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**Single Event Upset/Latchup
Test Report
for
UTMC UT22VP10
PROGRAMMABLE ARRAY LOGIC DEVICE**

Prepared by:
Jerry Wert
Pete Majewski

For:
UTMC

**BOEING RADIATION EFFECTS LABORATORY (BREL)
Boeing Defense & Space Group
Research & Technology
P.O. Box 3999
Seattle, WA 98124-2499**

SUMMARY OF TEST RESULTS

The UTMC UT22VP10 exhibited ionizing radiation induced upsets when exposed to energetic heavy ions. The ions apparently caused the devices to asynchronously clear all internal registers. Latchup was not observed in these tests.

Since this part built using a radiation tolerant process, it was not possible to verify the geometric assumptions for the conversion of the effective LET (linear energy transfer) and cross sections. Thus, there is some uncertainty regarding the generalized use of the following results for calculating upset rates.

Single event upsets were not detected at LET 54 MeV-cm²/mg but were detected at LETs of 64 MeV-cm²/mg and higher. The highest measured cross section was 3.8×10^{-6} cm² at LET 109 MeV-cm²/mg. Using the highest cross section and lowest LET, the mean device upset rate for Adam's 90% worst case solar activity environment at geosynchronous orbit is 1.5×10^{-7} upsets per device-day.

Latchup was not observed at effective LET values as high as 109 MeV-cm²/mg (angle of incidence of 55°) at high (+125° C) or ambient temperatures.

1. INTRODUCTION

This document describes the results of single event latchup (SEL) and single event upset (SEU) testing performed on the United Technologies Microelectronics Center (UTMC) UT22VP10 Programmable Array Logic (PAL) device. The devices were exposed to energetic heavy ions at the University of California Lawrence Berkeley Laboratory (LBL) 88" cyclotron facility. The purpose of the test was to determine ion induced latch-up and bit upset rates when exposed to an ionizing heavy-ion environment encountered at geosynchronous orbits. Testing was performed during the week of March 13th, 1995.

2. TEST SAMPLES

The UT22VP10 is a high performance, low power, radiation tolerant PAL. The devices, which are supported by industry-standard programmers, provide 22 input and 10 output drivers, 10 user-programmable macrocells (registered or combinatorial), 30 MHz clock speeds and 5.0 volt operation.

The devices were packaged in 24-pin 100-mil center ceramic DIP packages with removable kovar lids. A total of five test samples were irradiated. The devices provided for test, were programmed and pre-serialized by UTMC. Table I below, lists the serial numbers and wafer codes of the devices tested.

Table I. Test Sample Identification

Test Device	Serial Number	Wafer Code
1	17	02-6922
2	14	32-6922
3	20	02-6922
4	24	02-6922
5	46	32-6922

3. TEST METHODOLOGY

The devices were configured as a tri-statable 10-bit synchronous latch. The ABEL source code used to program the devices is shown in Appendix A.

The devices were tested in vacuum. Prior to exposure, the device lid material was removed and the devices were placed on the test fixture. Removal of lid material is necessary due to the relatively low range of the particles used to simulate cosmic rays. During vacuum pump down, the devices were heated and allowed to thermally stabilize. The devices were tested for upset at ambient temperature (approx. 40° C) and for latchup at high temperatures (125±5° C).

During exposure, the devices were continuously exercised using a Boeing-built memory test system. The test hardware performed a continuous loop in which all zeros, all ones, or an

alternating binary (0101...) user selectable register bit patterns were tested. The test fixture for the devices is shown in figure 1.

