Radiation Evaluation of 3.3 Volt 16 M-bit DRAMs for Solid State Mass Memory Space Applications.

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Abstract

This paper presents the results of a radiation evaluation programme carried out on 9 different types of commercially available low voltage (3.3 Volt) 16 Mbit DRAMs. Device preparation details, testing issues and results obtained, for both Single Event Effects (SEE) and Total Ionising Dose (TID), are individually presented and compared, and recommendations given in respect of earlier 5.0 Volt 16 Mbit types tested.

I. INTRODUCTION

With the demand for using low voltage 16 Mbit DRAM devices in current Solid State Mass Memory (SSMM) designs for Cluster II, METOP and Envisat, the European Space Agency initiated a radiation pre-screening programme on commercially available 3.3 Volt, 4Mx4 bit, 2K refresh, types. In order to start this radiation pre-screening programme, 15 devices per type were acquired, 5 specially prepared for heavy ion testing (die fully visible) and up to 10 plastic encapsulated for proton and Co-60 testing.

Having space requirements as the driver behind this evaluation, considerations such as bare die procurement and packaging aspects were essential for getting started (for heavy ion tests). Many other non-radiation related aspects like DRAM availability, reliability, failure rates, cost and flight packaging, are also essential points during the selection phase, however, only radiation aspects will be covered here.

II. 4Mx4 BIT DRAM DEVICES

In total nine 4Mx4 bit DRAM types, as shown in Table 1, were radiation tested during this programme. However, only the first 6 types were available in packages specially prepared for heavy ion SEE testing. Die's from these vendors were packaged as follows. The two types from IBM, ES3 1a) and ES4 2a), were packaged by Montpellier Technology, France. Hitachi 3a) and Samsung 4a) by HMP, UK via MSC, Germany, and Siemens 5a) and Micron 6a) by Telebus, Germany. Identification of the different packaged dies can be found in the columns "Die marking" and the die size under "die mm²", in Table 1.

The second block of devices, 1b) to 6b), were all commercially available plastic packaged types, suppose to compliment the 1a) to 6a) types as being identical. However, following the various radiation tests, destructive chemical analysis revealed the die's to be different in two cases. Hitachi devices contained revision "B" dies instead of revision "C" dies and the Siemens devices contained the new ES4 IBM/Siemens 1996 die. These details together with some information on additional device types (for comparison only, s/n 7 to 9) and packaging information, can be found in Table 1. Also given here are the number of devices exposed to Co-60, Heavy ion and Proton tests.

III. TEST SYSTEM AND TEST FACILITIES

All tests were carried out on the new memory test system with VDD = 3.3 Volt, running the MOVI 50/50 test pattern, checking for functionality errors and monitoring the current (ICCSB/ICCOP). CAS before RAS refresh was 15625 Hz, RAS precharge: 100 ns, RAS access: 200 ns, Row address hold time: 25 ns, Column address set up time: 50 ns and CAS access: 150 ns. Since obtained results are used on a comparative basis, all tests have been carried out with these timings even trough different access rate could influence the upset rate. Further test system details and test practise can be found [1][2].

Different test facilities were used during these tests. Heavy ion testing was performed at the CYCLONE Cyclotron at University Catholique de Louvain, Belgium (UCL9711) using the ion cocktail #1 and an alpha beam covering a LET

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Table 1. 3.3 Volt 4Mx4 bit DRAM identification chart.

