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

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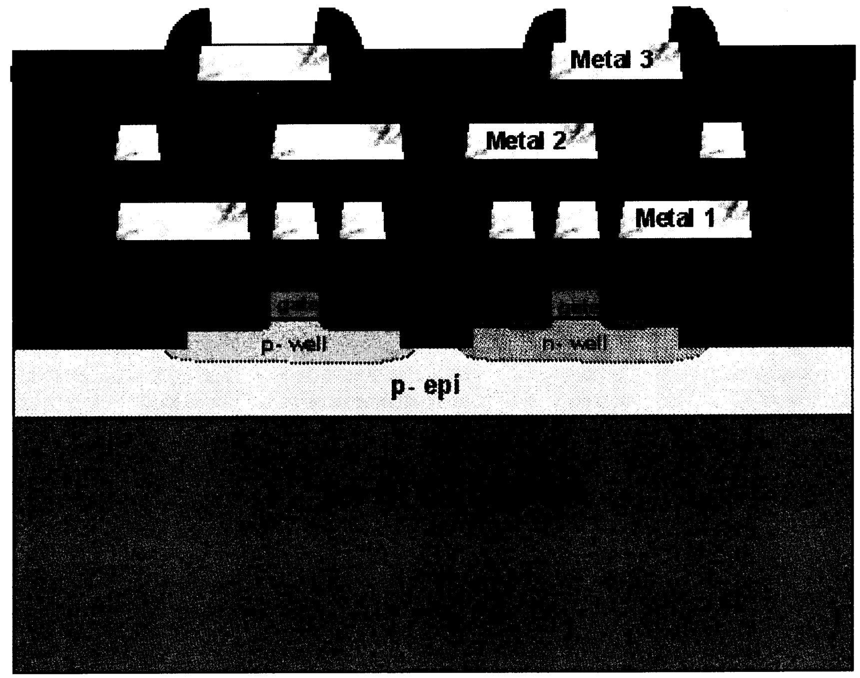
# Objective

