JEDEC STANDARD

TEST STANDARD FOR THE MEASUREMENT OF PROTON RADIATION SINGLE EVENT EFFECTS IN ELECTRONIC DEVICES

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Introduction

This standard establishes requirements for conducting a proton single event effects (SEE) test in electronic devices. The standard can be referred to as a “Proton SEE Test Standard”. Historically used documents for guidance in proton SEE testing have been the JESD57 standard, the JESD89A standard and the ASTM 1192 guideline. The basic drawbacks to these documents with respect to proton SEE testing are that JESD57 and ASTM 1192 pertain to heavy ions and JESD89 pertains to neutrons. Proton induced upsets (and failure) have some similarities with these other particles; but as a general rule, the facilities used for proton testing do differ from those used for heavy ion and neutron, and as technologies have scaled (beyond 90nm) new complex modes of upset/failure have been observed during proton testing. This standard assures the user of (1) bounding an acceptable indirect ionization upset test as being done with energies between 40 – 500 MeV, (2) that consideration must be given to device overlayers and package lids, (3) a discussion on the clarity between a destructive and non-destructive events, (4) angular testing is different from that described in heavy ion testing and (5) to provide a listing of proton induced dominant SEEs.

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(From JEDEC Board Ballot JCB-13-41, formulated under the cognizance of the JC-13.4 Subcommittee on Radiation hardness: Assurance and Characterization.)

1 Scope

This test standard defines the requirements and procedures for 40 to 500 MeV proton irradiation of electronic devices for Single Event Effects (SEE), and reporting the results. Protons are capable of causing SEE by both direct and indirect ionization, however, in this energy range, indirect ionization will be the dominant cause of SEE [1-3]. Indirect ionization is produced from secondary particles of proton/material nuclear reactions, where the material is Si or any other element present in the semiconductor. Direct proton ionization is thought to be a minor source of SEE, at these energies. This energy range is also selected to coincide with the commonly used proton facilities, and result in the fewest energy dependent issues during test.

Proton energy is the primary variable in these irradiations: However the energies used in a test do not necessarily reflect the proton spectrum in space. The limits of the test energy range versus the actual environment must be taken into consideration during data analysis. The overall proton SEE rate can sometimes be well characterized by the SEE cross section in the 40-100 MeV range. However, for certain categories of devices an energy dependence in SEE cross-section has been noted. Devices that manifest this energy dependent response are typically those fabricated with heavy metal materials (e.g. tungsten, W, and copper, Cu) residing in close proximity to the sensitive volume and that also exhibit a threshold high enough that the heavy element scattering events are not swamped by more common silicon events. In all cases, the possible secondary reactions are dependent on the incident proton energy.

Proton testing is usually performed in open air with test samples that are not delidded. It is always the experimenter's responsibility to have knowledge of the location of the active die and any overlayers of material (from all sources) which will degrade the raw beam energy, and to make the appropriate adjustments in reporting the results.

2 Normative references

The following standards contain provisions that, through reference in this text constitutes provisions for this test method. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

ASTM 1192, *Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices*, 2000

ESA/SCC 25100, *Single Event Effects Test Method and Guidelines*

IEC/TS 62396-2, *Process Management for Avionics – Atmospheric radiation effects – Part 2: Guidelines for single event effects testing for avionics systems*, August 2008

JEP133C, *Guide for the Production and Acquisition of Radiation Hardness-Assured Multichip Modules and Hybrid Microcircuits*, January, 2010

JESD57, *Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation*, December, 1996

JESD89A, *Measurement and Reporting of Alpha Particle and Terestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices*, October 1989

JESD89-3A, *Test Method for Beam Accelerated Soft Error Rate*, November, 2007

MIL-HDBK-814, *Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices*, 1994

MIL-STD-750, *Test Method 1080 Single Event Burnout and Single Event Gate Rupture*

3 Proton test considerations

3.1 Applicable test facilities

This test standard is only applicable when using a proton accelerator with proton energies in the range of 40-500 MeV. This test standard assumes that the selected accelerator test facility has the ability to mount and position the Device-Under-Test (DUT), provide proton dosimetry, calculate total ionizing dose (TID) and Non-Ionizing-Energy Loss (NIEL), and that the test organization exposing the parts has the capability for performing these tests

3.2 Basic effects addressed

This test specification is applicable to Single-Event Effects. These effects are manifested as soft errors (non-destructive) or hard errors (which may be directly destructive, or “hard” in that it requires power reset to resume proper operation) induced by either the proton or the byproducts of subsequent nuclear reactions with the target materials. The soft error effects include Single-Event Upset (SEU), Multiple-Bit Upset (MBU), and Single-Event Transient (SET). Hard errors effects include Single-Event Gate Rupture (SEGR), Single-Event Latchup (SEL), Single-Event Burnout (SEB) and Single-Event Functional Interrupt (SEFI). As technology changes, new effects are being observed regularly, and it is the responsibility of the tester to be ready for unanticipated results and report them promptly. The use of proton beams for displacement damage or total ionizing dose measurements is not covered by this test standard.

High current states caused by some of the hard errors described above may also lead to latent damage to metallization or junctions. These may result in reduced reliability of the device. While not a direct part of this test method, additional life test and analysis may be required to properly evaluate these effects.

3.3 Limits of the test standard

This test standard is strictly for SEE tests with moderate energy protons, and does not apply to SEE testing that uses heavy ions, neutrons, low energy protons and other lighter particles.

3.4 Test standard objective

The standard is written to observe the dominant proton SEEs in a test sample; these effects are usually produced by ionization caused by nuclear reaction byproducts of proton interactions with materials of the semiconductor device. Most experiments are not capable of determining the difference between a direct proton ionization SEE and one caused by the reaction particles, but at these energies direct proton ionization events are rare, unlike the direct ionization effects of heavy ions. Protons are the dominant source of radiation in many orbital regimes, so obtaining a correct rate prediction in the relevant environment is a primary reason proton tests are performed. The appropriate range of proton energies for a test is determined by system requirements. This is discussed further in 3.6.

3.4 Test standard objective (cont'd)

SEE effects from direct ionization have been observed in advanced technologies (below 100nm) primarily at proton energies below 5 MeV [4-10]. Test at these energies is specifically prohibited in this test method as all aspects of low energy test are significantly more complex than test in the 50-500 MeV range, and require expertise beyond the guidance herein. This is discussed further as a potential interference in 3.6.

