PHYS 575 - Radiation and Detectors

Neutron Generation and Effects on Materials and Electronics

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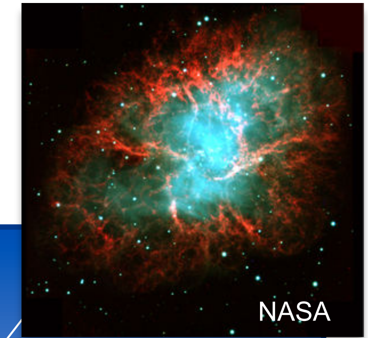
Outline

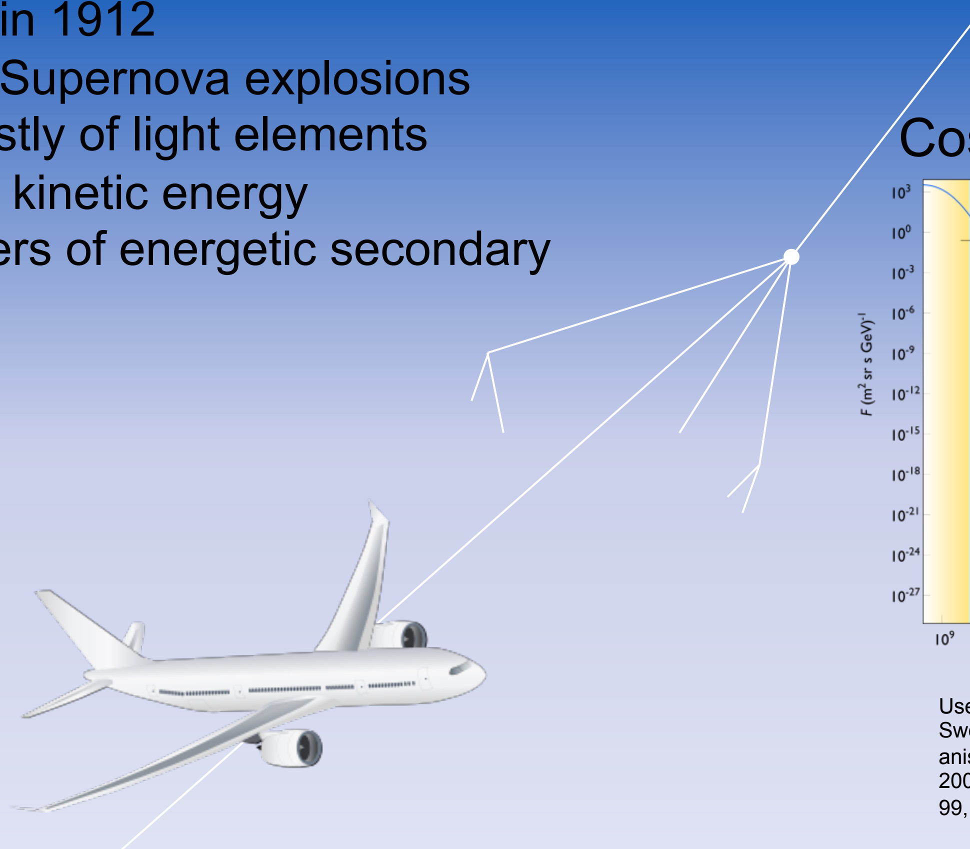
- **Setting the stage – cosmic rays to neutrons**
- **Single Event Effects (SEE)**
- **Neutron displacement damage**
- **Typical neutron sources**
- **Neutron Production**

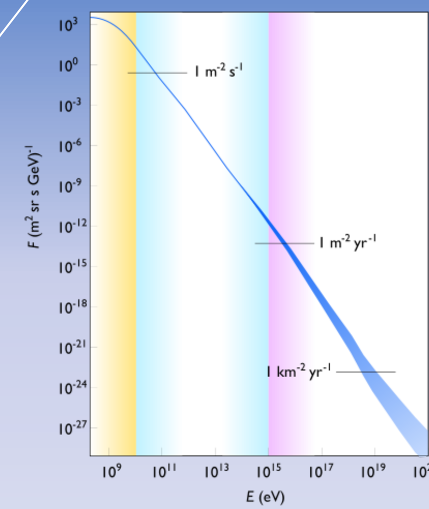
Setting the Stage



- Cosmic Rays
  - First observed in 1912
  - Originate from Supernova explosions
  - Composed mostly of light elements
  - Extremely high kinetic energy
  - Produce showers of energetic secondary particles

