Single Event Effects

Heavy Ions Test Report

Test type	Single-Event Upset, Single Event Latchup
Part Reference	MX68GL1G0G
Tested function	NOR Flash Memory
Chip manufacturer	Macronix
Test Facility	RADEF, Jyvaskyla, Finland, UCL, Louvain-la-neuve, Belgium
Test Date	December 2017, March 2018
Customer	ESA ESTEC

BCE 5524

Hirex reference :	HRX/SEE/00641	Issue : 02	Date :	10/08/2018
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DOCUMENTATION CHANGE NOTICE

Issue	Date	Page	Change Item	
01	12/06/2018	All	Original issue	
02	10/08/2018	14	Word errors analysis (run 45 / HIF) updated	
		15	Added: SEL have been observed with Xenon at run036/RADEF and run048/HIF. No SEL was observed at run049/HIF as the current threshold was increased to 200mA.	
		17	Was: Some SEL occurred during dynamic tests at Vddmin and ambient temperature under Xenon. Current spikes are smaller than the ones recorded for specific SEL runs with amplitude below 0.2 A. compared to 0.3A. Is: Some SEL occurred during dynamic tests at Vddmin and ambient temperature under Xenon (X=3 and X=2). Current spikes are smaller than the ones recorded for specific SEL runs with amplitude below or closed to 0.2 A compared to 0.3A. Run051 added in Table10	

Contributors to this work

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1 Introduction

This report presents results of SEE test campaign for the Macronix NOR Flash Memory MX68GL1G0G. A total of 14 parts were prepared with a minimum of 2 parts per test sequence. The test campaigns took place at RADEF, Jyvaskyla, Finland, UCL, Louvain-la-neuve, Belgium in December 2017, and UCL, Louvain-la-neuve, Belgium.

2 Applicable and Reference Documents

Applicable Documents

AD-1 Macronix MX68GL1G0G Datasheet, P/N:PM1910, MAY 29, 2014

AD-2 MX68GL1G0G physical analysis HRX/RCA/00108

Reference Documents

RD-1. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100

3 Device Information

Device description

MX68GL1G0G, NOR Flash Memory

Manufacturer:	Macronix
Package:	FBGA-64
Marking:	MXIC X151927 MX68GL1G0GHXFI-10G 8B18430FBA
Date code	1519
Technology :	CMOS
Die dimensions :	5.4 mm x 7.2 mm
Device assembly :	Top **dual die** on PCB with solder balls

This 1Gb memory is composed of 2 die of 512 blocks of 65536 x16 bits words. Write Buffer is 256 words while read buffer is 16 words.

Device and die identification

Figure 1: Package, top.

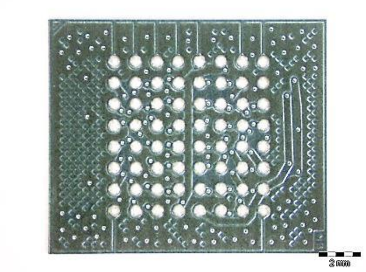


Figure 2: Package, bottom.

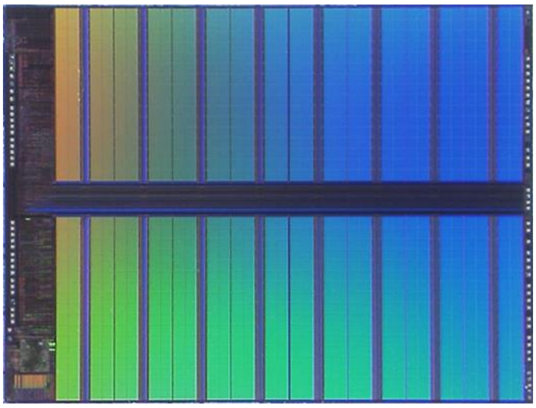


Figure 3: Die view (top die).

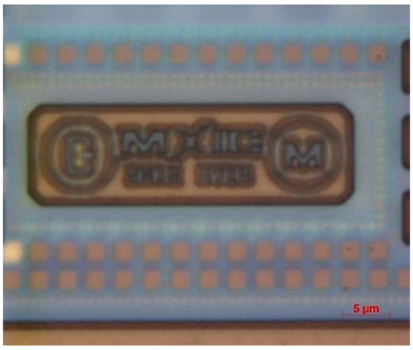


Figure 4: Die marking (top die).

Samples preparation

Samples have been opened chemically for top die exposure and tested for their functionality before the test campaign. 7 daughter boards with 2 samples / board were prepared for the overall test campaign.

4 Test Setup

Figure 5 shows the principle of the single event test system.
The test system is based on a Virtex4 FPGA (Xilinx). It runs at 50 MHz. The test board has 271 I/Os which can be configured using several I/O standards.
The test board includes the voltage/current monitoring and the latch-up management of the DUT power supplies up to 24 independent channels.
The communication between the test chamber and the controlling computer is effectively done by a 100 Mbit/s Ethernet link which safely enables high speed data transfer.
SEL event is detected when the supply current is over a configurable threshold (typically 5 to 10 times the nominal current) and processed:
Once detected, SEL state is maintained for typically 1 or 2ms and power supplies are cut off during a wait time of typically 1 s. These times are configurable.
Each power supply under supervision is monitored independently for SEL detection and processing but subsequent cut off is performed on all power supplies.

