Certification of Electronics with Heavy Ions for Deep Space

Radiation Technologies Event at JSC
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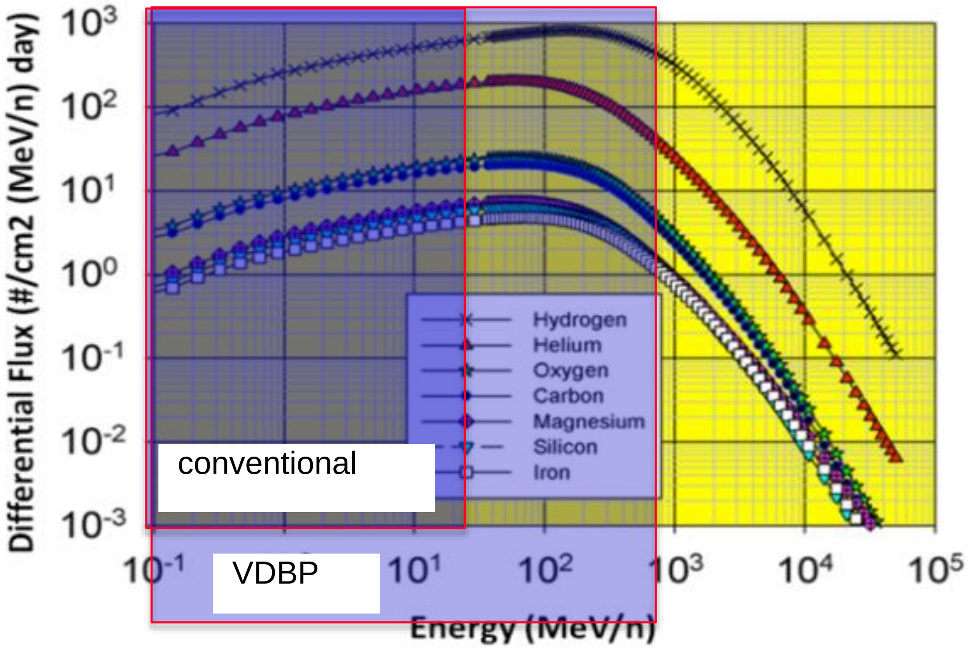
Brandon Reddell, PhD
NASA Johnson Space Center
Engineering Directorate
brandon.d.reddell@nasa.gov
281-483-5050

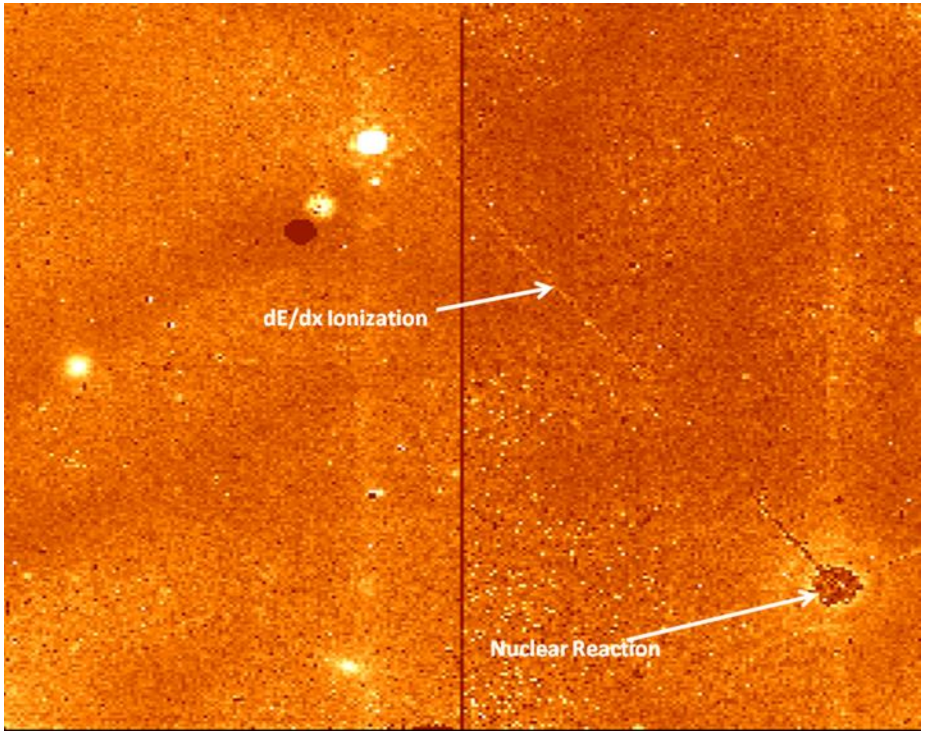
Outline

1. Purpose of Radiation Testing
2. Why a New Test Method?
3. Variable Depth Bragg Peak – Method
4. VDBP Validation & Results
5. VDBP Forward Work

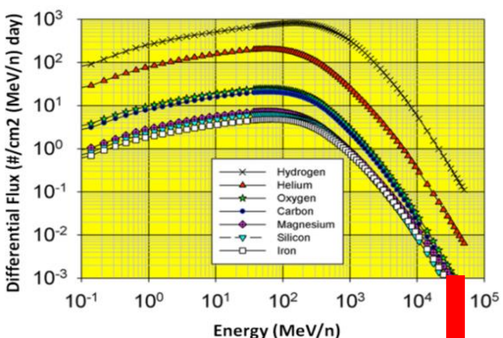
Galactic Cosmic Radiation (GCR)

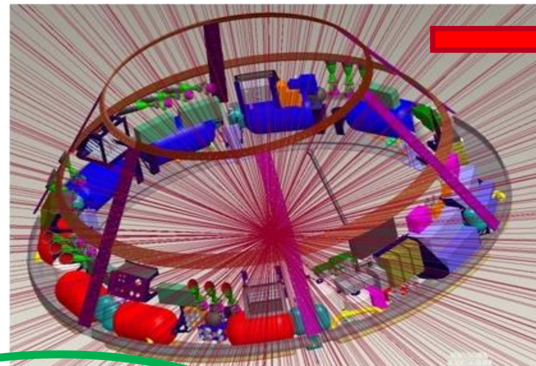


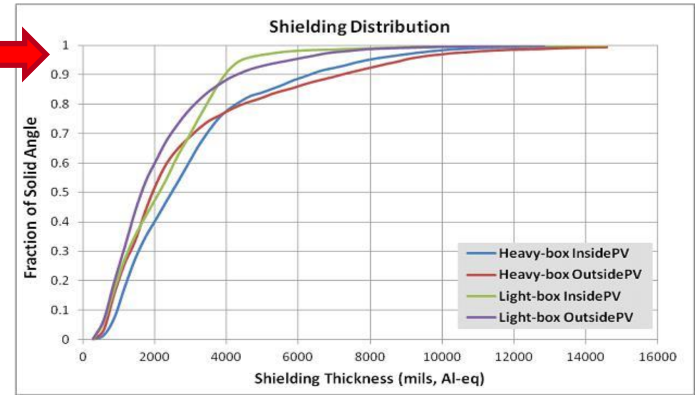
GCR inside material

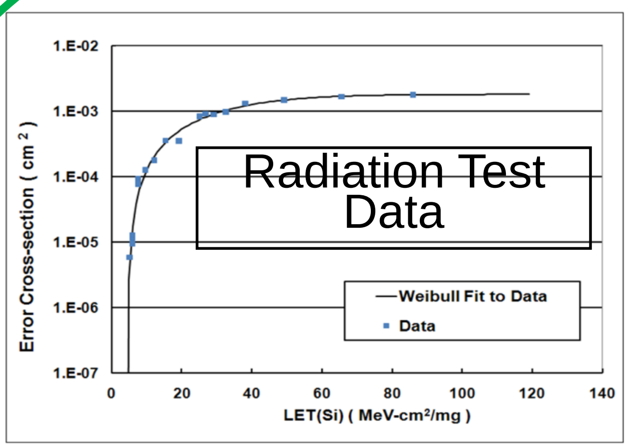


Process for Ionizing Radiation Analysis of Electronic Parts









Radiation Test Data

Part Failure Rate

Reliability Analysis

This is what we are after!

