Proton SEE Results - A Summary of ESA's Ground Test Data

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Abstract

This paper presents a summary of proton Single Event Effects (SEE) data taken by the European Space Agency on a wide range of memory devices. SRAM, DRAM, UV-EPROM, FLASH-EPROM and EEPROM data are compressed into a table format which gives a quick overview of what has been tested, where and when. Results are presented in a 5 column format giving test energy in MeV and SEU Cross section in cm^2/per bit.

I. Introduction

In order to predict and assess the frequency of upsets that can be expected for a device in space, a full characterisation covering both technology details and SEE testing is required. As proton orbital predictions are often based on heavy ion data or poor ground test data, the in-orbit performance differs, often significantly, from these predictions. Proton SEE prediction tools are widely used by ESA contractors today. However, very few contractors, if any, are contributing with ground test data. To compensate for this lack, all proton data taken on memory devices by the European Space Agency, are presented here and made available to the space community.

Since the first proton SEE test at Harwell in June 1989, ESA have performed proton tests at many different sites and covered increasingly complex technologies. The first test covered 4Kbit and 16Kbit Static Random Access Memories (SRAMs) whereas the latest in November 1996 at UCL covered 16Mbit Dynamic Random Access Memories (DRAMs), 8Mbit FLASH-Erasable and Programmable Read Only Memories (FLASH-EPROMs) and 1 Mbit SRAMs at both 5.0 and 3.3 Volt. Over this time period, a total of 165 proton tests have been carried out at different test sites and on different SRAMs, DRAMs, UV-EPROMs, FLASH-EPROMs and EEPROMs. Results from these tests are presented in a compressed table format, easily readable and ready for further use.

It is not the purpose of this paper to compare the results presented with other published proton data so only ESA references are given. However, it is interesting to note that a NSREC (IEEE Trans. on Nuc. Sci. Dec. 1984 to 1996), Data Workshop (IEEE 1992-1995) and RADECS (1991 to 1995) abstract search revealed 63 papers when using "PROTON-SEU" search, 18 papers when using "PROTON-SEL" search whereas only 25 papers were found when using "PROTON-TESTING" search. A detailed check of these 25 papers further revealed that only 18 actually included new proton test data, so annually, only 3 to 4 international published papers covers this important issue - proton SEE testing of semiconductors!

II. Proton Data

In general, the memory SEE data summarised in this paper are presented in a format considered to be the minimum required for a meaningful interpretation and allow rapid review. Even though most of the columns in the table are self explanatory, each column will briefly be described and abbreviations explained.

Following the functional grouping, the columns cover:

01) **Memory Organisation** - going from low to high memory capacity.

02) **Manufacturer** - in alphabetic order per memory type.

03) **Marking & Date Code** - external package marking including date code

04) **Die Information** - information derived from microscope examination in order to reveal Mask type.

05) **Die Size in mm^2** - obtained as for 04)

06) **Facility & Test Date** - identifies where and when testing was carried out:

VEC = Variable Energy Cyclotron, AERE Harwell, UK
PSI = Paul Scherrer Institut, Villigen, Switzerland
SAT = SATURNE, CEA, Sacley, France
UCL = University Catholique de Louvain, LLN, Belgium
8906 = year/month = 1989 June

07) **No. DUT** - Number of devices tested.

08-12) **Proton Energy - MeV/Cross Section (cm^2/per bit), < Test Level - no SEU or Latch-up** - reports results obtained against test energy in MeV followed by the average Cross Section value in cm^2/per bit for all tests performed at that device/site or the < value which mean no SEU observed but a test level given or LATCH which report the device to latch-up.

13) **Remarks & Ref.** - reference to previous published ESA papers [1] to [10] or test related information.

III. SEE Test Systems and Test Facilities

In general dedicated radiation memory test systems were used during most of these tests. Details of these test systems can be found in references [1] to [10]. However, for all tests, if nothing else is stated, Vdd = 5.0 Volt, a 50/50 test pattern was used and all bits tested. Testing was carried out in air on lidded devices with the incident beam normal to the lid surface.

Today, ESA primarily supports two European test facilities, the Proton Irradiation Facility (PIF) at PSI, Switzerland and the Heavy Ion Facility (HIF) at UCL, Belgium. Details of the PIF set-up can be found in [11] whereas the UCL test site also offers proton testing as detailed in [12]. The VEC facility does not existing anymore and SATURNE [13] has not been used by ESA since 1992.

IV. Discussion

Most proton data presented here were obtained on commercially available devices, where no or very little traceability exists. Device marking and die details, as given in the table, identify what has been tested. So before using any data, careful check should be made to establish the exact device type. However, external marking is often not enough identification, if different dies have been used over the years. For example, the Meteoset experiment and the ERS-1 PRARE instrument failure were difficult to simulate due to a large spread in ground test data and uncertainty in exact die type flown [5][6].

Furthermore, most devices were tested as received without any electrical characterisation, only functionality was checked. This lack of screening probably also explain some of the spread in data within groups.

