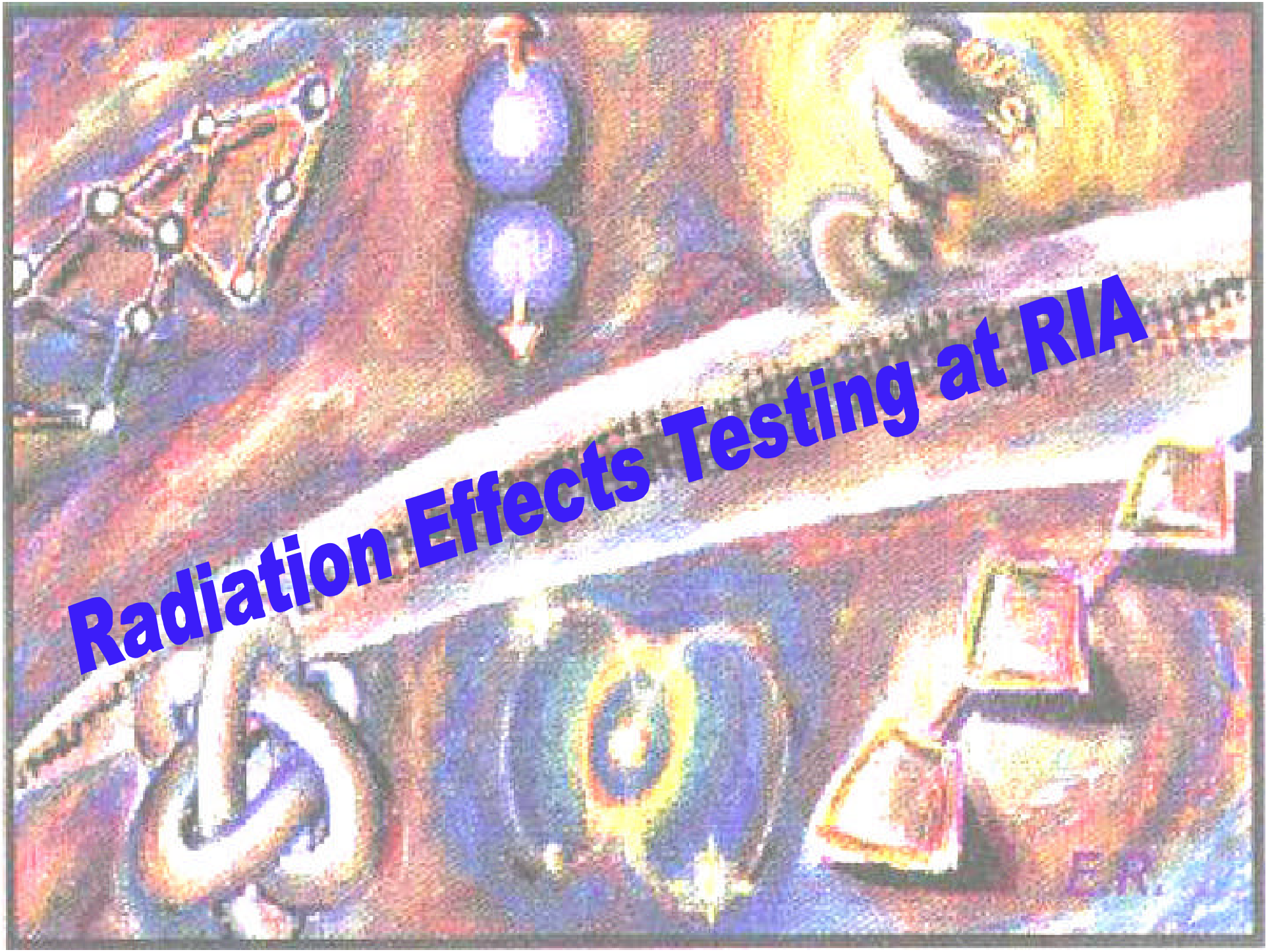
Radiation Effects Testing at RIA



88-Inch Cyclotron Applied Program (1993-2000)

- Space Applications
  - Single Event Radiation Effects (SEP)
  - Tests / Calibrations of Cosmic Ray Detectors
    - (balloon and space flights)
  - Total Dose Studies
  - Damage to CCDs
  - Damage of Bulk Material
  - Radiation Biology
- Materials Studies
  - Micropore Filters
  - Ion Implantation

Single Event Effects in Avionics

Boeing Radiation Effects Lab

Presented to C-17 Program

December 16, 1998

Dr. Eugene Normand

Chief Scientist, Boeing Radiation Effects Lab

Description of Various Types of Single Event Effects in ICs

- **Single Event Effects** [SEE]
  - Disturbance of an active electronic device caused by a single energetic particle
    - Upset (SEU) --change in logic state, simplest example is a memory cell in RAM
    - Latchup (SEL) --sharp increase in current resulting from turning on parasitic *pnpn*
    - Damage or burnout (SEB) of power transistor or other high voltage device
    - Functional interrupt (SEFI)- malfunctions in more complex parts sometimes as lockup, hard error, etc