- **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

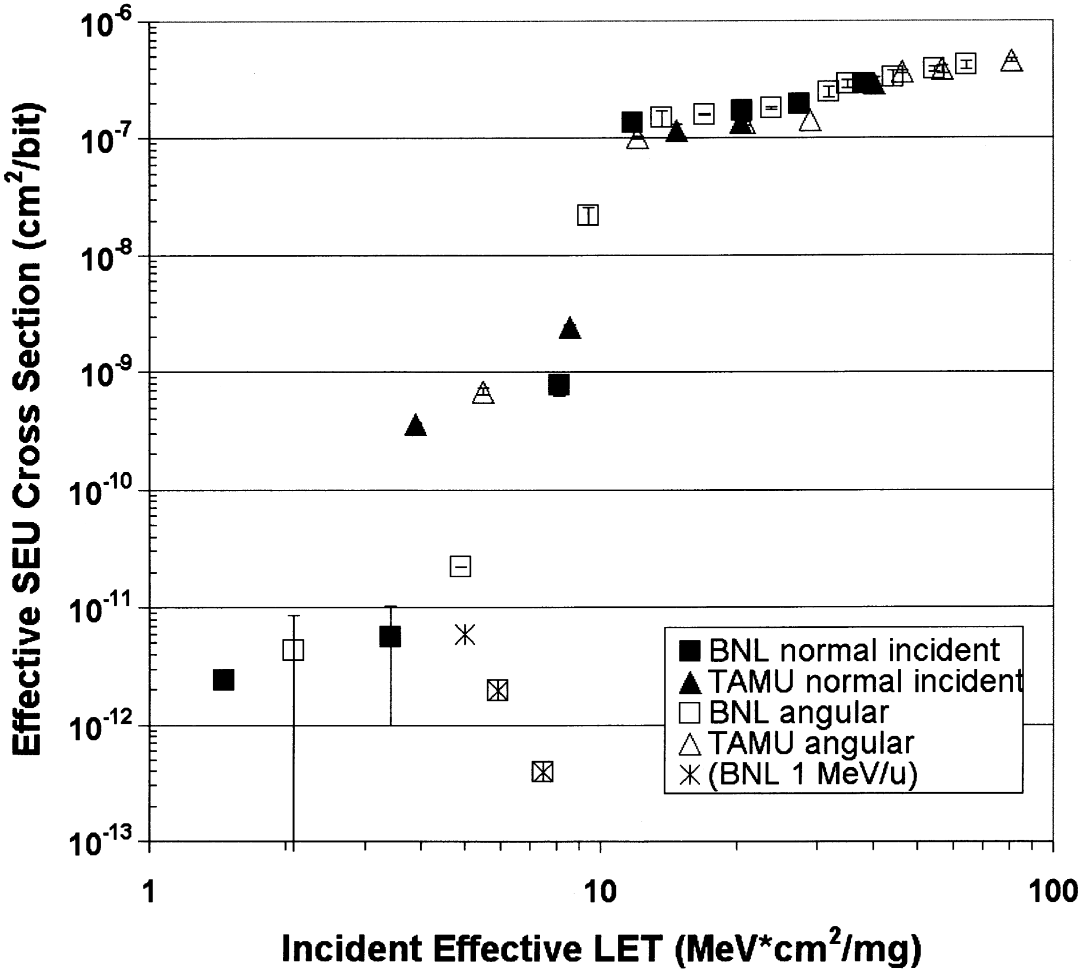
# Sandia CMOS6r technology

- **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**

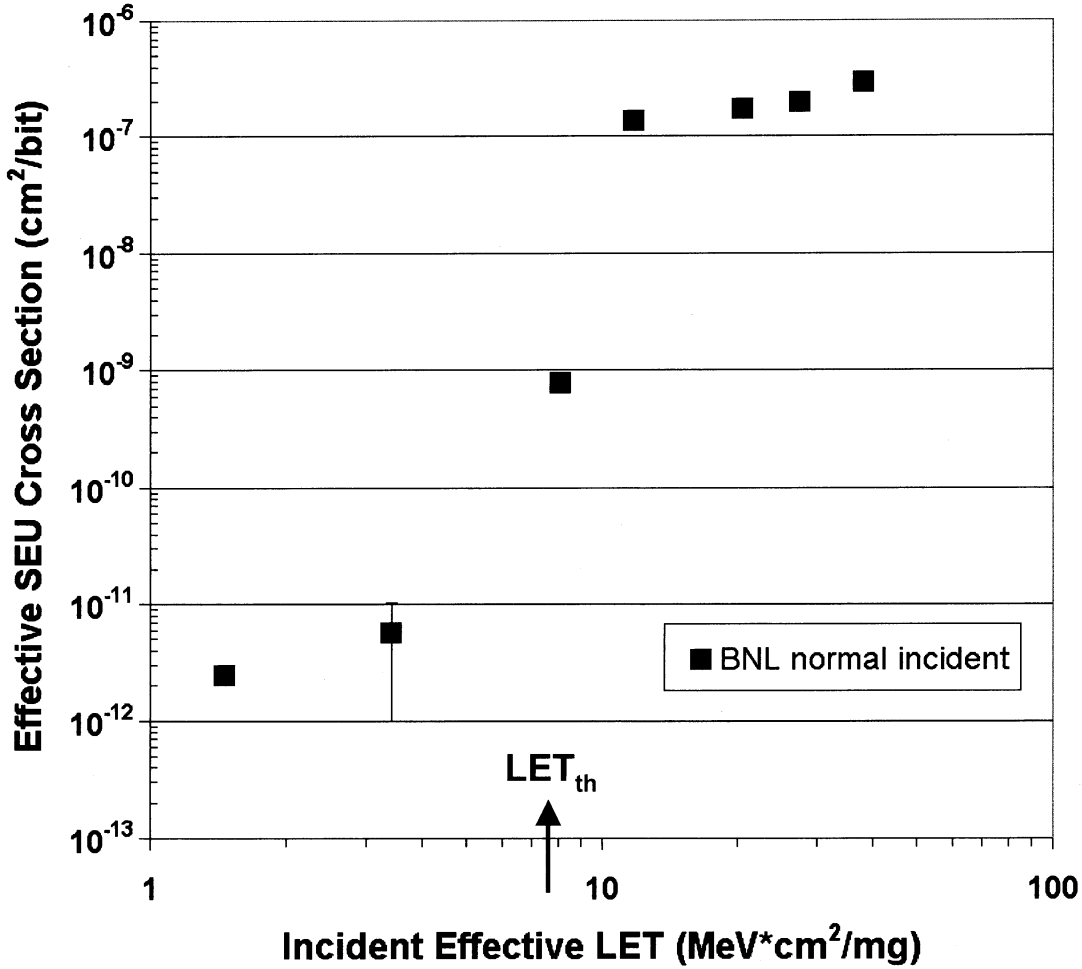
# Accelerator beam test data




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

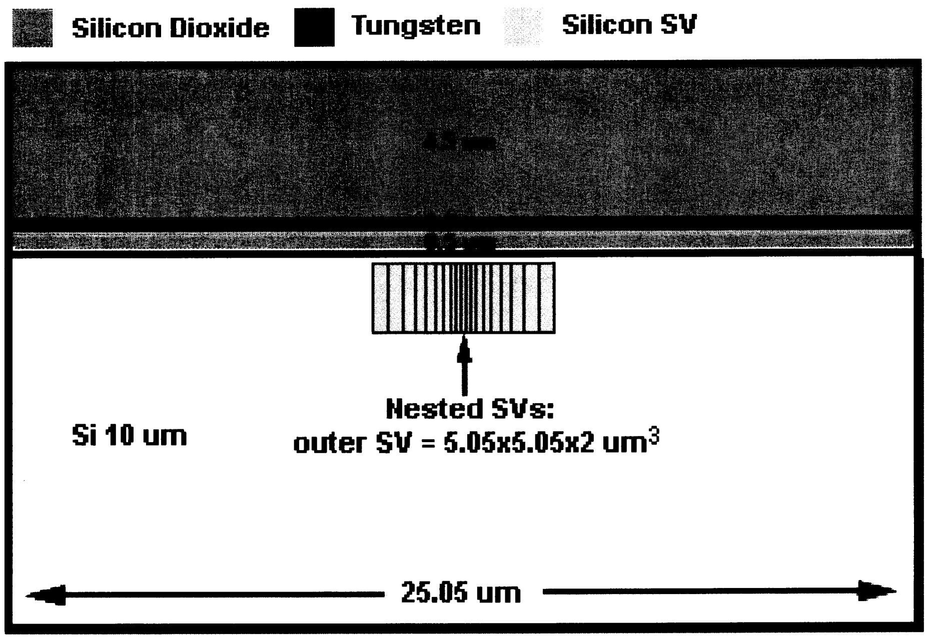
| Test Facility | Species-Atomic Mass | Energy (MeV) | LET (MeV-cm$^2$/mg) | Angles Tested |
|---|---|---|---|---|
| BNL | C-12 | 12 | 1.464 | 0, 30, 45 |
| BNL | C-12 | 98.7 | 5.07 | 0, 45 |
| BNL | F-19 | 141 | 3.428 | 0, 45 |
| BNL | Si-28 | 185 | 8.126 | 0, 30 |
| BNL | Ti-48 | 193.8 | 11.81 | 0, 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