All cross section results are given in cm^2 per bit for single bit upsets only. Multiple bit errors, row, column and block errors or any other types of errors, has been removed. Where errors clearly can be classified to one of these groups a comment under "Remarks" has been added.

There are significant points of interest in the table, some of which are briefly highlighted below.

SEE Testing

In general for high capacity SRAMs and DRAMs, the difference between cross section values for the highest energy, often 300 MeV, and the lowest, often 30 MeV, is less than a factor 1.5. This means that the threshold energy must be much lower so future testing require energies below 30 MeV. Recent low voltage testing at UCL, as shown in the table, was carried out over the energy range 20 to 60 MeV. Now a larger difference in cross section was observed but still not enough to determine a clear threshold value. So future proton testing probably requires even lower energies!

Multiple Upsets Within a Word

Detail analysis of error records obtained on 128K8 and 512K8 SRAMs from the PSI9405 campaign revealed multiple upsets within a single word on two device types. The NEC 128K8 showed 2-bit word errors at 300 MeV and at 200 MeV whereas the Hitachi 512K8 showed 2-bit word errors at all energies, 3-bit word errors at 300/200/100 MeV and one 4-bit word error at 200 MeV. Previously 2-bit word errors at 300/200 MeV was also observed in Hitachi 128K8 devices.

No multiple upsets within a single word were found for any of the DRAMs tested.

Stuck Bits

So far no stuck bits were experienced in any of the SRAMs tests whereas a few can be reported in 16-Mbit DRAMs. As detailed in [9],and indicated in the table, only Hitachi devices showed this effect.

Row/Column/Block Errors

Apart from a single block error at 200 MeV in a 16-Mbit Luna "E" DRAM from IBM and a number of row, column and block errors at 300 MeV in the 16-Mbit Luna "C" DRAM [9], none of the other tested DRAMs or SRAMs showed any proton related row, column or block errors.

UV-EPROMs

During heavy ion testing in read mode, six UV-EPROM types showed latch-ups. Proton tests of these six types at 300 MeV revealed none of them to latch-up. However, one type showed address errors as further detailed in [10].

FLASH-EPROMs

In the read mode of testing, two Intel FLASH-EPROM types showed latch-up during heavy ion tests. With 300 MeV protons, none of the tested types, including Intel, showed latch-ups or SEUs.

EEPROMs

Only write mode of testing was carried out on the listed EEPROM types. As can be seen in the table, three types passed the 300 MeV testing without errors, all other types showed SEUs as reported.

V. Conclusions

As mentioned in the introduction, the main purpose of this paper is to provide the space community with a large body of proton SEE data. As also stated, all data were taken by the European Space Agency and presented in a summary format without references to similar published data by others. It is up to the user to compare and use the presented data, and it is hoped, that the format provides sufficient information in a user friendly way, are easy to read and will be useful to many designers and engineers.

VI. Acknowledgements

The author would like to acknowledge the support of all authors/co-authors which paper have been referenced. Also a special thanks go to all test facility staff who have supported the various proton tests.

