Verify that this is the correct revision before use

Compliance is Mandatory

HIGH ENERGY/LET RADIATION EEE PARTS CERTIFICATION HANDBOOK

Responsible Office:
Engineering Directorate – Avionic Systems Division

HIGH ENERGY/LET RADIATION EEE PARTS CERTIFICATION HANDBOOK

Prepared by

/s/ Brandon Reddell

Brandon Reddell, Ph.D.
Engineering Directorate, Avionic Systems Division

Approved by

/s/ Greg Blackburn for

Pat Pilola
Division Chief, Avionic Systems Division

Approved by

/s/ Danny Punch

Danny Punch,
Chair, JSC Technical Standards Control Board

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-	07-001
Effective Date:	March 22, 2012
Expiration Date:	March 22, 2017

Page: 3 of 27

TABLE OF CONTENTS

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
                  Page: 4 of 27

LIST OF FIGURES

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 5 of 27

Change History Log

Revision	Date	Originator	Description of Changes
Basic	March 2012	Brandon Reddell	Initial Release

1.0   SCOPE

Certifying electronic components is a very involved process. It includes pre-coordination with the radiation test facility for time, schedule and cost, as well as intimate work with designers to develop test procedures and hardware. It also involves work with radiation engineers to understand the effects of the radiation field on the test article/setup as well as the analysis and production of a test report. The technical content of traditional ionizing radiation testing protocol is in wide use and generally follows established standards (ref. Appendix C). This document is not intended to cover all these areas but to cover the methodology of using Variable Depth Bragg Peak (VDBP) to accomplish the goal of characterizing an electronic component.

The Variable Depth Bragg Peak (VDBP) test method is primarily used for deep space applications of electronics. However, it can be used on any part for any radiation environment, especially those parts where the sensitive volume cannot be reached by the radiation beam. An example of this problem would be issues that arise in de-lidding of parts or in parts with flip-chip designs, etc.

The VDBP method is ideally suited to test modern avionics designs which increasingly incorporate commercial off-the-shelf (COTS) parts and units. Johnson Space Center (JSC) developed software provides assistance to users in developing the radiation characterization data from the raw test data.

1.1   Purpose

The purpose of this document is to provide an overview of the VDBP method and to provide test procedure guidelines to the user who chooses to implement this method over traditional heavy ion methods.

1.2   Applicability

This standard is applicable to all NASA JSC organizations including Ellington Field, the Sonny Carter Training Facility, and the White Sands Test Facility.

This handbook is applicable to any projects using the VDBP to test electronics and use of the supplied software to analyze the results. This method is usable for the electronics on all deep space missions.

1.3   Conventions

The specifics of the test and analysis procedures for VDBP will be discussed along with technical aspects of the methodology.

1.4   Measurement / Verification

Technical compliance to the methods described in this handbook will be verified by the successful completion of a Test Readiness Review prior to test activity.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 7 of 27

1.5   Cancellation / Rescission

Upon issuance of this handbook, no documents are cancelled:

2.0   REFERENCES

The latest issuances of cited documents shall apply unless specific versions are designated.

2.1   Applicable Documents

N/A

2.2   Resolving Conflicts

N/A

2.3   Reference Docs

Additional informative references are located in APPENDIX B .

3.0   ACRONYMS, TERMS, AND DEFINITIONS

Specialized terms, acronyms, and definitions used in this document are defined in APPENDIX A

High Energy/LET Radiation EEE Parts
Certification Handbook

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 8 of 27

4.0   SPACE RADIATION ENVIRONMENT

4.1   Overview

High energy heavy ions are required to test electronic parts for deep space environments since they will be encountered on deep space missions. Figure 4-1 shows the background galactic cosmic ray (GCR) environment computed from the Badhwar-O'Neill GCR model (reference APPENDIX B).
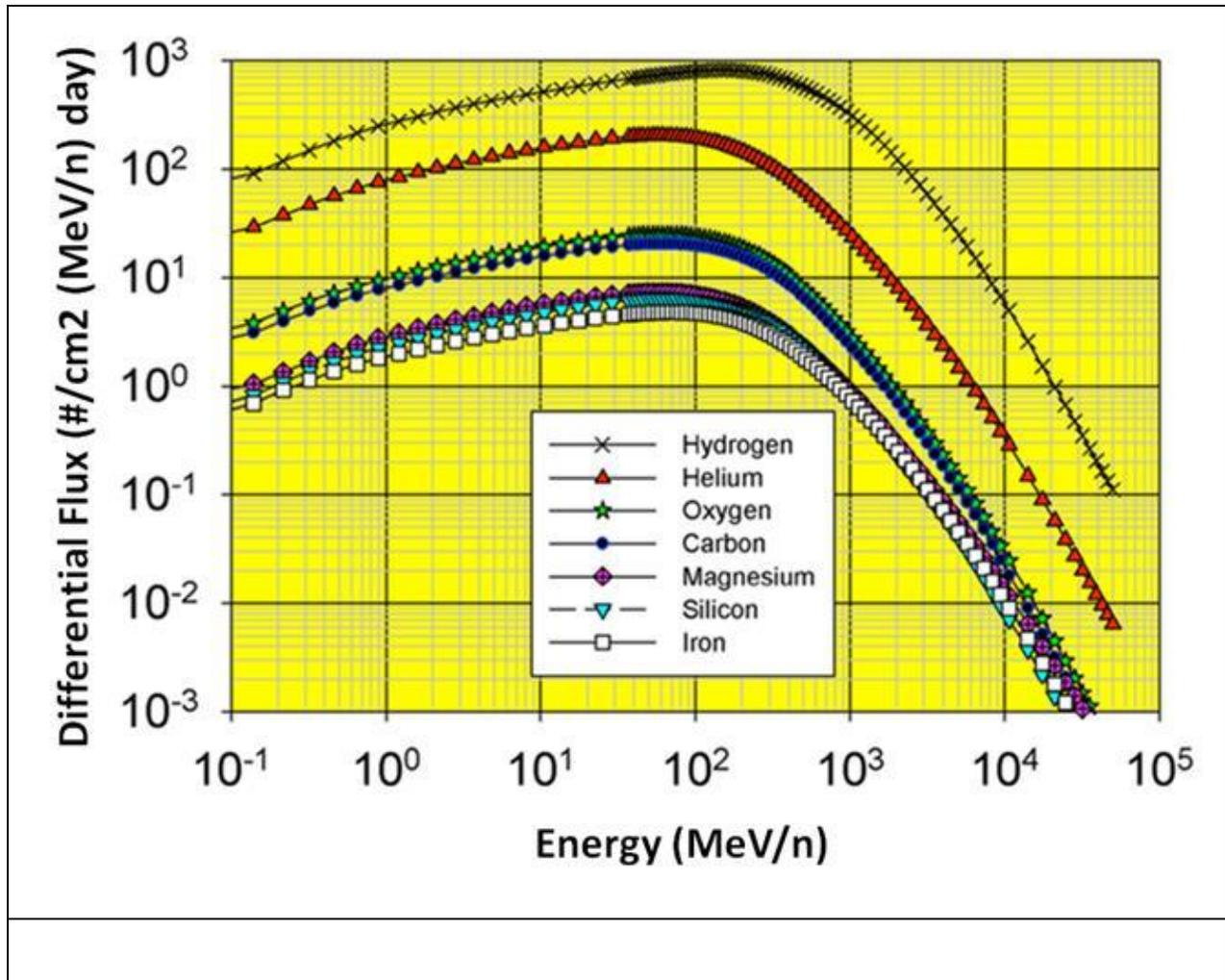
Figure 4-1   The Most Abundant Elements in the Galactic Cosmic Ray Environment

As can be seen from Figure 4-1, the range of energies of the particle extends over seven orders of magnitude. The fluxes peak around 100-200 MeV/n, however a significant flux of higher energies exist and can easily penetrate typical spacecraft shielding. These particles pose the greatest threat to active electronics.