Cosmic Ray





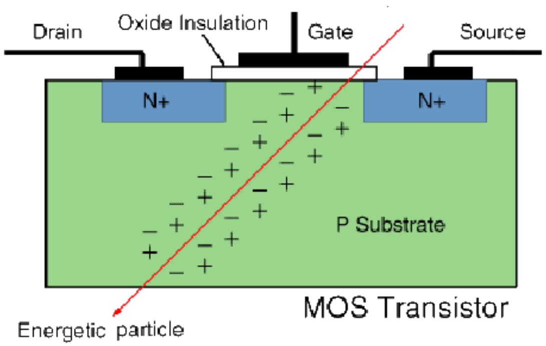
Used with permission. S. Swordy, The energy spectra and anisotropies of cosmic rays, 2001, Space Science Reviews 99, pp85–94

Single Event Effects (SEE) (CMOS or Bipolar)

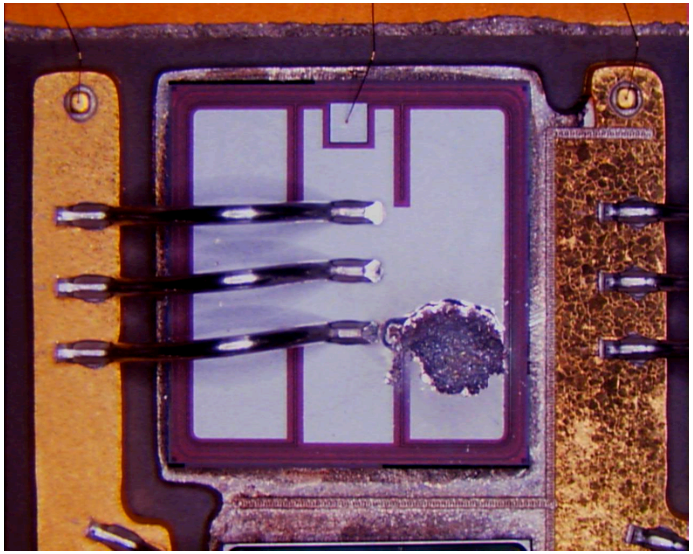
- **SEE has been known in the spacecraft industry since the ‘70s.**
- **Effects occur through direct ionization of single charged particles as they pass through (typically) silicon**
- **Neutron induced single event effects postulated in early 1980s by Boeing**
- **Verified in the late 1980s**
- **Neutrons do not ionize directly - events typically occur through secondary reactions**
  - Elastic scattering
  - Inelastic scattering
  - Thermal capture
- **Probabilistic**
  - Many neutrons (approx 1E6) to produce single interaction

Interaction of Neutron Induced Charged Particle on Silicon

- Secondary neutrons are uncharged so they don't generate ionization directly
- Neutrons interacts with atoms in an electronic device and energy is transferred to a recoiling ion which deposits charge in the surrounding atoms through ionization
- The probability for a SEE to occur is determined by testing the device for errors while being exposed to neutron beam
- Deposited charges result in a malfunction of the device



High voltage motor controller



Single Event Burnout

Neutron Displacement Damage (Bipolar)

- **Neutrons lose their energy in semiconducting materials by a nonionizing process**

- **In a nuclear collision a Silicon atom in the target is displaced**

- **Vacancies and Interstitials along with dopant and impurity atoms combine to form a variety of defects in semiconductor materials**

