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

Overview of Presentation

Boeing Radiation Effects Lab

- Introduction to Single Event Effects [SEE]
- Atmospheric Neutron Environment
- Evidence for Neutron-Induced SEU in Avionics
- Environments and Effects Related to Avionics SEU
- Results of Recent Avionics SEU Evaluation

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

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SEE: Which Environments are Important

- 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

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Neutron Environment in the Atmosphere

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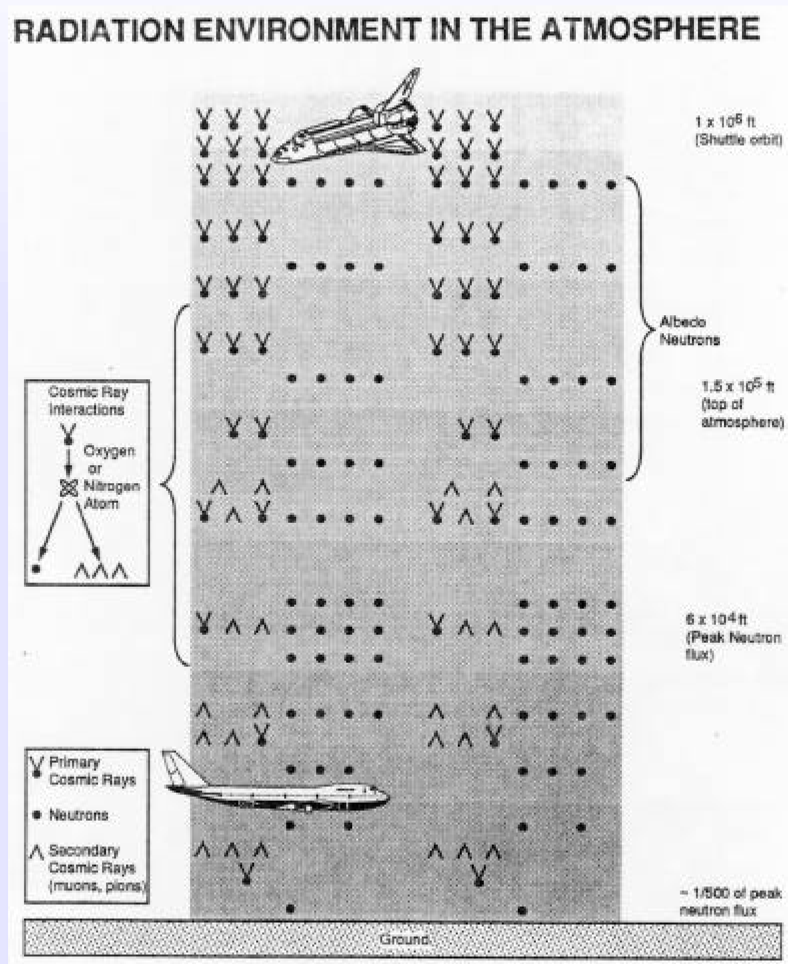
Neutrons, created by cosmic ray interactions with the O_2 and N_2 in the air, peak at ~60,000 ft. At 30,000 ft the neutrons are about 1/3 the peak flux, and on the ground, ~1/400 of the peak flux. The peak flux is ~4 neutron/cm^2sec. Other particles such as secondary protons and pions are also created, but for SEU the neutrons are the most important.



