ESCC

European Space Components Coordination

SINGLE EVENT EFFECTS TEST METHOD

AND GUIDELINES

ESCC Basic Specification No. 25100

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SINGLE EVENT EFFECTS TEST METHOD

AND GUIDELINES

ESA/SCC Basic Specification No. 25100

space components
coordination group

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		SCCG Chairman	ESA Director General or his Deputy
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DOCUMENTATION CHANGE NOTICE

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1. SCOPE

1.1 GENERAL

This specification defines the basic requirements applicable to the Single Event Effect (SEE) testing of integrated circuits and discrete semiconductors suitable for space applications.

1.2 PURPOSE

The purpose of this specification is to define the requirements for the testing of integrated circuits and discrete semiconductors for SEE arising from irradiation by energetic heavy ions or protons.

1.3 APPLICABLE DOCUMENTS

1.3.1 ESA/SCC Specifications

No. 21300, Terms, Definitions, Abbreviations, Symbols and Units.

1.3.2 Other (Reference) Documents

ASTM F1192-90, Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices.

JEDEC 13.4, Test Procedure for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation.

2. TERMS, DEFINITIONS, ABBREVIATIONS, SYMBOLS AND UNITS

The terms, definitions, abbreviations, symbols and units specified in ESA/SCC Basic Specification No. 21300 shall apply. For the purpose of this specification, the following additional definitions shall be applicable.

- Linear Energy Transfer (LET) or Stopping Power
  The amount of energy deposited per unit length along the path of the incident ion. Expressed in units of MeV/mg/cm^2 which is the energy per unit length divided by the density of the irradiated medium.

- Effective LET
  The equivalent LET obtained by tilting the device under test with respect to the beam axis, hence increasing the path length of the ion and the total energy deposited. Effective LET = Incident LET x 1/cos Θ where Θ is the tilt angle of the device.

  Effective LET may also be used in referring to the actual LET in a sensitive volume after taking into account the energy loss in 'dead layers' such as metallisation and passivation.

- Charge transfer or deposition
  The LET expressed as charge deposited per unit length (by electron-hole pair creation). Expressed in units of pC per µm.

  An LET of 96MeV/mg/cm^2 will give 1pC per µm in silicon.

- Flux
  The number of ions passing through a unit area perpendicular to the beam in one second.

  Units: ions/cm^2/sec.

- Fluence
  The flux integrated over time. Units ions/cm^2.

- Cross section
  The number of events per unit fluence. Expressed in units of cm^2/device or cm^2/bit. In the event of the device being tilted at an angle Θ, the fluence must be rected by multiplying the fluence by Cos Θ. See also Para. 4.2.3.

- Ion specie
  Type of ion being used for irradiation (e.g. oxygen, neon etc).

- Range
  The distance travelled, without straggling, in the target material by the specified ion of given charge state and energy.

- Energy
  The energy imparted to the ion by the accelerator. This may be in units of total energy (MeV) or energy per nucleon (MeV per AMU)

- Single Event Upset (SEU) also known as a Soft Error
  The change of state of a latched logic state from one to zero or vice-versa. A single event upset is non-destructive and the logic element can be rewritten or reset.

- Latch-up
  A permanent and potentially destructive state of the device under test whereby a parasitic thyristor structure is triggered and creates a low impedance, high current path.

- Soft Latch
  A condition in which the device under test will not respond to external stimulus but with all other electrical conditions (e.g. supply current) being normal.

- Single Hard Error (SHE) or Stuck Bit
  Permanent or semi-permanent damage of a cell by an ion strike.

- Multiple bit error
  A condition in which a single ion strike causes more than one bit to be upset. It is desirable for test software to be capable of identifying and logging multiple bit errors.

- Single Event Gate Rupture
  Destructive rupture of a gate oxide layer by a single ion strike. This leads to gate leakage currents under bias and can be observed as stuck bits in digital devices.

- Single Event Burn-out
  A form of latch-up whereby the device, unless suitably protected, passes sufficient current to cause destruction.

- Threshold LET or Energy
  The LET at which the cross-section is 1% of the saturated cross-section.

- Saturated Cross Section, also known as limiting or asymptotic cross-section
  The cross section for which an increase in LET does not result in an increased number of upsets.

- Level of Interest
  A cross section, energy, LET or fluence having some particular significance for a programme or project.

3. EQUIPMENT AND GENERAL PROCEDURES

The equipment shall consist of the radiation source, electrical measurement or monitoring system and test software, test circuit board(s), cable, interconnect board or switching system, test fixtures and the appropriate dosimetry and diagnostic instruments.