4M4 Mbit DRAMs - 3.3 Volt – RADIATION EVALUATED								
ID s/n	**MANUFA-CTURER**	**PACKAGE MARKING**	**DIE MARKING**	**DIE mm²**	**PAC-KAGE**	**Co-60**	**H. ION**	**PRO TON**
1a	IBM - ES3	No Marking - packaged by Montp. Tech.	M1611D2 SIEMENS 1994	74.6	SOJ28C		*3	
2a	IBM - ES4	No Marking - packaged by Montp. Tech.	M1606C6 IBM/SIEMENS 1996	58.5	SOJ28C		2	
3a	HITACHI	No Marking - packaged by HMP	HM51W16100C HITACHI	50.8	DIP32C		2	
4a	SAMSUNG	No Marking - packaged by HMP	KM44V4100AJ SAMSUNG 1993	88.1	DIP32C		2	
5a	SIEMENS	No Marking - packaged by Telebus	M1611D2 SIEMENS 1994	74.6	COFJ32		#2	
6a	MICRON	No Marking - packaged by Telebus	MT4LC4M4 D42 REV.T MICRON 1996	56.4	COFJ32		4	
1b	IBM - ES3	0117400BT1E-60 724MOPS32 Q 5352	M1611D2 SIEMENS 1994	74.6	TSOP24	4		3
2b	IBM - ES4	0117400BT1F-60 724MOPS4 PQ 5352	M1606C6 IBM/SIEMENS 1996	58.5	TSOP24	4		2
3b	HITACHI	51W16405BLS6 9622 6N1 JAPAN	HM51W16100B HITACHI	59.3	TSOP24	4		2
4b	SAMSUNG	KM44V4100ALS-7 613Y KOREA 6WL	KM44V4100AJ SAMSUNG 1993	88.1	TSOP24	4		2
5b	SIEMENS	HYB3116405BT-60 9720 FRANCE 732	M1606C6 IBM/SIEMENS 1996	58.5	SOJ 24	4		3
6b	MICRON	MT4LC4M4E8TG-6 9711 L USA HNC4	MT4LC4M4 D42 REV.T MICRON 1996	56.4	TSOP24	4		2
7	MICRON	MT4LC4M4B1Dj-6 9606 F USA	MT4LC4M4 D24 REV.C MICRON 1994	90.7	SOJ 24	3		2
8	SAMSUNG	KM44V4100AS-6 604Y KOREA	KM44V4100AJ SAMSUNG 1993	88.1	TSOP24	3		2
9	SAMSUNG	KM44V4100BS-6 UEG56CC KOREA	KM44C4100B SAMSUNG 1994	50.6	TSOP24			2

* SEE data not published # Devices not SEE tested.

range of 68 to 0.4 MeV/(mg/cm^2). Proton testing was carried out at the OPTIS (therapy) beam line at the Paul Scherrer Institute, Switzerland (PSI9711) using proton energies of 64.5, 43.8, 22.8, 15.0 and 10.9 MeV and TID (Co-60) testing at ESA/ESTEC, The Netherlands (ESA9709) using dose rates of 4.14 and 3.2 Krad(Si)/hour.

IV. HEAVY ION RESULTS

Only devices from four manufacturers (5 device types), could be heavy ion tested. Siemens 5a) could not be tested due to non working devices!. Also detailed analysis of all test files revealed the IBM ES3 1a) data set to contain an unexpected high number of 2-bit errors, stuck bits and no consistency in identical tests. Suspecting erroneous operation of these devices (possible due to the long bonding wires!) and not having the option of re-testing, no ES3 1) heavy ion results have been included in this paper.

Heavy ion Single Event Upset (SEU) test results for the other types can be found in a graphical form in Figures 1(a) and 1(b). These graphs show (x-lin, y-log), as a function of LET, the upset cross section (cm^2/bit) averaged for the two devices tested per type. Testing was carried out in vacuum on de-lidded devices with the incident beam normal to the lid surface, tilted 45° and 60° degrees. Very few 2 or more-bit errors can be reported. IBM ES4 2a) showed a few 2-bits errors at a LET 19.9 MeV/(mg/cm^2). Hitachi 3a) a few 4-bits errors at LETs of 68.0 and 8.3 MeV/(mg/cm^2). Samsung 4a) a few 2-bit errors when tested with Ar-ions and 606 errors when tested with Kr-ions having a LET of 34.0 MeV/(mg/cm^2). Micron 6a) showed a few 2-bit, 3-bit and 4-bit errors when tested with Ar-ions (LET 14.1 to 28.2 MeV/(mg/cm^2)) and a few when tested with Kr-ions (LET 34.0 to 68.0 MeV/(mg/cm^2)). Altogether no major block, row or column errors can be reported, neither any stuck bits or latch-ups in any of the tests reported here.

