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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

TN5.5
TID Test Report (LDR / HDR) for
Power Bipolar Transistor
BDS18

Manufacturer:
Semelab

Date code/Lot code: AF1615U

Report no.	Version	Date	NEO no.
018/2017	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 BDS18 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 BDS18, "Silicon Planar Epitaxial PNP Transistor", Semelab, Document number 8667, Issue 1

[5] TN2.5 "TID Test Plan BDS18 (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	018/2017
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	BDS18
Family	Power Bipolar Transistor
Technology	NPN high voltage bipolar transistor
Package	Hermetic TO220 Isolated Metal Package
Date code / Wafer lot	AF1615U
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	TN2.5 "TID Test Plan BDS18 (HDR+LDR)", Issue 1, 2016-02-02
Max. test level	200 krad(Si)
Dose steps	LDR: Multiple: 9, 19, 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 09:20 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	$V_{(Br)CEO}$ (I_C@-120V), I_{CEO}, I_{EBO},$V_{CE(sat)}1$, $V_{CE(sat)}2$,$V_{BE(sat)}$, $h_{FE}1$, $h_{FE}2$

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 BDS18 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 BDS16 were performed simultaneously to the tests of the BDS18.
- Comparison with respect to ELDRS:
  - A comparison of the tests at high and low dose rate shows no significant difference for any parameter.
  - 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	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
V_BR_CEO	On										
	Off										
I (V_BR_CEO)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VceSAT_1	On										
	Off										
VceSAT_2	On										
	Off										
VBEOn	On										
	Off										
HFE 1	On			1	5	5	5	5	5	5	1
	Off				5	5	5	5	5	5	3
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
V_BR_CEO	On										
	Off										
I (V_BR_CEO)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCESAT_1	On										
	Off										
VCESAT_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On				3	5	5	5	5	5	
	Off				2	5	5	5	5	5	
HFE 2	On										
	Off										

3 Sample preparations

3.1 Sample shipment

Initially a total of 30 Samples were procured by INT at a commercial supplier (Protec) for the conduction of these tests for ESA. The parcel contained devices from two different batches (19x AF1615U, 11xPA1608U). The devices were non-refundable. The maximum available five additional devices were procured from the AF1615U batch, so the number of devices from the same lot available for the tests was 24 in total.

Table 3: Sample shipment

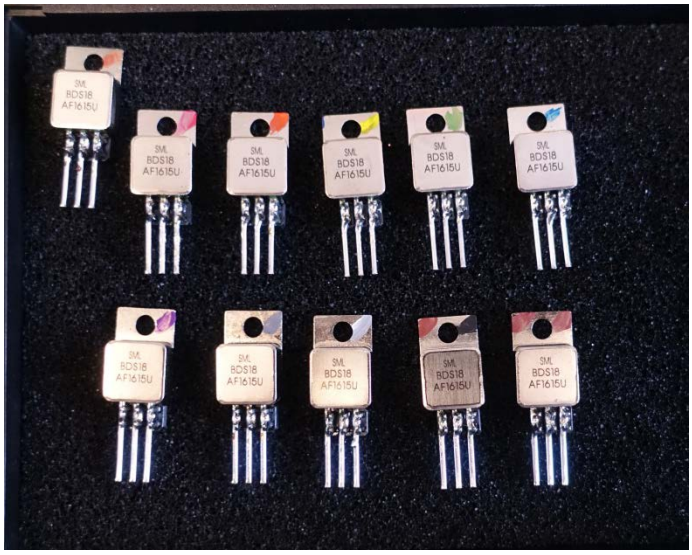
Samples ordered	Samples received	Samples sent back
December 2015	May and June 2016	still at INT

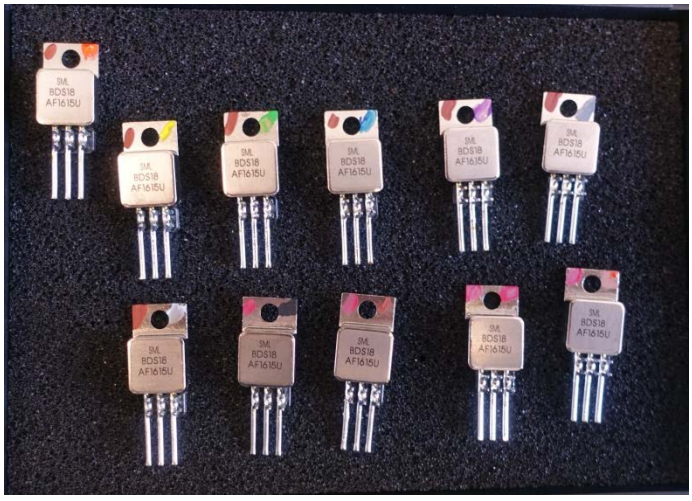
Figure 3: The ESD package with the samples (left: first charge from 2 batches, right and bottom: second procurement)

3.2 Sample identification/ marking

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

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





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

3.3 Sample safekeeping

The samples were stored in an Electro-Static Discharge (ESD) box (The samples were soldered to adapter pins, to ease the mounting to the board, exchanging, plugging and storage of the samples.

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 10:37	24.08.2016 11:44	1:07
1	9.33	9.33	0.0354	25. 08.2016 14:04:00	00:42:48	05. 09.2016 14:49:00	11d 00:45:00	05.09.2016 15:00	05.09.2016 15:39	0:39
2	9.25	18.58	0.0353	05. 09.2016 15:46:33	00:30:55	16. 09.2016 15:10:36	10d 23:24:03	16.09.2016 15:20	16.09.2016 15:59	0:39
3	11.70	30.28	0.0351	16. 09.2016 16:03:42	00:16:37	30. 09.2016 14:16:46	13d 22:13:04	30.09.2016 14:30	30.09.2016 15:09	0:39
4	20.63	50.91	0.0349	30. 09.2016 15:18:39	02:49:33	25. 10.2016 11:08:24	24d 19:49:45	25.10.2016 11:13	25.10.2016 12:01	0:48
5	46.69	97.6	0.0346	25. 10.2016 12:07:49	02:34:16	21. 12.2016 09:05:03	56d 20:57:14	21.12.2016 09:15	21.12.2016 09:57	0:42
6	55.29	152.89	0.0339	21. 12.2016 10:03:31	08:57:01	28. 02.2017 13:07:09	69d 03:03:38	28.02.2017 13:18	28.02.2017 14:22	1:04
7	49.28	202.17	0.0331	28. 02.2017 14:29:36	00:30:44	02. 05.2017 09:20:29	62d 18:50:53	02.05.2017 09:32	02.05.2017 10:06	0:34
8	24 h @ RT			02. 05.2017 10:22:00		03. 05.2017 10:22:00	1d 00:00:00	03.05. 10:25	03.05. 10:58	0:33
9	168 h @100°C			03. 05.2017 12:00:00		10. 05.2017 13:00:00	7d 00:00:00	10.05. 14:09	10.05. 14:51	0:42

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 BDS18 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 irradiation steps

#	Step [krad(Si)]	Total [krad (Si)]	Startrate [krad(Si)/h]	Start Irr.	Stop Irr.	Duration [h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0					02.06.2017 13:27	02.06.2017 13:58	0:31
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 06:15	06.06.2017 06:47	0:32
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 09:42	06.06.2017 10:26	0:44
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 12:24	06.06.2017 13:07	0:43
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 16:55	06.06.2017 17:40	0:45
5	50.00	100	9.1000	06.06.2017 18:29.28	06.06.2017 23:59.12	0d 05:29:44	07.06.2017 00:13	07.06.2017 01:03	0:50
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 07:54	07.06.2017 08:31	0:37
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 14:33	07.06.2017 15:15	0:42
8	24 h @ RT			07.06.2017 15:20.00	08.06.2017 15:20.00	1d 01:49	08.06.2017 15:31	08.06.2017 16:19	0:48
9	168 h @100°C			08.06.2017 16:40.00	16.06.2017 10:00.00	7d 17:20:00	16.06.2017 10:28	16.06.2017 11:03	0:35

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

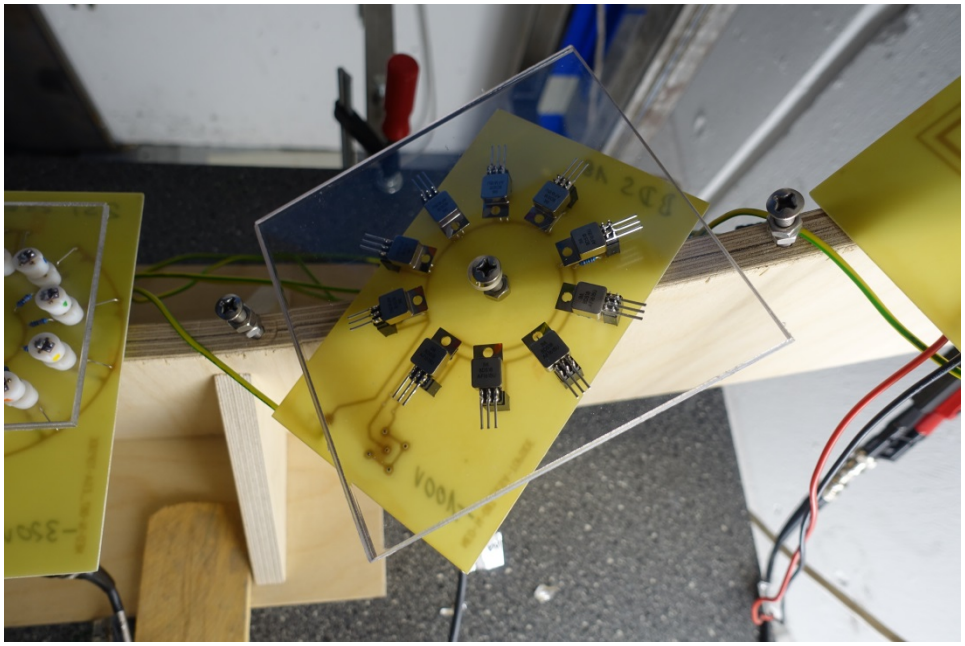


Figure 6: LDR tests: Board fixture at TK100

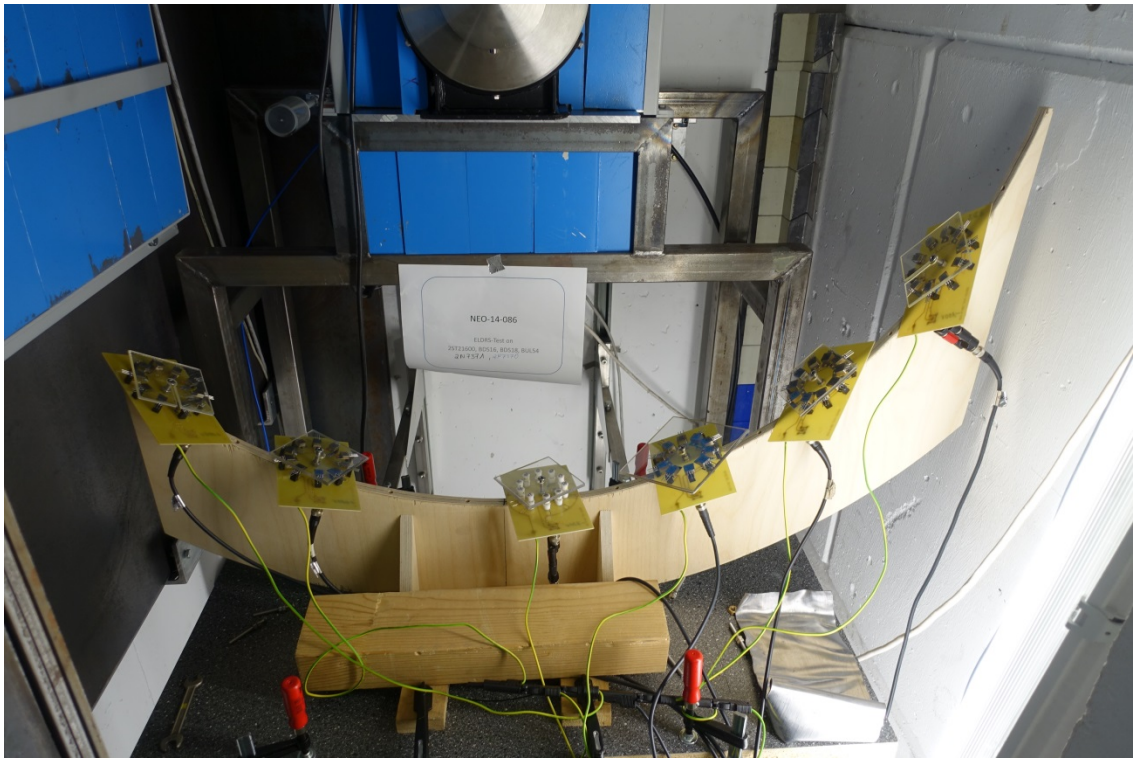
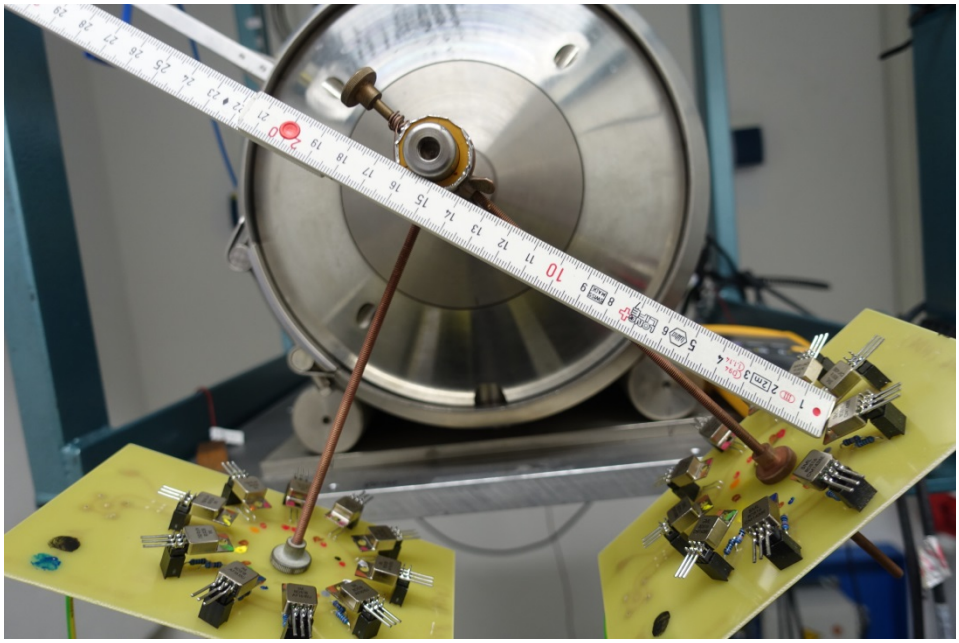


Figure 7: HDR tests: Board fixture at TK1000B



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 surface.

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 EA PS 3150-04B voltage supply (Eq.Id E-PS1-004) was used for biasing the low dose rate test.

HDR: A fug HCE 35-125 voltage supply (Eq.Id E-PS1-043) was used for biasing the low 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

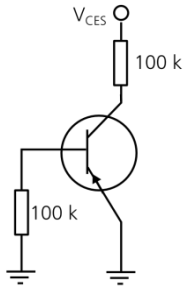
ON-Mode	OFF-Mode
 V_{CES} = -100 V (≥ 80% $V_{(BR)CEO}$)	All pins were short circuited and grounded.

Table 7: Biasing equipment. Left: LDR test (EA PS 3150-04B in middle of 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	37.7% ± 7.0%	Non-condensing, during irradiation and first annealing (24 h)
Temperature	25.6 °C ± 1.6 °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.

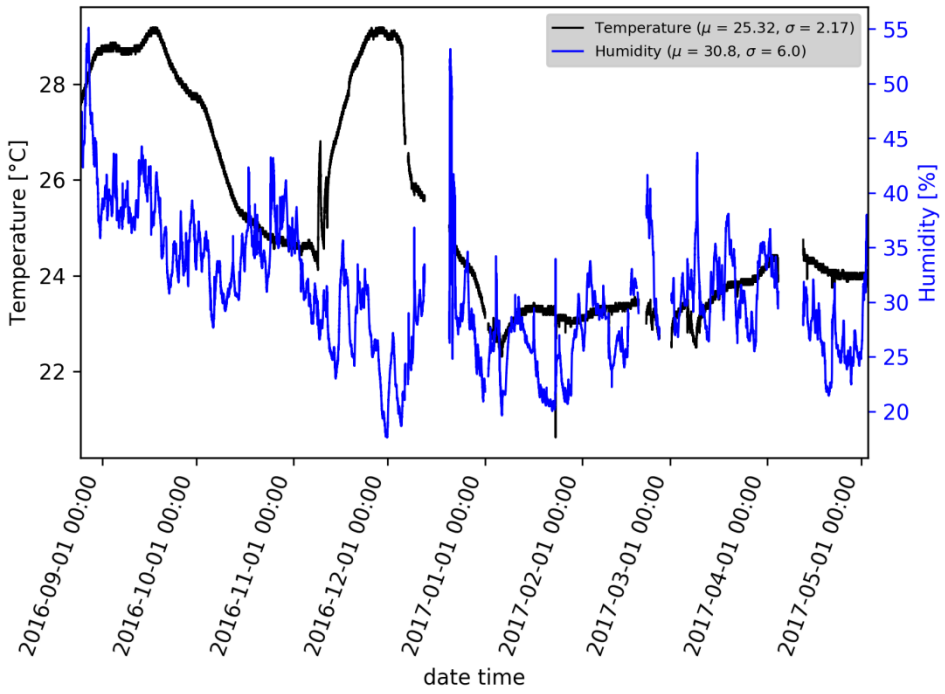
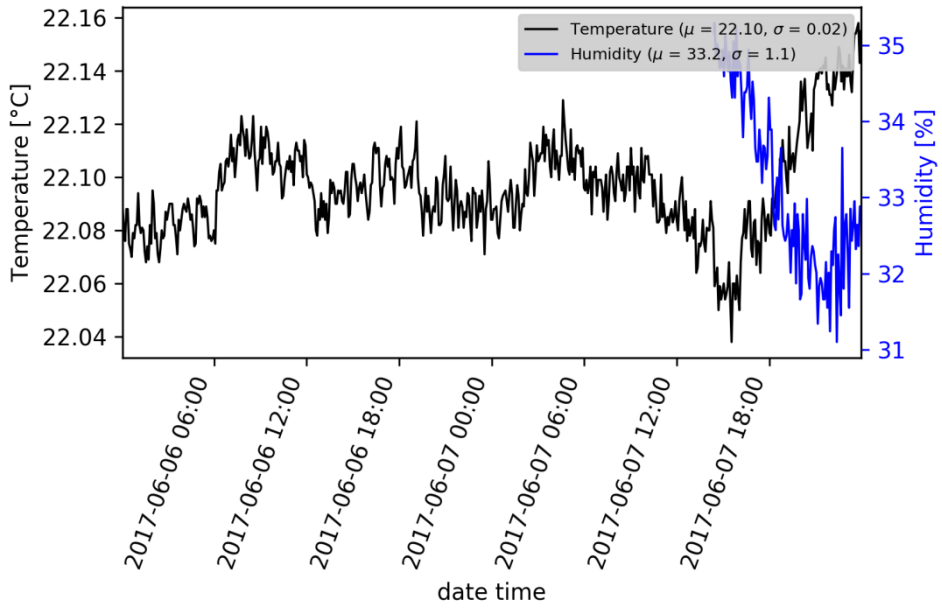


Table 9: HDR: Environmental variables during irradiation

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 Breakdown Voltage	$V_{CEO(br)}$ I_C@ -120V	3011, Note 2	I_C = -10 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, Notes 1
5		$V_{CE(sat)2}$		I_C = -0.5 A, I_B = -50 mA, Notes 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 $V_{BR(EBO)}$

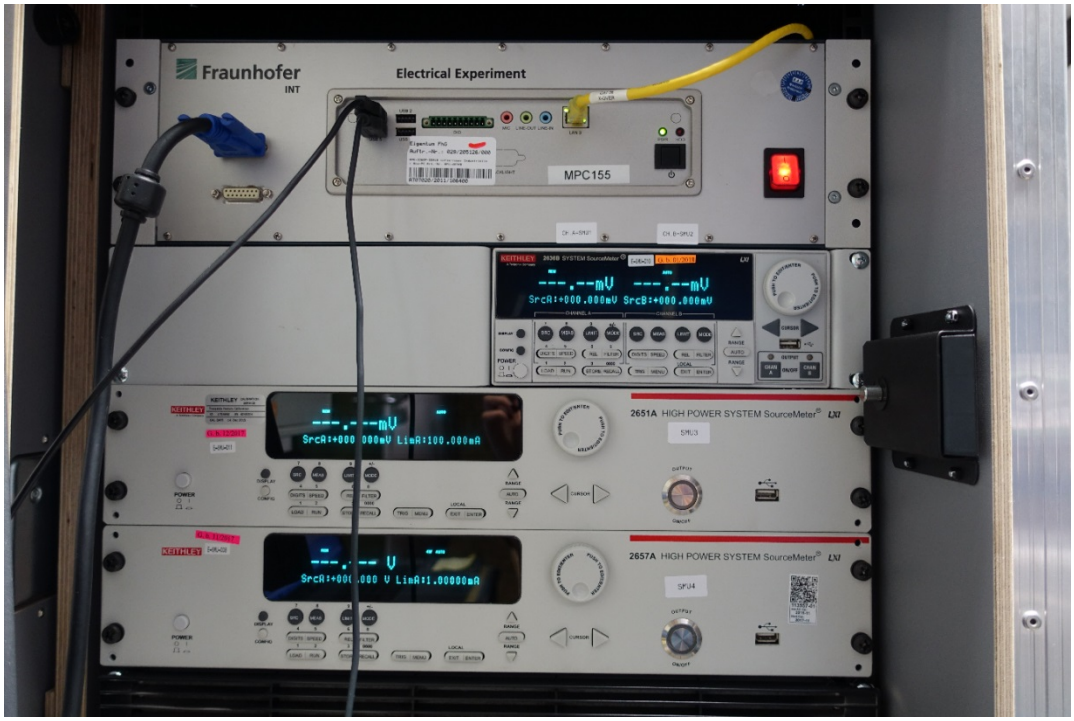
5.2 Measurement equipment

Table 11: Measurement equipment

Equipment	Manufacturer	Model	INT-Code	Calibr. due	Measurement
System Source-Meter	Keithley	2636B	E-SMU-010	01/2018	$V_{(BR)CEO}$ (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	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @ 100°C
Temperature [°C]	25.5E+0	26.6E+0	24.8E+0	21.2E+0	22.4E+0	22.8E+0	22.1E+0	26.0E+0	27.6E+0	25.6E+0
Humidity [%]	56.4E+0	56.9E+0	34.5E+0	43.5E+0	54.5E+0	40.5E+0	42.7E+0	34.0E+0	34.0E+0	33.9E+0

