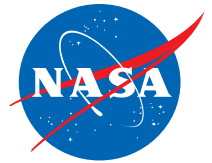


Simulation of SEU cross-sections using MRED under conditions of limited device information

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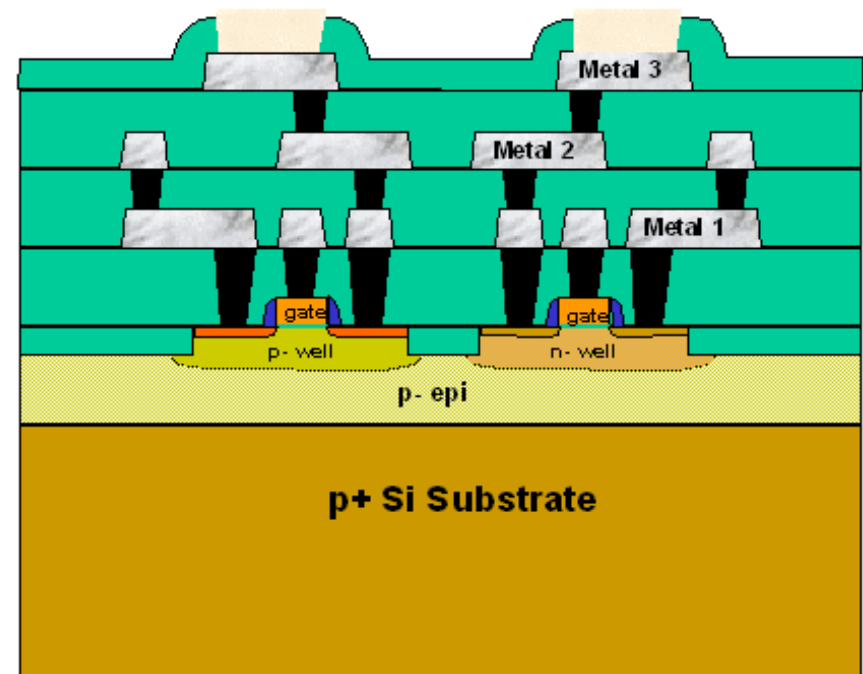


Objective

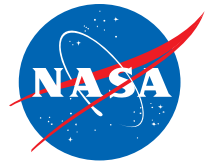
- **Develop an upset response model of a Sandia CMOS6r 16Kb SRAM block using:**
 - “Best guess” assumptions about the process and geometry (= naïve model)
 - Direct ionization, low-energy beam test results
- **Simulate single-event upset (SEU) cross-sections:**
 - Include angular and high-energy responses
 - Compare with beam test data for model validation