VII. References

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Proton SEE Results - A Summary of ESA's Ground Test Data - Page 1.												
Manufacturer		Marking -	Die - Info & Size		Facility	No.	Proton Energy - MeV/Cross Section (cm²/per bit),					Remarks
Function/Organ.		Date Code	Info	mm²	Test Date	DUT	< Test Level - no SEU or Latch-up.					Ref.
SRAM												
4K1	Harris	HM1-6504-5 7943	HM6504 7760	21.9	VEC8906	2		60/<5.3E-15				[1]
4K1	Harris	HM1-6504-2 R 8222	"H" HM 504 1978	19.5	VEC8906	3	45/<1.1E-14	60/<5.0E-15				[1][2]
4K1	Harris	HM1-6504S-9 SR 8508	HM504 7760	14.5	PSI8911	1				209/<8.4E-15		[1]
4K1	MHS	MM1-6504H11 8619	HMS AM6504 R78	19.2	VEC8906	2		60/1.0E-14				[1]
4K1	MHS	MM1-6504H11 8619	HMS AM6504 R78	19.2	PSI8911	2			100/9.0E-14			[1]
2K8	Cypress	CY7C128-35DC 8852	7C128O "C" 1987	9.9	PSI9408	1					300/2.1E-12	
2K8	Cypress	CY7C128A-35DC 8947	7C128A "C" 1984	12.3	PSI9408	1					300/1.3E-12	
2K8	Harris	HM1-6516-9 8313	HM65L16 '81	31.6	VEC8906	3	45/<3.1E-15	60/2.4E-14				[1][2]
2K8	Harris	HM1-6516-9 8313	HM65L16 '81	31.6	PSI8911	2			100/1.5E-13	200/1.5E-13		[1][2]
2K8	Hitachi	HM6116P-3 8638	TM6116P	25.2	VEC8906	3	45/3.1E-14	60/3.7E-14				[1][2][3]
2K8	Hitachi	HM6116P-3 8638	TM6116P	25.2	PSI8911	2				209/5.8E-13		[1][3]
2K8	Hitachi	HM6116P-3 8638	TM6116P	25.2	SAT9104	3		50/<5.7E-14	100/1.6E-13	200/1.8E-13	500/3.6E-13	[3]
2K8	Marconi	MAS6116M MEDL 8737	MA793	39.5	PSI8911	1			100/<1.5E-15	200/<2.0E-15		[1]
2K8	MHS	HM1-65162-2 MHS 8740	HM65162 '87MHS	22.2	PSI8911	3			100/4.2E-13	209/5.5E-13		[1]
2K8	MHS	HM1-65162-2 MHS 8740	HM65162 '87MHS	22.2	PSI9304	1				200/5.0E-13	300/6.2E-13	[4]
2K8	MHS	HMC-65162 ESB1 8902	HM65162 '87MHS	22.2	PSI9304	1			100/4.1E-13		300/7.6E-13	[4]
2K8	Toshiba	TC5516AP-2 8333	"T" C900 1980 TTH	26.5	SAT9104	3			100/5.9E-14	200/5.9E-14	500/1.6E-13	
2K8	Toshiba	TC5516AP-2 8340	"T" C900 1980 TTH	26.5	VEC8906	3	45/4.1E-15	60/1.3E-14				[1][2]
16K1	Cypress	CY7C167-35DC 8742	"C" C7167A 1984	12.1	PSI8911	1				**209/LATCH**		[1]
16K1	MHS	HM1-65262-2 8714	HMS 2298-71 1985	17.1	PSI8911	1			100/3.5E-13	209/6.6E-13		[1]
16K1	Texas I.	SMJ61CD16LA-25 8904			PSI8911	1				**209/LATCH**		[1]
8K8	Cypress	CY7C185-35DC 9006	"C" 7C185A 1986	18.4	PSI9408	1					300/1.4E-12	
8K8	Cypress	CY7C185-25PC 9214			PSI9408	1					300/1.3E-12	
8K8	EDI	EDI8808CB 35QB 9103	"C" MHS 7C185A 1986	18.4	PSI9408	1					300/2.0E-12	
8K8	EDI	EDI8810L 150DB 9033	61C65 ZC5A002 PHILI.	24.3	PSI9408	1					**300/LATCH**	
8K8	Fujitsu	MB8464-15 8431	"F" 8464	33.1	PSI8911	2			100/1.1E-13	209/3.7E-13		[1]
8K8	Hitachi	HM6264LP-15 8431	HM6264	34.8	VEC8906	2	45/3.9E-14	60/5.7E-14				[1][3]
8K8	Hitachi	HM6264LP-15 8431	HM6264	34.8	PSI8911	2			100/1.2E-13	209/7.7E-14		[1][2][3]
8K8	Hitachi	HM6264LP-15 8431	HM6264	34.8	SAT9104	3			100/1.0E-13	200/1.4E-13	500/2.9E-13	[3]
8K8	Hitachi	HM6264ALP-15 8901	"H" 6264A 1984	29.6	SAT9104	1			100/1.2E-13	200/2.1E-13	500/5.0E-13	[3]
8K8	MHS	HMCE-65664B-8 9232	HM65664 '91 MHS	22.8	PSI9304	1			100/3.9E-14		300/1.3E-13	[4]
8K8	MHS	HM1E-65664E-2 9114	HM65664 '89 MHS	22.8	PSI9304	1			100/6.3E-14		300/1.5E-13	[4]
8K8	IDT	IDT 7164 RE9101BI	IDT 7164 1987	29.6	SAT9104	2		50/<2.9E-14	100/8.4E-14	200/7.4E-14	500/1.7E-13	

