2nd RADECS Thematic Workshop – January 25th 2007.
"LET-Requirements and Testing for Space Applications"

Test Facility Status and Test Conditions

by

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European Space Agency/ESTEC - The Netherlands

- **Outline:**
  - Test Facilities – General
  - Ion Range in Silicon – HIF & RADEF
  - Linear Energy Transfer – Problems
  - Sample Preparations – Examples
  - Test Conditions – Complexity
  - Ion Beam Calibration – SEU Monitor
  - Conclusions

- **Main European Heavy Ion Test Facilities:**
  - HIF — Ion Range Medium
  - RADEF — Ion Range Medium
  - GANIL — Ion Range High
  - SIRAD — Ion Range Low

- **Main USA Heavy Ion Test Facilities:**
  - BNL — Ion Range Low
  - LBL — Ion Range Medium
  - Texas A&M — Ion Range High

- **Availability & Convenience:**
  - HIF/RADEF/GANIL-SIRAD (Europe)
  - BNL/LBL/Texas A&M (USA)
- **Performance (Ion Range):**
  - GANIL/RADEF/HIF/SIRAD (Europe)
  - Texas A&M/LBL/BNL (USA)
- **Facility Cost/Travel:**
  - HIF/RADEF/GANIL-SIRAD (Europe)
  - BNL/LBL/Texas A&M (USA)

HIF Cocktails - Today

Ion Cocktail M/Q=4.94	Energy MeV	Range μm Si	LET MeV(mg/cm²)
$^{10}B^{2+}$	41	80	1.7
$^{15}N^{3+}$	62	64	2.97
$^{20}Ne^{4+}$	78	45	5.85
$^{40}Ar^{8+}$	150	42	14.1
$^{84}Kr^{17+}$	316	43	34.0
$^{132}Xe^{26+}$	459	43	55.9
UCL – Ion Cocktail #1 produced for ESA			

Ion Cocktail M/Q=3.3	Energy MeV	Range μm Si	LET MeV(mg/cm²)
$^{13}C^{4+}$	131	266	1.2
$^{22}Ne^{7+}$	235	199	3.3
$^{28}Si^{8+}$	236	106	6.8
$^{40}Ar^{12+}$	372	119	10.1
$^{58}Ni^{18+}$	567	98	20.6
$^{83}Kr^{25+}$	756	92	32.4
UCL – Ion Cocktail #2 produced for ESA 2004			

RADEF Cocktails - Today

Ion Cocktail M/Q=4.7	Energy MeV	Range μm Si	LET MeV(mg/cm²)
$^{14}N^{3+}$	86	108	2.0
$^{28}Si^{6+}$	172	74	8.0
$^{56}Fe^{12+}$	345	64	22.0
$^{84}Kr^{18+}$	517	66	35.0
$^{136}Xe^{29+}$	830	68	64.0
JYFL – Ion Cocktail produced for ESA June 2001.			

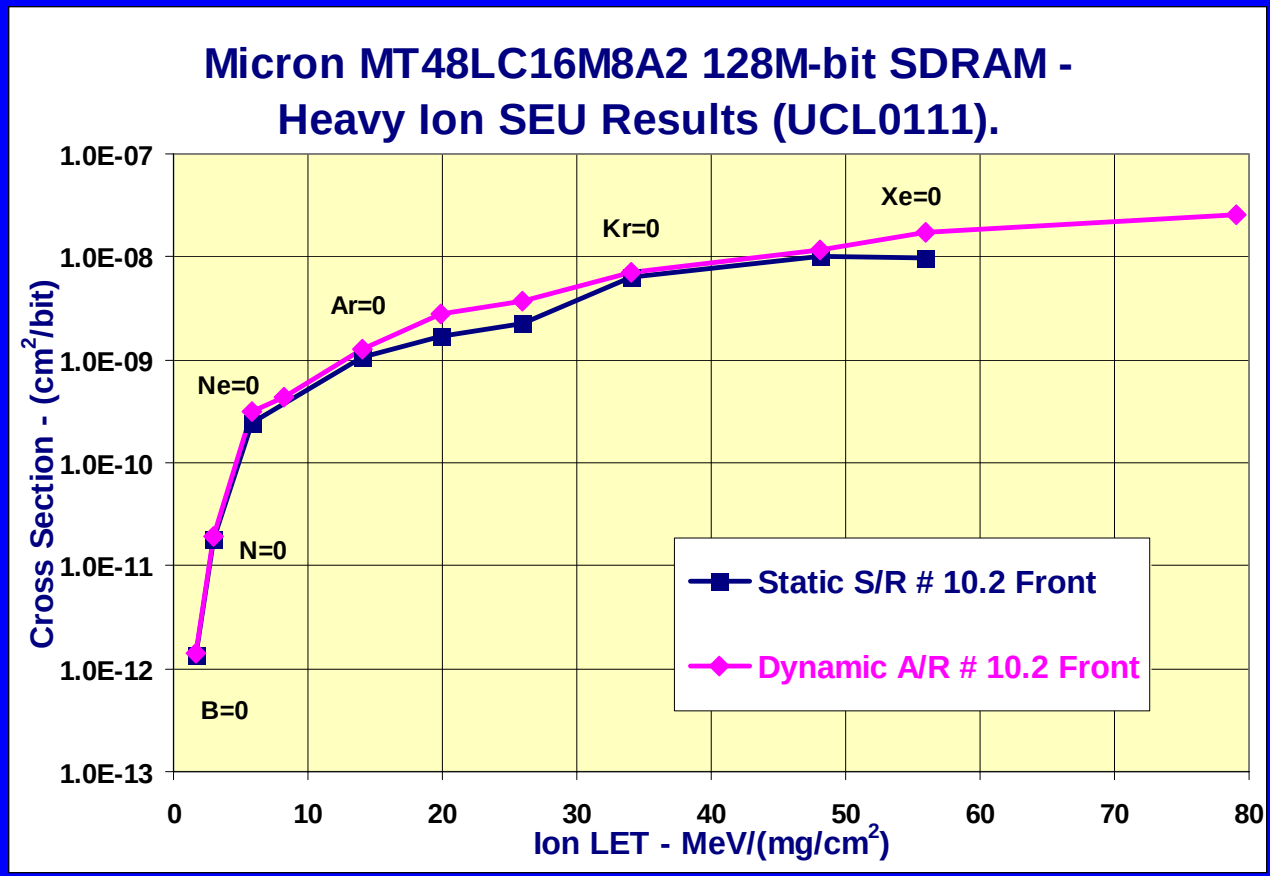
Ion Cocktail M/Q=3.7	Energy MeV	Range μm Si	LET MeV(mg/cm²)
$^{15}N^{4+}$	139	218	1.7
$^{20}Ne^{6+}$	186	149	3.5
$^{30}Si^{8+}$	278	132	6.0
$^{40}Ar^{12+}$	372	117	10.0
$^{56}Fe^{15+}$	523	99	18.0
$^{82}Kr^{22+}$	768	96	30.0
$^{131}Xe^{35+}$	1217	97	53.0
JYFL – Ion Cocktail produced for ESA April 2005			

