DOCUMENT

Single Event Latch-up (SEL) analysis of the 256k x 16 SRAM Samsung K6R4016V1D-TC10 Heavy ion and Proton Test Report Comparison with the Proba-2 GPS Phoenix SEL rate

Prepared by	**Véronique Ferlet-Cavrois, Michele Muschitiello, Marco D'Alessio**
Reference	
Issue	**1**
Revision	**2**
Date of Issue	**10/06/2013**
Status	**Issue 1**
Document Type	**TR**
Distribution	

APPROVAL

Title Single Event Latch-up analysis of the 256kx16 SRAM Samsung K6R4016V1D-TC10	
Issue 1	**Revision** 2
Author Véronique Ferlet-Cavrois (TEC-QEC)	**Date** 10/06/2013
Approved by	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue	Revision		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

Prepared by	**Véronique Ferlet-Cavrois, Michele Muschitiello, Marco D'Alessio**
Reference	
Issue	**1**
Revision	**2**
Date of Issue	**10/06/2013**
Status	**Issue 1**
Document Type	**TR**
Distribution	

Table of contents:

1 INTRODUCTION

This study was undertaken to analyse the latch-up rate observed on the GPS Phoenix receivers flying aboard Proba-2. A first experiment was performed in June 2010 at PSI (Villigen, Switzerland) on the flight model of the GPS receiver board under collimated proton irradiation [RD1]. This experiment was prepared by both ESA for radiation support and DLR who designed the GPS Phoenix board. The experiment identified that the latch-ups were generated in a 256k × 16bits SRAM K6R4016V1D-TC10 from Samsung.

Following this experiment of the complete board, it was decided that the memories should be tested as stand-alone devices to complete the characterisation under both protons and heavy ions. DLR provided memories to ESA from the same procurement batch as those flying aboard Proba-2 (date code DC220), and another batch procured after (date code DC328). In addition, ESA TEC-QEC procured a later date code (DC922) of the same Samsung reference, and another type of SRAM memory, 128k ×16bits SRAM IS61LV12816 from ISSI, for test and comparison.

This report gather the test results obtained on three date codes (DC220, DC328, DC922) of the Samsung SRAM, and one date code (DC1021) of the ISSI SRAM. Two experiments were performed, one under protons at KVI (Groningen, Netherlands), and another one under heavy ion at RADEF (Jyväskylä, Finland).

The expected latch-up rate is calculated from the KVI and RADEF test results for the DC220 Samsung memory, and compared to the Proba-2 GPS in-flight data.

The tests and analysis were performed in coordination with the Proba-2 project and DLR, and with the manpower and financial support from the TEC-QEC Technical Assessment.

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable documents

[AD1] ESCC25100, "Single Event Effect Test Method and Guidelines"

2.2 Reference documents

[RD1] DLR Phoenix GPS Receiver Radiation Characterisation Campaign Proton Irradiation Testing at PSI June 2010 Test Report

[RD2] KVI facility at Groningen, Netherlands, http://www.rug.nl/kvi/facilities/agor/

[RD3] A. Virtanen, R. Harboe-Sorensen, A. Javanainen, H. Kettunen, H. Koivisto, I. Riihimaki, "Upgrades for the RADEF Facility," IEEE Radiation Effects Data Workshop, pp. 38-41, July 2007.
See also RADEF facility at Jyväskylä, Finland, https://www.jyu.fi/fysiikka/en/research/accelerator/radef/.

[RD4] Datasheet of the 256k ×16bits CMOS SRAM, K6R4016V1D-TC10, 3.3V supply, from Samsung

[RD5] Datasheet of the 128K x 16bits CMOS SRAM, IS61LV12816-12T, 3.3V supply, from ISSI

[RD6] Guard Sytem User Guide provided by TRAD company, ref. TRAD/GRDSYS/USERMAN/DC/0506

[RD7] M. D'Alessio, C. Poivey, V. Ferlet-Cavrois, R. Harboe-Sørensen, F. X. Guerre, F. Lochon, S. Santandrea, A. Mohammadzadeh, M. Muschitiello, M. Markgraf, O. Montenbruck, A. Grillenberger, N. Fleurinck, K. Puimege, D. Gerrits, P. Matthijs "SRAMs SEL and SEU In-Flight Data From PROBA-II Spacecraft" RADECS 2013.

3 TESTED DEVICES

Procured by	Manufacturer	Reference	Date code	Lot code	Available samples at TEC-QEC
DLR Proba-2 FM	Samsung	K6R4016V1D-TC10	DC 220	TANAO6EE KOREA	6 samples
DLR 2nd batch	Samsung	K6R4016V1D-TC10	DC 328	TANE21A1 KOREA	10 samples
ESTEC TEC-QEC	Samsung	K6R4016V1D-TC10	DC 920	TAND51P4	~50 samples
ESTEC TEC-QEC	ISSI	IS61LV12816-12T	DC 1021	WB839206P	~50 samples

