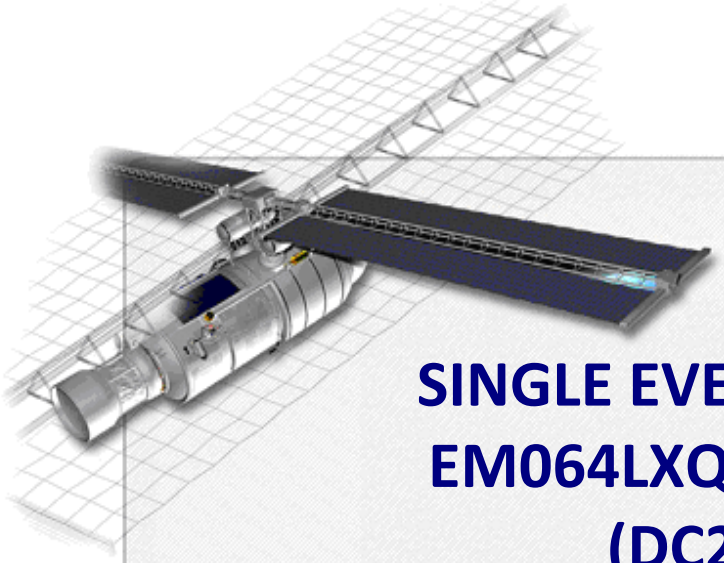
HEAVY ION
TEST REPORT



SINGLE EVENT EFFECTS
EM064LXQADG13IS1T
(DC2238)
Expanded Serial Peripheral Interface (xSPI)
Industrial STT-MRAM Persistent Memory
From
Everspin Technologies

TRAD/TI/EM064LXQADG13/2238/ASI/AAY/2306		Labège, December 19th, 2023
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To:	**A. BERNE**	Project/Program:
Company:	**THALES ALENIA SPACE TOULOUSE**	Ref:

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Abbreviations and acronyms

DUT	Device Under Test
LET	Linear Energy Transfer
MBU	Multiple Bit Upset
RADEF	RADiation Effects Facility
SEE	Single Event Effect
SEFI	Single Event Functional Interrupt
SEL	Single Event Latch-up
SEU	Single Event Upset
VASCO	VAcuum System for Californium Operation
TAS	THALES ALENIA SPACE TOULOUSE

Abstract

The main objective of this test was to evaluate the sensitivity of the EM064LXQADG13IS1T, an Expanded Serial Peripheral Interface (xSPI) Industrial STT-MRAM Persistent Memory versus SEL, SEU, MBU, Burst and SEFI.
The irradiation was performed at RADEF with a maximum LET of 60.29 MeV.cm²/mg.
The main conclusions are the following.

The SEL test was performed under SEL test conditions (see Table 7).

In SEL test configuration
SEL were observed with a minimum LET of 28.96 MeV.cm²/mg, Krypton heavy ion.
No SEL was observed with LET of 15.45 MeV.cm²/mg, Iron heavy ion.

The SEU, MBU, Burst and SEFI test were performed under SEE test conditions (see Table 8).

In SEU_READ test configuration
SEU were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

No MBU was observed with a maximum LET of 60.29 MeV.cm²/mg, Xenon heavy ion.

Burst were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

SEFI were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

1. Introduction

This report includes the test results of the heavy ion SEE test sequence carried out on the EM064LXQADG13IS1T, an Expanded Serial Peripheral Interface (xSPI) Industrial STT-MRAM Persistent Memory from Everspin Technologies, susceptible to show SEL, SEU, MBU and SEFI induced by heavy ions.

This test was performed for TAS at RADEF. Irradiations were performed from October 26th, 2023 to October 27th, 2023. During this test campaign, 3 samples were irradiated.

2. Documents

2.1. Applicable documents

[AD1] Technical proposal: TRAD/P/ASI/E-OSIP/DS/011021-Avenant/Rev0 dated 13/01/23
[AD2] Irradiation test plan: TRAD/ITP/TRA/TI/EM064LXQADG13/ASI/310723 Rev1 dated 31/07/2023

2.2. Reference documents

[RD1] ESCC Basic specification No. 25100 Issue 2 of October 2014
[RD2] Datasheet: EMxxLX v2.9, by Everspin Technologies dated december 2022

3. Organization of activities

The devices were procured by TAS to TRAD. The samples were delidded by TRAD. The testing board and testing software were developed by TRAD. Before the campaign the samples were checked-out and the test bench was validated with californium test at TRAD. The test campaign was performed by TRAD. The next table summarizes the responsible entity for each activity involved in this project:

1	Procurement of Test Samples	TAS
2	Preparation of Test Samples (delidding)	TRAD
3	Preparation of Test Hardware and Test Program	TRAD
4	Samples Check out	TRAD
5	Accelerator Test	TRAD
6	Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

The EMxxLX is the industry's first xSPI serial interface persistent memory based on Everspin's unique industrial STT MRAM technology. It is a high-performance, multiple I/O, SPI-compatible MRAM device featuring a high-speed, low pin count SPI compatible bus interface with a clock frequency of up to 200 MHz and a single 1.8V power supply. The EMxxLX delivers up to 400MBps reads and writes via eight I/O signals with a clock frequency of 200MHz.

4.2. Identification

Part designation	EM064LXQADG13IS1T
Manufacturer	Everspin Technologies
Part function	Expanded Serial Peripheral Interface (xSPI) Industrial STT-MRAM Persistent Memory

Table 2: Part identification

4.3. Procurement information

Package	8-Lead DFN
Date code	2238
Trace ID No.	F91J69S701
Number of tested parts	3 irradiated samples

Table 3: Part procurement information

4.4. Sample preparation

8 parts were delidded, no sample has been damaged during this operation.
A functional test was performed on delidded samples to check that devices were not degraded by the delidding operation.
Among the 8 delidded samples available for the test campaign, 3 were irradiated and 5 were not used.

4.5. Sample pictures

4.5.1. External view

The Figure 1 shows an external view of the parts. Left and right pictures are respectively the top and the bottom views of the package.

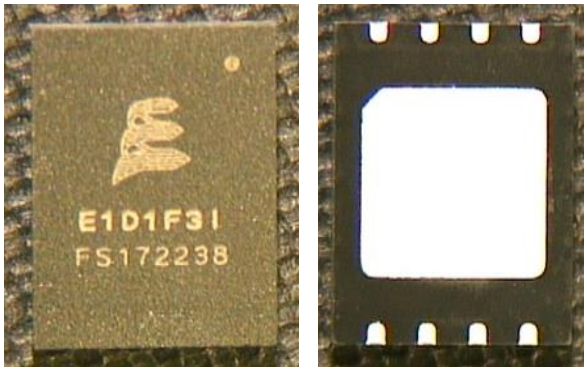


Figure 1: Pictures of the package

4.5.2. Internal view

Figure 2 gives an overview of the die. No internal markings were observed on the die.

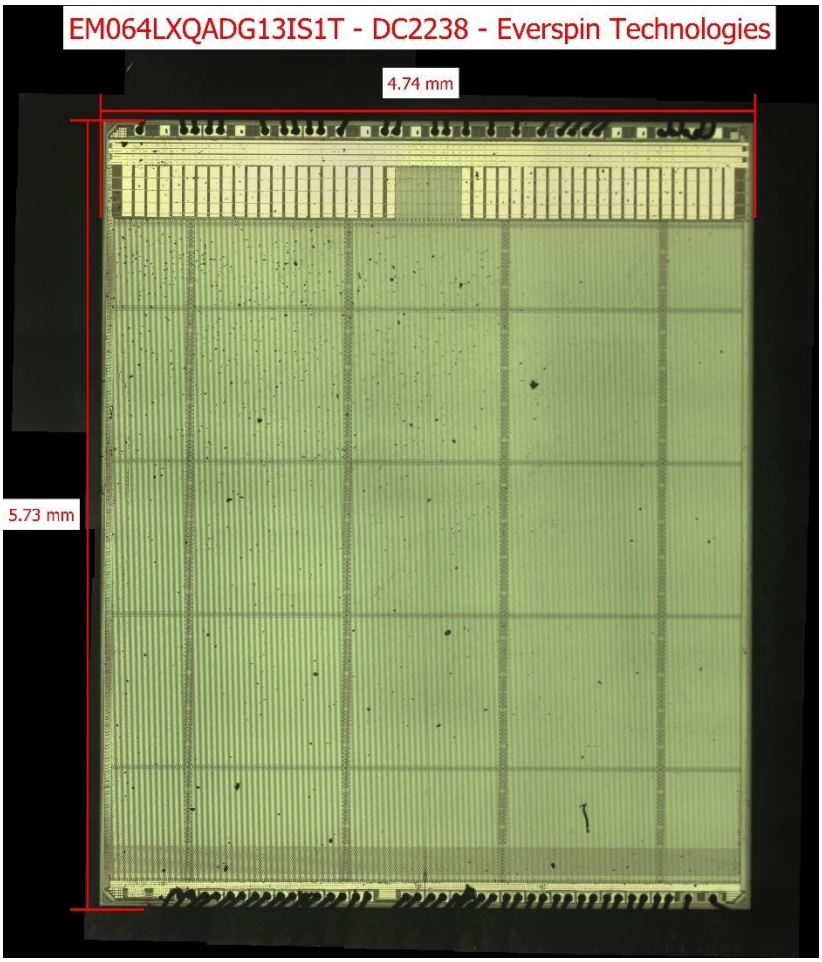


Figure 2: Picture of the internal overall view

5. Dosimetry and irradiation facility

5.1. RADEF heavy ion test facility

The cyclotron used is a versatile, sector-focused accelerator for producing beams from hydrogen to xenon.

