Single-Event Effects
Part 3 – Measuring SEE

Daniel Loveless
Director, IU Center for Reliable and Trusted Electronics (IU CREATE)
Associate Professor of Intelligent Systems Engineering
Luddy School of Informatics, Computing, and Engineering
Indiana University

Module 3: Objective and Outcomes

- This module will
  - Introduce the basic principles of accelerator facilities used for SEE testing
  - Describe the properties of ground test facilities related to microelectronics test requirements
  - Outline the necessary measurements for obtaining accurate SEE models
  - Provide a practical guide for preparing for an SEE experiment

- Student Outcomes
  - 1. Students will demonstrate an understanding of critical ground test properties and variables and how they influence test performance requirements.
  - 2. Students will be able to describe the beam structure, method of delivery, and the beam's influence on an experiment.

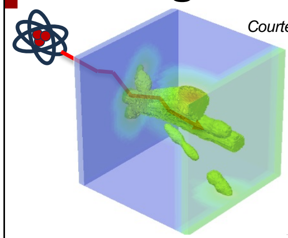
Outline

- Measuring SEE
  - SEE Cross Section and LET Threshold
  - Modeling SEE Cross Section
  - Sensitive Volume
  - From Experiment to On-orbit Rate Estimate
- Practical Considerations

05

MEASURING SEE

Single-Event Effects In Microelectronics



Courtesy Vanderbilt

Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response

- **Types:**

Non-destructive:
- Single-event transients
- Single-event upsets (soft errors)
- Single-event functional interrupt
- Multiple-bit upsets

Destructive:
- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

SEE can manifest in non-destructive (transient or temporary) and destructive effects [9]:

- **Non-destructive** effects include, but are not limited to, **Single-Event Transients (SET), Single-Event Upsets (SEU), Single-Event Functional Interrupts, and Multiple-Bit Upsets (MBU)**.
- **Destructive** effects include, but are not limited to, **Single-event latchup (SEL)**, Single-event burnout (SEB), Single-event gate rupture (SEGR), Single-event snap-back (SES) [10].

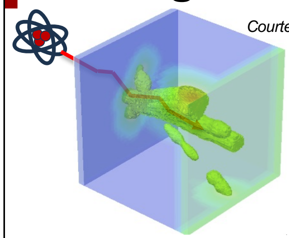
The presentation will focus on SET, SEU, SEFI, MBU, and SEL.

For those interested, brief descriptions of SEB, SEGR, and SES are provided:

- Single-event burnout (SEB): An event in which a single energetic-particle strike induces a localized high-current state in a device that results in catastrophic failure.
- Single-event gate rupture (SEGR): a single ion-induced condition in power MOSFETs, which may result in the formation of a conducting path in the gate oxide.
- Single-event snap-back (SES): Manifests in a similar way to SEL but caused by impact ionization in a MOS channel [10].

[9] SEE Specification, *NASA NEPP*, Online: https://nepp.nasa.gov/DocUploads/074CCC9D-51FB-4323-AB81F47E8F06FFDB/DraftSingleEventEffectSpecification.pdf
[10] P. E. Dodd et al., "Single-event upset and snapback in silicon-on-insulator devices and integrated circuits," *IEEE Trans. Nucl. Sci.*, vol. 47, no. 6, pp. 2165-2174, Dec. 2000.

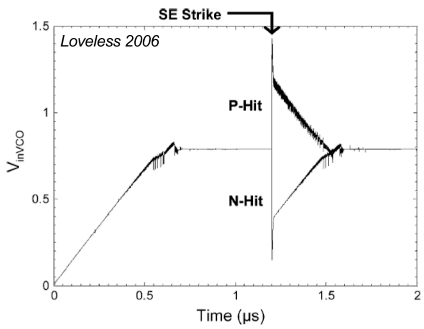
Single-Event Effects In Microelectronics



Courtesy Vanderbilt

Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response



- **Types:**

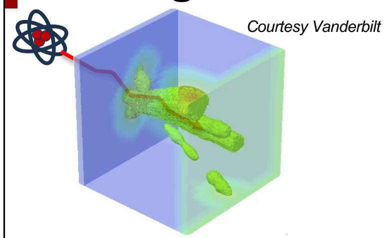
Non-destructive:
- **Single-event transients**
- Single-event upsets (soft errors)
- Single-event functional interrupt
- Multiple-bit upsets

Destructive:
- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

Single-event transients (SET): the fundamental response of a p-n junction resulting from charge collection. These signals can compete with legitimate signals, propagate through circuitry, and may be latched into memory [11].

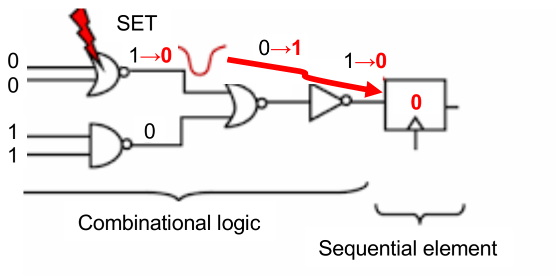
[11] T. D. Loveless, L. W. Massengill, B. L. Bhuva, W. T. Holman, A. F. Witulski and Y. Boulghassoul, "A Hardened-by-Design Technique for RF Digital Phase-Locked Loops," *IEEE Trans. Nucl. Sci.*, vol. 53, no. 6, pp. 3432–3438, Dec. 2006.

Single-Event Effects In Microelectronics



Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response



- **Types:**

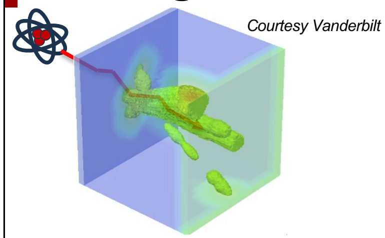
Non-destructive:
- **Single-event transients**
- Single-event upsets (soft errors)
- Single-event functional interrupt
- Multiple-bit upsets

Destructive:
- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

SETs can propagate through logic and be latched in a sequential element (manifesting as an SEU), subject to logical, electrical, and temporal masking effects [12].

[12] H. Kessler, B. Ferraz, L. da Rosa Jr., Y, Aguiar, and V. A. V. Camargo, "Single Event Transient on Combinational Logic: An Introduction and their Mitigation," *Journal of Integrated Circuits and Systems*, vol. 17, no. 3, 2022.