Table 1: description of tested SRAMs

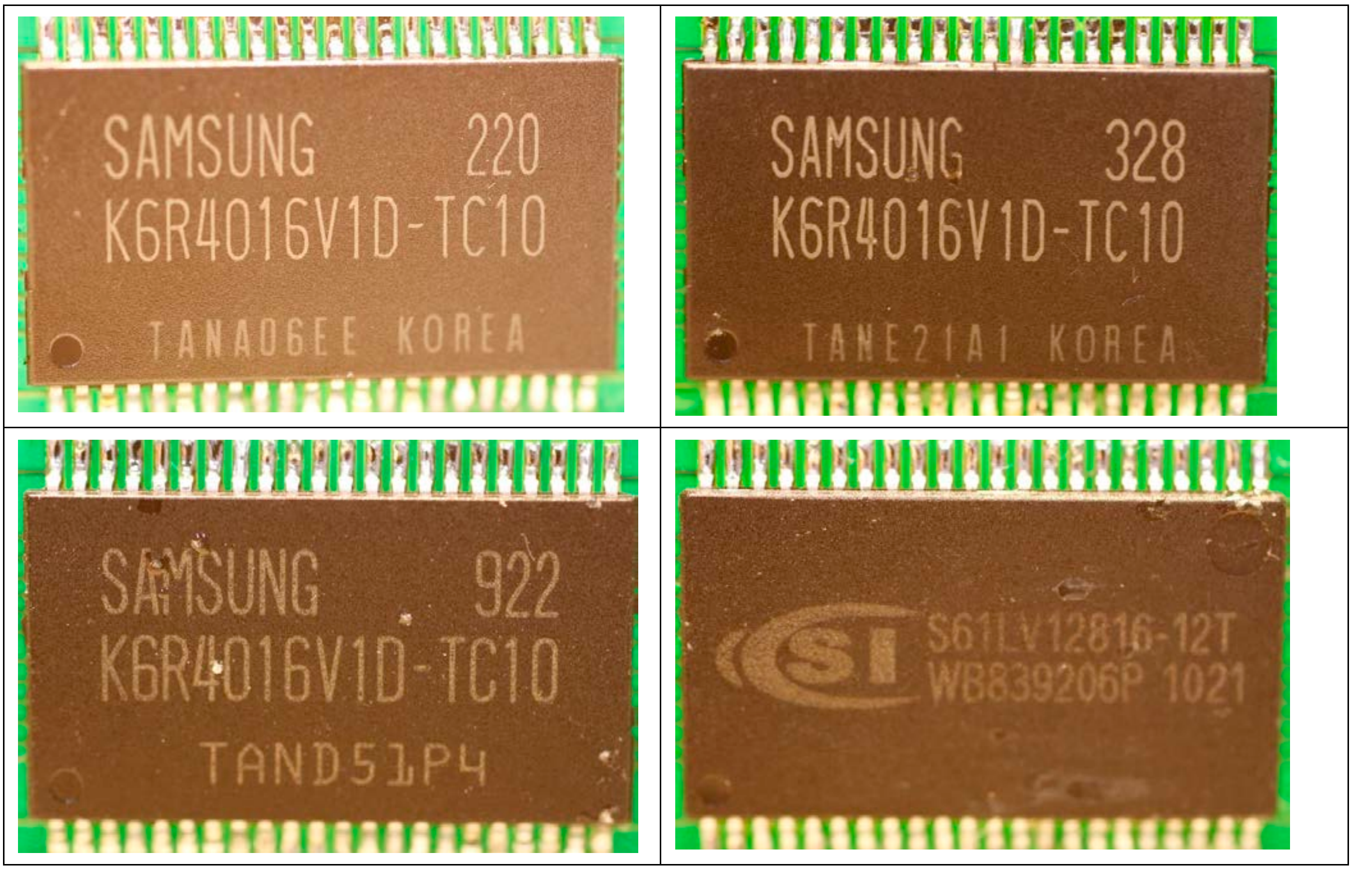


Figure 1 – Package pictures of tested devices

For proton tests, the devices were tested as is, without opening the packages. This is common practice for proton tests because the proton range, even at the lowest energy is large compared to the thickness of the plastic package. The plastic package of the SRAMs was open for heavy ion testing only. The pictures of the opened devices are gathered in Appendix 1.

4 TEST FACILITIES

Two experiments were performed, one at KVI in January 2012, one at RADEF in May 2012.
Both experiments were performed at **room temperature**.

Experimenters: Véronique Ferlet-Cavrois, Michele Muschitiello (ESA ESTEC, TEC-QEC)

Facility: KVI, Groningen, Netherlands [RD2]

Operator: **Reint Ostendorf (KVI)**

Date: 18 January 2012

Energy: primary energy 38.6 MeV

energy on DUT 27.9 MeV at maximum, Steps of energies, obtained with Al degrader

E (MeV) on DUT	27.9	25.8	23.5	21.1	18.4	15.4	11.8
Al deg. (mm)	0	0.5	1	1.5	2	2.5	3

Date: 19 January 2012

Energy: primary energy 190 MeV

energy on DUT 184.5 MeV at maximum, steps of energies, obtained with Al degrader

E (MeV) on DUT	184.5	150	120	100	80	60	50
Al deg. (mm)	0	32	56	70	81.5	91.5	95.5

Facility: RADEF, Jyväskylä, Finland [RD3]

Operators : Heikki Kettunen, Mikko Rossi (RADEF)

Cocktail 9.3 MeV/nucleon, test in vacuum with diffuser foil in place (1µm W)

Date: 29 May 2012

Ions: Ar 372 MeV, range 118µm, LET 10.1MeVcm^2/mg

Ne 186 MeV, range 146µm, LET 3.6MeVcm^2/mg

Date: 31 May 2012

Ions: Kr 768MeV, range 94µm, LET 32.1MeVcm^2/mg

N 139MeV, range 202µm, LET 1.8MeVcm^2/mg

5 TEST CONDITIONS

All SRAMs were irradiated at room temperature, at the maximum supply voltage, 3.6V [RD4, RD5]. Table 2 shows the bias current versus operating mode recorded before irradiation for the Samsung memory. These values are consistent with datasheet specifications.

Mode	Stand-by	Read	Write
Control signals	/CE high and /OE low	/CE low and /OE low	/CE low and /OE high
Bias current	~ 1-2 mA	~ 2 mA	~ 50mA

Table 2: Current levels vs. operating mode for the Samsung SRAMs

The effect of two operating modes, Read or Stand-by, was tested during the first runs of irradiation at KVI. However, no significant impact was noted. All irradiation test runs were then performed in stand-by. During irradiation, inputs are grounded (Addresses, Data, lower and upper byte control).

Latch-up are detected with the GUARD system from TRAD [RD6]. The power supply is applied to the device under test (DUT) through the GUARD system (Figure 2). A latch-up event is detected when the supply current exceeds the threshold current (Figure 3). The power supply is then maintained during the "Hold time" to check that the current is self-sustainable (latch-up signature) and not a current transient. It is then switched off ("Cut-off time") before being reapplied on the DUT. The values of the current threshold, hold and cut-off times, are specified in the irradiations logs.

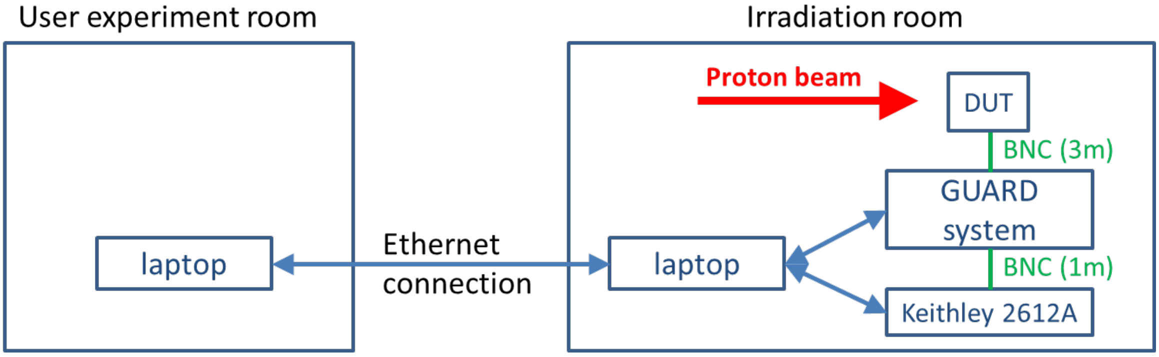


Figure 2 – Test setup

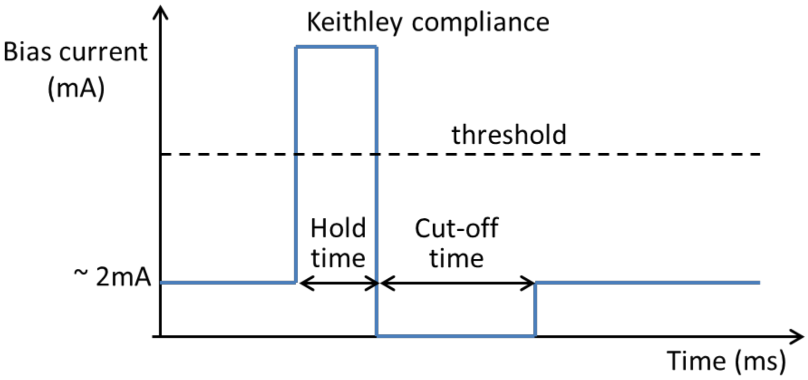


Figure 3 –GUARD system monitoring of a SEL event [RD6]

6 TEST RESULTS

6.1 KVI experiment

Irradiation test log is compiled in Appendix 2.