Figure 4-2 shows the full GCR differential spectrum as a function of Linear Energy Transfer (LET). All observed elements in the natural spectrum (up to Iron) and extrapolated up to Uranium are included in the plot. Also shown is the modified GCR behind 1 inch of aluminum shielding. The

High Energy/LET Radiation EEE Parts
Certification Handbook

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 9 of 27

shielding attenuates the spectrum only slightly showing that shielding doesn't have much effect in shielding GCRs. The NASA Space Radiation Laboratory (NSRL) gold beam can simulate most of the LET spectrum, ranging from approximately 24-86 MeV-cm2/mg.
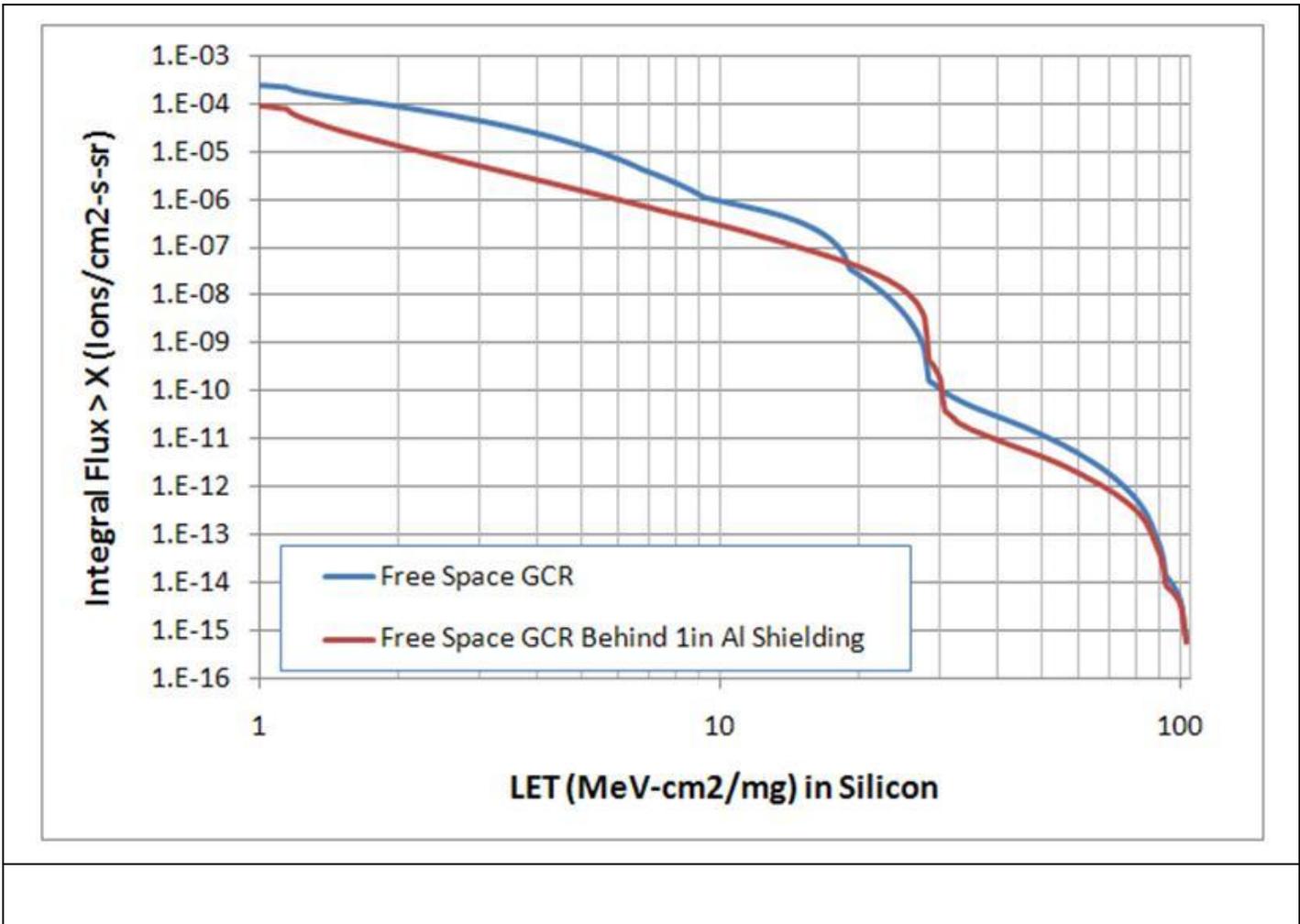
Figure 4-2   Differential Galactic Cosmic Ray Spectrum in Free Space and Behind 1 Inch of Aluminum Shielding

4.2   Induced Ionizing Radiation Environments

To date, traditional test facilities in the U.S., such as the Texas A&M Cyclotron Facility and the Lawrence Berkeley National Laboratory, only offer low energy heavy ion beams with energies in the range of 10-40 MeV/n. NSRL offers beams more much higher energy beams, 100-300 MeV/n, closer to what is expected in space. These energies are at or near the peak flux occurring in space. NSRL also provides the user with the ability to degrade the beams down (in energy/velocity) in order to position the Bragg Peak on sensitive areas in EEE parts.

5.0   General Design Considerations

5.1   Requirements for Resistance to Radiation

Avionics used in space are designed and certified to meet performance and reliability requirements while operating within the ionizing radiation environment of deep space. Both crewed vehicles and satellites must be able to meet mission goals while in the deep space environment considering both temporary and permanent failures of electronics due to ionizing radiation. Gathering the data required to make good decisions concerning electronic part performance in the ionizing radiation environment is time consuming and costly. The specific temporary and permanent failures will be described in Sections 6.1-6.5. The deep space environment is described in Section 4.1 .

5.2   Design Criteria

Spacecraft systems must be designed to perform satisfactorily while in the ionizing radiation environment. This may include mitigation of Single Event Upsets (SEU) and Single Event Latchup (SEL) and elimination of SEL or Single Event Gate Rupture (SEGR) in parts critical to mission success. Overall, an end-to-end approach to controlling ionizing radiation effects is required to achieve a successful design.

6.0   POTENTIAL EFFECTS OF RADIATION ON ELECTRONICS

Ionizing radiation can have a variety of effects on electronics. The effects fall into two categories: Single Event Effects (SEE) and total ionizing dose (TID) effects. SEEs are defined as a destructive or non-destructive effect caused by a single ionized particle. This term refers to a broad category of phenomena that are defined below. TID is the gradual degradation of a component over time due to repeated exposure to ionizing radiation. The traditional guidelines used by NASA and industry to test for the following error modes are referenced in APPENDIX B .

6.1   Single Event Upsets

SEU is unintentional changes in the state of a bistable device induced by ionizing radiation. The system level effects of these upsets as well as a statistically predictable rate (based on the environment) must be considered for proper safeguards to be designed into the circuit or system. Any SEU that propagates within the system causing an anomalous performance is equivalent to a failure mechanism. This effect is called Mean Time to Failure (MTBF).

6.2   Single Event Transients

Single Event Transients (SETs) are unintentional changes in the output of analog devices induced by ionizing radiation. The levels and signatures of these SETs must be catalogued for the specific input and output conditions under consideration for each circuit. A change in input voltage or output impedance for example can significantly change the SET signature. With the test data well

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 11 of 27

understood, designers can determine the extent of the SET on performance and determine mitigation techniques as required.

6.3 Functional Interrupt

Single Event Functional Interrupt (SEFI) is defined as SEE that results in a computer processor becoming stuck or hung up and not processing data. The system may begin processing data after a short time or may require a power cycle to regain function. In either case, the timing of the system is interrupted and normal data timing and flow are lost. In some cases, this can be a permanent failure mode if some means of power cycling is not available.

6.4 Single Event Latchup

SEL of an electronics part is a destructive failure mode that is generally equivalent to a failure of the system or circuit. This error mode usually manifests itself as a high current state of a device owing to the parasitic feedback circuit in p-n junctions in certain devices. It is acknowledged that power cycling may occasionally restore proper operation but latent damage may still exist that threatens the capability of the part to perform under stress. Due to the instantaneous effect in any case, this phenomenon represents a conventional failure mechanism.

6.5 Single Event Gate Rupture

SEGR results in permanent and unrecoverable damage to certain electronic components by the creation of a conducting path through the gate oxide. These components are generally a metal oxide semiconductor field transistor (MOSFET) or have a MOSFET structure within the component. Current research shows that some metal oxide semiconductor capacitors may show a similar mechanism having the same final result. This phenomenon represents a permanent failure mode. SEGR testing should be in accordance to MIL-STD-750, method 1080.