Single-Event Effects In Microelectronics



Control Registers/Logic

0
1
0
0

0	1	1	0	1	0
1	0	0	0	0	1
0	0	1	1	0	1
0	1	1	1	1	1

Conceptual Memory

Single-Event Effects (SEE):

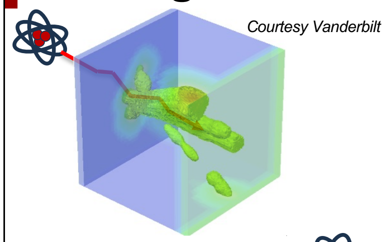
- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response
  - **Types:**

    Non-destructive:
    - Single-event transients
    - **Single-event upsets (soft errors)**
    - Single-event functional interrupt
    - Multiple-bit upsets

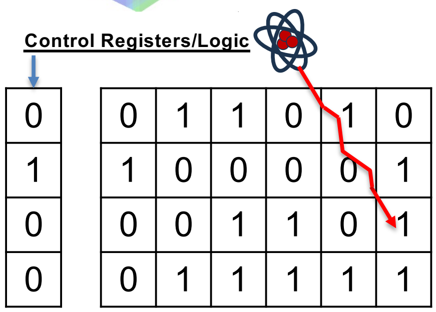
    Destructive:
    - Single-event latchup
    - Single-event burnout
    - Single-event gate rupture
    - Single-event snap-back

Consider this conceptual memory, consisting of control registers and a dense memory array.

Single-Event Effects In Microelectronics



Courtesy Vanderbilt



Example of an SEU causing a bit flip in a conceptual memory

Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response
- **Types:**

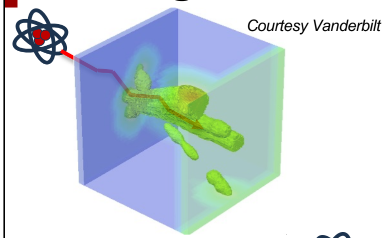
  Non-destructive:
  - Single-event transients
  - **Single-event upsets (soft errors)**
  - Single-event functional interrupt
  - Multiple-bit upsets

  Destructive:
  - Single-event latchup
  - Single-event burnout
  - Single-event gate rupture
  - Single-event snap-back

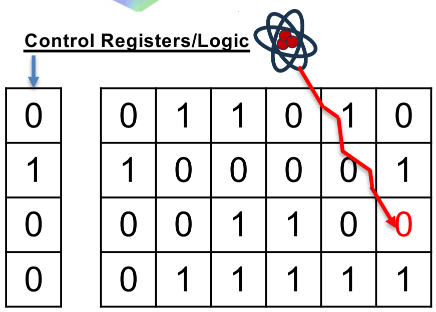
Single-event upsets (soft errors or SE): SEU occur when the interaction deposits enough energy to flip the state of a bit (e.g., from a 0 to a 1) and is generally used for sequential elements and memory. The image above shows a single bit within the conceptual memory being struck by an ion.

**Note that the term "soft error" is commonplace in terrestrial applications*

Single-Event Effects In Microelectronics



Courtesy Vanderbilt



Example of an SEU causing a bit flip in a conceptual memory

Single-Event Effects (SEE):

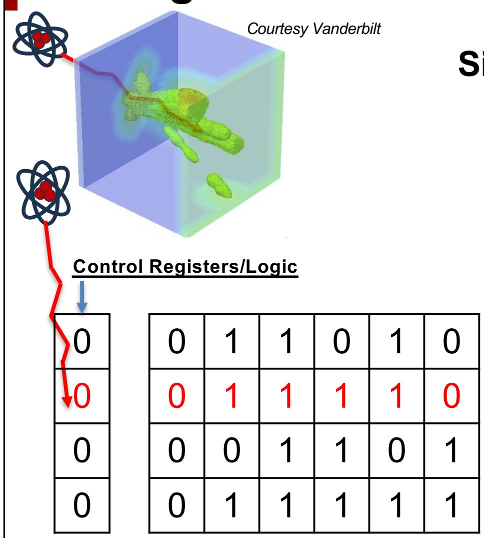
- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response
- **Types:**

Non-destructive:
- Single-event transients
- **Single-event upsets (soft errors)**
- Single-event functional interrupt
- Multiple-bit upsets

Destructive:
- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

An SEU occurs when the ion deposits enough energy to flip the state of a bit (e.g., from a 0 to a 1 or a 1 to a 0). Here, a single bit changes from a logic ‘1’ to a logic ‘0’.

Single-Event Effects In Microelectronics



Example of an SEU causing a bit flip in a conceptual memory

Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response

- **Types:**

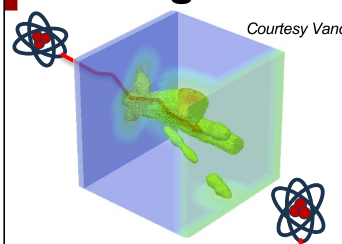
Non-destructive:
- Single-event transients
- Single-event upsets (soft errors)
- **Single-event functional interrupt**
- Multiple-bit upsets

Destructive:
- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

Single-event functional interrupt (SEFI): A SEFI is an SEU that causes undesirable changes in circuit function, and may manifest as corrupt data in blocks, rows, columns, or other complex patterns. In this example, and SEU in a control register is shown to corrupt an entire row of memory.

The manifestation of SEFI can vary. In complex systems-on-chip (SoC), if the application for a part is unknown, it is not uncommon to assume any SEU has the potential for resulting in a SEFI. Additionally, testing for SEFI adds an additional layer of complexity, as the event may disrupt normal operation, thus requiring a stop in execution. Often, a limited number of observations can be obtained for SEFI and the uncertainty in cross-section can be significant. Computing the average fluence until a SEFI occurs is another common way to quantify these vulnerabilities.

Single-Event Effects In Microelectronics



Courtesy Vanderbilt

Control Registers/Logic

0		0	1	1	0	1	0
1		1	0	1	0	0	1
0		0	0	0	0	0	1
0		0	1	1	1	1	1

Example of an SEU causing a bit flip in a conceptual memory

Single-Event Effects (SEE):

- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response
- **Types:**

Non-destructive:

- Single-event transients
- Single-event upsets (soft errors)
- Single-event functional interrupt
- **Multiple-bit upsets**

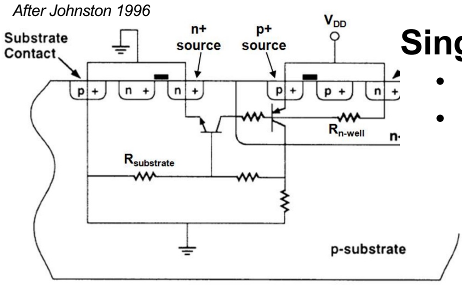
Destructive:

- Single-event latchup
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

Multiple-bit upsets (MBU) are SEE that results in multiple simultaneous SEUs. As opposed to SEFI, MBU are the direct corruption of bits within the radius of influence of the penetrating ion. Technology scaling tends to increase the likelihood of MBU due to the increased packing densities seen in advanced technology nodes.

