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EUROPEAN SPACE AGENCY
CONTRACT REPORT

ESA/ESTEC Contract No. 11755/95/NL/NB-WO1/CO1

Title

CXK581000AM-70LLX, 1 MBIT SRAM FROM SONY

HEAVY ION & PROTON
SEE CHARACTERIZATION
TEST REPORT

ESA/ESTEC Contract No. 11755/95/NL/NB-WO1/CO1

Summary :

Low Voltage memories were tested under heavy ion and proton irradiation, in order to study the effect of supply voltage on the SEE sensitivity. Additional results including study of operating and temperature effects is also addressed. This report presents the results obtained on 1 Mbit Sony SRAMs.

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Document type	**Nb WBS**	**Key Words**

SUMMARY OF RESULTS

Test sample characteristics :

Part Name :	CXK581000AM-70LLX	**Function :**	128K x 8 SRAM
Technology :	CMOS, 0.5 µm	**Package :**	32 pin SOP
Manufacturer :	Sony	**Location :**	Japan
Sample size :	4(H.I. tests), 3 (P. tests)	**Date Code :**	92XX

Heavy ion results

The following table summarizes the Heavy ion SEU test results:

	LET Threshold (MeV.cm²/mg)	**Saturated Cross-section (cm²/bit)**
Vcc=3.3V	<1.7	≈1.0 e-06
Vcc=5V	≈1.7	≈1.0 e-06

Heavy ion test conclusion :

The results of these experiments demonstrate that 1 Mbit SRAM CXK581000AM-70LLX (70ns) from Sony, when biased at 3.3V, is highly sensitive to heavy ion induced SEU : the threshold LET is <1.7 MeV.cm²/mg, and the saturated cross section is <1.0 e-06 cm²/bit. When biased at Vcc=5V, the saturated cross section is comparable, but the threshold LET is higher (≈1.7 MeV.cm²/mg).

Additional heavy ion results:

These devices also exhibited no Latch-up sensitivity, up to a LET of 68 MeV.cm²/mg.

No effect of frequency (fmax→fmax/4) can be evidenced on heavy ion cross section values at saturation.

No multiple errors within one 8 Bit word were recorded for LET≤ 68 MeV.cm²/mg.

No Single Hard Error sensitivity was found, up to a LET of 68 MeV.cm²/mg.

Proton results

The following table summarizes the proton SEE test results:

	Proton Energy Threshold (MeV)	Saturated Cross-section (cm²/bit)
Vcc=3.3V	<20	≈1e-13
Vcc=5V	<20	≈3e-14

Proton Test conclusion :

The results of these experiments demonstrate that 1 Mbit SRAM CXK581000AM-70LLX (70ns) from Sony biased at 3.3V, are sensitive to proton induced SEU : the saturated cross section is approximatively 1.0 e-13 cm²/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity to proton induced SEU : cross section are reduced by a factor 4 (for Ep=60MeV, and more at lower energies). Since the cross section curves are rather flat down to 20 MeV, no effect on Proton energy threshold can be evidenced.

Additional proton results:

These devices exhibit no Latch-up sensitivity, up to a proton energy of 60 MeV

No effect of frequency (Fmax→Fmax/4) can be evidenced on proton cross section values at saturation.

No multiple errors within one 8 bit word were recorded during the proton irradiation.

No Single Hard Error sensitivity was found during the proton irradiation, up to a proton energy of 60 MeV.

In both heavy ion and proton tests, the 1 to 0 transition error rate is fairly comparable to the 0 to 1 transition error rate (see results in the annex)

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1. INTRODUCTION

The aim of this work is to investigate radiation effects in low voltage and standard technologies. The study is focused on memory devices, which require lower voltage to achieve higher integration. Parts selected concern SRAM (1 Mbit, 2 types), DRAM (16 Mbit, 2 types), and FLASH memories (8 Mbit, 1 type).

The object of this document is to describe the irradiation performed on the Sony 1 Mbit CXK581000AM-70LLX (70ns), in order to measure their sensitivity to heavy ion and proton induced SEU. Influence of Supply Voltage, and operating Frequency is also addressed.

Irradiation were performed in November/December 1996 (30th-1st) according to the procedures referenced in the following paragraph.

This work was performed in the frame of the WO1/CO1 for ESTEC Contract n°11755/95/NL/NB.

2. REFERENCE DOCUMENTS

[1] ESA/SCC Basic Specification 25100

[2] Sony Manufacturer Data Sheet

[3] "Radiation Prescreening Programme On Low Voltage Memories - for ESA/ESTEC Contract N°11755/95/NL/NB" MMS Contract WP1 Report, Ref. DOF/DEC/TP6.577

[4] "The Heavy Ion Irradiation Facility at CYCLONE-a dedicated SEE beam line", G. Berger, G. Ryckewaert, R. Harboe-Sorensen, L. Adams, 1996 IEEE Radiation Effects Data Workshop

[5] "Testeur de mémoire haute densité", D. Winkel, TSEU-MAV-PE-000 (MMS report)

[6] Statement of work- QCA/RHS-CDS1.WP-MAR.'95, Issue 1, "Call-Off Order 1, Study and radiation testing of Low voltage Technologies".

3. PART DETAILS

3.1. DEVICE IDENTIFICATION

3.1.1. Références

Type : CXK581000AM-70LLX
Manufacturer : Sony
Place : /
Packaging : 32 pin SOP

3.1.2. Function

128K x 8 SRAM (70 ns)

3.1.3. Technology

CMOS, 0.5 µm, 4T+2TFT cells (See next page for further details)

3.1.4. Part Procurement

Origin : VTT, Finland
Level : Standard Level
Temperature range : -25°C, +85°C (Industrial)
Date code : 92XX
Screening : /
Sample size : 4 (heavy ion tests), 3 (proton tests)
Manufacturer Marking : CXK581000A Sony 1992 (Package)
Detailed specifications : Manufacturer Data sheet

3.1.5. Previous SEE details/history

No radiation data on this device

During this campaign, proton tests were performed prior to heavy ion tests ; samples irradiated with heavy ions are different from samples irradiated with protons.

3.2. TECHNICAL INFORMATION

The 1 Mbit CXK581000AM-70LLX SRAM from Sony is a dual supply voltage device, which means that it can be operated both at 3.3V and at 5V.

General information

Name	Sony CXK581000AM-70LLX
Package Marking	CXK581000A Sony 1992
Access time/ns at 5V	70
Temperature range/°C	-25, +85
Organisation	128K x 8
Supply Voltage/V	2.7-5.5

Technology

Name	Sony CXK581000AM-70LLX
CMOS	yes
Mask	*
Epitaxial layer	*
Design rules	0.5 µm, 3 Poly, 1 Al
Die size	4.76 mm x 8.33 mm
Cell type	4T+2TFT
Cell size	*

* The missing information was unsuccessfully required to the manufacturer.

A photography of the die is given in the annex.

4. TEST DESCRIPTION

4.1. IRRADIATION FACILITY

Name : Louvain-La-Neuve Cyclotron

Location : Université Catholique de Louvain
Centre de Recherches du Cyclotron
Chemin du Cyclotron, 2, 1348,
Louvain-La-Neuve, Belgium

4.1.1. Beams currently available

A cocktail of heavy ions can be provided, allowing quick (in a few minutes) changes of ion species. The characteristics of the associated LET are reported in table 1 (**X** in the last column refers to the type of ions used during this campaign) :

Ion	Energy (MeV)	Range [µm Si]	LET (MeV.cm²/mg)	Beam used
^{84}Kr	316	43	34	X
^{40}Ar	150	42	14.1	X
^{20}Ne	78	45	5.85	X
^{15}N	62	64	2.97	
^{10}B	41	80	1.7	X
^{132}Xe	459	43	55.9	

Table 1 Cocktail 1 that can be provided by LLN cyclotron.