Figure 13: LDR: Environment variables during measurements

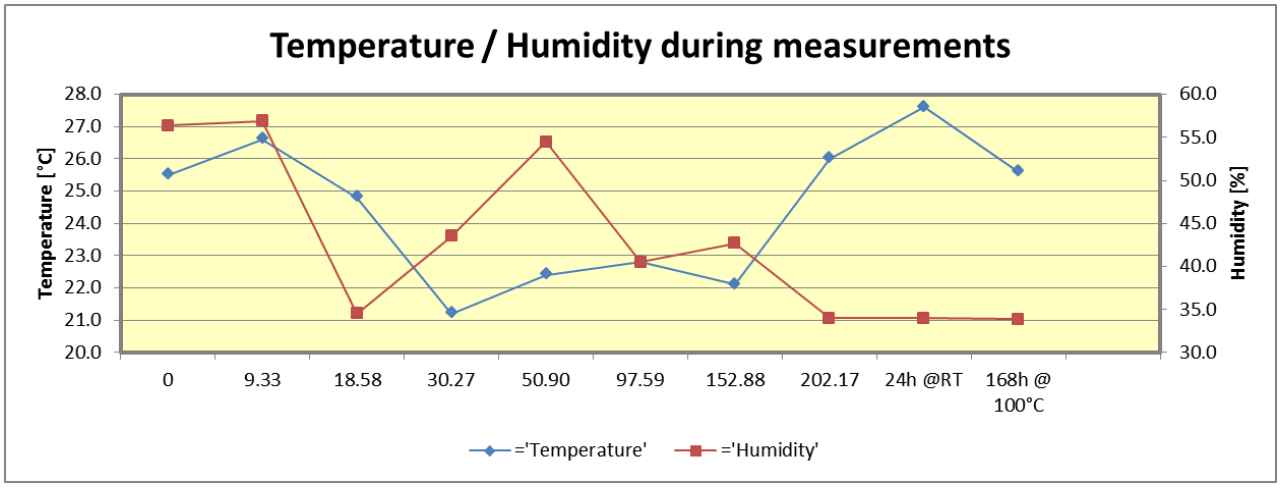
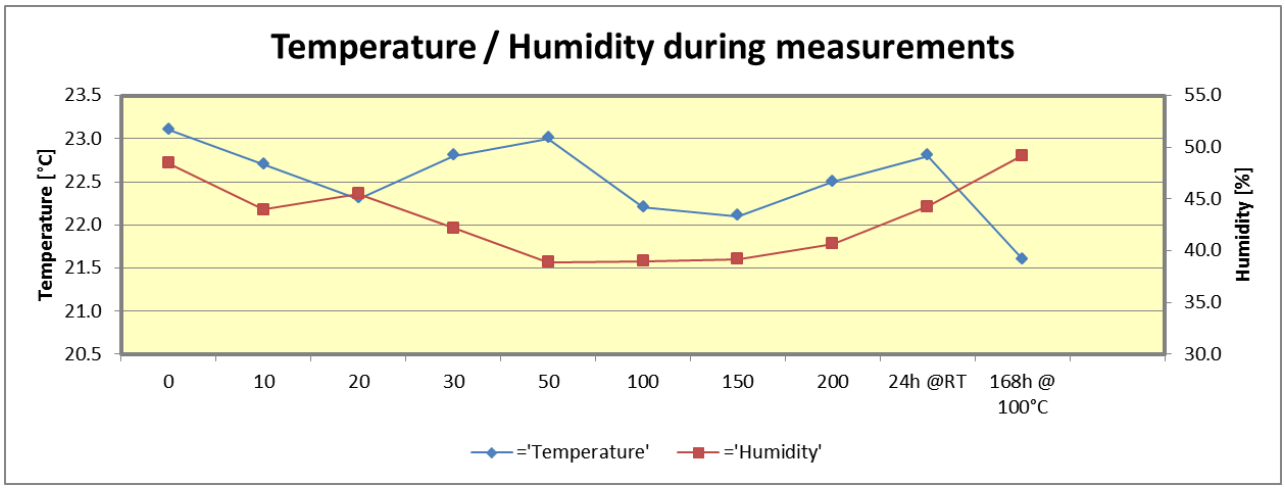


Table 13: HDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @ 100°C
Temperature [°C]	23.1E+0	22.7E+0	22.3E+0	22.8E+0	23.0E+0	22.2E+0	22.1E+0	22.5E+0	22.8E+0	21.6E+0
Humidity [%]	48.5E+0	44.0E+0	45.5E+0	42.2E+0	38.9E+0	39.0E+0	39.2E+0	40.7E+0	44.3E+0	49.2E+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	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
V_BR_CEO	On										
	Off										
I (V_BR_CEO)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VceSAT_1	On										
	Off										
VceSAT_2	On										
	Off										
VBEOn	On										
	Off										
HFE1	On			1	5	5	5	5	5	5	1
	Off				5	5	5	5	5	5	3
HFE2	On										
	Off										

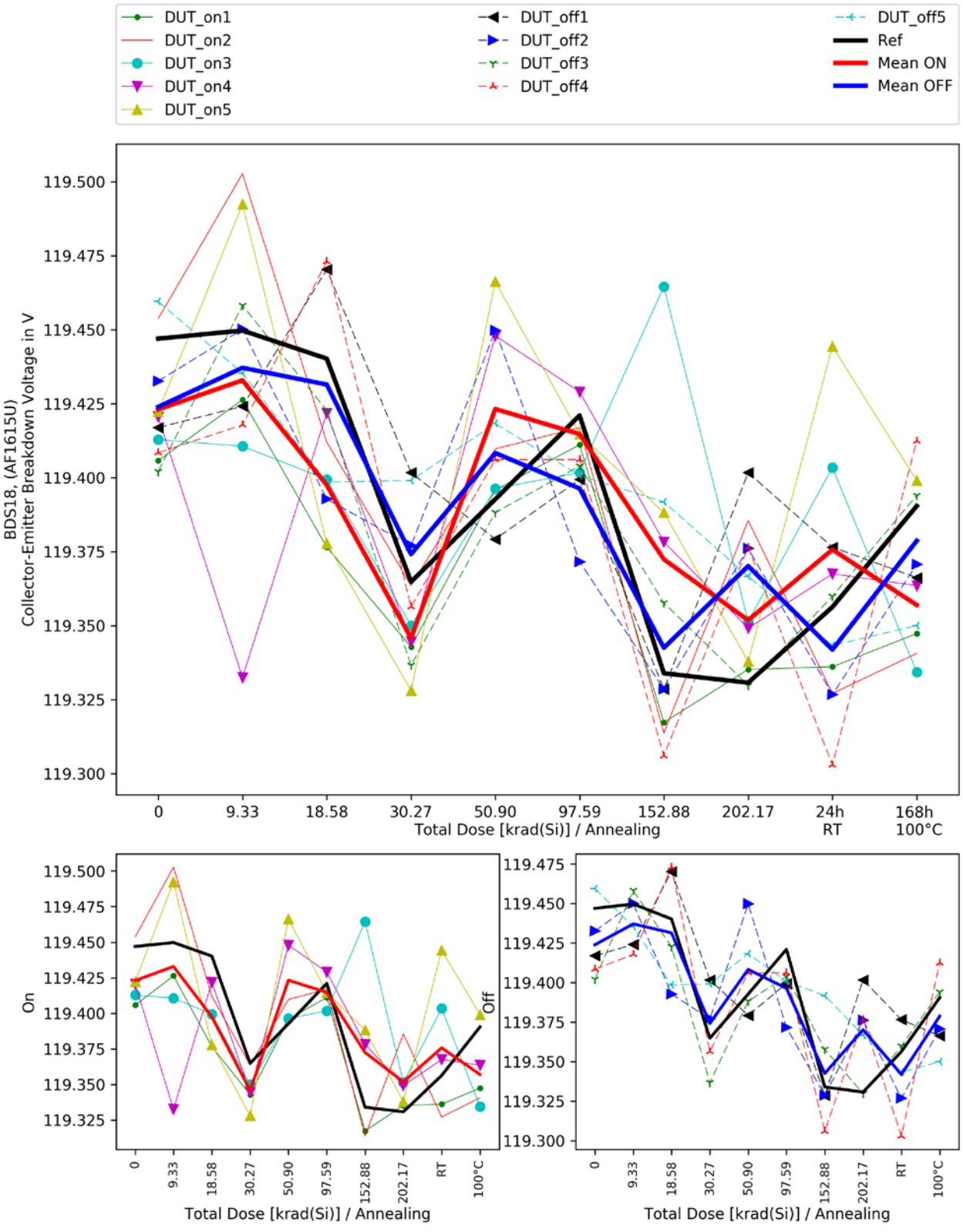
7.2 Collector-Emitter Breakdown Voltage

Collector-Emitter Breakdown Voltage **BDS18**
V_BR_CEO in V Date-/Lotcode: AF1615U
Limit: 119.3<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0	119.3E+0	119.3E+0	119.3E+0	119.3E+0
DUT_on2	119.5E+0	119.5E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.3E+0	119.3E+0
DUT_on3	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.5E+0	119.4E+0	119.4E+0	119.3E+0
DUT_on4	119.4E+0	119.3E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0
DUT_on5	119.4E+0	119.5E+0	119.4E+0	119.3E+0	119.5E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0
Radiation-Mean ON	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.3E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**
Standarddeviation	18.4E-3	69.0E-3	20.2E-3	12.8E-3	32.1E-3	9.9E-3	61.7E-3	20.1E-3	48.7E-3	25.9E-3
Mean + kσ	**119.5E+0**	**119.6E+0**	**119.5E+0**	**119.4E+0**	**119.5E+0**	**119.4E+0**	**119.5E+0**	**119.4E+0**	**119.5E+0**	**119.4E+0**
Mean - kσ	**119.4E+0**	**119.2E+0**	**119.3E+0**	**119.3E+0**	**119.3E+0**	**119.4E+0**	**119.2E+0**	**119.3E+0**	**119.2E+0**	**119.3E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	119.4E+0	119.4E+0	119.5E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0	119.4E+0
DUT_off2	119.4E+0	119.5E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.3E+0	119.4E+0
DUT_off3	119.4E+0	119.5E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.4E+0
DUT_off4	119.4E+0	119.4E+0	119.5E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0	119.3E+0	119.4E+0
DUT_off5	119.5E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.4E+0
Radiation-Mean OFF	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.3E+0**	**119.4E+0**	**119.3E+0**	**119.4E+0**
Standarddeviation	23.0E-3	17.0E-3	38.4E-3	27.9E-3	27.7E-3	14.1E-3	33.1E-3	26.0E-3	28.6E-3	24.6E-3
Mean + kσ	**119.5E+0**	**119.5E+0**	**119.5E+0**	**119.5E+0**	**119.5E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**	**119.4E+0**
Mean - kσ	**119.4E+0**	**119.4E+0**	**119.3E+0**	**119.3E+0**	**119.3E+0**	**119.4E+0**	**119.3E+0**	**119.3E+0**	**119.3E+0**	**119.3E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.4E+0	119.3E+0	119.3E+0	119.4E+0	119.4E+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
BDS18, (AF1615U)
Collector-Emitter Breakdown Voltage in V
119.500
119.475
119.450
119.425
119.400
119.375
119.350
119.325
119.300
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

7.3 ICE @ V_BR_CEO

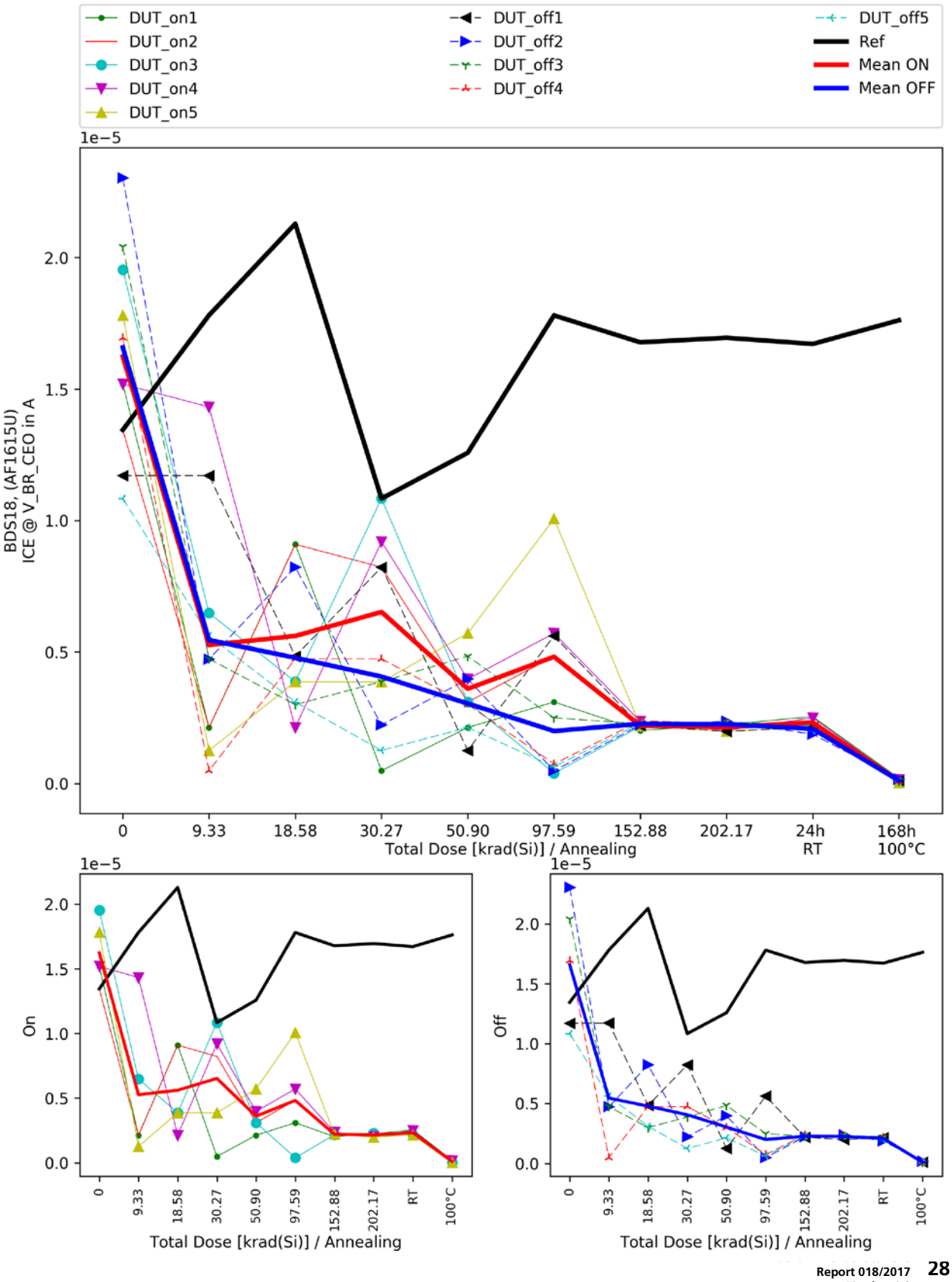
ICE@V_BR_CEO
I (V_BR_CEO) in A
Limit: x<0.01

BDS18
Date-/Lotcode: AF1615U

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	15.2E-6	2.1E-6	9.1E-6	485.5E-9	2.1E-6	3.1E-6	2.0E-6	2.2E-6	2.5E-6	197.8E-9
DUT_on2	13.4E-6	2.1E-6	9.1E-6	8.2E-6	3.1E-6	4.8E-6	2.3E-6	2.2E-6	2.2E-6	104.1E-9
DUT_on3	19.5E-6	6.5E-6	3.9E-6	10.8E-6	3.1E-6	387.0E-9	2.2E-6	2.3E-6	2.2E-6	18.5E-9
DUT_on4	15.2E-6	14.3E-6	2.1E-6	9.2E-6	4.0E-6	5.7E-6	2.4E-6	2.0E-6	2.5E-6	152.7E-9
DUT_on5	17.8E-6	1.3E-6	3.9E-6	3.9E-6	5.7E-6	10.1E-6	2.2E-6	2.0E-6	2.1E-6	22.1E-9
Radiation-Mean ON	**16.2E-6**	**5.3E-6**	**5.6E-6**	**6.5E-6**	**3.6E-6**	**4.8E-6**	**2.2E-6**	**2.1E-6**	**2.3E-6**	**99.0E-9**
Standarddeviation	**2.4E-6**	**5.5E-6**	**3.3E-6**	**4.2E-6**	**1.3E-6**	**3.6E-6**	**127.9E-9**	**135.0E-9**	**187.0E-9**	**79.2E-9**
Mean + kσ	**22.9E-6**	**20.2E-6**	**14.5E-6**	**18.2E-6**	**7.3E-6**	**14.6E-6**	**2.5E-6**	**2.5E-6**	**2.8E-6**	**316.1E-9**
Mean - kσ	**9.6E-6**	**-9.7E-6**	**-3.3E-6**	**-5.1E-6**	**-94.0E-9**	**-5.0E-6**	**1.8E-6**	**1.8E-6**	**1.8E-6**	**-118.0E-9**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	11.7E-6	11.7E-6	4.8E-6	8.2E-6	1.3E-6	5.6E-6	2.2E-6	2.0E-6	2.1E-6	108.5E-9
DUT_off2	23.0E-6	4.7E-6	8.2E-6	2.2E-6	4.0E-6	485.1E-9	2.2E-6	2.4E-6	1.9E-6	161.7E-9
DUT_off3	20.4E-6	4.7E-6	3.0E-6	3.9E-6	4.8E-6	2.5E-6	2.3E-6	2.3E-6	2.2E-6	98.7E-9
DUT_off4	16.9E-6	485.5E-9	4.7E-6	4.7E-6	3.0E-6	741.9E-9	2.4E-6	2.3E-6	2.1E-6	77.1E-9
DUT_off5	10.8E-6	5.6E-6	3.1E-6	1.3E-6	2.1E-6	634.2E-9	2.3E-6	2.3E-6	2.0E-6	81.5E-9
Radiation-Mean OFF	**16.6E-6**	**5.5E-6**	**4.8E-6**	**4.1E-6**	**3.0E-6**	**2.0E-6**	**2.3E-6**	**2.3E-6**	**2.1E-6**	**105.5E-9**
Standarddeviation	**5.3E-6**	**4.0E-6**	**2.1E-6**	**2.7E-6**	**1.4E-6**	**2.2E-6**	**72.4E-9**	**154.3E-9**	**139.8E-9**	**33.9E-9**
Mean + kσ	**31.2E-6**	**16.5E-6**	**10.6E-6**	**11.5E-6**	**6.9E-6**	**8.0E-6**	**2.5E-6**	**2.7E-6**	**2.5E-6**	**198.5E-9**
Mean - kσ	**2.0E-6**	**-5.6E-6**	**-1.0E-6**	**-3.3E-6**	**-866.4E-9**	**-4.0E-6**	**2.1E-6**	**1.8E-6**	**1.7E-6**	**12.5E-9**

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	13.4E-6	17.8E-6	21.3E-6	10.8E-6	12.6E-6	17.8E-6	16.8E-6	16.9E-6	16.7E-6	17.6E-6
Max. Value	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3	10.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−5
BDS18, (AF1615U)
ICE @ V_BR_CEO in A
Total Dose [krad(Si)] / Annealing
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
On
Off