Precautions shall be taken to obtain an electrical measurement or monitoring system, which by use of sufficient insulation, ample shielding, line drivers and receivers, satisfactory grounding etc. shall yield suitably low levels of interference from mains power supplies, magnets, switching systems and other sources of noise. The magnitude of interference from each of these items shall constitute the test requirements.

3.1 RADIATION SOURCE AND DOSIMETRY

3.1.1 Source, General

The radiation source used for SEE tests shall be a particle accelerator capable of delivering the required fluence of heavy ions or protons of suitable LET and energy. The radiation field shall be uniform to ± 10% over the area of the device(s) under test.

3.1.2 Source, Heavy Ions

The accelerator shall be capable of delivering ions with a range of at least 30μm in silicon with variable flux ranging from a few 100ions/cm^2/s to at least 10^{5}ions/cm^2/s on the device under test.

Unless the accelerator allows extraction of the beam in air, the accelerator beam-line shall be equipped with a suitable vacuum chamber allowing the irradiation of delidded components and accurate alignment of the device under test. Rotation of the axis of the component with respect to the beam is a desirable facility. The device under test shall be shielded from incident light during test.

3.1.3 Source, Protons

The accelerator shall be capable of delivering protons in the energy range 20 to 200 MeV with a variable flux ranging from 10^{5}p/cm^2/s to at least 10^8 p/cm^2/s on the device under test. Irradiations may be performed in air without delidding the components. Exposure shall be performed with the device normal to the beam.

3.1.4 Dosimetry

Dosimetry shall allow the continuous monitoring of the flux at the device throughout the test with an accuracy of ±10%. The dosimetry technique shall be reported. The device under test shall be mounted as close as possible to the monitor detectors in order to ensure accurate dosimetry.

The total ionising dose to the device under test shall be calculated and recorded.

If degraders are used for proton testing the energy spread shall be measured and recorded.

3.1.5 Temperature

The temperature of the device under test or as close as possible to the device under test shall be monitored and recorded.

3.2 TEST SYSTEM

3.2.1 Test Board and Cabling

The test board provides mechanical support for the device(s) under test and provides electrical connections to the feed through connectors which provide electrical connection from inside the vacuum chamber to the monitoring equipment cables. For certain testing the test board may be a full single board computer which provides all monitoring of the device under test. The full set-up of test board and cabling shall be proven to be noise free in the accelerator operating environment.

Inside the vacuum chamber a support frame is required for the test board and the frame/test board assembly must allow positioning of the device(s) in the path of the beam. It is desirable that it also allows accurate rotation about the X or Y axis for modification of the effective LET. The frame is generally facility specific and provided by the accelerator laboratory (see guidelines).

3.2.2. Device Test System

The device test system shall be designed to cover the needs of both SEU characterisation and latch-up characterisation. Further details are given in the guidelines.

4. TEST PLANNING AND PROCEDURES

Further information on test planning is given in the guidelines.

4.1 SAMPLE SIZE, SELECTION AND PREPARATION

The sample size shall be not less than 3 pieces of the same lot date code. The devices may be unscreened but the technology should be identical to that used, or intended to be used, for production of ESA/SCC devices. Delidding is required for heavy ion testing and a functional test shall be performed after delidding (care shall be taken to exclude all light during this test). Delidding is not required for proton testing.

Each sample shall be clearly marked to facilitate traceability of test data. A die photograph shall be taken to aid in data analysis and evaluation, the die size shall be measured and any die identification or marking shall be recorded. In the case of proton irradiation the device may be delidded for this purpose after testing.

4.2 ELECTRICAL MEASUREMENTS

4.2.1 Single Event Upset

The device architecture shall be studied to identify functional blocks containing bistable elements such as registers. Test hardware and software shall be designed to allow the monitoring of functional blocks, together with the possibility of writing different patterns (e.g. all zero's, all one's, checker board etc.) and the re-writing of an affected cell after an SEU. The test software shall be capable of logging the number of upsets, the location and the time.

A device may well contain a number of bistables of different design, each having a different single event sensitivity, test coverage should be such as to allow these different sensitivities to be identified.

Analogue and mixed analogue/digital technologies may generate false outputs or transients as the result of SEE. The test system shall be capable of monitoring and logging these effects.

4.2.2 Latch-up

Test hardware and software shall be designed for latch-up detection, protection and logging. The response time of latch-up protection shall ensure that there is no damage or degradation of the device under test.