Heavy ion irradiations are 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 5 minutes of pumping, and venting takes also only a few minutes. Irradiations can also be performed in air, therefore the LET and the range is calculated according the distance between the collimator and the component.
The components can be fixed on a 25x25cm^2 aluminium plate which will be mounted on the linear movement apparatus inside the chamber. The DUT can be moved in the X and Y directions and also tilting is possible.

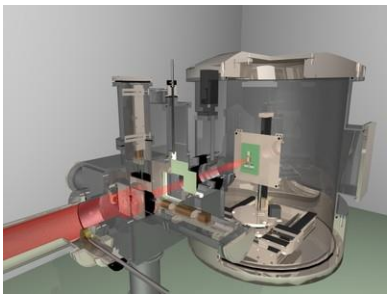


Figure 3: RADEF facility

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.

5.2. Dosimetry

To control and monitor the beam parameters, scintillation plastics connected to photomultiplier tubes are used as detectors. Four of such kinds of detectors are very close and placed around the edges of the beam. Detector can be moved to the front of the DUT and evaluate flux and homogeneity.
The spot size is 2 cm^2 and for special cases up to a diameter of 70 mm in vacuum. The Spot Homogeneity is ± 10 %

5.3. Beam characteristics

The beam flux is variable between a few particles s^{-1}cm^{-2} and 1.5E+4 s^{-1}cm^{-2} and is set depending on the device sensitivity. On special request, the users have the possibility to increase the flux up to 1E+6 s^{-1}cm^{-2}.
Characteristics of heavy ions available at RADEF during the test campaign are listed in Table 4 where heavy ions used for this test campaign are highlighted.
The tests on EM064LXQADG13IS1T are performed in air, therefore the LET and range are calculated according a 75µm of Kapton degrader, if there is one, and the distance between collimator and the component.

Ion	Energy (MeV)	Range (µm (Si))	LET (MeV.cm²/mg)
$^{126}Xe^{44+}$	2059	88	60.29
$^{83}Kr^{29+}$	1358	125	28.96
$^{57}Fe^{20+}$	941	150	15.45
$^{40}Ar^{14+}$	657	202	8.05
$^{20}Ne^{7+}$	328	295	2.59
$^{17}O^{6+}$	284	415	1.57

Table 4: RADEF heavy ion list

6. Test procedure and setup

6.1. Test method

With respect to reference documents (see 2 Documents), runs were performed:

- Up to a fluence of 1E+7 cm^{-2} with only SEL monitoring.
- Up to a fluence of 1E+6 cm^{-2} for the SEU, Burst and SEFI detection.

6.2. Test principle

6.2.1. SEL test principle

A SEL is a permanent event that results from the activation of a parasitic thyristor structure creating low impedance conduction path in the device. The consequent high current can potentially damage the device, possibly even leading to its destruction due to overcurrent. A power cycle is required to correct this situation.

GeV is a specific equipment developed by TRAD to protect the DUT and to perform SEL characterization. The power supply is applied to the DUT through GeV which protects the DUT against over consumption. Indeed, GeV continuously monitors and records the current. A programmable threshold current is set above the nominal operating value of the supply current. During irradiations, if the current consumption exceeds the threshold during a defined “hold time”, a SEL is counted and the DUT is switched off during a defined “off time”. Once the event is defused, the power supply is switched ON again with the nominal current consumption expected.

Figure 4 shows a common SEL characteristic, with and without the GeV system protection.

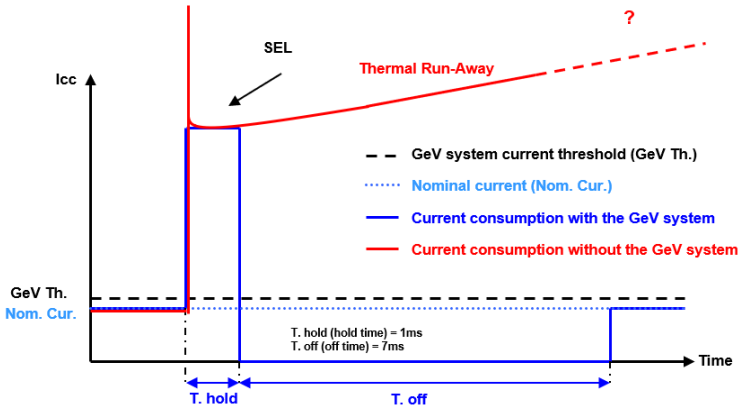


Figure 4: Common SEL characteristic

The SEL test was performed under SEL test conditions (see Table 7) in Read mode without recording errors.
TRAD uses a dedicated system to heat and regulate the DUT temperature. The temperature is visualized and regulated from outside of the vacuum chamber during the irradiation.

6.2.2. SEE Test Principle

SEU, MBU, Burst and SEFI tests were performed under SEE test conditions (see Table 7).

The SEU/Burst/SEFI detection is ensured by the FPGA, driven by the remote computer. The memory is continuously read back and data are compared to the expected data set contained in the FPGA. There are three types of events recorded during this test:

- **SEU**: Any mismatch of data reading with expected data is at first considered to be a SEU and the data is sent to the computer. A counter is incremented accordingly. This process is repeated from address 0 to the last address of the memory. An SEU is an isolated upset in the data array of a memory. At normal flux under beam (until 5000 part./s.cm²), the number of SEUs induced by heavy ions in the memory should not exceed a few events (less than 10 events).
- **MBU**: An MBU is detected when several bits change from state 0 to 1 or from state 1 to 0 in a single word.
- **Burst:** If the SEU/MBU error counter reach more than 10 events and less than 500 events of SEU before the last address is reached, then a Burst is considered.
- **SEFI:** If the error counter reach more than 500 events of SEU before the last address is reached, then a SEFI is considered and a power cycle is applied to the memory.

A checkerboard pattern ‘’AA/55’’ was written in the memory before the start of irradiation. Two test modes were performed during this test campaign as listed in Table 5.

Test Mode	Test Sequence
SEL	Read loop, without feedback of erroneous data. SEU/SEFI detection is bypassed.
Read Only	Read loop with SEU/MBU/SEFI detection during irradiation.

Table 5: Test Modes

The following diagrams represent the different test modes available for the test campaign.
During the SEL test, the memory is read continuously as represented in Figure 5, but its content is ignored. The test bench only checks the presence of latch-up on the power supplies. This functionality is ensured by GeV.

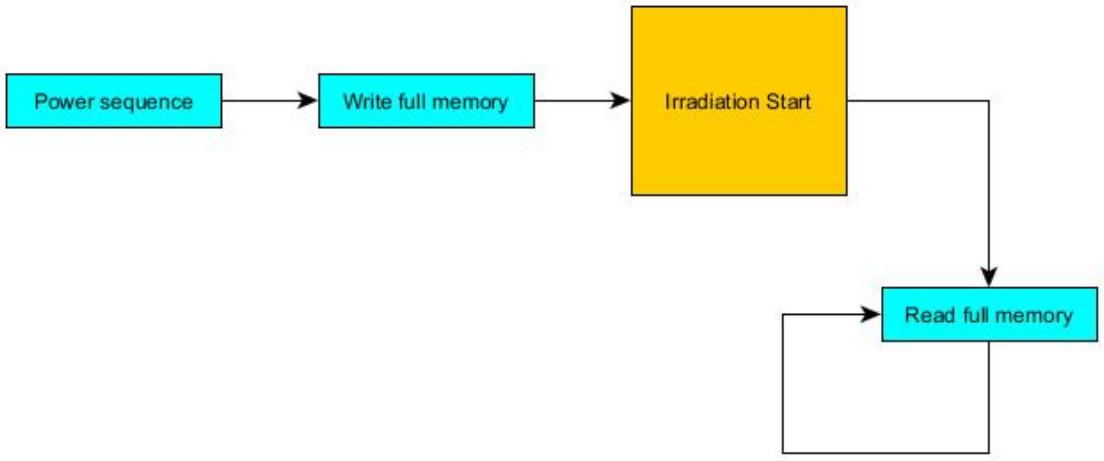


Figure 5 : SEL Test Flow Diagram.

In Read only, read operations occurs on the DUT, during irradiation. If an event occurs, the test bench tries to correct the data, implying write operation. Check Memory function is described in Figure 7.