RADEF Cocktails - Today

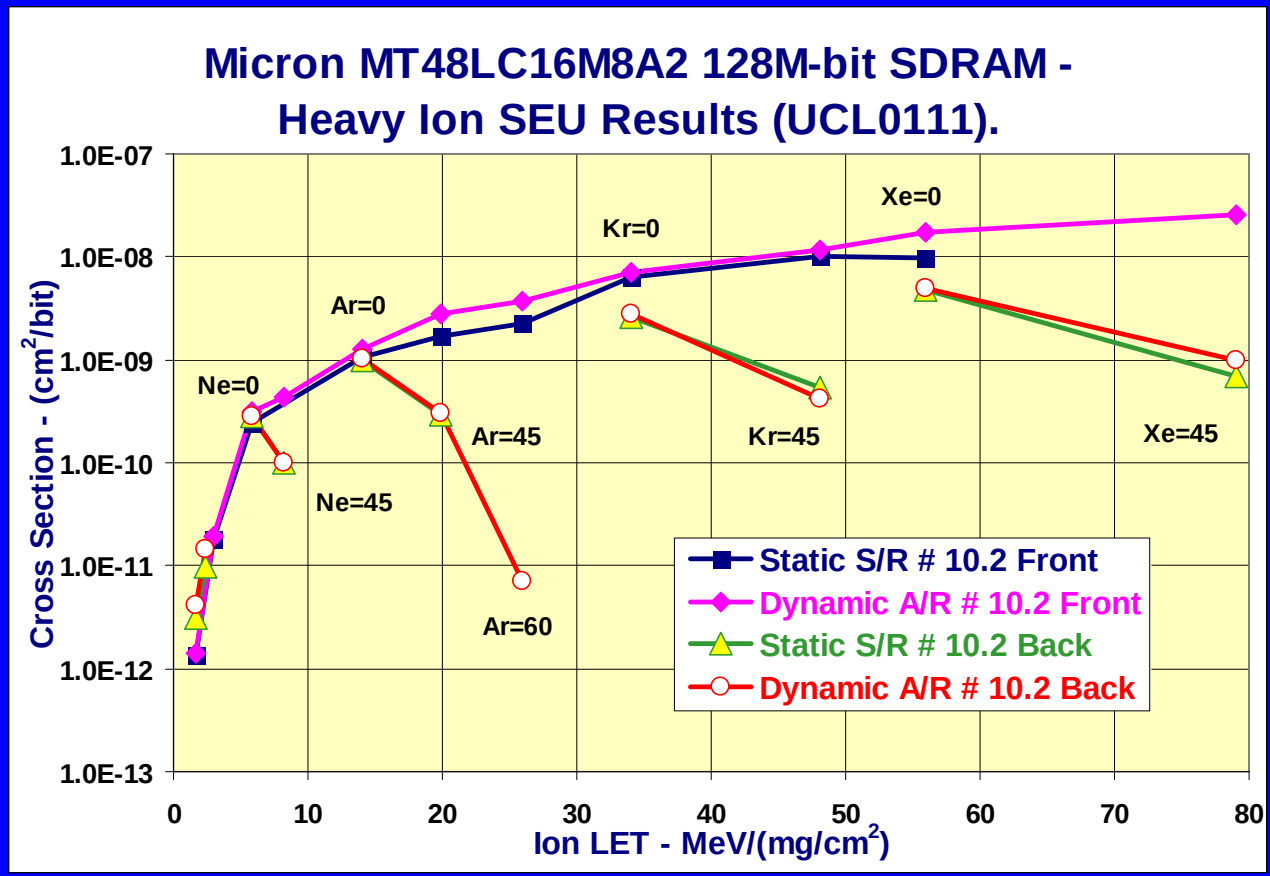
Ion Cocktail M/Q=3.7 $^{Isot}Ion^{Char}$	Energy MeV	Energy (MeV/A)	Range µm Si			LET MeV(mg/cm²)		
			Kantele	SRIM	BNL	Kantele	SRIM	BNL
$^{15}N^{4+}$	139	9.3	207.0	202.1	218.0	1.9	1.8	1.7
$^{20}Ne^{6+}$	186	9.3	156.0	145.8	149.0	3.4	3.6	3.5
$^{30}Si^{8+}$	278	9.3	132.0	130.1	132.0	7.0	6.4	6.0
$^{40}Ar^{12+}$	372	9.3	117.0	117.9	117.0	11.7	10.2	10.0
$^{56}Fe^{15+}$	523	9.3	104.0	97.4	99.0	17.9	18.5	18.0
$^{82}Kr^{22+}$	768	9.4	99.6	94.0	96.0	29.3	32.1	30.0
$^{131}Xe^{35+}$	1217	9.3	95.0	89.1	97.0	54.9	60.0	53.0

JYFL – Ion Range and LET values calculated using different codes.