Sandia CMOS6r technology

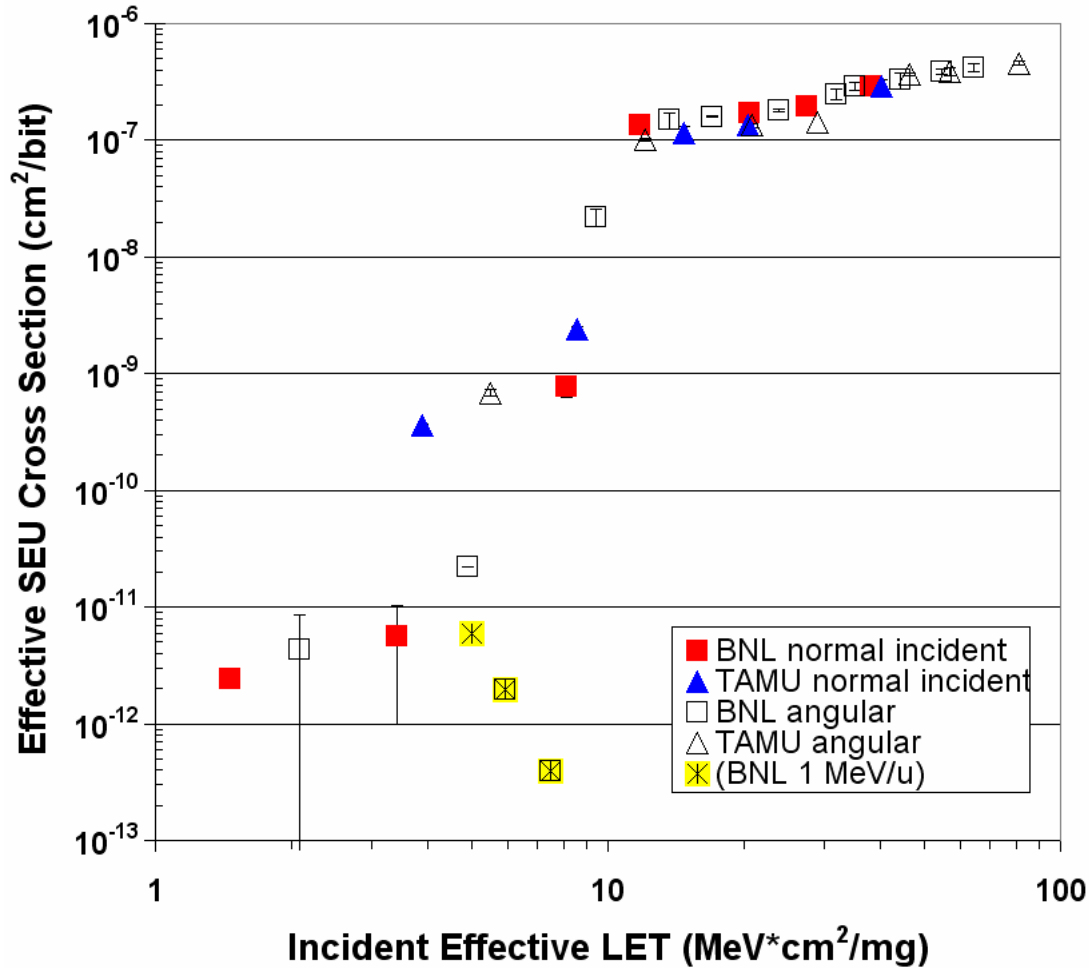
- 0.5 um rad hardened twin-well CMOS technology/process
- Tungsten vias
- Shallow-trench isolation
- 3 metal layers (Al/Cu)



