Radiation Report

TMP9R01-SP Single-Event Effects (SEE) Radiation Test Report

ABSTRACT

This report characterizes the effects of heavy-ion irradiation on the single-event effect (SEE) performance of the TMP9R01-SP 1-channel temperature sensor. Only the TMP9R01 local die was tested. Heavy ions with a LET_{EFF} of 75MeV-cm^2 /mg was used to irradiate the devices with a fluence of 1 × 10^7 ions/cm^2. The results demonstrate that the TMP9R01-SP is SEL-free up to LET_{EFF} = 75MeV-cm^2 /mg at 125°C, and a dynamic SET cross section is presented.

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1 Introduction

The TMP9R01-SP device is a radiation-hardened QMLP package, high-accuracy, low-power 1-channel remote temperature sensor monitor with a built-in local temperature sensor. The remote temperature sensors are typically low-cost discrete NPN or PNP transistors, or substrate thermal transistors or diodes that are integral parts of microprocessors, analog-to-digital converters (ADC), digital-to-analog converters (DAC), microcontrollers, or field-programmable gate arrays (FPGA). Temperature is represented as a 12-bit digital code for both local and remote sensors, giving a resolution of 0.0625°C. The two-wire serial interface accepts the SMBus communication protocol with up to nine different pin-programmable addresses.

Table 1-1 lists general device information and test conditions. See the TMP9R01-SP Product Page for more detailed technical specifications, user-guides, and application notes.

Table 1-1. Overview Information

Description	Device Information (1)
TI Part Number	TMP9R01-SP
SMD Number	5962R1721801VXC
Device Function	Remote and Local Digital Temperature Sensor
Technology	LCB8LV
Exposure Facility	Facility for Rare Isotope Beams, Michigan State University and TAMU Cyclotron
Heavy Ion Fluence per Run	$1 \times 10^6 – 1 \times 10^7$ ions/cm^2
Irradiation Temperature SET	25°C and 80°C
Irradiation Temperature SEL	125°C

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2 Sample Identification

A total of three temperature sensors where verified during SEL testing. A total of one temperature was verified during SET testing. The photos below show the bond wires of a DUT that was tested. All units were decapped before radiation exposure.