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Manufacturer / Function/Organ.		Marking - / Date Code	Die - Info & Size / Info	mm²	Facility / Test Date	No. / DUT	Proton Energy - MeV/Cross Section (cm²/per bit), < Test Level - no SEU or Latch-up.					Remarks / Ref.
SRAM cont.												
8K8	NEC	D4364C-20L 8436	NEC D4364 1983	34.9	PSI8911	2				209/9.7E-15		[1]
8K8	NEC	D4364C-20L 8426	NEC D4364 1983	34.9	PSI9202	1		60/1.4E-14				
8K8	NEC	D4464G-15L 8622	NEC D4464 1983	38.2	PSI9202	2	**33/LATCH**	**60/LATCH**				ERS-1, SEL values see[5][6]
8K8	NEC	D4464G-15L 8731	NEC D4464 1983	38.2	PSI9202	3	**33/LATCH**	**60/LATCH**				SEL values see [5][6]
8K8	NEC	D4464C-15 8945	NEC D4464A '85	34.8	PSI9209	1	**50/LATCH**	**60/LATCH**	**70/LATCH**	**100/LATCH**	**150/LATCH**	SEL values see [6]
8K8	Toshiba	TC5564PL-15 8514			VEC8906	1		**60/LATCH**				[1]
8K8	Toshiba	TC5564PL-15 8646			PSI8911	2				**209/LATCH**		[1]
64K1	Inmos	IMS1600S55 ABF 8534	IMS1600 Inmos 1984	23.4	PSI8911	1			100/5.1E-13			[1]
64K1	MHS	HM-65687E Sample	HM65687 '91 MHS	22.8	PSI9304	2			100/1.4E-14	200/5.3E-14	300/6.1E-14	[4]
32K8	EDI	EDH8832C10 KMHR 8652	M5256	48.9	SAT9104	1	50/1.8E-13	100/3.0E-13	200/2.1E-13	500/4.2E-13		Meteosat
32K8	EDI	EDH8832C-15JMHR 8738	M5256A	48.9	SAT9104	1	50/1.8E-13	100/2.3E-13	200/1.9E-13	500/2.1E-13		
32K8	EDI	EDH8832C100CL 8936	M5256B	37.3	SAT9103	1	50/9.5E-14	100/8.5E-14	200/1.1E-13	500/1.5E-13	800/2.5E-13	
32K8	EDI	EDH8832C100CL 8936	M5256B	37.3	SAT9104	1	50/1.5E-13	100/1.7E-13	200/1.2E-13	500/1.6E-13		
32K8	EDI	EDH8832C100CL 8936	M5256B	37.3	PSI8911	2		100/9.3E-13	209/1.0E-13			
32K8	Micron	JM38510/29308 2C9231	MT5C2568 S02A '90	36.3	PSI9405	2	30/9.3E-15	50/5.7E-15	100/1.1E-14	200/1.2E-14	300/1.4E-14	MARS-94
32K8	Micron	No Marking	MT5C256 S12 D 1993	20.6	PSI9408	2				200/2.3E-15	300/3.3E-15	
32K8	Mitsubishi	M5M5256BP-15 927111	M5256B	37.3	SAT9104	3	50/6.0E-14	100/6.5E-14	200/4.8E-14	500/6.7E-14		
32K8	NEC	D43256AC10LL 8839			PSI8911	3			209/4.7E-13			
32K8	Sony	CXK58258P-35 9F04E	99C327A 1987	60.7	SAT9104	4	30/7.3E-15	50/2.3E-14	100/2.7E-13	200/2.0E-13	500/3.0E-13	
32K8	Toshiba	TC55257P-10 8640			PSI8911	3		100/1.0E-13	209/1.0E-13			
32K8	Fujitsu	MB84256-15L 8650	"F" MB84256 M	55.1	SAT9104	1		100/1.2E-15		500/4.7E-15		[6] Meteosat
32K8	Fujitsu	MB84256-10L 8948	"F" MB84256.M	55.1	SAT9103	1	50/2.2E-13	100/1.8E-13	200/2.3E-13	500/3.6E-13	800/5.0E-13	[6]
32K8	Fujitsu	MB84256-10L 8948	"F" MB84256.M	55.1	SAT9104	2	50/2.5E-13	100/2.4E-13	200/2.5E-13	500/3.7E-13		[6]
32K8	Hitachi	HM62256LP-10 8817	"H" 62256R 1984	44.7	PSI8911	4			100/2.6E-13	209/1.6E-13		[3]
32K8	Hitachi	HM62256LP-10 8817	"H" 62256R 1984	44.7	SAT9104	3	30/1.8E-14	50/2.2E-13	100/1.5E-13	200/1.8E-13	500/2.9E-13	[3]
32K8	IDT	IDT 71256 9BC8943BAH	IDT DH71256ZHU '86	46.2	SAT9104	3		50/1.8E-13	100/2.9E-13	200/1.8E-13	500/2.4E-13	
32K8	IDT	IDT 71256 0C9103BI	IDT DH71256ZHU '86	46.2	SAT9104	2		50/1.7E-13	100/2.8E-13		500/2.9E-13	
32K8	MHS	HM-65656 Sample	M65656 MHS 1992	62.8	PSI9304	1			100/2.8E-13		300/3.9E-13	[4]
32K8	MHS	HM-65656E Sample	M65656 MHS 1990	62.8	PSI9304	2			100/7.8E-13	200/1.1E-13	300/1.6E-13	[4]
32K8	Quality	QS83280-15P 9302	QSI 1991	37.3	PSI9408	2	**30/LATCH**	**50/LATCH**	**100/LATCH**	**200/LATCH**	**300/LATCH**	Used for SEL study
32K8	UMC	UM62256A-10L 9036S			PSI9405	2	30/1.3E-13	50/1.7E-13	100/1.6E-13	200/1.5E-13	300/1.8E-13	VTT
256K1	Fujitsu	MB81C81A-45 8820	MB81C81A "F"	38.3	SAT9104	2		50/2.3E-13		200/1.1E-13	500/1.6E-13	
256K1	MHS	HM-65697 Sample	M65597 MHS 1992	63.5	PSI9304	2		50/7.6E-14	100/3.0E-13	200/3.0E-13	300/4.0E-13	[4]

