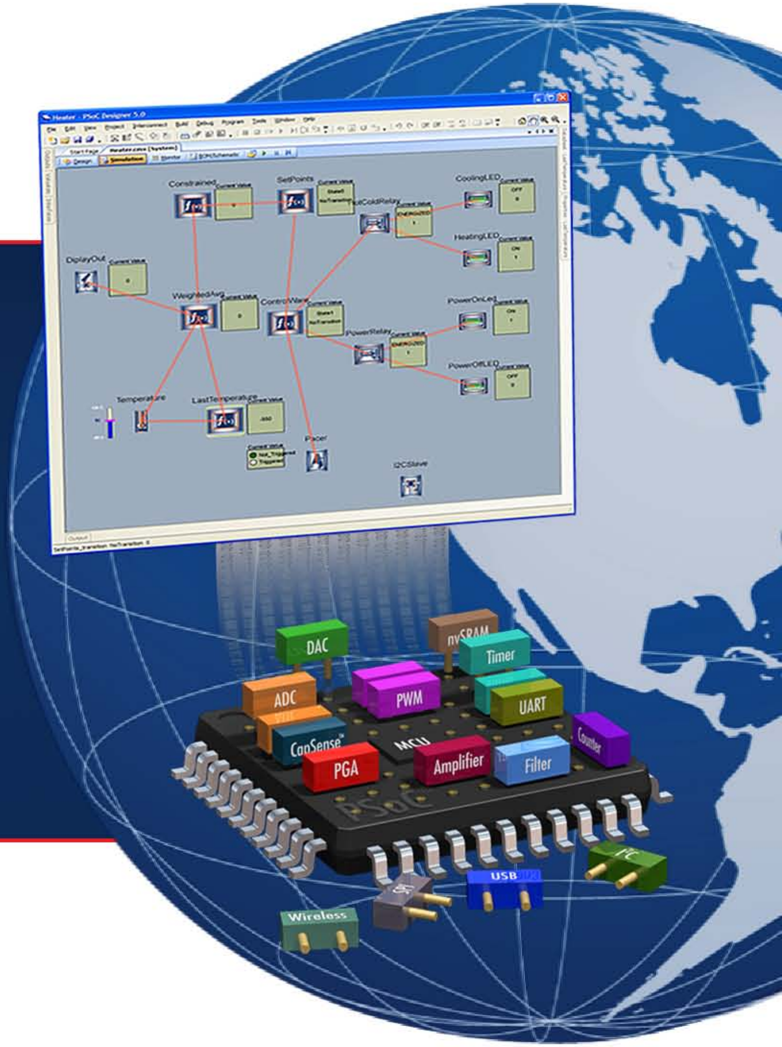
Correlation of Life Testing to Accelerated Soft Error Testing



Helmut Puchner

Cypress Semiconductor

Agenda

INTRODUCTION

SOURCES OF RADIATION

MEASUREMENT TECHNIQUES

90nm SRAM TECHNOLOGY DATA

SYSTEM SER AND ALPHA DETECTOR DATA

CONCLUSION

SOURCES OF RADIATION

Three Major Sources of Soft Errors

Alpha particles

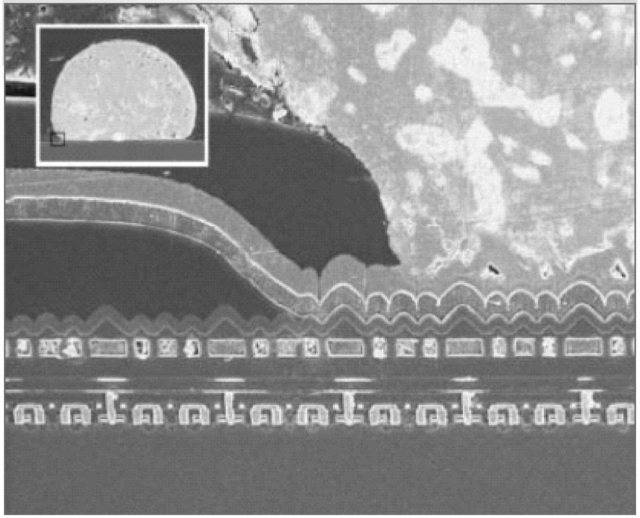
- Radioactive decay of ^{232}Th and ^{238}U
- **Mold compounds**, packages and other assembly materials;
- E ≈ 2MeV to 9MeV

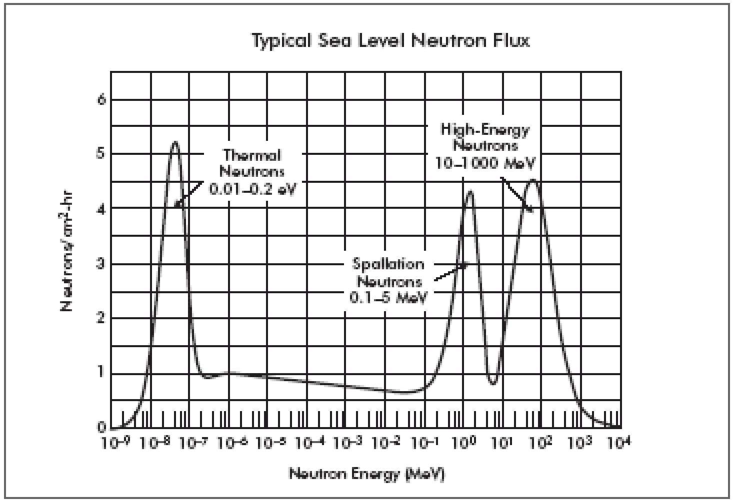
High-energy Neutrons

- Extraterrestrial cosmic rays
- Bombard earth continuously
- E ≈ 10MeV to 1GeV.

