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

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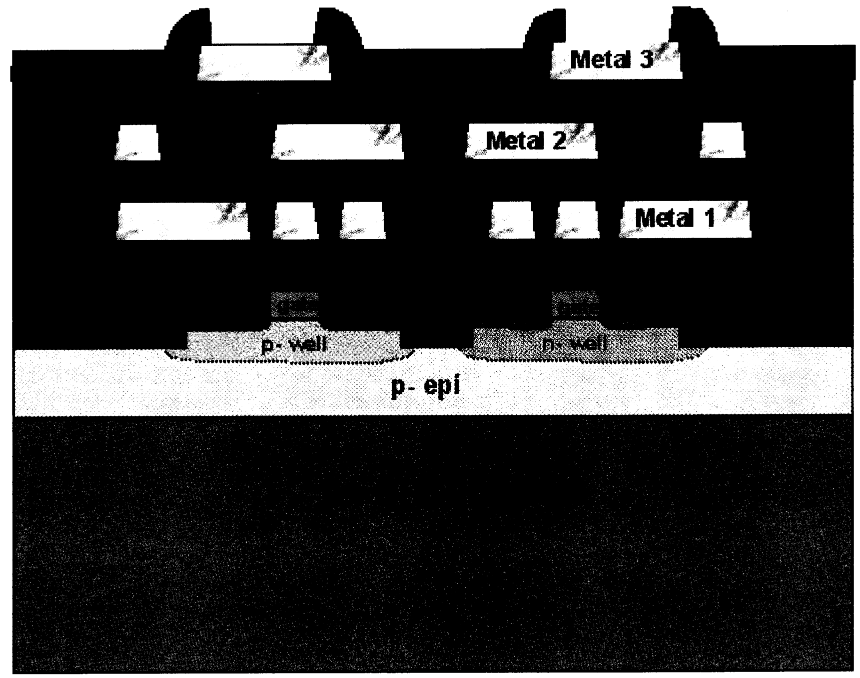
Objective