- **Defects negatively impact the function of semiconductor devices**

- **Transient (Short Term) Annealing**

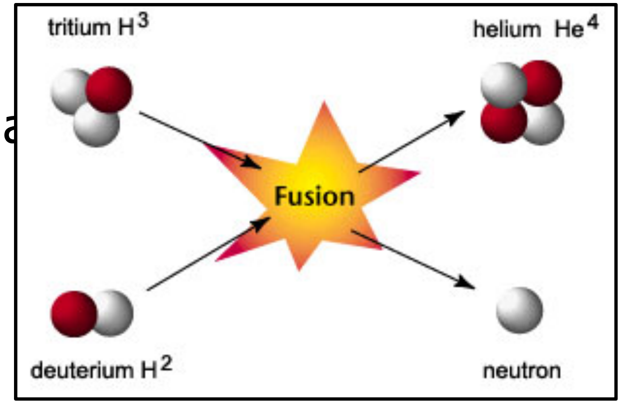
- **Long Term Annealing**

Typical Neutron Sources

- **Small Sized Devices**
  - Radioisotopes Which Undergo Spontaneous Fission
  - Radioisotopes Which Decay With Alpha Particles Packed In A Low-Z Elemental Matrix
  - Radioisotopes Which Decay With High Energy Photons Co-located With Beryllium or Deuterium
  - Sealed Tube Neutron Generators
- **Medium Sized Devices**
  - Plasma Focus and Plasma Pinch Devices
  - Inertial electrostatic confinement
  - Light Ion Accelerators
  - High Energy Bremsstrahlung Photoneutron/photofission Systems
- **Large Sized Devices**
  - Nuclear Fission Reactors
  - Nuclear Fusion Systems
  - High Energy Particle Accelerators

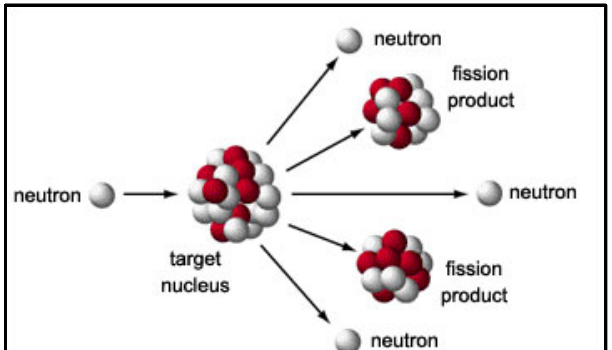
How Neutrons are Produced

Nuclear Fission Basics, http://www.atomicarchive.com/Fusion/Fusion1.shtml



Fusion

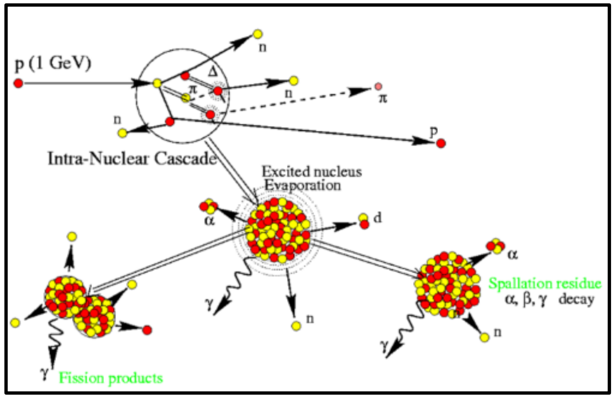
$_3$H ($_2$H, n) $_4$☞♏ ◆♒♏❒♏ T is struck by D a
results in a n + α



Nuclear Fission Basics, http://www.atomicarchive.com/Fission/Fission1.shtml

Fission

$_{235}$U (n, xn) heavy fragments where $_{235}$U is struck by a n and splits with xn neutrons (typically x=2.3)



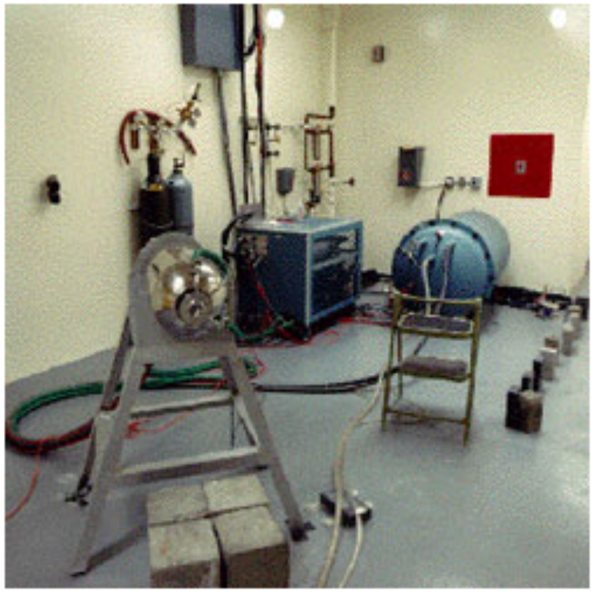
J.-C.David, "IAEA Benchmark of Spallation Models", https://www-nds.iaea.org/spallations/