Software shall be tested to establish the percentage of 'active time', that is the amount of time the device under test is in a condition to be sensitive to detectable SEE, the rest of the time being used for software operations (reading, writing, logging etc) when an SEE may occur without being detected. The percentage of active time shall be taken into account when calculating the cross-section of the device using raw fluence and event data.

4.2.3 Units of Measure

The SEE sensitivity of the device under test is the cross section and shall be expressed as the ratio of the number of upsets to the total particle fluence, that is for each LET, number of events/ions/cm^2 striking the device normal to the surface. If the angle of incidence of the beam relative to the device under test is varied (for heavy ion testing only), an effective LET shall be calculated as the normal incidence LET divided by the cosine of the angle:

$$\text{LET (eff)} = \text{LET}(\Theta)/\cos\Theta$$

If the angle of incidence is varied the effective fluence will also change. Therefore, the measured fluence shall also be corrected and the cross section shall be calculated as :

$$\sigma = \text{number of upsets}/F\cos\Theta$$

Where F is the Fluence measured in the plane normal to the beam.

4.3 TEST PLAN

Prior to performing the tests a Test Plan shall be prepared following the format given in Appendix 'A'. Ion species and energies shall be chosen to cover the LET range from upset threshold to saturated cross section for the device under test, with adequate penetration (typically 30μm in Silicon). Details of commonly available ions at different facilities are given in the Guidelines.

For LETs not directly available, the device may be tilted to give an increased 'effective LET'. For proton testing only a range of energies needs to be specified (typically 20 to 300 MeV) covering threshold to saturated cross section. The device under test shall be normal to the beam axis for all proton testing.

For both heavy ion and proton testing about 5 exposures (at different LET or Energy) are required to adequately plot a response curve.

The fluxes chosen should be such as to accumulate a meaningful number of upsets in one or multiple exposures of typical test time of 1 to 20 minutes each or, in the event of an insensitive device, to accumulate a fluence of at least 10^7ions/cm^2 for heavy ions or 10^{10}protons/cm^2 for protons. There are no dose rate effects in SEE testing but fluxes must be compatible with the response time of the device under test and the speed of test hardware and software. Careful note shall be kept of the total ionising dose delivered to the device under test. For proton testing in particular, the total dose delivered to the device under test may be significant and necessitate the use of new devices during the tests.

5. DOCUMENTATION

5.1 GENERAL

For each SEE test to be performed 2 sets of documents are required:-

(a) A Test Plan (prior to testing), defining the detailed requirements for the components to be tested including a description of the test hardware and a flow chart for the test software.

(b) A Test Report giving the actual test conditions and test results.

5.2 TEST PLAN

As a minimum the Test Plan shall contain the information below. The information shall be entered (preferably-type written) in boxes in the plan form given in Appendix 'A' or using a software routine (ESA Radiation Effects Database Data-Collection Tool).

Box No.

1 Reference number of Test Plan (3 digits starting from 001).

2 Reference (issue and revision with dates) of the Single Event Test Plan.

3 Equivalent SCC Component Number, if existing.

4 Component Designation e.g. integrated circuit, quad 2-input exclusive OR gate and commercial part number if necessary.

5 Manufacturer/User Single Event Test Specification (number, issue, revision).

6 Applicable ESA/SCC Generic and Detail Specifications (numbers, issues, revisions).

7 Type of radiation: Heavy Ions or Protons.

8 Type of test: (SEU, single event latch-up or single event burn-out), Other.

9 Project or Programme requiring this test.

10 Component Family

11 Component Group.

12 Device package.

13 Manufacturer's name and address.

14 Test House name and address.

15 Originator of Test Plan (name and telephone number).

16 Name of facility and type of radiation source.

17 Sample size and number of control devices.

18 Type of Irradiation exposure (single or multiple). See Box Nos. 21 & 22.

19 Device construction (technology): CMOS Bulk, CMOS EPI, CMOS SOS, CMOS SOI or other (specify). Enter also feature size/line width in µm.

20 Level of interest. (see Para. 2.19).

21 Single exposure: Specification of ion specie and charge state, energy in MeV and for heavy ions only, linear energy transfer.

22 Multiple exposure: Specification of ion specie and charge state, energy in MeV and linear energy transfer for each exposure.

23 Electrical conditions: Specification of test system used, cycle time, frequency or static condition, test pattern(s) used and supply voltage of device under test.

24 Irradiation test sequence describing each step of each test to be performed and requirements related to these steps. Page 2 of Appendix 'A' is to be used as a continuation sheet as necessary.

25 Remarks should contain items of special note or importance which should be considered during the test programme, especially the possibility of hard or soft latch-up, oxide rupture etc.