- By varying the ion species and angle of incidence, the error Cross-section (σ) can be determined as a function of LET. A controlled flux between 10 and 10^5 (part./cm²)/s is used for heavy ions tests. A complete presentation of the Cyclone Facility SEE beam line is presented in ref [4].

4.1.2. Proton energies available

- Proton energies available at the LLN cyclotron are ranging from 10 to 60 MeV. Low energies are obtained by degrading the 60 MeV beam. For these tests, 2e+07 to 1e+08 (part./cm²)/s proton fluxes were used.

4.2. TEST SET UP DESCRIPTION

4.2.1. Heavy ion test set-up

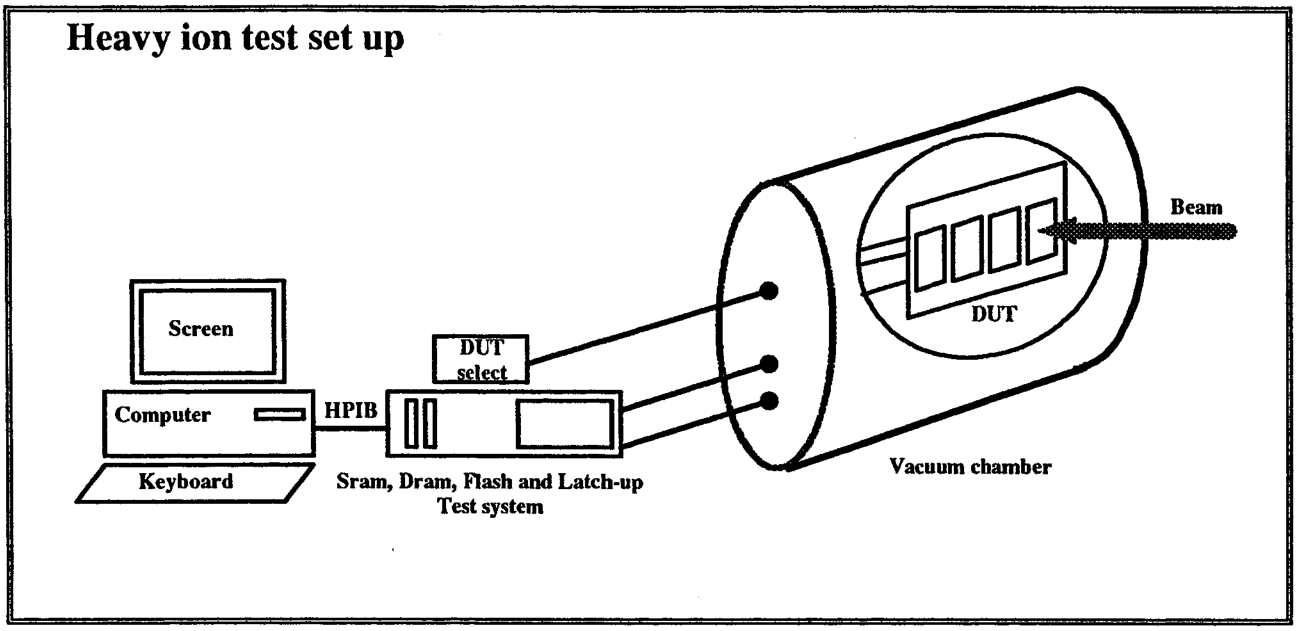


Fig. 1 Description of the heavy ion test set-up.

Comments :

The DUT are mounted on 4 zero-insertion-force sockets. Due to the low heavy ion penetration, parts were delidded for the heavy ion tests.

The tested device is selected by a switching commuter, located outside of the vacuum chamber.

The supply voltage is provided by the memory tester. The memory tester is also located outside of the vacuum chamber. The maximum frequency (Fmax) for tests is 1.25 MHz for SRAMs. This frequency can be divided by 2, 4, or 8. The maximum SEU rate is 625000 SEU/s (errors are systematically counted and recorded with the corresponding address).

The tester also includes a delatcher. The Latch-up detection threshold is programmable (set at 20 mA for the SRAM). The cut-off time is of 10 ms.

A complete description of the memory tester is given in [5].

4.2.2. Proton test set-up

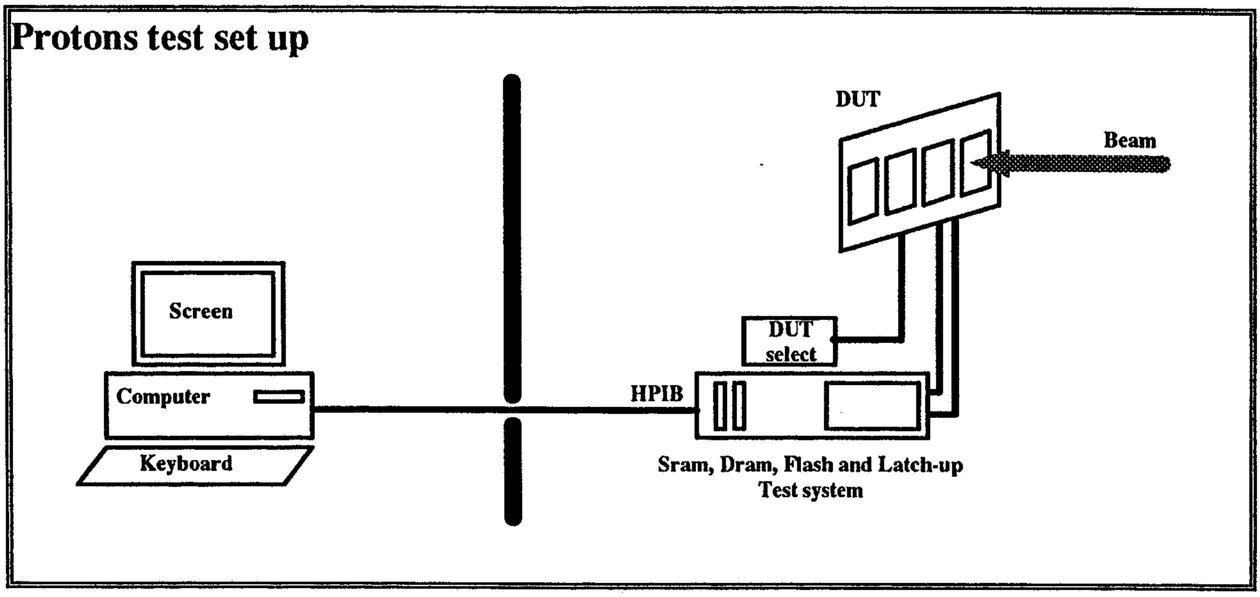
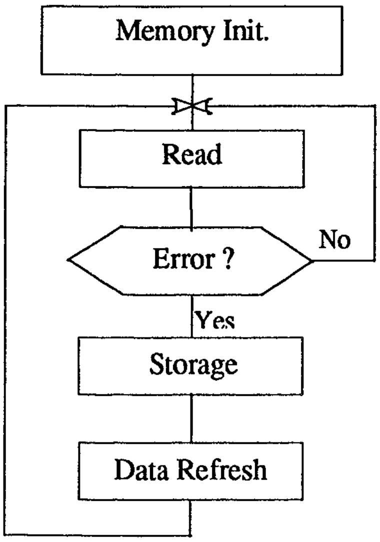


Fig. 2 Description of the proton test set-up

The proton test set-up is the same as the heavy ion test set-up. (see previous page for details). The main difference is that no vacuum chamber is needed for proton tests.

