131.2E-12	130.4E-12	140.2E-12
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

Fraunhofer
INT



8.5 Emitter-Base Cutoff Current

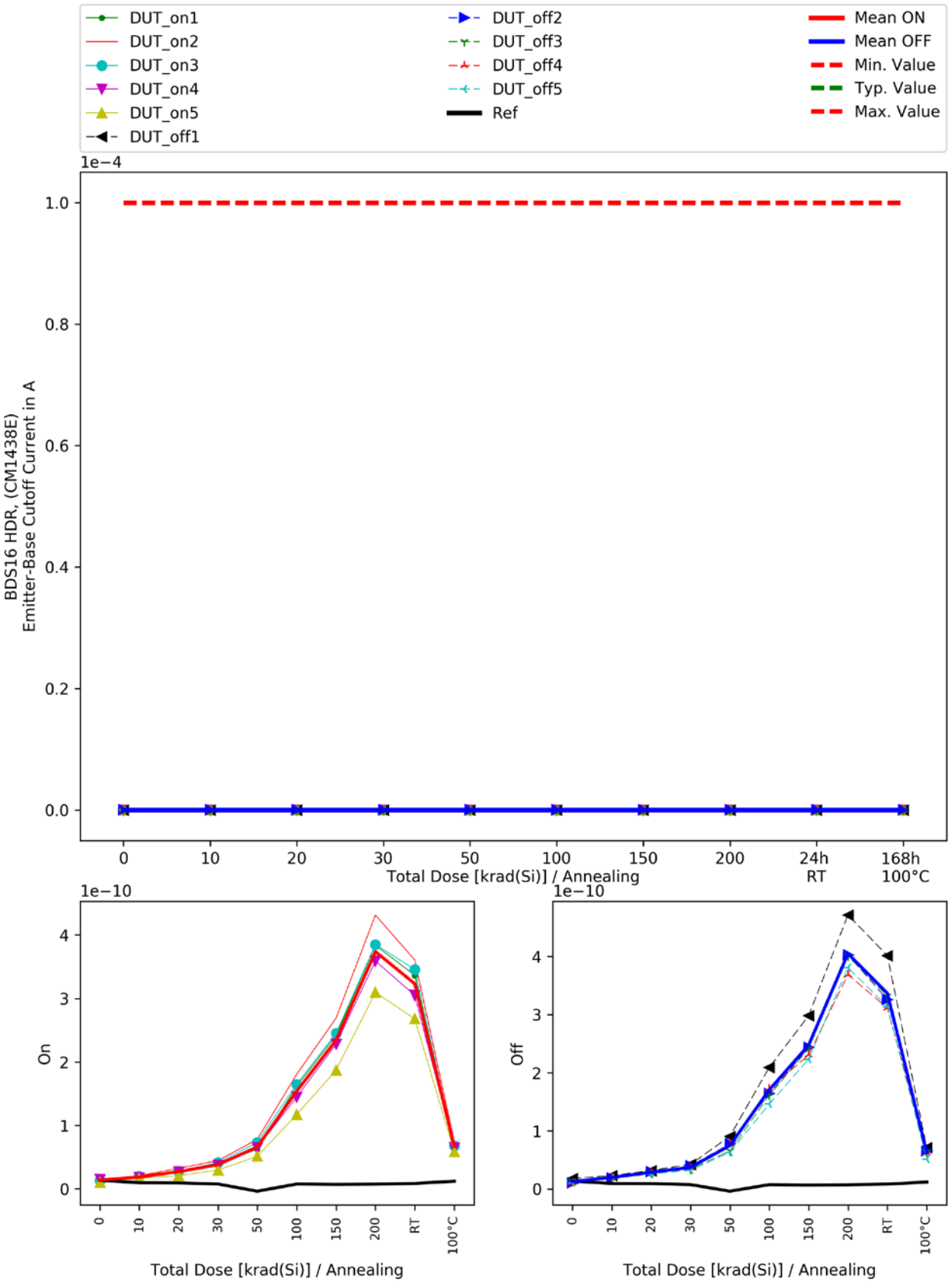
Emitter-Base Cutoff Current
IEBO in A
Limit: x < 0.0001

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	15.0E-12	17.8E-12	26.8E-12	37.4E-12	62.6E-12	161.4E-12	241.7E-12	383.7E-12	336.4E-12	67.3E-12
DUT_on2	14.7E-12	20.5E-12	32.2E-12	44.3E-12	77.8E-12	180.3E-12	268.8E-12	431.4E-12	360.4E-12	75.0E-12
DUT_on3	13.4E-12	19.8E-12	27.8E-12	41.1E-12	72.9E-12	164.8E-12	244.9E-12	384.9E-12	345.6E-12	67.9E-12
DUT_on4	14.7E-12	17.9E-12	26.8E-12	37.3E-12	64.8E-12	144.5E-12	228.0E-12	359.0E-12	304.8E-12	64.6E-12
DUT_on5	10.3E-12	16.1E-12	20.6E-12	29.4E-12	51.1E-12	116.8E-12	186.8E-12	309.5E-12	267.7E-12	58.5E-12
Radiation-Mean ON	13.6E-12	18.4E-12	26.8E-12	37.9E-12	65.8E-12	153.6E-12	234.0E-12	373.7E-12	323.0E-12	66.7E-12
Standarddeviation	2.0E-12	1.8E-12	4.1E-12	5.6E-12	10.3E-12	24.2E-12	30.2E-12	44.4E-12	37.0E-12	6.0E-12
Mean + kσ	19.0E-12	23.2E-12	38.1E-12	53.2E-12	93.9E-12	219.8E-12	316.9E-12	495.5E-12	424.4E-12	83.0E-12
Mean - kσ	8.2E-12	13.6E-12	15.5E-12	22.6E-12	37.7E-12	87.3E-12	151.2E-12	251.9E-12	221.5E-12	50.3E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	18.2E-12	22.9E-12	31.6E-12	42.4E-12	90.5E-12	209.1E-12	298.1E-12	471.4E-12	401.6E-12	70.9E-12
DUT_off2	10.4E-12	18.4E-12	29.2E-12	39.8E-12	77.4E-12	164.0E-12	243.5E-12	403.0E-12	325.7E-12	65.4E-12
DUT_off3	13.3E-12	17.6E-12	27.3E-12	34.2E-12	65.4E-12	161.3E-12	241.4E-12	400.7E-12	331.7E-12	63.1E-12
DUT_off4	11.0E-12	19.5E-12	29.1E-12	36.6E-12	76.8E-12	172.2E-12	230.5E-12	369.0E-12	311.4E-12	62.1E-12
DUT_off5	11.1E-12	19.9E-12	25.6E-12	32.2E-12	62.7E-12	146.0E-12	223.4E-12	380.8E-12	313.8E-12	51.0E-12
Radiation-Mean OFF	12.8E-12	19.7E-12	28.6E-12	37.0E-12	74.6E-12	170.5E-12	247.4E-12	405.0E-12	336.8E-12	62.5E-12
Standarddeviation	3.2E-12	2.0E-12	2.3E-12	4.1E-12	11.1E-12	23.6E-12	29.5E-12	39.7E-12	37.2E-12	7.3E-12
Mean + kσ	21.6E-12	25.2E-12	34.8E-12	48.3E-12	105.0E-12	235.1E-12	328.4E-12	513.9E-12	438.7E-12	82.5E-12
Mean - kσ	4.0E-12	14.1E-12	22.4E-12	25.7E-12	44.2E-12	105.9E-12	166.5E-12	296.0E-12	234.9E-12	42.5E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	13.5E-12	9.4E-12	9.2E-12	7.4E-12	-3.9E-12	7.4E-12	6.8E-12	7.2E-12	8.3E-12	11.8E-12
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
Min. Value
Typ. Value
Max. Value
1e−4
BDS16 HDR, (CM1438E)
Emitter-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
1e−10
On
Off
Total Dose [krad(Si)] / Annealing

