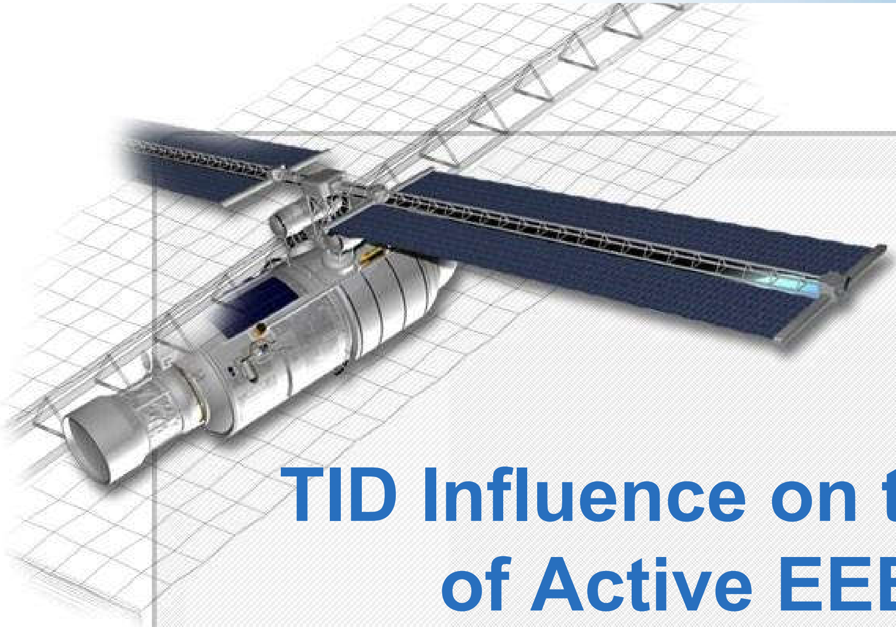


TID Influence on the SEE sensitivity of Active EEE components

ESA Contract No. 4000111336

Lionel Salvy, Benjamin Vandevelde, Lionel Gouyet
Anne Samaras, Athina Varotsou, Nathalie Chatry
Alexandre Rousset, Marc Poizat

Purpose of the study

During space application, devices are subject to TID and SEE at the same time.

But part radiation qualification process includes ionizing dose and SEE tests performed independently

⇒ Synergetic effect between Dose and SEE on electronic devices ?

Project organisation

- **Started July 2014 -> ended July 2015**
- **All developments and analysis were performed by TRAD near Toulouse, France**
    - Radiation Testing + Radiation Engineering Departments

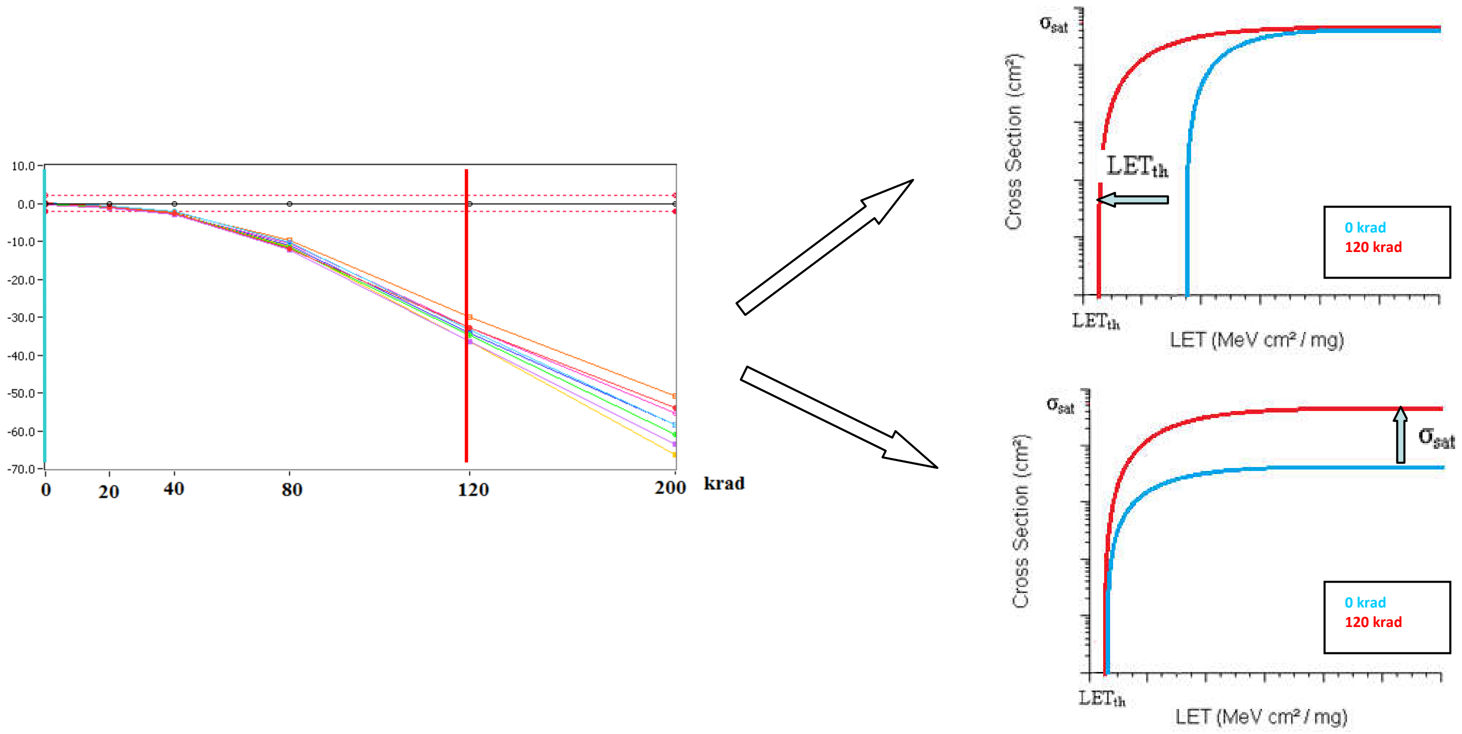
Some interesting numbers

- 400 parts procured
- 280 devices tested
- 214 devices delidded
- 145 hours of heavy ion beam tests
- 6 + 12 weeks of Cobalt 60 irradiation
- 88 devices measured at each Cobalt 60 step

Contents

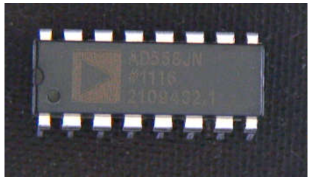
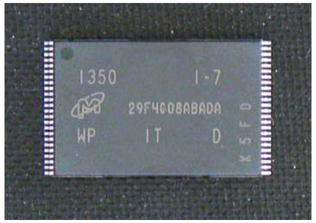
Component selection

- **The devices selected for the study should be :**
  - **Sensitive to TID in order to display parameter drift, but not too much to remain functional during the whole test campaign.**
  - **Sensitive to SEE, with :**
    - an LET threshold high enough to observe a potential drift towards zero
    - a saturated cross section low enough to measure a potential increase



Component selection

Four different type of devices have been selected in order to have different functions, manufacturers and technologies

	AD9042	AD558	MT29F4G08AAC	R1RW0416
Manufacturer	Analog Device	Analog Device	Micron	Renesas
Type	ADC 12bit	DAC 8bit	4 Gb NAND flash	SRAM 4Mb 16bit
				

Test plan principle

Pre-characterization

- Preliminary TID test

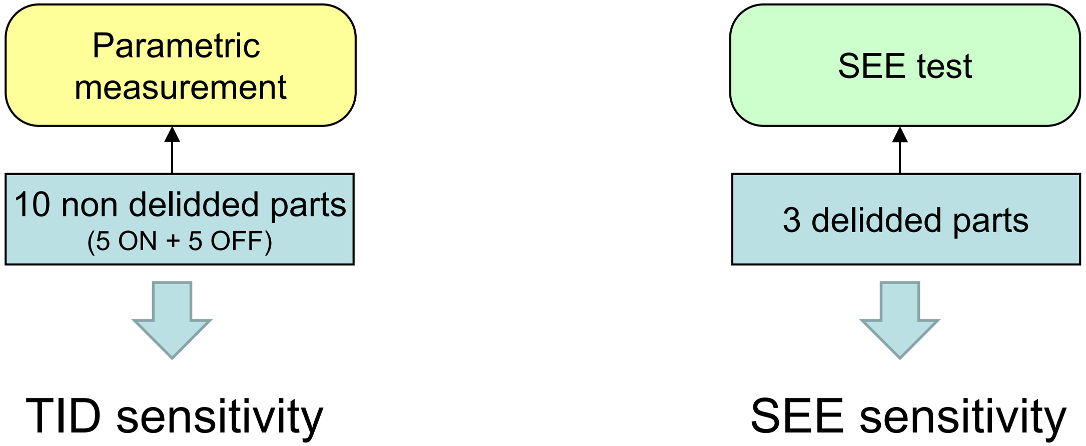
⇨ Devices behavior under total dose

⇨ Total dose level and dose steps for each reference for the combined TID and SEE tests

- Preliminary SEE test

⇨ SEE sensitivity before ^{60}Co irradiation

Standard Test


Parametric measurement

10 non delidded parts
(5 ON + 5 OFF)