4.2.3. Test sequence



Test sequence flow chart

5. HEAVY ION EXPERIMENTAL RESULTS

5.1. HEAVY ION IRRADIATION TEST SEQUENCE

The heavy ion irradiation test sequence is reported in the following tables. Fluences given in column 9 are corrected fluences, according to the tilt (corrected fluences = real fluences x cosθ). The run number refers to the total irradiation test sequence, including all the memories tested during this campaign.

All the devices were tested with a Cb (checkerboard) pattern during irradiations. Since they were also tested with All to 0, All to 1, and /Cb patterns between runs, it was also checked that they were not sensitive to Single Hard Errors (SHE), up to a LET of 34 MeV.cm²/mg. (a SHE is a stuck bit, due to deposited dose in the oxyde of the cell transistors. It is generally detected when testing a device under a pattern and its complementary pattern : the stuck bit remains in its initial configuration).

ICC+ is the consumption current for 4 memories biased together.

Run	Device	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Time (s)	Fluence [p/cm²]	ICC+ [mA]
3	SN3	3.3V/fmax	34	0	34	150	69	5657	+13
4	SN4	3.3V/fmax	34	0	34	150	40	3252	+14.2
7	SN3	3.3V/(fmax/4)	34	0	34	150	107	6352	+8.8
8	SN4	3.3V/(fmax/4)	34	0	34	150	69	4385	+9.8
9	SN4	3.3V/(fmax/4)	34	60	68	150	33	1281	+9.3
34	SN5	3.3V/fmax	14.1	0	14.1	240	24	5865	+12.7
35	SN1	3.3V/fmax	14.1	0	14.1	240	38	7468	+13.2

Table 2 : Heavy Ion Irradiation Test Sequence : runs 1-35

Run	Device	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Time (s)	Fluence [p/cm²]	ICC+ [mA]
44	SN5	3.3V/fmax	14.1	0	14.1	1000	42	35223	+12.7
45	SN1	3.3V/fmax	5.85	0	5.85	1000	41	29445	+12.7
46	SN1	3.3V/fmax	5.85	54	10	900	20	11653	+12.7
47	SN5	3.3V/fmax	5.85	54	10	900	13	13347	+12.7
62	SN5	3.3V/fmax	1.7	0	1.7	4000	150	504743	+12.2
63	SN1	3.3V/fmax	1.7	0	1.7	4000	148	503154	+12.2
74	SN5	5V/fmax	1.7	0	1.7	9000	115	1.0e+6	+14.7
75	SN1	5V/fmax	1.7	0	1.7	9000	103	1.0e+06	+14.7
76	SN1	5V/fmax	5.85	0	5.85	4000	/	2.82e+05	+14.7
77	SN5	5V/fmax	5.85	0	5.85	4000	/	1.40e+05	+14.7
97	SN5	5V/fmax	34	0	34	250	/	7902	+14.6
98	SN5	5V/fmax	34	0	34	150	/	1916	+11
99	SN1	5V/fmax	34	0	34	150	/	6267	/

Table 2 (end) : Heavy Ion Irradiation Test Sequence : run 36-99

5.2. ANALYSIS OF HEAVY ION RESULTS: METHOD

5.2.1. Calculation of SEE cross-sections

The cross-sections were calculated as follows :

$$\sigma(\mathrm{LET}) = \mathrm{N/F}$$

where :

σ is the SEE Cross-section (cm^2/device), expressed as a function of the Heavy Ion LET

LET is the Linear Energy Transfer $\left(\frac{1}{\rho}\frac{dE}{dx}\right)$, in MeV.cm^2/mg

N is the total Number of SEE

F = Fluence (part./cm^2) (corrected according to the incident angle).

The cross section per bit is obtained by dividing the cross section for the device by the total number of bits of the memory.

The minimum of fluence required is 1e+6 p/cm^2, if no event detected. By default, a value of 1 for N is used to calculate the cross-section when no event is observed (Cf statistical treatment).

The LET threshold is defined as the minimum LET value at which no event occurs at a fluence of 10^6 particle/cm^2.

5.2.2. Statistical treatement

The confidence limits shown in the following tables represent the values of the cross section between which the true value of cross section lies within a 90% probability.

The calculation of the confidence limits is made on the basis of a Poisson distribution for the events. Note that when large numbers of errors are observed, the statistical errors become insignificant. The assumptions made therefore are :

- only one event possible per incident ion
- small probability of event

For an event number > 600, no confidence limit is calculated.

5.3. HEAVY ION CROSS SECTION MEASUREMENTS

5.3.1. Tables of heavy ion results

The cross sections are expressed in cm²/bit, obtained by dividing the device cross section by the number of tested bits.

Test Sample	Test n°	SEU	Eff. Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/Bit]**	90% Conf. Limits [cm²]
SN1	63	6	5.0 e+05	**1.7**	**1.14e-11**	2.24e-11/4.95e-12
SN5	62	16	5.0 e+05	**1.7**	**3.02e-11**	4.59e-11/1.89e-11
SN1	45	449	2.9 e+04	**5.85**	**1.45e-08**	1.57e-08/1.34e-08
SN5	44	432	3.5 e+04	**5.85**	**1.17e-08**	1.26e-08/1.07e-08
SN5	47	657	1.3 e+04	**10**	**4.69e-08**	/
SN1	46	556	1.2 e+04	**10**	**4.55e-08**	4.88e-08/4.23e-08
SN1	35	589	7.5 e+03	**14.1**	**7.52e-08**	8.05e-08/7.01e-08
SN5	34	560	5.8 e+03	**14.1**	**9.11e-08**	9.76e-08/8.48e-08
SN4	4	1182	3.2 e+03	**34**	**3.47e-07**	/
SN3	3	1023	5.7 e+03	**34**	**1.72e-07**	/

Table 3 : Cross section measurements for Vcc=3.3V

Test Sample	Test n°	SEU	Eff. Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/Bit]**	90% Conf. Limits [cm²]
SN5	75	0	1.0 e+06	**1.7**	**9.54e-13**	4.52e-12/4.89e-14
SN3	74	1	1.0 e-06	**1.7**	**9.54e-13**	4.52e-12/4.89e-14
SN3	77	1037	1.4 e+05	**5.85**	**7.06e-09**	/
SN5	76	1115	2.8 e+05	**5.85**	**3.77e-09**	/
SN5	99	1037	6.3 e+03	**34**	**1.58e-07**	/
SN2	98	656	1.9 e+03	**34**	**3.27e-07**	/

Table 4 : Cross section measurements for Vcc=5V

Test Sample	Test n°	SEU	Eff. Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/Bit]**	90% Conf. Limits [cm²]
SN4	8	1546	4.4 e+03	**34**	**3.36e-07**	/
SN3	7	987	6.4 e+03	**34**	**1.48e-07**	/
SN4	9	1053	1.2 e+03	**68**	**7.83e-07**	/

Table 5 : Cross section measurements for Vcc=3.3V, fmax/4

5.3.2. Heavy ion Result Analysis

The figure 4 exhibits the heavy ion induced cross sections for SONY 1 Mbit SRAM.

A complete characterization was performed at Vcc=3.3V

Effect of supply voltage (Vcc=5V) was addressed at LET values of 1.7, 5.85, and 34 MeV.cm²/mg.

Effect of operating frequency was addressed at a LET values of 34 and 68 MeV.cm²/mg.