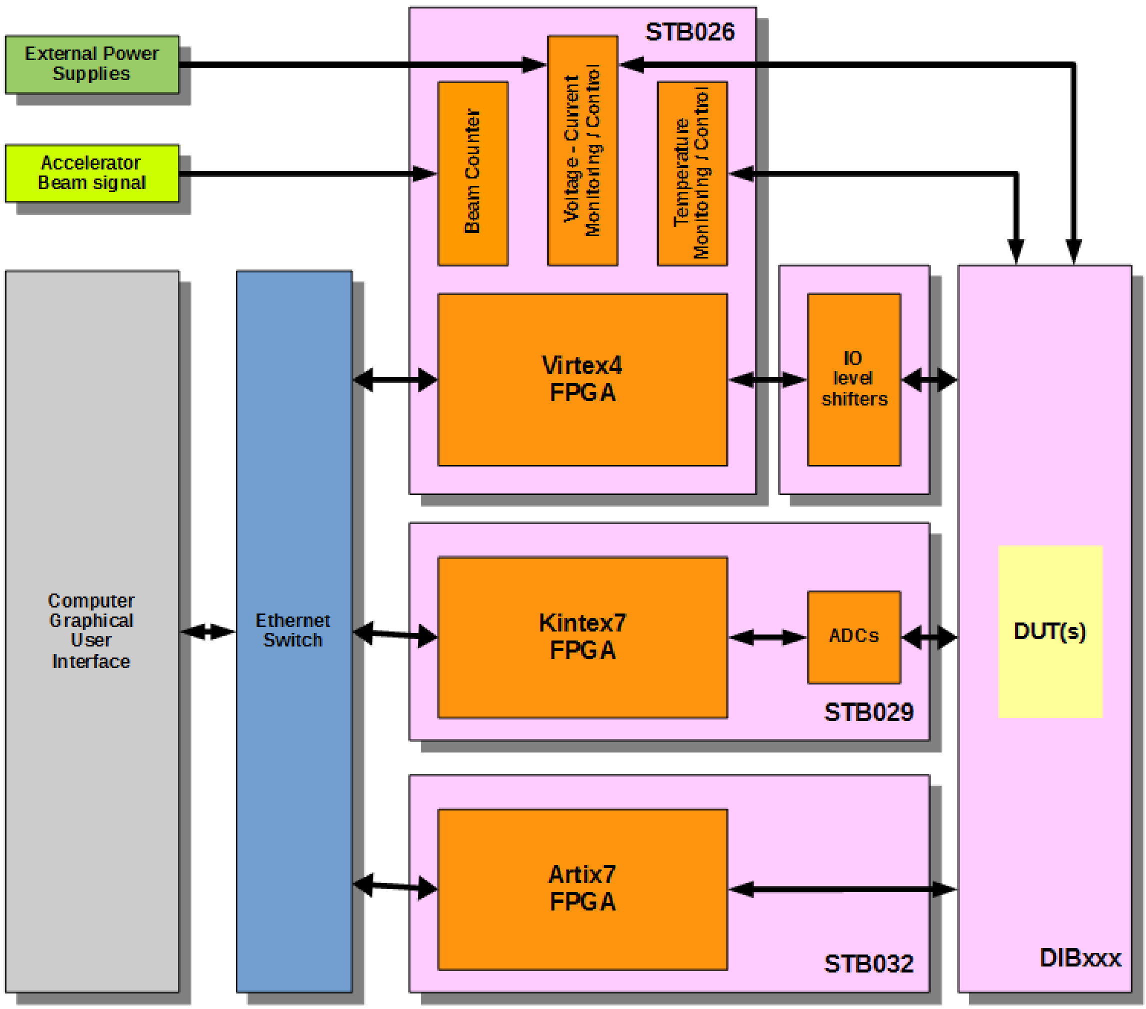


Figure 5: Hirex SEE test setup

A daughter board with 2 samples mounted on it has been designed for this test (DIB294A) and Figure 6 show a picture this board.

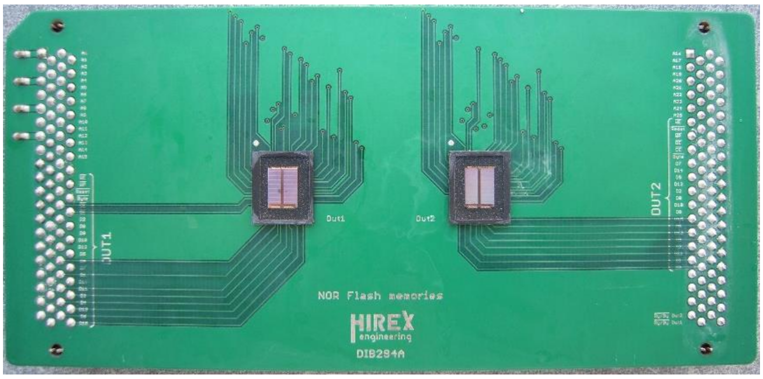


Figure 6 – DIB294A NOR flash daughter board

5 Test sequence

Test modes and their sequence used during the test campaign are summarized in Figure 7. Operations in grey boxes are performed before the irradiation. Operations in white boxes are performed outside the beam when the shutter is closed. Operation in blue boxes are performed under irradiation and operations in yellow boxes are performed once the beam is stopped at the end of the run.

Off sequence

The DUT is turned off after the pre-run. It is then turned back on once the total fluence has been reached and the full chip is read (X=1).

Read sequence

The read sequence (X=3) consists in a loop of a read operation followed by a power-cycle and a second read operation. This sequence focuses on the same 10 blocks of the memory. The pattern used is alternatively 0x66 and 0x99 pattern for this dynamic test.

Both static and dynamic results can be extrapolated based on a single run result. This is done by considering 10 blocks for dynamic behaviour (X=3) and 450 blocks of the chip for static behaviour (X=5).

Erase/Write sequence

During the erase/write (E/W) sequence (X=2), the same 10 blocks are erased and then written under the beam flux. The shutter is then closed to power-cycle the DUT and read twice the blocks outside irradiation. These operations are then looped for the duration of the run.