Why a new test method?

U.S. Radiation Facilities

Testing Facility	Beam Type	Cost
~~Indiana University Cyclotron Facility (IUCF)~~	~~High Energy Proton~~	~~$675/hour~~ *** Not available starting 2015**
Brookhaven Tandem Van de Graff Generator (TVDG)	Low Energy Heavy Ion	$1250/hour
Texas A&M University Cyclotron Facility (TAMU)	Low Energy Heavy Ion	$900/hour
Lawrence Berkeley National Laboratory - University of California at Berkley (LBNL)	Low Energy Heavy Ion	$1300/hour
NASA Space Radiation Laboratory (NSRL)	High Energy Heavy Ion	$5500/hour

Concerns for Traditional Radiation Testing of Electronic Parts for Deep Space

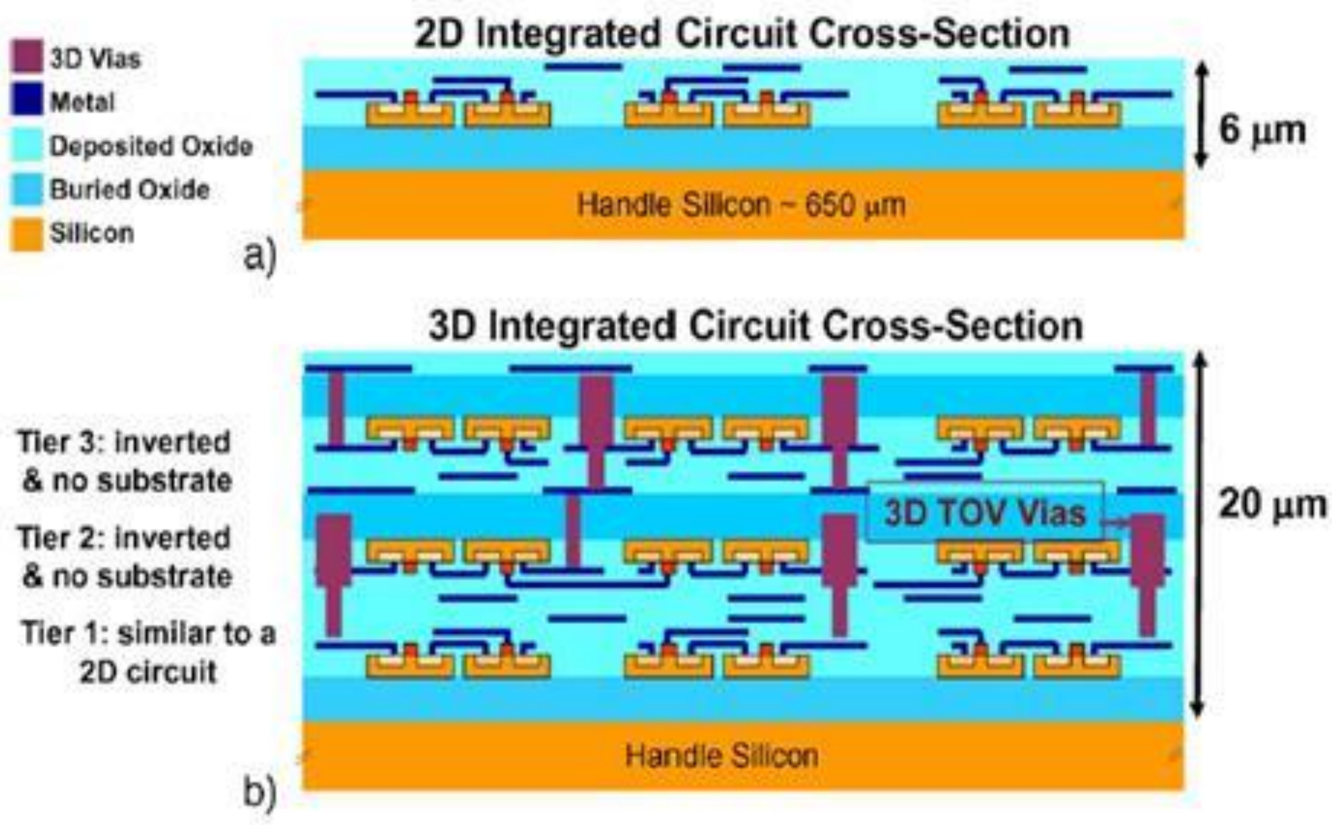
- **High Energy Protons (>= 200 MeV)**
  - **- can only test to LET < 15 MeV/mg/cm2**
  - **- can not be used to certify hardware for deep space**

- **Low Energy Heavy Ions (0<LET<100 MeV/mg/cm2)**
  - -**requires that parts have to have packaging removed (de-lidding)**
    - *** Extra parts required for purchase (~50% survive de-lidding process)**
  - **- De-lidding/test board setup process may impact schedule**
  - **- Limited ability to test circuit/system (only piece-part)**
  - **- Typically takes ~8 hours/part-type to characterize (at ~$1100/hr)**
  - **- Trends in part technology preclude the use of low energy heavy ions**

  - Costly! NASA/MPCV/Orion spent ~$1.2 million between 2011 and 2012 (beam time only - does not include any of the sub-contactor costs or associated labor hours)

***depends on packaging style**

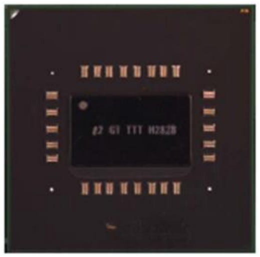
New Technologies & Commercial Parts

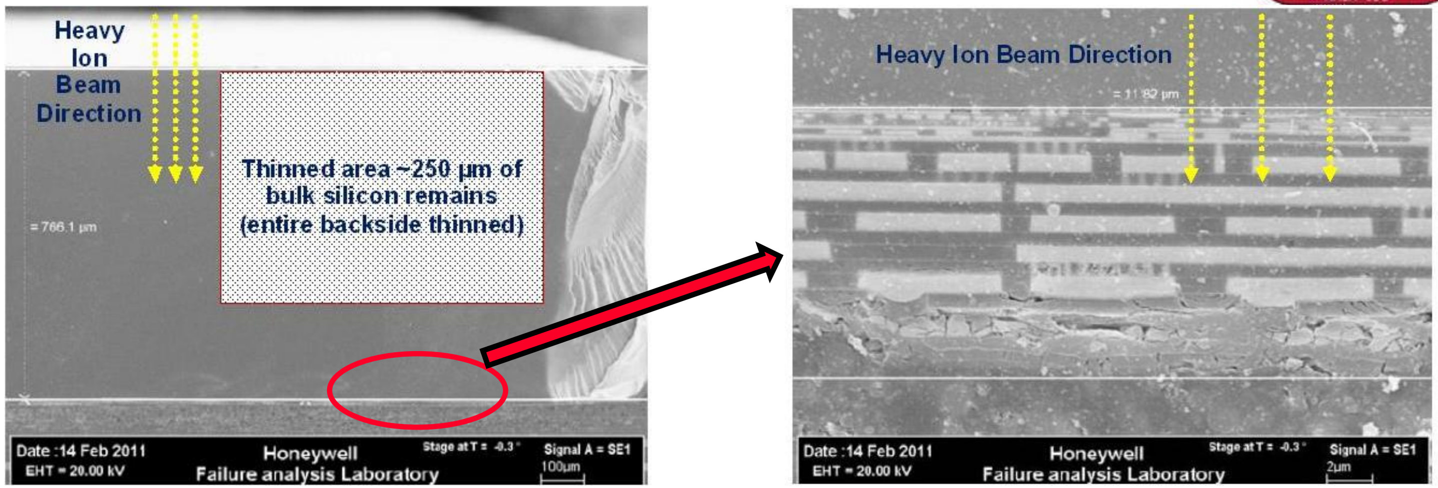


Can the packaging be removed? Is this a flip-chip technology?