TID sensitivity

SEE test

3 delidded parts

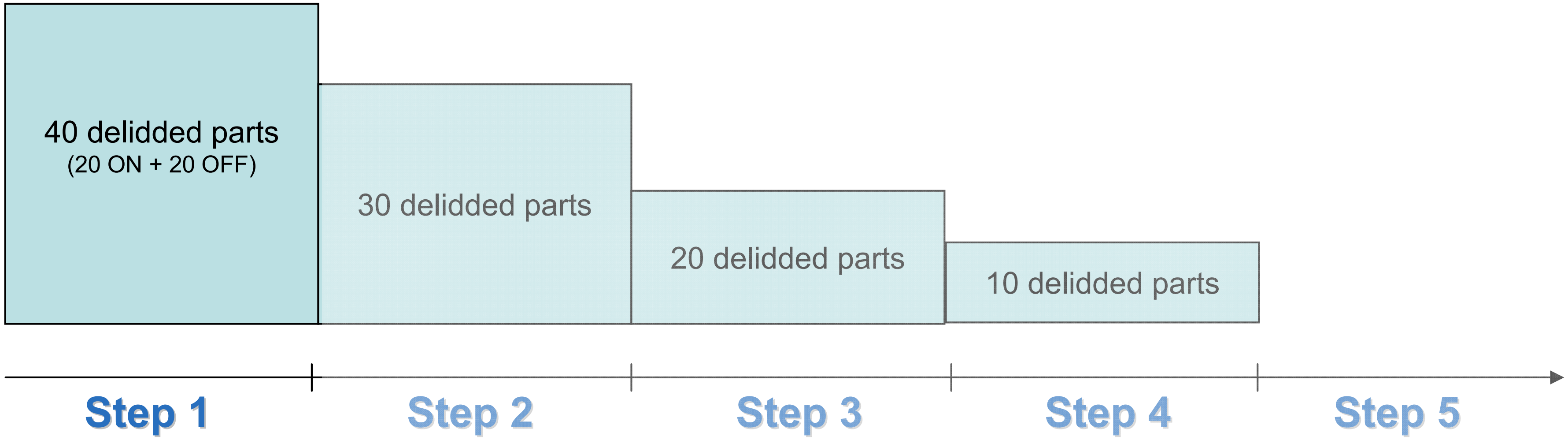
SEE sensitivity

Test plan principle

Combined TID & SEE test

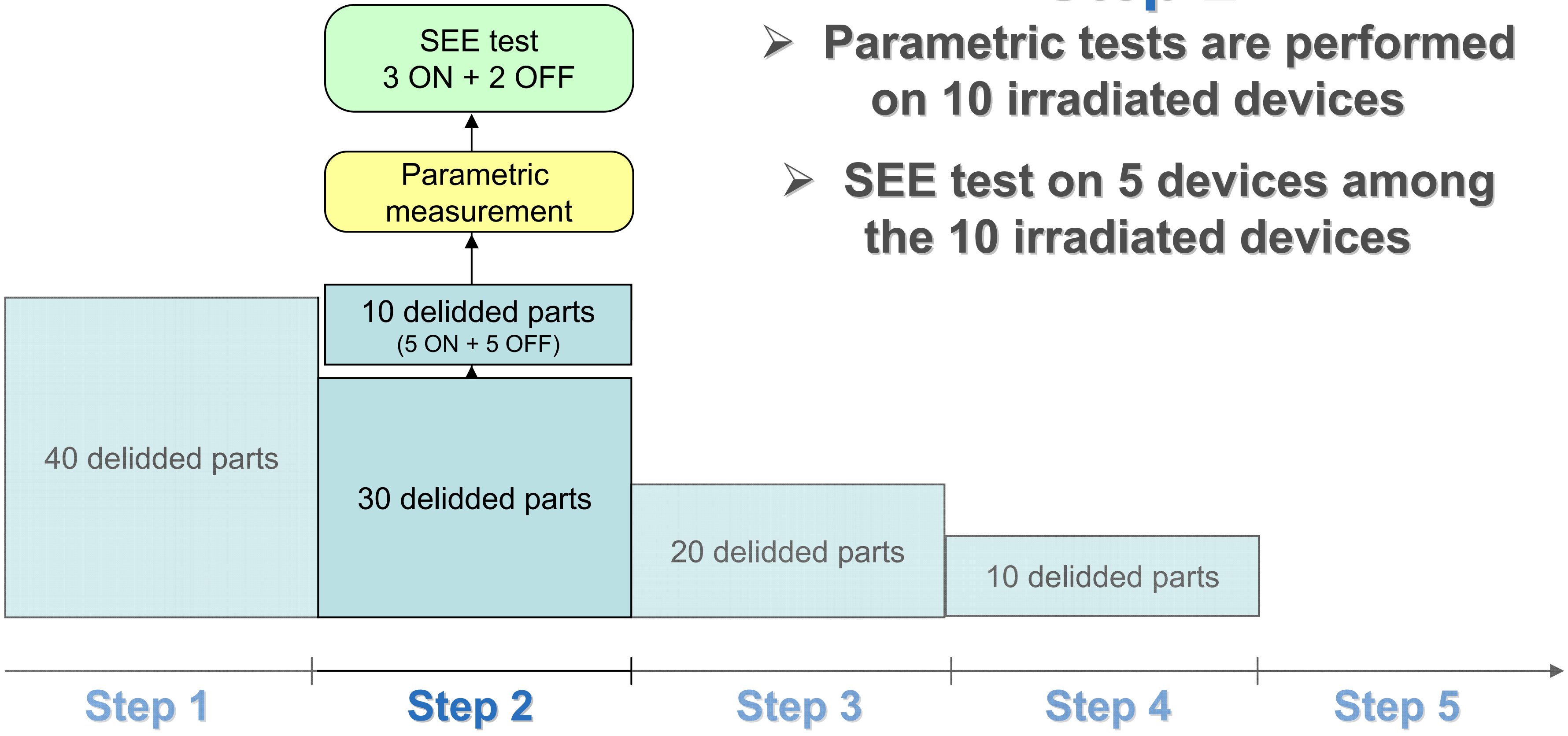
Step 1

- Parametric tests are performed on all devices before ^{60}Co irradiation



Test plan principle

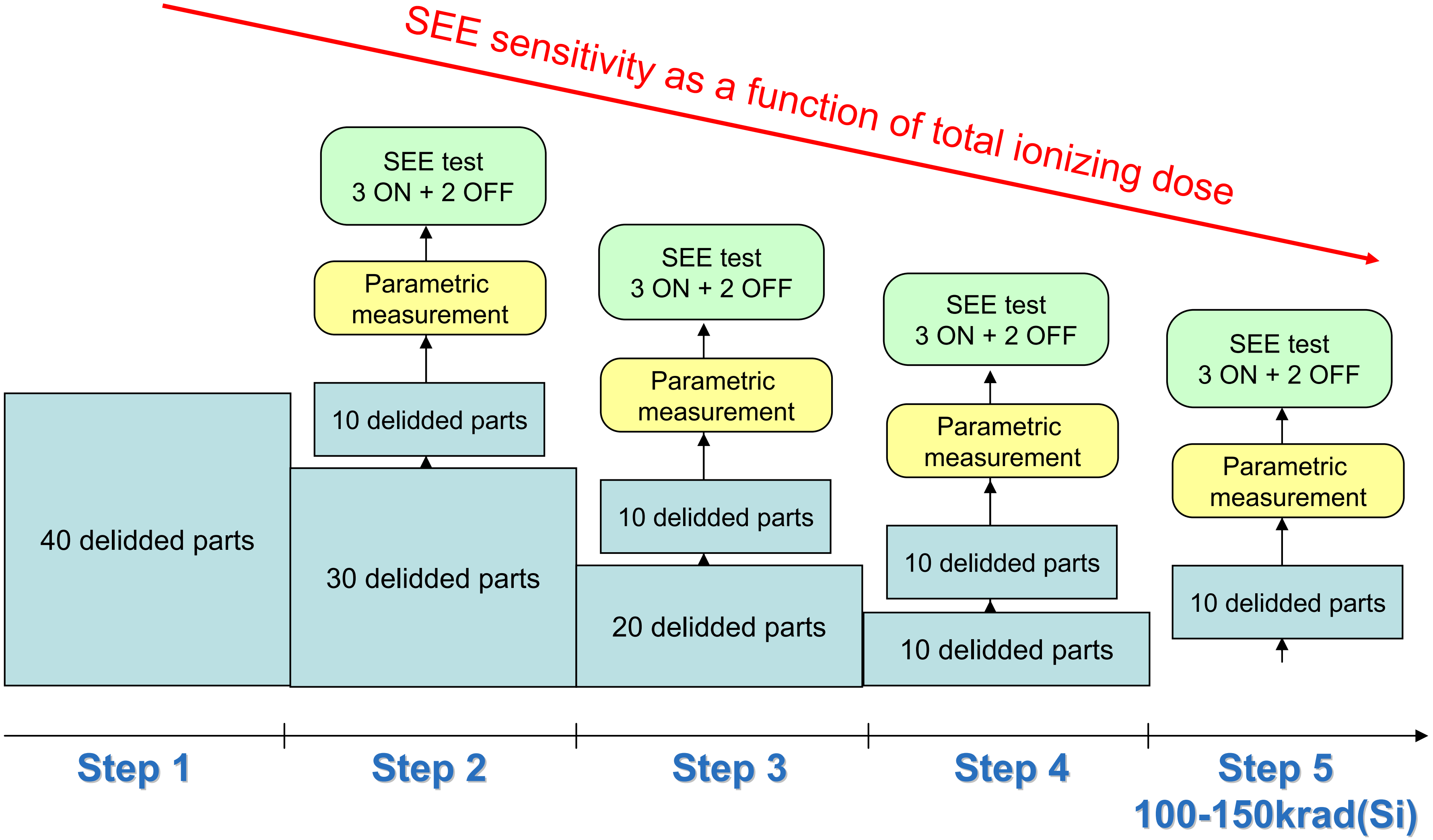
Combined TID & SEE test



Step 2

- Parametric tests are performed on 10 irradiated devices
- SEE test on 5 devices among the 10 irradiated devices

Test plan principle



SEE sensitivity as a function of total ionizing dose

40 delidded parts

30 delidded parts

10 delidded parts

Parametric measurement

SEE test
3 ON + 2 OFF

20 delidded parts

10 delidded parts

Parametric measurement

SEE test
3 ON + 2 OFF

10 delidded parts

10 delidded parts

Parametric measurement

SEE test
3 ON + 2 OFF

10 delidded parts

Parametric measurement

SEE test
3 ON + 2 OFF

Step 1

Step 2

Step 3

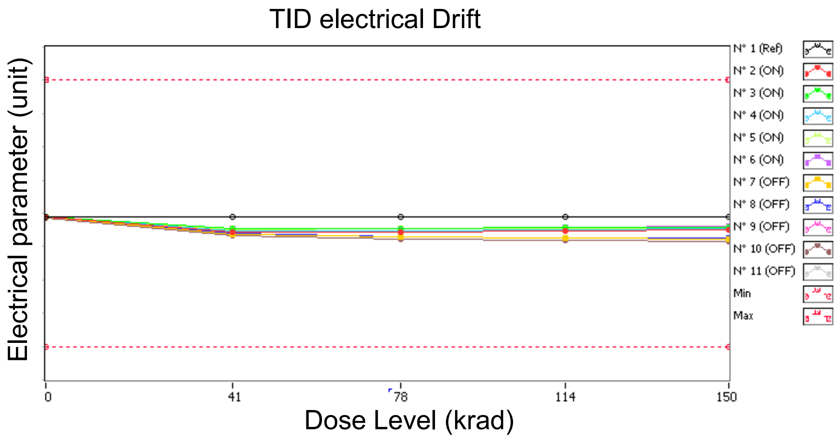
Step 4

Step 5
100-150krad(Si)

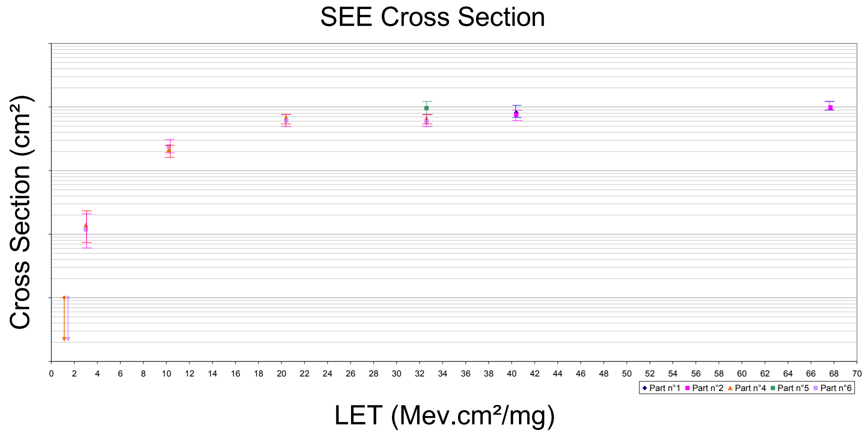
Monitored parameters

- **2 types of benches per reference**

  - **TID test bench**
    - Parametric measurement
    - Parameter drift versus dose level



  - **SEE test bench**
    - Dynamic functional testing
    - Error rates versus LET (cross section)



Monitored parameters

SEE parameters

- **Latchup detection and protection in all cases (SEL, HCE)**

- **Memory testing**

Upsets in Memory cells	(SEU , MBU)
Internal state machine malfunction	(SEFI, Flash only)
Failure	(Flash only)

- **ADC Testing**

Analogue conversion transient	(SET)
Digital output conversion Upset	(SEU)
Timing circuits stuck	(SEFI)

- **DAC testing**

Analogue output transient	(SET)
Control register stuck	(SEFI)

External parameters

- **Impact of external parameters**

1. **Annealing : Same facility for SEE and TID - UCL**
2. **Long time test bench stability**
3. **Long time opened condition**

☐ SEE performed on delidded parts

☐ TID performed on delidded parts

⇨ Long time opened condition in a non-controlled atmosphere

⇨ Monitoring of possible degradation due to external parameters to subtract it from a possible synergy effect

Results Analysis

- Synergy effect analysis
  - Impact of Total Ionizing Dose on SEE sensitivity
  - Impact of Total Ionizing Dose on SEE error bars
  - Impact of bias condition during TID irradiation on SEE sensitivity
  - Impact of TID on SEE signature