For SEU, SET, SEFI and SEL, the end product of the test is a plot of the appropriate single event effect cross-section as a function of proton energy. The plot should include the measured cross-sections for all proton energies measured. A typical cross-section curve increases in cross-section rapidly above a threshold value, and then tends to saturate above some energy. The key to achieving an adequate data set for subsequent rate predictions is to capture the "knee" region where the part achieves saturation. Multiple-bit upsets (MBU) are an increasing concern. The test report should either separate MBU from SBU, or expressly state this separation was not performed.

When no SEL are observed in a sample set during irradiations at the highest energy tested (whose fluence should be determined by the expected environment, with margin), the part has traditionally been defined as SEL immune, to the tested energy. This is an accurate statement of the test result, but not a guarantee of SEL immunity. It has been demonstrated that some devices only display SEL at energies >400 MeV [11]. These high energy SEL are primarily caused by proton reactions with heavy metals in the device, such as tungsten (W), and copper (Cu). The corresponding cross-section may be very low, but demonstrates the part is not immune to SEL. This risk must be evaluated by the individual system, and incorporated into the test planning appropriately. If SEL are observed, which is often defined as a part failure, it is good practice to look for the SEL threshold at reduced energies (as available), when possible. SEL is highly dependent on temperature and device voltage. This drives the test conditions utilized in 3.5 and 5.8. Proton irradiations should not be utilized to infer heavy ion SEL performance. Proton test energies are discussed further in 3.6.

SEB and SEGR require additional variable voltage sources and iterative exposures to establish safe degraded operational limits of the device. The details on this electrical test procedure can be found in MIL-STD-750, test method 1080.

These data can be combined with the predicted proton environment of the intended space application in order to determine the SEE rate for the microelectronic devices due to protons. This test method is directed towards the irradiation of a single DUT (integrated circuit) which is actively biased in a test configuration applicable for the expected use. It is also applicable for isolated irradiation of DUTs within a complex assembly, but the extra steps necessary for preparation are not detailed herein. Some facilities have the ability to spread the beam while maintaining uniformity. This may allow for irradiation of circuit cards or assemblies, but additional adaptations are required and not covered herein.

3.5 Warnings

These tests may involve hazardous materials, operations and equipment. Test hardware and parts are likely to become radioactive when exposed to proton radiation. It is the responsibility of the user of this test method, in consultation with the facility radiation safety personnel, to establish the appropriate safety and health practices and to determine the applicability of local, state and federal regulatory limitations and the compliance with those regulations prior to use. See Annex A.1.

3.6 Interferences

An accumulation of both TID and DD are inherent in proton irradiations. Each of these effects may act as an interference to the desired SEE data, and require preparation to assure data quality is not compromised. Since SEE, DD and TID effects all happen simultaneously in a proton-rich environment, it is important to consider combined effects as part of a SEE test.

For some devices, the SEU cross section changes with total dose [11-17]. For such devices, the worst-case test condition must include the maximum system total dose level. The worst-case bias configuration for total-dose degradation and SEU sensitivity must be established as part of the test matrix. For example, in some SRAMs the worst-case total-dose and SEU bias configuration is with the same pattern loaded to the memory array, while for other SRAMs, the worst-case SEU bias configuration is with the complement pattern written to the memory array – just the opposite [11]. Also, the effect of total dose on SEU sensitivity can depend on the radiation-induced leakage current that can have considerably different values at high and low dose rates for different technologies. When a DUT is sensitive to DD (e.g. bipolar, power devices, CCD’s and BiCMOS), normal test fluence accumulations may result in DUT electrical degradation during the exposure. This may also change the threshold and sensitivity of the DUT to the SEE effects being tested. This results in a bias in the data that may impact error rate calculations. As part of test planning for devices suspected of being DD sensitive, either investigate the damage threshold prior to test (most commonly with neutron exposure), or have test instrumentation at the proton facility to allow measurement of this degradation in near real time. When the DD degradation threshold is reached, the test sample should be changed to minimize this bias.

Proton irradiations have also been used as a source for TID and DD test, independent of SEE for many years. Such tests are not covered by this test method. Such test is critical when looking at materials (e.g. fiberoptic cables) and new technology, but its effectiveness for standard electronics technology is questioned by some.

When an active or a dynamic test is performed (i.e. errors are recorded in near real time during the exposure), it is critical to understand any deadtime (time the tester is not collecting error data) in the device, usually caused by the test equipment’s recording of errors. If errors occur too rapidly, events can be lost during this tester downtime. Thus the maximum allowable error rate is a function of the operation of the test equipment, and must be determined as part of pre-test planning.

3.6 Interferences (cont'd)

The maximum proton test energy required is ultimately determined by system requirements. It is a function of the expected space environment (both spectrum and maximum energy are a function of orbit [18]), and also the type of test and required level of confidence that a given event will not occur. In general, for a non-destructive SEU test, testing above 200 MeV is not considered necessary, as the relative rarity of higher energy protons in the environment makes only a small additional contribution to the SEE rate even if the cross section were to increase with energy. However, for SEL [11] where some systems forbid parts with any realizable SEL cross-section, test to energies of 40-500 MeV may be required. There is no general guidance, the specific requirements of the system ultimately dictate test energy requirements.

Direct ionization, usually observed as a sharp increase in cross-section as proton energy decreases, is primarily observed below 5 MeV. However, Heidel, et al. [6] demonstrated impact at energies of at least 25 MeV, during glancing angle exposures. The potential for direct ionization to impact future technologies is increasing, even at the energies relevant to this test method. If cross-section data is observed to rise with decreasing proton energy, additional analysis and potentially new test is required to understand and properly report this data.

4 Terms and definitions

Critical charge (Q_c): The minimum amount of collected charge that will cause a device node to change state.

Cross-section (in SEE testing) (σ): The number of events per unit fluence.

NOTE If the depth of the sensitive volume is small compared to its lateral dimensions, the SEE cross section (σ) can be calculated as follows:

$$\sigma = \text{number of events} / (\text{fluence} \times \cos\theta)$$

where θ is the angle of incidence of the ion.

Direct Ionization: The generation of charge directly by an incident proton (not due to secondary processes).

Displacement Damage: Damage induced by the displacement of atoms in a crystalline lattice, typically silicon, caused by the interaction of the incident neutrons, protons, or other energetic particles or ions with the crystalline lattice atoms.

NOTE Displacement damage can be measured by a displacement dose or, in the case where the incident particle is a neutron, by the 1-MeV(Si) equivalent fluence or by a number of Frenkel pairs created in the silicon lattice. Displacement dose captures the nonionizing portions of the deposited energy.