Figure 4 shows the measured SEL cross-section versus proton energy for the Samsung memories. The ISSI SRAM did not show latch-up up to a cumulated fluence of about 1E7 protons/cm2 at maximum energy (184.5MeV). SEL proton data for DC220 are fitted with a Weibull function (Table 3).

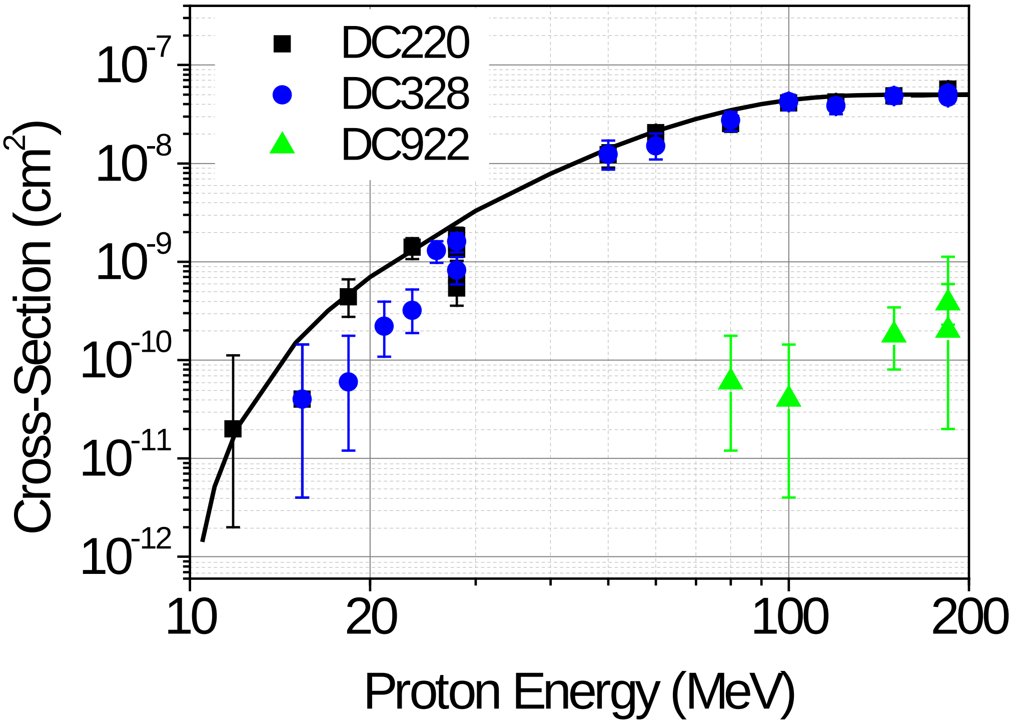


Figure 4: SEL Cross-section versus proton energy at KVI for the Samsung SRAMs. Error bars are plotted for a 95% confidence level.

Date Code	Onset Energy (MeV)	exponent	Width (MeV)	Asymptotic cross-section (cm^2)
DC220	9.8	2.3	65	5.0E-8

Table 3: Weibull fit for the proton data of the Samsung SRAMs, DC220

It was observed that DC220 is particularly sensitive to combined effects: the SEL cross-section increases when the cumulated dose under protons increases (Figure 5). The SEL rate increases linearly with dose: for the DC220, it increases by more than a factor of 2 every 50krad. DC328 is also sensitive, but to a lesser extent compared to DC220.

This increase of the SEL rate with dose is not a concern for LEO orbits (like Proba-2) because the dose received by electronic equipments is usually less than 5krad. It should rather be considered as an experimental artefact that can jeopardise test results when the received dose during experiments reaches several 10's of krad. In our case, these TID degraded SEL data have been removed from the SEL cross-section versus proton energy curves (Figure 4).

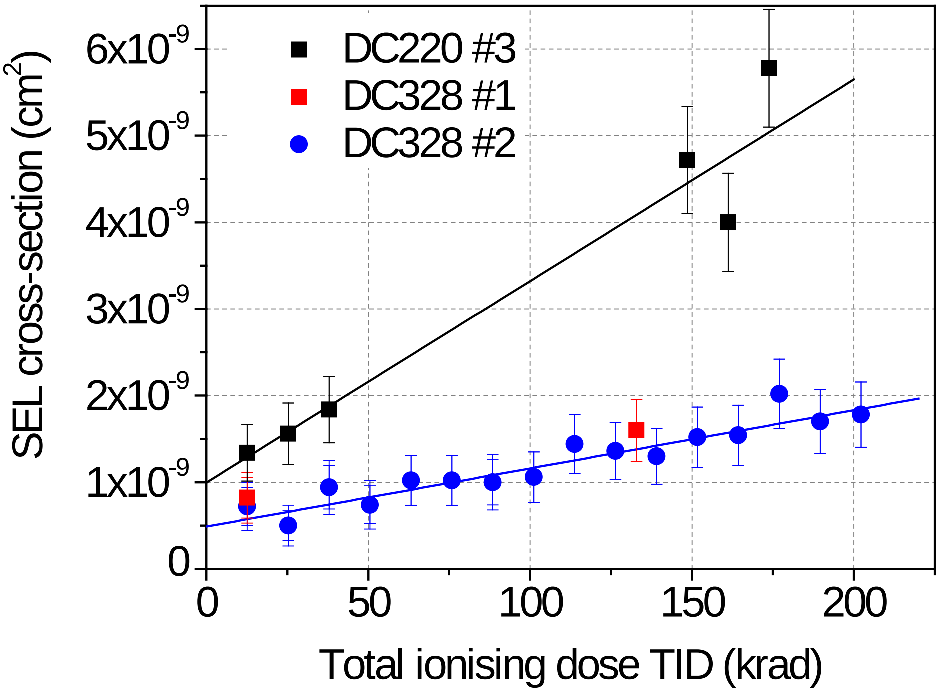


Figure 5: : SEL Cross-section versus received dose (TID) during proton irradiation at KVI for the Samsung SRAMs, DC220 and DC328, at proton energy of 27.9MeV. Error bars are plotted for a 95% confidence level.

6.2 RADEF experiment

Irradiation test log is in Appendix 3.

Figure 6 shows the measured SEL cross-section versus ion LET for the Samsung memories. The ISSI SRAM did not show latch-up up to a cumulated fluence of about 1E7 ions/cm2 under Kr irradiation (LET 32.1 MeVcm2/mg). SEL heavy ion data are fitted with a Weibull function (Table 4).For all samples during the heavy ion experiment, the received TID remained below 10krad. The TID induced variations on the measured SELs remained below the statistical and sample to sample variations.