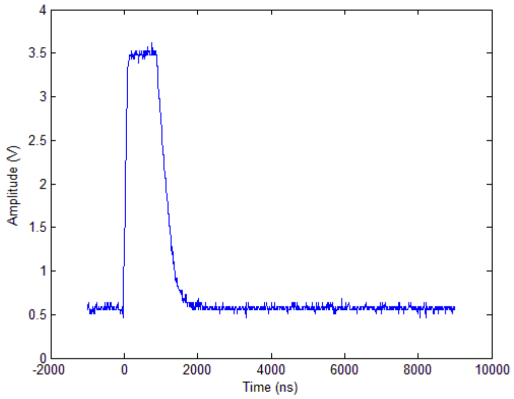
Results analysis

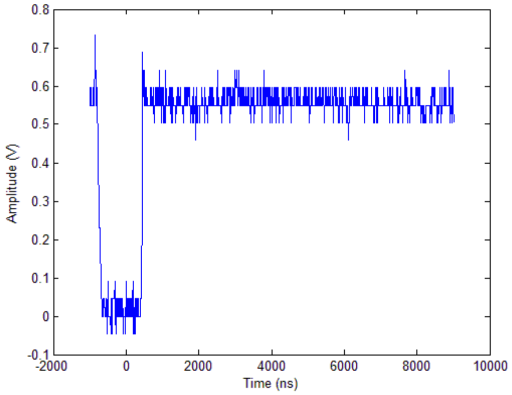
- Effect analysis per reference
  - Final Report available on ESCIES website
  - Paper published during RADECS 2016
- Case analysis
  - Impact of Total Ionizing Dose on SEE signature

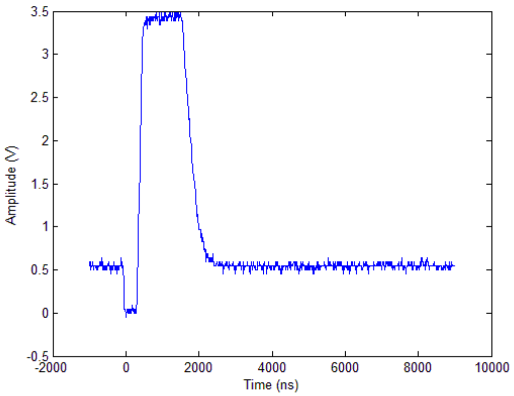
⇨ **Identify if TID has an impact on the SEE signature and then on the input used for the radiation analysis**

DAC AD558 from Analog Device

Impact of TID on SET signature





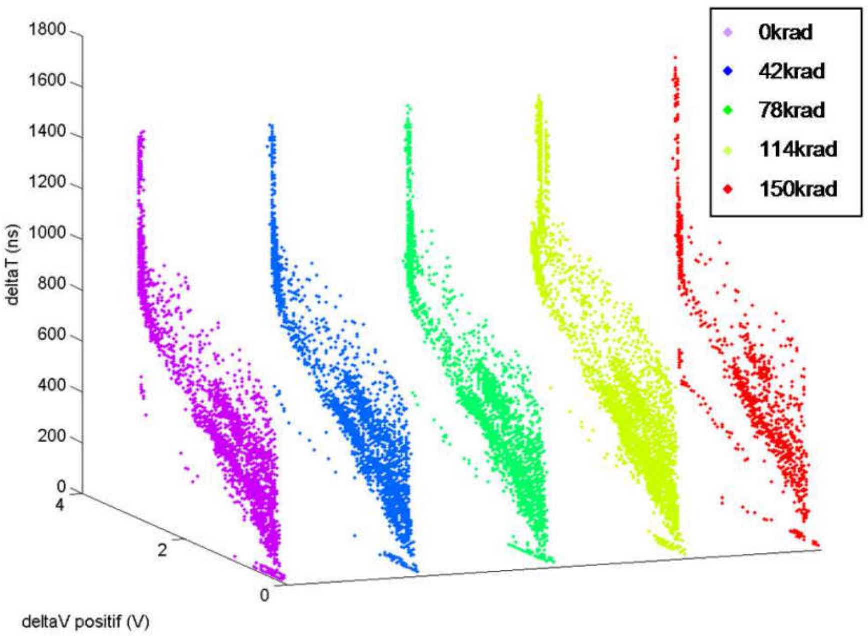


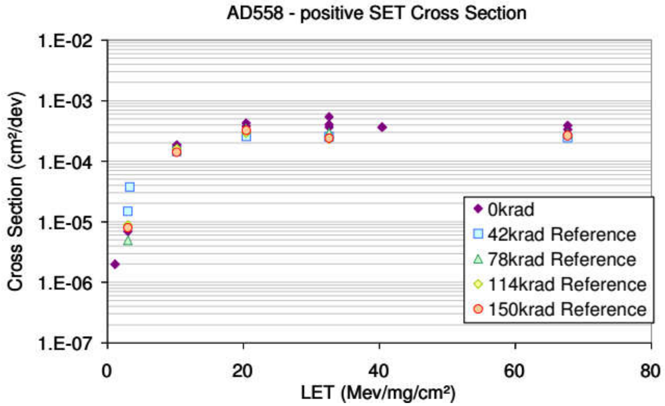
Three different signatures are observed during SET test

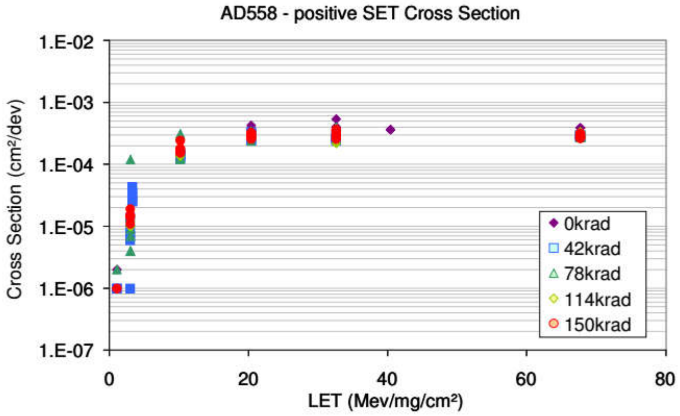
SET test results have been processed in order to evaluate if the dose level could have an impact on the SET signature

DAC AD558 from Analog Device

- Impact of TID on SET signature







LET (MeV.cm²/mg)

Analysis also performed on negative and double SET
No impact of TID level whatever the SET signature

Conclusion

- The effect of Total Ionizing Dose on the SEE sensitivity has been studied for 4 different devices
  - 400 devices procured
  - 280 devices tested
  - 214 devices delidded
  - 145H of heavy ion beam
  - 88 devices measured at each Co^{60} step

Conclusion

- External parameter continuous monitoring showed:
  - No Impact of delidding on TID degradation
  - No Impact of delidding on SEE sensitivity
  - Good testbench stability

Conclusion

- No Impact of TID on SEE sensitivity
  - Weibull parameters
  - Error bars
- No Impact of TID on SEE signature
  - SET shape
  - Imprint effect
  - MBU multiplicity

⇨ No impact of TID on SEE for these references up to 150krad(Si) (Flash: 100krad(Si))

Perspectives

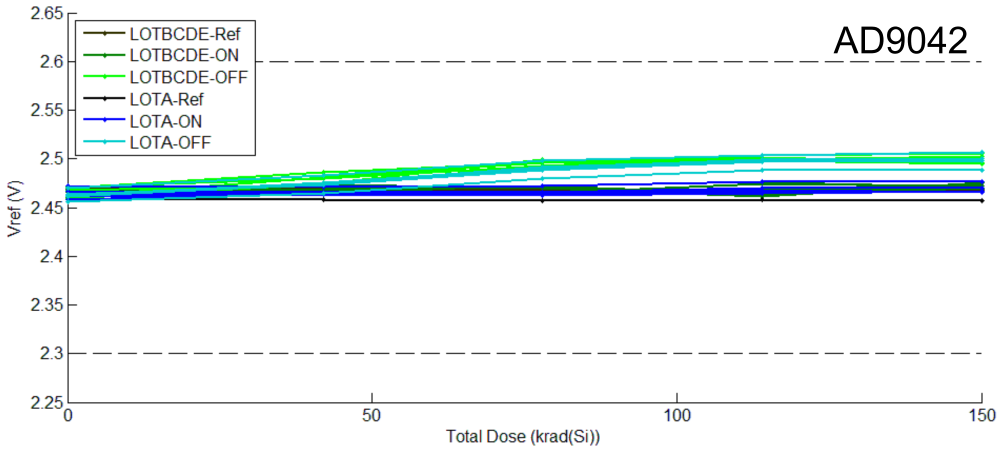
- Synergy study on other devices and effects (MOSFET / SEB & SEGR)
- Effect of TNID on the SEE sensitivity
- Effect of SEE on the TID sensitivity
- Further investigation on radiation effects on NAND Flash

TID Influence on the SEE sensitivity of Active EEE components

QUESTIONS

External parameter monitoring

- **Impact of long time opened condition on TID sensitivity**

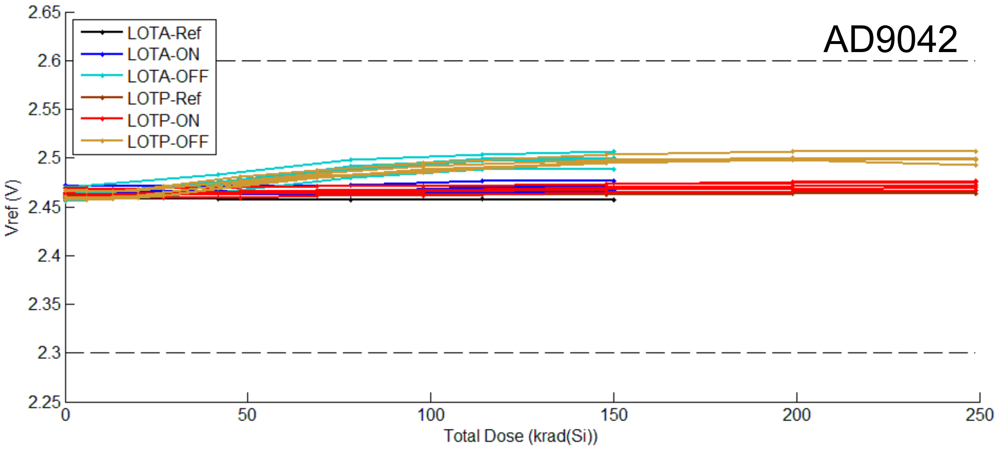


LOT A	74 rad/h	Non delidded
LOT BCDE	74 rad/h	Delidded

⇨ No impact of long time opened condition on TID sensitivity whatever the reference

External parameter monitoring

Impact of dose rate on TID sensitivity



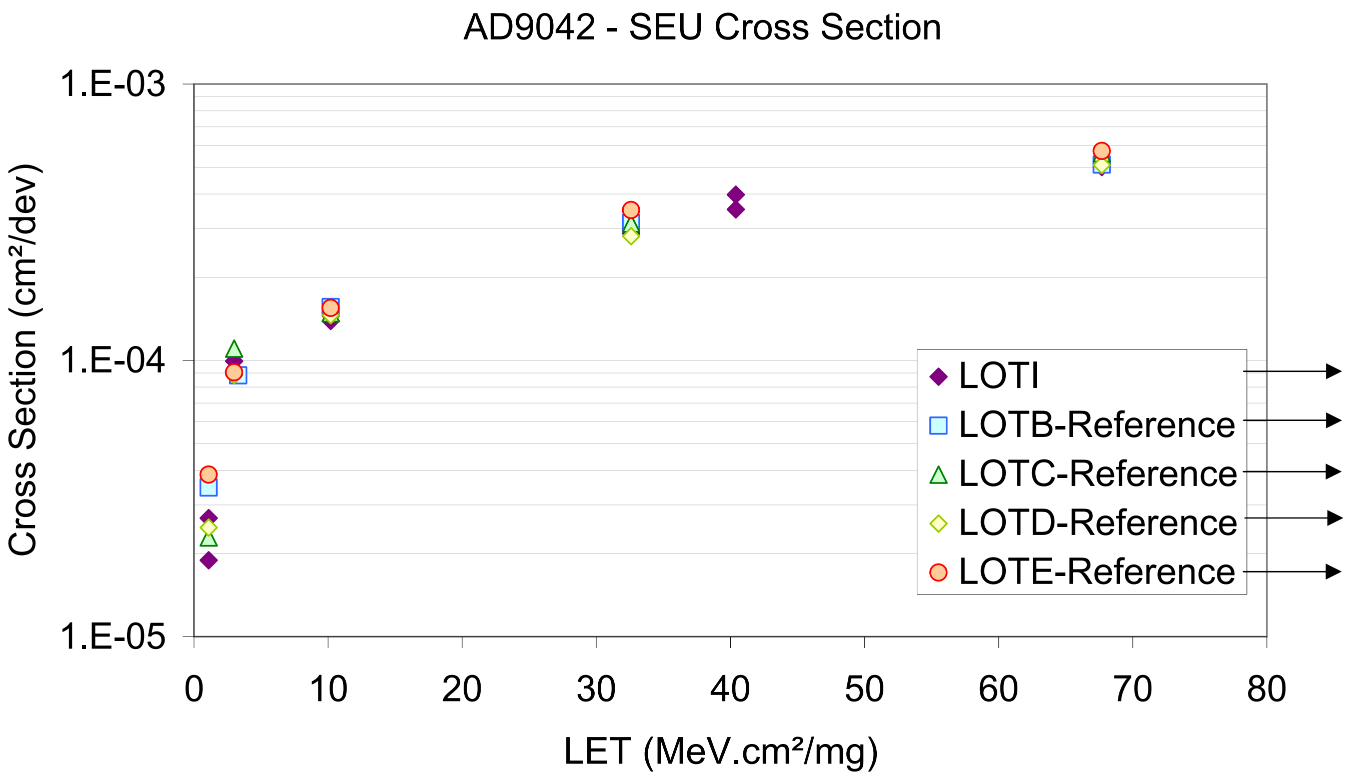
LOT P	310 rad/h	Non delidded
LOT A	74 rad/h	Non delidded