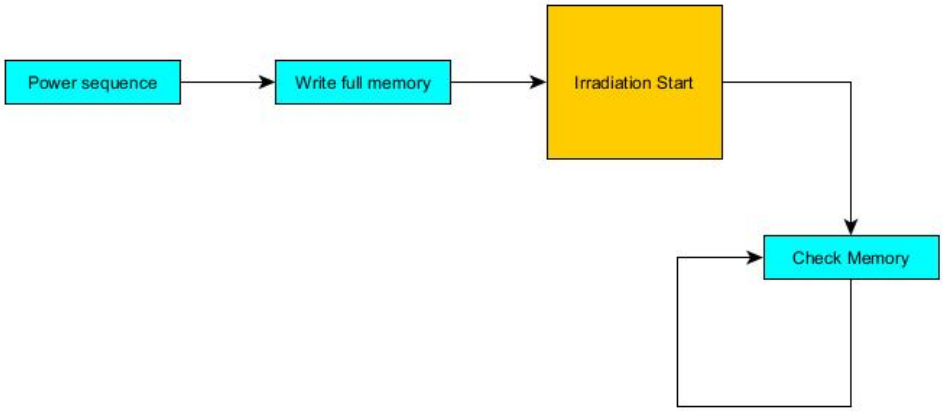


Figure 6 : Read only mode Test Flow Diagram.

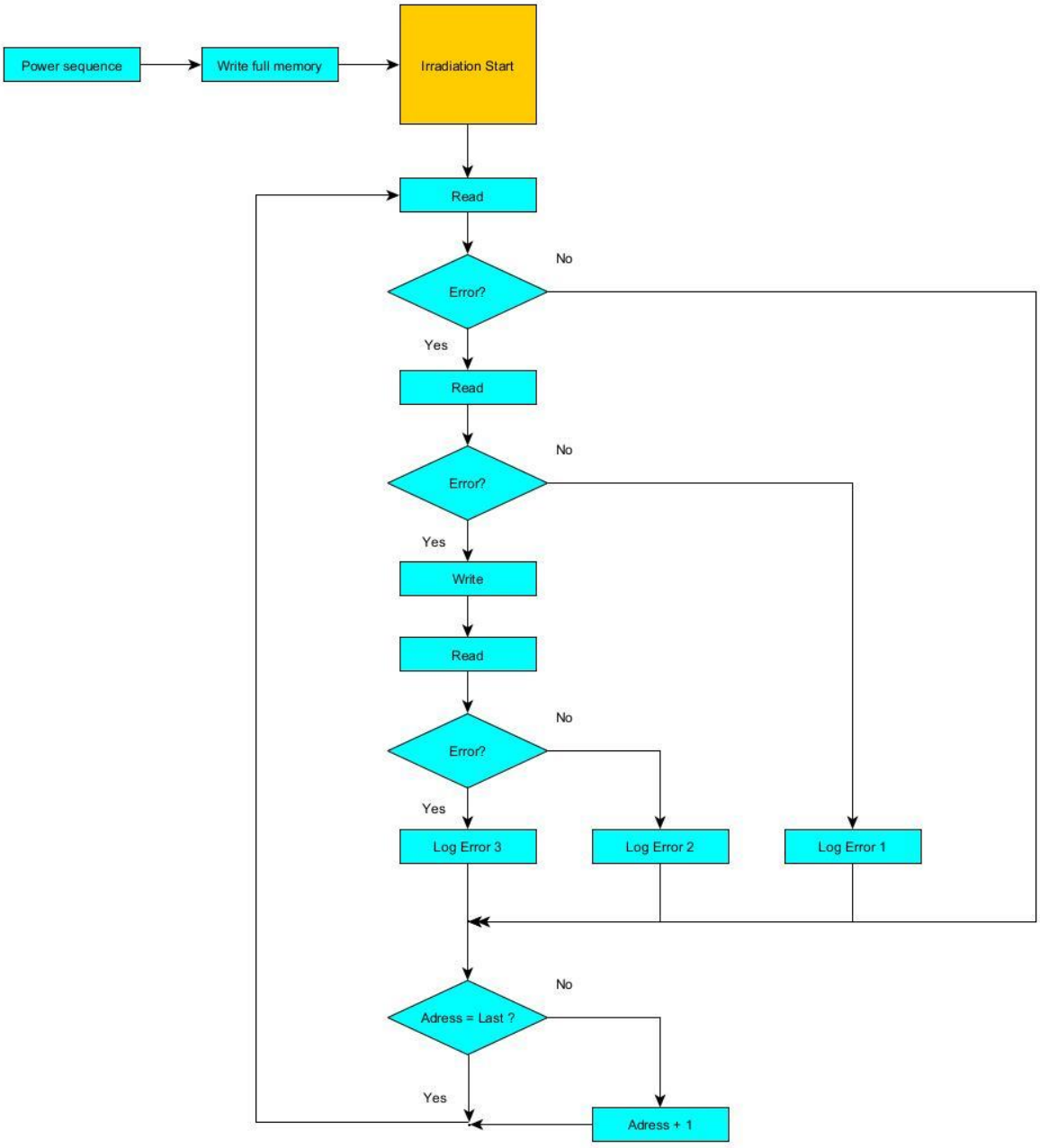


Figure 7 : Check Memory Flow Diagram.

6.3. Test bench description

6.3.1. Test bench overview

Figure 8 provides a global view of the test bench. It is composed by:

- A computer to control the test equipment and to record the SEE.
- An FPGA based board that computes the commands received by the computer.
- A daughter-board to bias and operate the DUT (schematic is shown in Figure 11).
- A power supply for the DUT and auxiliary components.
- A GeV System to protect the DUT, detect and record SEL.

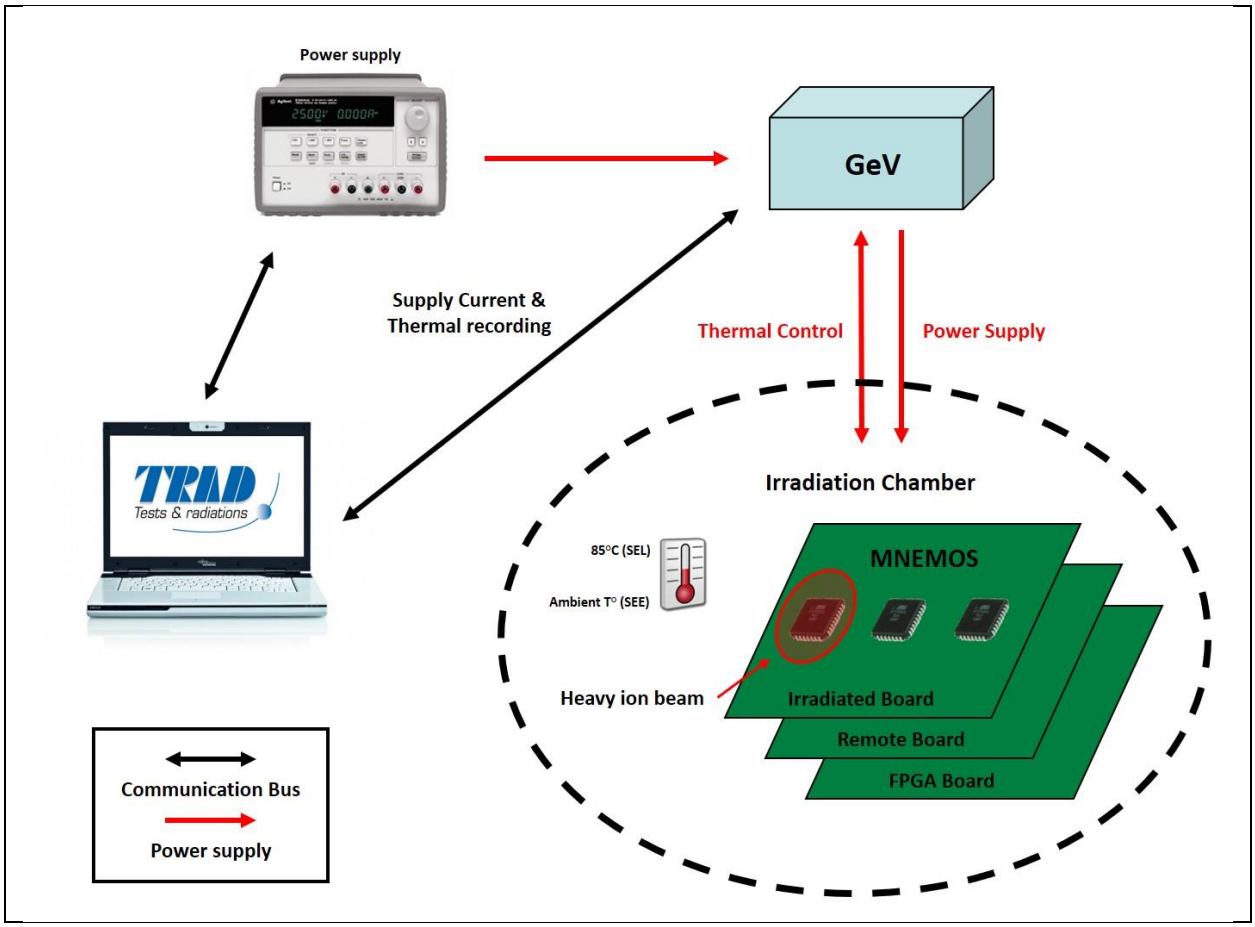


Figure 8: Test bench description

6.3.2. Validation of test hardware and program

Before performing the heavy ion test, the whole system (delidded sample, test board and software) was assembled and tested by TRAD in VASCO.