5.3 TEST REPORT

The Test Report shall be presented (preferably type written) in accordance with the format given in Appendix 'B' or using the ESA Radiation Effects Database Data-Collection Tool software and provide the following information:

Box No.

1 Single Event Test Report number (plus page number and total number of pages).

2 Reference (issue and revision with dates) of the Single Event Test report.

3 Equivalent SCC Component Number, if existing.

4 Component designation e.g. integrated circuit, quad 2-input exclusive or gate and commercial part number if necessary.

5 Manufacturer/User Single Event Test specification number, revision and issue.

6 Device Family.

7 Group of devices.

8 Device package.

9 Applicable ESA/SCC Generic and Detail Specifications (number, issue, revision).

10 Test facility, name and address.

11 Single Event Test Plan number, revision and issue.

12 Manufacturer's name and address.

13 Type of radiation: Heavy Ions or Protons.

14 Serial numbers of sample and control devices.

15 Manufacturing date code.

16 Device construction (technology): CMOS bulk, CMOS EPI, CMOS SOS, CMOS SOI, or other (specify). Enter also feature size/line-width in µm.

17 Die size in mm.

18 Depth of active region, measured or from Manufacturer's data.

19 Type of test: (SEU, single event latch-up or single event burn-out), Other.

20 Test Conditions.

21 Type of radiation source and dosimetry technique, ion specie and charge state, energy in MeV, linear energy transfer. Ambient temperature at device under test, tilt angle of device under test with respect to the beam axis, effective linear energy transfer, equivalent charge transfer.

22 Irradiation test sequence. The test sequence shall be prepared before the test is started and shall be based on the test sequence proposed in the relevant Single Event Test Plan. When test data is either voluminous or presented in special test form it can be submitted as an Appendix which shall be referenced under 'Results' and correspond to the appropriate step.

23 Name and telephone number of the person responsible for the test facility.

24 Name and telephone number of the person responsible for the electrical testing.

25 Plots of upset cross section (per bit or per device) versus LET or energy.

26 Remarks. The estimated total ionising dose received during testing should be recorded in this section. Reference to any special occurrences during the test such as soft or hard latches, software crashes or effect of total ionising dose (increased leakage etc) should be made. Die markings may also appear in this section (see Para. 4.1).

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SCC

SINGLE EVENT TEST PLAN NO.

1

Issue No. Rev.

Date Date

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2

SCC Component No. 3

Component Designation: 4

Irradiation Spec. No.

Iss. Rev. 5

Specifications

Generic Iss. Rev.

Detail Iss. Rev. 6

Radiation Type

Protons ☐

Heavy Ions ☐ 7

Test Other ☐

SEU ☐

SEL ☐

SEB ☐ 8

Project/ Programme 9

FAMILY: 10

GROUP 11

PACKAGE: 12

Manufacturer: Name:
Address: 13

Test House: Name:
Address: 14

Originator:
Name:

Telephone: 15

Facility: 16

Sample Size:

Control Devices: 17

IRRADIATION:

Single ☐

Multiple ☐ 18

CONSTRUCTION:
CMOS:
BULK ☐ EPI ☐ SOS ☐ SOI ☐

Other: 19

Level of Interest: 20

Single Irradiation

Ion:

Energy (MeV):

LET (MeV mg^{-1} cm^{-2} (Si)) 21

Multiple Irradiation Steps	1	2	3	4	5	6	7	8
Ion								
Energy (MeV)								
LET (MeV mg^{-1} cm^{-2} (Si))								

22

Electrical Conditions

Test System: Cycle Time/Frequency: V_{DD}:

Test Pattern 23

Irradiation Test Sequence 24

Test Step	Description	Requirements

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Irradiation Test Sequence (Cont') 24

Test Step	Description	Requirements

Remarks 25

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Issue No. Rev.

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SCC Component No. 3

Component Designation: 4

Irradiation Spec.
No.
Iss. Rev. 5

Family: 6

Group: 7

Package: 8

Comp. Specifications
Generic Iss. Rev.
Detail Iss. Rev. 9

Test Facility Name:
Address: 10

Irradiation
Test Plan
No. Iss.
Rev. 11

Manufacturer:
Name:
Address: 12

Acceptance
Diffusion ☐
Lot ☐ 13

Sample Serial Numbers:
Control Serial Numbers: 14

Manufacturing
Date Code: 15

Construction:
CMOS
Bulk ☐ Epi ☐ SOS ☐ SO1 ☐
Other: 16

Die Size: 17

Depth of Active
Region: 18

Test: Other ☐
SEU ☐
SEL ☐
SEB ☐ 19

Electrical Conditions:

Test System: Cycle Time Frequency: V_{DD}:

Test Pattern: Number of Bits Tested: 20

Facility:

Ion: Energy (MeV): LET (MeV mg^{-1} cm^{-2} (Si)): Temp: °C

Title Angle: Effective LET (MeV mg^{-1} cm^{-2} (Si)): Equivalent Charge Transfer (pC μm^{-1}) 21

Irradiation Test Sequence 22

Step No.	Description	Test Condition	Fluence	Time	No. of Events	Cross Section	Latch-up

Irradiation Test Facility: Responsible
Name:
Telephone: 23

Electrical Test: Responsible
Name:
Telephone: 24

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Step No.	Description	Test Condition	Fluence	Time	No. of Events	Cross Section	Latch-up

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Remarks 26

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APPENDIX 'C'

GUIDELINES FOR THE PERFORMANCE OF SEE TESTS

1.1. TEST BOARD AND CABLING

Figure I shows a typical test board design which is suitable for use in the SEU Facility at Brookhaven National Laboratory (Long Island. US), the ESA Proton Irradiation Facility (PIF) at the Paul Scherrer Institute (Villigen Switzerland) and the ESA Heavy Ion Facility (HIF) at the University of Louvain la Neuve (Belgium). ESA actively encourages the use of this standard board for any new facilities in Europe.

Cabling is also facility specific but many accelerator facilities may require a significant length of cabling (in the region of 20 to 30 metres) and this should be borne in mind when designing the test and monitoring system. Some facilities allow fairly close access (3 to 5 metres) to the vacuum chamber when using certain ions and for both heavy ions and protons. It is generally possible to have test and monitoring equipment installed close to the beam line but this has to be remotely operated over the longer distances mentioned earlier.

8.2 THE DESIGN OF A DEVICE TEST SYSTEM

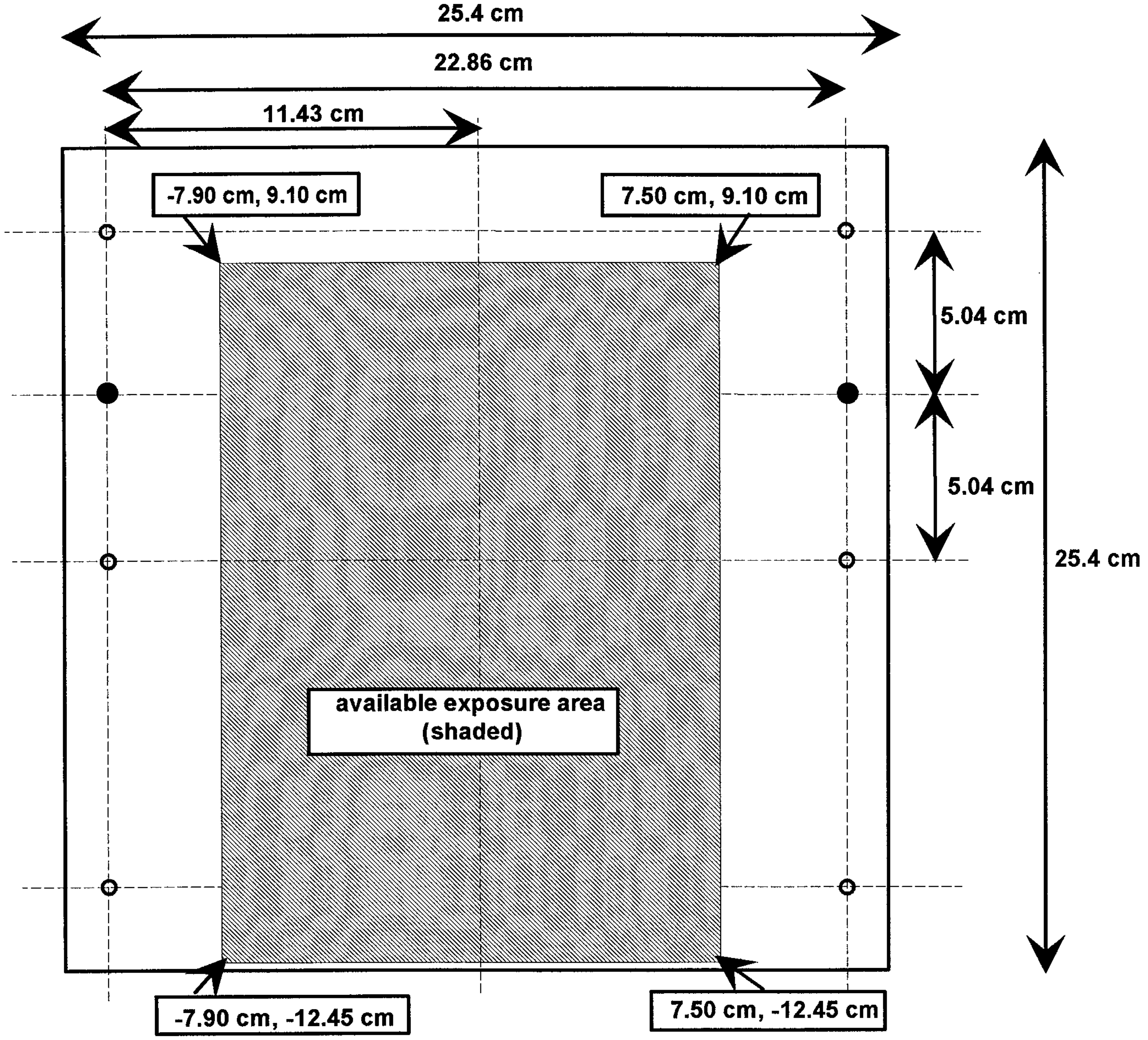
The Test System is device specific, however, there are a number of general principles which apply. The basic operations required of a Test System are:-