The SRAM block we are simulated has no feedback resistors

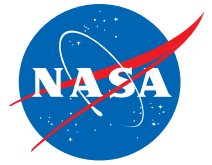


Accelerator beam test data

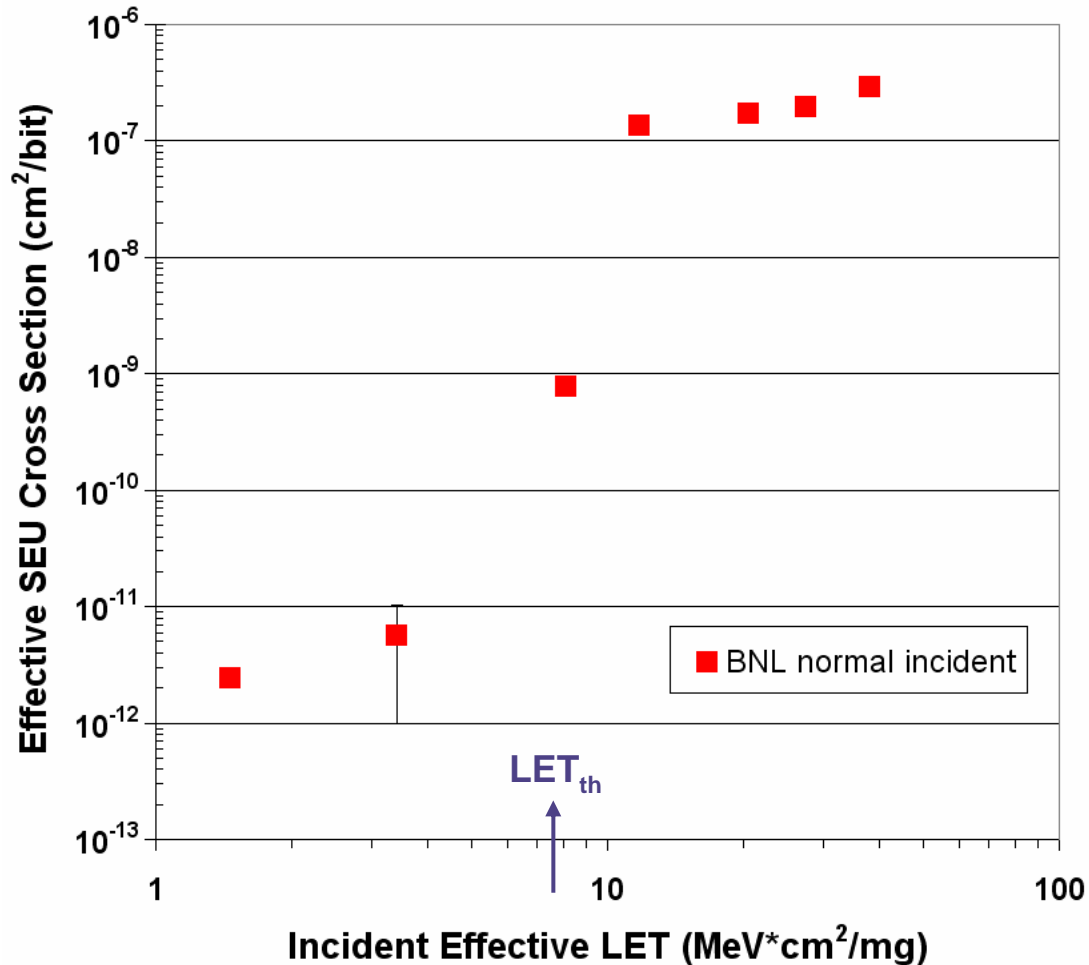


- Extensive set of test data available
- SEU cross-section for a fixed LET depends on ion energy and species

Test Facility	Species-Atomic Mass	Energy (MeV)	LET ($\text{MeV}\cdot\text{cm}^2/\text{mg}$)	Angles Tested
BNL	C-12	12	1.464	0, 30, 45
BNL	C-12	98.7	5.07	0, 45
BNL	F-19	141	3.428	0, 45
BNL	Si-28	185	8.126	0, 30
BNL	Ti-48	193.8	11.81	0, 30
BNL	Cl-35	210	20.54	0, 30, 45
BNL	Ni-58	265	27.49	0, 30
BNL	Br-81	279	38.24	0, 30, 45
TAMU	Ar-40	509	8.55	0, 45
TAMU	Ar-40	1560	3.9	0, 45
TAMU	Kr-84	1879	20.4	0, 45
TAMU	Kr-40	2981	14.7	0, 45
TAMU	Xe-136	2835	40.2	0, 30, 45