Figure 9: VASCO picture

The VASCO is a vacuum chamber developed by TRAD in order to test the complete setup in vacuum with all cables length and electrical feedthroughs as used on the irradiation site.
The VASCO main characteristics are:
Chamber dimensions: 400x400x400mm, pressure 5.10^{-2} mbar.
Electrical feedthroughs available:
16 isolated BNC, 16 isolated SMA, 16 isolated SMB, 4 DB25, 3 HE10-40.
Other possibility on request

Validation runs are performed using Californium-252 source.
Californium-252 is a fissionable, transuranic radionuclide which decays by alpha particle emission with a half-life of 2.72 years.
The source emits alpha particles, fission fragments and fast neutrons. The fission fragments are used for SEE testing and these have a mean LET of 43 MeV.cm²/mg (Si) with 95% of the particles having LETs between 41 and 45 MeV.cm²/mg (Si). The mean range of the fission particles in silicon is 14.2µm.

6.3.3. Heating system

TRAD has developed a specific heating system to heat and regulate the temperature of the DUT. Figure 10 shows a thermal image taken during the heating calibration of the DUT, the temperature of the die was set to 85°C as shown on the picture.

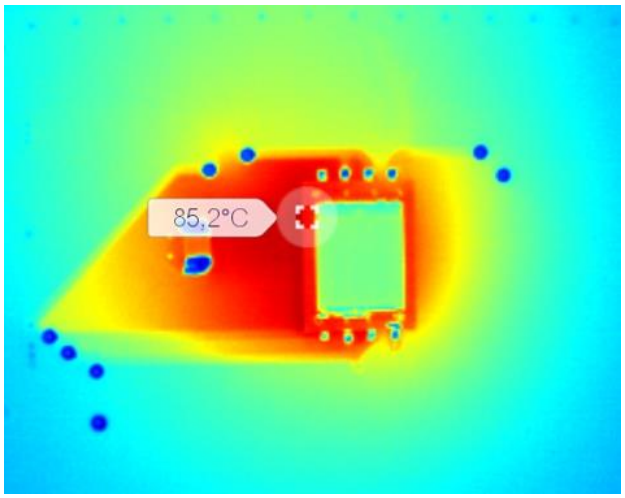


Figure 10: Thermal image of EM064LXQADG13IS1T heated to 85°C

6.3.4. Test equipment identification

TEST BOARD	TRAD_TA1_I_EM064LXQADG13_DFN-8_AAY_2307
EQUIPMENT	GeV1, MNEMOS2, SM-89
TEST PROGRAM	EM064LXQADG13_TI_XXX1_AAY_Bi_V10.llb EM064LXQADG13_TI_XXX1_AAY_Bi_V10.xise

Table 6: Equipment identification

6.3.5. Test board description

The TRAD test board schematic referenced "TRAD/TA1/I/EM064LXQADG13/DFN-8/AAY/2307" is illustrated in Figure 11.

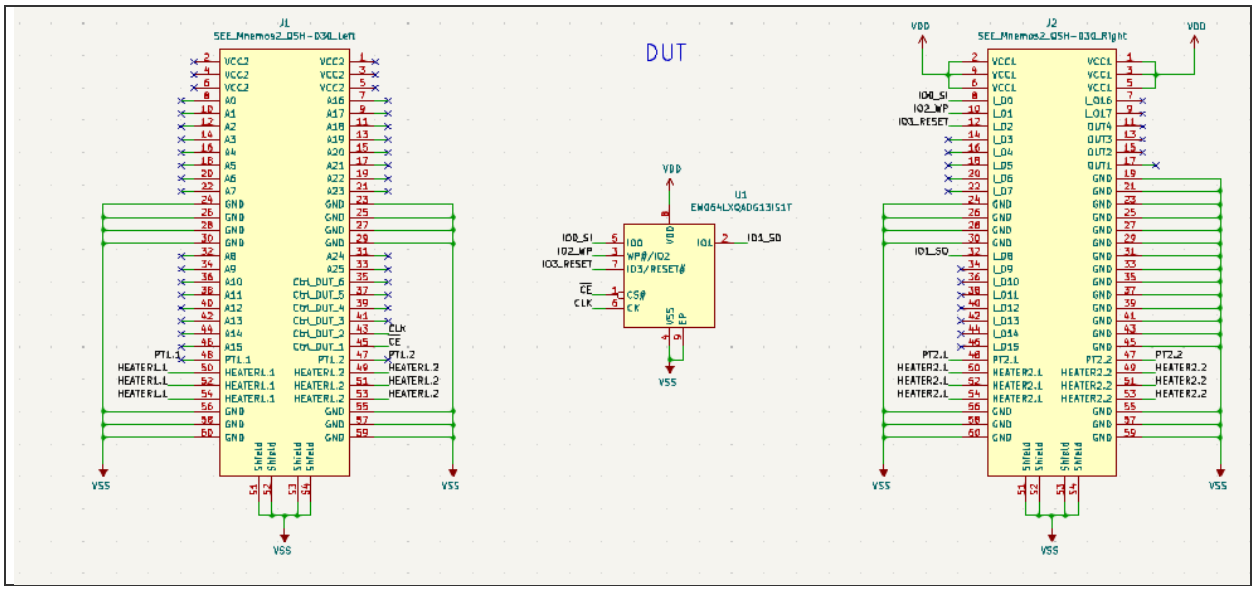


Figure 11: Test board schematic

6.3.6. Test conditions and event detection thresholds

SEL test

	VDD
Voltage	2 V
$I_{nominal}$	7 mA
$I_{threshold}$	20 mA
T_{hold}	1 ms
$T_{cut\ off}$	100 ms
Temperature	85°C

Table 7: SEL test conditions and detection thresholds

SEE test

	VDD
Voltage	1.8 V
$I_{nominal}$	7 mA
$I_{threshold}$	20 mA
T_{hold}	1 ms
$T_{cut\ off}$	100 ms
Temperature	Ambient

Table 8: SEE test conditions and detection thresholds

7. Test story

No atypical behaviour during the test to report.

8. Non conformance

Test sequence, test and measurement conditions were nominal.

9. Results

In this chapter are presented the SEE test results.
First, test runs summary tables provides details of the runs performed during this campaign, their parameters and results.
Then, for each event type are given their corresponding LET threshold, cross section and worst cases when it is applicable.
On the cross-section curves are plotted their corresponding error bars.
The following formulas is used to calculate these error bars. It can be found in ESCC Basic specification No. 25100.

$$\delta\sigma \times F = \sqrt{(\delta Nevents)^2 + (\mathrm{Nevents} \times \frac{\delta \mathrm{F}}{F})^2}$$

where :

- F is the fluence
- $\sigma = N_{events} / F$
- $\delta F/F$ is the uncertainty on the measured fluence (±10%).
- δN_{events} is the variance on the measured number of events.

Assuming that SEE events are random, the probability of events follows a Poisson distribution. The variance on the number of events is calculated from the chi-square distribution for a given confidence level. In this test report, we used a confidence level of 95%.