6.6 Total Dose Effects

Total dose effects degrade the performance of microcircuits, modify chip timing, and may lead to degraded electronic component performance or failure. Spacecraft systems are designed and certified to meet functional performance requirements after being subjected to the total dose derived by the mission. Total dose requirements should be derived by the mission and testing should be accomplished as described in MIL-STD-883, Method 1019. The user is referred to Section 10.0 for dose considerations involved with this test methodology.

7.0 FURTHER CONSIDERATIONS

It is intended that the radiation environment will be considered in the design process to the extent necessary to preclude poor design decisions. The challenge is to design and certify to the radiation requirements with minimal cost and schedule impact.

High Energy/LET Radiation EEE Parts
Certification Handbook

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 12 of 27

The approach described above allows the use of components with SEE rates that are acceptable for safety and mission requirements with the proper mitigation. This approach does not allow the use of components that have permanent failure modes that could disable the system. Selection of electronic parts with adequate resistance to radiation effects is an integral step in the design process. Engineering judgment is required to screen parts lists and identify specific electronic components whose function, quantity, and generic susceptibility warrant analysis or testing to provide the data necessary to support design decisions. Where the electronic part requires the VDBP to be used, the procedures in Section11.0 should be used.

8.0   NSRL FACILITY AND TESTING CAPABILITIES

http://www.bnl.gov/medical/nasa/nsrl_description.asp

The NSRL, of Brookhaven National Laboratories (BNL), facility consists of a Dosimetry (control) Room, several support rooms for biological and physical experiments and a secure radiation area, see Figure 8-1. Entrance to the secure exposure area (not shown) is at bottom near the Dosimetry (Control) Room. Data stations may be setup in the Dosimetry and Physics rooms where cables are provided by the facility or in the corridor near the Dosimetry room where the user must provide cables. During exposure (beam run time) personnel run and monitor the devices under test (DUTs) from the dosimetry or physics room. Instrumentation and power supplies are positioned within the beam line room and operated remotely from the dosimetry/physics room. Test electronics that may be sensitive to upset by neutrons should be located upstream of the DUT location or cables long enough to place the test equipment further away in the shielding maze. There is no vacuum chamber used in the system, and the instrumentation can be placed within several feet of the DUT, therefore cabling from the instrumentation to the card should be a minimum of five feet in length. Facility provided cables from the instrumentation to the dosimetry and physics rooms are run through the ceiling. User supplied cabling, if required, should be a minimum of 150 feet in length, but can be as short as 100 feet under special circumstances. During testing, users monitoring their DUTs outside of the chamber are nearby the beam physicists control station for verbal communication

The heavy ions available at NSRL have sufficient energy to penetrate the DUT packaging and even the aluminum containers for box level testing. The DUTs, circuits, or other test items are placed in front of the beam using available mounting hardware.

Cabling provided by NSRL includes approximately 96 signal cables with BNC connectors on them, 64 HV cables with SHV connectors on them in both the control room, and the physics room and they also have 3 low-loss high-speed triax cables with BNC connectors.

Figure 8-1   Experimental Support Area at NSRL

Board clamps are used, as shown in Figure 8-2 are used to hold the circuit boards in front of the beam. The NSRL laser alignment system is used to position and align the DUT in front of the beam.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 14 of 27

Figure 8-2   Board Clamps to Hold DUT Circuit Board In Front Of NSRL Beam

SEE tests are performed with the device or circuit target area centered in the beam spot. The beam spot is defined by the degrader system to be 10 cm by 10 cm. It may be further collimated by a manually operated copper collimator provided by the facility. Laser alignment and other mechanisms are available for centering the DUT in the beam and providing rotation for off-normal exposures. By stepping through the various degrader thicknesses available, the SEE LET(Si) threshold, knee, and saturation cross-section of the particular sample can be determined.

Typical instrumentation employed in these tests consists of the remotely controlled power supplies in the beam line room. It is best to place the supplies close to the test card to minimize noise pickup and inductance which can droop power at the card should an SEL or other burnout event occur in tests. It's important to simulate the low impedance for power applied to the test card as would generally be seen in flight applications. Oscilloscopes using scope probes are also located near the test card and remotely viewed and controlled from the control room to monitor the quality of selected critical signals and to capture SEE mode temporal profiles. Clocks, picoammeters, and data processors may also be located in the control room to minimize the noise, loads, and signal degradation associated with long cable lengths.

High Energy/LET Radiation EEE Parts Certification Handbook

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 15 of 27

A translation table and rotation table, shown in Figure 8-3, are available for use to rotate test articles to various angles with respect to the beams.
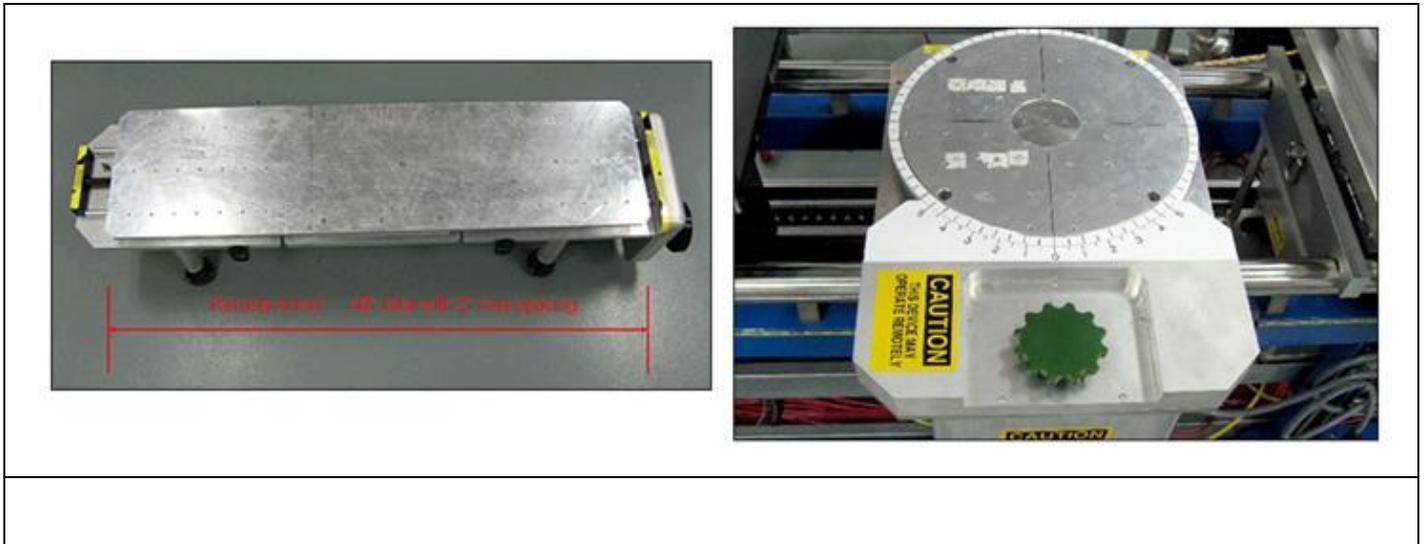