Otherwise quite similar SEU behaviour can be reported for the four types tested with threshold LET values pointing towards 0.4/0.8 MeV/(mg/cm^2). Some variations are noticeable in the knee regions followed by saturated levels of about 1e-7 cm^2 for Samsung 4a) down to 3e-9 cm^2 for IBM ES4 2a).

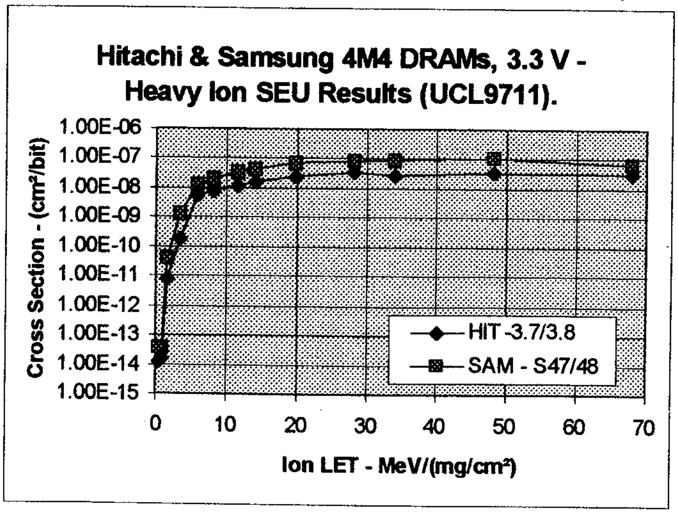

Figure 1(a). Hitachi 3a) and Samsung 4a) SEU results.

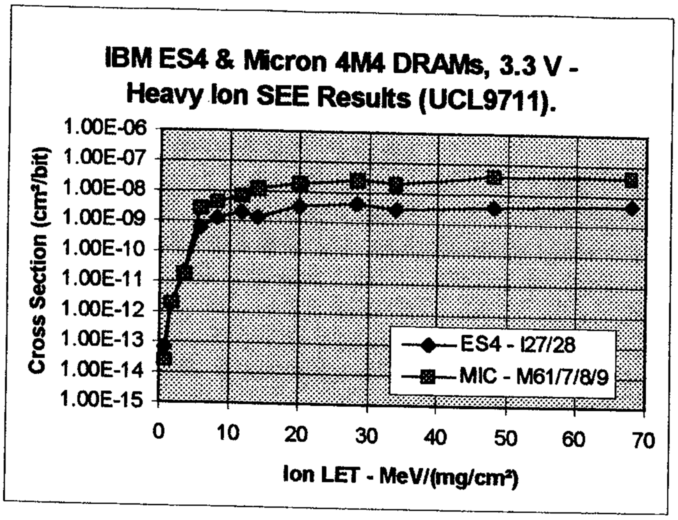

Figure 1(b). IBM ES4 2a) and Micron 6a) SEU results.

V. PROTON RESULTS

Proton SEU results for all nine 16 Mbit DRAM types listed in Table 1 can be found in Figures 2(a) to 2(d). These graphs show the upset cross section (cm^2/bit) as a function of proton energy (x-lin, y-log). The data points are average values derived from all tests at that energy. Testing was carried out in air on lidded devices with the incident beam normal to the lid surface.

The data in Figures 2(a) to 2(d) show some sort of threshold values for all types tested. Various levels can be read from these graphs as well as quite a difference in saturated cross section levels. It is interesting to note, that the new IBM ES4 is more sensitive than the old ES3, see Figure 2(a). Note also the difference sensitivity for the two Micron lots, see Figure 2(b). Good consistency was found between the two Samsung "A" lots, however, the new "B" version appear less sensitive, see Figure 2(c). Hitachi, in Figure 2(d) shows a very clear, rather low, threshold value compared to Siemens which sensitivity match very well the IBM ES4 2b).