Single-Event Effects In Microelectronics

After Johnston 1996



Cross-section of typical CMOS technology showing **parasitic thyristor** that can be triggered into low impedance state

Single-Event Effects (SEE):

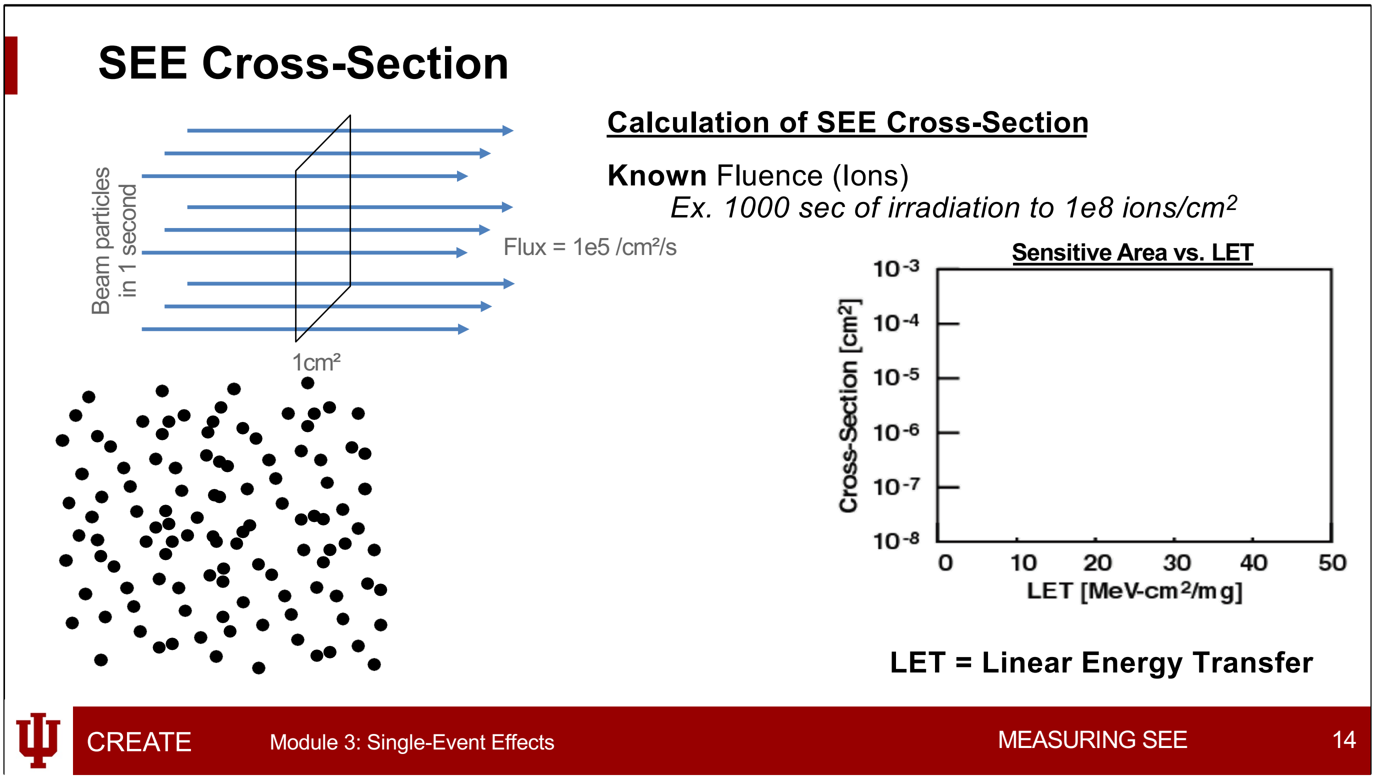
- **Caused by the interaction of a single energetic particle**
- **SEE are determined by:**
  - Charge generation
  - Charge collection
  - Circuit response
- **Types:**

Non-destructive:
- Single-event transients
- Single-event upsets (soft errors)
- Single-event functional interrupt
- Multiple-bit upsets

Destructive:
- **Single-event latchup**
- Single-event burnout
- Single-event gate rupture
- Single-event snap-back

Latchup is a low-resistance condition that can occur for semiconductor structures with four distinct regions that are physically interconnected (*i.e.*, a p-n-p-n thyristor structure) in which the middle junction is reverse biased, and the other two junctions are forward biased [13]. For latchup to occur, the structure must be regenerative: the gains of the parasitic bipolar transistors must be at least 1, and the internal current must be maintained at high values after it exceeds a certain threshold condition. Favorable conditions for lathcup occur when the coupling resistances are minimal and the shunt (to well or substrate) resistances are maximal. Heavy-ions may induce latchup (*i.e.*, **single-event latchup or SEL**) by injecting current into the base of either bipolar, potentially triggering the positive feedback loop [13]-[15].

[13] Johnston, A. H. "The influence of VLSI technology evolution on radiation-induced latchup in space systems." *IEEE Trans. Nucl. Sci.*, 43.2 (1996): 505-521.
[14] Boselli, V. Reddy, and C. Duvvury, “Latch-up in 65 nm CMOS technology: A scaling perspective,” *Proc. IEEE Int. Rel. Phys. Symp.*, pp. 137–144, 2005.
[15] D. G. Mavis and D. R. Alexander, “Employing radiation hardness by design techniques with commercial integrated circuit processes,” *Proc. 16th AIAA/IEEE DASC*, vol.1, pp. 26–30, Oct. 1997.



Now that we have a fundamental grasp of the types of SEE and how the transfer of energy from radiation is quantified– what do we measure?

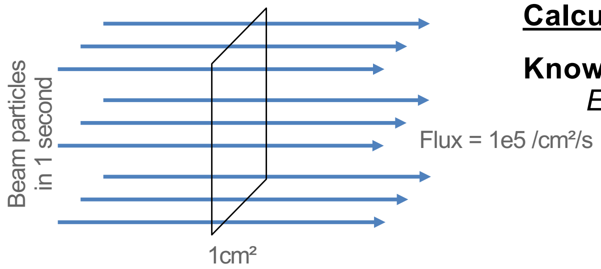
For most SEE, we aim to determine the **cross-section**, which is a measure of a device's sensitivity to radiation. Cross-section can be thought of as a probability of an upset occurring or as the amount of sensitive area (with typical units of cm^2) projected to the surface of a part that is sensitive to the radiation.