Figure 8-3   Translation and Rotation Tables

8.1   Degrader System

NSRL has developed a degrader wheel that contains various thickness of polyethylene. The system is show in Figure 8-4. It is arranged in a binary type system, so that an almost continuous depth from 0 to 9.9 mm of polyethylene can be selected to position the Bragg Peak in the DUT. The degrader system is a series of two wheels, one for a 'coarse' setting and one for a 'fine' setting. The 'coarse' wheel that has stops in 1 mm steps from 0 to 9 mm, and a 'fine' wheel that has steps from 0.0 to 0.9 mm in 0.1 mm steps. The degrader system is operated from the dosimetry room. Changing degrader thicknesses takes only a few seconds. The facility provides a table of the actual measured thicknesses of the degrader foils to be accounted for in the analysis.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 16 of 27
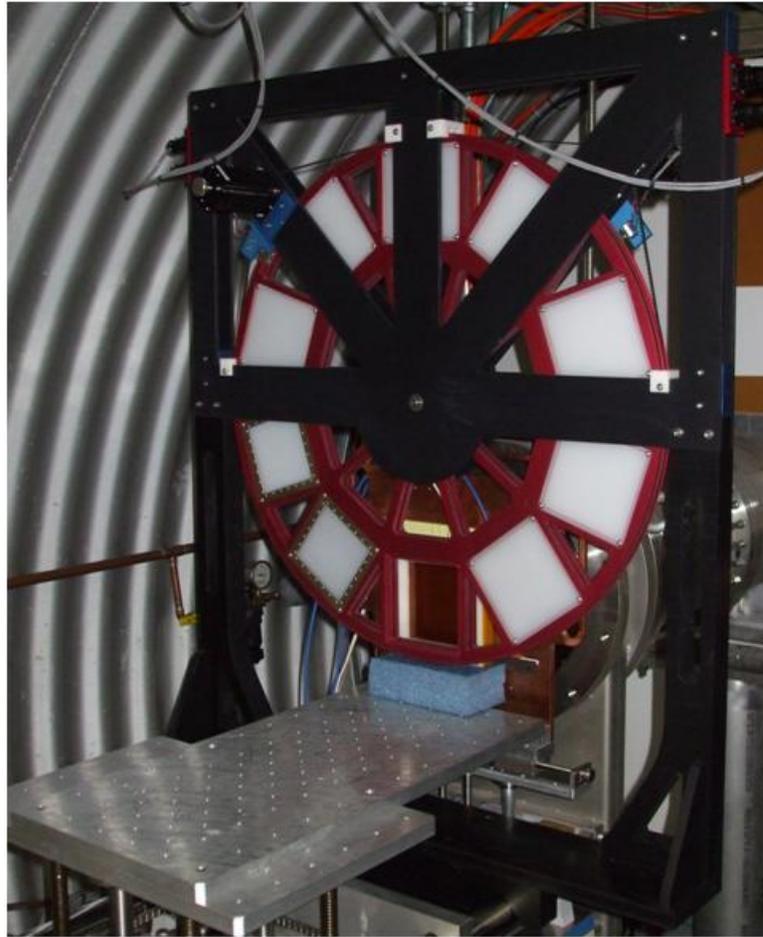
Figure 8-4   NSRL Degrader System

The degrader wheel is formally documented in NSRL-TN-10-004.pdf at the following website.

http://www.bnl.gov/medical/NASA/CAD/docs/technotes/tech.asp

8.2   NSRL Beam Selection

Currently, for electronics parts characterization and qualification, NSRL provides high-energy
carbon, iron, and gold beams to fully measure part/circuit response ranging from ~0 – 85 MeV-
cm2/mg. The nominal (booster) energy of these beams are 65 MeV/n for carbon, 165 MeV/n for
iron, and 210 MeV/n for gold. Actual beam energies depend on beam calibration parameters the
day of the test. Figure 8-5 shows the range of these ions in silicon, also displaying their maximum
LET in silicon. It should be noted that the VDBP method is not limited to just carbon, iron, and
gold ions. Other ions may be utilized depending on the needs of the user.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 17 of 27
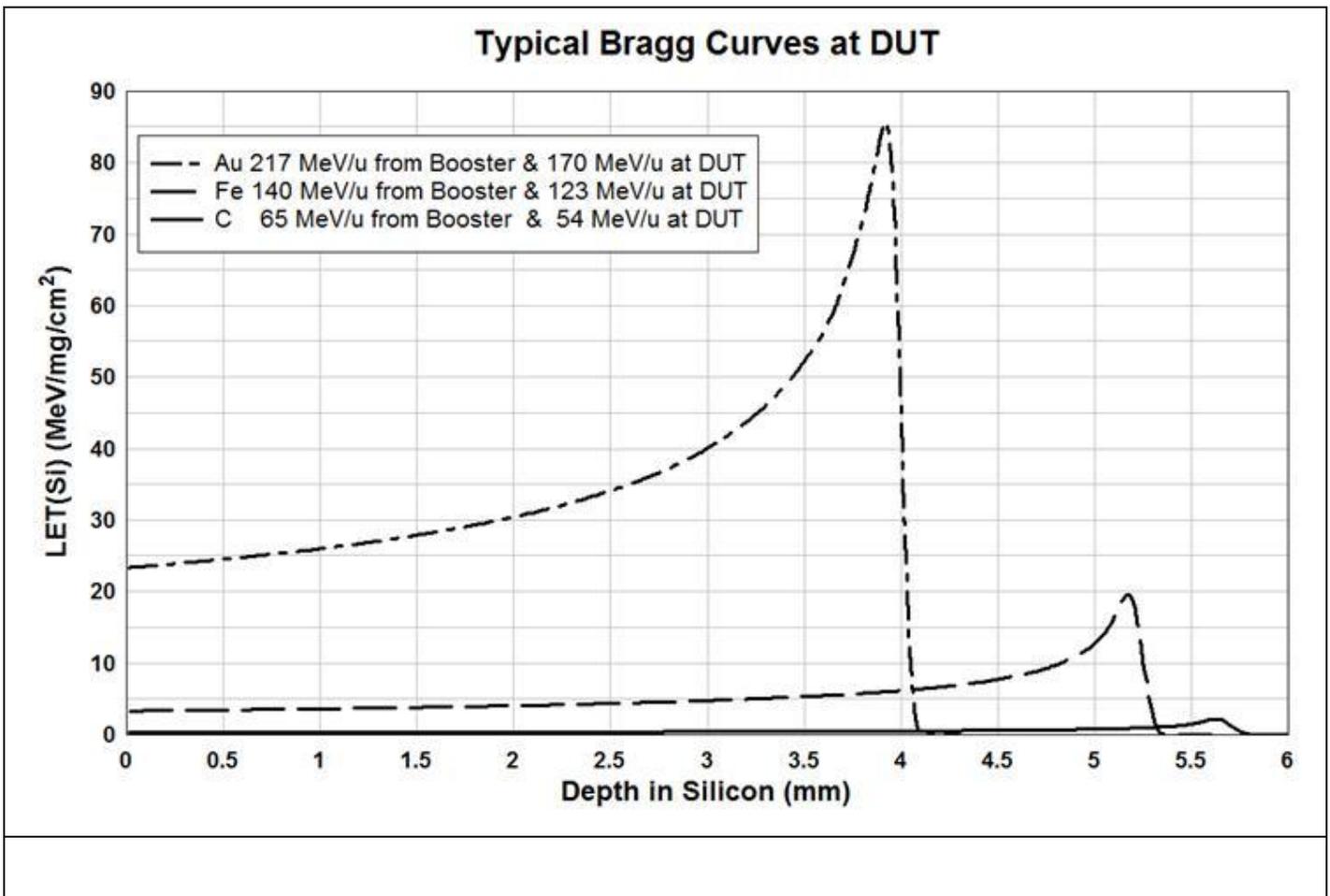
Figure 8-5   Typical Bragg Curves in Silicon for Carbon, Iron and Gold Beams at NSRL

Beam dosimetry information can be found at:

http://www.bnl.gov/medical/NASA/CAD/Dosimetry_Calibration.asp

8.3   Beam Size

NSRL information regarding the beam spot size can be found at:

http://www.bnl.gov/medical/NASA/CAD/Beam_Uniformity_and_Profile.asp

For parts testing with the VDBP method, a uniform ranging from $2x2$ cm^2 up to $10x10$ cm^2 is available. If the degrader is not used, then a beam area of $20x20$ cm^2 can be achieved. Figure 8-6 shows the beam uniformity over a $20x20$ cm^2 area.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 18 of 27
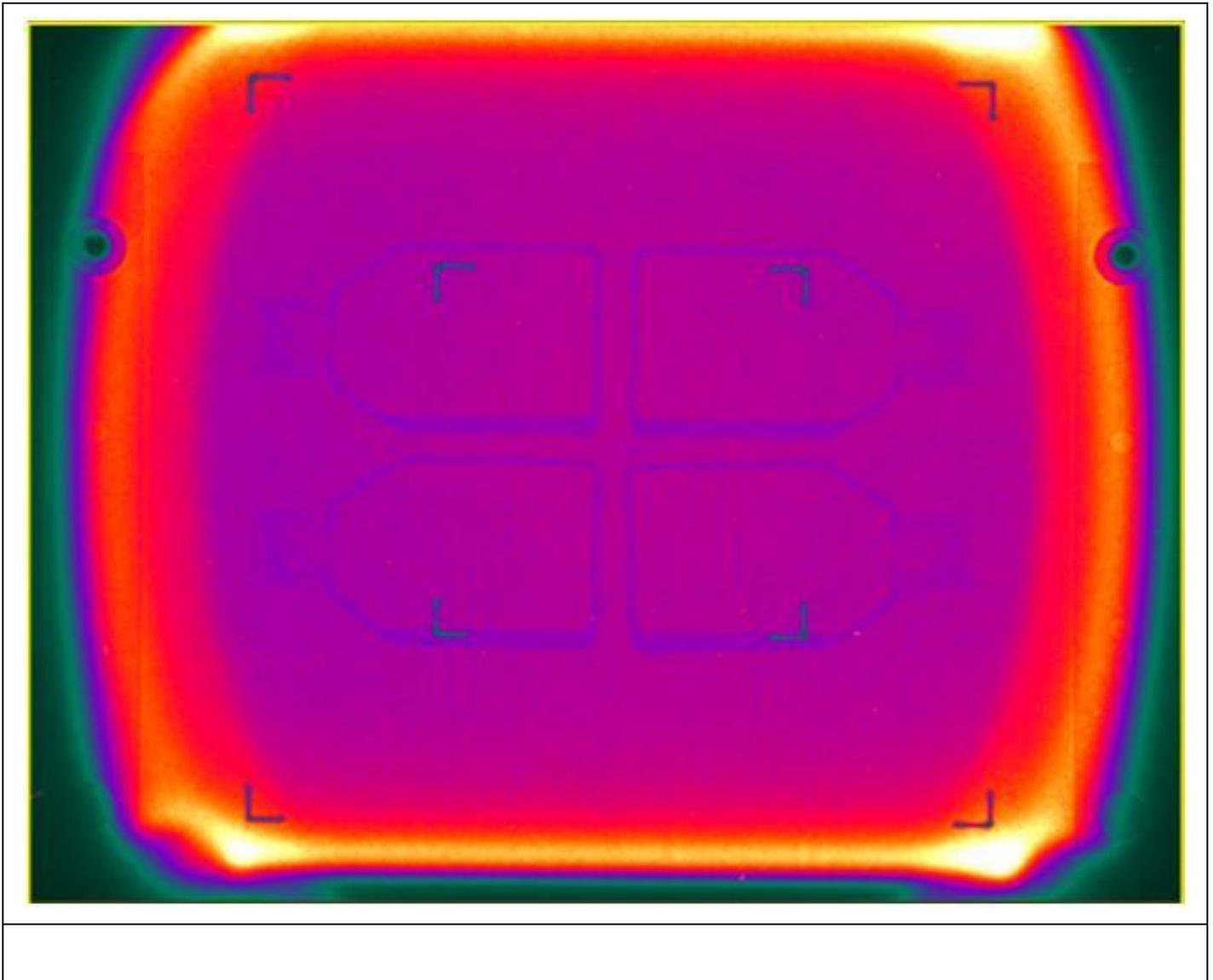
Figure 8-6   NSRL 20cm x 20cm Beam Intensity

The range of fluxes that can be provided are: $1e^3$-$1e^6$ particles/cm^2/s. The beam physicists control the beam and can place stops to stop the beam at user specified fluence levels if necessary.

9.0   PART RADIATION CHARACTERIZATION FROM VDBP

The VDBP method was developed by Dr. Chuck Foster and Dr. Pat O'Neill, which is described in detail in NASA-TP-TBD, and it is currently being implemented at the NASA Space Radiation Laboratory at the BNL. This method of heavy ion testing is slightly different from conventional heavy ion testing, although the end results are the same in that they both produce part characterization curves. The assumption in this test is that the sensitive volume(s) is not known, and that the maximum error cross section occurs at the Bragg Peak LET (Si) value. Depending

High Energy/LET Radiation EEE Parts Certification Handbook

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 19 of 27

on how high of an LET the user wants to characterize to, this sets the minimum degrader step size.

Figure 9-1shows a cartoon of how the VDBP works. At first, typically, the beam with no degrader is used. This provides the minimum LET the part sees in addition to a distribution of LET values within the part with higher LET. Also, one can put the maximum degrader thickness in front of the beam to verify that the beam stops before the part, to confirm part functionality. The user can either walk the Bragg Peak from the front to the back or vice-versa, depending on how the degrader steps are incremented/decremented.

Starting with the maximum degrader setting and pulling out the minimum degrader size allows for the Bragg Peak to start near the back of the part and will walk it towards the front. The part characterization curve is constructed by analyzing the measured error cross section with the Bragg Peak location. This can be done in post test or real-time during the test with JSC VDBP Software (described in NASA-JSC-SW-TBD), or by analytical methods similar to those described in NASA-TP-TBD (document describing theoretical details of VDBP).
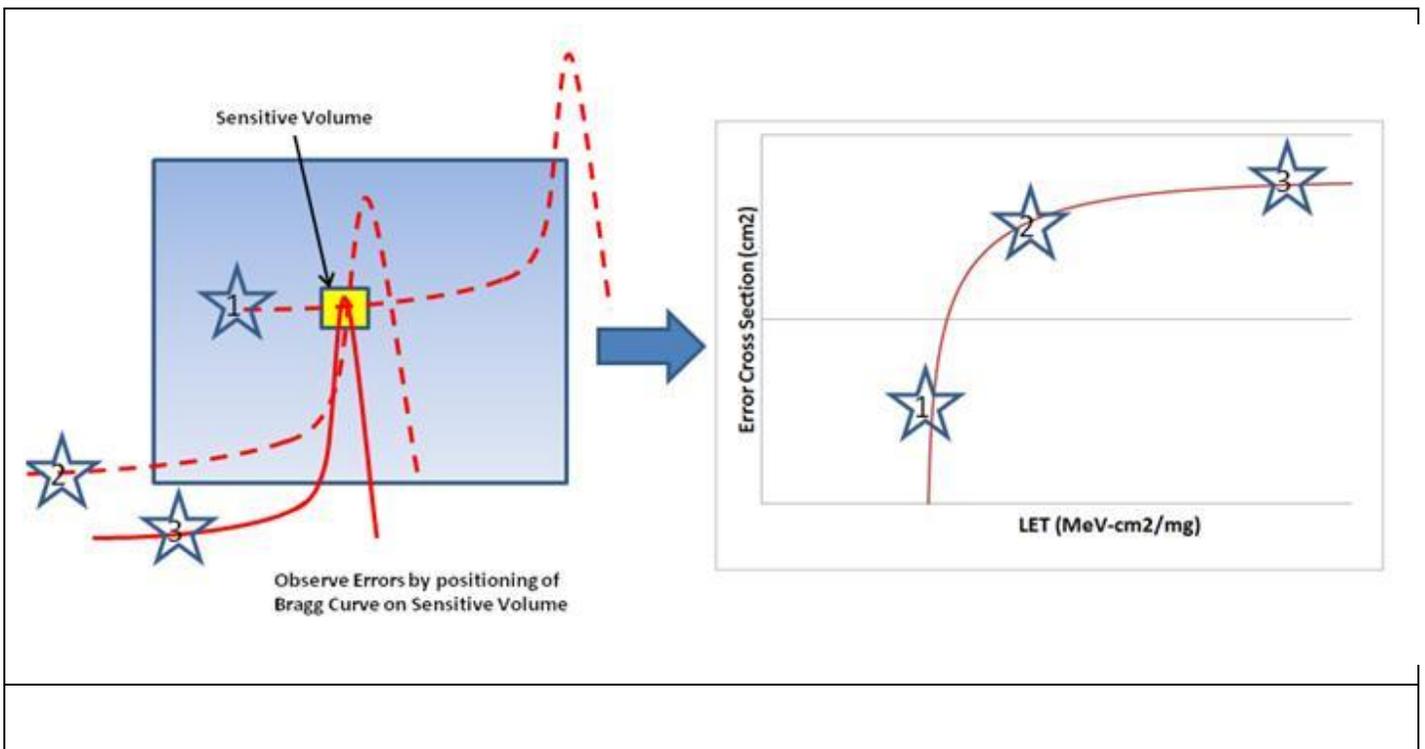

Figure 9-1   Obtaining Part Radiation Characterization Data with VDBP

Starting with the minimum size and incrementing this after each exposure walks the Bragg Peak through the part, and at each run, the error cross section is noted. The JSC-developed Bragg Peak Analysis code is benchmarked against the well known Stopping and Range of Ions in Matter (SRIM) and Fluktuierende Kaskade (FLUKA) codes (reference APPENDIX B).