Spallation

W (p, xn) heavy fragments where tungsten is stuck by a energetic proton and splits with xn of energetic neutrons + heavy fragments

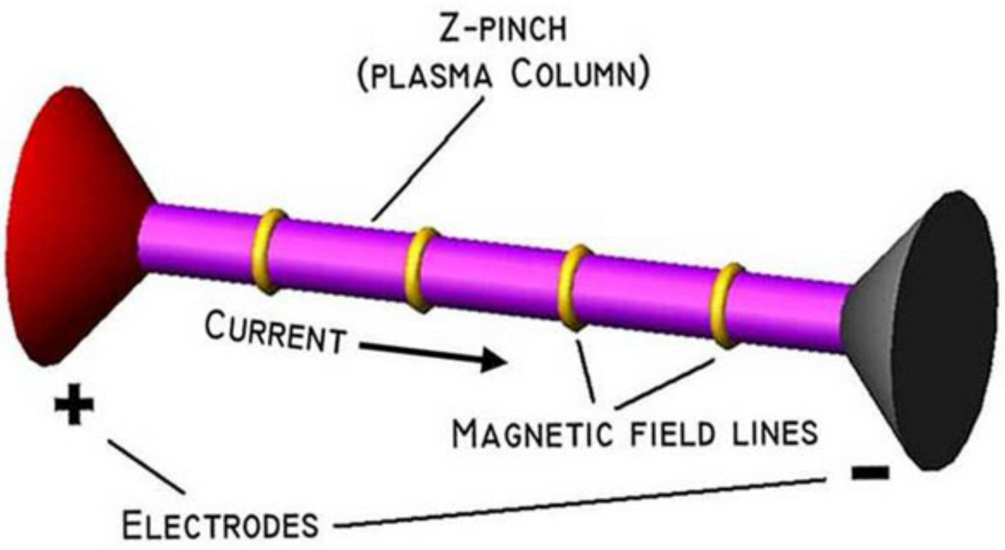
Boeing Sealed Tube Neutron Generator

- **Type of Simulator**
  - Kaman Sciences 14-MeV Neutron Generator
  - Deuterium-Tritium (D-T) Reaction
- **Application**
  - Neutrons for TREE, SEE, neutron damage studies and activation analysis.
- **Test Object Size**
  - Variable, depending on application
- **General Description**
  - The facility consists of a Kaman Sciences neutron generator (accelerator type) that can produce high fluxes of nominally 14-MeV neutrons.
  - Dosimetry support is available and operating parameters are flexible.
- **Technical Characteristics**
  - Neutron flux (max) > 1.0x10^10 n/cm^2-s
  - Target area (max) limited only by room and doorway
- **Special Features & Requirements**
  - High-flux source of monoenergetic neutrons