(a) Device initialisation and function test.
(b) Device operation, dynamic or static during exposure.
(c) Device latch-up protection, logging and re-initialisation.
(d) Error detection, logging and rewriting of an affected cell.
(e) Measurement and logging of the 'duty cycle' (fraction of time the device is active and vulnerable to upset compared with the test time).
(f) Logging of test time, count rates, fluence and beam diagnostics to be attached to the test data.

The following additional features enhance test throughput and flexibility:-

(a) Real time data processing, storage and retrieval.
(b) Reconfiguration under software control, particularly for the testing of different memory organisations.
(c) High operating speed and duty factor.
(d) Real time device under test data display.
(e) Data reduction while tests are in progress to allow test conditions to be modified depending on results achieved.

FIGURE I - SEU TEST BOARD



SEU Test Board

1.3 THE USE OF THE RADIO-ACTIVE SOURCE CALIFORNIUM-252

Californium-252 is a fissionable, transuranic radionuclide which decays by alpha particle emission with a half life of 2.72 years. Californium-252 also undergoes spontaneous fission with a half life of 85 years. The source emits alpha particles, fission fragments and fast neutrons.

The fission fragments are used for SEE testing and these have a mean LET of 43 MeV/mg/cm^2 (Si) with 95% of the particles having LETs between 41 and 45 MeV/mg/cm^2 (Si). The mean range of the fission particles in silicon is 14.2μm.

A Californium-252 source does not meet the full requirements for SEE testing but may be used for the pre-test of components and validation of test hardware and software. The source shall have a nominal activity in the range 1 to 5 μCi and be used under vacuum (better than 10^{-3} Torr) with the component delidded. If the vacuum chamber is a glass bell-jar this shall be fitted with a safety shield and a light tight cover. Sufficient feed through connectors shall be provided for the monitoring of the device under test. The source shall be calibrated at least once a year using a charged particle detector and pulse height analyser. The flux shall be measured at different distances from the source and a calibration curve of flux/distance constructed.

1.4 TEST PLANNING

The use of a Californium-252 source (see above) is highly recommended as an aid to test planning and initial screening. Verification of test hardware and software set-up can be performed in the User's laboratory rather than at the test site.

The technology shall be studied with a view to estimating its likely sensitivity to SEU. This may be done by researching data bases such as the ESA Components Radiation Effects Database and JPL 'RADATA' as well as recent Nuclear and Space Radiation Effects Conference Proceedings published annually in the December issues of the IEEE Transactions on Nuclear Science. Ideally, there may be data available on devices in the same technology from the same Manufacturer. If not then some 'generic' estimates can be made according to technology (CMOS Bulk, CMOS Epitaxial, SOS, GaAs etc), feature sizes and junction depths. Possession of such data allows more efficient use of accelerator time in terms of setting initial fluxes, ion species and energies.

1.5 FACILITIES COMMONLY USED FOR SEE TESTING

The facilities listed below are those commonly used by virtue of being able to meet the requirements of the Test Method as detailed in Para. 3.1.

Accelerator facilities are subject to change and it is the responsibility of the User that they still meet the requirements of Para. 3.1 and the needs of the specific test to be carried out.