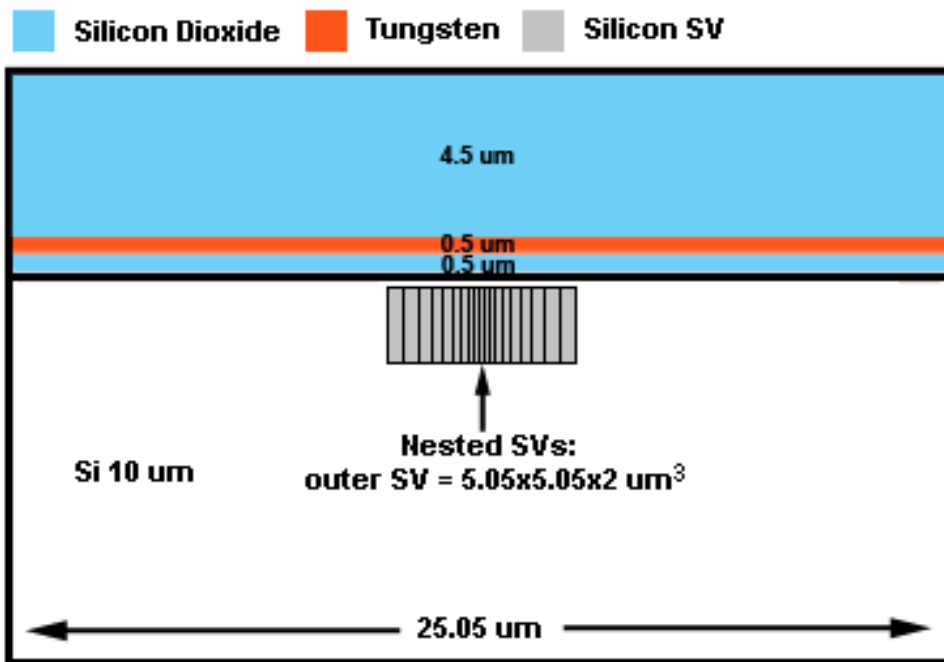


Accelerator beam test data



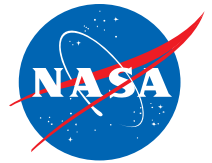
- Developed MRED model based solely upon normal-incident, low-energy BNL test data
- Defined threshold LET as **7.5 $\text{MeV}\cdot\text{cm}^2/\text{mg}$**
 - for upsets induced by direct ionization