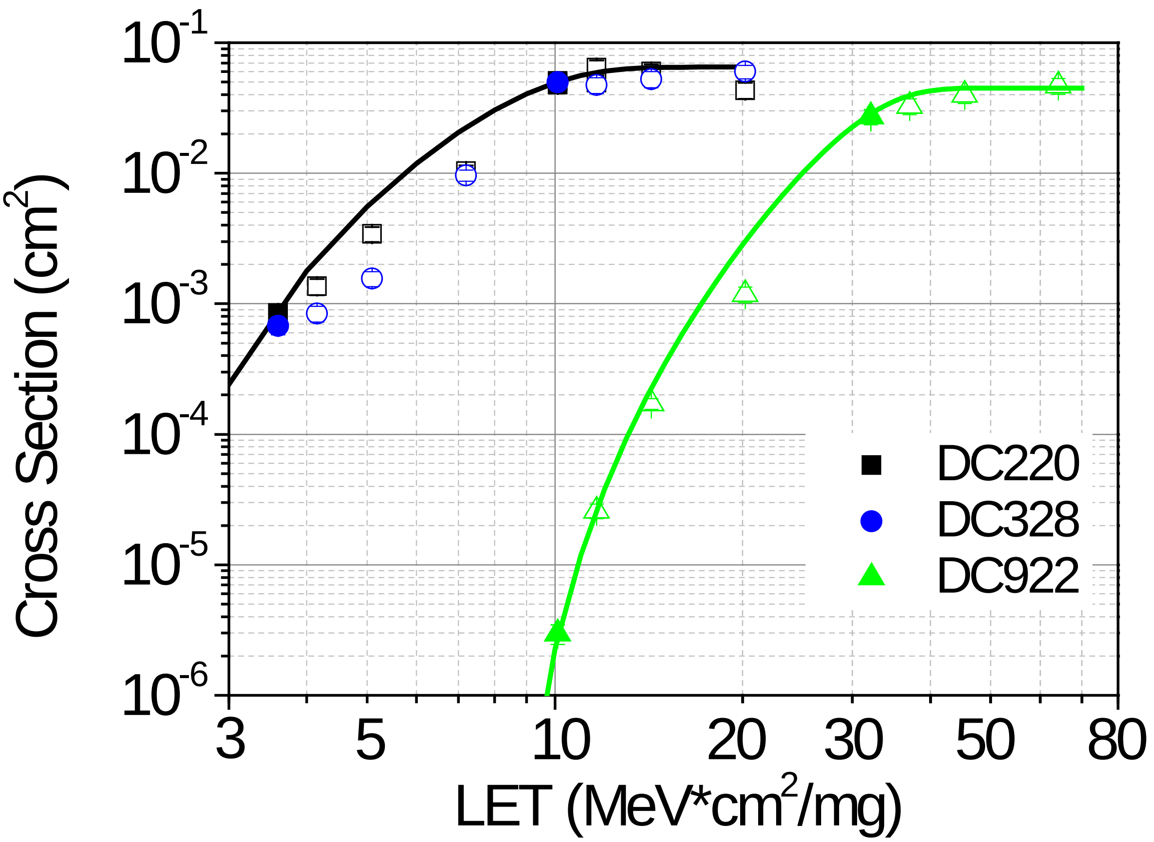


Figure 6: SEL Cross-section versus proton energy at RADEF for the Samsung SRAMs. SELs in normal incidence are in full symbols; tilted SELs (30°, 45°, 60°) are in open symbols. Error bars are plotted for a 95% confidence level (i.e. 2 σ)

Date Code	Onset LET (MeVcm²/mg)	exponent	Width (MeVcm²/mg)	Asymptotic cross-section (cm²)
DC220 and DC328	1.0	3.5	9	6.0E-2
DC922	8.1	3.9	24	4.5E-2

Table 4: Weibull fit for the heavy ion data of the Samsung SRAMs

7 SEL RATE CALCULATION– COMPARISON WITH THE PROBA-2 GPS IN-FLIGHT DATA

Figure 7 shows the observed SELs from October 2010 to December 2012. A large majority of the SELs are observed in the South Atlantic anomaly, due to trapped protons in the radiation belts. The others are mostly found in the polar regions, and few are randomly distributed on the map.

The details of the SEL rate calculation from ground test results (protons and heavy ions) for the Proba-2 orbit (sun-synchronous LEO, 800km, 98deg.) are provided in [RD7]. The results are gathered in Table 5. We considered 10 mm of Aluminium shielding, and, for the memory, 4M 1 µm thick sensitive volumes. The SEL rate calculations were obtained with CREME96, and from the average of the solar maximum and minimum conditions. This is to reflect the fact that the evaluated time period (Oct. 2010 – Dec. 2012) is between these two conditions (Appendix 4).

The calculated SEL rate (0.3 SEL/day) is lower than the measured in-flight value (0.4 SEL/day) by a factor of 1.3.

The origin of this discrepancy can be a combination of the following reasons:

- Temperature of the GPS aboard Proba-2 is about 43-46°C, while all tests in this report have been done at room temperature. However, it has been shown before in many works that SEL increases with temperature. The SEL prediction from ground test therefore underestimates the in-flight SEL rate.
- Proton test of unopened devices. The sensitivity to protons at low energy might be underestimated. However this is partly compensated by the fact that the tested SRAMs (especially DC220) are sensitive to cumulated effects; their SEL rate increases with TID, i.e. proton fluence at low energy.
- Sample to sample variations
- Uncertainty on the space radiation environment.

Solar activity	Trapped protons	GCR protons	GCR heavy ions	Total (#SEL/day)	Average calculated SEL (#SEL/day)	Proba-2 GPS (#SEL/day)
Maximum	0.207	0.0027	0.0039	0.214	**0.3**	**0.4**
Minimum	0.352	0.0075	0.0187	0.378		

Table 5: SEL rate calculations for the Samsung DC220 flying on the Proba-2 GPS. CREME96 in solar maximum and minimum conditions