- **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

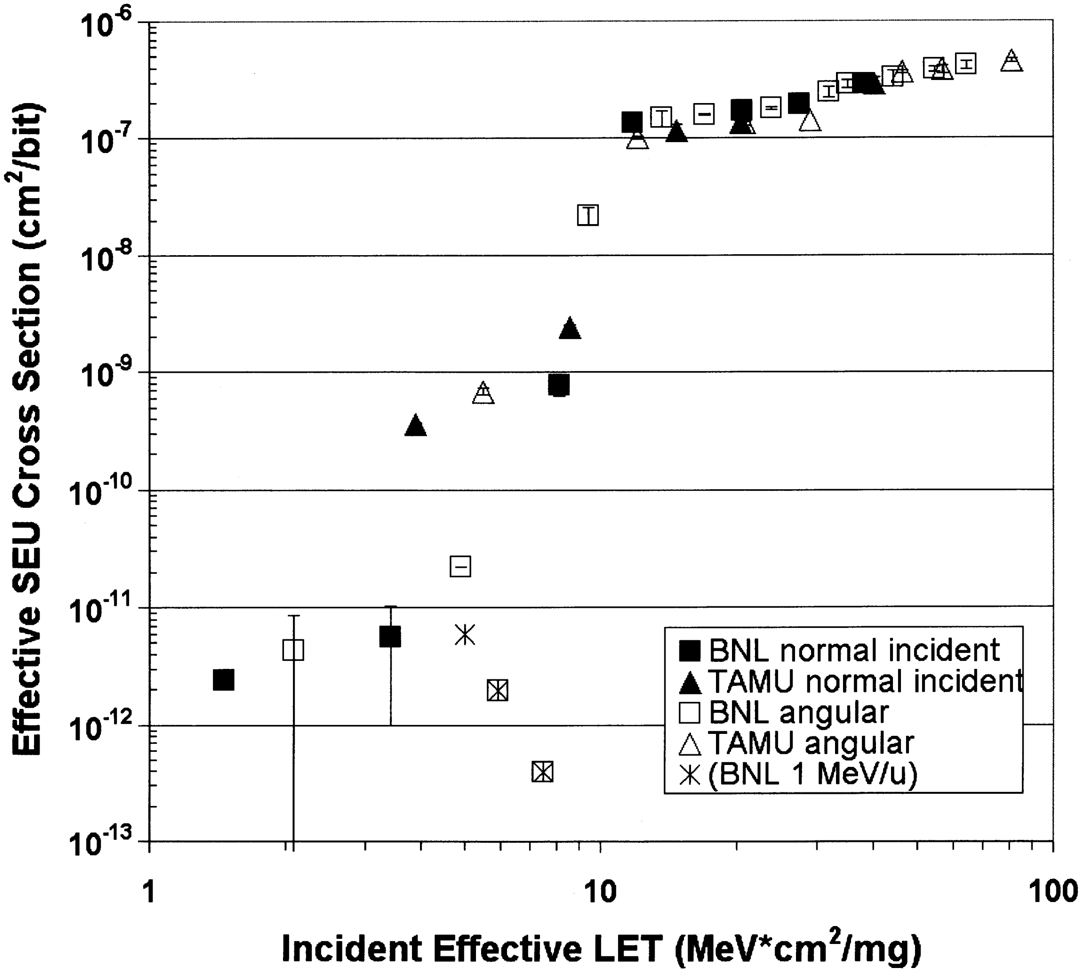
Sandia CMOS6r technology

- **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

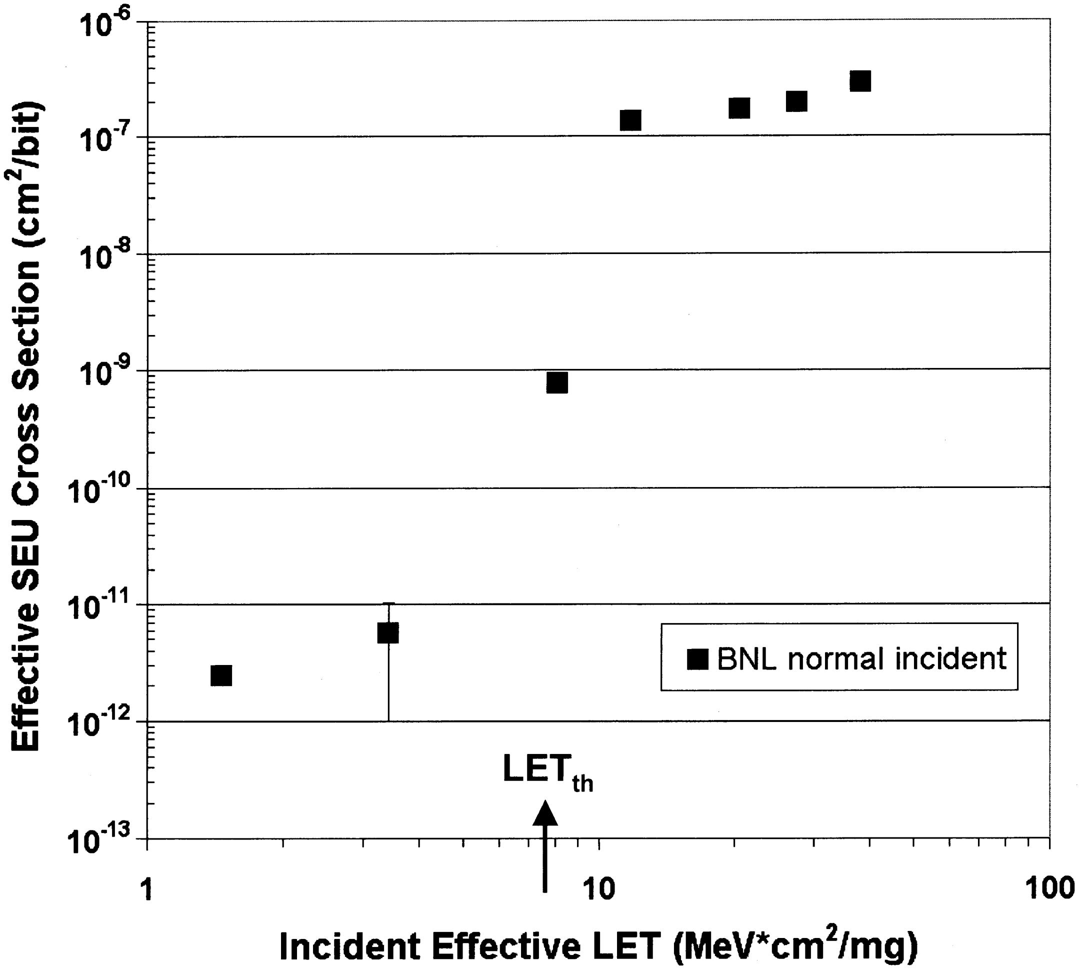
Accelerator beam test data



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

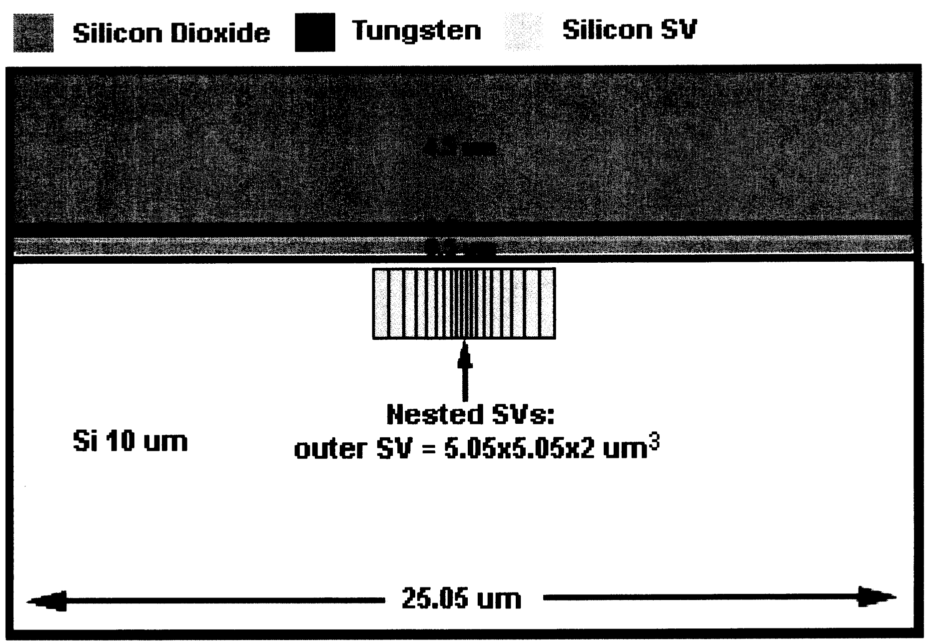
Test Facility	Species-Atomic Mass	Energy (MeV)	LET (MeV-cm^2/mg)	Angles Tested
BNL	C-12	12	1.464	0, 30, 45
BNL	C-12	98.7	5.07	0, 45
BNL	F-19	141	3.428	0, 45
BNL	Si-28	185	8.126	0, 30
BNL	Ti-48	193.8	11.81	0, 30
BNL	Cl-35	210	20.54	0, 30, 45
BNL	Ni-58	265	27.49	0, 30
BNL	Br-81	279	38.24	0, 30, 45
TAMU	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