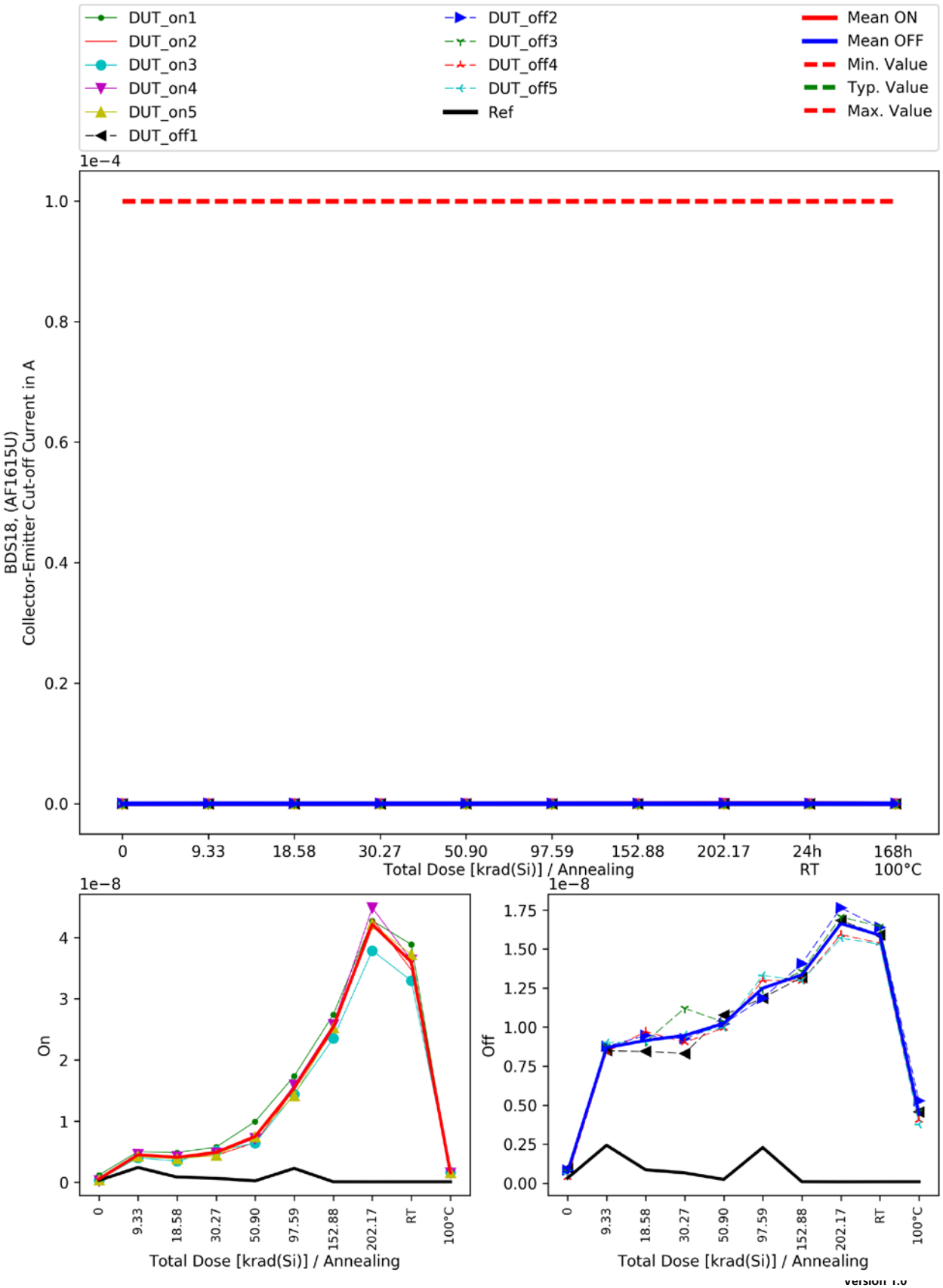
7.4 Collector-Emitter Cut-off Current

Collector-Emitter Cut-off Current **BDS18**
ICEO in A Date-/Lotcode: AF1615U
Limit: x < 0.0001

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	1.2E-9	5.0E-9	4.9E-9	5.7E-9	9.9E-9	17.3E-9	27.4E-9	42.7E-9	38.8E-9	1.6E-9
DUT_on2	485.6E-12	4.7E-9	4.1E-9	4.4E-9	6.5E-9	15.2E-9	24.8E-9	43.1E-9	34.7E-9	1.6E-9
DUT_on3	402.8E-12	4.0E-9	3.5E-9	5.1E-9	6.4E-9	14.4E-9	23.5E-9	37.8E-9	32.9E-9	1.6E-9
DUT_on4	298.1E-12	4.6E-9	4.2E-9	4.8E-9	7.2E-9	15.9E-9	25.8E-9	44.8E-9	36.3E-9	1.5E-9
DUT_on5	367.2E-12	4.2E-9	3.8E-9	4.4E-9	7.4E-9	14.2E-9	25.2E-9	42.2E-9	37.2E-9	1.6E-9
Radiation-Mean ON	548.1E-12	4.5E-9	4.1E-9	4.9E-9	7.5E-9	15.4E-9	25.3E-9	42.1E-9	36.0E-9	1.6E-9
Standarddeviation	363.5E-12	389.2E-12	524.5E-12	560.5E-12	1.4E-9	1.3E-9	1.4E-9	2.6E-9	2.3E-9	39.0E-12
Mean + kσ	1.5E-9	5.6E-9	5.5E-9	6.4E-9	11.4E-9	18.9E-9	29.2E-9	49.2E-9	42.2E-9	1.7E-9
Mean - kσ	-448.5E-12	3.4E-9	2.6E-9	3.4E-9	3.6E-9	11.9E-9	21.4E-9	35.0E-9	29.7E-9	1.5E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	968.7E-12	8.5E-9	8.4E-9	8.3E-9	10.8E-9	11.9E-9	13.2E-9	16.8E-9	15.9E-9	4.6E-9
DUT_off2	825.8E-12	8.8E-9	9.5E-9	9.3E-9	10.2E-9	11.8E-9	14.1E-9	17.6E-9	16.4E-9	5.3E-9
DUT_off3	717.2E-12	8.7E-9	9.1E-9	11.2E-9	10.3E-9	12.4E-9	13.6E-9	17.1E-9	16.4E-9	4.6E-9
DUT_off4	360.5E-12	8.4E-9	9.7E-9	9.0E-9	9.9E-9	13.0E-9	12.9E-9	15.9E-9	15.4E-9	4.0E-9
DUT_off5	615.1E-12	9.0E-9	9.0E-9	9.5E-9	9.9E-9	13.3E-9	13.0E-9	15.7E-9	15.3E-9	3.8E-9
Radiation-Mean OFF	697.5E-12	8.7E-9	9.1E-9	9.5E-9	10.2E-9	12.5E-9	13.3E-9	16.6E-9	15.9E-9	4.4E-9
Standarddeviation	229.6E-12	241.2E-12	489.0E-12	1.1E-9	338.0E-12	660.7E-12	472.0E-12	807.6E-12	531.6E-12	573.1E-12
Mean + kσ	1.3E-9	9.3E-9	10.5E-9	12.4E-9	11.2E-9	14.3E-9	14.6E-9	18.8E-9	17.3E-9	6.0E-9
Mean - kσ	68.0E-12	8.0E-9	7.8E-9	6.5E-9	9.3E-9	10.7E-9	12.0E-9	14.4E-9	14.4E-9	2.9E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	321.8E-12	2.4E-9	859.0E-12	661.1E-12	239.1E-12	2.3E-9	97.1E-12	87.6E-12	92.2E-12	93.9E-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
BDS18, (AF1615U)
Collector-Emitter Cut-off Current in A
Total Dose [krad(Si)] / Annealing
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
1e−8
On
Off
Total Dose [krad(Si)] / Annealing

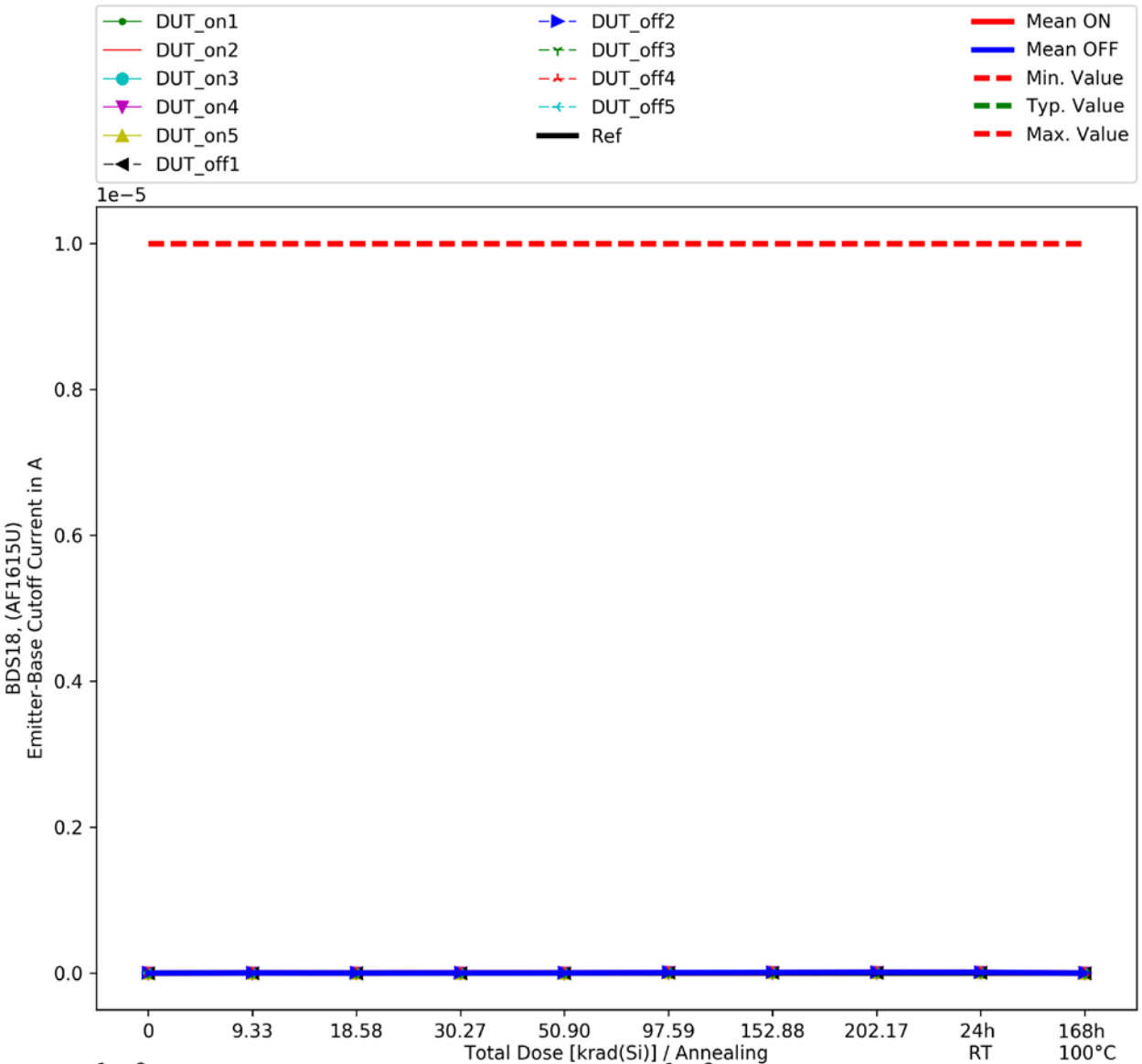
7.5 Emitter-Base Cutoff Current

Emitter-Base Cutoff Current **BDS18**
IEBO in A Date-/Lotcode: AF1615U
Limit: x < 1e-05

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	862.9E-12	2.4E-9	1.2E-9	3.4E-9	2.1E-9	5.6E-9	6.3E-9	9.0E-9	8.4E-9	622.7E-12
DUT_on2	40.9E-12	2.2E-9	1.7E-9	3.2E-9	2.0E-9	4.7E-9	6.0E-9	8.1E-9	7.7E-9	628.7E-12
DUT_on3	310.2E-12	2.4E-9	1.4E-9	3.2E-9	2.3E-9	4.7E-9	6.2E-9	8.2E-9	7.6E-9	628.9E-12
DUT_on4	456.3E-12	2.2E-9	1.5E-9	3.0E-9	2.9E-9	5.0E-9	6.5E-9	9.0E-9	8.1E-9	600.4E-12
DUT_on5	447.6E-12	2.8E-9	1.8E-9	2.8E-9	2.5E-9	4.6E-9	6.0E-9	8.3E-9	7.9E-9	617.6E-12
Radiation-Mean ON	423.6E-12	2.4E-9	1.5E-9	3.1E-9	2.4E-9	4.9E-9	6.2E-9	8.5E-9	7.9E-9	619.7E-12
Standarddeviation	297.5E-12	245.9E-12	258.8E-12	224.9E-12	365.3E-12	397.2E-12	219.9E-12	456.8E-12	341.7E-12	11.7E-12
Mean + kσ	1.2E-9	3.1E-9	2.2E-9	3.8E-9	3.4E-9	6.0E-9	6.8E-9	9.8E-9	8.9E-9	651.8E-12
Mean - kσ	-392.1E-12	1.7E-9	803.6E-12	2.5E-9	1.4E-9	3.8E-9	5.6E-9	7.3E-9	7.0E-9	587.5E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	1.0E-9	2.6E-9	1.8E-9	3.2E-9	2.4E-9	5.1E-9	6.6E-9	9.1E-9	8.3E-9	663.2E-12
DUT_off2	1.1E-9	2.2E-9	1.1E-9	1.9E-9	2.3E-9	4.9E-9	7.3E-9	9.5E-9	8.8E-9	711.0E-12
DUT_off3	50.0E-12	3.1E-9	1.8E-9	2.6E-9	2.8E-9	5.4E-9	7.6E-9	9.6E-9	8.8E-9	683.7E-12
DUT_off4	428.1E-12	2.9E-9	1.6E-9	1.9E-9	3.0E-9	4.9E-9	7.0E-9	9.1E-9	8.2E-9	508.0E-12
DUT_off5	143.4E-12	3.3E-9	1.3E-9	2.6E-9	2.4E-9	5.0E-9	7.1E-9	9.2E-9	8.4E-9	476.3E-12
Radiation-Mean OFF	551.6E-12	2.8E-9	1.5E-9	2.4E-9	2.6E-9	5.1E-9	7.1E-9	9.3E-9	8.5E-9	608.4E-12
Standarddeviation	492.0E-12	435.8E-12	294.3E-12	563.1E-12	280.5E-12	201.5E-12	369.2E-12	220.8E-12	269.0E-12	108.1E-12
Mean + kσ	1.9E-9	4.0E-9	2.3E-9	4.0E-9	3.4E-9	5.6E-9	8.1E-9	9.9E-9	9.3E-9	904.8E-12
Mean - kσ	-797.5E-12	1.6E-9	718.1E-12	898.3E-12	1.8E-9	4.5E-9	6.1E-9	8.7E-9	7.8E-9	312.1E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	398.8E-12	1.0E-9	718.0E-12	479.2E-12	576.6E-12	41.3E-12	12.5E-12	47.3E-12	42.7E-12	40.7E-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
BDS18, (AF1615U)
Emitter-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
1e−8
On
Off
Total Dose [krad(Si)] / Annealing

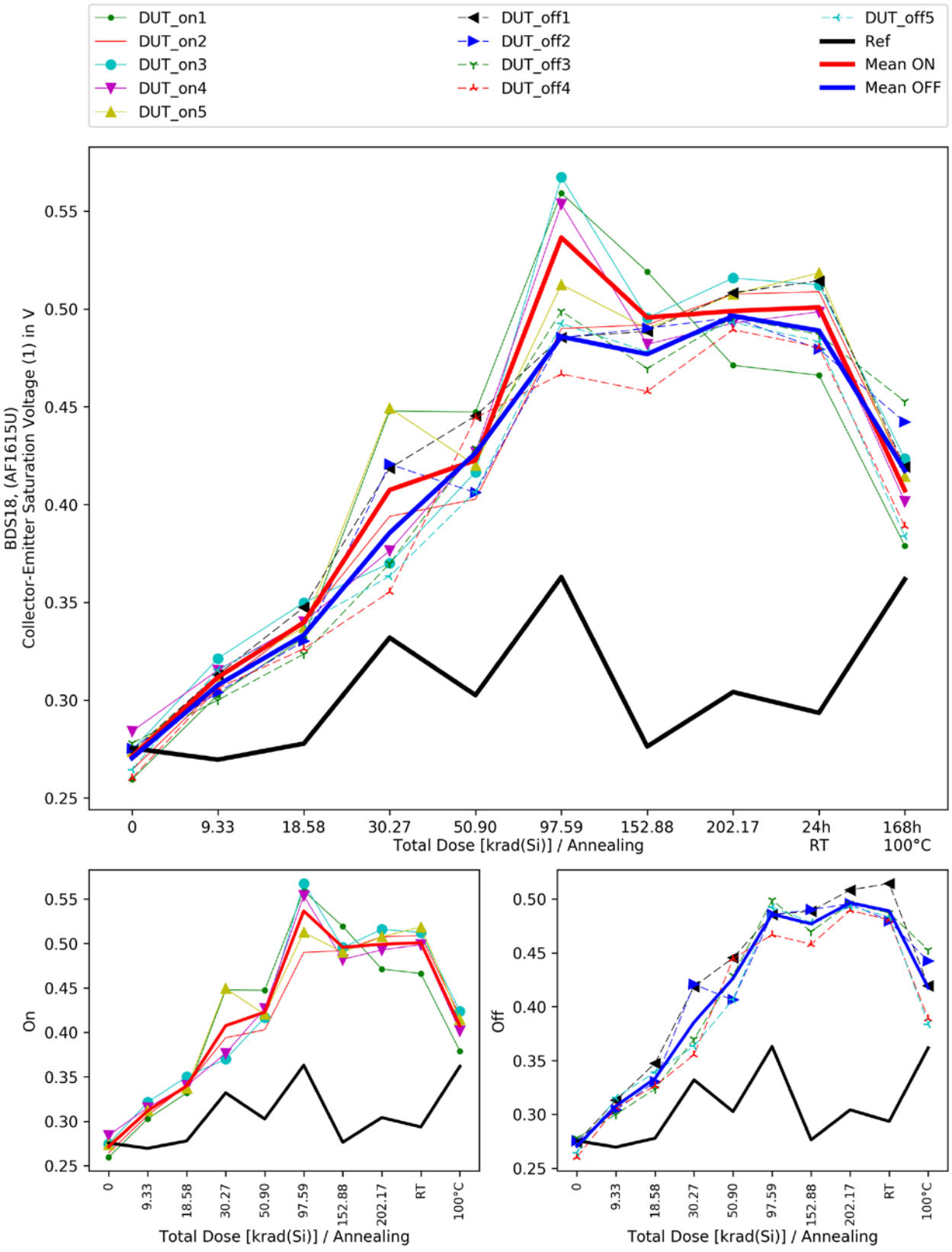
7.6 Collector-Emitter Saturation Voltage (1)

Collector-Emitter Saturation Voltage (1) **BDS18**
VceSAT_1 in V Date-/Lotcode: AF1615U
Limit: x<1.5

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	259.5E-3	302.6E-3	331.8E-3	447.8E-3	447.3E-3	569.2E-3	519.1E-3	471.2E-3	466.1E-3	378.9E-3
DUT_on2	264.3E-3	306.8E-3	339.6E-3	393.9E-3	402.8E-3	489.9E-3	491.9E-3	507.6E-3	508.8E-3	418.2E-3
DUT_on3	274.4E-3	321.4E-3	349.9E-3	369.9E-3	416.6E-3	567.4E-3	495.4E-3	515.8E-3	512.3E-3	423.4E-3
DUT_on4	284.1E-3	315.3E-3	340.0E-3	376.4E-3	426.6E-3	563.5E-3	481.9E-3	492.8E-3	498.5E-3	401.6E-3
DUT_on5	273.8E-3	312.2E-3	337.1E-3	449.3E-3	420.1E-3	512.4E-3	489.9E-3	507.5E-3	518.4E-3	414.4E-3
Radiation-Mean ON	271.2E-3	311.7E-3	339.7E-3	407.5E-3	422.7E-3	536.5E-3	495.6E-3	498.9E-3	500.8E-3	407.3E-3
Standarddeviation	9.6E-3	7.3E-3	6.6E-3	38.5E-3	16.3E-3	33.6E-3	14.0E-3	17.6E-3	20.7E-3	17.8E-3
Mean + kσ	297.6E-3	331.7E-3	357.7E-3	513.1E-3	467.3E-3	628.6E-3	534.1E-3	547.2E-3	557.6E-3	456.1E-3
Mean - kσ	244.9E-3	291.6E-3	321.7E-3	301.9E-3	378.0E-3	444.4E-3	457.2E-3	450.7E-3	444.0E-3	358.5E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	274.0E-3	313.1E-3	347.4E-3	418.6E-3	445.3E-3	485.5E-3	488.6E-3	508.3E-3	514.4E-3	419.3E-3
DUT_off2	275.3E-3	304.0E-3	330.2E-3	420.6E-3	406.2E-3	485.4E-3	490.1E-3	495.6E-3	479.4E-3	442.1E-3
DUT_off3	278.0E-3	300.0E-3	323.6E-3	369.8E-3	429.0E-3	498.9E-3	469.6E-3	495.6E-3	487.0E-3	452.8E-3
DUT_off4	260.2E-3	306.2E-3	326.2E-3	355.3E-3	444.3E-3	466.8E-3	457.9E-3	489.4E-3	480.4E-3	388.9E-3
DUT_off5	264.5E-3	315.5E-3	339.0E-3	363.3E-3	406.7E-3	492.5E-3	478.2E-3	493.2E-3	483.4E-3	383.8E-3
Radiation-Mean OFF	270.4E-3	307.8E-3	333.3E-3	385.5E-3	426.3E-3	485.8E-3	476.9E-3	496.4E-3	488.9E-3	417.4E-3
Standarddeviation	7.7E-3	6.4E-3	9.8E-3	31.5E-3	19.3E-3	12.0E-3	13.5E-3	7.1E-3	14.5E-3	30.9E-3
Mean + kσ	291.4E-3	325.4E-3	360.2E-3	472.0E-3	479.1E-3	518.8E-3	513.9E-3	515.9E-3	528.8E-3	502.0E-3
Mean - kσ	249.4E-3	290.1E-3	306.3E-3	299.1E-3	373.4E-3	452.9E-3	439.9E-3	477.0E-3	449.0E-3	332.8E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	275.4E-3	269.6E-3	277.8E-3	332.0E-3	302.6E-3	362.9E-3	276.3E-3	304.1E-3	293.5E-3	361.8E-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
BDS18, (AF1615U)
Collector-Emitter Saturation Voltage (1) in V
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