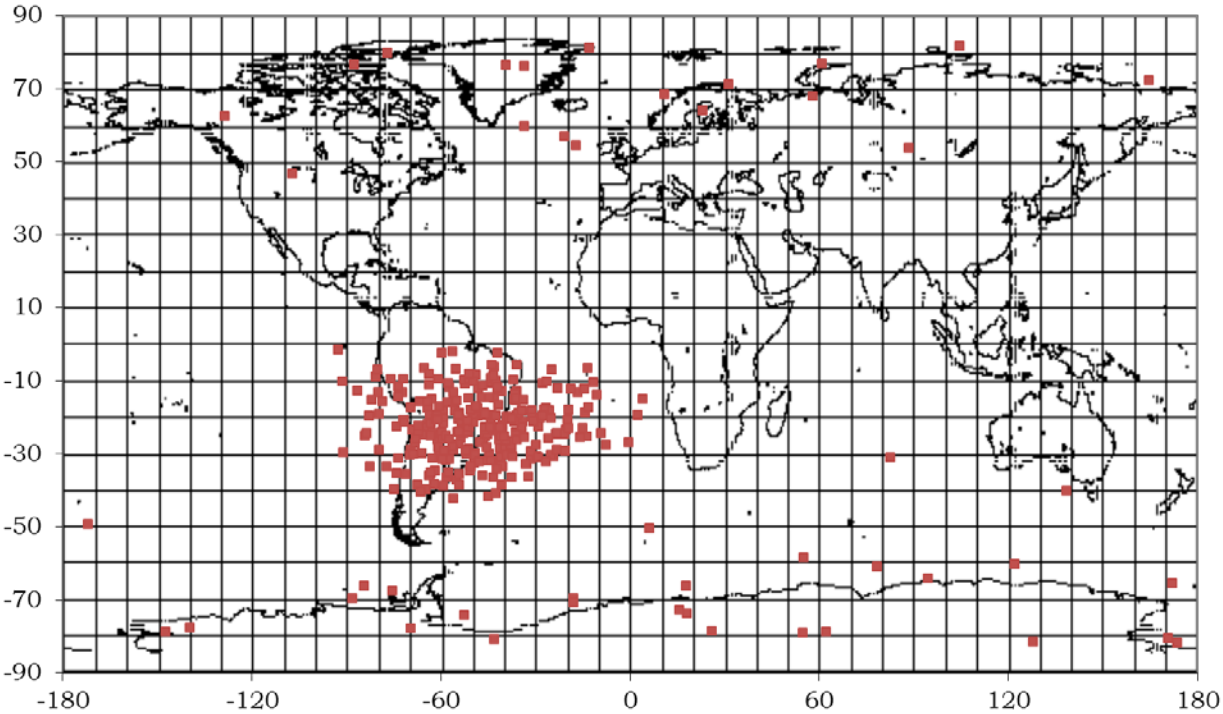
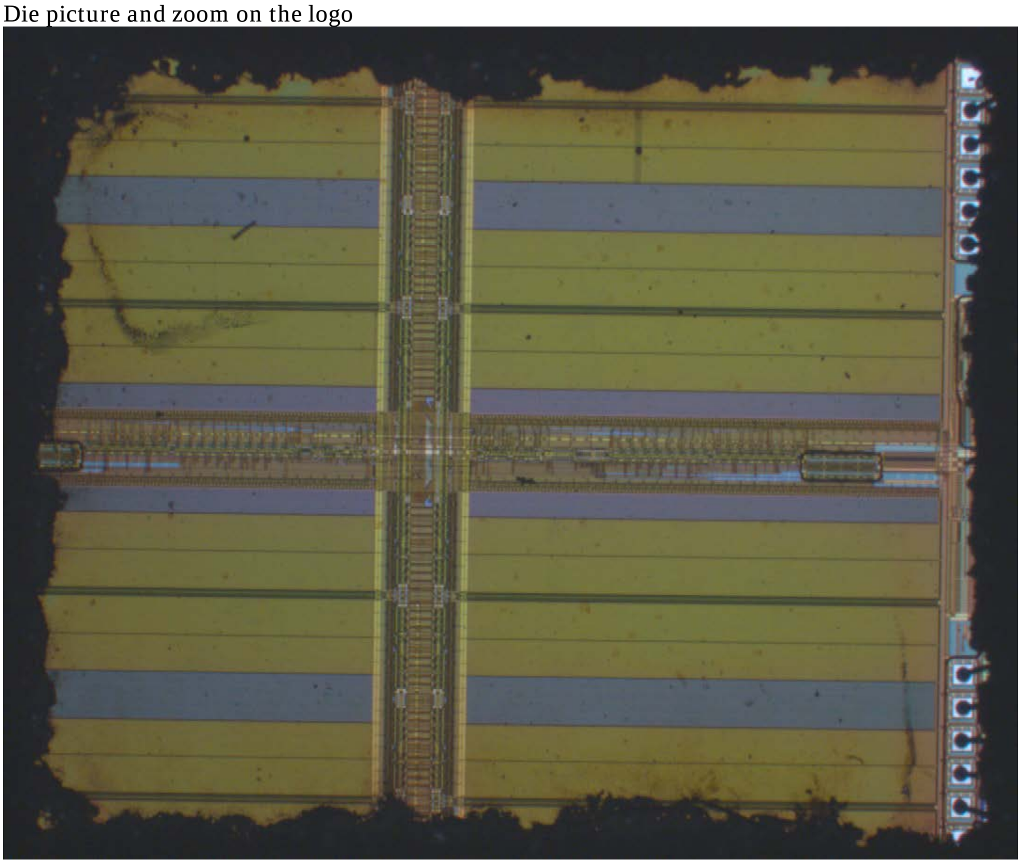
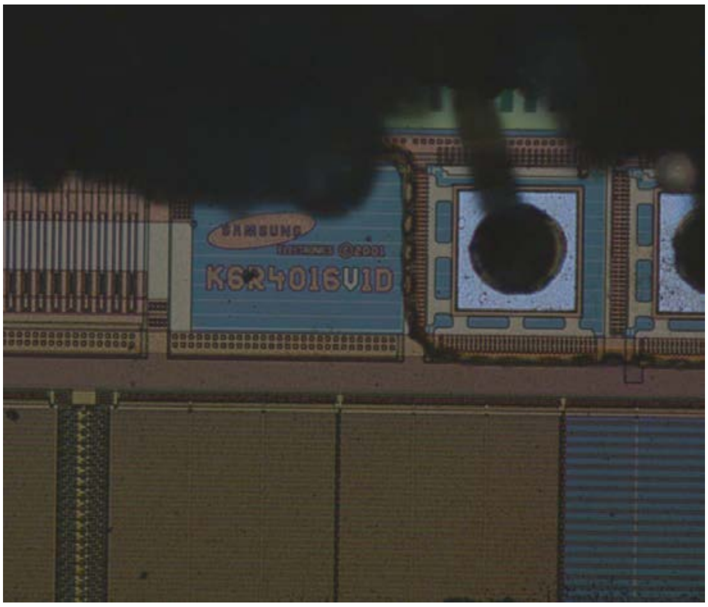


Figure 7: Location of all SEL events on the Phoenix GPS SRAM, Samsung K6R4016V1D-TC10, DC220, from October 2010 to December 2012.