How do we test these technologies at low energy facilities?

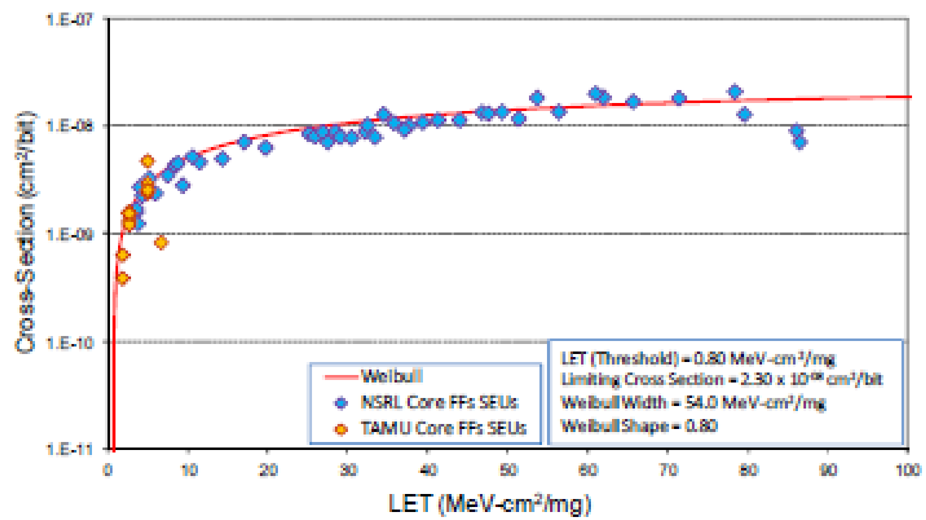
Modern Parts Example: Altera Hardcopy IV ASIC





ASIC 40 nm technology – high priority part for Orion Flight Computer

- Expensive part (several $100k)
- For Orion Lunar mission, need to qualify part to LET >= 75 MeV-cm2/mg
- Attempted to remove ~750 microns of Si, but couldn't without damaging part
- At conventional heavy ion facility (TAMU), max LET achievable was 18 MeV-cm2/mg
- Part successfully characterized using VDBP at NSRL



Ref: "Qualification of an Automotive-Grade, State-of-the-Art ASIC for Natural Space Applications", L. Hoffmann, IEEE NSREC REDW 2013.

Variable Depth Bragg Peak (VDBP) Method

NASA ~ Johnson Space Center - Houston, Texas

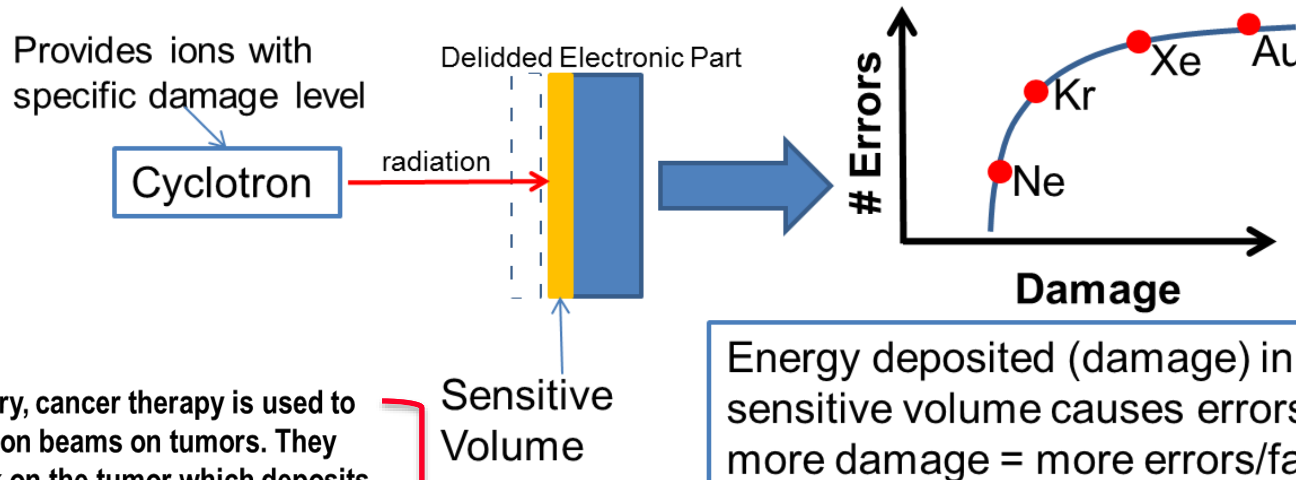
Brookhaven National Laboratory

NASA Space Radiation Laboratory (NSRL)

1) Tandem (2-20 MeV/n) or EBIS/LINAC (200 MeV)
2) **Booster: 20 MeV/n – 2 GeV/n (NSRL gets beam from here)**
3) AGS: 2 GeV/n – 28 GeV/n
4) RHIC: 20 GeV/n – 200 GeV/n

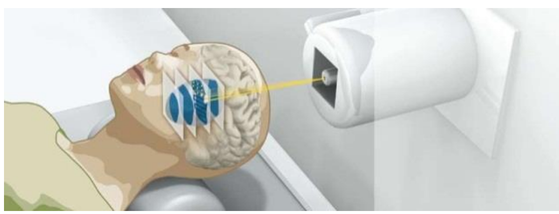
NASA ~ Johnson Space Center - Houston, Texas

Traditional Test

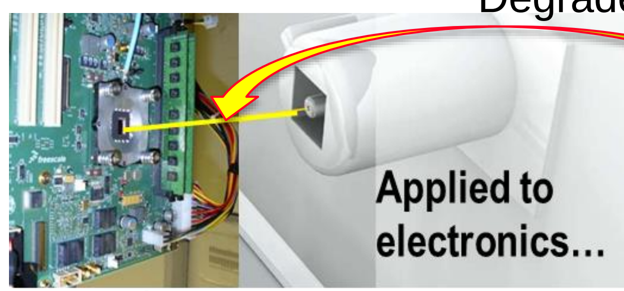


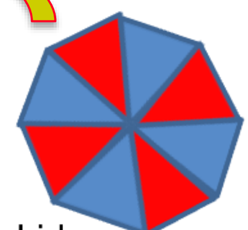
Energy deposited (damage) in the sensitive volume causes errors.
more damage = more errors/failure

In the medical industry, cancer therapy is used to focus ionizing radiation beams on tumors. They place the Bragg Peak on the tumor which deposits energy in the tumor thus destroying it.