DUT: Device Under Test. This could be a monolithic device, hybrid microcircuit, or an assembly.

4 Terms and definitions (cont'd)

Energy: The kinetic energy (usually expressed in MeV) of a proton .

Fluence (of particle radiation): The number of radiant-energy particles emitted from or incident on a surface during a given period of time, divided by the area of the surface.

NOTE 1 The equation "fluence = N/A" applies, where N and A represent the quantities number of particles and area. Fluence can be calculated by integrating the flux density over the given period of time, e.g., a run.

NOTE 2 The unit symbol (e.g., cm^{-2}) does not identify particle type because there are no standardized unit symbols for "particle" and types of particles. The particle name may be placed before the term, e.g., "neutron fluence", or in the spelled-out unit name, e.g., "neutrons per square centimeter".

NOTE 3 Fluence of particle radiation incident on a surface is maximized when the surface is perpendicular to the direction of the incident particle flow.

Flux (luminous): The time rate of flow of luminous energy.

Flux (radiant): The time rate of flow of radiant energy.

Flux (of particle radiation): Used as a synonym for "flux density" in JESD57 and JESD89A.

Indirect Ionization: The generation of charge by secondary byproducts of nuclear reactions between the DUT (the silicon lattice, dopant atoms, metallization and other elements contained in the device) and the incident proton.

Ion Range: The total distance a proton traverses through a material as it loses all of its kinetic energy to ionization. In most high-energy proton tests, the proton will penetrate the device and package completely, but the energy loss in these materials should be calculated in case it significantly changes the energy of the protons reaching the sensitive volume of the device.

Linear Energy Transfer (LET): The amount of energy per unit length deposited or transferred by radiation traversing a material.

NOTE 1 The energy carried away by the secondary electrons that are produced must be taken into account when calculating the energy deposition.

NOTE 2 The energy deposition or charge transfer mechanism will depend on the type and energy of the radiation, e.g., pair-production, Compton scattering, Bremsstrahlung, collisions, photoelectric effect, and radiative capture.

NOTE 3 LET is strictly defined in terms of energy divided by distance, e.g., MeV/cm, eV/nm, keV/µm. However, since the energy lost is directly proportional to the density of the material traversed, it is useful to divide the LET by the density of the material. For the purposes of certain publications, this derived quantity, whose units are typically expressed as MeV·cm2/mg (i.e., MeV/cm divided by mg/cm3), is often also referred to as linear energy transfer (LET), but more often has been loosely designated as "LET effective", which is not to be confused with "effective LET".

4 Terms and definitions (cont'd)

Multiple-Bit Upset (MBU): Two or more single-event-induced bit errors occurring in the same nibble, byte, or word.

NOTE An MBU cannot be corrected by a simple ECC (such as single-bit error correction).

Multiple-Cell Upset (MCU): A single event that induces several bits in an IC to fail at the same time.

NOTE The error bits are usually, but not always, physically adjacent.

Saturated cross-section; section; limiting cross section: The maximum observable cross section.

NOTE On many softer devices, the saturated, i.e., limiting, cross section appears as the asymptotic upper section of the linear-energy-transfer (LET) vs cross-section curve. An additional increase in LET will not increase the cross section of the device. On harder devices, the cross section may not reach saturation.

Sensitive volume: A region, or multiple regions, in which the charge imparted by incident radiation is collected and can then change the state of a node.

NOTE The sensitive volume is dependent on the angle of incident particle radiation, the mass and energy of incident particle radiation, and the density and type of material in the volume being penetrated by the incident radiation.

Single-Event Burnout (SEB): An event in which a single energetic-particle strike induces a localized high-current state in a device, resulting in catastrophic failure.

Single-Event Effects (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from the passage of a single energetic particle.

NOTE Single-event effects include single-event upset (SEU), single-bit upset (SBU), multiple-bit SEU (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latchup (SEL), single-event hard error (SHE), single-event transient (SET), single-event burnout (SEB), and single-event gate rupture (SEGR).

Single-Event Functional Interrupt (SEFI): A soft error that causes the component to reset, lock up, or otherwise malfunction in a detectable way but does not require power cycling of the device (off and back on) to restore operability, unlike single-event latch-up (SEL) or single-event burnout (SEB).

NOTE An SEFI is often associated with an upset in a control bit or register.

4 Terms and definitions (cont'd)

Single-Event Gate Rupture (SEGR): An event in which a single energetic-particle strike results in a breakdown and subsequent conducting path through the gate oxide of a MOSFET.

NOTE An SEGR is manifested by an increase in gate leakage current and can result in either the degradation or the complete failure of the device.

Single Event Latchup (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.

NOTE 1 SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.

NOTE 2 An example of SEL in a CMOS device occurs when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground.

Single-Event Transient (SET): A momentary voltage excursion (voltage spike) at a node in an integrated circuit caused by the passage of a single energetic particle.

Single-Event Upset (SEU): A soft error caused by the signal induced by the passage of a single energetic particle..

Soft error: (1) An erroneous signal, from a device, that can be corrected by performing one or more normal functions of the device.

NOTE 1 The error is called "soft" because the device or circuit behaves normally after the correction is made.

NOTE 2 See also "soft error, device" for use in a radiation context.

(2) An error in a device or circuit cell that can be corrected.

NOTE See note 1 to "soft error" (1).

Stopping Power: Of a substance, for charged particles of specified energy, the average energy loss in passing through a thin layer of that substance, divided by the thickness of that layer.

Stuck bit. Permanent or semi-permanent damage to a memory cell by an energetic particle strike.

Total Ionizing Dose (TID) effects: Circuit degradation or failure resulting from ionizing radiation-induced charge trapped in insulating layers (usually oxides).

5 Test facilities and test equipment

A list of proton facilities with their addresses is referenced in Annex B.

5.1 Test facility guideline

There are few proton facilities available. When selecting a facility, it is important to understand its beam characteristics, proton range, dosimetry, measurement system, test area and testing support.

This test method only addresses test at energies of 40-500 MeV.

It is highly recommended the tester perform a survey of the selected facility before attempting to do actual part testing.

5.2 Proton range

Test facility personnel shall provide documentation that the chosen test energy has sufficient proton range and energy to deliver the particles to the critical volume of the DUT. The test team must document package overlayers that may degrade beam energy prior to delivery to the DUT.

5.3 Beam characteristics

The characteristics of the proton beam to be used must be fully known and understood as part of test preparation.