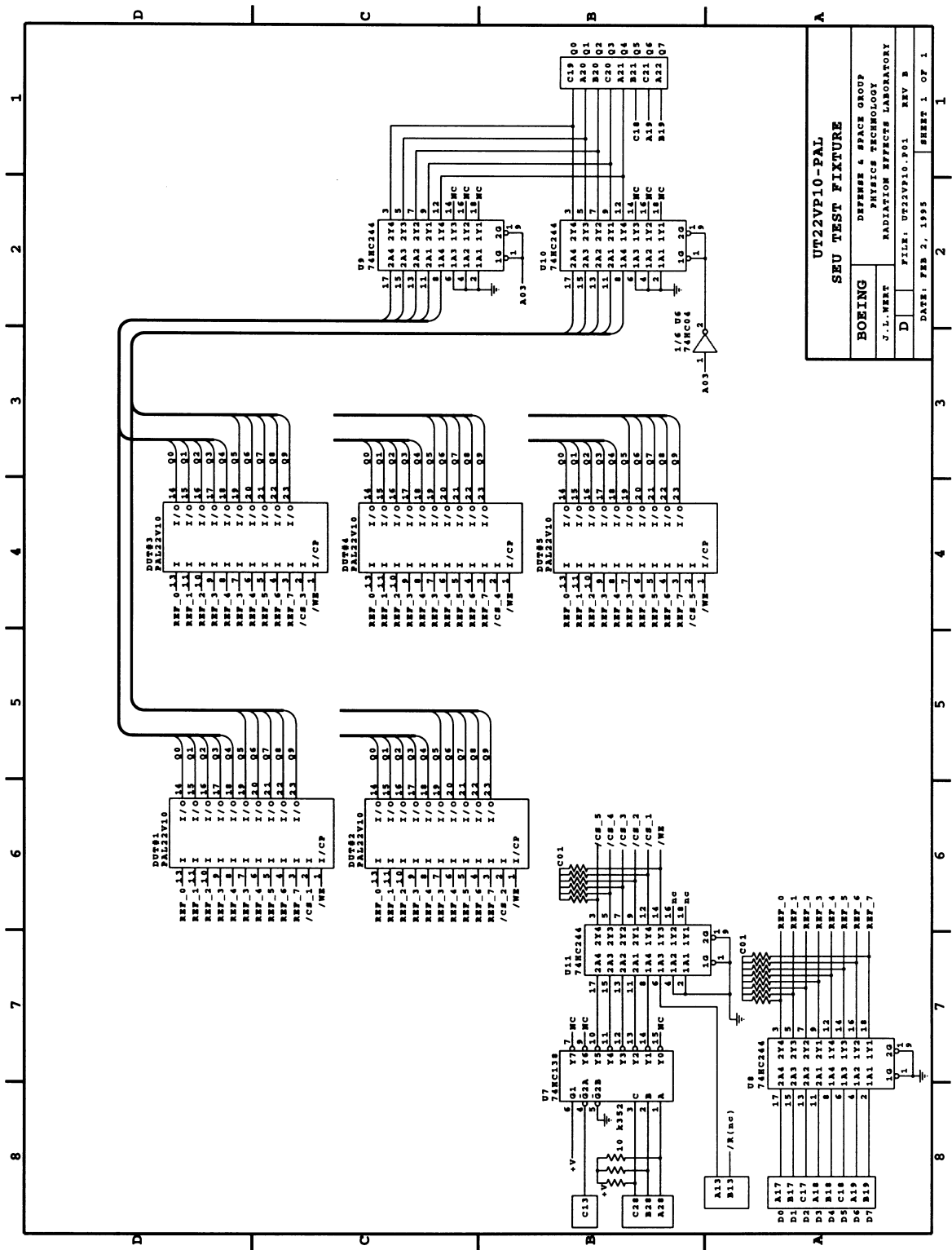
During the test, the supply voltages were 4.5 VDC for upset and 5.5 VDC for latchup. Heavy ion induced latchup is determined as an event which causes the test sample supply current to increase beyond a predetermined value (in this case 100 mA). The device power supply current was continuously monitored during exposure to detect latchup. When such an event occurs, the power is interrupted for approximately 10 ms and then restored. The latch-up events are recorded using a scalar. The test system block diagram is represented in Figure 2.

The ions, energies and LETs available at the time of testing are listed in Table II.

Table II. Ions available at LBL 88-inch Cyclotron

ion	Energy (MeV)	LET in Silicon (MeV-cm ² /mg)
Boron (B)	45	1.5
Nitrogen (N)	68	2.8
Neon (Ne)	90	5.5
Argon (Ar)	180	14.3
Cobalt (Co)	265	26
Krypton (Kr)	387	38
Xenon (Xe)	612	63

Since these devices are relatively immune to ionizing radiation, only krypton and xenon were used in the testing. For most common device geometries, an effective LET can be generated by varying the incidence angle of the ions. The effective LET is taken to be the LET of the ion divided by the cosine of the angle of incidence. These devices were individually exposed at varying angles of incidence, starting with the highest xenon at 55°, having an effective LET of 109 MeV-cm²/mg. Subsequent exposures were performed at lower effective LET values until no effects were detected. The geometry of these parts may invalidate use of the effective LET for these parts. This is discussed in the DATA ANALYSIS section of this report.