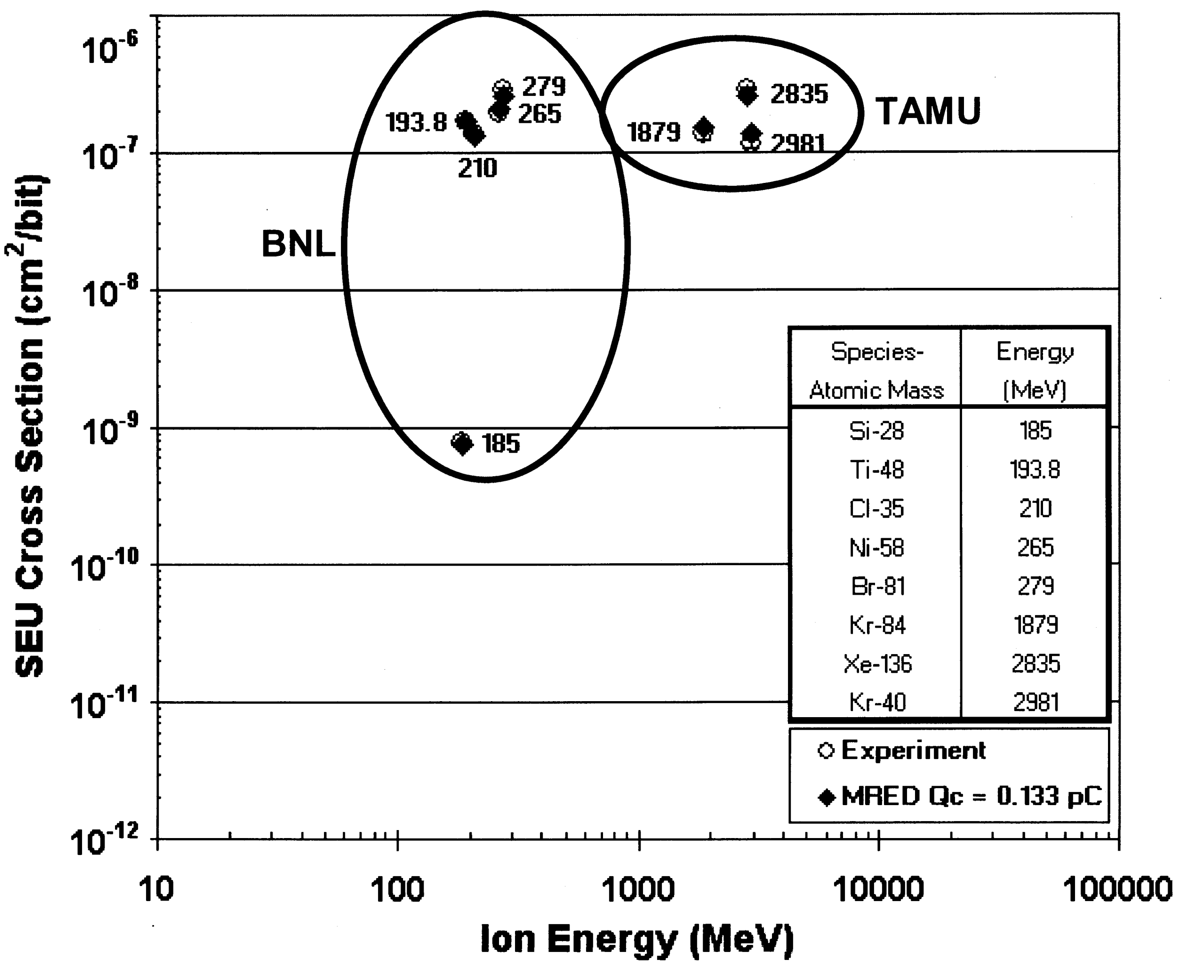

- **Developed MRED model based solely upon normal-incident, low-energy BNL test data**
- **Defined threshold LET as 7.5 MeV*cm²/mg**
  - –for upsets induced by direct ionization