9.1. Test run summary

Run	Test configuration	Part	T° (°C)	Ion	Energy (MeV)	Eff. LET (MeV.cm²/mg)	Eff. Range (µm Si)	Flux (φ) (cm⁻².s⁻¹)	Time (s)	Run Fluence (cm⁻²)	Run Dose (krad)	Cumulated Dose (krad)	SEL	SEL Cross Section (cm²)	SEU	SEU Cross Section (cm²)	MBU	MBU Cross Section (cm²)	Burst	Burst Cross Section (cm²)	SEFI	SEFI Cross Section (cm²)
1	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	1.99E+03	155	3.09E+05	0.30	0.24	-	-	0	<3.24E-06	-	-	-	-	0	<3.24E-06
2	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	1.00E+00	1	1.00E+00	0.00	0.24	-	-	0	<1.00E+00	-	-	-	-	0	<1.00E+00
3	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	1.69E+03	593	1.00E+06	0.96	1.02	-	-	0	<1.00E-06	-	-	-	-	0	<1.00E-06
4	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	1.00E+00	1	1.00E+00	0.00	1.02	-	-	0	<1.00E+00	-	-	-	-	0	<1.00E+00
5	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	5.40E+02	298	1.61E+05	0.16	1.14	-	-	0	<6.21E-06	-	-	-	-	0	<6.21E-06
6	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	5.11E+02	272	1.39E+05	0.13	1.25	-	-	0	<7.19E-06	-	-	-	-	0	<7.19E-06
7	SEU_READ	1	AMB	126 Xe 44+	2059	60.3	157.0	1.67E+03	600	1.00E+06	0.96	2.02	0	<1.00E-06	2	2.00E-06	0	<1.00E-06	1	1.00E-06	25	2.50E-05
8	SEL	1	85	126 Xe 44+	2059	60.3	157.0	1.42E+04	705	1.00E+07	9.65	9.78	19	1.90E-06	-	-	0	<1.00E-07	-	-	-	-
9	SEU_READ	2	AMB	126 Xe 44+	2059	60.3	157.0	1.95E+03	513	1.00E+06	0.96	0.78	0	<1.00E-06	1	1.00E-06	0	<1.00E-06	0	<1.00E-06	64	6.40E-05
10	SEL	2	85	126 Xe 44+	2059	60.3	157.0	1.53E+04	654	1.00E+07	9.65	8.54	22	2.20E-06	-	-	0	<1.00E-07	-	-	-	-
11	SEU_READ	3	AMB	126 Xe 44+	2059	60.3	157.0	2.11E+03	474	1.00E+06	0.96	0.78	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	58	5.80E-05
12	SEL	3	85	126 Xe 44+	2059	60.3	157.0	1.69E+04	593	1.00E+07	9.65	8.54	19	1.90E-06	-	-	0	<1.00E-07	-	-	-	-
13	SEL	1	85	126 Xe 44+	2059	60.3	157.0	1.56E+04	17	2.66E+05	0.26	9.99	-	-	-	-	-	-	-	-	-	-
14	SEL	1	85	126 Xe 44+	2059	60.3	157.0	1.63E+04	31	5.05E+05	0.49	10.38	-	-	-	-	0	<1.98E-06	-	-	-	-
15*	SEL	1	85	126 Xe 44+	2059	60.3	157.0	1.60E+04	626	1.00E+07	9.65	18.14	-	-	-	-	0	<1.00E-07	-	-	-	-
16	SEL	2	85	83 Kr 29+	1358	29.0	185.0	1.49E+04	670	1.00E+07	4.63	12.46	3	3.00E-07	-	-	0	<1.00E-07	-	-	-	-
17	SEL	3	85	83 Kr 29+	1358	29.0	185.0	1.53E+04	653	1.00E+07	4.63	12.46	2	2.00E-07	-	-	0	<1.00E-07	-	-	-	-
18	SEU_READ	2	AMB	83 Kr 29+	1358	29.0	185.0	1.38E+04	723	1.00E+07	4.63	16.38	1	1.00E-07	24	2.40E-06	0	<1.00E-07	9	9.00E-07	16	1.60E-06
19	SEU_READ	3	AMB	83 Kr 29+	1358	29.0	185.0	1.36E+04	734	1.00E+07	4.63	16.38	0	<1.00E-07	16	1.60E-06	0	<1.00E-07	4	4.00E-07	32	3.20E-06
20	SEU_READ	3	AMB	57 Fe 20+	941	15.5	214.0	1.55E+04	647	1.00E+07	2.47	18.50	1	1.00E-07	5	5.00E-07	0	<1.00E-07	4	4.00E-07	12	1.20E-06
21	SEL	3	85	57 Fe 20+	941	15.5	214.0	1.59E+04	630	1.00E+07	2.47	20.63	0	<1.00E-07	-	-	0	<1.00E-07	-	-	-	-
22	SEU_READ	3	AMB	57 Fe 20+	941	15.5	214.0	1.62E+04	617	1.00E+07	2.47	22.76	0	<1.00E-07	1	1.00E-07	0	<1.00E-07	0	<1.00E-07	10	1.00E-06
23	SEL	3	85	57 Fe 20+	941	15.5	214.0	1.72E+04	582	1.00E+07	2.47	24.89	0	<1.00E-07	-	-	0	<1.00E-07	-	-	-	-
24	SEU_READ	2	AMB	57 Fe 20+	941	15.5	214.0	1.78E+04	562	1.00E+07	2.47	18.50	0	<1.00E-07	10	1.00E-06	0	<1.00E-07	2	2.00E-07	5	5.00E-07
25	SEL	2	85	57 Fe 20+	941	15.5	214.0	1.76E+04	569	1.00E+07	2.47	20.63	0	<1.00E-07	-	-	0	<1.00E-07	-	-	-	-
26	SEU_READ	2	AMB	40 Ar 14+	657	8.1	264.0	1.49E+04	672	1.00E+07	1.29	21.78	0	<1.00E-07	0	<1.00E-07	0	<1.00E-07	1	1.00E-07	2	2.00E-07
27	SEU_READ	3	AMB	40 Ar 14+	657	8.1	264.0	1.46E+04	686	1.00E+07	1.29	26.04	0	<1.00E-07	6	6.00E-07	0	<1.00E-07	1	1.00E-07	6	6.00E-07
28	SEU_READ	3	AMB	83 Kr 29+	1358	29.0	185.0	1.78E+04	563	1.00E+07	4.63	29.96	0	<1.00E-07	6	6.00E-07	0	<1.00E-07	1	1.00E-07	12	1.20E-06

Table 9: EM064LXQADG13IS1T test run table

*run 15 is a destructive test run (there is no protection on power supply).

Setting run not taken into account

SEE detailed results are described in the following sections.

9.2. Cumulated dose table

Part No.	Cumulated Dose (krad)
1	18.14
2	21.78
3	29.96

Table 10: Cumulated dose table

9.3. SEL test results

9.3.1. SEL LET threshold

The SEL test was performed under SEL test conditions (see Table 7).

In SEL test configuration

SEL were observed with a minimum LET of 28.96 MeV.cm²/mg, Krypton heavy ion.
No SEL was observed with LET of 15.45 MeV.cm²/mg, Iron heavy ion.

9.3.2. SEL cross sections

Hereafter are shown the SEL cross section values for each tested component.

In SEL test configuration

	EM064LXQADG13IS1T SEL Cross Section (cm²) in SEL test configuration								
LET Eff (MeV.cm²/mg)	Part No. 1			Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	7.56E-07	1.90E-06	1.07E-06	8.21E-07	2.20E-06	1.13E-06	7.56E-07	1.90E-06	1.07E-06
29.0	-	*Not tested*	-	2.38E-07	3.00E-07	5.77E-07	1.76E-07	2.00E-07	5.22E-07
15.5	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07	0.00E+00	<1.00E-07	3.69E-07