UT22VP10-PAL

DEFENSE & SPACE GROUP
PHYSICS TECHNOLOGY
RADIATION EFFECTS LABORATORY

BOEING
J. L. WERT
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FILE: UT22VP10.P01
REV B

SHEET 1 OF 1

Figure 1. UT22VP10 Test Fixture

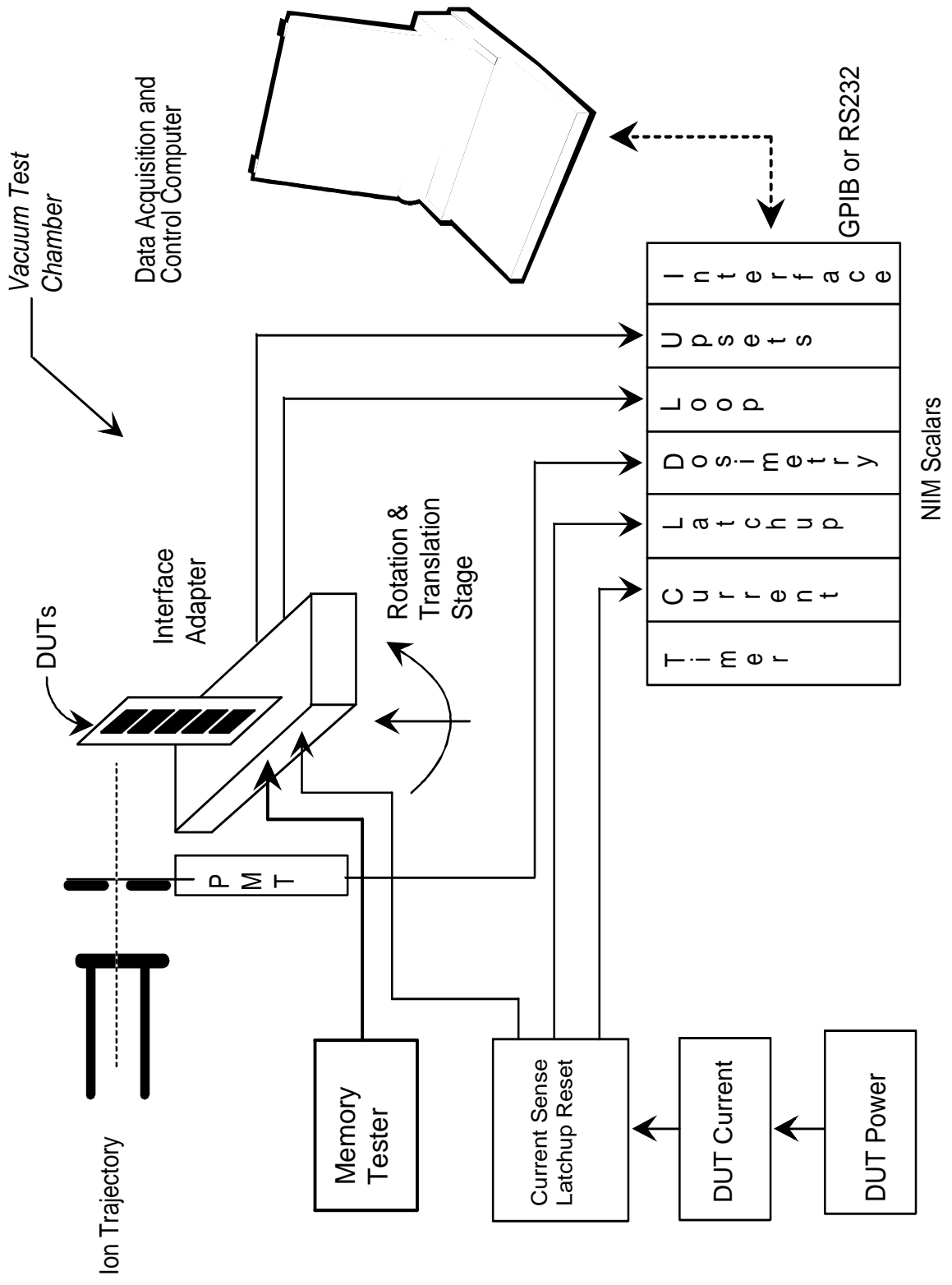


Figure 2. SEE Test System Block Diagram

4. TEST RESULTS

The data obtained from the testing are shown below in Table III and analyzed in the following section.