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Manufacturer / Function/Organ.		Marking - / Date Code	Die - Info & Size / Info	mm²	Facility / Test Date	No. / DUT	Proton Energy - MeV/Cross Section (cm²/per bit), < Test Level - no SEU or Latch-up.					Remarks / Ref.
SRAM cont.												
256K1	Performa.	P4C1257-35CC 8943	"P" 256K 1988	31.9	SAT9104	2		50/<3.4E-15		200/4.4E-15	500/9.4E-15	
128K8	EDI	EDI88128C100CM 9102	"M" M5M51008 BE	92.5	SAT9104	4	30/1.2E-14	50/1.3E-13	100/1.2E-13	200/1.2E-13	500/1.3E-13	
128K8	EDI	EDI88130H45CM 9111	"P" ZH5A112	92.2	PSI9304	1			100/1.7E-13		300/2.5E-13	[4]
128K8	Hitachi	HM628128L-10 9009	"H" HM628128	78.4	SAT9104	4	30/1.1E-14	50/9.1E-14	100/9.7E-14	200/9.3E-14	500/1.0E-13	[3]
128K8	Hitachi	HM628128L-10 9009/35	"H" HM628128	78.4	PSI9304	2		50/4.5E-14	100/8.3E-14	200/7.8E-14	300/9.0E-14	[3][4]
128K8	Hybrid MP	MSM8128S-85 9252	"S" CXK581000 1987	80.5	PSI9304	1		50/3.2E-14	100/5.8E-14		300/8.4E-14	[4]
128K8	Hybrid MP	MSM8128S-70 9210	"S" CXK581001 1988	87.2	PSI9304	1		50/1.5E-14	100/8.3E-15		300/1.5E-14	[4]
128K8	Hybrid MP	MSM8128SLMB-45 9108	"S" CXK581020 1988	87.2	PSI9304	1			100/1.3E-15		300/3.4E-15	[4]
128K8	Hybrid MP	MSM8128SLMB-45 9108	"S" CXK581020 1988	87.2	PSI9405	2	30/7.0E-15	50/5.5E-15	100/6.2E-15	200/8.9E-15	300/1.1E-14	
128K8	Micron	MT5C1008C-25 QP 9110	MT5C1008 '89 S01 A	81.1	SAT9104	4	30/2.4E-14	50/1.2E-13	100/1.8E-13	200/1.3E-13	500/2.8E-13	
128K8	NEC	D431000ACZ-85LL 9146	NEC D431000A 1990	79.5	PSI9405	2	30/1.2E-13	50/1.5E-13	100/1.4E-13	200/1.5E-13	300/1.6E-13	
128K8	Samsung	KM681000LP-8 214Y	"S" KM681000 1988		PSI9405	2			100/2.8E-13	200/2.6E-13	300/3.0E-13	
128K8	Sony	CXK581000P-10L 0714E	"S" CXK581000 1987	80.5	SAT9104	4	30/<1.0E-15	50/1.7E-15	100/3.7E-15	200/3.7E-15	500/4.5E-15	
128K8	Sony	CXK581000AM-70LLX 1992	"S" CXK581000A 1992	41.2	UCL9611	2	20/6.2E-15	40/1.7E-14	60/2.2E-14			[7]
128K8	Sony	CXK581000AM-70LLX 1992	"S" CXK581000A 1992	41.2	UCL9611	2	20/5.1E-14	40/8.6E-14	60/8.7E-14			[7] VCC=3.3V
128K8	Toshiba	TC55B8128P-20 9230	"T" ERIOB 1991	95.4	PSI9405	2	30/1.6E-13	50/2.0E-13	100/2.1E-13	200/1.8E-13	300/2.1E-13	
128K8	Toshiba	TC551001BPL-70L 9623	"T" ET99A 1992	44.1	UCL9611	2	20/6.3E-15	40/1.6E-14	60/1.0E-14			[7]
128K8	Toshiba	TC551001BPL-70L 9623	"T" ET99A 1992	44.1	UCL9611	2	20/2.8E-14	40/7.0E-14	60/7.0E-14			[7] VCC=3.3V
512K8	Hitachi	HM628512P-7 9235	"H" HM628512	107.8	PSI9304	1		50/1.6E-13	100/2.3E-13		300/2.3E-13	[3][4]
512K8	Hitachi	HM628512P-7 9235	"H" HM628512	107.8	PSI9405	1	30/1.8E-13	50/2.2E-13	100/2.0E-13	200/1.8E-13	300/2.2E-13	
512K8	Samsung	KM6840000LP-5 310Y	"S" KM684000 1991	114.8	PSI9405	2	30/1.5E-13	50/1.8E-13	100/1.7E-13	200/1.7E-13	300/2.0E-13	[4]
DRAM												
16K4	Texas I.	TMS4416-12NL 8844			PSI8911				100/1.3E-12	209/1.4E-12		[2]
256K4	Mitsubishi	M5M44C256P 8662			PSI8911	2			100/3.1E-13	209/2.7E-13		
256K4	NEC	D424256C-80 8923			PSI8911	2			100/8.1E-13	209/8.9E-13		
256K4	NEC	D424256V-80 8919			SAT9104	2	30/5.9E-14	50/5.1E-13	100/6.2E-13	200/6.7E-13	500/1.2E-12	
256K4	Siemens	HYB514256A-70 9028			SAT9104	2	30/4.5E-14	50/3.1E-13	100/2.2E-13	200/1.4E-13	500/1.2E-13	
256K4	Toshiba	TC514256P-10 8811			PSI8911	2			100/4.3E-13	209/3.9E-13		
1M1	Mitsubishi	M5M4C1000P 7152E2-12			PSI8911	2			100/3.9E-13	209/3.1E-13		
1M1	NEC	D421000C-10 8839			PSI8911	2			100/7.4E-13	209/7.3E-13		
1M1	Siemens	HYB511000A-70 8846			PSI8911	2			100/4.5E-13	209/4.0E-13		
1M1	Texas I	SMJ4C1024-12JDM 8840	4C1024 TI 1985	50.2	PSI8911	4				209/4.7E-13		
1M1	Toshiba	TC511000AP-10 8748			PSI8911	2			100/4.8E-13	209/3.7E-13		