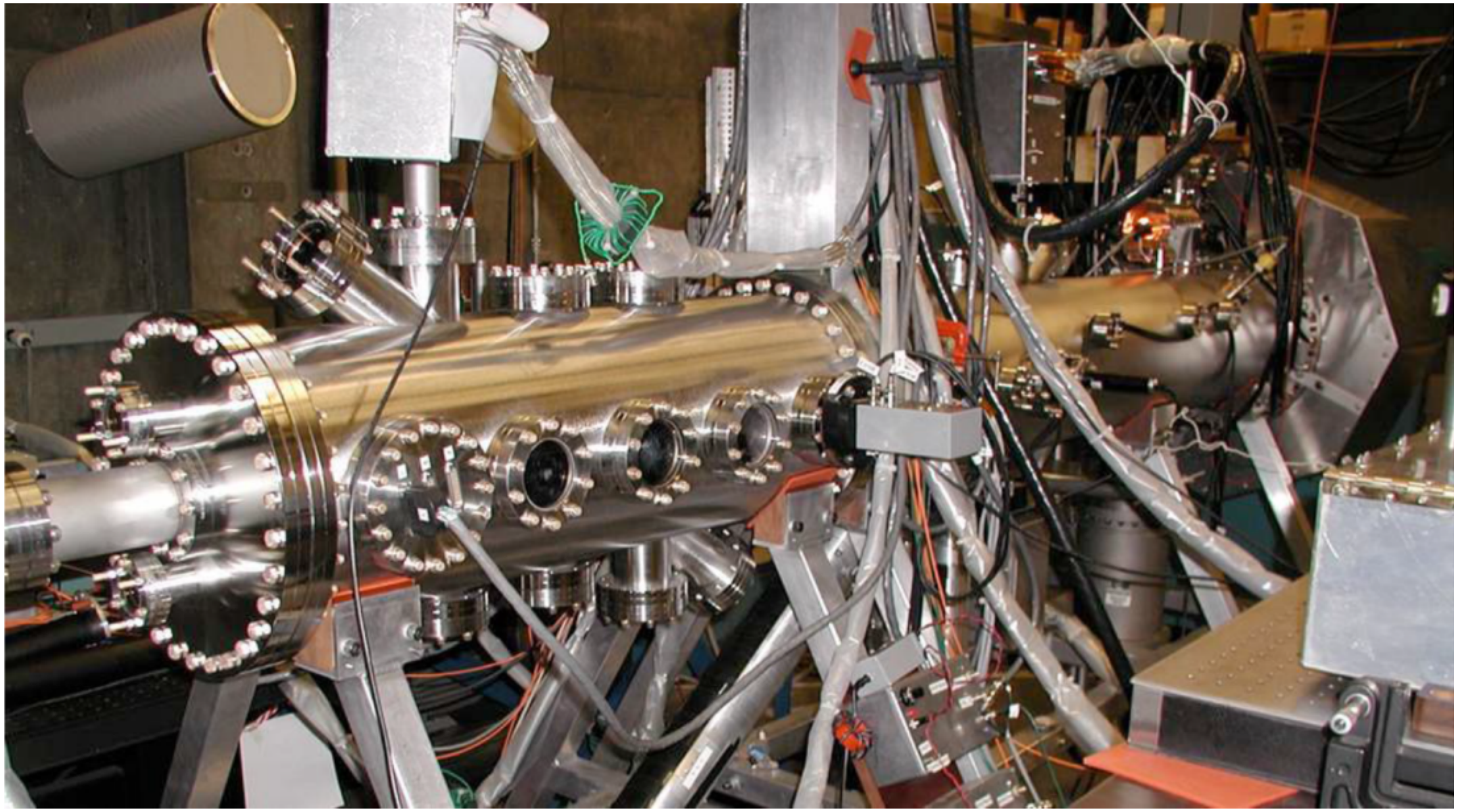
Plasma Pinch Neutron Generator

- **Z-pinch refers to a classic plasma configuration in which a plasma column is self contained by running high current through it**
  - System uses the electrical current in the plasma to generate a magnetic field that compresses the plasma
- **Stable z-pinches have implications for neutron generation and energy production and thrust generation**
- **Neutrons are 14.1 MeV and generated by fusing D-T**