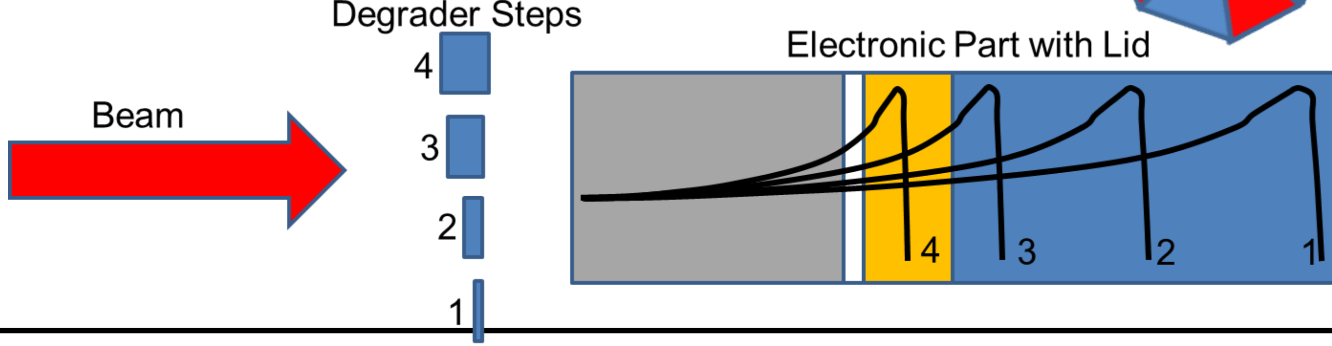
Degrader Wheel Placed Here





VDBP Test

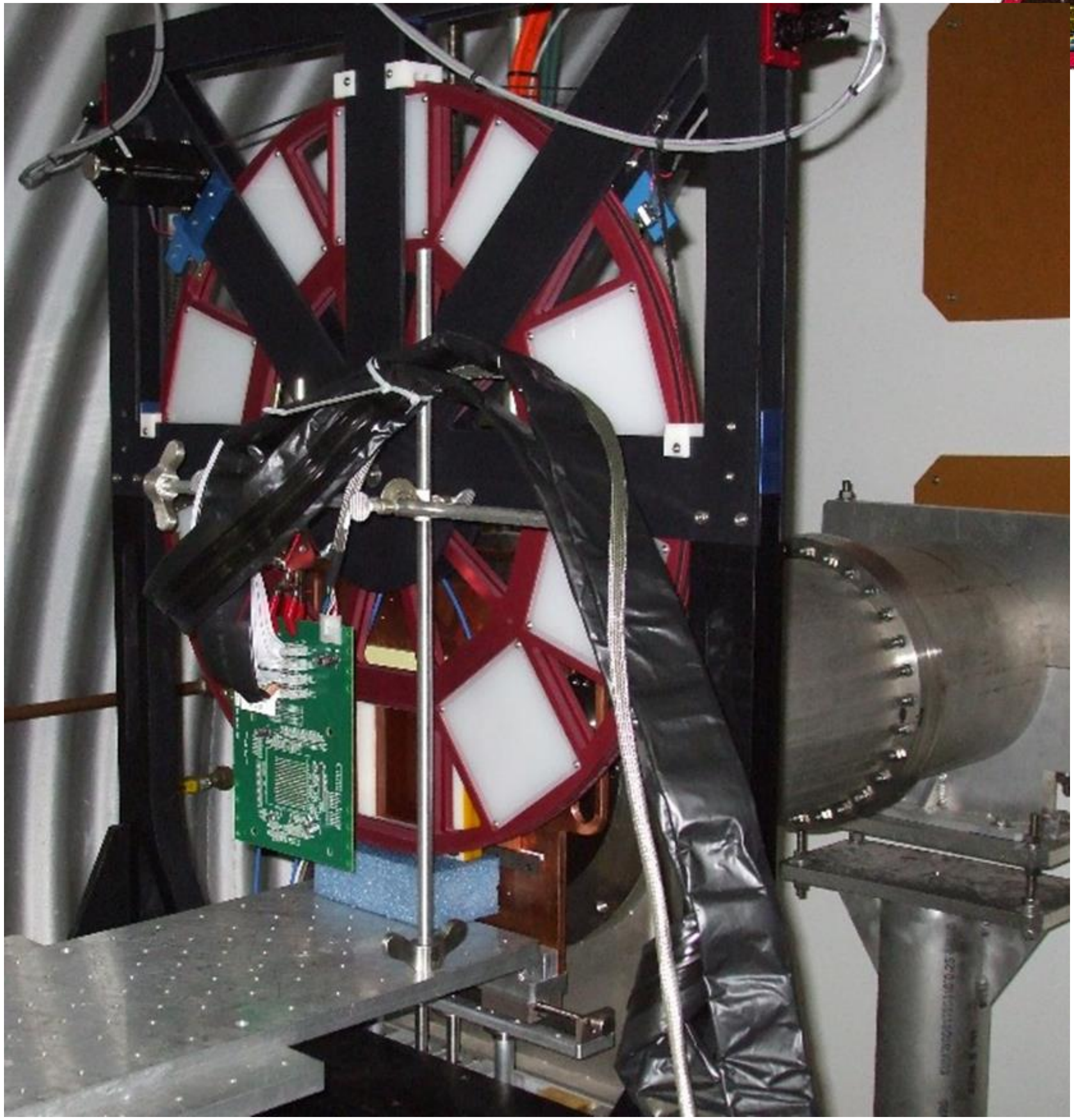
(C. Foster, P. O'Neill – NASA JSC)



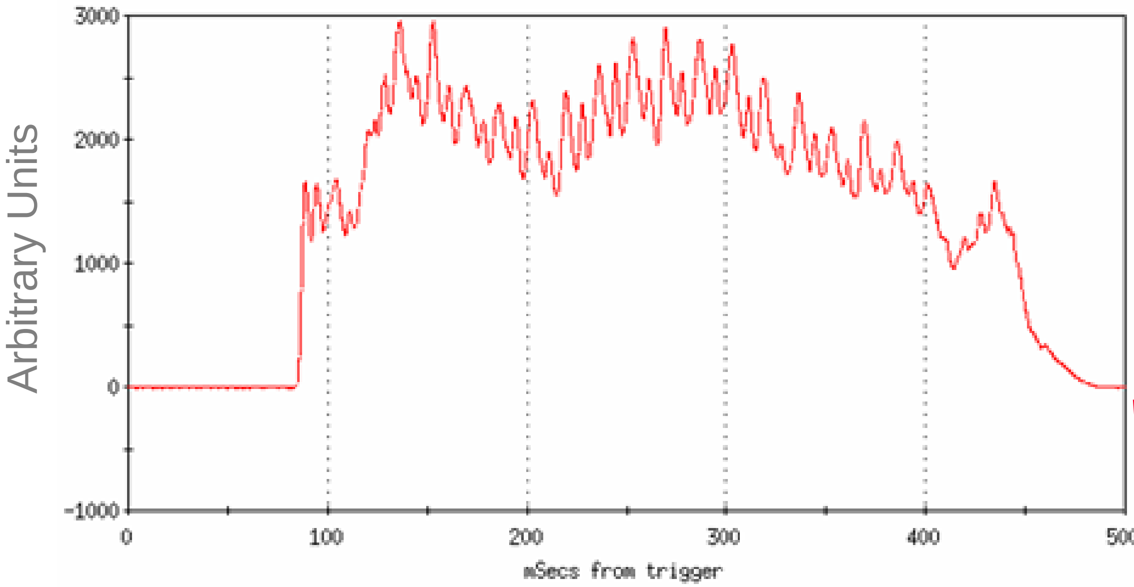
Ref: "High Energy/LET Radiation EEE Parts Certification Handbook", B. Reddell, JSC-HDBK-07-0001, 2012.