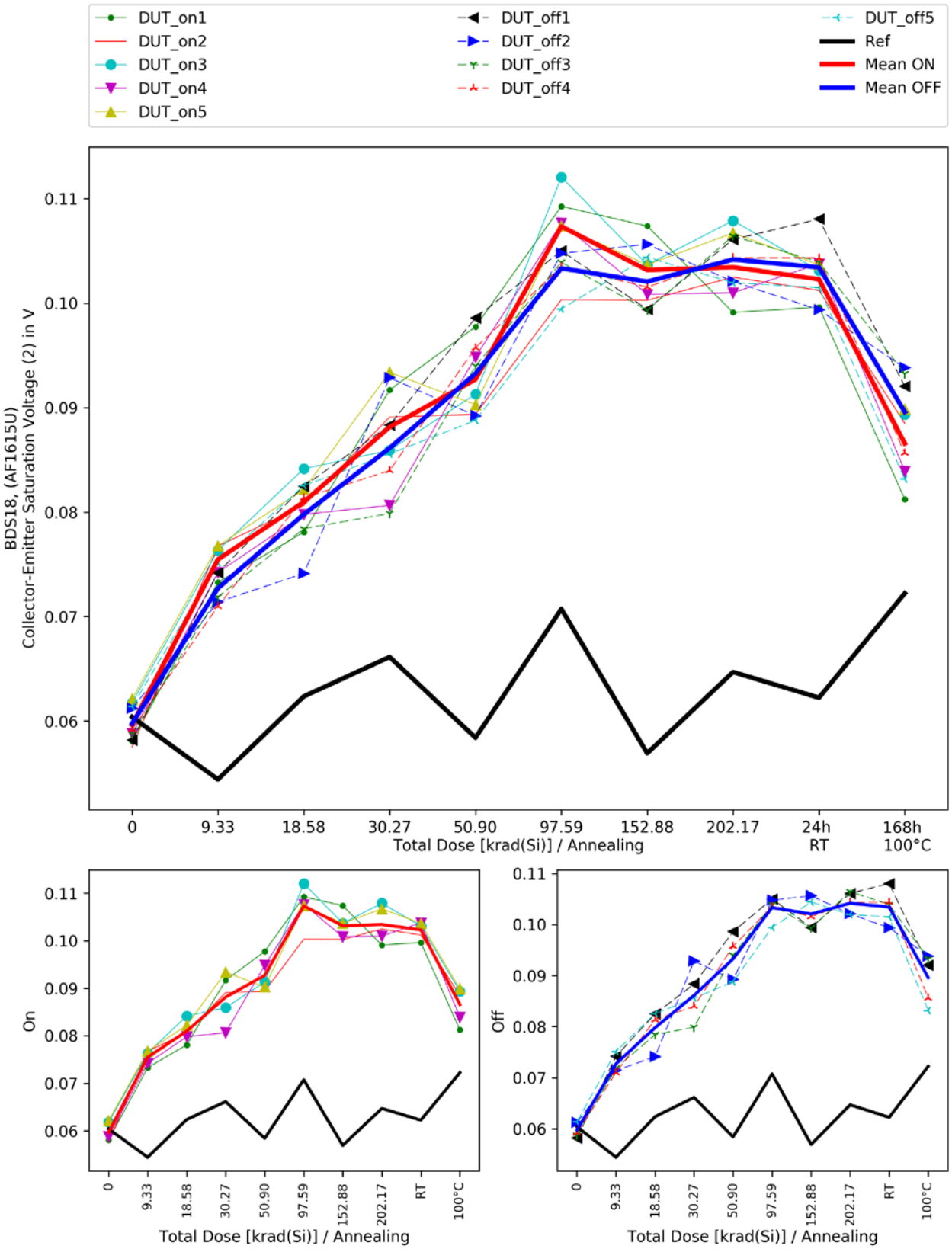
7.7 Collector-Emitter Saturation Voltage (2)

Collector-Emitter Saturation Voltage (2) **BDS18**
VceSAT_2 in V Date-/Lotcode: AF1615U
Limit: x<0.4

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	58.1E-3	73.3E-3	78.1E-3	91.7E-3	97.7E-3	109.3E-3	107.4E-3	99.1E-3	99.6E-3	81.2E-3
DUT_on2	57.5E-3	76.7E-3	80.6E-3	89.1E-3	89.4E-3	100.3E-3	100.3E-3	102.5E-3	101.2E-3	88.5E-3
DUT_on3	61.8E-3	76.3E-3	84.1E-3	85.9E-3	91.3E-3	112.1E-3	103.7E-3	107.9E-3	103.1E-3	89.3E-3
DUT_on4	58.8E-3	74.2E-3	79.8E-3	80.6E-3	94.8E-3	107.7E-3	100.8E-3	101.0E-3	103.8E-3	83.9E-3
DUT_on5	62.1E-3	76.8E-3	82.2E-3	93.4E-3	90.3E-3	107.4E-3	103.7E-3	106.7E-3	103.7E-3	89.8E-3
Radiation-Mean ON	59.6E-3	75.5E-3	81.0E-3	88.1E-3	92.7E-3	107.3E-3	103.2E-3	103.4E-3	102.3E-3	86.6E-3
Standarddeviation	2.2E-3	1.6E-3	2.3E-3	5.0E-3	3.5E-3	4.3E-3	2.8E-3	3.8E-3	1.8E-3	3.8E-3
Mean + kσ	65.5E-3	79.9E-3	87.3E-3	102.0E-3	102.3E-3	119.2E-3	110.9E-3	113.7E-3	107.2E-3	97.0E-3
Mean - kσ	53.7E-3	71.0E-3	74.6E-3	74.3E-3	83.1E-3	95.4E-3	95.4E-3	93.1E-3	97.3E-3	76.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	58.2E-3	74.2E-3	82.5E-3	88.3E-3	98.6E-3	105.0E-3	99.4E-3	106.1E-3	108.0E-3	92.0E-3
DUT_off2	61.2E-3	71.4E-3	74.1E-3	92.8E-3	89.2E-3	104.8E-3	105.6E-3	102.1E-3	99.4E-3	93.8E-3
DUT_off3	58.8E-3	71.9E-3	78.4E-3	79.9E-3	94.0E-3	103.9E-3	99.3E-3	106.4E-3	103.9E-3	93.3E-3
DUT_off4	59.2E-3	71.0E-3	81.4E-3	84.0E-3	95.7E-3	103.5E-3	101.5E-3	104.3E-3	104.3E-3	85.6E-3
DUT_off5	61.4E-3	75.1E-3	82.5E-3	85.6E-3	88.8E-3	99.4E-3	104.4E-3	101.9E-3	101.5E-3	83.2E-3
Radiation-Mean OFF	59.8E-3	72.7E-3	79.8E-3	86.1E-3	93.3E-3	103.3E-3	102.0E-3	104.2E-3	103.4E-3	89.6E-3
Standarddeviation	1.5E-3	1.8E-3	3.6E-3	4.8E-3	4.2E-3	2.3E-3	2.9E-3	2.1E-3	3.3E-3	4.8E-3
Mean + kσ	63.7E-3	77.7E-3	89.6E-3	99.4E-3	104.8E-3	109.5E-3	109.9E-3	110.0E-3	112.4E-3	102.9E-3
Mean - kσ	55.8E-3	67.7E-3	70.0E-3	72.8E-3	81.7E-3	97.1E-3	94.2E-3	98.3E-3	94.5E-3	76.3E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	60.4E-3	54.4E-3	62.4E-3	66.1E-3	58.4E-3	70.7E-3	56.9E-3	64.7E-3	62.2E-3	72.2E-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
BDS18, (AF1615U)
Collector-Emitter Saturation Voltage (2) in V
0.11
0.10
0.09
0.08
0.07
0.06
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

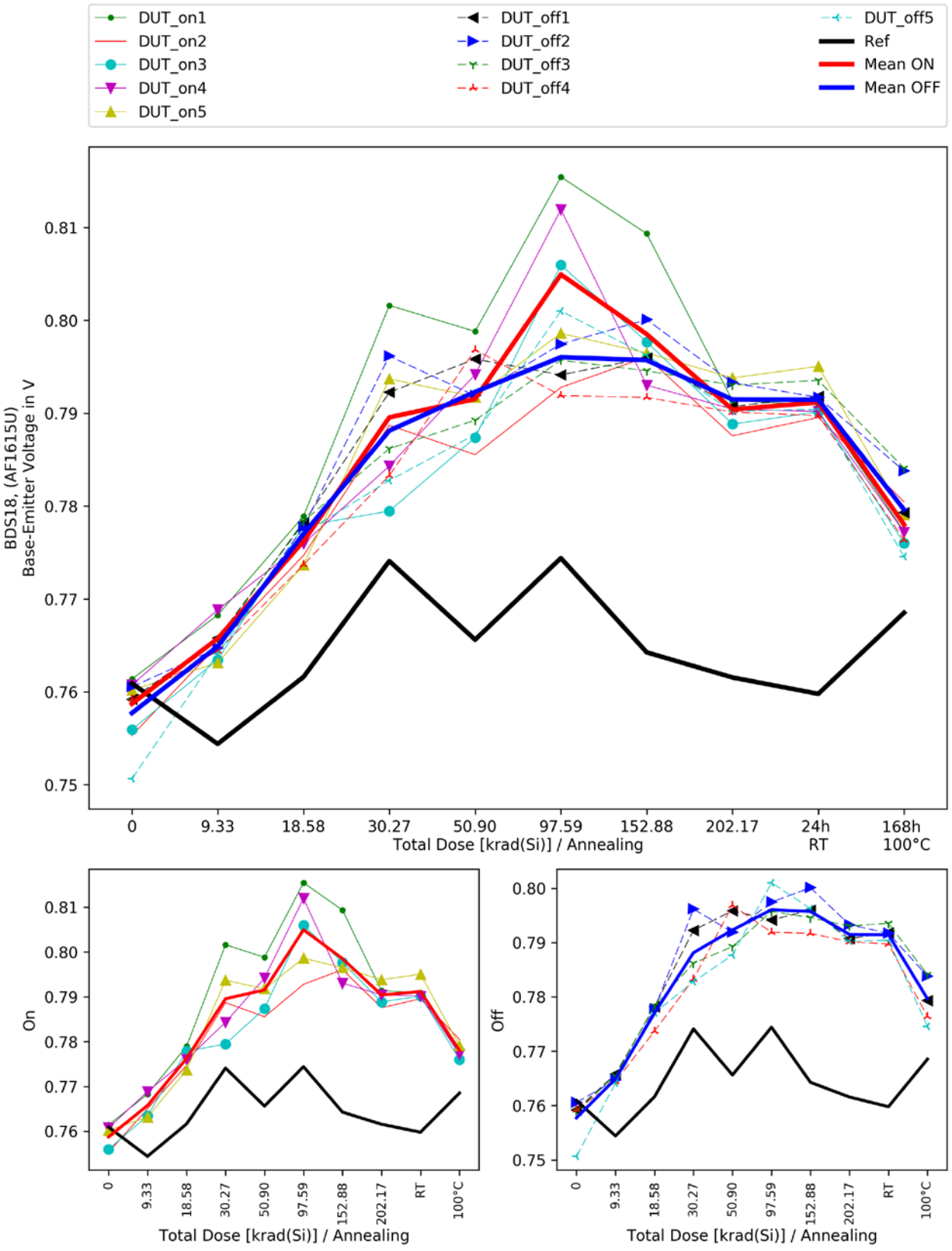
7.8 Base-Emitter Voltage

Base-Emitter Voltage **BDS18**
VBEOn in V Date-/Lotcode: AF1615U
Limit: x<1.4

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	761.4E-3	768.3E-3	778.9E-3	801.6E-3	798.8E-3	815.4E-3	809.3E-3	791.3E-3	790.9E-3	777.3E-3
DUT_on2	755.3E-3	765.0E-3	774.7E-3	788.7E-3	785.5E-3	792.8E-3	796.1E-3	787.6E-3	789.5E-3	780.5E-3
DUT_on3	755.9E-3	763.5E-3	777.9E-3	779.5E-3	787.4E-3	806.0E-3	797.7E-3	788.8E-3	790.2E-3	776.0E-3
DUT_on4	760.7E-3	768.8E-3	776.0E-3	784.3E-3	794.2E-3	811.9E-3	793.0E-3	790.4E-3	790.2E-3	777.2E-3
DUT_on5	760.2E-3	763.1E-3	773.7E-3	793.7E-3	791.8E-3	798.6E-3	796.5E-3	793.8E-3	795.0E-3	779.1E-3
Radiation-Mean ON	758.7E-3	765.7E-3	776.2E-3	789.6E-3	791.5E-3	804.9E-3	798.5E-3	790.4E-3	791.2E-3	778.0E-3
Standarddeviation	2.9E-3	2.7E-3	2.2E-3	8.6E-3	5.3E-3	9.3E-3	6.3E-3	2.4E-3	2.2E-3	1.8E-3
Mean + kσ	766.6E-3	773.1E-3	782.2E-3	813.0E-3	806.1E-3	830.5E-3	815.7E-3	797.0E-3	797.3E-3	782.8E-3
Mean - kσ	750.9E-3	758.4E-3	770.2E-3	766.1E-3	777.0E-3	779.3E-3	781.3E-3	783.8E-3	785.1E-3	773.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	759.2E-3	765.8E-3	778.2E-3	792.3E-3	795.8E-3	794.1E-3	796.0E-3	790.7E-3	791.8E-3	779.3E-3
DUT_off2	760.5E-3	764.7E-3	777.8E-3	796.2E-3	791.9E-3	797.4E-3	800.1E-3	793.3E-3	791.7E-3	783.8E-3
DUT_off3	759.0E-3	765.5E-3	778.4E-3	786.2E-3	789.2E-3	795.7E-3	794.6E-3	793.0E-3	793.5E-3	784.1E-3
DUT_off4	759.2E-3	764.4E-3	773.7E-3	783.3E-3	796.8E-3	791.9E-3	791.7E-3	790.1E-3	789.7E-3	776.4E-3
DUT_off5	750.6E-3	764.1E-3	777.0E-3	782.8E-3	787.7E-3	801.0E-3	796.2E-3	790.2E-3	790.4E-3	774.6E-3
Radiation-Mean OFF	757.7E-3	764.9E-3	777.0E-3	788.1E-3	792.3E-3	796.0E-3	795.7E-3	791.5E-3	791.4E-3	779.6E-3
Standarddeviation	4.0E-3	711.7E-6	1.9E-3	5.9E-3	4.0E-3	3.4E-3	3.0E-3	1.6E-3	1.5E-3	4.3E-3
Mean + kσ	768.7E-3	766.8E-3	782.3E-3	804.2E-3	803.2E-3	805.5E-3	804.0E-3	795.7E-3	795.5E-3	791.4E-3
Mean - kσ	746.7E-3	762.9E-3	771.7E-3	772.0E-3	781.4E-3	786.6E-3	787.4E-3	787.2E-3	787.4E-3	767.9E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	760.9E-3	754.4E-3	761.6E-3	774.1E-3	765.6E-3	774.4E-3	764.3E-3	761.6E-3	759.8E-3	768.5E-3
Max. Value	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+0	1.4E+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
BDS18, (AF1615U)
Base-Emitter Voltage in V
0.81
0.80
0.79
0.78
0.77
0.76
0.75
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off

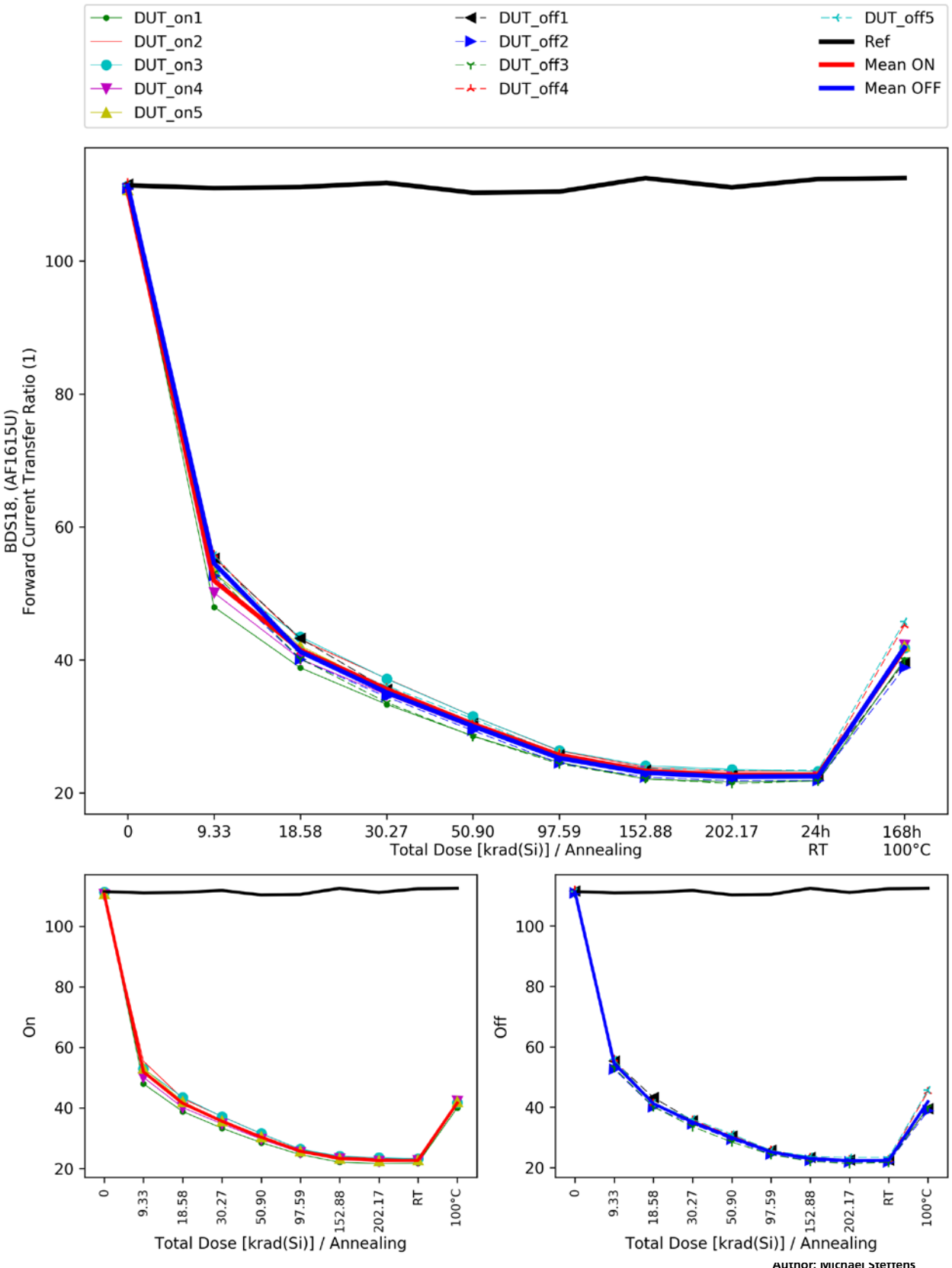
7.9 Forward Current Transfer Ratio (1)

Forward Current Transfer Ratio (1) **BDS18**
HFE 1 Date-/Lotcode: AF1615U
Limit: 40.0<x<250.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	110.3E+0	47.9E+0	38.8E+0	33.3E+0	28.5E+0	24.6E+0	22.1E+0	21.6E+0	21.8E+0	40.0E+0
DUT_on2	110.0E+0	55.4E+0	43.1E+0	37.2E+0	31.5E+0	26.3E+0	23.8E+0	23.2E+0	23.3E+0	42.0E+0
DUT_on3	111.3E+0	52.9E+0	43.5E+0	37.1E+0	31.5E+0	26.4E+0	24.1E+0	23.5E+0	23.2E+0	41.8E+0
DUT_on4	110.4E+0	50.1E+0	40.1E+0	34.7E+0	29.7E+0	25.3E+0	23.2E+0	22.4E+0	22.5E+0	42.2E+0
DUT_on5	110.7E+0	53.2E+0	42.1E+0	35.7E+0	30.5E+0	25.8E+0	23.3E+0	22.6E+0	22.8E+0	42.0E+0
Radiation-Mean ON	110.5E+0	51.9E+0	41.5E+0	35.6E+0	30.3E+0	25.7E+0	23.3E+0	22.7E+0	22.7E+0	41.6E+0
Standarddeviation	499.2E-3	2.9E+0	2.0E+0	1.6E+0	1.3E+0	756.0E-3	775.9E-3	747.0E-3	603.7E-3	917.3E-3
Mean + kσ	111.9E+0	59.9E+0	47.0E+0	40.1E+0	33.8E+0	27.7E+0	25.4E+0	24.7E+0	24.4E+0	44.1E+0
Mean - kσ	109.2E+0	43.9E+0	36.0E+0	31.1E+0	26.9E+0	23.6E+0	21.2E+0	20.6E+0	21.1E+0	39.1E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	111.6E+0	55.3E+0	43.2E+0	35.6E+0	30.4E+0	25.7E+0	23.4E+0	22.6E+0	22.6E+0	39.6E+0
DUT_off2	110.9E+0	52.6E+0	40.0E+0	34.4E+0	29.4E+0	24.4E+0	22.3E+0	21.8E+0	21.8E+0	38.8E+0
DUT_off3	111.0E+0	53.1E+0	40.2E+0	33.6E+0	28.5E+0	24.3E+0	22.1E+0	21.4E+0	21.8E+0	40.0E+0
DUT_off4	111.8E+0	55.9E+0	41.3E+0	35.8E+0	30.6E+0	25.8E+0	23.4E+0	22.7E+0	22.7E+0	45.2E+0
DUT_off5	111.4E+0	55.8E+0	41.4E+0	36.1E+0	31.1E+0	25.7E+0	23.7E+0	23.4E+0	23.4E+0	45.8E+0
Radiation-Mean OFF	111.3E+0	54.5E+0	41.2E+0	35.1E+0	30.0E+0	25.2E+0	23.0E+0	22.4E+0	22.5E+0	41.9E+0
Standarddeviation	380.5E-3	1.6E+0	1.3E+0	1.1E+0	1.1E+0	750.7E-3	719.8E-3	798.7E-3	673.5E-3	3.3E+0
Mean + kσ	112.4E+0	58.8E+0	44.7E+0	38.0E+0	32.9E+0	27.3E+0	25.0E+0	24.6E+0	24.3E+0	51.0E+0
Mean - kσ	110.3E+0	50.3E+0	37.7E+0	32.2E+0	27.1E+0	23.1E+0	21.0E+0	20.2E+0	20.6E+0	32.7E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	111.4E+0	111.0E+0	111.1E+0	111.8E+0	110.3E+0	110.4E+0	112.5E+0	111.1E+0	112.3E+0	112.5E+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


