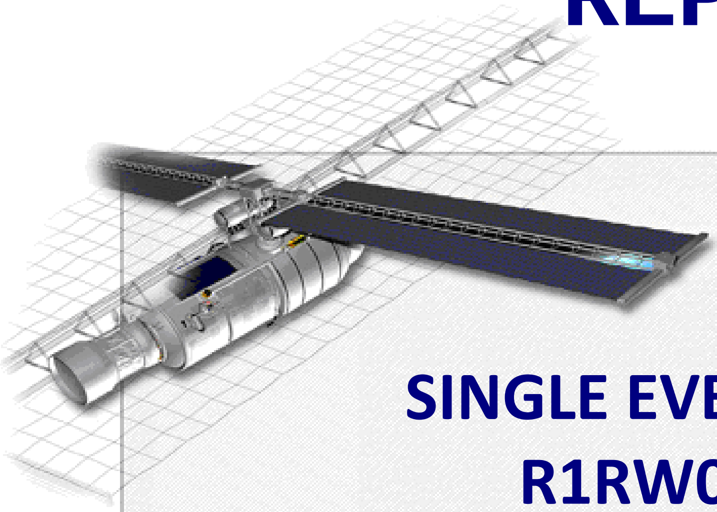
HEAVY IONS TEST REPORT



SINGLE EVENT EFFECTS
R1RW0416DSB
(DC1346)
4M High Speed SRAM
From
Renesas

TRAD/TI/R1RW0416DSB/1346/ESA/LG/1409		Labège, 10 September 2015
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Revision: 1		
To: **ESA** **Marc POIZAT**		Project/Program: TID influence on the SEE sensitivity of active EEE components **Ref: ESTEC Contract No.4000111336/14/NL/SW**

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1. Introduction

This report includes the test results of the heavy ions Single Event Effects (SEEs) test sequence carried out on the **R1RW0416DSB**, a **4M High Speed SRAM** from **Renesas**.

This test was performed for **ESA** at U.C.L (Université Catholique de Louvain, Louvain la Neuve, Belgium) on October 27th and 28th, 2014. Five samples were irradiated.

This test was performed for **ESA** on the **R1RW0416DSB** susceptible to show Single Event Latchups (SELs), Single Event Upsets (SEUs) and Multiple Bit Upsets (MBUs) induced by heavy ions. This test was performed as part of a global study to evaluate the potential synergetic effects of TID on SEE sensitivity. As a result, the development strategy for this test was not the characterization of the R1RW0416DSB itself, but the evolution of its SEE sensitivity after submission to TID. The results presented in this report were obtained before TID irradiation (0 krad).

2. Documents

2.1. Applicable documents

Financial and technical proposal: TRAD/P/ESA/AO7751/AV/130214 Rev.0
Irradiation test plan: ITP/TRA/TI/R1RW0416D/TSOPII-44/REN/190814 issue 1 of 15/10/2014

2.2. Reference documents

Data-sheet: Renesas REJ03C0109-0201 Rev.2.01 of 16/06/2010

3. Organization of Activities

The relevant company has performed the following tasks during this evaluation:

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

Table 1: Organization of activities

4. Parts information

4.1. Device description

The R1RW0416D is a 4-Mbit high speed static RAM organized 256-kword × 16-bit. It has high speed access time by employing CMOS process (6-transistor memory cell) and high speed circuit designing technology. It is most appropriate for the application which requires high speed, high density memory and wide bit width configuration, such as cache and buffer memory in system.

4.2. Identification

Type:	R1RW0416DSB
Manufacturer:	Renesas
Function:	4M High Speed SRAM

4.3. Procurement information

Packaging:	TSOP II - 44
Sample size:	10 parts procured by TRAD

4.4. Sample Preparation

All parts were delidded by TRAD.
No samples were damaged during this operation.
A functional test sequence was performed on delidded samples to check that devices were not degraded by the delidding operation.
Among the 10 delidded samples available for the test campaign, 5 were irradiated and 5 were not used.

4.5. Sample pictures

4.5.1. External view

No marking was observed at the bottom of the package.

