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**Survey of Total Ionising Dose Tolerance of Power Bipolar Transistors and Silicon  
Carbide Devices for JUICE**

**TN5.1  
TID Test Report (LDR / HDR) for  
Power Bipolar Transistor  
2ST21600**

**Manufacturer:  
STmicroelectronics, France**

**Date code/Lot code: 33528003ZT**

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## Document Approval

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## Version history

Table 1: Revision history

Version	Date	Changed by	Changes
1.0	2018-09-27	Steffens	Initial release
2.0	-	-	
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## Table of contents

<b>Document Approval .....</b>	<b>2</b>
<b>1 Introduction .....</b>	<b>5</b>
<b>2 Summary .....</b>	<b>6</b>
<b>3 Sample preparations .....</b>	<b>10</b>
<b>4 Irradiation conditions.....</b>	<b>13</b>
<b>5 Measurement parameters.....</b>	<b>19</b>
<b>6 Enhancement Factor Calculation.....</b>	<b>23</b>
<b>7 Results LDR.....</b>	<b>24</b>
<b>8 Results HDR .....</b>	<b>51</b>
<b>9 Results of Enhancement Calculation .....</b>	<b>78</b>
<b>A Fraunhofer INT.....</b>	<b>86</b>
<b>B Irradiation details LDR .....</b>	<b>89</b>
<b>C Irradiation Documentation LDR .....</b>	<b>92</b>
<b>D Irradiation details HDR.....</b>	<b>93</b>
<b>E Irradiation documentation HDR .....</b>	<b>96</b>

## List of figures

Figure 1: LDR: Overview of results .....	8
Figure 2: HDR: Overview of results .....	8
Figure 3: The ESD package with the samples .....	10
Figure 4: Sample marking. ....	11
Figure 5: Bias board.....	14
Figure 6: LDR tests: Board fixture at TK100 .....	15
Figure 7: HDR tests: Board fixture at TK1000B.....	15
Figure 8: Bias conditions and equipment. ....	16
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. ....	17
Figure 10: HDR: Environment variables during irradiation.....	18
Figure 11: Measurement equipment/setup .....	20
Figure 12: Test setup: SMUs .....	21
Figure 13: LDR: Environment variables during measurements .....	22
Figure 14: HDR: Environment variables during measurements .....	22
Figure 15: TK100 irradiation facility.....	89
Figure 16: TK1000B irradiation facility.....	93

## List of tables

Table 1: Revision history .....	2
Table 2: Summary .....	6
Table 3: Sample shipment.....	10
Table 4: Sample marking .....	12
Table 5: LDR: Irradiation steps.....	13
Table 6: HDR irradiation steps.....	13
Table 7: LDR: Environmental variables during irradiation .....	17
Table 8: HDR: Environmental variables during irradiation .....	18
Table 9: Measurement parameters. ....	19
Table 10: Measurement equipment .....	20
Table 11: LDR: Environment variables during measurements .....	22
Table 12: HDR: Environment variables during measurements .....	22



## 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 2ST21600 from STmicroelectronics, France 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 2ST21600, "Hi-Rel PNP high voltage bipolar transistor 600 V, 0.5 A", STmicroelectronics, France, DocID026987 Rev 1, 2014-10-03
- [5] TN2.1 "TID Test Plan 2ST21600 (HDR+LDR)", Issue 1, 2016-08-09
- [6] MIL-STD-883K w/CHANGE 2, Method 1019.9, "Ionizing Radiation (Total Dose) Test Procedure", 2017

## 2 Summary

Table 2: Summary

<b>Test Report Number</b>	014/2017
<b>Project (INT)</b>	NEO-14-086
<b>Customer</b>	European Space Agency (ESA), contract number 4000113976/15/NL/RA
<b>Contact</b>	Project Coordinator: Stefan Höffgen (INT) ESA Technical Project Officer: Marc Poizat (ESA/ESTEC)
<b>ESA project / contract number</b>	AO/1-8148/14/NL/SFe 4000113976/15/NL/RA
<b>Device under test</b>	2ST21600
<b>Family</b>	Power Bipolar Transistor
<b>Technology</b>	Hi-Rel PNP high voltage bipolar transistor
<b>Package</b>	SMD.22
<b>Date code / Wafer lot</b>	33528003ZT
<b>SN</b>	Low dose rate (LDR-Test): Biased (5x ):       # 302, 303, 304, 305, 306 Unbiased (5x):    # 307, 308, 309, 310, 311 Reference (1x):   # 301 High dose rate (HDR-Test): Biased (5x ):       # 313, 315, 316, 317, 318 Unbiased (5x):    # 319, 320, 321, 322, 324 Reference (1x):   # 314
<b>Manufacturer</b>	STmicroelectronics, France
<b>Irradiation test house</b>	Fraunhofer INT
<b>Radiation source</b>	Co-60
<b>Irradiation facility</b>	LDR: TK100, HDR: TK1000B
<b>Generic specification</b>	ESCC 22900 Iss. 5
<b>Detail specification</b>	ESCC 22900 Iss. 5
<b>Test plan</b>	TN2.1 "TID Test Plan 2ST21600 (HDR+LDR)", Issue 1, 2016-08-09
<b>Max. test level</b>	200 krad(Si)
<b>Dose steps</b>	LDR: Multiple: 9, 18, 30, 51, 98, 152, 202 krad(Si) HDR: Multiple: 10, 20, 30, 50, 100, 150, 200 krad(Si)
<b>Dose rate</b>	LDR: Start @ 35.4 rad(Si)/h – Stop @ 32.3 rad(Si)/h HDR: 10.9 krad(Si)/h

<b>Start of irradiation</b>	LDR: 2016-08-25 14:04, HDR: 2017-08-07 05:13
<b>Stop of irradiation</b>	LDR: 2017-05-02 13:15 HDR: 2017-08-08 10:20
<b>Non-Homogeneity in DUT</b>	LDR: < 2% HDR: 5.3%
<b>Annealing</b>	24h @RT, 168h @ 100°C
<b>Electrical measurements/ Parameters tested</b>	$V_{(Br)CEO}$ ( $I_C@400V$ ), $V_{(Br)CBO}$ ( $I_C@600V$ ), $V_{(Br)EBO}$ ( $I_E@6V$ ), $I_{CBO}$ , $I_{EBO}$ , $V_{CE(sat)}$ , $V_{BE(sat)}$ , $h_{FE1}$ , $h_{FE2}$ , $h_{FE3}$

## 2.1 Comments

- During the conduction of both test campaigns, some deviations from the requirements of ESCC 22900 occurred, each related to the electrical tests taking longer than anticipated and thus having a longer time gap between stop of irradiation and the start of the next step.
- 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 2ST21600 these interruptions were approx. 9 minutes on average and max. 1h15min.
  - 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%.
  - During the  $V_{EBO}$  and  $V_{CBO}$  measurements in the LDR test, the SMU stopped slightly below the programmed voltage.  
To avoid false-negative results indicating the device failing at that level, the limit of the parameter was reduced from 600 V to 598.5 V in the case of  $V_{CBO}$  and from 6 V to 5.9 V in the case of  $V_{EBO}$ .
  - Some tests of the  $h_{FE1}$  parameter showed much lower values than anticipated. This is limited to the low dose rate tests starting at the 30 krad(Si) step and is apparently also limited to the tests of the control sample. Checks with other non-irradiated samples showed, that this is not related to problems specific to the control sample itself.
- Comparison with respect to ELDRS:
  - Some parameters show a slightly higher degradation at high dose rates. The calculated enhancement factors are thus smaller than 1 in several cases.
  - As the more sensitive parameters (e.g. the HFEs) do not show an enhanced low dose rate sensitivity, 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	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	168h @ 100°C
BVCEO	On										
	Off										
BIECO	On										
	Off										
BV CBO	On						5	5	5	5	
	Off										1
BICBO	On			5	5		1	2	5	5	
	Off										
ICBO	On				5		5	5	5	5	
	Off										1
BVEBO	On										
	Off										1
BIEBO	On										
	Off										1
IEBO	On										
	Off										1
Vcesat	On						5	5	5	5	
	Off						1	5	5	5	
Vbesat	On										
	Off										
HFE1	On		4	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
HFE2	On				5	5	5	5	5	5	5
	Off				5	5	5	5	5	5	5
HFE3	On				5	5	5	5	5	5	5
	Off				5	5	5	5	5	5	5

Figure 2: HDR: Overview of results

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
BVCEO	On										
	Off										
BICEO	On										
	Off										
BV CBO	On					2	5	5	5	5	
	Off										
BICBO	On					4	5	5	4	5	
	Off										
ICBO	On					3	5	5	5	5	
	Off										
BVEBO	On										
	Off										
BIEBO	On										
	Off										
IEBO	On										
	Off										
Vcesat	On						5	5	5	5	
	Off						5	5	5	5	
Vbesat	On										
	Off										
HFE1	On		5	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
HFE2	On			5	5	5	5	5	5	5	5
	Off			5	5	5	5	5	5	5	5
HFE3	On			5	5	5	5	5	5	5	5
	Off			4	5	5	5	5	5	5	5

cells with red back color indicate parametric failures, the number of affected devices is given



### 3 Sample preparations

#### 3.1 Sample shipment

Samples were provided by STMicroelectronics (Tours) for the conduction of these tests for ESA.

Table 3: Sample shipment

Samples received	Samples sent back
April 2016	still at INT

Figure 3: The ESD package with the samples



### 3.2 Sample identification/ marking

The samples were mounted on an adapter, to ease the exchanging, plugging and storage of the samples.

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



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

### 3.3 Sample safekeeping

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

Table 4: Sample marking

Test	Condition	Label	S/N	S/N (INT)	Color Code	
Low dose rate	Control sample	REF#1	301	1		
	Biased	ON#1	302	2		
		ON#2	303	3		
		ON#3	304	4		
		ON#4	305	5		
		ON#5	306	6		
	Unbiased	OFF#1	307	7		
		OFF#2	308	8		
		OFF#3	309	9		
		OFF#4	310	10		
		OFF#5	311	11		
High dose rate	Control sample	REF#1	314	14		
	Biased	ON#1	313	13		
		ON#2	315	15		
		ON#3	316	16		
		ON#4	317	17		
		ON#5	318	18		
	Unbiased	OFF#1	319	19		
		OFF#2	320	20		
		OFF#3	321	21		
		OFF#4	322	22		
		OFF#5	324	24		



## 4 Irradiation conditions

### 4.1 Irradiation steps

Table 5: LDR: Irradiation steps

	Step [krad(Si)]	Total [krad (Si)]	Startrate [rad(Si)/h]	Start Irr.	Total Breaks [h:m]	Stop Irr.	Duration [d:h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0						24.08.2016 08:56	24.08.2016 10:25	1:29
1	9.17	9.17	35.4	25. 08.2016 14:04:00	00:23	05. 09.2016 10:07:44	10d 20:03:44	05.09.2016 10:27	05.09.2016 11:26	0:59
2	9.33	18.5	35.3	05. 09.2016 11:54:08	00:41	16. 09.2016 13:39:58	11d 01:45:50	16.09.2016 13:49	16.09.2016 15:09	1:20
3	11.52	30.02	35.1	16. 09.2016 15:14:36	00:07	30. 09.2016 08:21:18	13d 17:06:42	30.09.2016 08:29	30.09.2016 09:54	1:25
4	20.80	50.82	34.9	30. 09.2016 10:03:13	00:34	25. 10.2016 08:38:36	24d 22:35:23	25.10.2016 08:59	25.10.2016 11:02	2:03
5	46.85	97.67	34.6	25. 10.2016 11:08:24	03:12	21. 12.2016 13:22:03	57d 02:13:39	21.12.2016 13:28	21.12.2016 14:44	1:16
6	54.32	151.99	33.9	21. 12.2016 14:52:56	06:25	27. 02.2017 10:09:38	67d 19:16:42	27.02.2017 10:45	27.02.2017 12:39	1:54
7	50.25	202.24	33.1	27. 02.2017 12:42:25	01:06	02. 05.2017 13:15:32	64d 00:33:07	02.05.2017 13:23	02.05.2017 14:13	0:50
8	24 h @ RT			02. 05.2017 14:21:00		03. 05.2017 14:21:00	01:00:00	03.05.2017 14:28	03.05.2017 15:16	0:48
9	168 h @100°C			03. 05.2017 15:20:00		10. 05.2017 15:20:00	07:00:00	10.05.2017 15:24	10.05.2017 16:16	0:52

Table 6: HDR irradiation steps

	Step [krad(Si)]	Total [krad (Si)]	Startrate [rad(Si)/h]	Start Irr.	Stop Irr.	Duration [h:m:s]	Start Tests	Stop Tests	Dur. [h:m]
0	0.00	0					04.08.2017 13:24	04.08.2017 15:37	2:13
1	10.00	10	10.9000	07. 08.2017 05:13:47	07. 08.2017 06:08:52	00:55:05	07.08.2017 06:15	07.08.2017 06:50	0:35
2	10.00	20	10.8995	07. 08.2017 08:07:44	07. 08.2017 09:02:49	00:55:05	07.08.2017 09:06	07.08.2017 09:36	0:30
3	10.00	30	10.8990	07. 08.2017 11:02:25	07. 08.2017 11:57:30	00:55:05	07.08.2017 12:47	07.08.2017 14:20	1:33
4	20.00	50	10.8985	07. 08.2017 14:26:11	07. 08.2017 16:16:21	01:50:10	07.08.2017 16:24	07.08.2017 17:07	0:43
5	50.00	100	10.8979	07. 08.2017 17:49:06	07. 08.2017 22:24:23	04:35:17	07.08.2017 22:31	07.08.2017 23:04	0:33
6	50.00	150	10.8969	08. 08.2017 00:19:53	08. 08.2017 04:55:10	04:35:17	08.08.2017 05:06	08.08.2017 05:37	0:31
7	50.00	200	10.8960	08. 08.2017 05:45:16	08. 08.2017 10:20:32	04:35:16	08.08.2017 10:24	08.08.2017 10:48	0:24
8	24 h @ RT			08. 08.2017 11:00:00	09. 08.2017 12:25:00	1d 01:25:00	09.08.2017 12:34	09.08.2017 12:59	0:25
9	168 h @100°C			09. 08.2017 12:59:00	16. 08.2017 13:05:00	7d 00:06:00	16.08.2017 13:26	16.08.2017 13:52	0:26

During the conduction of both test campaigns, some deviations from the requirements of ESCC 22900 occurred, each related to the electrical tests taking longer than anticipated and thus having a

longer time gap between stop of irradiation and the start of the next step. These are highlighted in the tables above.

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 2ST21600 these interruptions were approx. 9 minutes on average and max. 1h15min.

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%.

## 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 59 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

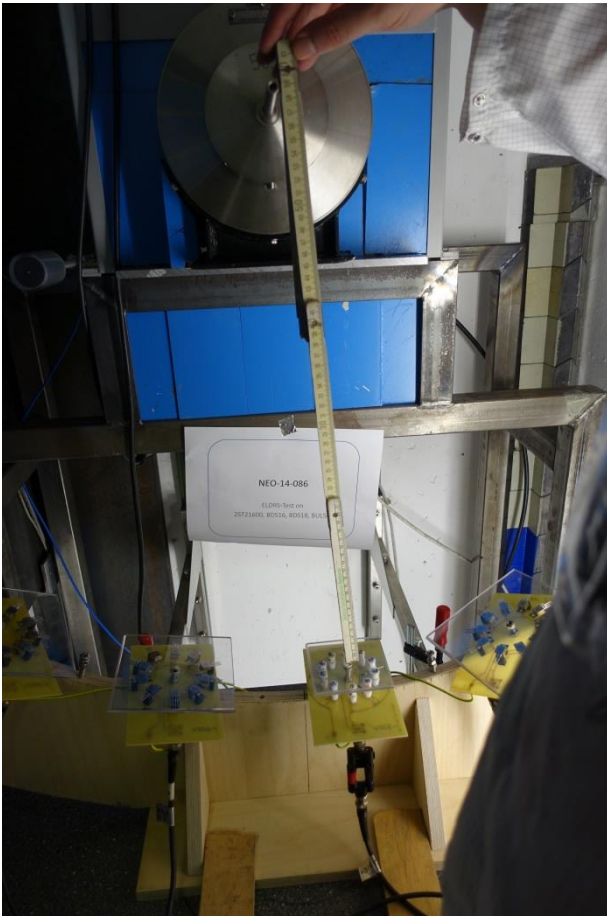
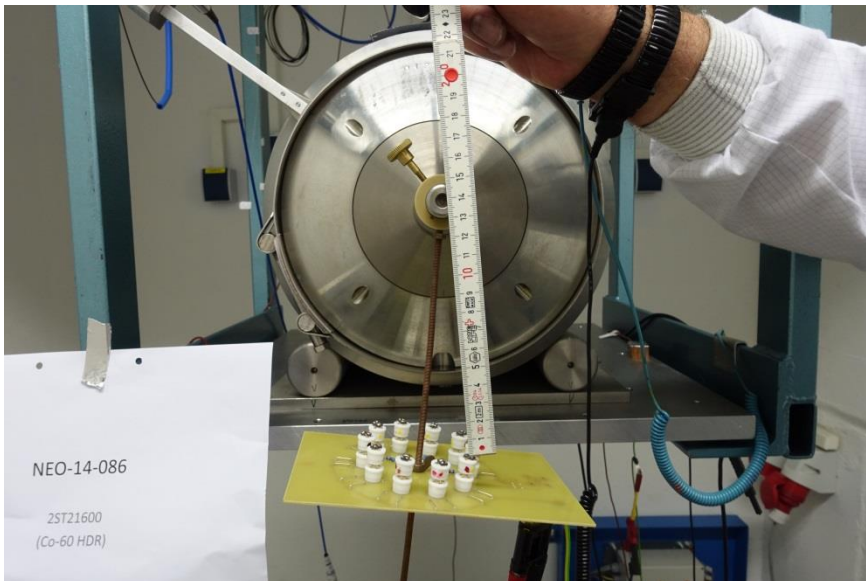


Figure 7: HDR tests: Board fixture at TK1000B



### 4.3 Geometry

LDR tests: The irradiation parameters correspond to a sample-distance of 59 cm from the source at TK100 (Figure 6) to the object minimum.

HDR tests: The irradiation parameters correspond to a sample-distance of 14 cm from the TK1000B source (Figure 7) to the object minimum.

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

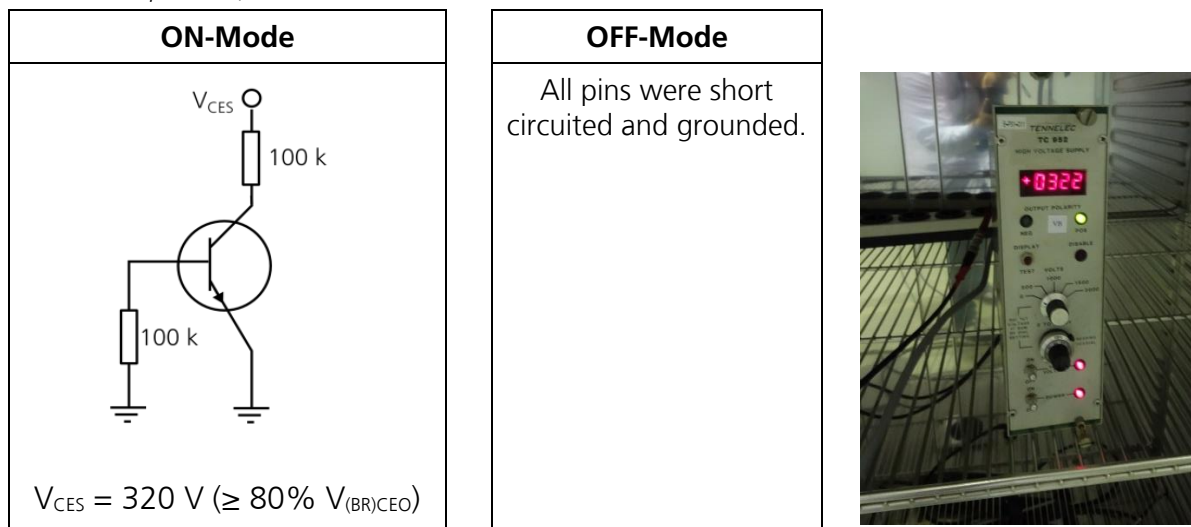
### 4.4 Bias conditions

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

A Tenelec TC 952 high voltage supply (Eq.Id E-PS1-011) was used for biasing in both tests. The supply itself was not calibrated but the voltage was checked with a calibrated voltmeter.

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

Figure 8: Bias conditions and equipment. The identical Tenelec HV supply was used for LDR and HDR testing (both campaigns did not overlap in time).



#### 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 table and figure.

Table 7: LDR: Environmental variables during irradiation

Parameter	Value and Unit	Remarks
Humidity	31.5% $\pm$ 6.9%	Non-condensing, during irradiation and first annealing (24 h)
Temperature	24.9 °C $\pm$ 1.9 °C	During irradiation and first annealing (24 h)
Temperature	100.0 $\pm$ 3.0 °C	During second annealing (168 h)

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.

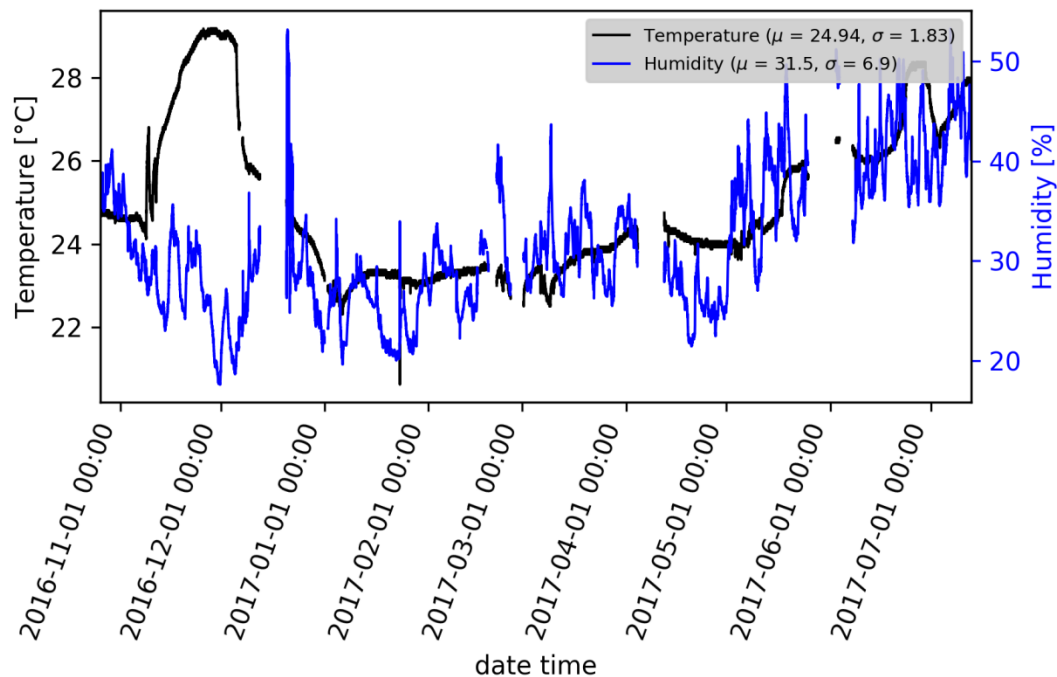
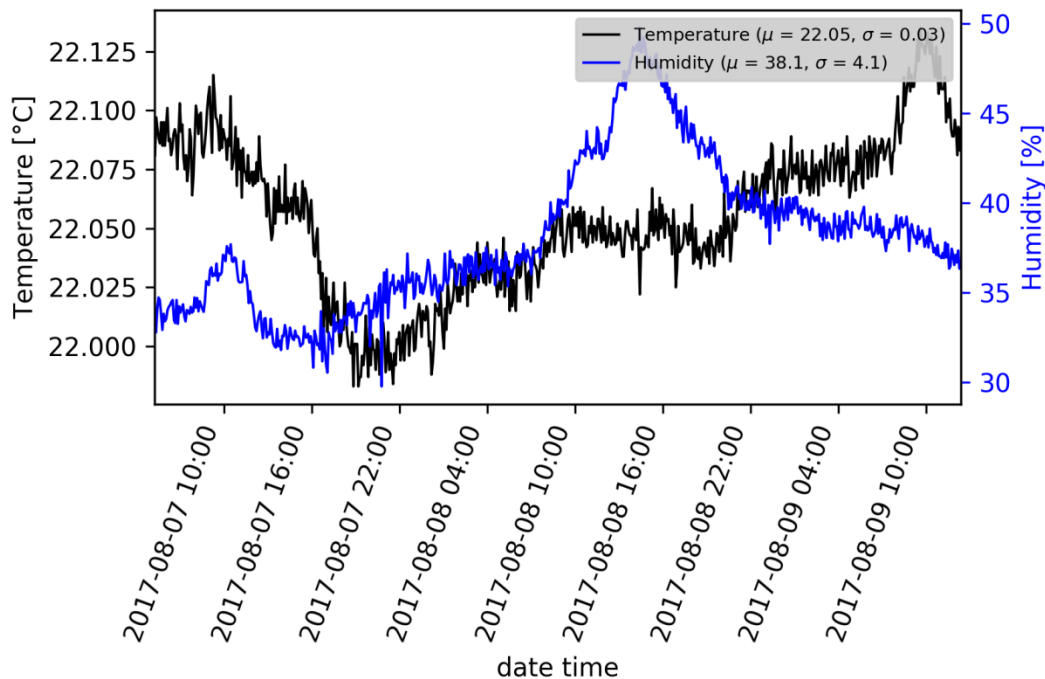


Table 8: HDR: Environmental variables during irradiation

Parameter	Value and Unit	Remarks
Humidity	$38.1\% \pm 4.1\%$	Non-condensing, during irradiation and first annealing (24 h). Monitoring of the humidity at the source was not running during the tests. Measurements from the next representative sensor in the experimental hall are used.
Temperature	$22.1\text{ }^{\circ}\text{C} \pm 0.1\text{ }^{\circ}\text{C}$	During irradiation and first annealing (24 h)
Temperature	$100.0 \pm 3.0\text{ }^{\circ}\text{C}$	During second annealing (168 h)

Figure 10: HDR: Environment variables during irradiation. Monitoring of the humidity at the source was not running during the tests. Measurements from the next representative sensor in the experimental hall are displayed.



## 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 9 were measured before and after each irradiation step and each annealing step.

In one case the measuring of all parameters exceeded two hours. In that and in two other cases 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 9: Measurement parameters. Based on [4], taken from [5]

No.	Characteristics	Symbol	MIL-STD-750 Test Method	min	max	Unit	Test Conditions
1	Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$ $I_C@400V$	3011, Note 2	400		V	$I_C = 1\text{ mA}$ , $I_B = 0\text{ A}$ , Bias Condition D, Note 1, Note 2
2	Collector-Base Breakdown Voltage	$V_{(BR)CBO}$ $I_C@600\text{ V}$	3001	600		V	$I_C = 10\text{ }\mu\text{A}$ , $I_E = 0\text{ A}$ , Bias Condition D, Note 1
3	Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$ $I_E@6\text{ V}$	3026	6		V	$I_E = 50\text{ }\mu\text{A}$ , $I_C = 0\text{ A}$ , Bias Condition D, Note 1
4	Collector-Base Cutoff Current	$I_{CBO}$	3036		1	$\mu\text{A}$	$V_{CB} = 500V$ , $I_E = 0$ , Bias Condition D
5	Emitter-Base Cutoff Current	$I_{EBO}$	3061		1	$\mu\text{A}$	$V_{EB} = 6\text{ V}$ , $I_C = 0\text{ A}$ , Bias Condition D
6	Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	3071		0.5	V	$I_C = 25\text{ mA}$ , $I_B = 2.5\text{ mA}$ , Notes 1
7	Base-Emitter Saturation Voltage	$V_{BE(sat)}$	3066		1	V	$I_C = 25\text{ mA}$ , $I_B = 2.5\text{ mA}$ , Test Condition A, Notes 1
8	Forward Current Transfer Ratio (DC Current Gain)	$h_{FE1}$	3076	150			$V_{CE} = 10\text{ V}$ , $I_C = 1\text{ mA}$ , Notes 1
9		$h_{FE2}$		150			$V_{CE} = 10V$ , $I_C = 25\text{ mA}$ , Notes 1
10		$h_{FE3}$		150			$V_{CE} = 10V$ , $I_C = 50\text{ mA}$ , Notes 1

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

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



- $V_{CE}$  was increased until either (whatever criteria is met first)
  - a) the specified test current is achieved
  - or b) the allowed max. rating of  $V_{CE}$  (identical with the min. Limit of  $V_{(Br)CEO}$ ) is applied
- If case b) is met then the device is automatically acceptable according to the purpose and acceptance criteria of Test Method 3011, which only gives a lower limit for  $V_{(Br)CEO}$ . In this case,  $I_C @ V_{CE} = 400 \text{ V}$  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  $V_{CE} < V_{(Br)CEO \text{ min}}$
- The same applies likewise for  $V_{BR(CBO)}$  or  $V_{BR(EBO)}$

## 5.2 Measurement equipment

Table 10: Measurement equipment

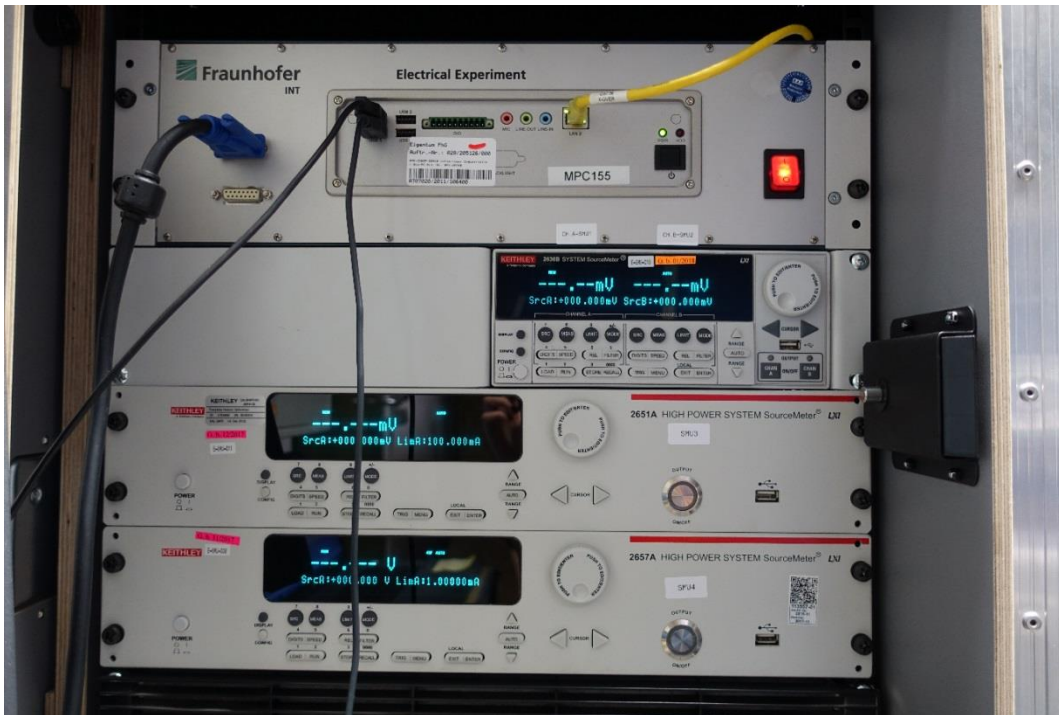
Equipment	Manufacturer	Model	INT-Code	Calibr. due	Measurement
System Source-Meter	Keithley	2636B	E-SMU-010	01/2018	$V_{(Br)CEO}$ , $V_{(Br)CBO}$ , $V_{(Br)EBO}$ , $I_{CBO}$ , $I_{EBO}$
High Power System Source-Meter	Keithley	2657A	E-SMU-008	11/2017	$V_{CE(sat)}$ , $V_{BE(sat)}$ , $h_{FE1}$ , $h_{FE2}$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

Figure 11: Measurement equipment/setup





Figure 12: Test setup: SMUs



### 5.3 Measurement procedures

Procedures according to the MIL test methods given in Table 9 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 11: LDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Temperature [°C]	24.6	25.5	26.1	21	21.5	23.1	22.6	26.3	28.5	25.5
Humidity [%]	57.7	52	45.9	48	56.4	44.3	46	34.4	38.7	30.2

Figure 13: LDR: Environment variables during measurements

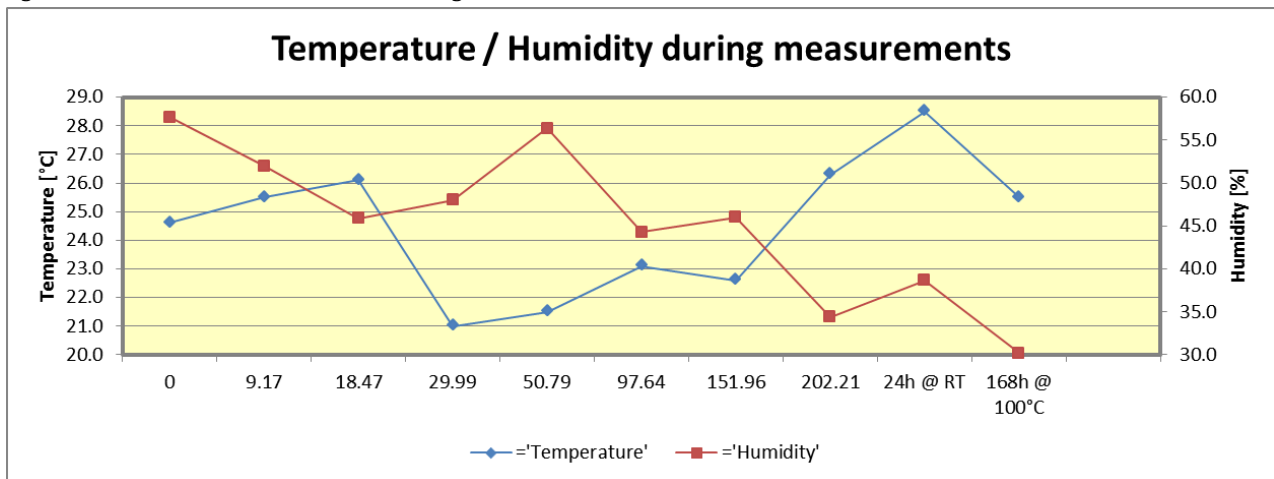
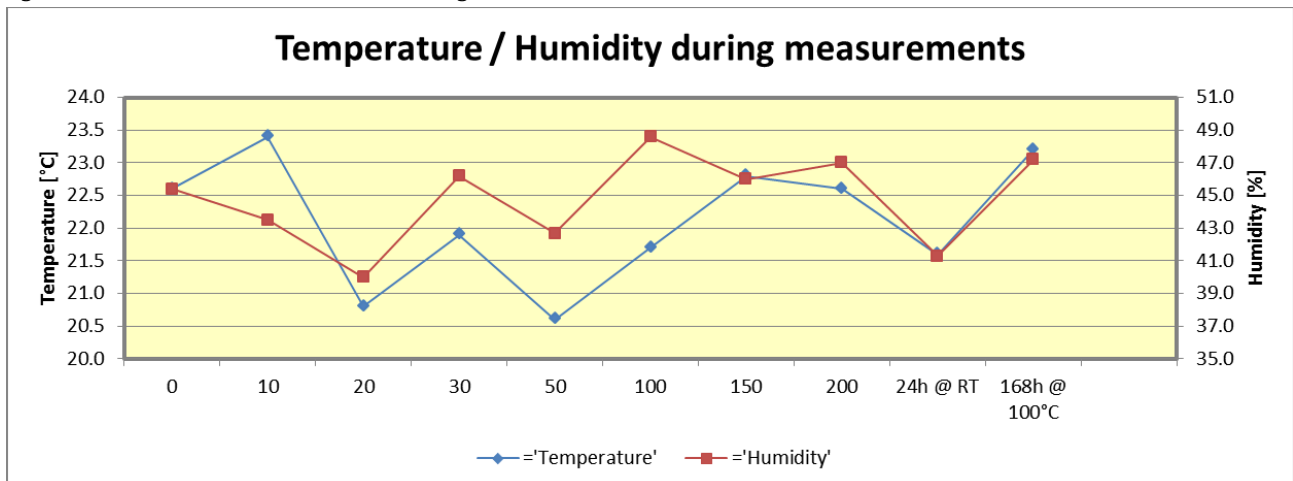


Table 12: HDR: Environment variables during measurements

Test cond.	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Temperature [°C]	22.6	23.4	20.8	21.9	20.6	21.7	22.8	22.6	21.6	23.2
Humidity [%]	45.4	43.5	40.0	46.2	42.7	48.6	46.0	47.0	41.3	47.2

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:

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

with

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

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 calculating and reporting the enhancement factors in this report, we mostly adapt the criteria from MIL-STD-883K for two reasons: First, if the change at high dose rates is negligibly small, the enhancement factor could get very large even if no difference between LDR and HDR test results is apparent. Second, some parameters, e.g. the cut-off-currents, might show enhancement to some degree while still being several orders of magnitude below the datasheets limitations.