SEE: Which Environments are Important

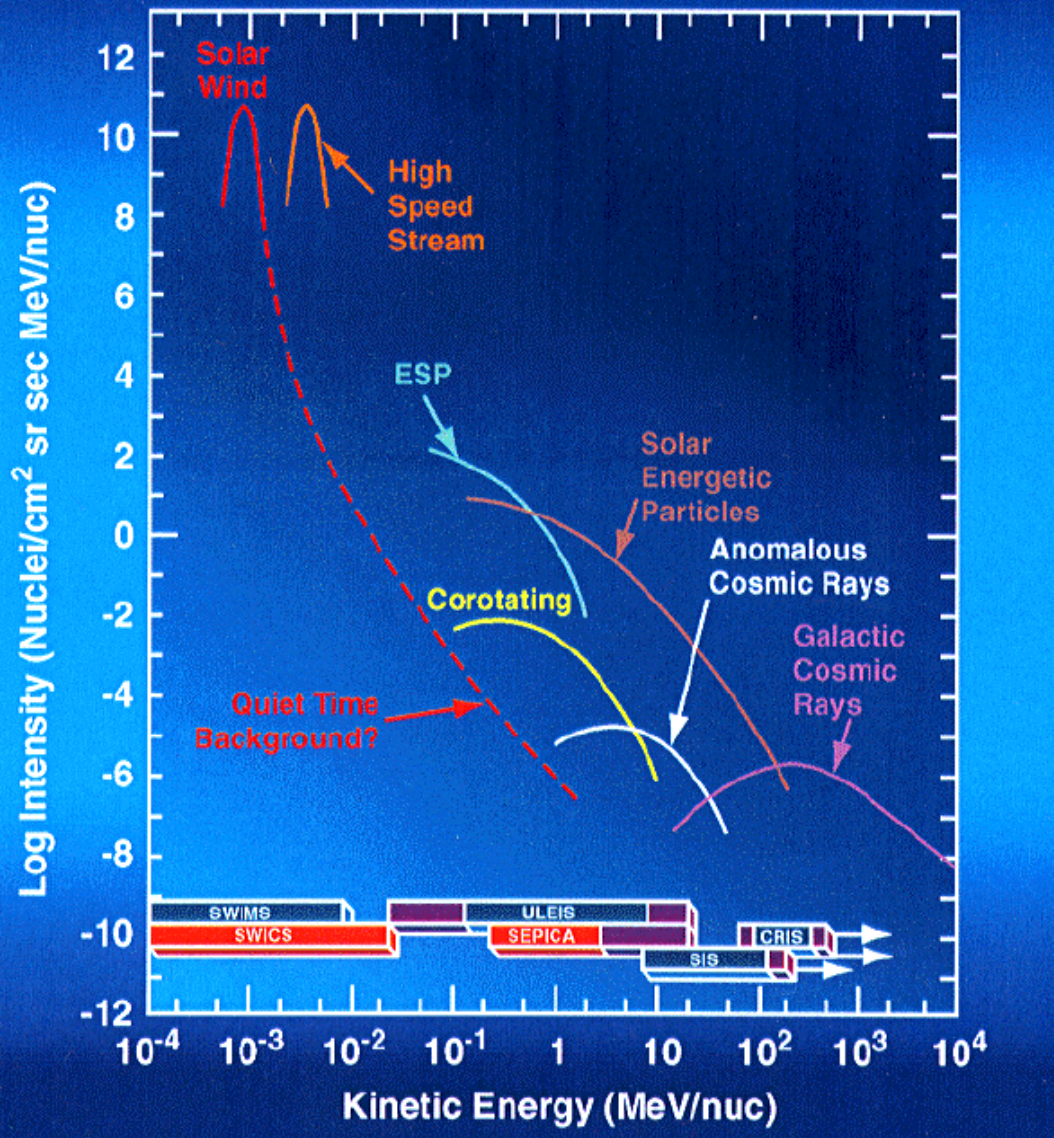
Boeing Radiation Effects Lab

- **Space**
  - **Galactic Cosmic Rays (heavy ions)**
  - **Trapped Belts (protons)**
  - **Solar Flares (protons & heavy ions)**
- **Aircraft Altitudes**
  - **Neutrons and Protons (Pions)**
- **Ground Level**
  - **Neutrons and Protons**