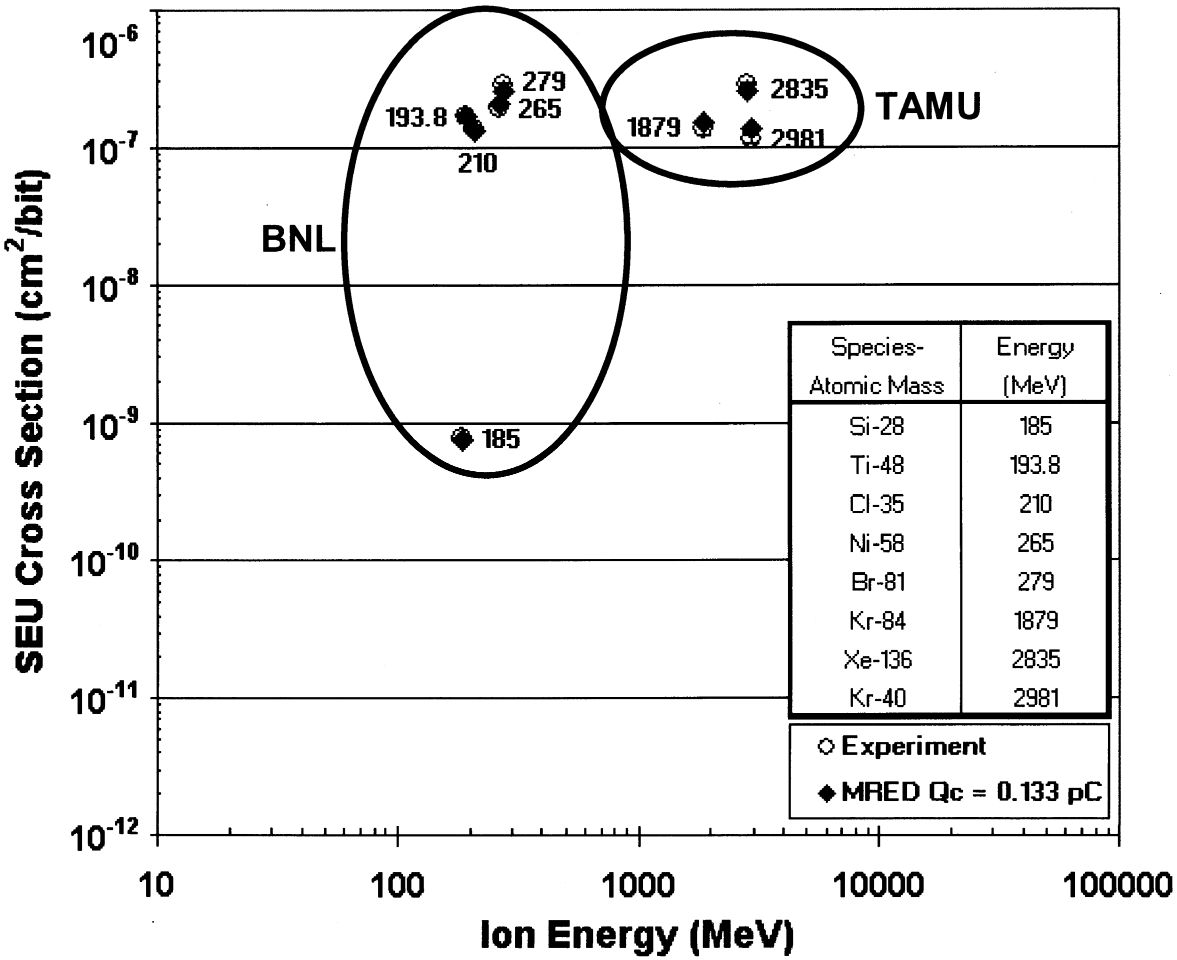
- **Developed MRED model based solely upon normal-incident, low-energy BNL test data**
- **Defined threshold LET as 7.5 MeV*cm^2/mg**
  - –for upsets induced by direct ionization

MRED model



- **Sensitive volume (SV) defines region of charge collection**
  - –is for a single bit
- **SV constructed from concentrically-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 0.5μm layer 0.5μm above the base of a 5.5μm SiO_2 overlayer