Results are shown in Section 9. All enhancement factors are shown for any situation where the respective parameter is out of specs. Some apparent issues, e.g. the above-mentioned small signal variations or real enhancement, are discussed in Section 9.1.

## 7 Results LDR

### 7.1 Overview: Pass/Fail

Pass/Fail		Total Dose [krad (Si)]								Annealing	
		0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	168h @ 100°C
BVCEO	On										
	Off										
BIECO	On										
	Off										
BVCBO	On						5	5	5	5	
	Off										1
BICBO	On			5	5		1	2	5	5	
	Off										
ICBO	On				5		5	5	5	5	
	Off										1
BVEBO	On										
	Off										1
BIEBO	On										
	Off										1
IEBO	On										
	Off										1
Vcesat	On						5	5	5	5	
	Off						1	5	5	5	
Vbesat	On										
	Off										
HFE1	On		4	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
HFE2	On				5	5	5	5	5	5	5
	Off				5	5	5	5	5	5	5
HFE3	On				5	5	5	5	5	5	5
	Off				5	5	5	5	5	5	5

## 7.2 Collector-emitter breakdown voltage

### Collector-emitter breakdown voltage

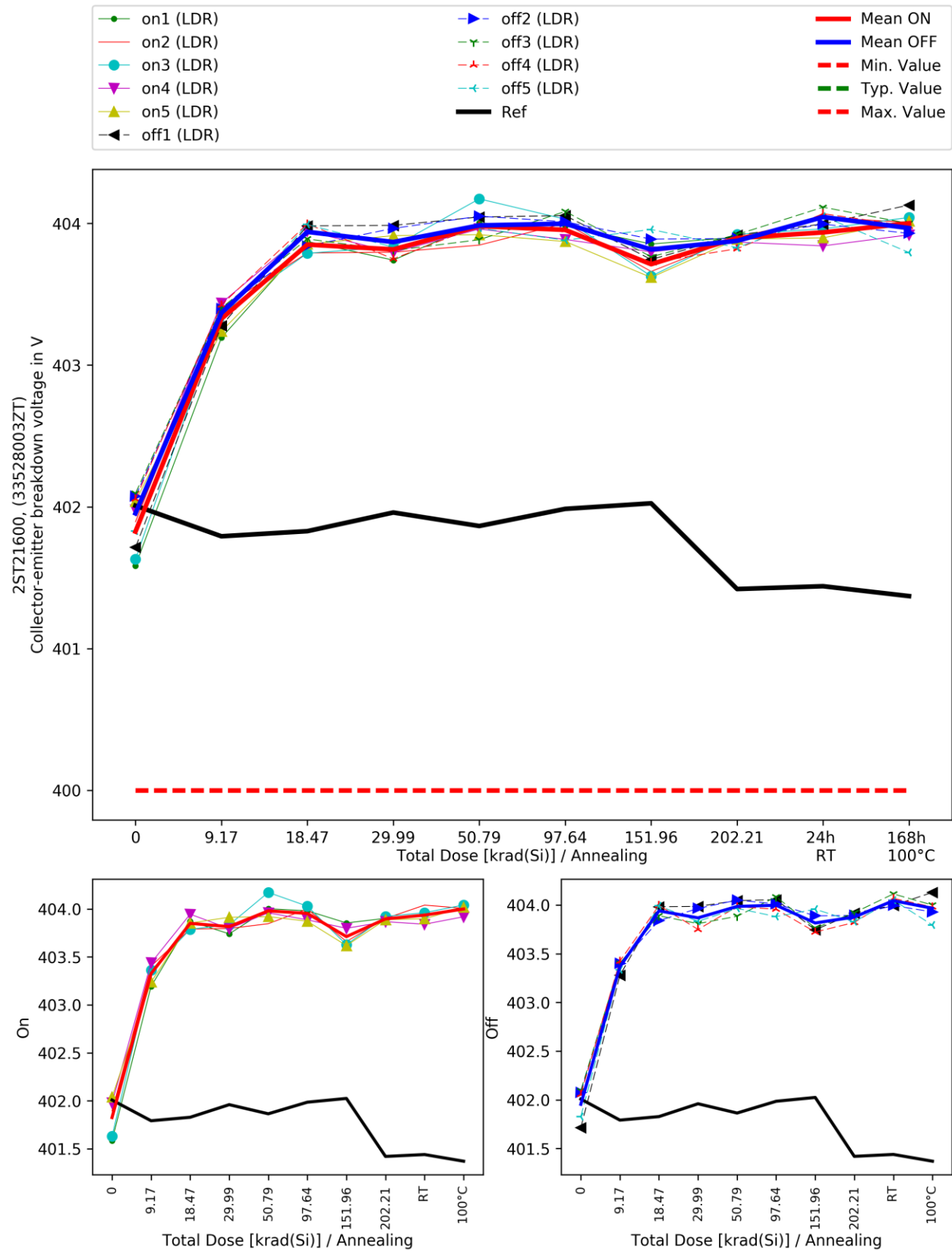
BVCEO in V

Limit: 400.0 < x

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	401.6E+0	403.2E+0	403.9E+0	403.7E+0	404.0E+0	404.0E+0	403.9E+0	403.9E+0	403.9E+0	404.0E+0
on2 (LDR)	401.9E+0	403.4E+0	403.8E+0	403.8E+0	403.8E+0	404.0E+0	403.7E+0	403.9E+0	404.0E+0	404.0E+0
on3 (LDR)	401.6E+0	403.4E+0	403.8E+0	403.8E+0	404.2E+0	404.0E+0	403.6E+0	403.9E+0	404.0E+0	404.0E+0
on4 (LDR)	402.0E+0	403.4E+0	403.9E+0	403.8E+0	404.0E+0	403.9E+0	403.8E+0	403.9E+0	403.8E+0	403.9E+0
on5 (LDR)	402.0E+0	403.2E+0	403.9E+0	403.9E+0	403.9E+0	403.9E+0	403.6E+0	403.9E+0	403.9E+0	404.0E+0
Radiation-Mean ON	401.8E+0	403.3E+0	403.9E+0	403.8E+0	404.0E+0	404.0E+0	403.7E+0	403.9E+0	403.9E+0	404.0E+0
Standarddeviation	205.8E-3	106.2E-3	65.0E-3	63.8E-3	122.0E-3	70.3E-3	107.7E-3	20.0E-3	74.2E-3	47.1E-3
Mean + kσ	402.4E+0	403.6E+0	404.0E+0	404.0E+0	404.3E+0	404.1E+0	404.0E+0	404.0E+0	404.1E+0	404.1E+0
Mean - kσ	401.3E+0	403.0E+0	403.7E+0	403.6E+0	403.6E+0	403.8E+0	403.4E+0	403.8E+0	403.7E+0	403.9E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	401.7E+0	403.3E+0	404.0E+0	404.0E+0	404.0E+0	404.1E+0	403.7E+0	403.9E+0	404.0E+0	404.1E+0
off2 (LDR)	402.1E+0	403.4E+0	403.8E+0	404.0E+0	404.1E+0	404.0E+0	403.9E+0	403.9E+0	404.0E+0	403.9E+0
off3 (LDR)	402.1E+0	403.4E+0	403.9E+0	403.8E+0	403.9E+0	404.1E+0	403.8E+0	403.9E+0	404.1E+0	404.0E+0
off4 (LDR)	402.1E+0	403.4E+0	404.0E+0	403.8E+0	404.0E+0	404.0E+0	403.7E+0	403.8E+0	404.1E+0	404.0E+0
off5 (LDR)	401.8E+0	403.3E+0	404.0E+0	403.8E+0	404.0E+0	403.9E+0	404.0E+0	403.8E+0	404.1E+0	403.8E+0
Radiation-Mean OFF	402.0E+0	403.4E+0	403.9E+0	403.9E+0	404.0E+0	404.0E+0	403.8E+0	403.9E+0	404.0E+0	404.0E+0
Standarddeviation	172.2E-3	60.5E-3	70.8E-3	102.6E-3	67.7E-3	80.9E-3	101.9E-3	48.4E-3	50.6E-3	121.4E-3
Mean + kσ	402.4E+0	403.5E+0	404.1E+0	404.1E+0	404.2E+0	404.2E+0	404.1E+0	404.0E+0	404.2E+0	404.3E+0
Mean - kσ	401.5E+0	403.2E+0	403.7E+0	403.6E+0	403.8E+0	403.8E+0	403.5E+0	403.7E+0	403.9E+0	403.6E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	402.0E+0	401.8E+0	401.8E+0	402.0E+0	401.9E+0	402.0E+0	402.0E+0	401.4E+0	401.4E+0	401.4E+0
Min. Value	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0



### 7.3 IEC @ 400 V

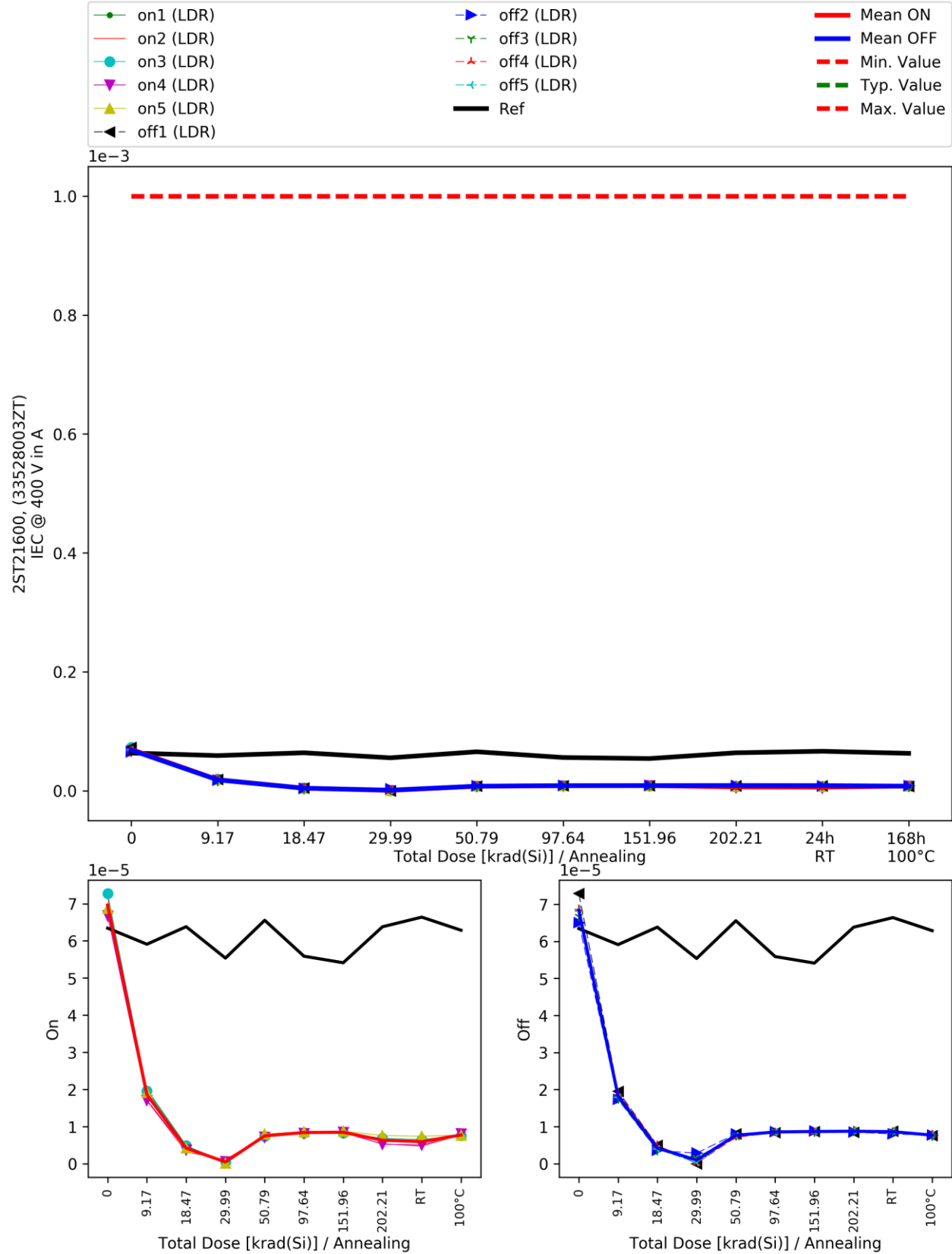
IEC @ 400 V  
BIECO in A

Limit:  $x < 0.001$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	67.9E-6	20.0E-6	5.0E-6	49.1E-9	7.5E-6	8.4E-6	8.5E-6	6.6E-6	6.0E-6	7.6E-6
on2 (LDR)	71.8E-6	17.0E-6	3.3E-6	1.1E-6	7.5E-6	8.6E-6	8.4E-6	5.4E-6	4.8E-6	7.8E-6
on3 (LDR)	72.8E-6	19.6E-6	4.9E-6	531.7E-9	7.4E-6	8.3E-6	8.3E-6	6.9E-6	6.5E-6	7.6E-6
on4 (LDR)	66.8E-6	17.2E-6	3.8E-6	621.1E-9	7.2E-6	8.2E-6	8.6E-6	5.3E-6	5.1E-6	8.1E-6
on5 (LDR)	68.7E-6	19.3E-6	4.3E-6	219.0E-9	8.0E-6	8.7E-6	8.8E-6	7.6E-6	7.4E-6	7.8E-6
Radiation-Mean ON	69.6E-6	18.6E-6	4.2E-6	506.6E-9	7.5E-6	8.4E-6	8.5E-6	6.4E-6	6.0E-6	7.8E-6
Standarddeviation	2.6E-6	1.4E-6	720.0E-9	410.1E-9	303.6E-9	182.8E-9	201.8E-9	1.0E-6	1.1E-6	200.8E-9
Mean + $k\sigma$	76.7E-6	22.5E-6	6.2E-6	1.6E-6	8.4E-6	8.9E-6	9.0E-6	9.1E-6	8.9E-6	8.3E-6
Mean - $k\sigma$	62.5E-6	14.7E-6	2.3E-6	-617.8E-9	6.7E-6	7.9E-6	7.9E-6	3.6E-6	3.0E-6	7.2E-6
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	72.9E-6	19.5E-6	5.0E-6	4.4E-9	8.1E-6	8.4E-6	8.7E-6	8.5E-6	8.8E-6	7.6E-6
off2 (LDR)	65.0E-6	17.3E-6	3.5E-6	2.9E-6	8.0E-6	8.6E-6	8.8E-6	8.5E-6	8.0E-6	7.7E-6
off3 (LDR)	66.7E-6	17.5E-6	3.6E-6	1.6E-6	7.6E-6	8.7E-6	8.6E-6	8.8E-6	8.8E-6	7.5E-6
off4 (LDR)	68.7E-6	19.0E-6	5.0E-6	138.4E-9	7.1E-6	8.5E-6	8.5E-6	9.0E-6	8.6E-6	7.9E-6
off5 (LDR)	68.6E-6	17.9E-6	4.0E-6	263.6E-9	7.5E-6	8.5E-6	8.8E-6	9.0E-6	8.9E-6	7.8E-6
Radiation-Mean OFF	68.4E-6	18.3E-6	4.2E-6	982.0E-9	7.7E-6	8.6E-6	8.7E-6	8.8E-6	8.6E-6	7.7E-6
Standarddeviation	3.0E-6	968.2E-9	717.8E-9	1.2E-6	413.1E-9	130.3E-9	116.2E-9	220.4E-9	358.3E-9	146.4E-9
Mean + $k\sigma$	76.5E-6	20.9E-6	6.2E-6	4.4E-6	8.8E-6	8.9E-6	9.0E-6	9.4E-6	9.6E-6	8.1E-6
Mean - $k\sigma$	60.3E-6	15.6E-6	2.3E-6	-2.4E-6	6.5E-6	8.2E-6	8.4E-6	8.2E-6	7.7E-6	7.3E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	63.4E-6	59.1E-6	63.8E-6	55.4E-6	65.5E-6	55.9E-6	54.1E-6	63.8E-6	66.4E-6	62.9E-6
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3





## 7.4 Collector-base breakdown voltage

Collector-base breakdown voltage  
BVCBO in V

Limit: 598.5 < x

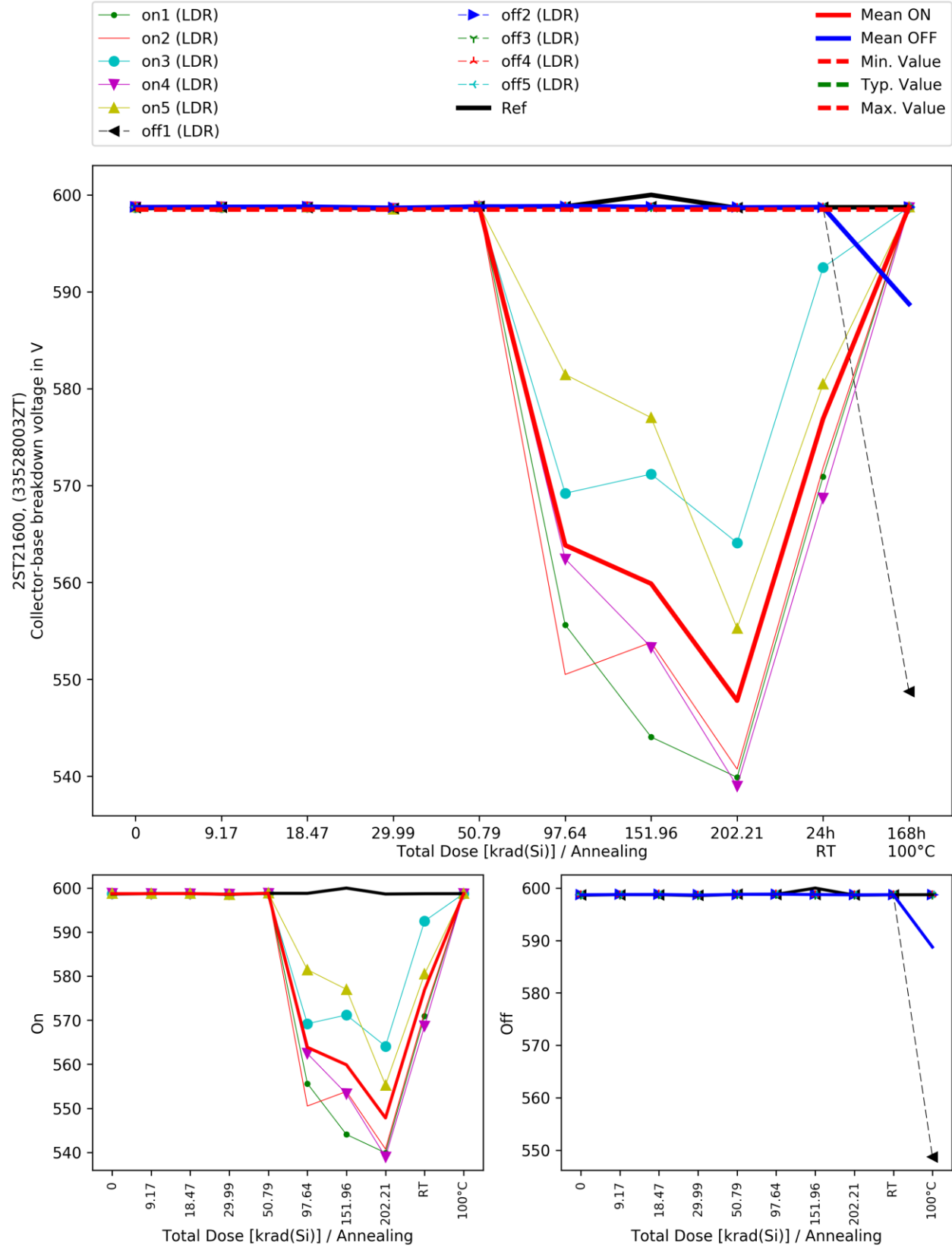
2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	598.7E+0	598.7E+0	598.7E+0	598.6E+0	598.8E+0	555.6E+0	544.0E+0	539.9E+0	570.9E+0	598.8E+0
on2 (LDR)	598.7E+0	598.7E+0	598.8E+0	598.6E+0	598.8E+0	550.5E+0	553.8E+0	540.7E+0	571.8E+0	598.7E+0
on3 (LDR)	598.7E+0	598.7E+0	598.7E+0	598.6E+0	598.8E+0	569.2E+0	571.2E+0	564.1E+0	592.5E+0	598.7E+0
on4 (LDR)	598.8E+0	598.8E+0	598.8E+0	598.6E+0	598.8E+0	562.4E+0	553.3E+0	539.0E+0	568.7E+0	598.7E+0
on5 (LDR)	598.8E+0	598.8E+0	598.8E+0	598.6E+0	598.9E+0	581.5E+0	577.0E+0	555.3E+0	580.5E+0	598.8E+0
Radiation-Mean ON	598.7E+0	598.7E+0	598.8E+0	598.6E+0	598.8E+0	563.8E+0	559.9E+0	547.8E+0	576.9E+0	598.7E+0
Standarddeviation	40.3E-3	34.7E-3	36.0E-3	42.4E-3	45.0E-3	12.1E+0	13.7E+0	11.3E+0	9.8E+0	43.2E-3
Mean + kσ	598.8E+0	598.8E+0	598.8E+0	598.7E+0	598.9E+0	597.1E+0	597.5E+0	578.8E+0	603.8E+0	598.9E+0
Mean - kσ	598.6E+0	598.6E+0	598.7E+0	598.5E+0	598.7E+0	530.6E+0	522.3E+0	516.8E+0	550.0E+0	598.6E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	598.7E+0	598.7E+0	598.7E+0	598.6E+0	598.8E+0	598.8E+0	598.8E+0	598.7E+0	598.8E+0	548.7E+0
off2 (LDR)	598.7E+0	598.8E+0	598.8E+0	598.7E+0	598.7E+0	598.8E+0	598.8E+0	598.7E+0	598.7E+0	598.8E+0
off3 (LDR)	598.7E+0	598.7E+0	598.8E+0	598.7E+0	598.8E+0	598.9E+0	598.8E+0	598.7E+0	598.8E+0	598.7E+0
off4 (LDR)	598.8E+0	598.8E+0	598.8E+0	598.6E+0	598.8E+0	598.8E+0	598.7E+0	598.7E+0	598.7E+0	598.7E+0
off5 (LDR)	598.7E+0	598.8E+0	598.8E+0	598.7E+0	598.8E+0	598.9E+0	598.7E+0	598.7E+0	598.8E+0	598.8E+0
Radiation-Mean OFF	598.7E+0	598.8E+0	598.8E+0	598.7E+0	598.8E+0	598.8E+0	598.8E+0	598.7E+0	598.7E+0	588.7E+0
Standarddeviation	23.2E-3	31.6E-3	46.4E-3	24.6E-3	43.7E-3	22.2E-3	29.9E-3	14.0E-3	32.1E-3	22.4E+0
Mean + kσ	598.8E+0	598.8E+0	598.9E+0	598.7E+0	598.9E+0	598.9E+0	598.8E+0	598.7E+0	598.8E+0	650.1E+0
Mean - kσ	598.7E+0	598.7E+0	598.7E+0	598.6E+0	598.7E+0	598.8E+0	598.7E+0	598.7E+0	598.7E+0	527.4E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	598.6E+0	598.7E+0	598.7E+0	598.6E+0	598.8E+0	598.8E+0	600.0E+0	598.6E+0	598.7E+0	598.7E+0
Min. Value	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0	598.5E+0

Comment:

- During these tests the SMU stopped slightly below the programmed 600 V. For a proper execution the programmed voltage should have been significantly higher, e.g. at 610 V. To avoid false-negative results indicating the device failing at that level, the limit of the parameter was reduced from 600 V to 598.5 V.



## 7.5 ICB @ 600 V

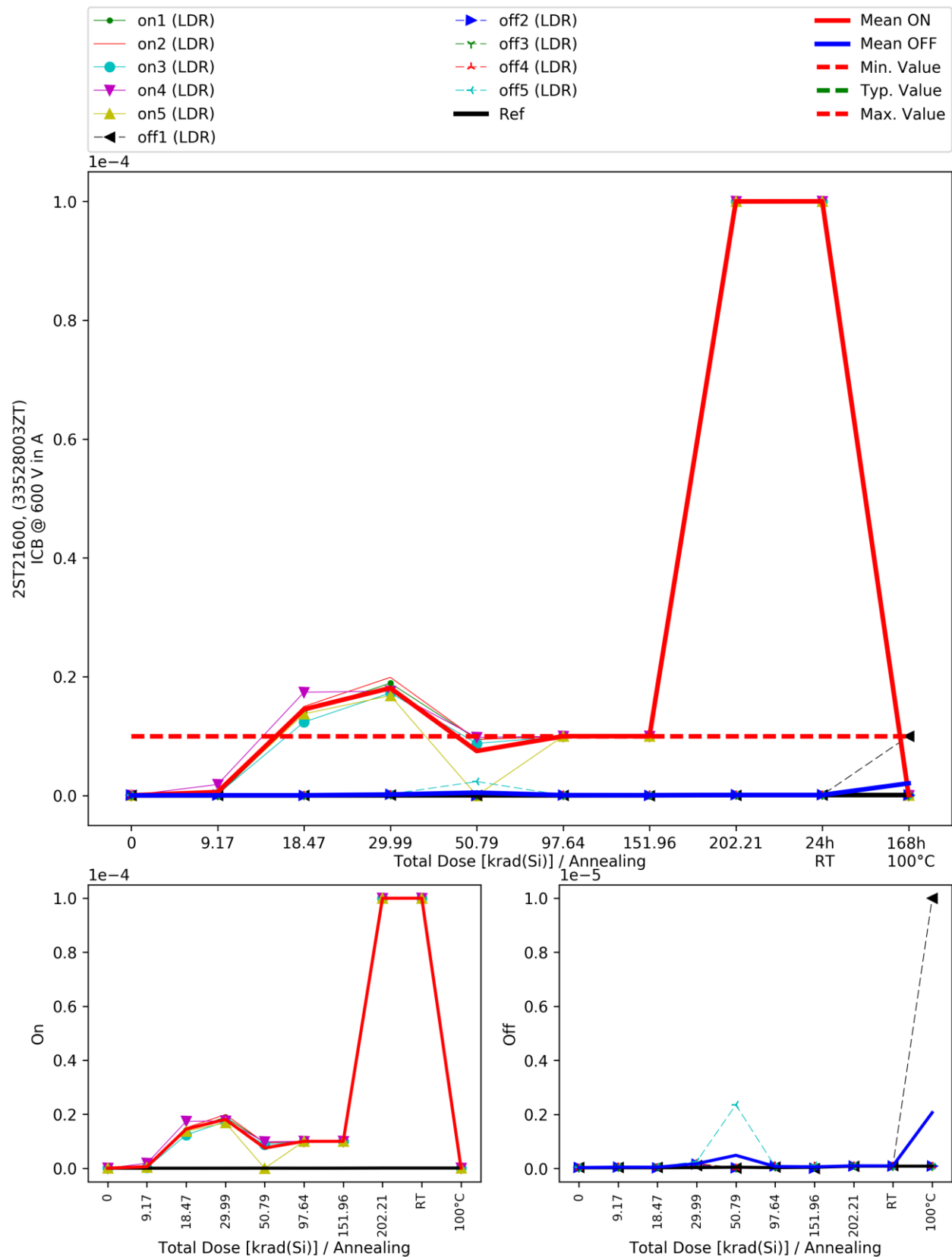
ICB @ 600 V  
BICBO in A

Limit:  $x < 1e-05$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	43.1E-9	32.5E-9	14.1E-6	18.9E-6	9.5E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	72.9E-9
on2 (LDR)	44.6E-9	528.8E-9	15.0E-6	19.9E-6	9.4E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	85.4E-9
on3 (LDR)	33.4E-9	214.3E-9	12.4E-6	17.3E-6	8.8E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	74.9E-9
on4 (LDR)	47.6E-9	1.9E-6	17.4E-6	17.6E-6	9.8E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	83.8E-9
on5 (LDR)	49.1E-9	320.2E-9	13.7E-6	16.8E-6	15.3E-9	10.0E-6	10.0E-6	100.0E-6	100.0E-6	84.8E-9
Radiation-Mean ON	43.6E-9	591.9E-9	14.5E-6	18.1E-6	7.5E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	80.4E-9
Standarddeviation	6.2E-9	733.2E-9	1.9E-6	1.3E-6	4.2E-6	6.0E-9	335.5E-12	7.0E-9	9.6E-9	6.0E-9
Mean + $k\sigma$	60.5E-9	2.6E-6	19.6E-6	21.6E-6	19.0E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	96.8E-9
Mean - $k\sigma$	26.6E-9	-1.4E-6	9.4E-6	14.6E-6	-4.0E-6	10.0E-6	10.0E-6	100.0E-6	100.0E-6	63.9E-9
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	40.9E-9	40.9E-9	40.9E-9	110.8E-9	25.1E-9	65.7E-9	10.6E-9	84.2E-9	113.7E-9	10.0E-6
off2 (LDR)	37.9E-9	46.1E-9	22.2E-9	158.8E-9	16.9E-9	83.0E-9	11.9E-9	90.6E-9	92.2E-9	84.7E-9
off3 (LDR)	33.4E-9	55.9E-9	78.5E-9	187.3E-9	31.1E-9	71.0E-9	90.7E-9	123.2E-9	92.3E-9	82.9E-9
off4 (LDR)	24.4E-9	59.6E-9	37.9E-9	181.3E-9	16.1E-9	95.0E-9	89.2E-9	107.4E-9	92.7E-9	93.5E-9
off5 (LDR)	44.6E-9	55.1E-9	69.5E-9	257.1E-9	2.4E-6	69.7E-9	118.0E-9	105.6E-9	102.8E-9	83.4E-9
Radiation-Mean OFF	36.2E-9	51.5E-9	49.8E-9	179.1E-9	489.2E-9	76.9E-9	64.1E-9	102.2E-9	98.7E-9	2.1E-6
Standarddeviation	7.8E-9	7.8E-9	23.4E-9	53.0E-9	1.0E-6	12.0E-9	49.6E-9	15.3E-9	9.5E-9	4.4E-6
Mean + $k\sigma$	57.6E-9	72.8E-9	114.0E-9	324.4E-9	3.4E-6	109.8E-9	200.0E-9	144.2E-9	124.8E-9	14.2E-6
Mean - $k\sigma$	14.8E-9	30.3E-9	-14.4E-9	33.7E-9	-2.4E-6	44.0E-9	-71.9E-9	60.2E-9	72.7E-9	-10.1E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	24.4E-9	28.2E-9	27.4E-9	34.2E-9	50.0E-9	32.0E-9	44.4E-9	87.8E-9	88.5E-9	89.3E-9
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6