5.4 Operating conditions

The description of the program(s), test procedures, device configuration, electrical bias, stimulus inputs, temperatures, current limiting conditions, clock rate, reset conditions, maximum total ionizing dose level, etc., must be established and documented. While it is often considered that the worst-case test condition for upset is at minimum operating voltage and highest operating frequency, this may not be representative of the actual system requirements, which should be incorporated into the test, if known.

The worst-case test condition for latchup is maximum operating voltage and maximum operating temperature. These are typically required conditions for SEL, and any exceptions must be noted in the test report. However, the effects of other “worst-case” parameters, such as loading, should be ascertained for each device type, and recorded in the test report.

5.5 Experimental set-up

The physical arrangement of the proton beam, dosimetry electronics, test device, cabling; and other mechanical or electrical test elements must be established and documented. Test locations are usually at large distances from the test equipment bay, with remote operation of the test equipment required. The ability to demonstrate correct DUT operation in the test configuration prior to irradiation, is a critical part of test documentation.

When test equipment is located in the exposure area (even if shielded from direct irradiation), it is necessary to demonstrate that upsets are not caused by stray particles (commonly, but not limited to neutrons) upsetting the test equipment. One common technique for this is moving the part out of the beam and demonstrating no test equipment errors during this trial run.

5.6 SEE detection

The basis for detecting SEE is a comparison of the test device responses with a pre-determined set of reference states, or a comparison of post-irradiation bit patterns with the pre-irradiation pattern. This comparison can be done during the exposures or afterwards. The ability to observe the effects in near-real time is invaluable to maximizing test results and every attempt should be made to allow this during the irradiations. Tests of proton induced transients in either analog or digital circuits, require special techniques whose extent depends on the objectives and resources of the experimenter. Typically, SEL is denoted by a device manifesting a high current state during irradiation, however for some cases, e.g. 90nm bulk with high standby leakage current, the high current state may not be obvious, and functional failures must be checked.

5.7 Flux range

For SEE testing, a typical proton flux range is 10^5 to 10^9 protons/cm^{2}s. The flux for a particular irradiation is selected to accommodate tester limits, effects of interest and dosimetry limits.

5.8 Fluence levels

The total number of protons must be sufficient to establish with a high statistical confidence that all sensitive volumes of the DUT have been irradiated. This is most critical when establishing the threshold energy where very few upsets occur. This must be traded off against the parts total dose capability [see 3.6]. For sensitive parts, multiple DUTs may be required to complete all test variations and also avoid total dose damage or degradation of the SEE data. For this purpose, a nominal fluence of $1X10^{10}$ protons/cm^2 for soft devices or $1X10^{12}$ protons/cm^2 for hard devices is often used. A general rule of thumb is to collect a minimum of 100 events, but note this is impractical for rare events. For the region above threshold, a fluence is typically used that will induce upsets. When selecting a fluence level, ionizing dose effects and displacement damage must also be considered, as these accumulate with the time the DUT is under irradiation.

6 Dosimetry

The equipment and techniques needed to measure the proton beam flux, fluence, energy and uniformity must be identified and documented. The equipment and techniques will, in nearly all cases, be provided by the accelerator facility. Facility specific Dosimetry information can be found in annex B, and their associated web sites.

6.1 Beam dosimetry systems

There are three primary dosimetry systems used to determine the energy, flux and uniformity of the beam: scintillators, secondary electron monitors and Faraday cups. Most tester teams primarily utilize the facilities' systems. Beam verification is done by testing a part with known response and comparing to existing data.

Additionally, radiochromic films may be utilized to qualitatively determine the beam uniformity.

Most proton accelerators are accurate to within +/- 10% in beam energy. Discuss the impact of any available beam energy degrader on the Dosimetry system with facility personnel.

6.2 Beam degraders

Beam energy is controlled by two primary methods: either the accelerator energy is changed, or in-line degraders are inserted. This choice is usually made by the facility. It should be noted that if a degrader is positioned between the Dosimetry system and the DUT, the Dosimetry will be altered. The user must make the necessary corrections to allow for the broadening and shifting of the peak in the energy spectrum as a result of energy loss. The broadening and shifting depends on the type of materials used in the degrader as well as on its thickness. In nearly all cases, this is accomplished with support of facility personnel. The test team must discuss the degrader systems at the chosen facility and plan appropriately for their use in the test plan.

When the facility (and time) allows, a cleaner spectrum can be achieved with a upstream degrader, when the beam is retuned with subsequent bending magnets to select the desired energy.

7 Test procedures

7.1 Test plan

7.1.1 Test plan guideline

A test plan shall be developed to support each test. The key point of this plan is the development of a test matrix that includes all required test variations to achieve test goals. The test plan will serve as a guide for the procedures and real time decisions to be made during the actual irradiation period, and will be of great value in optimizing time spent at the testing facility. However, the test plan should allow flexibility to adapt the test because accelerator variations and the results of the earlier runs must be factored into later decisions. The test plan should also contain contingency plans, if possible, to minimize impact of unforeseen problems.

7.1.2 Test plan contents

The test plan shall include at a minimum the following:

a) Test matrix (see 7.1.3)

b) Facility information

c) Purpose or objective of test

d) Description of test setup and schematic

e) List of required equipment

f) Detailed test procedures

g) List of proton energies to be utilized

h) Data collection

7.1.3 Minimum test matrix

a) Bias condition

b) Static or dynamic [frequency]

c) Input Patterns, Operational Modes

d) Temperature (note if ambient or junction temperature)

e) Fluence

f) Flux

g) Angle of beam incidence

7.1 Test plan (cont'd)

7.1.4 Accumulated total ionizing dose (TID) and displacement damage (DD)

The test sample is subjected to accumulated degradation from TID and DD during irradiation (see 3.6). This is an interference to the planned SEE testing. It is helpful to have knowledge of the device tolerance to TID and DD, but not always practical. Both parametric degradation (e.g. supply current increase) and functional failure are possible, and must be monitored during the test. It is strongly suggested that the failure level parametric limits be determined prior to test, and samples replaced prior to significant degradation or failure (a common rule of thumb is to replace part at 20-50% of its established failure limit). In addition, SEE rates have been shown to be sensitive to TID and DD degradation. It is desirable to rerun an early test condition when degradation is observed to verify potential changes in the SEE rate. The TID from each irradiation, shall be recorded from dosimetry readings by test facility. One alternative is to expose a small sample set primarily to establish device TID failure level at the facility, prior to SEE test. If the device is soft, multiple devices may be required to take a full cross section versus energy curve.