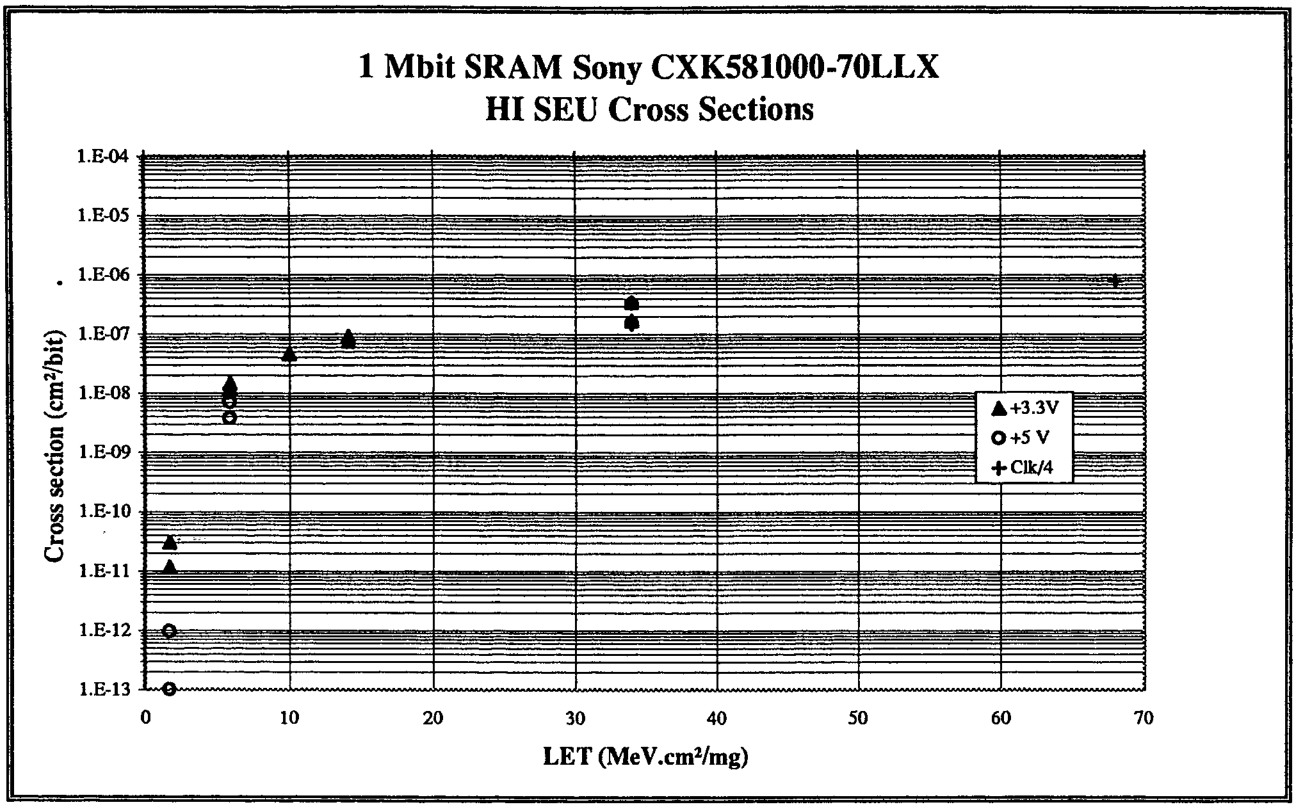


Fig. 4 Heavy ion cross section measurements for SONY SRAM 1 Mbit

This figure evidences the following results :

Effect of supply voltage :

The effect of supply voltage variation is not important for this device at high LET. But at the minimum LET, the cross section is much greater at Vcc=3.3V than at Vcc=5V . The cross section increases from 9e-13 cm²/bit at 5V to 1.2e-11 cm²/bit at 3.3V, at LET=1.7 MeV.cm²/mg.

Effect of the operating frequency (Fmax→Fmax/4) :

No operating frequency effect is clearly evidenced at 34 and 68 MeV.cm²/mg (the only tested LET for these tests).

5.3.3. Problems encountered/Discussion

No specific problem was encountered during irradiation.

5.4. HEAVY ION TEST CONCLUSIONS

The results of these experiments demonstrate that 1 Mbit SRAM CXK581000AM-70LLX from Sony, biased at 3.3V, is sensitive to heavy induced SEU : the threshold LET is <1.7 MeV.cm²/mg, and the cross section at 34 MeV.cm²/mg is about 4e-07 cm²/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity : the LET threshold is ≈1.7 MeV.cm²/mg, but the cross section near saturation is comparable.

Additional heavy ion results:

These devices also exhibited no Latch-up sensitivity, up to a LET of 68 MeV.cm²/mg.

No effect of frequency (fmax→fmax/4) can be evidenced on heavy ion cross section values at saturation.

No multiple errors within one 8 Bit word were recorded during the heavy ion irradiation, for LET≤ 68 MeV.cm²/mg.

No Single Hard Error sensitivity was found at heavy ion irradiation, up to a LET of 68 MeV.cm²/mg.

The 1 to 0 transition error rate is equivalent to the 0 to 1 transition error rate (see results in the annex 1).

6. PROTON EXPERIMENTAL RESULTS

6.1. PROTON IRRADIATION TEST SEQUENCE

The proton irradiation test sequence is given in the following tables.

The run number refers to the total irradiation test sequence, including all the memories tested during this campaign. Flux values are averaged values.

ICC+ is the consumption current for 4 memories biased together.

Run	Device	Vcc/f	Energy (p) [MeV]	Flux [p/cm^2/s]	Time (s)	Fluence [p/cm^2]	Depos./cumul. dose (kRad[Si])	ICC+ [mA]
3	SN2	5V/fmax	60	2.4e+07	425	1e+10	1.5/1.5	+17.6
4	SN1	5V/fmax	60	2.2e+07	452	1e+10	1.5/3	+16
12	SN3	5V/fmax	40	3.4e+07	297	1e+10	2/2	+16
13	SN2	5V/fmax	40	3.8e+07	262	1e+10	2/3.5	+17
14	SN2	5V/fmax	20	3.1e+07	322	1e+10	3.5/7	+16
15	SN3	5V/fmax	20	3.8e+07	262	1e+10	3.5/5.5	+16
31	SN1	3.3V/fmax	60	9.4e+07	106	1e+10	1.5/4.5	+12.7
32	SN3	3.3V/fmax	60	9.2e+07	109	1e+10	1.5/7	+12.7
33	SN3	3.3V/fmax	60	9.8e+07	102	1e+10	1.5/9	+13.9
34	SN1	3.3V/fmax	60	1.0e+08	100	1e+10	1.5/6	+13.2
39	SN1	3.3V/fmax	20	9.8e+07	102	1e+10	3.5/9.5	+13.2
40	SN3	3.3V/fmax	20	1.0e+08	97	1e+10	3.5/12.5	+13.7
41	SN3	3.3V/(fmax/4)	20	1.0e+08	84	1e+10	3.5/16	+9.3
42	SN3	3.3V/(fmax/4)	60	9.6e+07	104	1e+10	1.5/17.5	+9.3
43	SN1	3.3V/(fmax/4)	60	1.0e+08	99	1e+10	1.5/11	/

Table 7: Proton Irradiation Test Sequence

6.2. ANALYSIS OF PROTON RESULTS : METHOD

6.2.1. Calculation of SEE cross-sections

The cross-sections were calculated as follows :

$$\sigma(Ep) = N/F$$

where :

σ is the SEE Cross-section (cm^2/device), expressed as a function of the Proton Energy

N is the total Number of SEE

F = Fluence (part./cm^2).

The cross section per bit is obtained by dividing the cross section for the device by the total number of bits of the memory.

The fluence is set at 1e+10 p/cm^2 for all the runs. By default, a value of 1 for N is used to calculate the cross-section when no event is observed (Cf statistical treatment).

6.2.2. Statistical treatement

The confidence limits shown in the following tables represent the values of the cross section between which the true value of cross section lies within a 90% probability.

The calculation of the confidence limits is made on the basis of a Poisson distribution for the events. Note that when large numbers of errors are observed, the statistical errors become insignificant. The assumptions made therefore are :

- only one event possible per incident proton
- small probability of events

For an event number > 600, no confidence limit is calculated.