## 7.6 Collector cut-off current

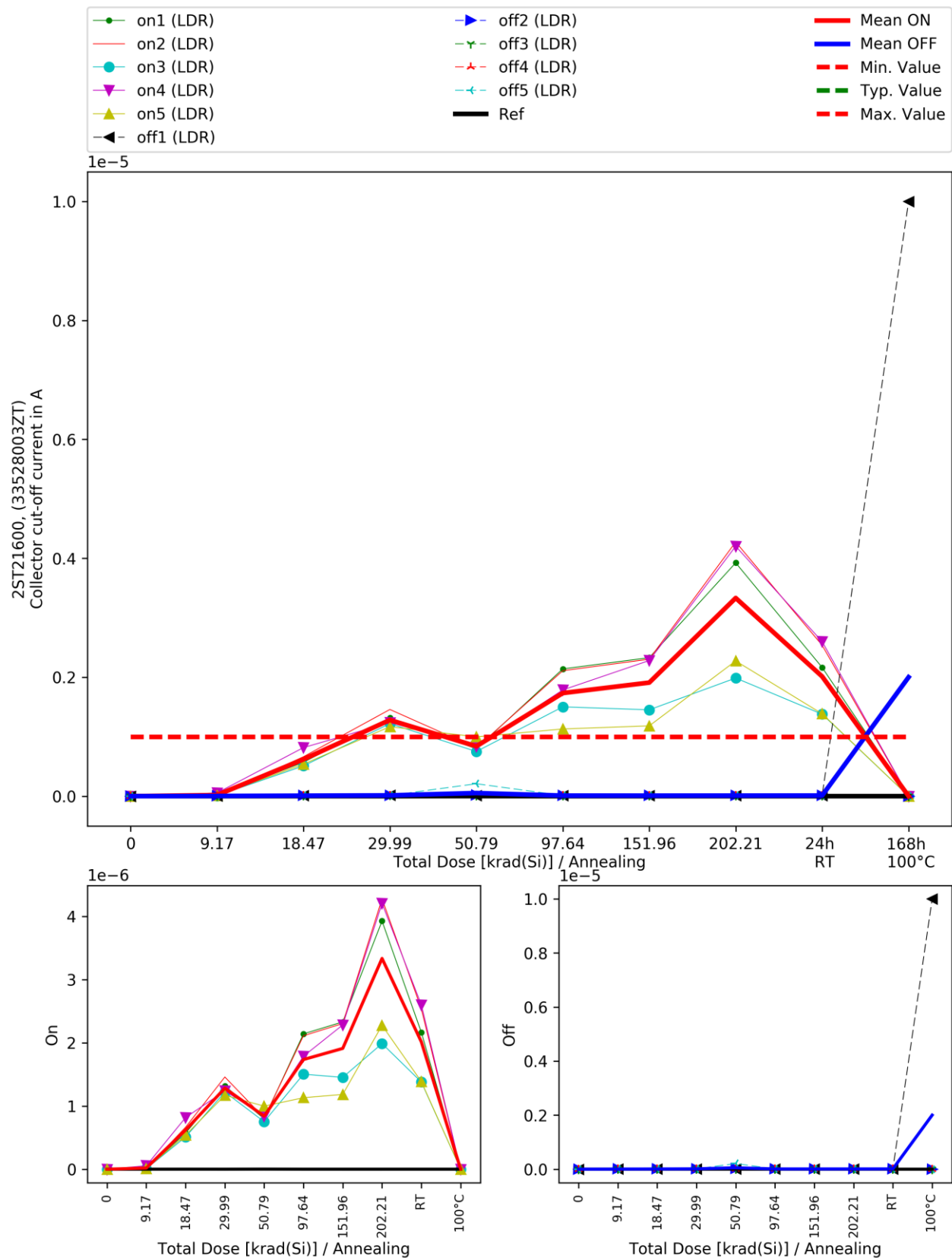
Collector cut-off current  
ICBO in A

Limit:  $x < 1e-06$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	165.9E-12	8.5E-9	570.2E-9	1.3E-6	796.4E-9	2.1E-6	2.3E-6	3.9E-6	2.2E-6	802.8E-12
on2 (LDR)	165.8E-12	11.6E-9	662.8E-9	1.5E-6	811.3E-9	2.1E-6	2.3E-6	4.3E-6	2.5E-6	692.3E-12
on3 (LDR)	161.4E-12	6.9E-9	508.9E-9	1.2E-6	750.9E-9	1.5E-6	1.5E-6	2.0E-6	1.4E-6	773.4E-12
on4 (LDR)	170.6E-12	54.4E-9	816.4E-9	1.2E-6	838.6E-9	1.8E-6	2.3E-6	4.2E-6	2.6E-6	784.2E-12
on5 (LDR)	166.9E-12	8.7E-9	538.0E-9	1.2E-6	997.3E-9	1.1E-6	1.2E-6	2.3E-6	1.4E-6	795.2E-12
Radiation-Mean ON	166.1E-12	18.0E-9	619.2E-9	1.3E-6	838.9E-9	1.7E-6	1.9E-6	3.3E-6	2.0E-6	769.6E-12
Standarddeviation	3.3E-12	20.4E-9	124.5E-9	112.6E-9	94.1E-9	426.4E-9	549.5E-9	1.1E-6	599.7E-9	44.6E-12
Mean + $k\sigma$	175.2E-12	74.0E-9	960.5E-9	1.6E-6	1.1E-6	2.9E-6	3.4E-6	6.4E-6	3.7E-6	891.9E-12
Mean - $k\sigma$	157.0E-12	-38.0E-9	278.0E-9	971.8E-9	580.9E-9	564.4E-9	402.9E-9	289.8E-9	368.6E-9	647.2E-12
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	169.2E-12	3.6E-9	8.4E-9	14.6E-9	11.3E-9	10.0E-9	8.7E-9	8.7E-9	10.1E-9	10.0E-6
off2 (LDR)	165.4E-12	3.7E-9	8.1E-9	10.8E-9	17.0E-9	8.9E-9	7.9E-9	8.6E-9	9.8E-9	1.2E-9
off3 (LDR)	622.0E-12	3.7E-9	8.5E-9	14.2E-9	11.6E-9	9.0E-9	8.3E-9	9.0E-9	10.0E-9	1.2E-9
off4 (LDR)	163.8E-12	3.7E-9	8.3E-9	13.5E-9	12.8E-9	9.0E-9	8.2E-9	9.2E-9	10.3E-9	1.3E-9
off5 (LDR)	163.7E-12	3.8E-9	8.4E-9	12.2E-9	209.3E-9	10.7E-9	11.2E-9	11.6E-9	12.2E-9	1.2E-9
Radiation-Mean OFF	256.8E-12	3.7E-9	8.3E-9	13.1E-9	52.4E-9	9.5E-9	8.9E-9	9.4E-9	10.5E-9	2.0E-6
Standarddeviation	204.1E-12	41.0E-12	148.6E-12	1.6E-9	87.7E-9	811.0E-12	1.3E-9	1.2E-9	969.9E-12	4.5E-6
Mean + $k\sigma$	816.6E-12	3.8E-9	8.7E-9	17.4E-9	293.0E-9	11.8E-9	12.6E-9	12.8E-9	13.1E-9	14.3E-6
Mean - $k\sigma$	-302.9E-12	3.6E-9	7.9E-9	8.7E-9	-188.2E-9	7.3E-9	5.2E-9	6.1E-9	7.8E-9	-10.3E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	188.1E-12	155.1E-12	491.0E-12	135.6E-12	1.3E-9	136.1E-12	97.8E-12	102.1E-12	130.5E-12	102.4E-12
Max. Value	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6



## 7.7 Emitter-base breakdown voltage

Emitter-base breakdown voltage  
BVEBO in V

Limit: 5.9 < x

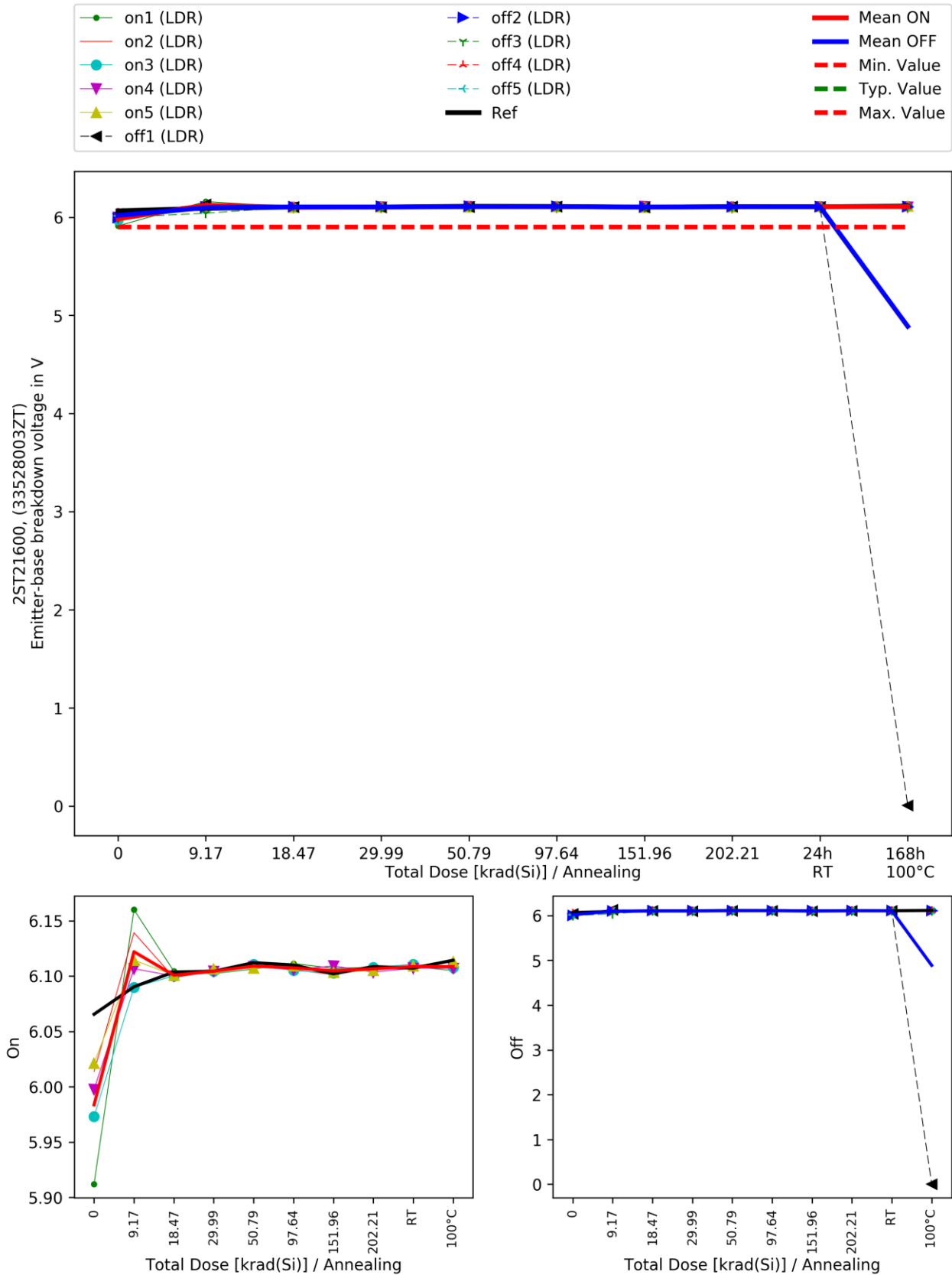
2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	5.9E+0	6.2E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on2 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on3 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on4 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on5 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Radiation-Mean ON	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Standarddeviation	44.0E-3	27.7E-3	2.1E-3	1.5E-3	2.4E-3	2.8E-3	3.2E-3	2.2E-3	1.5E-3	3.0E-3
Mean + kσ	6.1E+0	6.2E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Mean - kσ	5.9E+0	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	7.3E-3
off2 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off3 (LDR)	6.0E+0	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off4 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off5 (LDR)	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Radiation-Mean OFF	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	4.9E+0
Standarddeviation	23.2E-3	34.4E-3	2.0E-3	2.9E-3	2.0E-3	1.4E-3	2.6E-3	870.8E-6	1.3E-3	2.7E+0
Mean + kσ	6.1E+0	6.2E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	12.4E+0
Mean - kσ	6.0E+0	6.0E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	2.6E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Min. Value	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0	5.9E+0

Comment:

- During these tests the SMU stopped slightly below the programmed 6 V (not visible in the rounded values displayed here). For a proper execution the programmed voltage should have been significantly higher, e.g. at 6.1 V.  
To avoid false-negative results indicating the device failing at that level, the limit of the parameter was reduced from 6 V to 5.9 V.





## 7.8 IEB @ 6 V

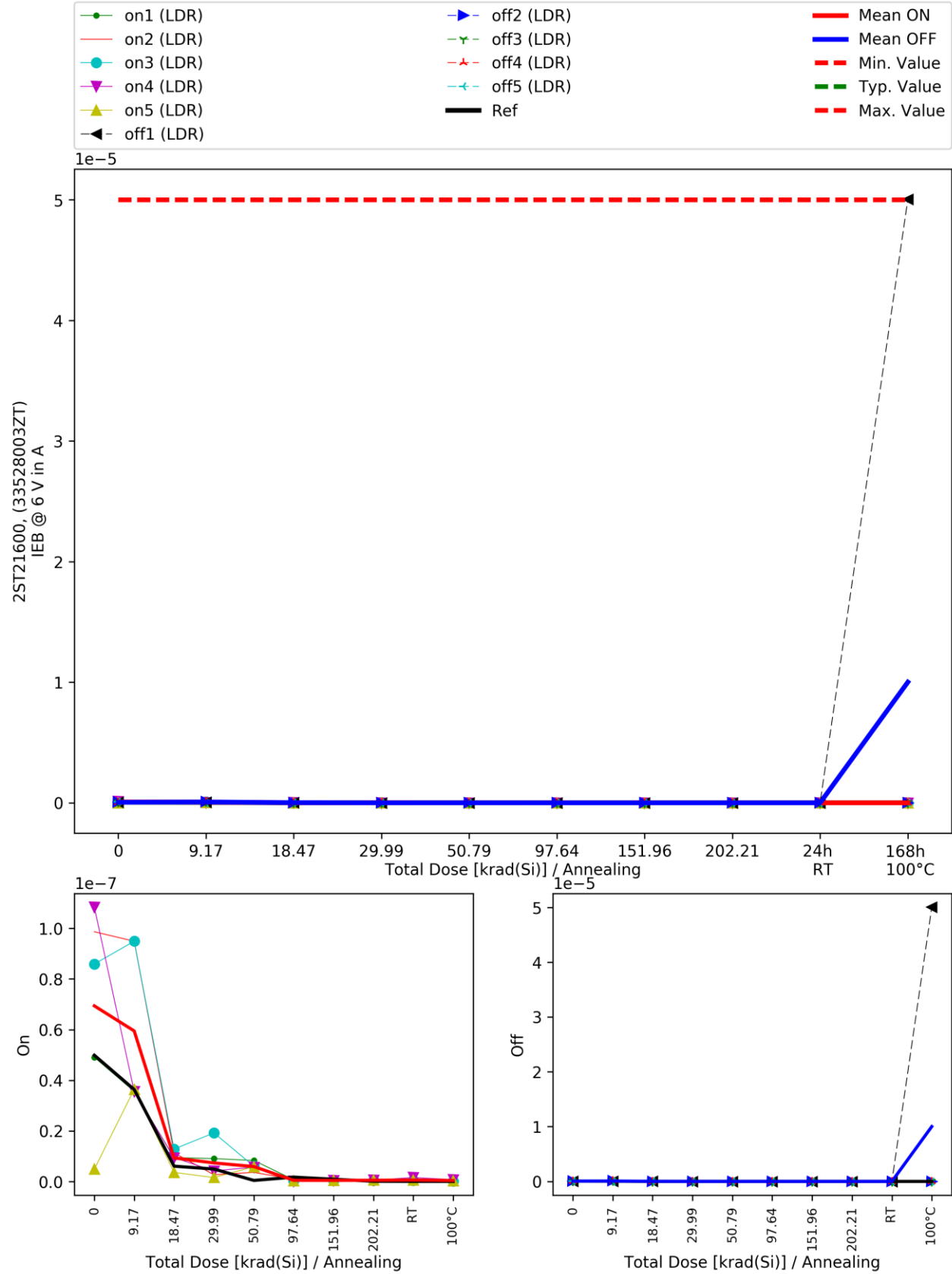
IEB @ 6 V  
BIEBO in A

Limit:  $x < 5e-05$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	49.1E-9	35.6E-9	9.5E-9	9.1E-9	8.4E-9	733.9E-12	627.3E-12	518.7E-12	264.0E-12	745.7E-12
on2 (LDR)	98.7E-9	94.9E-9	11.4E-9	2.7E-9	3.7E-9	954.3E-12	428.6E-12	575.9E-12	241.0E-12	152.8E-12
on3 (LDR)	85.9E-9	94.9E-9	12.9E-9	19.2E-9	6.1E-9	382.1E-12	422.7E-12	486.5E-12	460.1E-12	151.9E-12
on4 (LDR)	108.4E-9	35.6E-9	9.5E-9	4.2E-9	5.7E-9	239.1E-12	513.7E-12	579.1E-12	1.6E-9	811.2E-12
on5 (LDR)	4.9E-9	36.4E-9	3.7E-9	1.6E-9	5.9E-9	274.8E-12	444.5E-12	586.7E-12	619.0E-12	381.1E-12
Radiation-Mean ON	69.4E-9	59.5E-9	9.4E-9	7.4E-9	6.0E-9	516.8E-12	487.4E-12	549.4E-12	640.6E-12	448.5E-12
Standarddeviation	42.5E-9	32.3E-9	3.5E-9	7.2E-9	1.7E-9	313.2E-12	86.2E-12	44.4E-12	568.3E-12	316.1E-12
Mean + $k\sigma$	185.9E-9	148.1E-9	18.9E-9	27.2E-9	10.5E-9	1.4E-9	723.9E-12	671.0E-12	2.2E-9	1.3E-9
Mean - $k\sigma$	-47.1E-9	-29.1E-9	-207.2E-12	-12.4E-9	1.4E-9	-342.0E-12	250.9E-12	427.8E-12	-917.7E-12	-418.3E-12
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	53.6E-9	58.1E-9	30.1E-9	280.0E-12	113.6E-12	354.3E-12	421.5E-12	490.6E-12	1.4E-9	50.0E-6
off2 (LDR)	44.6E-9	99.5E-9	4.2E-9	1.0E-9	3.5E-9	578.3E-12	412.6E-12	511.8E-12	370.7E-12	234.7E-12
off3 (LDR)	53.6E-9	95.0E-9	4.6E-9	3.5E-9	97.8E-12	397.1E-12	480.5E-12	526.1E-12	562.0E-12	535.3E-12
off4 (LDR)	17.6E-9	89.7E-9	5.4E-9	1.6E-9	3.7E-9	348.1E-12	370.3E-12	437.5E-12	549.4E-12	521.6E-12
off5 (LDR)	72.5E-9	5.2E-9	25.6E-9	2.7E-9	5.5E-9	390.5E-12	489.5E-12	527.7E-12	530.4E-12	656.7E-12
Radiation-Mean OFF	48.4E-9	69.5E-9	14.0E-9	1.8E-9	2.6E-9	413.7E-12	434.9E-12	498.7E-12	675.9E-12	10.0E-6
Standarddeviation	20.0E-9	39.4E-9	12.8E-9	1.3E-9	2.4E-9	94.5E-12	49.8E-12	37.3E-12	394.0E-12	22.4E-6
Mean + $k\sigma$	103.2E-9	177.6E-9	49.1E-9	5.3E-9	9.1E-9	672.9E-12	571.4E-12	601.0E-12	1.8E-9	71.4E-6
Mean - $k\sigma$	-6.4E-9	-38.7E-9	-21.1E-9	-1.7E-9	-4.0E-9	154.5E-12	298.4E-12	396.4E-12	-404.4E-12	-51.4E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	49.9E-9	36.4E-9	6.1E-9	5.0E-9	477.3E-12	1.8E-9	954.7E-12	139.2E-12	95.4E-12	87.0E-12
Max. Value	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6



## 7.9 Emitter cut-off current

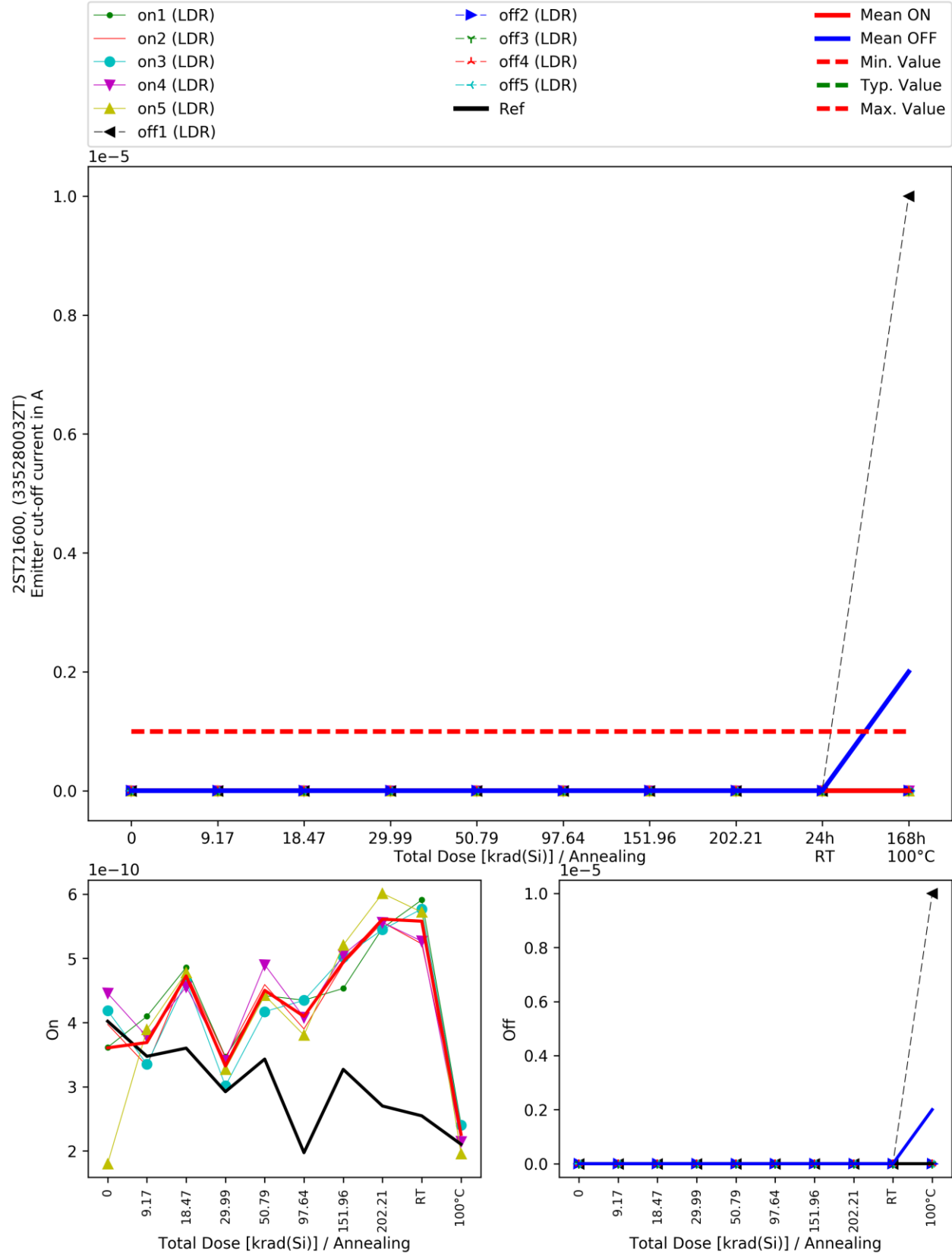
Emitter cut-off current  
IEBO in A

Limit:  $x < 1e-06$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	361.4E-12	409.6E-12	485.8E-12	346.5E-12	441.9E-12	434.8E-12	453.1E-12	547.0E-12	591.1E-12	242.0E-12
on2 (LDR)	397.2E-12	332.6E-12	478.3E-12	345.5E-12	459.1E-12	390.0E-12	490.9E-12	556.3E-12	522.5E-12	236.6E-12
on3 (LDR)	418.5E-12	335.0E-12	464.7E-12	301.4E-12	417.1E-12	434.5E-12	502.1E-12	544.7E-12	577.0E-12	239.8E-12
on4 (LDR)	445.6E-12	378.0E-12	455.7E-12	340.9E-12	490.1E-12	408.0E-12	505.6E-12	566.1E-12	526.7E-12	214.6E-12
on5 (LDR)	180.0E-12	388.9E-12	477.9E-12	327.3E-12	442.3E-12	380.4E-12	520.8E-12	601.2E-12	572.0E-12	195.5E-12
Radiation-Mean ON	360.5E-12	368.8E-12	472.5E-12	332.3E-12	450.1E-12	409.5E-12	494.5E-12	561.0E-12	557.9E-12	225.7E-12
Standarddeviation	105.5E-12	33.9E-12	12.1E-12	18.9E-12	26.9E-12	25.0E-12	25.5E-12	23.0E-12	31.2E-12	20.1E-12
Mean + $k\sigma$	649.8E-12	461.9E-12	505.6E-12	384.2E-12	524.0E-12	478.1E-12	564.4E-12	624.2E-12	643.4E-12	280.9E-12
Mean - $k\sigma$	71.2E-12	275.7E-12	439.4E-12	280.4E-12	376.2E-12	341.0E-12	424.7E-12	497.9E-12	472.4E-12	170.5E-12
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	420.9E-12	424.4E-12	453.7E-12	360.2E-12	441.3E-12	429.2E-12	513.2E-12	552.6E-12	537.1E-12	10.0E-6
off2 (LDR)	396.2E-12	374.9E-12	484.2E-12	338.4E-12	453.5E-12	403.0E-12	515.5E-12	561.5E-12	558.3E-12	262.3E-12
off3 (LDR)	412.9E-12	384.9E-12	506.6E-12	338.1E-12	456.4E-12	426.9E-12	514.2E-12	554.7E-12	594.6E-12	186.8E-12
off4 (LDR)	378.4E-12	375.4E-12	481.8E-12	319.4E-12	420.3E-12	457.2E-12	469.9E-12	547.1E-12	577.0E-12	194.3E-12
off5 (LDR)	402.0E-12	357.4E-12	493.9E-12	331.8E-12	447.6E-12	418.4E-12	561.7E-12	552.6E-12	612.2E-12	196.9E-12
Radiation-Mean OFF	402.1E-12	383.4E-12	484.0E-12	337.6E-12	443.8E-12	427.0E-12	514.9E-12	553.7E-12	575.8E-12	2.0E-6
Standarddeviation	16.3E-12	25.0E-12	19.6E-12	14.8E-12	14.4E-12	19.8E-12	32.5E-12	5.2E-12	29.5E-12	4.5E-6
Mean + $k\sigma$	446.9E-12	451.9E-12	537.7E-12	378.2E-12	483.2E-12	481.2E-12	603.9E-12	568.0E-12	656.8E-12	14.3E-6
Mean - $k\sigma$	357.3E-12	314.9E-12	430.4E-12	297.0E-12	404.4E-12	372.7E-12	425.9E-12	539.4E-12	494.9E-12	-10.3E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	402.0E-12	347.4E-12	360.1E-12	292.2E-12	343.0E-12	197.2E-12	327.0E-12	269.9E-12	254.6E-12	210.3E-12
Max. Value	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6



## 7.10 Collector-emitter saturation voltage

### Collector-emitter saturation voltage

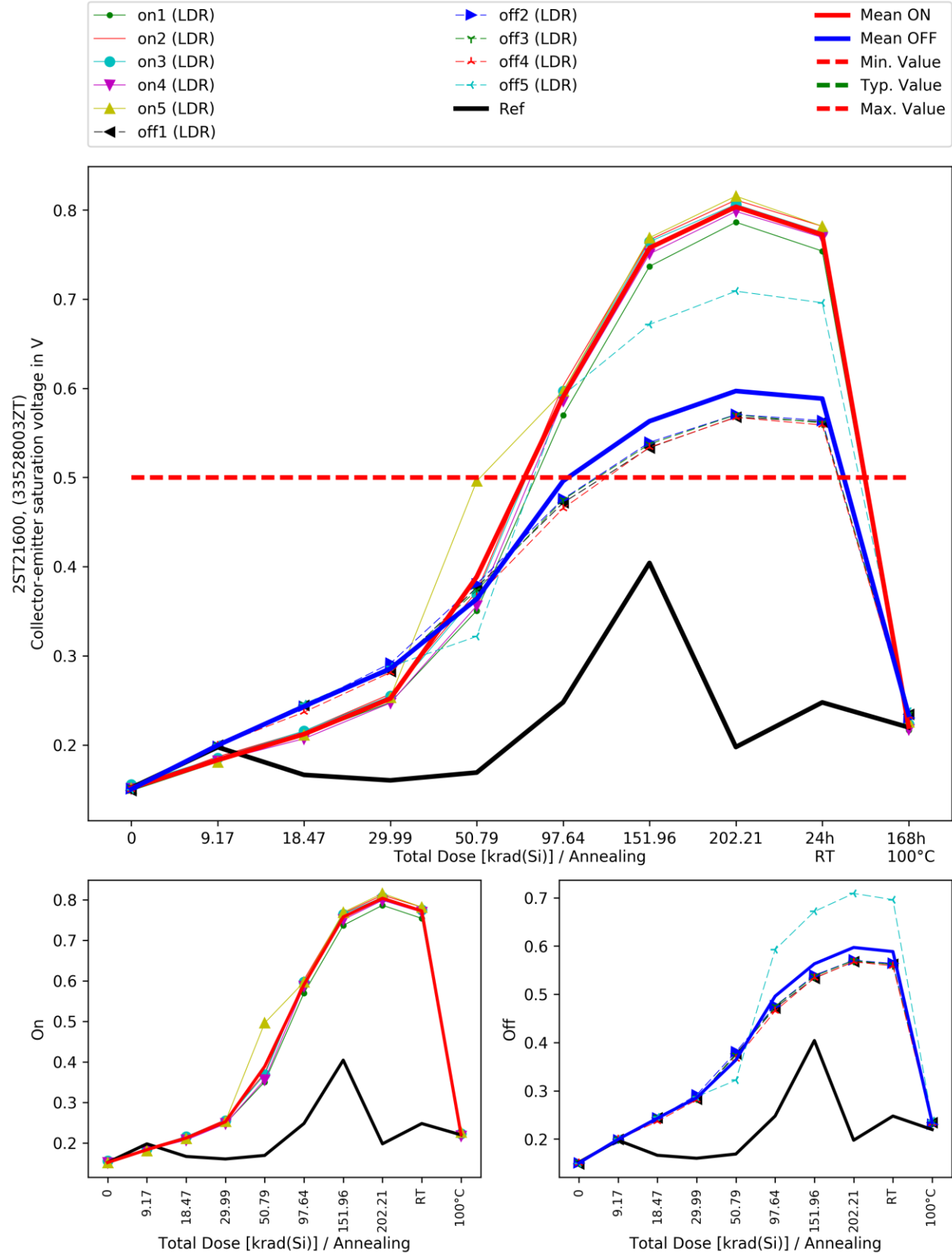
Vcesat in V

Limit:  $x < 0.5$

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	148.6E-3	180.8E-3	211.3E-3	247.6E-3	350.6E-3	569.8E-3	736.8E-3	786.4E-3	754.0E-3	216.6E-3
on2 (LDR)	151.7E-3	186.8E-3	215.4E-3	257.2E-3	372.0E-3	602.7E-3	766.5E-3	811.3E-3	781.8E-3	219.6E-3
on3 (LDR)	155.5E-3	185.3E-3	215.7E-3	255.0E-3	368.6E-3	597.0E-3	764.5E-3	806.3E-3	775.1E-3	223.1E-3
on4 (LDR)	150.9E-3	182.0E-3	207.0E-3	247.1E-3	356.1E-3	585.9E-3	750.8E-3	798.5E-3	769.3E-3	217.2E-3
on5 (LDR)	151.2E-3	180.6E-3	210.9E-3	253.3E-3	495.9E-3	596.8E-3	768.9E-3	815.6E-3	781.8E-3	225.9E-3
Radiation-Mean ON	151.6E-3	183.1E-3	212.1E-3	252.0E-3	388.6E-3	590.4E-3	757.5E-3	803.6E-3	772.4E-3	220.5E-3
Standarddeviation	2.5E-3	2.8E-3	3.6E-3	4.5E-3	60.6E-3	13.0E-3	13.5E-3	11.6E-3	11.5E-3	3.9E-3
Mean + $k\sigma$	158.5E-3	190.7E-3	222.0E-3	264.4E-3	554.8E-3	626.2E-3	794.7E-3	835.3E-3	804.0E-3	231.3E-3
Mean - $k\sigma$	144.8E-3	175.4E-3	202.2E-3	239.7E-3	222.4E-3	554.7E-3	720.4E-3	771.9E-3	740.8E-3	209.7E-3
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	149.0E-3	199.8E-3	244.3E-3	282.6E-3	376.7E-3	471.6E-3	533.3E-3	567.7E-3	562.5E-3	234.5E-3
off2 (LDR)	150.6E-3	198.3E-3	243.4E-3	291.4E-3	380.7E-3	476.0E-3	539.4E-3	570.6E-3	563.8E-3	230.2E-3
off3 (LDR)	152.3E-3	200.0E-3	245.8E-3	285.0E-3	373.5E-3	475.1E-3	537.5E-3	570.3E-3	561.2E-3	234.3E-3
off4 (LDR)	150.1E-3	199.2E-3	236.7E-3	281.3E-3	365.8E-3	465.3E-3	533.9E-3	567.4E-3	558.9E-3	232.5E-3
off5 (LDR)	149.7E-3	200.5E-3	246.0E-3	287.7E-3	321.8E-3	592.4E-3	671.7E-3	709.0E-3	696.0E-3	237.9E-3
Radiation-Mean OFF	150.3E-3	199.6E-3	243.3E-3	285.6E-3	363.7E-3	496.1E-3	563.2E-3	597.0E-3	588.5E-3	233.9E-3
Standarddeviation	1.2E-3	851.2E-6	3.8E-3	4.1E-3	24.1E-3	54.0E-3	60.7E-3	62.6E-3	60.1E-3	2.8E-3
Mean + $k\sigma$	153.7E-3	201.9E-3	253.7E-3	296.7E-3	429.7E-3	644.1E-3	729.7E-3	768.7E-3	753.4E-3	241.6E-3
Mean - $k\sigma$	147.0E-3	197.2E-3	232.8E-3	274.5E-3	297.7E-3	348.0E-3	396.6E-3	425.3E-3	423.6E-3	226.1E-3
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	151.8E-3	197.5E-3	166.4E-3	160.3E-3	169.0E-3	247.8E-3	404.1E-3	197.7E-3	247.7E-3	219.7E-3
Max. Value	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3