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

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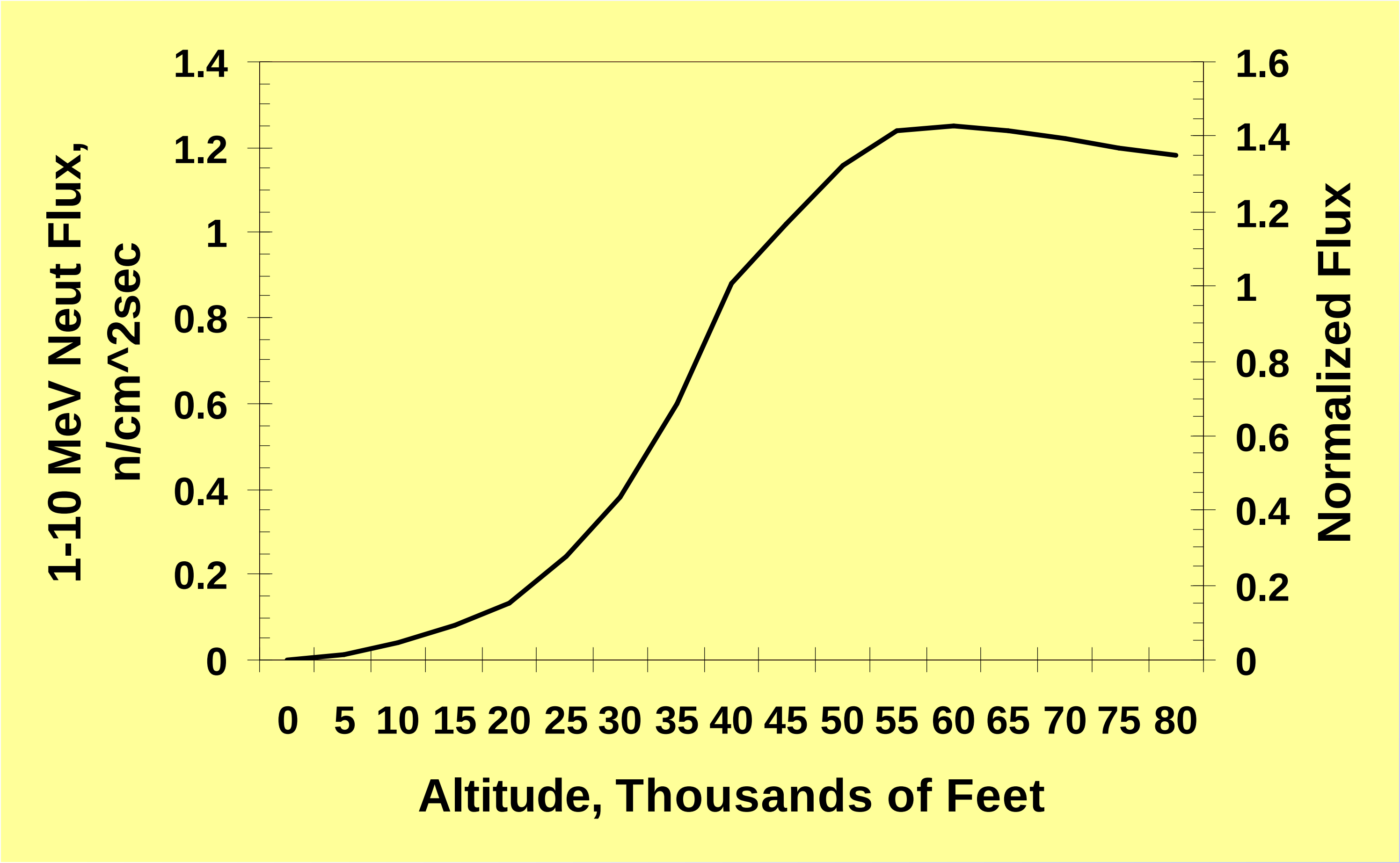

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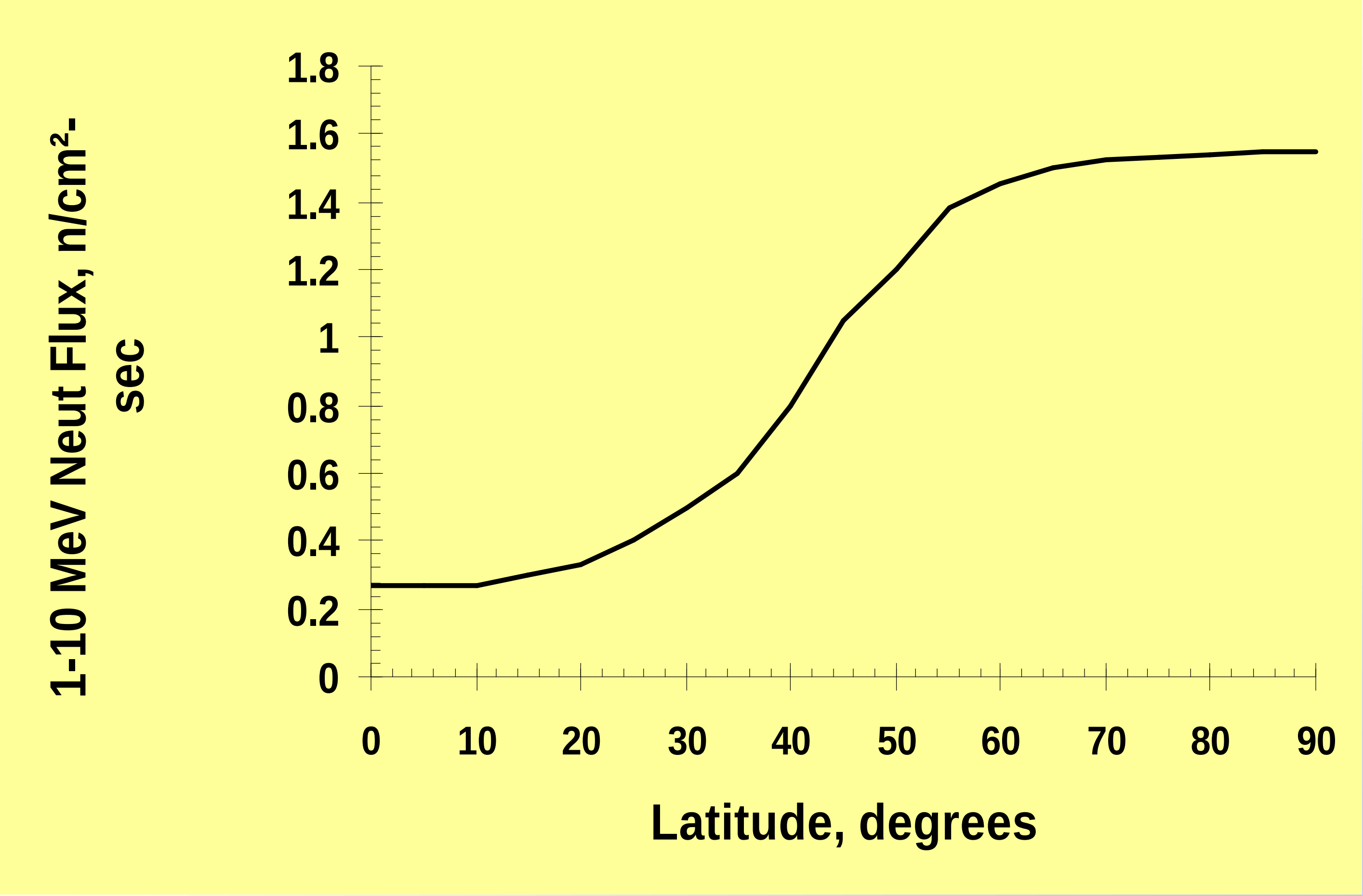