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Manufacturer		Marking -	Die - Info & Size		Facility	No.	Proton Energy - MeV/Cross Section (cm²/per bit),					Remarks
Function/Organ.		Date Code	Info	mm²	Test Date	DUT	< Test Level - no SEU or Latch-up.					Ref.
DRAM cont.												
1M4	EDI	EDI44102C100ZC 9110	M5M44100A	72.2	SAT9104	2		50/3.7E-14		200/3.2E-14	500/4.6E-14	[8]
1M4	IBM	014400MJ1D IBM 9314			PSI9408	2		51/4.9E-16	100/6.5E-16	200/1.6E-15	300/2.1E-15	
1M4	Micron	4C4001JC-00E EG.S.9244	MT4C1004 D15B '92	55.8	PSI9405	2	29/3.4E-14	51/4.4E-14	100/5.3E-14	200/5.9E-14	300/7.4E-14	
4M1	Fujitsu	MBB14100-10PSZ 9025	MB814100/1-400/1	59.5	SAT9104	4	30/2.0E-14	50/1.1E-13	100/1.3E-13	200/1.3E-13	500/1.7E-13	[8]
4M1	Hitachi	HM514100ZP8 9010	HM514100AR "H"	65.4	PSI9405	1	29/3.0E-14	51/4.8E-14	100/5.6E-14	200/5.6E-14	300/6.4E-14	
4M1	Micron	MT4C1004C EG. S. 9102	MT4C001 D02A 1990	69.6	SAT9104	4	30/1.4E-14	50/6.7E-14	100/6.8E-14	200/7.8E-14	500/9.1E-14	[8]
4M1	Micron	5962-9062202MTA 9236C	MT4C4001 D02A '90	74.7	PSI9405	2	29/2.6E-14	51/3.6E-14	100/5.2E-14	200/5.4E-14	300/7.3E-14	
4M1	Micron	NO MARKING	MT4LC4001 D22 "A" 93	39.2	PSI9408	2	29/1.1E-14	51/1.5E-14	100/1.5E-14	200/2.1E-14	300/2.6E-14	300-200 MeV 1 Row Error
4M1	Motorola	MCM514100Z80 8951	"T" T5M320 1989	91.6	SAT9104	4	30/4.5E-15	50/1.2E-13	100/1.7E-13	200/1.6E-13	500/2.3E-13	[8]
4M1	NEC	D424100V-80 NEC 9005	KD424100AV/424400	85.6	SAT9104	4	30/2.9E-14	50/2.9E-13	100/3.4E-13	200/3.6E-13	500/4.1E-13	[8]
4M1	OKI	M515100-80J 9A9Z 9010	M514100A OKI	86.9	SAT9104	4	30/1.0E-14	50/7.0E-14	100/7.6E-14	200/6.2E-14	500/8.2E-14	[8]
4M1	Samsung	KM41C4000J-8 019	KM41C4000-J 1988	84.1	SAT9104	4	30/1.1E-14	50/6.4E-14	100/6.6E-14	200/6.6E-14	500/7.8E-14	[8]
4M1	Siemens	HYB514100J-10 008	SIEMENS 1988 (1989)	83.7	SAT9104	4	30/2.2E-14	50/2.3E-13	100/2.8E-13	200/2.4E-13	500/3.5E-13	[8]
4M1	Texas I.	TMS44100DM-80 0485	44100A 1989 TI	82.9	SAT9104	4	30/1.6E-15	50/8.1E-14	100/1.5E-13	200/1.8E-13	500/2.2E-13	[8]
4M1	Texas I.	SMX44100-80HLM 9218 B	44100B 1990 TI	70.6	PSI9405	2	29/6.3E-14	51/1.2E-13	100/1.9E-13	200/2.1E-13	300/2.6E-13	
