Radiation Effects Studies at NASA's Center for Radiation Research (CARR)

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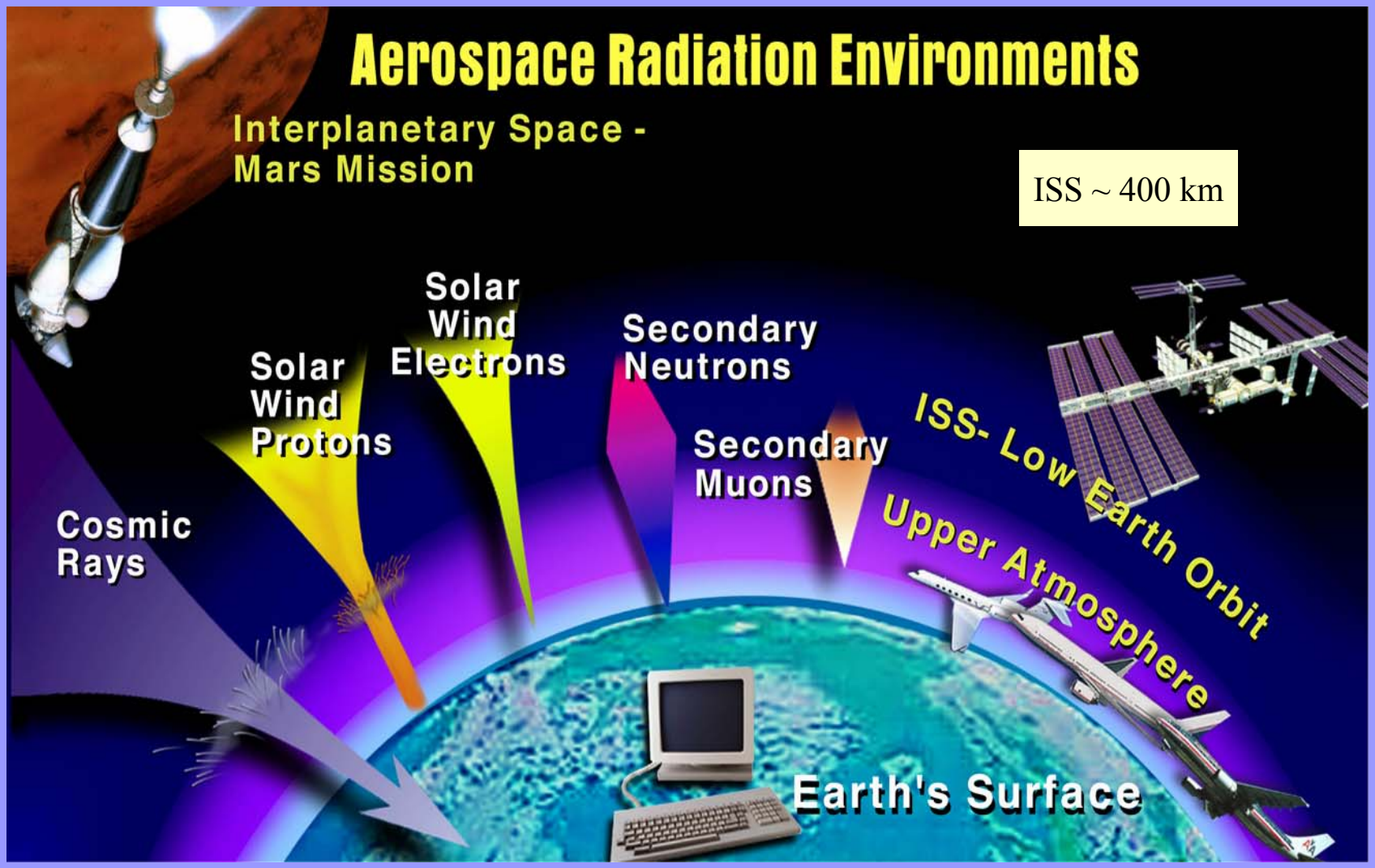
Outline

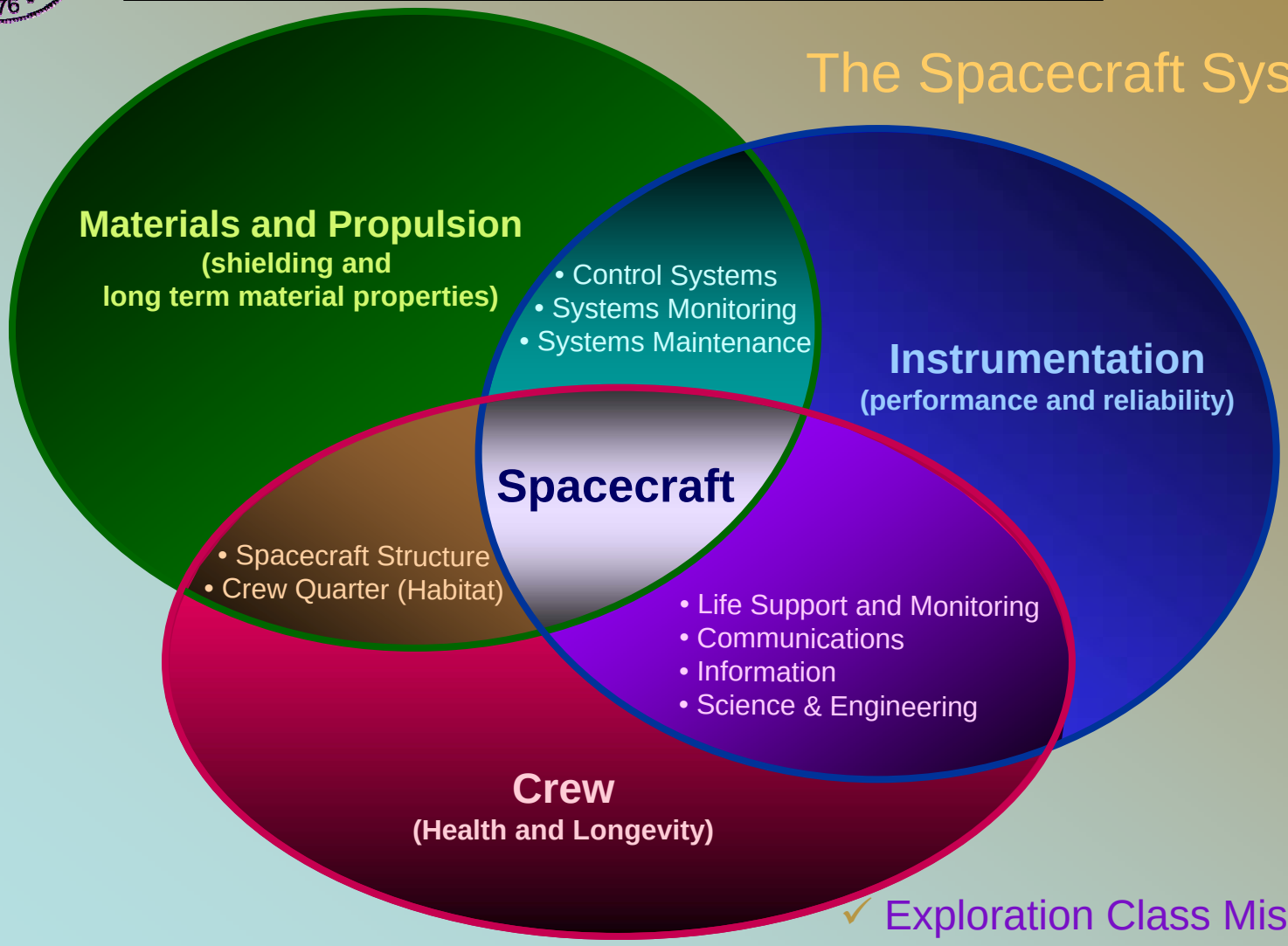
- Overview
- Space Radiation Environment
  - Characterization
  - Ground base testing - NASA facilities and other
- Neutron Experiments
  - LANL LANCE Spectrum characterization
  - UT TRIGA spectrum characterization
  - Space Suit secondary radiation environment
- Collaborations
  - Student interns
  - Faculty summer internships

Space Radiation From Mission Prospective



NASA Space Radiation Concerns

The Spacecraft System



- ✓ Exploration Class Missions
- ✓ Long term Low Earth Orbit (LEO)
- ✓ High Altitude Aviation

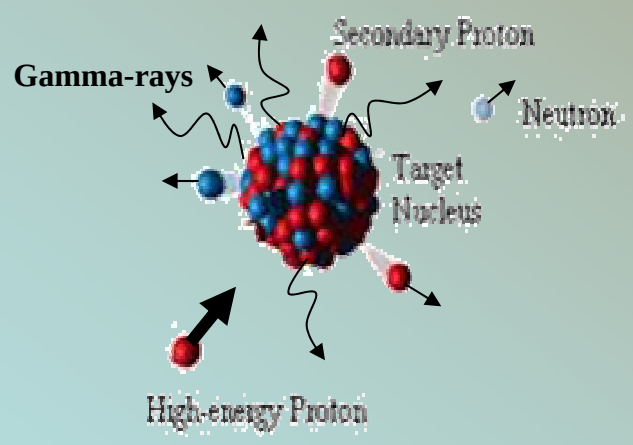
Primary Space Radiation Environment

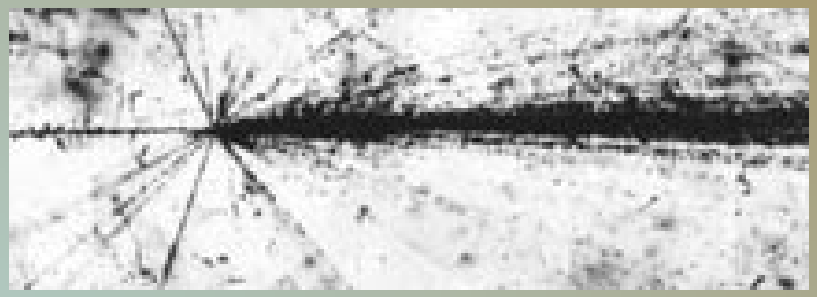
- Trapped Radiation
  - from Earth's magnetic pole
  - electrons and protons
- Galactic Cosmic Rays
  - Includes alpha particles, neutrons, heavy ions, x-rays, delta-rays and γ-rays
  - 85% Proton
  - Low fluxes, high energies (GeV/nucleon)
- Solar flare
  - Solar eruptions produce energetic protons along with alpha particles, heavy ions, and electrons
  - Energies in MeV region