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
BDS18, (AF1615U)
Forward Current Transfer Ratio (1)
100
80
60
40
20
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

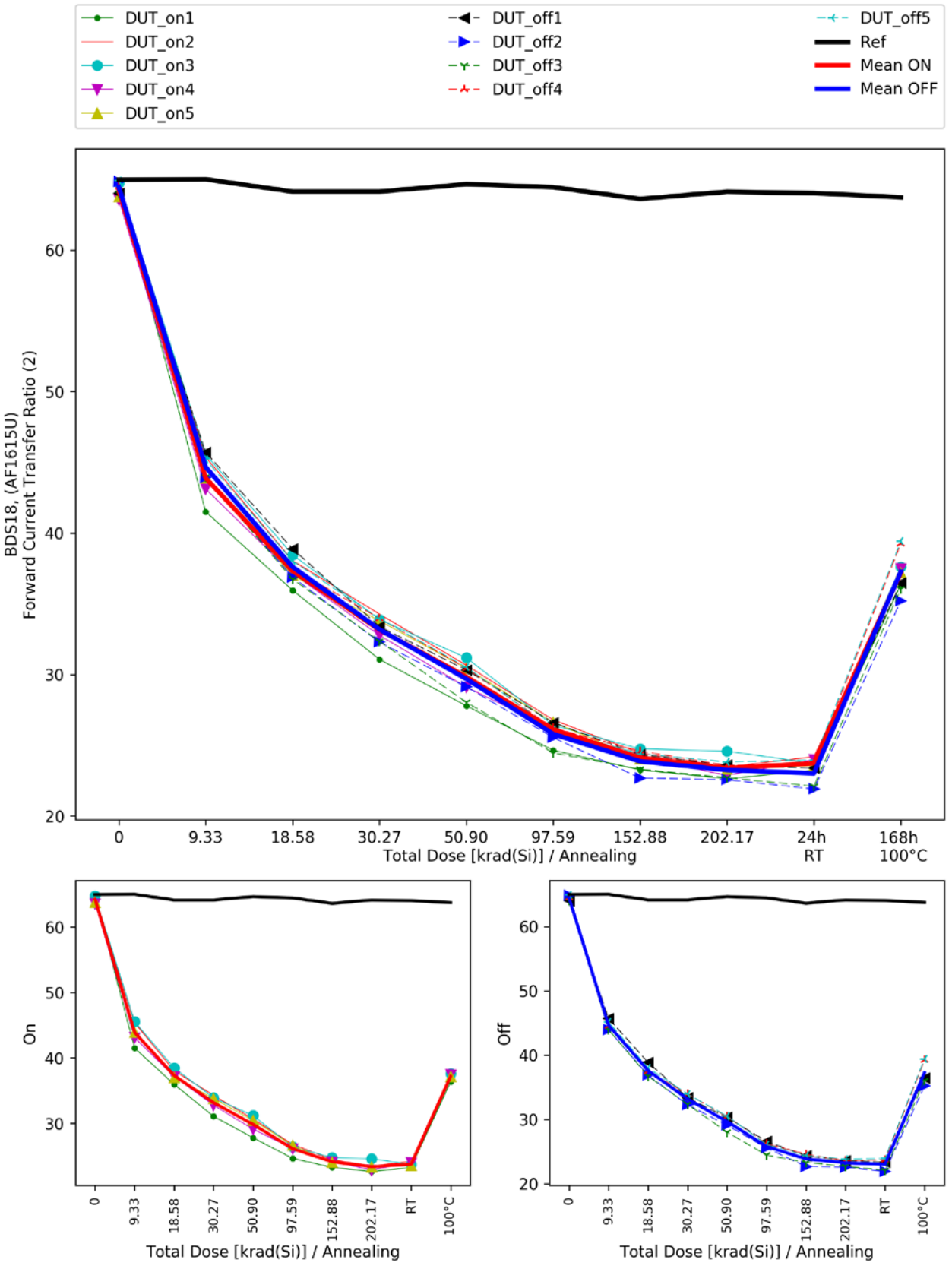
7.10 Forward Current Transfer Ratio (2)

Forward Current Transfer Ratio (2) **BDS18**
HFE 2 Date-/Lotcode: AF1615U
Limit: 15.0<x<150.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_on1	64.5E+0	41.5E+0	36.0E+0	31.1E+0	27.8E+0	24.6E+0	23.3E+0	22.6E+0	23.2E+0	36.4E+0
DUT_on2	64.7E+0	45.4E+0	38.1E+0	34.3E+0	30.7E+0	26.8E+0	24.4E+0	23.5E+0	24.2E+0	37.3E+0
DUT_on3	64.7E+0	45.5E+0	38.5E+0	33.9E+0	31.2E+0	26.4E+0	24.7E+0	24.6E+0	23.7E+0	37.6E+0
DUT_on4	63.6E+0	43.1E+0	37.1E+0	32.8E+0	29.1E+0	26.1E+0	24.1E+0	22.9E+0	24.0E+0	37.5E+0
DUT_on5	63.8E+0	43.9E+0	37.0E+0	33.8E+0	30.4E+0	26.6E+0	24.0E+0	23.3E+0	23.5E+0	37.2E+0
Radiation-Mean ON	64.2E+0	43.9E+0	37.3E+0	33.2E+0	29.8E+0	26.1E+0	24.1E+0	23.4E+0	23.7E+0	37.2E+0
Standarddeviation	533.4E-3	1.7E+0	980.4E-3	1.3E+0	1.4E+0	861.3E-3	556.2E-3	754.2E-3	368.2E-3	497.2E-3
Mean + kσ	65.7E+0	48.5E+0	40.0E+0	36.7E+0	33.6E+0	28.5E+0	25.7E+0	25.4E+0	24.7E+0	38.6E+0
Mean - kσ	62.8E+0	39.3E+0	34.6E+0	29.6E+0	26.1E+0	23.8E+0	22.6E+0	21.3E+0	22.7E+0	35.8E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
DUT_off1	64.0E+0	45.7E+0	38.9E+0	33.4E+0	30.3E+0	26.6E+0	24.3E+0	23.6E+0	23.4E+0	36.5E+0
DUT_off2	64.8E+0	43.9E+0	36.9E+0	32.3E+0	29.1E+0	25.5E+0	22.7E+0	22.6E+0	21.9E+0	35.2E+0
DUT_off3	64.0E+0	44.0E+0	36.7E+0	32.4E+0	28.0E+0	24.5E+0	23.3E+0	22.7E+0	22.1E+0	36.1E+0
DUT_off4	64.5E+0	44.5E+0	37.5E+0	34.0E+0	30.4E+0	26.2E+0	24.6E+0	23.6E+0	23.7E+0	39.2E+0
DUT_off5	64.9E+0	45.2E+0	38.0E+0	34.0E+0	30.5E+0	26.1E+0	24.4E+0	23.8E+0	24.0E+0	39.4E+0
Radiation-Mean OFF	64.5E+0	44.7E+0	37.6E+0	33.2E+0	29.7E+0	25.8E+0	23.9E+0	23.3E+0	23.0E+0	37.3E+0
Standarddeviation	429.2E-3	773.8E-3	881.0E-3	828.8E-3	1.1E+0	832.9E-3	823.8E-3	568.8E-3	947.3E-3	1.9E+0
Mean + kσ	65.6E+0	46.8E+0	40.0E+0	35.5E+0	32.7E+0	28.1E+0	26.1E+0	24.8E+0	25.6E+0	42.6E+0
Mean - kσ	63.3E+0	42.5E+0	35.2E+0	30.9E+0	26.7E+0	23.5E+0	21.6E+0	21.7E+0	20.4E+0	32.0E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	9.33	18.58	30.27	50.90	97.59	152.88	202.17	24h @RT	168h @100°C
Ref1	65.0E+0	65.0E+0	64.1E+0	64.1E+0	64.7E+0	64.4E+0	63.6E+0	64.1E+0	64.0E+0	63.7E+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


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
BDS18, (AF1615U)
Forward Current Transfer Ratio (2)
Total Dose [krad(Si)] / Annealing
0
9.33
18.58
30.27
50.90
97.59
152.88
202.17
24h
RT
168h
100°C
On
Off

8 Results HDR

8.1 Overview: Pass/Fail

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	10	20	30	50	100	150	200	24h @RT	168h @100°C
V_BR_CEO	On										
	Off										
I (V_BR_CEO)	On										
	Off										
ICEO	On										
	Off										
IEBO	On										
	Off										
VCESAT_1	On										
	Off										
VCESAT_2	On										
	Off										
VBEon	On										
	Off										
HFE 1	On				3	5	5	5	5	5	
	Off				2	5	5	5	5	5	
HFE 2	On										
	Off										

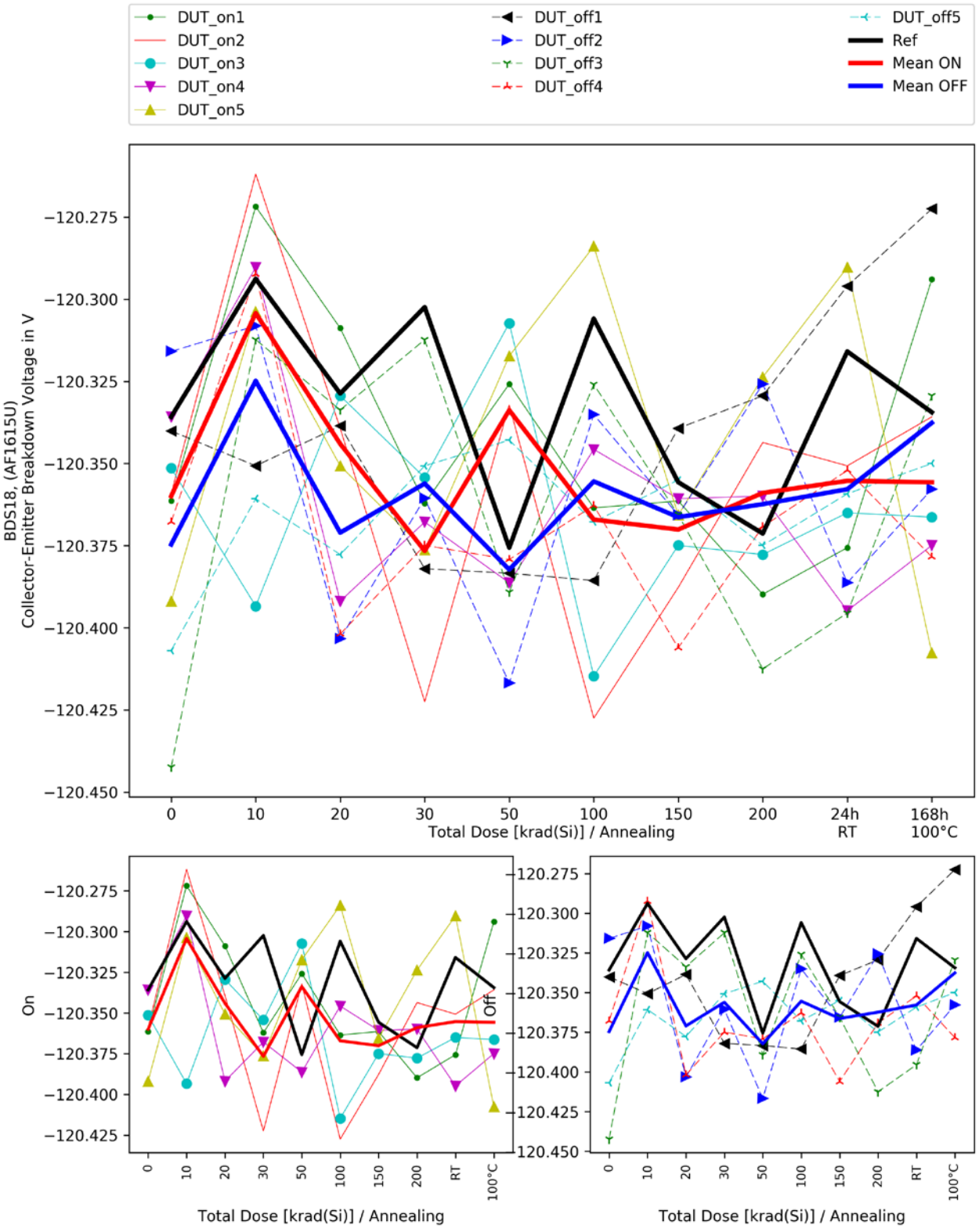
8.2 Collector-Emitter Breakdown Voltage

Collector-Emitter Breakdown Voltage **BDS18**
V_BR_CEO in V Date-/Lotcode: AF1615U
Limit: x <-120.0

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	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.3E+0
DUT_on2	-120.4E+0	-120.3E+0	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.3E+0
DUT_on3	-120.4E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0
DUT_on4	-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	-120.4E+0
DUT_on5	-120.4E+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	-120.4E+0
Radiation-Mean ON	-120.4E+0	-120.3E+0	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0
Standarddeviation	20.5E-3	52.4E-3	30.9E-3	26.9E-3	30.8E-3	57.7E-3	11.4E-3	26.4E-3	39.7E-3	43.0E-3
Mean + kσ	-120.3E+0	-120.2E+0	-120.3E+0	-120.3E+0	-120.2E+0	-120.2E+0	-120.3E+0	-120.3E+0	-120.2E+0	-120.2E+0
Mean - kσ	-120.4E+0	-120.4E+0	-120.4E+0	-120.5E+0	-120.4E+0	-120.5E+0	-120.4E+0	-120.4E+0	-120.5E+0	-120.5E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0
DUT_off2	-120.3E+0	-120.3E+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_off3	-120.4E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.3E+0
DUT_off4	-120.4E+0	-120.3E+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
DUT_off5	-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	-120.4E+0
Radiation-Mean OFF	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.4E+0	-120.3E+0
Standarddeviation	50.8E-3	29.3E-3	33.5E-3	27.4E-3	26.5E-3	24.5E-3	24.7E-3	35.9E-3	39.0E-3	40.4E-3
Mean + kσ	-120.2E+0	-120.2E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.2E+0
Mean - kσ	-120.5E+0	-120.4E+0	-120.5E+0	-120.4E+0	-120.5E+0	-120.4E+0	-120.4E+0	-120.5E+0	-120.5E+0	-120.4E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-120.3E+0	-120.3E+0	-120.3E+0	-120.3E+0	-120.4E+0	-120.3E+0	-120.4E+0	-120.4E+0	-120.3E+0	-120.3E+0
Max. 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
BDS18, (AF1615U)
Collector-Emitter Breakdown Voltage in V
−120.275
−120.300
−120.325
−120.350
−120.375
−120.400
−120.425
−120.450
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

8.3 ICE @ V_BR_CEO

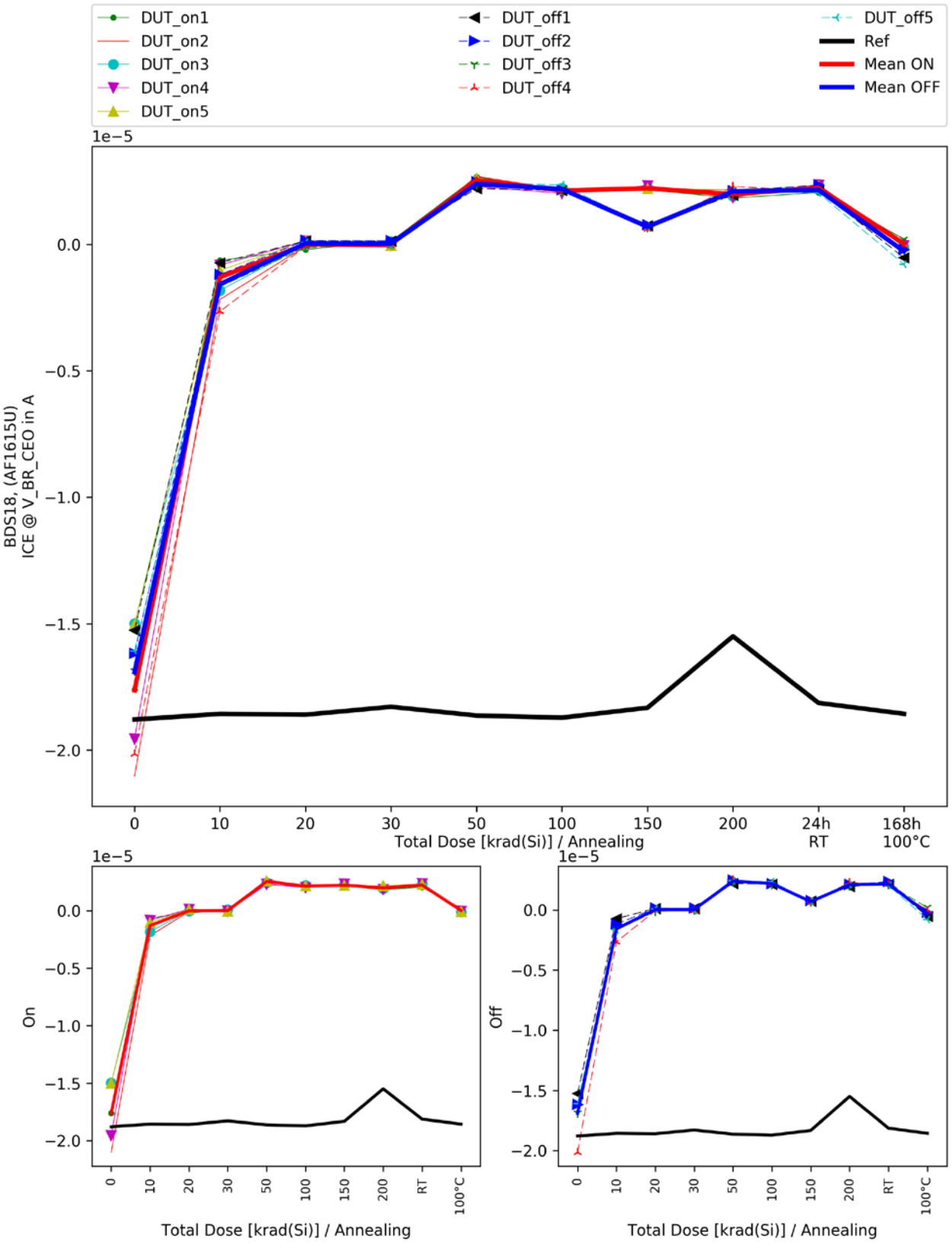
ICE@V_BR_CEO
I (V_BR_CEO) in A
Limit: -0.01<x

BDS18
Date-/Lotcode: AF1615U

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-17.6E-6	-635.7E-9	-203.1E-9	125.7E-9	2.7E-6	2.1E-6	2.2E-6	1.8E-6	2.1E-6	112.2E-9
DUT_on2	-21.0E-6	-2.2E-6	-77.1E-9	-104.0E-9	2.7E-6	2.2E-6	2.1E-6	2.2E-6	2.1E-6	206.8E-9
DUT_on3	-15.0E-6	-1.8E-6	-18.5E-9	107.7E-9	2.4E-6	2.2E-6	2.3E-6	1.9E-6	2.4E-6	-108.6E-9
DUT_on4	-19.6E-6	-820.6E-9	139.2E-9	-32.0E-9	2.3E-6	2.0E-6	2.3E-6	1.9E-6	2.4E-6	-36.6E-9
DUT_on5	-15.0E-6	-1.0E-6	134.7E-9	-36.5E-9	2.6E-6	2.2E-6	2.2E-6	2.2E-6	2.3E-6	-68.0E-9
Radiation-Mean ON	-17.6E-6	-1.3E-6	-5.0E-9	12.2E-9	2.5E-6	2.1E-6	2.2E-6	2.0E-6	2.2E-6	21.2E-9
Standarddeviation	2.7E-6	667.1E-9	145.7E-9	99.8E-9	168.4E-9	79.2E-9	73.4E-9	165.1E-9	146.6E-9	133.1E-9
Mean + kσ	-10.3E-6	532.5E-9	394.6E-9	285.8E-9	3.0E-6	2.3E-6	2.4E-6	2.4E-6	2.6E-6	386.1E-9
Mean - kσ	-25.0E-6	-3.1E-6	-404.5E-9	-261.4E-9	2.1E-6	1.9E-6	2.0E-6	1.5E-6	1.8E-6	-343.8E-9

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-15.3E-6	-726.0E-9	134.7E-9	130.2E-9	2.2E-6	2.1E-6	734.6E-9	1.9E-6	2.1E-6	-532.2E-9
DUT_off2	-16.2E-6	-1.2E-6	152.7E-9	139.2E-9	2.5E-6	2.2E-6	760.0E-9	2.1E-6	2.3E-6	-212.1E-9
DUT_off3	-16.9E-6	-1.7E-6	-122.1E-9	8.6E-9	2.4E-6	2.1E-6	662.9E-9	2.0E-6	2.1E-6	202.3E-9
DUT_off4	-20.2E-6	-2.7E-6	-77.1E-9	-59.0E-9	2.5E-6	2.2E-6	610.4E-9	2.3E-6	2.1E-6	-50.0E-9
DUT_off5	-16.1E-6	-1.6E-6	89.7E-9	-72.5E-9	2.4E-6	2.4E-6	700.2E-9	2.1E-6	2.0E-6	-789.1E-9
Radiation-Mean OFF	-16.9E-6	-1.6E-6	35.6E-9	29.3E-9	2.4E-6	2.2E-6	693.6E-9	2.1E-6	2.2E-6	-276.2E-9
Standarddeviation	1.9E-6	713.4E-9	126.5E-9	101.1E-9	117.3E-9	94.7E-9	59.2E-9	129.1E-9	113.8E-9	391.4E-9
Mean + kσ	-11.7E-6	380.2E-9	382.5E-9	306.4E-9	2.7E-6	2.4E-6	855.8E-9	2.4E-6	2.5E-6	797.0E-9
Mean - kσ	-22.1E-6	-3.5E-6	-311.4E-9	-247.8E-9	2.1E-6	1.9E-6	531.4E-9	1.7E-6	1.8E-6	-1.3E-6