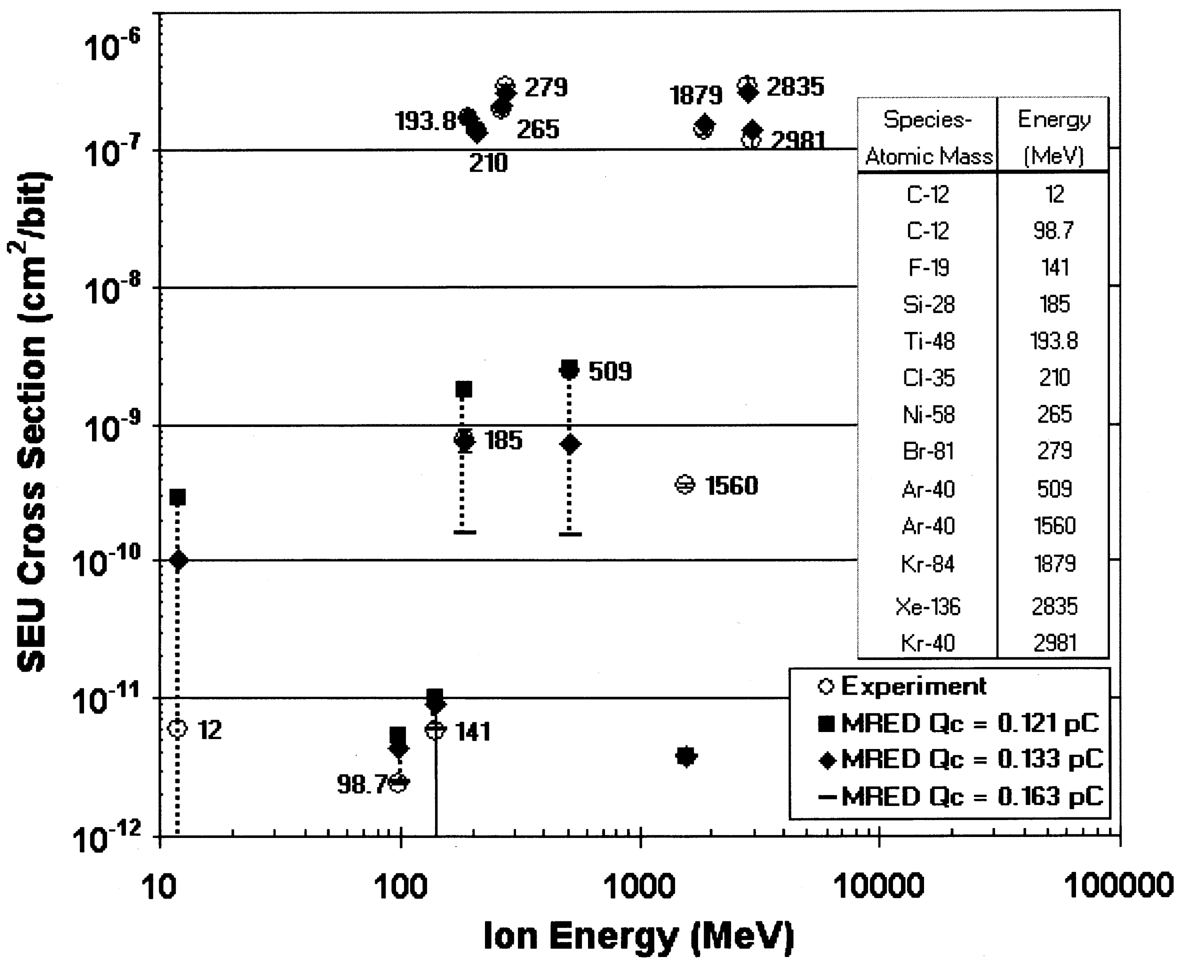
Model calibration and results: Direct ionization events at 0° incidence



Species-Atomic Mass	Energy (MeV)
Si-28	185
Ti-48	193.8
Cl-35	210
Ni-58	265
Br-81	279
Kr-84	1879
Xe-136	2835
Kr-40	2981

- **Value for critical charge (Qcrit) 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

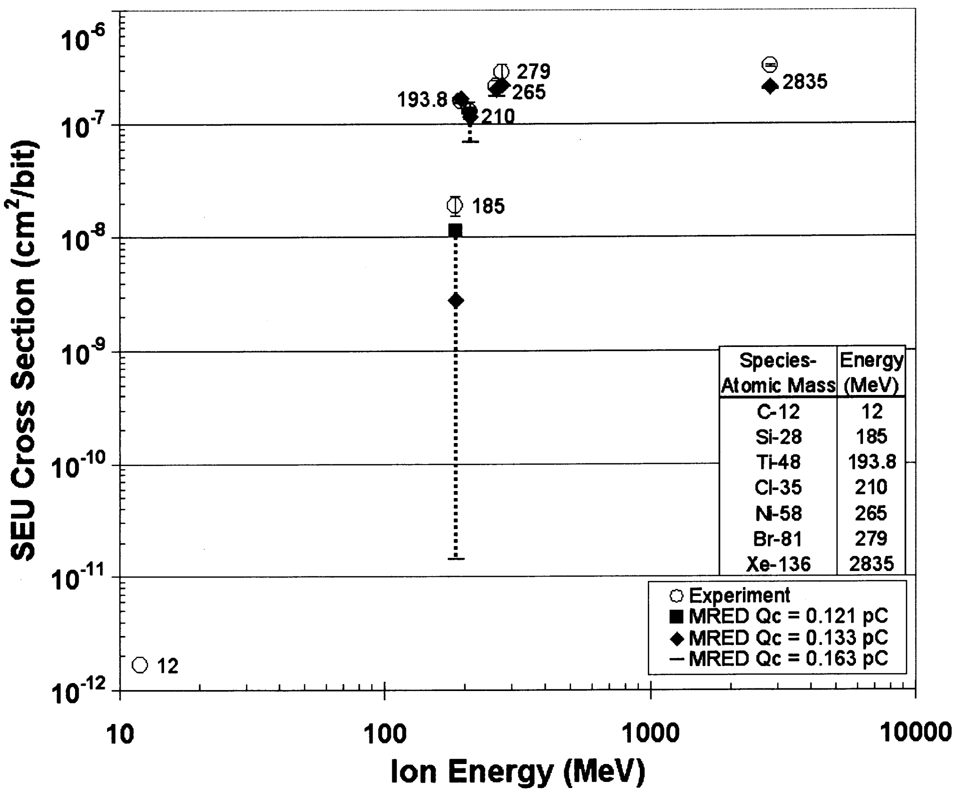
Model calibration and results: 0° incidence