Secondary Radiation

- Primary radiation often interacts with the surrounding material
  - e.g. the outer shell of the spacecraft, space suit

- This interactions result in secondary radiation





- Evaluation of secondary radiation is a complex problem
  - Sources of secondary radiation: Spallation, (γ, n), (α, n)

Center for Applied Radiation Research

CARR

Education

- Electrical Engineering, Mechanical Engineering, Physics
- Nuclear Engineering
- Tuition Assistance

Research

Materials and Shielding

- Composites
- Inflatable and Layered Structures
- Carbon Nano tubes

Radiation Environment and Dosimetry

- Particle Accelerator Experiments
- Flight Dosimetry
- 3-D Computer Modeling
- Transport and Track Structure Modeling
- Radiation Biology

Electronics

- COTS Electronics
- Photonics
- Quantum and Nanoscale Devices

Outreach

- Community Outreach
- Recruiting
- K-12

Established in 1995

CARR's Research Focus

I. Electronics Testing and Instrumentation (Experiments)

- ♦ Dr. R. Wilkins
- ♦ Dr. J. O. Attia
- ◙ Dr. S. Aghara
- ♦ Dr. C. Akujuobi
- ♦ Dr. K. Kirby
- ● Mr. R. Dwivedi
- ♦ Dr. T. Fogarty
- ● Mr. S. Ardalan

II. Materials and Shielding (Experiments & Modeling)

- ♦ Dr. R. Wilkins
- ■ Dr. J. Zhou
- ◙ Dr. S. Aghara
- ■ Dr. S. Lin
- ◊ Dr. Store

III. Radiation Environment and Dosimetry (Experiments and Modeling)

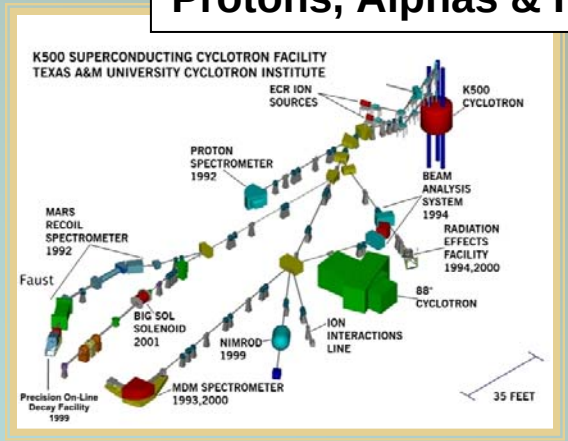
- ◊ Dr. P. Saganti
- ◙ Dr. S. Aghara
- ● Mr. B. Gersey

♦	Dept. of Electrical Engineering
■	Dept. of Mechanical Engineering
◊	Dept. of Physics
◙	Dept. of Chemical Engineering
●	Staff

Ground Based Radiation Test Facility

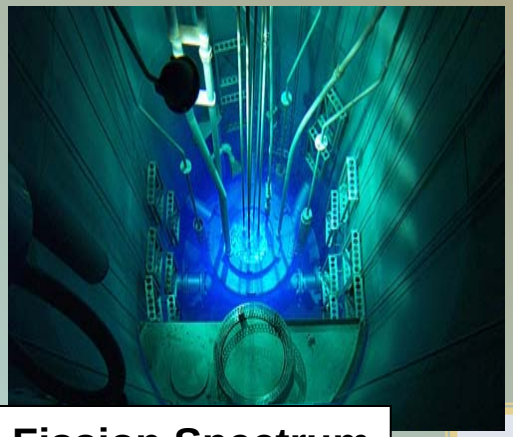
CYCLOTRON INSTITUTE
Texas A&M University

Mid Energy (< 100 MeV)
Protons, Alphas & Heavy Ions



LANSCE

High Energy (>100 MeV)
Neutrons & Protons



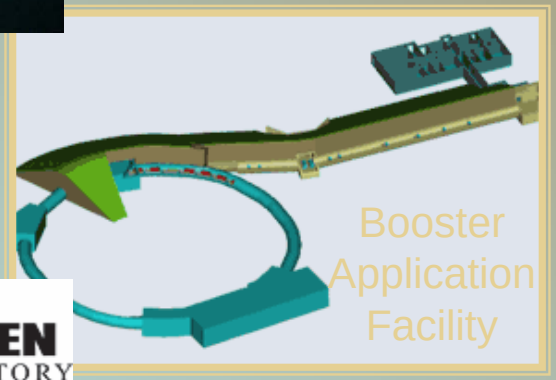
Fission Spectrum
Neutrons

LOMA LINDA UNIVERSITY
MEDICAL CENTER

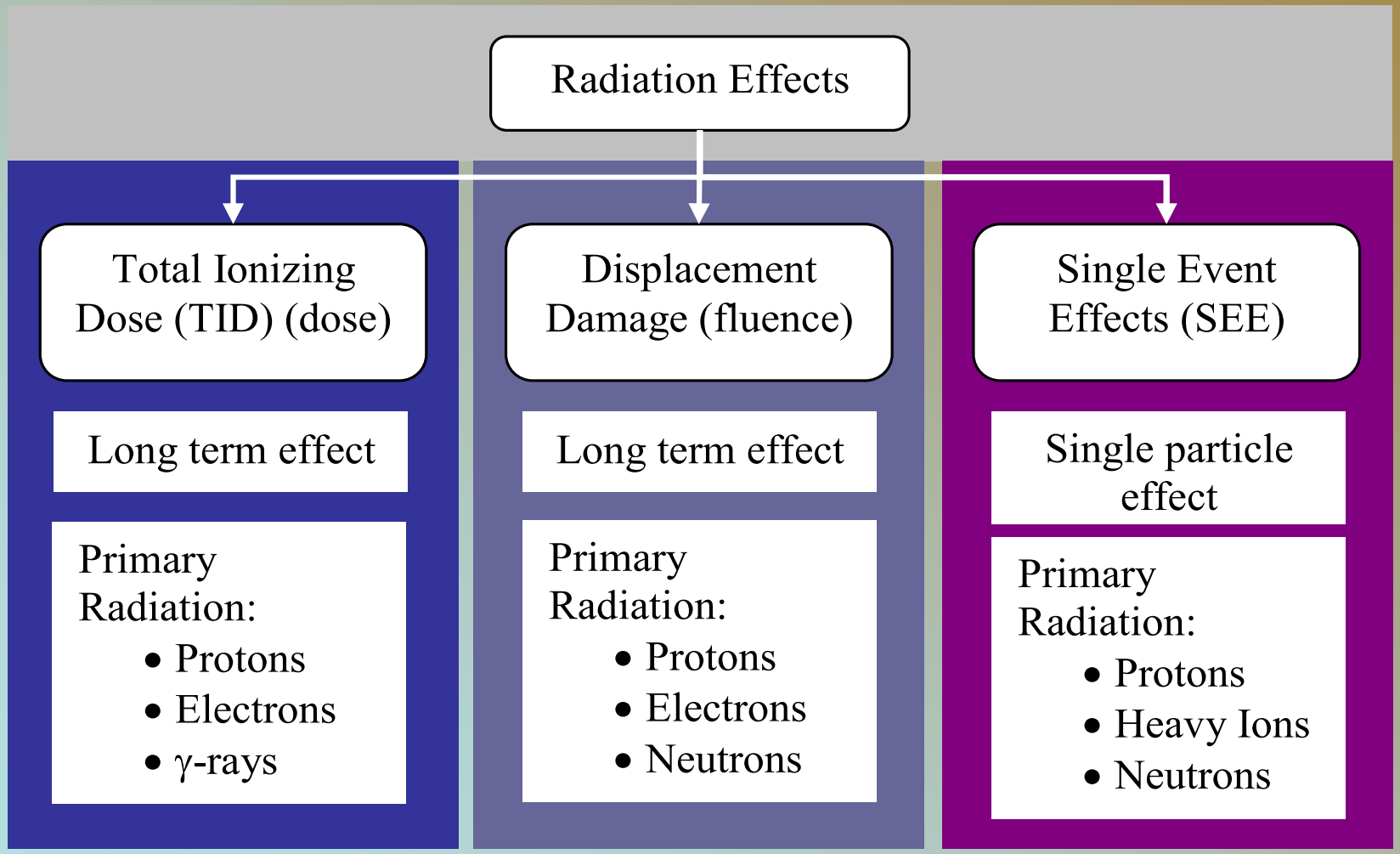
Protons & Electrons
CT Scan

HEAVY IONS

BROOKHAVEN
NATIONAL LABORATORY



Electronic Testing

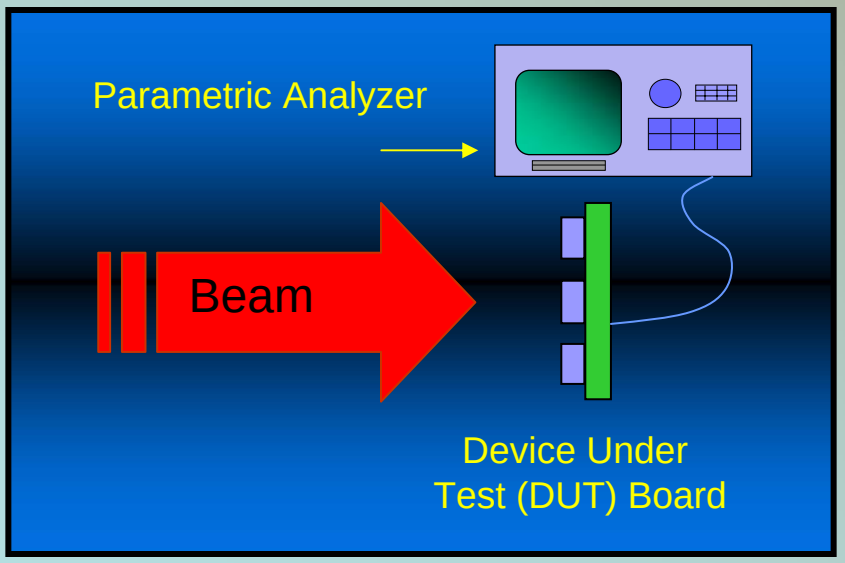


"Point and Shoot Experiments"