UW Plasma Pinch Experiments

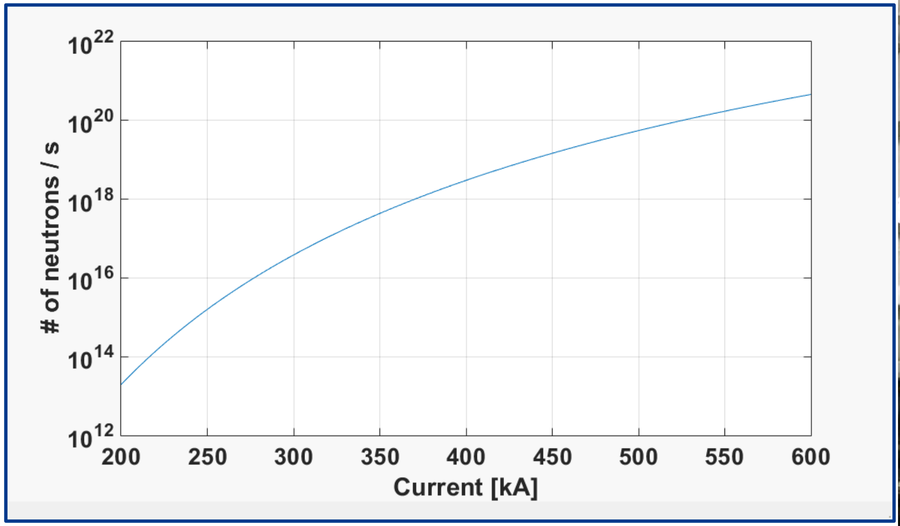
- **UW has an experiment called ZaP looking into stabilization of z-pinch plasmas using sheared flow for DOE energy production**



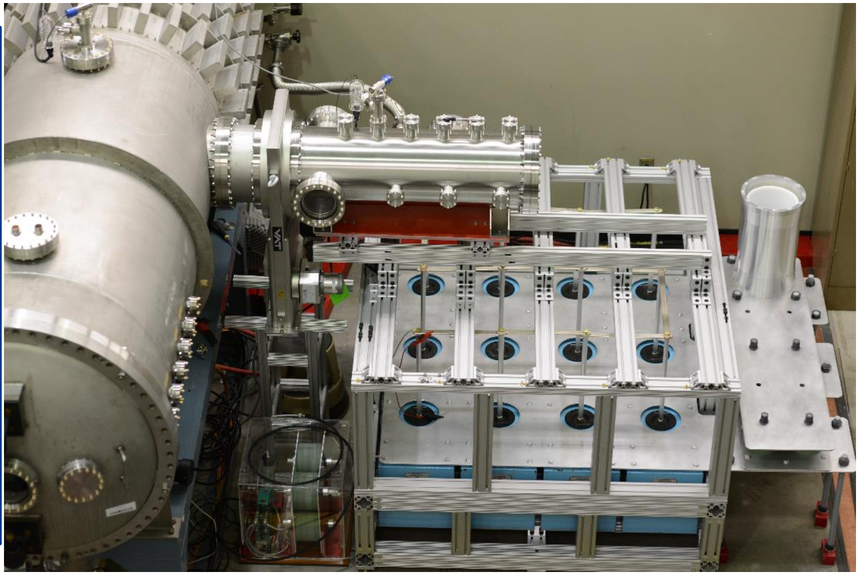
UW ZAP Setup

Boeing Plasma Pinch Development

- **Boeing is in the process of developing their own z-pinch for testing neutron generation technology and other applications**