⇨ No dose Rate effect on TID sensitivity

⇨ Parametric degradation during synergy study always represents the worst case whatever the reference

External parameter monitoring

Impact of long time opened condition on SEE sensitivity

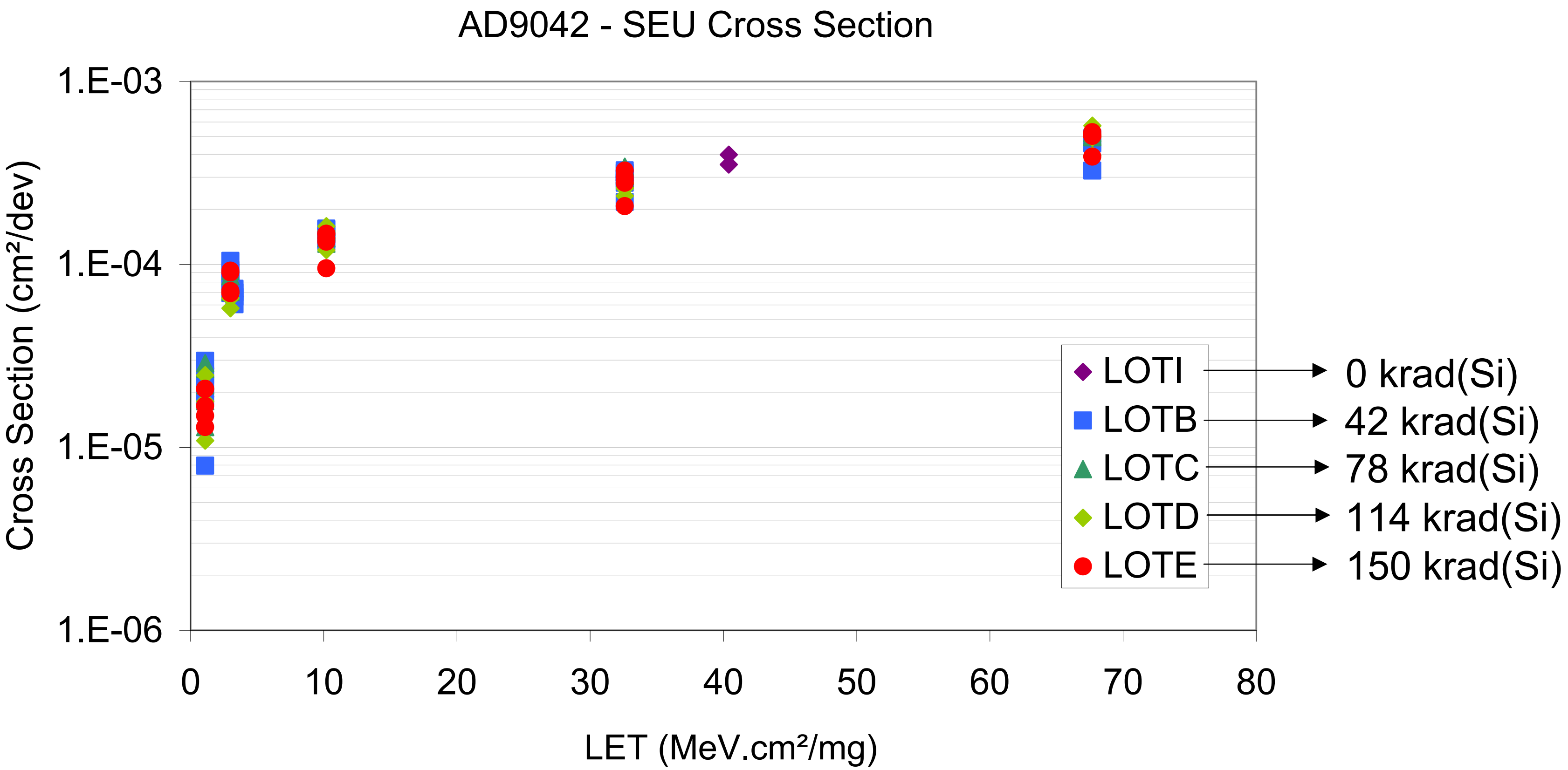


SEE pre-characterization
T_0 + 3 weeks
T_0 + 6 weeks
T_0 + 9 weeks
T_0 + 12 weeks

⇨ No impact of long time opened condition on SEE sensitivity whatever the reference

Synergy effect analysis

- **Impact of TID on SEE sensitivity**

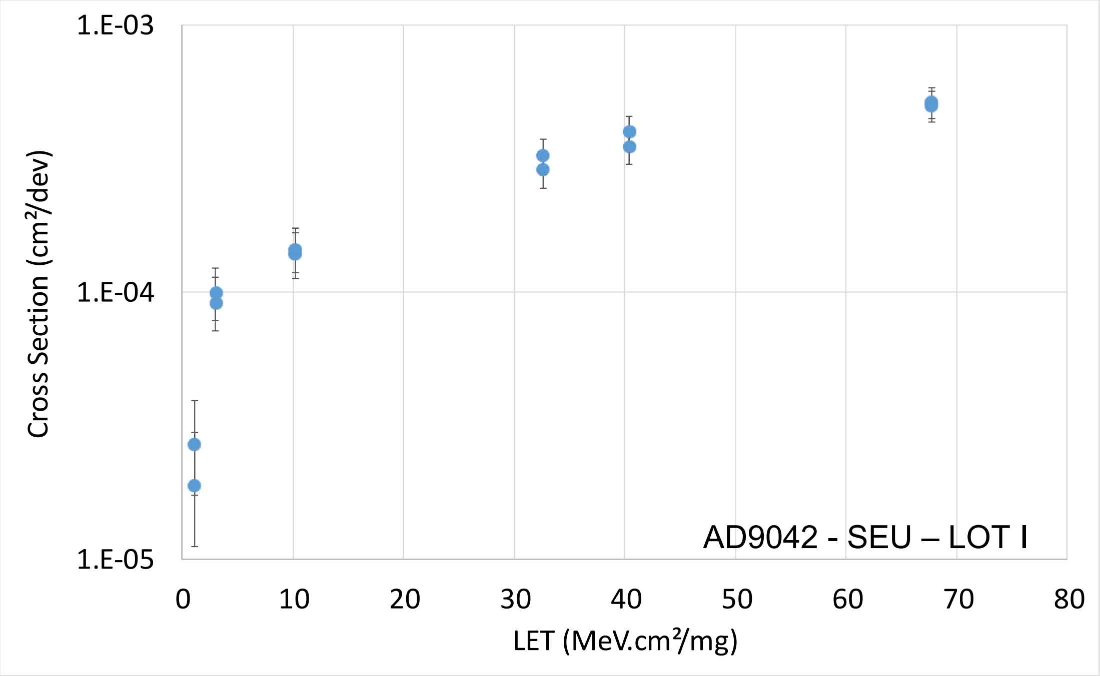


⇨ No impact of TID on SEE sensitivity whatever the reference

Synergy effect analysis

Impact of TID on SEE error bars

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

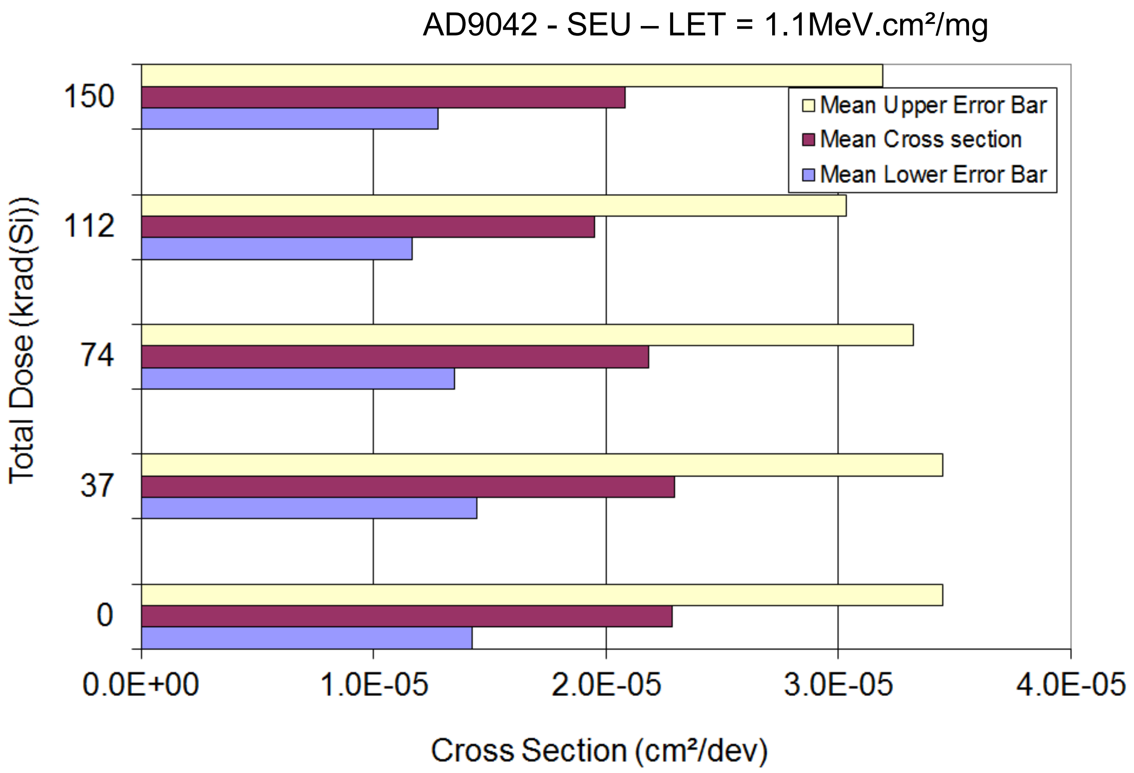


Error bars are more important for lower LET due to small statistics of events

⇒ Comparison performed for the LET closest to the LET threshold

Synergy effect analysis

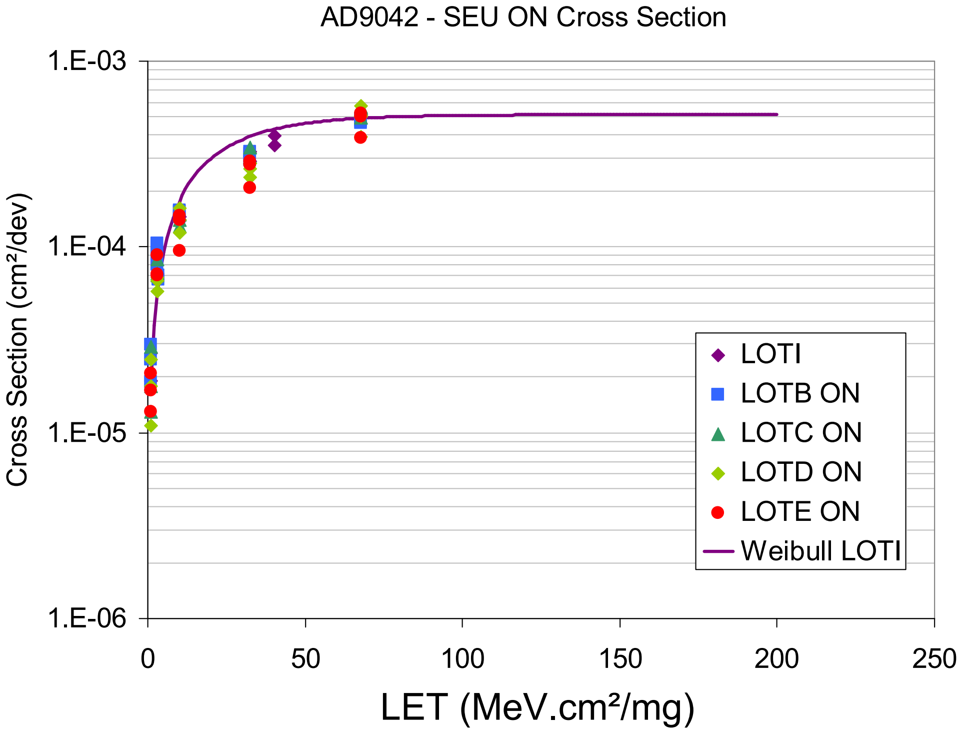
Impact of TID on SET and SEU error bars



⇨ Received dose does not have any impact on the error bars close to the LET threshold whatever the reference