Total Ionization Dose and Displacement Damage

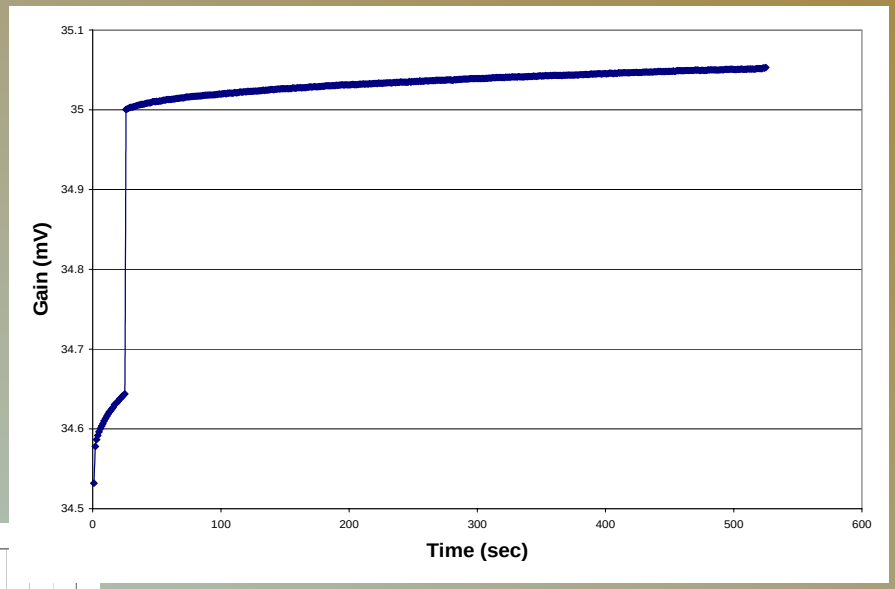
- Samples are evaluated both *in situ* (Dynamic testing) and *ex situ* (Static testing)
- Samples are compared to pre-irradiation characteristics and control samples

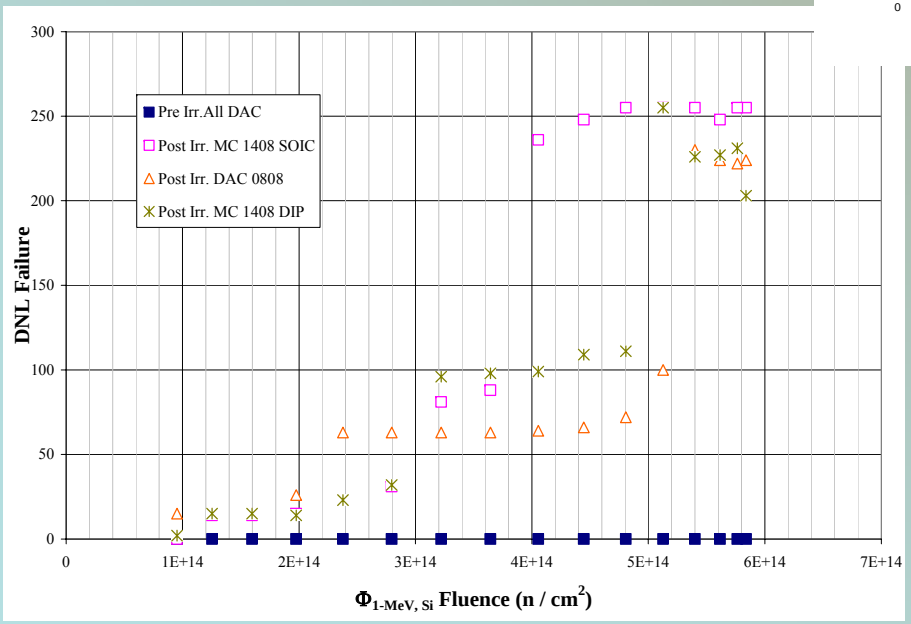
Outcome: Radiation tolerance data and radiation damage curves



"Point and Shoot Experiments" (Cont.)

- Displacement damage results in parametric changes in Digital-to-Analog Converters (DAC)
  - 1 MeV equivalence neutron irradiation >2E+14 per cm^2 resulted in complete device failure

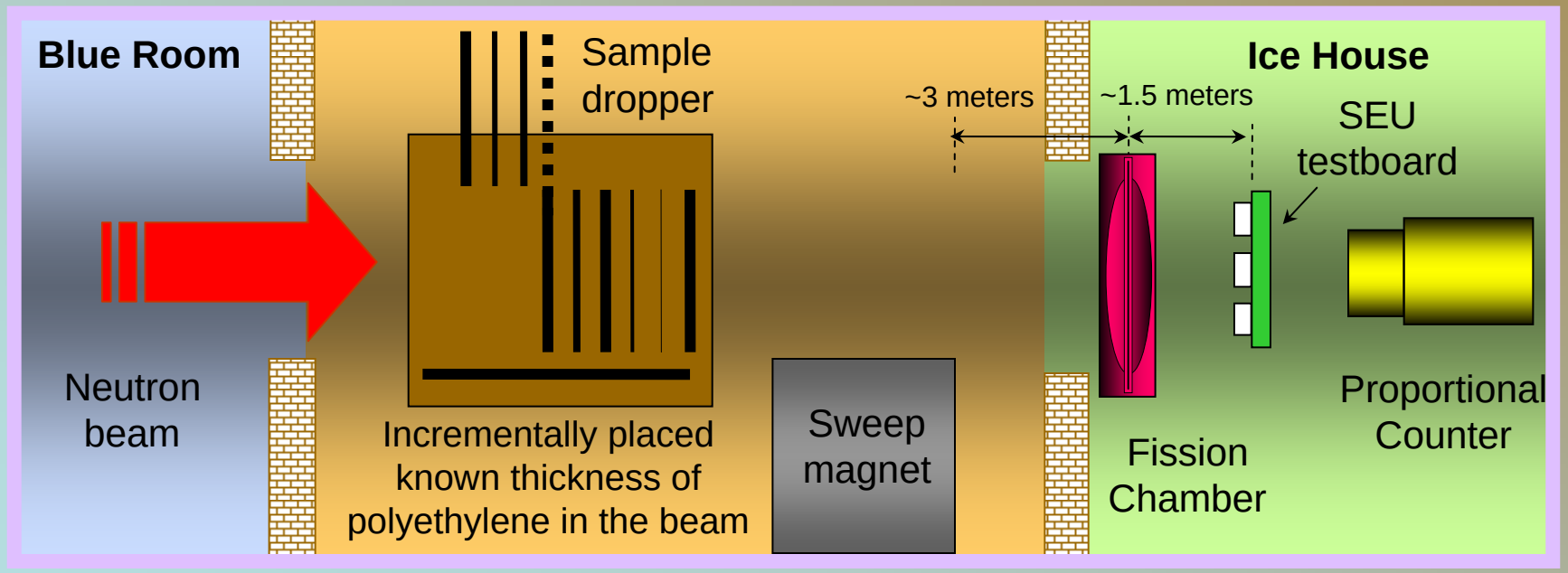




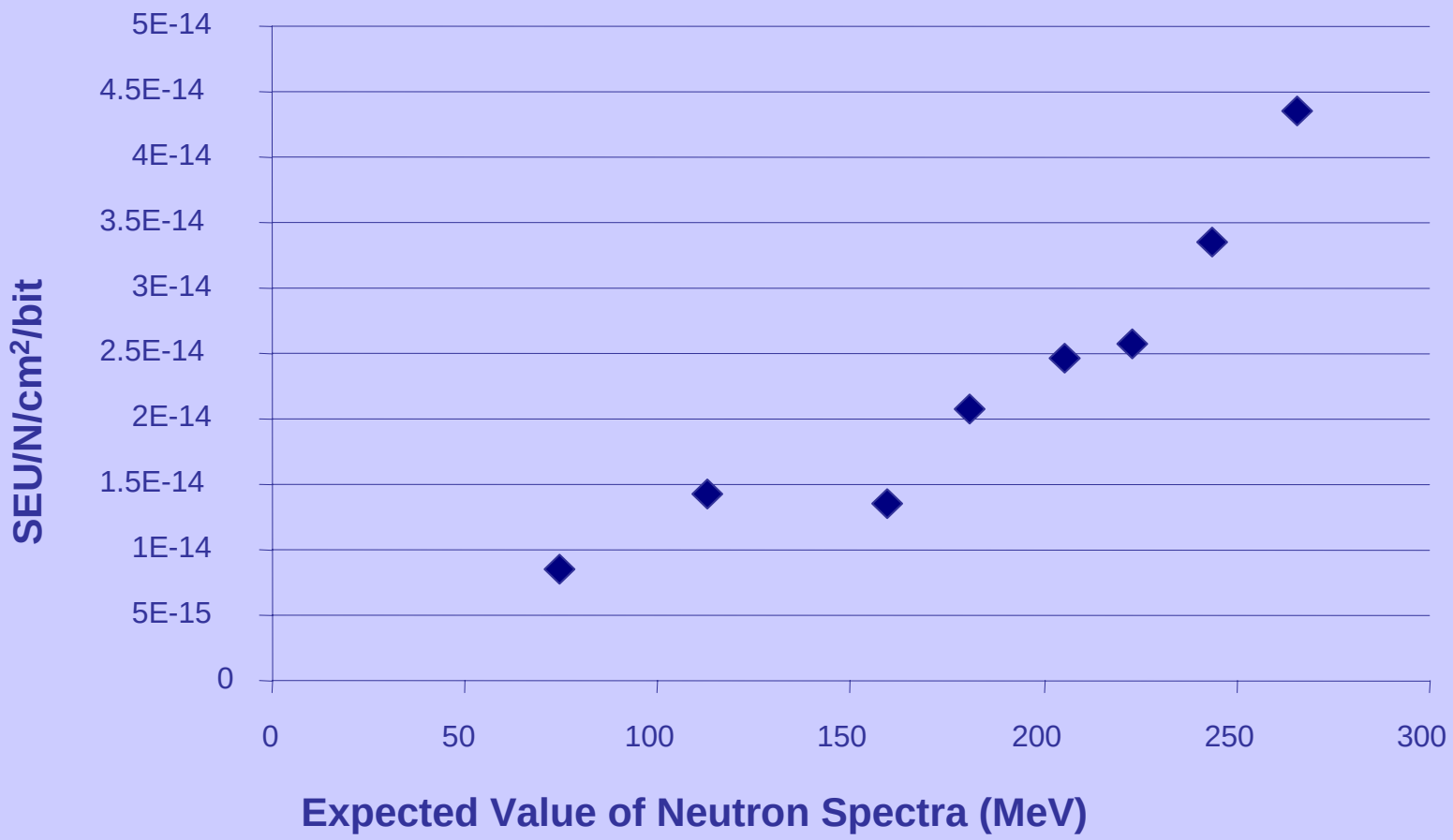
- Displacement damage is reversible by temperature elevation
  - Device was heated for 10 mins at 100 °C a noticeable recovery is observed