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 20 of 27

10.0   POTENTIAL ISSUES

The total ionizing dose imparted in the device varies through the thickness owing to the energy distribution of the beam particles. At any given point, the dose is equal to the fluence times the LET at that point. For qualifying parts to high LET, this requires multiple runs with each run using a slightly incremented degrader selection. This insures that all depths in the part will see the high LET value needed for desired qualification level. This means that there is a potential to exposing the part to high doses, typically on the order of 20-40 krads (Si). Figure 10-1 shows a typical dose distribution through a part when qualifying the part for destructive errors to an LET of 60 MeV-cm2/mg. The user must evaluate their part for dose sensitivity when performing VDBP qualification testing.
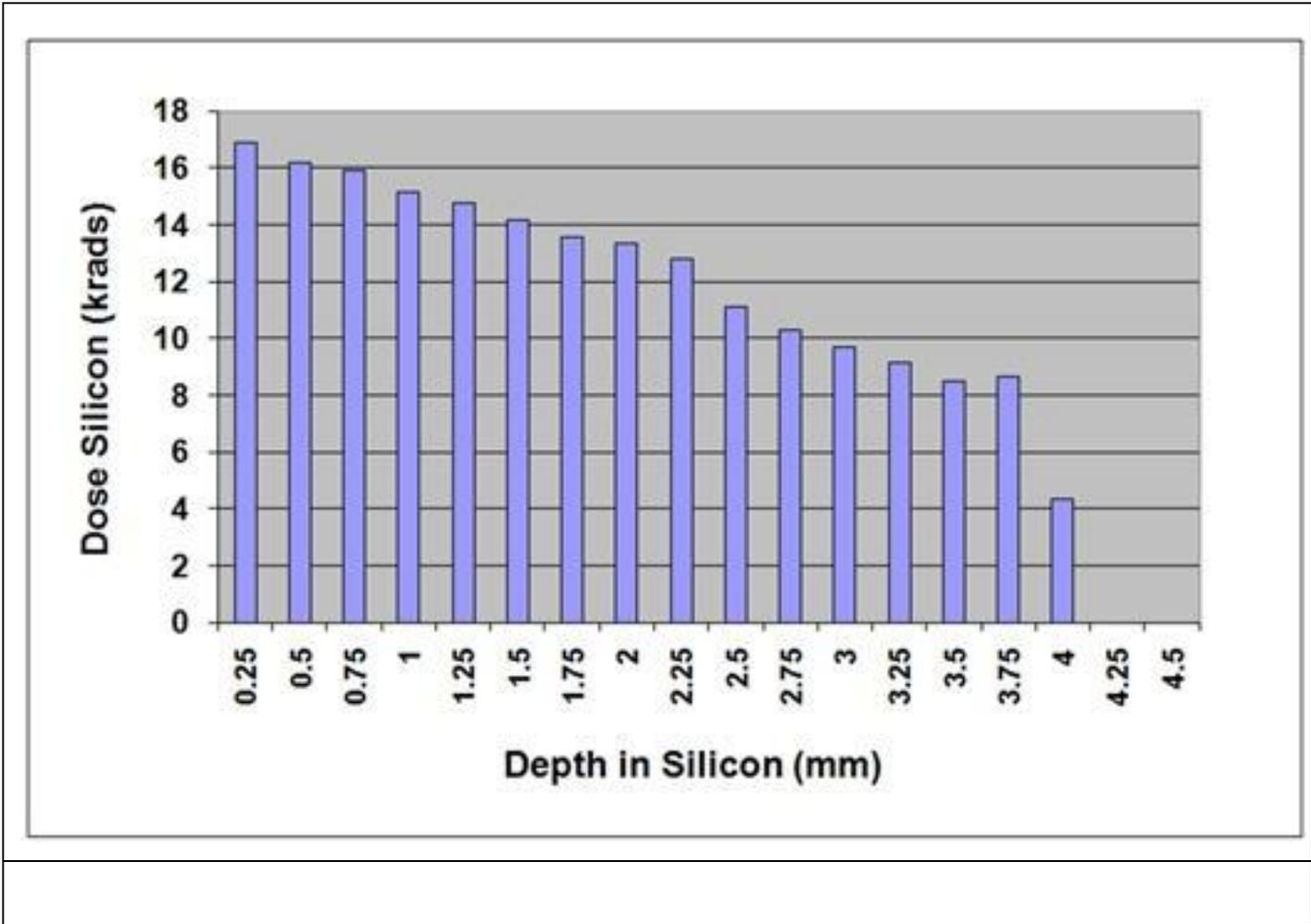

Figure 10-1 Typical Dose Distribution Certifying Parts to 60 MeV-cm2/mg using VDBP

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 21 of 27

11.0   VDBP Generic Run Procedure

The purpose of this test is to characterize radiation induced non-destructive errors, such as SEU's and SEFI's, and to find the SEL threshold, if one exists, up to at least an LET > 75 MeV-cm2/mg with the gold beam (see Note 1 below). To accomplish this task a series of exposures are required to probe the DUT at all internal locations. The nominal flux setting, which is worked out with the beam physicists prior to start, will be such that a fluence of $1e^6$ ions/cm2 is reached in about 60 seconds. This may be modified depending on part response and other timing issues. If transient waveforms need to be captured or observed, additional timing/runs might be required to set up waveform capture settings.

The following set of instructions is a template procedure that can be implemented when using the gold, iron, and carbon beams. These basic set of instructions are to guide the tester through the steps of the VDBP method. It is up to the tester to monitor properly the specific error modes that are unique for the type of part being tested. If adequate SEL data is captured with gold beam data, then only the soft radiation errors will be measured with the iron beam.

1. Set degrader system with 0 degrader (i.e. no degrader in front of part).

    a. If transients are to be monitored, perform an exposure to set up oscilloscope settings.

        i.   Repeat as necessary.

    b. During exposure, monitor appropriate signals for soft radiation errors and appropriate signals (device specific), such as part current supply, for indication of SEL.

        i.   If SEL is detected, stop beam immediately.

    c. Record the degrader step setting, fluence, and the number of errors.

2. Set the degrader wheel such that there is enough polyethylene to stop beam in front of part, and verify part functionality.

3. Decrease degrader step by 0.1 and repeat the $1e^6$ ions/cm2 measurement.
    (See Note 1 and Note 2 for this step.)

    a. If too many soft errors, stop beam at lower fluence and record number of soft errors, then continue beam until a fluence of $1e^6$ ions/cm2 has been reached. This is required in order to verify no SEL has occurred with the range of LET's provided by this degrader setting.

    b. At any point, once the soft error saturation has occurred, this measurement is no longer needed and the test becomes purely an SEL test.

    c. During exposure, monitor and record appropriate signals for radiation induced soft errors and appropriate signals, such as part current supply, for indication of SEL.

        i.   If SEL is detected, stop beam immediately, record fluence and verify if part is still functional. If part is not functional this concludes the test

    d. At each step, record the degrader step setting, fluence and number of errors.

> Note 1: If it is desired to qualify a destructive error to a lower LET value, degrader increments greater than 0.1 mm may be used. For example, using degrader step sizes of 0.3 mm will guarantee that the LET will be at least 60 MeV-cm2/mg or higher.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 22 of 27

> Note 2: In some cases, it may be desired to walk the Bragg Peak from the rear of the DUT to the front. In this case, step #2 above is skipped and starting with step #3, degrader steps, at the appropriate increment, are added instead of subtracted.

4. Repeat step #3 until all degrader pieces have been removed, thereby duplicating step #1. After this step has been achieved, the full Bragg Peak curve has been moved throughout the device and guaranteeing that each point in the device was exposed to an LET >= 75 MeV-cm2/mg (this LET level with gold beam only).

5. NASA/JSC developed software, will be used to perform near-real time analysis on the raw test data to produce part characterization data

6. Repeat steps 1-5 using iron beam. Note: SEL testing may not be required with this beam. Note: Do not need to use 0.1 mm steps for iron or carbon beams since they are just for characterizing the part and not for certifying it to high LET values.

12.0   JSC REAL TIME ANALYSIS SOFTWARE

Because the VDBP method requires analysis of the Bragg Peak and energy distributions, both of which depend on the accelerator settings, full LET determination cannot easily be done prior to testing because the beam calibration settings are not known. JSC has developed test software which performs Bragg Peak analysis, called Spread-out Bragg Peak (SOBP). This software includes the effects of beam energy spreading and straggling, and can be implemented in real time during the test to produce part characterization as a function of LET. This software has been validated to be in agreement with the SRIM and the FLUKA Monte Carlo Radiation Transport Code, although requiring 1/100 the run time. This analysis software can be available to users for VDBP testing; all requests need to be sent to brandon.d.reddell@nasa.gov . The following is an overview of the software.