Figure 1: Package marking

4.5.2. Internal view

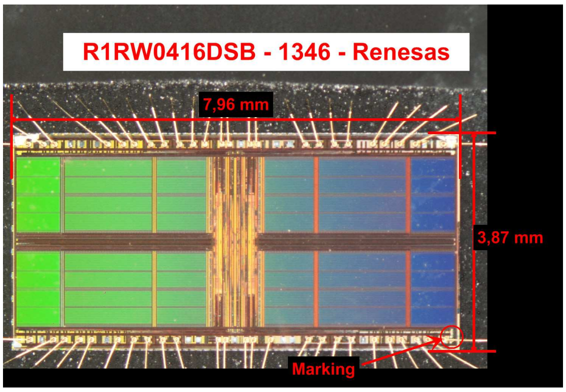


Figure 2: Internal overall view

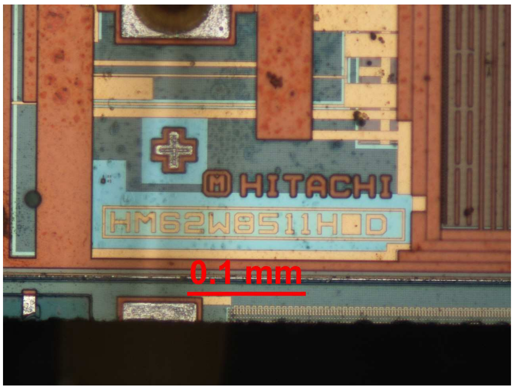


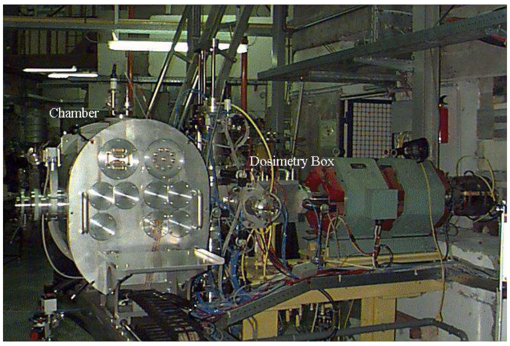
Figure 3: Die marking

5. Dosimetry and Irradiation Facilities

The test performed at U.C.L (Université Catholique de Louvain) on October 27th and 28th, 2014. Five delidded samples were irradiated.

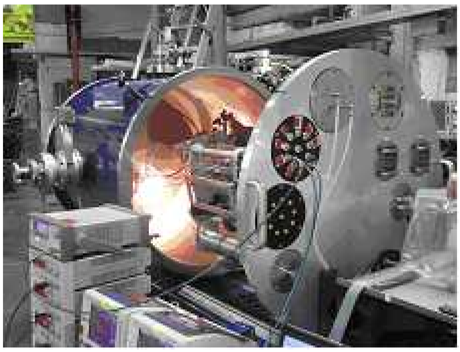
5.1. UCL Heavy Ion Test Facility (Université Catholique de Louvain - Belgique)

The CYClotron of LOuvain la NEuve (CYCLONE) is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 85 MeV), alpha particles and heavy ions.
For the heavy ions, the covered LET range is between 1.2 MeV.cm².mg^{-1} and 67.7 MeV.cm².mg^{-1}. Heavy ions available are separated in two “Ion Cocktails” named M/Q=5 and M/Q=3.3.



One of the main advantages of the UCL Heavy Ion Test Facility is the fast changing of ion species. Within the same cocktail, it takes only a few minutes to change from one ion to another.

The chamber has the shape of a barrel stretched vertically; its internal dimensions are 71 cm in height, 54 cm in width and 76 cm in depth. One side flange is used to support the board frame (25 X 25 cm) and user connectors.
The chamber is equipped with a vacuum system.



5.2. Dosimetry

To control and monitor the beam parameters, a dosimetry box is placed in front of the chamber.
It contains a faraday cup, 2 Parallel Plate Avalanche Counters (PPAC).
Two additional surface barrier detectors are placed in the test chamber.
The faraday cup is used during beam preparation at high intensity.
A beam uniformity measurement is performed with a collimated surface barrier detector. This detector is placed on a X and Y movement. The final profile is drawn and the ± 10 % width is calculated. The Homogeneity is ± 10 % on a 25 mm diameter.
During the irradiation, the flux is integrated in order to give the delivered total fluence (particule.cm^{-2}) on the device.

5.3. Beam characteristics

The beam flux is variable between a few particles $s^{-1}cm^{-2}$ and $1.8 \cdot 10^4 s^{-1}cm^{-2}$ depending on the device sensitivity.

Available heavy ion characteristics are listed in the following tables (heavy ions used during the experiment are highlighted in yellow):

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{15}N^{3+}$	60	59	3.3
$^{20}Ne^{4+}$	78	45	6.4
$^{40}Ar^{8+}$	151	40	15.9
$^{84}Kr^{17+}$	305	39	40.4
$^{124}Xe^{25+}$	420	37	67.7

Table 2: UCL cocktail M/Q=5

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{13}C^{4+}$	131	292	1.1
$^{22}Ne^{7+}$	235	216	3
$^{40}Ar^{12+}$	372	117	10.2
$^{58}Ni^{18+}$	567	100	20.4
$^{83}Kr^{25+}$	756	92	32.6

Table 3: UCL cocktail M/Q=3.3

6. Test Procedure and Setup

6.1. Test procedure

6.1.1. Description of the test method

The test was divided in two parts, with respect to reference or applicable documents:

- Runs were performed up to a fluence of 1.10^{7} cm^{-2} with only SEL monitoring. This configuration allowed to verify the latchup sensitivity of the device.
- Runs were performed up to a fluence of 1.10^{6} cm^{-2} for the SEU and MBU detection. A latchup monitoring was used during these tests in order to protect the component. This configuration allowed to verify the SEU and MBU sensitivity of the device.