Single Event Upsets (SEU) in SRAM

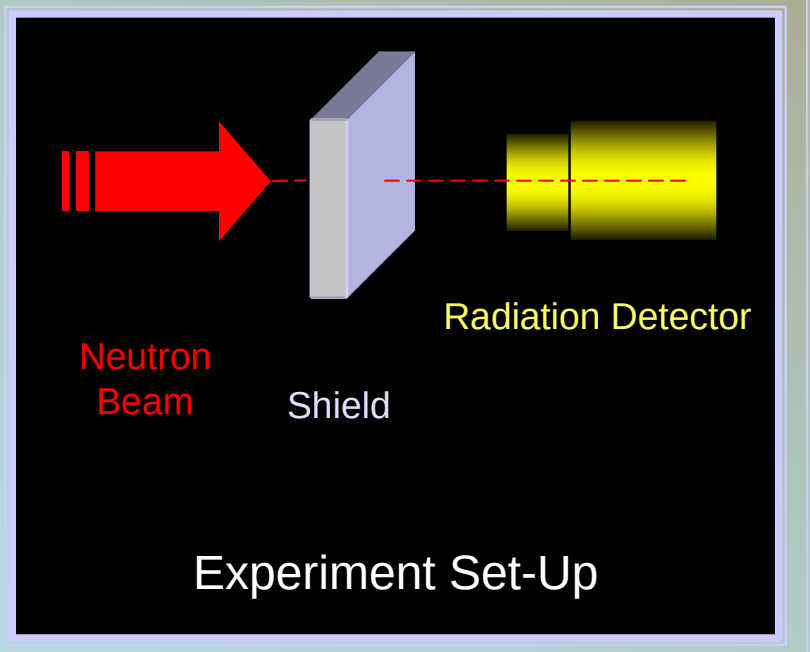
- Neutron energy spectrum is changed by inserting neutron scattering material such as polyethylene

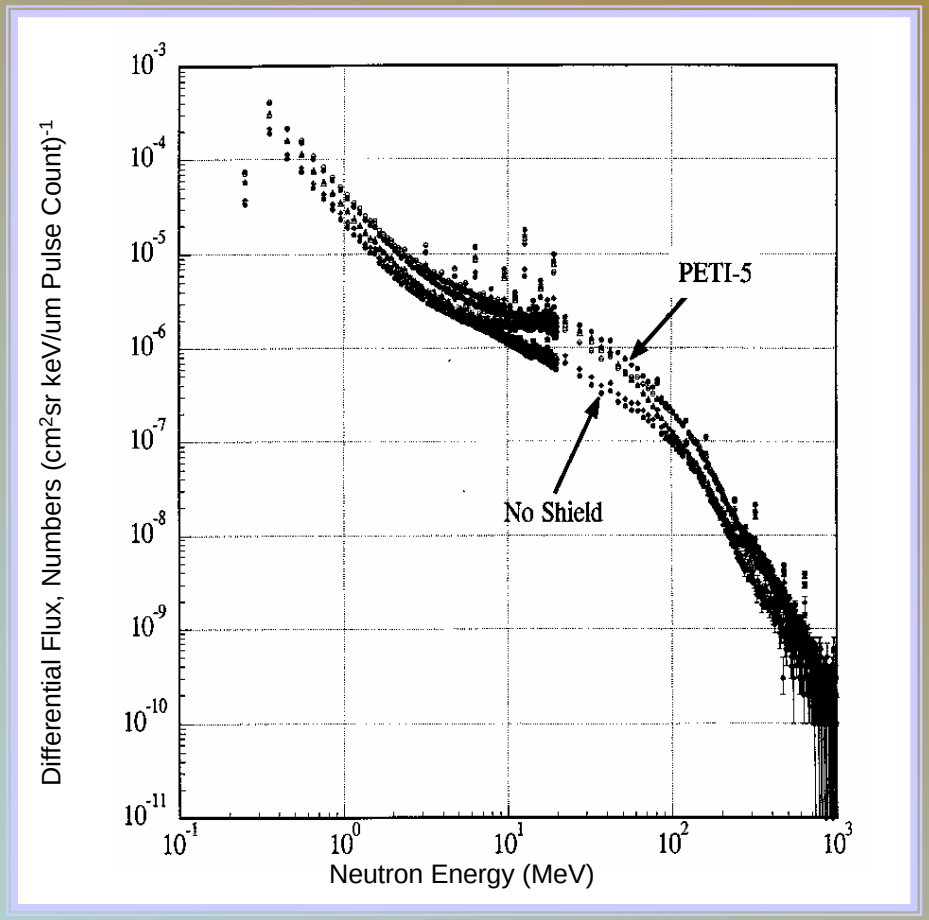


SEU Cross-section as a function of Neutron Spectra



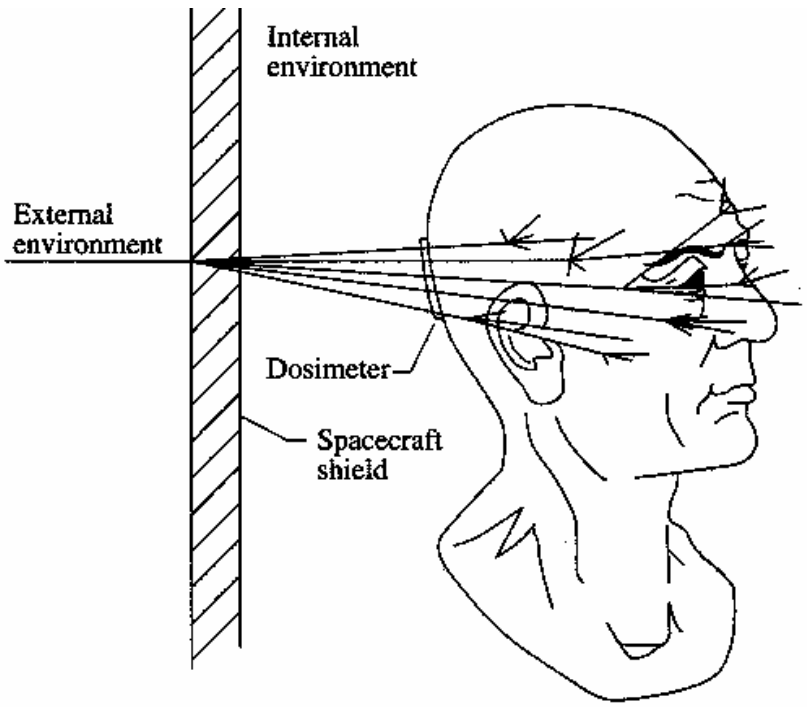
Shielding Experiments



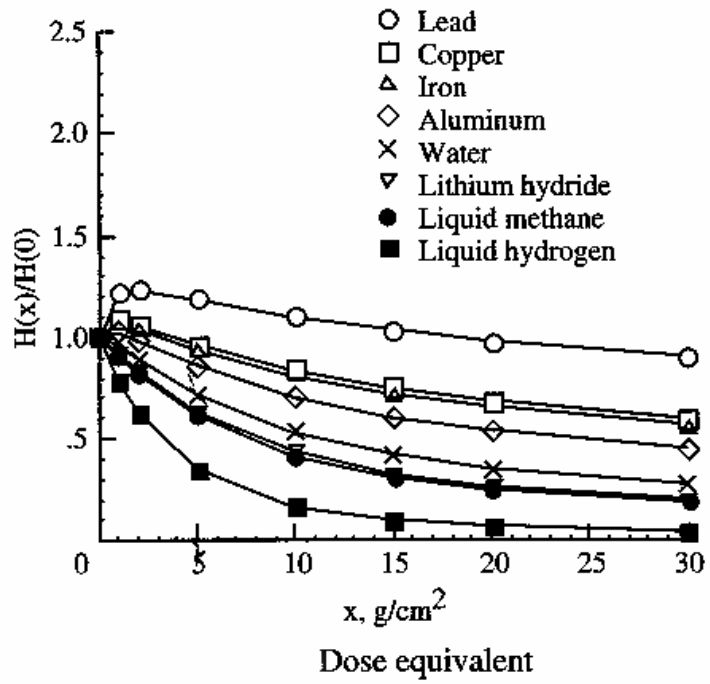


Differential lineal energy spectra for various shielding materials in the undegraded LANSCE neutron beam

Shielding Experiments (Cont.)



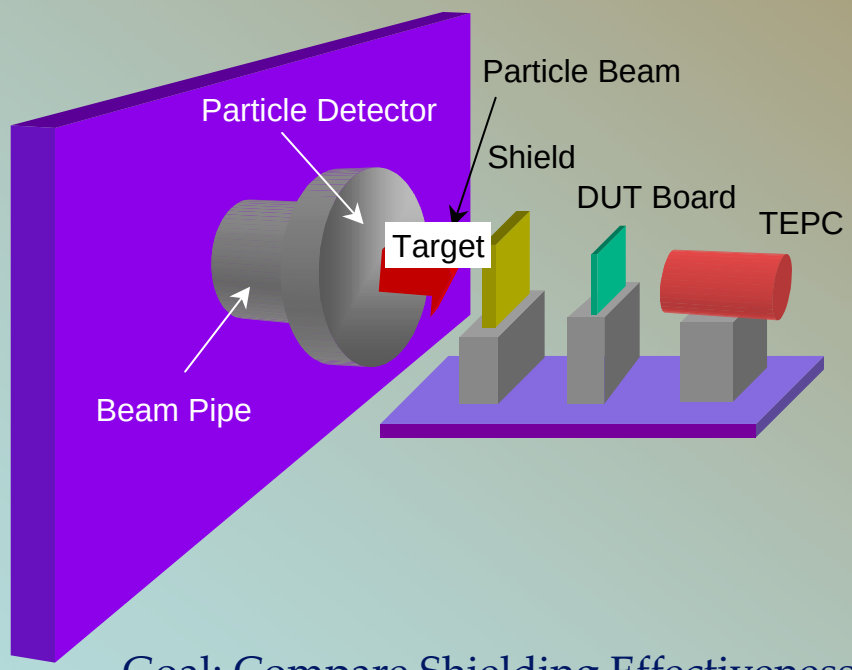
The astronauts environment



Calculated attenuation of dose equivalent for one year space exposure

- ✓ Materials with low-Z atoms best for high-energy particulate radiation shielding
- ✓ Low-Z atoms reduced nuclear fragmentation

Shielding Experiments (Cont.)