8.6 Collector-Emitter Saturation Voltage (1)

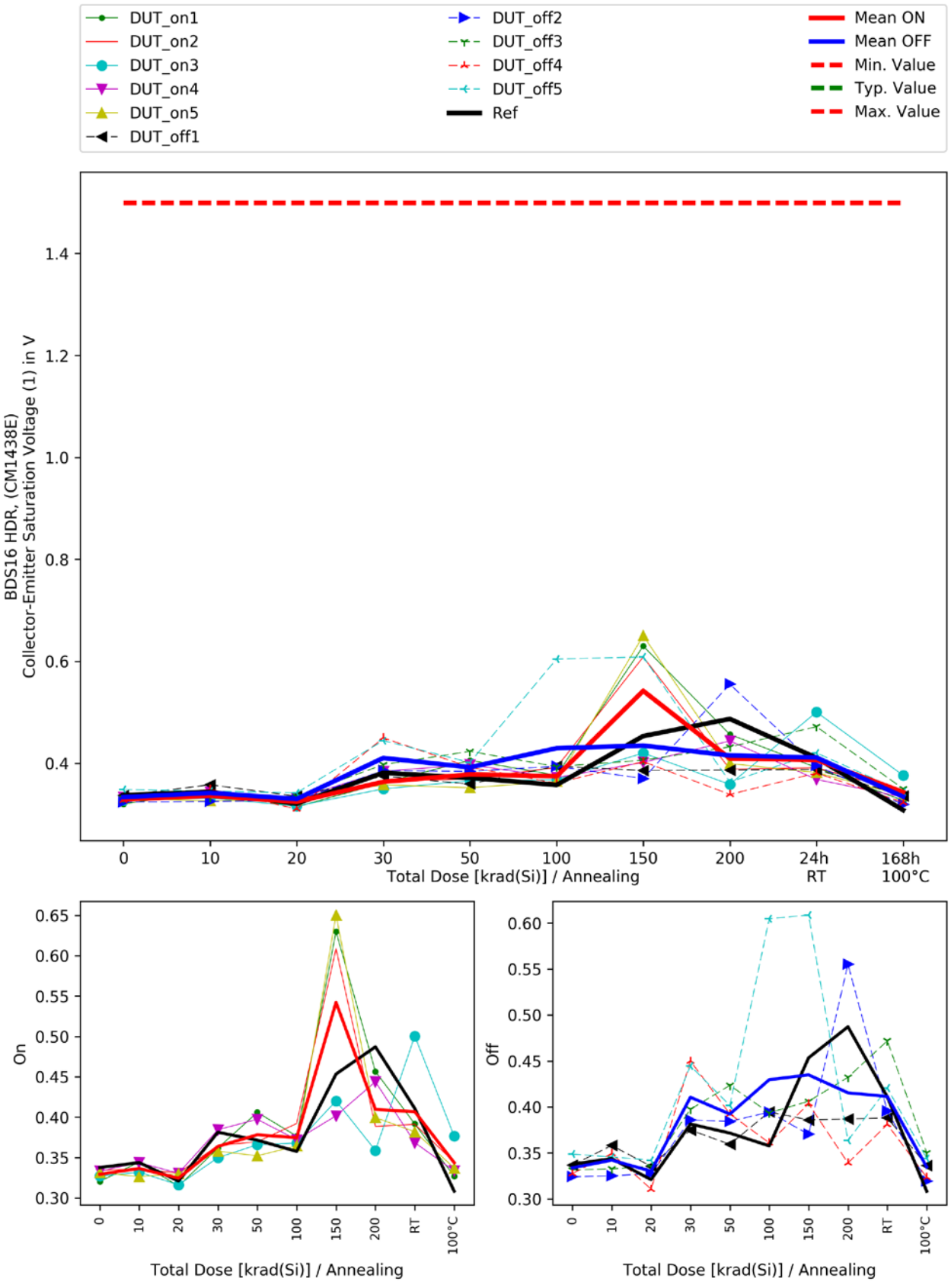
Collector-Emitter Saturation Voltage (1) **BDS16 HDR**
VCEsat_1 in V Date-/Lotcode: CM1438E
Limit: x<1.5

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	320.4E-3	344.6E-3	314.6E-3	361.7E-3	406.0E-3	376.7E-3	630.0E-3	456.7E-3	391.7E-3	326.9E-3
DUT_on2	334.5E-3	335.9E-3	330.8E-3	365.0E-3	369.6E-3	392.2E-3	608.7E-3	388.7E-3	391.3E-3	344.4E-3
DUT_on3	327.2E-3	331.9E-3	316.2E-3	349.9E-3	365.9E-3	368.0E-3	420.2E-3	358.8E-3	500.6E-3	376.5E-3
DUT_on4	333.2E-3	343.7E-3	330.7E-3	384.6E-3	397.4E-3	372.1E-3	401.8E-3	444.1E-3	368.5E-3	333.6E-3
DUT_on5	331.4E-3	326.5E-3	330.0E-3	358.0E-3	352.2E-3	364.4E-3	650.4E-3	399.6E-3	382.0E-3	337.1E-3
Radiation-Mean ON	329.3E-3	336.5E-3	324.5E-3	363.8E-3	378.2E-3	374.7E-3	542.2E-3	409.6E-3	406.8E-3	343.7E-3
Standarddeviation	5.7E-3	7.7E-3	8.3E-3	12.9E-3	22.6E-3	10.8E-3	120.9E-3	40.4E-3	53.3E-3	19.4E-3
Mean + kσ	344.9E-3	357.7E-3	347.1E-3	399.1E-3	440.2E-3	404.3E-3	873.6E-3	520.4E-3	552.8E-3	396.9E-3
Mean - kσ	313.7E-3	315.3E-3	301.8E-3	328.5E-3	316.2E-3	345.1E-3	210.8E-3	298.8E-3	260.8E-3	290.5E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	336.7E-3	358.1E-3	335.5E-3	374.9E-3	359.3E-3	394.5E-3	385.9E-3	387.0E-3	388.2E-3	336.2E-3
DUT_off2	324.2E-3	325.1E-3	327.4E-3	385.9E-3	384.3E-3	394.4E-3	370.3E-3	555.3E-3	395.4E-3	319.2E-3
DUT_off3	331.6E-3	332.6E-3	335.3E-3	397.5E-3	423.5E-3	393.6E-3	406.2E-3	432.3E-3	472.0E-3	350.2E-3
DUT_off4	327.6E-3	349.3E-3	310.6E-3	449.9E-3	392.4E-3	361.0E-3	403.4E-3	339.0E-3	381.0E-3	323.4E-3
DUT_off5	348.7E-3	345.6E-3	342.2E-3	444.6E-3	401.7E-3	604.7E-3	608.8E-3	363.5E-3	420.4E-3	344.2E-3
Radiation-Mean OFF	333.8E-3	342.1E-3	330.2E-3	410.6E-3	392.3E-3	429.6E-3	434.9E-3	415.4E-3	411.4E-3	334.6E-3
Standarddeviation	9.6E-3	13.2E-3	12.1E-3	34.5E-3	23.5E-3	98.9E-3	98.3E-3	85.4E-3	37.0E-3	13.2E-3
Mean + kσ	360.0E-3	378.4E-3	363.5E-3	505.2E-3	456.8E-3	700.8E-3	704.3E-3	649.6E-3	512.8E-3	370.9E-3
Mean - kσ	307.5E-3	305.9E-3	296.9E-3	315.9E-3	327.7E-3	158.4E-3	165.5E-3	181.2E-3	310.0E-3	298.4E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	337.7E-3	343.8E-3	320.9E-3	381.4E-3	371.6E-3	357.6E-3	453.5E-3	487.2E-3	410.8E-3	308.4E-3
Max. Value	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0