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-18.8E-6	-18.6E-6	-18.6E-6	-18.3E-6	-18.6E-6	-18.7E-6	-18.3E-6	-15.5E-6	-18.1E-6	-18.6E-6
Min. Value	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3	-10.0E-3


DUT_on1
DUT_on2
DUT_on3
DUT_on4
DUT_on5
DUT_off1
DUT_off2
DUT_off3
DUT_off4
DUT_off5
Ref
Mean ON
Mean OFF
1e−5
BDS18, (AF1615U)
ICE @ V_BR_CEO in A
Total Dose [krad(Si)] / Annealing
On
Off

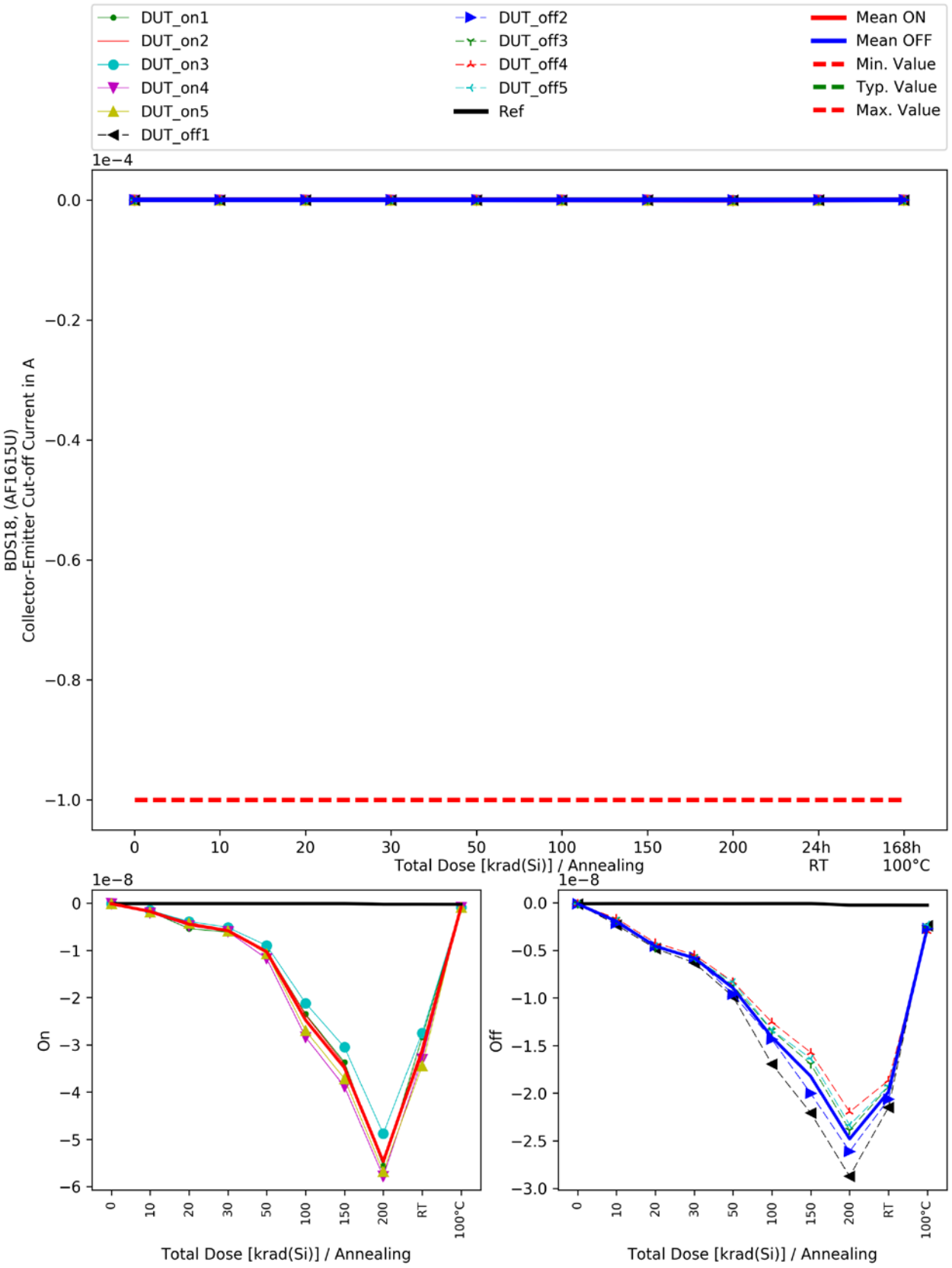
8.4 Collector-Emitter Cut-off Current

Collector-Emitter Cut-off Current **BDS18**
ICEO in A Date-/Lotcode: AF1615U
Limit: -0.0001<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-118.0E-12	-1.8E-9	-5.4E-9	-6.1E-9	-10.0E-9	-23.5E-9	-33.7E-9	-55.6E-9	-28.4E-9	-866.3E-12
DUT_on2	-112.8E-12	-1.5E-9	-4.1E-9	-5.9E-9	-10.0E-9	-23.7E-9	-34.1E-9	-54.5E-9	-32.4E-9	-941.4E-12
DUT_on3	-120.5E-12	-1.5E-9	-3.9E-9	-5.1E-9	-9.0E-9	-21.2E-9	-30.5E-9	-48.8E-9	-27.5E-9	-865.1E-12
DUT_on4	-113.2E-12	-2.1E-9	-4.8E-9	-6.0E-9	-11.7E-9	-28.4E-9	-38.8E-9	-57.8E-9	-33.1E-9	-899.2E-12
DUT_on5	-121.6E-12	-1.9E-9	-4.3E-9	-5.9E-9	-10.7E-9	-27.0E-9	-37.2E-9	-56.8E-9	-34.5E-9	-882.4E-12
Radiation-Mean ON	-117.2E-12	-1.8E-9	-4.5E-9	-5.8E-9	-10.3E-9	-24.7E-9	-34.9E-9	-54.7E-9	-31.2E-9	-890.9E-12
Standarddeviation	4.1E-12	236.4E-12	612.9E-12	393.1E-12	1.0E-9	2.9E-9	3.2E-9	3.5E-9	3.0E-9	31.5E-12
Mean + kσ	-106.1E-12	-1.1E-9	-2.8E-9	-4.7E-9	-7.5E-9	-16.8E-9	-26.0E-9	-45.0E-9	-22.8E-9	-804.6E-12
Mean - kσ	-128.4E-12	-2.4E-9	-6.2E-9	-6.9E-9	-13.1E-9	-32.7E-9	-43.8E-9	-64.4E-9	-39.5E-9	-977.2E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-116.0E-12	-2.3E-9	-4.8E-9	-6.3E-9	-9.9E-9	-16.9E-9	-22.1E-9	-28.7E-9	-21.5E-9	-2.4E-9
DUT_off2	-116.4E-12	-2.2E-9	-4.6E-9	-5.7E-9	-9.6E-9	-14.3E-9	-20.0E-9	-26.1E-9	-20.6E-9	-2.7E-9
DUT_off3	-118.5E-12	-1.8E-9	-4.7E-9	-5.6E-9	-8.7E-9	-13.4E-9	-16.9E-9	-23.9E-9	-19.3E-9	-2.7E-9
DUT_off4	-114.0E-12	-1.7E-9	-4.2E-9	-5.5E-9	-8.3E-9	-12.5E-9	-15.7E-9	-22.0E-9	-18.7E-9	-3.0E-9
DUT_off5	-115.4E-12	-1.9E-9	-4.5E-9	-5.9E-9	-8.3E-9	-13.4E-9	-16.4E-9	-23.3E-9	-19.2E-9	-2.3E-9
Radiation-Mean OFF	-116.1E-12	-2.0E-9	-4.6E-9	-5.8E-9	-9.0E-9	-14.1E-9	-18.2E-9	-24.8E-9	-19.9E-9	-2.6E-9
Standarddeviation	1.6E-12	281.0E-12	231.9E-12	313.6E-12	731.0E-12	1.7E-9	2.7E-9	2.7E-9	1.2E-9	279.1E-12
Mean + kσ	-111.6E-12	-1.2E-9	-3.9E-9	-4.9E-9	-7.0E-9	-9.5E-9	-10.8E-9	-17.5E-9	-16.7E-9	-1.9E-9
Mean - kσ	-120.5E-12	-2.7E-9	-5.2E-9	-6.7E-9	-11.0E-9	-18.8E-9	-25.7E-9	-32.1E-9	-23.1E-9	-3.4E-9

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-112.7E-12	-92.8E-12	-96.4E-12	-93.4E-12	-99.7E-12	-90.6E-12	-89.3E-12	-252.6E-12	-250.7E-12	-263.1E-12
Min. 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
BDS18, (AF1615U)
Collector-Emitter Cut-off Current in A
Total Dose [krad(Si)] / Annealing
1e−8
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

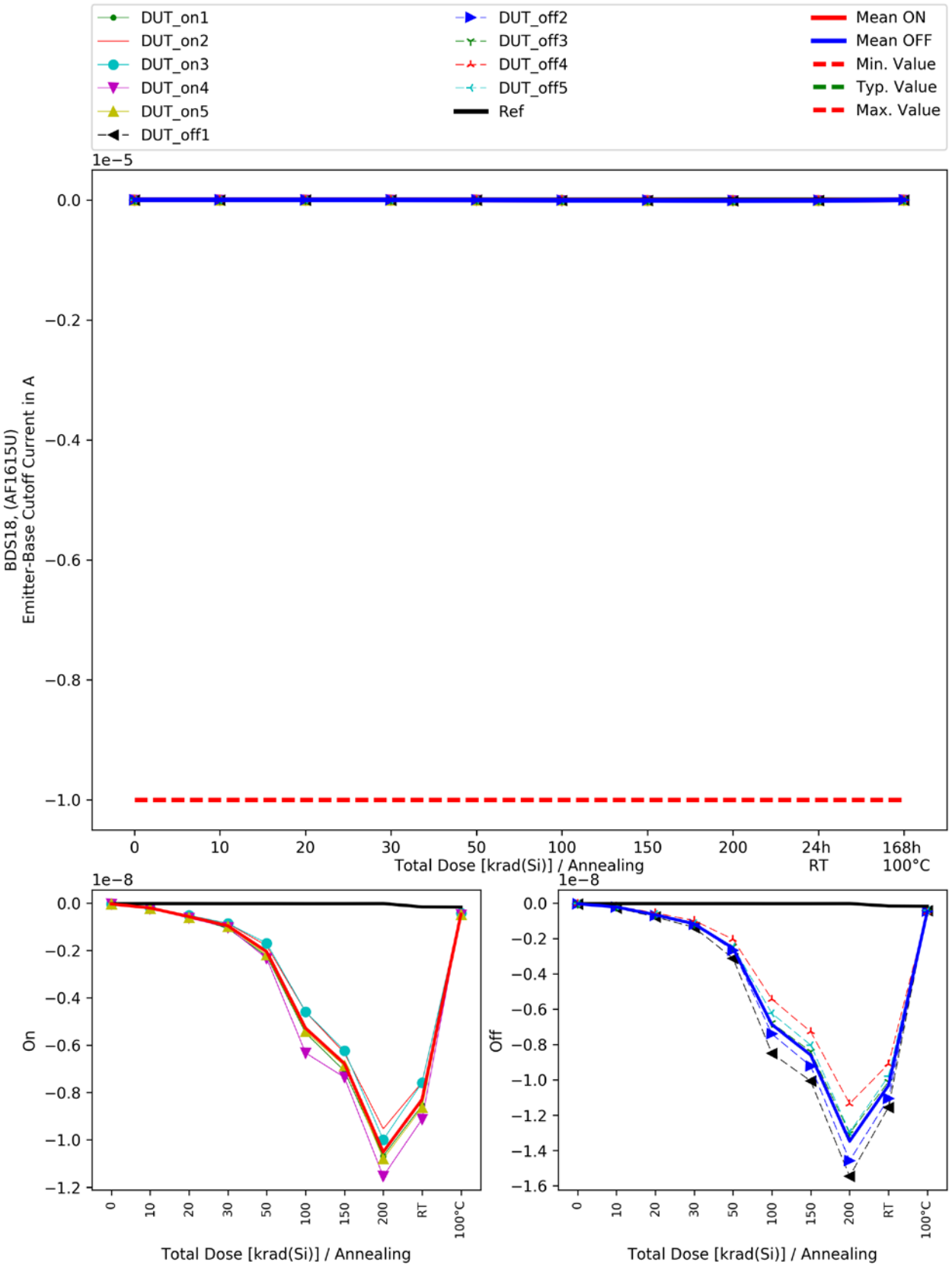
8.5 Emitter-Base Cutoff Current

Emitter-Base Cutoff Current **BDS18**
IEBO in A Date-/Lotcode: AF1615U
Limit: -1e-05<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-32.7E-12	-217.7E-12	-577.8E-12	-1.1E-9	-2.2E-9	-5.5E-9	-7.1E-9	-10.7E-9	-8.5E-9	-442.9E-12
DUT_on2	-36.5E-12	-174.6E-12	-519.0E-12	-866.4E-12	-1.8E-9	-4.6E-9	-6.3E-9	-9.5E-9	-7.6E-9	-464.3E-12
DUT_on3	-38.6E-12	-185.3E-12	-521.3E-12	-866.9E-12	-1.7E-9	-4.6E-9	-6.2E-9	-10.0E-9	-7.6E-9	-429.3E-12
DUT_on4	-34.7E-12	-232.4E-12	-634.3E-12	-1.0E-9	-2.3E-9	-6.3E-9	-7.4E-9	-11.5E-9	-9.1E-9	-485.4E-12
DUT_on5	-35.5E-12	-215.9E-12	-607.0E-12	-988.1E-12	-2.2E-9	-5.4E-9	-6.9E-9	-10.8E-9	-8.6E-9	-483.1E-12
Radiation-Mean ON	-35.6E-12	-205.2E-12	-571.9E-12	-958.7E-12	-2.1E-9	-5.3E-9	-6.8E-9	-10.5E-9	-8.3E-9	-461.0E-12
Standarddeviation	2.2E-12	24.2E-12	51.3E-12	97.4E-12	283.6E-12	726.7E-12	486.1E-12	774.1E-12	685.6E-12	24.6E-12
Mean + kσ	-29.5E-12	-138.8E-12	-431.3E-12	-691.7E-12	-1.3E-9	-3.3E-9	-5.4E-9	-8.4E-9	-6.4E-9	-393.5E-12
Mean - kσ	-41.6E-12	-271.6E-12	-712.5E-12	-1.2E-9	-2.8E-9	-7.3E-9	-8.1E-9	-12.6E-9	-10.2E-9	-528.5E-12

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-33.6E-12	-267.0E-12	-777.4E-12	-1.4E-9	-3.1E-9	-8.5E-9	-10.1E-9	-15.5E-9	-11.6E-9	-412.8E-12
DUT_off2	-34.4E-12	-231.9E-12	-715.0E-12	-1.2E-9	-2.7E-9	-7.4E-9	-9.2E-9	-14.6E-9	-11.1E-9	-460.8E-12
DUT_off3	-34.5E-12	-204.9E-12	-639.4E-12	-1.2E-9	-2.5E-9	-6.8E-9	-8.4E-9	-13.0E-9	-10.1E-9	-490.3E-12
DUT_off4	-29.2E-12	-171.9E-12	-549.2E-12	-986.7E-12	-2.0E-9	-5.4E-9	-7.3E-9	-11.4E-9	-9.1E-9	-509.3E-12
DUT_off5	-31.7E-12	-196.6E-12	-604.7E-12	-1.1E-9	-2.5E-9	-6.2E-9	-8.0E-9	-13.0E-9	-9.8E-9	-396.8E-12
Radiation-Mean OFF	-32.7E-12	-214.5E-12	-657.2E-12	-1.2E-9	-2.5E-9	-6.9E-9	-8.6E-9	-13.5E-9	-10.3E-9	-454.0E-12
Standarddeviation	2.2E-12	36.4E-12	90.2E-12	141.4E-12	392.7E-12	1.2E-9	1.1E-9	1.6E-9	983.1E-12	48.5E-12
Mean + kσ	-26.5E-12	-114.7E-12	-409.9E-12	-787.4E-12	-1.5E-9	-3.7E-9	-5.6E-9	-9.1E-9	-7.6E-9	-321.2E-12
Mean - kσ	-38.8E-12	-314.2E-12	-904.4E-12	-1.6E-9	-3.6E-9	-10.1E-9	-11.6E-9	-17.8E-9	-13.0E-9	-586.9E-12

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-30.2E-12	-19.0E-12	-19.6E-12	-22.8E-12	-21.0E-12	-24.8E-12	-23.8E-12	-19.5E-12	-160.4E-12	-171.0E-12
Min. 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
BDS18, (AF1615U)
Emitter-Base Cutoff Current in A
Total Dose [krad(Si)] / Annealing
1e−8
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

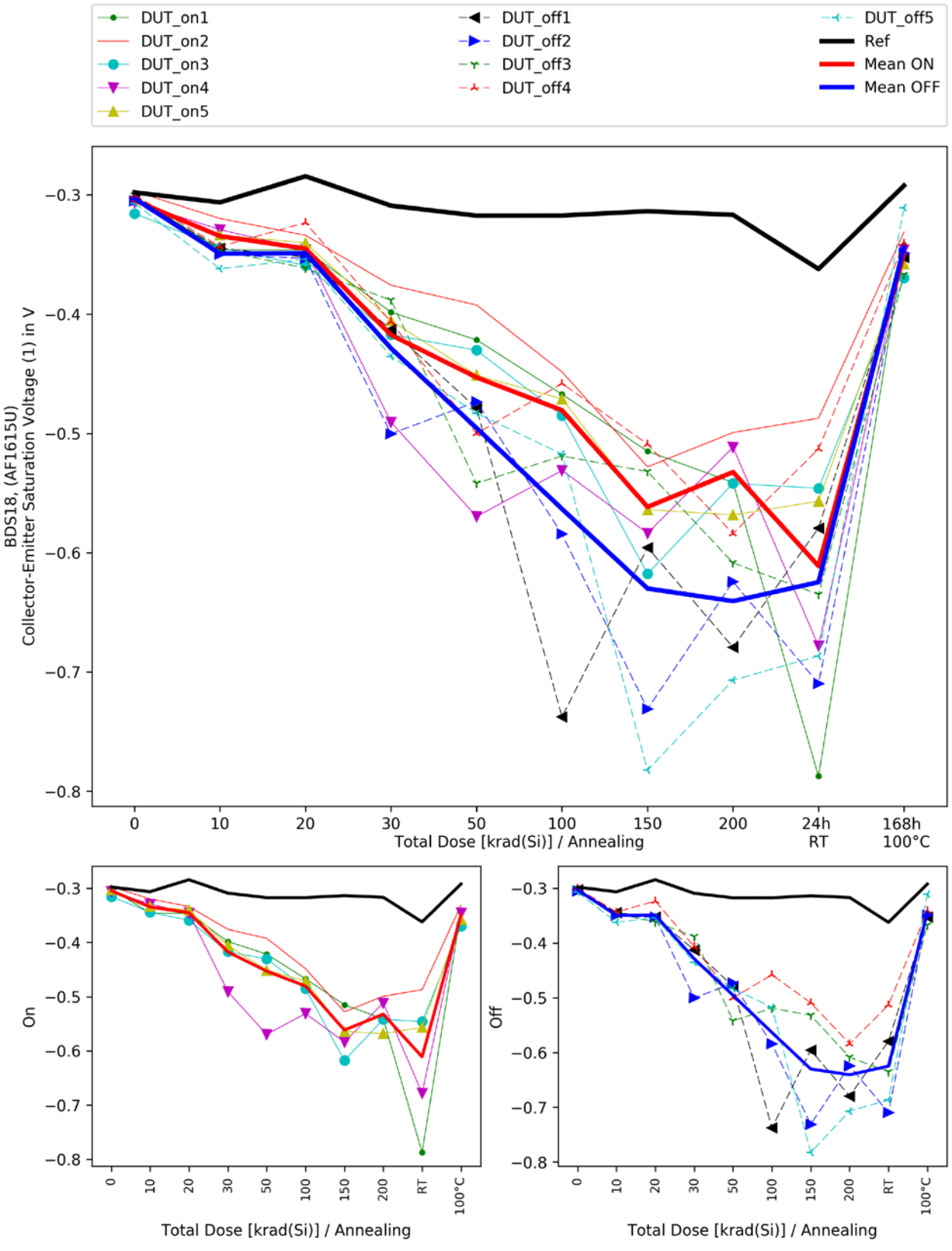
8.6 Collector-Emitter Saturation Voltage (1)