Material Targets Studied:

1. Various thicknesses of Polyethylene
2. Various thicknesses of Carbon
3. Various thicknesses of Aluminum
4. Boron and Lithium Enriched Polyethylene
5. Simulated Mars Regolith with Epoxy Binder
6. Transhab Cross-sections
7. ISS Food Containers
8. Carbon Composites

Goal: Compare Shielding Effectiveness of Various Materials for Both Human and Electronics

TEPC = Tissue Equivalent Proportional Counter.

- Measure Radiation Dose Equivalent Rates
- Changes In The Lineal Energy Spectra

CARR students at Los Alamos conducting shielding test with a simulated ISS food container

Radiation Materials Testing

In Situ Materials Utilization:

Materials were composites of simulated Moon (Regolith 101) and Mars (Regolith 102) regolith and a polyimide binder

Goal:

Study change in materials properties with radiation exposure

Neutron Experiments

at higher neutron fluences (>1E+14)

High Energy Proton experiments

800MeV irradiation did not show any changes at fluences of ~2E+10

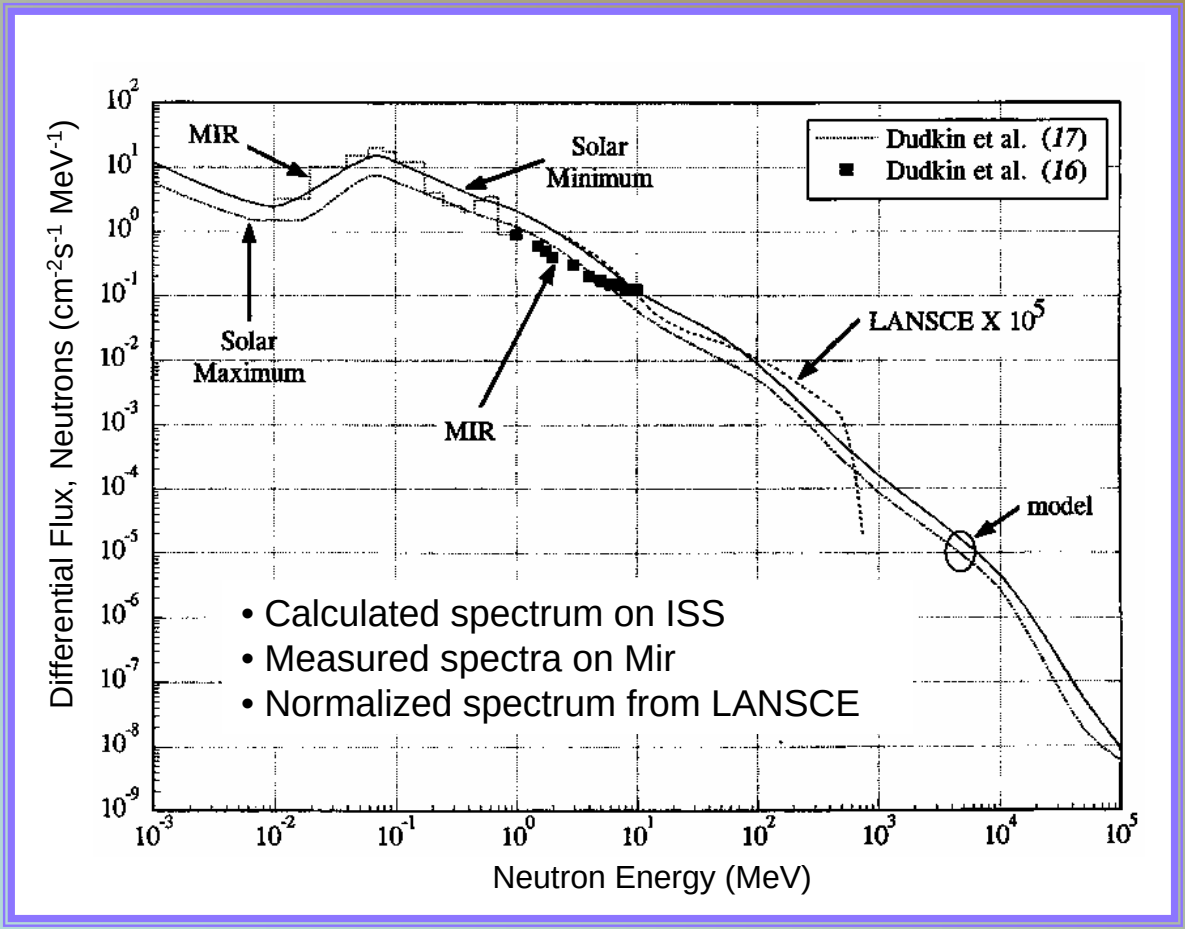
Radiation Conditions	Glass Transition Temperature (ºC)	
	Regolith 101 (Polyimide/Regolith 40/60)	Regolith 102 (Polyimide/Regolith 20/80)
Baseline (No radiation exposure)	232.92	233.46
55 MeV proton	232.88	233.77
800 MeV proton (Fluence: 5.34×10^{9} proton/cm^2)	233.25	234.62
800 MeV proton (Fluence: 1.78×10^{10} proton/cm^2)	231.71	234.22

High Energy Neutron and Proton Source

Weapons Neutron Research (WNR) facility at LANL LANSCE

Provides Protons (**Blue Room**) and Secondary Neutrons similar in energies to the cosmic ray interactions in planetary atmospheres

- Target 2 (Blue Room): Proton E = 800 MeV (linac)
- Target 4 (tungsten spallation source) : Neutron 0.1 MeV $\leq E_n \geq$ 600 MeV



LANL: LANSCE

- WNR is used extensively for:
  - Electronics Testing – SEU, advanced devices, novel electronic materials
  - Dosimetry – Neutron dose contribution to small volumes of tissue, silicon, carbon, lead
  - Materials – Neutron shielding effectiveness of materials
- *new data suggest SEU at lower energies $E_n < 10$ MeV*
- *lower energy neutron spectrum is not well characterized*