Cross-section is calculated using:

$$\sigma = \frac{\textit{Number of Upsets}}{\textit{Fluence (ions/cm}^2)}$$

In the provided example assume that a sample is irradiated for 1000 seconds at a flux of 1×10^5 ions/cm²/s, resulting in a fluence of 1×10^8 ions/cm².

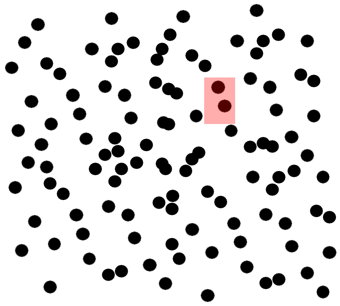
SEE Cross-Section



Calculation of SEE Cross-Section

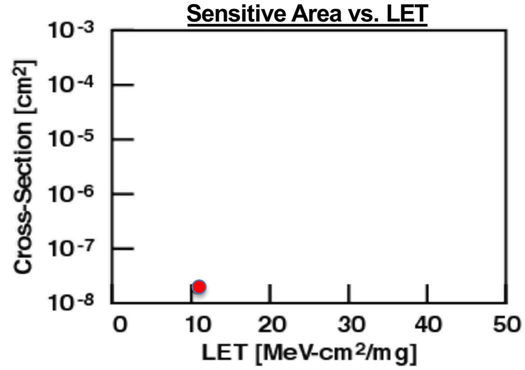
Known Fluence (Ions)

Ex. 1000 sec of irradiation to 1e8 ions/cm²



$$\text{Cross-section} = \frac{2 \text{ upsets/device}}{1e8 \text{ ions/cm}^2}$$

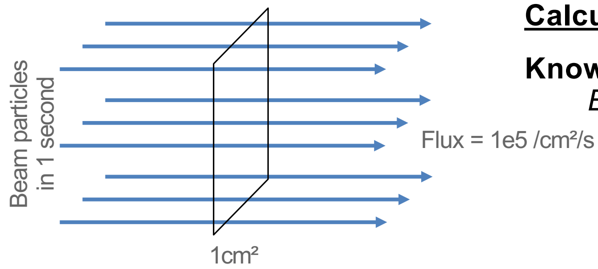
$= 2e\text{-}8$ cm²/device

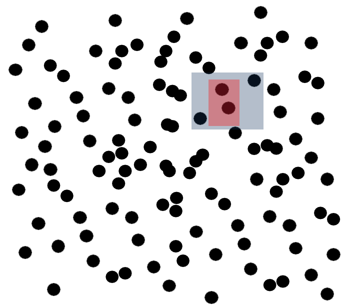


LET = Linear Energy Transfer

This cartoon approximation of the observed SEU shows 2 upsets at a fluence of 1×10^8 ions/cm², thus cross-section = 2×10^{-8} cm²/device.

SEE Cross-Section





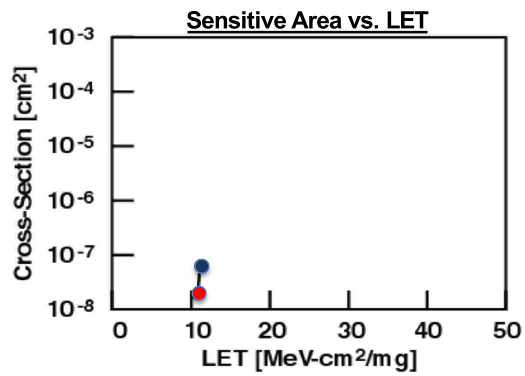
Cross-section = $\frac{\text{4 upsets/device}}{\text{1e8 ions/cm}^2}$

= 4e-8 cm²/device

Calculation of SEE Cross-Section

Known Fluence (Ions)

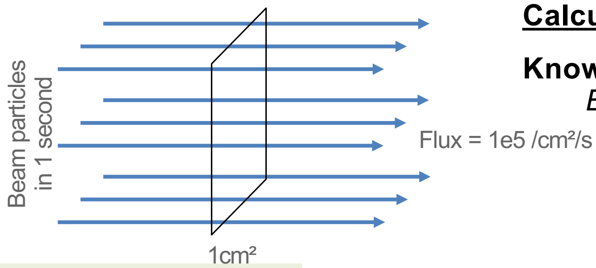
Ex. 1000 sec of irradiation to 1e8 ions/cm²



LET = Linear Energy Transfer

As LET is increased 4 upsets are measured at a fluence of 1×10^{8} ions/cm², thus cross-section = 4×10^{-8} cm²/device.

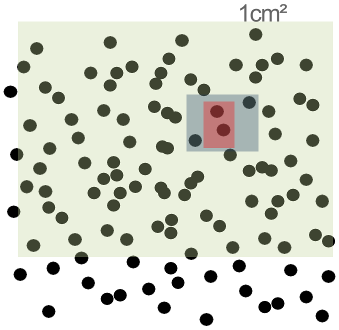
SEE Cross-Section



Calculation of SEE Cross-Section

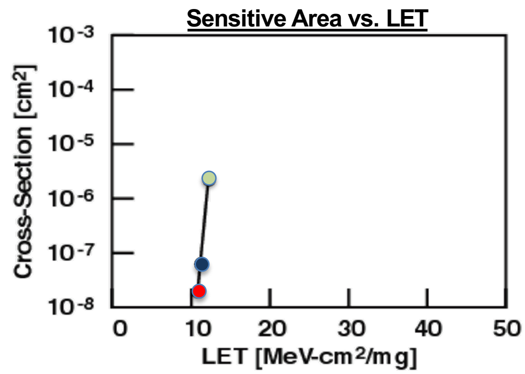
Known Fluence (Ions)

Ex. 1000 sec of irradiation to 1e8 ions/cm²



Cross-section = $\frac{\text{120 upsets/device}}{\text{1e8 ions/cm}^2}$

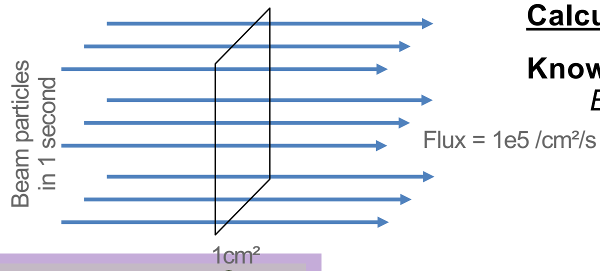
= 1.2e-6 cm²/device

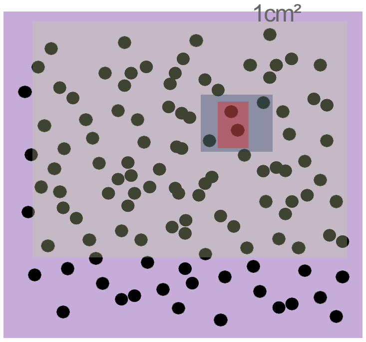


LET = Linear Energy Transfer

As LET is increased again, 120 upsets are measured at a fluence of $1{\times}10^{8}$ ions/cm², thus cross-section = $1.2{\times}10^{-6}$ cm²/device.