The test was terminated when the maximum fluence was reached or when enough events were recorded to be statistically representative of the part behaviour.

6.1.2. SEL Test Principle

The test was performed at nominal operating voltage and ambient temperature.
TRAD has developed a fully integrated test bench to perform Single Event Latchup tests (SEL). The GUARD system (Graphical Universal Autorange Delatcher) allows the user to easily protect his device under test and perform SEL characterization.
The power supply is applied to the device under test through the GUARD system.
The threshold current of the GUARD system is set according to the nominal current. If the nominal current exceeds the threshold current, the GUARD system is triggered and the event is counted as an SEL. Then, the GUARD system sends a trigger command to the oscilloscope, maintains the power supply during a defined ‘Time hold’ and cuts it off during a defined ‘Time cut’. Then, the power supply is restarted with the nominal current expected consumption.
At the end of each run, the test program reads the oscilloscope’s “Local Scope Counter” which represents the total event counts and downloads the recorded current waveforms to store them.

Figure 4 shows an example of the SEL detection.

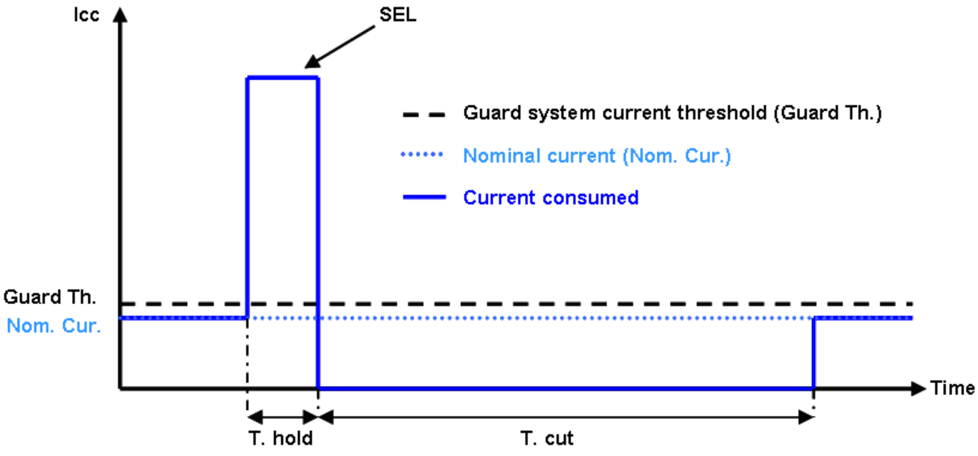


Figure 4: Common SEL characteristic.

6.1.3. SEU/MBU Test Principle

Before each run, a reference memory and the Device Under Test (DUT) are filled with a checker-board pattern (e.g 10101010 at even addresses and 01010101 at odd addresses) from address 0 up to the maximum address of the DUT. A first verification of their contents is performed off beam to ensure proper functionality of both DUT and reference.
During irradiation, the test bench reads both memories and compares their contents one address at a time. When the last address is reached, the FPGA sends a command to the Labview software to indicate the end of the read/compare cycle and a new read/compare order is immediately sent back to the FPGA. If there is no event during the cycle, this operation is performed at the maximum system speed. However, if the data read from the DUT doesn’t fit the data from the reference memory, an error is counted: a SEU if the number of bits impacted is only 1 and an MBU for other cases.

6.2. Test bench description

6.2.1. Preparation of test hardware and program

TRAD has developed a specific test program and a specific motherboard to feed power supply to components.
The test system is driven by a personal computer through a standard IEEE488 communication interface. All signals are delivered and monitored by this equipment and SEE curves are saved in its memory.
At the end of each test run, data is transferred to the hard disk for storage. An overall description of the test system is given in Figure 5.

6.2.2. Test equipment identification

The tests were carried out with evaluation test boards developed by TRAD.