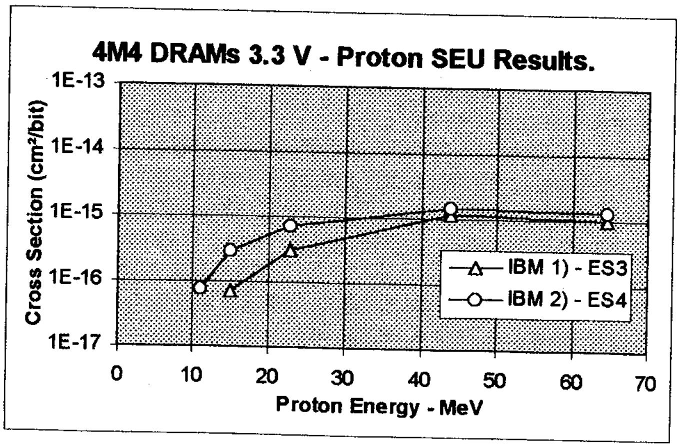

Figure 2(a). IBM ES3 1b) and ES4 2b) SEU results.

In general, no block, column or row errors were observed, nor any stuck bits or latch-ups, in any of the tests. However, when reporting this, it should also be noted, that previous testing was carried out at 5.0 V over the energy range of 30 to 300 MeV [1].

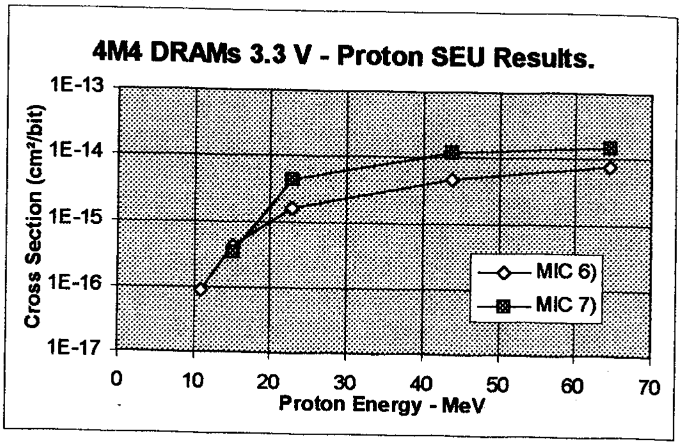

Figure 2(b). Micron 6b) and 7) SEU results.

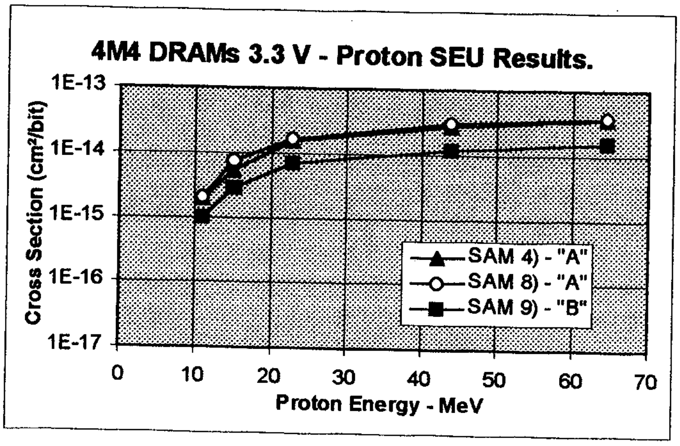

Figure 2(c). Samsung 4b), 8) and 9) SEU results.

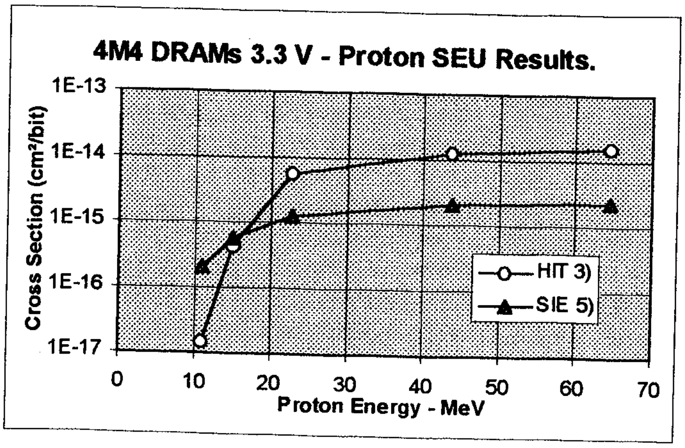

Figure 2(d). Hitachi 3b) and Siemens 5b) SEU results.