Table III. UT22VP10 SEE Test Results

SN	Ion	Angle	LET	Fluence	Temp.	Upset	Latch- up	Upset Cross Section	Vcc
		deg.	MeV cm ² / mg	cm ²	° C			cm ²	volts
14	Kr	45	54	7.1E+6	~45	0	0	0.0E+0	4.5
14	Xe	0	64	1.1E+6	~35	0	0	0.0E+0	4.5
14	Xe	45	91	3.0E+6	~35	3	0	9.9E-7	4.5
14	Xe	55	112	1.2E+6	~35	4	0	3.4E-6	4.5
14	Xe	55	112	1.3E+6	120	2	0	1.6E-6	5.5
17	Kr	0	38	1.2E+6	~35	0	0	0.0E+0	4.5
17	Kr	45	54	7.1E+6	~45	0	0	0.0E+0	4.5
17	Xe	0	64	1.3E+7	~45	11	0	8.8E-7	4.5
17	Kr	55	66	1.0E+7	~45	3	0	3.0E-7	4.5
17	Xe	45	90.5	2.1E+6	~35	1		4.7E-7	4.5
17	Xe	55	112	1.1E+6	~35	1	0	9.5E-7	4.5
17	Xe	0	64	5.2E+6	120	0	0	0.0E+0	5.5
17	Xe	55	112	1.4E+6	120	4	0	2.8E-6	5.5
20	Kr	45	54	7.1E+6	~45	0	0	0.0E+0	4.5
20	Xe	0	64	1.1E+7	~35	8	0	7.0E-7	4.5
20	Kr	55	66.3	1.3E+7	~45	3	0	2.3E-7	4.5
20	Xe	45	91	2.0E+6	~35	3	0	1.5E-6	4.5
20	Xe	55	112	1.2E+6	~35	3	0	2.5E-6	4.5
20	Xe	55	112	1.1E+6	120	0	0	0.0E+0	5.5
24	Kr	45	54	7.1E+6	~45	0	0	0.0E+0	4.5
24	Xe	0	64	1.1E+6	~35	0	0	0.0E+0	4.5
24	Xe	45	91	2.1E+6	~35	4	0	1.9E-6	4.5
24	Xe	55	112	1.4E+6	~35	7	0	5.1E-6	4.5
24	Xe	55	112	1.1E+6	120	0	0	0.0E+0	5.5
46	Kr	45	54	7.1E+6	~45	0	0	0.0E+0	4.5
46	Xe	0	64	1.1E+6	~35	0	0	0.0E+0	4.5
46	Xe	45	91	1.1E+6	~35	2	0	1.9E-6	4.5
46	Xe	55	112	1.0E+6	~35	2	0	1.9E-6	4.5
46	Xe	55	112	1.1E+6	120	3	0	2.7E-6	5.5

5. DATA ANALYSIS

5.1 Latch-up

All five test samples were irradiated to greater than $1E6$ ions/cm² 612 MeV Xe at angles of 55° (effective LET = 109 MeV-cm²/mg), with $V_{cc} = 5.5V$ and 125(±5) ° C. Neither single event latch-up nor loss of functionality were observed on any of the devices during the ambient and elevated temperature exposures.

5.2 Upset

The devices exhibited a unique upset mode in which all registers are reset to a logic low state as a result of an ion strike. This phenomenon was attributed to an upset in the reset circuitry, which is common to all registers in the devices. One device, serial number 17, was used to determine the worst case test pattern that gave the highest rate of event occurrences. During pattern dependency testing, only "RESET" errors were observed. Therefore, all subsequent testing was performed with the registers preset in a logic high state.

The radiation hard nature of these devices led to two difficulties in generating test data that would be usable in a normal analysis to calculate upset rates: The first difficulty was obtaining a large enough count of events to have meaningful statistics. Extending the test duration is expensive in terms of personnel costs and beam costs, as well as leading to the possibility of total dose effects influencing the SEE values. The second difficulty involves the concept of effective LET and will be discussed in more detail in the following paragraphs.