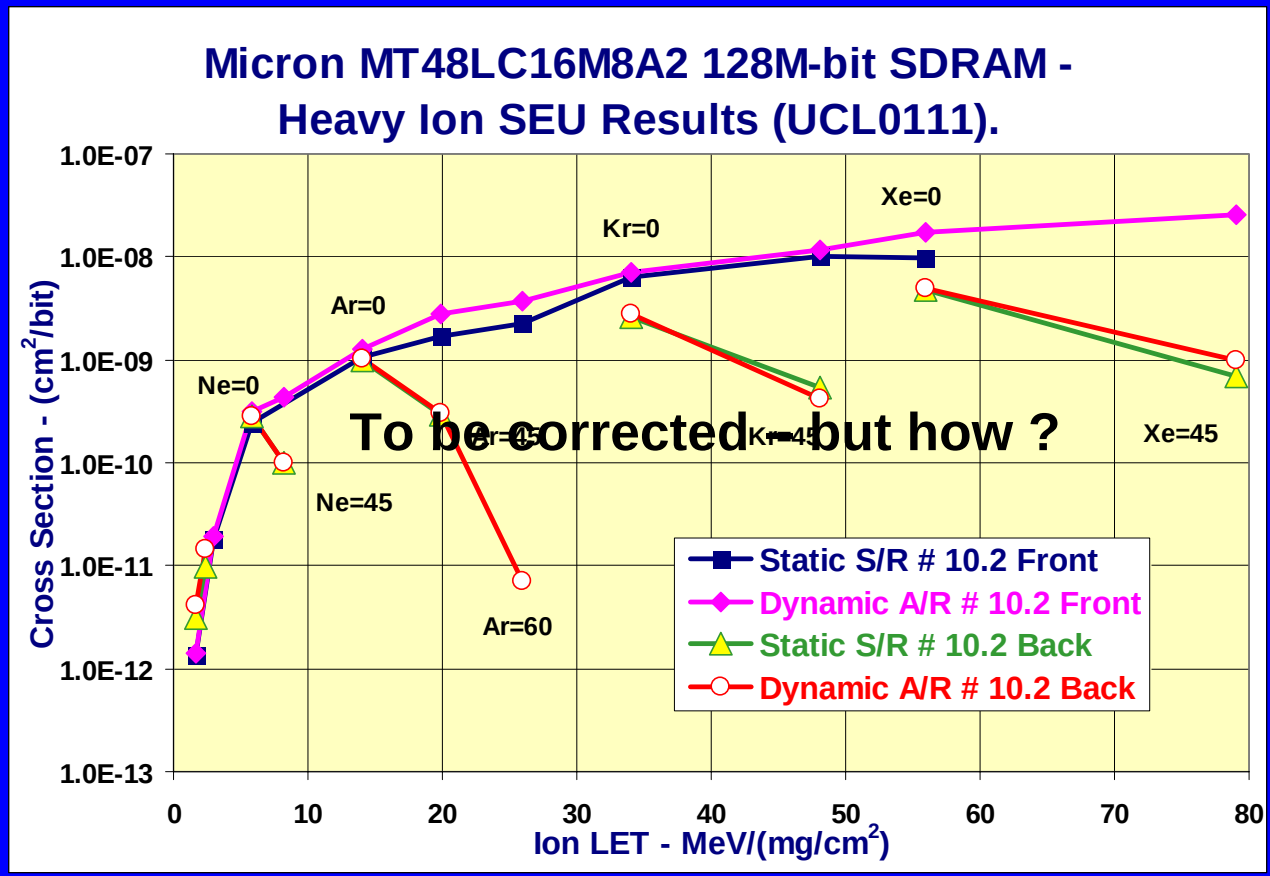
Heavy Ion SEU Results - HIF Cocktail 1



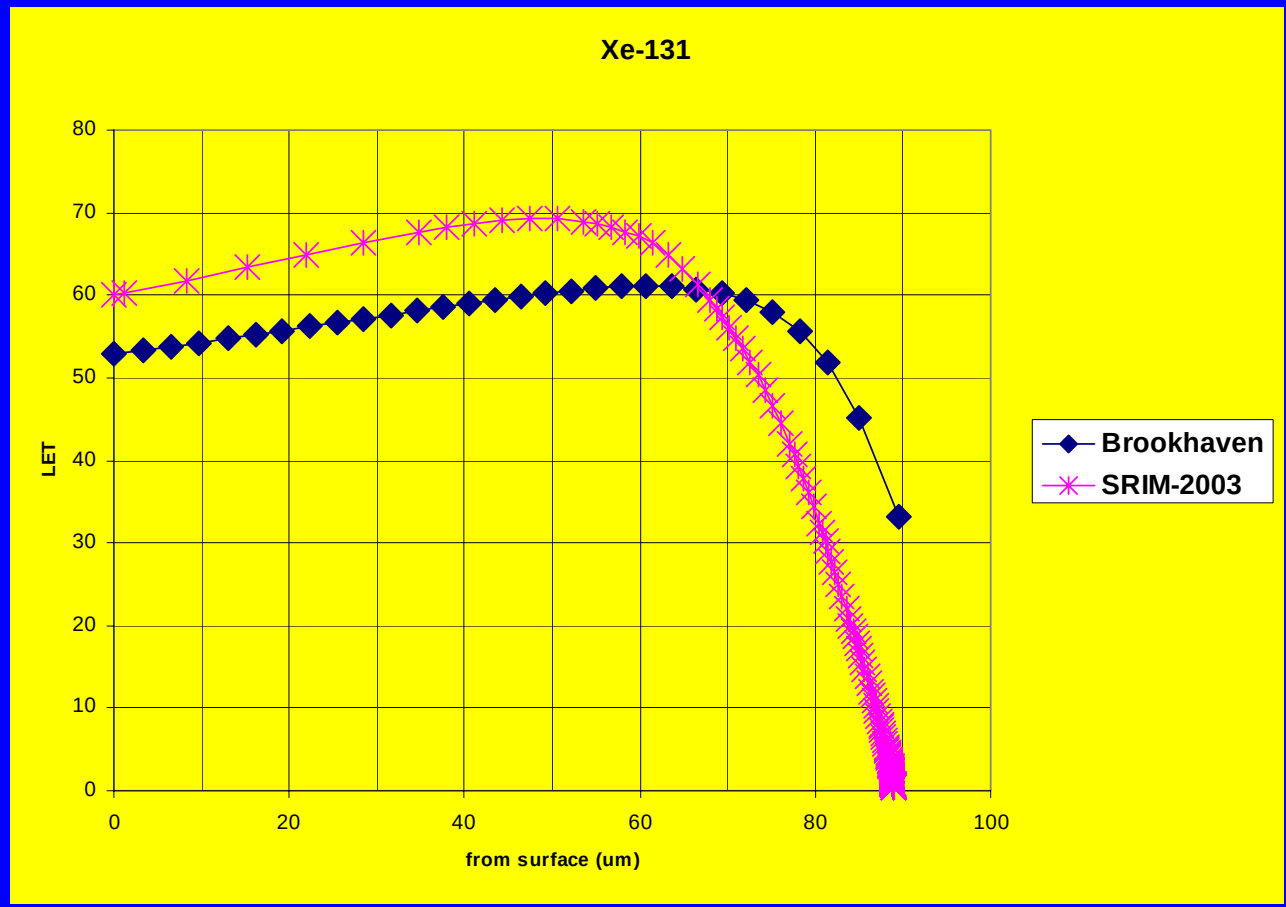
Heavy Ion SEU Results - HIF Cocktail 1



Heavy Ion SEU Results - HIF Cocktail 1



RADEF – Xe LET versus Distance



LET/Penetration

- So how can we compare SEE data from different facilities – if different LET codes are used ?