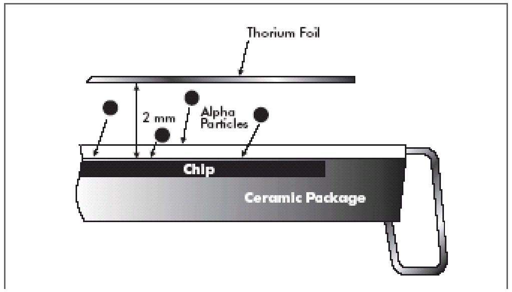
Thermal Neutrons

- Thermal equilibrium neutrons with atmosphere
- Boron isotope (^{10}B) used in BPSG interacts with thermal neutrons and decays into Lithium, Helium nuclei, and a gamma ray.
- E ≈ 25meV





SE MEASUREMENT TECHNIQUES



Alpha Particles:

Accelerated alpha measurements with Th^{232} foil

Neutron Particles:

Accelerated neutrons measurements at LANL, TRIUMF, TSL

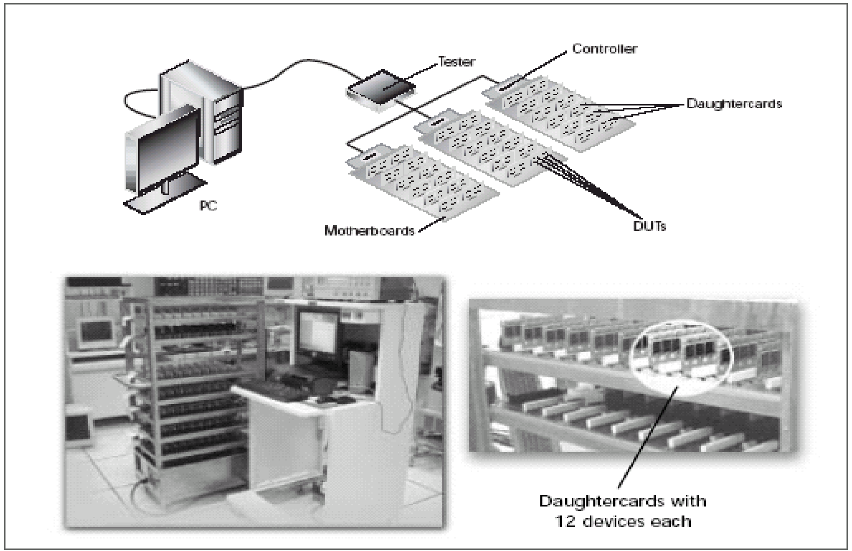
Accelerated proton measurements at Harvard, UI, UC Davis, etc

Thermal Neutrons:

Measurements taken by using nuclear reactors (UC Davis)

Life Testing:

- Cypress developed own tester
- Measuring “real” soft error rate in large electronic systems (alpha +cosmic)
- Mauna Kea, Colorado, Philippines and Soudan (cave) as test sites