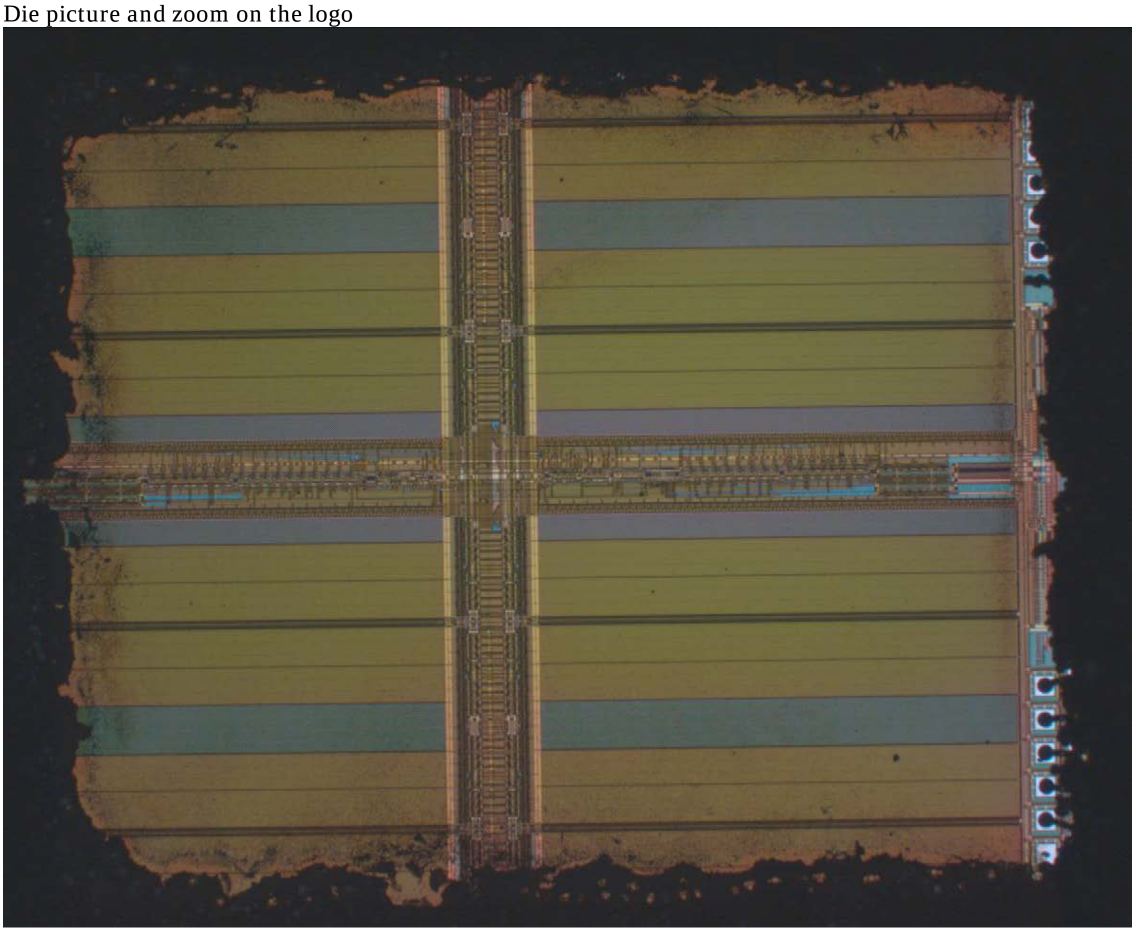
Appendix 1
Pictures of the opened tested devices

SRAM: Samsung K6R4016V1D-TC10, DC 220
Die picture and zoom on the logo



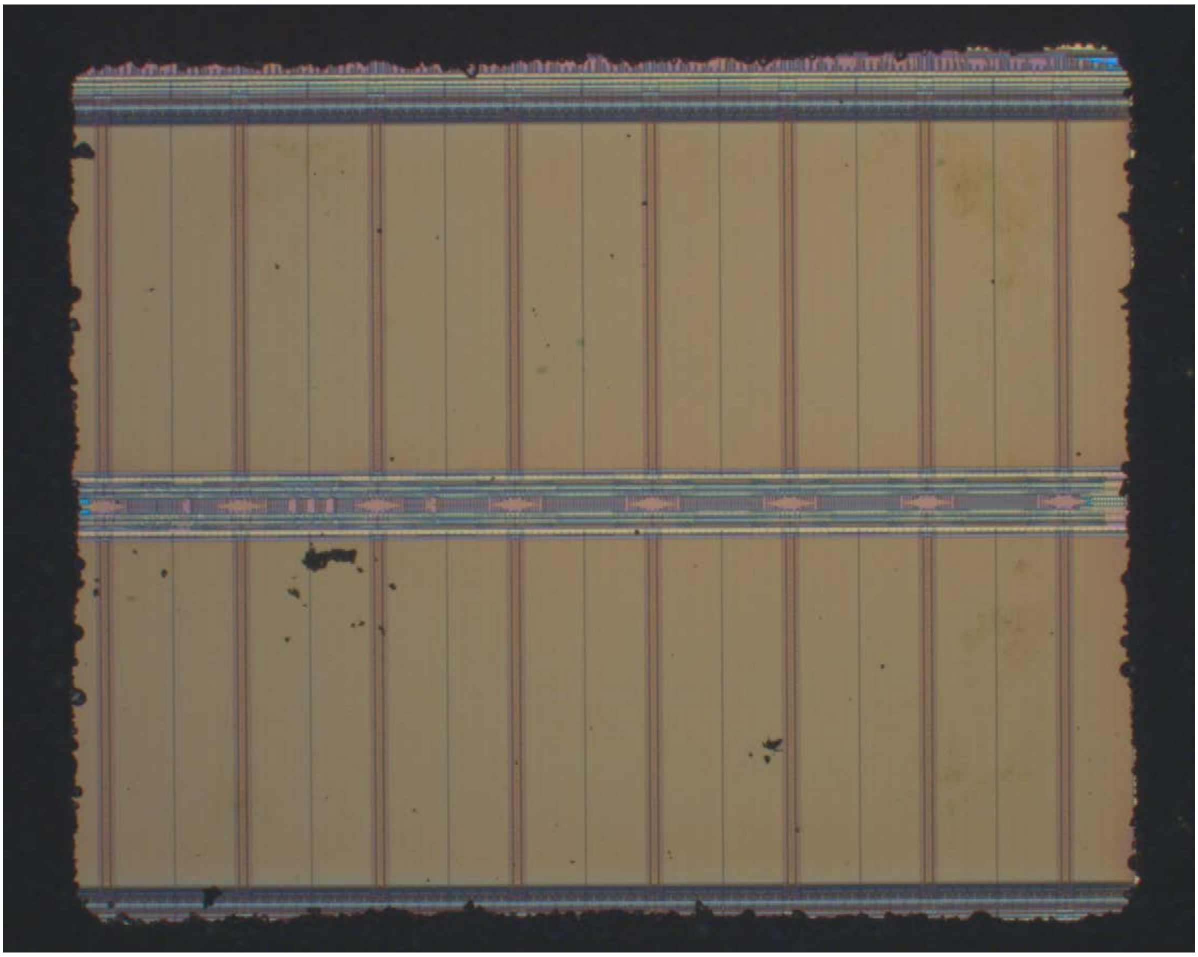


SRAM: Samsung K6R4016V1D-TC10, DC 328
Die picture and zoom on the logo



SRAM: Samsung K6R4016V1D-TC10, DC 922
Die picture and zoom on the logo

SRAM: ISSI IS61LV12816-12T, DC 1021
Die picture. The logo is not visible after opening, covered by the plastic.