6.3. PROTON CROSS SECTION MEASUREMENTS

6.3.1. Tables of proton results

The cross sections are expressed in cm^2/bit, obtained by dividing the device cross section by the number of tested bits.

Test Sample	Test n°	SEU	Fluence (part/cm^2)	**P. Energy [MeV]**	**X-Section [cm^2/bit]**	90% Conf. Limits [cm^2]
SN2	31	931	1.0 e+10	**60**	**8.88e-14**	/
SN3	32	898	1.0 e+10	**60**	**8.56e-14**	/
SN3	33	858	1.0 e+10	**40**	**8.18e-14**	/
SN1	34	935	1.0 e+10	**40**	**8.92e-14**	/
SN1	39	687	1.0 e+10	**20**	**6.55e-14**	/
SN3	40	389	1.0 e+10	**20**	**3.71e-14**	4.03e-14/3.4e-14

Table 8 : Cross section measurements for Vcc=3.3V

Test Sample	Test n°	SEU	Fluence (part/cm^2)	**P. Energy [MeV]**	**X-Section [cm^2]**	90% Conf. Limits [cm^2]
SN2	3	195	1.0 e+10	**60**	**1.86e-14**	2.08e-14/1.64e-14
SN1	4	268	1.0 e+10	**60**	**2.56e-14**	2.82e-14/2.3e-14
SN3	12	185	1.0 e+10	**40**	**1.76e-14**	1.99e-14/1.55e-14
SN2	13	163	1.0 e+10	**40**	**1.55e-14**	1.77e-14/1.36e-14
SN2	14	93	1.0 e+10	**20**	**8.87e-15**	1.05e-14/7.41e-15
SN3	15	37	1.0 e+10	**20**	**3.53e-15**	4.64e-15/2.63e-15

Table 9 : Cross section measurements for Vcc=5V

Test Sample	Test n°	SEU	Fluence (part/cm^2)	**P. Energy [MeV]**	**X-Section [cm^2]**	90% Conf. Limits [cm^2]
SN3	42	985	1.0 e+10	**60**	**9.39e-14**	/
SN1	43	956	1.0 e+10	**60**	**9.12e-14**	/
SN3	41	378	1.0 e+10	**20**	**3.60e-14**	3.92e-14/3.30e-14

Table 10 : Cross section measurements for Vcc=3.3V, fmax/4

6.3.2. Proton Result Analysis

The figure 5 exhibits the proton induced SEU cross sections for SONY 1 Mbit SRAM.

A characterization was performed at Vcc=3.3V for 3 proton energies (20 MeV, 40 MeV, 60 MeV)

Effect of supply voltage (Vcc=5V) was also addressed at these 3 proton energy values.

Effect of operating frequency was addressed at 60 MeV.

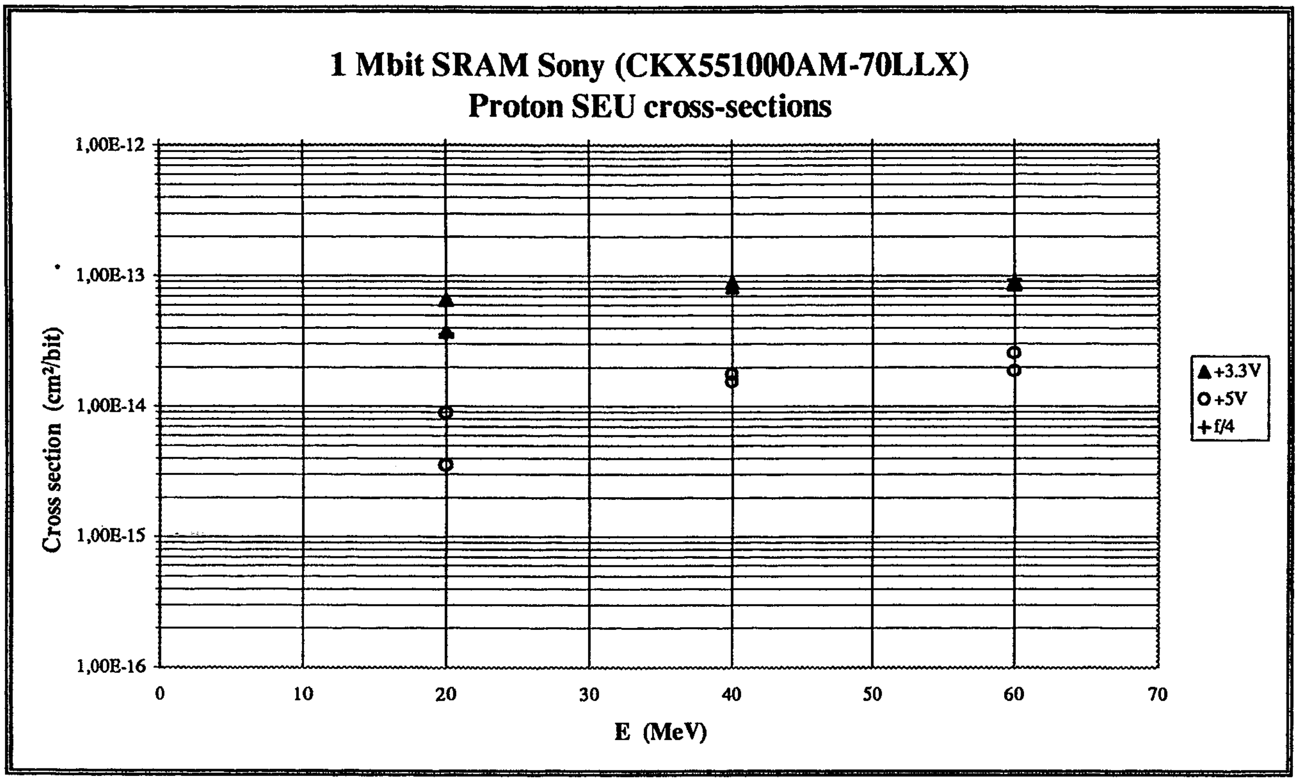


Fig. 5 Proton cross section measurements for SONY SRAM 1 Mbit

This figure evidences the following results :

Effect of supply voltage :

When the devices are biased at 5V the sensitivity of the devices to proton induced SEU is lowered. The average saturated cross-section is divided by a factor 4 at 60 MeV, by a factor 5.2 at 40 MeV, and 8.3 at 20 MeV : the effect is stronger at lower energies.

Effect of the operating frequency (Fmax→Fmax/4) :

No specific effect was evidenced at the 60 MeV energy.

6.3.3. Problems encountered/Discussion

No specific problem was encountered during irradiations.

6.4. PROTON TEST CONCLUSIONS

The results of these experiments demonstrate that 1 Mbit SRAM CKX581000AM-70LLX (70ns) from SONY, biased at 3.3V, are sensitive to proton induced SEU : the saturated cross section is approximately 1e-13 cm^2/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity to proton induced SEU : cross section are reduced by a factor between 4 and 8. Since the cross section curves are rather flat down to 20 MeV, no effect on Proton energy threshold can be evidenced.

Additional proton results:

These devices exhibit no Latch-up sensitivity, up to a proton energy of 60 MeV

No effect of frequency (Fmax→Fmax/4) can be evidenced on proton cross section values at saturation.

As shown in Annex 2, the sensitivity is slightly higher for an initial content of 0 and the energy threshold seems lower.

No Single Hard Error sensitivity was found under proton irradiations, up to a proton energy of 60 MeV.

No multiple errors were recorded within one 8 bit word, up to a proton energy of 60 MeV.

7. CONCLUSION

Heavy ion and proton SEU tests were performed on the 1 Mbit SRAM CXK581000AM-70LLX from SONY, with complete characterization at 3.3V, and additional points at 5V, and at a lower operating frequency. Results are summarized in the following tables.