MRED model

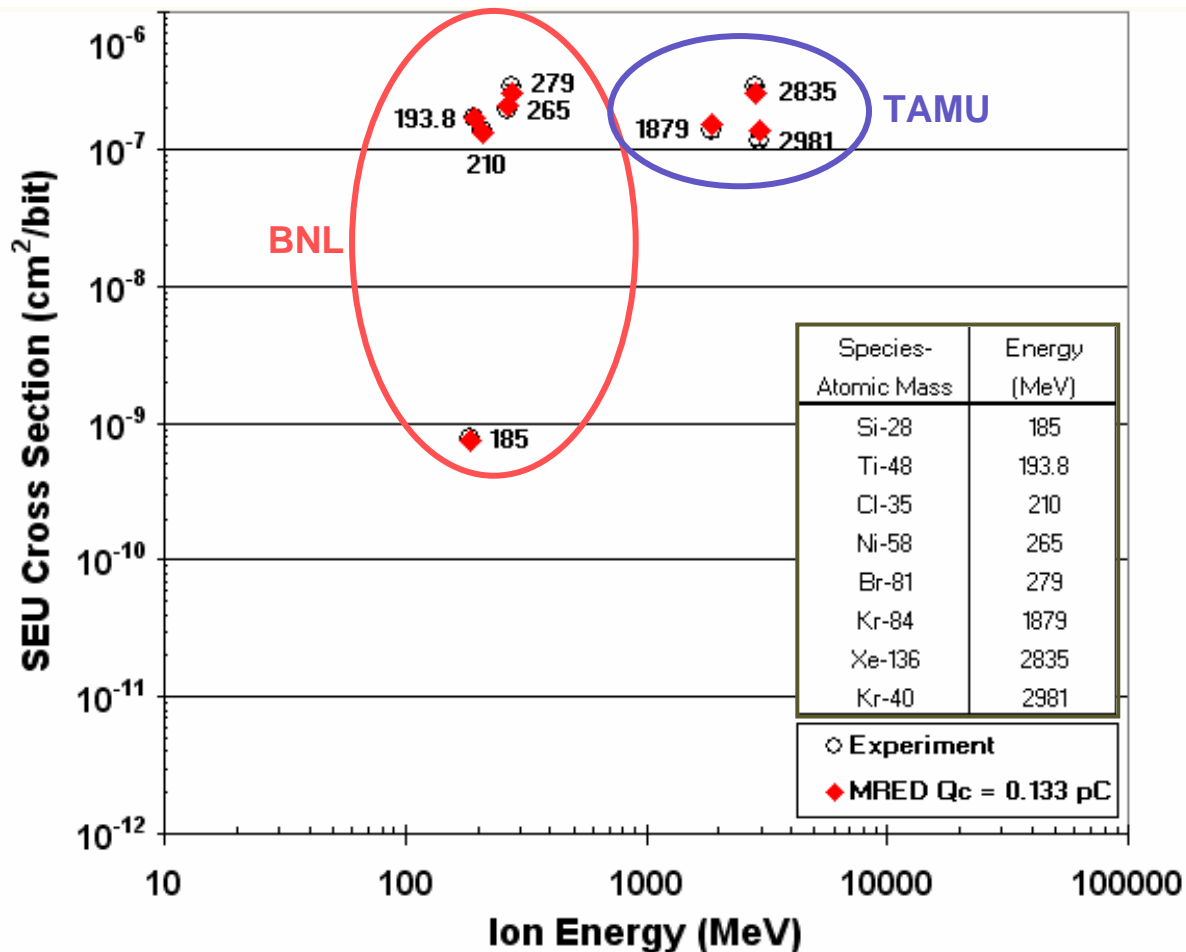


- **Sensitive volume (SV) defines region of charge collection**
 - is for a single bit
- **SV constructed from concentric-nested set of 10 regions having different charge collection efficiencies***
 - Regions sized according to cross-section area at each of 10 logarithmically uniform points along the BNL normal-incident upset curve
- **Simple overlayer composition:**
 - Tungsten vias modeled as $0.5 \mu\text{m}$ layer $0.5 \mu\text{m}$ above the base of a $5.5 \mu\text{m}$ SiO_2 overlayer

*Method: Warren, K.M., *et al.*,
 IEEE Trans. Nucl. Sci., vol. 54, no. 3, June 2007



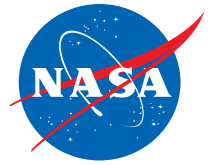
Model calibration and results: Direct ionization events at 0° incidence



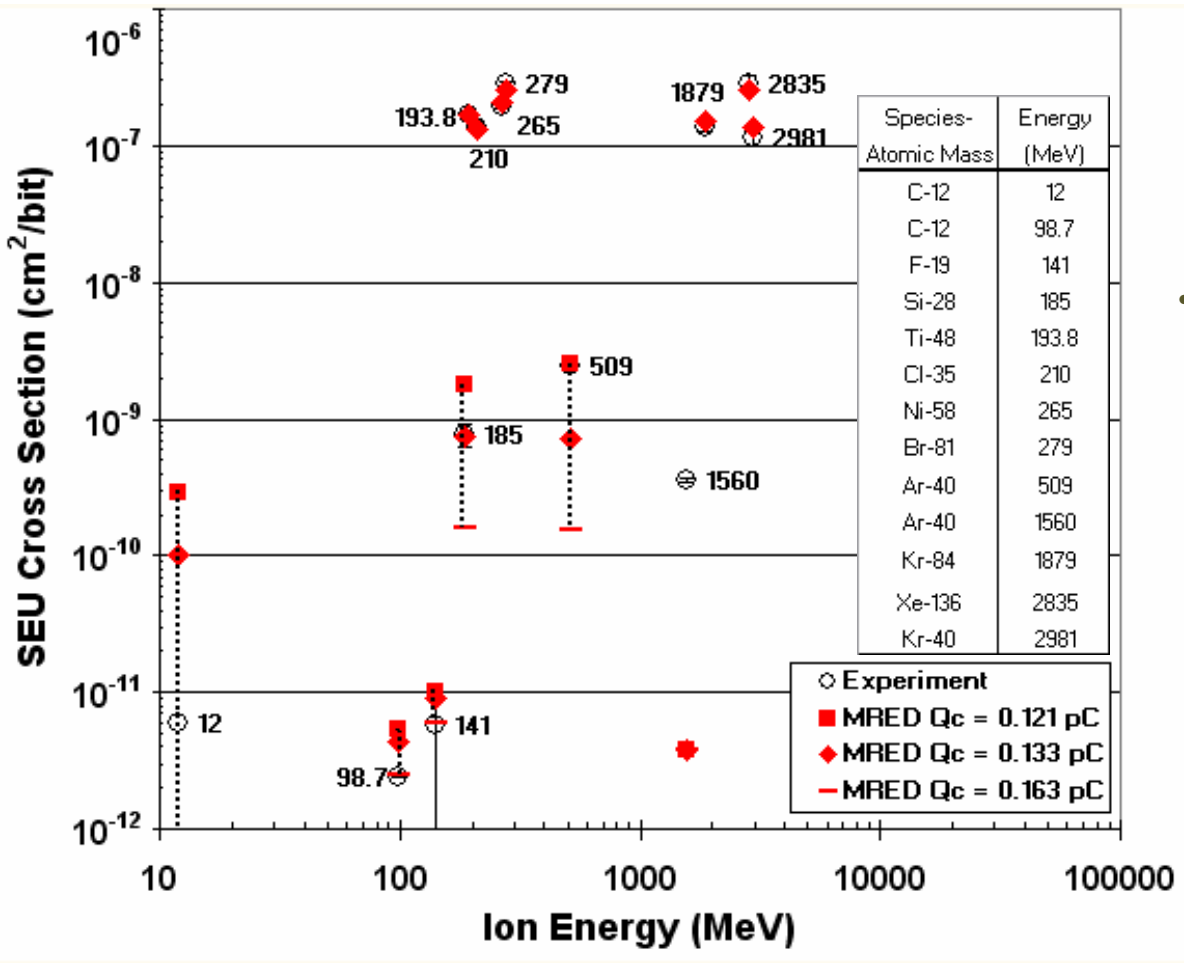
Value for critical charge (Q_{crit}) determined to be 0.133 pC for normally incident direct ionization events