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Paper Presented at RADECS'06 and Accepted for TNS Publication:

Linear Energy Transfer of Heavy Ions in Silicon

A. Javanainen[1], T. Malkiewicz[1], J. Perkowski[2], W.H. Trzaska[1], G. Berger[3], W. Hajdas[4], R. Harboe- Sørensen[5], H. Kettunen[1], V.Lyapin[6], M. Mutterer[7], A. Pirojenko[1], I. Riihimäki[1], T. Sajavaara[1], G. Tyurin[1], H. Whitlow[1], A. Virtanen[1]

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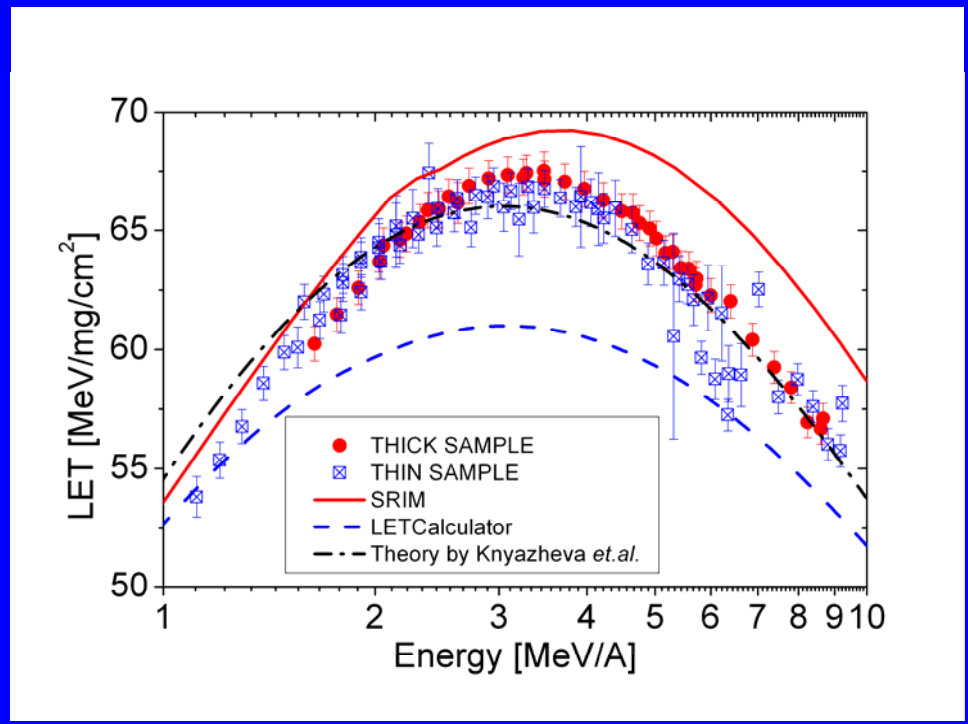
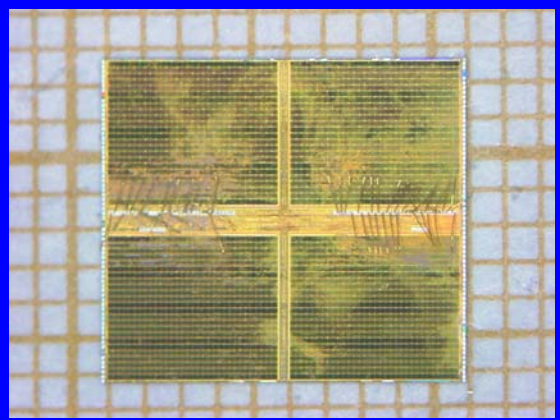
[2] University of Lodz, Nuclear Physics Division, POLAND
[3] Université Catholique de Louvain, Louvain-la-Neuve, BELGIUM
[4] Paul Scherrer Institut, Villigen, SWITZERLAND
[5] ESA/ESTEC, Noordwijk, THE NETHERLANDS
[6] Helsinki Institute of Physics, FINLAND
[7] Institute of Nuclear Physics, Darmstadt University of Technology,, Darmstadt, GERMANY