COMPUTER	PO-TE-097
REF. TEST BOARD	TRAD/DEV-SP3/BVLG/1309/Rev1 Irradiation_board/MNEMOS Remote_board/MNEMOS
EQUIPMENT	MI-60, ME-79, SM-92
TEST PROGRAM	TI_MNEMOS_BV-LG_1407_rev5.llb MNEMOS5_SRAM.xise

6.2.3. Test Bench description

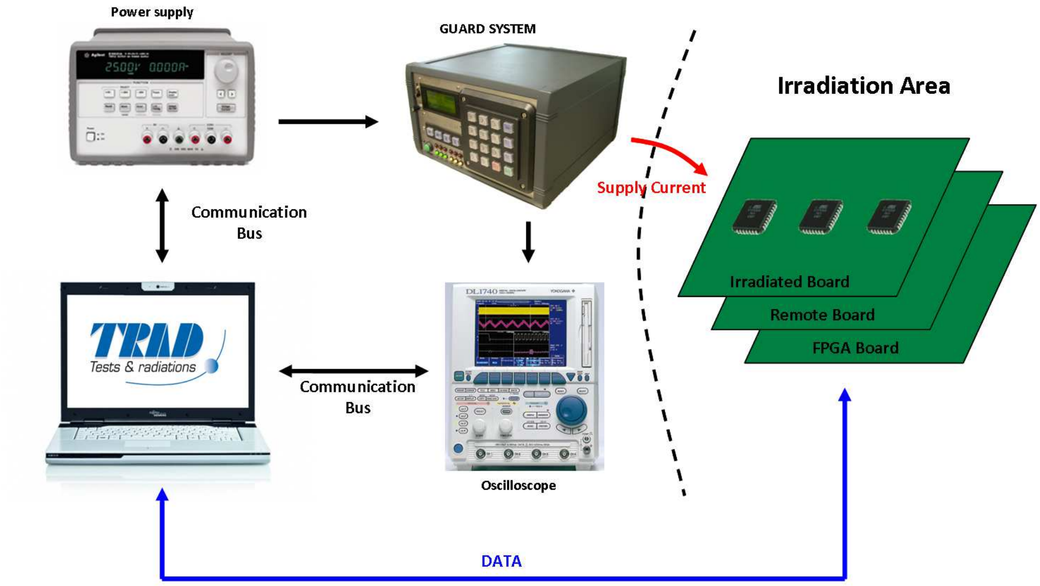


Figure 5: Test system description

6.2.4. Device setup and Test conditions

The trigger threshold for SEL test is defined in the following table:

Power Supply	Vcc
Voltage Value	3.3V
$I_{nominal}$	100mA
$I_{threshold}$	150mA
T_{hold}	1ms
T_{cut}	7ms
Temperature	25°C

Table 4: SEL detection threshold

7. Test Story

Test sequence, test and measurement conditions were nominal.

8. RESULTS

8.1. Summary of runs.

Runs performed during this campaign are summarized in the following table.