Degrader System at NSRL

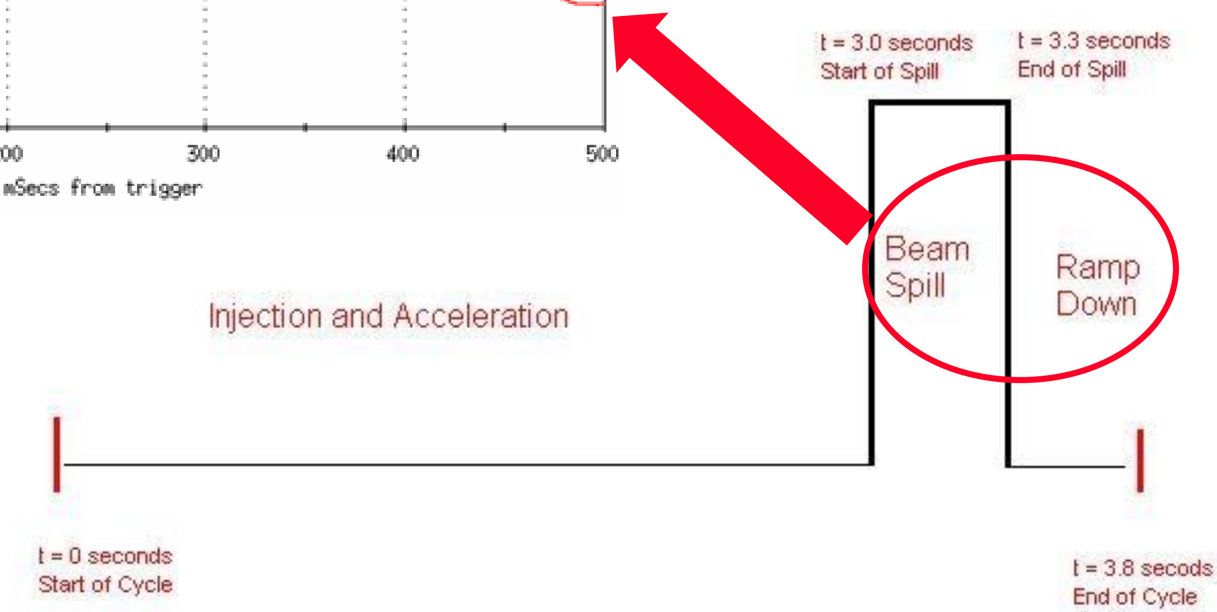
NASA Space Radiation Laboratory at Brookhaven spent ~$50k to develop degrader system for VDBP



NSRL Spill/Intensity vs. Time

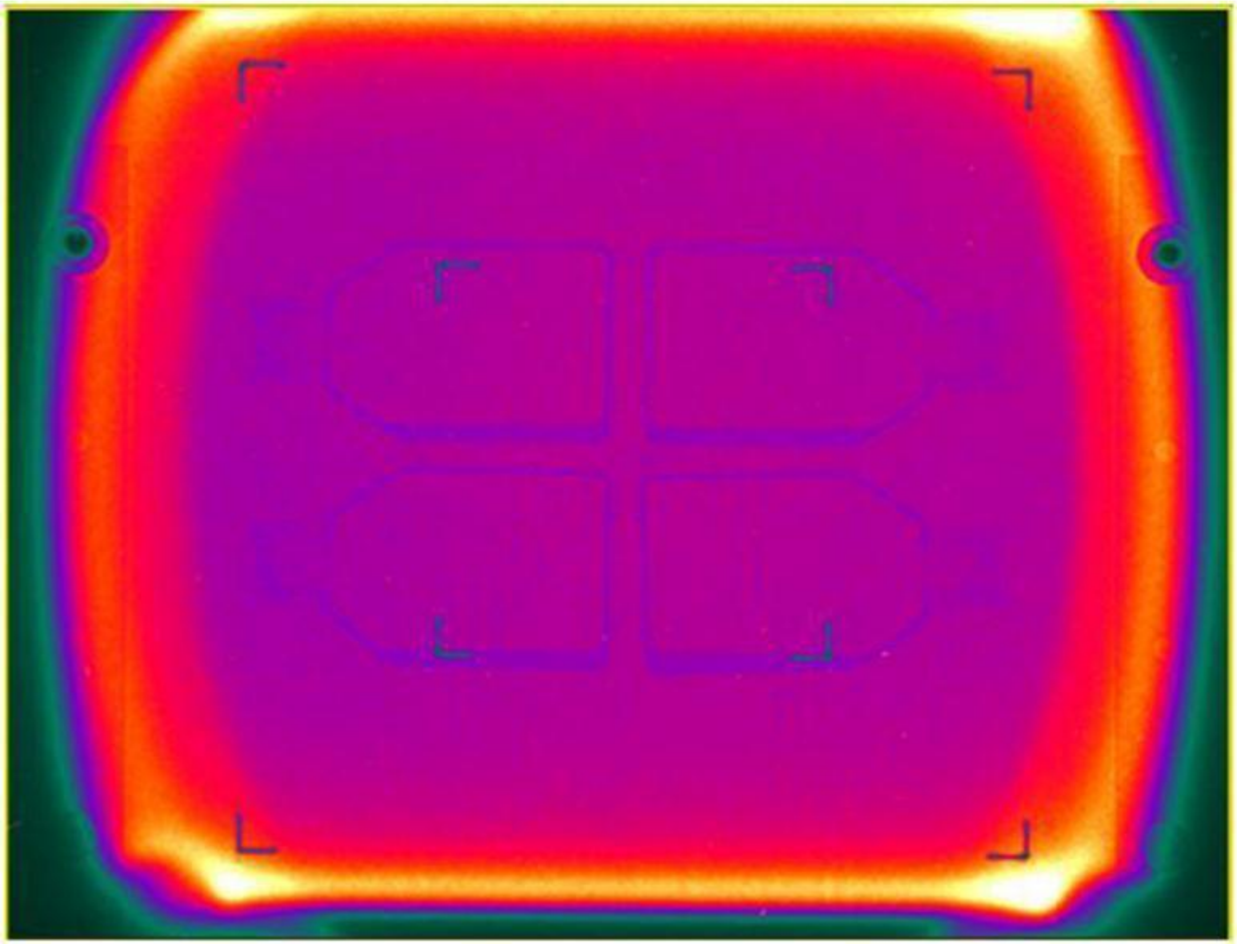


There is a concern for certain error modes that this beam profile will impact testing: This has not been observed to date.



- **Nominally a 0.4 sec spill every 4 seconds**

NSRL 20cm x 20cm Beam Intensity



- ~100<Flux< 1e6 (or higher) particles/cm2/spill (spill every 4-5 seconds)
- Beam spot as low as ~ 1in x 1in for piece part testing

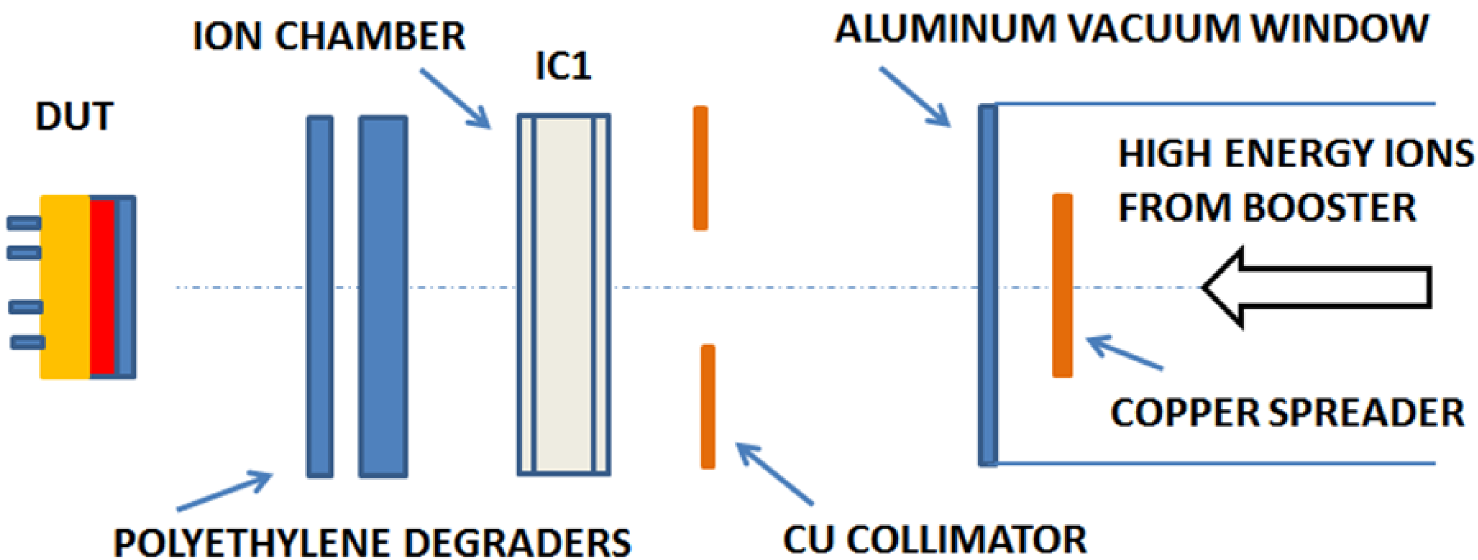
- Large beam spot can be used for system level testing