LET of Heavy Ions in Silicon

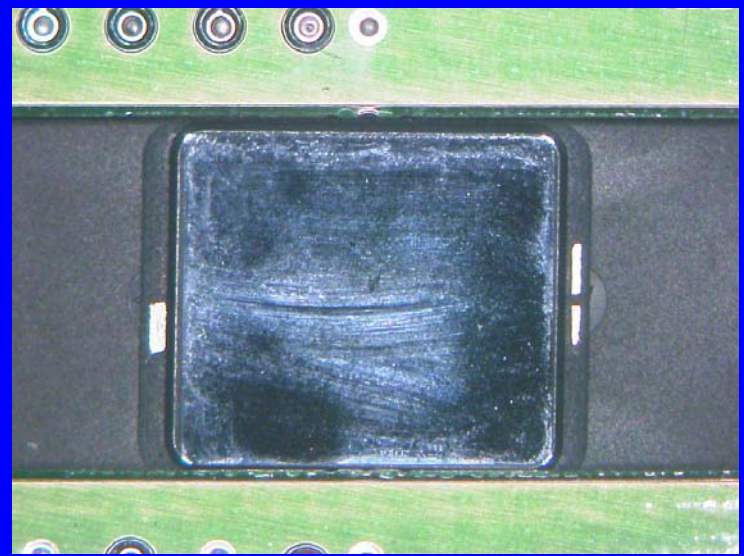


RADEF Results for Xenon ions in Silicon

Sample Preparations – SDRAM Example

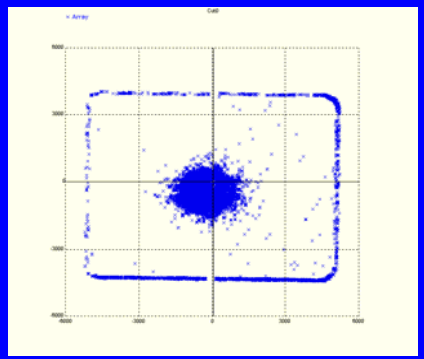


Front side of die

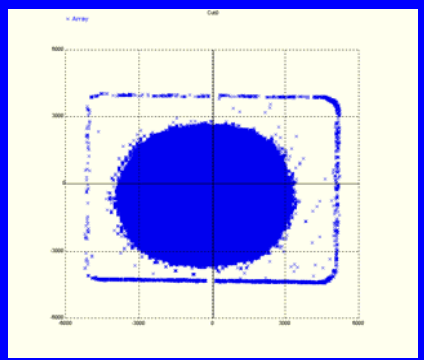


Back side of thinned die – thinned to um ?

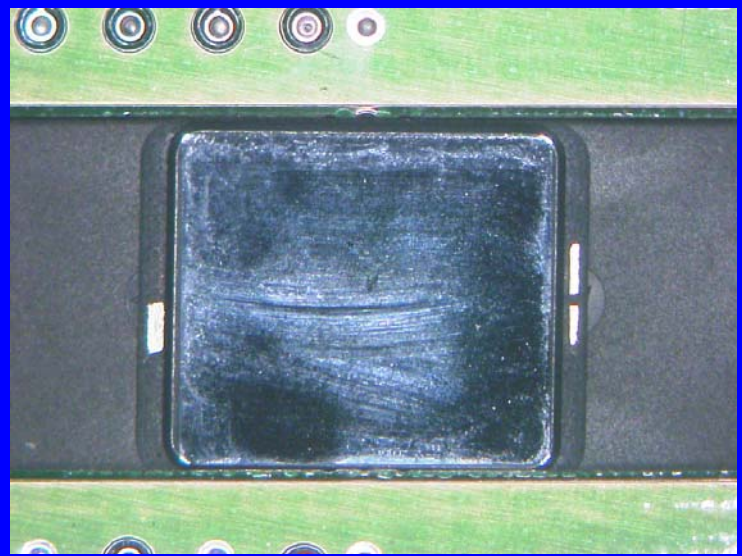
Sample Preparations – SDRAM Example



< 75 um

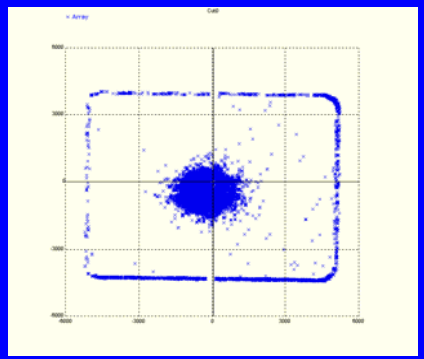


< 85 um

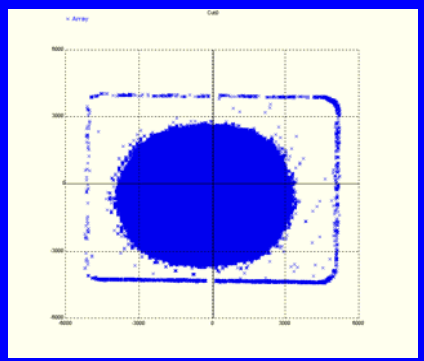


Die thickness measured using Interferometry!