Collector-Emitter Saturation Voltage (1) **BDS18**
VCESAT_1 in V Date-/Lotcode: AF1615U
Limit: -1.5<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-301.2E-3	-346.1E-3	-346.2E-3	-398.4E-3	-421.6E-3	-467.2E-3	-514.9E-3	-541.1E-3	-787.3E-3	-341.8E-3
DUT_on2	-297.0E-3	-319.8E-3	-333.9E-3	-375.8E-3	-392.4E-3	-448.4E-3	-528.0E-3	-499.3E-3	-487.3E-3	-331.1E-3
DUT_on3	-315.6E-3	-344.3E-3	-359.2E-3	-417.2E-3	-430.3E-3	-485.1E-3	-617.7E-3	-541.9E-3	-545.9E-3	-369.8E-3
DUT_on4	-306.1E-3	-329.2E-3	-345.9E-3	-490.6E-3	-569.7E-3	-531.1E-3	-583.7E-3	-511.6E-3	-678.2E-3	-345.9E-3
DUT_on5	-303.1E-3	-333.6E-3	-340.4E-3	-405.5E-3	-451.2E-3	-471.0E-3	-563.8E-3	-568.3E-3	-556.8E-3	-357.8E-3
Radiation-Mean ON	-304.6E-3	-334.6E-3	-345.1E-3	-417.5E-3	-453.0E-3	-480.6E-3	-561.6E-3	-532.5E-3	-611.1E-3	-349.3E-3
Standarddeviation	7.0E-3	10.9E-3	9.3E-3	43.6E-3	68.5E-3	31.1E-3	41.7E-3	27.3E-3	120.5E-3	14.9E-3
Mean + kσ	-285.5E-3	-304.8E-3	-319.5E-3	-298.0E-3	-265.1E-3	-395.3E-3	-447.3E-3	-457.5E-3	-280.7E-3	-308.4E-3
Mean - kσ	-323.8E-3	-364.4E-3	-370.7E-3	-537.0E-3	-641.0E-3	-565.9E-3	-675.9E-3	-607.4E-3	-941.5E-3	-390.2E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-302.5E-3	-344.7E-3	-352.1E-3	-412.9E-3	-478.9E-3	-737.6E-3	-595.6E-3	-679.3E-3	-579.4E-3	-352.5E-3
DUT_off2	-305.2E-3	-350.0E-3	-353.3E-3	-500.4E-3	-473.5E-3	-584.4E-3	-731.1E-3	-624.3E-3	-709.8E-3	-349.0E-3
DUT_off3	-300.2E-3	-346.6E-3	-361.5E-3	-388.3E-3	-541.8E-3	-519.0E-3	-532.0E-3	-608.5E-3	-634.9E-3	-366.9E-3
DUT_off4	-300.2E-3	-343.4E-3	-323.3E-3	-406.5E-3	-500.2E-3	-458.1E-3	-509.1E-3	-583.9E-3	-513.0E-3	-340.7E-3
DUT_off5	-306.9E-3	-362.0E-3	-354.0E-3	-435.3E-3	-483.2E-3	-517.3E-3	-782.3E-3	-706.8E-3	-686.6E-3	-310.7E-3
Radiation-Mean OFF	-303.0E-3	-349.3E-3	-348.8E-3	-428.7E-3	-495.5E-3	-563.3E-3	-630.0E-3	-640.6E-3	-624.7E-3	-344.0E-3
Standarddeviation	3.0E-3	7.5E-3	14.7E-3	43.5E-3	27.8E-3	107.2E-3	121.3E-3	51.0E-3	80.1E-3	20.9E-3
Mean + kσ	-294.8E-3	-328.8E-3	-308.4E-3	-309.5E-3	-419.4E-3	-269.3E-3	-297.5E-3	-500.8E-3	-405.0E-3	-286.8E-3
Mean - kσ	-311.3E-3	-369.9E-3	-389.3E-3	-547.8E-3	-571.6E-3	-857.3E-3	-962.6E-3	-780.3E-3	-844.5E-3	-401.2E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-298.0E-3	-306.4E-3	-284.4E-3	-309.1E-3	-317.4E-3	-317.3E-3	-313.7E-3	-316.8E-3	-362.2E-3	-292.2E-3
Min. 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
BDS18, (AF1615U)
Collector-Emitter Saturation Voltage (1) in V
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

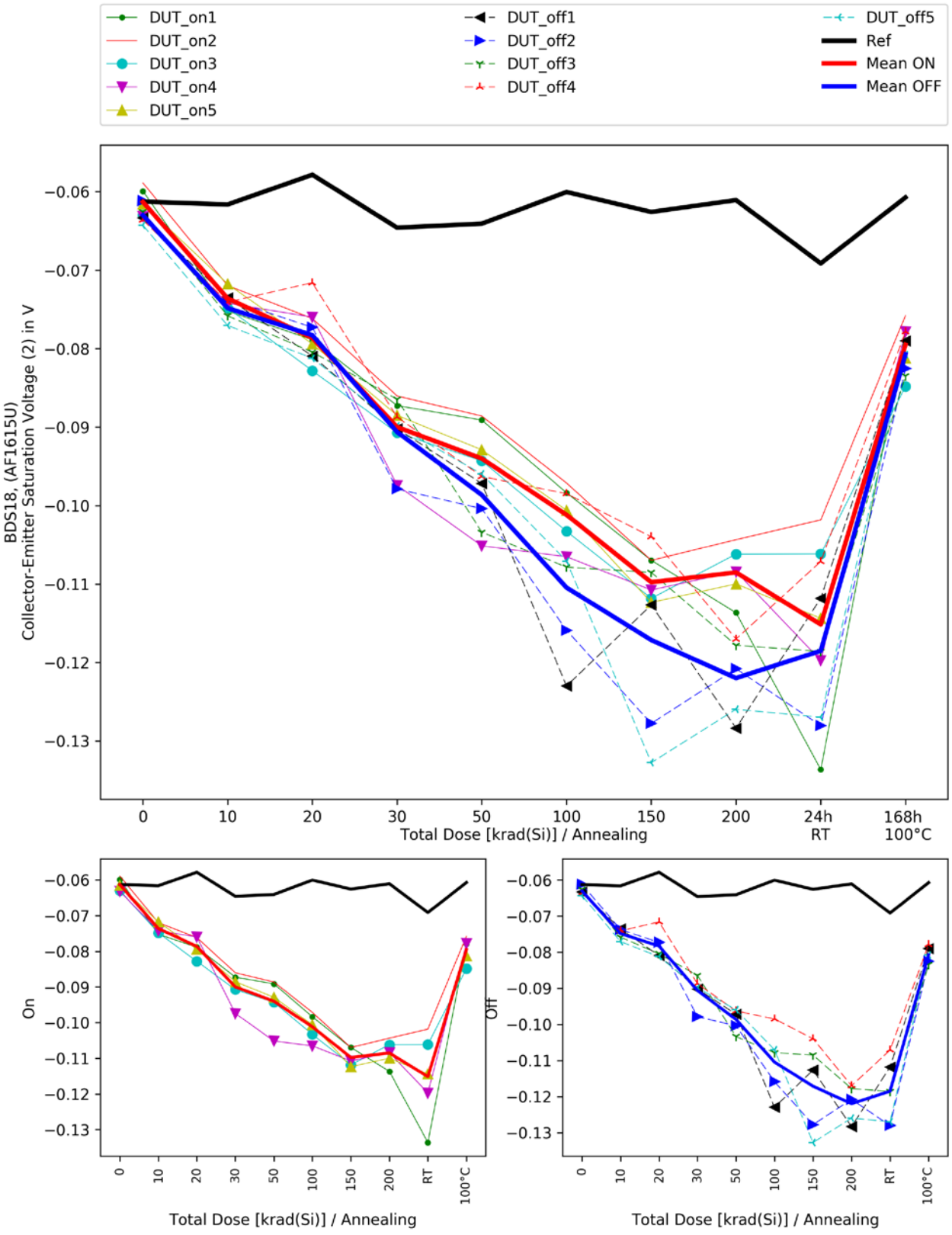
8.7 Collector-Emitter Saturation Voltage (2)

Collector-Emitter Saturation Voltage (2) **BDS18**
VCESAT_2 in V Date-/Lotcode: AF1615U
Limit: -0.4<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-59.9E-3	-75.2E-3	-78.9E-3	-87.3E-3	-89.1E-3	-98.4E-3	-107.0E-3	-113.7E-3	-133.6E-3	-77.9E-3
DUT_on2	-58.9E-3	-72.0E-3	-76.2E-3	-86.0E-3	-88.6E-3	-97.1E-3	-107.0E-3	-104.4E-3	-101.8E-3	-75.8E-3
DUT_on3	-63.0E-3	-74.8E-3	-82.8E-3	-90.7E-3	-94.3E-3	-103.3E-3	-111.8E-3	-106.2E-3	-106.2E-3	-84.8E-3
DUT_on4	-63.2E-3	-74.2E-3	-76.0E-3	-97.4E-3	-105.1E-3	-106.5E-3	-110.8E-3	-108.4E-3	-119.7E-3	-77.8E-3
DUT_on5	-61.6E-3	-71.8E-3	-79.4E-3	-88.5E-3	-92.9E-3	-100.6E-3	-112.3E-3	-110.0E-3	-114.4E-3	-81.2E-3
Radiation-Mean ON	-61.3E-3	-73.6E-3	-78.6E-3	-90.0E-3	-94.0E-3	-101.2E-3	-109.8E-3	-108.5E-3	-115.1E-3	-79.5E-3
Standarddeviation	1.9E-3	1.6E-3	2.8E-3	4.5E-3	6.7E-3	3.8E-3	2.6E-3	3.6E-3	12.5E-3	3.6E-3
Mean + kσ	-56.2E-3	-69.1E-3	-71.0E-3	-77.6E-3	-75.7E-3	-90.8E-3	-102.6E-3	-98.7E-3	-81.0E-3	-69.8E-3
Mean - kσ	-66.5E-3	-78.1E-3	-86.3E-3	-102.3E-3	-112.3E-3	-111.6E-3	-116.9E-3	-118.4E-3	-149.3E-3	-89.3E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-63.4E-3	-73.5E-3	-80.9E-3	-90.2E-3	-97.2E-3	-123.0E-3	-112.7E-3	-128.4E-3	-111.8E-3	-79.0E-3
DUT_off2	-61.2E-3	-73.7E-3	-77.3E-3	-97.9E-3	-100.4E-3	-115.9E-3	-127.8E-3	-120.8E-3	-128.0E-3	-82.6E-3
DUT_off3	-62.6E-3	-75.8E-3	-80.4E-3	-86.5E-3	-103.4E-3	-107.8E-3	-108.5E-3	-117.8E-3	-118.6E-3	-83.5E-3
DUT_off4	-63.6E-3	-74.1E-3	-71.6E-3	-88.7E-3	-96.3E-3	-98.5E-3	-104.0E-3	-117.0E-3	-107.1E-3	-77.8E-3
DUT_off5	-64.3E-3	-77.1E-3	-81.2E-3	-89.9E-3	-96.0E-3	-107.1E-3	-132.8E-3	-126.0E-3	-127.0E-3	-80.8E-3
Radiation-Mean OFF	-63.0E-3	-74.8E-3	-78.3E-3	-90.6E-3	-98.7E-3	-110.5E-3	-117.1E-3	-122.0E-3	-118.5E-3	-80.7E-3
Standarddeviation	1.2E-3	1.5E-3	4.1E-3	4.3E-3	3.2E-3	9.3E-3	12.5E-3	5.0E-3	9.2E-3	2.4E-3
Mean + kσ	-59.7E-3	-70.6E-3	-67.2E-3	-78.8E-3	-89.9E-3	-84.9E-3	-82.9E-3	-108.3E-3	-93.3E-3	-74.3E-3
Mean - kσ	-66.3E-3	-79.1E-3	-89.4E-3	-102.5E-3	-107.4E-3	-136.0E-3	-151.4E-3	-135.7E-3	-143.7E-3	-87.2E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-61.3E-3	-61.6E-3	-57.8E-3	-64.6E-3	-64.1E-3	-60.0E-3	-62.6E-3	-61.1E-3	-69.1E-3	-60.7E-3
Min. 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
BDS18, (AF1615U)
Collector-Emitter Saturation Voltage (2) in V
−0.06
−0.07
−0.08
−0.09
−0.10
−0.11
−0.12
−0.13
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
Off
Total Dose [krad(Si)] / Annealing
Total Dose [krad(Si)] / Annealing

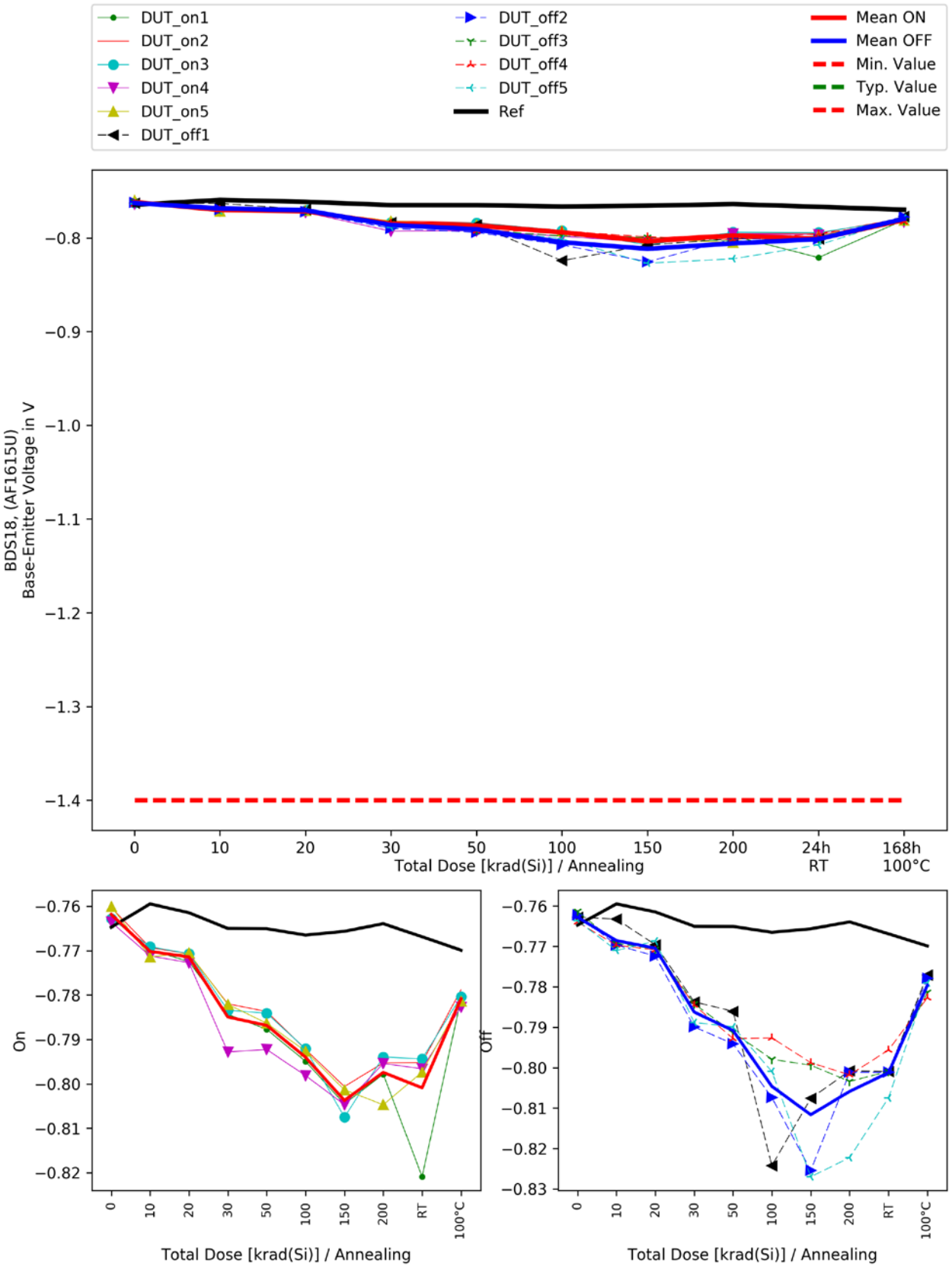
8.8 Base-Emitter Voltage

Base-Emitter Voltage **BDS18**
VBEon in V Date-/Lotcode: AF1615U
Limit: -1.4<x

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	-762.4E-3	-769.8E-3	-772.5E-3	-784.3E-3	-787.7E-3	-794.9E-3	-804.5E-3	-797.8E-3	-820.9E-3	-780.9E-3
DUT_on2	-760.3E-3	-769.3E-3	-770.7E-3	-782.0E-3	-783.7E-3	-792.2E-3	-800.6E-3	-795.3E-3	-795.2E-3	-778.8E-3
DUT_on3	-762.8E-3	-769.1E-3	-770.7E-3	-783.4E-3	-784.1E-3	-792.1E-3	-807.5E-3	-794.0E-3	-794.4E-3	-780.4E-3
DUT_on4	-763.6E-3	-771.2E-3	-772.7E-3	-792.8E-3	-792.3E-3	-798.1E-3	-804.7E-3	-795.4E-3	-796.6E-3	-782.7E-3
DUT_on5	-760.1E-3	-771.4E-3	-770.6E-3	-782.1E-3	-786.3E-3	-792.6E-3	-801.3E-3	-804.7E-3	-797.4E-3	-781.4E-3
Radiation-Mean ON	-761.8E-3	-770.2E-3	-771.4E-3	-784.9E-3	-786.8E-3	-794.0E-3	-803.7E-3	-797.4E-3	-800.9E-3	-780.8E-3
Standarddeviation	1.5E-3	1.1E-3	1.1E-3	4.5E-3	3.5E-3	2.6E-3	2.8E-3	4.3E-3	11.3E-3	1.4E-3
Mean + kσ	-757.6E-3	-767.3E-3	-768.5E-3	-772.6E-3	-777.4E-3	-786.9E-3	-796.1E-3	-785.7E-3	-770.0E-3	-777.0E-3
Mean - kσ	-766.1E-3	-773.1E-3	-774.4E-3	-797.3E-3	-796.3E-3	-801.1E-3	-811.4E-3	-809.2E-3	-831.7E-3	-784.7E-3

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	-762.8E-3	-763.3E-3	-769.6E-3	-783.7E-3	-786.1E-3	-824.2E-3	-807.6E-3	-800.8E-3	-800.9E-3	-777.1E-3
DUT_off2	-762.2E-3	-769.7E-3	-772.4E-3	-789.9E-3	-794.1E-3	-807.4E-3	-825.5E-3	-801.2E-3	-801.2E-3	-777.9E-3
DUT_off3	-761.3E-3	-769.2E-3	-770.7E-3	-784.2E-3	-791.3E-3	-797.9E-3	-799.4E-3	-803.4E-3	-800.9E-3	-781.3E-3
DUT_off4	-764.0E-3	-769.7E-3	-770.9E-3	-784.5E-3	-792.8E-3	-792.6E-3	-798.8E-3	-801.8E-3	-795.6E-3	-782.7E-3
DUT_off5	-763.6E-3	-771.0E-3	-768.7E-3	-788.8E-3	-789.9E-3	-801.0E-3	-827.0E-3	-822.3E-3	-807.5E-3	-779.1E-3
Radiation-Mean OFF	-762.8E-3	-768.6E-3	-770.5E-3	-786.2E-3	-790.8E-3	-804.6E-3	-811.6E-3	-805.9E-3	-801.2E-3	-779.6E-3
Standarddeviation	1.1E-3	3.0E-3	1.4E-3	2.9E-3	3.1E-3	12.2E-3	13.8E-3	9.2E-3	4.2E-3	2.4E-3
Mean + kσ	-759.9E-3	-760.2E-3	-766.6E-3	-778.3E-3	-782.3E-3	-771.2E-3	-773.9E-3	-780.6E-3	-789.7E-3	-773.2E-3
Mean - kσ	-765.7E-3	-776.9E-3	-774.3E-3	-794.2E-3	-799.3E-3	-838.1E-3	-849.4E-3	-831.2E-3	-812.7E-3	-786.1E-3

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	-764.8E-3	-759.5E-3	-761.5E-3	-765.0E-3	-765.1E-3	-766.5E-3	-765.7E-3	-764.0E-3	-766.9E-3	-769.9E-3
Min. Value	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+0	-1.4E+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
BDS18, (AF1615U)
Base-Emitter Voltage in V
−0.8
−0.9
−1.0
−1.1
−1.2
−1.3
−1.4
0
10
20
30
50
100
150
200
24h
RT
168h
100°C
Total Dose [krad(Si)] / Annealing
On
−0.76
−0.77
−0.78
−0.79
−0.80
−0.81
−0.82
Total Dose [krad(Si)] / Annealing
Off
−0.76
−0.77
−0.78
−0.79
−0.80
−0.81
−0.82
−0.83
Total Dose [krad(Si)] / Annealing