Report 014/2017

Version 1.0

42

## 7.11 Base emitter saturation voltage

### Base emitter saturation voltage

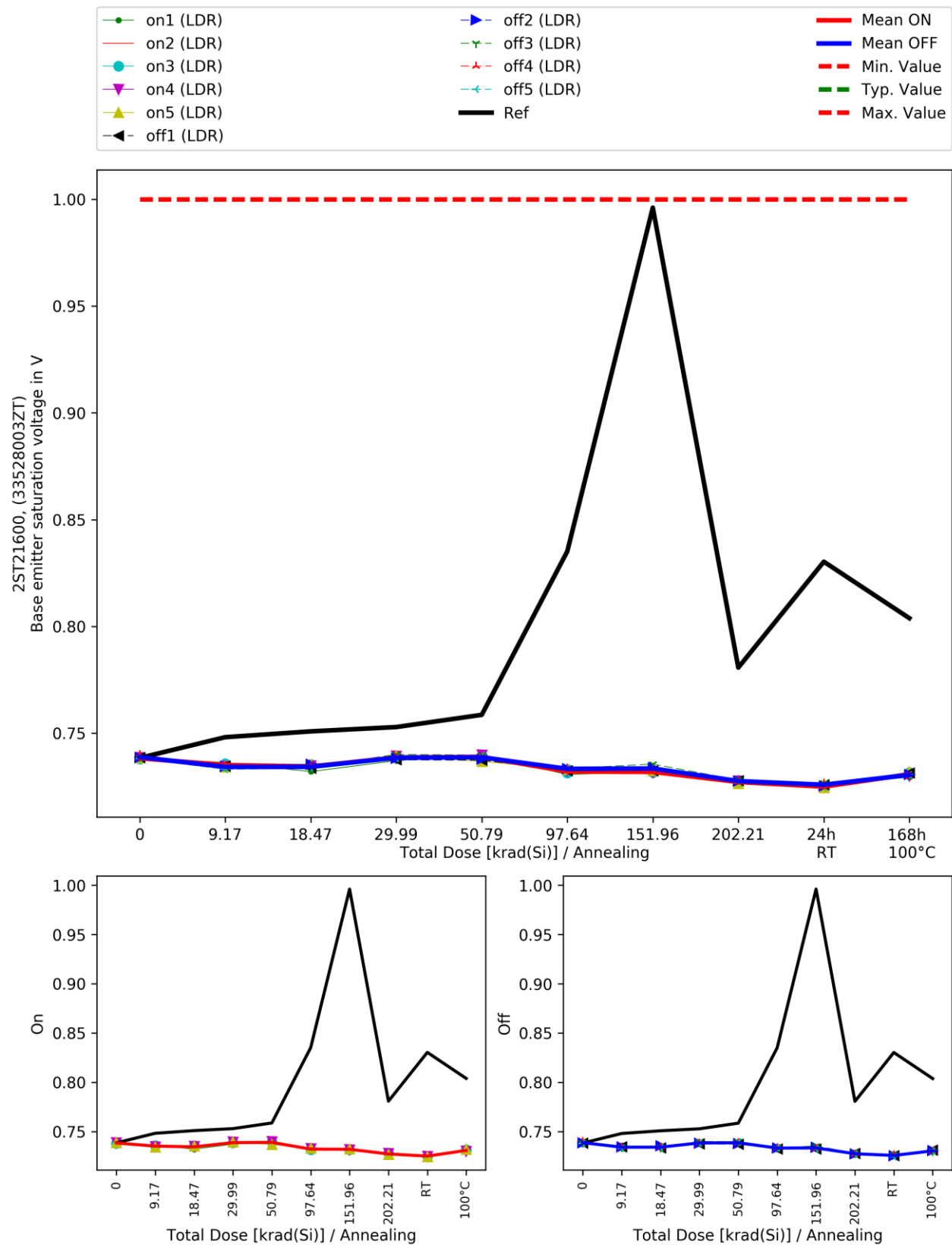
V<sub>besat</sub> in V

Limit: x < 1.0

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	738.5E-3	736.2E-3	732.0E-3	737.1E-3	739.6E-3	730.7E-3	731.9E-3	727.2E-3	726.0E-3	729.4E-3
on2 (LDR)	737.7E-3	734.7E-3	734.3E-3	738.8E-3	738.7E-3	732.6E-3	731.8E-3	726.4E-3	724.8E-3	731.0E-3
on3 (LDR)	738.0E-3	735.8E-3	735.5E-3	738.5E-3	739.5E-3	731.5E-3	731.6E-3	728.0E-3	724.8E-3	731.6E-3
on4 (LDR)	738.7E-3	734.5E-3	734.8E-3	739.3E-3	739.8E-3	732.5E-3	731.6E-3	727.7E-3	724.7E-3	730.0E-3
on5 (LDR)	738.5E-3	734.2E-3	735.3E-3	739.4E-3	736.8E-3	733.1E-3	732.5E-3	726.5E-3	724.6E-3	731.9E-3
Radiation-Mean ON	738.3E-3	735.1E-3	734.4E-3	738.6E-3	738.9E-3	732.1E-3	731.9E-3	727.1E-3	725.0E-3	730.8E-3
Standarddeviation	418.5E-6	881.6E-6	1.4E-3	910.8E-6	1.3E-3	976.9E-6	349.1E-6	688.8E-6	568.6E-6	1.1E-3
Mean + kσ	739.4E-3	737.5E-3	738.2E-3	741.1E-3	742.4E-3	734.8E-3	732.8E-3	729.0E-3	726.5E-3	733.7E-3
Mean - kσ	737.1E-3	732.7E-3	730.6E-3	736.1E-3	735.4E-3	729.4E-3	730.9E-3	725.3E-3	723.4E-3	727.8E-3
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	738.6E-3	734.7E-3	733.6E-3	737.5E-3	737.4E-3	732.5E-3	732.5E-3	727.8E-3	725.9E-3	731.5E-3
off2 (LDR)	738.4E-3	734.4E-3	735.4E-3	738.2E-3	737.8E-3	733.3E-3	733.9E-3	727.4E-3	725.2E-3	730.5E-3
off3 (LDR)	738.9E-3	734.5E-3	734.1E-3	740.1E-3	739.8E-3	733.5E-3	735.5E-3	728.1E-3	726.7E-3	730.2E-3
off4 (LDR)	740.0E-3	734.4E-3	734.4E-3	738.6E-3	738.9E-3	733.6E-3	732.8E-3	727.3E-3	726.6E-3	729.8E-3
off5 (LDR)	738.1E-3	733.1E-3	733.6E-3	738.2E-3	739.7E-3	733.7E-3	732.6E-3	727.3E-3	724.8E-3	730.5E-3
Radiation-Mean OFF	738.8E-3	734.2E-3	734.2E-3	738.5E-3	738.7E-3	733.3E-3	733.5E-3	727.6E-3	725.8E-3	730.5E-3
Standarddeviation	710.4E-6	661.2E-6	760.2E-6	943.6E-6	1.1E-3	468.3E-6	1.3E-3	366.7E-6	842.5E-6	604.1E-6
Mean + kσ	740.7E-3	736.0E-3	736.3E-3	741.1E-3	741.7E-3	734.6E-3	736.9E-3	728.6E-3	728.2E-3	732.2E-3
Mean - kσ	736.9E-3	732.4E-3	732.1E-3	735.9E-3	735.7E-3	732.0E-3	730.0E-3	726.6E-3	723.5E-3	728.9E-3
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	738.4E-3	748.1E-3	750.9E-3	752.9E-3	758.6E-3	835.1E-3	996.1E-3	780.7E-3	830.3E-3	803.8E-3
Max. Value	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0





## 7.12 DC current gain (1)

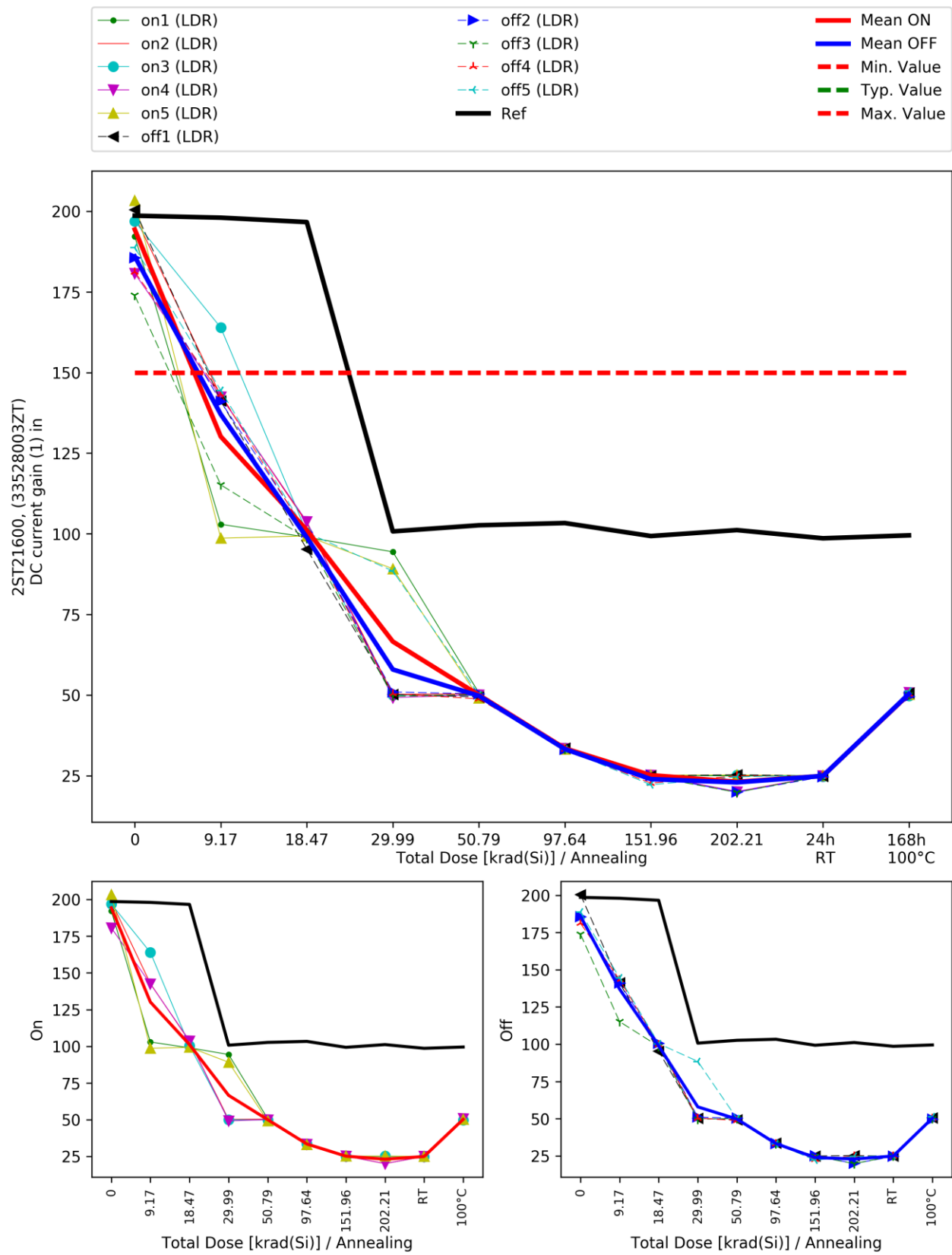
DC current gain (1)  
HFE1 in

Limit: 150.0 < x

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	192.2E+0	102.9E+0	99.0E+0	94.4E+0	50.7E+0	33.6E+0	25.1E+0	24.9E+0	24.9E+0	49.7E+0
on2 (LDR)	198.6E+0	142.7E+0	103.4E+0	50.2E+0	50.4E+0	33.6E+0	25.2E+0	20.1E+0	25.0E+0	50.9E+0
on3 (LDR)	196.9E+0	163.9E+0	100.4E+0	50.0E+0	49.9E+0	33.5E+0	25.0E+0	25.2E+0	24.7E+0	49.8E+0
on4 (LDR)	180.7E+0	142.5E+0	103.8E+0	49.2E+0	50.1E+0	33.4E+0	25.2E+0	20.1E+0	25.0E+0	50.8E+0
on5 (LDR)	203.3E+0	98.7E+0	99.3E+0	89.1E+0	49.1E+0	33.2E+0	25.2E+0	25.2E+0	25.1E+0	50.2E+0
Radiation-Mean ON	194.3E+0	130.1E+0	101.2E+0	66.6E+0	50.0E+0	33.5E+0	25.2E+0	23.1E+0	24.9E+0	50.3E+0
Standarddeviation	8.6E+0	28.2E+0	2.3E+0	23.1E+0	600.6E-3	180.4E-3	80.5E-3	2.8E+0	114.1E-3	567.2E-3
Mean + kσ	217.9E+0	207.5E+0	107.4E+0	129.8E+0	51.7E+0	34.0E+0	25.4E+0	30.6E+0	25.2E+0	51.8E+0
Mean - kσ	170.8E+0	52.8E+0	94.9E+0	3.4E+0	48.4E+0	33.0E+0	24.9E+0	15.5E+0	24.6E+0	48.7E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	200.5E+0	141.2E+0	95.3E+0	50.2E+0	49.4E+0	33.6E+0	24.9E+0	25.3E+0	24.9E+0	50.6E+0
off2 (LDR)	185.5E+0	141.0E+0	100.4E+0	51.0E+0	50.4E+0	33.1E+0	25.0E+0	19.9E+0	24.7E+0	49.5E+0
off3 (LDR)	173.9E+0	115.2E+0	98.6E+0	49.6E+0	50.2E+0	33.2E+0	24.8E+0	19.8E+0	25.0E+0	50.1E+0
off4 (LDR)	181.2E+0	143.3E+0	99.8E+0	50.4E+0	48.8E+0	33.2E+0	22.7E+0	24.9E+0	24.9E+0	50.3E+0
off5 (LDR)	188.7E+0	144.4E+0	100.4E+0	88.5E+0	50.1E+0	33.2E+0	22.2E+0	24.6E+0	25.2E+0	51.2E+0
Radiation-Mean OFF	186.0E+0	137.0E+0	98.9E+0	57.9E+0	49.8E+0	33.3E+0	23.9E+0	22.9E+0	24.9E+0	50.4E+0
Standarddeviation	9.8E+0	12.3E+0	2.2E+0	17.1E+0	650.0E-3	193.9E-3	1.4E+0	2.8E+0	197.0E-3	623.1E-3
Mean + kσ	212.9E+0	170.7E+0	104.8E+0	104.7E+0	51.6E+0	33.8E+0	27.7E+0	30.6E+0	25.5E+0	52.1E+0
Mean - kσ	159.0E+0	103.3E+0	93.0E+0	11.1E+0	48.0E+0	32.7E+0	20.2E+0	15.3E+0	24.4E+0	48.7E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	198.6E+0	198.0E+0	196.6E+0	100.7E+0	102.6E+0	103.3E+0	99.3E+0	101.1E+0	98.6E+0	99.5E+0
Min. 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



### 7.13 DC current gain (2)

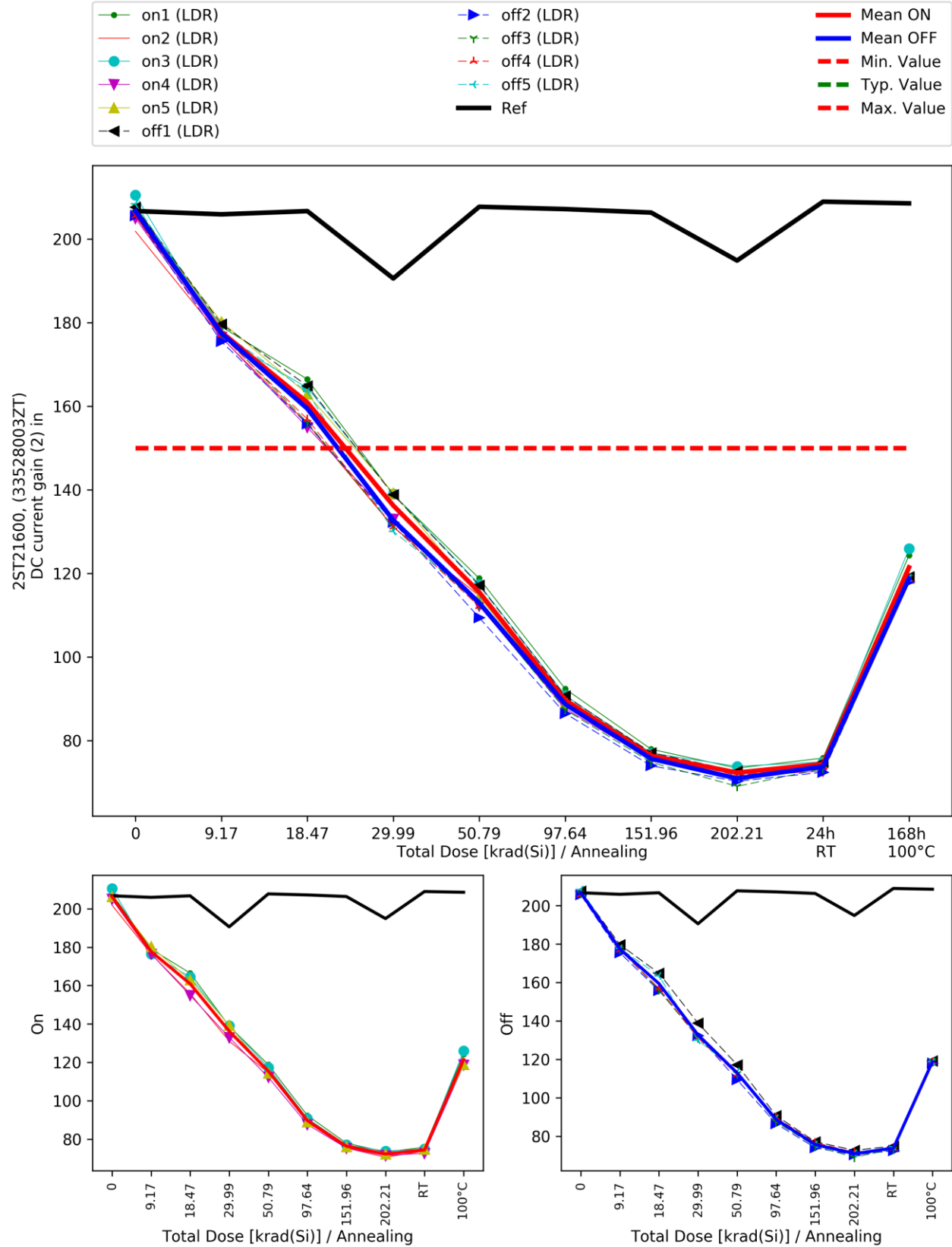
DC current gain (2)  
HFE2 in

Limit: 150.0 < x

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	207.8E+0	179.0E+0	166.5E+0	138.9E+0	118.8E+0	92.4E+0	77.9E+0	73.4E+0	75.8E+0	124.3E+0
on2 (LDR)	201.9E+0	176.5E+0	155.8E+0	131.1E+0	114.6E+0	88.8E+0	75.4E+0	70.6E+0	73.9E+0	119.5E+0
on3 (LDR)	210.5E+0	176.4E+0	164.4E+0	139.0E+0	117.4E+0	90.8E+0	77.0E+0	73.8E+0	74.9E+0	125.9E+0
on4 (LDR)	204.9E+0	176.5E+0	154.9E+0	133.0E+0	112.3E+0	87.7E+0	75.4E+0	71.5E+0	72.7E+0	118.7E+0
on5 (LDR)	206.3E+0	180.2E+0	162.9E+0	139.3E+0	114.5E+0	89.0E+0	76.1E+0	72.3E+0	74.7E+0	118.8E+0
Radiation-Mean ON	206.3E+0	177.7E+0	160.9E+0	136.2E+0	115.5E+0	89.7E+0	76.4E+0	72.3E+0	74.4E+0	121.5E+0
Standarddeviation	3.2E+0	1.8E+0	5.2E+0	3.9E+0	2.6E+0	1.9E+0	1.1E+0	1.3E+0	1.2E+0	3.4E+0
Mean + kσ	215.1E+0	182.6E+0	175.2E+0	146.9E+0	122.6E+0	94.8E+0	79.4E+0	76.0E+0	77.6E+0	130.8E+0
Mean - kσ	197.4E+0	172.9E+0	146.6E+0	125.5E+0	108.4E+0	84.7E+0	73.4E+0	68.7E+0	71.2E+0	112.1E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	207.6E+0	179.7E+0	164.9E+0	138.8E+0	117.2E+0	90.7E+0	77.1E+0	72.7E+0	74.8E+0	119.2E+0
off2 (LDR)	205.6E+0	175.5E+0	155.8E+0	132.3E+0	109.4E+0	86.5E+0	74.0E+0	70.3E+0	72.4E+0	118.0E+0
off3 (LDR)	206.4E+0	177.3E+0	156.1E+0	131.2E+0	112.4E+0	87.4E+0	74.8E+0	69.1E+0	73.3E+0	119.1E+0
off4 (LDR)	205.6E+0	177.0E+0	156.9E+0	131.2E+0	112.1E+0	89.7E+0	76.7E+0	71.7E+0	73.8E+0	118.7E+0
off5 (LDR)	208.4E+0	177.8E+0	163.5E+0	130.1E+0	113.7E+0	89.3E+0	75.7E+0	71.1E+0	74.6E+0	118.9E+0
Radiation-Mean OFF	206.7E+0	177.5E+0	159.4E+0	132.7E+0	113.0E+0	88.7E+0	75.7E+0	71.0E+0	73.8E+0	118.8E+0
Standarddeviation	1.3E+0	1.5E+0	4.4E+0	3.5E+0	2.8E+0	1.7E+0	1.3E+0	1.4E+0	979.4E-3	499.4E-3
Mean + kσ	210.2E+0	181.6E+0	171.5E+0	142.4E+0	120.7E+0	93.4E+0	79.2E+0	74.7E+0	76.5E+0	120.1E+0
Mean - kσ	203.2E+0	173.3E+0	147.4E+0	123.1E+0	105.2E+0	84.0E+0	72.1E+0	67.2E+0	71.1E+0	117.4E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	206.7E+0	205.9E+0	206.7E+0	190.6E+0	207.7E+0	207.2E+0	206.3E+0	194.9E+0	208.9E+0	208.5E+0
Min. 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



## 7.14 DC current gain (3)

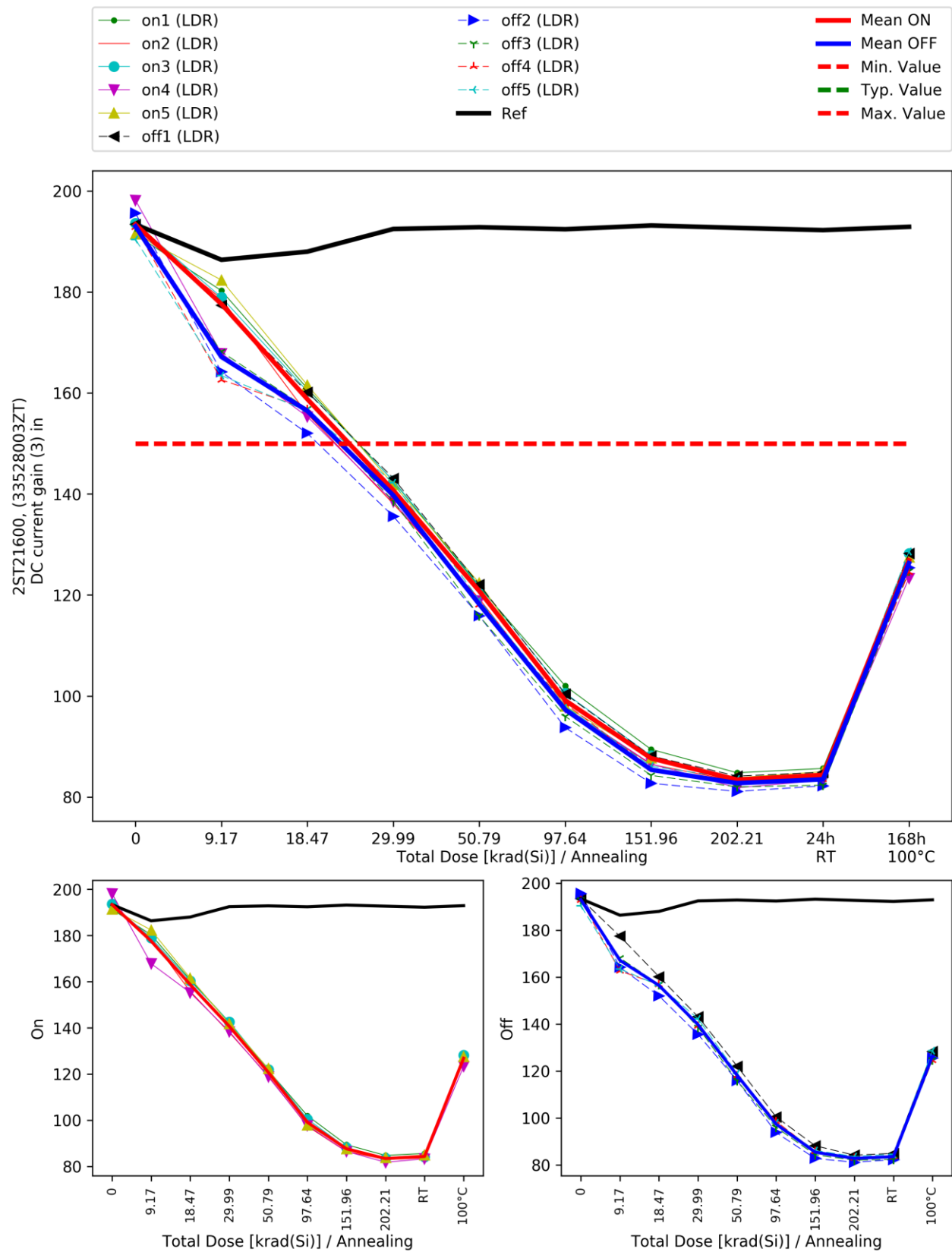
DC current gain (3)  
HFE3 in

Limit: 150.0 < x

2ST21600

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
on1 (LDR)	191.4E+0	180.3E+0	160.9E+0	142.5E+0	121.6E+0	102.0E+0	89.4E+0	84.8E+0	85.7E+0	127.3E+0
on2 (LDR)	192.2E+0	178.7E+0	155.8E+0	138.1E+0	119.3E+0	97.4E+0	86.5E+0	83.1E+0	83.6E+0	127.9E+0
on3 (LDR)	193.6E+0	178.9E+0	160.3E+0	142.6E+0	121.9E+0	100.5E+0	88.1E+0	83.6E+0	84.2E+0	128.2E+0
on4 (LDR)	198.2E+0	167.8E+0	155.3E+0	138.5E+0	118.8E+0	97.7E+0	86.5E+0	81.8E+0	83.3E+0	123.4E+0
on5 (LDR)	191.5E+0	182.4E+0	161.6E+0	141.9E+0	122.4E+0	98.0E+0	87.7E+0	83.8E+0	85.0E+0	127.5E+0
Radiation-Mean ON	193.4E+0	177.6E+0	158.8E+0	140.7E+0	120.8E+0	99.1E+0	87.7E+0	83.4E+0	84.4E+0	126.9E+0
Standarddeviation	2.8E+0	5.7E+0	3.0E+0	2.3E+0	1.6E+0	2.0E+0	1.2E+0	1.1E+0	964.7E-3	2.0E+0
Mean + $\kappa\sigma$	201.1E+0	193.1E+0	166.9E+0	146.9E+0	125.2E+0	104.7E+0	91.0E+0	86.4E+0	87.0E+0	132.3E+0
Mean - $\kappa\sigma$	185.6E+0	162.1E+0	150.6E+0	134.5E+0	116.3E+0	93.6E+0	84.3E+0	80.4E+0	81.7E+0	121.4E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
off1 (LDR)	193.4E+0	177.4E+0	160.2E+0	143.1E+0	122.1E+0	100.4E+0	88.1E+0	84.1E+0	84.9E+0	128.3E+0
off2 (LDR)	195.6E+0	164.2E+0	152.0E+0	135.6E+0	115.9E+0	93.7E+0	82.7E+0	81.1E+0	82.2E+0	125.4E+0
off3 (LDR)	192.8E+0	168.2E+0	156.9E+0	138.6E+0	115.8E+0	96.0E+0	84.3E+0	82.0E+0	82.3E+0	124.8E+0
off4 (LDR)	192.8E+0	162.6E+0	156.8E+0	139.1E+0	118.1E+0	98.5E+0	85.7E+0	82.9E+0	83.5E+0	124.5E+0
off5 (LDR)	190.4E+0	163.5E+0	156.4E+0	142.2E+0	119.0E+0	98.0E+0	86.1E+0	83.6E+0	84.5E+0	128.6E+0
Radiation-Mean OFF	193.0E+0	167.2E+0	156.5E+0	139.7E+0	118.2E+0	97.3E+0	85.4E+0	82.7E+0	83.5E+0	126.3E+0
Standarddeviation	1.8E+0	6.1E+0	2.9E+0	3.0E+0	2.6E+0	2.5E+0	2.0E+0	1.2E+0	1.2E+0	2.0E+0
Mean + $\kappa\sigma$	198.1E+0	183.9E+0	164.5E+0	148.0E+0	125.2E+0	104.3E+0	91.0E+0	86.1E+0	86.9E+0	131.7E+0
Mean - $\kappa\sigma$	187.9E+0	150.4E+0	148.5E+0	131.4E+0	111.1E+0	90.3E+0	79.8E+0	79.4E+0	80.1E+0	120.9E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	9.17	18.47	29.99	50.79	97.64	151.96	202.21	24h @ RT	68h @ 100°C
Ref1 (LDR)	193.4E+0	186.4E+0	188.0E+0	192.5E+0	192.8E+0	192.4E+0	193.2E+0	192.7E+0	192.2E+0	192.9E+0
Min. 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



## 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	68h @ 100°C
BVCEO	On										
	Off										
BICEO	On										
	Off										
BVCEO	On					2	5	5	5	5	
	Off										
BICEO	On					4	5	5	4	5	
	Off										
ICBO	On					3	5	5	5	5	
	Off										
BVEBO	On										
	Off										
BIEBO	On										
	Off										
IEBO	On										
	Off										
Vcesat	On						5	5	5	5	
	Off						5	5	5	5	
Vbesat	On										
	Off										
HFE1	On		5	5	5	5	5	5	5	5	5
	Off		5	5	5	5	5	5	5	5	5
HFE2	On			5	5	5	5	5	5	5	5
	Off			5	5	5	5	5	5	5	5
HFE3	On			5	5	5	5	5	5	5	5
	Off			4	5	5	5	5	5	5	5

- In this campaign, several parameters were read and recorded with a negative sign, while the same parameters were recorded without the sign in the low dose rate tests. To make the values comparable, the values in this campaign were appropriately multiplied with (-1). This is indicated in the respective tabulated values in the tables.