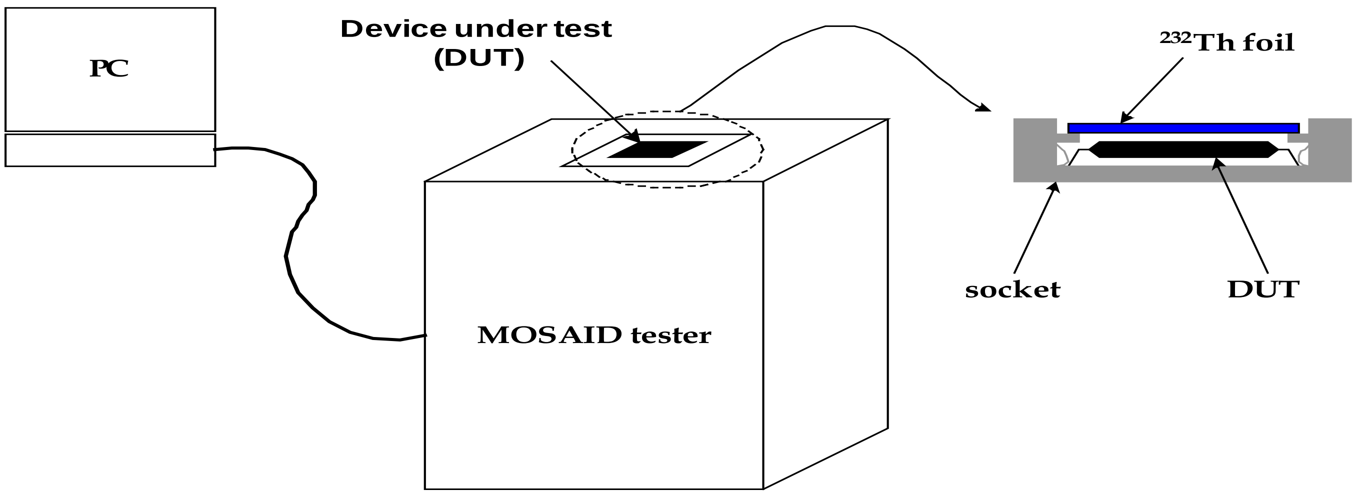
ALPHA MEASUREMENT SETUP

Tester with open top DUT and ^{232}Th foil positioned at a predefined distance from the die surface (<1mm to avoid scattering in air).

The alpha particle source ^{232}Th is calibrated and its flux (α/cm^2/min) is known.

Test flow (static):

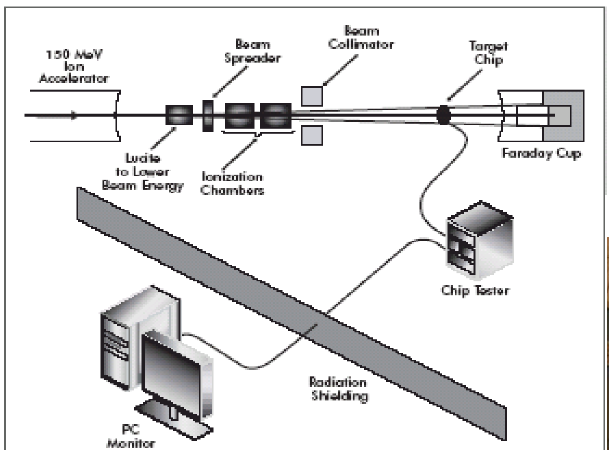
- Write/Verify of a known data pattern (CHKB, ALL0, or ALL1)
- Wait period with the alpha source in position
- Read to monitor and log all the “bit-flip” occurred.

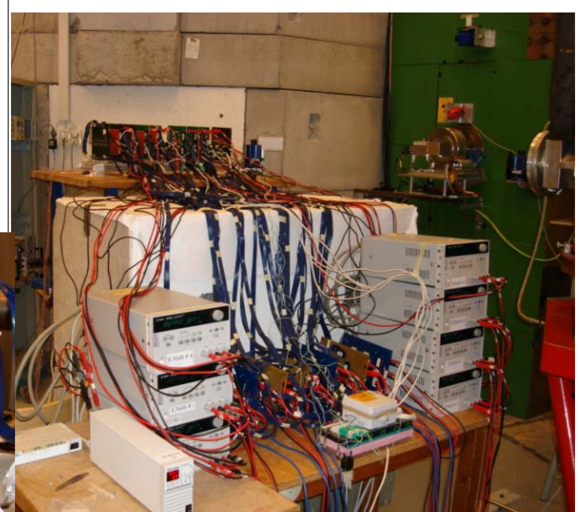


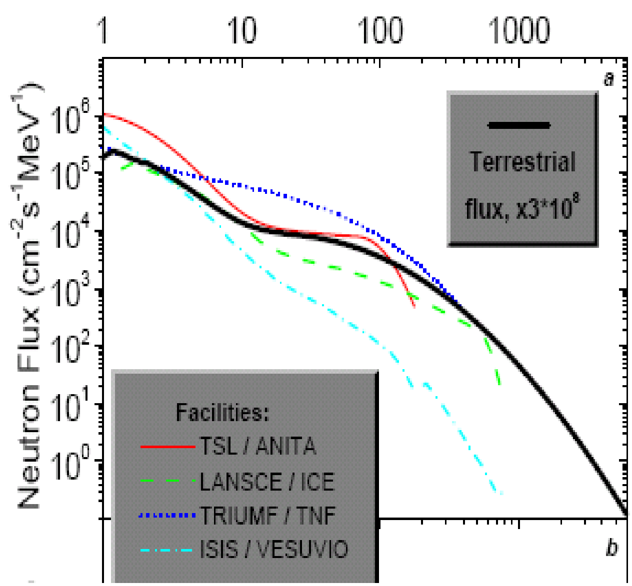
ISSUE: Loosing MBU information due to static test

ACCELERATED PARTICLE TESTING

- Protons and Neutron generated by collisions from Protons with a specific target (Li, W) are widely used
- About 20 frequently used sites worldwide (JEDEC89)
- Beams can be mono-energetic (25MeV-180MeV) or spectral (<400MeV)
- Accelerated beam flux is calibrated/integrated to natural cosmic flux at sea level to extract FIT rate





