



# **Evaluating SEE Rate Prediction Methods for Complex Devices**

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**NEPP Electronics Technology Workshop, 2021  
This work supported by NASA NEPP Grant #80NSSC20K0424**

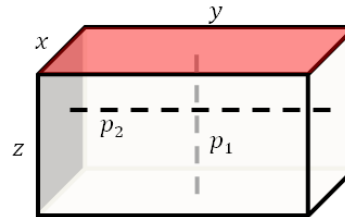
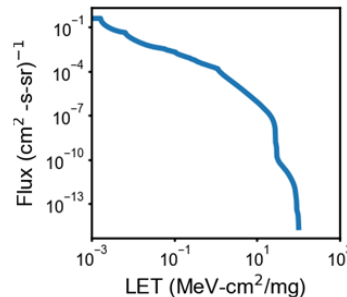


- **Evaluate single event reliability of complex devices**
  - Complex device – *collection of circuits that consists of more than one basic repeated structure or demonstrates dynamic behavior*
- **Single event analysis increasingly needed**
  - Test considerations covered in JPL Pubs 08-13, 18-2
  - How do we make use of the data? New tools? Guidelines?
- **Complex systems invoke unique *challenges* for rate predictions**
  - How many sensitive volumes?
  - What technology?
  - How much derating/masking?
  - Error latency? Observability?
  - Fluence dependencies?



- **Single event effects reported in FPGA, DDR-II, PWM, rad-hard microprocessor, angular position sensor, video codec, analog switch, resolver-to-digital converter, technology comparison of flip-flop chains**
- **Experiments produce macroscopic cross section curves ( $\text{cm}^2/\text{device}$ ) for output errors, functional interrupts**
- **Authors have taken different approaches to predicting component level ion-induced errors (e.g. SEFI)**
  - CREME96 on saturated or normalized cross sections
  - Effective flux approach
  - Undocumented

- RPP model for device SEE cross sections implies a large-area, contiguous sensitive volume
  - Depth usually assumed to be known
  - Assumes macroscopic sensitive volume represents aggregate contribution of individual sensitive volumes
  - Modifies limit of integration and path-length distribution



$$Q_{crit} = \frac{z \cdot LET_{th}}{22.5}$$

$$A = xy = \sigma_{bit}$$

$$\lambda_{ion} = 22.5 \cdot Q_{crit} \cdot \pi \cdot A \int_{22.5 \cdot Q_{crit} / p_{max}}^{L_{max}} D[p(L)] \cdot \phi(L) / L^2 dL$$

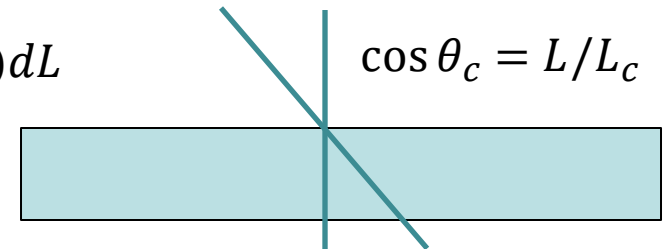


# Effective Flux Approach

- **Binder's effective flux approach implemented**
  - Replaces complicated chord distributions
  - Eliminates need for sensitive volume dimensions
  - Calculates normal-incident flux of ions  $\Phi_{eff}$  with effective LET above LET threshold,  $L_c$
- **Ion-induced SEE rate,  $\lambda$ , depends on  $L_c$  and cross section  $\sigma$** 
  - Can be integrated over cross LET curve
- **Intriguing for complex devices**

$$\phi_{eff}(L_c) = \frac{1}{2} \int_{L_{min}}^{L_c} \phi(L)(L/L_c)^2 dL + \frac{1}{2} \int_{L_c}^{L_{max}} \phi(L) dL$$