The Space Environment

Rice University

Spectra of Energetic Oxygen Nuclei

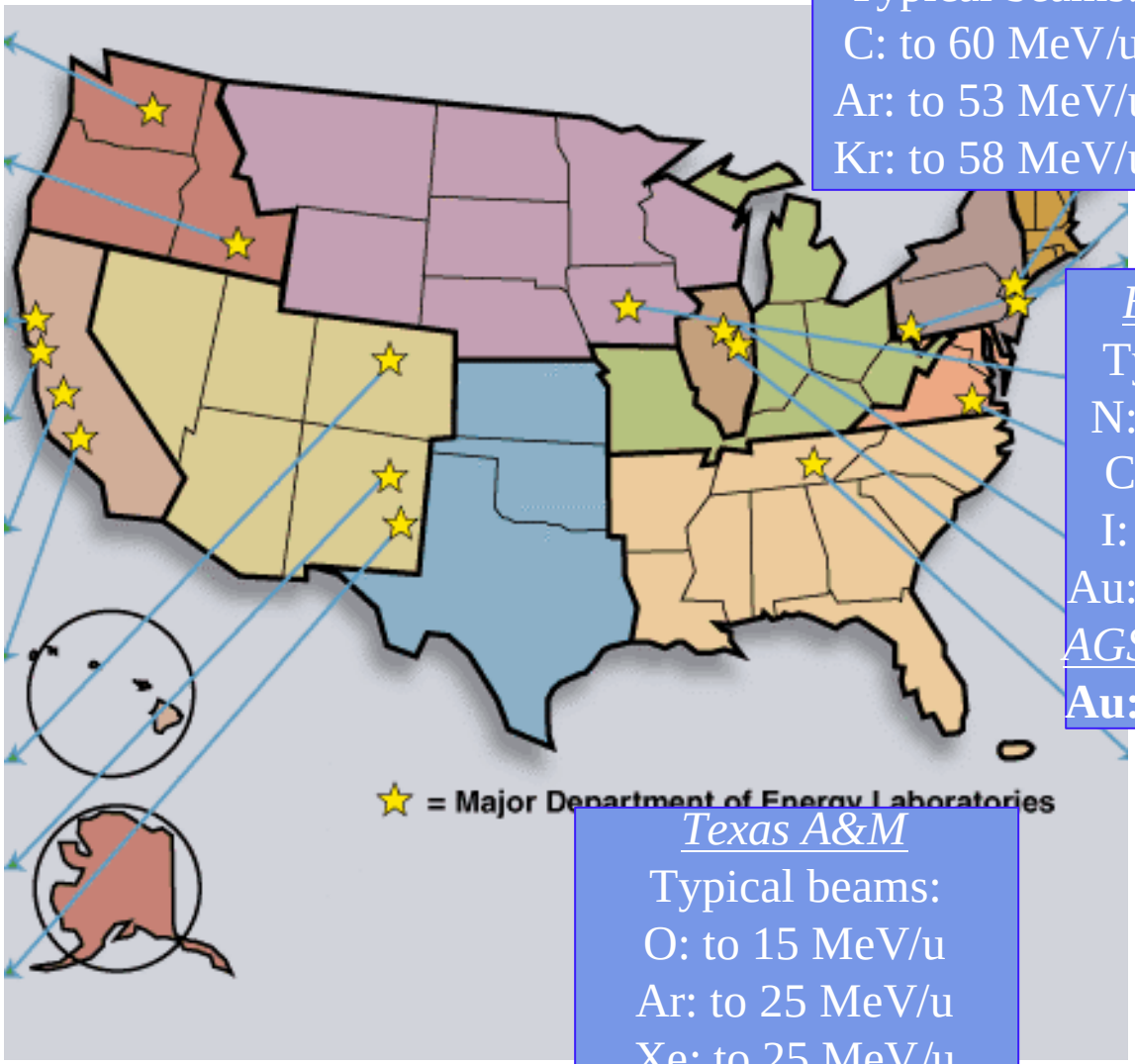


Isotopic Composition Elemental Composition Charge State

Heavy Ion Facilities

Michigan State
Typical beams:
C: to 60 MeV/u
Ar: to 53 MeV/u
Kr: to 58 MeV/u

88" Cyclotron
Typical beams:
N: to 32.5 MeV/u
Ar: to 10 MeV/u
Xe: to 10 MeV/u
Bi: to 4.4 MeV/u
FY00: 750 hrs



BNL Tandem
Typical beams:
N: to 8.4 MeV/u
Cl: to 6 MeV/u
I: to 2.5 MeV/u
Au: to 1.75 MeV/u
AGS (limited avail)
Au: to 11.5 GeV/u

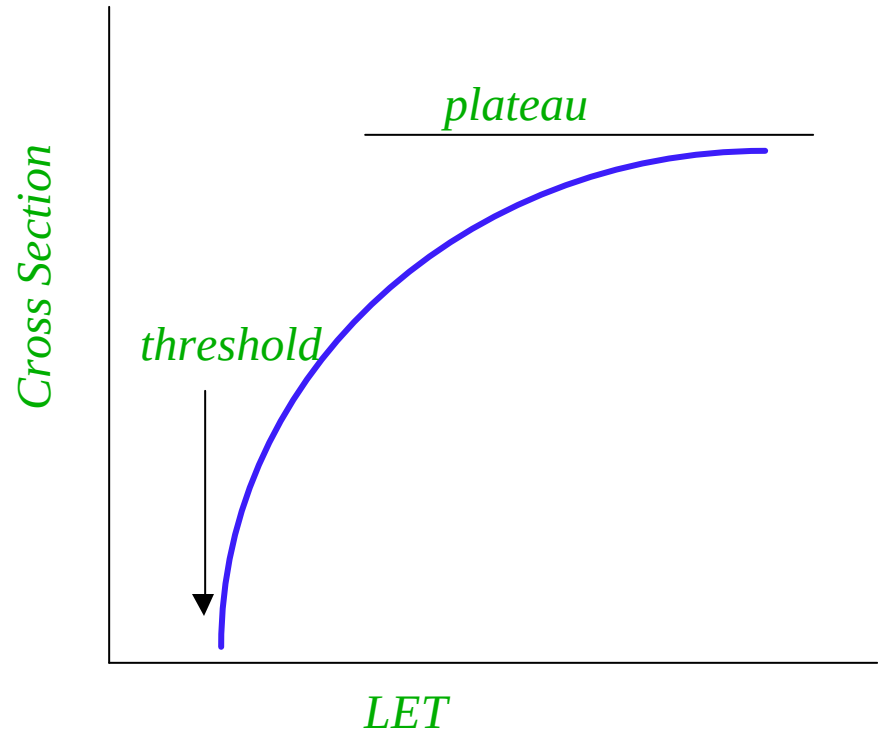
Texas A&M
Typical beams:
O: to 15 MeV/u
Ar: to 25 MeV/u
Xe: to 25 MeV/u
Au: to 10.5 MeV/u
1999-00: 548 hrs