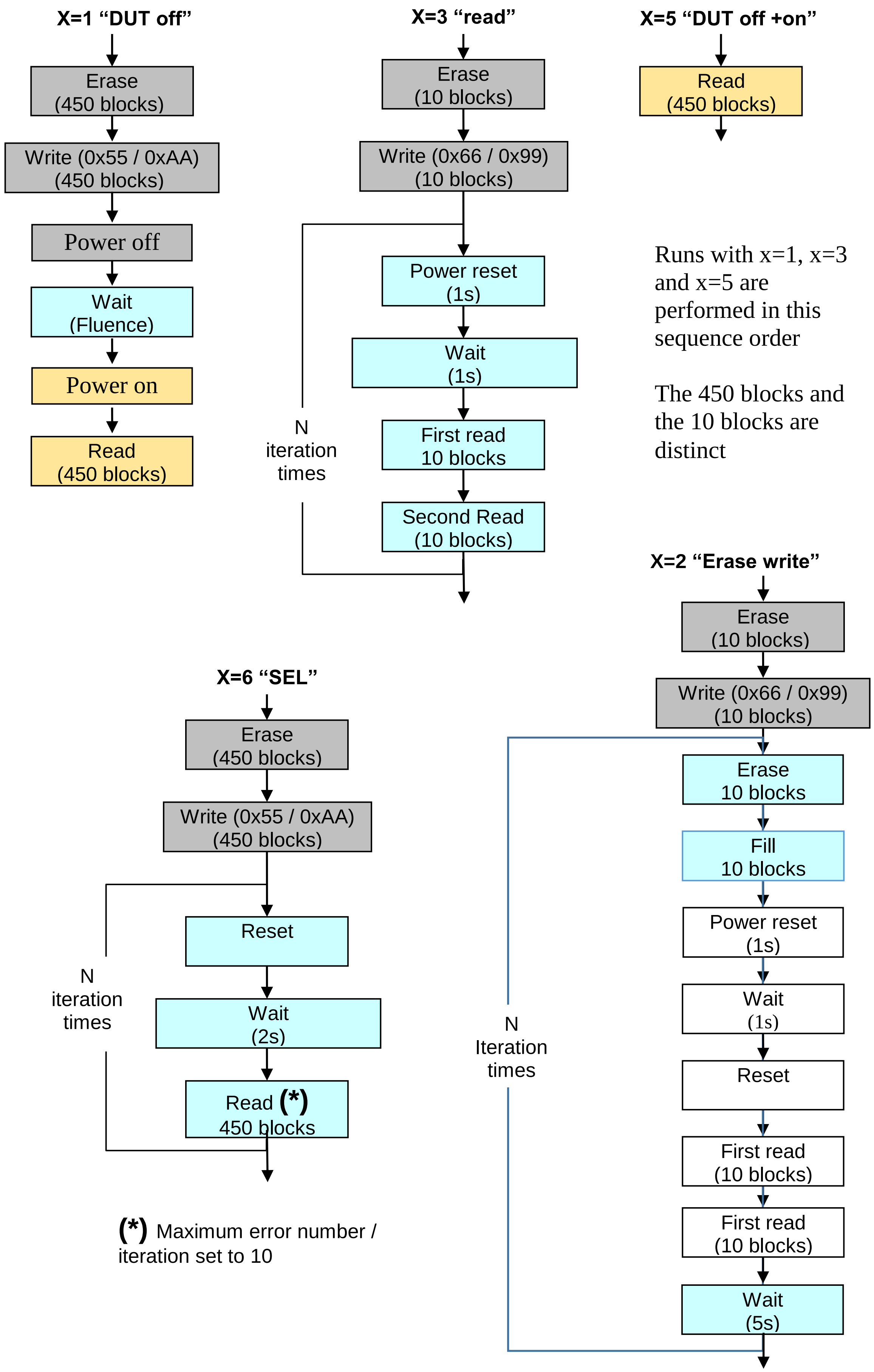


Figure 7 - NOR Flash test sequences

6 RADEF facility

The facility includes a special beam line dedicated to irradiation studies of semiconductor components and devices. It consists of a vacuum chamber including component movement apparatus and the necessary diagnostic equipment required for the beam quality and intensity analysis.

The cyclotron is a versatile, sector-focused accelerator of beams from hydrogen to xenon equipped with three external ion sources: two electron cyclotron resonance (ECR) ion sources designed for high-charge-state heavy ions, and a multicusp ion source for intense beams of protons. The ECR's are especially valuable in the study of single event effects (SEE) in semiconductor devices. For heavy ions, the maximum energy attainable can be determined using the formula,

$$130\ Q^2/M,$$

where Q is the ion charge state and M is the mass in Atomic Mass Units.

Test chamber

Irradiation of components is performed in a vacuum chamber with an inside diameter of 75 cm and a height of 81 cm.

The vacuum in the chamber is achieved after 15 minutes of pumping, and the inflation takes only a few minutes. The position of the components installed in the linear movement apparatus inside the chamber can be adjusted in the X, Y and Z directions. The possibility of rotation around the Y-axis is provided by a round table. The free movement area reserved for the components is 25 cm x 25 cm, which allows one to perform several consecutive irradiations for several different components without breaking the vacuum. The assembly is equipped with a standard mounting fixture. The adapters required to accommodate the special board configurations and the vacuum feed-throughs can also be made in the laboratory's workshops. The chamber has an entrance door, which allows rapid changing of the circuit board or individual components.

A CCD camera with a magnifying telescope is located at the other end of the beam line to determine accurate positioning of the components. The coordinates are stored in the computer's memory allowing fast positioning of various targets during the test.

Beam quality control

For measuring beam uniformity at low intensity, a CsI(Tl) scintillator with a PIN-type photodiode readout is fixed in the mounting fixture. The uniformity is measured automatically before component irradiation and the results can be plotted immediately for more detailed analysis.

A set of four collimated PIN-CsI(Tl) detectors is located in front of the beam entrance. The detectors are operated with step motors and are located at 90 degrees with respect to each other. During the irradiation and uniformity scan they are set to the outer edge of the beam in order to monitor the stability of the homogeneity and flux.

Two beam wobblers and/or a 0.5 microns diffusion Gold foil can be used to achieve good beam homogeneity. The foil is placed 3 m in front of the chamber. The wobbler-coils vibrate the beam horizontally and vertically, the proper sweeping area being attained with the adjustable coil-currents.

Dosimetry

The flux and intensity dosimeter system contains a Faraday cup, several collimators, a scintillation counter and four PIN-CsI(Tl) detectors. Three collimators of different size and shape are placed 25 cm in front of the device under test. They can be used to limit the beam to the active area to be studied.

At low fluxes a plastic scintillator with a photomultiplier tube is used as an absolute particle counter. It is located behind the vacuum chamber and is used before the irradiation to normalize the count rates of the four PIN-CsI(Tl) detectors.

Used ions

Table 1: Ion beam setting.

Ion	LET^{SRIM} at surface [$MeV.cm^2.mg^{-1}$]	Range [µm]	Beam energy [MeV]
$^{15}N^{4+}$	1.83	202	139
$^{20}Ne^{6+}$	3.63	146	186
$^{40}Ar^{12+}$	10.2	118	372
$^{56}Fe^{15+}$	18.5	97	523
$^{82}Kr^{22+}$	32.1	94	768
$^{131}Xe^{35+}$	60.0	89	1217

SRIM-2003.26

7 HIF Facility

Test at the cyclotron accelerator was performed at Université de Louvain (UCL) in Louvain-La-Neuve (Belgium) under HIREX Engineering responsibility.

Beam Source
In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions was built and installed on the HIF beam line in the experimental hall of Louvain-La-Neuve cyclotron.
CYCLONE is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the covered energy range is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximal energy can be determined by the formula:

110 Q2/M,

where Q is the ion charge state, and M is the mass in Atomic Mass Units.
The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source. Such a source allows producing highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. This method is very convenient for a quick change of ion (in a few minutes) which is equivalent to a LET variation.

7.1 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

7.2 Used ions

UCL cocktail ions are listed in the table below.

M/Q	Ion	DUT energy [MeV]	Range [µm Si]	LET [MeV/mg/cm²]
3.25	$^{13}C^{4+}$	131	269.3	1.3
3.14	$^{22}Ne^{7+}$	238	202.0	3.3
3.37	$^{27}Al^{8+}$	250	131.2	5.7
3.33	$^{40}Ar^{12+}$	379	120.5	10.0
3.31	$^{53}Cr^{16+}$	513	107.6	16.0
3.218	$^{58}Ni^{18+}$	582	100.5	20.4
3.35	$^{84}Kr^{25+}$	769	94.2	32.4
3.54	$^{124}Xe^{35+}$	995	73.1	62.5

Table 2 – Ion beam setting

8 Test conditions.

SEU tests were carried out at Vddmin (2.7 V) and room temperature.
Samples for SEL were tested at Vddmax (3.6 V) and a junction temperature of 85°C while performing a dynamic test (read).

9 Results

Detailed results are provided in section 10 with error bars taking into account a 95% confidence level and 10% beam uniformity. For each data set, a Weibull curve has been proposed based on the following equation:

$$F(x) = Sat\left(1 - \exp\left\{-\left[\frac{x - x_0}{W}\right]^S\right\}\right)$$

SEL runs exhibits events on the Vcc line with high current steps around 0.3 A over the detection limit of 100mA. Some SEL were recorded at high LET for dynamic test runs (read and erase/write) at ambient temperature with amplitude below 0.2 A.
Data and a chronogram example of SEL recorded are presented at the end of section 10. The SEL cross-section at a LET of 60 MeV/mg/cm² is below 5.0E-4 cm²/device.

Some DUTs failed when tested with Nickel, Krypton or Xenon during erase write mode (X=2).