SEE caused by ionizing radiation occur when a sufficiently large charge is deposited in a sensitive volume of a device. The charge deposited is the product of the energy deposited per unit length times the chord length through the sensitive volume. The energy deposited per unit length is the LET. For simple sensitive volume geometries, where the surface dimensions of the sensitive volume are greater than its depth, the chord length is simply the depth divided by the cosine of the ion's angle of incidence (relative to normal). Since the depth of the sensitive volume is usually unknown to the SEE testers, it is the conventional practice to associate the cosine factor with the LET to generate the "effective" LET ($= LET/\cos(\text{incident angle})$). Similarly, the effective cross section is typically defined as $\# \text{ upsets}/[\text{fluence} \times \cos(\text{incident angle})]$.

Since the geometry of the sensitive volume is, typically, also unknown, the use of effective LET and effective cross section is justified after the fact by comparing the cross section values from tests at normal incidence to those at other angles. If the effective cross section vs. effective LET data form a "smooth" curve, the use of effective LET and effective cross section are considered justified. For this comparison to be possible, at least two cross section values measured at normal incidence but with different LET are needed. As Table III shows, no events were observed with krypton at normal incidence, LET 38 MeV-cm²/mg. Since krypton is the second highest LET available at the LBL 88" facility (see Table II), that meant that only one cross section value could be determined at normal incidence using xenon at LET 63 MeV-cm²/mg.

The remainder of the data were taken at incidence angles of 45° and 55° and do not seem to fall on a smooth curve with the data using xenon at normal incidence. From what data are available, it does not seem that the geometry of the sensitive volume of this part lends itself to applying the effective LET and effective cross section concepts in the conventional way. Rather more complex geometrical factors can be included if we have adequate data, e.g., where the effective cross section is a function of both the sine and cosine of the angle of incidence [see "Geometrical Factors in SEE Rate Calculation," E. Petersen et al., *IEEE Trans. Nucl. Sci.*, 40, 1888 (1993)].

In analyzing the data from this test, it was clear that the high temperature data at 5.5 VDC was significantly different from the ambient temperature data at 4.5 and 5.0 VDC. Only a very limited amount of data were available at high temperature, and these had uniformly lower cross sections than did the ambient temperature data. For this reason, the high temperature data were dropped from the analysis. Since not enough information was available to generate an alternate geometric model, the effective LET concept was applied in a conservative manner. Since no events were observed with krypton at 45°, the data for krypton at normal incidence were also eliminated from the analysis.

The remaining data were combined for all parts at each effective LET to improve the event statistics. The resulting reduced effective SEU cross section curve is shown in Figure 3. The error bars represent one standard deviation in the Poisson distribution. This figure gives an indication of the error introduced by assuming an effective LET and effective cross section for this part. However, it cannot be determined from this data what the correct geometric correction is. The reduced data are not sufficient for a fit to the smooth curve Weibull distribution, so a step function will be considered instead. The step function is more conservative, in that it generally yields higher values for the upset rate than use of the Weibull distribution. In this case, the conservatism from the step function assumption will tend to offset the error caused by the uncertainty in the geometric effects.

The step function SEU cross section model for the upset cross section was constructed in the following manner: the krypton at 45° point was used as the LET threshold (54 MeV-cm²/mg), and the xenon 55° point at the upper end of the error bar was used as the asymptotic cross section, 3.8 X 10⁻⁶ cm². With this step function SEU cross section model the SEU rate from heavy ions due to two different environments was calculated. A rate of 1.5 X 10⁻⁷ upsets per device day was calculated for the Adam's 90% worst solar conditions in a geosynchronous orbit. For the Adam's model of the August 1972 flare, the rate is 2.5 X 10⁻³ upsets per device day.

Reference: *Cosmic Ray Effects on Microelectronics, Part IV*, James H. Adams, Jr. (NRL Memorandum Report 5901, Dec. 31, 1986)

UTMC PAL 22VP10 Upset Data (Combined for 4.5 & 5.0 V, 40°C)