Other Facilities Worldwide

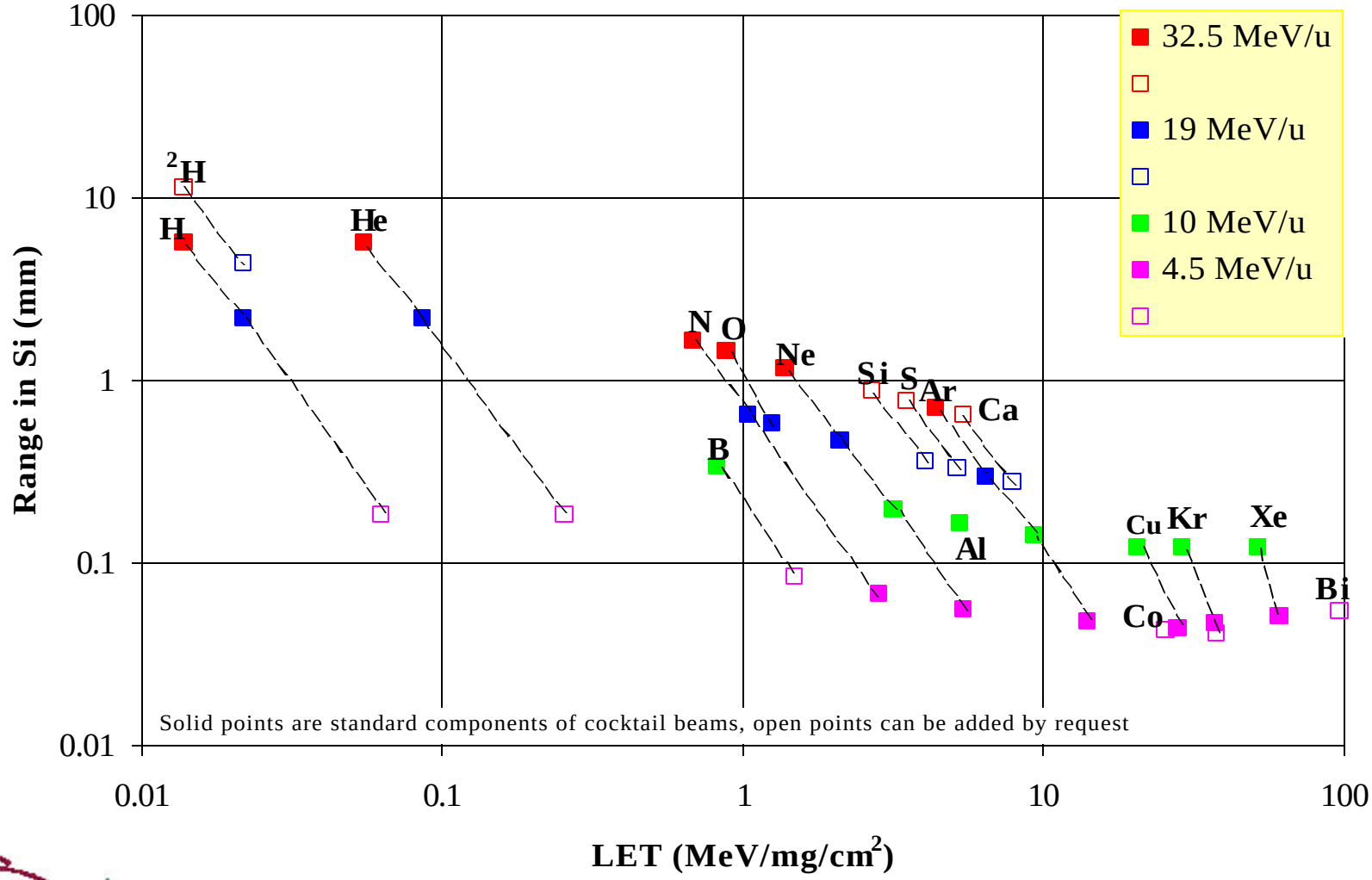
- Europe
  - GANIL
  - GSI (microprobe facility)
  - Louvain-le-Neuve
  - Orsay
- Japan
  - JAERI

Most RET Heavy Ion Testing has been done at low energies (<10's of MeV/u)

- Advantages
  - availability of facilities
  - simple dosimetry
  - negligible radio activity
  - lower cost
- Useful parameters
  - LET (energy loss)
  - Range (to reach depth of interest)



LET vs Range - 88" Cyclotron Cocktail Beams



Why go to higher energies?

- More modern chips often have “lids” which can’t be removed (need more range)
- Recent studies suggest additional effects could be important
  - Ion track structure (role of generated charge / charge collection)
  - Experimental data shows there may be an energy dependence effect when comparing upset rates for ions with the same LET but differing energy
  - Epitaxial layer and Multiple layer structure (geometry effects become important)

R. Koga, et al., preprint

Experiment (Koga et al)

- Took identical model of SRAM to:

	E / A	LET	Range (μ)
■ 88” Cyclotron	4.5-27	0.9-95	46-1100
■ TASCC*	8.7-34.5	9.9-91	80-560
■ NSCL	53-60	0.3-10	1180-5510
■ GANIL	16-30	34-47	160-380
■ LBL Bevalac*	282-410	0.6-1.7	4500-38000
■ BNL AGS	11,400	12.5	400,000

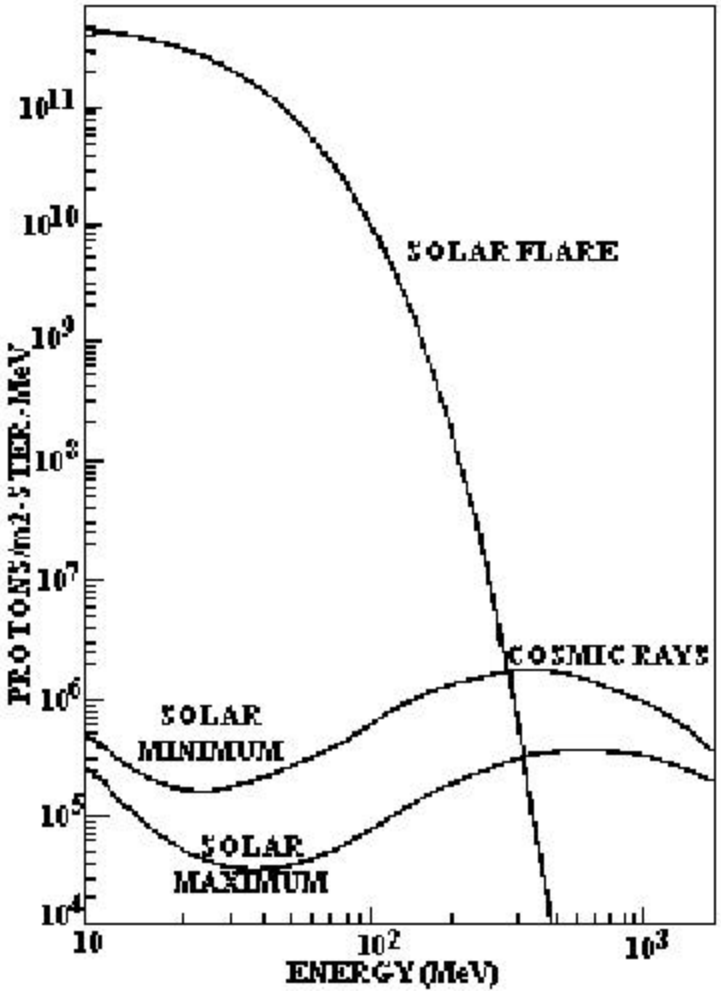
** now closed*

Conclusions

- LET seems to be a useful parameter over a wide range of energies
- Fragmentation and interaction of secondaries at high energies may be a secondary effect
- Nuclear interactions may become a factor at very low LET (when RET due to ionization is small)
- Similar ion interaction studies need to be carried out with more complex structures