Energy Dependence of Atmospheric Neutron Flux, Simplified Boeing Model

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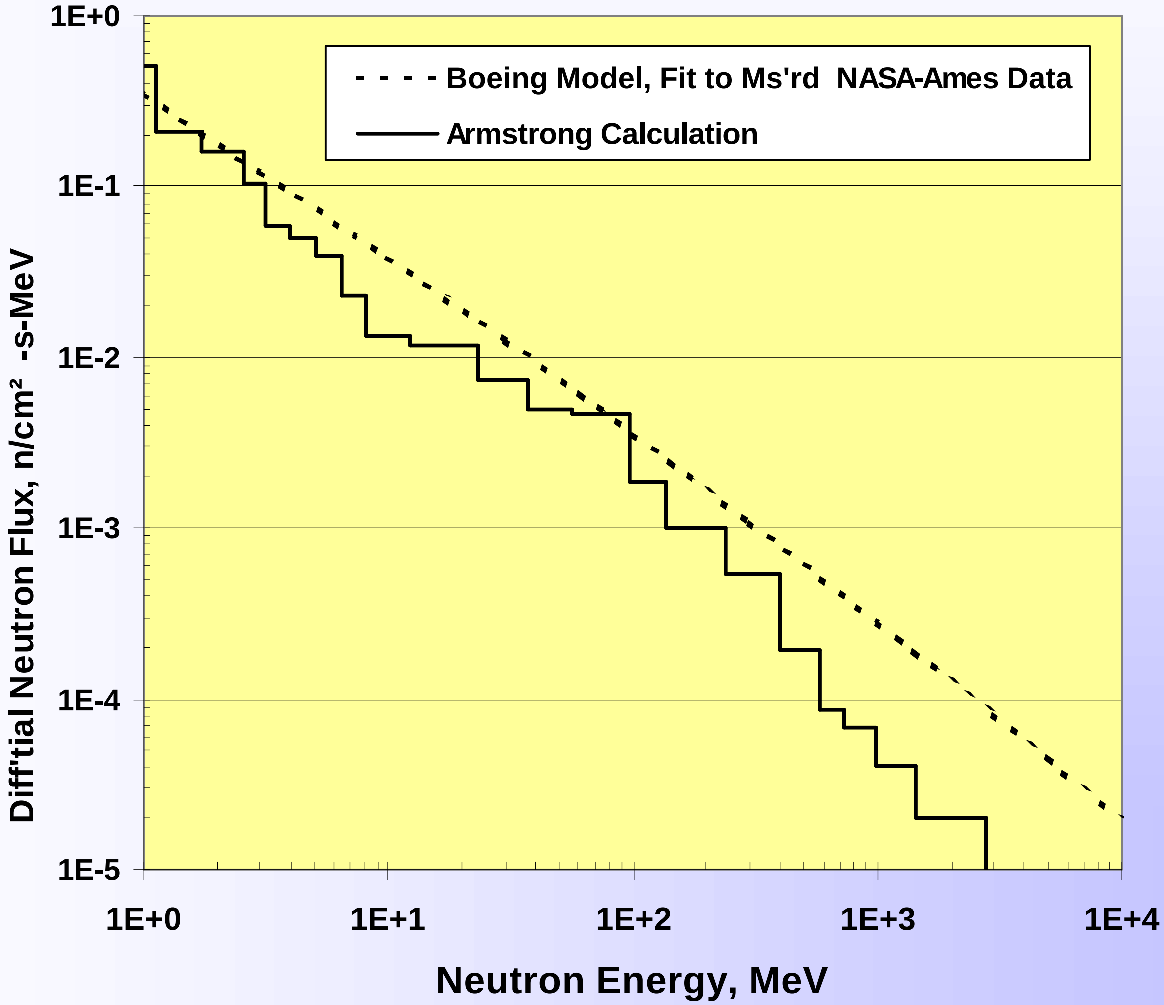