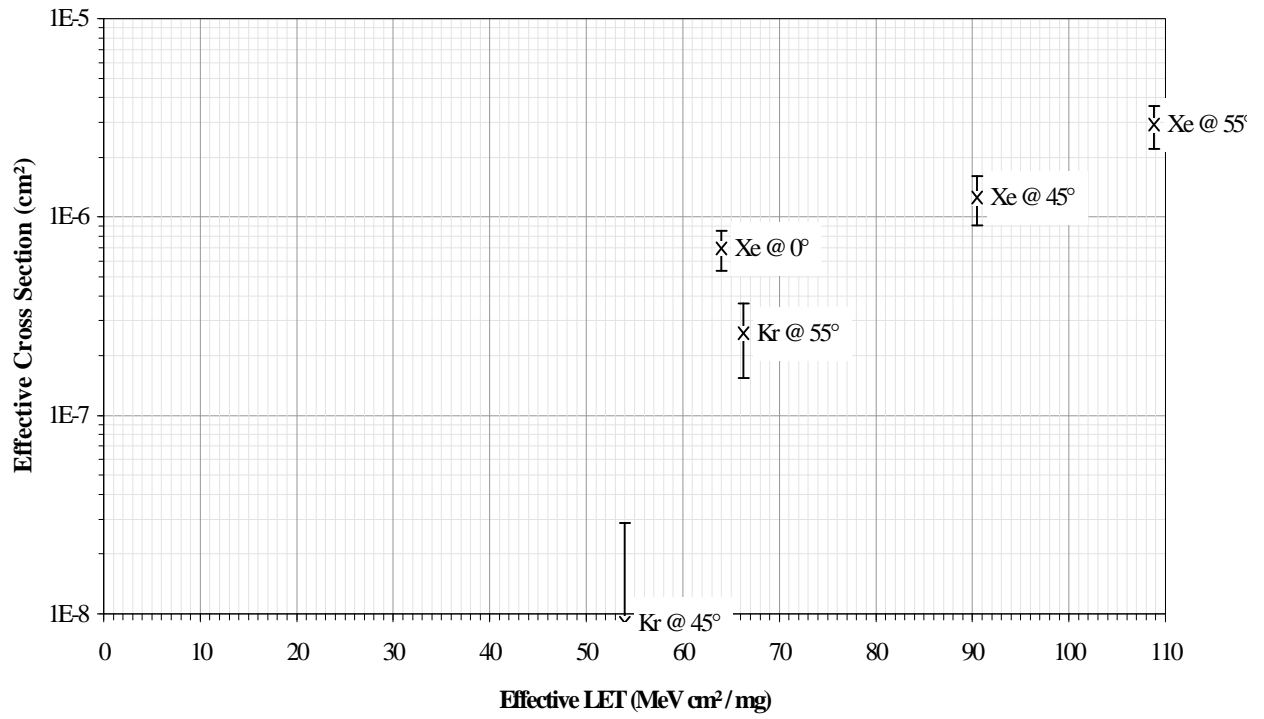


Figure 3. SEU Cross Section vs LET- UTMC UT22VP10

Appendix A

Device Configuration

```
module SEE22v10
title 'UTMC UT22VP10 PAL SEE testing - rev A
Jerry Wert - Boeing Space & Defense Group'
"+++++
"Pal is designed to provide a SEE test vehicle for ionizing
"radiation characterization of the UTMC UT22VP10 programmable array logic
"(PAL) device.
"REV notes:
" New: Jan 26,1995
"+++++
see22V10 device 'P22VP10';

"Input Pins:
CLK,nOE,D_0,D_1,D_2,D_3,D_4,D_5,D_6,D_7,D_8,D_9
Pin 1,2,3,4,5,6,7,8,9,10,11,13;

"Outputs:
Q_9,Q_8,Q_7,Q_6,Q_5,Q_4,Q_3,Q_2,Q_1,Q_0
Pin 14,15,16,17,18,19,20,21,22,23;
H,L,X = 1,0,.X.;

equations
"Registers
"active high
    Q_0 := D_0;
    Q_1 := D_1;
    Q_2 := D_2;
    Q_3 := D_3;
    Q_4 := D_4;
    Q_5 := D_5;
    Q_6 := D_6;
    Q_7 := D_7;
    Q_8 := D_8;
    Q_9 := D_9;

"Output Enables
"active low
    Q_0.OE = !nOE;
    Q_1.OE = !nOE;
    Q_2.OE = !nOE;
    Q_3.OE = !nOE;
    Q_4.OE = !nOE;
    Q_5.OE = !nOE;
    Q_6.OE = !nOE;
    Q_7.OE = !nOE;
    Q_8.OE = !nOE;
    Q_9.OE = !nOE;

end
```