12.1   NASA/JSC SOBP Code Overview

The following is a top-level overview of the NASA/JSC SOBP code. It describes the analysis steps necessary to properly use the experiment geometry, ion chamber data, and degrader settings to obtain the correct error cross section data.

Obtain from NSRL beam physicists, the ion chamber ratios versus degrader settings and the energy of the beam at the booster. Figure 12-1 shows a schematic of the setup showing the items and materials that need to be taken into account to determine E_0, the energy of the beam prior to entering the degrader.

High Energy/LET Radiation EEE Parts Certification Handbook

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 23 of 27
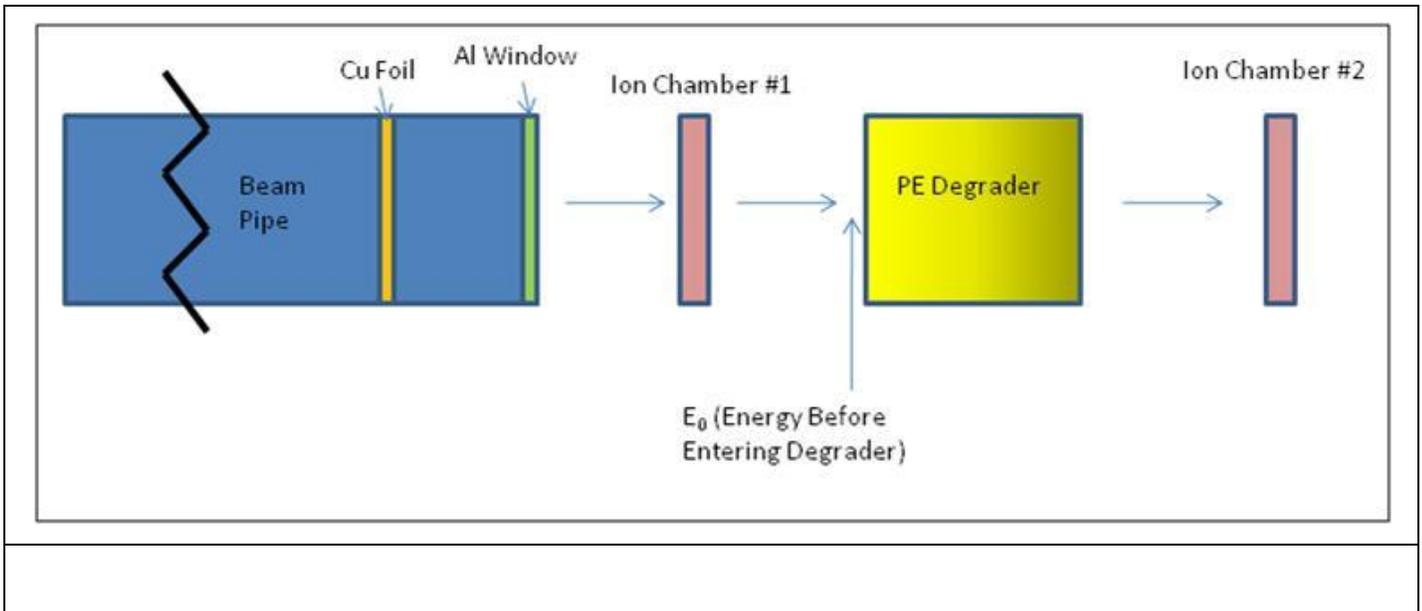
Figure 12-1 Schematic of Beam, Showing Placement of Ion Chambers with Respect to the Degrader System.

The ion chamber data should be in a file, typically named AU215IC.DAT for example, which is the beam element – gold in this case, and the energy, IC meaning ion chamber file. The first column of the data is the nominal degrader step; the second column is the ion chamber ratio.

A second file, called AU215STU.DAT, for example, should be created. This file is simply just seven numbers, the Z of the beam species (79 for gold, 26 for iron, and 6 for carbon), the second number is the energy of the beam at the booster (in MeV/n), and all other numbers are zeros, placeholders for subsequent steps in the program.

12.2 Modes of Execution and Resulting Output

When executed, the SOBP runs in three modes.

MODE 1 calculates the energy of the beam just prior to the degrader, how many mm of polyethylene it will take to stop the beam, updates the ion chamber ratio file correcting for the materials in the ion chamber (i.e., kapton and nickel – see Figure 12-1), and It updates the STU file with these calculations.

MODE 2 runs similar calculations as in MODE 1, but in silicon instead of polyethylene. It then runs through half of the stopping thickness in polyethylene and then to some thickness in silicon where the beam is stopped. It then computes a factor to shift the stopping power curve in silicon to the actual stopping curve consisting of two materials, the first part being polyethylene and the second part being silicon. This ratio factor holds for the whole stopping curve and is the key factor to calculating the exact LET at various degrader settings. The STU file is updated with the ratio factor.

MODE 3 is the main mode that is run after the data file of error cross sections vs. degrader steps is established. When executed, a table of values is read in that converts the generic degrader

setting to the actual polyethylene thickness. In addition, the STU parameters are read in. An input file containing raw data is required for this step to work, typically named AU215R01.DAT, which could represent data for the test sample 1 of the 215 MeV/n gold beam, for example. This file contains the exposure number, the number of errors observed (i.e. SEU's or SET's, etc.), the fluence in which those errors were obtained, and the degrader step number.

Until this step is complete, the raw data will not exhibit the standard shape expected for a characterization curve. Figure 12-2 shows a typical plot of the raw data prior to processing.
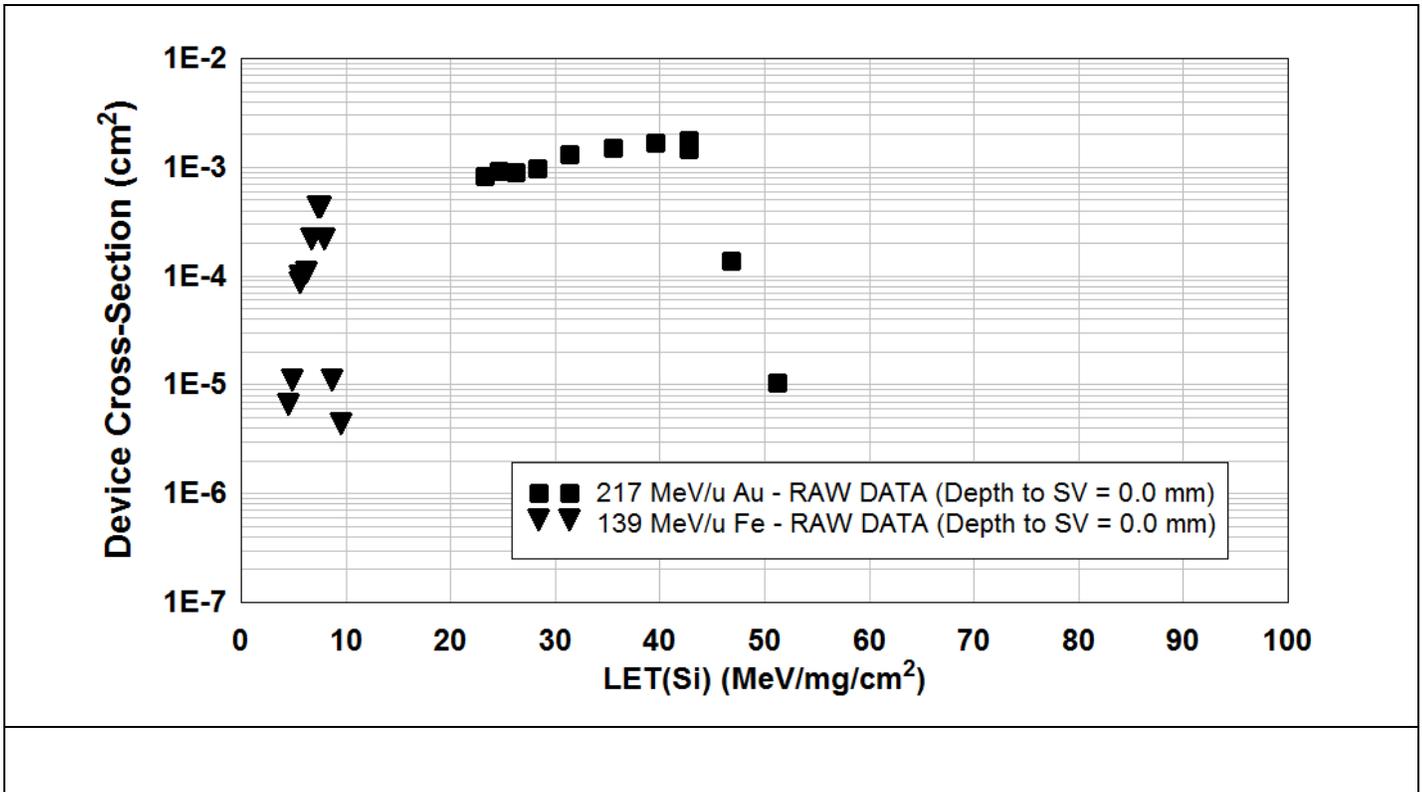