10 Detailed results

10.1 SEE

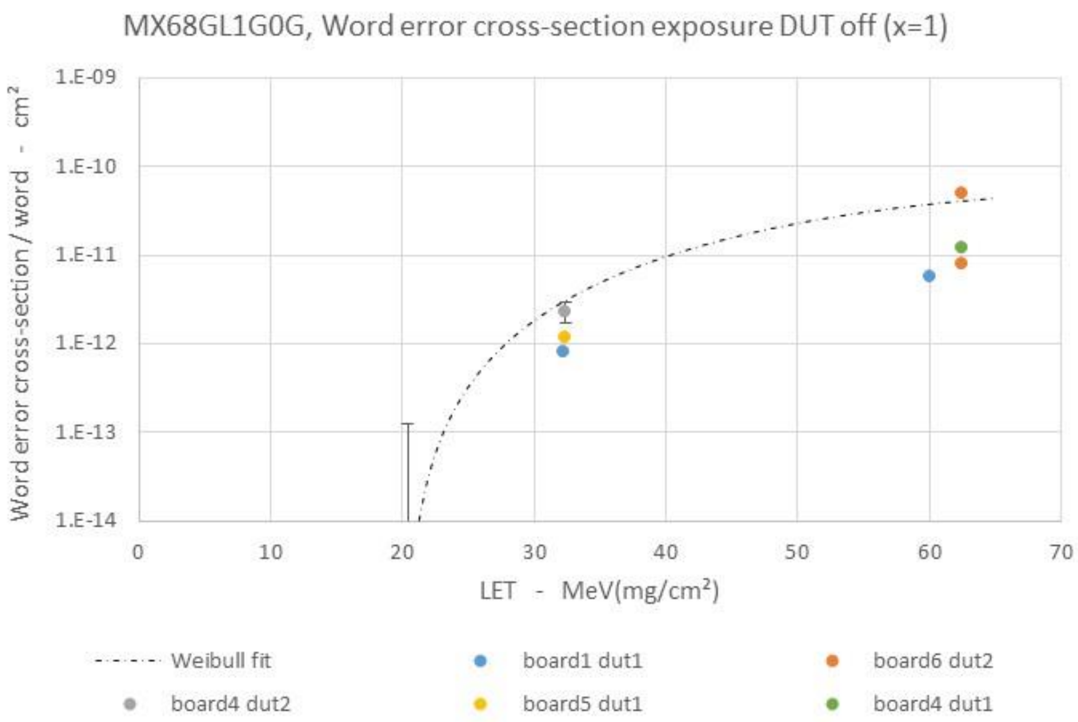
X=1 Off sequence

Results for X=1 “off” sequence runs are summarized in Table 3 which gives the number of word errors recorded at the end of each run.

Table 3: SEE results for X=1 "Off" sequence.

Facility	dut_medium	bias_config	test_mode	run_number	Facility_run_number	board_id	DUT_part_id	power_config	temperature	Ion	tilt	LET	run_duration	entered_fluence	first block	last block	Nb Blocks	Word Capacity under test	Words in error	Word error cross-section	error bar up	error bar down	delta up	delta down
RADEF	vacuum	x=1	SEU	17	106	1	1	2.7V	room	Ar	0		218	1.00E+06	522	971	450	29491200	0		1.3E-13		1.3E-13	
RADEF	vacuum	x=1	SEU	25	113	1	1	2.7V	room	Fe	0		214	1.00E+06	512	909	398	26083328	0		1.4E-13		1.4E-13	
RADEF	vacuum	x=1	SEU	29	117	1	1	2.7V	room	Xe	0	60	165	1.00E+06	512	909	398	26083328	148	5.7E-12	6.8E-12	4.6E-12	1.1E-12	1.0E-12
RADEF	vacuum	x=1	SEU	30	118	1	1	2.7V	room	Kr	0	32.2	208	1.00E+06	512	909	398	26083328	21	8.1E-13	1.2E-12	4.9E-13	4.3E-13	3.2E-13
HIF	vacuum	x=1	SEU	54	64	4	1	2.7V	room	Xe	0	62.5	66	1.02E+06	522	821	300	19660800	210	1.0E-11	1.2E-11	8.7E-12	1.8E-12	1.7E-12
HIF	vacuum	x=1	SEU	4	34	4	2	2.7V	room	Ar	0	10	257	1.01E+06	522	971	450	29491200	0		1.2E-13		1.2E-13	
HIF	vacuum	x=1	SEU	18	43	4	2	2.7V	room	Ni	0	20.4	139	1.02E+06	522	971	450	29491200	0	1.0E-15	1.2E-13		1.2E-13	
HIF	vacuum	x=1	SEU	30	50	4	2	2.7V	room	Kr	0	32.4	87	1.01E+06	522	971	450	29491200	68	2.3E-12	2.9E-12	1.7E-12	6.5E-13	5.6E-13
HIF	vacuum	x=1	SEU	10	37	5	1	2.7V	room	Ar	0	10	245	1.01E+06	522	971	450	29491200	0		1.2E-13		1.2E-13	
HIF	vacuum	x=1	SEU	14	40	5	1	2.7V	room	Ni	0	20.4	245	1.01E+06	522	971	450	29491200	0		1.2E-13		1.2E-13	
HIF	vacuum	x=1	SEU	25	47	5	1	2.7V	room	Kr	0	32.4	104	1.01E+06	522	971	450	29491200	35	1.2E-12	1.6E-12	8.0E-13	4.7E-13	3.8E-13
HIF	vacuum	x=1	SEU	45	59	6	2	2.7V	room	Xe	0	62.5	407	5.99E+06	522	971	450	29491200	8892	5.0E-11	5.5E-11	4.5E-11	5.1E-12	5.1E-12
HIF	vacuum	x=1	SEU	46	60	6	2	2.7V	room	Xe	0	62.5	71	1.02E+06	522	971	450	29491200	244	8.1E-12	9.5E-12	6.8E-12	1.4E-12	1.3E-12

Cross-section results are plotted in Figure 8 along with a Weibull fit curve.



Weibull parameters

W	40
xo	20
s	2.5
Sat	6E-11

Figure 8: SEU static cross-section for X=1 "OFF" sequence.

Word errors analysis (run 45 / HIF)

SBU and MBU contributions are summarized in Table 4. SBU are counted in the second column (“SBU”), MBU of size 2 are counted in the third column (“mbu2”) and MBU of size 3 are counted in the fourth column (“mbu3”).

Bit error distribution per bit and bit flip transitions are summarised in Table 5.
It can be observed that each bit presents about the same sensitivity and that the cell erase, loss of a charge by an ion hit, (transition 0->1) is 8 times more likely than the cell write, acquisition of a charge (transition 1->0).

For each word error address, the corresponding read buffer number is identified.
Considering the word errors addresses, even not knowing the memory cells array mapping, it is very likely that an ion hit can upset more than 1 word as buffer reads numbers are distant of each other. This can be derived from the number of buffer read numbers involved (on a total of 1 843 200 buffer read numbers) and the number of words in error, see Table 6

Table 4: Run045 / HIF, MBU contribution to overall word errors

Word errors	SEU	mbu2	mbu3
8892	7846	1021	25

Table 5: Run045 / HIF, Distribution of bit flips per bit and per transition.

Word errors	bit flip	trans 1->0	trans 0->1	bit0	bit1	bit2	bit3	bit4	bit5	bit6	bit7	bit8	bit9	bit10	bit11	bit12	bit13	bit14	bit15
8892	9963	1125	8838	552	662	654	631	597	658	645	665	667	669	650	549	645	630	662	427

Table 6: Run045 / HIF, Distribution of word errors per buffer reads.