$$\lambda_{ion} = \phi_{eff}(L_c) \cdot \sigma$$

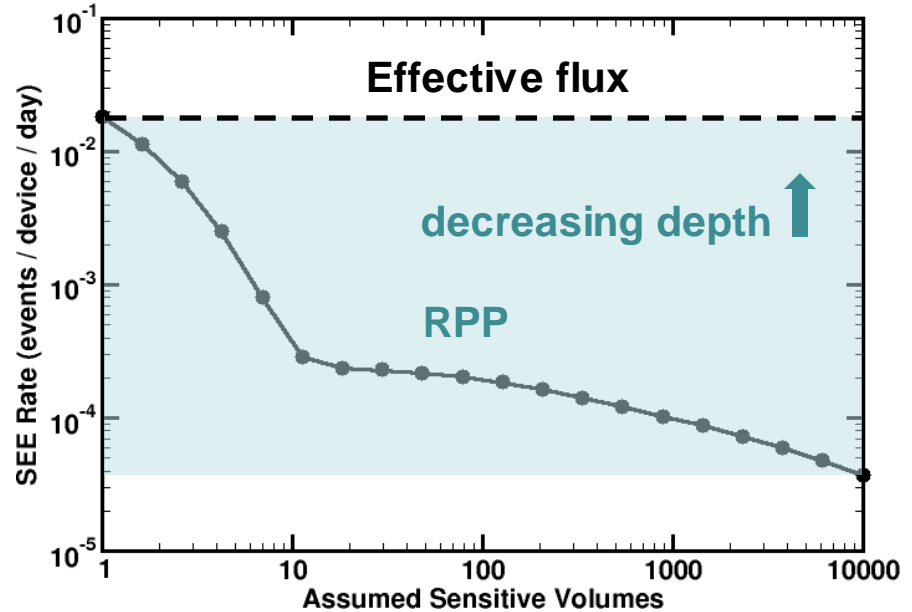


D. Binder, "Analytic SEU Rate Calculation Compared to Space Data," *IEEE Trans. Nucl. Sci.*, vol. 35, no. 6, pg. 1570, Dec. 1988.



# Challenge: Number of Volumes

- **Complex ICs typically have an unknown number of sensitive volumes and/or unknown resource utilization**
  - *Is rate conservative and by how much?*
- **Calculated rates for 10,000  $1 \times 1 \times 1 \mu\text{m}$  sensitive volumes**
- ***RPP approach can be strongly affected by assumed bits, depth***
  - Least amount of information yields largest rates
- ***Effective flux approach unaffected by assumed bits***
  - Proportional to cross section
  - Consistent with single volume, depth  $\rightarrow 0$



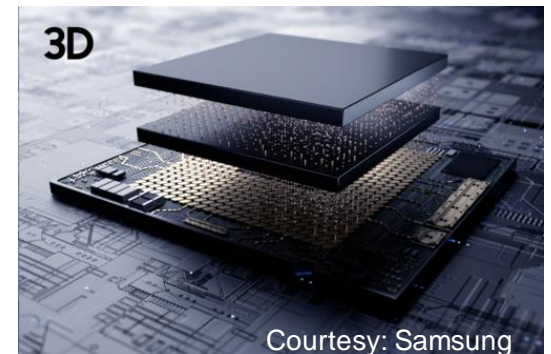
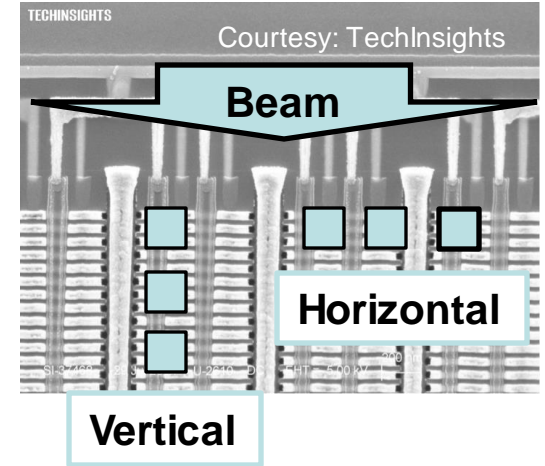
# Challenge: Stacked Devices



- **Memories, die stacks, integrated processes**
  - *Are cross sections similar for stacked devices?*
- **3 horizontal and 3 vertical volumes irradiated with 100k 10 MeV alphas in CRÈME-MC**
  - 3x fewer events (vert.), events have order of 3