4M1	Toshiba	TC514100Z-10 HDK 9007	"T" J417CB 1988	92.8	SAT9104	4	30/2.3E-15	50/1.2E-13	100/1.7E-13	200/1.8E-13	500/2.3E-13	[8]
4M4	Hitachi	HM5116400Z8 9233	"H" HM5116100RS	120	PSI9408	1	29/2.8E-14	51/3.6E-14	100/3.6E-14	200/3.6E-14	300/4.0E-14	[9] 300 MeV Stuck bit
4M4	Hitachi	HM5116400AS6 9402	"H" HM5116100AR	93.3	PSI9405	1	29/5.4E-15	51/8.2E-15	100/1.1E-14	200/1.1E-14	300/1.2E-14	[9]
4M4	Hitachi	HM5116400AS6 9402	"H" HM5116100AR	93.3	PSI9408	2	29/6.6E-15	51/8.7E-15	100/1.1E-14	200/1.2E-14	300/1.3E-14	[9] 100 MeV Stuck bit
4M4	IBM "L-E"	IBM401070804 5352 9237		100.6	PSI9408	2	29/3.7E-16	51/4.4E-16	100/5.8E-16	200/8.0E-16	300/8.9E-16	[9] 200 MeV 1 Block Error
4M4	IBM "L-C"	63F9221 N13226TC 9314	WHALE'	139.1	PSI9408	2					300/<4.8E-19	[9] Row/Column/Block Errors
4M4	IBM "L-E3"	NO MARKING - LUNA ES/3		87.6	UCL9611	2		40/6.0E-18	60/3.0E-17			[7] VDD=4.5V
4M4	IBM "L-E3"	NO MARKING - LUNA ES/3		87.6	UCL9611	2	20/3.0E-18	40/9.2E-17	60/1.9E-16			[7] VDD=3.3V
4M4	Micron	MT4C4M4B1DW 9406B	MT4C40004 D21 A'92	128	PSI9408	2	29/1.5E-14	51/1.9E-14	100/2.0E-14	200/2.4E-14	300/2.8E-14	[9]
4M4	Micron	NO MARKING	MT4C40004 D21 A'92	128	PSI9408	2	29/1.6E-14	51/2.1E-14	100/2.2E-14	200/2.4E-14	300/3.1E-14	[9]
4M4	Micron	MT4LC4M4B1D28M		57.1	UCL9611	2	20/5.9E-16	40/2.0E-15	60/2.7E-15			[7] VDD=4.5V
4M4	Micron	MT4LC4M4B1D28M		57.1	UCL9611	2	20/1.8E-15	40/3.9E-15	60/4.9E-15			[7] VDD=3.3V
4M4	Texas I.	NO MARKING	TMS416400A T.I.1992	96.7	PSI9408	2	29/1.4E-14	51/2.1E-14	100/3.0E-14	200/3.4E-14	300/3.7E-14	[9]
4M4	Toshiba	TC5116400J-60 9334MCD	EP06C SOJ B	129.3	PSI9405	1	29/5.7E-14	51/9.2E-14	100/1.2E-13	200/1.2E-13	300/1.4E-13	[9]
4M4	Toshiba	TC5116400J-60 9334MCD	EP06C SOJ B	129.3	PSI9408	2	29/7.1E-14	51/1.0E-13	100/1.2E-13	200/1.3E-13	300/1.6E-13	[9]
16M1	Fujitsu	8116100-60PJ T32 9305	"F" MB8116100/1	132.7	PSI9408	2	29/1.2E-14	51/1.6E-14	100/1.7E-14	200/2.0E-14	300/2.3E-14	[9]
16M1	Fujitsu	8116100-60PJ T32 9305	"F" MB8116100/1	132.7	PSI9405	1	29/1.1E-14	51/1.5E-14	100/1.6E-14	200/1.8E-14	300/2.0E-14	[9]
16M1	Hitachi	HM5116100Z8 9228	"H" HM5116100RS	120	PSI9408	1	29/2.4E-14	51/3.2E-14	100/3.3E-14	200/3.1E-14	300/3.5E-14	[9] 51 MeV Stuck bit