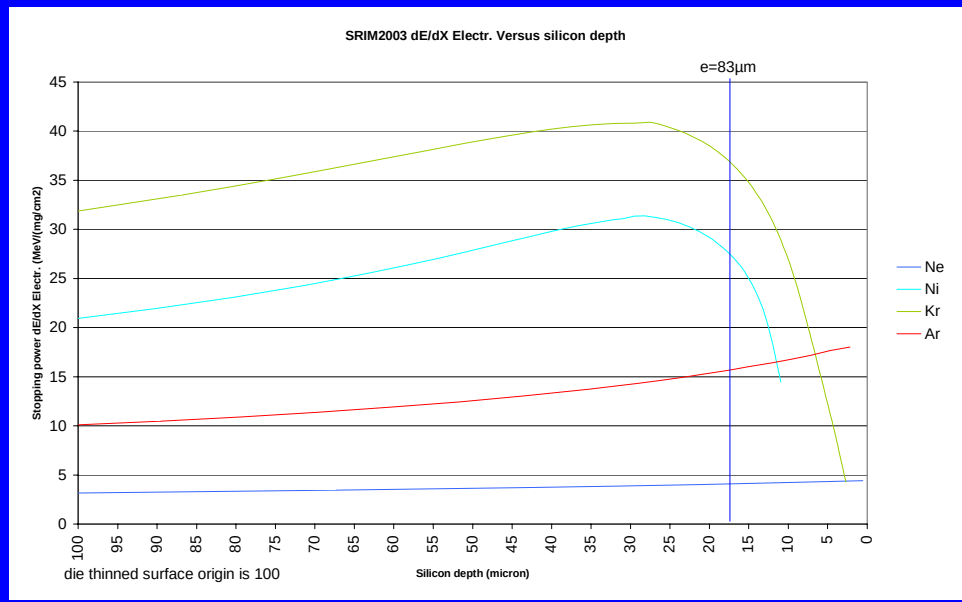
Sample Preparations – SDRAM Example



< 75 um

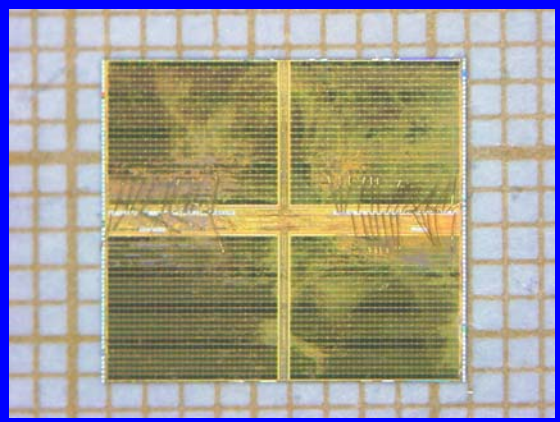


< 85 um

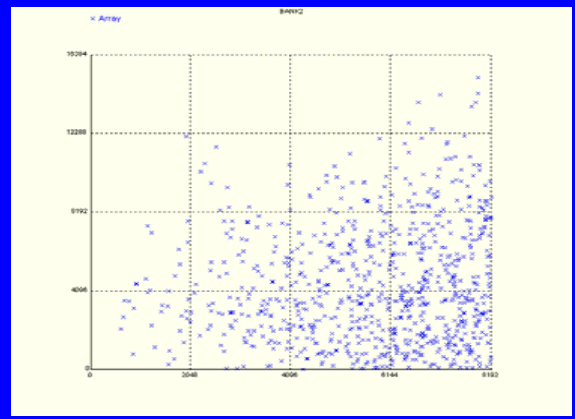


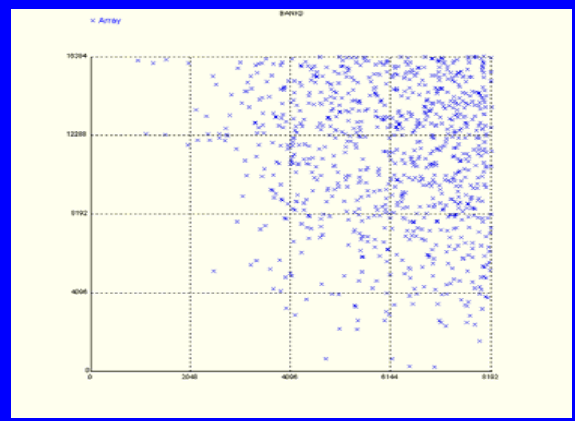
Stopping Power versus Si depth

Sample Preparations – SDRAM Example



Front side of die





Bit Error Map/Block

Sample Preparations – SDRAM Example

SEE Data Analysis:

- Thickness measurements vital!
- Requires Bit-mapping of SEU Data
- Based on Physical address locations

Test Conditions – Complex!

- **DUT:**
  - Unbiased — Biased
  - Static — Dynamic
  - Read — Write
  - Application — "Special"
- **Accelerator:**
  - Ion Types — LET Range
  - flux – s/cm^2 — Low/Medium/High
  - Fluences — 1.0E3-1.0E7 ions/cm^2

Test Conditions – FLASH Memories – IDA

Example: 1

Earlier SEE Results: Nov. 2004

- Samsung SEL/SEFI at LET=14.1-19.9 MeV/(mg/cm^2)
- Toshiba SEL/SEFI/Device Failure at LET=8.3-11.7 MeV/(mg/cm^2)

Test Conditions – FLASH Memories - IDA

Manufacturer			Ion / LET [MeV/mg/cm²]									
Part Number	Device		N 0°	Ne 0°	Si 0°	Ar 0°	Fe 0°	Kr 0°	Fe 60°	*Kr 0°	Xe 0°	*Kr 60°
Size	ID	Mode	1.8	3.6	6.4	10.1	18.5	32.1	37.0	39.2	60.0	78.2
Samsung	S6f	M1d	SEU	SEU	SEU	SEU	BE	BE			BE	
K9F1G08U0M		M5	SEU	SEU	SEU	SEU	BE	BE	SEFI	BE	SEU	
128Mx8 (1GBit)		M2b	SEU	SEU	SEU	SEU	BE	SEFI			BE	
		M3a	none	none	none	none	SEFI	none	none	SEFI	none	
		M3b	none	none	none	none	none	none			none	
		M4	none	none	SEU	SEU	SEU	SEU			SEU	
Toshiba	T4k	M1d	none	none	BE	BE	BE	SEU			BE	
TC58NVG0S3AFT00		M5	none	SEU	BE	BE	BE	BE	SEFI	BE	BE	SEFI
128Mx8 (1GBit)		M2b	none	none	BE	BE	BE	BE			BE	
		M3a	none	none	none	none	BE	BE	BE	SEFI	BE	
		M3b	none	none	none	none	SEU	SEU			SEU	
		M4	none	none	BE	BE	BE	BE			BE	