R1RW0416DSB Vcc = 3.3V T = 25°C										LATCHUP		SEE			
Run	**Part**	**Ion**	**Energy (MeV)**	**Range (µm)**	**LET (MeV.cm²/mg)**	**Flux (φ) ($cm^{-2}.s^{-1}$)**	**Time (s)**	**Run Fluence (Φ) (cm^{-2})**	**Run Dose (krad)**	**Cumulated Dose (krad)**	**Vcc**	**Cross Section**	**SEU**	**Cross Section**	**MBU**	**Cross Section**
High LET M/Q=5																
1	**1**	**124Xe 26+**	420	37	67.7	9.15E+03	**1094**	**1.00E+07**	10.847	10.847	**0**	<1.00E-07	**-**	-	**-**	-
2	**2**	**124Xe 26+**	420	37	67.7	1.01E+04	**996**	**1.00E+07**	10.847	10.847	**0**	<1.00E-07	**-**	-	**-**	-
3	**2**	**124Xe 26+**	420	37	67.7	1.04E+03	**409**	**4.24E+05**	0.459	11.307	**0**	<2.36E-06	**101021**	2.38E-01	**14**	3.30E-05
4	**1**	**124Xe 26+**	420	37	67.7	1.05E+03	**399**	**4.18E+05**	0.453	11.300	**0**	<2.39E-06	**100605**	2.41E-01	**9**	2.15E-05
5	**1**	**124Xe 26+**	420	37	67.7	5.04E+02	**166**	**8.36E+04**	0.091	11.390	**0**	<1.20E-05	**20343**	2.43E-01	**4**	4.78E-05
6	**1**	**84 Kr 17+**	305	39	40.4	1.01E+03	**536**	**5.43E+05**	0.351	11.741	**0**	<1.84E-06	**99912**	1.84E-01	**5**	9.21E-06
7	**2**	**84 Kr 17+**	305	39	40.4	1.01E+03	**551**	**5.56E+05**	0.360	11.666	**0**	<1.80E-06	**100421**	1.80E-01	**9**	1.62E-05
High Range M/Q=3.3																
8	**3**	**83 Kr 25+**	756	92	32.6	1.58E+03	**417**	**6.58E+05**	0.343	0.343	**0**	<1.52E-06	**100170**	1.52E-01	**13**	1.98E-05
9	**4**	**83 Kr 25+**	756	92	32.6	1.51E+03	**411**	**6.20E+05**	0.323	0.323	**0**	<1.61E-06	**100595**	1.62E-01	**7**	1.13E-05
10	**5**	**83 Kr 25+**	756	92	32.6	1.45E+03	**12**	**1.74E+04**	0.009	0.009	▨ -	▨ -	▨ -	▨ -	▨ -	▨ -
11	**4**	**58 Ni 18+**	567	100	20.4	2.00E+03	**433**	**8.64E+05**	0.282	0.605	**0**	<1.16E-06	**100315**	1.16E-01	**15**	1.74E-05
12	**3**	**58 Ni 18+**	567	100	20.4	2.05E+03	**452**	**9.27E+05**	0.303	0.646	**0**	<1.08E-06	**100511**	1.08E-01	**10**	1.08E-05
13	**3**	**40 Ar 12+**	372	117	10.2	2.32E+03	**433**	**1.00E+06**	0.164	0.809	**0**	<1.00E-06	**47559**	4.74E-02	**0**	<1.00E-06
14	**4**	**40 Ar 12+**	372	117	10.2	2.77E+03	**363**	**1.00E+06**	0.164	0.769	**0**	<1.00E-06	**51031**	5.08E-02	**4**	3.98E-06
15	**4**	**22 Ne 7+**	235	216	3	5.03E+03	**201**	**1.01E+06**	0.048	0.818	**0**	<1.00E-06	**10949**	1.08E-02	**0**	<1.00E-06
16	**3**	**22 Ne 7+**	235	216	3	5.11E+03	**197**	**1.01E+06**	0.048	0.858	**0**	<1.00E-06	**10648**	1.06E-02	**0**	<1.00E-06
17	**3**	**13 C 4+**	131	292	1.1	7.60E+03	**133**	**1.01E+06**	0.018	0.875	**0**	<1.00E-06	**27**	2.67E-05	**0**	<1.00E-06
18	**4**	**13 C 4+**	131	292	1.1	8.17E+03	**124**	**1.01E+06**	0.018	0.018	**0**	<1.00E-06	**28**	2.76E-05	**0**	<1.00E-06
19	**4**	**83 Kr 25+**	756	92	32.6	9.99E+03	**102**	**1.02E+06**	0.532	0.549	**0**	<1.00E-06	**164653**	1.62E-01	**94**	9.22E-05
20	**3**	**83 Kr 25+**	756	92	32.6	5.17E+01	**1275**	**6.59E+04**	0.034	0.910	**0**	<1.52E-05	**10067**	1.53E-01	**1**	1.52E-05

Table 5: R1RW0416DSB test results

▨ : Handling settings.

No SEL was detected during this test.
Both SEU and MBU events were detected during this test.
Test results are described hereafter.

8.2. SEL test results.

The SEL test was performed at 25°C.
No SEL was observed during this test under Xenon irradiation with a total fluence equal to 1E+7 cm^{-2}:

- with a 0° particle angle (LET = 67.7 MeV.cm²/mg and range = 37µm).

8.3. SEE tests results

The SEE test was performed at 25°C.

SEUs were observed during the irradiation with the Carbon Heavy Ion (LET = 1.1 MeV.cm²/mg).
MBUs were observed during the irradiation with minimum LET = 10.2 MeV.cm²/mg (Argon).

8.3.1. SEU Cross section

R1RW0416DSB SEU Cross Section (cm^2)

LET Eff (MeV.cm².mg^{-1})	SEU			
	N° 1	N° 2	N° 3	N° 4
67.7	2.41E-01	2.38E-01	-	-
40.4	1.84E-01	1.80E-01	-	-
32.6	-	-	1.52E-01	1.62E-01
20.4	-	-	1.08E-01	1.16E-01
10.2	-	-	4.74E-02	5.08E-02
3	-	-	1.06E-02	1.08E-02
1.1	-	-	2.67E-05	2.76E-05

Table 6: R1RW0416DSB SEU cross section results

The following figure presents the cross section of the SEU event on the R1RW0416DSB part.
Error bars are calculated as described in the ESCC25100, using 95% confidence level and 10% fluence uncertainty.