7.2 Pre-test preparation

Validate the entire test set-up as a system before shipping to the proton test facility. This pre-test validation shall include all software as well as hardware (DUTs, cables), fixtures and interfaces. Cable lengths equivalent to those at the test facility must be used. Each DUT shall be functionally and parametrically verified prior to departure. DUT verification should be repeated to the extent possible at the facility prior to irradiations.

7.2.1 Test equipment shielding

The test equipment may have to be as close to the DUT holder as possible and will need to be well shielded from the proton beam. In addition, proton beams usually release a significant number of neutrons within the test chamber. Neutron-induced upsets have been observed in many test setups and require shielding with high hydrogen content material (e.g. paraffin): Boron or boronated substances are also used for thermal neutron shielding. The experimenter should take advantage of any existing or locally available shielding as needed. Note that there are numerous cases where test equipment has been destroyed on site by incident irradiation.

7.2.2 Device preparation

7.2.2.1 Lid/Encapsulant removal

A decision must be made as to whether it is necessary to remove device packaging materials, i.e. lid for ceramics, and encapsulant for plastics. The decision shall be based on the ranges of the protons used as determined from the proton energy and the material through which it passes. For energies above 60 MeV, it is usually not necessary to remove the lid or encapsulant for normal incidence measurements. However, for irradiations at non-normal incidence, it may be necessary to remove not only the lid/encapsulant, but to remove some of the housing. Parts that have been modified may be fragile, and require special handling. Some lid materials (e.g. BeO) may require environmental considerations prior to removal to prevent contamination or injury.

7.3 DUT placement

Facilities with protons in the 40-500 MeV range typically allow mounting and positioning the DUT in air. Coordinate test board dimensions and mounting technique with the facility prior to board construction. A standard distance is usually pre-calculated and the effect of the short air path to the device is incorporated into the facilities dosimetry system (verify with facility). In addition, the lid material and thickness will reduce the energy of the protons impinging on the active die. This may require a correction for broadening and shifting of the proton energy spectrum by these overlayers - utilize facility procedures for corrections. Complex device package construction varies widely. Determine the thickness of the package overlayers for each DUT type, either from manufacturer supplied information or destructive physical analysis (DPA), prior to the test.

7.4 Latchup detection and protection

Single-event latchup can result in catastrophic system failure. Thus, devices that latch are often not allowed in systems, or the system requires device protection. Separate test conditions are frequently utilized to maximize either SEL (see 7.8) or SEU (see 7.9), but either effect may be observed during any irradiation. This requires special consideration during the construction of the test setup.

7.4.1 Test for catastrophic effects

If the test is designed to observe catastrophic effects, then the power must be minimally current limited, and the latch maintained for a sufficient time (as determined in the test plan) to maximize damage. Ideally, the impedance of the supply will emulate the system, if known, or else be as low as practical. In any test for catastrophic effects, the test sequence is modified. One does not count events, but rather waits for the single, run-ending event to occur. Thus, the time of the latch (from start of irradiation) must be recorded accurately, to determine fluence (flux times irradiation time). In this type of test, the cross-section is equal to 1/fluence. It takes many runs to achieve statistical confidence in the latchup cross-section.

7.4.2 Automated latchup detection and monitoring

To increase test throughput during SEL test, it is pragmatic to consider an automated latchup monitoring system that is able to detect the latch event (which must be defined by the user, and may vary during the test), and rapidly remove power from the DUT (in the ms timeframe) whenever a latch occurs. If test throughput is the primary concern, the system then reconnects power after a preset time (for example after 1 second). In this case, the test is designed to observe latchups while reducing the probability the test sample will be destroyed. This requires the design of special power monitoring and automated power removal circuitry. In these tests, latchup is usually defined as a predetermined sudden increase in supply current (e.g. a 20 to 50% increase, as required to achieve an unambiguous result), and, once detected, the circuit automatically removes device power.

7.4.2 Automated latchup detection and monitoring (cont'd)

This also requires a sophisticated time management system to accurately measure the accumulated fluence of each latch event (i.e. measure the time from power on to latch), but many cross-sections can usually be collected from a single sample in one exposure. However, this detection and current limiting system must not prevent a latchup from occurring. Any detection circuit is acceptable, but the test plan must include an adequate description. The rate of SEL is very important. It cannot be too high especially considering that the part must be debiased for a given amount of time. The fluence corresponding to the time that the part is debiased bust be subtracted from the total fluence when calculating the SEL cross section.

7.4.3 Latent damage

The fact that a part that has latched and appears to be functional after power cycling does NOT imply latent damage effects have not occurred. The high current states typically observed during latchup can cause DUT heating or damage to metallization or junctions, which may reduce operating life. If a part type that exhibits high-current latchup is to be used in a system, post-irradiation life testing of the test samples is recommended to evaluate reliability impact. Power devices often require a post-irradiation gate stress test as a further check of latent damage (see MIL-STD-750 TM 1080). A second concern is that previous latch events could impact subsequent SEL test data.

7.4.4 SEFI and separation of SEFI and SEL events

Single Event Functional Interrupts (SEFI) as defined in 1.4, include a wide variety of hard error types. In all cases, the expected functional operation of the device has been modified in a undesired manner. In many cases it has been observed that the device requires power cycling to reset the device to operation. This is often, but not always accompanied by a high current state. For such conditions, it is difficult to differentiate a SEFI event from a SEL event. This may be critical to some system requirements. In some cases the device power does not dramatically increase, as in SEL, and this alone is adequate differentiation. When device power does increase, additional steps are required. Possible methods include incrementally decrementing supply voltage to find a holding voltage (a sign of SEL), and varying test voltage and/or temperature (high temperature sensitivity is a sign of SEL). There is no simple guideline, and when doubt as to event cause exists, this must be documented in the test report.

7.5 Data recording requirements

The following information relating to the proton beam at a minimum should be recorded for each run: proton energy, flux, incremental fluence, total fluence, incremental ionizing dose, total ionizing dose and angle of incidence. The minimum device related data includes temperature, number of events, supply voltage(s) and pre- and post-supply currents, and all other parametric data recorded. It is recommended that this information be captured in a spreadsheet. The spreadsheet could also record information about the experiment after each exposure including test operator(s), date, device type, date and lot codes, whether delidded or not, and the effects measured such as the number of upsets, latchups, etc. The facility usually provides both hard copies and soft copies of the proton beam parameters for each exposure.