NSRL Available Beams

Electronics Testing

Ion Species [1]	Max Energy [2] (MeV/n)	LET in silicon at Max Energy [6] (MeV/(mg/cm²))	Peak LET in silicon (MeV/(mg/cm²))	Range in silicon (millimeters)	Max Flux [3] (ions/spill)
$_{1}H^{1}$	2500	0.00171	0.530	5470	$2.2x10^{11}$
$_{2}He^{3}$	1000	0.0069	1.45	1910	$0.88x10^{10}$
$_{2}He^{4}$	1000	0.0072	1.5	1705	$0.88x10^{10}$
$_{6}C^{12}$	1000	0.066	5.4	568	$1.2x10^{10}$
$_{8}O^{16}$	1000	0.117	7.44	426	$0.4x10^{10}$
$_{10}Ne^{20}$	1000	0.183	9.77	341	$1.2x10^{10}$
$_{14}Si^{28}$	1000	0.358	14.5	243	$0.3x10^{10}$
$_{17}Cl^{35}$	1000	0.528	18.1	206	$0.2x10^{10}$
$_{18}Ar^{40}$	350	0.857	19.27	43.3	$0.02x10^{10}$
$_{22}Ti^{48}$	1000	0.884	24.0	169	$0.08x10^{10}$
$_{26}Fe^{56}$	1000	1.235	28.6	141	$0.2x10^{10}$
$_{36}Kr^{84}$	383	3.28	40.1	26.5	$2.0x10^{7}$
$_{54}Xe^{132}$	228	9.75	61.1	8.23	$5.0x10^{7}$
$_{73}Ta^{181}$	342	14.8	83.3	10.6	$3.0x10^{8}$
$_{79}Au^{197}$	165	24.7	90.2	3.70	$1.0x10^{8}$

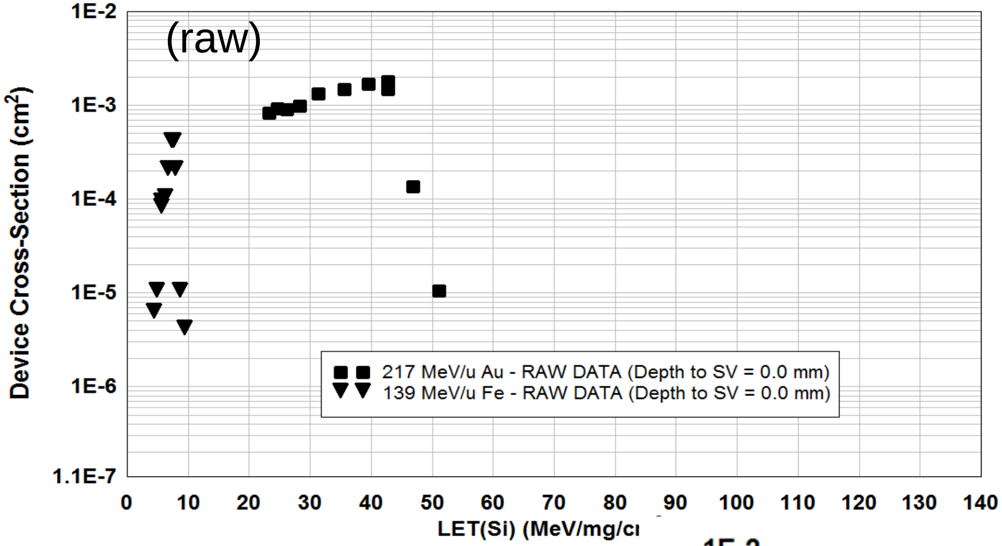
Exposure Set Up



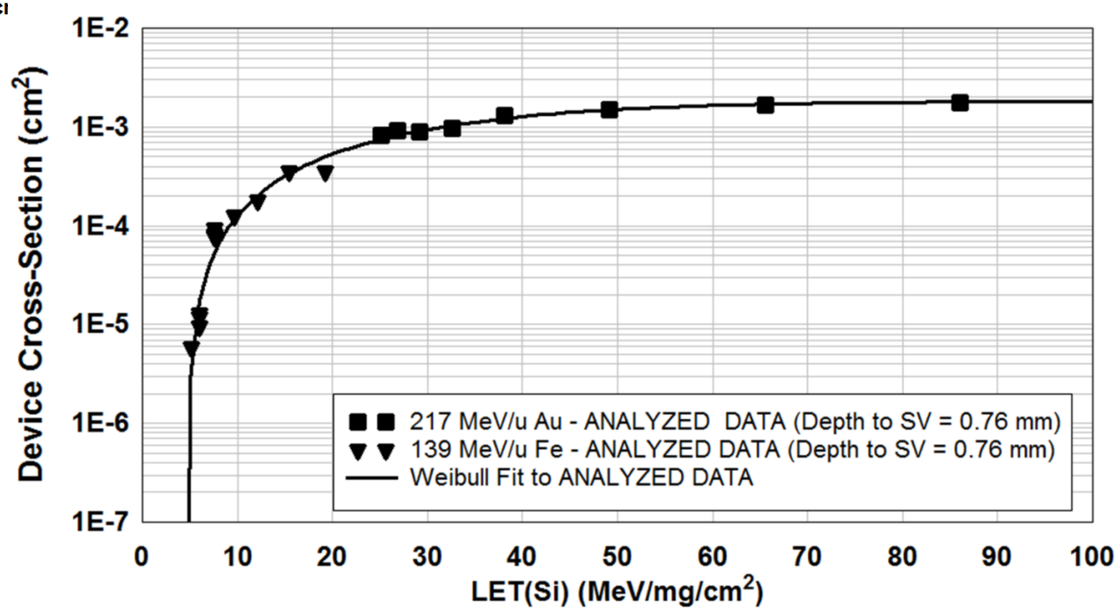
Known: Ion Species (Gold, Iron, Carbon, etc.)