Proton Spectra in Inner Van Allen Belt

- Sources of Protons
  - Cosmic Rays
    - (greater at solar minimum)
    - 10^4-10^6 / m^2-ster / MeV
  - Solar Flares
    - 5-6 orders of magnitude more intense than cosmic ray flux
    - must design for worst case

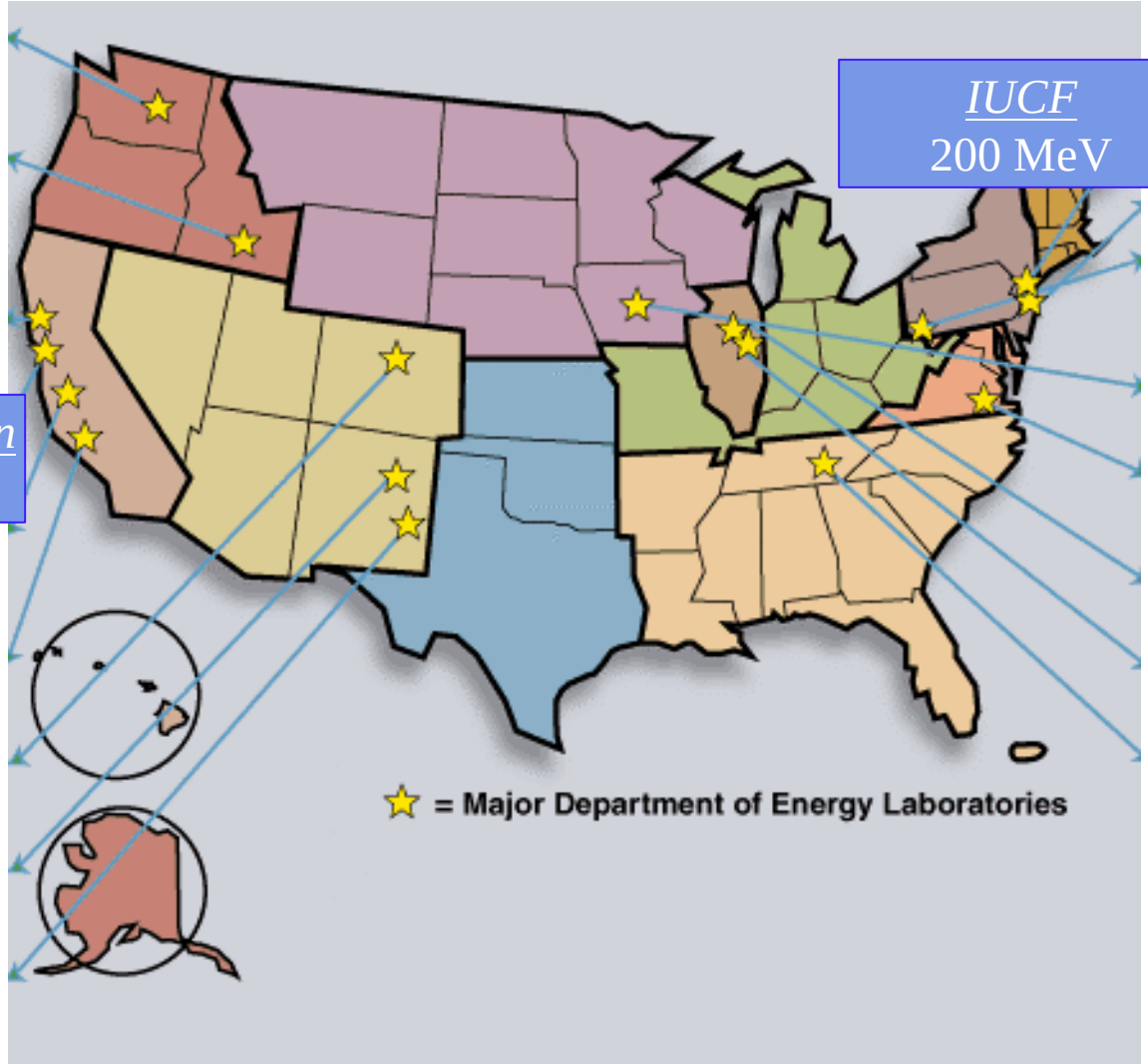


after J.H. Adans, et al., NRL Report 4506 (1981).