	LET Threshold (MeV.cm²/mg)	**Saturated Cross-section (cm²/bit)**
Vcc=3.3V	<1.7	<1.0e-06
Vcc=5V	≈1.7	<1.0e-06

Summary of heavy ion results

	Proton Energy Threshold (MeV)	**Saturated Cross-section (cm²/bit)**
Vcc=3.3V	<20	≈1e-13
Vcc=5V	<20	≈3e-14

Summary of proton results

Analysis of the results shows that no effect of operating frequency was evidenced on the heavy ion and proton the cross sections.

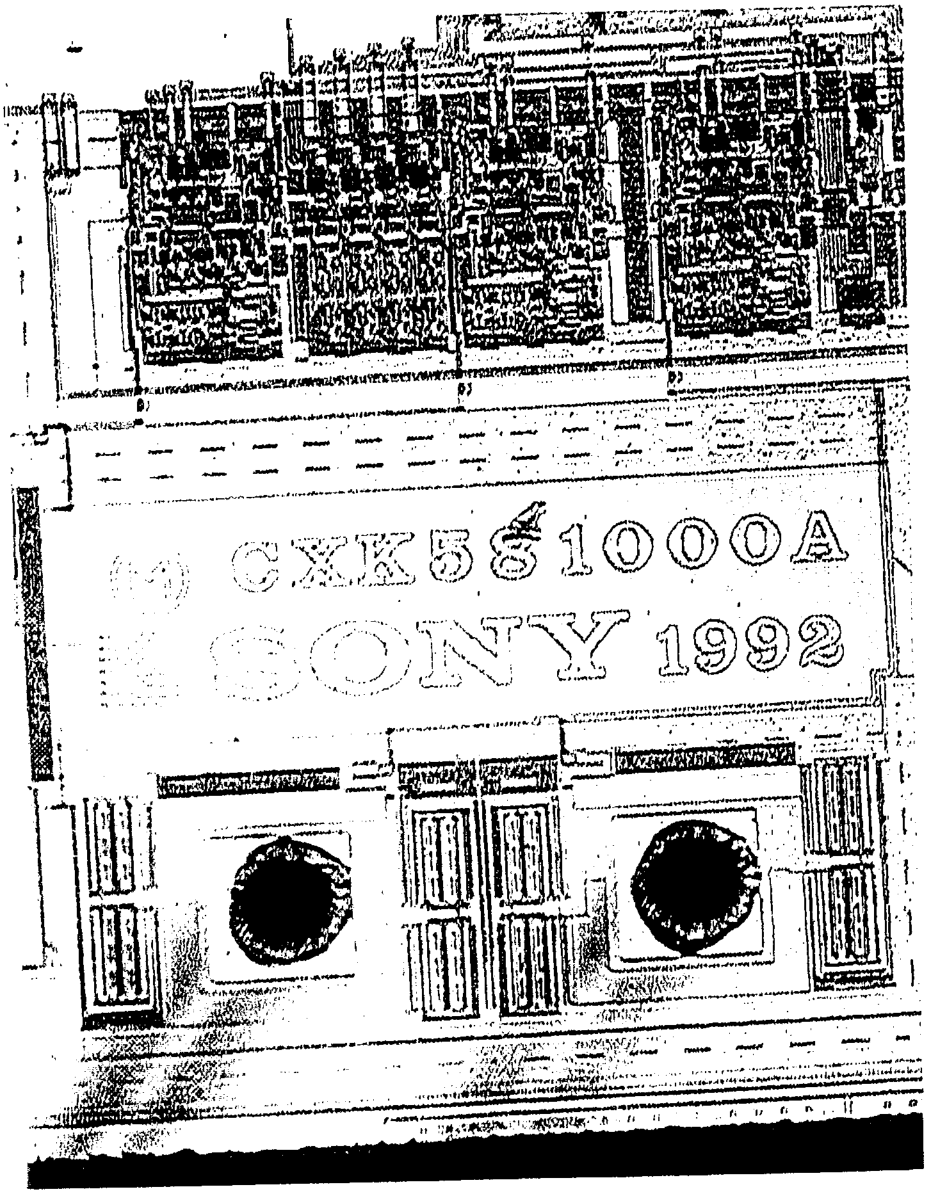
The effect of supply voltage tends to modify the SEU sensitivity of the devices : the SEU susceptibility is higher at 3.3V than at 5V.

- Heavy ion threshold LET is higher at 5V than at 3.3V, but the effect at high LET values (near the saturation cross-section) is low.

- On the contrary, this cross section decrease is important for proton irradiation.

8. ANNEX

8.1. DIE PHOTOGRAPHY



Photography of the die marking

8.2. DETAILS OF RESULT ANALYSIS

Heavy ion additional test results

The following tables exhibit the heavy ion SEU results separating the 1 → 0 from the 0 → 1 transition results, and comparing with the "total" results. These tables clearly show that the sensitivity of the device is not dependent on the bit transition type. Figures a-1 and a-2 also exhibit these results.

Sony	**Vcc=3.3V**									
RUN	**SN**	**Upsets**			**Size**	**Eff. Fluence**	**Eff. LET**	**Cross Sect. (cm^2/bit)**		
		0→1	**1→0**	**Total**	**(bits)**	**(part/cm^2)**	**(MeV.cm^2/mg)**	**0→1**	**1→0**	**Total**
3	3	512	511	1023	1048576	5657	34	**1,73E-07**	**1,72E-07**	**1,72E-07**
4	4	603	579	1182	1048576	3232	34	**3,56E-07**	**3,42E-07**	**3,49E-07**
34	5	291	269	560	1048576	5865	14,1	**9,46E-08**	**8,75E-08**	**9,11E-08**
35	1	334	255	589	1048576	7468	14,1	**8,53E-08**	**6,51E-08**	**7,52E-08**
46	1	316	240	556	1048576	11653	10	**5,17E-08**	**3,93E-08**	**4,55E-08**
47	5	350	307	657	1048576	13347	10	**5,00E-08**	**4,39E-08**	**4,69E-08**
44	5	255	177	432	1048576	35223	5,85	**1,38E-08**	**9,58E-09**	**1,17E-08**
45	1	257	192	449	1048576	29445	5,85	**1,66E-08**	**1,24E-08**	**1,45E-08**
62	5	9	7	16	1048576	504743	1,7	**3,40E-11**	**2,65E-11**	**3,02E-11**
63	1	6	0	6	1048576	503154	1,7	**2,27E-11**	**3,70E-12**	**1,14E-11**

**Table a-1 Separation of 1 → 0 from the 0 → 1 transitions,
and comparison with total error results, at Vcc=3.3V**

Sony Vcc=5V

RUN	SN	Upsets			Size	Fluence	LET	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(part/cm^2)	(MeV.cm^2/mg)	0→1	1→0	Total
98	5	363	293	656	1048576	1916	34	**3,61E-07**	**2,92E-07**	**3,27E-07**
99	1	585	452	1037	1048576	6267	34	**1,78E-07**	**1,38E-07**	**1,58E-07**
76	1	556	559	1115	1048576	282000	5,85	**3,76E-09**	**3,78E-09**	**3,77E-09**
77	5	641	396	1037	1048576	140000	5,85	**8,73E-09**	**5,40E-09**	**7,06E-09**
74	5	0	1	1	1048576	1000000	1,7	**9,53E-13**	**9,53E-13**	**9,53E-13**
75	1	0	0	0	1048576	1000000	1,7	**9,53E-13**	**9,53E-13**	**9,53E-13**

Table a-2 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=5V

Sony Vcc=3.3V f/4

RUN	SN	Upsets			Size	Eff. Fluence	Eff. LET	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(part/cm^2)	(MeV.cm^2/mg)	0→1	1→0	Total
9	4	530	515	1045	1048576	1281	68	**7,89E-07**	**7,67E-07**	**7,78E-07**
7	3	520	467	987	1048576	6352	34	**1,56E-07**	**1,40E-07**	**1,48E-07**
8	4	809	737	1546	1048576	4385	34	**3,52E-07**	**3,21E-07**	**3,36E-07**

Table a-3 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

These results clearly show that the sensitivity of the device is not strongly dependent on the transition type.