Nb words/block/bufr	nb_bufr clusters	nb_words
1	278	278
2	1498	2996
3	1852	5556
4	14	56
6	1	6
	3643	8892

Read sequence

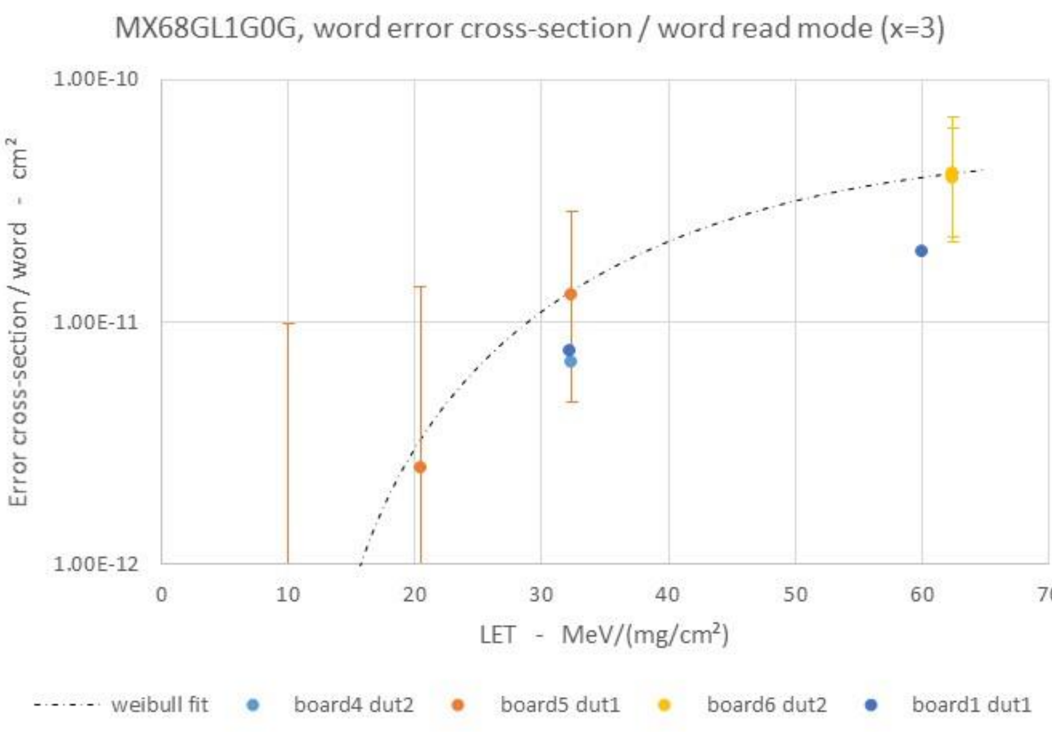
Results for X=3 “read” sequence runs are given in Table 7. The SEU static value is computed from the blocks that are not used during read operation (X=5).

SEL have been observed with Xenon at run036/RADEF and run048/HIF. No SEL was observed at run049/HIF as the current threshold was increased to 200mA.

Table 7: SEE results for X=3 "Read" sequence.

Facility	dut_medium	test_mode	power_config	run_number	Facility_run_number	board_id	DUT_part_id	temperature	Ion	tilt	LET	run_duration	entered_fluence	eff.fluence	bock start	block end	nb blocks	Nb wordes	SELs	SEUs read	SEUs cells	bufr error	logic	total SEU events	Error cross-section / word
HIF	vacuum	SEU	2.7V	5	35	4	2	room	Ar	0	10	248	1.00E+06	5.77E+05	512	521	10	655360	0	0	0	0	0	0	
HIF	vacuum	SEU	2.7V	31	51	4	2	room	Kr	0	32.4	208	1.01E+06	8.88E+05	512	521	10	655360	0	2	0	0	2	4	6.87E-12
HIF	vacuum	SEU	2.7V	11	38	5	1	room	Ar	0	10	244	1.01E+06	5.75E+05	512	521	10	655360	0	0	0	0	0	0	1.00E-15
HIF	vacuum	SEU	2.7V	15	41	5	1	room	Ni	0	20.4	250	1.01E+06	6.05E+05	512	521	10	655360	0	0	0	0	1	1	2.52E-12
HIF	vacuum	SEU	2.7V	26	48	5	1	room	Kr	0	32.4	252	1.01E+06	7.03E+05	512	521	10	655360	0	2	0	1	3	6	1.30E-11
HIF	vacuum	SEU	2.7V	48	61	6	2	room	Xe	0	62.5	528	1.00E+06	4.84E+05	512	521	10	655360	89	4	6	1	2	13	4.10E-11
HIF	vacuum	SEU	2.7V	49	62	6	2	room	Xe	0	62.5	284	1.01E+06	6.61E+05	512	521	10	655360	0	6	4	1	6	17	3.92E-11
RADEF	vacuum	SEU	2.7V	20	110	1	1	room	Ar	0	10.2	219	1.00E+06	6.71E+05	0	9	10	655360	0	0	0	0	0	0	
RADEF	vacuum	SEU	2.7V	31	119	1	1	room	Kr	0	32.2	181	1.00E+06	7.98E+05	512	521	10	655360	0	1	0	0	3	4	7.65E-12
RADEF	vacuum	SEU	2.7V	36	122	1	1	room	Xe	0	60	995	1.00E+06	6.24E+05	512	521	10	655360	67	3	1	1	3	8	1.96E-11

SEU Read correspond to a word error detected during 1 read only out of the two consecutive reads.
SEU Cells correspond to 1 a word error detected at each read out of the two consecutive reads.
Buffer error corresponds to the entire buffer read (16 words) in error at one of the two consecutive reads
Logic error: 1 or several blocks in error either during one read or the two consecutive reads



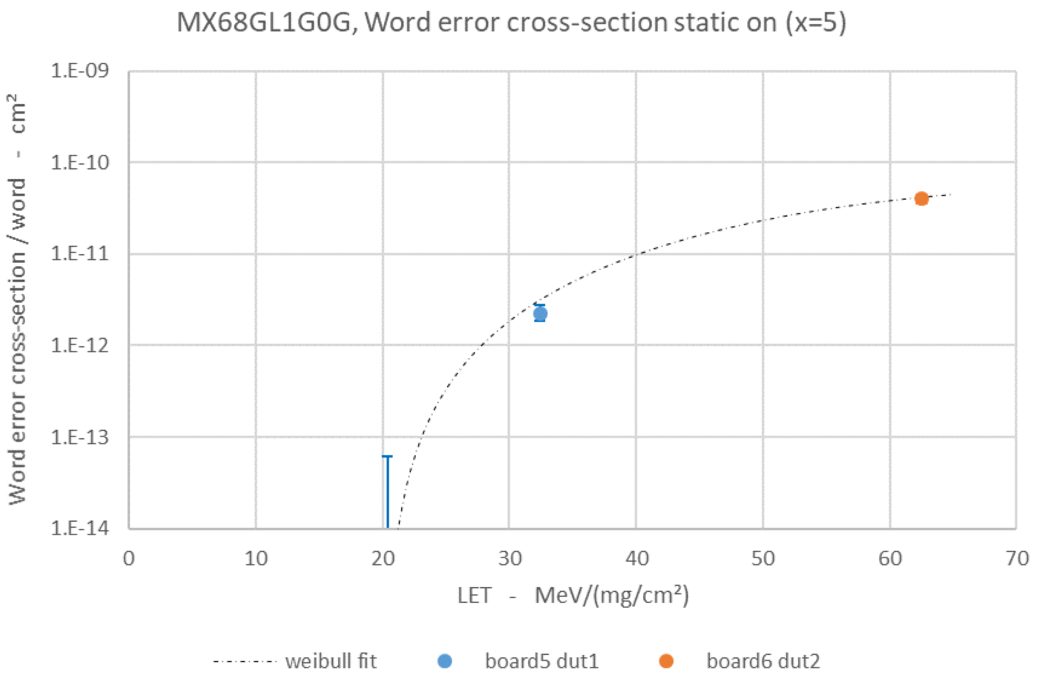
Weibull parameters:

W	40
xo	10
s	2
Sat	5.00E-11

Figure 9: SEU event cross-section / word for X=3 "read" sequence.

Table 8: SEE results for X=5 "Static on" sequence.

Facility	dut_medium	bias_config	test_mode	run_number	Facility_run_number	DUT_under_beam	board_id	power_config	temperature	Ion	tilt	Eff. LET	Fluence of previous runs (x=1 & x=3)	bock start	block end	nb blocks	Nb words	SEUs	SEU word X-section /word
HIF	vacuum	x=5	SEU	6	-	2	4	2.7V	ROOM	Ar	0	10	2.00E+06	522	971	450	29491200	0	
HIF	vacuum	x=5	SEU	12	-	1	5	2.7V	ROOM	Ar	0	10	2.00E+06	522	971	450	29491200	0	
HIF	vacuum	x=5	SEU	16	-	1	5	2.7V	ROOM	Ni	0	20.4	2.00E+06	522	971	450	29491200	0	
HIF	vacuum	x=5	SEU	27	-	1	5	2.7V	ROOM	Kr	0	32.4	2.00E+06	522	971	450	29491200	134	2.27E-12
HIF	vacuum	x=5	SEU	50	-	2	6	2.7V	ROOM	Xe	0	62.5	2.00E+06	522	971	450	29491200	2361	4.00E-11



Weibull parameters:

W	40
xo	20
s	2.5
A	6.00E-11

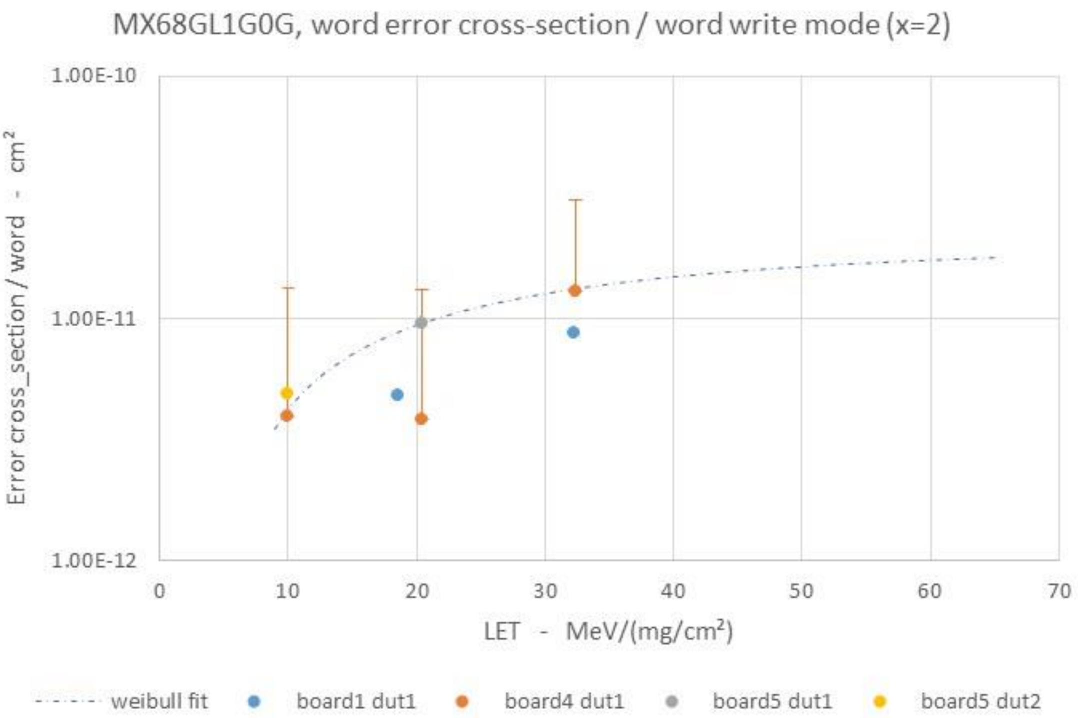
Erase/Write sequence

Results for “Erase/Write” sequence runs are given in Table 9. Devices lost their functionality during Xenon test runs.

Table 9: SEE results for "Erase/Write" sequence (X=2).

Facility	dut_medium	test_mode	power_config	run_number	Facility_run_number	board_id	DUT_part_id	temperature	Ion	LET	tilt	Eff. LET	run_duration	entered_fluence	Eff. Fluence	SEU cell	bufW	Block	Fill error	erase error	total	blck start	block end	nb blocks	Nb wordes	Error cross-section / word
RADEF	vacuum	SEU	2.7V	43	125	1	1	room	Fe	18.5	0	18.5	296	1.00E+06	9.57E+05	0	0	1	2	0	3	512	521	10	655360	4.78E-12
RADEF	vacuum	SEU	2.7V	46	128	1	1	room	Kr	32.2	0	32.2	1338	1.00E+06	**5.28E+05**	0	0	0	2	1	3	512	521	10	655360	8.67E-12
HIF	vacuum	SEU	2.7V	7	36	4	1	room	Ar	10	0	10	322	1.01E+06	9.31E+05	1	0	0	2	0	3	512	521	10	655360	4.92E-12
HIF	vacuum	SEU	2.7V	22	45	4	1	room	Ni	20.4	0	20.4	304	1.01E+06	9.51E+05	1	0	0	1	1	3	512	521	10	655360	4.81E-12
HIF	vacuum	SEU	2.7V	34	52	4	1	room	Kr	32.4	0	32.4	371	1.00E+06	9.50E+05	9	0	3	6	2	20	512	521	10	655360	3.21E-11
HIF	vacuum	SEU	2.7V	24	46	5	1	room	Ni	20.4	0	20.4	318	1.01E+06	9.44E+05	7	0	0	3	2	12	512	521	10	655360	1.94E-11
HIF	vacuum	SEU	2.7V	13	39	5	2	room	Ar	10	0	10	317	1.01E+06	9.41E+05	0	0	1		2	3	512	521	10	655360	4.87E-12

- SEU Cells correspond to 1 a word error detected at each read out of the two consecutive reads.
- Buffer write error corresponds to the entire buffer write (256 words) in error.
- Block corresponds to 1 block in error
- Fill error: 1 or more buffer write fill operation exceeds the allocated time of 10ms.
- Erase error: 1 or more block erase operation exceeds the allocated time of 4s.