Fraunhofer
INT



8.7 Collector-Emitter Saturation Voltage (2)

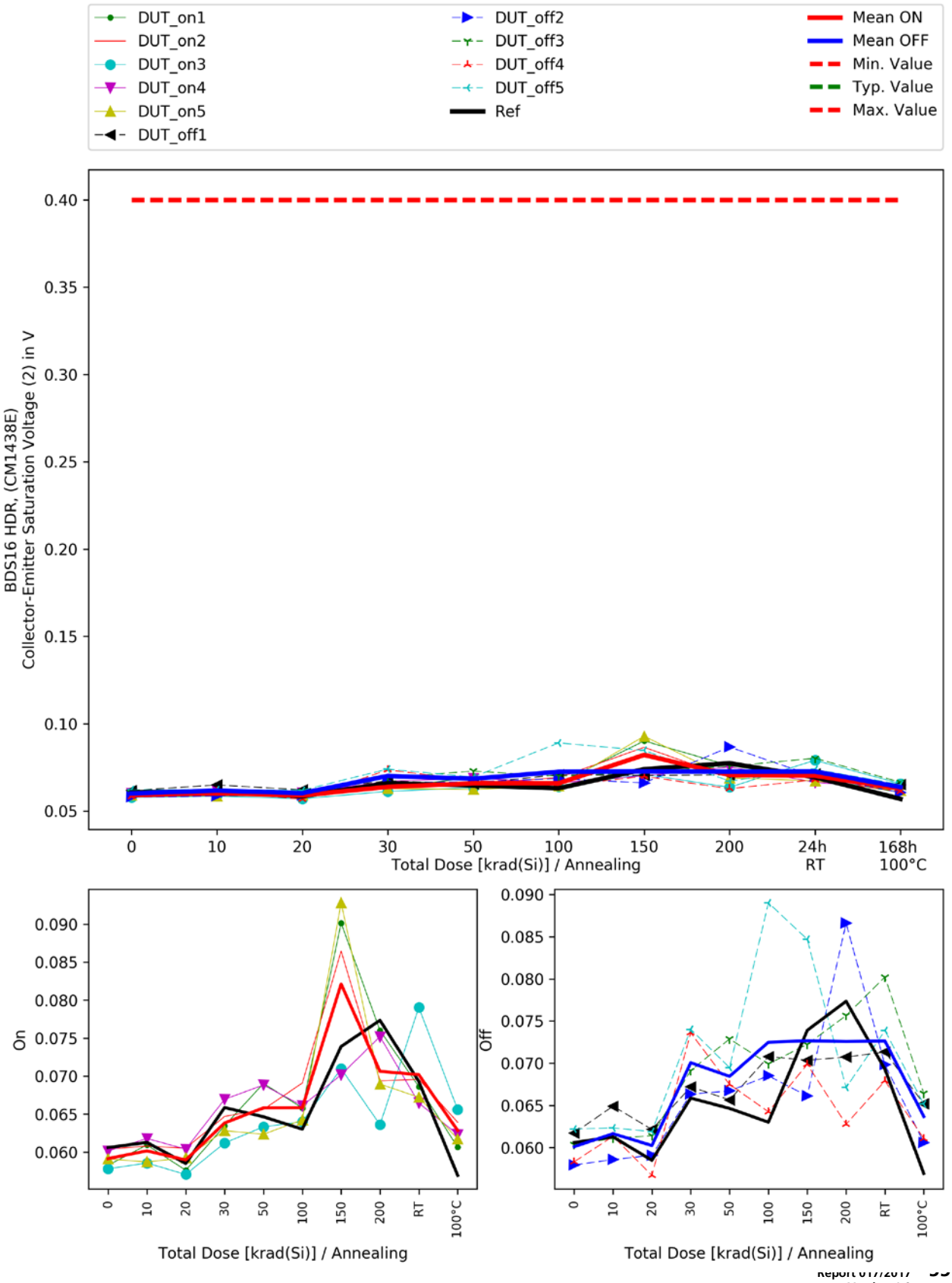
Collector-Emitter Saturation Voltage (2)
VCEsat_2 in V
Limit: x<0.4

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	58.3E-3	60.9E-3	57.6E-3	63.5E-3	69.0E-3	65.8E-3	90.1E-3	76.0E-3	68.6E-3	60.6E-3
DUT_on2	60.4E-3	60.8E-3	60.5E-3	64.7E-3	65.6E-3	69.1E-3	86.4E-3	69.4E-3	69.6E-3	63.9E-3
DUT_on3	57.8E-3	58.6E-3	57.1E-3	61.2E-3	63.3E-3	64.0E-3	71.0E-3	63.6E-3	79.1E-3	65.6E-3
DUT_on4	60.1E-3	61.8E-3	60.4E-3	67.0E-3	68.8E-3	66.1E-3	70.2E-3	75.2E-3	66.5E-3	62.3E-3
DUT_on5	59.1E-3	58.7E-3	59.3E-3	62.8E-3	62.3E-3	64.2E-3	92.8E-3	68.9E-3	67.2E-3	61.7E-3
Radiation-Mean ON	59.1E-3	60.2E-3	59.0E-3	63.8E-3	65.8E-3	65.8E-3	82.1E-3	70.6E-3	70.2E-3	62.8E-3
Standarddeviation	1.1E-3	1.4E-3	1.6E-3	2.2E-3	3.1E-3	2.0E-3	10.8E-3	5.1E-3	5.1E-3	1.9E-3
Mean + kσ	62.3E-3	64.1E-3	63.3E-3	69.7E-3	74.2E-3	71.4E-3	111.6E-3	84.6E-3	84.2E-3	68.2E-3
Mean - kσ	56.0E-3	56.2E-3	54.6E-3	57.9E-3	57.4E-3	60.3E-3	52.6E-3	56.7E-3	56.2E-3	57.5E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	61.7E-3	64.9E-3	62.1E-3	67.2E-3	65.7E-3	70.8E-3	70.4E-3	70.7E-3	71.3E-3	65.2E-3
DUT_off2	57.9E-3	58.6E-3	59.1E-3	66.3E-3	66.7E-3	68.5E-3	66.1E-3	86.6E-3	69.8E-3	60.6E-3
DUT_off3	60.4E-3	61.1E-3	61.4E-3	69.1E-3	72.9E-3	69.9E-3	72.2E-3	75.6E-3	80.2E-3	66.4E-3
DUT_off4	58.3E-3	61.3E-3	56.7E-3	73.6E-3	67.5E-3	64.2E-3	69.9E-3	62.8E-3	67.9E-3	61.1E-3
DUT_off5	62.2E-3	62.3E-3	61.9E-3	74.0E-3	69.5E-3	89.0E-3	84.7E-3	67.1E-3	73.9E-3	65.1E-3
Radiation-Mean OFF	60.1E-3	61.6E-3	60.2E-3	70.1E-3	68.4E-3	72.5E-3	72.7E-3	72.6E-3	72.6E-3	63.7E-3
Standarddeviation	1.9E-3	2.3E-3	2.3E-3	3.6E-3	2.8E-3	9.6E-3	7.1E-3	9.2E-3	4.8E-3	2.7E-3
Mean + kσ	65.4E-3	67.9E-3	66.6E-3	79.9E-3	76.2E-3	98.7E-3	92.1E-3	97.7E-3	85.7E-3	71.0E-3
Mean - kσ	54.8E-3	55.4E-3	53.9E-3	60.3E-3	60.6E-3	46.3E-3	53.2E-3	47.5E-3	59.5E-3	56.4E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	60.6E-3	61.3E-3	58.5E-3	65.9E-3	64.6E-3	63.0E-3	73.9E-3	77.3E-3	69.3E-3	56.9E-3
Max. Value	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-3	400.0E-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
Min. Value
Typ. Value
Max. Value
BDS16 HDR, (CM1438E)
Collector-Emitter Saturation Voltage (2) in V
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
0.090
0.085
0.080
0.075
0.070
0.065
0.060
Total Dose [krad(Si)] / Annealing