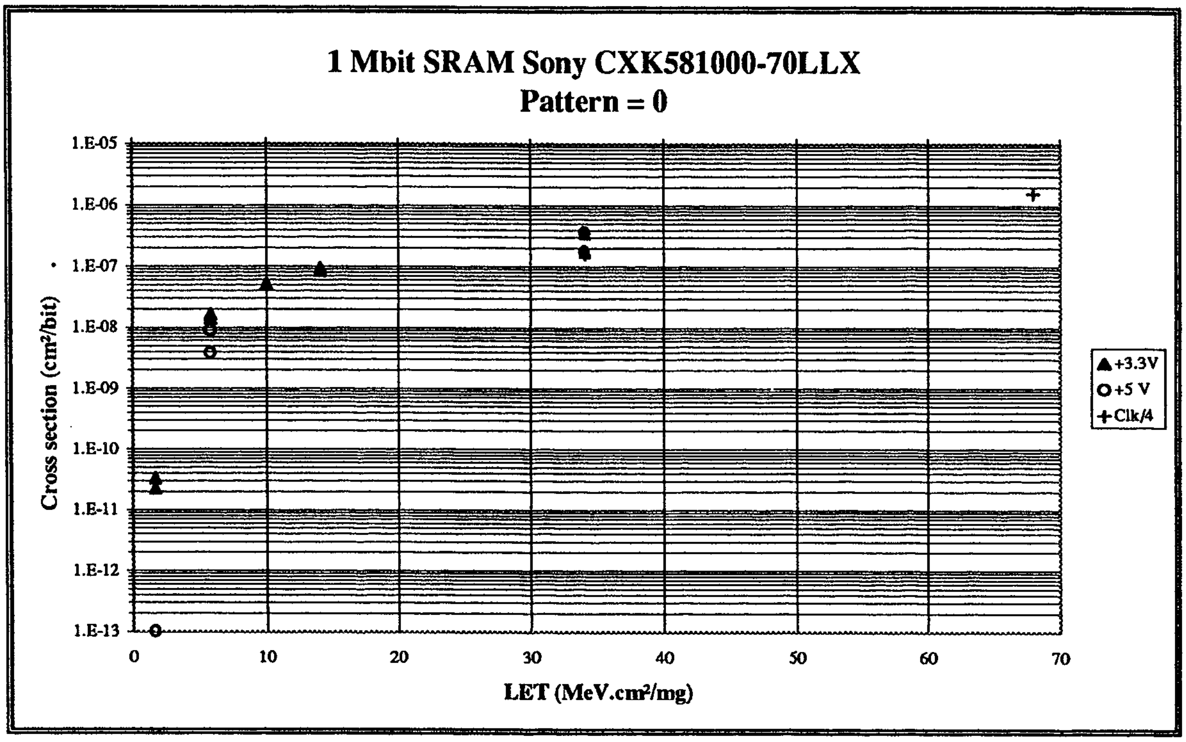


Fig. a-1 Heavy Ion SEU Cross section measurements for 0→1 transitions

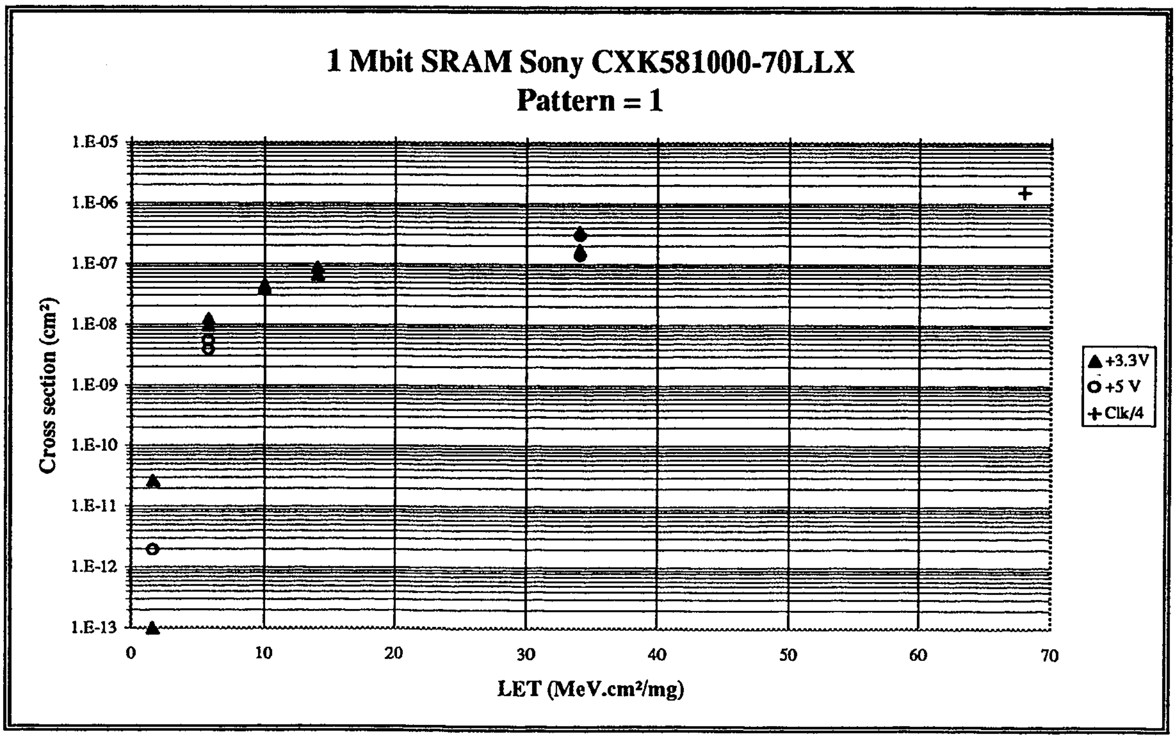


Fig. a-2 Heavy ion SEU Cross section measurements for 1→0 transitions

Proton additional test results

The following tables exhibit the proton SEU results, separating the 1 → 0 from the 0 → 1 transition results, and comparing with the "total" results. These tables clearly show that the sensitivity of the device is not dependent on the bit transition type. Figures a-3 and a-4 also exhibit these results.