Weibull Parameters:

W	25
xo	5
s	0.9
Sat	2.00E-11

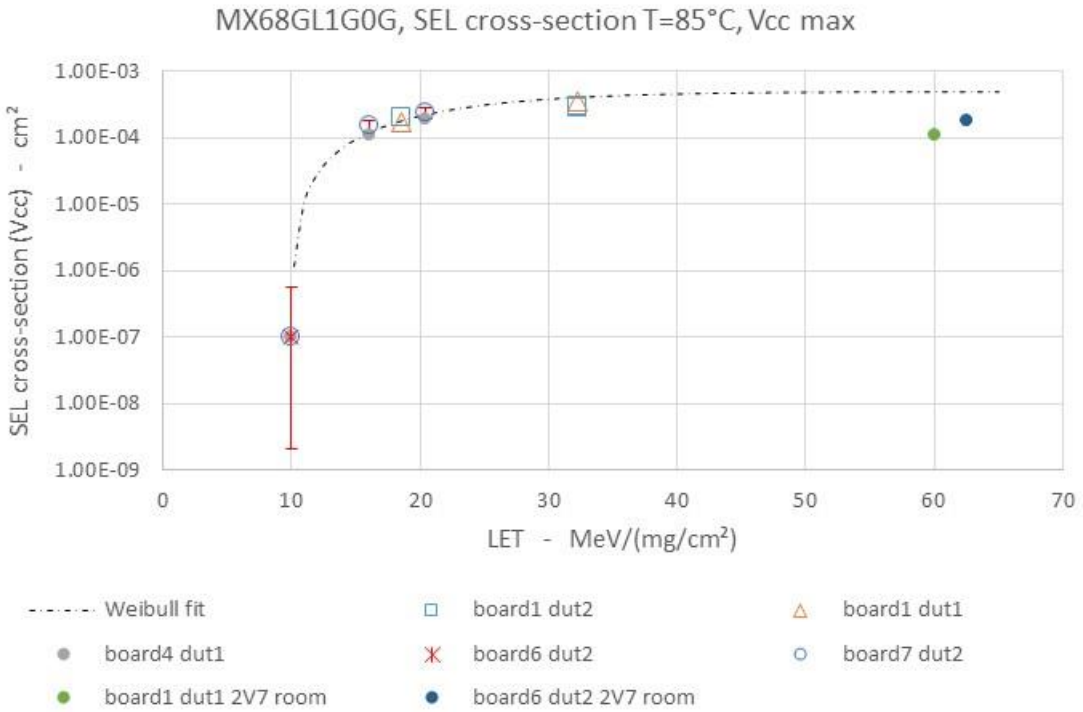
Figure 10: SEU dynamic cross-section for "Erase/Write" sequence.

10.2 SEL tests

Specific runs were carried out at high temperature and Vddmax. During these runs devices are in read mode. Some SEL occurred during dynamic tests at Vddmin and ambient temperature under Xenon (X=3 and X=2). Current spikes are smaller than the ones recorded for specific SEL runs with amplitude below or closed to 0.2 A compared to 0.3A.

Table 10: SEL results for MX68GL1G0G.

Facility	dut_medium	run_number	Facility_run_number	test_mode	board_id	DUT_part_id	power_config	temperature	bias_config	Ion	LET	Tilt	Eff. LET	run_duration	entered_fluence	Eff. Fluence	LET Threshold mA	sel Vcc	sel Vccq	X-section sel Vcc	error bar up	error bar down	delta up	delta down
RADEF	vacuum	36	122	SEU	1	1	**2.7V**	**room**	x=3	Xe	60	0	60.0	995	1.00E+06	6.24E+05	100	**67**	0	1.07E-04	1.4E-04	8.1E-05	3.1E-05	2.6E-05
RADEF	vacuum	48	130	SEL	1	1	**2.7V**	85	x=6	Kr	32.2	0	32.2	538	4.80E+05	3.68E+05	100	106	0	2.88E-04	3.6E-04	2.3E-04	6.7E-05	6.0E-05
RADEF	vacuum	51	133	SEL	1	1	3.6V	85	x=6	Kr	32.2	0	32.2	491	3.98E+05	3.08E+05	100	110	0	3.57E-04	4.4E-04	2.8E-04	8.2E-05	7.3E-05
RADEF	vacuum	52	134	SEL	1	1	3.6V	85	x=6	Fe	18.5	0	18.5	455	8.58E+05	6.34E+05	100	110	0	1.74E-04	2.1E-04	1.4E-04	4.0E-05	3.5E-05
RADEF	vacuum	49	131	SEL	1	2	**2.7V**	85	x=6	Kr	32.2	0	32.2	482	4.67E+05	3.61E+05	100	104	0	2.88E-04	3.6E-04	2.3E-04	6.7E-05	6.0E-05
RADEF	vacuum	50	132	SEL	1	2	3.6V	85	x=6	Kr	32.2	0	32.2	414	4.91E+05	3.60E+05	100	110	0	3.05E-04	3.8E-04	2.4E-04	7.0E-05	6.2E-05
RADEF	vacuum	53	135	SEL	1	2	3.6V	85	x=6	Fe	18.5	0	18.5	355	7.95E+05	5.47E+05	100	110	0	2.01E-04	2.5E-04	1.6E-04	4.6E-05	4.1E-05
HIF	vacuum	36	53	SEL	4	1	3.6V	85	x=6	Ar	10	0	10.0	763	1.00E+07	9.99E+06	100	1	0	1.00E-07	5.6E-07	2.0E-09	4.6E-07	9.8E-08
HIF	vacuum	37	54	SEL	4	1	3.6V	85	x=6	Ni	20.4	0	20.4	275	4.03E+06	1.04E+06	100	204	0	1.96E-04	2.3E-04	1.6E-04	3.5E-05	3.3E-05
HIF	vacuum	38	55	SEL	4	1	3.6V	85	x=6	Cr	16	0	16.0	221	2.27E+06	1.05E+06	100	118	0	1.13E-04	1.4E-04	9.0E-05	2.5E-05	2.2E-05
HIF	vacuum	43	58	SEL	6	2	3.6V	85	x=6	Ar	10	0	10.0	686	1.00E+07	9.98E+06	100	1	0	1.00E-07	5.6E-07	2.0E-09	4.6E-07	9.8E-08
HIF	vacuum	48	61	SEU	6	2	**2.7V**	**room**	x=3	Xe	62.5	0	62.5	528	1.00E+06	4.84E+05	100	**89**	0	1.84E-04	2.3E-04	1.4E-04	4.6E-05	4.1E-05
HIF	vacuum	51	63	SEU	6	2	**2.7V**	**room**	x=2	Xe	62.5	0	62.5	726	1.00E+06	8.89E+05	200	**4**	0	Vcc LET Threshold increased to 300mA after the 4 SELs				
HIF	vacuum	62	66	SEL	7	2	3.6V	85	x=6	Cr	16	0	16.0	198	2.12E+06	8.10E+05	100	122	0	1.51E-04	1.8E-04	1.2E-04	3.3E-05	3.0E-05
HIF	vacuum	63	67	SEL	7	2	3.6V	85	x=6	Ar	10	0	10.0	666	1.00E+07	9.98E+06	100	1	0	1.00E-07	5.6E-07	2.0E-09	4.6E-07	9.8E-08
HIF	vacuum	64	68	SEL	7	2	3.6V	85	x=6	Ni	20.4	0	20.4	174	1.94E+06	5.36E+05	100	125	0	2.33E-04	2.8E-04	1.9E-04	5.0E-05	4.5E-05



Weibull parameters:

W	15
xo	10
s	1.4
Sat	5.00E-04

Figure 11 – SEL cross-section / device

The chronogram for SEL run number 037 / HIF is given in Figure 12. SEL occurred on Vcc line (Icc current) with no abnormal behaviour on Vccq line. Temperature at die surface was measured with an IR thermometer at 85°C with a monitoring temperature set to 73°C for the thermocouple close to DUT case.