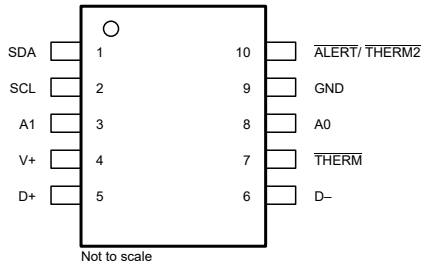

Figure 2-1. TMP9R01-SP DGS Package 10-Pin VSSOP Top View - Pinout

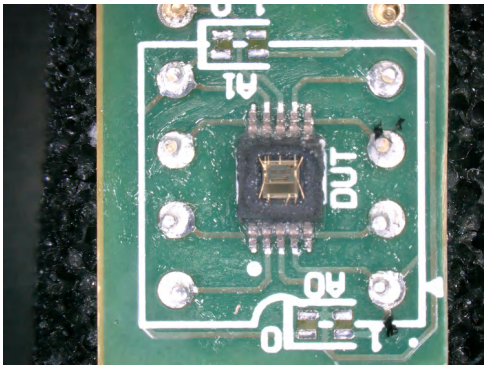

Figure 2-2. TMP9R01 Optical Image

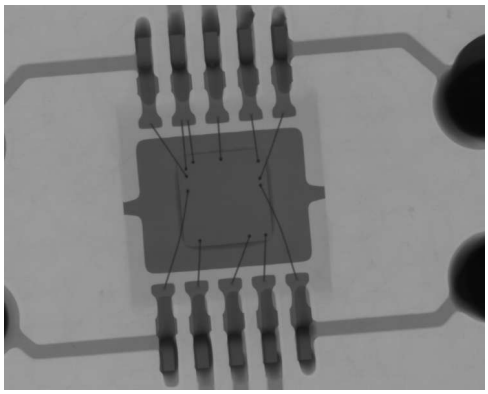

Figure 2-3. TMP9R01 XRay Image

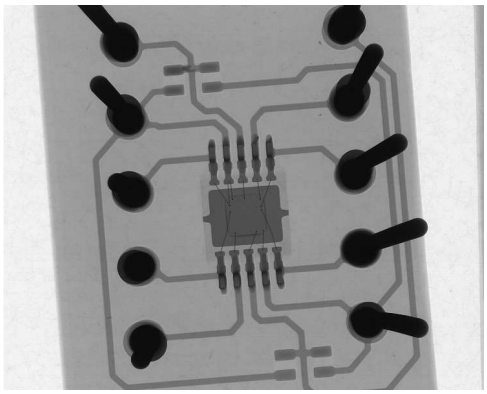

Figure 2-4. TMP9R01 XRay Image

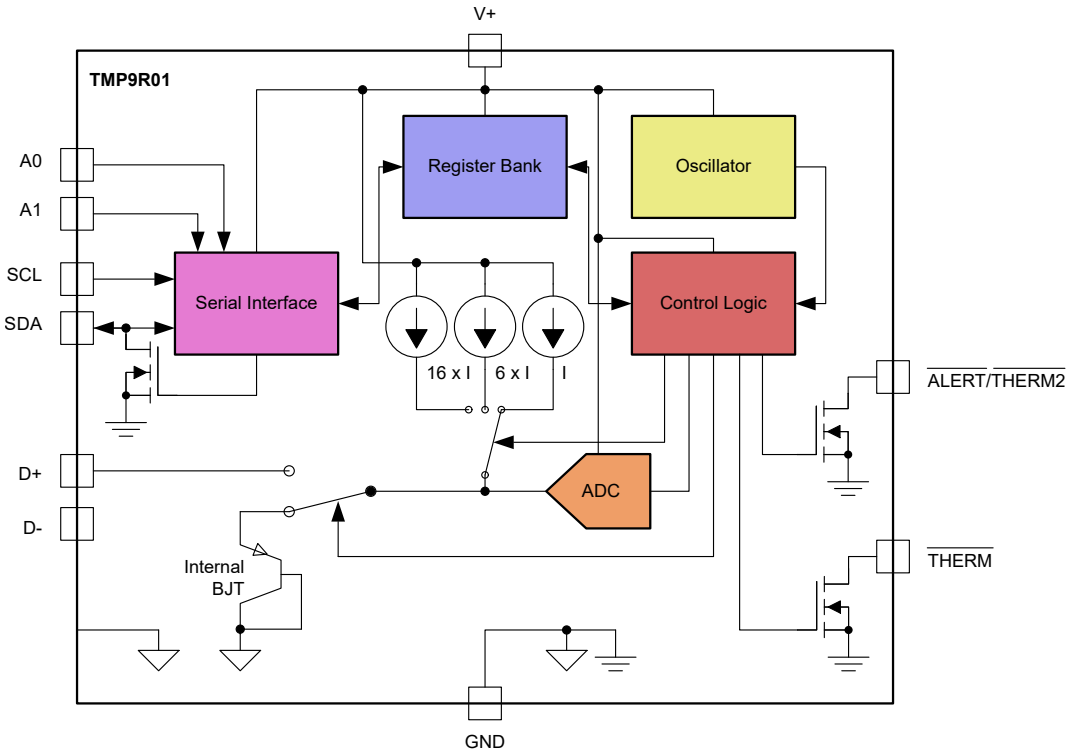

Figure 2-5. Functional Block Diagram of the TMP9R01-SP

3 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by two facilities:

- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a linear accelerator and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 20mm x 20mm square cross-sectional area for the in-vacuum scintillator. Uniformity is achieved by scattering on a Cu foil and then performing magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 9.36 x 10^4 to 1.07 x 10^5 ions/cm^2 ·s was used to provide heavy-ion fluences of 1.00 x 10^7 ions/cm^2.
- Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1-in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 5.08 x 10^4 to 6.39 x 10^4 ions/cm^2 ·s was used to provide heavy-ion fluences of 1.00 x 10^7 ions/cm^2 .