# MRED model



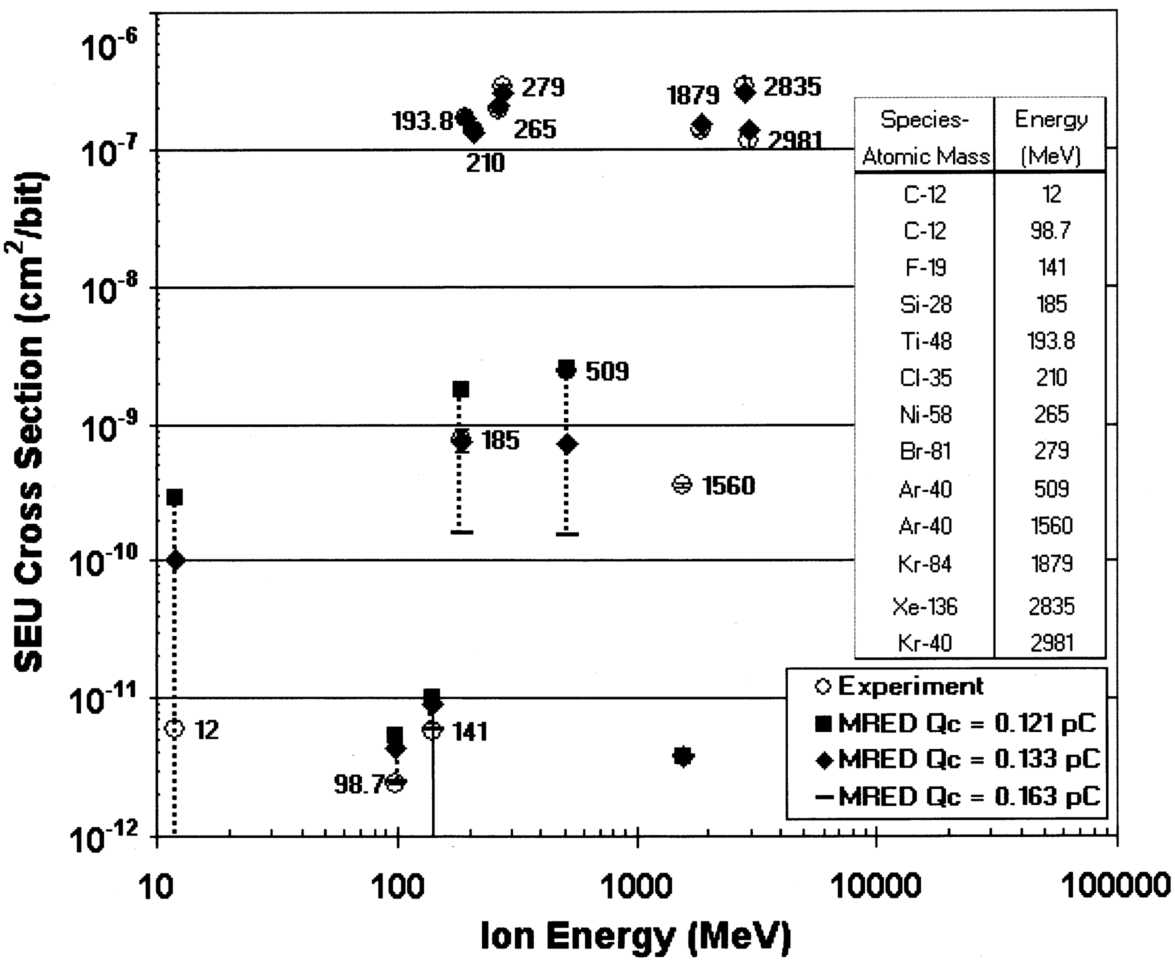

- **Sensitive volume (SV) defines region of charge collection**
  - –is for a single bit
- **SV constructed from concentrically-nested set of 10 regions having different charge collection efficiencies**
  - –Regions sized according to cross-section area at each of 10 logarithmically uniform points along 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