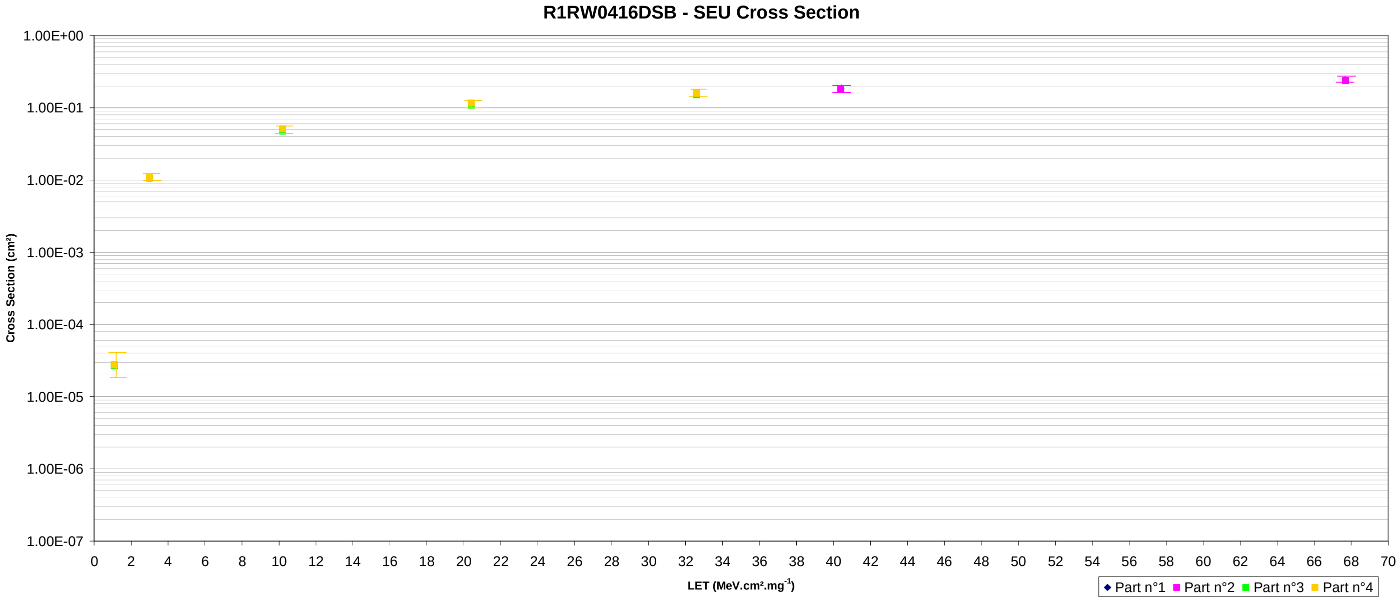


Figure 6: SEU cross section curve for R1RW0416DSB

8.3.2. MBU Cross section

R1RW0416DSB MBU Cross Section (cm2)				
LET Eff (MeV.cm².mg^{-1})	**MBU**			
	N° 1	N° 2	N° 3	N° 4
67.7	3.83E-05	4.01E-05		
40.4	2.95E-05	5.21E-05		
32.6			1.99E-04	2.03E-04
20.4			9.06E-05	6.83E-05
10.2			<1E-06	3.98E-06
3			<1E-06	<1E-06
1.1			<1E-06	<1E-06

Table 7: R1RW0416DSB MBU cross section results

The following figure presents the cross section of the MBU event on the R1RW0416DSB part.
Error bars are calculated as described in the ESCC25100, using 95% confidence level and 10% fluence uncertainty.