Neutrons vs. Current



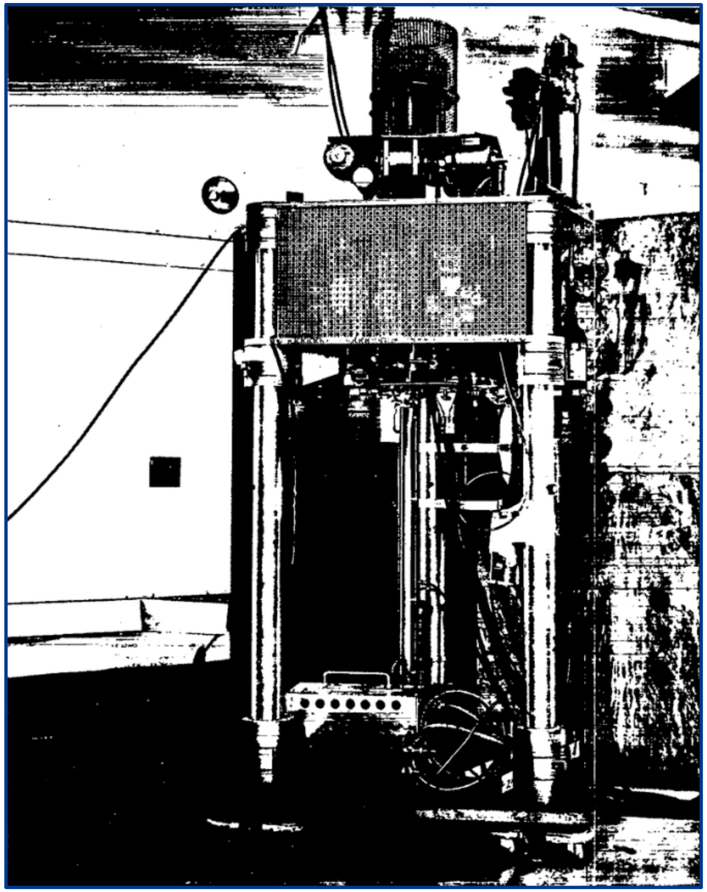
Boeing Z-Pinch

Lady Godiva Pulsed Reactor

- Experimenters produced bursts of gamma rays and neutrons:
- The three parts were brought together to form a sphere of $_{235}$U, forming a critical mass
- The center piece holds two control rods to moderate the reaction
- The bottom hemisphere was raised manually and then the top hemisphere is dropped to create a brief or pulsed nuclear chain reaction.
- This image shows it in the safe, scrammed, state.

White Sands Missile Range Godiva-II Reactor

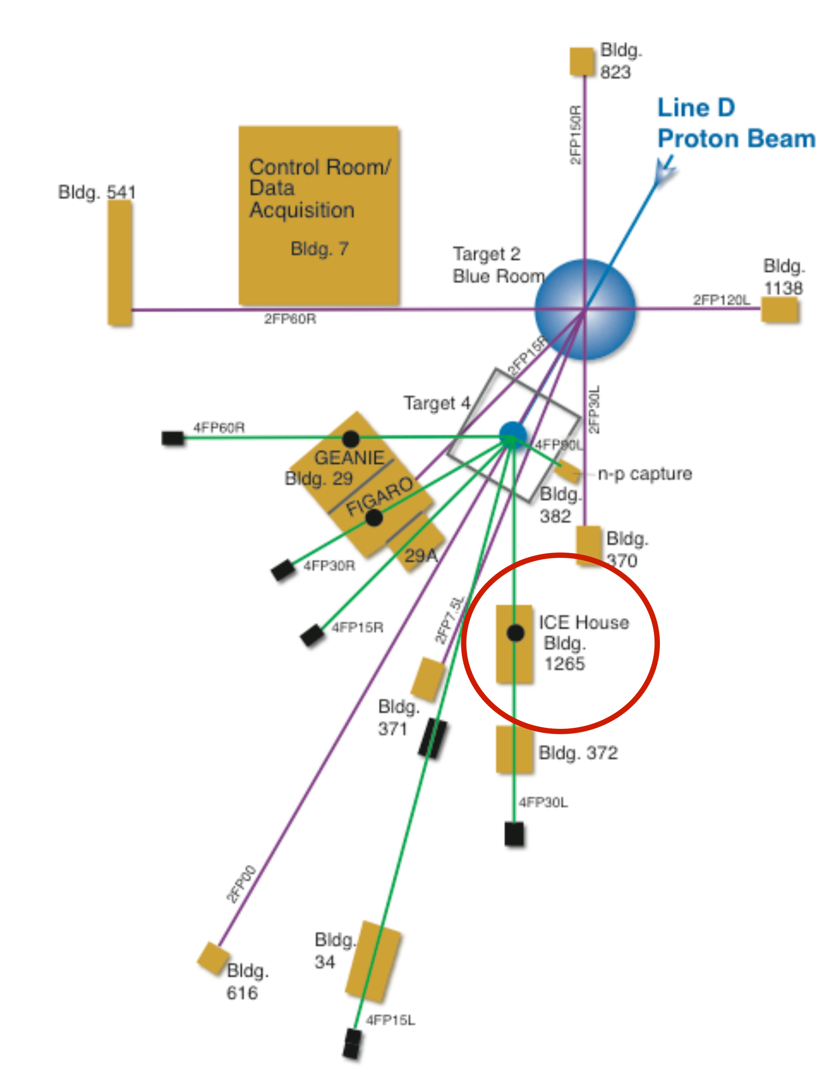
- **Pulsed Fission Molly-G Godiva Type Re-ac-tor**
- **Lower Energy Neutrons Centered Around 1MeV**
- **Primarily Used for Displacement Damage**