(a) AEA TECHNOLOGY, HARWELL, U.K., TANDEM - 7MeV

This Tandem is a vertically mounted electrostatic particle accelerator of the Van de Graaff type. Ion beams can be produced with up to 45MeV of energy. Change of ion species takes approximately 2 hours. A dedicated SEU beam line is available with a target chamber diameter of 25cm, height 30cm. The test board area is 80 x 69 mm of which the DUT/beam irradiation area covers 20 x 69 mm. Particle fluence at DUT position is related to a chopper detector, Faraday Cup arrangement calibrated against the target chamber heavy ion detector. The experimental area is 25 meters away.

Only limited SEU/latch-up characterisation possible due to the short range of the ions available.

(b) IPN, ORSAY, F., TANDEM - 15MeV

This Tandem is a horizontally mounted electrostatic particle accelerator of the Van de Graaff type. Ion beams can be produced with up to 238MeV of energy. Change of ion species takes approximately 2 hours. A dedicated SEU beam line is available with a target chamber diameter of 60cm, height 40cm. The test board area is 165 x 233 mm of which the DUT/beam irradiation area covers 20 x 165 mm. Particle fluence at DUT position is related to a scattering chamber detector calibrated against the target chamber detector (17 x 22 mm) which also checks beam uniformity. The DUT board with several devices and the large detector can be remotely controlled (DUT positioning and angling) from the experimental room 60 meters away.

Full device SEU/latch-up characterisation over the LET range can be covered. Several DUTs can be tested at the same time.

(c) BNL, UPTON, LONG ISLAND, USA, TANDEM - 15MeV

This Tandem is a horizontally mounted electrostatic particle accelerator of the Van de Graaff type. Ion beams can be produced with up to 345MeV of energy. Change of ion species takes approximately 30 minutes. A dedicated SEU beam line is available with a target chamber diameter of 92cm, height 92cm. The test board area is 254 x 254 mm of which the DUT/beam irradiation area covers 150 x 220 mm. Particle fluence at DUT position is based on five detectors in the diagnostic chamber where the flux and beam uniformity are constantly monitored. The DUT board with several devices can be remotely controlled (DUT positioning and inclination) from the experimental area 2 to 3 meters away. The DUT position can be checked by simulating the beam with visible laser light.

Full device SEU/latch-up characterisation over the LET range can be covered. Several DUTs can be tested at the same time.

(d) CYCLONE, LOUVAIN-LA-NEUVE, B. CYCLOTRON - 3 to 30MeV/n

The CYCLONE (the Cyclotron of Louvain-la-Neuve) cyclotron has all heavy ions produced by a two stages ECR (Electron Cyclotron Resonance) source. By using "ion cocktails" having the same M/Q ratio, the change to a different ion species only takes a few minutes of fine tuning the cyclotron. Two different cocktails will be available for SEU/SEL testing, M/Q = 4 = 6.87MeV/n and M/Q = 5 = 4.4MeV/n. An ESA coordinated Heavy Ion Facility (HIF) with dedicated beam line and target chamber is under construction. The target chamber diameter will be 50cm, height 50cm. The experimental area will be 4 to 6 meters away. The ESA HIF will be fully operational by mid 1996.

Full device SEU/latch-up characterisation over the LET "cocktail" range can be covered in a very short period of time.

Protons from 20 to 80 MeV are also available on another beam line.

(e) GANIL, CAEN, F., CYCLOTRON - 10 to 100 MeV/n

The GANIL (Grand Accelerateur National D'Ions Lourds) consists of a compact cyclotron injector and two identical Separated-Sector Cyclotrons where particles at 10 to 100 MeV/nucleon can be obtained. The change of ion species takes 1 to 2 days. A dedicated SEU beam line is available. SEU testing is carried out in air. A scanned beam of approximately 30cm x 2.0cm is available at the DUT frame which has space for four Eurocard DUT cards. The frame can be angled up to 70 degrees. Particle fluence at DUT position determined by pin diode and solid detector. The experimental room is 8 to 10 meters away.

Full device SEU/latch-up characterisation covering an extended LET range can be covered. Several DUTs and several DUT types can be tested at the same time. However, matching of DUT technologies and particle flux is essential before irradiation.

(f) GSI, DARMSTADT, D. CYCLOTRON - 10 to1000 MeV/n

The GSI (Gesellschaft für Schwerionenforschung) facility consists of a UNILAC (UNIversal Linear Accelerator), a SIS (Schwer-Ionen-Synchtotron) and an ERS (Experimentier-Speicher-Ring) where particles at 10 to 1000 MeV/nucleon can be obtained. Change of ion species takes 1 to 2 days. A dedicated SEU beam line is not yet available. SEU testing is carried out in air. A target board having up to 8 temperature controlled DUTs, detectors and tilting capability is available. Experimental rooms are 20 to 25 meters away.