7.6 DUT handling

All parts must be handled with proper precautions for parts susceptible to damage from electrostatic discharge. The use of ground planes and straps is highly recommended. Parts will likely become radioactive (activated) and must be cleared for release by the test facility. If the test requires time critical return of the samples for additional test at another facility, discuss release procedures in detail with accelerator personnel prior to test, in accordance with radioactive material transportation regulation.

7.7 Sample selection

7.7.1 DUT selection

Any irradiation test on a sample of parts is an attempt to establish statistical confidence in the data set. SEE test has often used smaller sample sizes than either TID or DD tests, due to cost and time considerations. The homogeneity of the lot should be considered, and the largest sample size possible used (see MIL-HDBK-814 for standard sampling procedures). It is important to verify if different die revisions may exist in a lot, as changes, e.g. a die shrink can dramatically alter SEE performance

7.7.2 Soft error variability

Device-to-device soft error variability, in particular when sample lots are non-homogeneous can be large. System users qualifying parts must be sure that flight devices are truly equivalent to those tested, because manufacturers often make process changes affecting SEE sensitivity without changing the device's numerical designation. Such information is usually available from Defense Logistics Agency (DLA) qualified vendors.

7.7.3 Minimum sample size

The recommended minimum sample size is 5 devices per test for homogeneous lots, e.g. single wafer or single diffusion lot. For non-homogeneous lots, i.e., a random lot that may be composed of multiple diffusion lots, then the sample size needs to be expanded such that there is an acceptable probability that the sample size will contain parts from each diffusion lot. Spare samples to replace TID or other loss during test are also recommended.

7.8 Destructive single event test procedure (latchup, burnout, SEFI)

7.8.1 Beam setup

Request the desired beam characteristics from the facility operators. It is common to start at the highest available energy, as the effects of TID and DD are lower. Facility personnel will tune the accelerator for the required experimental conditions. Such tuning will establish the desired flux, energy and uniformity. The exact sequence will depend on the facility and beam requirements. Facility shall determine beam uniformity and report to testers. A uniformity of +/- 10% over the die is often obtainable. A good flux to start with is $10^7 – 10^9$ protons/cm^{2}s, for many part types.

7.8.2 Test fixture mounting

Position the DUT fixture on the stage mounting bracket. Ensure that the cable to the DUT fixture does not limit the free movement of the x-y stage (and rotation, if used), and that the cables do not shadow the DUT from the beam. Assure the DUT is in the beam path, as designed. When the test board incorporates additional active parts, shielding (columniation, which may be available at the facility) must be designed so that just the DUT is irradiated. Otherwise upsets from peripheral devices cannot be separated from DUT upsets. This also limits activation of fixtures.

7.8.3 Control part check

A control part should be inserted in the DUT socket and checked for correct performance. If performance is not as expected, debug and correct prior to starting irradiations.

7.8.4 Load and irradiate DUT

Position the device to be tested in the DUT fixture.

Set the device operating conditions per the experimental test plan. For destructive events, the most common conditions are all supplies at maximum value, and device temperature maximum. Note: SEB and SEGR require variable voltage sources that are not explicitly described herein. MIL-STD-883, TM 1080 provides details of this testing.

Begin electrical test sequence on the DUT; verify correct DUT operation.

Begin proton exposure of the DUT and record time.

Verify the SEL rate is as anticipated (neither too rapid or slow, see 3.6, and 7.4). Raise or lower the flux to ensure that the latch rate is consistent with the test equipment capability, as specified in the test plan. Non-destructive events (e.g. SEU) will occur simultaneously, record these events as required in the test plan.

Expose the DUT until the desired number of latch events has been measured (record fluence separately for each event) or until the desired maximum fluence has been reached, whichever comes first. Close beam shutter and record time.

If the planned exposure is for SEB or SEGR, then see 1.6 for additional instructions.

7.8.4 Load and irradiate DUT (cont'd)

7.8.4.1 If the DUT does latch/SEFI

If a potentially destructive event occurs, there are several options available to complete the planned test program. Note the order of the following options will depend upon the capabilities of the test facility:

a) Change flux/fluence to get a statistically meaningful number of events without overloading device tester or dosimetry. Common figures of merit include the average time to the event is greater than 10 seconds (to minimize non-uniform flux during opening and closing the shutter) or a fluence of 10^{10} proton/cm^2, whichever comes first.

b) Repeat runs two or three times as required to establish test repeatability (assumes the part remains apparently undamaged).

c) Change beam tilt angle to a grazing angle (typically 85 degrees) to look for change in upset rate, if part of test plan. This effect has been observed in some part types, but is not universal. This is not the secant relationship, as observed in heavy ions [see JESD57].

d) Change the beam roll angle to a grazing angle. Some parts have shown unique response depending on which direction a part is angled. In this case "roll" is an angle 90 degrees from the "tilt" in paragraph c, above.

e) Change the operating parameters, including supply voltage(s) initial load configuration, clocking, and, if applicable, input data patterns.

f) Change to another temperature (if applicable).

g) Select another device of the same device type to measure part-to part variability.

h) Select another energy value.

7.8.4.2 If the DUT does not latch/SEFI

If no potentially destructive events are observed in the initial run, the following test parameters can be varied in an attempt to obtain destructive events:

a) Verify correct test system operation.

b) Increase the fluence.

c) Change the chip operating parameters, including the initial loaded pattern.

d) Vary chip supply voltage in accordance with test plan limits. In general, a lower chip supply voltage (minimum specified operating range) promotes bit-flips and high chip supply voltage (maximum specification) promotes latchup (may not be true for SOI MOS devices).

e) Select a higher energy level.

f) Select another device of the same type.

g) Test at an angle.

7.9 Non-destructive single event test procedure (upsets, transients)

7.9.1 Beam setup

Request the desired beam characteristics from the facility operators. It is common to start at the highest available energy, as the effects of TID and DD are lower. Facility personnel will tune the accelerator for the required experimental conditions. Such tuning will establish the desired flux, energy and uniformity. The exact sequence will depend on the facility and beam requirements. Facility shall determine beam uniformity and report to testers. A uniformity of +/- 10% over the die is often obtainable. A good flux to start with is $10^7 – 10^9$ protons/cm^{2}s, for many part types.

7.9.2 Test fixture mounting

Position the DUT fixture on the stage mounting bracket. Ensure that the cable to the DUT fixture does not limit the free movement of the x-y stage (and rotation, if used), and that the cables do not shadow the DUT from the beam. Assure the DUT is in the beam path, as designed. When the test board incorporates additional active parts, shielding (columniation, which may be available at the facility) must be designed so that just the DUT is irradiated. Otherwise upsets from peripheral devices cannot be separated from DUT upsets. This also limits activation of fixtures.