–Fit the BNL data off which the model was developed

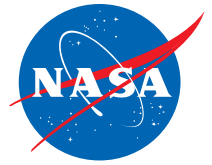
–AND high energy, directly ionizing events



Model calibration and results: 0° incidence

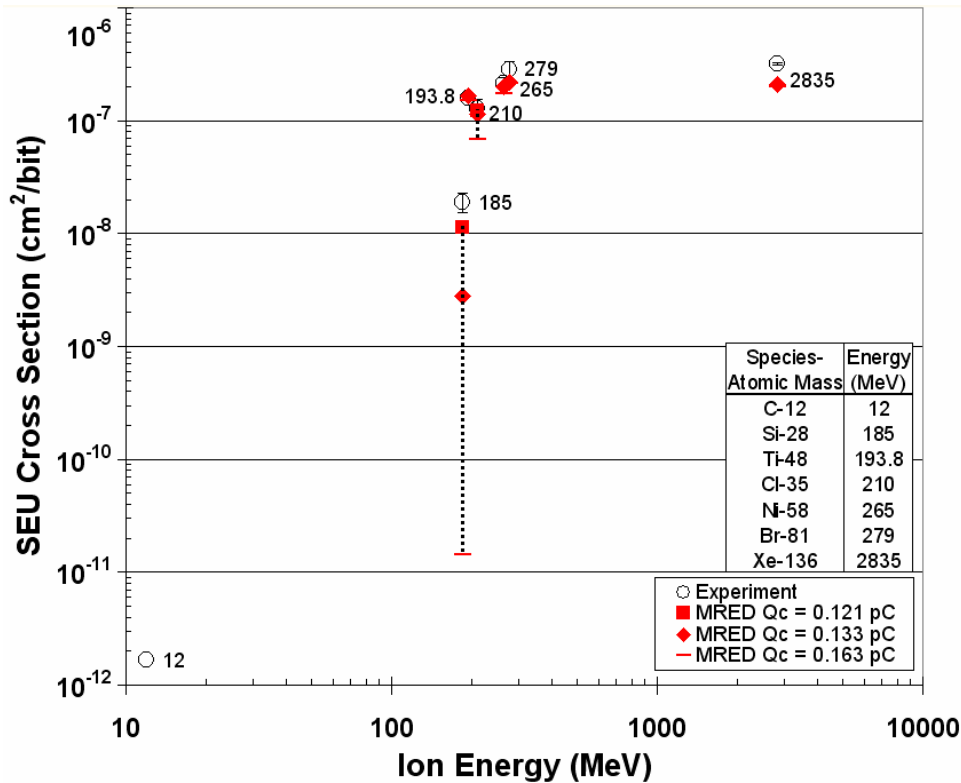


- **Qcrit for indirect ionization events: 0.121 pC - 0.163 pC**
 - Range due to simplified model geometry and Geant4 systematic errors
- **Good prediction of normally-incident cross-section data**
 - Directly ionizing events, threshold events showing possible Coulombic scattering contribution, and low-energy indirectly ionizing events are well-simulated
 - High-energy Argon cross-section is due to indirect ionization; limitations in Geant4 preclude accurate fit