Synergy effect analysis

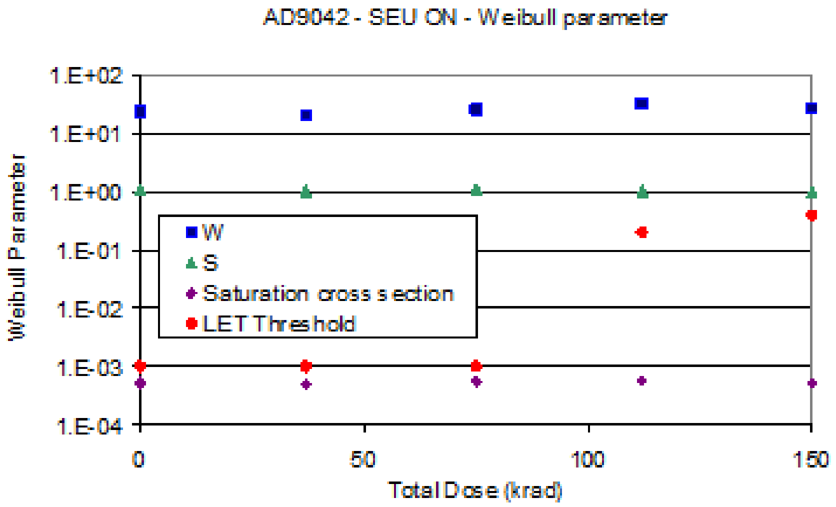
- **Impact of bias condition during TID irradiation on SEE sensitivity**

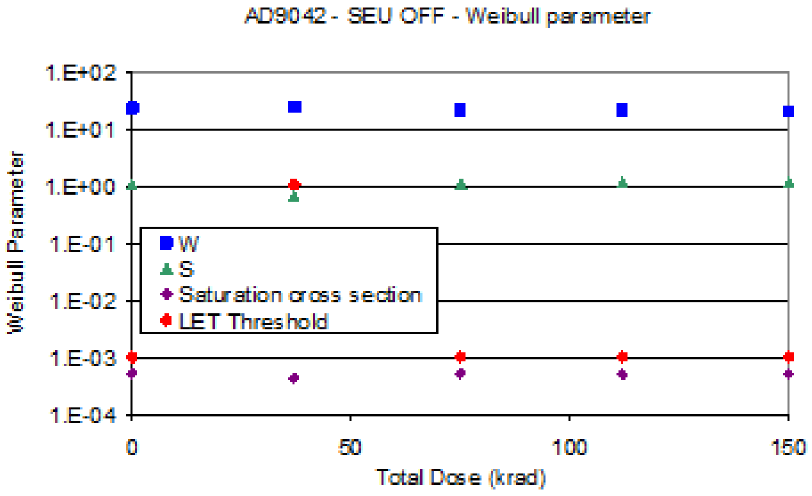


Weibull parameters are determined using the automatic fit available in the OMERE software

Synergy effect analysis

- **Impact of bias condition during TID irradiation on SEE sensitivity**

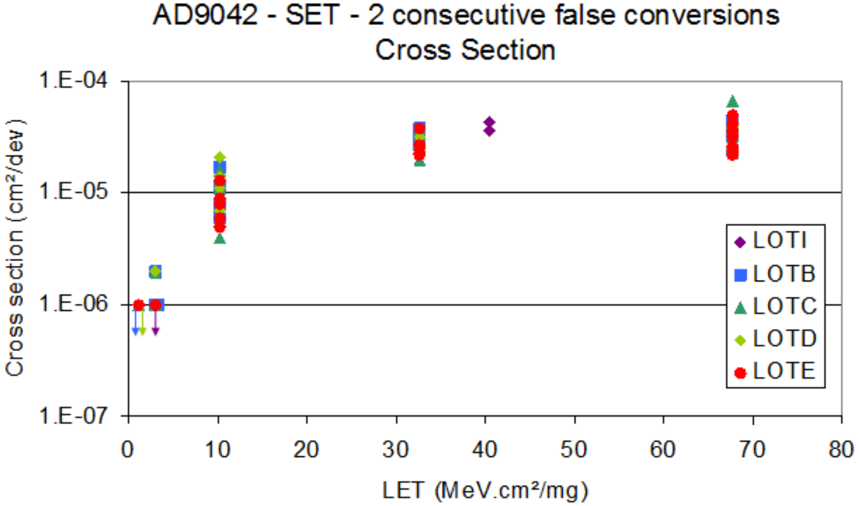


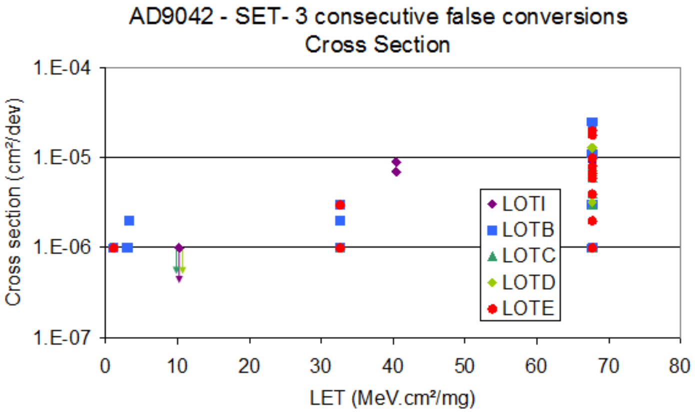


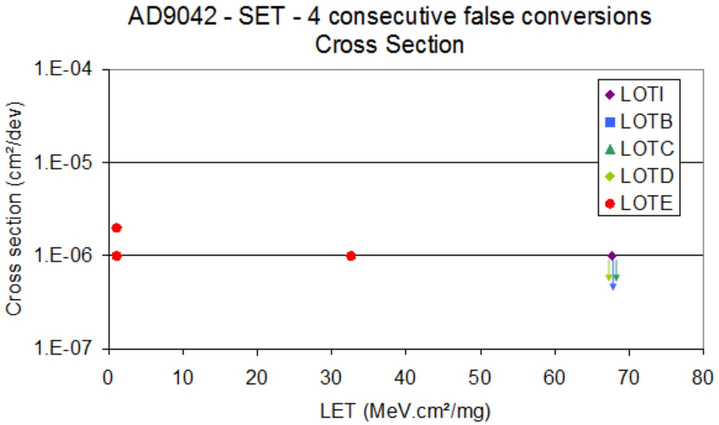
For all reference, SEU cross section curves are equivalent whatever the received dose and the bias condition during TID exposure

ADC AD9042 from Analog Device

- **Impact of TID on SET signature**



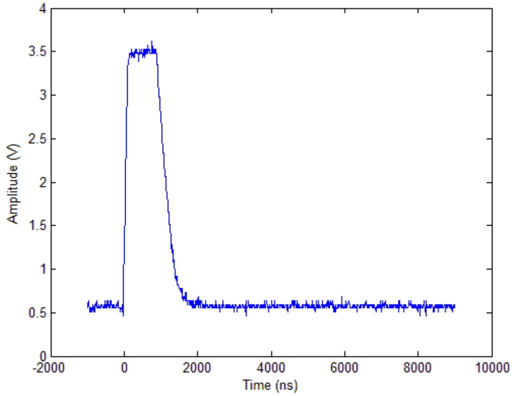


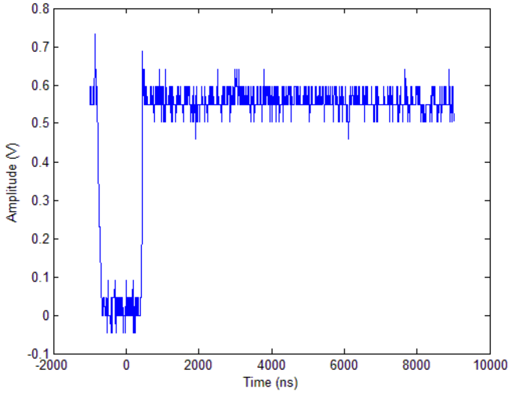


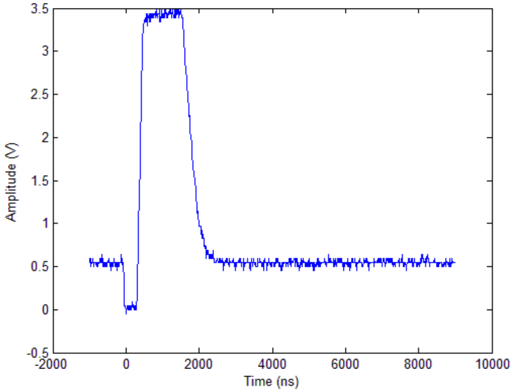
No impact of TID level on SET signature

DAC AD558 from Analog Device

Impact of TID on SET signature





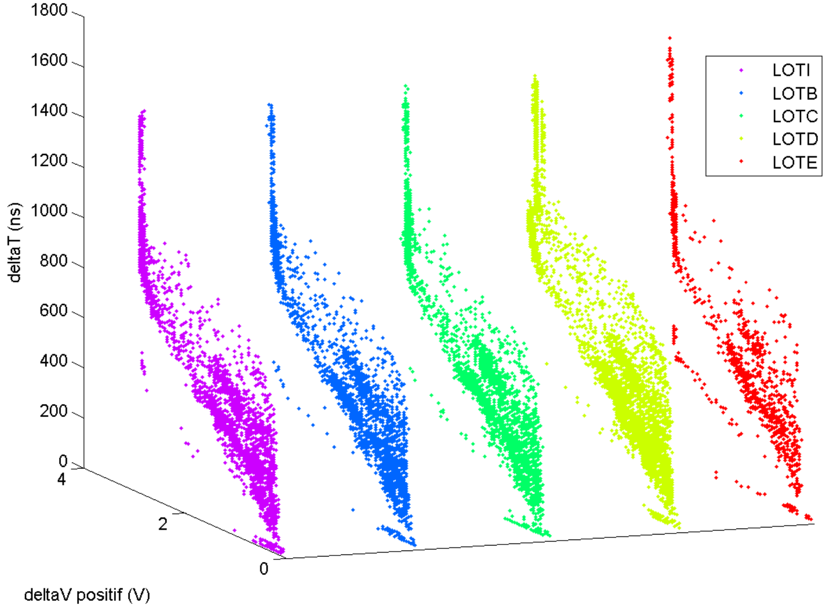


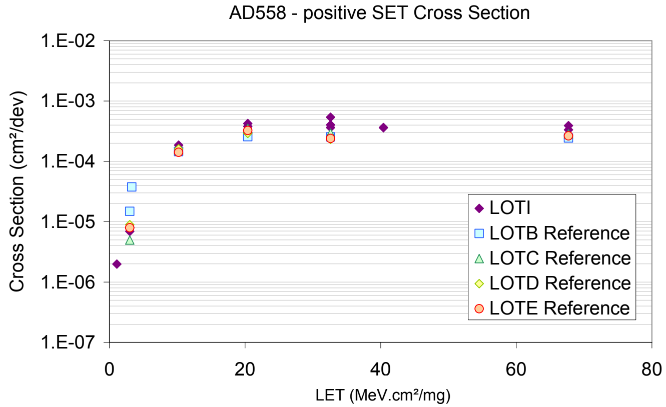
Three different signatures are observed during SET test