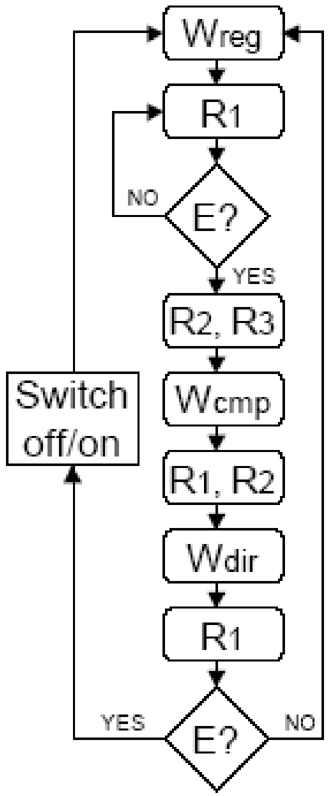


NEUTRON/PROTON TEST FLOW

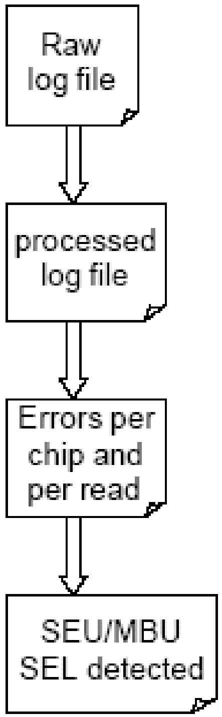
State-of-the-art test flow to catch MBU,SEL (IRoC)

Eliminate tester hardware differences

Test algorithm :



Flow detection :



Each error line contains one failing logical address (can be several failing data bits).

Errors are detected again in consecutive read operations.

Each error line contains one failing data bit. Only new errors appear in this file (re-read errors do not appear anymore).

Count number of failing bits per read and per chip. (an example of this file is given in the next slide).

single failing bit in three read ops : SEU

less than 64 failing bits per read : MBU

at least one read has more than 64 failing bits : SEL (confirmed in next read ops after re-write operation)

SRAM SYSTEM SER TESTING

- Hundreds of devices are mounted on a system (up to >30Gb) and accessed serially.
- Device access depends on system architecture (FPGA < 3min)
- Currently the systems are installed at Mauna Kea, Hawaii, Soudan,MN and Cavite, Philippines.
- Extraction of Alpha and Neutron FIT rates through measurements at different altitudes

Rev1

Rev2

ALPHA SER FIT RATES

Technology	Part Number	Number of Samples	Architecture	Test Location	Test Type	FIT Lower Limit*	FIT Actual	FIT Upper Limit*
90nm SRAM	9M	3	Sync	Cypress	Alpha SER	0.93	1.00	1.07
	18M	3	Sync	Cypress	Alpha SER	1.01	1.09	1.16
	72M	3	Sync	Cypress	Alpha SER	1.04	1.12	1.20
	18M	3	QDRII	Cypress	Alpha SER	1.05	1.13	1.21

*95% Confidence Level

- FIT rates well behaved for our Lab environment
- Dynamic vs. Static Alpha testing shows large differences (dynamic 20x lower due to tester speed
- Distance to source and foil geometry can change results significantly
- Difficult to bitmap at full speed testing
- Part exercised at operation speed and temp (temp forcer)
- Final FIT Rate scaled to ULA Mold compound (0.001 alpha/cm.hr)

=> ALPHA MEASUREMENTS WELL BEHAVED?

NEUTRON SER FIT RATES

Technology	Part Number	Number of Samples	Architecture	Test Location	Test Type	FIT Lower Limit*	FIT Actual	FIT Upper Limit*
90nm SRAM	9M	6	Sync	TSL	Neutron SER	0.61	1.00	1.77
	9M	6	Sync	TRIUMF	Neutron SER	1.26	1.34	1.41
	72M	6	QDRII	TRIUMF	Neutron SER	0.82	0.86	0.90
	72M	3	QDRII	TSL	Neutron SER	0.42	0.58	0.81
	72M	6	QDRII	TSL	Neutron SER	1.48	1.52	1.56
	36M	6	QDRII	TSL	Neutron SER	0.46	0.86	1.76
	72M	6	Sync	LANCE	Neutron SER	1.34	1.44	1.54
	72M	6	Sync	TSL	Neutron SER	0.80	0.84	0.88
	72M	6	Sync	LANCE	Neutron SER	1.14	1.52	1.99

*95% Confidence Level

- FIT rates vary widely between beams and test campaigns
- LANCE, TRIUMF FIT rates are expected to be higher due to higher energetic Neutrons in the spectrum tail distribution
- TSL FIT rates vary widely due to integration method, tail correction factor
- General poor statistics can influence failure rates significantly

=> WHAT IS THE REAL NEUTRON FIT RATES IN APPLICATIONS?

ISSUES ACC. NEUTRON TESTING

Delicate balance between beam flux, error logging capability of tester, and failure statistic

Part is not stressed at operating conditions:

- Tester frequency limited due to distance tester/test head to 10-20MHz
- Operating temperature therefore below full speed operation – hence require external heating

Beam purity – are there still Protons contributions?