8.8 Base-Emitter Voltage

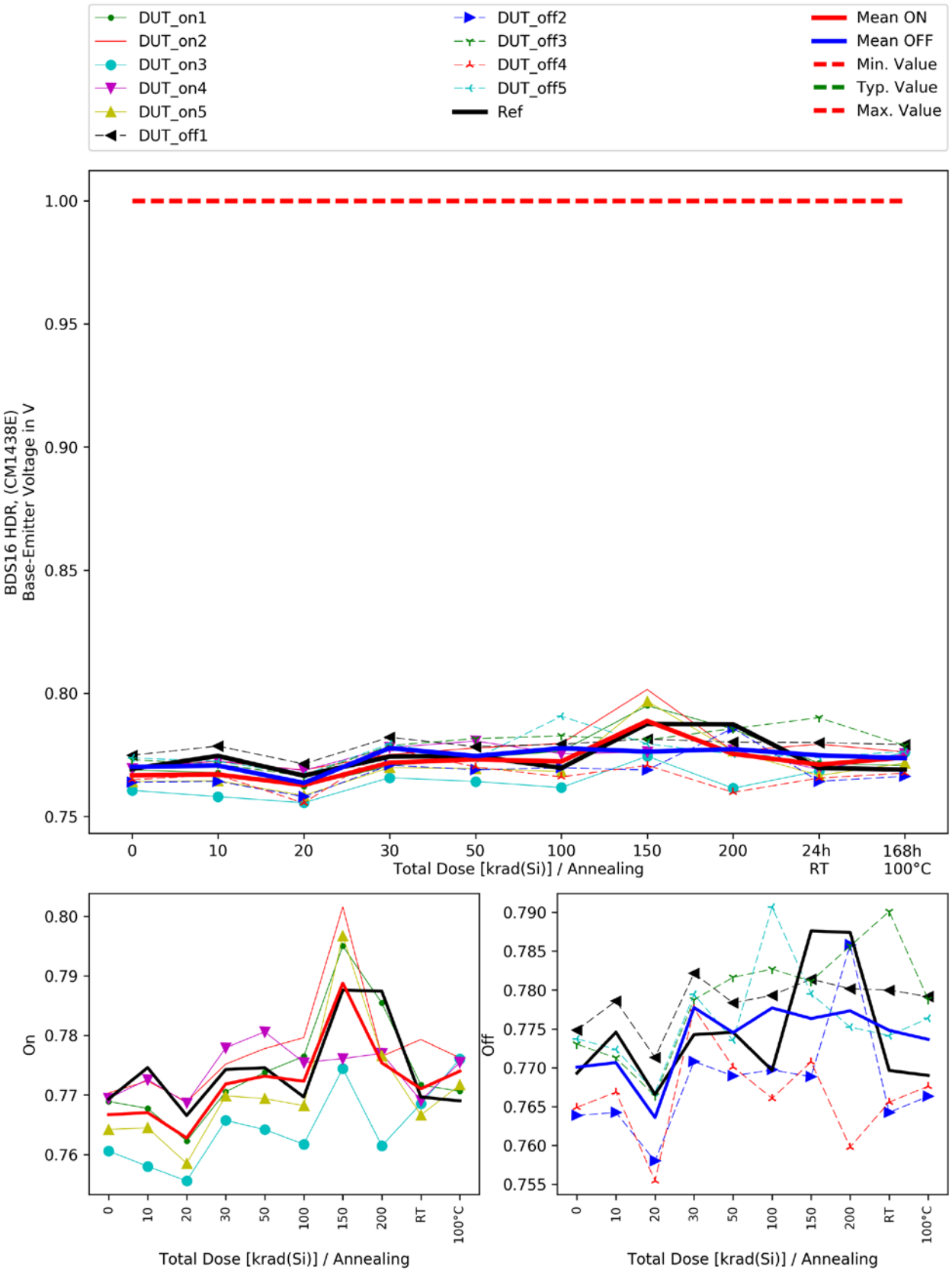
Base-Emitter Voltage
VBEon in V
Limit: x<1.0