## 8.2 Collector-emitter breakdown voltage

Collector-emitter breakdown voltage

BVCEO in V

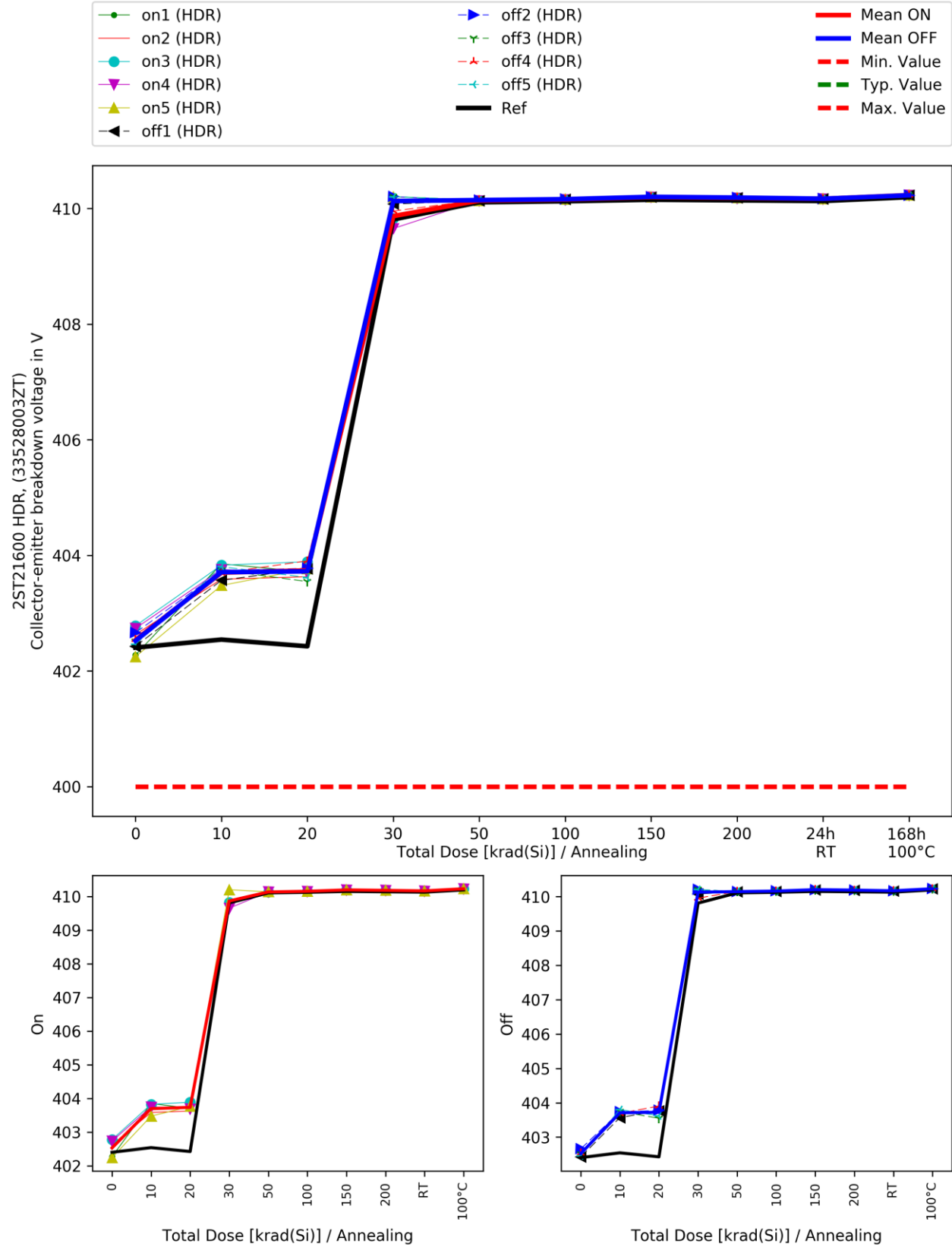
Corrected data:  $x^*(-1)$ Limit:  $400.0 < x$ 

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	402.3E+0	403.9E+0	403.7E+0	409.8E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
on2 (HDR)	402.6E+0	403.6E+0	403.6E+0	409.8E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
on3 (HDR)	402.8E+0	403.8E+0	403.9E+0	409.8E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
on4 (HDR)	402.7E+0	403.8E+0	403.7E+0	409.7E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
on5 (HDR)	402.2E+0	403.5E+0	403.8E+0	410.2E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Radiation-Mean ON	402.5E+0	403.7E+0	403.7E+0	409.9E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Standarddeviation	255.1E-3	162.0E-3	97.7E-3	201.7E-3	3.0E-3	2.0E-3	2.1E-3	1.7E-3	507.0E-6	559.5E-6
Mean + $k\sigma$	403.2E+0	404.1E+0	404.0E+0	410.4E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Mean - $k\sigma$	401.8E+0	403.3E+0	403.5E+0	409.3E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	402.4E+0	403.6E+0	403.8E+0	410.1E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
off2 (HDR)	402.7E+0	403.7E+0	403.8E+0	410.2E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
off3 (HDR)	402.5E+0	403.7E+0	403.5E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
off4 (HDR)	402.5E+0	403.7E+0	403.9E+0	410.0E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
off5 (HDR)	402.5E+0	403.8E+0	403.6E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Radiation-Mean OFF	402.5E+0	403.7E+0	403.7E+0	410.1E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Standarddeviation	90.7E-3	88.3E-3	142.0E-3	111.2E-3	4.8E-3	1.8E-3	1.4E-3	370.1E-6	1.5E-3	822.8E-6
Mean + $k\sigma$	402.8E+0	404.0E+0	404.1E+0	410.4E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Mean - $k\sigma$	402.3E+0	403.5E+0	403.3E+0	409.8E+0	410.1E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0	410.2E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	402.4E+0	402.5E+0	402.4E+0	409.8E+0	410.1E+0	410.1E+0	410.2E+0	410.1E+0	410.1E+0	410.2E+0
Min. Value	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0	400.0E+0



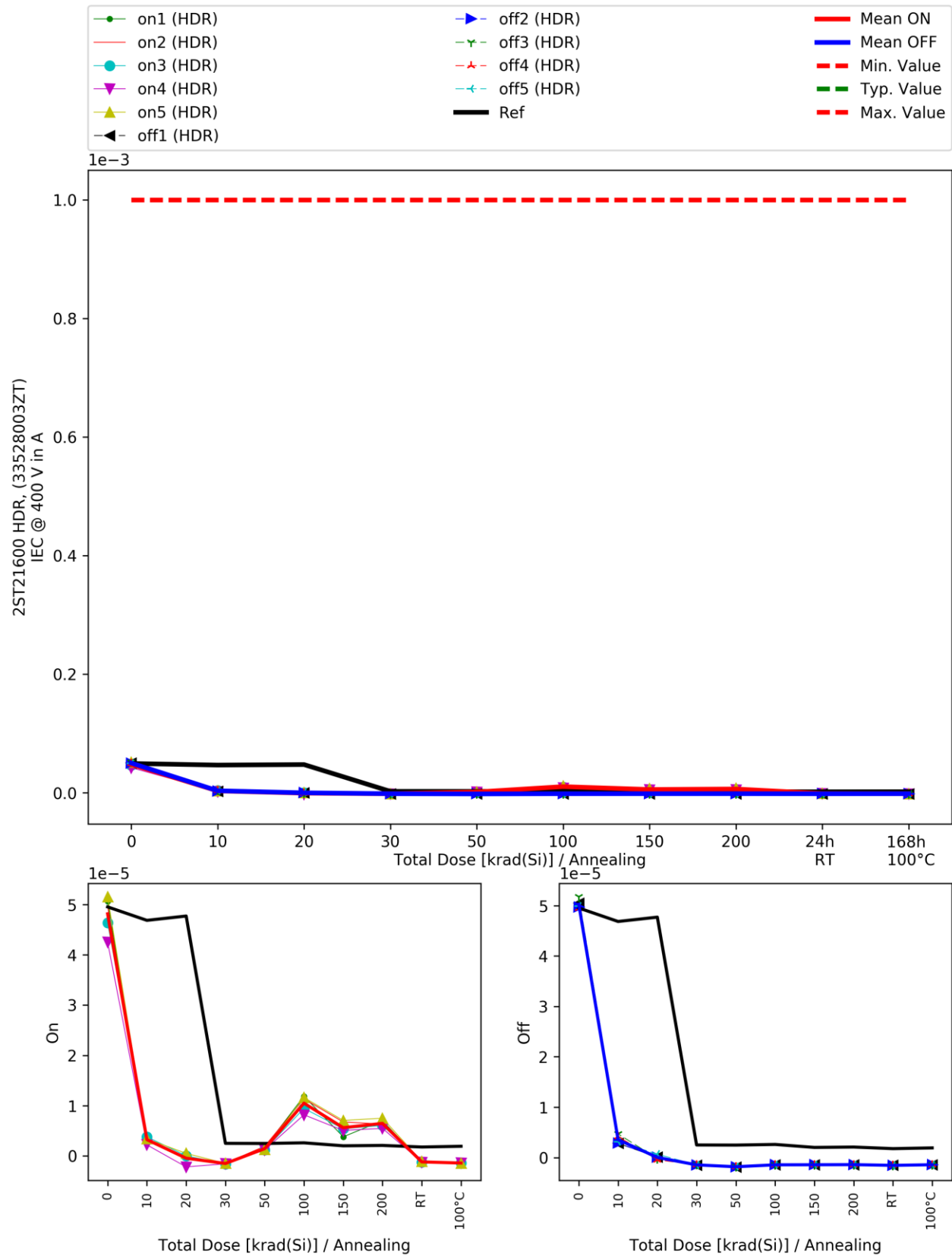


### 8.3 IEC @ 400 V

IEC @ 400 V  
BICEO in A  
Corrected data:  $x^*(-1)$   
Limit:  $x < 0.001$

**2ST21600 HDR**  
Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	50.7E-6	3.3E-6	-308.3E-9	-1.5E-6	1.7E-6	11.9E-6	3.8E-6	7.0E-6	-1.2E-6	-1.4E-6
on2 (HDR)	49.7E-6	3.5E-6	-308.3E-9	-1.4E-6	1.9E-6	11.3E-6	6.7E-6	6.3E-6	-1.2E-6	-1.4E-6
on3 (HDR)	46.3E-6	3.8E-6	4.5E-9	-1.6E-6	1.2E-6	9.4E-6	5.4E-6	6.1E-6	-1.2E-6	-1.4E-6
on4 (HDR)	42.5E-6	2.2E-6	-2.2E-6	-1.6E-6	1.2E-6	8.2E-6	5.1E-6	5.5E-6	-1.2E-6	-1.4E-6
on5 (HDR)	51.5E-6	3.4E-6	496.3E-9	-1.5E-6	1.3E-6	11.6E-6	7.1E-6	7.5E-6	-1.1E-6	-1.4E-6
Radiation-Mean ON	48.1E-6	3.2E-6	-460.2E-9	-1.5E-6	1.4E-6	10.5E-6	5.6E-6	6.5E-6	-1.2E-6	-1.4E-6
Standarddeviation	3.7E-6	613.4E-9	1.0E-6	61.1E-9	328.1E-9	1.6E-6	1.3E-6	794.6E-9	56.2E-9	12.6E-9
Mean + $k\sigma$	58.3E-6	4.9E-6	2.3E-6	-1.3E-6	2.3E-6	14.9E-6	9.2E-6	8.7E-6	-1.0E-6	-1.4E-6
Mean - $k\sigma$	38.0E-6	1.6E-6	-3.3E-6	-1.7E-6	548.0E-9	6.1E-6	2.0E-6	4.3E-6	-1.3E-6	-1.5E-6
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	50.5E-6	2.8E-6	93.8E-9	-1.5E-6	-1.9E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
off2 (HDR)	49.6E-6	2.9E-6	49.1E-9	-1.5E-6	-1.9E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
off3 (HDR)	51.7E-6	4.7E-6	-218.9E-9	-1.4E-6	-1.8E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.6E-6	-1.4E-6
off4 (HDR)	49.5E-6	4.2E-6	-442.4E-9	-1.4E-6	-1.8E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
off5 (HDR)	49.9E-6	3.2E-6	674.9E-9	-1.5E-6	-1.8E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
Radiation-Mean OFF	50.2E-6	3.5E-6	31.3E-9	-1.5E-6	-1.8E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
Standarddeviation	919.3E-9	841.7E-9	419.9E-9	52.2E-9	28.1E-9	3.8E-9	16.3E-9	7.6E-9	20.5E-9	16.5E-9
Mean + $k\sigma$	52.8E-6	5.9E-6	1.2E-6	-1.3E-6	-1.7E-6	-1.4E-6	-1.4E-6	-1.4E-6	-1.5E-6	-1.4E-6
Mean - $k\sigma$	47.7E-6	1.2E-6	-1.1E-6	-1.6E-6	-1.9E-6	-1.5E-6	-1.5E-6	-1.4E-6	-1.6E-6	-1.5E-6
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	49.5E-6	46.8E-6	47.7E-6	2.5E-6	2.5E-6	2.6E-6	2.0E-6	2.1E-6	1.8E-6	1.9E-6
Max. Value	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3



## 8.4 Collector-base breakdown voltage

Collector-base breakdown voltage

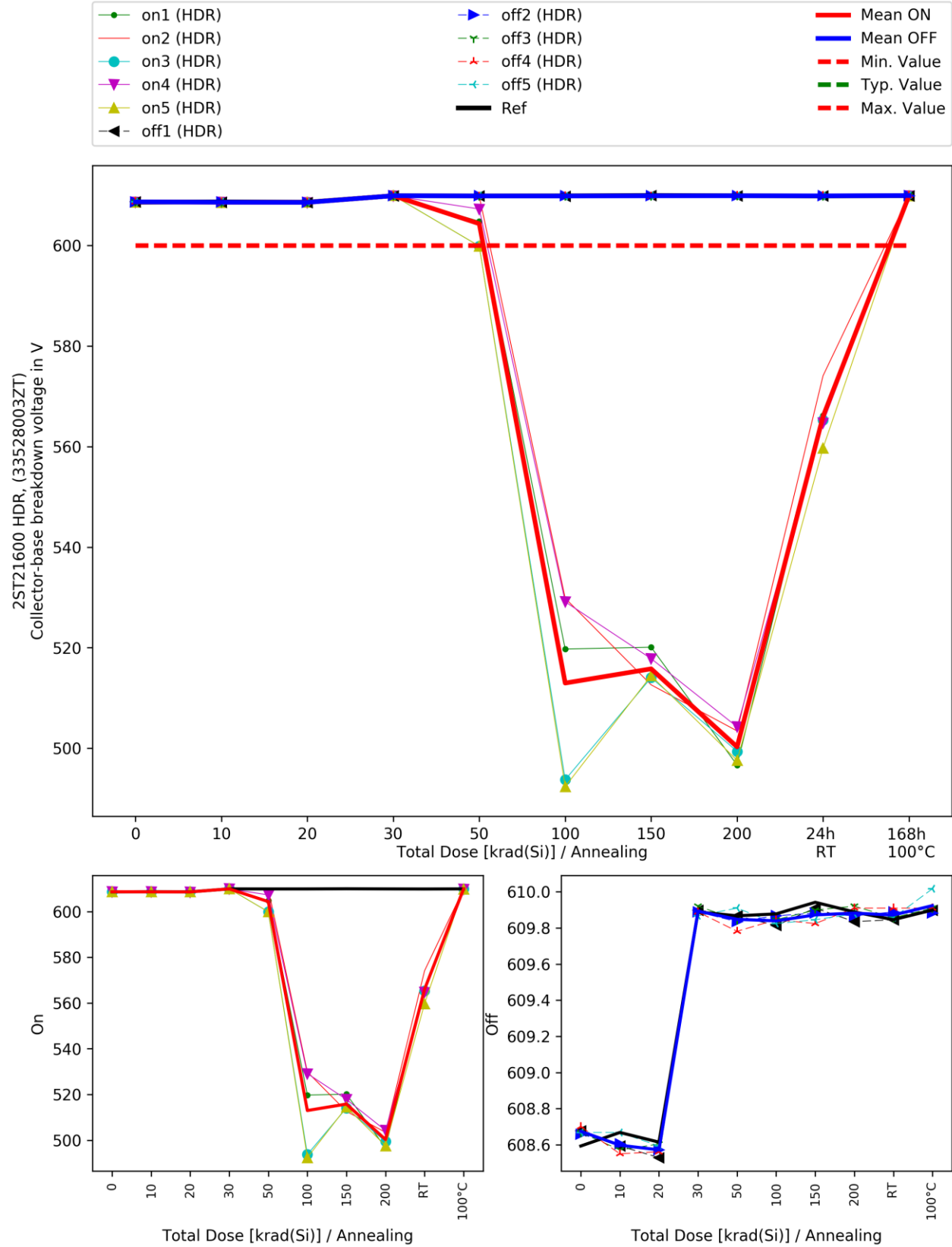
BVCBO in V

Corrected data:  $x^*(-1)$ Limit:  $600.0 < x$ 

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	608.6E+0	608.6E+0	608.5E+0	609.9E+0	604.8E+0	519.7E+0	520.1E+0	496.7E+0	566.2E+0	610.0E+0
on2 (HDR)	608.6E+0	608.6E+0	608.6E+0	609.9E+0	609.8E+0	529.8E+0	512.6E+0	503.5E+0	574.1E+0	609.9E+0
on3 (HDR)	608.7E+0	608.6E+0	608.6E+0	610.0E+0	599.9E+0	493.8E+0	514.0E+0	499.4E+0	565.3E+0	609.9E+0
on4 (HDR)	608.7E+0	608.6E+0	608.5E+0	609.9E+0	607.3E+0	529.1E+0	517.8E+0	504.3E+0	564.7E+0	609.9E+0
on5 (HDR)	608.6E+0	608.6E+0	608.6E+0	609.9E+0	599.9E+0	492.4E+0	514.4E+0	497.6E+0	559.7E+0	609.9E+0
Radiation-Mean ON	608.6E+0	608.6E+0	608.6E+0	609.9E+0	604.3E+0	513.0E+0	515.8E+0	500.3E+0	566.0E+0	609.9E+0
Standarddeviation	15.9E-3	26.8E-3	47.2E-3	33.8E-3	4.4E+0	18.6E+0	3.1E+0	3.4E+0	5.2E+0	35.5E-3
Mean + $k\sigma$	608.7E+0	608.7E+0	608.7E+0	610.0E+0	616.5E+0	564.0E+0	524.2E+0	509.7E+0	580.2E+0	610.0E+0
Mean - $k\sigma$	608.6E+0	608.5E+0	608.4E+0	609.8E+0	592.2E+0	461.9E+0	507.4E+0	490.9E+0	551.8E+0	609.8E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	608.7E+0	608.6E+0	608.5E+0	609.9E+0	609.9E+0	609.8E+0	609.9E+0	609.8E+0	609.8E+0	609.9E+0
off2 (HDR)	608.7E+0	608.6E+0	608.6E+0	609.9E+0	609.8E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0
off3 (HDR)	608.7E+0	608.6E+0	608.6E+0	609.9E+0	609.8E+0	609.8E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0
off4 (HDR)	608.7E+0	608.5E+0	608.6E+0	609.9E+0	609.8E+0	609.8E+0	609.8E+0	609.9E+0	609.9E+0	609.9E+0
off5 (HDR)	608.7E+0	608.7E+0	608.6E+0	609.9E+0	609.9E+0	609.8E+0	609.8E+0	609.9E+0	609.9E+0	610.0E+0
Radiation-Mean OFF	608.7E+0	608.6E+0	608.6E+0	609.9E+0	609.8E+0	609.8E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0
Standarddeviation	16.2E-3	44.5E-3	29.3E-3	19.4E-3	46.9E-3	20.9E-3	36.2E-3	34.3E-3	26.9E-3	53.4E-3
Mean + $k\sigma$	608.7E+0	608.7E+0	608.7E+0	609.9E+0	610.0E+0	609.9E+0	610.0E+0	610.0E+0	609.9E+0	610.1E+0
Mean - $k\sigma$	608.6E+0	608.5E+0	608.5E+0	609.8E+0	609.7E+0	609.8E+0	609.8E+0	609.8E+0	609.8E+0	609.8E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	608.6E+0	608.7E+0	608.6E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0	609.9E+0	609.8E+0	609.9E+0
Min. Value	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0	600.0E+0



## 8.5 ICB @ 600 V

ICB @ 600 V

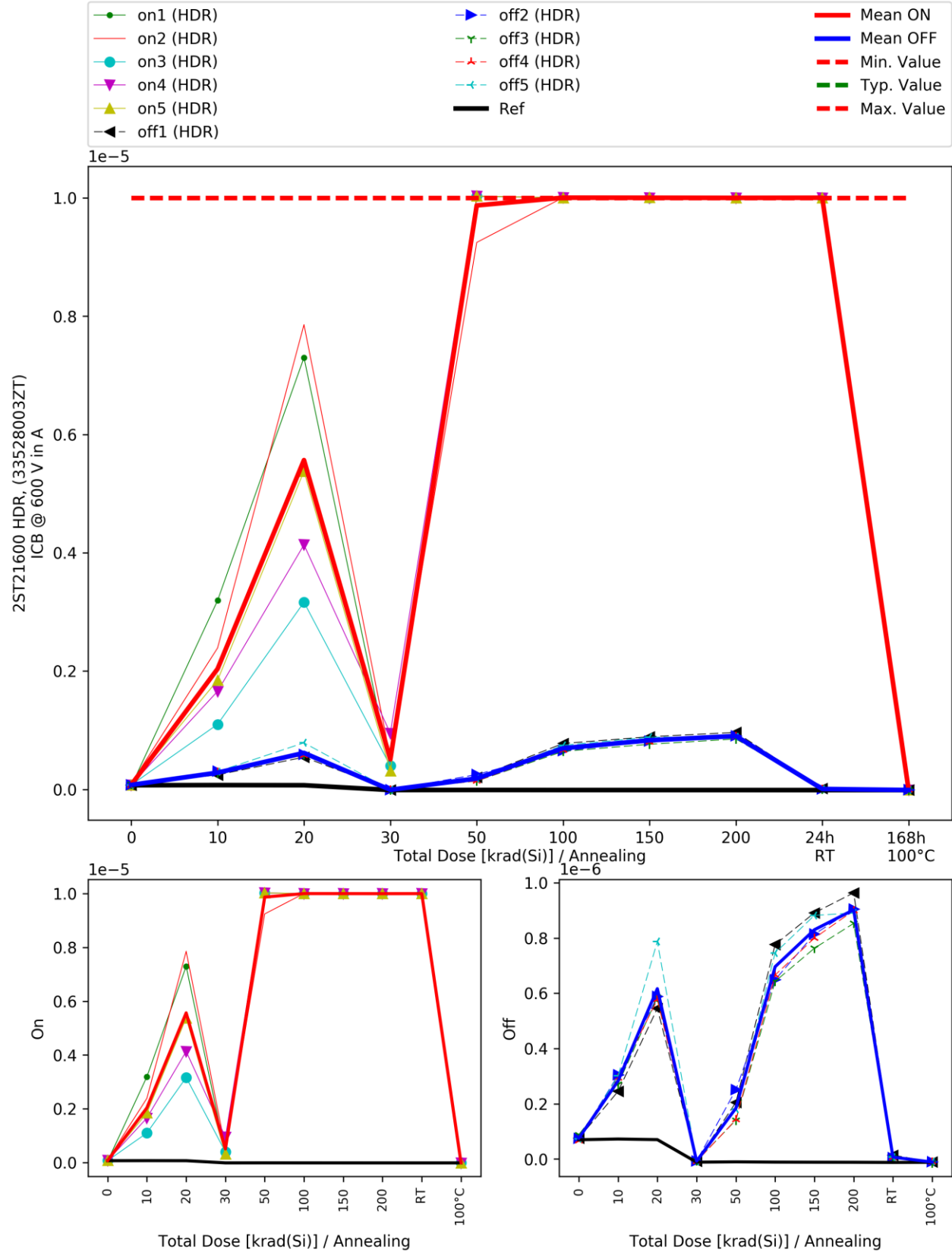
BICBO in A

Corrected data:  $x^*(-1)$ Limit:  $x < 1e-05$ 

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	56.1E-9	3.2E-6	7.3E-6	350.3E-9	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-7.0E-9
on2 (HDR)	101.4E-9	2.4E-6	7.9E-6	534.6E-9	9.2E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-11.8E-9
on3 (HDR)	74.6E-9	1.1E-6	3.2E-6	396.8E-9	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-7.7E-9
on4 (HDR)	75.3E-9	1.7E-6	4.1E-6	947.7E-9	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-11.2E-9
on5 (HDR)	75.2E-9	1.8E-6	5.4E-6	310.8E-9	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-9.8E-9
Radiation-Mean ON	76.5E-9	2.0E-6	5.6E-6	508.0E-9	9.9E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-9.5E-9
Standarddeviation	16.1E-9	793.7E-9	2.0E-6	259.9E-9	349.7E-9	1.3E-9	593.7E-12	1.9E-9	1.6E-9	2.1E-9
Mean + $k\sigma$	120.8E-9	4.2E-6	11.1E-6	1.2E-6	10.8E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-3.7E-9
Mean - $k\sigma$	32.3E-9	-138.4E-9	65.3E-9	-204.6E-9	8.9E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	-15.3E-9
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	75.5E-9	245.1E-9	545.2E-9	-7.5E-9	205.0E-9	776.2E-9	891.0E-9	963.4E-9	14.3E-9	-10.5E-9
off2 (HDR)	74.7E-9	303.8E-9	587.9E-9	-7.1E-9	250.6E-9	649.0E-9	813.9E-9	904.8E-9	4.1E-9	-10.7E-9
off3 (HDR)	88.4E-9	271.2E-9	585.4E-9	-6.5E-9	140.9E-9	643.0E-9	762.9E-9	852.8E-9	4.4E-9	-13.8E-9
off4 (HDR)	66.9E-9	293.6E-9	577.1E-9	-8.6E-9	142.6E-9	666.1E-9	799.7E-9	898.9E-9	5.9E-9	-10.8E-9
off5 (HDR)	72.6E-9	301.4E-9	787.2E-9	-6.8E-9	180.4E-9	746.1E-9	881.8E-9	890.5E-9	7.1E-9	-8.9E-9
Radiation-Mean OFF	75.6E-9	283.0E-9	616.6E-9	-7.3E-9	183.9E-9	696.1E-9	829.8E-9	902.1E-9	7.1E-9	-10.9E-9
Standarddeviation	7.9E-9	24.8E-9	96.9E-9	820.8E-12	46.0E-9	60.9E-9	54.9E-9	39.8E-9	4.2E-9	1.8E-9
Mean + $k\sigma$	97.2E-9	351.1E-9	882.2E-9	-5.1E-9	310.0E-9	863.2E-9	980.5E-9	1.0E-6	18.6E-9	-6.0E-9
Mean - $k\sigma$	54.0E-9	215.0E-9	350.9E-9	-9.6E-9	57.9E-9	529.0E-9	679.2E-9	792.9E-9	-4.3E-9	-15.9E-9
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	70.0E-9	72.6E-9	70.4E-9	-11.1E-9	-10.0E-9	-10.9E-9	-11.3E-9	-11.5E-9	-12.1E-9	-11.6E-9
Max. Value	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6	10.0E-6



## 8.6 Collector cut-off current

Collector cut-off current

ICBO in A

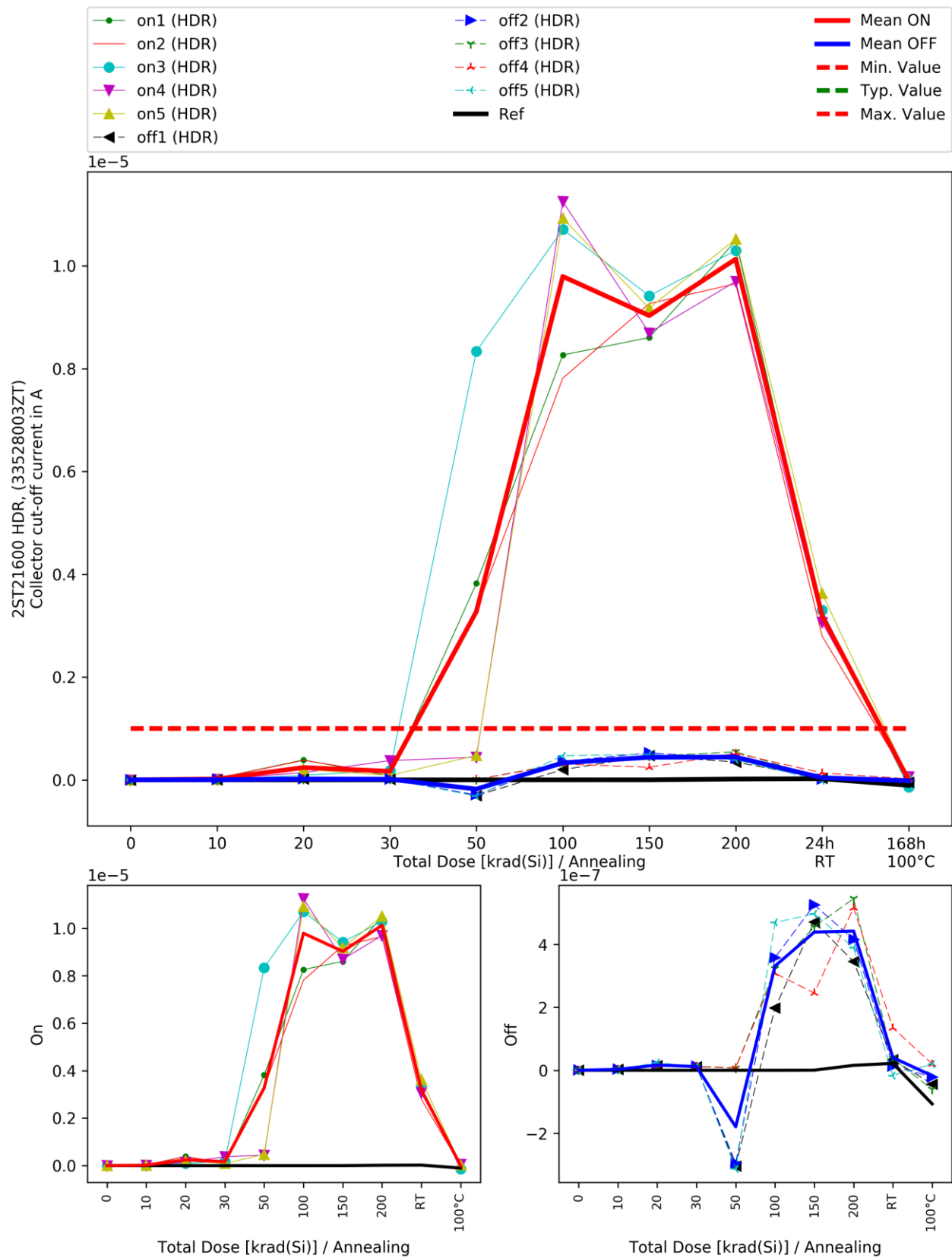
Corrected data:  $x^*(-1)$ Limit:  $x < 1.0$ 

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	284.9E-12	30.1E-9	387.2E-9	77.1E-9	3.8E-6	8.3E-6	8.6E-6	10.5E-6	3.2E-6	37.4E-9
on2 (HDR)	272.4E-12	27.2E-9	380.2E-9	110.7E-9	3.3E-6	7.8E-6	9.3E-6	9.7E-6	2.8E-6	-3.2E-9
on3 (HDR)	272.4E-12	6.4E-9	87.3E-9	184.4E-9	8.3E-6	10.7E-6	9.4E-6	10.3E-6	3.3E-6	-138.3E-9
on4 (HDR)	266.7E-12	9.6E-9	141.2E-9	375.1E-9	439.2E-9	11.3E-6	8.7E-6	9.7E-6	3.1E-6	62.7E-9
on5 (HDR)	255.5E-12	12.4E-9	203.8E-9	87.8E-9	472.8E-9	10.9E-6	9.2E-6	10.5E-6	3.6E-6	28.4E-9
Radiation-Mean ON	270.4E-12	17.2E-9	239.9E-9	167.0E-9	3.3E-6	9.8E-6	9.0E-6	10.1E-6	3.2E-6	-2.6E-9
Standarddeviation	10.7E-12	10.8E-9	137.6E-9	123.6E-9	3.2E-6	1.6E-6	360.2E-9	426.6E-9	307.6E-9	79.4E-9
Mean + $k\sigma$	299.6E-12	46.7E-9	617.2E-9	506.0E-9	12.1E-6	14.2E-6	10.0E-6	11.3E-6	4.0E-6	215.2E-9
Mean - $k\sigma$	241.2E-12	-12.4E-9	-137.3E-9	-172.0E-9	-5.6E-6	5.4E-6	8.0E-6	9.0E-6	2.3E-6	-220.4E-9
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	259.8E-12	3.0E-9	15.3E-9	11.8E-9	-304.5E-9	197.7E-9	471.7E-9	345.4E-9	33.8E-9	-43.7E-9
off2 (HDR)	244.4E-12	2.8E-9	15.2E-9	12.2E-9	-295.3E-9	358.2E-9	525.7E-9	415.8E-9	13.0E-9	-21.2E-9
off3 (HDR)	239.5E-12	2.8E-9	13.1E-9	11.3E-9	7.3E-9	322.1E-9	456.3E-9	545.6E-9	37.4E-9	-60.8E-9
off4 (HDR)	233.7E-12	2.8E-9	15.1E-9	12.2E-9	8.2E-9	308.6E-9	245.5E-9	516.6E-9	134.7E-9	20.3E-9
off5 (HDR)	229.8E-12	2.9E-9	24.0E-9	12.4E-9	-313.3E-9	469.9E-9	497.6E-9	389.7E-9	-16.7E-9	19.4E-9
Radiation-Mean OFF	241.4E-12	2.9E-9	16.5E-9	12.0E-9	-179.5E-9	331.3E-9	439.3E-9	442.6E-9	40.5E-9	-17.2E-9
Standarddeviation	11.7E-12	108.6E-12	4.3E-9	455.6E-12	171.1E-9	97.9E-9	111.5E-9	85.2E-9	56.9E-9	36.6E-9
Mean + $k\sigma$	273.4E-12	3.2E-9	28.2E-9	13.2E-9	289.6E-9	599.8E-9	745.2E-9	676.3E-9	196.5E-9	83.2E-9
Mean - $k\sigma$	209.4E-12	2.6E-9	4.8E-9	10.7E-9	-648.6E-9	62.7E-9	133.5E-9	209.0E-9	-115.5E-9	-117.6E-9
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	267.8E-12	229.8E-12	86.2E-12	132.0E-12	153.2E-12	154.6E-12	453.3E-12	15.8E-9	22.1E-9	-106.8E-9
Max. Value	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6