SEE Cross-Section

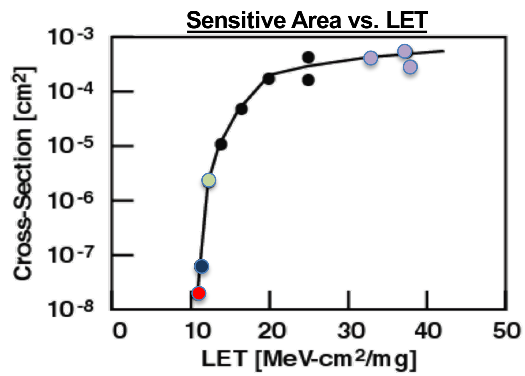




Calculation of SEE Cross-Section

Known Fluence (Ions)

Ex. 1000 sec of irradiation to 1e8 ions/cm²



Cross-sections are measured vs. LET until the LET threshold (onset LET) and saturated (or limiting) cross-section can be determined

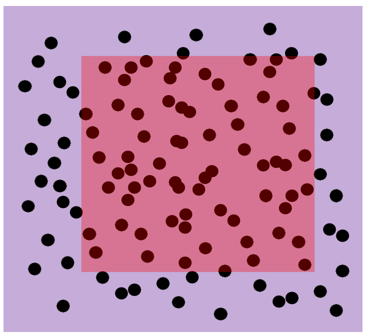
LET = Linear Energy Transfer

This continues until **saturation** is observed.

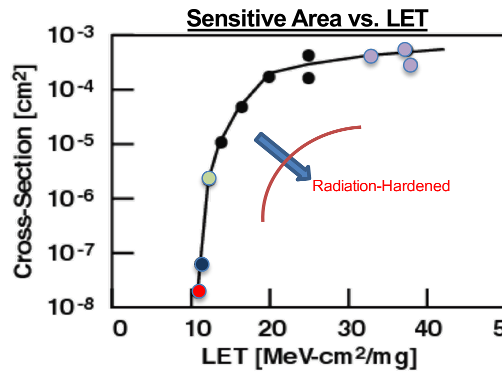
SEE Cross-Section

Radiation hardening aims to increase the LET threshold and decrease the saturation cross-section

Rad-Hard Parts may have very few events and require long exposures – this can be particularly challenging in complex parts



Cross-sections are measured vs. LET until the LET threshold (onset LET) and saturated (or limiting) cross-section can be determined



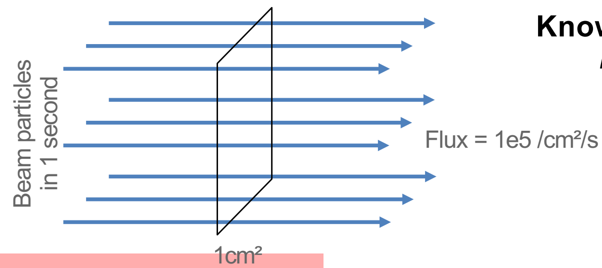
LET = Linear Energy Transfer

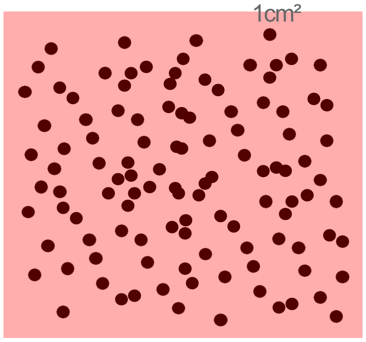
Radiation-hardened (RH) devices aim to:

- Increase onset LET.
- Reduce saturation cross-section.

RH parts may show **very few upsets**, requiring **longer test times**. Hardening shifts the curve to the right and flattens it. But it also makes testing more difficult, sometimes requiring hours of beam time to see a single event.

SEE Cross Section





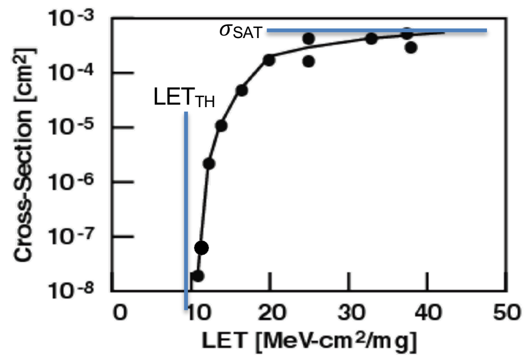
Cross-sections are measured vs. LET until the LET threshold (onset LET) and saturated (or limiting) cross-section can be determined

<u>Calculation of Cross-Section</u>

Known Fluence (Ions), LET

Ex. 1000 sec of irradiation to 1e8 ions/cm²

<u>Sensitive Area vs. LET</u>

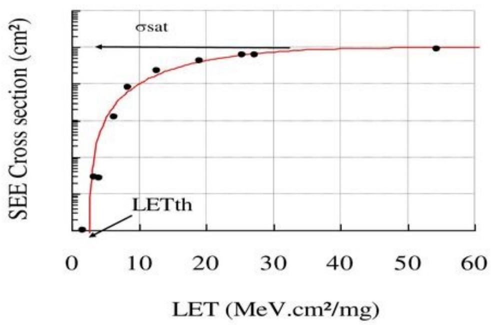


LET = Linear Energy Transfer

Goal, LET thresh, sat cross section, and “enough” points in between

Modeling the SEE Cross Section – more in Module 12

- Model cross-section data with a Weibull curve (use a semi-log y scale)
- Fit the model by minimizing the sum of the squared residuals



Source: ESA presentation by C. B. Polo

$$[cm^2] \longrightarrow \sigma = \frac{N_{events}}{Fluence} \longleftarrow [N_{particules}/cm^2]$$

Fit with Weibull (integral form)

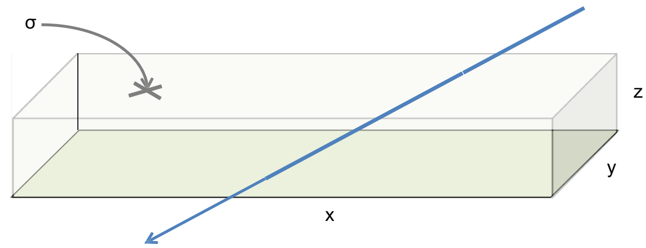
$$\sigma = \sigma_{sat}\left(1 - \exp\left(\frac{LET - LET_{th}}{W}\right)^{S}\right)$$

W and S are fitting parameters

SEE cross-section is a crucial input for in-orbit SEE rate prediction.