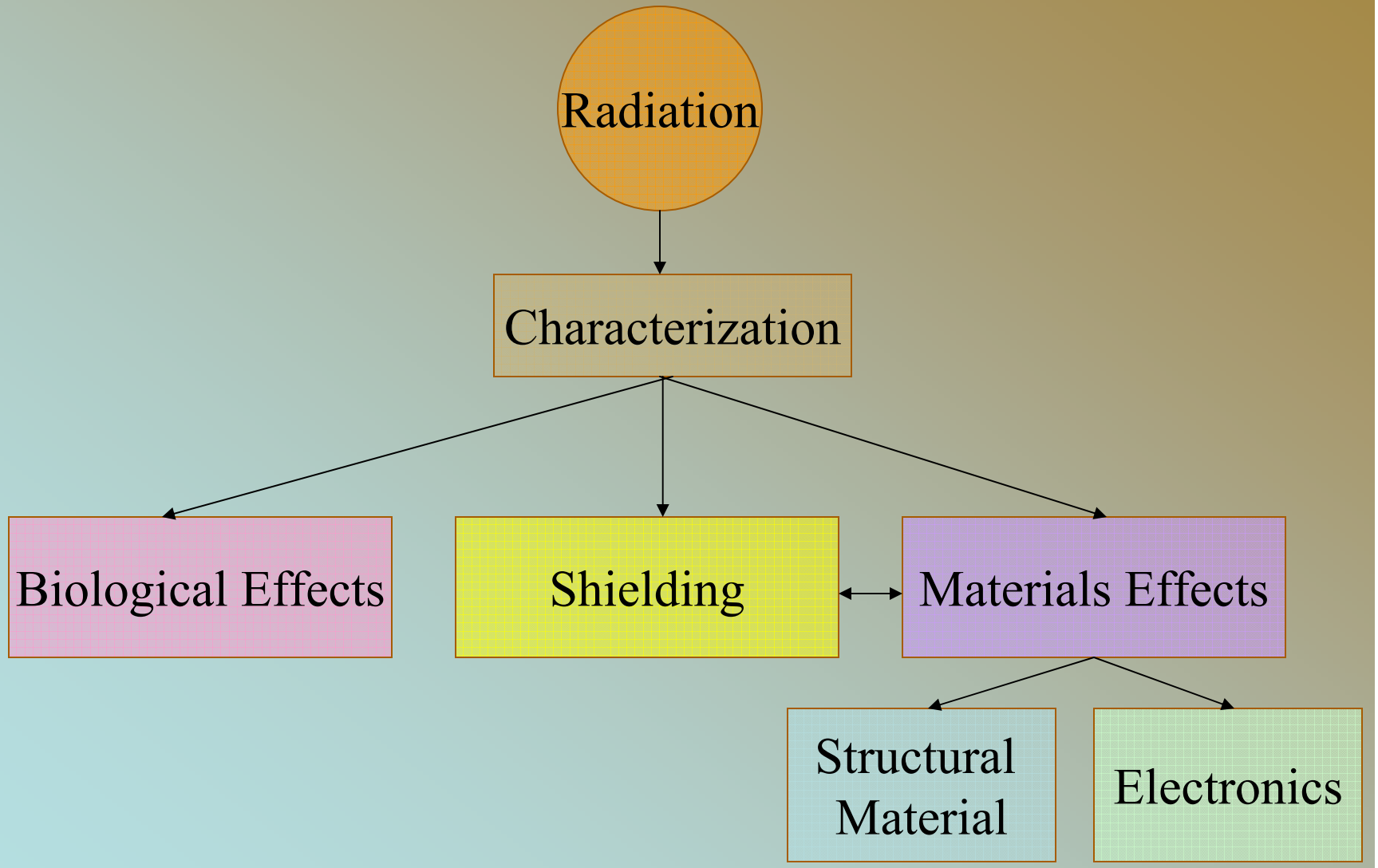
Current and Planned Research

1. Characterize the lower energy neutron spectrum at LANSCE

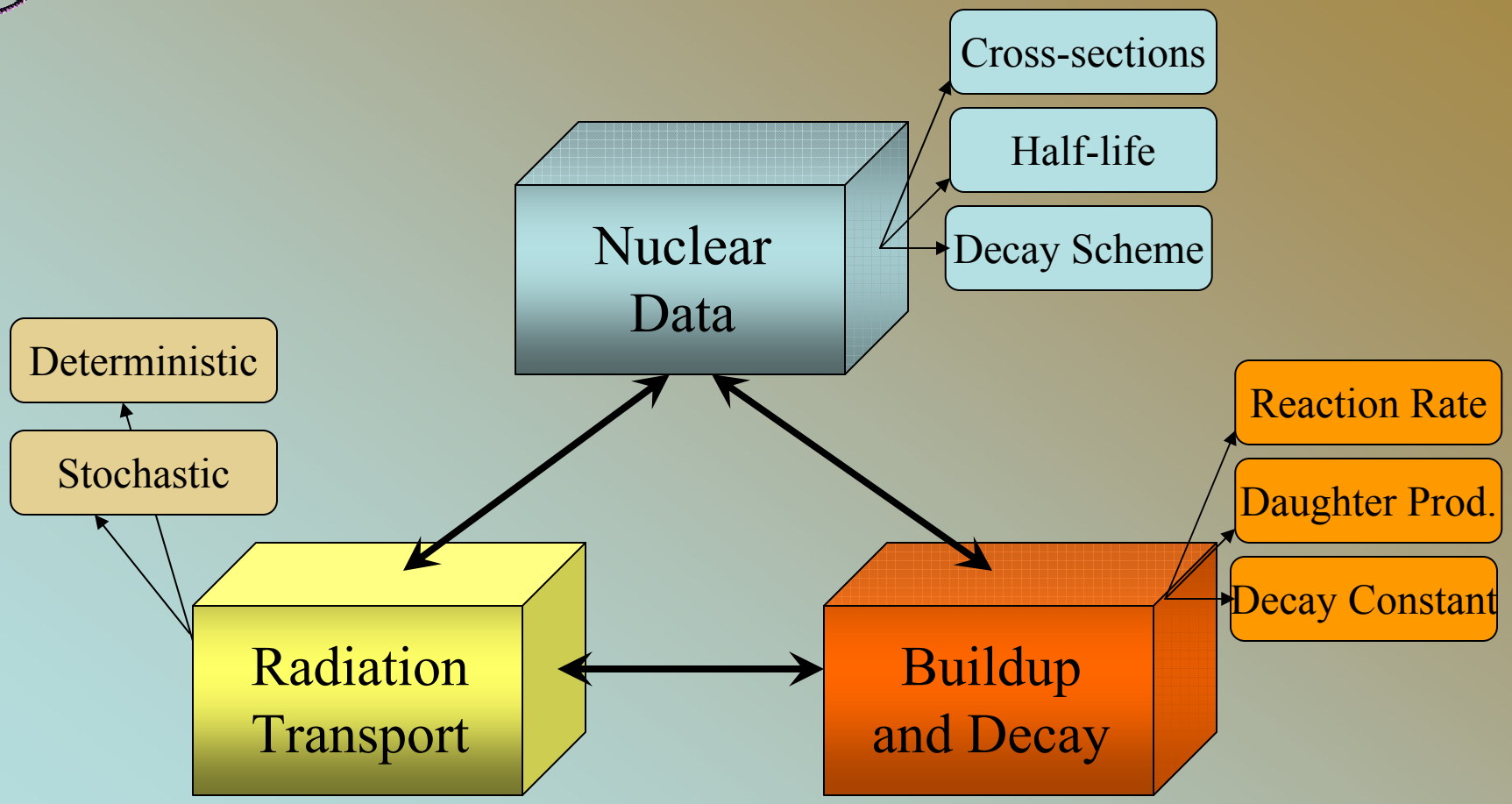
2. Characterize the thermal and epithermal neutron beams at the UT NETL
   - Talks are also on way for TAMU reactor

3. Characterize secondary radiation environment on the US and Russian space suit for EVA on ISS

Radiation: Characterization and Effects



Radiation Characterization



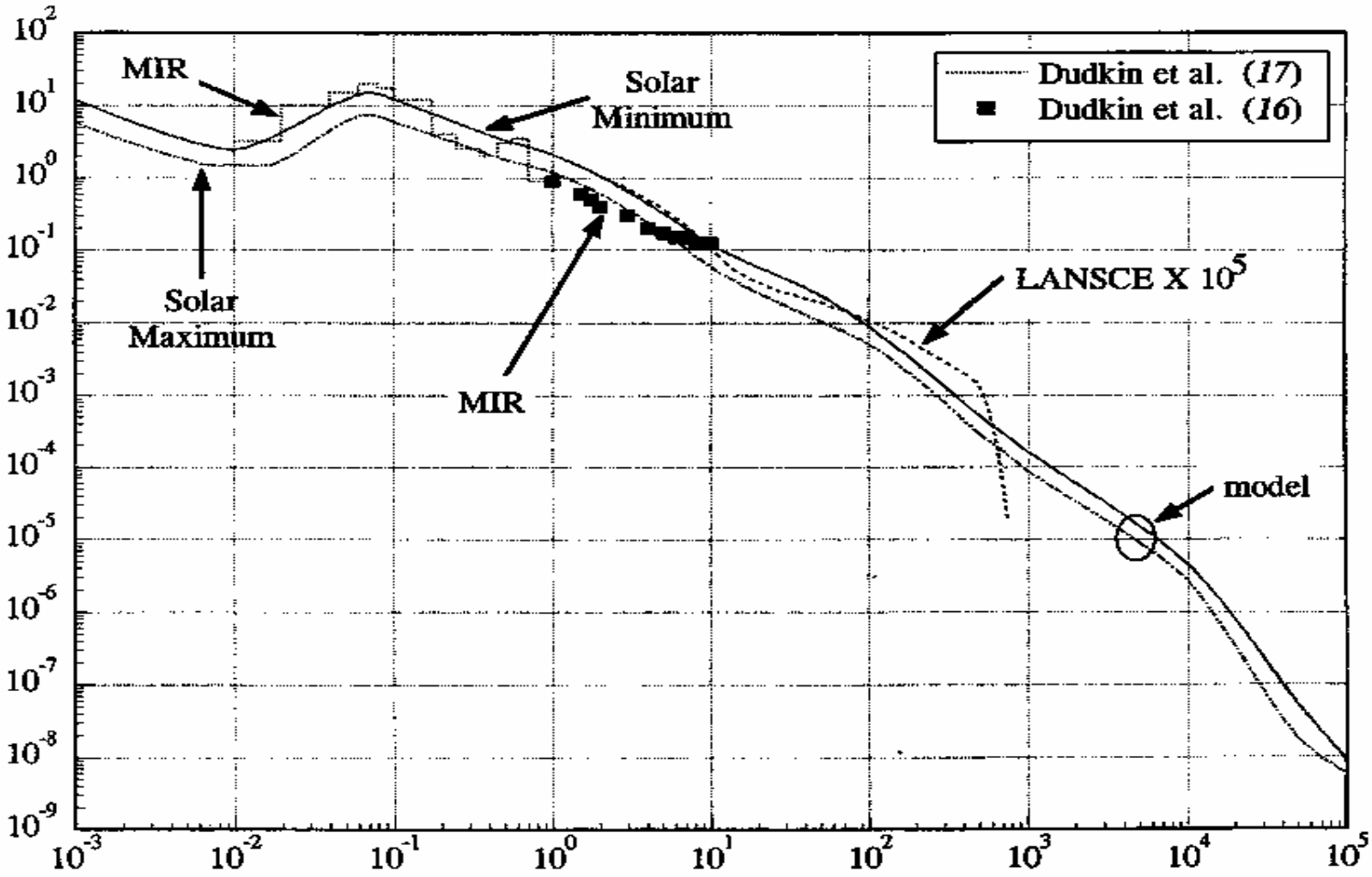
LANL: LANSCE Spectrum Characterization

- Characterize upper energy neutron beam (En > 10MeV) using n_TOF

- Characterize the lower energy neutron beam (En < 10MeV)
  - foil activation a challenge at low fluxes
  - TEPC does not have a good response at lower energy
  - n_TOF may not be well suited for lower energy due to pulse buildup
  - Bonner Sphere may be an option
    - Calibration and response function is a huge challenge
    - Equipment and data analysis is a long term project with funding commitment