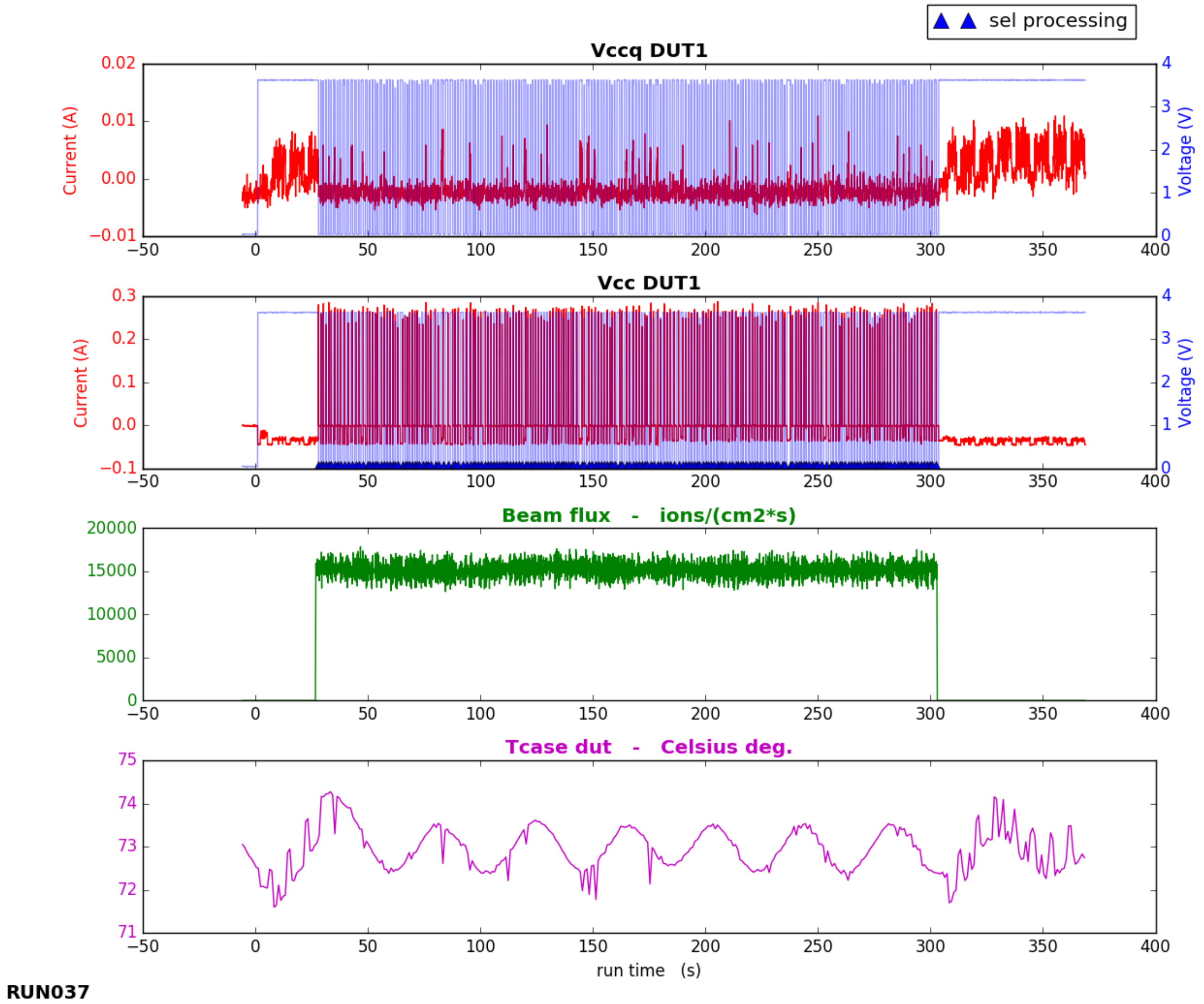


Figure 12: Campaign 1 run 37 / HIF chronograms for Vccq and Vcc lines along with temperature and flux.

11 Glossary

DUT: Device under test.

Fluence (of particle radiation incident on a surface): The total amount of particle radiant energy incident on a surface in a given period of time, divided by the area of the surface.
In this document, Fluence is expressed in ions per cm².

Flux: The time rate of flow of particle radiant energy incident on a surface, divided by the area of that surface.
In this document, Flux is expressed in ions per cm².s.

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic particle strike.
Single-event effects include single-event upset (SEU), multiple-bit upset (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latch-up (SEL).

Single Event Gate Rupture (SEGR) **/ Single Event Dielectric Rupture (**SEDR**):** Destructive rupture of the gate oxide layer or dielectric layer by a single ion strike. This leads to leakage currents under bias and can be observed as stuck bits in digitals devices

Single-Event Upset (SEU)**:** A soft error caused by the transient signal induced by a single energetic particle strike.

Single-Event Transient (SET): A transient signal induced by a single energetic particle strike.

Single-Event Latch-up (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.
SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.
An example of SEL in a CMOS device is when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground.

Single-Event Functional Interrupt (SEFI): A soft error that causes the component to reset, lock-up, or otherwise malfunction in a detectable way, but does not require power cycling of the device (off and back on) to restore operability, unlike single-event latch-up (SEL), or result in permanent damage as in single-event burnout (SEB).
A SEFI is often associated with an upset in a control bit or register.

Error cross-section: the number of errors per unit fluence. For device error cross-section, the dimensions are cm² per device. For bit error cross-section, the dimensions are cm² per bit.

Tilt angle: tilt angle, rotation axis of the DUT board is perpendicular to the beam axis; roll angle, board rotation axis is parallel to the beam axis

Weibull fit: $F(x) = A (1- \exp\{-[(x-x_0)/W]^s\})$ with:

> x = effective LET in MeV/(mg/cm^2);
> F(x) = SEE cross-section in cm^2;
> A = limiting or plateau cross-section;
> x_0 = onset parameter, such that F(x) = 0 for $x < x_0$;
> W = width parameter;
> s = a dimensionless exponent.

Error bars: error bars are computed using a confidence level of 95% and a beam flux uncertainty of +/-10% as recommended by Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100.