Goal, LET thresh, sat cross section, and "enough" points in between

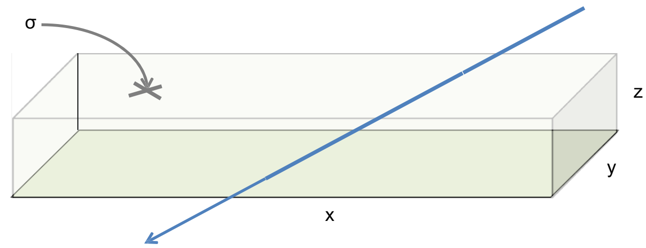
Rectangular Parallel Piped (RPP) Model



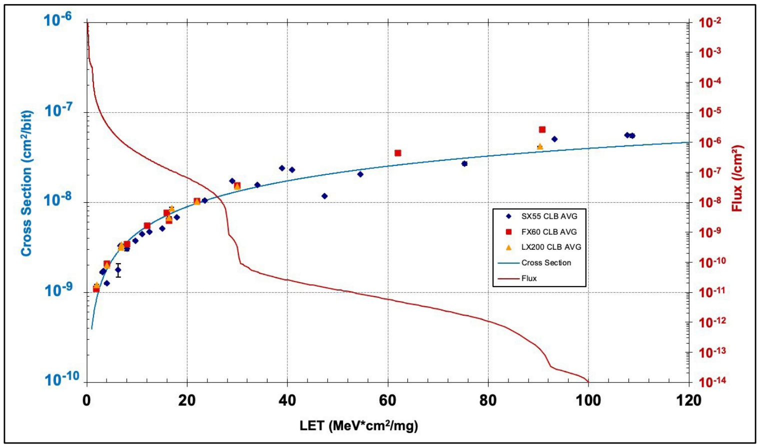
- Cross-Section:
  - σ = x * y
  - The top-down area of the SV (or sensitive area)
- Depth of sensitive volume, z
- Path Length, distance traveled by ion through the SV (———)

Measuring SV?

- You may need to estimate the SV to use error rate modeling tools
- Experimentally:
  - Measure N, the number of SEE, during a run to fluence, Calculate:
    - $\sigma = N/\Phi$
    - $x = y = \sqrt{\sigma}$
    - z
- Many organizations use a "rule of thumb" for determining z
  - Example
    - Typical: $z = x/5$
    - Worst-case: $z = x/100$



From Experiment to On-orbit Rate Estimate
more on this later



$$Rate = \int \underbrace{\frac{dflux(LET,\Theta)}{dLET}}_{\text{environment}} \times \underbrace{\sigma(LET,\Theta)}_{\text{device response}}\, d\Theta\, dLET$$

06

PRACTICAL CONSIDERATIONS

Example: LBNL 88” Cyclotron BASE Facility

About the facility

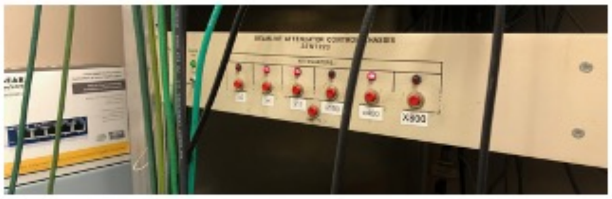
- 88" Cyclotron built in the 60s
- Heavy ions available in "cocktails"
- Example 16 MeV/amu cocktail below – don't rely on quoted LET values!

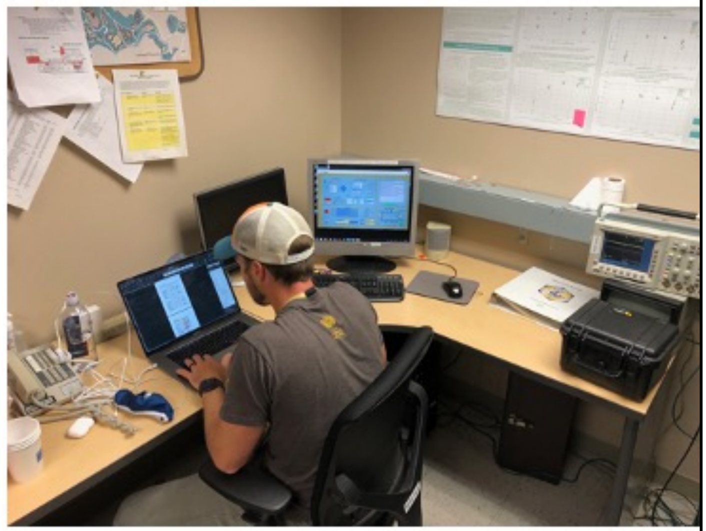
Ion	Cocktail (AMeV)	Energy (MeV)	Z	A	Chg. State	% Nat. Abund.	LET (Entrance) (MeV/mg/cm2)
He*	16	43.46	2	3	+1	0.000137	**0.11**
N	16	233.75	7	14	+5	99.63	**1.16**
O	16	277.33	8	17	+6	0.04	**1.54**
Ne	16	321.00	10	20	+7	90.48	**2.39**
Si	16	452.10	14	29	+10	4.67	**4.56**
Cl	16	539.51	17	35	+12	75.77	**6.61**
Ar	16	642.36	18	40	+14	99.600	**7.27**
V	16	832.84	23	51	+18	99.750	**10.90**
Cu	16	1007.34	29	63	+22	69.17	**16.53**
Kr	16	1225.54	36	78	+27	0.35	**24.98**
Xe*	16	1954.71	54	124	+43	0.1	**49.29**

Source: LBNL Cyclotron Ion Cocktails

About the facility

- Advantages
  - Changing ions (LET) is fast and easy
    - Usually just a few minutes
    - Not the case at other facilities!
  - Flux can be tuned with attenuators
  - They have a sparkling water machine