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Manufacturer / Function/Organ.		Marking - / Date Code	Die - Info & Size / Info	mm²	Facility / Test Date	No. / DUT	Proton Energy - MeV/Cross Section (cm²/per bit), < Test Level - no SEU or Latch-up.					Remarks / Ref.
DRAM cont.												
16M1	Hitachi	HM5116100Z8 9228	"H" HM5116100RS	120	PSI9405	1	29/2.3E-14	51/3.1E-14	100/3.2E-14	200/3.0E-14	300/3.3E-14	[9]
16M1	NEC	D4216100V-70 9249	D4216100/400 NEC	137.9	PSI9408	2	29/3.3E-14	51/3.9E-14	100/4.0E-14	200/4.1E-14	300/4.7E-14	[9]
16M1	Samsung	KM41C16000J-7 311	"S" KM41C16000 '92	120.8	PSI9405	1	29/3.1E-14	51/3.9E-14	100/4.1E-14	200/4.2E-14	300/4.8E-14	[9]
16M1	Samsung	KM41C16000J-7 311	"S" KM41C16000 '92	120.8	PSI9408	2	29/2.7E-14	51/3.3E-14	100/3.6E-14	200/3.9E-14	300/4.4E-14	[9]
UV-EPROM												
8K8	Cypress	CY7C263-25PC 91411 9224	7C263A "C" 1990	12.5	PSI9405	1					300/1.6E-14	[10] Heavy ion SEL, Addr. fail.
8K8	Fujitsu	MBM27C64-25x 8636			PSI8911	2				209/<2.3E-16		
32K8	NEC	D27C256D-15 8748			PSI8911	2				209/<2.5E-17		
32K8	SGS-Tho.	M27C256B-15XFI B88 9222	27C256 ST 1988	16.9	PSI9405	1					300/<3.5E-16	[10] Heavy ion SEL
64K8	SGS-Tho.	M27C512-15FI B88AF 9214	M302 ST 1988	27.5	PSI9405	1					300/<1.7E-16	[10] Heavy ion SEL
128K8	Texas I.	TMS27C010A-15 EUE 9222	27C010GU 1989TI	14.6	PSI9405	1					300/<8.8E-17	[10] Heavy ion SEL
128K8	Intel	D27C010-150V10 U2201986	27C010 INTEL 1988	23.8	PSI9405	1					300/<8.8E-17	[10] Heavy ion SEL
256K8	NEC	D27C2001D-15 FD111 9150	D27C2001A NEC 1988	45.9	PSI9405	1					300/<4.2E-17	[10] Heavy ion SEL
FLASH-EPROM												
32K8	SGS-Tho.	M28F256-15BI VP8A 9309	28F256 1989	23.2	PSI9405	1					300/<3.5E-16	[10] Tested in Read mode
64K8	Intel	P28F512-120 U10938P2	28F512 INTEL 1990	24.2	PSI9405	1					300/<1.5E-16	[10] Tested in Read mode
64K8	Texas I.	TMS28F512-120C3NL9331	T28F512 1992TI	16.7	PSI9405	1					300/<1.8E-16	[10] Tested in Read mode
128K8	Catalyst	CAT28F010P-15 OES 9213	28F010B 1990 CSI OKI	45.4	PSI9405	1					300/<8.8E-17	[10] Tested in Read mode
128K8	Intel	P28F010-120 U13602P1	28F010 INTEL 1989	35.3	PSI9405	1					300/<7.6E-17	[10] Tested in Read mode
128K8	Mitsubishi	M5M28F101P-12 312107	M5M28F010 "M"	36.5	PSI9405	1					300/<8.8E-17	[10] Tested in Read mode
128K8	SGS-Tho.	M28F101-150PI VP8 9344	28F101B 1991	32.1	PSI9405	1					300/<8.8E-17	[10] Tested in Read mode
1M8	AMD	AM29LV800B-120 9625	98921A 1995 "F" & "A"	47.3	UCL9611	2			60/<6.0E-18			[7] VDD=3.3V Read mode
EEPROM												
8K8	Hitachi	HN58C66P-25 S04323 9050	58C66S HITACHI	24	PSI9405	1					300/<1.4E-15	[10] Tested in Write mode
8K8	Samsung	KM28C64-20 104 KOREA	KM28C64Z SAM. 1986	24.5	PSI9405	1	29/3.7E-14	51/3.8E-14	100/5.4E-14		300/2.3E-14	[10] Tested in Write mode
8K8	SGS-Tho.	M28C64C-20P1 G993 9248	28C64CC 1992 ST	20.3	PSI9405	1	29/<5.4E-15	51/<3.5E-15	100/<3.2E-15		300/2.8E-15	[10] Tested in Write mode
32K8	Hitachi	HN58C256P-20 R3102 9232	58C256R HITACHI	33.1	PSI9405	1					300/3.6E-16	[10] Tested in Write mode
32K8	Hybrid M.P	MEM832VMB-20 6675 9246	15105 ATMEL 1989	44.7	PSI9405	1					300/<3.5E-16	[10] Tested in Write mode
32K8	Samsung	KM28C256-20 142 KOREA	KM28C256Y "S" 1988	45.6	PSI9405	2		51/2.8E-15	100/1.6E-15	200/4.7E-16	300/1.6E-15	[10] Tested in Write mode
32K8	Seeq	5962-8852506XA C 9223B	57C53B-5001 "S" 1989	38.4	PSI9405	1					300/<3.5E-16	[10] Tested in Write mode
32K8	Seeq	FM28C256-200 9331	52C53 1021 "S" 1986	47.9	PSI9405	1			100/<8.6E-16	200/<5.0E-16	300/7.0E-16	[10] Tested in Write mode
64K8	Xicor	X28C512D-15 V9144ES	X28C512A XICOR 1989	48.5	PSI9405	1					300/1.7E-16	[10] Tested in Write mode
128K8	Xicor	X28C010D-20 V9236ES	X28C010A XICOR 1988	79.4	PSI9405	1		51/4.5E-16	100/1.1E-15	200/2.2E-16	300/4.4E-16	[10] Tested in Write mode