Table 11: EM064LXQADG13IS1T SEL cross section values in SEL test configuration

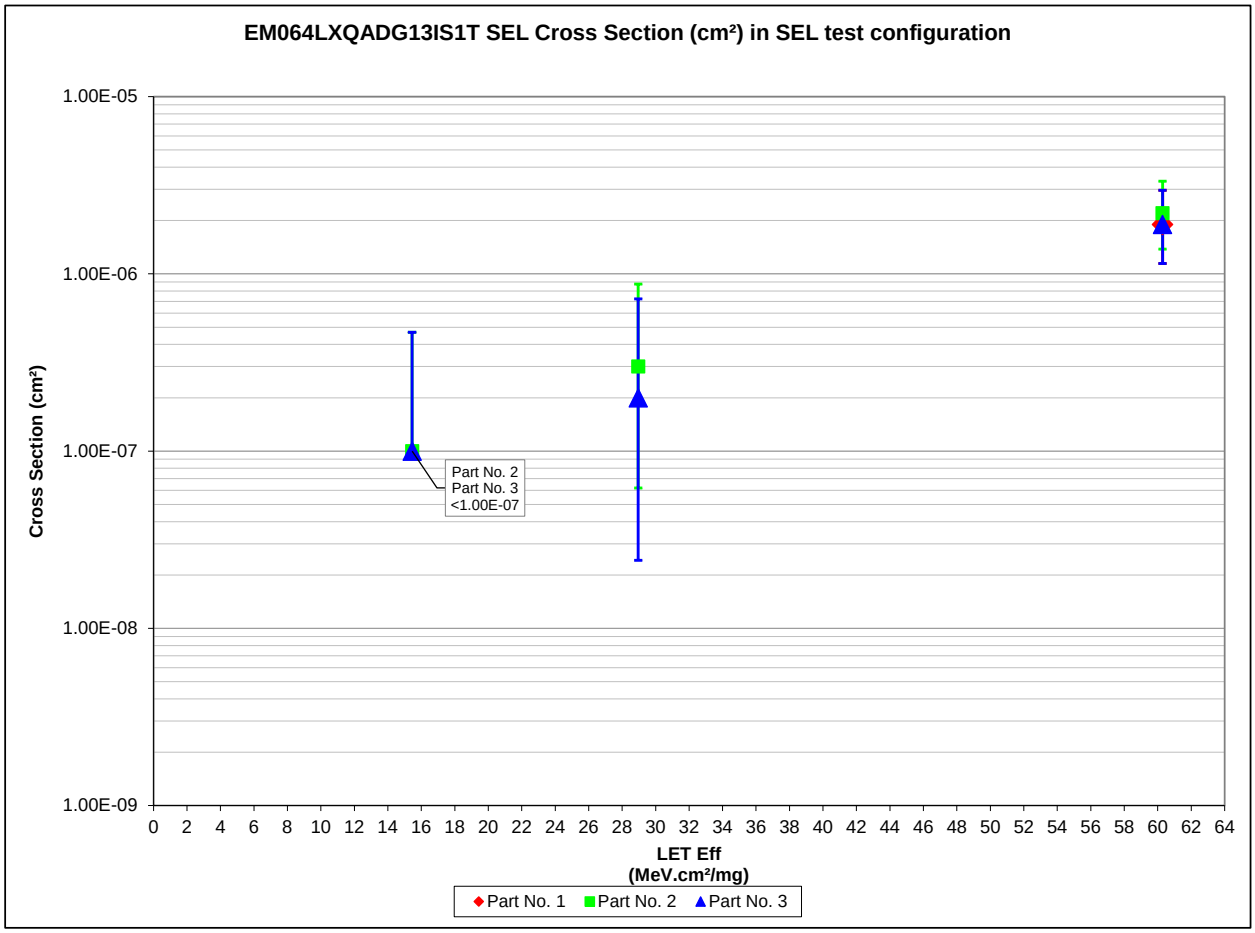


Figure 12: EM064LXQADG13IS1T SEL cross section curve in SEL test configuration

9.3.3. SEL worst case

This section presents the worst SEL observed during the test of the EM064LXQADG13IS1T.

In SEL test configuration

The worst amplitude SEL observed on VCC occurred during run No. 10 on part No. 2.

Run No.	10
Part No.	2
Test configuration	**SEL**
Type event	SEL
Ion LET (MeV.cm²/mg)	60.29
Relative amplitude	159 mA

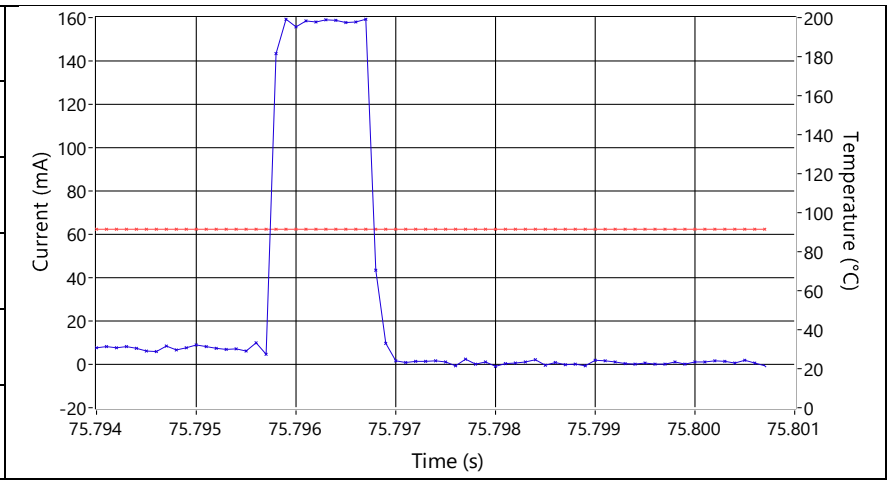


Figure 13: SEL worst case

9.3.4. Destructive test run

A destructive run was conducted as part of this test campaign, during which the protection system (GeV) was deactivated. The monitoring of current consumption revealed a significant increase, reaching 662 mA, as illustrated in Figure 14. Post-irradiation testing of the memory revealed no sign of damage.

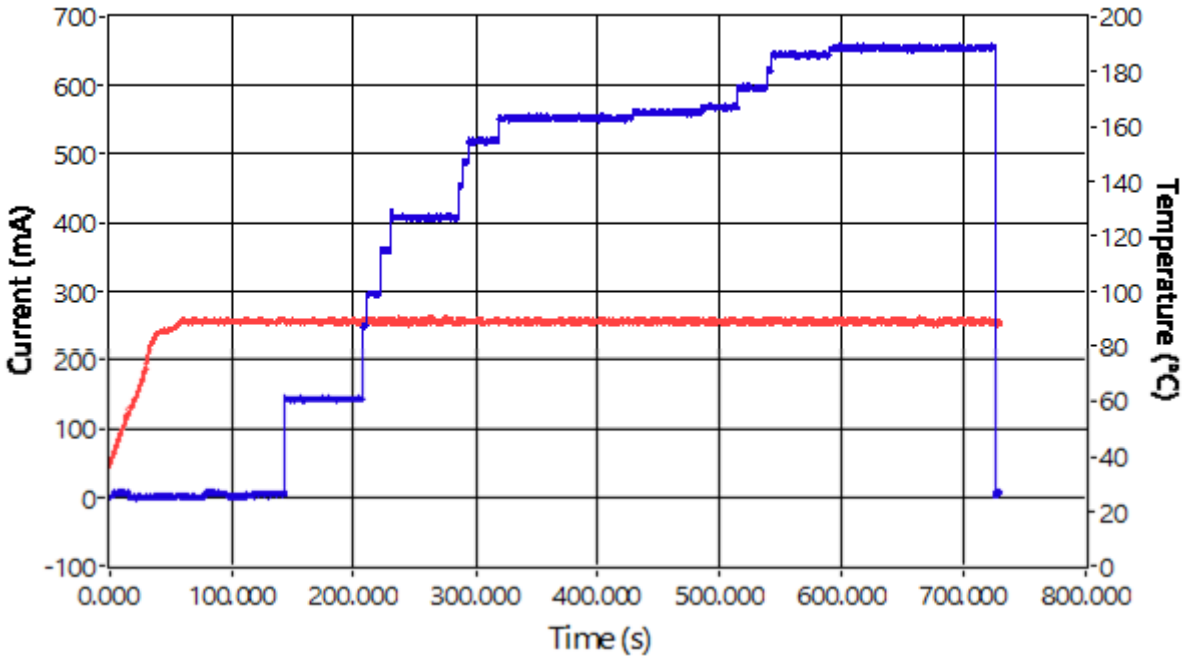


Figure 14: Current consumption monitoring during destructive test run

9.4. SEU test results

9.4.1. SEU LET threshold

The SEU test was performed under SEE test conditions (see Table 8).

In SEU_READ test configuration

SEU were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

9.4.2. SEU cross sections

Hereafter are shown the SEU cross section values for each tested component.

In SEU_READ test configuration

	EM064LXQADG13IS1T SEU Cross Section (cm²) in SEU_READ test configuration					
LET Eff (MeV.cm²/mg)	Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	9.75E-07	1.00E-06	4.57E-06	0.00E+00	<1.00E-06	3.69E-06
29.0	8.62E-07	2.40E-06	1.17E-06	-	*Not tested*	-
15.5	-	*Not tested*	-	9.75E-08	1.00E-07	4.57E-07
8.1	0.00E+00	<1.00E-07	3.69E-07	3.80E-07	6.00E-07	7.06E-07

Table 12: EM064LXQADG13IS1T SEU cross section values in SEU_READ test configuration