4 Independent Sources Confirm Atmospheric Neutrons as Cause of Avionics SEU

Basis of Neutrons as Cause	Airborne Data Serving as Basis
1. Variation of in-flight SEU rates with altitude and latitude have the same behavior as the variation of atmospheric neutron flux with altitude and latitude	1. In-flight SEU rates from IBM experiments (over, Seattle, northern California and Norway) and from CC-2E computer in TS-3 E-3 aircraft (mainly over West Coast)
2. Agreement between the measured in-flight upset rates and the upset rates calculated using the atmospheric neutron flux and laboratory-measured SEU cross section data	2. In-flight SEU rates from IBM experiments (over Seattle, northern California and Norway), CC-2E computer on TS-3 (West Coast), CC-2E computer on military aircraft in Europe and SRAMs in other aircraft (trans-Atlantic and worldwide)

4 Independent Sources Confirm Atmospheric Neutrons as Cause of Avionics SEU, Cont'd

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Basis of Neutrons as Cause	Airborne Data Serving as Basis
3.Agreement between ground level SEU rates in SRAMs and DRAMs and those at aircraft altitudes, when accounting for the difference in atmospheric neutron flux at ground and 4E4 Ft.	3. In-flight SEU rates in 1 and 2 above and measured ground level rates at various locations in US (Seattle, Austin, TX and Batavia, IL)
4. Agreement between the energy deposition spectrum measured in the airborne CREAM detector and the spectrum measured in Boeing's surface barrier detector in the WNR high energy neutron beam at Los Alamos	4. Energy deposition spectra in the CREAM detector onboard Concorde on London-Washington, D.C., London-New York and Washington-Miami routes