Order	Horizontal		Vertical	
	Count	$\sigma$ (cm <sup>2</sup> )	Count	$\sigma$ (cm <sup>2</sup> )
1	$4.99 \times 10^3$	$1.18 \times 10^{-7}$	8.49	$2 \times 10^{-10}$
2	5.52	$1.3 \times 10^{-10}$	6.37	$1.5 \times 10^{-10}$
3	-	-	$1.67 \times 10^3$	$3.94 \times 10^{-8}$

- **Event  $\sigma$  differ, but total upset  $\sigma$  remains  $\rightarrow$  *both rate predictions unchanged***



# Challenge: Fluence Dependencies

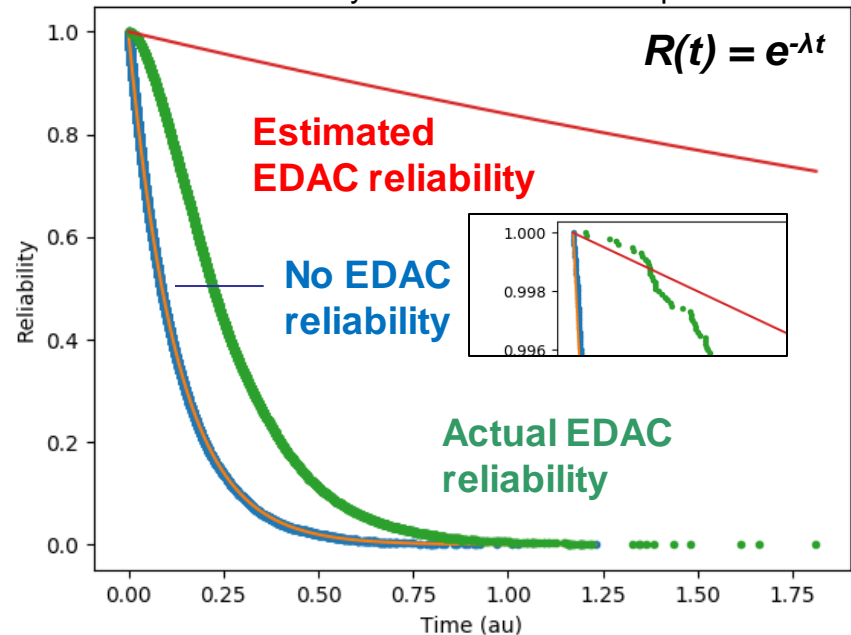


- **Complex systems may include fluence-dependent errors**
  - EDAC (parity) common in cache, processors, ...
  - Observable *error* occurs as a result of two or more *upsets*
- **Cannot estimate rates from EDAC cross sections**
  - Error cross section changes over time/fluence (i.e. non-constant rate)
- **Reliability predictions depend on assumed form**

Simulated Random Upset Times

1.65	1.24	0.51	0.07	0.40	0.26	0.33	1.47
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Simulated Reliability of 8-bits with  $\lambda = 1$  upset/bit/time





# Challenge: Fluence Dependencies



Vanderbilt Engineering

- Open-source simulator for Intel 8085 microprocessors
  - Executes assembly code using behavioral model
  - Injects random single event upsets and monitors for faults
- Routine to extract faults and analyze reliability developed
  - *Selected algorithm demonstrates no fluence dependence*