Figure 12-2 Raw Part Characterization Data

The code then automatically computes the sensitive volume depth, which gives the maximum error cross section at the maximum LET. There are options for the user to do this manually. The output file, such as AU215S01.DAT, is produced and contains the corrected error cross section verses LET data. This file is the desired result for the part characterization response. It is expected that after each run in which the degrader setting has changed, that this mode should be run to compute the true LET for the observed errors. Using a plotting package, like Microsoft Excel™, the characterization data can easily be plotted and studied. For the example shown above, Figure 12-3 below shows a plot of the same data, but when the maximum LET is aligned with the maximum error cross section. When this is found, the rest of the data points comprising the part characterization function fall out and the Weibull curve can then be found.

At the conclusion of MODE 3, the process is considered complete and the part characterization data can then be considered in the design process and for in-space error rate estimation.
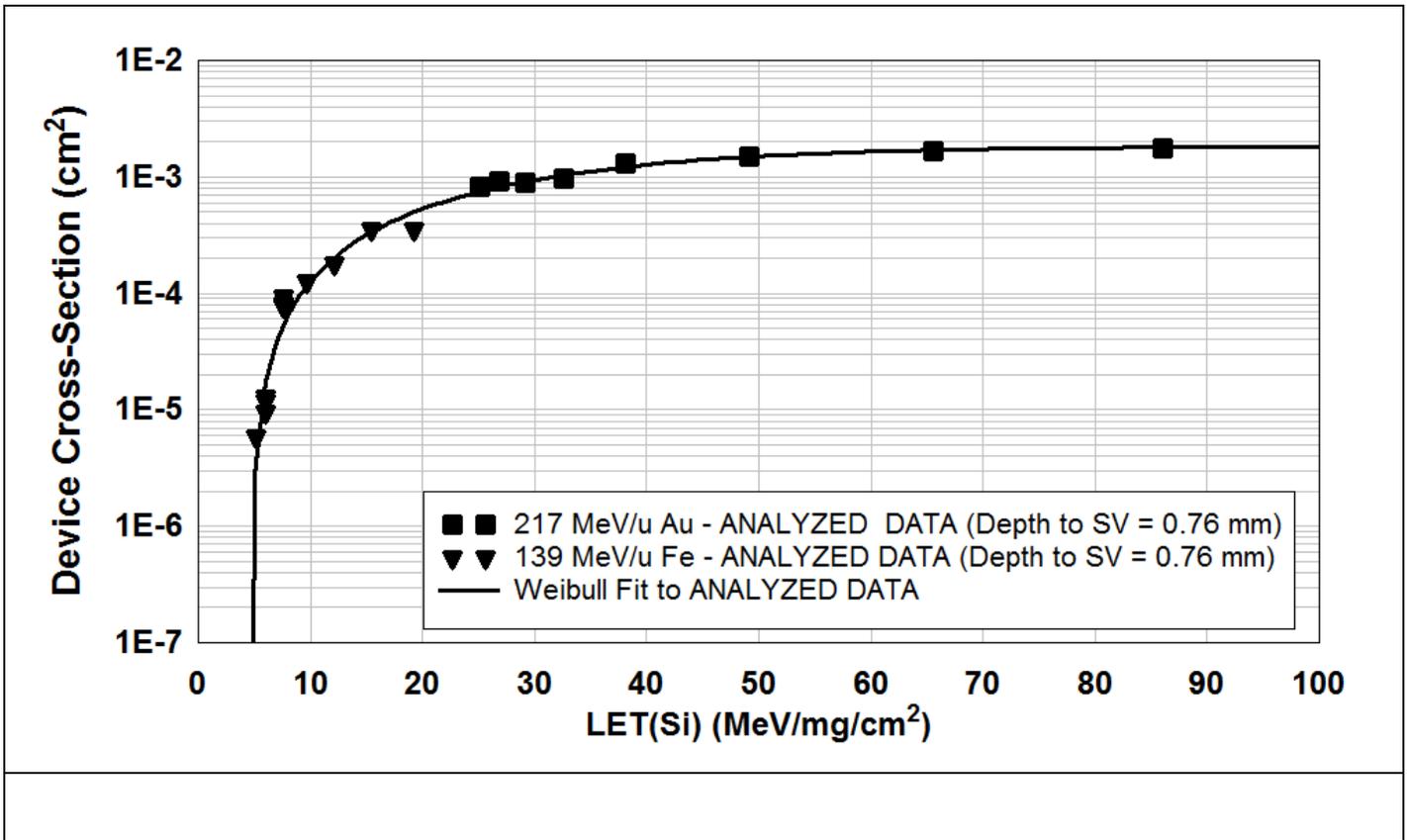
Figure 12-3 Analyzed/Corrected Part Characterization Data

13.0   SUMMARY

The Variable Depth Bragg Peak methodology has been provided to give the user an understanding of this technique and a description of the facility and procedure to use high-energy beams to certify their packaged electronics to high LET levels for typical NASA radiation environments. Additionally, NSRL facility reference material is provided along with guidance on when to use this technique has been discussed. All questions regarding this subject and obtaining access to the NSRL facility should be directed towards the NASA/JSC/EV5 radiation team.

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK-   07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 26 of 27

APPENDIX A   ACRONYM LIST

Acronym	Term
BNC	Bayonet Neill-Concelman
BNL	Brookhaven National Laboratory
COTS	Commercial Off-the-Shelf
DUT	Device Under Test
EEE	Electrical, Electronic and Electromechanical (EEE)
EV5	Electronic Design and Manufacturing Branch
GCR	Galactic Cosmic Ray
FLUKA	Fluktuierende Kaskade
JSC	Johnson Space Center
LET	Linear Energy Transfer
MeV	Million Electron Volts
MOSFET	Metal Oxide Semiconductor Field Transistor
MTBF	Mean Time to Failure
NSRL	NASA Space Radiation Laboratory
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SET	Single Event Transients
SEU	Single Event Upsets
SOBP	Spread-out Bragg Peak
SRIM	Stopping and Range Ions in Matter
TID	Total Ionizing Dose
VDBP	Variable Depth Bragg Peak

**High Energy/LET Radiation EEE Parts
Certification Handbook**

JSC-HDBK- 07-001
Effective Date: March 22, 2012
Expiration Date: March 22, 2017
Page: 27 of 27

APPENDIX B   INFORMATIVE REFERENCES

The following documents, though not formally a part of this handbook, amplify or clarify its content:

Rev / Date.	Document No.	Title	Source or Location
2010	N/A	Badhwar-O'Neill 2010 Galactic Cosmic Ray Flux Model - revised	IEEE Transactions on Nuclear Science, Vol. 57, Issue 6, Dec. 2010
Latest	MIL-STD-883, Method 1080	Ionizing Radiation (Total Dose) Test Procedure	http://www.landandmaritime.dla.mil/Programs/MilSpec/
Latest	MIL-STD-750, Method 1080	Single Event Burnout and Single Event Gate Rupture	http://www.landandmaritime.dla.mil/Programs/MilSpec/
Latest	EIA/JESD57	Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy ion Irradiation	http://www.jedec.org/sites/default/files/docs/jesd57.pdf
Latest	ASTM F1192	Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices	http://www.astm.org/Standards/F1192.htm
N/A	N/A	The Stopping Range of Ions in Matter (SRIM)	http://www.srim.org/
N/A	N/A	FLUKA	http://www.fluka.org/