Correlation of SEU Rate and Atmos. Neutron Flux with Altitude

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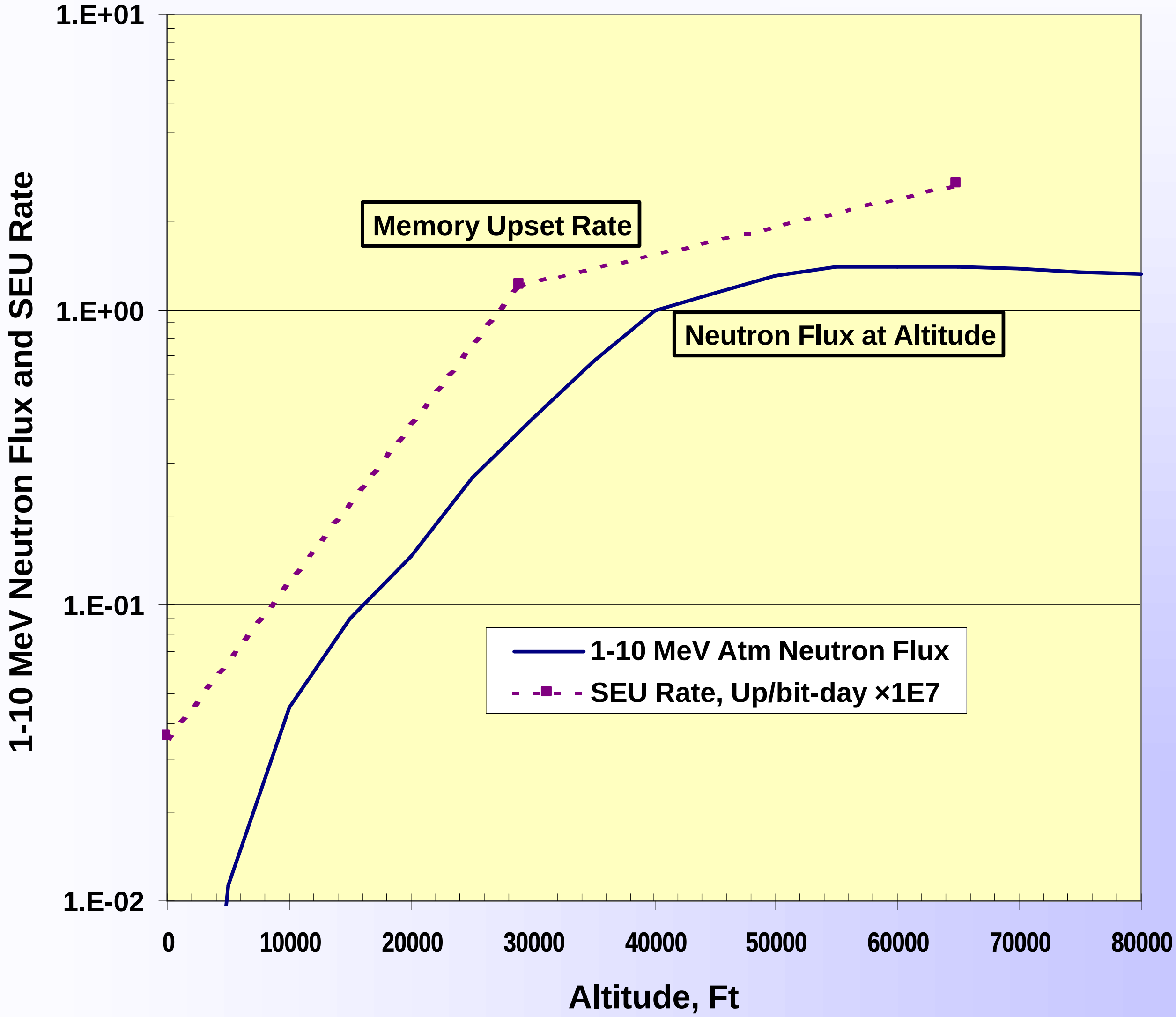

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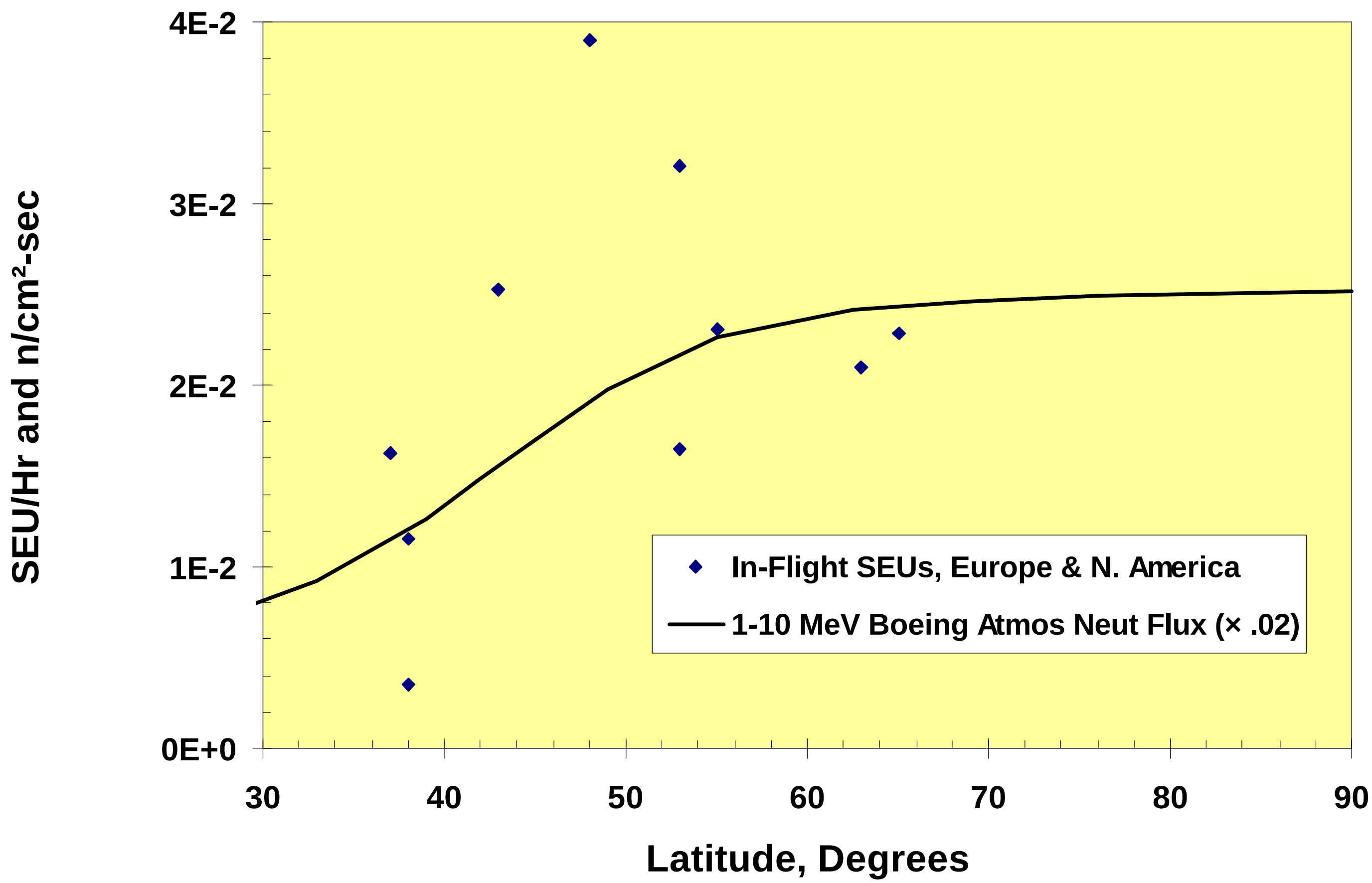