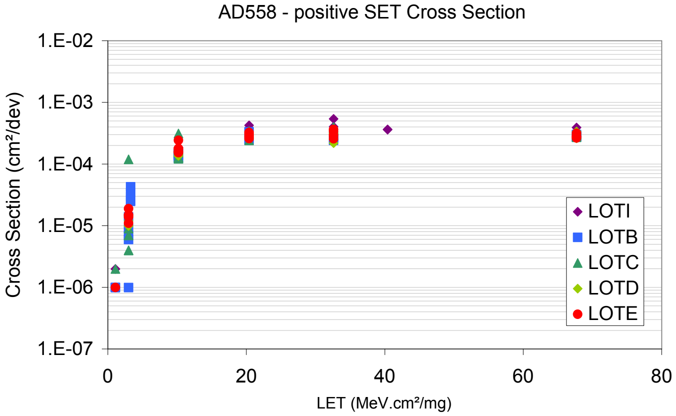
SET test results have been processed in order to evaluate if the dose level could have an impact on the SET signature

DAC AD558 from Analog Device

- **Impact of TID on SET signature**







Analysis also performed on negative and double SET
No impact of TID level whatever the SET signature

Flash NAND MT29F4G08AAC from Micron

Impact of SEE test on NAND Flash functionality

SEE test performed with Xenon ion LET (67.7 MeV.cm^2/mg)

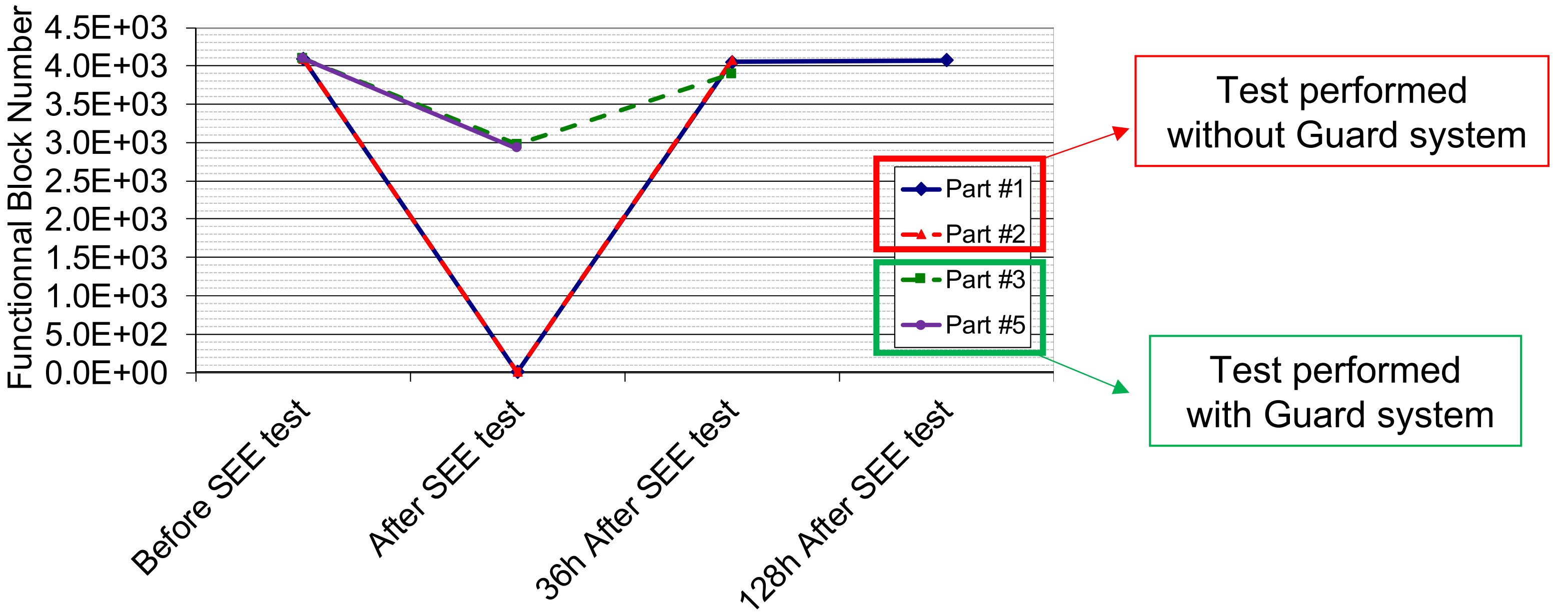
MT29F4G08ABADAWP Vcc = 3.3V T = 25°C											LATCHUP		SEE				Post Run Part Status
Run	Part	Config	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm^2/mg)	Flux (φ) (cm^{-2}.s^{-1})	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	Vcc	Cross Section	SEU	Cross Section	SEFI	Cross Section	
High LET M/Q=5																	
1	1	SEL without GUARD	124Xe 26+	420	37	67.7	7.93E+03	112	8.88E+05	0.962	0.962	-	-	-	-	-	-	Failure
2	1	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4096 Bad Block Functional Failure
3	2	SEL without GUARD	124Xe 26+	420	37	67.7	1.00E+04	1000	1.00E+07	10.853	10.853	-	-	-	-	-	-	Failure
4	2	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4096 Bad Block Functional Failure
5	3	SEU Ro	124Xe 26+	420	37	67.7	9.51E+03	17	1.62E+05	0.175	0.175	0	<6.18E-06	3084	1.91E-02	49	3.03E-04	Functional
6	3	SEL 50mA	124Xe 26+	420	37	67.7	9.81E+03	1020	1.00E+07	10.843	11.018	22	2.20E-06	-	-	-	-	Failure
7	3	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1124 Bad Block Functional Failure
8	4	SEU Ret	124Xe 26+	420	37	67.7	9.09E+03	112	1.02E+06	1.103	1.103	-	-	-	-	-	-	Failure
9	4	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	out of beam errors Functional Failure
10	5	SEU Ro	124Xe 26+	420	37	67.7	2.23E+02	497	1.11E+05	0.120	0.120	0	<9.03E-06	4848	4.38E-02	45	4.06E-04	Functional
11	5	SEU Ro	124Xe 26+	420	37	67.7	5.32E+02	411	2.19E+05	0.237	0.357	0	<4.58E-06	11042	5.05E-02	9	4.12E-05	Functional
12	5	SEL 50mA	124Xe 26+	420	37	67.7	9.80E+03	1022	1.00E+07	10.852	11.209	21	2.10E-06	-	-	-	-	Failure
13	5	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1172 Bad Block Functional Failure
14	6	SEU Ro	124Xe 26+	420	37	67.7	4.62E+02	350	1.62E+05	0.175	0.175	0	<6.19E-06	10159	6.28E-02	5	3.09E-05	Functional
15	6	Functional Test	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Functional

This tendency is observed for various fluences (from 1.65E5 p/cm^2 to 1E7 p/cm^2) and for various cumulated doses due to heavy ions .

Flash NAND MT29F4G08AAC from Micron

▪ Impact of SEE test on NAND Flash functionality

SEE test performed with Xenon ion LET (67.7 MeV.cm²/mg)



Test performed without Guard system

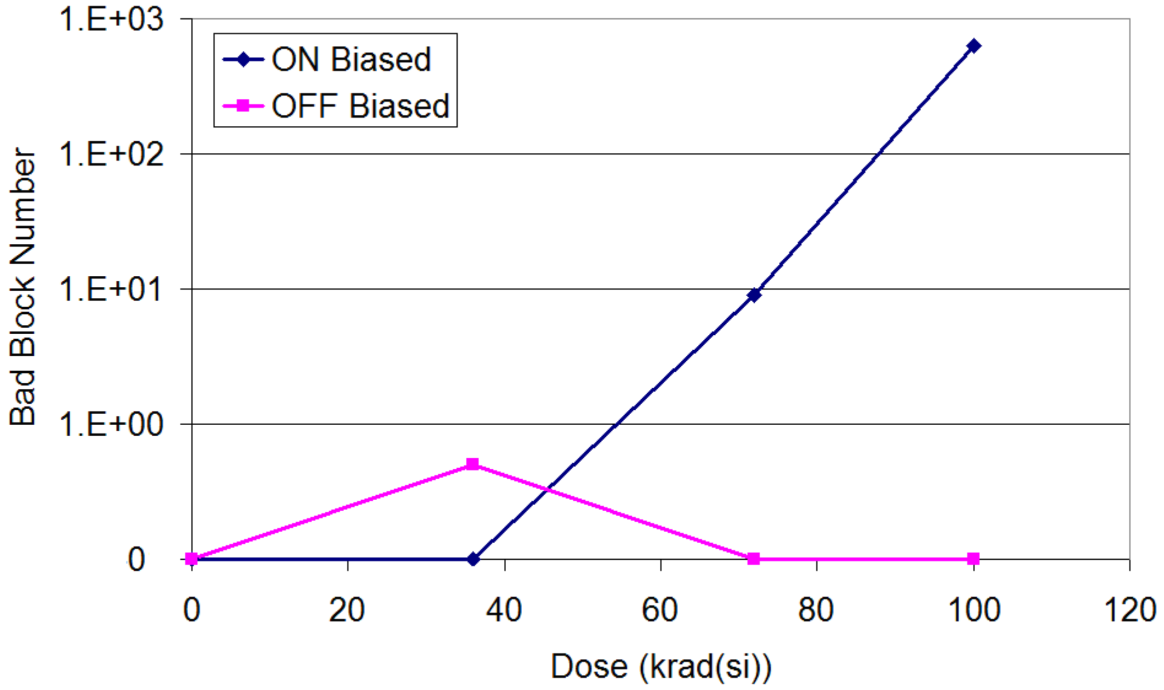
Test performed with Guard system

Component irradiated without guard system, so subject to HCE with high current, shows a more important degradation compared to part protected against SEL

=> Non permanent effect induced by High Current Event (HCE)