Proton Facilities

88" Cyclotron
55 MeV

U.C. Davis Cyclotron
65 MeV

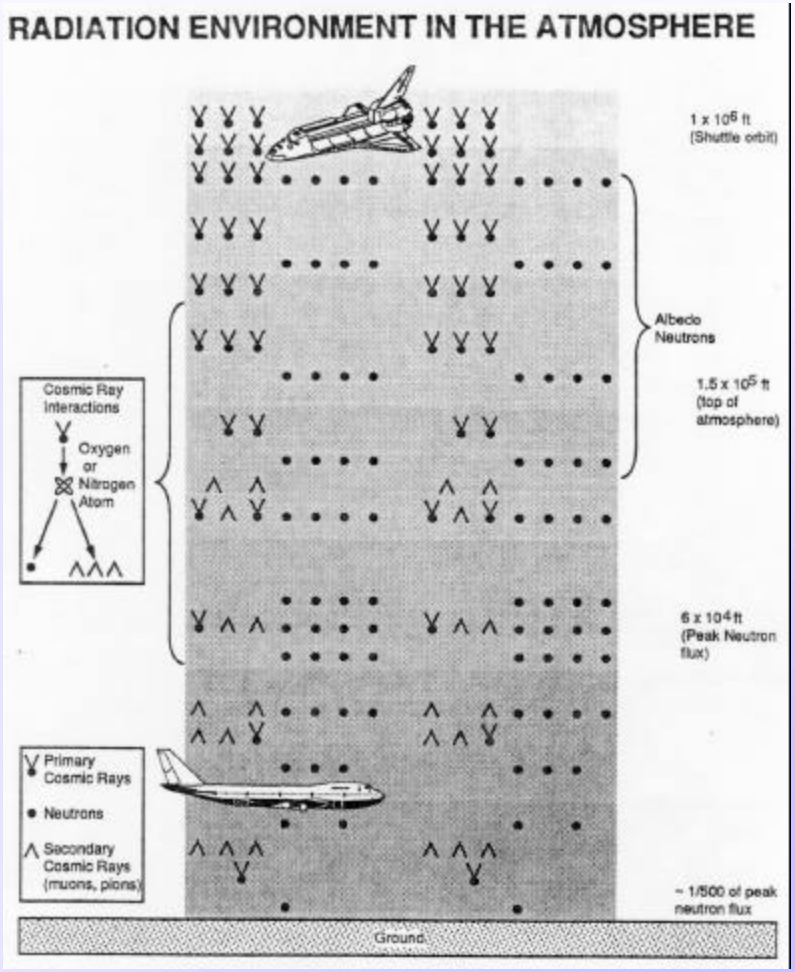


IUCF
200 MeV

Neutron Environment in the Atmosphere

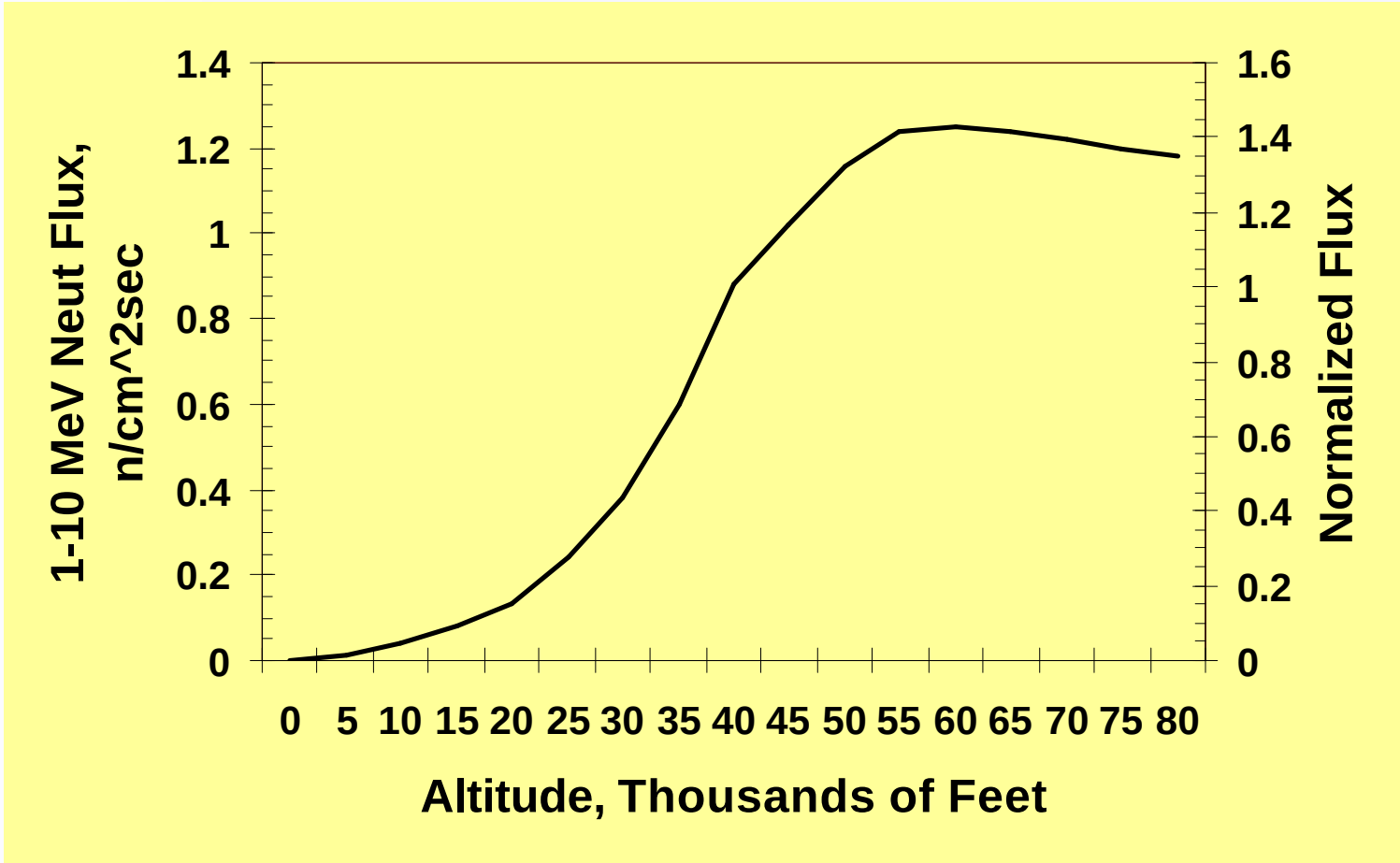
Boeing Radiation Effects Lab

Neutrons, created by cosmic ray interactions with the O_2 and N_2 in the air, peak at ~60,000 ft. At 30,000 ft the neutrons are about 1/3 the peak flux, and on the ground, ~1/400 of the peak flux. The peak flux is ~4 neutron/cm²sec. Other particles such as secondary protons and pions are also created, but for SEU the neutrons are the most important.