VI. Co-60 TID RESULTS

Total ionising dose data are presented in a summary format in Figures 3(a), 3(b) and 3(c). These figures show the TID level in Krad(Si) as a function of manufacturer and number of devices tested. As can be seen, three criteria for failures are presented; (a) the Krad(Si) level where ICCSB (stand-by current) increased to 120 %, (b) the Krad(Si) level where the first bit failure occur and (c) the Krad(Si) level where functional failure occur (defined as showing 1024 errors or more in a single run). The two first devices in each of the first six groups, were tested with a dose rate of 4.14 Krad(Si)/hour, whereas all other devices were tested with a dose rate of 3.2 Krad(Si)/hour.

Strong ICCSB increases were observed in nearly all tests except for Micron 6b). The values actually given for this device type in Figure 3(a) are the functional failure levels taken from Figure 3(c). The 20 % stand-by current increase level is believed, in general, to indicate the failure level where possible parametric and AC failures could be expected. Further fairly consistent 1st error and functional failure levels were found except for Micron 7) where all three devices passed the end of test (71.4 Krad(Si)). It should be noted that all b) marked devices were selected from initial shmoo plot test over the temperature range -40 °C to +120 °C, thus "screened" devices.

VII. ORBITAL PREDICTIONS

CREME96 and the experimentally determined cross section curves presented in Figures 1 a)b) and Figures 2 a)b)c)d), were used for computing upset rates for Interplanetary environments. Magnetic weather quiet and all elements (1-92) were used. Shielding was assumed to be 1 g/cm^2 and the device depth to be 2 um (for all devices).

For Galactic Cosmic Ray (GCR) heavy ions, the in-orbit upset rate for four DRAM types can be found in Table 2a. The columns "GCR + SEU Curve" presents the upset rate, SEU/bit/day or SEU/device/day, based on predictions using the full cross section curve. The second part shows the results if using the 1% threshold criteria as often given in papers. In summary, IBM 2a) showed the best performance with approximately 35 days between upset. Samsung 4a) the worst, with approximately 10 hours between SEUs. The 1% threshold approach predict a factor 7 to 14 higher SEU rates! The IBM 2a) upset rate now predict values of 4 days between upsets and Samsung 4a) 1 hour between SEUs.

In order to compare these prediction results with earlier performances from 5.0 V DRAMs, the same CREME96 routine was used on two sets of curves from the 5.0 V DRAM paper [1]. Predictions for Micron gave upset rates of 1.0E-7 SEU/bit/day or 2 SEU/device/day whereas the old Samsung gave numbers of 3.0E-7 SEU/bit/day or 5 SEU/device day, values which still favour the new 3.3 V DRAM types.

Table 2a). Interplanetary - Heavy ion in-orbit upset rate predictions.

4M4 DRAMs	GCR + SEU Curve		GCR + SEU 1%Th.	
SEU/-	bit/day	device/day	bit/day	device/day
IBM 2a)	1.7E-9	0.03	1.5E-8	0.3
Micron 6a)	2.3E-8	0.38	3.3E-7	5.5
Hitachi 3a)	3.3E-8	0.55	2.3E-7	3.9
Samsung 4a)	1.4E-7	2.35	1.4E-6	24

Table 2b). Interplanetary - Proton in-orbit upset rate predictions.