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	768.9E-3	767.7E-3	762.3E-3	770.5E-3	773.8E-3	776.5E-3	795.0E-3	785.4E-3	771.7E-3	770.6E-3
DUT_on2	770.3E-3	772.3E-3	768.8E-3	775.2E-3	777.8E-3	779.6E-3	801.5E-3	776.5E-3	779.3E-3	776.2E-3
DUT_on3	760.6E-3	758.0E-3	755.6E-3	765.7E-3	764.2E-3	761.7E-3	774.4E-3	761.4E-3	768.5E-3	776.0E-3
DUT_on4	769.4E-3	772.6E-3	768.7E-3	777.9E-3	780.6E-3	775.4E-3	776.1E-3	777.0E-3	769.1E-3	775.5E-3
DUT_on5	764.2E-3	764.5E-3	758.5E-3	769.8E-3	769.4E-3	768.2E-3	796.7E-3	776.6E-3	766.6E-3	771.7E-3
Radiation-Mean ON	766.7E-3	767.0E-3	762.8E-3	771.8E-3	773.1E-3	772.3E-3	788.8E-3	775.4E-3	771.0E-3	774.0E-3
Standarddeviation	4.2E-3	6.1E-3	6.0E-3	4.8E-3	6.6E-3	7.2E-3	12.6E-3	8.7E-3	5.0E-3	2.6E-3
Mean + kσ	778.1E-3	783.7E-3	779.1E-3	784.9E-3	791.1E-3	792.1E-3	823.2E-3	799.1E-3	784.6E-3	781.3E-3
Mean - kσ	755.3E-3	750.4E-3	746.4E-3	758.7E-3	755.2E-3	752.5E-3	754.3E-3	751.6E-3	757.4E-3	766.7E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	774.8E-3	778.6E-3	771.3E-3	782.1E-3	778.3E-3	779.3E-3	781.4E-3	780.2E-3	780.0E-3	779.2E-3
DUT_off2	763.9E-3	764.2E-3	758.0E-3	770.8E-3	769.0E-3	769.7E-3	768.8E-3	785.8E-3	764.2E-3	766.3E-3
DUT_off3	773.0E-3	771.2E-3	766.4E-3	778.8E-3	781.6E-3	782.7E-3	781.1E-3	785.6E-3	790.1E-3	778.8E-3
DUT_off4	764.9E-3	766.9E-3	755.4E-3	777.6E-3	770.1E-3	766.1E-3	770.7E-3	759.8E-3	765.6E-3	767.6E-3
DUT_off5	773.7E-3	772.4E-3	766.8E-3	779.4E-3	773.5E-3	790.7E-3	779.5E-3	775.2E-3	774.1E-3	776.3E-3
Radiation-Mean OFF	770.1E-3	770.7E-3	763.6E-3	777.7E-3	774.5E-3	777.7E-3	776.3E-3	777.3E-3	774.8E-3	773.6E-3
Standarddeviation	5.2E-3	5.5E-3	6.6E-3	4.2E-3	5.4E-3	9.9E-3	6.0E-3	10.7E-3	10.7E-3	6.2E-3
Mean + kσ	784.5E-3	785.8E-3	781.8E-3	789.3E-3	789.3E-3	804.9E-3	792.9E-3	806.8E-3	804.2E-3	790.7E-3
Mean - kσ	755.7E-3	755.5E-3	745.4E-3	766.1E-3	759.7E-3	750.5E-3	759.8E-3	747.9E-3	745.5E-3	756.6E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	769.3E-3	774.6E-3	766.5E-3	774.3E-3	774.6E-3	769.7E-3	787.6E-3	787.4E-3	769.6E-3	769.0E-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
Min. Value
Typ. Value
Max. Value
BDS16 HDR, (CM1438E)
Base-Emitter Voltage in V
1.00
0.95
0.90
0.85
0.80
0.75
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
0.80
0.79
0.78
0.77
0.76
Off
0.790
0.785
0.780
0.775
0.770
0.765
0.760
0.755
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.9 Forward Current Transfer Ratio (1)

Forward Current Transfer Ratio (1) **BDS16 HDR**
HFE 1 Date-/Lotcode: CM1438E
Limit: 40.0<x<250.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	99.5E+0	111.3E+0	111.8E+0	112.0E+0	110.2E+0	100.7E+0	100.0E+0	101.4E+0	100.0E+0	99.8E+0
DUT_on2	100.2E+0	101.1E+0	101.0E+0	90.5E+0	91.6E+0	90.8E+0	90.6E+0	91.5E+0	91.1E+0	90.1E+0
DUT_on3	143.9E+0	125.0E+0	124.5E+0	125.8E+0	124.5E+0	125.7E+0	125.6E+0	110.6E+0	124.5E+0	125.5E+0
DUT_on4	99.5E+0	100.0E+0	101.1E+0	99.9E+0	91.6E+0	90.1E+0	90.5E+0	91.1E+0	91.8E+0	90.7E+0
DUT_on5	111.2E+0	111.8E+0	111.8E+0	111.1E+0	111.7E+0	110.4E+0	111.5E+0	99.8E+0	100.4E+0	100.1E+0
Radiation-Mean ON	**110.9E+0**	**109.8E+0**	**110.0E+0**	**107.9E+0**	**105.9E+0**	**103.6E+0**	**103.6E+0**	**98.9E+0**	**101.6E+0**	**101.2E+0**
Standarddeviation	**19.1E+0**	**10.1E+0**	**9.7E+0**	**13.4E+0**	**14.2E+0**	**14.9E+0**	**15.0E+0**	**8.1E+0**	**13.5E+0**	**14.4E+0**
Mean + kσ	**163.3E+0**	**137.5E+0**	**136.7E+0**	**144.5E+0**	**145.0E+0**	**144.5E+0**	**144.8E+0**	**121.0E+0**	**138.7E+0**	**140.6E+0**
Mean - kσ	**58.4E+0**	**82.2E+0**	**83.4E+0**	**71.2E+0**	**66.9E+0**	**62.6E+0**	**62.5E+0**	**76.8E+0**	**64.4E+0**	**61.8E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	82.8E+0	83.0E+0	82.8E+0	82.9E+0	83.8E+0	76.5E+0	77.6E+0	77.1E+0	76.6E+0	77.5E+0
DUT_off2	124.9E+0	111.5E+0	110.6E+0	111.2E+0	111.5E+0	110.6E+0	112.0E+0	111.8E+0	112.6E+0	112.8E+0
DUT_off3	91.7E+0	91.6E+0	91.0E+0	91.0E+0	90.8E+0	91.5E+0	83.3E+0	82.9E+0	83.1E+0	83.1E+0
DUT_off4	125.3E+0	123.2E+0	125.7E+0	111.2E+0	110.2E+0	111.1E+0	109.4E+0	111.3E+0	110.9E+0	110.9E+0
DUT_off5	100.1E+0	100.1E+0	100.4E+0	100.3E+0	90.3E+0	90.7E+0	91.2E+0	90.8E+0	90.7E+0	90.2E+0
Radiation-Mean OFF	**105.0E+0**	**101.9E+0**	**102.1E+0**	**99.3E+0**	**97.3E+0**	**96.1E+0**	**94.7E+0**	**94.8E+0**	**94.8E+0**	**94.9E+0**
Standarddeviation	**19.4E+0**	**15.9E+0**	**16.8E+0**	**12.5E+0**	**12.7E+0**	**14.8E+0**	**15.4E+0**	**16.1E+0**	**16.3E+0**	**16.1E+0**
Mean + kσ	**158.1E+0**	**145.4E+0**	**148.2E+0**	**133.5E+0**	**132.0E+0**	**136.6E+0**	**137.0E+0**	**138.9E+0**	**139.4E+0**	**139.2E+0**
Mean - kσ	**51.8E+0**	**58.3E+0**	**56.0E+0**	**65.1E+0**	**62.6E+0**	**55.6E+0**	**52.3E+0**	**50.7E+0**	**50.2E+0**	**50.6E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	101.0E+0	100.0E+0	100.8E+0	99.8E+0	99.6E+0	111.7E+0	100.2E+0	99.7E+0	111.6E+0	99.4E+0
Min. 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
Max. Value	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0	250.0E+0