## 8.7 Emitter-base breakdown voltage

Emitter-base breakdown voltage

BVEBO in V

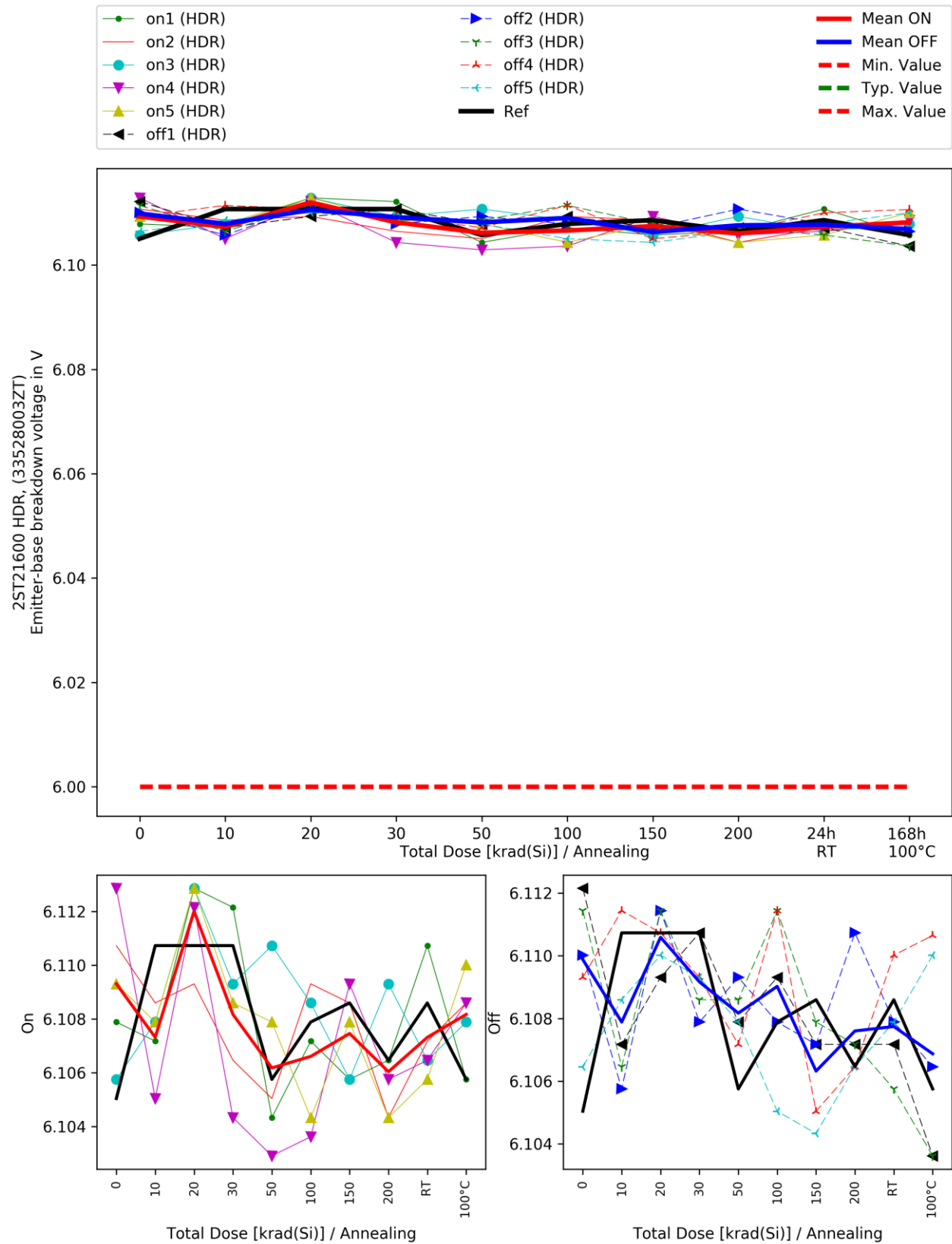
Corrected data:  $x^*(-1)$

Limit:  $6.0 < x$

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on2 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on3 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on4 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
on5 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Radiation-Mean ON	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Standarddeviation	2.7E-3	1.4E-3	1.5E-3	3.0E-3	3.1E-3	2.5E-3	1.6E-3	2.0E-3	2.0E-3	1.6E-3
Mean + $k\sigma$	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Mean - $k\sigma$	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off2 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off3 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off4 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
off5 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Radiation-Mean OFF	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Standarddeviation	2.2E-3	2.2E-3	927.0E-6	1.1E-3	810.7E-6	2.7E-3	1.5E-3	1.8E-3	1.5E-3	3.4E-3
Mean + $k\sigma$	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Mean - $k\sigma$	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0	6.1E+0
Min. Value	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0	6.0E+0



## 8.8 IEB @ 6 V

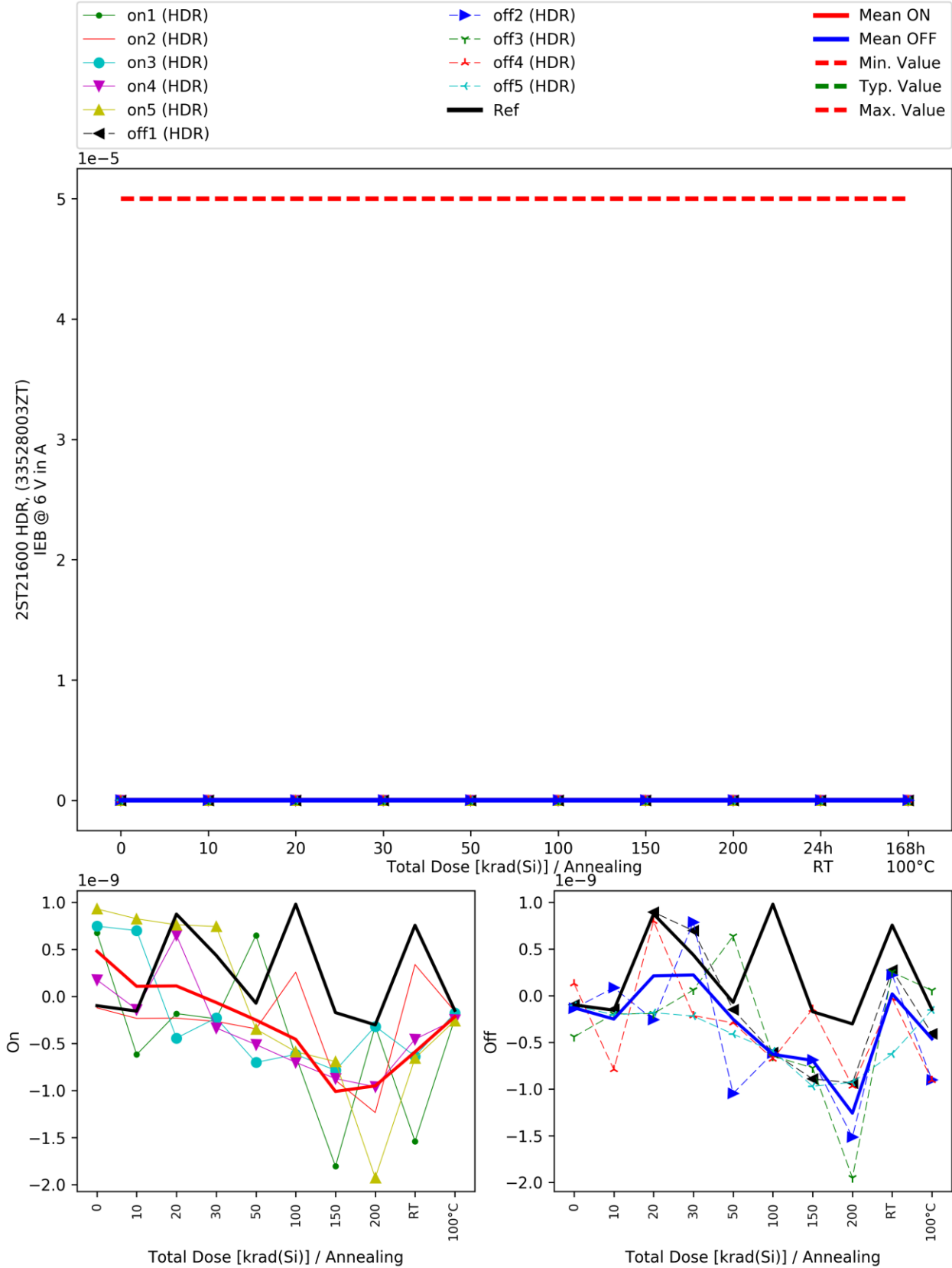
IEB @ 6 V  
BIEBO in A

Limit:  $x < 5e-05$

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	673.4E-12	-618.1E-12	-183.1E-12	-238.1E-12	646.8E-12	-633.2E-12	-1.8E-9	-315.5E-12	-1.5E-9	-237.8E-12
on2 (HDR)	-122.6E-12	-234.0E-12	-231.5E-12	-265.9E-12	-345.2E-12	256.1E-12	-891.6E-12	-1.2E-9	336.8E-12	-159.1E-12
on3 (HDR)	744.7E-12	698.8E-12	-442.9E-12	-229.7E-12	-701.8E-12	-616.3E-12	-786.1E-12	-318.6E-12	-635.5E-12	-177.3E-12
on4 (HDR)	174.8E-12	-138.8E-12	648.8E-12	-335.8E-12	-512.3E-12	-700.9E-12	-873.7E-12	-960.4E-12	-455.6E-12	-249.5E-12
on5 (HDR)	928.5E-12	823.3E-12	760.1E-12	741.6E-12	-347.5E-12	-587.8E-12	-693.1E-12	-1.9E-9	-656.9E-12	-259.6E-12
Radiation-Mean ON	479.8E-12	106.3E-12	110.3E-12	-65.6E-12	-252.0E-12	-456.4E-12	-1.0E-9	-950.8E-12	-590.0E-12	-216.6E-12
Standarddeviation	437.3E-12	625.6E-12	552.5E-12	453.1E-12	523.4E-12	400.5E-12	451.1E-12	677.2E-12	667.9E-12	45.4E-12
Mean + $k\sigma$	1.7E-9	1.8E-9	1.6E-9	1.2E-9	1.2E-9	641.7E-12	227.2E-12	906.1E-12	1.2E-9	-92.2E-12
Mean - $k\sigma$	-719.3E-12	-1.6E-9	-1.4E-9	-1.3E-9	-1.7E-9	-1.6E-9	-2.2E-9	-2.8E-9	-2.4E-9	-341.0E-12
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	-98.1E-12	-147.1E-12	892.7E-12	694.5E-12	-150.5E-12	-610.7E-12	-893.2E-12	-935.2E-12	272.5E-12	-408.8E-12
off2 (HDR)	-136.7E-12	83.8E-12	-260.3E-12	786.5E-12	-1.0E-9	-617.3E-12	-689.5E-12	-1.5E-9	221.7E-12	-903.2E-12
off3 (HDR)	-441.9E-12	-197.3E-12	-192.7E-12	59.7E-12	636.0E-12	-648.5E-12	-773.9E-12	-2.0E-9	251.7E-12	54.4E-12
off4 (HDR)	128.3E-12	-792.2E-12	796.3E-12	-214.4E-12	-291.8E-12	-677.9E-12	-144.3E-12	-966.6E-12	-28.8E-12	-906.2E-12
off5 (HDR)	-107.8E-12	-205.5E-12	-182.8E-12	-219.7E-12	-413.0E-12	-593.8E-12	-971.7E-12	-928.6E-12	-627.0E-12	-154.0E-12
Radiation-Mean OFF	-131.2E-12	-251.6E-12	210.7E-12	221.3E-12	-253.5E-12	-629.7E-12	-694.5E-12	-1.3E-9	18.0E-12	-463.6E-12
Standarddeviation	203.4E-12	324.3E-12	580.4E-12	488.3E-12	604.2E-12	33.5E-12	326.1E-12	459.2E-12	380.5E-12	434.8E-12
Mean + $k\sigma$	426.5E-12	637.7E-12	1.8E-9	1.6E-9	1.4E-9	-537.8E-12	199.7E-12	-136.4E-15	1.1E-9	728.7E-12
Mean - $k\sigma$	-689.0E-12	-1.1E-9	-1.4E-9	-1.1E-9	-1.9E-9	-721.5E-12	-1.6E-9	-2.5E-9	-1.0E-9	-1.7E-9
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	-99.5E-12	-157.0E-12	872.9E-12	435.4E-12	-72.6E-12	978.2E-12	-172.7E-12	-303.1E-12	754.3E-12	-148.8E-12
Max. Value	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6	50.0E-6



## 8.9 Emitter cut-off current

Emitter cut-off current

IEBO in A

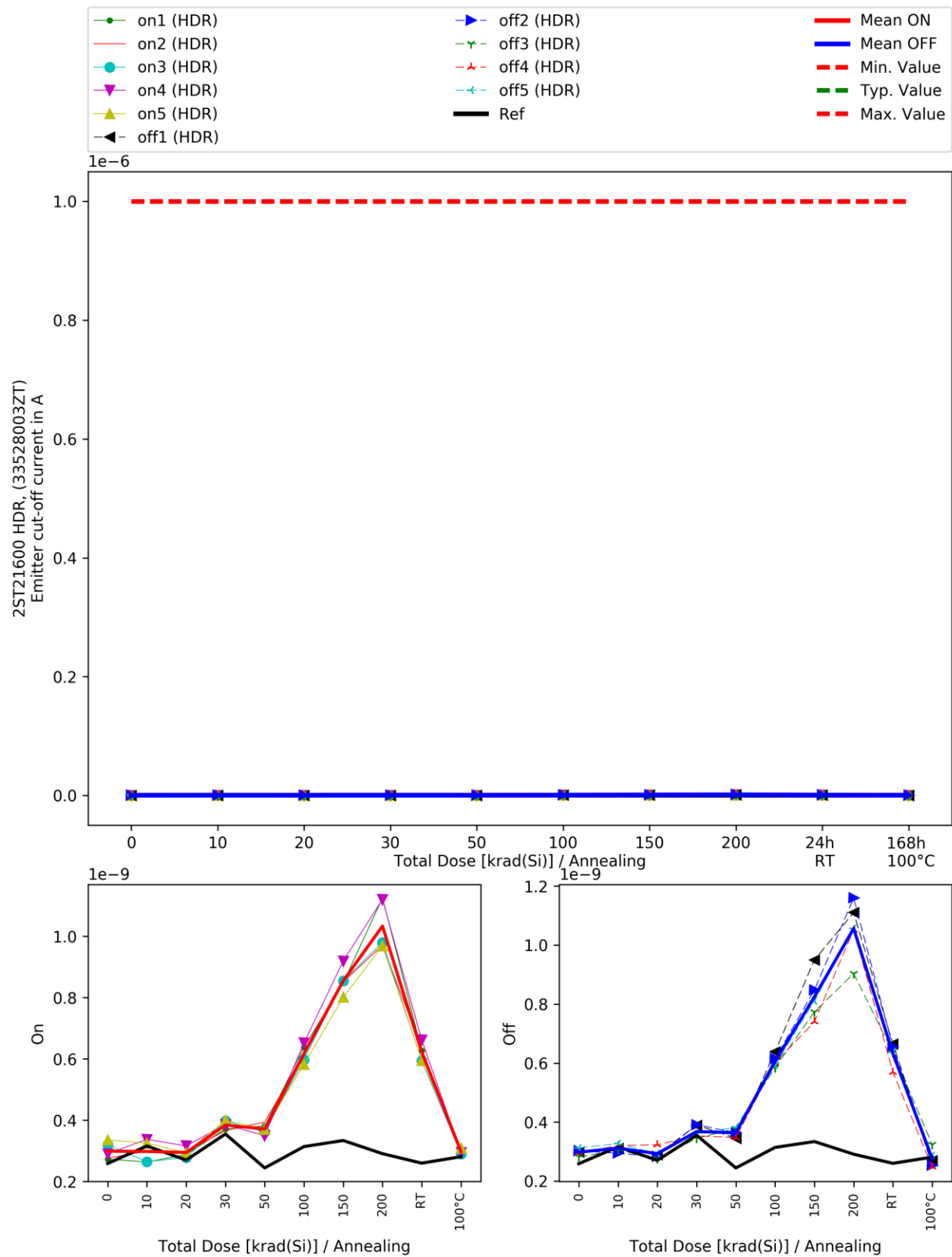
Corrected data:  $x^*(-1)$

Limit:  $x < 1.0$

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	273.4E-12	264.1E-12	288.2E-12	371.9E-12	381.3E-12	638.1E-12	848.6E-12	1.1E-9	627.7E-12	296.2E-12
on2 (HDR)	276.3E-12	299.3E-12	296.9E-12	366.4E-12	394.4E-12	613.2E-12	851.2E-12	971.6E-12	633.9E-12	296.7E-12
on3 (HDR)	320.2E-12	265.1E-12	278.5E-12	397.6E-12	361.4E-12	598.5E-12	855.0E-12	980.2E-12	594.0E-12	290.3E-12
on4 (HDR)	290.6E-12	337.9E-12	316.4E-12	385.9E-12	350.0E-12	652.3E-12	920.0E-12	1.1E-9	662.2E-12	295.2E-12
on5 (HDR)	335.8E-12	325.4E-12	294.3E-12	400.5E-12	370.6E-12	582.7E-12	801.3E-12	969.2E-12	596.2E-12	309.4E-12
Radiation-Mean ON	299.3E-12	298.4E-12	294.9E-12	384.5E-12	371.5E-12	616.9E-12	855.2E-12	1.0E-9	622.8E-12	297.5E-12
Standarddeviation	27.6E-12	33.8E-12	14.0E-12	15.1E-12	17.2E-12	28.4E-12	42.3E-12	81.9E-12	28.4E-12	7.1E-12
Mean + $k\sigma$	374.8E-12	391.1E-12	333.2E-12	426.0E-12	418.8E-12	694.8E-12	971.2E-12	1.3E-9	700.7E-12	317.0E-12
Mean - $k\sigma$	223.7E-12	205.6E-12	256.6E-12	343.0E-12	324.3E-12	539.1E-12	739.2E-12	808.7E-12	544.8E-12	278.1E-12
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	297.9E-12	311.1E-12	289.9E-12	389.7E-12	345.6E-12	638.9E-12	950.2E-12	1.1E-9	664.6E-12	268.9E-12
off2 (HDR)	302.5E-12	294.1E-12	283.3E-12	391.0E-12	363.9E-12	615.3E-12	848.3E-12	1.2E-9	655.1E-12	253.6E-12
off3 (HDR)	281.5E-12	305.7E-12	276.1E-12	344.9E-12	378.4E-12	584.9E-12	773.9E-12	903.8E-12	636.2E-12	323.9E-12
off4 (HDR)	295.6E-12	320.3E-12	323.2E-12	353.0E-12	348.0E-12	601.1E-12	740.3E-12	1.1E-9	569.0E-12	247.5E-12
off5 (HDR)	312.5E-12	326.9E-12	292.8E-12	360.5E-12	383.2E-12	592.2E-12	811.2E-12	1.1E-9	637.2E-12	287.6E-12
Radiation-Mean OFF	298.0E-12	311.6E-12	293.1E-12	367.8E-12	363.8E-12	606.5E-12	824.8E-12	1.1E-9	632.4E-12	276.3E-12
Standarddeviation	11.3E-12	12.7E-12	18.0E-12	21.3E-12	17.1E-12	21.4E-12	80.9E-12	96.2E-12	37.5E-12	30.8E-12
Mean + $k\sigma$	328.9E-12	346.6E-12	342.5E-12	426.2E-12	410.7E-12	665.1E-12	1.0E-9	1.3E-9	735.2E-12	360.8E-12
Mean - $k\sigma$	267.1E-12	276.7E-12	243.6E-12	309.4E-12	317.0E-12	547.8E-12	602.9E-12	792.9E-12	529.7E-12	191.8E-12
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	258.9E-12	316.1E-12	270.3E-12	355.3E-12	244.5E-12	314.2E-12	334.0E-12	291.1E-12	260.2E-12	281.3E-12
Max. Value	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6	1.0E-6



## 8.10 Collector-emitter saturation voltage

Collector-emitter saturation voltage

Vcesat in V

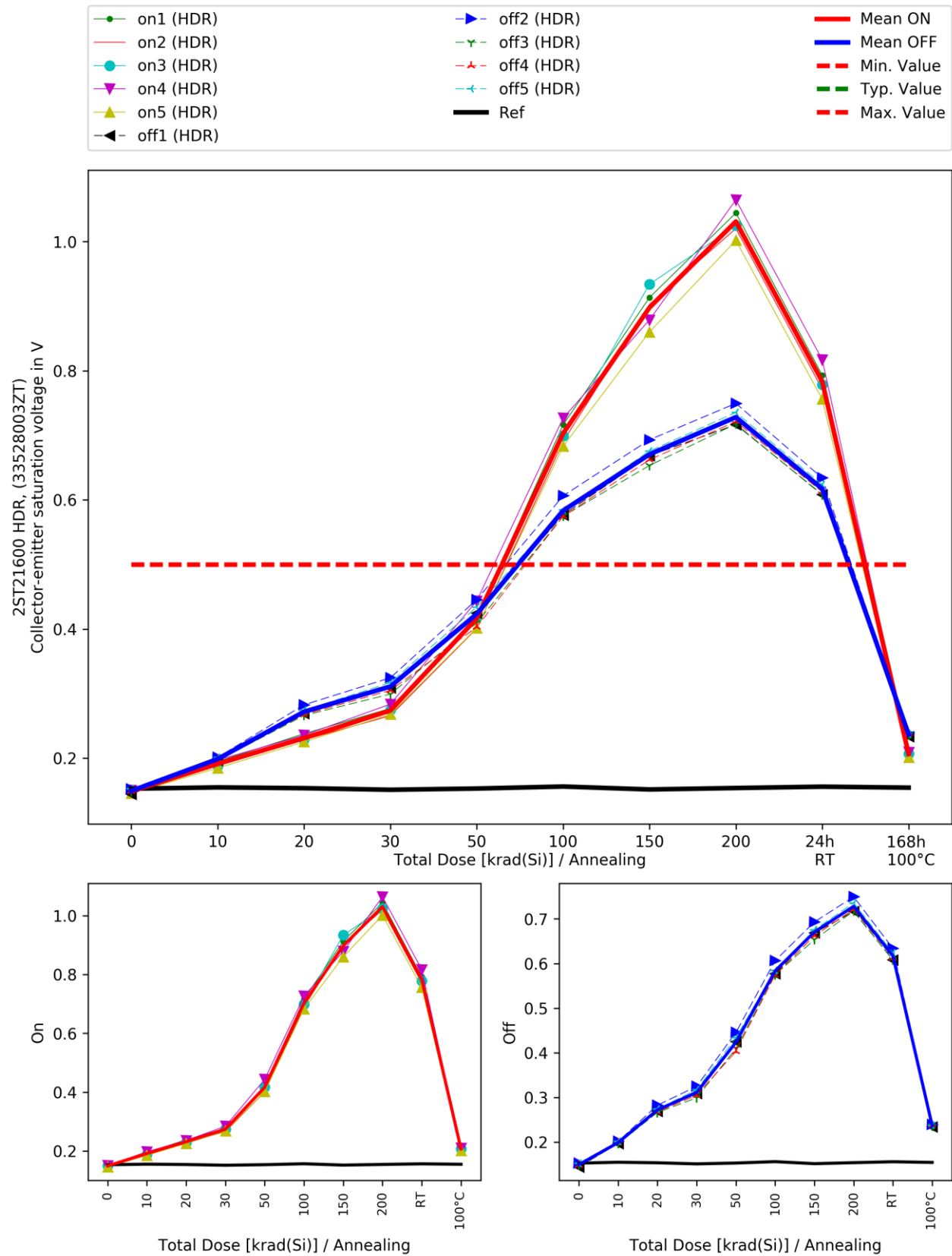
Corrected data:  $x^*(-1)$ Limit:  $x < 0.5$ 

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	150.5E-3	194.6E-3	237.8E-3	277.0E-3	418.9E-3	716.3E-3	913.5E-3	1.0E+0	792.9E-3	210.5E-3
on2 (HDR)	146.6E-3	191.4E-3	228.3E-3	265.8E-3	400.9E-3	690.5E-3	903.0E-3	1.0E+0	771.4E-3	204.1E-3
on3 (HDR)	150.5E-3	188.0E-3	228.6E-3	274.7E-3	417.5E-3	699.0E-3	934.1E-3	1.0E+0	778.9E-3	207.0E-3
on4 (HDR)	150.3E-3	196.9E-3	235.5E-3	283.7E-3	443.5E-3	726.6E-3	878.9E-3	1.1E+0	817.2E-3	209.0E-3
on5 (HDR)	145.4E-3	184.7E-3	225.3E-3	267.8E-3	401.6E-3	683.0E-3	860.0E-3	1.0E+0	756.0E-3	201.2E-3
Radiation-Mean ON	148.7E-3	191.1E-3	231.1E-3	273.8E-3	416.5E-3	703.1E-3	897.9E-3	1.0E+0	783.3E-3	206.4E-3
Standarddeviation	2.5E-3	4.9E-3	5.3E-3	7.2E-3	17.3E-3	18.1E-3	29.1E-3	24.1E-3	23.2E-3	3.8E-3
Mean + $k\sigma$	155.4E-3	204.7E-3	245.6E-3	293.6E-3	464.0E-3	752.6E-3	977.6E-3	1.1E+0	846.8E-3	216.7E-3
Mean - $k\sigma$	141.9E-3	177.6E-3	216.6E-3	253.9E-3	369.0E-3	653.5E-3	818.2E-3	965.3E-3	719.7E-3	196.1E-3
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	144.3E-3	196.6E-3	269.0E-3	309.0E-3	424.7E-3	576.8E-3	668.5E-3	716.7E-3	608.3E-3	233.6E-3
off2 (HDR)	152.5E-3	201.2E-3	282.5E-3	324.5E-3	445.5E-3	606.4E-3	693.1E-3	749.5E-3	633.9E-3	238.9E-3
off3 (HDR)	148.3E-3	196.3E-3	266.1E-3	299.3E-3	409.4E-3	574.9E-3	653.4E-3	717.7E-3	607.6E-3	236.0E-3
off4 (HDR)	148.5E-3	197.9E-3	267.5E-3	305.0E-3	403.0E-3	574.6E-3	662.2E-3	721.5E-3	612.4E-3	238.2E-3
off5 (HDR)	152.6E-3	201.2E-3	274.1E-3	316.9E-3	434.0E-3	584.4E-3	675.6E-3	735.5E-3	623.7E-3	237.1E-3
Radiation-Mean OFF	149.3E-3	198.6E-3	271.9E-3	311.0E-3	423.3E-3	583.4E-3	670.6E-3	728.2E-3	617.2E-3	236.8E-3
Standarddeviation	3.5E-3	2.4E-3	6.7E-3	9.9E-3	17.4E-3	13.4E-3	15.0E-3	14.1E-3	11.4E-3	2.0E-3
Mean + $k\sigma$	158.7E-3	205.3E-3	290.2E-3	338.2E-3	471.1E-3	620.3E-3	711.8E-3	766.9E-3	648.3E-3	242.4E-3
Mean - $k\sigma$	139.8E-3	192.0E-3	253.5E-3	283.7E-3	375.6E-3	546.6E-3	629.4E-3	689.4E-3	586.1E-3	231.2E-3
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	152.8E-3	154.7E-3	153.5E-3	151.1E-3	153.0E-3	156.1E-3	151.5E-3	153.8E-3	155.9E-3	154.4E-3
Max. Value	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3	500.0E-3





## 8.11 Base emitter saturation voltage

Base emitter saturation voltage

V<sub>besat</sub> in V

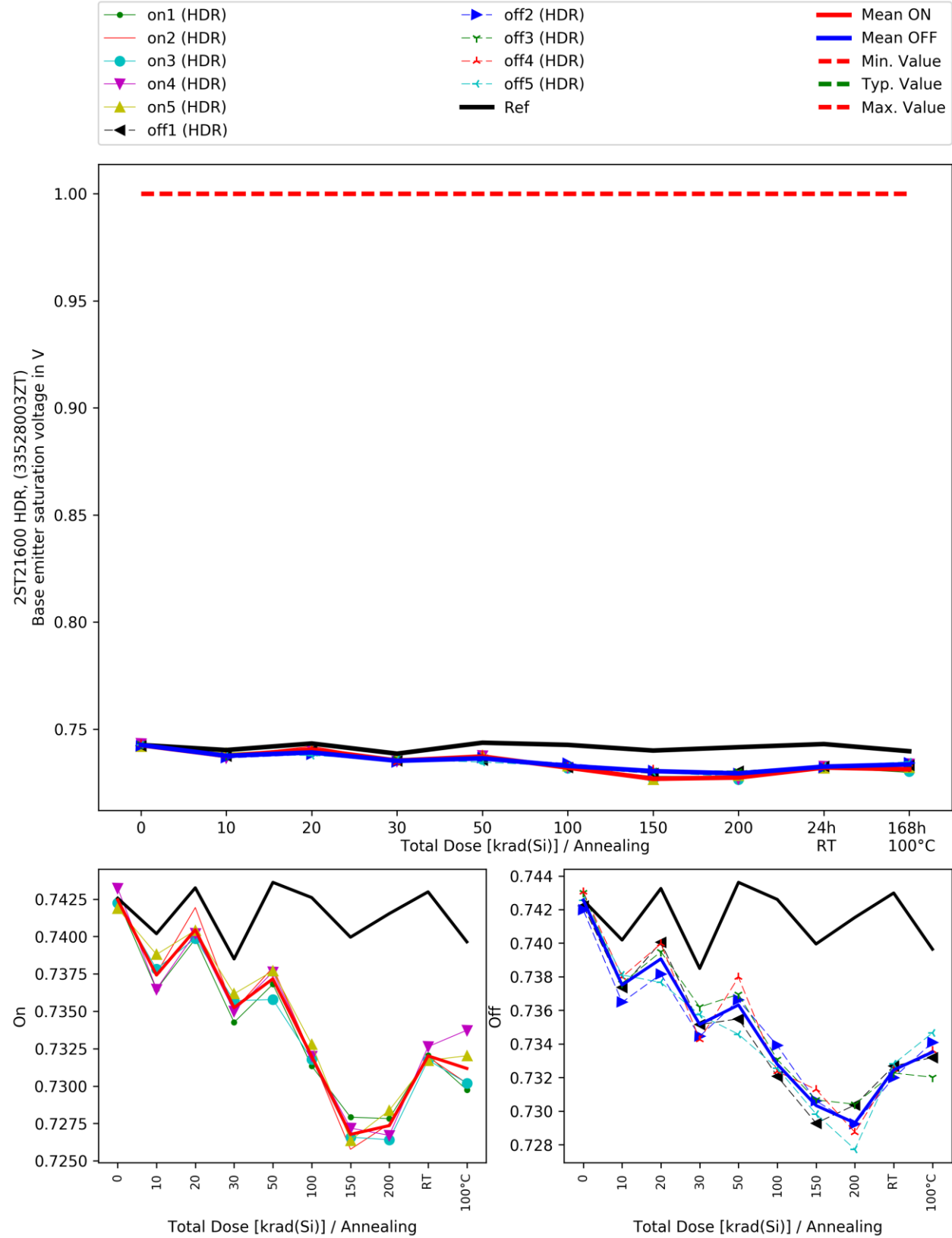
Corrected data: x\*(-1)