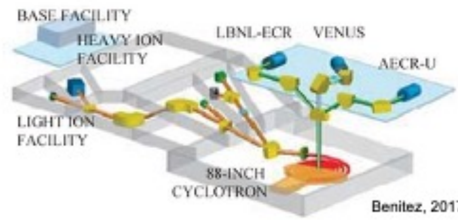




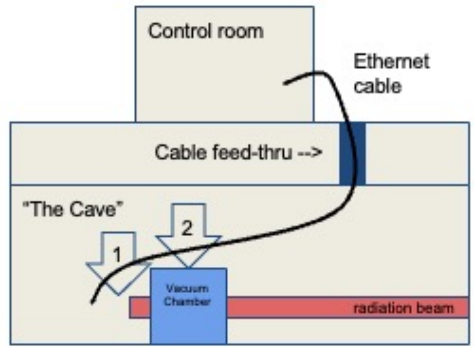
About the facility

- Disadvantages
  - The beam goes down often for hours at a time
  - The beam runs 24 hours/day so you lose a lot of sleep

Setting up your system



- The control room sits directly above the beam chamber
- There is a tube into the chamber where you can run cables
- 60 feet of cables will be plenty to reach your test system
- Outside the vacuum chamber (position 1) you do not need to worry about bulkhead connectors
- Using the vacuum chamber (position 2) you need to know what connections will be available and will need extra cables
- Some cocktails (such as 10 MeV/amu) require the vacuum chamber

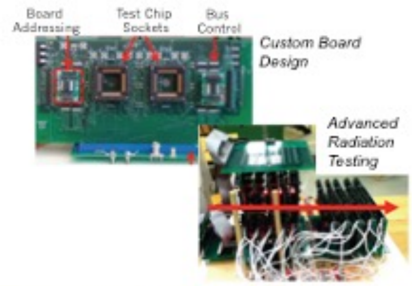


Setting up your system

Pro tip: They will have plenty of clamps and mounts there. You should worry more about cabling

Cabling

Pro tip: Bring extra cables (of every type), connectors. Use the cables you have tested with and verified



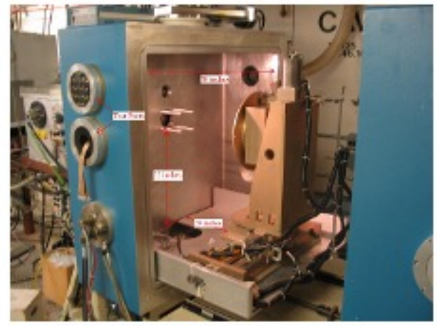
Courtesy NASA GSFC

Vacuum chamber bulkhead connections

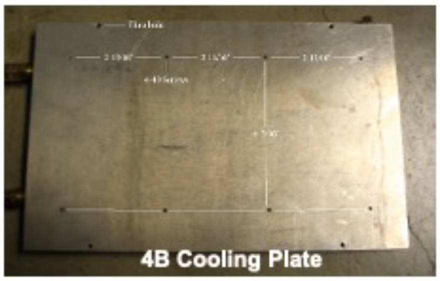
More info:
[88-Inch Cyclotron - Heavy Ions (lbl.gov)]

Vacuum chamber

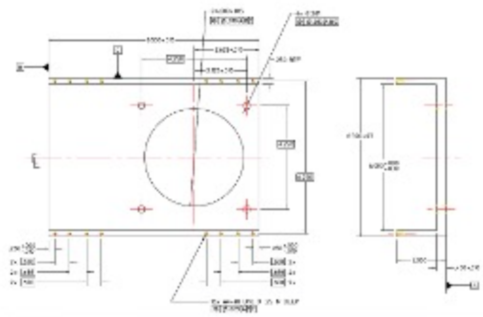
- Tests can be performed in **air** for the 16, 20, and 30 MeV Cocktails
- All cocktails can be performed under vacuum
- While in vacuum the angel can be changed from the control room
- More info: [88-Inch Cyclotron - 4B Drawings (lbl.gov)]



4B Mounting Bracket



4B Cooling Plate

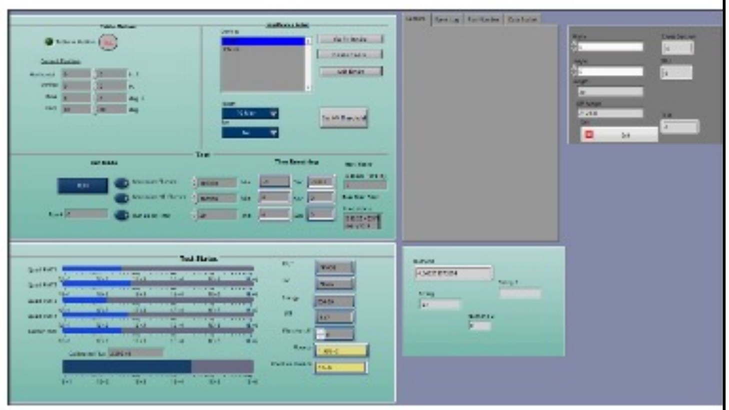


Before heading to California...

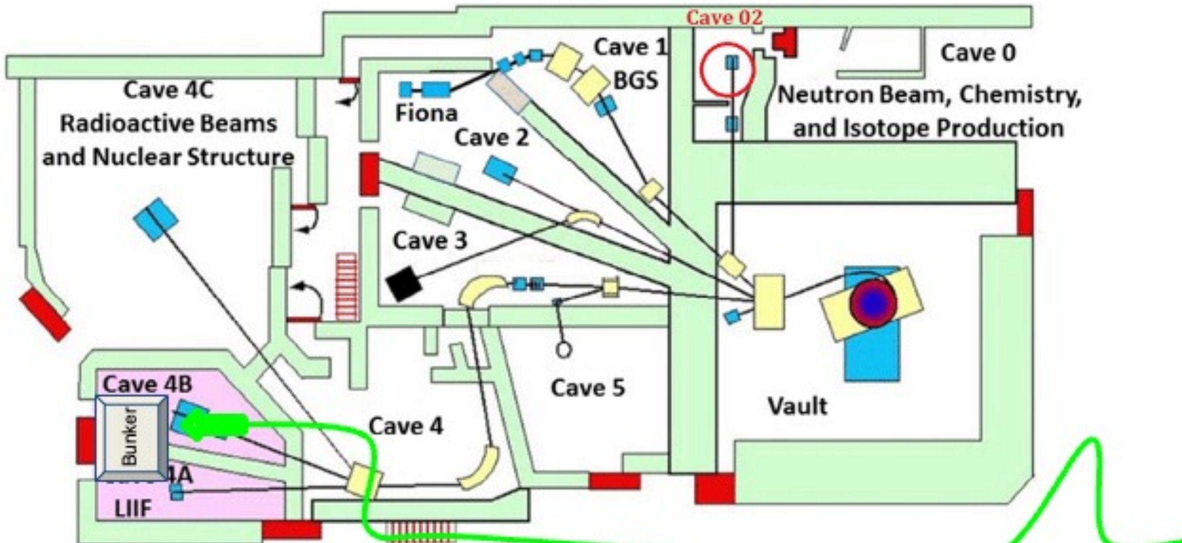
- Decapsulate your parts as soon as possible
- Ship your gear early
- Checked baggage has to be ≤ 99lb
- Request specific ions if necessary