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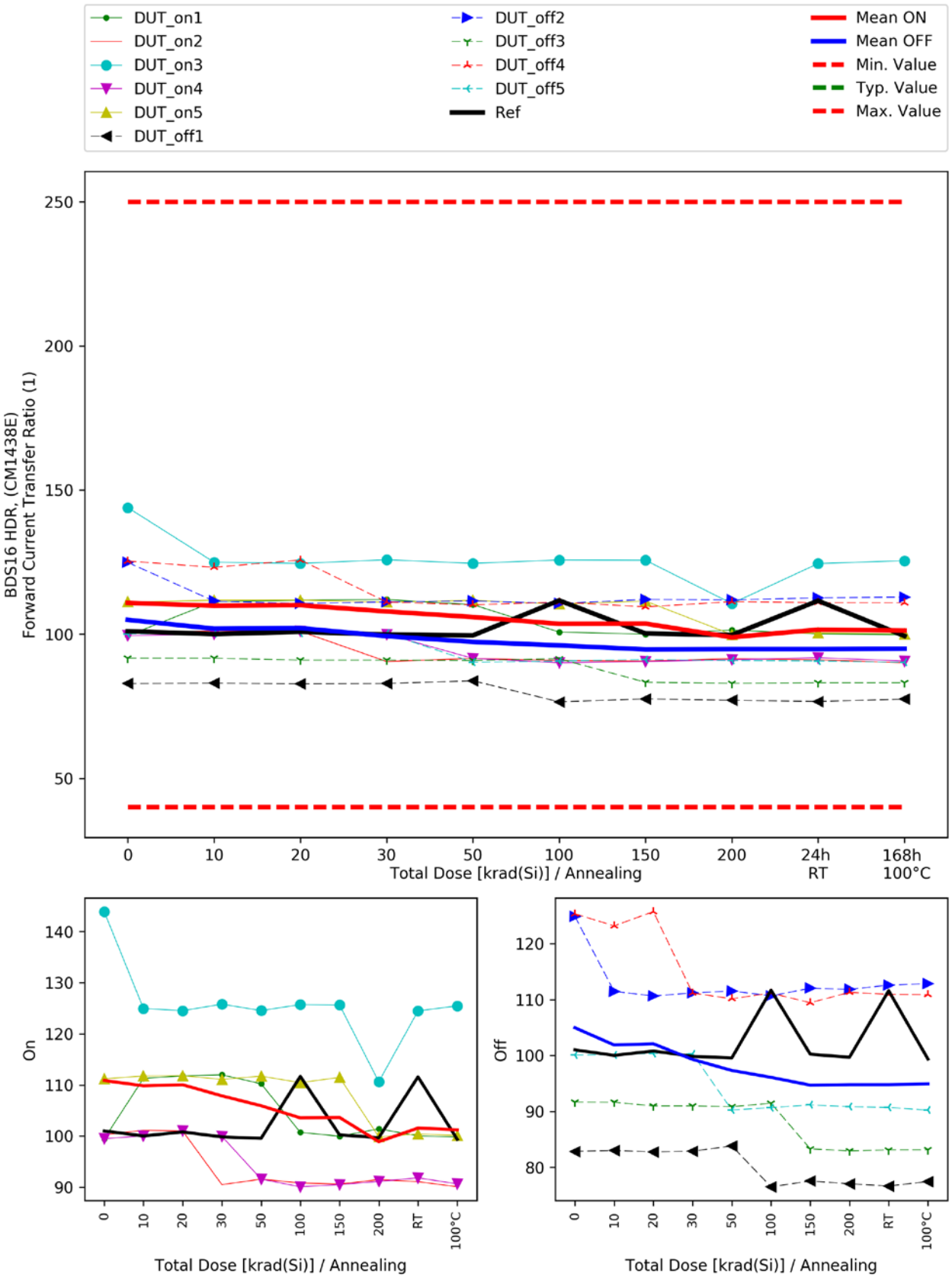

8.10 Forward Current Transfer Ratio (2)

Forward Current Transfer Ratio (2)
HFE 2
Limit: 15.0<x<150.0

BDS16 HDR
Date-/Lotcode: CM1438E

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	65.0E+0	66.1E+0	66.8E+0	65.9E+0	65.6E+0	65.3E+0	63.0E+0	63.7E+0	64.2E+0	64.5E+0
DUT_on2	63.7E+0	62.9E+0	63.2E+0	62.5E+0	62.5E+0	61.6E+0	60.4E+0	60.3E+0	60.8E+0	60.4E+0
DUT_on3	70.6E+0	70.3E+0	70.2E+0	69.6E+0	68.9E+0	68.3E+0	68.4E+0	67.7E+0	67.0E+0	67.4E+0
DUT_on4	63.5E+0	63.3E+0	63.4E+0	62.4E+0	62.7E+0	61.7E+0	61.7E+0	60.4E+0	61.2E+0	61.1E+0
DUT_on5	67.5E+0	67.1E+0	67.1E+0	66.6E+0	66.2E+0	65.6E+0	63.3E+0	64.4E+0	64.3E+0	64.6E+0
Radiation-Mean ON	66.0E+0	65.9E+0	66.1E+0	65.4E+0	65.2E+0	64.5E+0	63.3E+0	63.3E+0	63.5E+0	63.6E+0
Standarddeviation	3.0E+0	3.0E+0	2.9E+0	3.0E+0	2.7E+0	2.8E+0	3.0E+0	3.1E+0	2.5E+0	2.9E+0
Mean + kσ	74.3E+0	74.3E+0	74.1E+0	73.7E+0	72.5E+0	72.3E+0	71.7E+0	71.8E+0	70.5E+0	71.4E+0
Mean - kσ	57.8E+0	57.6E+0	58.2E+0	57.1E+0	57.8E+0	56.7E+0	55.0E+0	54.8E+0	56.5E+0	55.8E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	59.9E+0	59.3E+0	59.1E+0	58.7E+0	58.8E+0	58.0E+0	57.4E+0	56.8E+0	56.9E+0	56.5E+0
DUT_off2	68.2E+0	68.0E+0	67.8E+0	67.2E+0	67.1E+0	66.4E+0	66.2E+0	63.9E+0	65.2E+0	64.1E+0
DUT_off3	62.3E+0	61.5E+0	62.2E+0	60.7E+0	60.6E+0	60.6E+0	59.6E+0	58.6E+0	58.9E+0	59.3E+0
DUT_off4	69.0E+0	68.5E+0	68.4E+0	67.1E+0	67.0E+0	66.9E+0	66.1E+0	65.9E+0	65.8E+0	66.1E+0
DUT_off5	63.1E+0	63.6E+0	62.9E+0	62.1E+0	62.2E+0	61.0E+0	60.4E+0	60.9E+0	60.6E+0	60.8E+0
Radiation-Mean OFF	64.5E+0	64.2E+0	64.1E+0	63.2E+0	63.1E+0	62.6E+0	61.9E+0	61.2E+0	61.5E+0	61.3E+0
Standarddeviation	3.9E+0	4.0E+0	4.0E+0	3.8E+0	3.8E+0	3.9E+0	4.0E+0	3.7E+0	3.9E+0	3.8E+0
Mean + kσ	75.3E+0	75.3E+0	74.9E+0	73.7E+0	73.5E+0	73.3E+0	72.8E+0	71.4E+0	72.2E+0	71.8E+0
Mean - kσ	53.7E+0	53.1E+0	53.2E+0	52.6E+0	52.8E+0	51.9E+0	51.0E+0	51.0E+0	50.8E+0	50.9E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	65.1E+0	65.2E+0	65.3E+0	64.6E+0	65.1E+0	65.0E+0	64.3E+0	64.3E+0	64.3E+0	64.9E+0
Min. 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
Max. Value	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0	150.0E+0