LANSCE Neutron and Nuclear Science (WNR) Facility

- **800 MeV proton hits tungsten cylinder**
- **Neutron beams with energies ranging from approximately 0.1 MeV to greater than 600 MeV.**
- **Neutron SEE testing done at Ice House part of this facility**
- **Neutron spectrum very similar to that of neutrons produced in the atmosphere by cosmic rays**
  - Neutron flux a million times higher.
  - This large flux allows testing of semiconductor devices at greatly accelerated rates.

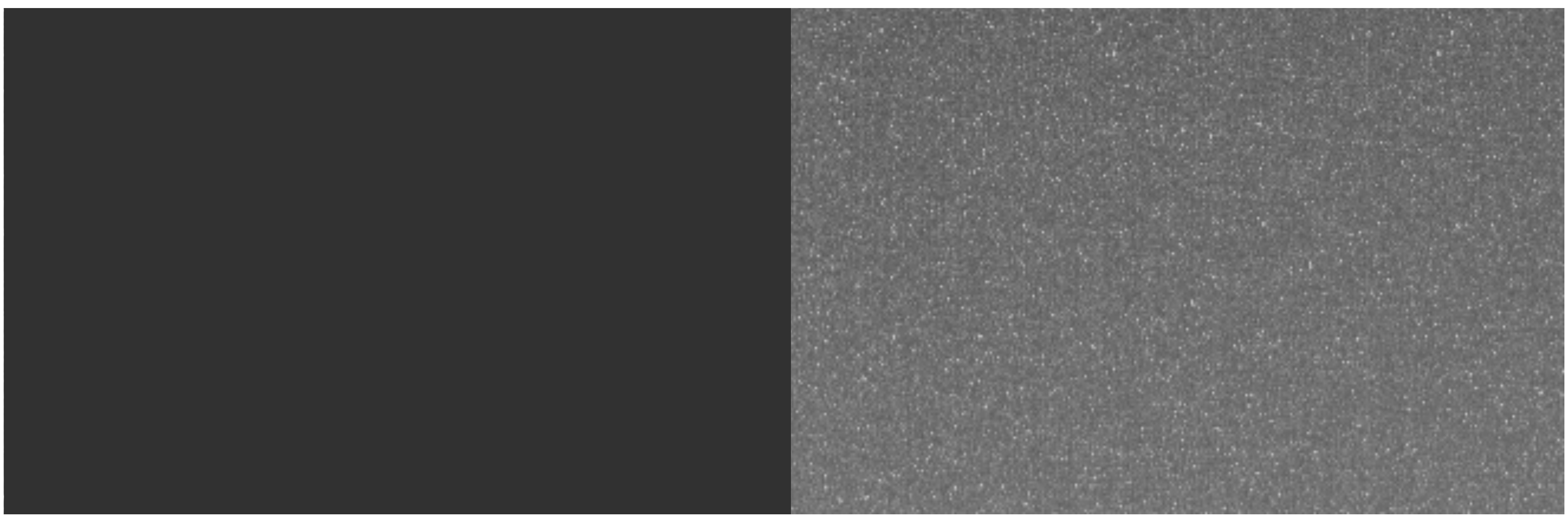
The layout of the flight paths at the LANSCE neuron sources.



A schematic drawing of the Target-2 and Target-4 flight paths.

Summary

- **Neutron Testing is used to qualify CMOS and Bipolar technologies in intense neutron environments**
- **This testing is necessary in order to minimize the effects of displacement and SEE neutron damage on critical components**
- **There is a range of different neutron generation techniques that are required in order to meet testing requirements**
- **Some of these techniques are still in the development phase**



CCD array before and after long term exposure to neutrons