7.9.3 Control part check

A control part should be inserted in the DUT socket and checked for correct performance. If performance is not as expected, debug and correct prior to starting irradiations.

7.9.4 Load and irradiate DUT

Position the device to be tested in the DUT fixture.

Set the device operating conditions per the experimental test plan. The common starting condition for non-destructive is minimum supplies and room temperature.

Begin electrical test sequence on the DUT; verify correct DUT operation.

Begin proton exposure of the DUT and record local time.

Verify the error rate is as anticipated (neither too rapid or slow, see 3.6). Raise or lower the flux to ensure that the errors per second are as specified in the test plan.

Expose the DUT until the desired number of errors has been measured or until the desired maximum fluence has been reached, whichever comes first. Close beam shutter and record time.

7.9.4 Load and irradiate DUT (cont'd)

7.9.4.1 If the DUT does upset

If the device upsets, there are several options available for follow-on tests to complete the planned test program. Note the order of the following options will depend upon the capabilities of that test facility:

a) Change flux/fluence to get a statistically meaningful number of upsets without overloading device tester or dosimetry. Common figures of merit include at least 100 upsets or a fluence of 10^{10} proton/cm^2 whichever comes first.

b) Repeat runs two or three times as required to establish test repeatability.

c) Change beam angle (typically, but not limited to a grazing angle, e.g. 85 degrees), to look for change in upset rate, if part of test plan. This effect has been observed in some part types, but is not universal. This is not the secant relationship, as observed in heavy ions. In a similar manner observe changes in the upset rate for backside irradiations.

d) Change the operating parameters, including supply voltage(s) initial load configuration, clocking, and for RAMs, input data patterns.

e) Change to another temperature (if applicable).

f) Select another device of the same device type to measure part-to-part variability.

g) Select another energy value.

7.9.4.2 If the DUT does not upset

If the device does not upset in the initial run, the following test parameters can be varied in an attempt to obtain upsets:

a) Verify correct test system operation.

b) Increase the fluence.

c) Change the chip operating parameters, including the initial loaded pattern.

d) Vary chip supply voltage in accordance with test plan limits. In general, a lower chip supply voltage (minimum specified operating range) promotes bit-flips and high chip supply voltage (maximum specification) promotes latchup (may not be true for SOI MOS devices). If the onset of SEE occurs with a small chip supply voltage change, then this indicates that the original conditions are close to the threshold energy.

e) Select a higher energy level.

f) Select another device of the same type.

g) Test at an angle.

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Annex A Pre-test requirements

A.1 Safety

Performing proton testing presents serious potential health hazards due to the exposure to radiation caused by proton testing. Equipment and material may become radioactive; this radioactivity is a function of proton energy and the nature and half-life of all the materials involved with the testing. Therefore, it is imperative that the test engineer accept all required safety training and follow all facility safety procedures specified during the tests.

A.2 Interferences

Protection of support equipment is necessary, especially if it is located near the proton beam. Proton beams usually release a significant number of neutrons within the test chamber. Neutron-Induced upsets have been observed in many test setups and require shielding with high hydrogen content material (e.g. paraffin): Boron or boronated substances are also used for thermal neutron shielding.

Secondary neutrons are sometimes a source of degradation to the DUT. However, these secondary neutrons could make a significant contribution to device degradation when there is thick shielding consisting of heavy metals.

Make sure that the proton energy requested is at the DUT and not at the exit port of the proton beam line.

Annex B Proton test facilities

B.1 Test facilities

B.1.1 University of California, Davis

- Crocker Nuclear lab: http://crocker.ucdavis.edu/
- Contacts: Dr. Carlos Castaneda 530-752-4228, http://crocker.ucdavis.edu/cnl/people/staff.htm
- Accelerator: Isochronal Cyclotron
- Energies: 1-68 MeV tunable, Helium beam is also available, degraders available. Beam intensity adjusted by accelerator operator.
- Beam Information: single user, beam spot is 3 cm radius or collimators for smaller size and in other shapes, 22.5 MHz – 7 MHz AC, full pulse is 44.4 ns (high E) to 143 ns (low E, p+ pulse width is 15. ns, independent of energy.
- Beam Location: Beam in air, in vault. Table for mounting experiments gives controlled motion only vertically. Alignment of target achieved with pointer and with laser beam. Not controllable remotely.
- User Interface: Computer driven by user, very user friendly.
- Additional Facilities for Users: electronics shop and machine shop with techs are available to users.
- Work Area/Cabling: lab area with direct access to cable run, cable run of ~60 feet.
- Dosimetry: direct current read from foils compared with respect to faraday cup to calculate # particles and then dose secondary electron emission monitors.

B.1.2 Lawrence Berkeley National Laboratory

- 88” Cyclotron http://cyclotron.lbl.gov/home
- Contacts: Mike Johnson, 510-486-4389, http://cyclotron.lbl.gov/base-rad-effects
- Accelerator: Sector-focused cyclotron (K=140)
- Energies: 3-55 MeV tunable, Intensity adjusted in steps by user, scale adjusted by operator.
- Beam Information: single user, beam spot up to 6 inches in diameter. Collimators available for smaller spot. Heavy ion beams available at same facility.
- Beam Location: Beam in air, in vault. Parts mounted on fixed table and aligned with laser beam. Not controllable remotely.
- User Interface: Computer driven by user, very user friendly.
- Additional Facilities for Users: electronics shop and machine shop with techs on site, use requires coordination.
- Work Area/Cabling: experiment shack sits directly above vault with comfortable working space. Cable runs are about 10m to the beamline.
- Dosimetry: In-beam ion chamber gives continuous flux, fluence, and radial profile measurement during exposure.