Sony		**Vcc=3.3V**								
RUN	**SN**	**Upsets**			**Size**	**Fluence**	**E**	**Cross Sect. (cm^2/bit)**		
		0→1	**1→0**	**Total**	**(bits)**	**(p/cm^2)**	**(MeV)**	**0→1**	**1→0**	**Total**
31	2	508	423	931	1048576	1,00E+10	60	**9,69E-14**	**8,07E-14**	**8,88E-14**
32	3	491	407	898	1048576	1,00E+10	60	**9,37E-14**	**7,76E-14**	**8,56E-14**
33	3	465	393	858	1048576	1,00E+10	40	**8,87E-14**	**7,50E-14**	**8,18E-14**
34	1	519	416	935	1048576	1,00E+10	40	**9,90E-14**	**7,93E-14**	**8,92E-14**
39	1	375	312	687	1048576	1,00E+10	20	**7,15E-14**	**5,95E-14**	**6,55E-14**
40	3	227	162	389	1048576	1,00E+10	20	**4,33E-14**	**3,09E-14**	**3,71E-14**

Table a-4 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V

Sony Vcc=5V

RUN	**SN**	**Upsets**			**Size**	**Fluence**	**E**	**Cross Sect. (cm^2/bit)**		
		0→1	**1→0**	**Total**	**(bits)**	**(p/cm^2)**	**(MeV)**	**0→1**	**1→0**	**Total**
3	2	105	90	195	1048576	1,00E+10	60	**2,00E-14**	**1,72E-14**	**1,86E-14**
4	1	139	129	268	1048576	1,00E+10	60	**2,65E-14**	**2,46E-14**	**2,56E-14**
12	3	103	82	185	1048576	1,00E+10	40	**1,96E-14**	**1,56E-14**	**1,76E-14**
13	2	97	66	163	1048576	1,00E+10	40	**1,85E-14**	**1,26E-14**	**1,55E-14**
14	2	56	37	93	1048576	1,00E+10	20	**1,07E-14**	**7,06E-15**	**8,87E-15**
15	3	22	18	37	1048576	1,00E+10	20	**4,20E-15**	**3,43E-15**	**3,53E-15**

Table a-5 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

Sony Vcc=3.3V f/4

RUN	**SN**	**Upsets**			**Size**	**Fluence**	**E**	**Cross Sect. (cm^2/bit)**		
		0→1	**1→0**	**Total**	**(bits)**	**(p/cm^2)**	**(MeV)**	**0→1**	**1→0**	**Total**
42	3	499	486	985	1048576	1,00E+10	60	**9,52E-14**	**9,27E-14**	**9,39E-14**
43	1	524	432	956	1048576	1,00E+10	60	**9,99E-14**	**8,24E-14**	**9,12E-14**
41	3	197	181	378	1048576	1,00E+10	20	**3,76E-14**	**3,45E-14**	**3,60E-14**

Table a-6 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

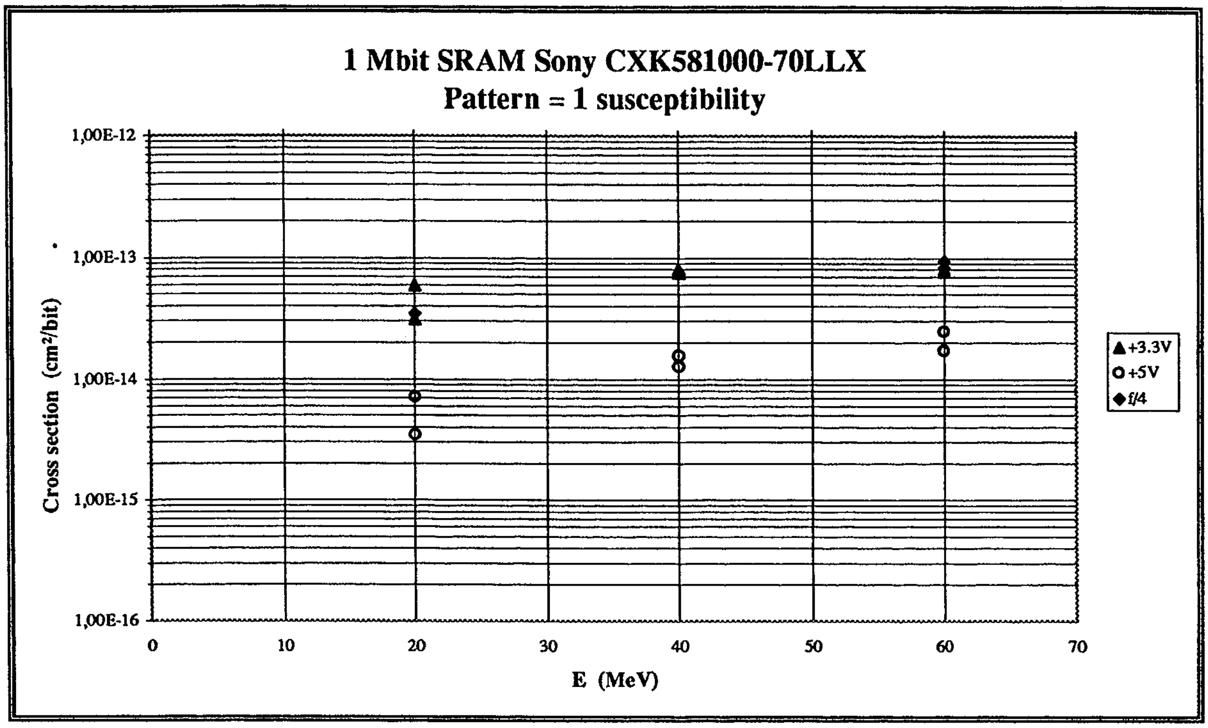


Fig. a-3 Proton SEU Cross section measurements for 1→0 transitions

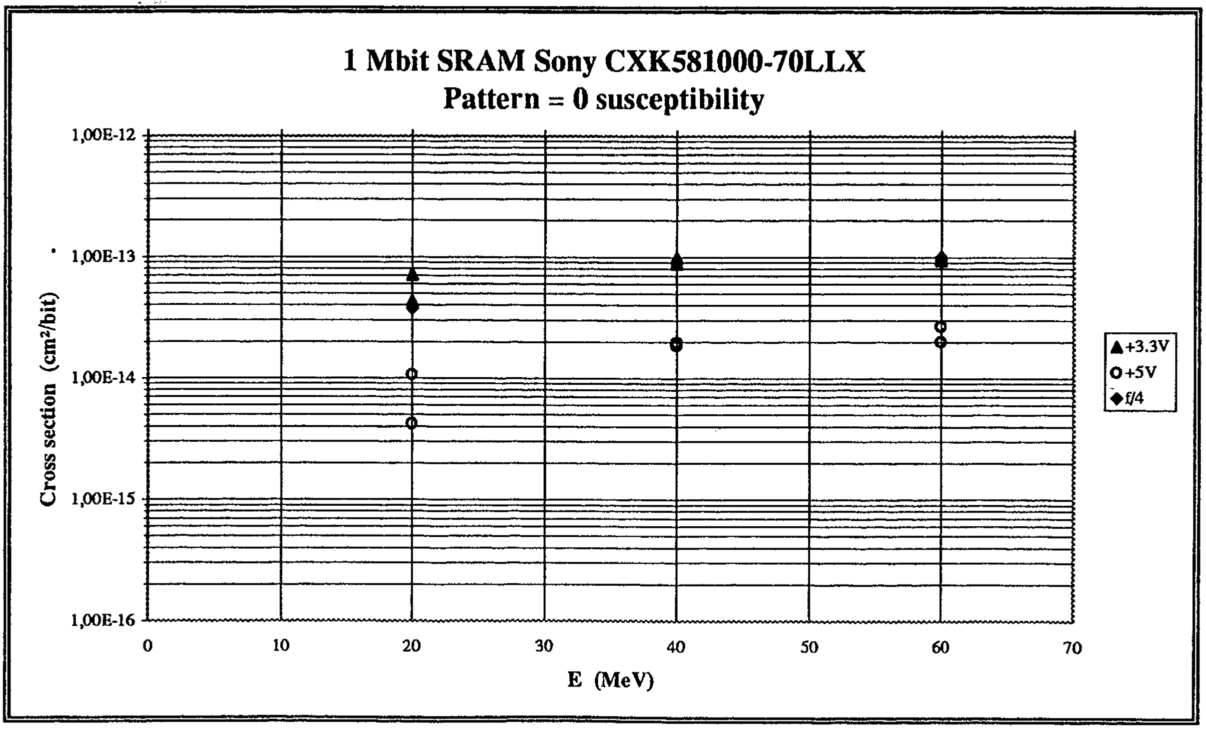


Fig. a-4 Proton SEU Cross section measurements for 1→0 transitions