APPENDIX 2
KVI, 18-19 JAN. 2012, IRRADIATION TEST LOGS

Primary energy 38.6MeV
18 Jan. 2012

GUARD system parameters:
Hold time 10ms, Cut-off time 200ms (unless noted), Threshold current I-th 100mA (or 20mA when indicated)

DUT in place: Samsung SRAM, DC220, Vcc=3.6V, samples #1, #2, #3
Operations: Stand-by (/CE high) or Read (/CE low). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID krad	Comments
16:23	1	27.9	Sa-220#1	low	100	2	1.0E+09	1E+07	2	2.00E-09	0.3	Flux too low
	2	27.9	Sa-220#1	low	100	2	5.0E+10	2E+08	37	7.40E-10	12.9	
	3	27.9	Sa-220#2	low	100	2	5.0E+10	2E+08	27	5.40E-10	12.6	
	4	27.9	Sa-220#3	low	100	2	5.0E+10	2E+08	67	1.34E-09	12.6	
	5	27.9	Sa-220#3	high	100	0.8	5.0E+10	2E+08	78	1.56E-09	25.3	
	6	27.9	Sa-220#3	high	20	0.8	5.0E+10	2E+08	92	1.84E-09	37.9	
	7	15.4	Sa-220#3	high	100	0.8	5.0E+10	2E+08	2	4.00E-11	57.9	
	8	15.4	Sa-220#3	high	20	0.8	5.0E+10	2E+08	2	4.00E-11	77.9	
	9	23.5	Sa-220#3	high	100	0.8	5.0E+10	2E+08	70	1.40E-09	92.7	
	10	18.4	Sa-220#3	high	100	0.8	5.0E+10	2E+08	22	4.40E-10	110.3	
	11	11.8	Sa-220#3	high	100	0.8	5.0E+10	2E+08	1	2.00E-11	135.9	
	12	27.9	Sa-220#3	high	100	0.8	5.0E+10	2E+08	236	4.72E-09	148.6	
22:52	40	27.9	Sa-220#3	high	100	0.8	5.0E+10	2E+08	200	4.00E-09	161.2	
	41	27.9	Sa-220#3	high	100	0.8	5.0E+10	2E+08	289	5.78E-09	173.8	Cut-off time 20ms

DUT in place: Samsung SRAM, DC328, Vcc=3.6V, sample #1
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID krad	Comments
18:36	13	27.9	Sa-328#1	high	100	1.8	5.0E+10	2E+08	41	8.20E-10	12.6	
	14	23.5	Sa-328#1	high	100	1.8	5.0E+10	2E+08	16	3.20E-10	27.4	
	15	11.8	Sa-328#1	high	100	1.8	5.0E+10	2E+08	0	0.00E+00	53.0	
	16	15.4	Sa-328#1	high	100	1.8	5.0E+10	2E+08	2	4.00E-11	73.0	
	17	18.4	Sa-328#1	high	100	1.8	5.0E+10	2E+08	3	6.00E-11	90.6	
	18	21.1	Sa-328#1	high	100	1.8	5.0E+10	2E+08	11	2.20E-10	106.6	
	19	25.8	Sa-328#1	high	100	1.8	5.0E+10	2E+08	65	1.30E-09	120.2	
	20	27.9	Sa-328#1	high	100	1.8	5.0E+10	2E+08	80	1.60E-09	132.9	

DUT in place: Samsung SRAM, DC328, Vcc=3.6V, sample #2
Investigation of TID effect
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID krad	Comments
20:30	24	27.9	Sa-328#2	high	100	1.8	5.0E+10	2E+08	36	7.20E-10	12.6	
	25	27.9	Sa-328#2	high	100	1.8	5.0E+10	2E+08	25	5.00E-10	25.3	
	26	27.9	Sa-328#2	high	100	1.8	5.0E+10	2E+08	47	9.40E-10	37.9	
	27	27.9	Sa-328#2	high	100	1.82	5.0E+10	2E+08	37	7.40E-10	50.6	
	28	27.9	Sa-328#2	high	100	1.82	5.0E+10	2E+08	51	1.02E-09	63.2	
	29	27.9	Sa-328#2	high	100	1.82	5.0E+10	2E+08	51	1.02E-09	75.8	
	30	27.9	Sa-328#2	high	100	1.82	5.0E+10	2E+08	50	1.00E-09	88.5	
	31	27.9	Sa-328#2	high	100	1.82	5.0E+10	2E+08	53	1.06E-09	101.1	
	32	27.9	Sa-328#2	high	101	1.82	5.0E+10	2E+08	72	1.44E-09	113.8	
	33	27.9	Sa-328#2	high	102	1.82	5.0E+10	2E+08	68	1.36E-09	126.4	
	34	27.9	Sa-328#2	high	103	1.826	5.0E+10	2E+08	65	1.30E-09	139.0	
	35	27.9	Sa-328#2	high	104	1.826	5.0E+10	2E+08	76	1.52E-09	151.7	
	36	27.9	Sa-328#2	high	105	1.827	5.0E+10	2E+08	77	1.54E-09	164.3	
	37	27.9	Sa-328#2	high	106	1.827	5.0E+10	2E+08	101	2.02E-09	177.0	
	38	27.9	Sa-328#2	high	107	1.827	5.0E+10	2E+08	85	1.70E-09	189.6	
	39	27.9	Sa-328#2	high	108	1.829	5.0E+10	2E+08	89	1.78E-09	202.2	

DUT in place: Samsung SRAM, DC922, Vcc=3.6V, samples #1, #2
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm2)	TID krad	Comments
20:05	21	27.9	Sa-922#1	high	100	1.9	5.0E+10	2E+08	0		12.6	No SELs
	22	27.9	Sa-922#1	high	100	1.9	5.0E+10	2E+08	0		25.3	No SELs
	23	27.9	Sa-922#2	high	100	1.8	5.0E+10	2E+08	0		12.6	No SELs

DUT in place: ISSI SRAM, DC1021, Vcc=3.6V, samples #1, #2, #3, sample #1 not working (Icc about 10nA – noise)
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID krad	Comments
23:15	42	27.9	IS-1021#2	high	100	?mA	5.0E+10	2E+08	0			No SELs
	43	27.9	IS-1021#3	high	100	?mA	5.0E+10	2E+08	0			No SELs

24:00 stop the beam

Primary energy 190MeV
19 Jan. 2012
GUARD system parameters:
Hold time 10ms, Cut-off time 50ms, Threshold current I-th 100mA

DUT in place: Samsung SRAM, DC220, Vcc=3.6V, sample #1
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID (krad)	Comments
14:20	44	184.5	Sa-220#1	high	100	1.3	1.2E+10	2E+08	303	2.53E-08	13.6	
	45	184.5	Sa-220#1	high	100	1.3	5.0E+09	2E+07	280	5.60E-08	13.9	
	46	50	Sa-220#1	high	100	1.3	5.0E+09	2E+07	61	1.22E-08	14.7	
	47	60	Sa-220#1	high	100	1.3	5.0E+09	2E+07	102	2.04E-08	15.4	
	48	80	Sa-220#1	high	100	1.3	5.0E+09	2E+07	127	2.54E-08	16.0	
	49	100	Sa-220#1	high	100	1.3	5.0E+09	2E+07	205	4.10E-08	16.4	
	50	120	Sa-220#1	high	100	1.3	5.0E+09	2E+07	210	4.20E-08	16.8	
	51	150	Sa-220#1	high	100	1.3	5.0E+09	1E+07	243	4.86E-08	17.2	lower flux to avoid pill-up
	52	184.5	Sa-220#1	high	100	1.3	5.0E+09	1E+07	284	5.68E-08	17.5	