Limit: x &lt; 1.0

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	742.4E-3	736.5E-3	739.8E-3	734.3E-3	736.8E-3	731.3E-3	727.9E-3	727.8E-3	732.0E-3	729.7E-3
on2 (HDR)	742.4E-3	737.5E-3	741.9E-3	735.1E-3	737.9E-3	732.0E-3	725.8E-3	727.5E-3	731.9E-3	730.2E-3
on3 (HDR)	742.3E-3	737.8E-3	739.9E-3	735.7E-3	735.8E-3	731.8E-3	726.6E-3	726.4E-3	731.7E-3	730.2E-3
on4 (HDR)	743.2E-3	736.5E-3	740.2E-3	735.0E-3	737.6E-3	732.0E-3	727.2E-3	726.7E-3	732.6E-3	733.7E-3
on5 (HDR)	741.9E-3	738.8E-3	740.4E-3	736.2E-3	737.7E-3	732.8E-3	726.4E-3	728.4E-3	731.7E-3	732.0E-3
Radiation-Mean ON	742.4E-3	737.4E-3	740.4E-3	735.2E-3	737.2E-3	732.0E-3	726.8E-3	727.4E-3	732.0E-3	731.2E-3
Standarddeviation	492.0E-6	982.2E-6	863.0E-6	727.8E-6	880.0E-6	525.5E-6	818.8E-6	805.3E-6	373.0E-6	1.7E-3
Mean + kσ	743.8E-3	740.1E-3	742.8E-3	737.2E-3	739.6E-3	733.4E-3	729.0E-3	729.6E-3	733.0E-3	735.8E-3
Mean - kσ	741.1E-3	734.7E-3	738.1E-3	733.2E-3	734.8E-3	730.5E-3	724.5E-3	725.1E-3	731.0E-3	726.6E-3
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	742.2E-3	737.4E-3	740.1E-3	735.2E-3	735.5E-3	732.1E-3	729.3E-3	730.4E-3	732.7E-3	733.2E-3
off2 (HDR)	742.0E-3	736.5E-3	738.1E-3	734.5E-3	736.6E-3	733.9E-3	730.6E-3	729.2E-3	732.0E-3	734.1E-3
off3 (HDR)	743.0E-3	737.6E-3	739.5E-3	736.2E-3	737.0E-3	733.1E-3	730.7E-3	730.4E-3	732.3E-3	732.0E-3
off4 (HDR)	743.1E-3	738.0E-3	740.0E-3	734.3E-3	738.0E-3	732.4E-3	731.3E-3	728.7E-3	732.5E-3	733.6E-3
off5 (HDR)	742.6E-3	738.1E-3	737.7E-3	735.7E-3	734.6E-3	732.6E-3	729.8E-3	727.7E-3	732.8E-3	734.7E-3
Radiation-Mean OFF	742.6E-3	737.5E-3	739.1E-3	735.2E-3	736.3E-3	732.8E-3	730.3E-3	729.3E-3	732.4E-3	733.5E-3
Standarddeviation	474.3E-6	645.6E-6	1.1E-3	823.2E-6	1.3E-3	718.5E-6	782.7E-6	1.1E-3	329.0E-6	999.2E-6
Mean + kσ	743.9E-3	739.3E-3	742.1E-3	737.4E-3	739.9E-3	734.8E-3	732.5E-3	732.4E-3	733.4E-3	736.3E-3
Mean - kσ	741.3E-3	735.7E-3	736.1E-3	732.9E-3	732.7E-3	730.8E-3	728.2E-3	726.2E-3	731.5E-3	730.8E-3
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	742.6E-3	740.2E-3	743.3E-3	738.5E-3	743.6E-3	742.6E-3	740.0E-3	741.5E-3	743.0E-3	739.6E-3
Max. Value	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0



## 8.12 DC current gain (1)

DC current gain (1)  
HFE1

Limit: 150.0 < x

2ST21600 HDR

Date-/Lotcode: 33528003ZT

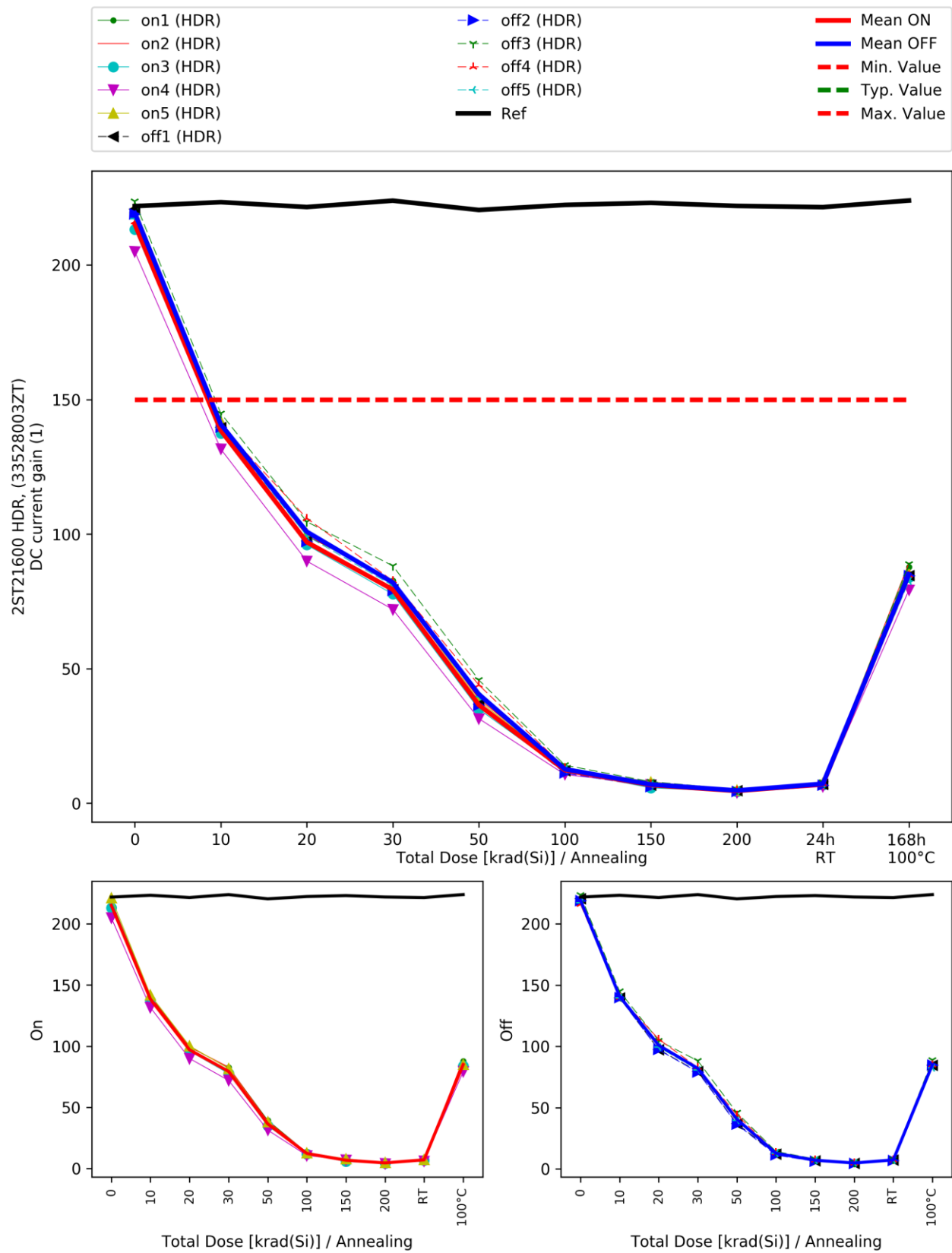
ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	218.6E+0	141.0E+0	99.4E+0	82.6E+0	39.4E+0	13.0E+0	7.0E+0	4.8E+0	7.4E+0	87.8E+0
on2 (HDR)	217.9E+0	140.6E+0	99.5E+0	82.8E+0	38.8E+0	13.0E+0	6.3E+0	4.8E+0	7.5E+0	89.3E+0
on3 (HDR)	213.2E+0	137.4E+0	96.0E+0	77.7E+0	35.0E+0	12.0E+0	5.7E+0	4.3E+0	6.8E+0	83.9E+0
on4 (HDR)	205.0E+0	131.6E+0	90.0E+0	72.1E+0	31.5E+0	10.7E+0	7.0E+0	4.1E+0	6.2E+0	79.2E+0
on5 (HDR)	221.4E+0	141.9E+0	100.3E+0	81.8E+0	38.1E+0	12.9E+0	8.0E+0	4.9E+0	7.4E+0	85.1E+0
Radiation-Mean ON	215.2E+0	138.5E+0	97.0E+0	79.4E+0	36.5E+0	12.3E+0	6.8E+0	4.6E+0	7.1E+0	85.1E+0
Standarddeviation	6.4E+0	4.2E+0	4.3E+0	4.6E+0	3.3E+0	998.2E-3	830.9E-3	369.3E-3	561.5E-3	3.9E+0
Mean + kσ	232.8E+0	150.0E+0	108.7E+0	92.0E+0	45.6E+0	15.1E+0	9.1E+0	5.6E+0	8.6E+0	95.8E+0
Mean - kσ	197.6E+0	127.0E+0	85.3E+0	66.8E+0	27.5E+0	9.6E+0	4.5E+0	3.6E+0	5.5E+0	74.4E+0

OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	220.8E+0	139.6E+0	97.4E+0	79.4E+0	36.8E+0	12.1E+0	6.8E+0	4.7E+0	7.1E+0	84.7E+0
off2 (HDR)	218.8E+0	139.7E+0	97.2E+0	79.0E+0	36.4E+0	11.2E+0	6.1E+0	4.3E+0	6.6E+0	84.5E+0
off3 (HDR)	223.7E+0	144.9E+0	104.6E+0	88.2E+0	45.8E+0	14.2E+0	8.0E+0	5.2E+0	7.9E+0	88.8E+0
off4 (HDR)	216.1E+0	140.4E+0	105.9E+0	82.7E+0	44.0E+0	13.3E+0	7.2E+0	4.8E+0	7.3E+0	84.8E+0
off5 (HDR)	217.3E+0	139.5E+0	99.4E+0	80.8E+0	39.6E+0	12.6E+0	6.9E+0	4.8E+0	7.2E+0	82.5E+0
Radiation-Mean OFF	219.3E+0	140.8E+0	100.9E+0	82.0E+0	40.5E+0	12.7E+0	7.0E+0	4.7E+0	7.2E+0	85.1E+0
Standarddeviation	3.0E+0	2.3E+0	4.1E+0	3.8E+0	4.2E+0	1.1E+0	676.7E-3	324.6E-3	453.9E-3	2.3E+0
Mean + kσ	227.6E+0	147.2E+0	112.1E+0	92.4E+0	52.1E+0	15.8E+0	8.9E+0	5.6E+0	8.5E+0	91.4E+0
Mean - kσ	211.1E+0	134.5E+0	89.7E+0	71.7E+0	28.9E+0	9.6E+0	5.1E+0	3.9E+0	6.0E+0	78.8E+0

Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	221.9E+0	223.4E+0	221.5E+0	223.9E+0	220.5E+0	222.3E+0	223.1E+0	222.0E+0	221.5E+0	224.0E+0
Min. 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



### 8.13 DC current gain (2)

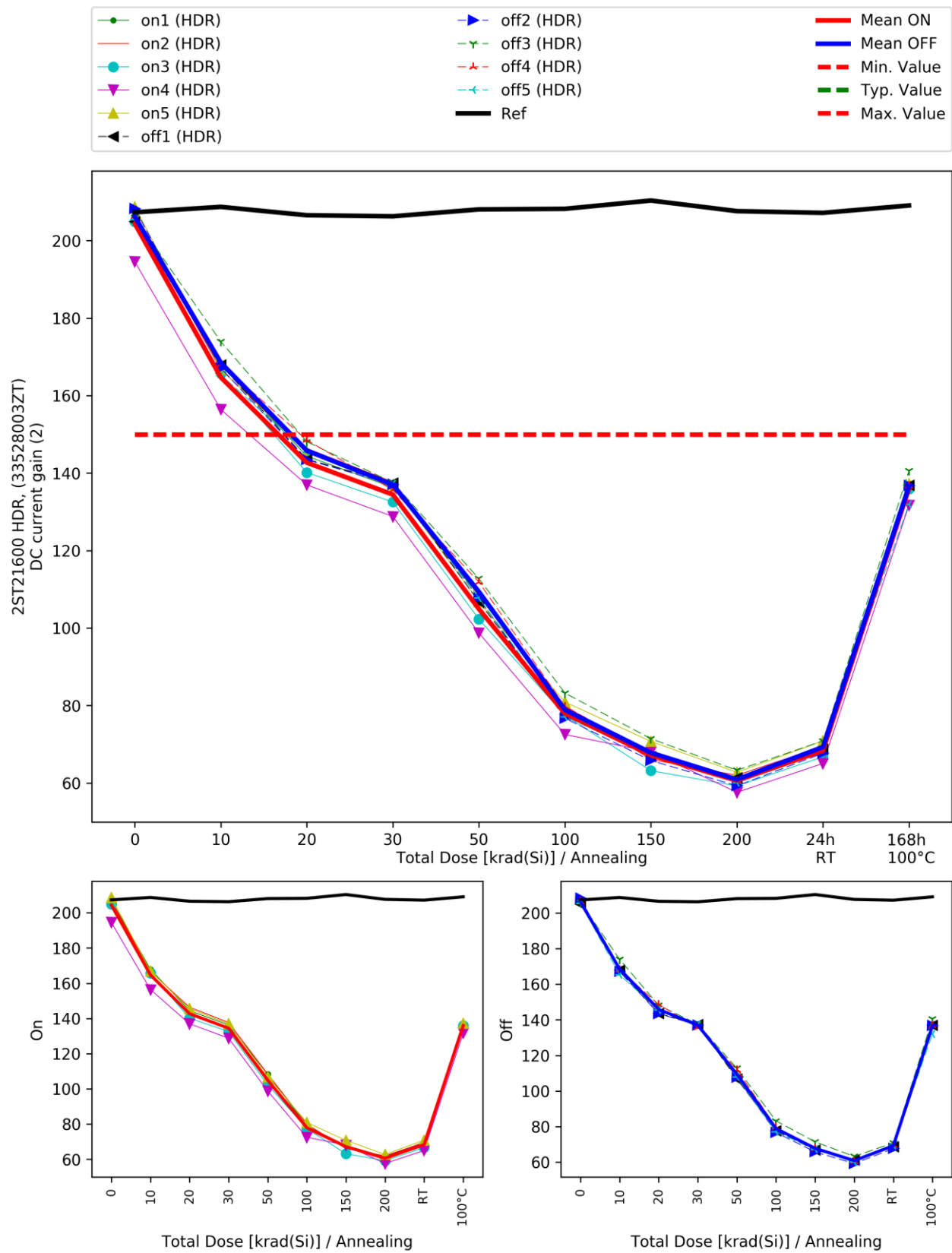
DC current gain (2)  
HFE2

Limit: 150.0 < x

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	207.0E+0	167.9E+0	144.4E+0	136.3E+0	108.4E+0	78.9E+0	67.9E+0	61.5E+0	69.8E+0	137.0E+0
on2 (HDR)	206.7E+0	166.7E+0	146.4E+0	137.7E+0	108.4E+0	80.0E+0	66.1E+0	62.0E+0	69.5E+0	138.1E+0
on3 (HDR)	204.9E+0	165.7E+0	140.2E+0	132.5E+0	102.3E+0	77.5E+0	63.2E+0	59.3E+0	66.8E+0	135.9E+0
on4 (HDR)	194.5E+0	156.4E+0	137.0E+0	128.8E+0	98.8E+0	72.5E+0	68.1E+0	57.6E+0	65.1E+0	131.7E+0
on5 (HDR)	208.7E+0	166.8E+0	145.6E+0	136.9E+0	106.8E+0	80.9E+0	70.8E+0	62.8E+0	70.9E+0	137.3E+0
Radiation-Mean ON	204.4E+0	164.7E+0	142.7E+0	134.5E+0	104.9E+0	78.0E+0	67.2E+0	60.6E+0	68.4E+0	136.0E+0
Standarddeviation	5.7E+0	4.7E+0	4.0E+0	3.7E+0	4.3E+0	3.3E+0	2.8E+0	2.1E+0	2.4E+0	2.5E+0
Mean + kσ	219.9E+0	177.6E+0	153.7E+0	144.7E+0	116.6E+0	87.0E+0	74.8E+0	66.5E+0	75.0E+0	142.9E+0
Mean - kσ	188.9E+0	151.8E+0	131.7E+0	124.2E+0	93.3E+0	68.9E+0	59.5E+0	54.8E+0	61.8E+0	129.1E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	204.9E+0	167.9E+0	143.6E+0	137.5E+0	106.8E+0	77.8E+0	66.8E+0	61.4E+0	68.8E+0	136.9E+0
off2 (HDR)	208.2E+0	167.1E+0	143.5E+0	137.0E+0	107.7E+0	76.7E+0	65.8E+0	59.3E+0	67.7E+0	136.8E+0
off3 (HDR)	206.0E+0	173.9E+0	148.1E+0	137.6E+0	112.8E+0	83.2E+0	71.4E+0	63.3E+0	70.9E+0	140.6E+0
off4 (HDR)	206.3E+0	168.2E+0	148.5E+0	135.7E+0	111.9E+0	79.8E+0	67.6E+0	60.6E+0	69.7E+0	136.7E+0
off5 (HDR)	205.4E+0	165.3E+0	145.4E+0	137.3E+0	107.8E+0	77.1E+0	67.3E+0	60.1E+0	69.4E+0	132.0E+0
Radiation-Mean OFF	206.2E+0	168.5E+0	145.8E+0	137.0E+0	109.4E+0	78.9E+0	67.8E+0	60.9E+0	69.3E+0	136.6E+0
Standarddeviation	1.3E+0	3.2E+0	2.4E+0	777.3E-3	2.7E+0	2.7E+0	2.1E+0	1.5E+0	1.2E+0	3.1E+0
Mean + kσ	209.7E+0	177.4E+0	152.4E+0	139.1E+0	116.9E+0	86.3E+0	73.7E+0	65.1E+0	72.5E+0	145.0E+0
Mean - kσ	202.7E+0	159.6E+0	139.2E+0	134.9E+0	101.9E+0	71.5E+0	61.9E+0	56.7E+0	66.1E+0	128.2E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	207.3E+0	208.7E+0	206.6E+0	206.3E+0	208.1E+0	208.2E+0	210.4E+0	207.6E+0	207.2E+0	209.1E+0
Min. 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



## 8.14 DC current gain (3)

DC current gain (3)  
HFE3

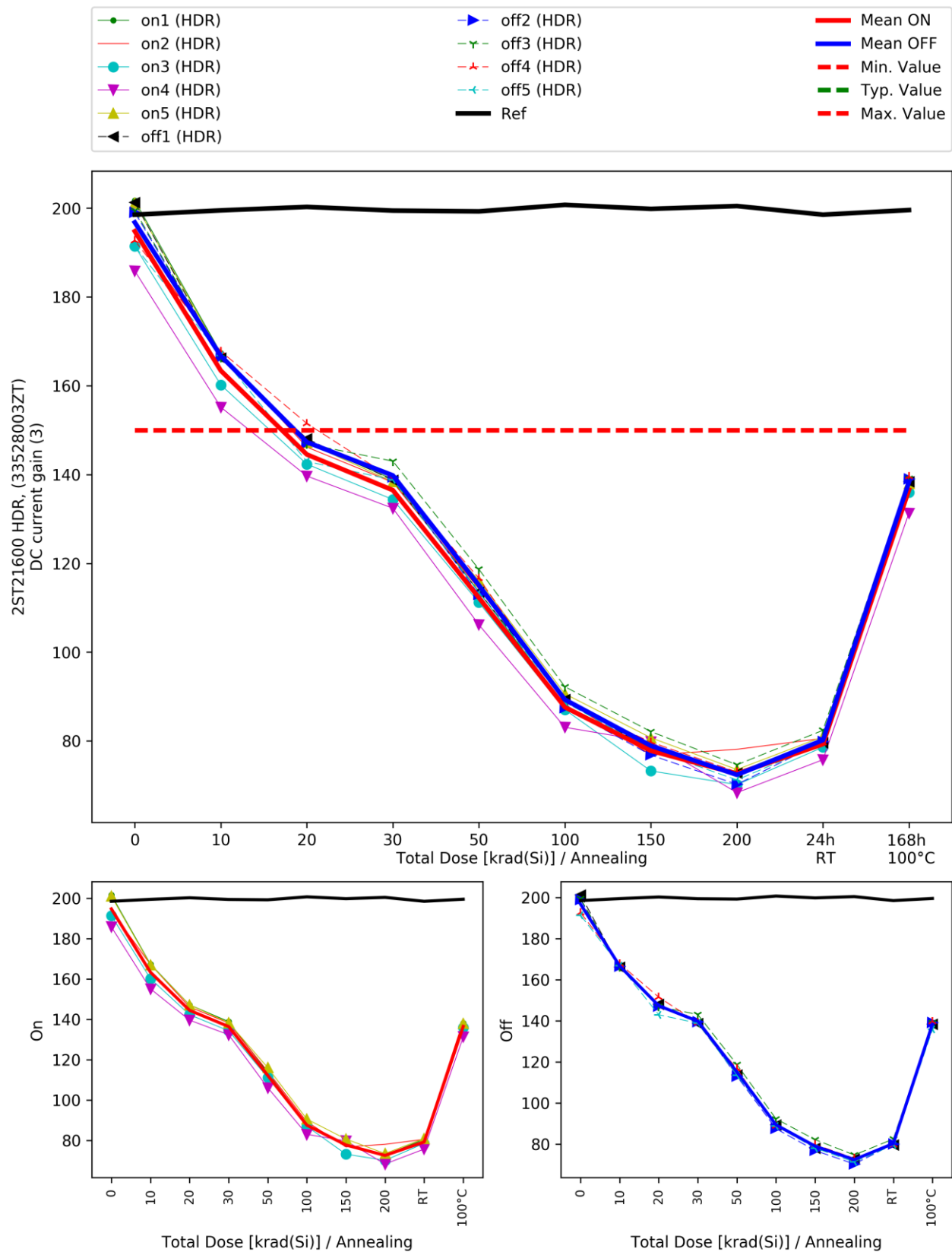
Limit: 150.0 < x

2ST21600 HDR

Date-/Lotcode: 33528003ZT

ON-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
on1 (HDR)	201.7E+0	167.4E+0	147.2E+0	139.0E+0	113.6E+0	88.0E+0	78.4E+0	72.9E+0	80.5E+0	138.2E+0
on2 (HDR)	193.9E+0	167.2E+0	146.2E+0	138.3E+0	114.3E+0	89.3E+0	76.8E+0	78.1E+0	80.6E+0	139.3E+0
on3 (HDR)	191.5E+0	160.2E+0	142.4E+0	134.4E+0	111.2E+0	87.1E+0	73.3E+0	70.2E+0	78.6E+0	136.0E+0
on4 (HDR)	185.9E+0	155.2E+0	139.7E+0	132.4E+0	106.2E+0	83.1E+0	79.8E+0	68.4E+0	75.8E+0	131.4E+0
on5 (HDR)	201.1E+0	167.1E+0	147.2E+0	138.4E+0	116.2E+0	90.6E+0	80.7E+0	73.6E+0	81.0E+0	137.9E+0
Radiation-Mean ON	194.8E+0	163.4E+0	144.5E+0	136.5E+0	112.3E+0	87.6E+0	77.8E+0	72.6E+0	79.3E+0	136.6E+0
Standarddeviation	6.7E+0	5.5E+0	3.4E+0	2.9E+0	3.8E+0	2.9E+0	2.9E+0	3.7E+0	2.2E+0	3.1E+0
Mean + kσ	213.2E+0	178.5E+0	153.8E+0	144.5E+0	122.8E+0	95.5E+0	85.9E+0	82.8E+0	85.2E+0	145.2E+0
Mean - kσ	176.5E+0	148.3E+0	135.3E+0	128.5E+0	101.8E+0	79.7E+0	69.7E+0	62.4E+0	73.3E+0	127.9E+0
OFF-Mode	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
off1 (HDR)	201.3E+0	166.2E+0	148.1E+0	138.7E+0	113.6E+0	89.4E+0	78.0E+0	72.8E+0	79.6E+0	138.4E+0
off2 (HDR)	199.0E+0	166.4E+0	147.1E+0	139.4E+0	113.0E+0	87.5E+0	76.8E+0	70.2E+0	79.9E+0	139.0E+0
off3 (HDR)	199.5E+0	166.4E+0	146.9E+0	143.0E+0	118.7E+0	92.2E+0	82.1E+0	74.6E+0	82.4E+0	139.2E+0
off4 (HDR)	192.7E+0	167.8E+0	151.5E+0	139.1E+0	116.7E+0	88.8E+0	79.7E+0	73.0E+0	79.6E+0	139.6E+0
off5 (HDR)	191.5E+0	166.8E+0	142.9E+0	138.8E+0	113.5E+0	88.8E+0	78.0E+0	71.2E+0	79.5E+0	135.8E+0
Radiation-Mean OFF	196.8E+0	166.7E+0	147.3E+0	139.8E+0	115.1E+0	89.3E+0	78.9E+0	72.4E+0	80.2E+0	138.4E+0
Standarddeviation	4.4E+0	632.1E-3	3.1E+0	1.8E+0	2.5E+0	1.8E+0	2.1E+0	1.7E+0	1.2E+0	1.5E+0
Mean + kσ	208.9E+0	168.5E+0	155.7E+0	144.8E+0	121.9E+0	94.2E+0	84.6E+0	77.0E+0	83.6E+0	142.5E+0
Mean - kσ	184.7E+0	165.0E+0	138.9E+0	134.8E+0	108.3E+0	84.5E+0	73.3E+0	67.7E+0	76.8E+0	134.2E+0
Reference	Total Dose [krad (Si)]								Annealing	
	0	10	20	30	50	100	150	200	24h @ RT	68h @ 100°C
Ref1 (HDR)	198.5E+0	199.5E+0	200.3E+0	199.5E+0	199.3E+0	200.8E+0	199.8E+0	200.5E+0	198.5E+0	199.6E+0
Min. 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





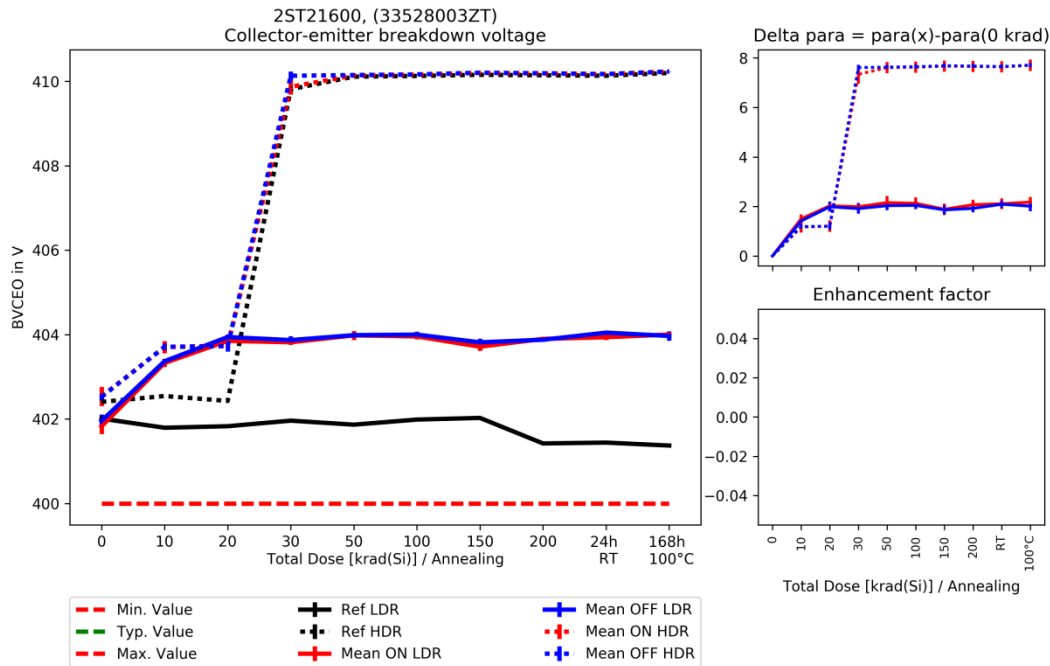
## 9 Results of Enhancement Calculation

### 9.1 Overview of Enhanced low dose rate sensitivity

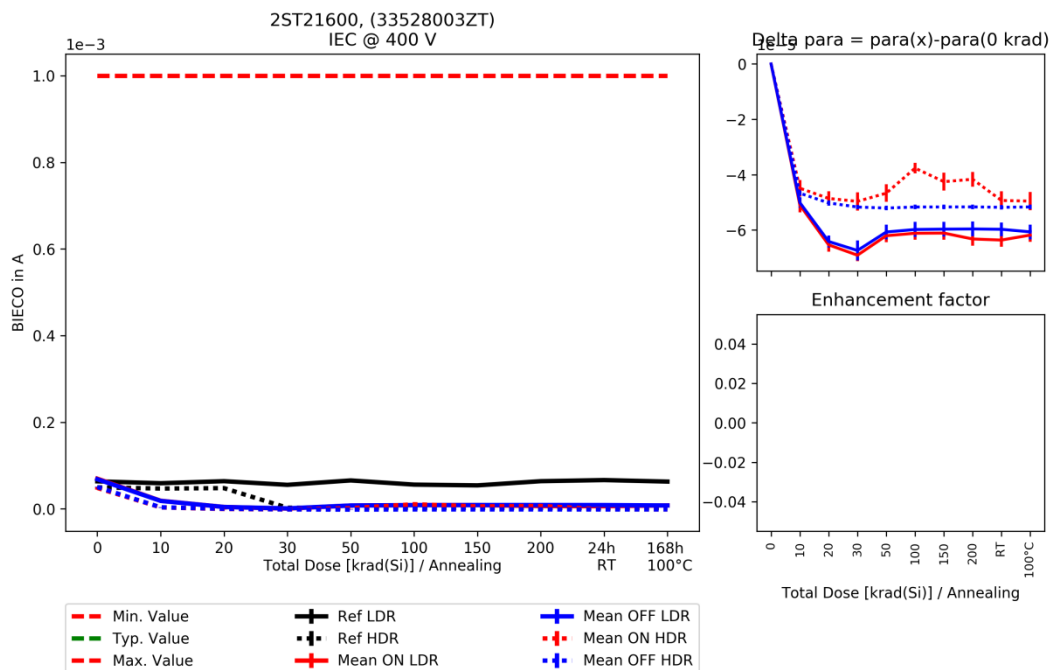
No.	Characteristics	Values out of specs during irradiation?	Enhancement factor applicable (ELDRS?)	max. Calculated enhancement factor	Comment
1	Collector-Emitter Breakdown Voltage	no	no	--	
2	Collector-Base Breakdown Voltage	yes	no	<1	larger degradation in HDR test
3	Emitter-Base Breakdown Voltage	no	no	--	out of specs after annealing
4	Collector-Base Cutoff Current	yes	<b>yes</b>	<b>7.7</b>	at 30 krad(Si), for higher dose levels <1
5	Emitter-Base Cutoff Current	no	no	--	out of specs after annealing
6	Collector-Emitter Saturation Voltage	yes	no	<1	larger degradation in HDR test
7	Base-Emitter Saturation Voltage	no	no	--	
8	Forward Current Transfer Ratio (DC Current Gain)	yes	no	<1.2	partially larger degradation in HDR test
9		yes	no	<1.1	partially larger degradation in HDR test
10		yes	no	<1	larger degradation in HDR test

- A comparison of the tests at high and low dose rate mostly shows a larger degradation at high dose rates.
- If only the out-of-spec-results during irradiation steps are considered, only one parameter ( $I_{CBO}$ ) at one dose step would qualify for ELDRS sensitivity
- As there are other more sensitive parameters (e.g. the HFEs) which do not show an enhanced sensitivity, we would argue that the part is not susceptible to ELDRS.