Fluence detectors and beam calibration

=> Required to run "Golden Units" to have additional beam calibration pathway

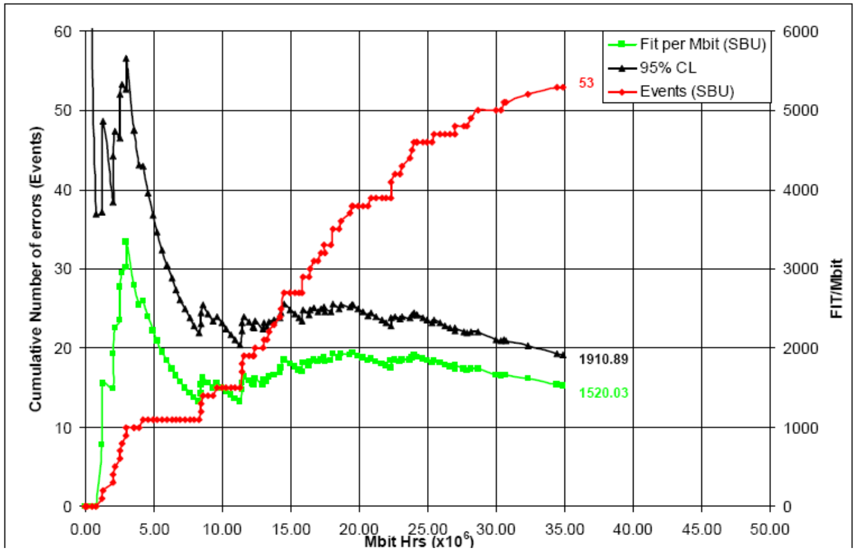
SYSTEM SER HIGH ELEVATION

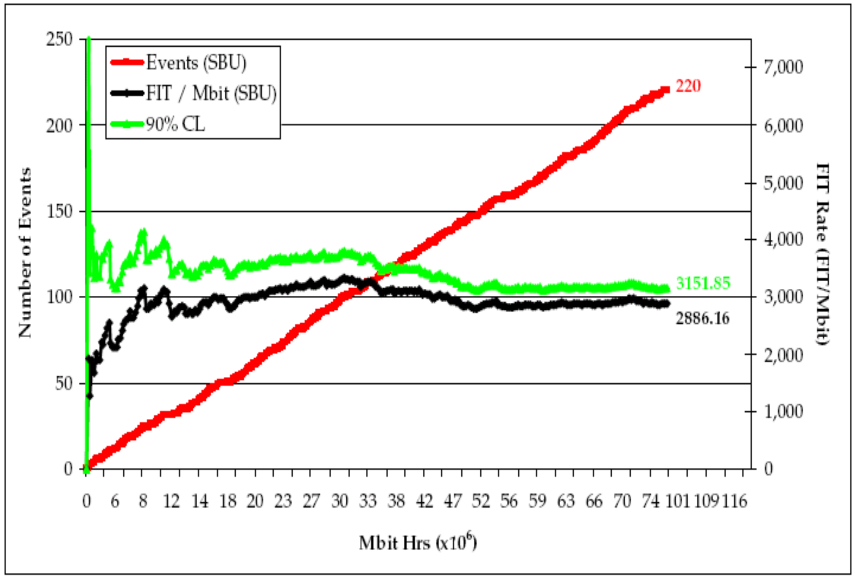
Colorado: 386x 36M SYNC

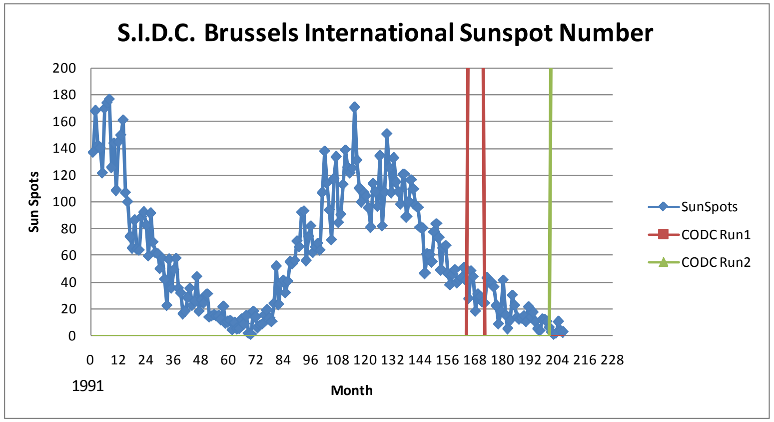
- 4.3x Acceleration over NYC
- Test Time: Sept07-Mar08
- 5.1 Gb.yrs/1.24M device hrs completed
- Current FIT rate: 326 FIT/Mb (no alpha)
- Elevated FIT rates due to Solar Cycle (close to 0% activity)

Mauna Kea: 269x 72M SYNC

- 9.22x Acceleration over NYC (13.7kft)
- Test Time: Jun08-Dec08
- 8.7 Gb.yrs/1.06M device hrs completed
- Current FIT rate: 313 FIT/Mb (no alpha)