8.9 Forward Current Transfer Ratio (1)

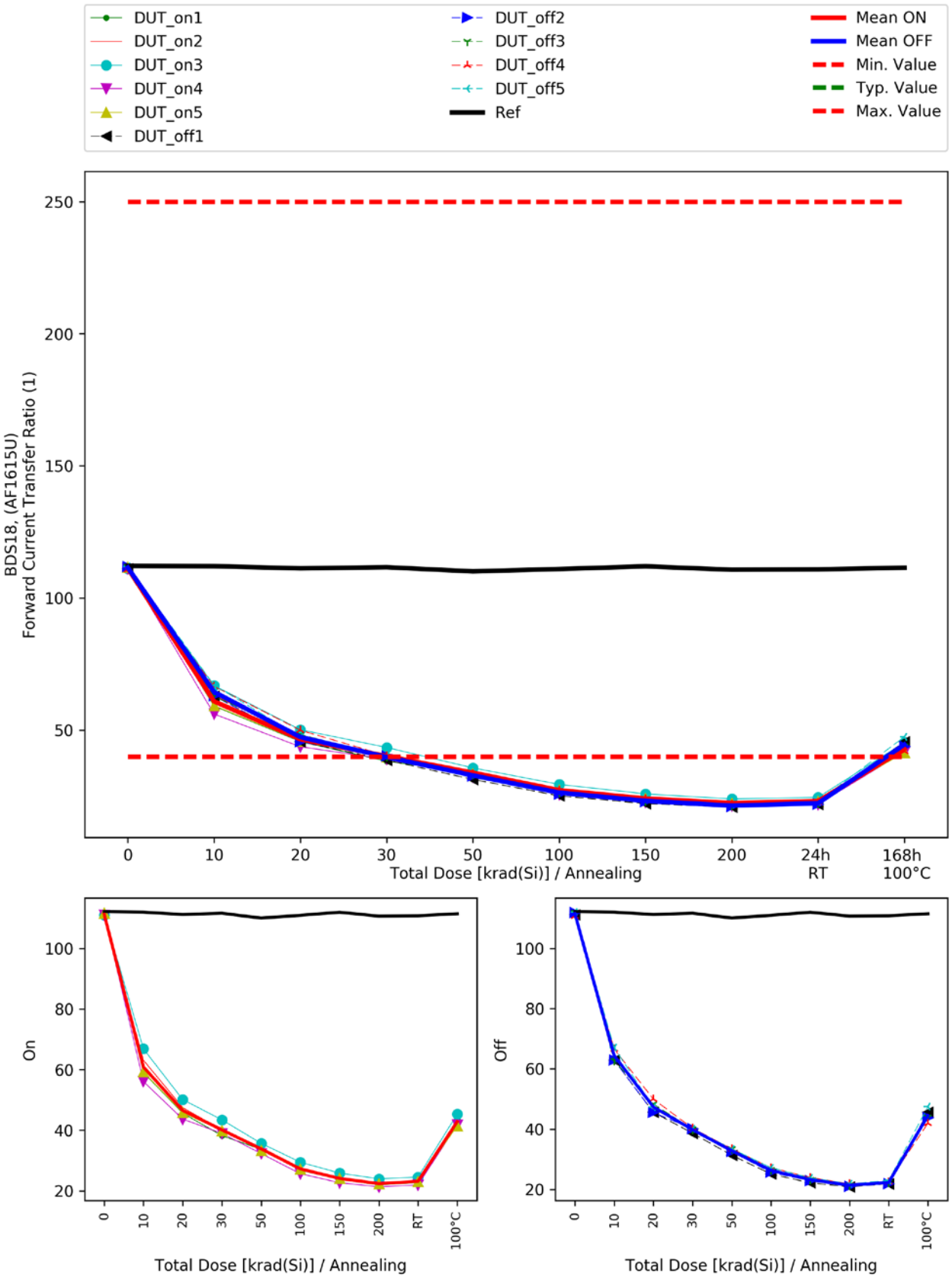
Forward Current Transfer Ratio (1) **BDS18**
HFE 1 Date-/Lotcode: AF1615U
Limit: 40.0<x<250.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	111.8E+0	59.1E+0	45.6E+0	38.2E+0	33.7E+0	26.8E+0	23.8E+0	21.9E+0	22.7E+0	43.6E+0
DUT_on2	110.8E+0	63.1E+0	47.5E+0	40.1E+0	34.2E+0	27.1E+0	24.0E+0	22.3E+0	23.3E+0	41.9E+0
DUT_on3	111.1E+0	66.9E+0	50.1E+0	43.4E+0	35.7E+0	29.4E+0	25.8E+0	23.9E+0	24.5E+0	45.3E+0
DUT_on4	111.0E+0	56.1E+0	43.7E+0	39.0E+0	32.3E+0	25.6E+0	22.7E+0	21.3E+0	21.9E+0	41.8E+0
DUT_on5	111.7E+0	59.3E+0	45.8E+0	39.9E+0	33.4E+0	27.2E+0	24.1E+0	22.3E+0	23.0E+0	41.4E+0
Radiation-Mean ON	111.3E+0	60.9E+0	46.5E+0	40.1E+0	33.8E+0	27.2E+0	24.1E+0	22.3E+0	23.1E+0	42.8E+0
Standarddeviation	441.7E-3	4.2E+0	2.4E+0	2.0E+0	1.2E+0	1.4E+0	1.1E+0	972.0E-3	953.3E-3	1.6E+0
Mean + kσ	112.5E+0	72.3E+0	53.1E+0	45.6E+0	37.2E+0	31.0E+0	27.2E+0	25.0E+0	25.7E+0	47.3E+0
Mean - kσ	110.1E+0	49.4E+0	39.9E+0	34.6E+0	30.4E+0	23.4E+0	20.9E+0	19.7E+0	20.5E+0	38.3E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	111.2E+0	62.9E+0	45.6E+0	38.6E+0	31.3E+0	25.1E+0	22.1E+0	20.8E+0	21.8E+0	45.6E+0
DUT_off2	111.7E+0	62.9E+0	45.5E+0	40.0E+0	32.5E+0	25.6E+0	22.9E+0	21.0E+0	21.9E+0	43.7E+0
DUT_off3	111.9E+0	62.7E+0	48.3E+0	39.9E+0	33.4E+0	26.5E+0	23.2E+0	21.4E+0	22.3E+0	43.9E+0
DUT_off4	110.7E+0	66.6E+0	49.9E+0	40.3E+0	33.4E+0	27.2E+0	23.9E+0	21.8E+0	22.5E+0	41.9E+0
DUT_off5	112.0E+0	67.0E+0	47.4E+0	40.1E+0	33.4E+0	27.2E+0	23.8E+0	21.8E+0	22.9E+0	47.4E+0
Radiation-Mean OFF	111.5E+0	64.4E+0	47.3E+0	39.8E+0	32.8E+0	26.3E+0	23.2E+0	21.4E+0	22.3E+0	44.5E+0
Standarddeviation	556.6E-3	2.2E+0	1.9E+0	659.9E-3	938.8E-3	932.7E-3	720.6E-3	466.3E-3	453.9E-3	2.1E+0
Mean + kσ	113.0E+0	70.4E+0	52.5E+0	41.6E+0	35.4E+0	28.9E+0	25.2E+0	22.7E+0	23.5E+0	50.2E+0
Mean - kσ	110.0E+0	58.5E+0	42.2E+0	38.0E+0	30.2E+0	23.7E+0	21.2E+0	20.1E+0	21.0E+0	38.8E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	112.2E+0	112.0E+0	111.2E+0	111.6E+0	110.0E+0	111.0E+0	112.0E+0	110.7E+0	110.8E+0	111.5E+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

8.10 Forward Current Transfer Ratio (2)

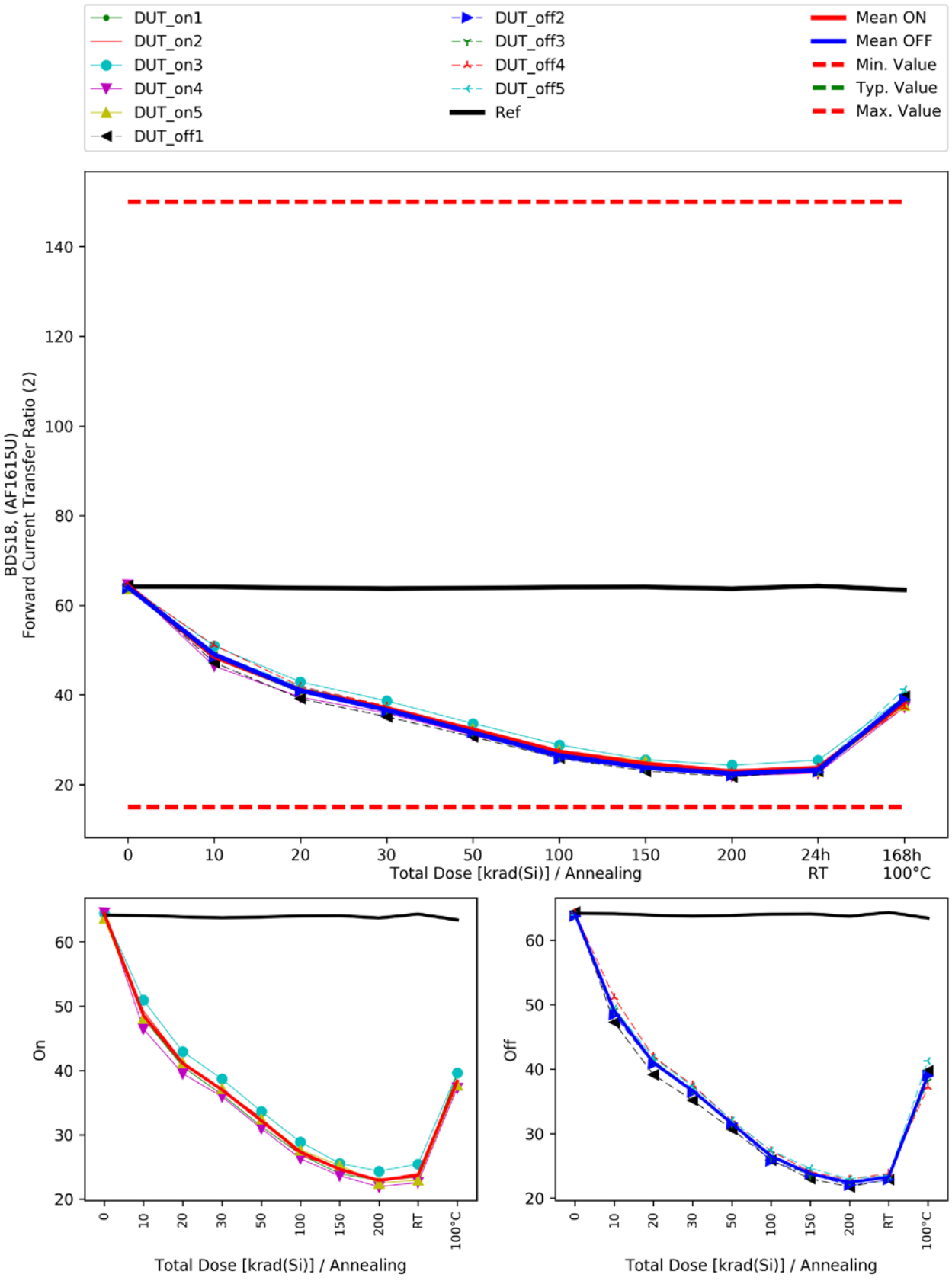
Forward Current Transfer Ratio (2) **BDS18**
HFE 2 Date-/Lotcode: AF1615U
Limit: 15.0<x<150.0

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_on1	64.7E+0	48.1E+0	40.6E+0	36.2E+0	31.3E+0	27.0E+0	24.0E+0	22.9E+0	23.4E+0	39.4E+0
DUT_on2	64.7E+0	49.3E+0	41.4E+0	37.0E+0	32.7E+0	26.8E+0	24.8E+0	22.9E+0	24.0E+0	37.7E+0
DUT_on3	64.5E+0	50.9E+0	42.9E+0	38.7E+0	33.6E+0	28.9E+0	25.6E+0	24.3E+0	25.4E+0	39.6E+0
DUT_on4	64.5E+0	46.5E+0	39.5E+0	35.9E+0	31.0E+0	26.3E+0	23.6E+0	21.9E+0	22.6E+0	37.3E+0
DUT_on5	63.7E+0	48.1E+0	41.2E+0	37.2E+0	32.4E+0	27.6E+0	25.3E+0	22.5E+0	22.9E+0	37.7E+0
Radiation-Mean ON	**64.4E+0**	**48.6E+0**	**41.1E+0**	**37.0E+0**	**32.2E+0**	**27.3E+0**	**24.6E+0**	**22.9E+0**	**23.7E+0**	**38.3E+0**
Standarddeviation	**422.8E-3**	**1.7E+0**	**1.2E+0**	**1.1E+0**	**1.1E+0**	**1.0E+0**	**829.5E-3**	**897.8E-3**	**1.1E+0**	**1.1E+0**
Mean + kσ	**65.6E+0**	**53.1E+0**	**44.5E+0**	**39.9E+0**	**35.2E+0**	**30.1E+0**	**26.9E+0**	**25.4E+0**	**26.8E+0**	**41.3E+0**
Mean - kσ	**63.3E+0**	**44.0E+0**	**37.7E+0**	**34.1E+0**	**29.3E+0**	**24.6E+0**	**22.4E+0**	**20.4E+0**	**20.6E+0**	**35.3E+0**

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
DUT_off1	64.4E+0	47.3E+0	39.2E+0	35.2E+0	30.7E+0	25.9E+0	23.0E+0	21.7E+0	22.9E+0	39.8E+0
DUT_off2	63.7E+0	48.4E+0	40.8E+0	36.4E+0	31.6E+0	25.7E+0	23.7E+0	22.0E+0	22.8E+0	39.0E+0
DUT_off3	64.0E+0	49.1E+0	41.3E+0	36.8E+0	31.6E+0	26.3E+0	23.5E+0	22.6E+0	23.2E+0	38.1E+0
DUT_off4	64.3E+0	51.1E+0	41.9E+0	37.6E+0	32.1E+0	27.3E+0	24.1E+0	22.9E+0	23.9E+0	37.2E+0
DUT_off5	63.9E+0	49.4E+0	41.8E+0	37.3E+0	32.1E+0	27.4E+0	24.6E+0	23.0E+0	23.5E+0	41.3E+0
Radiation-Mean OFF	**64.1E+0**	**49.1E+0**	**41.0E+0**	**36.7E+0**	**31.6E+0**	**26.5E+0**	**23.8E+0**	**22.4E+0**	**23.3E+0**	**39.1E+0**
Standarddeviation	**296.8E-3**	**1.4E+0**	**1.1E+0**	**946.9E-3**	**571.0E-3**	**772.0E-3**	**615.4E-3**	**553.0E-3**	**431.7E-3**	**1.6E+0**
Mean + kσ	**64.9E+0**	**53.0E+0**	**44.1E+0**	**39.2E+0**	**33.2E+0**	**28.6E+0**	**25.5E+0**	**24.0E+0**	**24.4E+0**	**43.4E+0**
Mean - kσ	**63.3E+0**	**45.2E+0**	**37.9E+0**	**34.1E+0**	**30.0E+0**	**24.4E+0**	**22.1E+0**	**20.9E+0**	**22.1E+0**	**34.8E+0**

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @RT	168h @100°C
Ref1	64.2E+0	64.1E+0	63.9E+0	63.7E+0	63.9E+0	64.0E+0	64.1E+0	63.7E+0	64.3E+0	63.4E+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

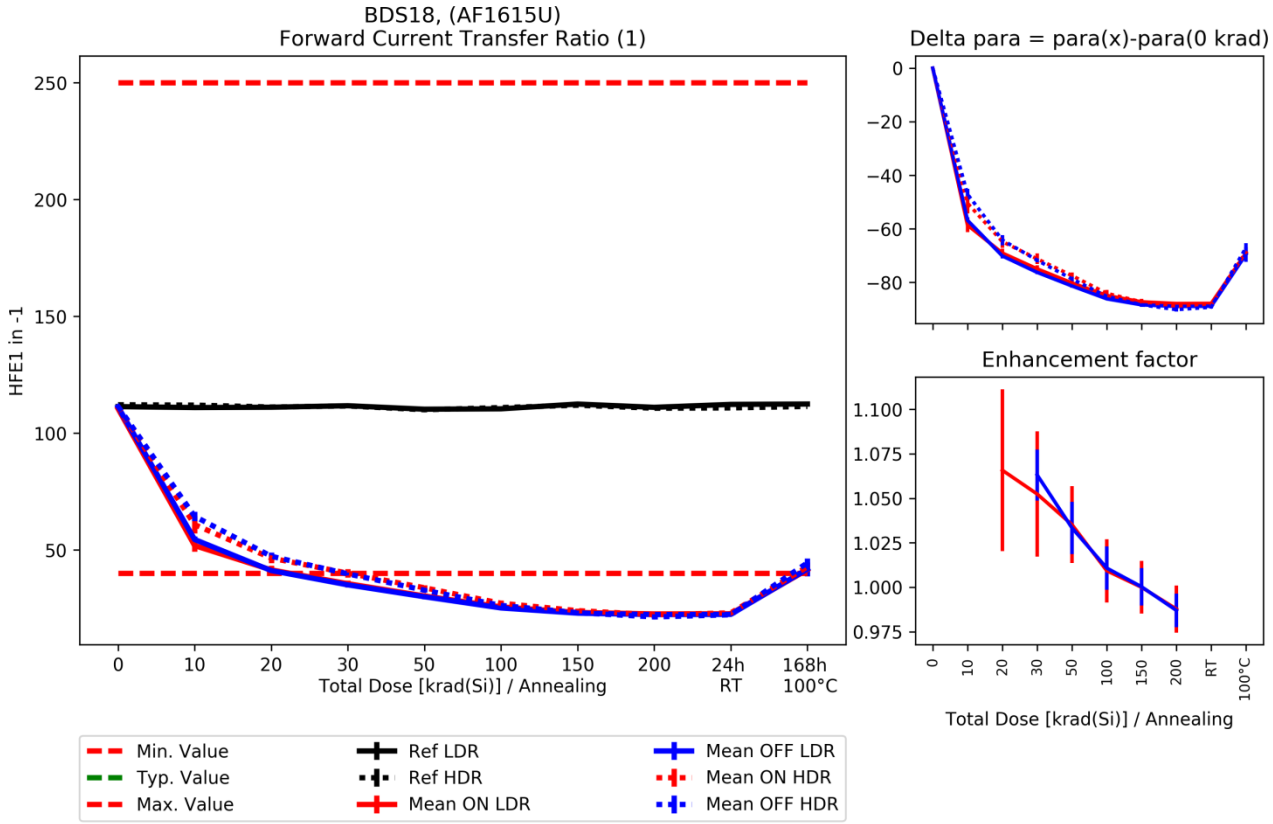


9 Results of Enhancement Calculation

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 Breakdown 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	yes	no	--	
7	Forward Current Transfer Ratio	**yes**	**no**	<1.1	
8		yes	no	--	

9.2 Forward Current Transfer Ratio (1)



A Fraunhofer INT

A.1. About the institute

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

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

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

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

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

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

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

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

The activities within NEO are:

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

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

A.3. Irradiation facilities

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

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

These irradiation facilities are:

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

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

A.4. QM-Certificate

DNV·GL

MANAGEMENT SYSTEM CERTIFICATE

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

This is to certify that the management system of

Fraunhofer INT

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

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

ISO 9001:2015

This certificate is valid for the following scope:

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

Place and date:
Essen, 29. March 2018

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

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

Thomas Beck
Technical Manager

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

B Irradiation details LDR

B.1. Irradiation facility TK100

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

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

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

Figure 15: TK100 irradiation facility

B.2. Radiation properties of TK100

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

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

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

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

B.3. Dosimetry at TK100

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

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

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

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

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

B.4. Certificate of TK100 irradiation source

IT-Service Leipzig

Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik

Qualitätszertifikat

für umschlossene Strahlenquelle

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

Dichtheitsbescheinigung

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

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

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

Datum: 17.12.2015 Signum IT-Service:

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

C Irradiation Documentation LDR

Irradiation Test Documentation

Fraunhofer INT

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

Reference Data for Dose Rate Calculation

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

Geometry of Irradiated Object (As defined or measured):

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

Distances of Point Source:

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

Dose Rates in Object

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

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

Dose in Object

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

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

Standard Irradiation Test Documentation Sheet, 2015-12-18

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

D Irradiation details HDR

D.1. Irradiation facility TK1000B

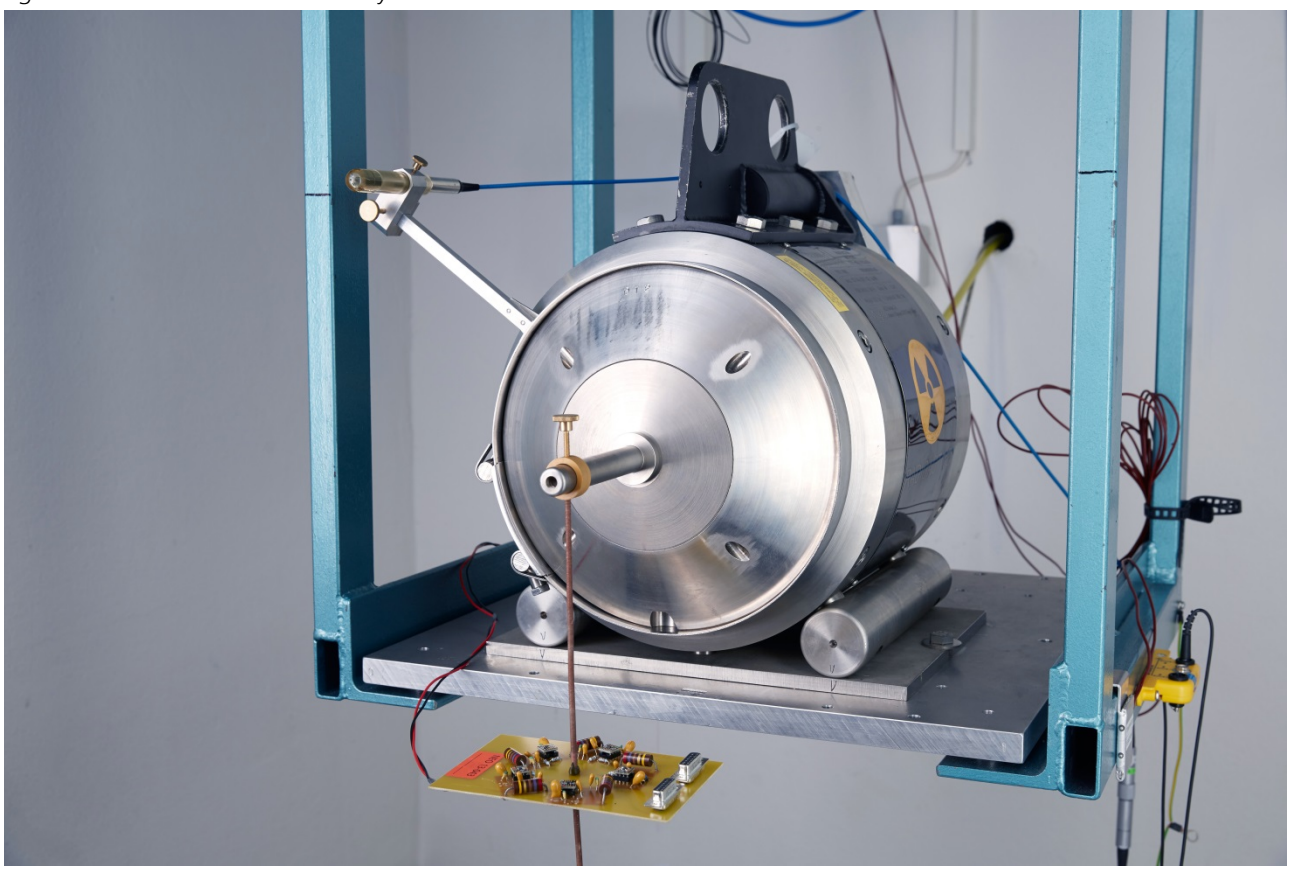
The TK1000B is a Co-60 gamma irradiator manufactured by Sauerwein Isotopentechnik, Germany. Inside the shielding container is a small radioactive pellet with a diameter of 7 mm and a length of 10.4 mm. The activity decreases with a physical half-life of 5.27 years. The current radioactive pellet was 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

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