Comparison of Measured and Calculated In-flight SEU Rates

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Aircraft	Flight Path	Altitude, ft (×E3)	System	Operat'g Condt'ns	SRAM	# Upset	Meas'd Up/bit-hr	Calct'd Up/bit-hr
E-3	Seattle	29	IBM Exp't	2.5 V	IMS 64K	10	5E-9	4.4-8 E-9
ER-2	N. Cal.	65	IBM Exp't	2.5 V	IMS 64K	12	1.1E-8	1-2 E-8
ER-2	Norway.	65	IBM Exp't	2.5 V	EDI 256K	6	4.6E-9	8-14 E-9
E-3	Europe-1	29	CC-2E	5 V	IMS 64K	53	2.3 E-9	1.8-4.7E-9
E-3	Europe-2	29	CC-2E	5 V	IMS 64K	83	1.6E-9	1.3-2.7E-9
Com'cll Jetliner	Trans-Altlantic	~35	PERF. computer	5 V -	EDI 256K	14	4.8E-8	2.3E-8
F-4	S. Calif.	<25	AP-102	5 V	IMS 64K	4	5.4E-8	3.4E-10
Com'cl Jetliner	World-wide	~33	Avionics computer	5 V	IDT 256K	-----	3.3E-10	5E-10

Comparison of SEU Rates on Ground, Field Data and WNR Rates

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	Observed Rate From Field		Upset Rate From WNR	
RAM	System/SER Source of Data	hr	Similar RAM at WNR	Up/b-hr
DRAM	ACPMAPS Computer Fermila	7E-13	TC514400-80	2E-12
"	IBM Field Tests	3E-13	MSM514400-80	4E-13
"	CRAY YMP-8, Bulk Storage	6E-13	TMS44100	2E-12
"	Nite Hawk 5800 Computer	2E-12		
DRAM	Simple Average	1E-12	Simple Average	2E-12
SRAM	Motorola Field SER tests	2E-12	IDT71256	1E-12
"	ICDs within patients	2E-12	HM65656	4E-12
"	CRAY YMP-8 Main Memory	2E-12	MCM6206	3E-12
"			MCM6246	2E-13
SRAM	Simple Average	2E-12	Simple Average (4)	2E-12

Conclude that field Upset rates (large computers, RAM vendor tests, etc.) agree with upset rates based on measured SEU rates in WNR neutron beam combined with measured cosmic ray neutron flux at ground level

Comparison of Ground-Level SEU Rates with Rates in Aircraft

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RAM	Vendor/ RAM Type (D or S)	Measr'd WNR SEU X-Sct'n, cm^2/bit	Gr'nd level SEU Rate, Up/bit-hr, WNR-Scaled	Calculated Ground SEU Rate, Up/bit-hr, BGR Method
TC514400	Toshiba/D	1.2E-13	2.3E-12	2.1E-12*
MSM514400	Oki/D	2.2E-14	4.3E-13	N/A
TMS44100	TI/D	9.3E-14	1.8E-12	2.3E-12
IDT71256	IDT/S	6.5E-14	1.3E-12	2.3E-12
HM65656	Matra/S	1.9E-13	3.7E-12	1.2E-12
MCM6206	Motorola/S	1.4E-13	2.7E-12	7E-13*
MCM6246	Motorola/S	1.3E-14	2.4E-13	3.4E-13
Average (7 RAMs)		1.9E-13	1.8E-12	2.5E-12