4M4 DRAMs	GCR + SEU Curve		GCR Worst Day	
SEU/-	bit/day	device/day	bit/day	device/day
IBM 2b)	5.E-10	0.008	2.1E-6	35
Micron 6b)	2.9E-9	0.05	7.8E-6	130
Hitachi 3b)	5.9E-9	0.10	1.9E-5	319
Samsung 4b)	1.4E-8	0.23	4.7E-5	789

Upset rates for GCR proton nuclear reaction events can be found in Table 2b. Again the two first columns presents the upset rate, SEU/bit/day –device/day, as detailed for Table 2a. These SEU rates have to be added to the heavy ion results for a true in-orbit prediction. However, for Hitachi, the heavy ion predictions are valid for revision "C" dies whereas the proton predictions are valid for revision "B" dies, so a true in-orbit upset rate, for one die, can not be predicted.

Using the proton data from [1] and running CREME96 under the same conditions, the old 5.0 V Micron gave numbers of 1.0E-8 SEU/bit/day or 0.2 SEU/device/day. The old Samsung gave numbers of 1.6E-8 or 0.3 SEU/device/day, results, which still favour the new 3.3 V DRAM types tested here.

In order to get a first feeling for flare conditions, GCR worst day proton events have also been added in Table 2b. Noticeable here is the rapid upset rate increase e.g for IBM 2b) from 0.008 SEU/device/day to 35 SEU/device/day!. .

In general for all 3.3 Volt 4M4 bit DRAMs, the in-orbit predictions favour these new technologies in respect to the older 5.0 Volt types [1].

IIX. DISCUSSION

Detailed checking and analysis of the various radiation files showed no block, column or row errors neither any stuck bits, latch-ups or low current latch-ups. Multiple upsets within a word, as already detailed earlier, were seen but not considered critical as no consistency in the events could be found. In contrast to this, earlier 16 Mbit 5.0 V tested DRAMs showed worrying radiation results as previously reported in [1][3][4][5][6][7]. Unfortunately, none of the referenced papers has low voltage SEE data taken on

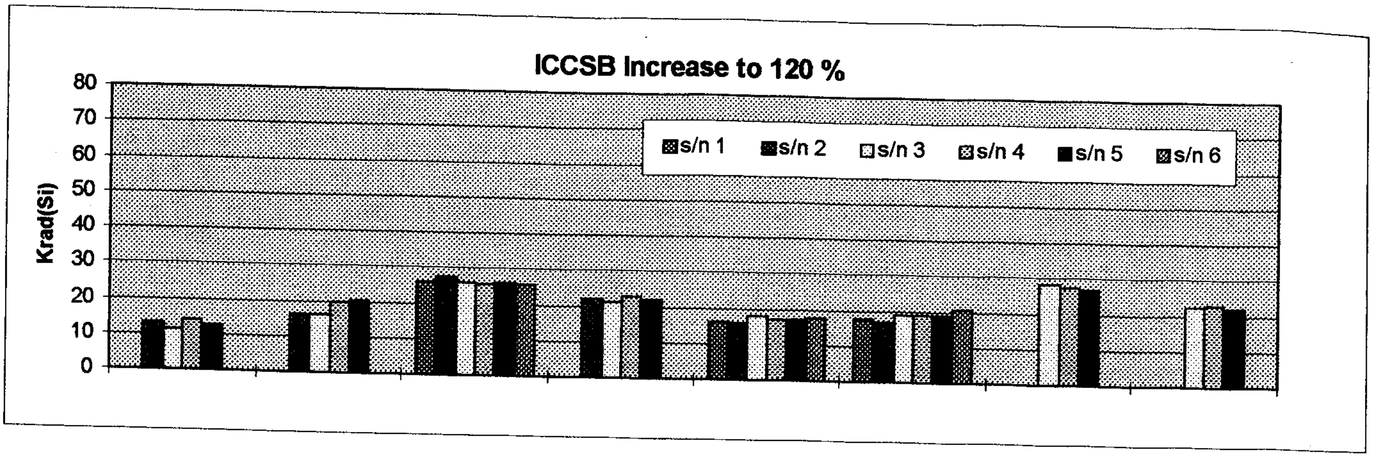

Figure 3(a). Krad(Si) levels where ICCSB (stand-by current) increased to 120 %.