Tips on being prepared

- Familiarize yourself with the software
- Bring snacks and something to kill time
- Rest as much as possible beforehand



Walking to the Bunker



Walking to the Bunker

Cave 4B

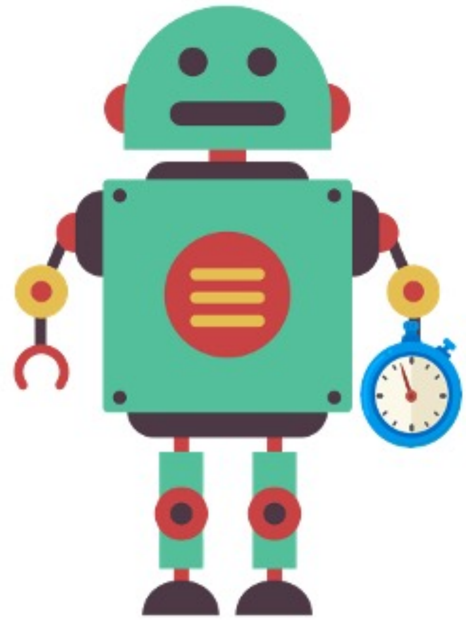
Getting data

- Usually tests are broken up into short runs 1 to 5 minutes long
- You can do longer runs, you just need to plan accordingly
- Make sure that all data logs have the same run numbers
- Periodically check that the run numbers are in sync
- Spreadsheets are great!
- You can also generate them automatically with scripts

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	#	Ion	LET (er	DUTs	File	Dist	Time	VDD (V)	Fluence (cm	Avg I	Peak	A1 SEUs	A2 SEUs	A3 SEUs			C1 SEUs	C2 SEUs	C3 SEUs	Dose (rac	TID (krac	SEU XS (1)	SEU XS (2)
2	0	N	1.16	H01, H02, H0	data/sram/seu/H_check.csv	1	60	0.7	4.20E+06			0*								78.05	0.08	#DIV/0!	
3	1	N	1.16	H01, H02, H0	data/sram/seu/H_check.csv	1	60	0.7	5.32E+06			0*								96.86	0.18	#DIV/0!	
4	2	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar.csv	1	60	0.7	5.22E+06			144384	129024	137216			11264			607.95	0.78	2.62E-02	
5	3	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar.csv	1	60	0.7	6.46E+06			8192	7168	14336			142336			635.90	1.42	1.61E-03	
6	4	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar.csv	1	60	1	5.19E+06			6144	4096	3072			8192			604.46	2.03	8.55E-04	
7	5	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar.csv	1	60	1.3	5.34E+06			6144	2048	2048			4096			621.93	2.65	6.39E-04	
8	6	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar.csv	1	60	3.3	6.30E+06			3072	4096	3072			1024			617.27	3.26	6.44E-04	
9	7	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar_new.csv	1	60	0.7	6.70E+06											663.65	3.93	#DIV/0!	
10	8	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar_new.csv	1	60	1	6.71E+06			131072*	6755	131072*			12541			665.02	4.59	1.18E-03	
11	9	Ar	7.27	H01, H02, H0	data/sram/seu/H_Ar_new.csv	1	60	1.3	5.48E+06											638.23	5.23	#DIV/0!	
12	10	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	60	0.7	5.23E+06			24816	24745	23564						609.11	0.61	4.86E-03	
13	11	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	60	0.7	5.11E+06			24478	23879	22624						595.14	1.20	4.63E-03	
14	12	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	60	0.6	6.18E+06			21601	21923	20889						603.29	1.81	4.14E-03	
15	13	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	60	1.5	6.36E+06			20691	18395	16824						740.72	2.55	2.93E-03	
16	14	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	60	2.4	1.33E+06											15.49	2.56	#DIV/0!	
17	15	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	11	2.4	4.52E+06			????								52.64	2.62	#DIV/0!	
18	16	Ar	7.27	I01, I02, I03	data/sram/seu/I_Ar.csv	1	10	2.4	4.36E+06			Suspected latchup								50.78	2.67	#DIV/0!	

Getting data

- Automate, automate, automate!
- This will save a lot of time and headache
- Use Python, MATLAB, VBA, or whatever tools are available
- Minimize user interactions
- Move quickly - time is a commodity
- Prioritize the most relevant data and optimize the run order
- Consider testing multiple parts or conditions simultaneously



Acronyms

- B: Magnetic Field
- BNL: Brookhaven National Laboratory
- δ: Density
- FRIB: Facility for Rare Isotopes Beam
- IU: Indiana University
- LBNL: Lawrence Berkeley National Laboratory
- LET: Linear Energy Transfer
- LET_{TH}: Threshold LET
- LINAC: Linear accelerator
- MSU: Michigan State University
- N: Number of Events or Particles
- NSRL: NASA Space Radiation Laboratory
- Q_{CRIT}: Critical Charge
- RF: Radio Frequency
- RPP: Rectangular Parallel Piped
- s: Path Length (& sometimes range)
- σ: Cross section
- σ_{SAT}: Saturated σ
- S: Shape Parameter in Weibull Distribution
- SEE: Single Event Effects
- SRIM: Stopping Range of Ions in Matter
- SUESS: TAMU's Cyclotron Institute Radiation Effects Facility Control Software
- SV: Sensitive Volume
- t: Thickness
- θ : Incident Angle
- TAMU: Texas A&M University
- TID: Total Ionizing Dose
- TRIUMF: Tri-University Meson Facility
- TvdG: Tandem Van der Graff
- W: Width Parameter in Weibull Distribution
- x: Length of SV
- y: Width of SV
- z: Depth of SV
- Z: Atomic Number

Pause, ask question to connect to accel type