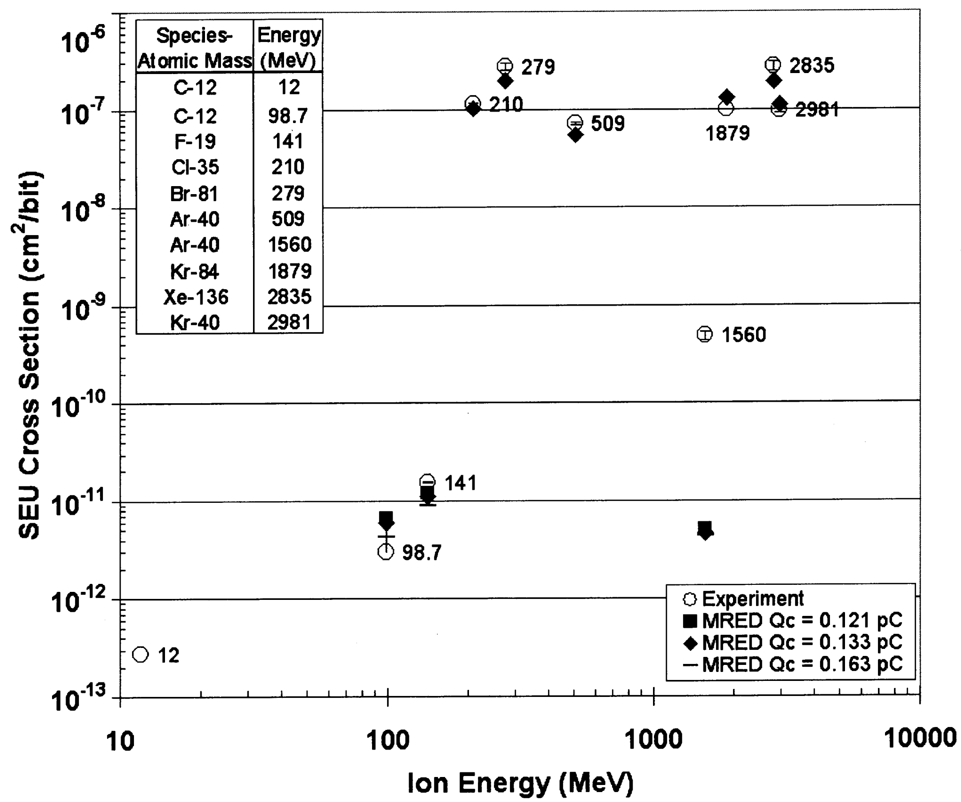
- **Qcrit for indirect ionization events: 0.121 pC - 0.163 pC**
  - –Range due to simplified model geometry and Geant4 systematic errors
- **Good prediction of normally-incident cross-section data**
  - –Directly ionizing events, threshold events showing possible Coulombic scattering contribution, and 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

Sponsors

- **NASA Electronic Parts and Packaging Program**
- **Defense Threat Reduction Agency Radiation Hardened Microelectronics Program**
- **U.S. Department of Energy**