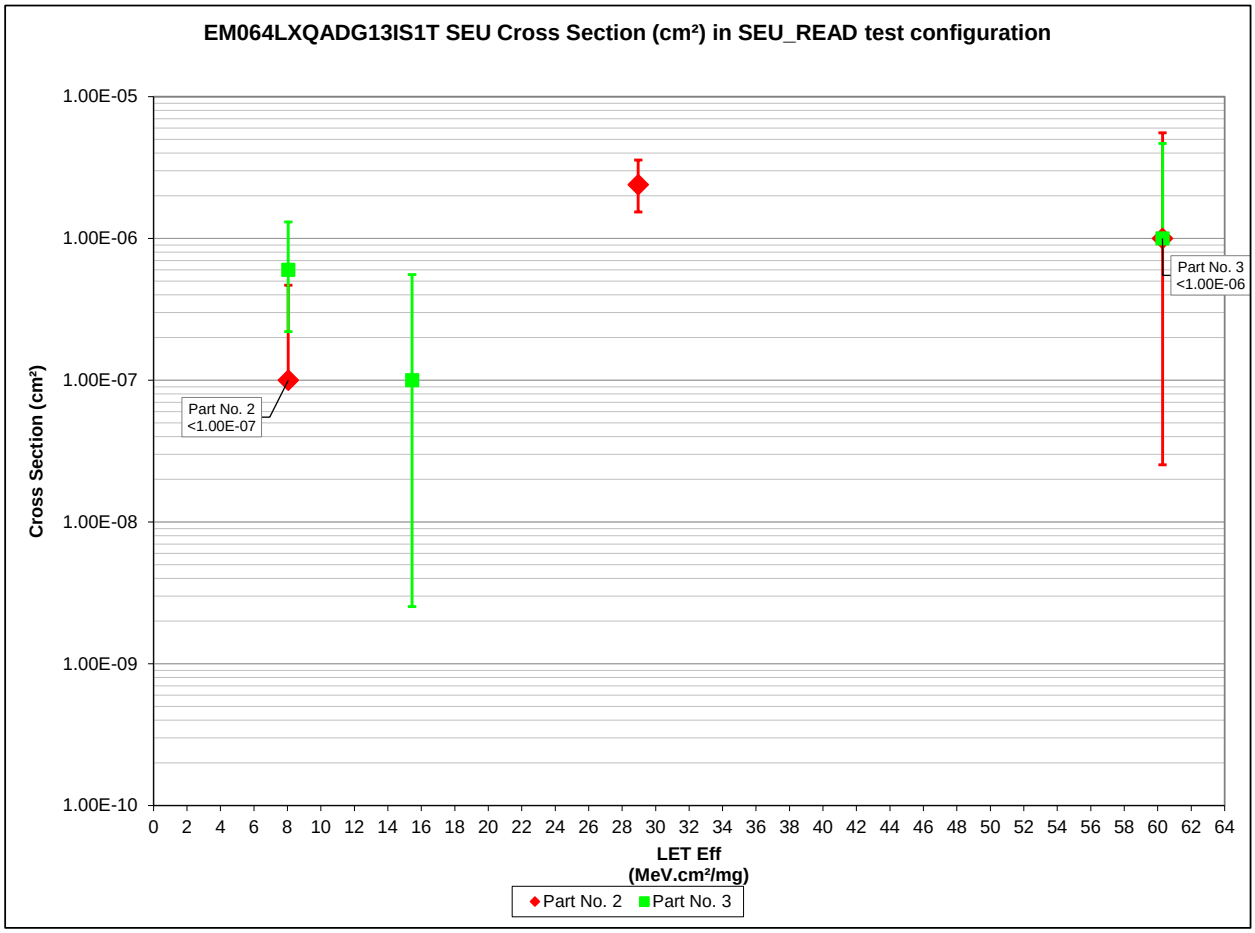


Figure 15: EM064LXQADG13IS1T SEU cross section curve in SEU_READ test configuration

Hereafter are shown the SEU per bit cross section values for each tested component.

In SEU_READ test configuration

	EM064LXQADG13IS1T SEU_bit Cross Section (cm²) in SEU_READ test configuration								
LET Eff (MeV.cm²/mg)	Part No. 1			Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	-	*Not tested*	-	-	1.49E-14	3.69E-06	0.00E+00	<1.00E-015	3.69E-06
29.0	-	*Not tested*	-	-	3.58E-14	3.69E-07	-	*Not tested*	-
15.5	-	*Not tested*	-	-	*Not tested*	-	-	1.49E-15	3.69E-07
8.1	-	*Not tested*	-	0.00E+00	<1.00E-015	3.69E-07	-	8.94E-15	3.69E-07

Table 13: EM064LXQADG13IS1T SEU per bit cross section values in SEU_READ test configuration

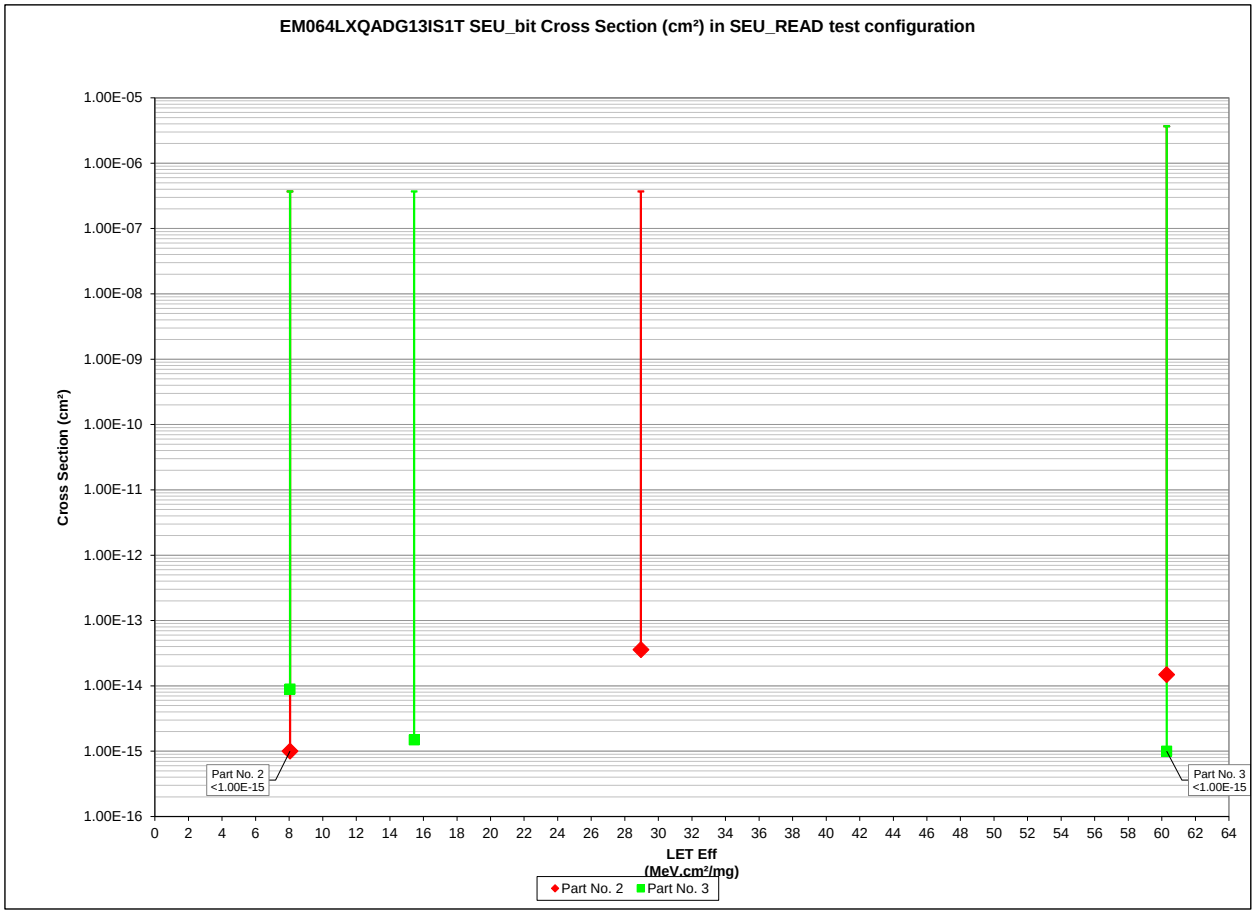


Figure 16: EM064LXQADG13IS1T SEU per bit cross section curve in SEU_READ test configuration

9.5. MBU test results

9.5.1. MBU LET threshold

The MBU test was performed under SEE test conditions (see Table 8).

In SEU_READ test configuration

No MBU was observed with a maximum LET of 60.29 MeV.cm²/mg, Xenon heavy ion.

9.5.2. MBU cross sections

Hereafter are shown the MBU cross section values for each tested component.

In SEU_READ test configuration

	EM064LXQADG13IS1T MBU Cross Section (cm²) in SEU_READ test configuration								
LET Eff (MeV.cm²/mg)	Part No. 1			Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	-	*Not tested*	-	0.00E+00	<1.00E-06	3.69E-06	0.00E+00	<1.00E-06	3.69E-06
29.0	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07	-	*Not tested*	-
15.5	-	*Not tested*	-	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07
8.1	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07	0.00E+00	<1.00E-07	3.69E-07

Table 14: EM064LXQADG13IS1T MBU cross section values in SEU_READ test configuration

9.6. Burst test results

9.6.1. Burst LET threshold

The Burst test was performed under SEE test conditions (see Table 8).

In SEU_READ test configuration

Burst were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

9.6.2. Burst cross sections

Hereafter are shown the Burst cross section values for each tested component.