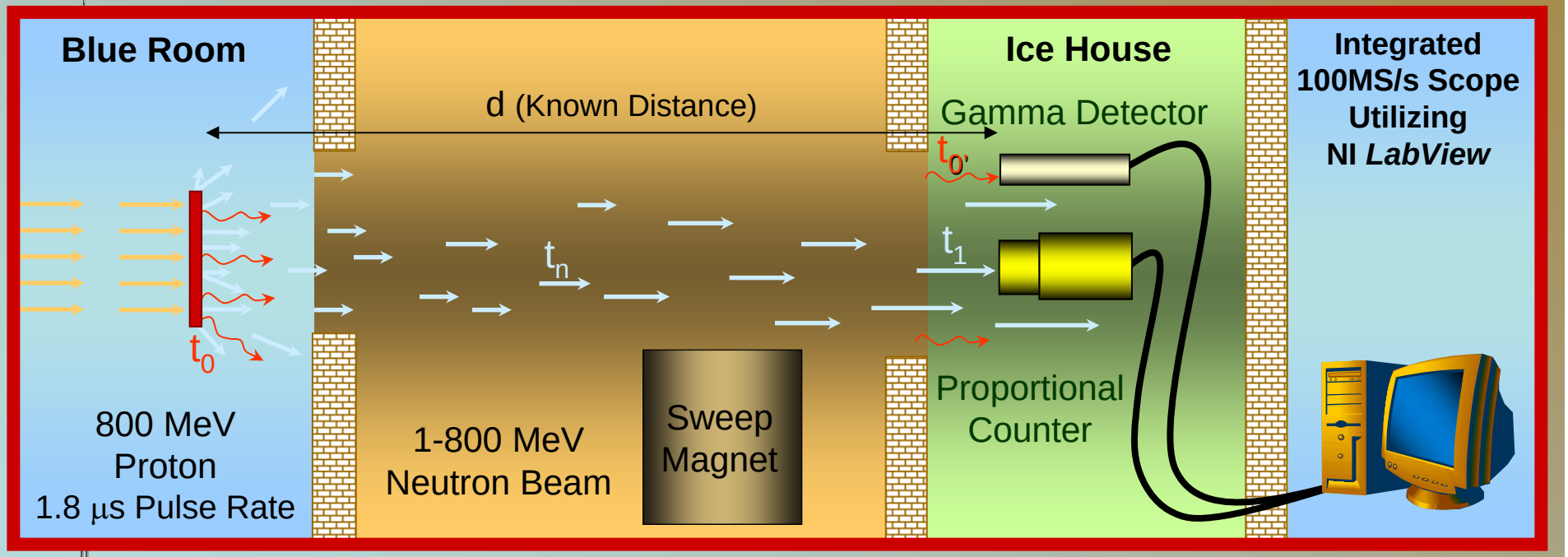
- Model the neutron beam using MCNPX

Recall the Neutron Spectrum at LEO



N_TOF at LANL: LANSCE

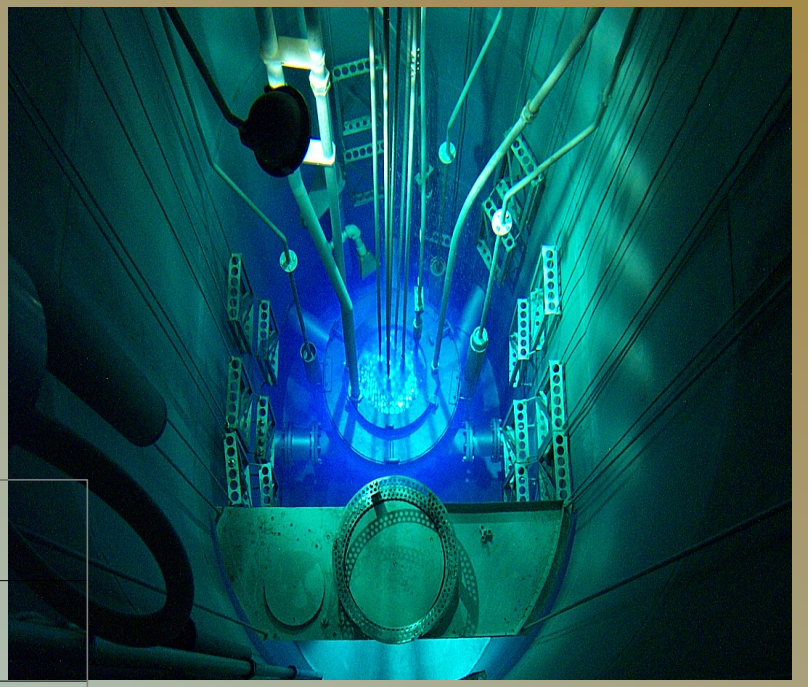
Experiment Set-Up (30L Beam line)

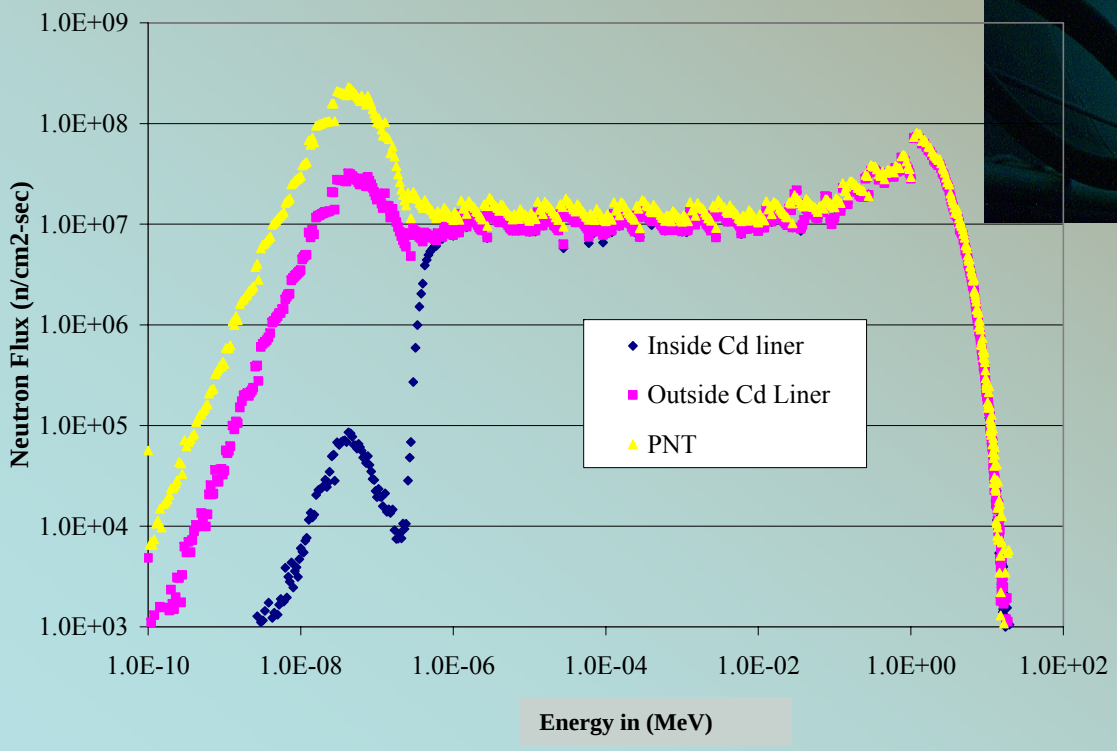


- Challenges:
  - Exact time estimation, t_o
  - Instrumentation and *LabView* interface
  - Potential detector saturation from gamma flash

Research Reactor Source of Neutrons

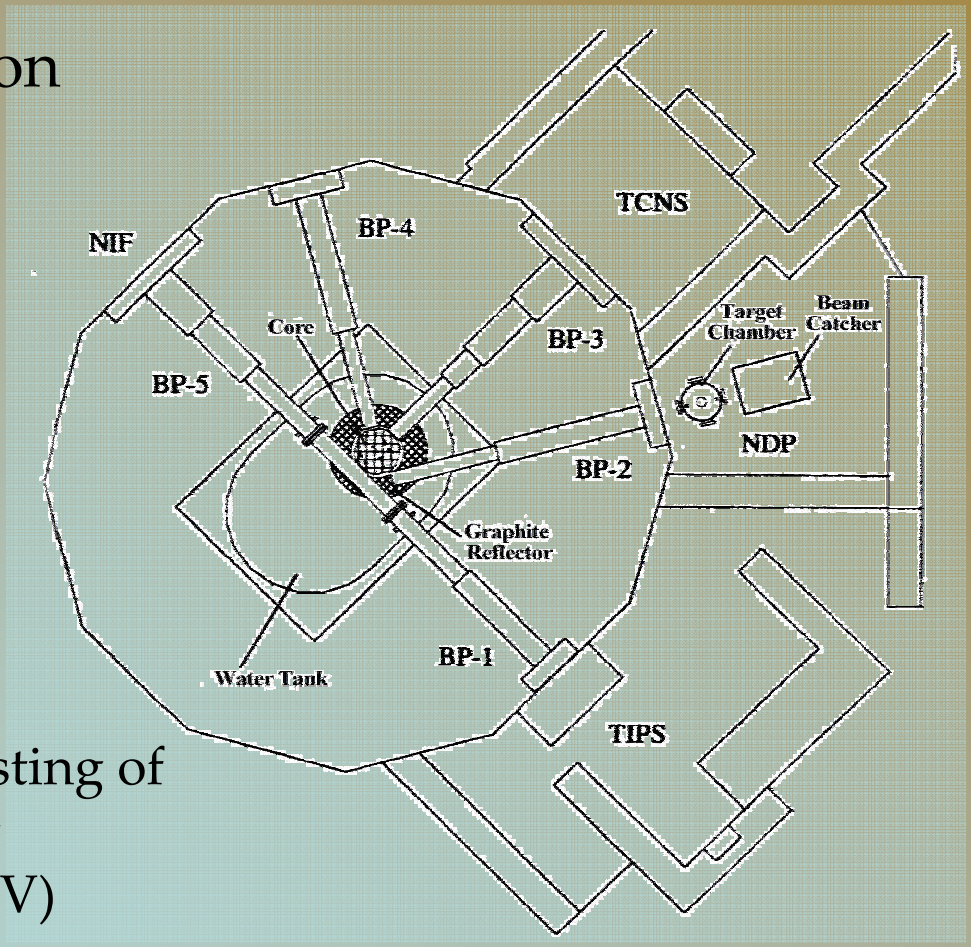
- Fission Neutron Spectrum
  - Spectrum can be characterized using standard foil activation techniques
  - Pulse mode operation could provide a means to test n_TOF at lower energies





Neutron Energy Spectrum at Different Locations

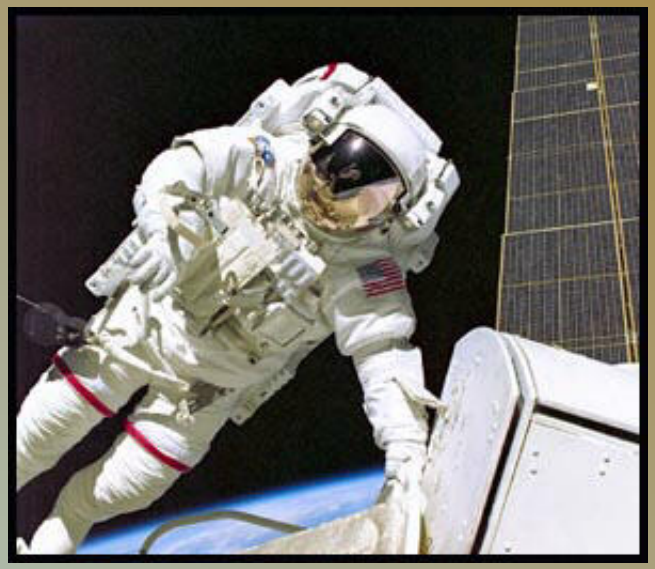
- Research Reactor Neutron Beam:
  - Higher neutron fluence
  - Student training and involvement
  - Close proximity and easy availability



- Experiments planned:
  - Materials performance testing of Moon and Mars Regolith at Epithermal (1 MeV – 20 MeV) neutron energies
  - Epithermal and Thermal neutron induced SEU in SRAM

Space Suits : Designed for extreme environment

- Temperature
  - direct sunlight: 248 ºF (120 ºC)
  - shade: -148 ºF (-100 ºC)
- Pressure
  - Maintain 1 atm
- Micrometeoroids
  - Maintain flexibility and dexterity