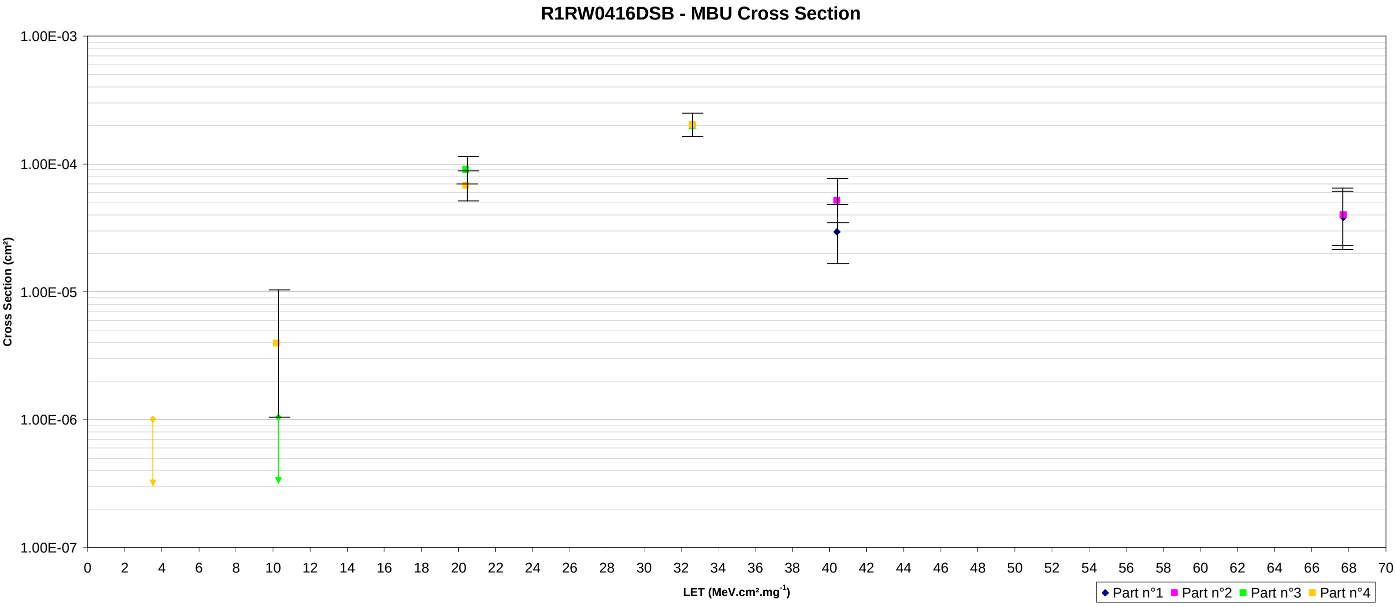


Figure 7: MBU cross section curve for R1RW0416DSB

As shown in figure 7, MBU cross section shows lower values at higher LET (Kr and Xe). Moreover MBU signatures are unusual: MBU multiplicities are of even multiplicity.

The next table present some examples of MBU detected during the test campaign.

Erroneous word	Expected word	Multiplicity
5445	5555	2
BAAB	AAAA	2
455D	5555	2
D55D	5555	2
5595	5555	2
28AA	AAAA	2
D455	5555	2
AAA0	AAAA	2
1455	5555	2
AEBA	AAAA	2
8AAE	AAAA	2
D551	5555	2
4557	5555	2
22AA	AAAA	2
ABEA	AAAA	2
5555	0505	4
8E8E	AAAA	4
4554	0404	4
A0A0	AAAA	4
AAAA	A0FA	4
A0A0	AAAA	4
AAAA	A0A0	4
5555	0505	4
2020	AAAA	6
0404	5555	6
0	AAAA	8
BAAB	2020	8

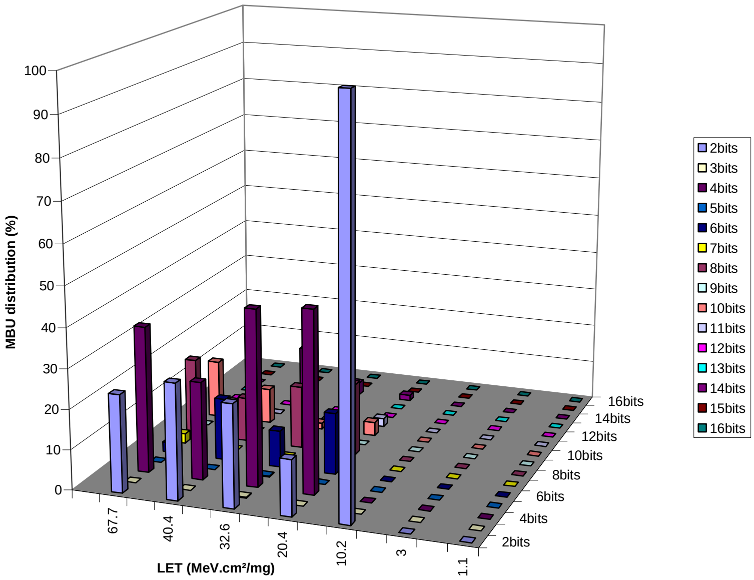


Figure 8: R1RW0416 Mean MBU distribution percentage function multiplicity

TABLE 8 : example of erroneous pattern detected during MBU test on R1RW0416

Some of these errors are very symmetric; E.g. 5445 and 8E8E, which may indicate that the detected MBU are potentially not real MBU.

The flux used has an impact on the measured MBU cross section.
As MBU events also include SEE on peripheral circuitry, an MBU post-treatment has been performed in order to suppress these errors from MBUs.