Full device SEU/latch-up characterisation covering an extended LET range can be covered. Several DUTs can be tested at the same time.

(g) SATURNE, CEA, SACLAY, F., SYNCHROTRON - 20 to 2950 MeV PROTON

The SATURNE synchrotron at CEA (Commissariat a l'Energie Atomique) can supply proton energies from 200 to 2950 MeV. From 200MeV Al-absorbers can further degrade the energy of the proton beam down to 20MeV. Particle fluence for the DUT position comes from a detector system calibrated against carbon cartridges. Beam stability and homogenity can be followed on a oscilloscope. Irradiation is carried out in air. The experimental area is 20 meters away. Several DUTs can be irradiated at the same time.

(h) PSI, VILLIGEN, CH., CYCLOTRON - 10 to 600 MeV PROTON

The PSI (Paul Scherrer Institute) Cyclotron has a primary beam of 600MeV which can be degraded to lower energies by Al-absorbers. At the ESTEC coordinated Proton Irradiation Facility (PIF) beam line which is dedicated to SEU work, degraded calibrated beams from 300 to 30 MeV can be delivered. Additionally, at the OPTIS (eye therapy) beam line 60MeV and lower energies can be covered. At the PIF beam line energy change is under the control of the experimenter by means of a PC. Using the same PC, beam stability and homogenity can be followed. Particle fluence for the DUT position is coming from a target detector. At both beam lines irradiation is carried out in air. The experimental area for PIF is 40 meters (OPTIS 15 meters) away. Several DUTs can be irradiated at the same time.

Reference :

'Test methods for Single Event Upset and Latch-up'. R. Harboe-Sorensen. Radiation Physics and Chemistry Vol 43 No 1/2. January/February 1994. Special edition on 'Space Radiation Environment and Effects'. Pergamon Press.

TABLE I - HEAVY ION FACILITIES AND BEAMS

FACILITY	ION	ENERGY (MeV/Nucleon)	LET in Si (MeV/mg/cm^2)	RANGE IN Si (µm)
AEA Harwell UK 7MeV Tandem	35 Cl 16 O 12 C 7 Li 7 Li	1.3 2.2 2.9 1.0 2.1	18.5 5.4 2.9 1.4 0.9	12 23 39 17 47
IPN Orsay France 15MeV Tandem	127 I 79 Br 35 Cl 19 F 12 C	1.8 2.8 4.4 5.9 7.0	53.0 36.0 12.7 4.0 1.7	26 30 45 77 139
BNL. Long Island. USA. 15MeV Tandem	127 I 58 Ni 35 Cl 24 Mg 19 F	2.5 4.4 6.0 6.6 7.6	59.7 26.9 11.4 6.1 3.3	31 41 64 82 133
CYCLONE. M/Q=4 Louvain. Belgium. Cyclotron 3 to 30 MeV/n	40 Ar 20 Ne 16 O 12 C 4 He	6.9 6.9 6.9 6.9 6.9	12.5 5.7 2.9 1.7 0.2	89 51 116 138 375
CYCLONE. M/Q=5	130 Xe 80 Kr 40 Ar 20 Ne 15 N	4.4 4.4 4.4 4.4 4.4	69.0 41.3 15.0 5.7 2.9	75 58 54 51 74
GANIL. Caen. France. Cyclotron 10 to 1000 MeV/n	129 Xe 129 Xe 40 Ar 40 Ar 16 O 16 O	5.0 31.0 5.5 33.0 5.0 34.0	70 33 13 4.2 3.5 0.85	50 382 61 814 66 1579
GSI. Darmstadt. Germany. Cyclotron 10 to 1000 MeV/n	197 Au 197 Au 40 Ar 20 Ne 20 Ne	9.9 386.5 12.7 9.1 350.0	89.6 11.9 8.5 3.7 0.3	102 15000 178 143 70350

TABLE II - PROTON FACILITIES

FACILITY	ENERGY RANGE (MeV)	ENERGIES USED
Proton Therapy CYCLONE Louvain Belgium. Cyclotron	20 to 80	20, 40, 60
Proton Irradiation Facility (PIF). PSI Switzerland Cyclotron	20 to 590	30, 50, 100, 150, 200, 300
OPTIS Therapy facility PSI Switzerland Cyclotron	20 to 60	20, 30, 40, 60
SATURNE. CEA France Synchrotron	20 to 2950	30, 50, 100, 200, 500, 800