Introduction

- Neutron Effects
  - –Displacement Damage
  - –NSEU
  - –Total Ionizing Dose
- Neutron Testing Basics
- User Requirements
- Conclusions

Neutron Effects: Displacement Damage

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

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

- Vacancies and Interstitials along with dopant and impurity atoms combine to form a variety of defects in semiconductor materials
  - Divacancy
  - Defect-impurity clusters
  - Vacancy-phosphorus pair (E center)

- Defects negatively impact the function of semiconductor devices

Neutron Effects: Displacement Damage

- Transient (Short Term) Annealing
    - Recombination of Interstitials and Vacancies
    - Reordering of Defects
    - Begins with onset of radiation
    - Complete in minutes to hours

- Long Term Annealing
    - Decades to complete
    - Defect migration

Neutron Effects: Neutron Induced Single Event Effects (NSEE)

- Neutron Induced Single Event Effects
  - Passage of a neutron spallation recoil through a sensitive junction
  - Mechanism is similar to that for Proton SEU

- Neutron Single Event Upset (NSEU)

- Neutron Single Event Burnout (NSEB)

- Neutron Single Event Latchup (NSEL)

- Others

Neutron Effects: Total Ionizing Dose (TID)

- As neutrons have no charge they are a form of non-ionizing radiation

- Neutrons cannot induce TID damage directly
    - Secondaries from spallation reaction can ionize material

- Much smaller impact than displacement damage effects

Neutron Testing Basics

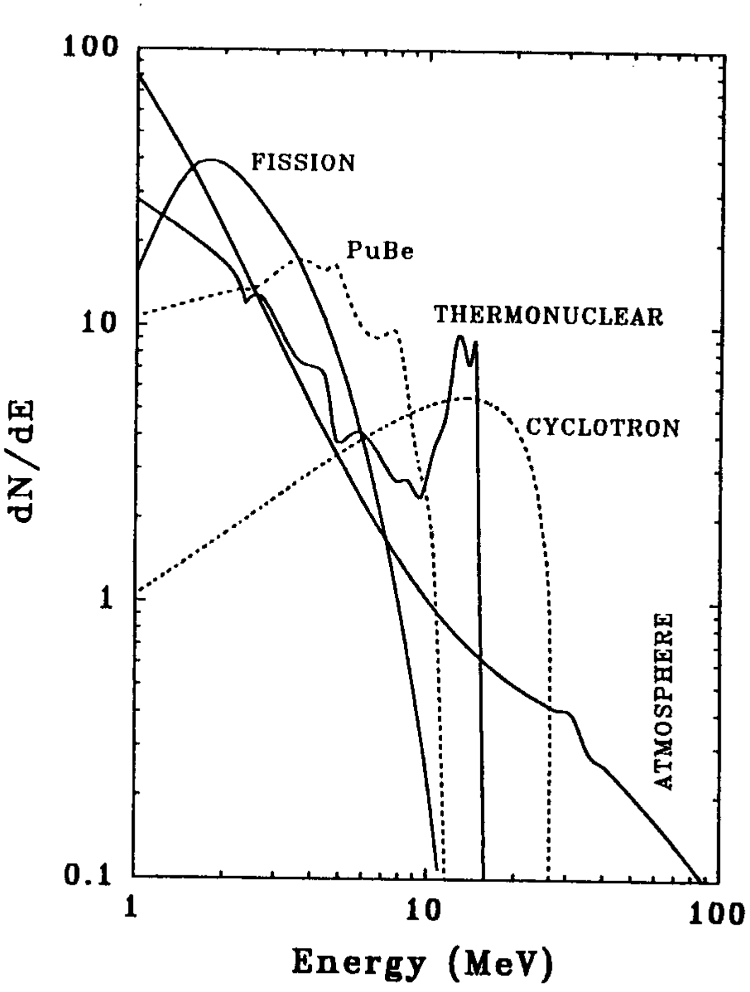
- Neutron Displacement Damage Testing
  - Initially characterize electronic parts
  - Package parts for shipment to test facility
  - Parts are then irradiated to a set flux
    - Flux is set by the program office
  - Parts are shipped back to lab
  - Parts are then tested for functional failure

- Neutron Single Event Testing
  - Similar to Proton SEE testing
  - Test is On-site
  - Shielding of test equipment is a requirement

- Devices can become radioactive (Activated) during irradiation

User Requirements

- Aerospace and Ground environment
  - Atmospheric
- Strategic Environment
  - Weapons Spectrum
- Space
  - Results from scattering



From J.R. Letaw and E. Normand, "GUIDELINES FOR PREDICTING SINGLE-EVENT UPSETS IN NEUTRON ENVIRONMENTS," IEEE Trans. Nucl. Sci., NS-38 (6), 1500-1506 (1991)

User Requirements

- Neutron fluence. The neutron fluence used for device irradiation shall be obtained by measuring the amount of radioactivity induced in a fast-neutron threshold activation foil such as 32S, 54Fe, or 58Ni, irradiated simultaneously with the device. A standard method for converting the measured radioactivity in the specific activation foil employed into a neutron fluence is given in the following Department of Defense adopted ASTM standards:

• E263	Standard Test Method for Measuring Fast-Neutron Flux by Radioactivation of Iron.
• E264	Standard Test Method for Measuring Fast-Neutron Flux by Radioactivation of Nickel.
• E265	Standard Test Method for Measuring Fast-Neutron Flux by Radioactivation of Sulfur.

User Requirements

- The conversion of the foil radioactivity into a neutron fluence requires a knowledge of the neutron spectrum incident on the foil. If the spectrum is not known, it shall be determined by use of the following DoD adopted ASTM standards, or their equivalent:

• E720	Standard Guide for Selection of a Set of Neutron-Activation Foils for Determining Neutron Spectra used in Radiation-Hardness Testing of Electronics.
• E721	Standard Method for Determining Neutron Energy Spectra with Neutron-Activation Foils for Radiation-Hardness Testing of Electronics.
• E722	Standard Practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics.

User Requirements

- Once the neutron energy spectrum has been determined and the equivalent monoenergetic fluence calculated, then an appropriate monitor foil (such as 32S, 54Fe, or 58Ni) should be used in subsequent irradiations to determine the neutron fluence as discussed in E722. Thus, the neutron fluence is described in terms of the equivalent monoenergetic neutron fluence per unit monitor response. Use of a monitor foil to predict the equivalent monoenergetic neutron fluence is valid only if the energy spectrum remains constant.

- If absorbed dose measurements of the gamma-ray component during the device test irradiations are required, then such measurements shall be made with CaF2 TLDs, or their equivalent. These TLDs shall be used in accordance with the recommendations of the following DoD adopted ASTM standard:

    - E668 Standard Practice for the Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices.

User Requirements

- The test devices and dosimeters shall be exposed to the neutron fluence as specified. The exposure level may be obtained by operating the reactor in either the pulsed or power mode. If multiple exposures are required, the post-irradiation electrical tests shall be performed (see 3.5.1) after each exposure. A new set of dosimeters are required for each exposure level. Since the effects of neutrons are cumulative, each additional exposure level will have to be determined to give the specified total accumulated fluence. All exposures shall be made at 20°C ±10°C and shall be correlated to a 1 MeV equivalent fluence.

Conclusions

- Dosimetry

- Reliability
  - Facility must be operational for long periods of time
  - Facility must be able to repeatedly meet target fluxes (±20%)

- Cost