*** Indicates Heavy ion SEU data from related RAM**

Ground level SEU rate ~2E-12 Upset/bit-hr

Aircraft SEU rate (neutron flux ~300 times higher) is 300×2E-12, ~6E-10 Upset/bit-hr, agrees w/ in-flight SEU rates

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

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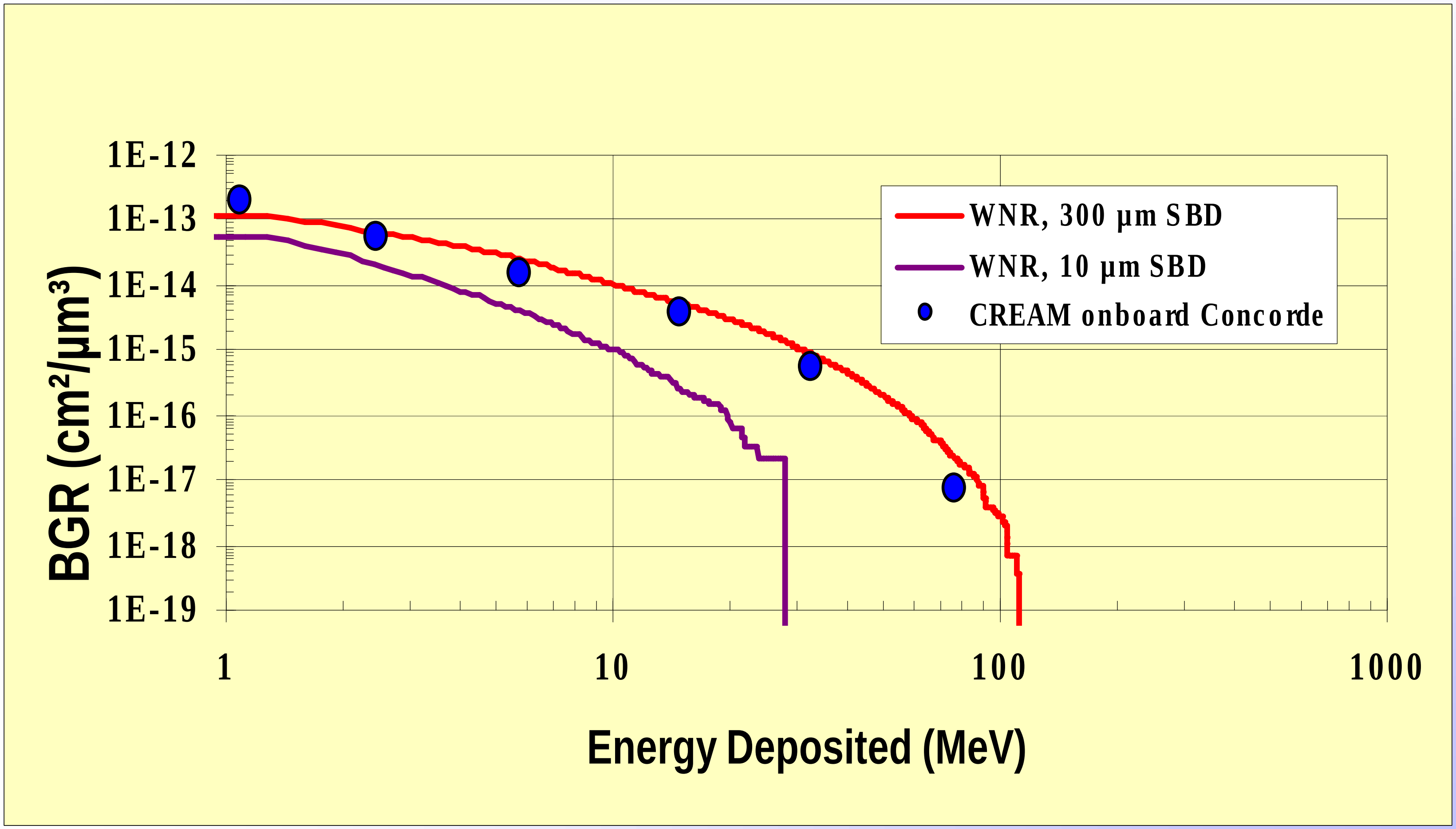