NEUTRON FLUX 2004-2008

90nm 72M SRAM was measured 09/04-03/05 in CODC

90nm 36M SRAM was measured 09/07-03/08 in CODC

90nm 72M SRAM was again measured 06/08-12/08 at Mauna Kea

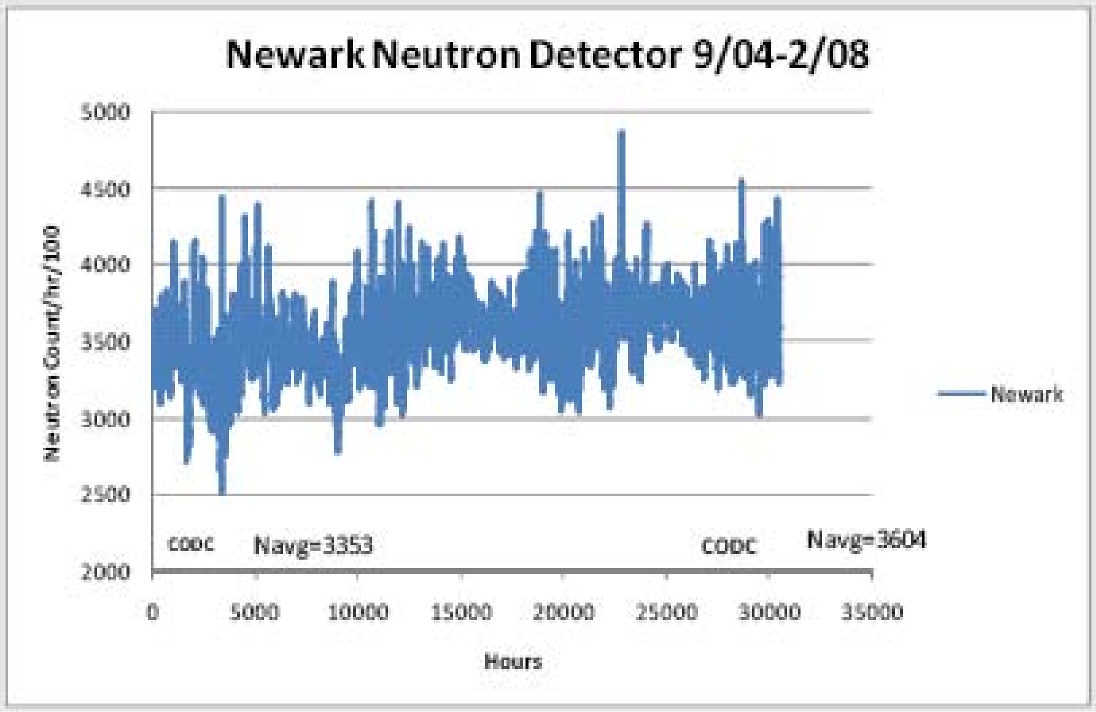
Cosmic ray flux depends on:

- Solar Activity
- Barometric Pressure

Average Neutron Rate :

- 09/04-03/05: 3353
- 09/07-02/08: 3604

SSER NYC failure rate needs to be corrected for the solar activity



ISSUES WITH SYSTEM SER

Units tested at lower speed and frequency

Daisy chain cycling only check units every 3-4 hrs or min depending on the architecture. However the memory acts as SE storage

Due to the long runtime you face tester issues:

- Power outage on Mauna Kea when a storm hits
- UPS not guaranteed above 3000m
- Remote operation needed

Expensive (BOM – could have sold the parts, resources, logistics) cost of systems $100k – $150k

Building Shielding can reduce flux

=> Neutron Environment Close to Reality

ALPHAS vs NEUTRONS

90nm SSER data collected at Mauna Kea and Colorado

SSER= nSER + αSER + n_{TH}SER ← zero for 90/65nm (no BPSG)

- SSER at both locations can be split in two components

$$SSER_{KEA} = \alpha_{KEA} + N_{KEA}$$
$$SSER_{CODC} = \alpha_{CODC} + N_{CODC}$$

$$\alpha_{KEA} = \alpha_{CODC} = \alpha$$
$$\frac{N_{KEA}}{N_{CODC}} = 2.23$$

- **Resulting FIT rates:**

Tech	Site	n+α @ Site FIT/Mb	n_{acc} / n_{NYC}	Solar Activity	α@Site FIT/Mb	n@Site FIT/Mb	n@NYC FIT/Mb
90nm	KEA	3922	9.22	115%	308	3614	340
90nm	CODC	1928	4.13	115%	308	1620	340
90nm	Cypress	N/A	N/A	N/A	225	N/A	N/A
90nm	TSL	N/A	N/A	N/A	N/A	N/A	360

Conclusion:

- Significant contribution from Alpha to total SER FIT rate
- Good agreement within +-25% of accelerated testing
- **System SER measures elevated Alpha FIT Rate**

TRUE ALPHA CONTRIBUTION

Low Altitude Testing:

- System SER currently running in CML (Neutron Flux = 0.6 NYC) with low alpha (192pc) / std. mold (60pc)compound units
- No significant difference in failure rate observed (low statistics)

Cave Testing:

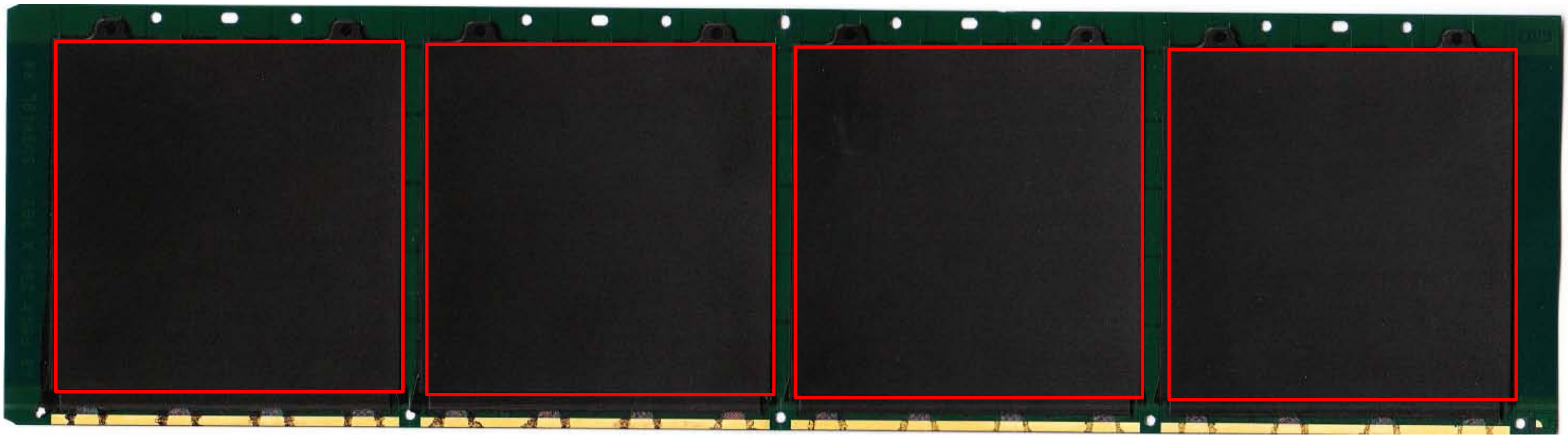
- System SER installed at Univ. of Minnesota, Soudan mine (2300ft below ground)
- Neutron flux is reduced by 10000x over NYC => pure alpha contribution will be measured
- Like most mines contains Radon gas, but not deemed an issue for close top packages

- Data collected from Oct 09 – March 10 and still ongoing
- Status March 2010: 32 SBU errors => 405FIT/Mb

Cave System SER suggests also elevated Alpha FIT Rates over ULA

Mold Compound?

- Only Mold compound can emit Alpha particles close enough to the Si surface for wire bond packages
- Alpha FIT rate should be proportional to Mold compound emission measurements (Alpha Science)
- BGA Substrate Molding Strips have been cut into 2in x 2in squares completely covered with Mold Compound



- 36 Mold Squares have been prepared for each Supplier Mold Samples
- Mold Samples have been cleaned prior to measurement

Alpha Measurement Technique

- Alpha Science Alpha Detector 1950 has been used
- Samples aligned as flat 1000cm2 area on tray
- Background alpha rate determined prior to measurement for Alpha Sensor (3 α/hr)
- Samples Measured for >50hrs
- Alpha ER calculated:

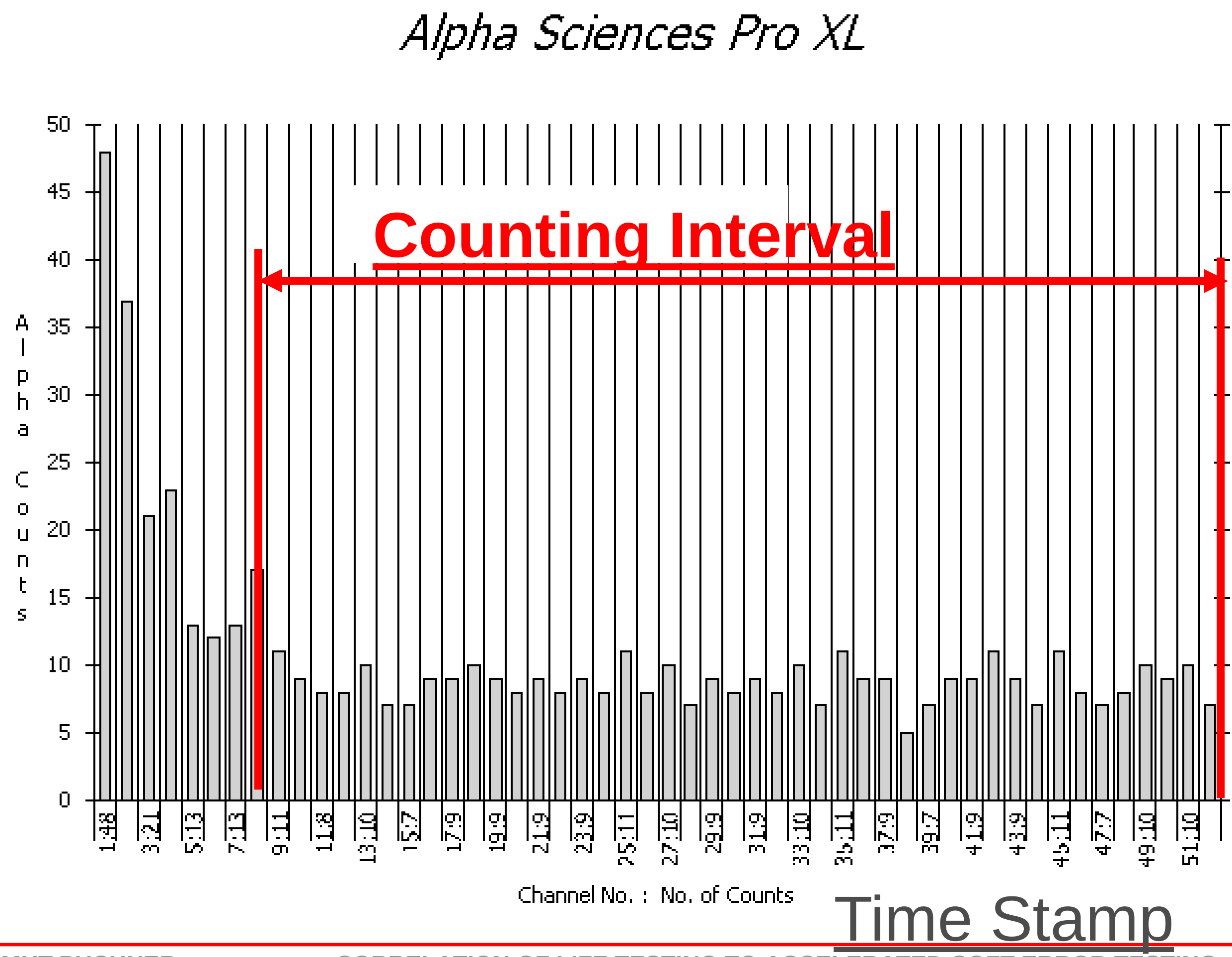
$$\frac{\text{Gross } \alpha/\text{Hr.} - \text{Bkg. } \alpha/\text{Hr.}}{\text{Sample Area cm}^2} = \text{Net } \alpha/\text{cm}^2/\text{Hr}$$

- Scaled with Detector Efficiency:

84% provided by Alpha Science

Alpha Emission Time Dependence

- Counting Plot shows time dependent emission rate
- Counting interval adjusted to eliminate early emissions



90nm Mold Alpha Detector Data

- 90nm Mold Compound Measurement:

Date of Assay:	09.11.08
Detector:	98-002, Unit 1
α Counts / Time:	178/40 hours
Gross α / Hour:	4.450
Bkg. α / Hour:	3.000 (LLD = 0.0013)
Sample Area (cm^2):	678
Net α / cm^2 / Hour:	0.0021 ± .0004
Data Correction for Detector Efficiency:	0.0025 ± .0005 α / cm^2 / Hour

Additional Information: Material supplied as: 60 pieces of underfill material in disc format, 38mm diameter each, for total of 678 sq cm.

- **90nm Acc SER Alpha FIT Rate (0.0025 α/cm2.hr) = 562 ±112 FIT/Mb**

Alpha Detectors - Accuracy

Blind Sample Experiment:

- Same samples measured

Mold Compound	Alpha Science [a/cm2/hr]	XIA LLC [a/cm2/hr]	Δ [%]
Type A	0.0068±0.0006	0.0136±0.0005	100
Type B	0.0019±0.0005	0.0024±0.0003	26
Type C	0.0022±0.0005	0.0034±0.0003	54
Type D	0.0032±0.0004	0.0029±0.0003	9

- Large variability found due to sample preparation, methodology, counting area, counting time

So what do we do now?

90nm Alpha Data Summary

- Accelerated Alpha Measurements:
- ULA assumed (0.001 α/cm.hr) = 225 FIT/Mb
- System SER Measurements:
- Different Altitudes = 308 FIT/Mb
- Cave Testing = 405 FIT/Mb
- Alpha Detector (0.0025 α/cm.hr) = 562 ±112 FIT/Mb

Conclusion:

- **None of the data confirms ULA Mold Compound !!**
  Maybe I’m not getting what I’m paying for?

CONCLUSIONS

- Alpha SER Data easy to obtain but cannot be added to Neutron Data directly
- Neutron SER Data still major source of Industry Data gathering, however, several Issues with Methodology
- System SER close to reality, however, expensive
- System SER and Alpha detector emission data needed to validate packaging materials