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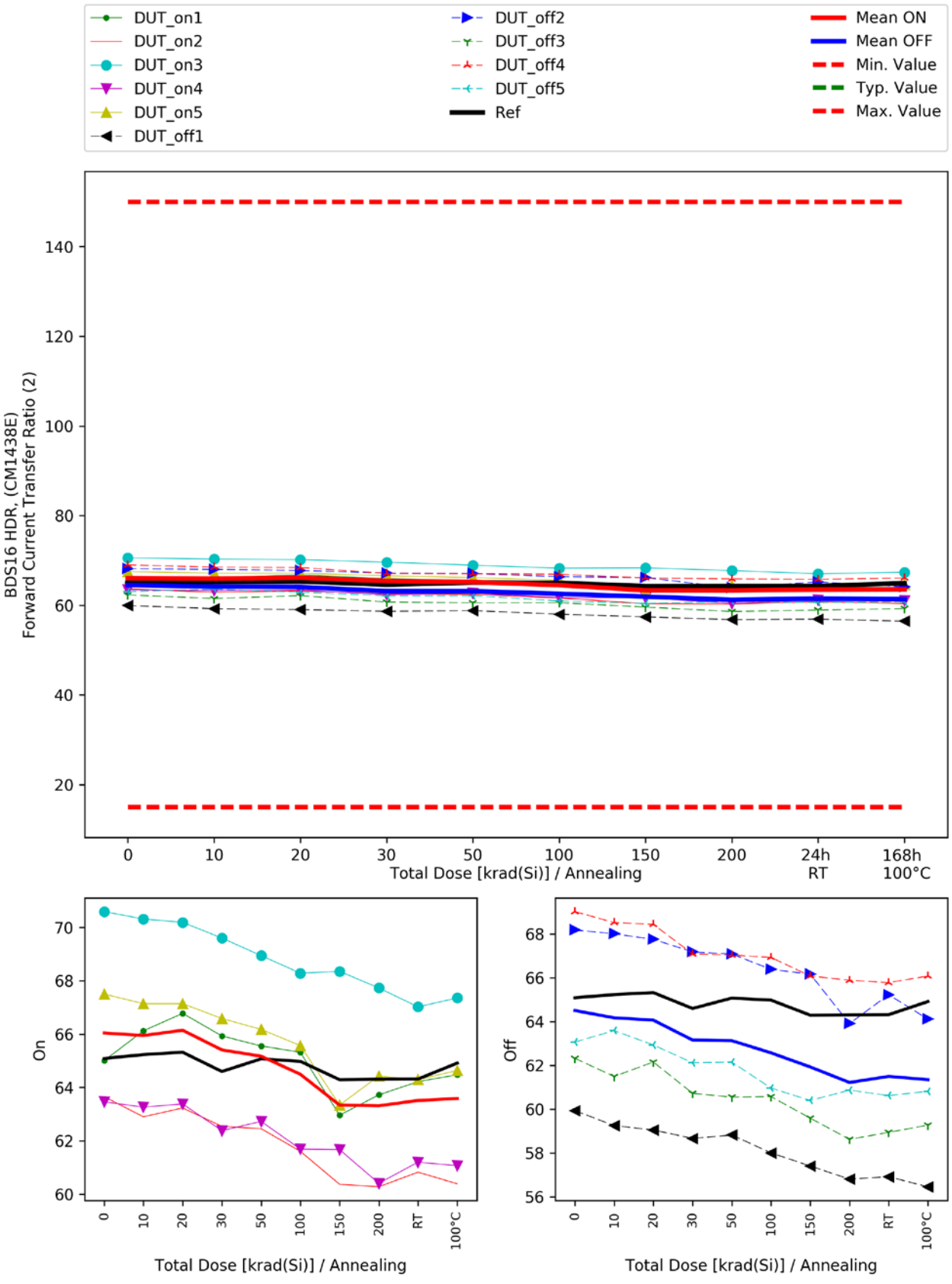

Version 1.0

9 Results of Enhancement Calculation

9.1 Overview of Enhanced low dose rate sensitivity

No.	Characteristics	Values out of specs during irradiation?	Enhancement factor applicable (ELDRS?)	max. Calculated enhancement factor	Comment
1	Collector-Emitter Sustaining Voltage	no	no	--	
2	Collector-Emitter Cut-off Current	no	no	--	larger degradation in HDR test, but well within specs
3	Emitter-Base Cutoff Current	no	no	--	
4	Collector-Emitter Saturation Voltage	no	no	--	
5		no	no	--	
6	Base-Emitter Voltage	no	no	--	
7	Forward Current Transfer Ratio	no	no	--	
8		no	no	--	

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.
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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 TK1000B

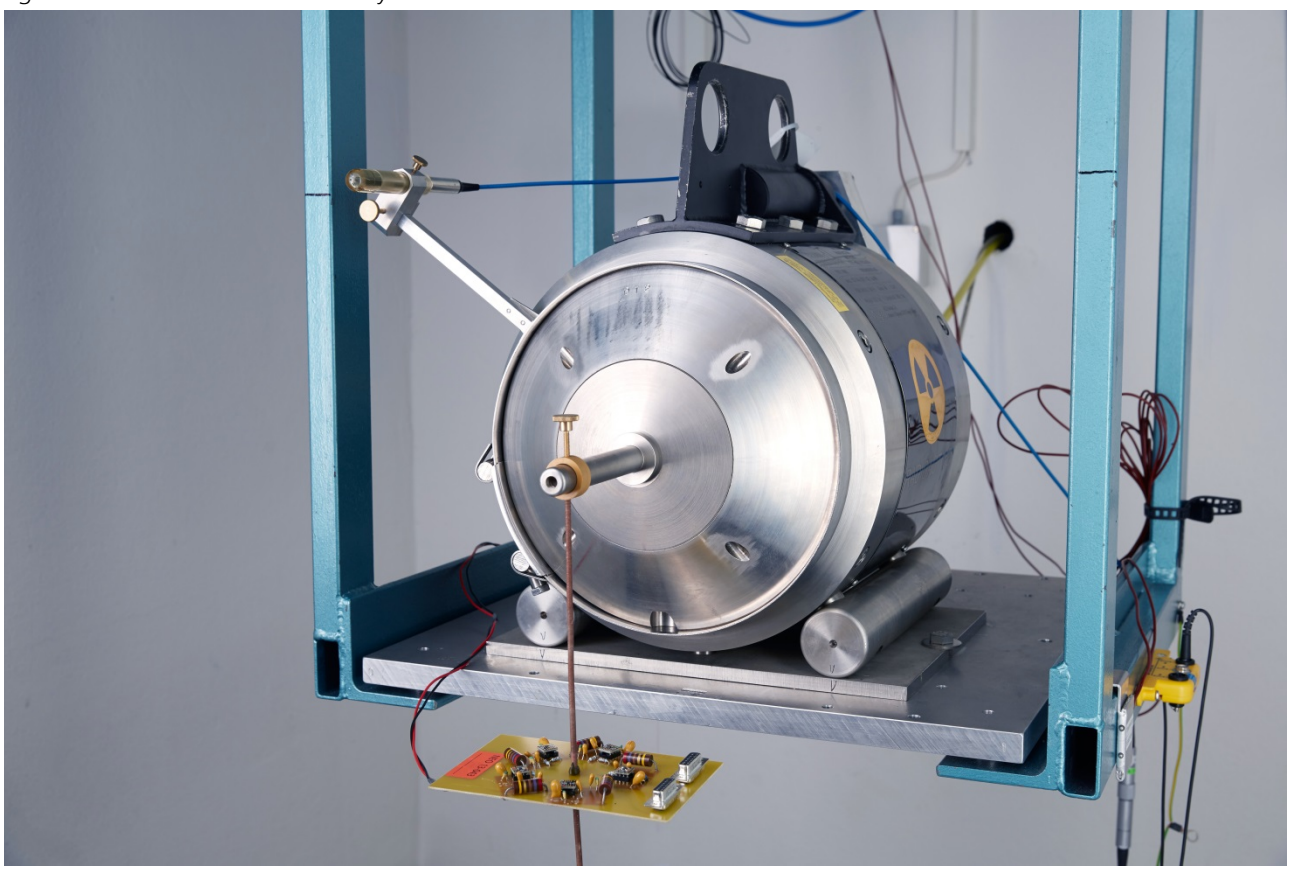
The TK1000B is a Co-60 gamma irradiator manufactured by Sauerwein Isotopentechnik, Germany. Inside the shielding container is a small radioactive pellet with a diameter of 7 mm and a length of 10.4 mm. The activity decreases with a physical half-life of 5.27 years. The current radioactive pellet was installed in the irradiator at 2012-01-25. The activity at that time was 16526 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 D.4.