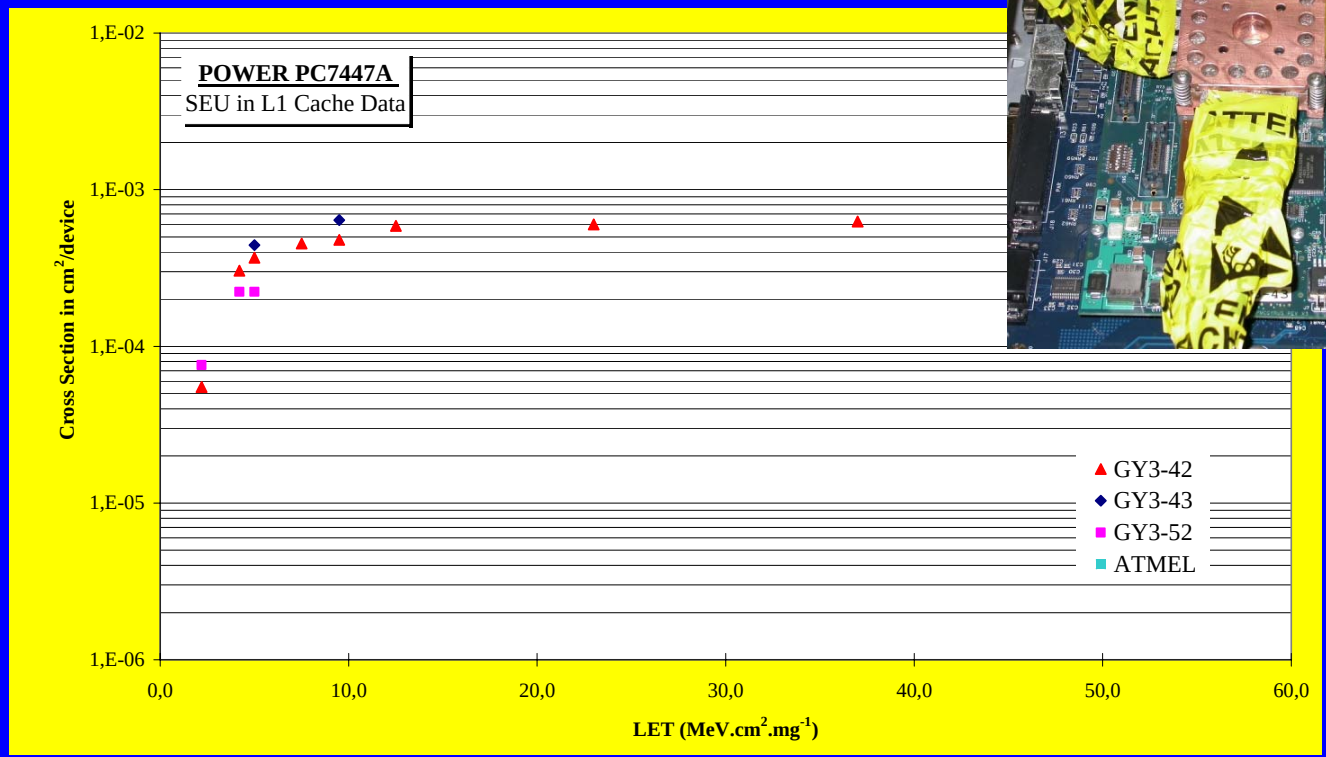
Test Conditions – FLASH Memories - IDA

Operational Modes:

- **M1d:** Marching with power cycle after erase,
- **M3a:** Storage, biased
- **M3b:** Storage, unbiased
- **M2b:** Read, Write Protection on
- **M4:** Write
- **M5:** Marching, modification of M1d - in order to differentiate between "cell errors" and "read access errors".

Sample Preparations – PowerPC – Alcatel Space

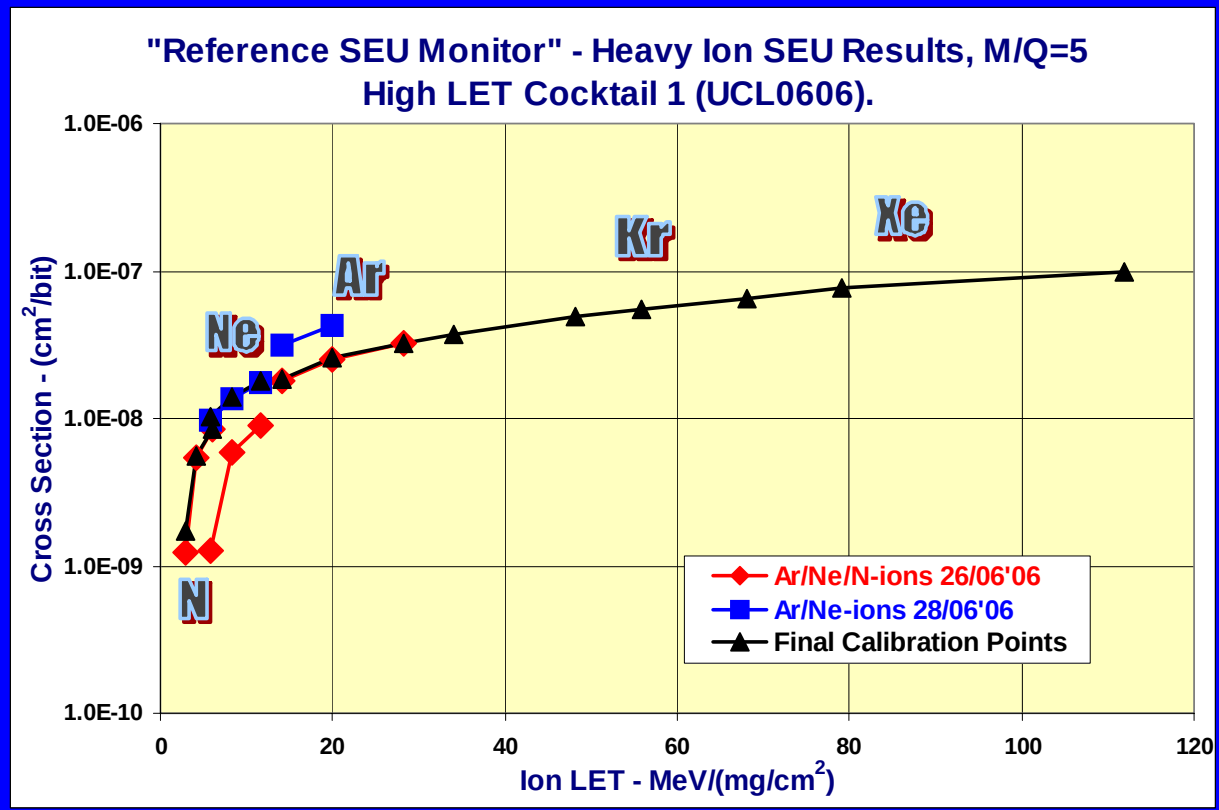
Example: 2



SEU Data corrected for:

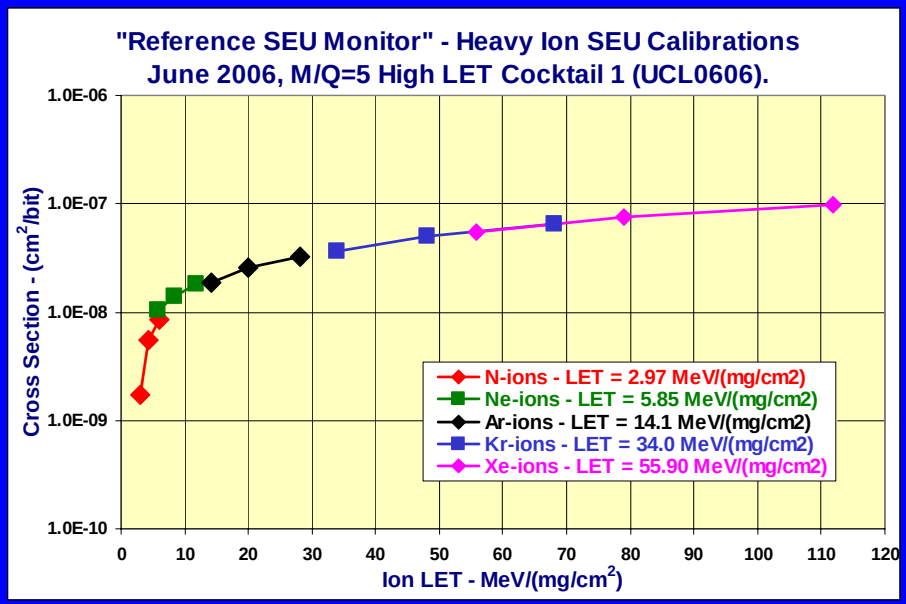
1st Test 80 um
2nd Test 40 um

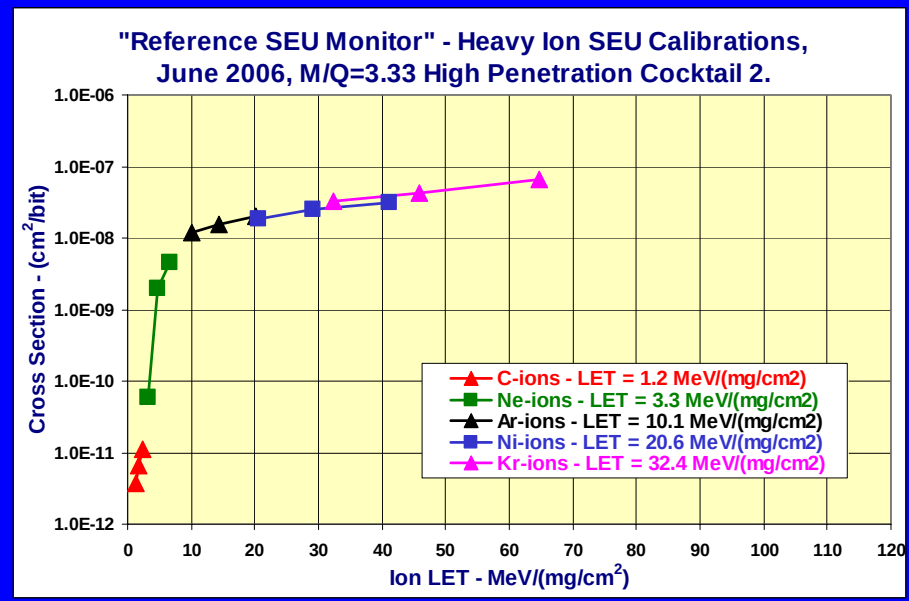
Ion Beam Calibrations – SEU Monitor



HIF Cocktail 1 – Ion Calibration problems – June 2006.

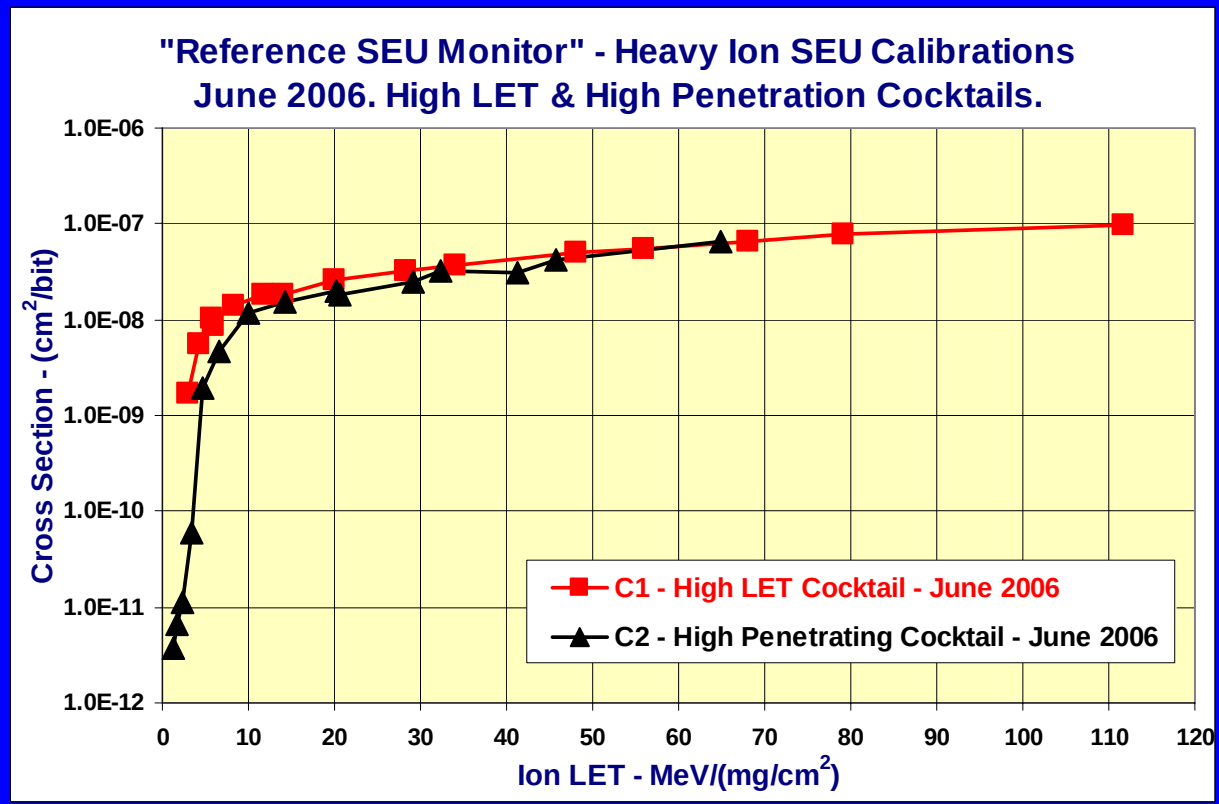
Ion Beam Calibrations – SEU Monitor





HIF Cocktail 1 & 2 – Calibration – June 2006.
Ions at 0, 45 & 60º Inclinations.

Ion Beam Calibrations – SEU Monitor



HIF Cocktail 1 & 2 – Final Calibration – June 2006.

Conclusions:

Facilities:

- We need accelerators with cm of ion beam penetration - but have to live with HIF and RADEF!
- LET, ion range and calibration problems are currently being addressed and recommendations given!
- SEE testing in general are becoming more complex and could benefit from lower LET test requirements!