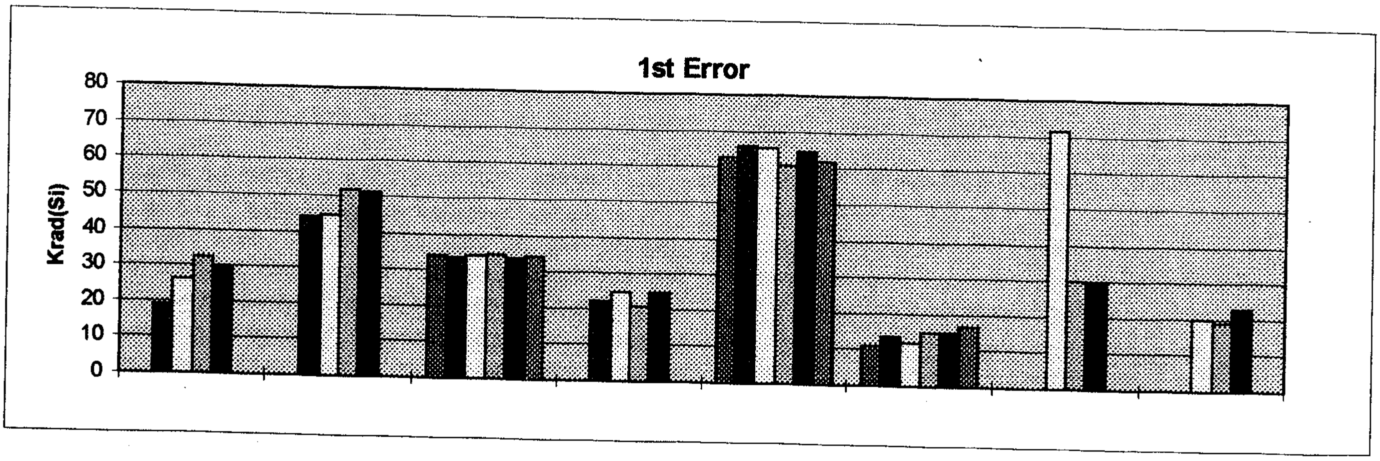

Figure 3(b). Krad(Si) levels for first error.