B.1.3 TRIUMF

- http://www.triumf.ca/homepage.html & http://www.triumf.ca/welcome/
- Contacts: http://admin.triumf.ca/ Dr. Ewart Blackmore 604-222-7461
- Accelerator: Cyclotron (for more facility information see: http://www.triumf.ca/pif/)
- Energies (Tune or Degraded): 60 MeV – 500 MeV on two lines with variable energy extraction 65 to 120 MeV (line one) and 180 to 500 Mev (line two); degraders to cover gap and down to 20 MeV; two lines in the same vault, both simultaneous and completely independent with fluxes of 100 to 10^8 or 10^9 p/cm^2/s (smaller beam spot for 10^9).
- Beam Information: dual user with simultaneous variable energy extraction, 2” x 2” uniform beam spot, high E line ~ 3” x 3”, 25 MHz AC, 43 ns pulse with 4 ns p+ pulse, and 10 µs hole every 1 ms for diagnostics.
- Beam Location: closed vault, XY remote control table, rotation is manual, 4’ x 4’ area in the room for equipment, beam at 54” high.
- User Interface: both lines have computer controlled user interface and low energy line has super fine control (used for medical applications).
- Additional Facilities for Users: staffed machine shop and electronics shop, stores as well (cables and connectors)
- Work Area/Cabling: 20’ x 40’ with some equipment and tables in this area, 65’ cabling run.
- Dosimetry: primary: ion chambers calibrated against externally calibrated ion chamber, secondary: faraday cup for up to 200 MeV there is a 500 MeV but infrequently used, and third: plastic scintillators, all agree very closely.
- Facility Note: beam time is scheduled very far in advance. Beams run April to December, usually closed January to March for upgrades. Time on the low-energy beam line is usually more available. Also investigate and understand all applicable export issues surrounding shipment of test equipment to Canada.

B.1.4 Indiana University Cyclotron Facility

- http://www.iucf.indiana.edu/
- Contact: Dr. Barbara Von Przewoski (812) 855-2913, Facility: (812) 855-9365, Fax (812) 855-6645.
- Accelerators: Cyclotron
- Energies: 205 MeV peak and can be degraded. Beam intensity adjusted by accelerator operator.
- Beam Information: Beam shared with clinic between 7:00 and 19:00, up to 30cm diameter beam spot with collimators available, the beam is 35 MHz with pulses on 2nd or 3rd harmonic: 50 to 100ns pulse with 0.4 ns p+ pulse,
- Beam Location: Beam in air, in vault. X-Y translator (remote control) with manual rotation vise, Two beam lines are available.
- User Interface: Extensive user beam control computer with complete automatic control over beam; automatically calculates dosimetry.
- Additional Facilities for Users: auxiliary electronic equipment available, limited access to machine/electronics shop.
- Work area: Approximately 20ft x10ft beamline area, 40ft x20ft data acquisition and setup area. 50' cabling run.
- Dosimetry: Faraday cup and secondary electron emission monitors, profile check with gafchromic film and scanner readout. Scintillator dosimetry available for low flux tests.

B.1.5 Francis H. Burr Proton Therapy Center

http://www.massgeneral.org/radiationoncology/BurrProtonCenter.aspx

Medical Facility: Beam usually only available for SEE on weekends

B.1.6 The Svedberg Laboratory

www.tsl.uu.se

Energies: 20-175 MeV

B.1.7 Paul Scherrer Institute

www.psi.ch

Energies: 8-250 MeV

Annex C Final report

C.1 Test objectives

a) Determine Single Event Effect (SEE) susceptibility for various flight application environments.

b) Simulate the actual or "worst-case" space radiation environment.

c) Provide useful and precise test data in order to perform "risk" analysis.

d) Test for any failure modes.

e) Ascertain maximum safe operation limits.

f) Evaluate the amount and type of shielding required.

g) Provide accurate data for SEE error rate prediction analysis

C.2 Test plan (see 5.1)

C.3 Tested product description

a) Part Number

b) Product Block Diagram

c) Product Functional Description

d) Manufacturing Process

   i. Technology Type (CMOS, BiCMOS, SOI, GaAs)

   ii. Lot date code, and/or wafer lot code

   iii. Feature Size

   iv. Number of Metal Layers

   v. Final Passivation (oxide, nitride, polyamide), thickness

   vi. Package Type Description (plastic, ceramic, BGA), number of pins

C.4 Description of test setup

a) Electrical schematic of equipment connections

b) Equipment List (Manufacturers, serial numbers, calibration dates)

c) Special Designed Test Equipment

d) Describe beam source

C.5 Description of test methodology

a) Static or Dynamic
b) If dynamic, state operational test frequency
c) Test Pattern (Checker-Board, all-ones, all-zeros, other)
d) Test Duration
e) Refresh Rate, if applicable
f) Derating Factors (ECC, EDAC)
g) Include single-bit and multi-bit components. Describe how multi-bit component determined.

C.6 Description of bias and ambient conditions.

a) Ambient Temperature (Cryogenic, Room, Elevated)
b) Junction Temperature
c) Operational Voltage (minimum, maximum)

C.7 Test data sheet

C.7.1 Form for recording proton test results

The test data sheet shall as a minimum contain the following information:

a) Name of Test Facility
b) Dates, times, names of test personnel.
c) Type of accelerator, name and location; proton energy.
d) DUT types, serial numbers, functional description, technology, manufacturer, date code and mask number if known.
e) Device duty factor and fractional portion of the chip tested; if applicable.
f) Purpose for each test run and any changes from previous test run.
g) DUT operating parameters (bias, clock frequency, temperature, etc.)
h) DUT test patterns or operational modes, including duty factor.
i) Beam angle is always stated even if it is 90°.
j) Proton count (related to fluence), run time.
k) Number of errors, locations, and special comments (anomalous incidents).
l) Transient events and recovery time when applicable.
m) Special test results; e.g., latchup, burnout, SEGR, etc.
n) Summary of results.
o) Record Accumulated TID, Accumulated NIEL and Accumulated Total Fluence
p) Conclusion

C.8 Output- (raw data, statistical data, plots)

a) SEL – Plot, raw data , previous data – spreadsheets, tables

b) SEU – Plot, raw data, previous data – spreadsheets, tables

c) SET – Plot

d) SEB – raw data

e) SEGR – raw data

f) TID – raw data

g) Displacement Damage – raw data

Standard Improvement Form JEDEC JESD234

The purpose of this form is to provide the Technical Committees of JEDEC with input from the industry regarding usage of the subject standard. Individuals or companies are invited to submit comments to JEDEC. All comments will be collected and dispersed to the appropriate committee(s).

If you can provide input, please complete this form and return to:

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Arlington, VA 22201-2107

Fax: 703.907.7583

1. I recommend changes to the following:

☐ Requirement, clause number ________

☐ Test method number ________ Clause number ________

The referenced clause number has proven to be:

☐ Unclear ☐ Too Rigid ☐ In Error

☐ Other ________

2. Recommendations for correction:

____
____
____
____

3. Other suggestions for document improvement:

____
____
____
____

Submitted by

Name: ________ Phone: ________

Company: ________ E-mail: ________

Address: ________

City/State/Zip: ________ Date: ________

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