Flash NAND MT29F4G08AAC from Micron

Impact of TID on NAND Flash Functionality

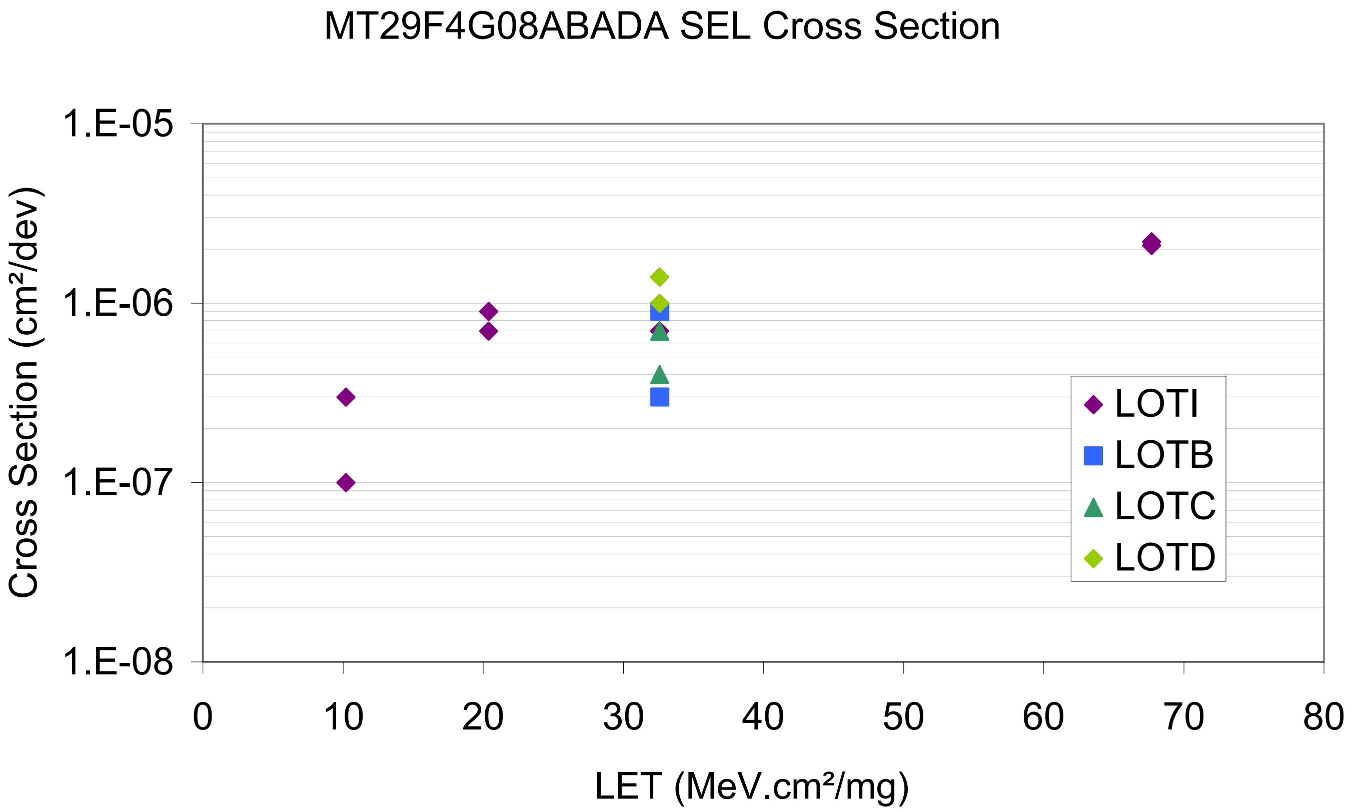


Bad Block number increases with TID level for ON biased part during Cobalt 60 irradiation.

This means that one or more memory cell is no more writable in the bad block after TID exposure.

Flash NAND MT29F4G08AAC from Micron

▪ Impact of TID on HCE sensitivity

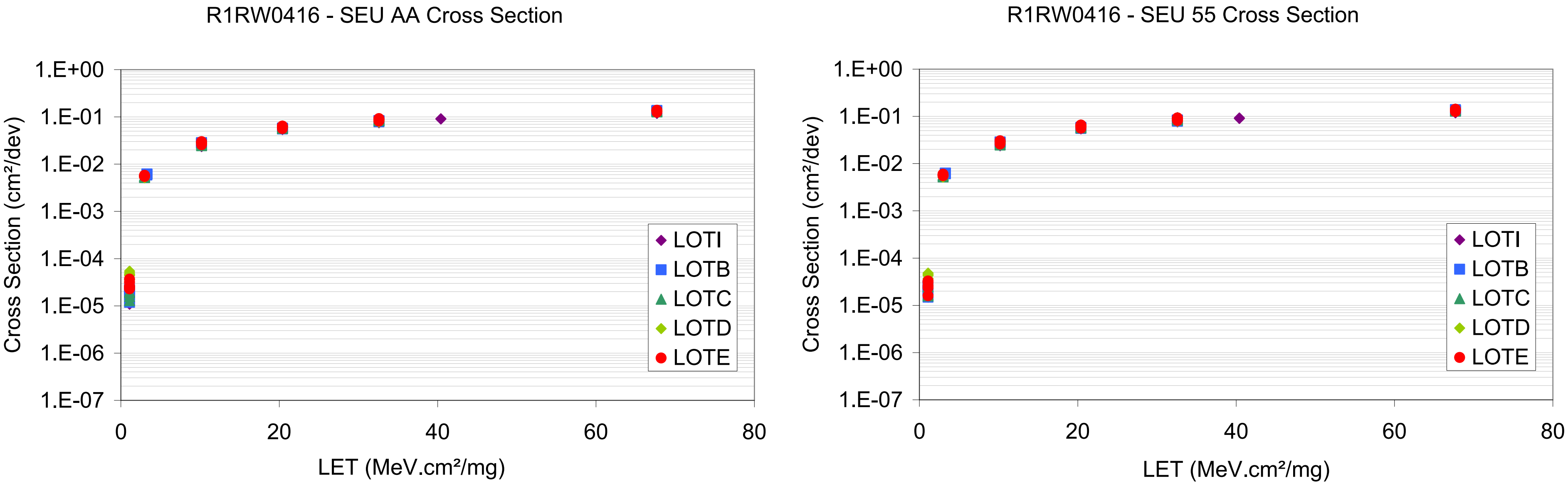


TID does not have any impact on HCE number

SRAM R1RW0416 from Renesas

Impact of TID on SEU signature: imprint effect

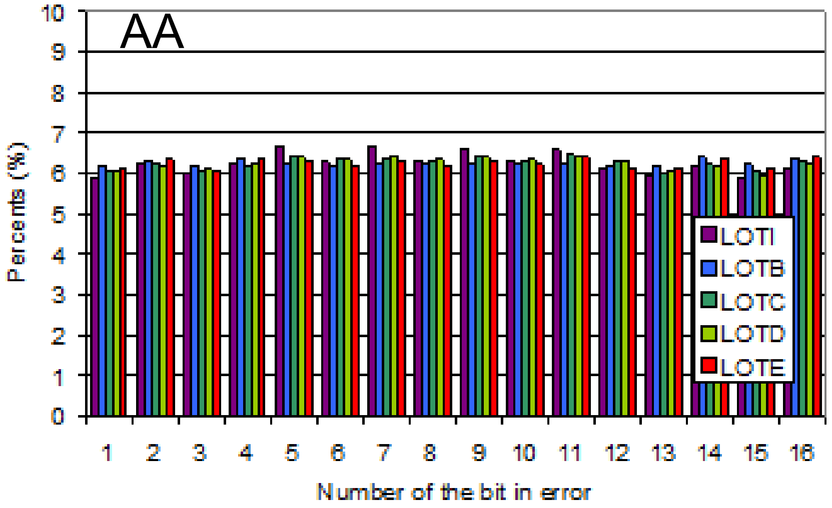
- During TID test, all devices were written using the pattern AA. All components were tested under heavy ions using the pattern AA on half of the memory and using 55 on the other half.

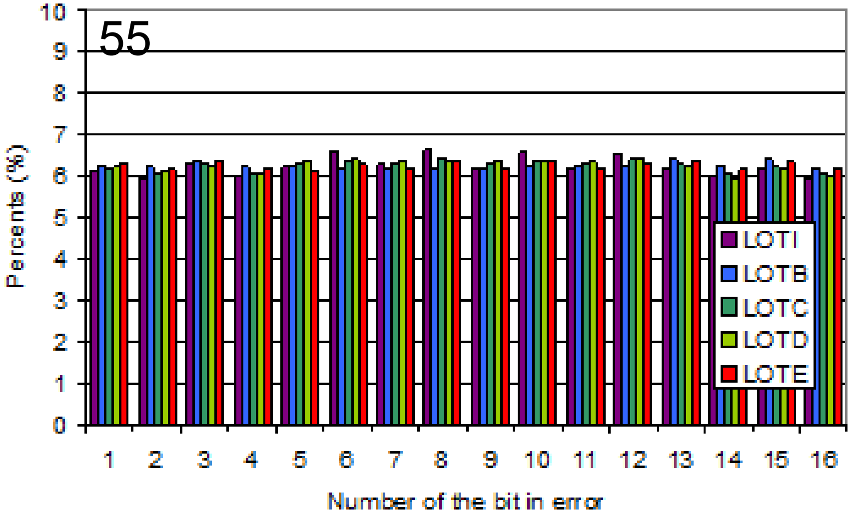


No imprint effect is observed

SRAM R1RW0416 from Renesas

- **Impact of TID on SEU signature: imprint effect**

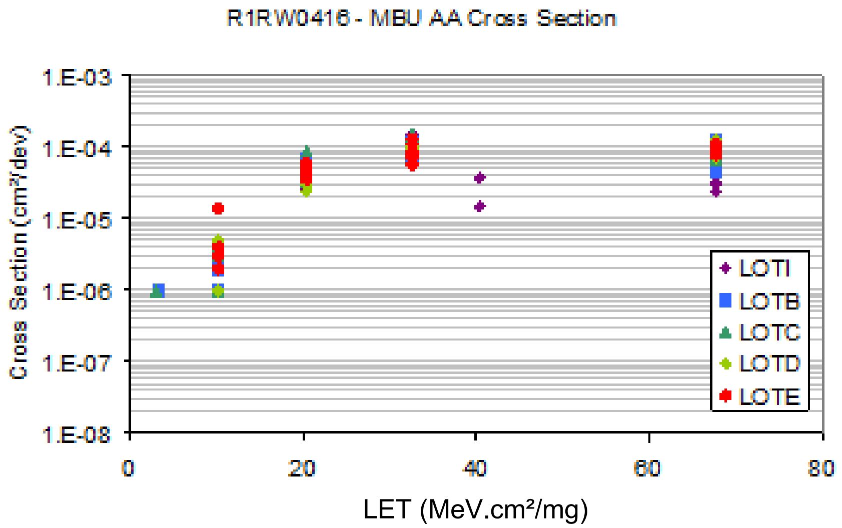


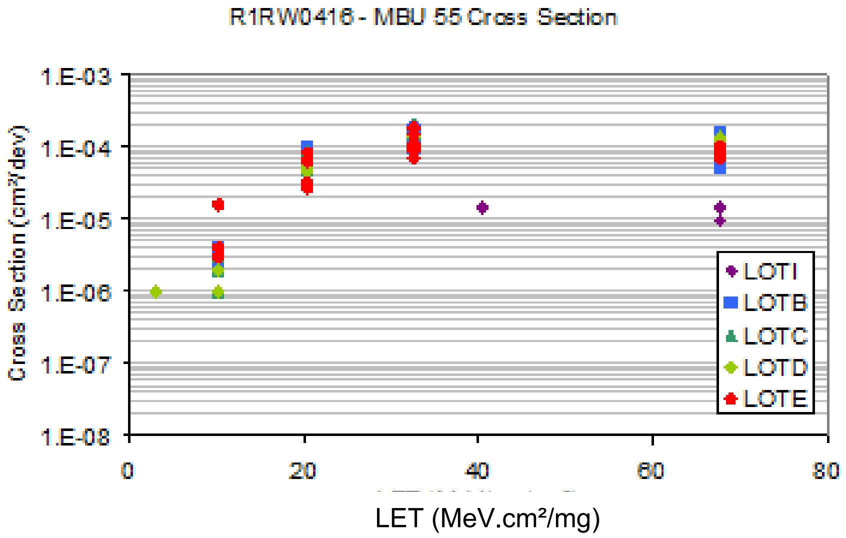


TID has no impact on SEU localisation in the tested word

SRAM R1RW0416 from Renesas

Impact of TID on MBU multiplicity

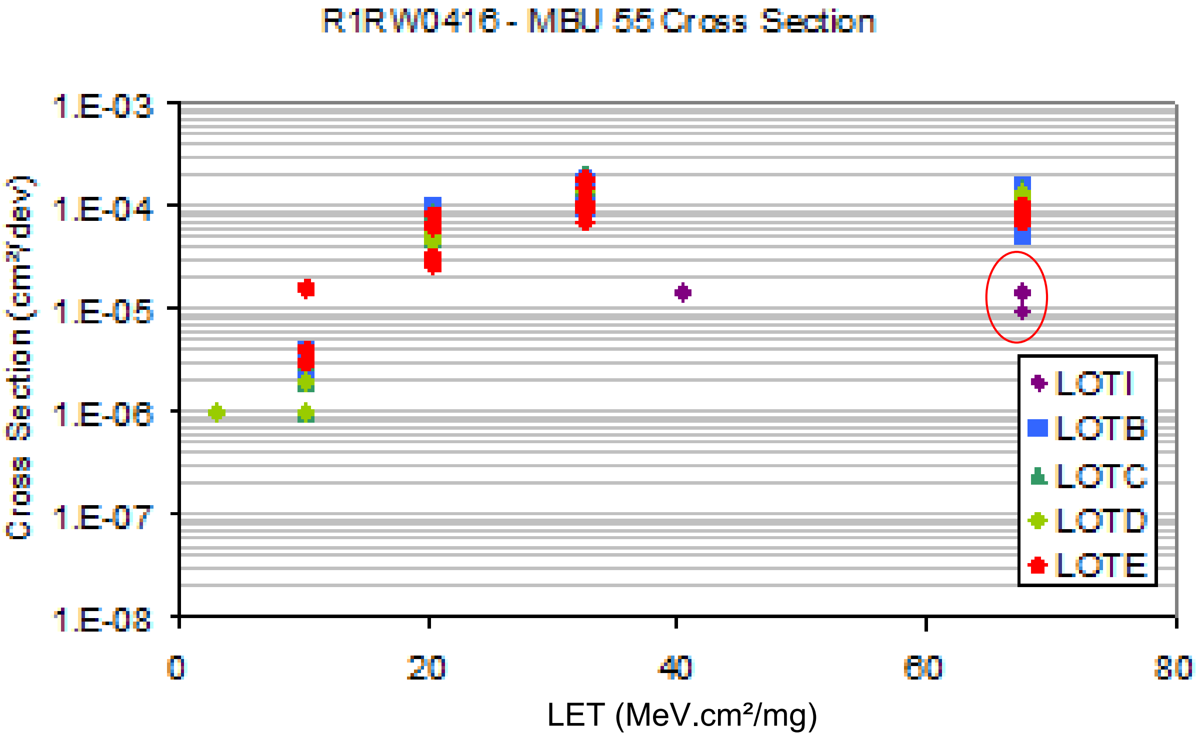




No sensitivity difference is observed whatever the pattern used.
No Imprint effect is observed on MBU effect