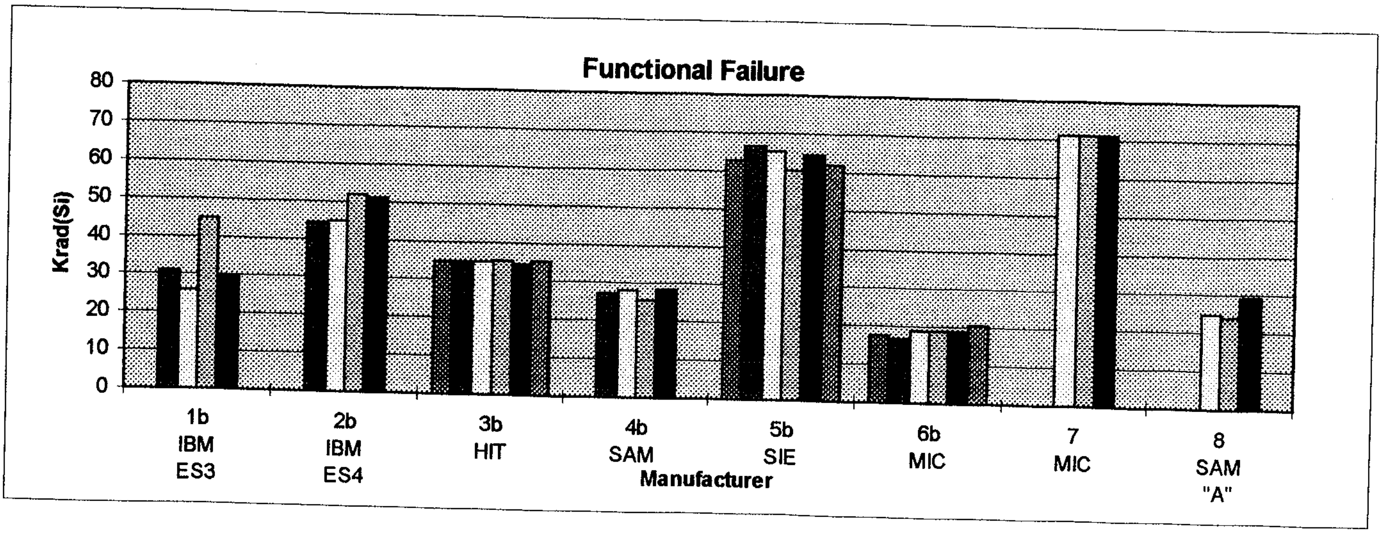

Figure 3(c). Krad(Si) levels for functional failure.

device types as tested here. Obviously it would be nice to get these radiation results confirmed, however, for the time being this new vintage of low voltage 3.3 V DRAM types, appears less sensitive then the older 5.0 V types.

The importance of reporting on what have been tested is apparent in this paper. In two out of six cases the dies procured for the heavy ion testing did not match the dies found in the plastic encapsulated devices. Also noticeable is the fact that two different dies were found within date codes 9606/9711. So without the die identification, the presented radiation data would have been difficult to understand and be of little value to other users.

IX. CONCLUSIONS

This radiation evaluation of low voltage, 3.3 volt, 16Mbit DRAM types, showed in general very encouraging results. All types tested showed behaviour indicating acceptability for space usage. No negative surprises can be reported nor any major concerns. Obviously variations in radiation response as reported here will favour certain types.

In summary, the 3.3 volt results appear more attractive than the 5.0 volt types previously tested. Comparable TID performance can be reported but their better SEE behaviour is particularly noticeable. The range of SEE effects observed in 5.0 volt devices was of great concern. In 3.3 volt devices, no or very few SEE effects were found.

X. REFERENCES

[1] R. Harboe Sørensen, R. Müller, and S. Fraenkel, "Heavy ion, Proton and Co-60 Radiation Evaluation of 16-Mbit DRAM Memories for Space Application", IEEE NSREC'95, Workshop Record, Madison, pp 42-49.

[2] R. Harboe Sørensen and R. Müller, "Cost Effective Radiation Testing of Commercially Available Memories", 3rd EECC, ESTEC, Noodwijk, April 1997. Conference Proceedings, ESA SP-395, pp 245-50.

[3] B. Doucin, C. Poivey, C. Carlotti, P. Poirot, L. Baudry and R. Harboe Sørensen, "Study of Radiation Effects on Low Voltage Memories", Paper presented at RADECS'97

[4] P.Calvel, P.Lamothe, C.Barillot, R.Ecoffet, S.Duzellier and E.G.Stassinopoulos,"Space Radiation Evaluation of 16 Mbit DRAMs for Mass Memory Applications", IEEE Trans. on Nucl. Sci., NS-41, No 6, Dec.'94, pp 2267-71.

[5] K.LaBel, A.Moran, D.Hawkins, A.Sanders, C.Seidleck, H.Kim, J.Forney, E.G.Stassinopoulos, P.Marshall, C.Dale and R.Barry, "SEE Proton and Heavy ion Test Results in Support of Candidate NASA Programs", IEEE NSREC'95, Workshop Record, Madison, pp 16-32.

[6] K.A.LaBel, M.M.Gates, .A.K.Moran, H.S.Kim, C.M.Seidleck, P.Marshall, J.Kinnison, B.Carkhuff, "Radiation Effect Characterization and Test Methods of Single-Chip and Multi-Chip Stacked 16Mbit DRAMs", IEEE Trans. on Nucl. Sci., NS-43, No 6, Dec.'96, pp 2974-81.

[7] K.A.LaBel, A.K.Moran, C.Seidleck, J.M.Barth, E.G.Stassinopoulos, P.Marshall, M.Carts, C.Marshall, J.Kinnison, B.Carkhuff, "SEE Test Results for Candidate Spacecraft Electronics", IEEE NSREC'97, Workshop Record, Snowmass, pp 14-32.