Energy of Ions from Booster Synchrotron, E_B +/- ΔE_B

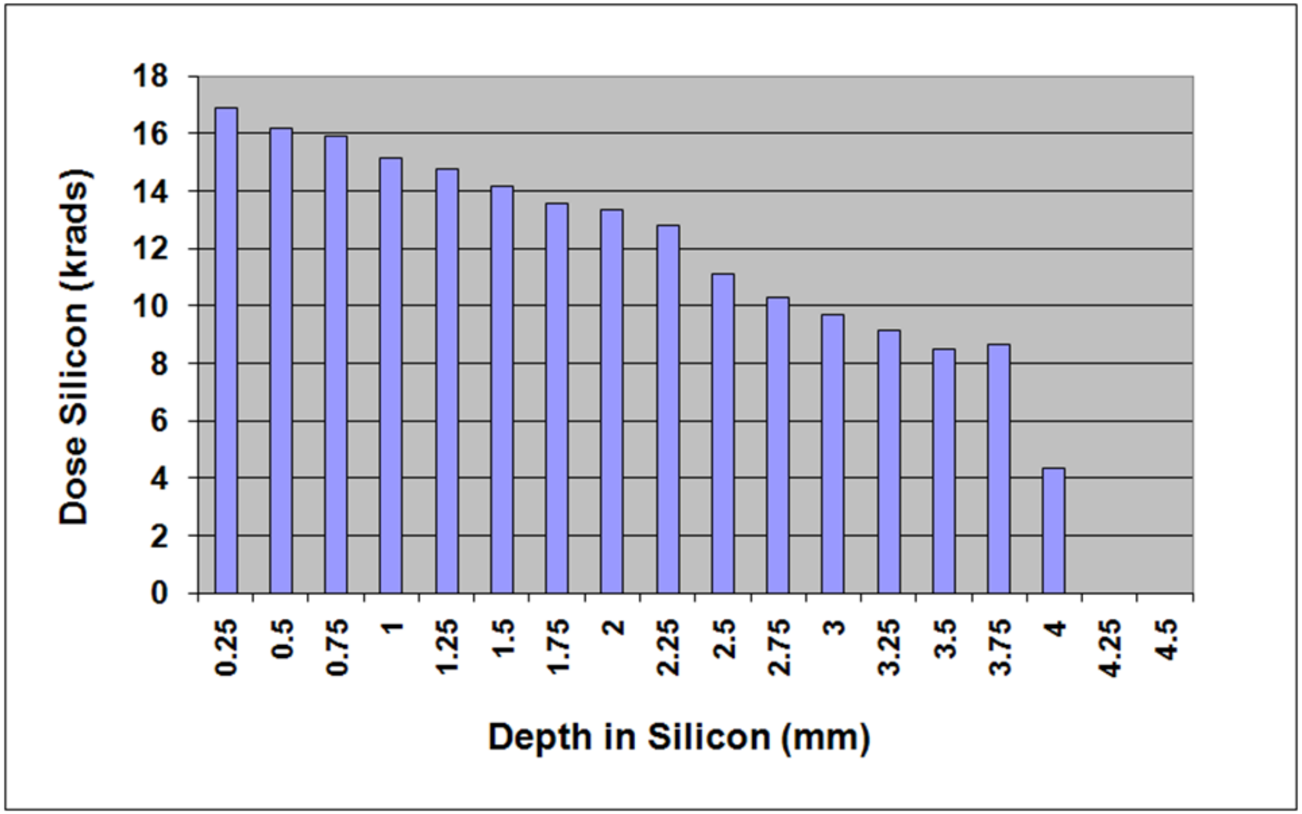
Need to know: Energy of Ions at DUT, E_D +/- ΔE_D