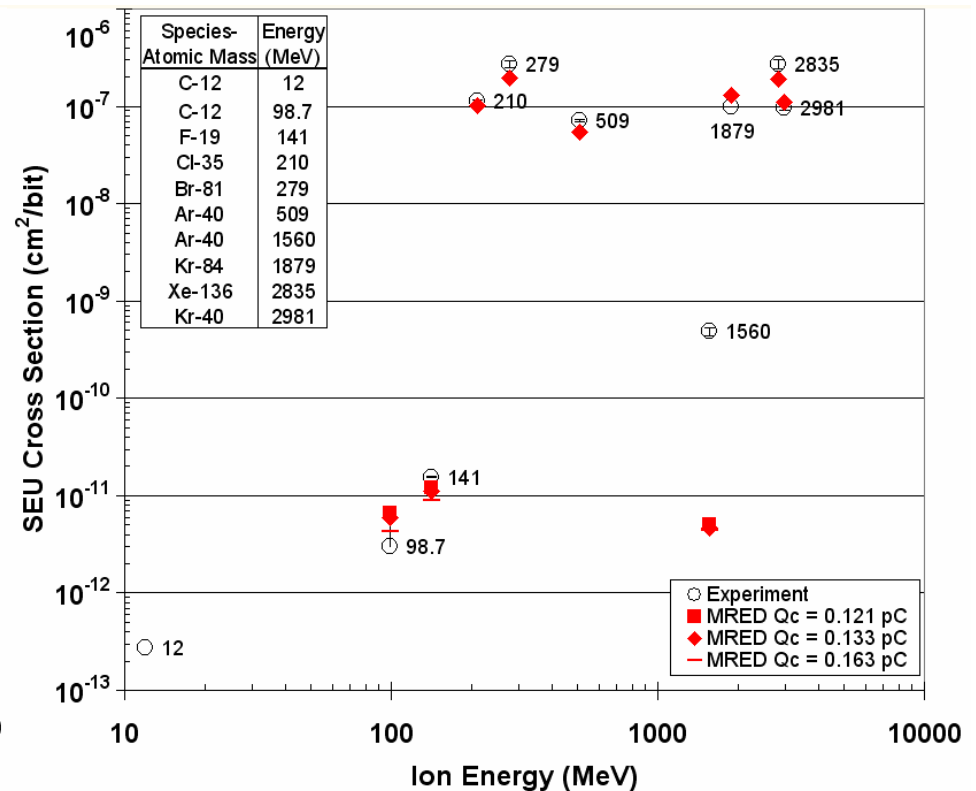


Angle dependence

30° incidence

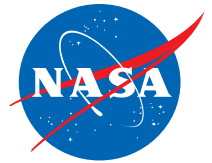


45° incidence



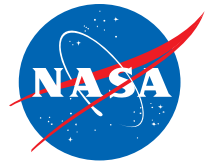
- **MRED simulations reproduce 30° and 45° angle dependence for SEU response without any adjustable parameters**

–Measured data presented without angular correction to fluence



Summary

- **Using MRED, we produced a reasonably accurate upset response model of a low-critical charge SRAM without detailed information about the circuit, device geometry, or fabrication process**
 - The detailed physical processes included in the Geant4-based MRED tool enabled us to capture the complexities of the experimental cross-section curve
- **The model was developed from low-energy, normally-incident test data**
 - Angle dependence of upset response was successfully predicted from the normally-incident data
 - Simulation results suggest that for some devices and technologies, MRED may prove useful to guide limited high-energy testing for model validation and bounding in the areas of Geant4 physics limitations, possibly reducing the cost of SEU testing



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