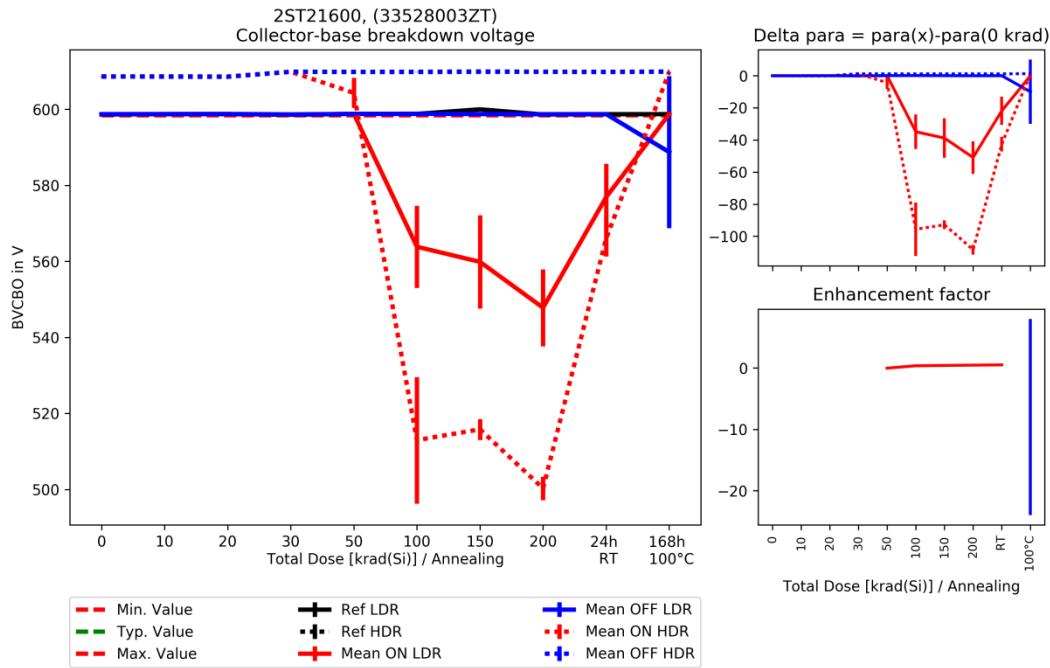
## 9.2 Collector-emitter breakdown voltage



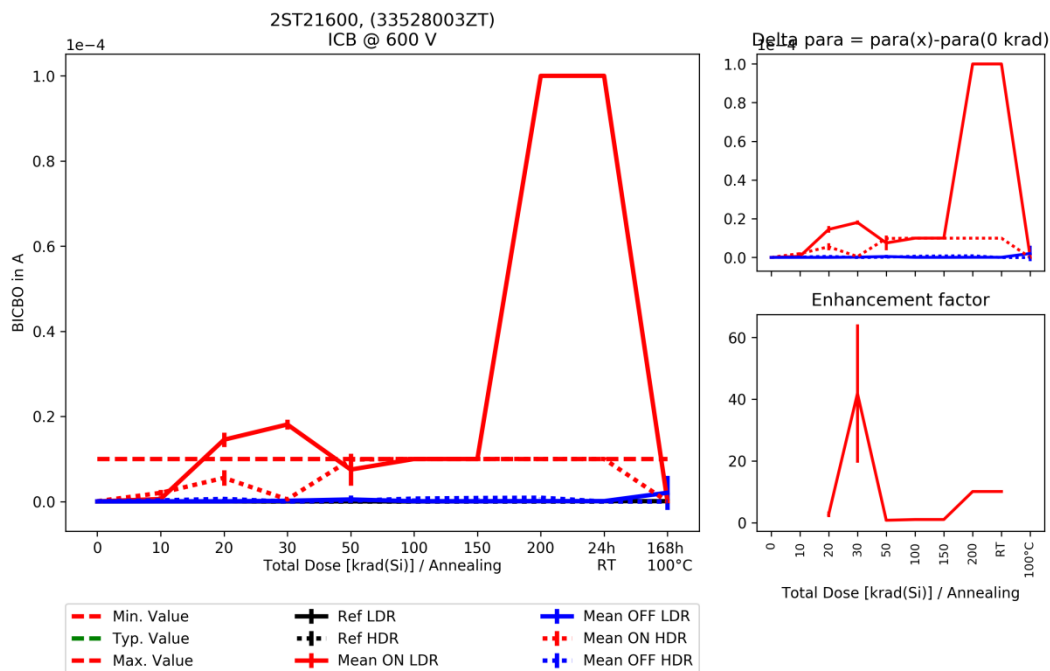
## 9.3 IEC @ 400 V



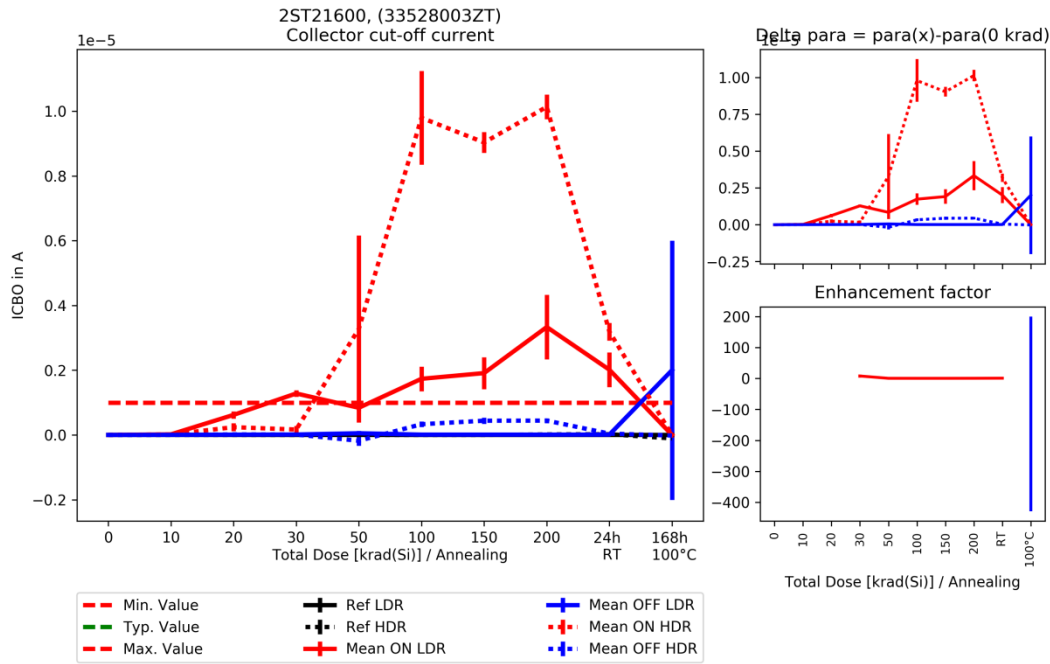
## 9.4 Collector-base breakdown voltage



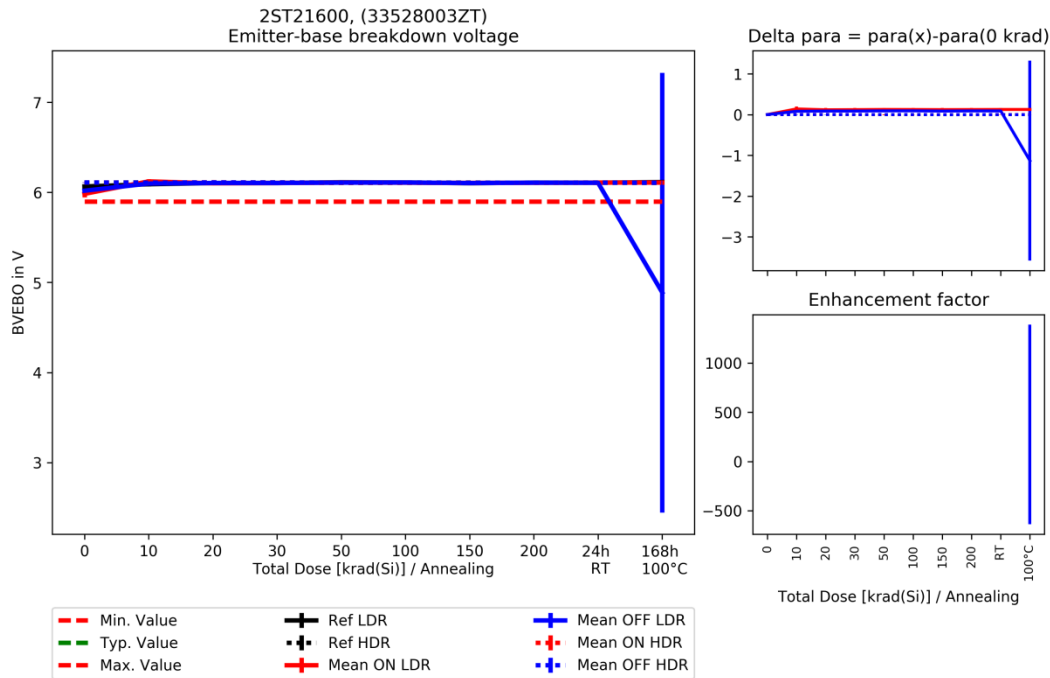
## 9.5 ICB @ 600 V



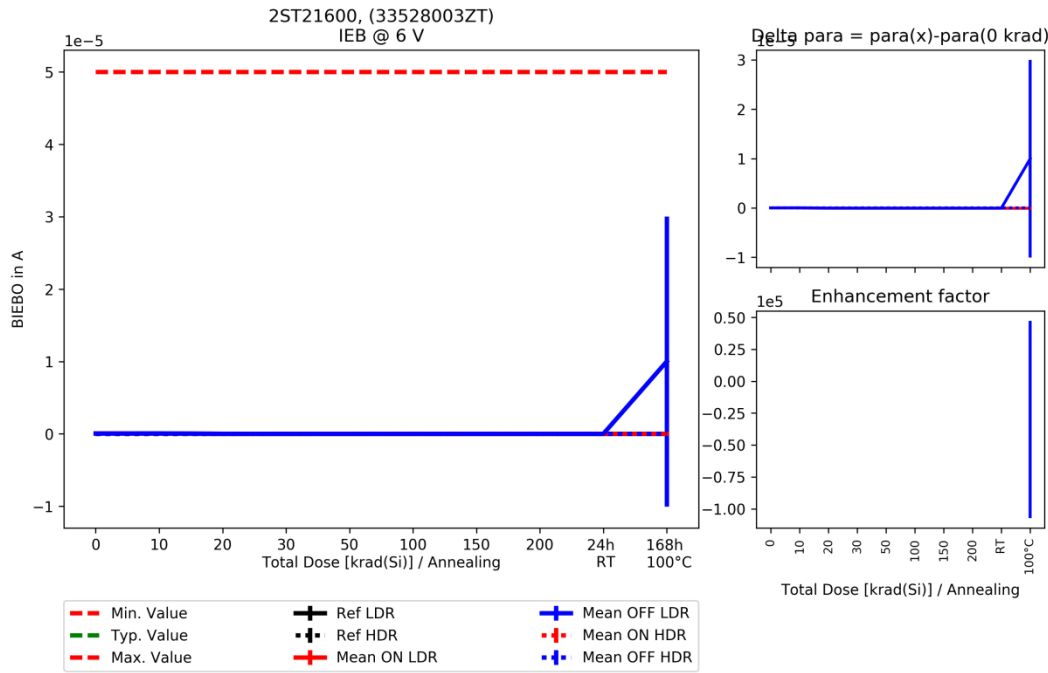
9.6 Collector cut-off current



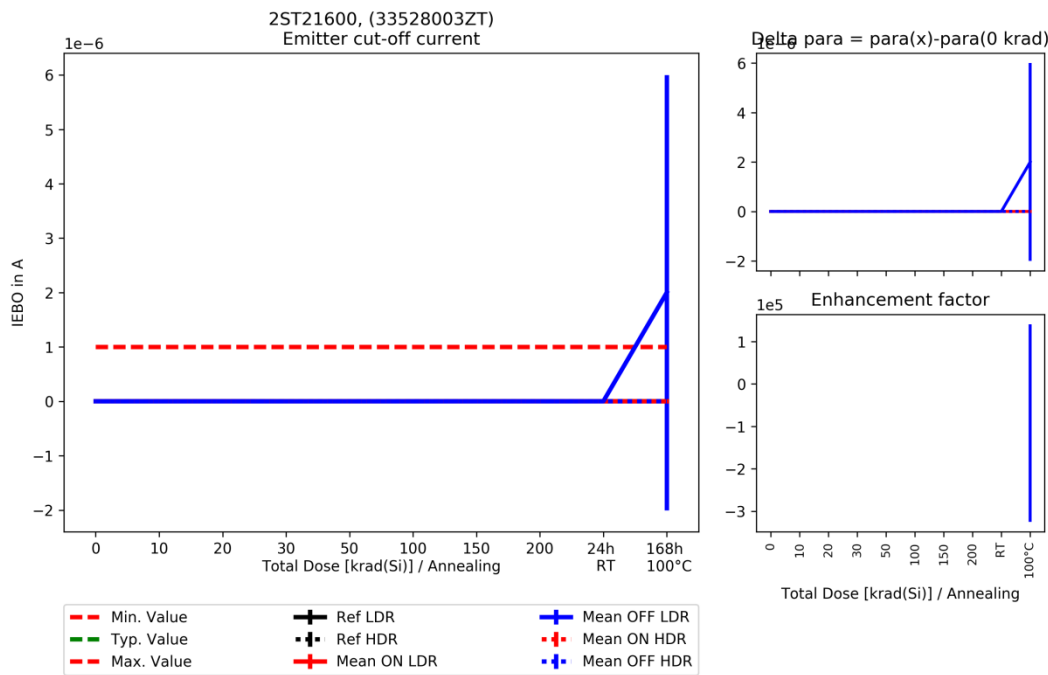
9.7 Emitter-base breakdown voltage



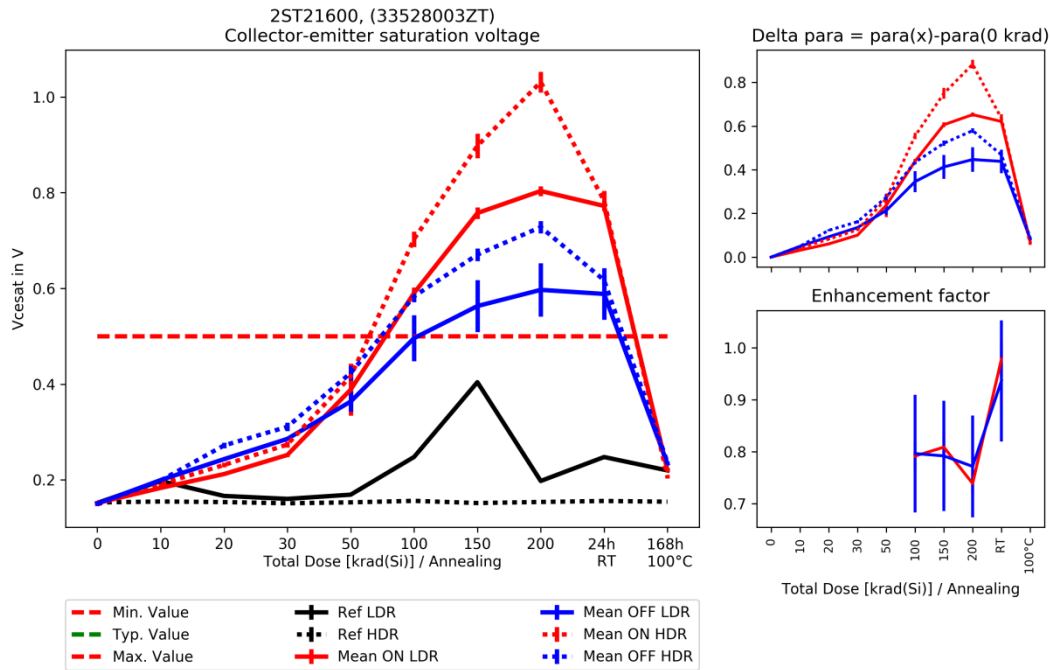
9.8 IEB @ 6 V



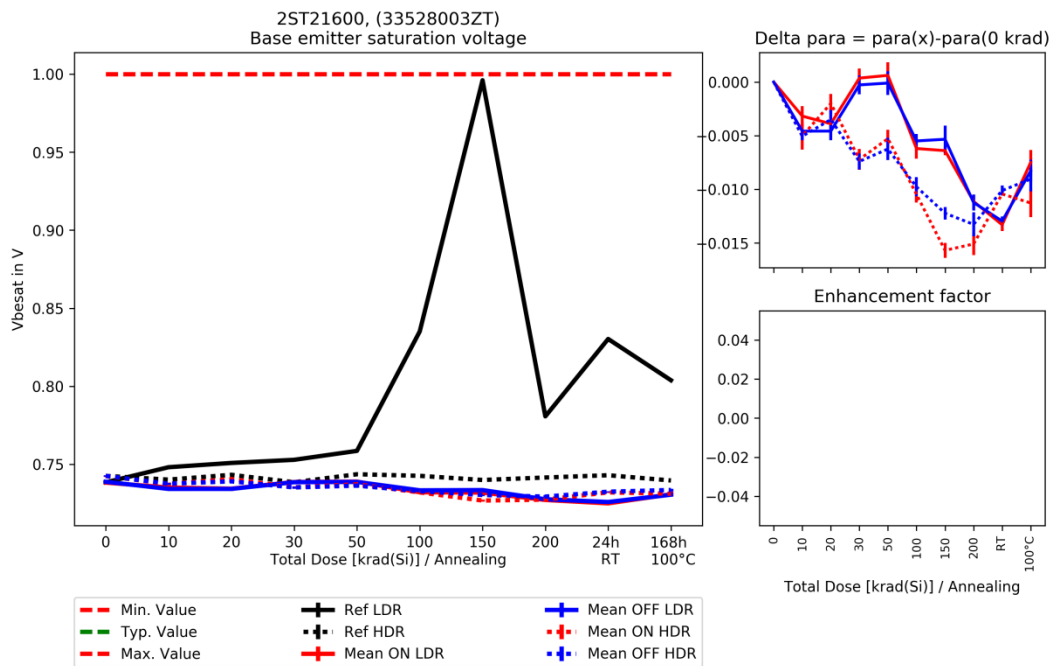
9.9 Emitter cut-off current



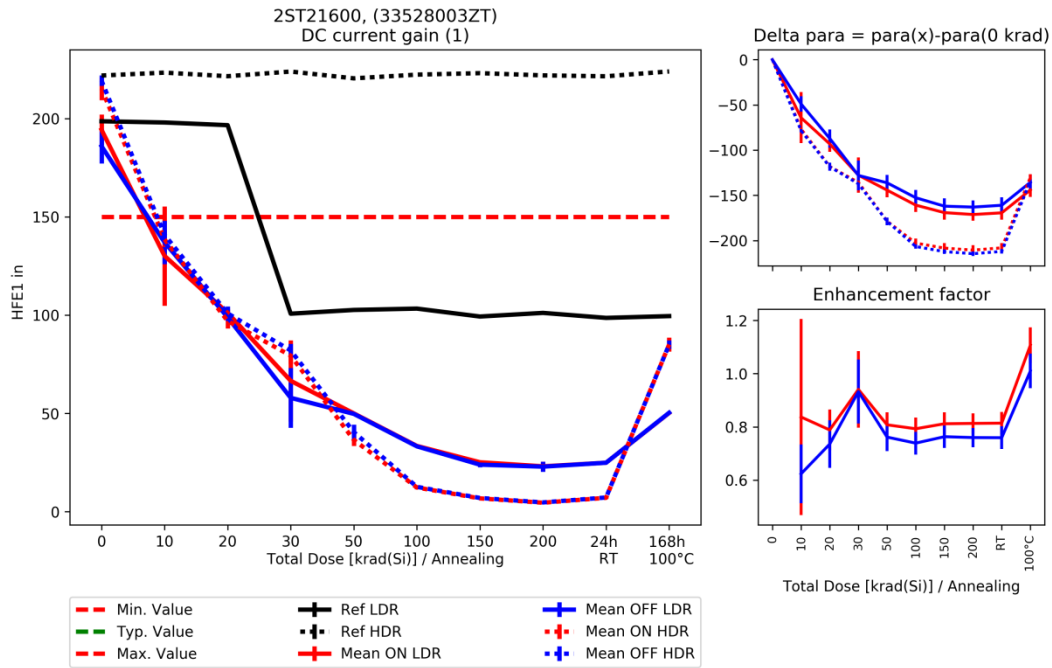
## 9.10 Collector-emitter saturation voltage



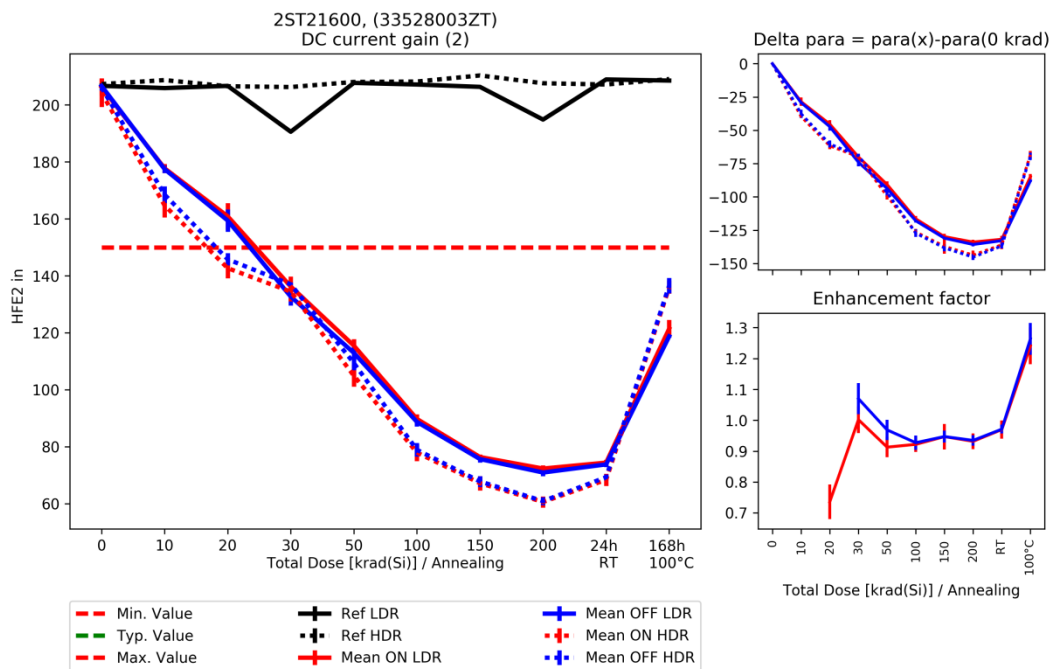
## 9.11 Base emitter saturation voltage



## 9.12 DC current gain (1)

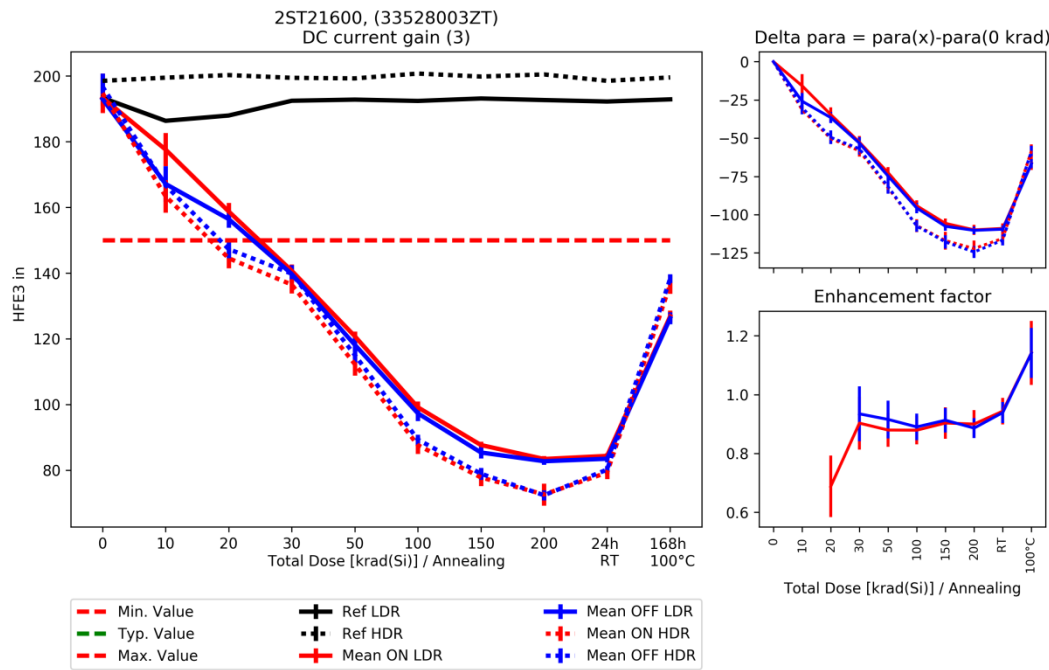


## 9.13 DC current gain (2)





9.14 DC current gain (3)



## A Fraunhofer INT

### A.1. About the institute

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

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

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

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

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

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

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

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

The activities within NEO are:

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

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

### **A.3. Irradiation facilities**

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

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

These irradiation facilities are:

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

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

#### A.4. QM-Certificate

DNV·GL

## MANAGEMENT SYSTEM CERTIFICATE

Certificate No:  
126306-2012-AQ-GER-DAkKS

Initial certification date:  
13. February 2013

Valid:  
29. March 2018 - 12. February 2019

This is to certify that the management system of



### **Fraunhofer-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



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](http://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

<b>IT-Service Leipzig</b>		<small>Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik</small>
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**Qualitätszertifikat**  
für umschlossene Strahlenquelle

Prüfungszeugnis - Nr.:	15805
Kunde:	Fraunhofer Institut
Strahler/HRQ Ident. Nr.:	<b>RU002</b>
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:	<b>Co-60</b>
Physikalische Form:	<b>fest, umschlossen</b>
Chemische Form:	<b>Element, metallisch</b>
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
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## C Irradiation Documentation LDR

Irradiation Test Documentation			
Irradiation Source	TK100 (2015)	Date	13.05.2016
Responsible Employee	MS		
Project Description	ESA-PowerBipolar ELDRS		
<b>Reference Data for Dose Rate Calculation</b>			
Reference Activity	0.44 TBq $\pm$ 10.0%	Standard uncertainty <sup>1)</sup>	
Reference Dose Rate	0.1187 Gy/s $\pm$ 2.5%	Standard uncertainty <sup>1)</sup>	
Reference Distance	10 cm $\pm$ 0.5%	Standard uncertainty <sup>1)</sup>	
Reference Date	01.01.1990		
<b>Geometry of Irradiated Object (As defined or measured):</b>			
Inner Diameter	4.50 cm $\pm$ 0.05 cm	Standard uncertainty <sup>1)</sup>	
Outer Diameter	5.50 cm $\pm$ 0.05 cm	Standard uncertainty <sup>1)</sup>	
Height	0.50 cm $\pm$ 0.05 cm	Standard uncertainty <sup>1)</sup>	
<b>Distances of Point Source:</b>			
Surface of Object	60.00 cm $\pm$ 0.05 cm	Standard uncertainty <sup>1)</sup>	
Object Minimum	60.04 cm $\pm$ 0.05 cm	Standard uncertainty <sup>2)</sup>	
Object Maximum	60.56 cm $\pm$ 0.07 cm	Standard uncertainty <sup>2)</sup>	
Mean Distance	<b>60.30 cm <math>\pm</math> 0.11 cm</b>	<i>Expanded uncertainty<sup>3)</sup></i>	
<b>Dose Rates in Object</b>			
Minimum	0.0001 Gy/s $\pm$ 2.7%	Standard uncertainty <sup>2)</sup>	
Mean	<b>0.0001 Gy/s <math>\pm</math> 2.7%</b>	Standard uncertainty <sup>2)</sup>	
Maximum	0.0001 Gy/s $\pm$ 2.7%	Standard uncertainty <sup>2)</sup>	
Irradiation Time	<b>20342698 s <math>\pm</math> 1 s</b>	Standard uncertainty <sup>1)</sup>	
in MM DD HH:MM:SS	08 22 10:44:58 $\pm$ 1 s	Standard uncertainty <sup>1)</sup>	
<b>Dose in Object</b>			
Minimum	1983 Gy $\pm$ 2.7%	Standard uncertainty <sup>2)</sup>	
Maximum	2017 Gy $\pm$ 2.7%	Standard uncertainty <sup>2)</sup>	
Mean	<b>2000 Gy <math>\pm</math> 5.4%</b>	<i>Expanded uncertainty<sup>3)</sup></i>	
Homogeneity	1.7%		
<sup>1)</sup> Experience or statistics based estimation of standard uncertainty with a coverage factor k=1 <sup>2)</sup> Combined standard uncertainty with a coverage factor k=1 <sup>3)</sup> 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 n 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

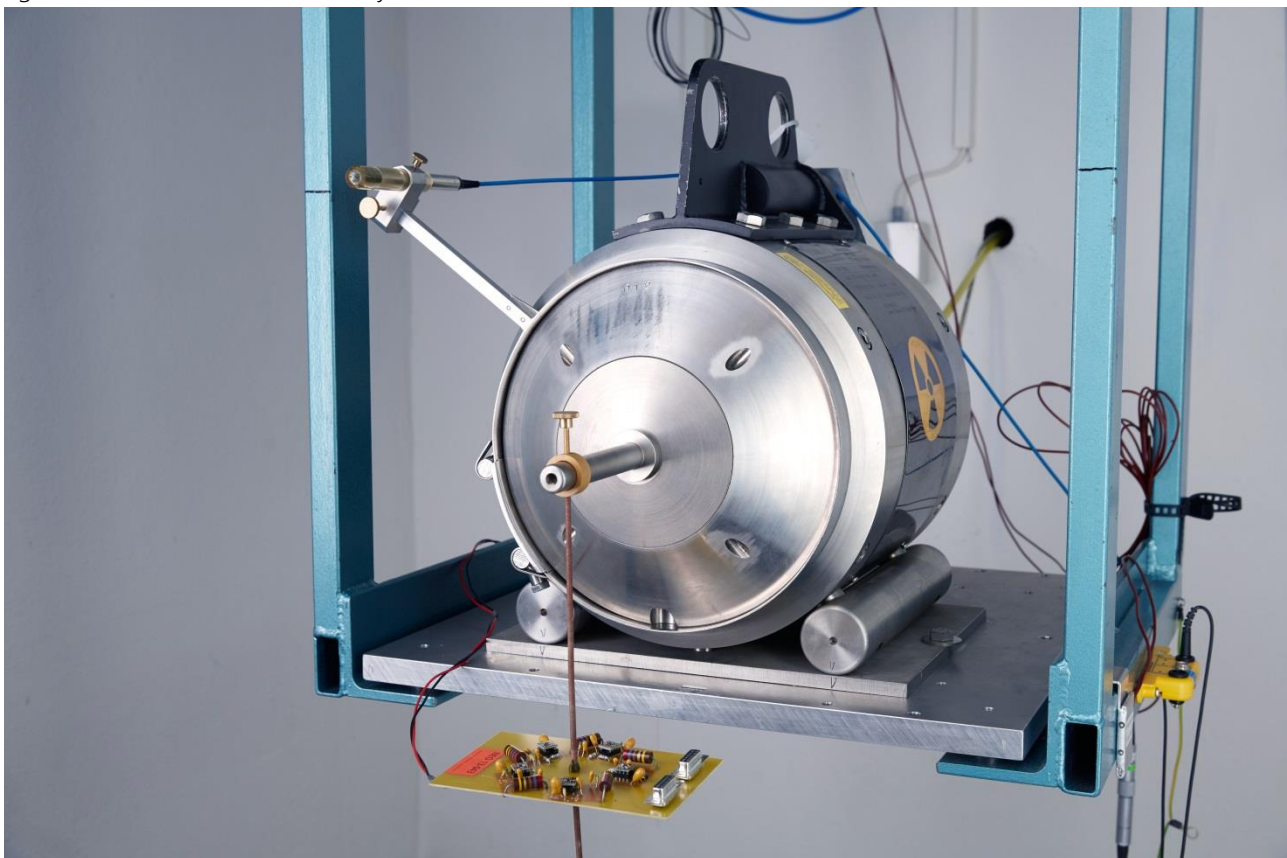
The TK1000B is a Co-60 gamma irradiator manufactured by Sauerwein Isotopentechnik, Germany. Inside the shielding container is a small radioactive pellet with a diameter of 7 mm and a length of 10.4 mm. The activity decreases with a physical half-life of 5.27 years. The current radioactive pellet was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

<b>IT-Service Leipzig</b>		<small>Ingenieur-Technischer Geräte- und Produktservice für Werkstoffprüfung und Medizintechnik</small>
<b>Qualitätszertifikat</b> für umschlossene Strahlenquelle		
<span style="color: red; font-family: cursive;">TK 1000 B</span>		
Prüfungszeugnis - Nr.: Kunde:  Strahler/HRQ Ident. Nr.: Kapsel Typ: ISO Code: AFNOR Code: Zertifikat Nr.:	12061 Fraunhofer Institut  <b>001-2010(GK60R01</b> GK60R01 ISO/99/E 65546 NF/99/E 65546 RUS/5614/S-96 (Rev. 0)	
Radionuklid: Physikalische Form: Chemische Form:	<b>Co-60</b> <b>fest, umschlossen</b> <b>metallisch</b>	
Brennfleck in mm x mm: Herstellungsaktivität: Herstellungsdatum:	7,0x10,4 mm 20102,1 GBq ( 543,3 Ci ) 30.07.2010	
<b>Dichtheitsbescheinigung</b>		
Oberflächenkontaminationstest: Datum:	ohne Beanstandung Ergebnis: < 185 Bq	
Lecktest: Datum:	ohne Beanstandung 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:		
		
<small>IT-Service Leipzig GmbH, BS Haan, Bergische Straße 16, 42781 Haan</small>		
<small>Tel.: 02129 / 377595</small>		<small>Fax: 02129 / 378794</small>

## E Irradiation documentation HDR

Irradiation Test Documentation		
Irradiation Source	TK1000B (2012)	Date
	13.05.2016	
Responsible Employee	MS	
Project Description	NEO-14-086 HDR(4 - 2ST21600)	
<b>Reference Data for Dose Rate Calculation</b>		
Reference Activity	7.98 TBq ± 10.0%	Standard uncertainty <sup>1)</sup>
Reference Dose Rate	2.35 Gy/s ± 2.5%	Standard uncertainty <sup>1)</sup>
Reference Distance	10 cm ± 0.5%	Standard uncertainty <sup>1)</sup>
Reference Date	01.01.1990	
<b>Geometry of Irradiated Object (As defined or measured):</b>		
Inner Diameter	4.50 cm ± 0.05 cm	Standard uncertainty <sup>1)</sup>
Outer Diameter	5.50 cm ± 0.05 cm	Standard uncertainty <sup>1)</sup>
Height	0.50 cm ± 0.05 cm	Standard uncertainty <sup>1)</sup>
<b>Distances of Point Source:</b>		
Surface of Object	13.95 cm ± 0.05 cm	Standard uncertainty <sup>1)</sup>
Object Minimum	14.12 cm ± 0.05 cm	Standard uncertainty <sup>2)</sup>
Object Maximum	14.72 cm ± 0.07 cm	Standard uncertainty <sup>2)</sup>
Mean Distance	14.42 cm ± 0.11 cm	Expanded uncertainty <sup>3)</sup>
<b>Dose Rates in Object</b>		
Minimum	0.0291 Gy/s ± 2.9%	Standard uncertainty <sup>2)</sup>
Mean	0.0303 Gy/s ± 2.8%	Standard uncertainty <sup>2)</sup>
Maximum	0.0316 Gy/s ± 2.8%	Standard uncertainty <sup>2)</sup>
Irradiation Time	66062 s ± 1 s	Standard uncertainty <sup>1)</sup>
in DD HH:MM:SS	00 18:21:02 ± 1 s	Standard uncertainty <sup>1)</sup>
<b>Dose in Object</b>		
Minimum	1919 Gy ± 2.9%	Standard uncertainty <sup>2)</sup>
Maximum	2086 Gy ± 2.8%	Standard uncertainty <sup>2)</sup>
Mean	2000 Gy ± 5.6%	Expanded uncertainty <sup>3)</sup>
Homogeneity	8.3%	
<sup>1)</sup> Experience or statistics based estimation of standard uncertainty with a coverage factor k=1 <sup>2)</sup> Combined standard uncertainty with a coverage factor k=1 <sup>3)</sup> 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