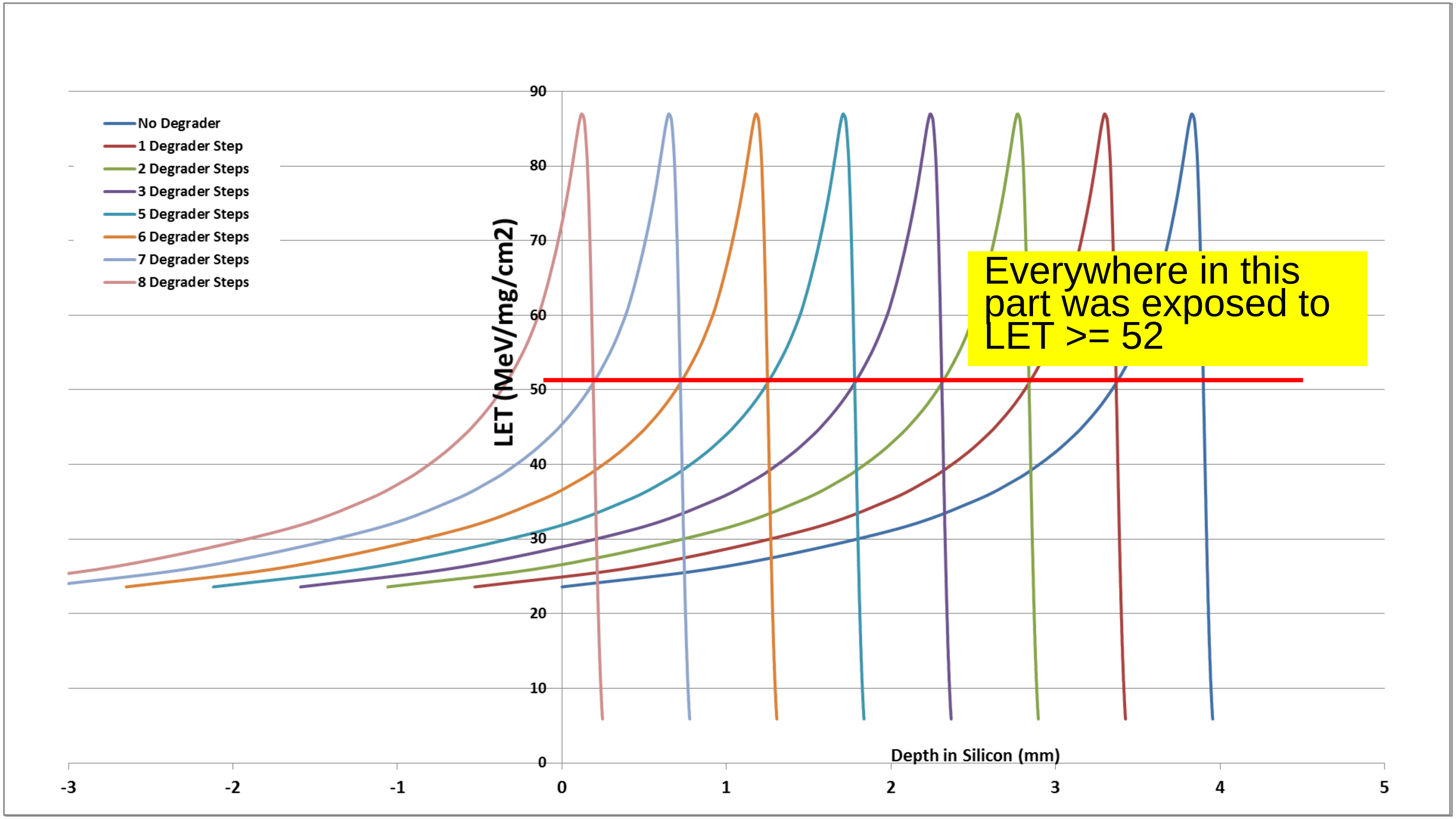
VDBP – Analyzed Data



VDBP – Total Ionizing Dose

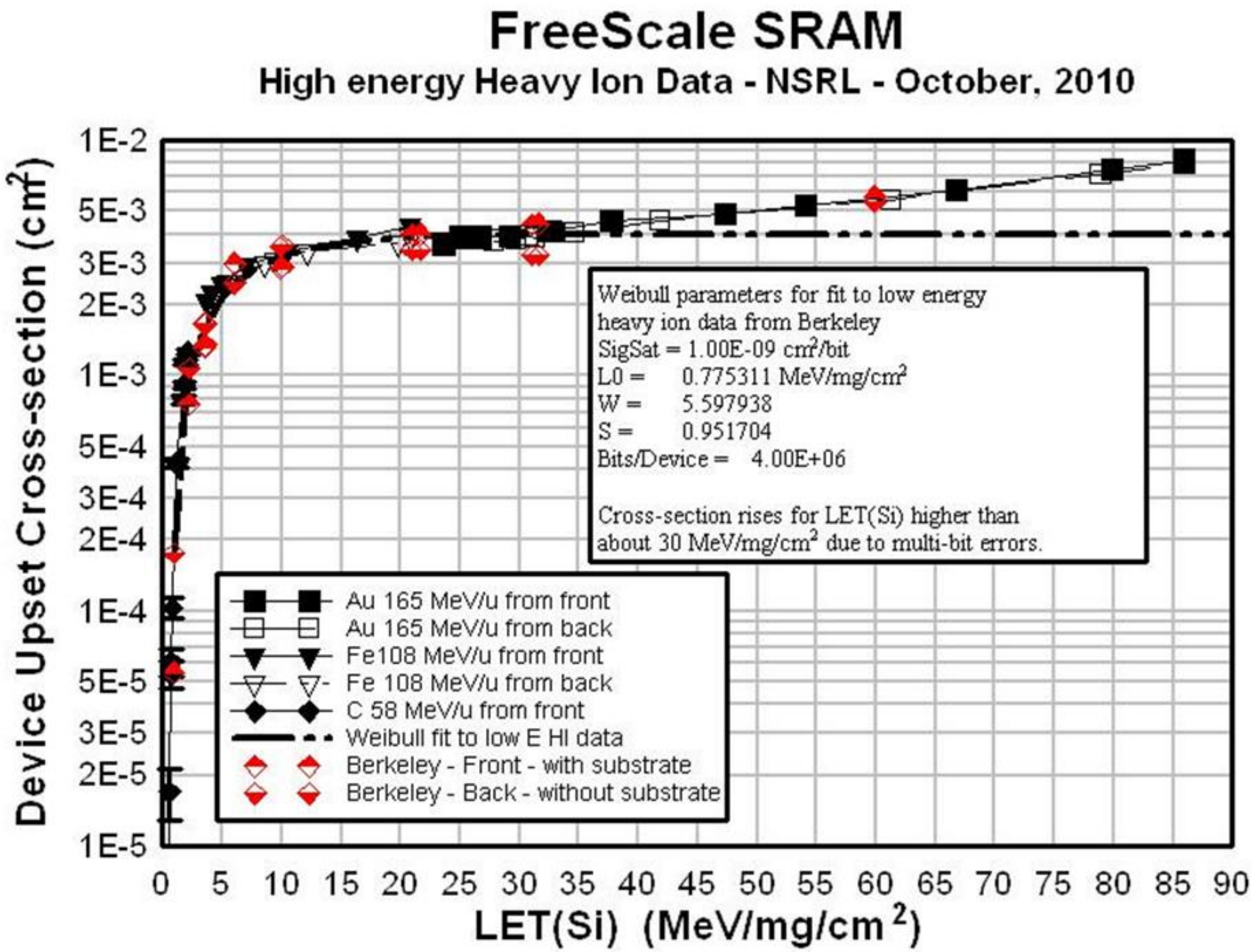


VDBP – Quick (< 1hr) screen, i.e. Destructive Errors



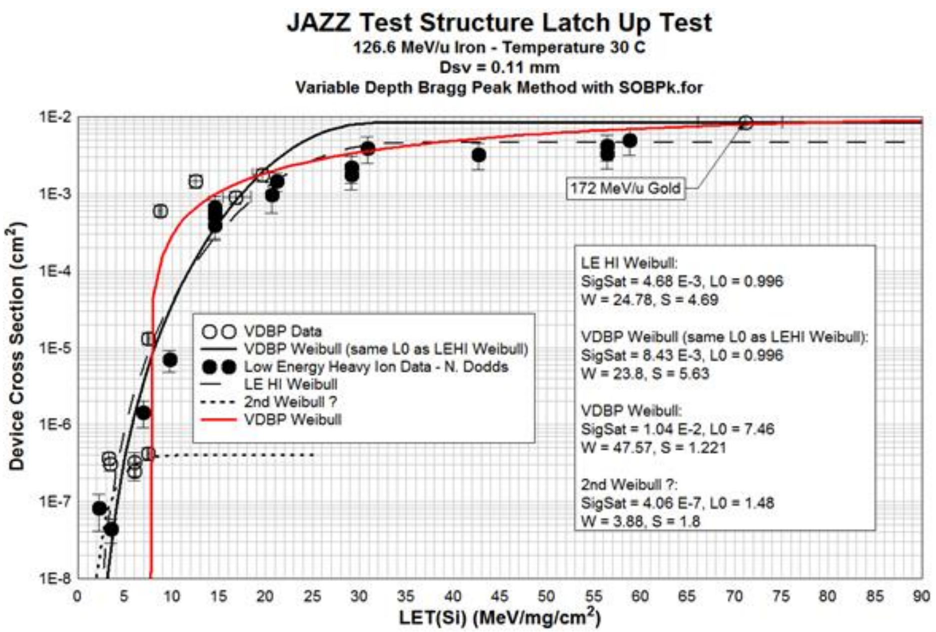
VDBP Validation/Results Examples

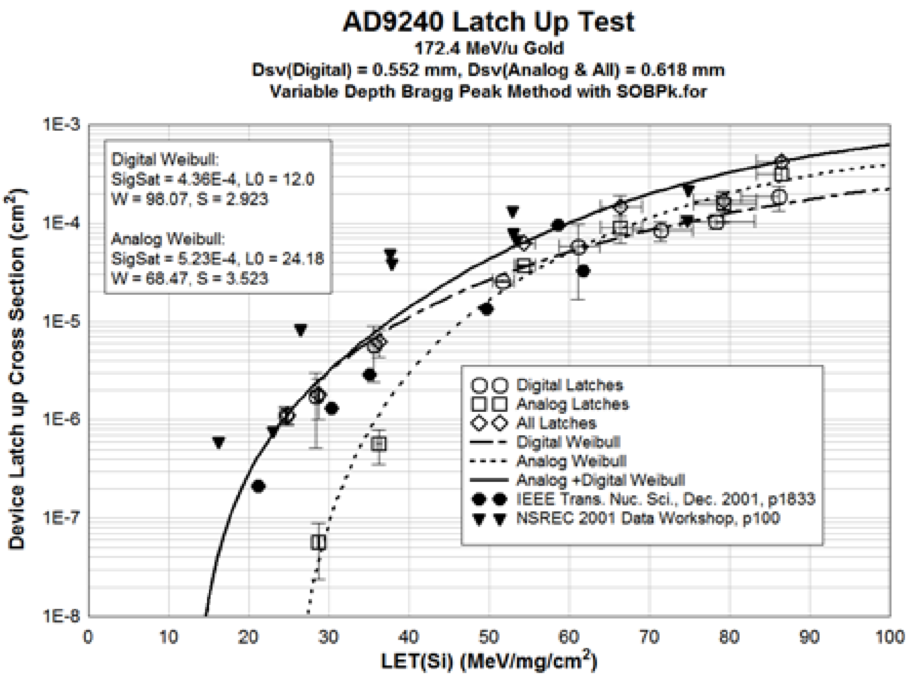
VDBP Validation (Single Event Upset)



Ref: "Variable Depth Bragg Peak Method for Single Event Effects Testing", S. Buchner, P. O'Neill, K. Nguyen, et al., IEEE Trans. On Nuclear Science, Vol. 58, No. 6, December 2011. (IEEE NSREC 2011 Outstanding Paper Award)

Single Event Latch Up Validation





Results of the VDBP measurements of the latch up cross-sections versus LET(Si) for the Analog Devices Inc. Vertical error bars are for counting statistics only. Horizontal error bars indicate the estimated uncertainty in assignment of the LET(Si) values.

Ref: “Validation of the Variable Depth Bragg Peak Method for Single Event Latchup Testing Using Ion Beam Characterization”, S. Buchner, et al., IEEE Trans. On Nuclear Science, December 2014 (TBD).

The End – Thanks!