BREL Approach for Dealing with SEE in Avionics

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- **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

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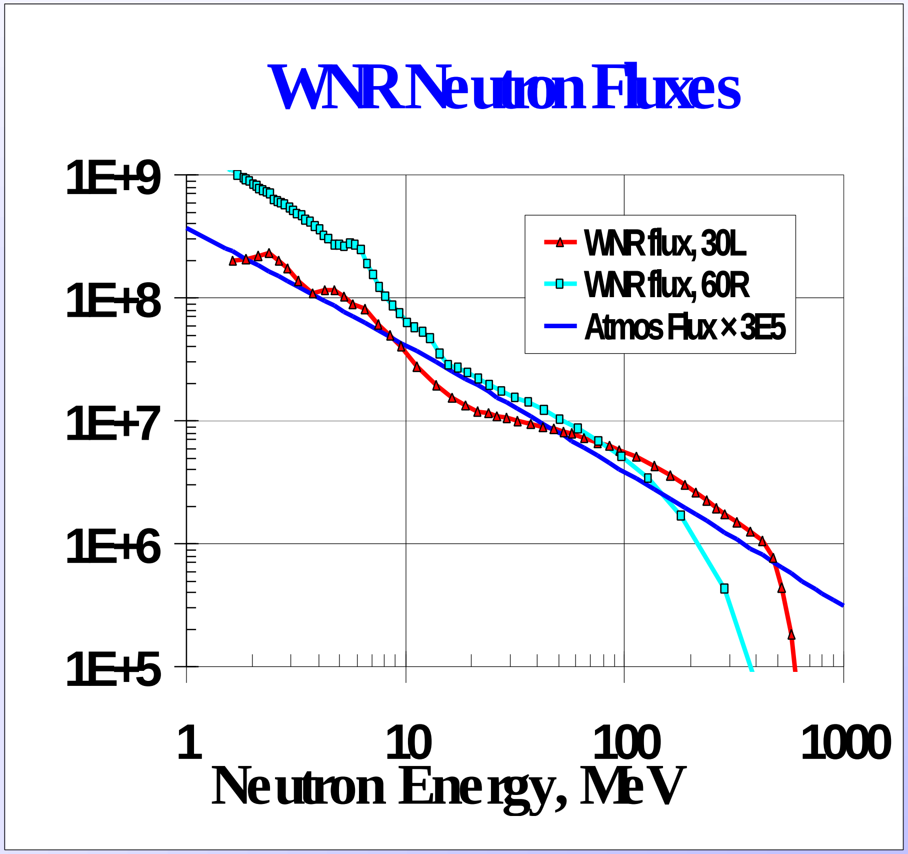
- **BREL has used WNR beam (LANL) to measure SEU in RAMs, µprocessors, SEL in gate arrays and SEB in power MOSFETs and high voltage diodes**
- **This means that these SEEs can be induced by neutrons in aircraft and on ground**



Results of Recent SEE Evaluation of Avionics System

- **Based on new mission computing and communications subsystems, total of ~20-30 SBCs**
  - **SEU in main memory well protected by EDAC**
  - **SEU in cache memory (protected by parity checking) will result in "reconfiguration" ~once every 2-3 hours**
  - **SEU in unprotected devices results in reboot once every ~100-200 hours (cumulative, all devices)**
    - **Includes microprocessors, FPGAs, MBU in main memory**
  - **Still large uncertainties in response of some devices that can only be reduced by SEU testing**
    - **Microprocessor response based only on PowerPC 603 that was tested with protons for space applications**

Perceived Current Status of SEE in C-17 Avionics Systems

- **Flight Controls**
  - Appears to be adequately protected through combination of EDAC and redundancy
- **Mission Avionics**
  - More likely to have subsystems that may not be adequately protected
  - Anecdotal story (from Wright-Patt, ~4 years ago) of upsets in computer during flight, fixed via EDAC
  - Could check operational logs for evidence of malfunctions during flight that could not be detected when box tested in the lab (Could Not Duplicate, Retest OK)
    - In commercial avionics experience, »20% of all CNDs are due to SEUs

How Can BREL Help?

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- **Provide environmental requirements section (atmospheric neutrons) to be incorporated into specs for future upgrades**
- **Assist in carrying out SEU evaluations/reviews of future avionics upgrades**
- **Carry out SEU evaluations of existing systems in which SEU problems most likely, e.g. new flat panel display**
- **Identify current systems containing EDAC protection from which direct evidence of SEU occurrences may be derived from operational logs**
- **Incorporate error logging features into EDAC protection to allow SEU occurrences to be monitored, thereby providing feedback for design of future systems**