SRAM R1RW0416 from Renesas

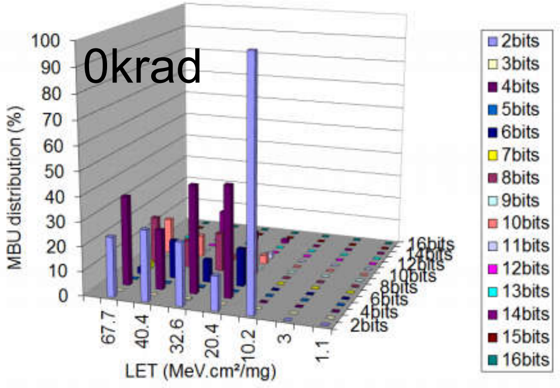
MBU test results

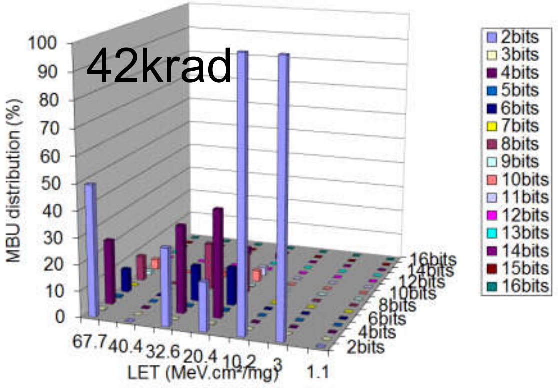


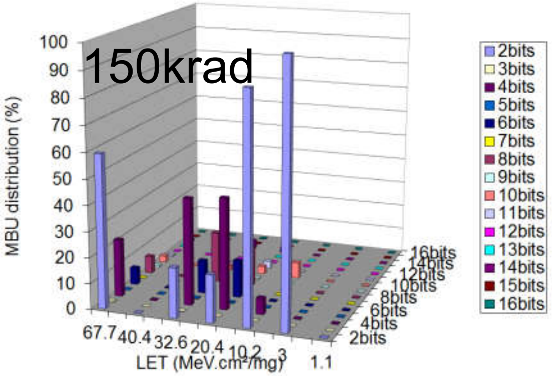
MBU cross section curves are different between LOTI and other LOTs

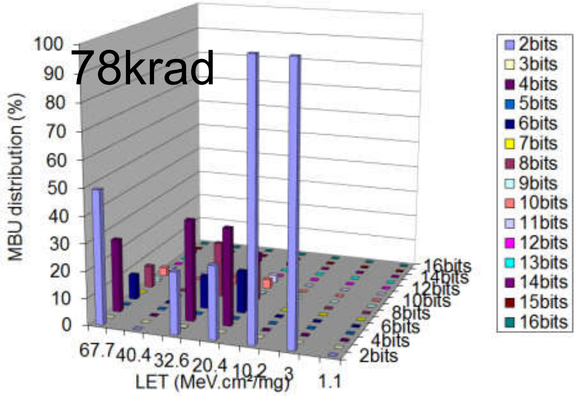
SRAM R1RW0416 from Renesas

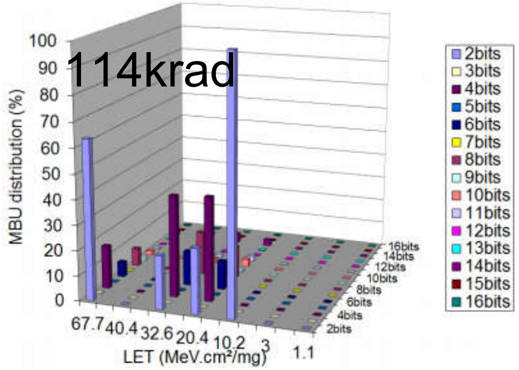
▪ MBU test results







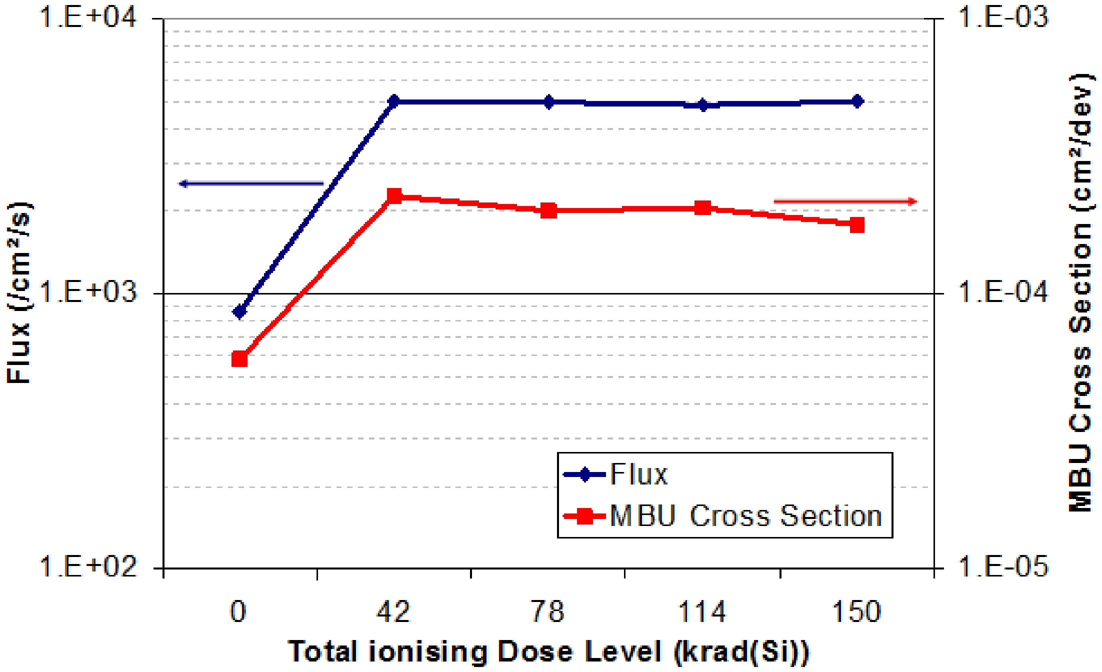




Atypical MBU multiplicity

SRAM R1RW0416 from Renesas

- ## MBU test results



Mean cross section obtained at 67.7MeV.cm²/mg and flux used in function of LOT tested

MBU event increase when flux increase

SRAM R1RW0416 from Renesas

MBU test results

DUT data	Reference Data	Address	Error Type	Address cycle	Timestamp
0505	5555	2152D	4	8	20.878111
0505	5555	2152D	4	8	20.878111
5555	0505	2152D	2	9	20.993462

SEU

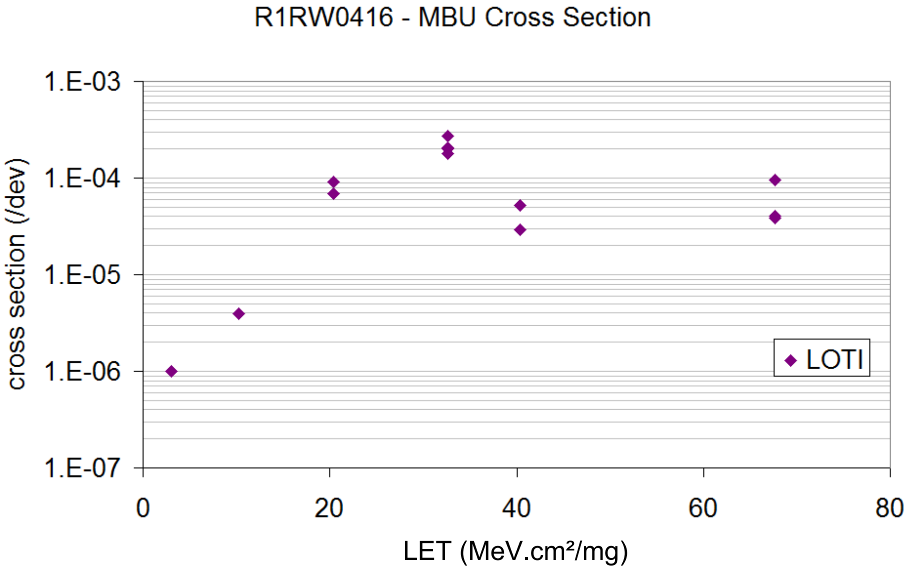
Stuck Bit => erroneous pattern is written in the reference memory

next read cycle, at same address, pattern 5555 is read instead of 0505.

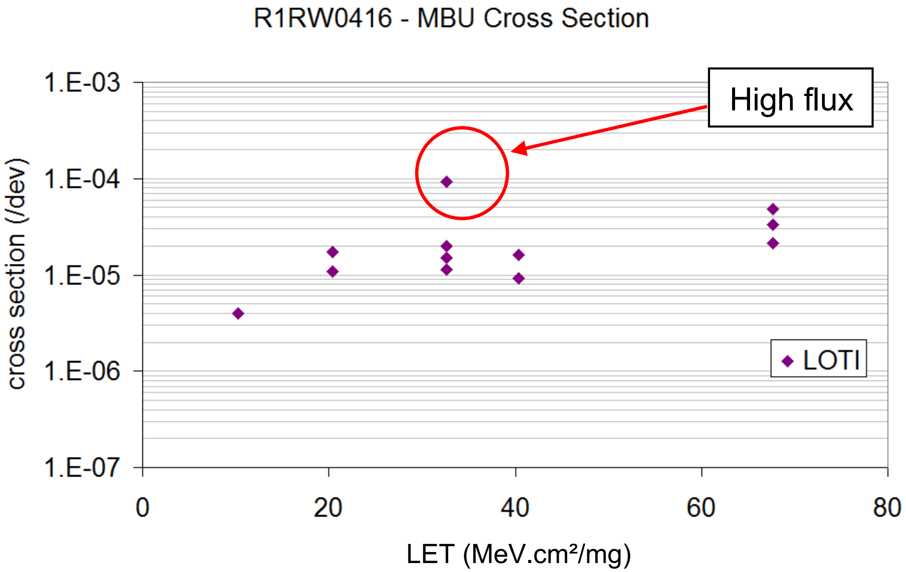
⇒ SEE on the peripheral circuitry of the SRAM detected as transient MBU on the memory array

SRAM R1RW0416 from Renesas

MBU test results



Before treatment



After treatment

⇒ All SEE on peripheral circuitry are not suppressed during treatment

⇒ No sufficient information on recorded errors are available to perform a complete treatment