In SEU_READ test configuration

	EM064LXQADG13IS1T Burst Cross Section (cm²) in SEU_READ test configuration					
LET Eff (MeV.cm²/mg)	Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	0.00E+00	<1.00E-06	3.69E-06	0.00E+00	<1.00E-06	3.69E-06
29.0	4.88E-07	9.00E-07	8.08E-07	-	*Not tested*	-
15.5	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07
8.1	9.75E-08	1.00E-07	4.57E-07	9.75E-08	1.00E-07	4.57E-07

Table 15: EM064LXQADG13IS1T Burst cross section values in SEU_READ test configuration

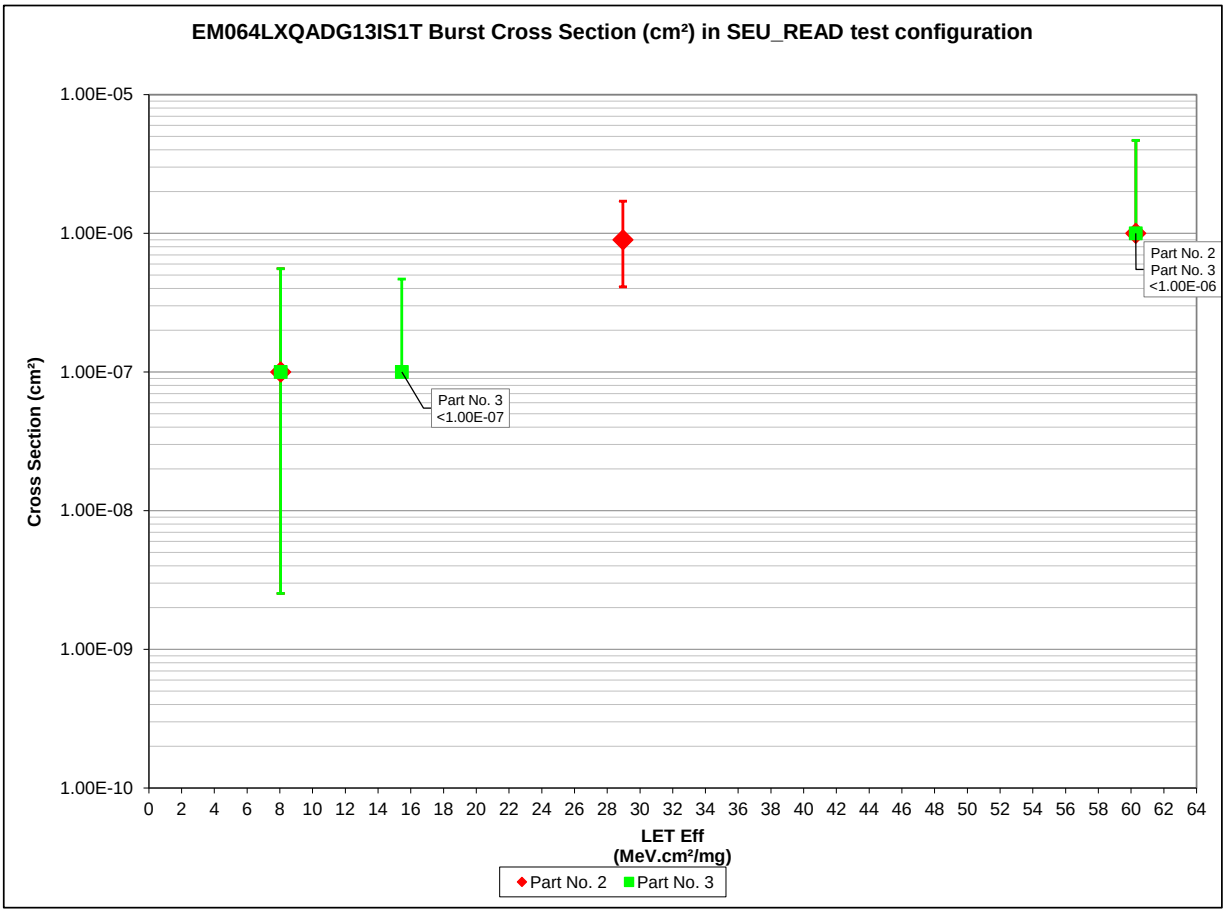


Figure 17: EM064LXQADG13IS1T Burst cross section curve in SEU_READ test configuration

9.7. SEFI test results

9.7.1. SEFI LET threshold

The SEFI test was performed under SEL test conditions (see Table 8).

In SEU_READ test configuration

SEFI were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET tested during this test campaign.

9.7.2. SEFI cross sections

Hereafter are shown the SEFI cross section values for each tested component.

In SEU_READ test configuration

	EM064LXQADG13IS1T SEFI Cross Section (cm²) in SEU_READ test configuration					
LET Eff (MeV.cm²/mg)	Part No. 2			Part No. 3		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)
60.3	1.47E-05	6.40E-05	1.77E-05	1.40E-05	5.80E-05	1.70E-05
29.0	6.85E-07	1.60E-06	9.98E-07	-	*Not tested*	-
15.5	-	*Not tested*	-	5.20E-07	1.00E-06	8.39E-07
8.1	1.76E-07	2.00E-07	5.22E-07	3.80E-07	6.00E-07	7.06E-07

Table 16: EM064LXQADG13IS1T SEFI cross section values in SEU_READ test configuration

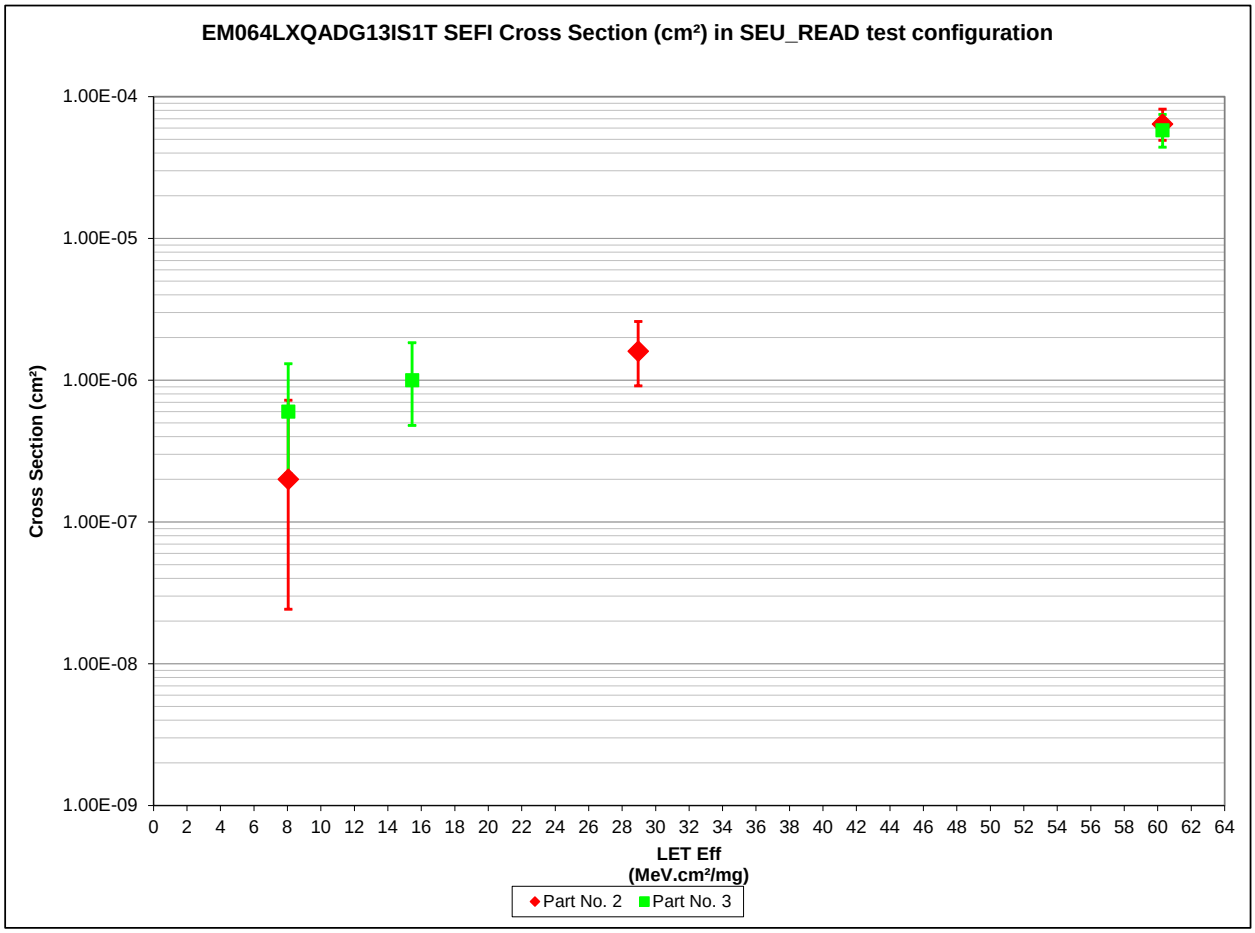


Figure 18: EM064LXQADG13IS1T SEFI cross section curve in SEU_READ test configuration

10. Conclusion

The heavy ions test was performed on EM064LXQADG13IS1T. The aim of the test was to evaluate the sensitivity of the device versus SEL, SEU, BURST and SEFI.

The SEL test was performed under SEL test conditions (see Table 7).

In SEL test configuration
SEL were observed with a minimum LET of 28.96 MeV.cm²/mg, Krypton heavy ion.
No SEL was observed with LET of 15.45 MeV.cm²/mg, Iron heavy ion.

The SEU, MBU, Burst and SEFI test were performed under SEE test conditions (see Table 8).

In SEU_READ test configuration
SEU were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

No MBU was observed with a maximum LET of 60.29 MeV.cm²/mg, Xenon heavy ion.

BURST were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.

SEFI were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
No lower LET was tested during this test campaign.