DUT in place: Samsung SRAM, DC922, Vcc=3.6V, sample #1
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID (krad)	Comments
16:43	53	184.5	Sa-922#1	high	100	1.9	5.0E+09	1E+07	1	2.00E-10	25.6	
	54	184.5	Sa-922#1	high	100	1.9	5.0E+10	3E+08	19	3.80E-10	28.7	
	55	100	Sa-922#1	high	100	1.9	5.0E+10	3E+08	2	4.00E-11	33.3	
	56	80	Sa-922#1	high	100	1.9	5.0E+10	3E+08	3	6.00E-11	38.9	
	57	50	Sa-922#1	high	100	1.9	5.0E+10	3E+08	0	0.00E+00	46.8	
	58	150	Sa-922#1	high	100	1.9	5.0E+10	3E+08	9	1.80E-10	50.3	

DUT in place: ISSI SRAM, DC1021, Vcc=3.6V, sample #1
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID (krad)	Comments
18:20	59	184.5	IS-1021#2	high	100	40.6	5.0E+10	3E+08	0			No SELs
	60	184.5	IS-1021#2	high	100	40.6	5.0E+10	3E+08	0			No SELs

DUT in place: Samsung SRAM, DC328, Vcc=3.6V, sample #3
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.

Time	Run	Energy (MeV)	DUT	/CE	I-th (mA)	Icc (mA)	Fluence (cm^{-2})	Flux ($cm^{-2}.s^{-1}$)	SELs	Cross-section (cm^2)	TID (krad)	Comments
20:05	61	184.5	Sa-328#3	high	100	1.8	5.0E+09	2E+07	234	4.68E-08	0.3	
	62	184.5	Sa-328#3	high	100	1.8	3.0E+09	1E+07	153	5.10E-08	0.5	
	63	50	Sa-328#3	high	100	1.8	3.0E+09	1E+07	37	1.23E-08	1.0	
	64	60	Sa-328#3	high	100	1.8	3.0E+09	1E+07	45	1.50E-08	1.4	
	65	80	Sa-328#3	high	100	1.8	3.0E+09	1E+07	82	2.73E-08	1.7	
	66	100	Sa-328#3	high	100	1.8	3.0E+09	1E+07	127	4.23E-08	2.0	
	67	120	Sa-328#3	high	100	1.8	3.0E+09	1E+07	116	3.87E-08	2.2	
	68	150	Sa-328#3	high	100	1.8	3.0E+09	1E+07	145	4.83E-08	2.4	
	69	184.5	Sa-328#3	high	100	1.8	3.0E+09	1E+07	155	5.17E-08	2.6	

APPENDIX 3
RADEF, 29 - 31 MAY 2012, COCKTAIL 9.3MEV/N, TEST IN VACUUM IRRADIATION TEST LOGS

GUARD system parameters: Hold time 10ms, Cut-off time 50ms, Threshold current I-th 100mA

DUTs in place: Samsung SRAM, DC220 (samples #4), DC328 (sample #3), DC922 (sample #3), Vcc=3.6V
ISSI SRAM, DC1021 (sample#3), Vcc=3.6V

DUT is tilted to increase the effective LET (LETeff)
Operations: Stand-by (/CE high). The SRAM current consumption Icc is noted.
For this heavy ion RADEF experiment, TID is noted in rad (it was noted in krad for protons).

29 May 2012

Ion: Ar 372 MeV, range 118µm, LET 10.1MeVcm²/mg

3 runs were first performed in air for calibration purposes on sample Sa-328#2 (received cumulated dose 1.88 rad). The following runs are done in vacuum.

Time	Run	LETeff MeVcm²/mg	Angle (°)	DUT	Icc (mA)	Fluence (cm⁻²)	Flux (cm⁻².s⁻¹)	SELs	Cross-section (cm²)	TID rad	Comments
20:05	4	10.1	0	Sa-328#3	1.75	4.72E+03	20	234	4.96E-02	2.6	
	5	11.7	30			4.36E+03		207	4.75E-02	3.3	
	6	14.3	45			3.86E+03		203	5.26E-02	4.0	
	7	20.2	60			4.78E+03		287	6.00E-02	4.75	

20:55	8	10.1	0	Sa-220#4		4.41E+03	20	211	4.78E-02	0.7	
	9	11.7	30			3.37E+03		217	6.44E-02	1.3	
	13	10.1	0			4.18E+03		212	5.07E-02	1.9	
	14	11.7	30			4.12E+03		203	4.93E-02	2.6	
	15	14.3	45			3.35E+03		201	6.00E-02	3.1	
	16	20.2	60			4.63E+03		200	4.32E-02	3.9	

22:05	17-18	10.1	0	Sa-922#3	1.8	4.67E+07	2.00E+05	138	2.96E-06	7547	Flux increased
	19-20	14.3	45			2.61E+06		448	1.72E-04	9080	
	21	20.2	60			1.74E+05		205	1.18E-03	9502	
	22	11.7	30			9.49E+06		245	2.58E-05	9530	

22:50	24	10.1	0	ISSI-1021#3	1.8	9.14E+06	2.00E+05	0		1477	No SEL

30 May 2012

Ion: Ne 186 MeV, range 146µm, LET 3.6MeVcm²/mg

Time	Run	LETeff MeVcm²/mg	Angle (°)	DUT	Icc (mA)	Fluence (cm⁻²)	Flux (cm⁻².s⁻¹)	SELs	Cross-section (cm²)	TID rad	Comments
00:00	29	3.6	0	Sa-220#4		2.45E+05	800	207	8.45E-04	18	
	30	4.2	30			1.51E+05		205	1.36E-03	27	
	31	5.1	45			7.02E+04		240	3.42E-03	31	
	32	7.2	60			3.06E+04	400	316	1.03E-02	33	

00:35	33	3.6	0	Sa-328#3		3.01E+05	800	203	6.74E-04	22	
	34	4.2	30			2.46E+05		207	8.41E-04	36	
	35	5.1	45			1.51E+05		235	1.56E-03	45	
	36	7.2	60			4.31E+04	400	414	9.61E-03	47	

31 May 2012

Ion: Kr 768 MeV, range 94µm, LET 32.1MeVcm²/mg

Time	Run	LETeff MeVcm²/mg	Angle (°)	DUT	Icc (mA)	Fluence (cm⁻²)	Flux (cm⁻².s⁻¹)	SELs	Cross-section (cm²)	TID rad	Comments
14:46	38	32.1	0	Sa-922#3	1.8	3.64E+03	100	103	2.83E-02	9538	Flux too high
	39	32.1	0			8.35E+03	20	227	2.72E-02	9540	Flux ok
	40	37.1	30			6.16E+03		201	3.26E-02	9545	
	41	45.4	45			5.07E+03		202	3.98E-02	9548	
	42	64.2	60			4.30E+03		201	4.67E-02	9550	

APPENDIX 4
PROGRESSION OF THE SOLAR CYCLE, FROM: HTTP://WWW.SWPC.NOAA.GOV/SOLARCYCLE/