- **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




| Species-Atomic Mass | Energy (MeV) |
|---|---|
| C-12 | 12 |
| C-12 | 98.7 |
| F-19 | 141 |
| Si-28 | 185 |
| Ti-48 | 193.8 |
| Cl-35 | 210 |
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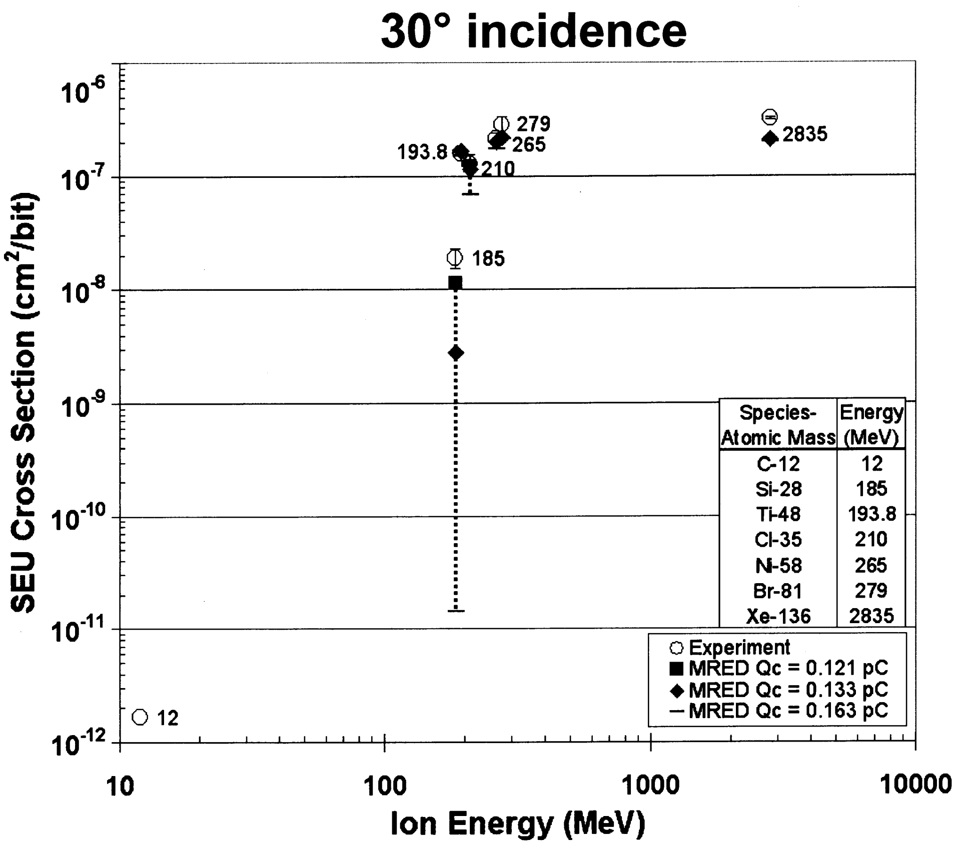
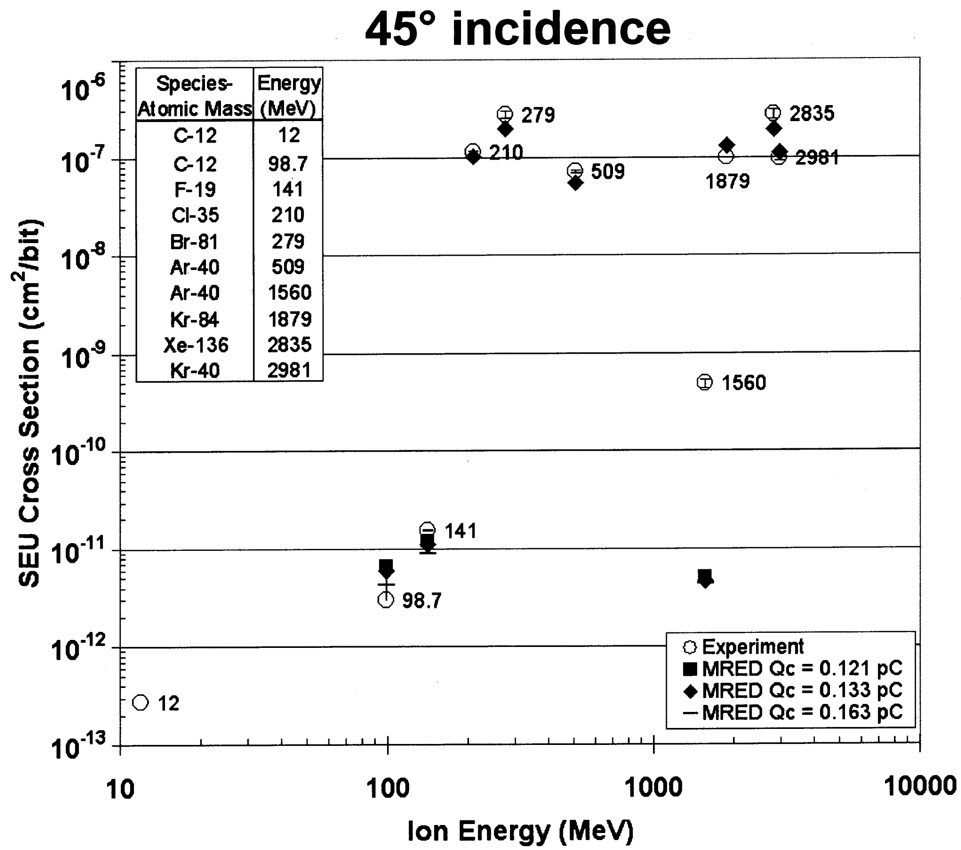
| Ar-40 | 1560 |
| Kr-84 | 1879 |
| Xe-136 | 2835 |
| Kr-40 | 2981 |

- **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




- **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

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