- Radiation
  - Primary and secondary radiation environment
    - Protons, electrons and neutrons
  - For International Space Station (ISS) construction astronauts are expected to spend 1000 hours EVA

Photo courtesy NASA

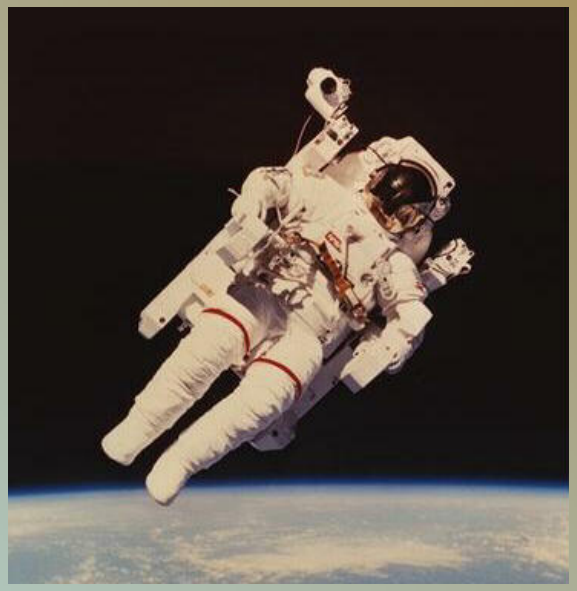
Secondary Radiation from Space Suit

- Goals:

1. Evaluate the secondary radiation coming from the space suit and helmet
2. Calculate the dose received by astronauts during EVA

- Purpose:
  - Plan future EVA
  - Design and improve new suits

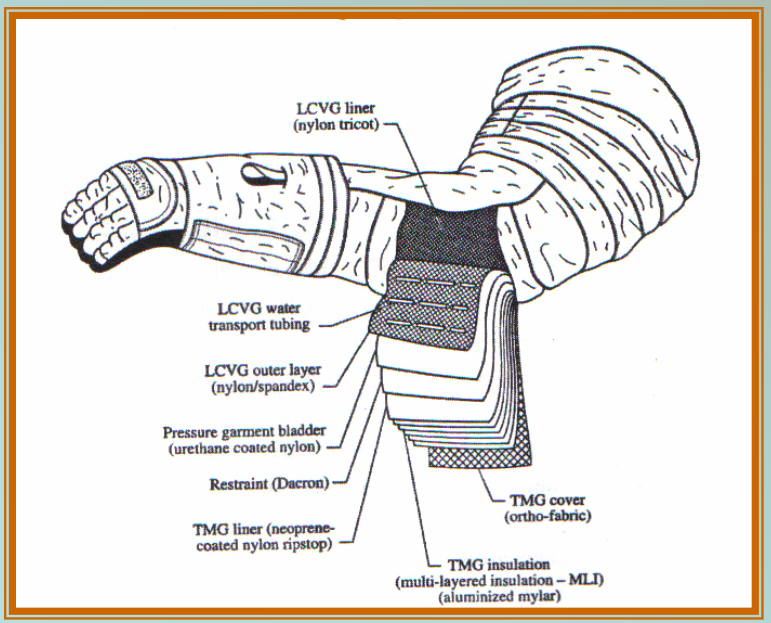
- Challenges:
  - Cross-sections data is limited for many materials at very high energies >150 MeV



Nuclear Data

Secondary Radiation from Space Suit (Cont.)

- Monte Carlo transport code MCNPX can be employed to simulate the secondary radiation environment
  - The US NASA space suit for space station consists of 12 layers of different materials
  - Addition complications from multiple components on the suit



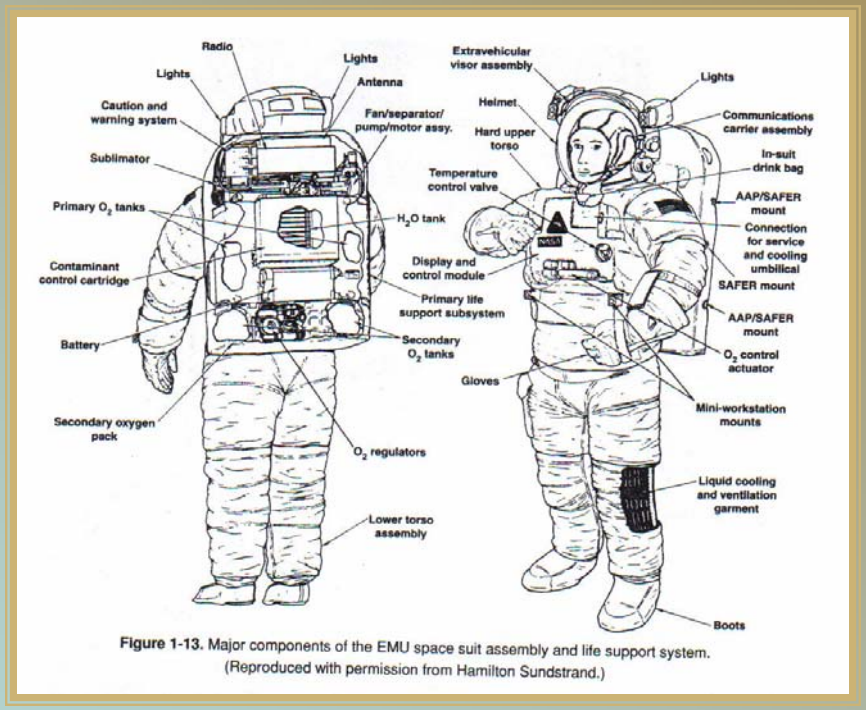
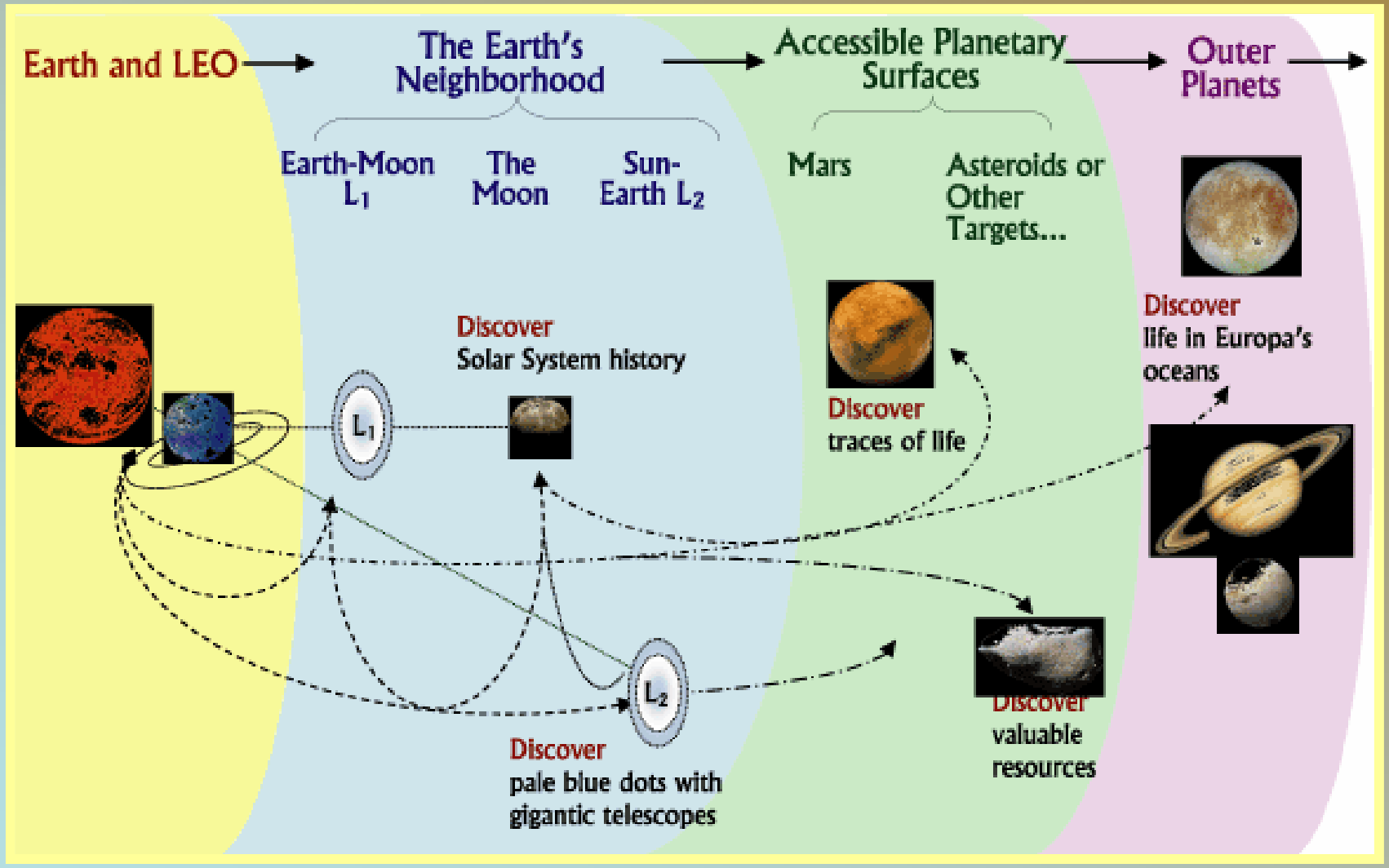


Figure 1-13. Major components of the EMU space suit assembly and life support system.
(Reproduced with permission from Hamilton Sundstrand.)

Collaboration

- *CARR does electron testing but the research emphasis has been reduced based on NASA needs*
  - Still involved with SEU work in advance electronics
- *CARR;s new focus is*
  - Radiation shielding,
  - Analysis of radiation effects in advance materials and
  - Radiation source characterization and microdosimetry using TEPC
- *Student internship*
- *Faculty internship*

NASA Long Term Vision



Reference: http://hedsadvprograms.nasa.gov/spaceexploration.html

Questions

NASA Groups

Shielding and Radiation Dosimetry:

• Dr. Frank Cucinotta, Space Radiation Health Program, Johnson Space Center

Materials:

• Dr. Sheila Thibeault, Advanced Materials and Processing Branch Structures and Materials Competency, Langley Flight Research Center

• Dr. Robert Singleterry and Dr. John Wilson, Structures and Materials Analytical and Computational Methods Branch, Radiation Physics Group, Langley Flight Research Center

Electronics & Environment:

• Dr. E.G. Stassinopoulos, Radiation Physics Group, Goddard Space Flight Center