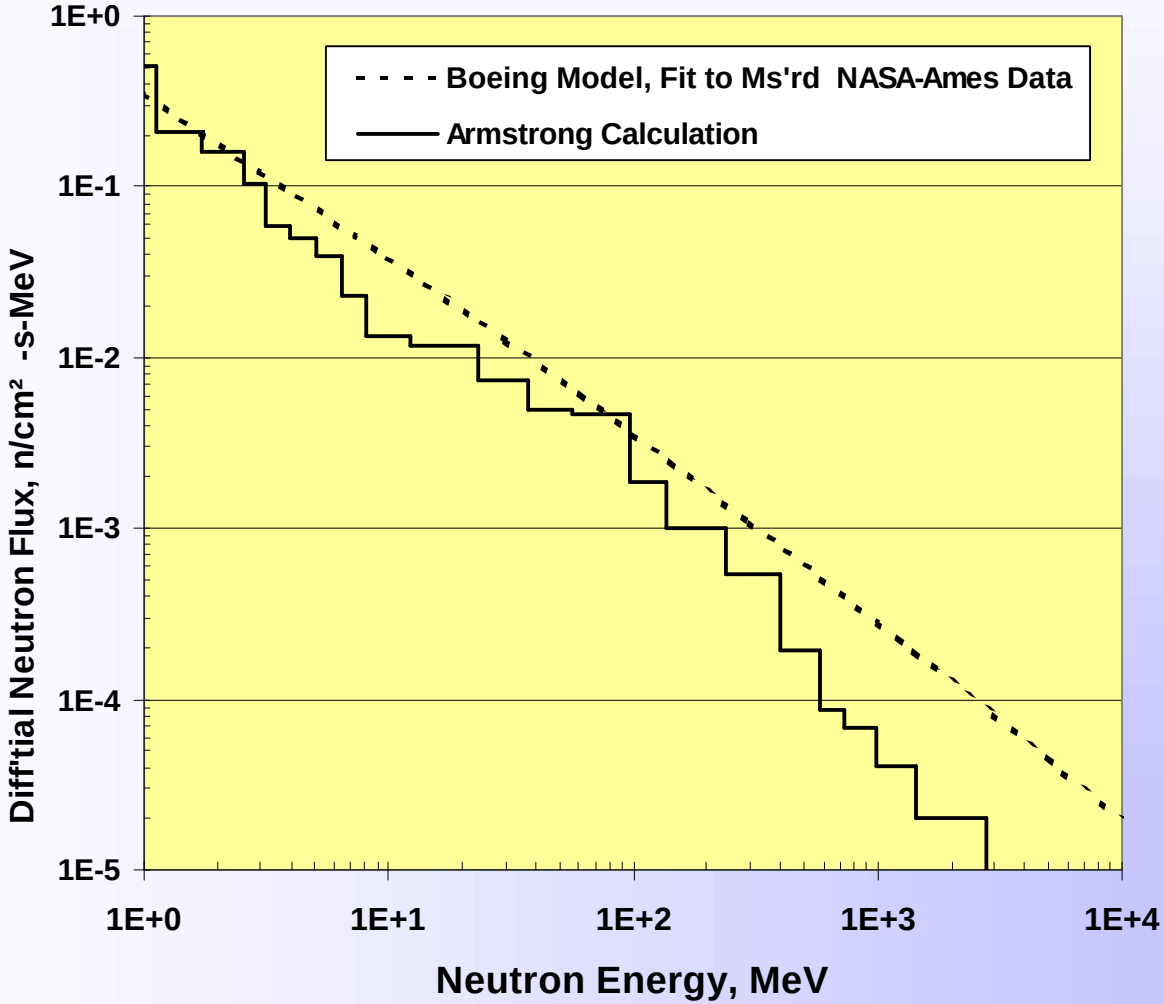
1-10 MeV Atmospheric Neutron Flux vs. Altitude, Simplified Boeing Model

Boeing Radiation Effects Lab



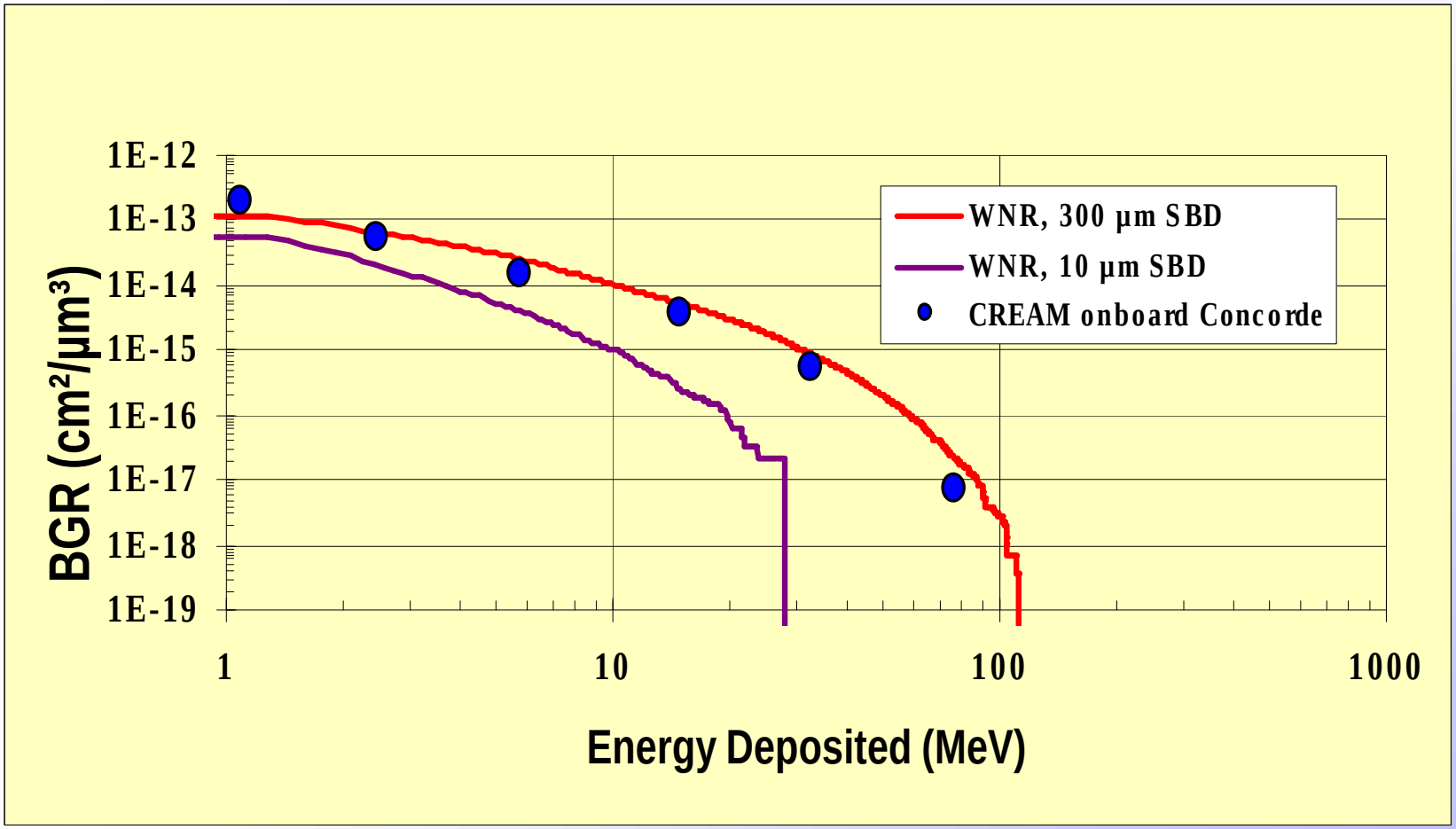
Energy Dependence of Atmospheric Neutron Flux, Simplified Boeing Model