Figure 16: TK1000B irradiation facility



D.2. Radiation properties of TK1000B

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 TK1000B

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

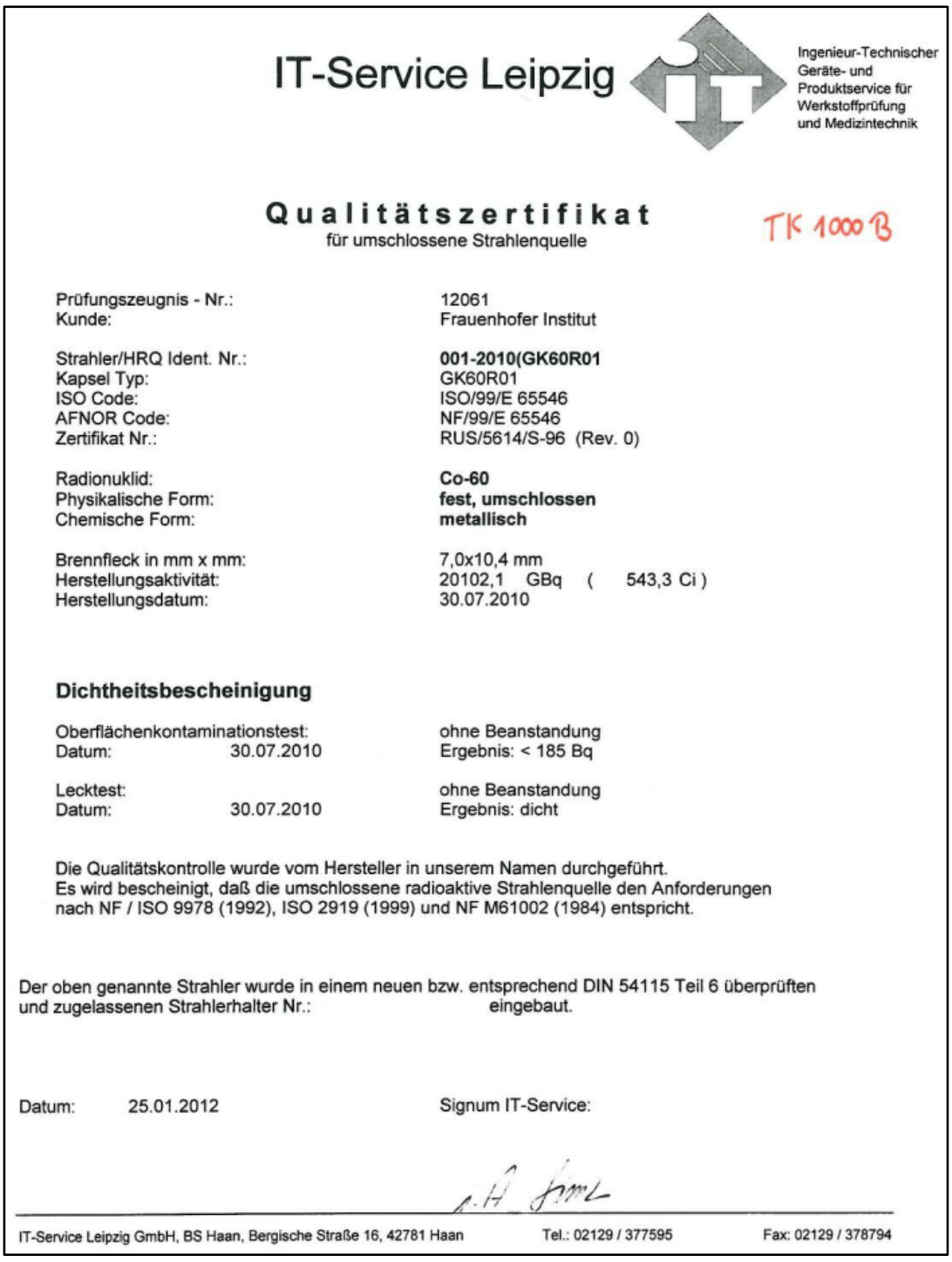
The dose rates obtained at varying distances between 2 cm and 50 cm and in different directions relative to the source are used to develop a model of the dose rate distribution around the source as a function of distance and direction. The dose rate of an individual measurement is scaled to a reference 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 TK1000B irradiation source



IT-Service Leipzig

Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik

Qualitätszertifikat
für umschlossene Strahlenquelle

TK 1000 B

Prüfungszeugnis - Nr.:	12061
Kunde:	Frauenhofer Institut
Strahler/HRQ Ident. Nr.:	**001-2010(GK60R01**
Kapsel Typ:	GK60R01
ISO Code:	ISO/99/E 65546
AFNOR Code:	NF/99/E 65546
Zertifikat Nr.:	RUS/5614/S-96 (Rev. 0)
Radionuklid:	**Co-60**
Physikalische Form:	**fest, umschlossen**
Chemische Form:	**metallisch**
Brennfleck in mm x mm:	7,0x10,4 mm
Herstellungsaktivität:	20102,1 GBq (543,3 Ci)
Herstellungsdatum:	30.07.2010

Dichtheitsbescheinigung

Oberflächenkontaminationstest:		ohne Beanstandung
Datum:	30.07.2010	Ergebnis: < 185 Bq
Lecktest:		ohne Beanstandung
Datum:	30.07.2010	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.: eingebaut.

Datum: 25.01.2012 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

Fraunhofer INT

Irradiation Source	TK1000B (2012)	Date	13.05.2016
Responsible Employee	MS		
Project Description	NEO-14-086 HDR(BDS16, BDS18)		

Reference Data for Dose Rate Calculation

Reference Activity	8.16 TBq ± *10.0%*	Standard uncertainty[1]
Reference Dose Rate	2.35 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	15.50 cm ± *0.05* cm	Standard uncertainty[1]
Object Minimum	15.66 cm ± 0.05 cm	Standard uncertainty[2]
Object Maximum	16.24 cm ± 0.07 cm	Standard uncertainty[2]
Mean Distance	**15.95 cm ± 0.11 cm**	*Expanded uncertainty*[3]

Dose Rates in Object

Minimum	0.0244 Gy/s ± 2.8%	Standard uncertainty[2]
Mean	**0.0253 Gy/s ± 2.8%**	Standard uncertainty[2]
Maximum	0.0262 Gy/s ± 2.8%	Standard uncertainty[2]

Irradiation Time	**79096 s ± *1* s**	Standard uncertainty[1]
in DD HH:MM:SS	00 21:58:16 ± *1* s	Standard uncertainty[1]

Dose in Object

Minimum	1928 Gy ± 2.8%	Standard uncertainty[2]
Maximum	2076 Gy ± 2.8%	Standard uncertainty[2]
Mean	**2000 Gy ± 5.6%**	*Expanded uncertainty*[3]
Homogeneity	7.4%	

[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