Post-treated data are reported in the following table:

R1RW0416DSB MBU Cross Section (cm2)				
LET Eff (MeV.cm².mg^{-1})	**MBU**			
	N° 1	N° 2	N° 3	N° 4
67.7	2.15E-05	3.30E-05		
40.4	9.21E-06	1.62E-05		
32.6			1.98E-05	1.13E-05
20.4			1.08E-05	1.74E-05
10.2			<1E-06	3.98E-06
3			<1E-06	<1E-06
1.1			<1E-06	<1E-06

Table 9: R1RW0416DSB MBU cross section results

The following figure presents the reprocessed cross section of the MBU event on the R1RW0416DSB part. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.10^{-6}cm^{-2}, value corresponding to one event at maximum fluence.

Error bars are calculated as described in the ESCC25100, using 95% confidence level and 10% fluence uncertainty.

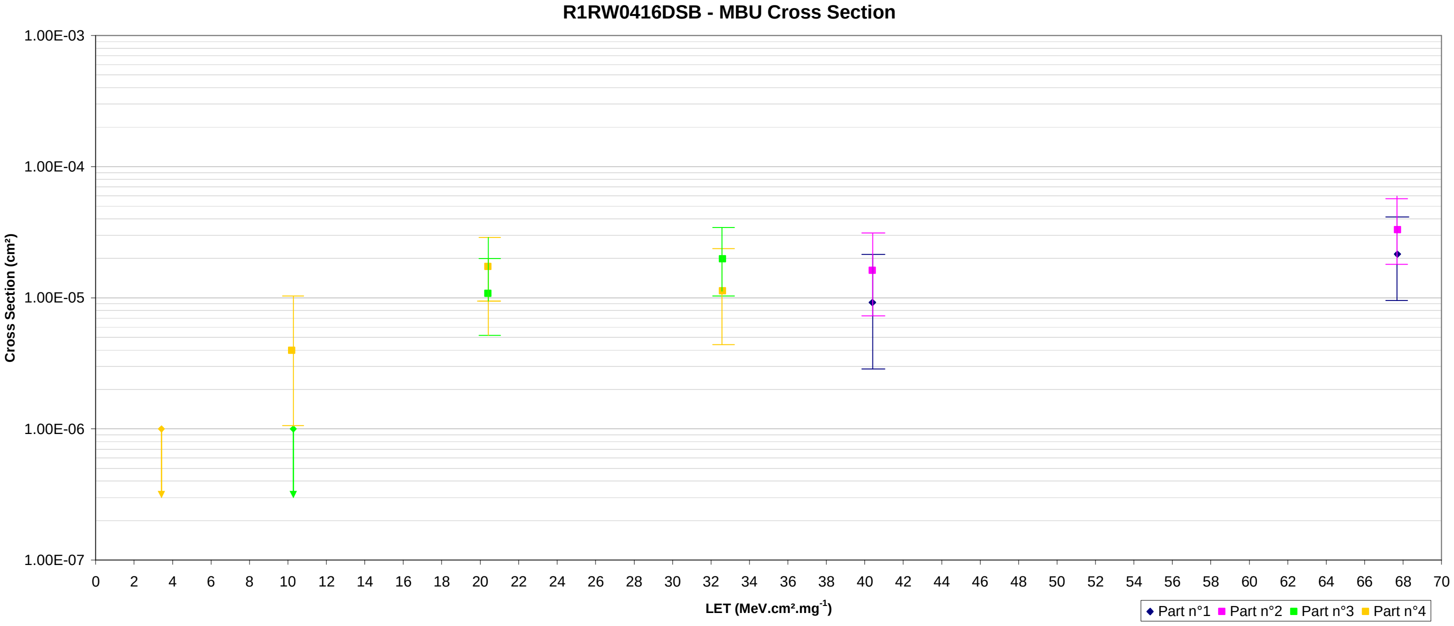


Figure 9: MBU cross section curve for R1RW0416DSB

9. Conclusion

Heavy ion tests were performed on R1RW0416DSB. The aim of the test was to evaluate the sensitivity of the device versus SEL, SEU and MBU. This test was performed as part of a global study to evaluate the potential synergetic effects of TID on SEE sensitivity. As a result, the development strategy for this test was not the characterization of the R1RW0416DSB itself, but the evolution of its SEE sensitivity after submission to TID. The results presented in this report were obtained before TID irradiation (0 krad).

No SELs were observed at LET = 67.7MeV.cm²/mg (Xenon heavy ions).

SEUs were observed on the R1RW0416DSB with a minimum LET of 1.1MeV.cm²/mg (Carbon heavy ions).

MBUs were observed on the R1RW0416DSB with a minimum LET of 10.2MeV.cm²/mg (Argon heavy ions). No MBU was detected at LET = 3 MeV.cm²/mg (Neon heavy ions).