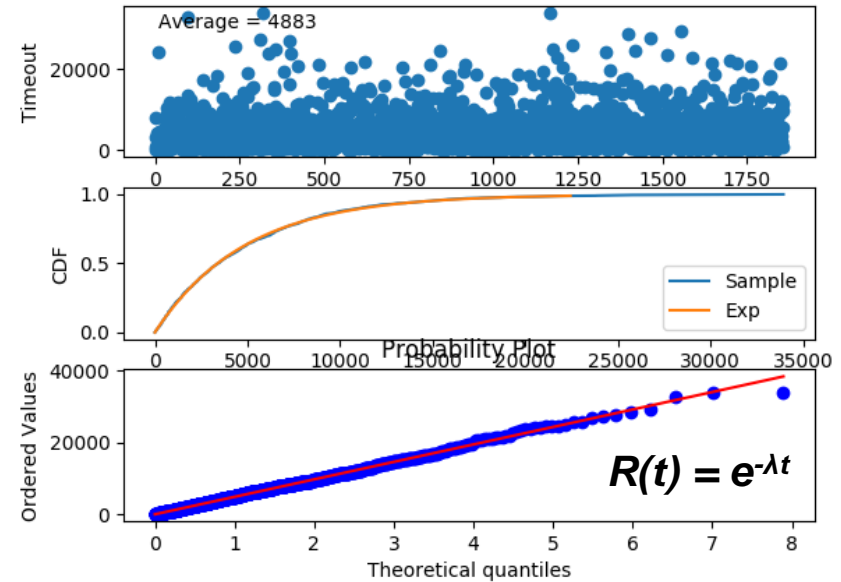
gnusim8085

```
Small C 8085
Code: (2.4.84/11/27)
Print End (2.7.84/11/28)
Print End For AS5000 (2.8.13/01/20)

;program area SMALLC GENERATED IS RELICATABLE
;smallc SMALLC GENERATED
;list terr. loc. bit, oct, cyc. lin, src, list, mem
;title SMALLC
;smallc SMALLC GENERATED (REL.CDN.C55G)

11:      jmp     h,#0
12:      ldi    h,#1
13:      and    sp
14:      call  cgsplit
15:      mov    h,#0
16:      ldi    h,#1
17:      pop    creg
18:      ora    l
19:      mov    a,h
20:      ldi    h,#1
21:      ldi    h,#1
22:      jmp     h,#0
23:      jmp     h,#0
24:      jmp     h,#0
25:      ldi    h,#1
26:      and    sp
27:      call  cgsplit
28:      mov    h,#0
29:      ldi    h,#1
30:      and    sp
31:      call  cgsplit
32:      mov    h,#0
33:      ldi    h,#1
34:      pop    creg
35:      call  ccsub
36:      mov    h,#1
37:      and    sp
38:      call  fact
39:      jmp     d
40:      pop    d
41:      call  ccsud
42:      jmp     h,#0
43:      ret
44:      ldi    h,#0
45:      jmp     h,#0
```

Evaluated recursive factorial algorithm





- **Significant uncertainties can exist in SEE rate predictions for complex devices**
- **Effective fluence approaches require fewer parameters, but can be highly conservative**
  - Some suggestion limits of integration could be defined by process
- **RPP approaches can vary over  $100\times$  depending on assumptions**
  - Per bit cross sections only appropriate if mechanism directly associated with each bits
- **Cross sections and rates aren't the whole picture, dependencies affects reliability**
- **Methods and assumptions should be documented!**

# Acknowledgments



Vanderbilt Engineering

- **SCALE Workforce Development**
  - Undergraduate student participation enriched aspects of this program

**David Pauls**

Investigating Randomness of Functional Failures in Complex Systems and Implications for Cross Sections

**Stefania Esquer**

Fault Injection Emulator in the MSP430FR5969 microcontroller

STUDENTS: STEFANIA ESQUER & ANGEL FAVELA

TECHNICAL ADVISORS:  
DR. BRIAN SIERAWSKI, VANDERBILT UNIVERSITY.  
DR. RODRIGO ROMERO, THE UNIVERSITY OF TEXAS AT EL PASO.

The slide features logos for The University of Texas at El Paso and Vanderbilt University, along with images of a circuit board and a satellite in space.

**Chloe Champagne**

Extending A Probabilistic Method for Total Ionizing Dose Failure to Multi-Component Systems

By Chloe Champagne  
Mentored by Dr. Brian Sierawski  
Vanderbilt University

This work was partially supported by the SCALE workforce development program and NASA Grant 80NSSC20K0424. Special thanks to Ray Ladbury and Michael Campola for their contributions to this work.

The slide includes logos for Vanderbilt University and ISDE, and a background image of a particle detector or similar scientific instrument.