Boeing Radiation Effects Lab



Correlation of Energy Deposition Spectra, CREAM on Concorde and SBD in WNR Beam

Boeing Radiation Effects Lab



BREL Approach for Dealing with SEE in Avionics

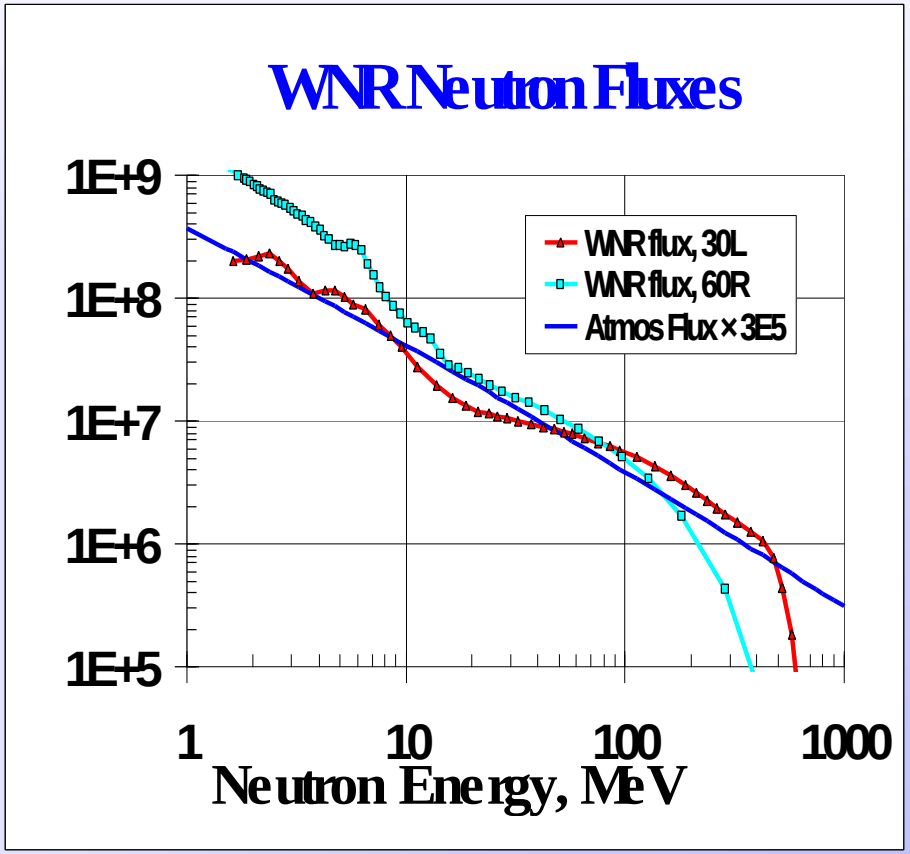
Boeing Radiation Effects Lab

- **Testing**
  - **WNR (at LANL) same neutron spectrum as atmospheric neutrons**
  - **14 MeV generator (BREL)**
- **Analysis**
  - **BGR method can utilize heavy ion data to estimate neutron-induced SEU response**
  - **New BGR-based model to explain neutron-induced latchup (SEL)**

Use of the WNR Beam

Boeing Radiation Effects Lab

- **BREL has used WNR beam (LANL) to measure SEU in RAMs, µprocessors, SEL in gate arrays and SEB in power MOSFETs and high voltage diodes**
- **This means that these SEEs can be induced by neutrons in aircraft and on ground**



Radiation Biology

- Needs for a future manned mission to Mars (based on recent international workshop)
  - space radiation biology:
    - exposure to low fluences of high LET particles
    - long term exposure
    - simulation of space radiation constituents
    - single particle exposures with microprobe technique
  - effects of neutrons created by cosmic rays in space vehicle (0.01-100 MeV)
  - High-Z, high energy heavy ions
    - single particle effects and track structure
    - extrapolation from low-LET radiation
    - comparisons between dose-based and fluence-based approaches

Other needs for biology

- High Energy Microprobes (or nanoprobes)
  - allow study of the effect of a single particle interacting in a cell and localization within a cell
- Neutrons (cold to thermal)
  - neutron scattering to determine structure
  - boron neutron capture therapy

Space Applications in the future

- Need continued access to low-energy heavy ion facilities for RET
- Need increasing access to high energy heavy ion facilities for RET as parts become more complex and delidding becomes impossible
- Protons at a wide range of energies are needed for a variety of applications
- Need from NASA to calibrate detectors for space is ongoing but variable
- Cost is a factor

Possibilities at RIA

- Use of high energy heavy ions from primary accelerator
  - Use of unwanted heavy ion fragments at the end of the mass separator in a parasitic mode??
    - Range of LETs available for typical case
    - Use of degraders to change LET
  - Possible problems
    - activation of parts from radioactive fragments