Table 3-1. Ions and LET_{EFF} Used for SEE Characterization

Ion Type	Location	Angle of Incidence	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	LET_{EFF} (MeV-cm^2/mg)
^{169}Tm	MSU	0°	1.00 × 10^5	1.00 × 10^7	75
^{165}Ho	TAMU	0°	1.00 × 10^5	1.00 × 10^7	75.1
^{129}Xe	MSU	0°	1.00 × 10^5	1.00 × 10^7	50.5
^{84}Kr	MSU	0°	1.00 × 10^4	1.00 × 10^6	35.4
^{40}Ar	MSU	0°	1.00 × 10^4	1.00 × 10^6	7.9

4 Die Micro-section

The TMP9R01-SP is fabricated in the TI Linear BiCMOS 180-nm process with a back-end-of-line (BEOL) stack consisting of 3 levels of standard thickness aluminum metal on a 0.6µm pitch. The total stack height from the surface of the passivation to the silicon surface is 3.825µm based on nominal layer thickness as shown in Figure 4-1. Accounting for energy loss through the 1mil thick Aramica beam port window, the 40mm air gap, and the BEOL stack over the TMP9R01-SP, the effective LET (LETEFF) at the surface of the silicon substrate, the depth, and the ion range was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 models). The stack was modeled as a homogeneous layer of silicon dioxide (valid since SiO2 and aluminum density are similar). At MSU, the LETEFF reported is the surface-level LET.

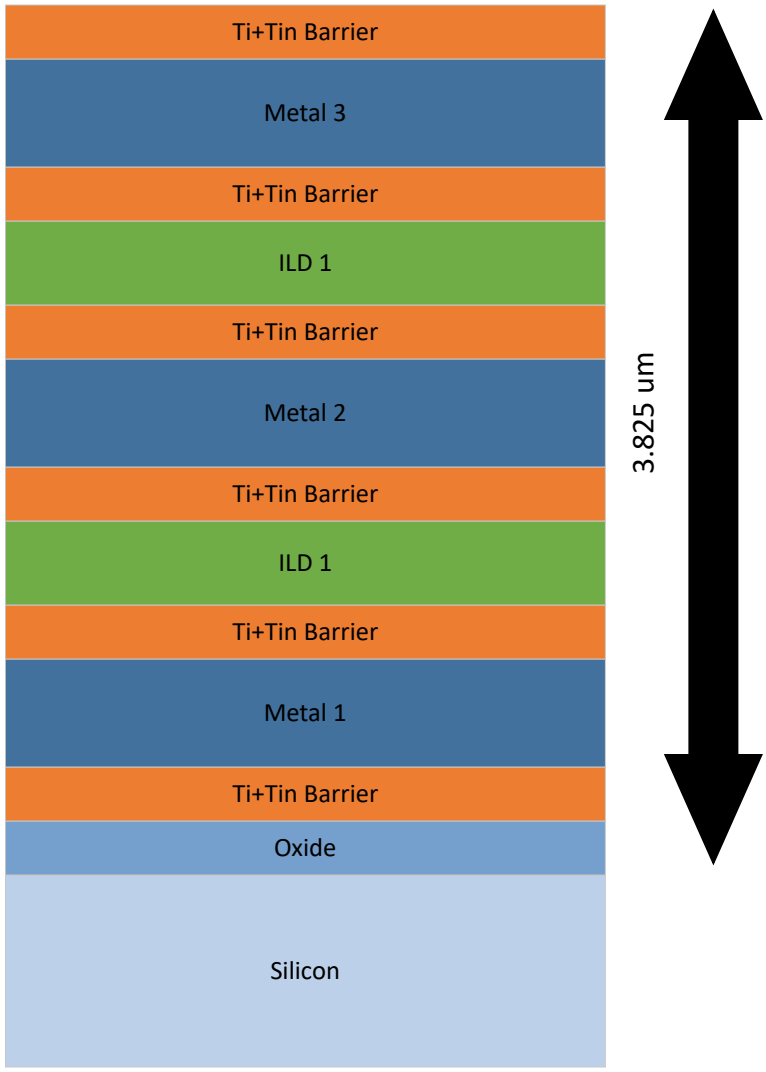

Figure 4-1. Generalized Cross-Section of the LBC8 Technology BEOL Stack on the TMP9R01-SP

5 Test Set-Up

SEL and SET data had two different test set ups. SEL data was captured at TAMU Cyclotron. SET data was captured at Facility for Rare Isotope Beams at Michigan State University.

SEL testing was captured with the TMP9R01EVM. An SMU was used to supply max voltage (3.6V) and measure current through TP2 and GND. The R21 resistor was removed, the Subregulator Switch was switched off, and TP1 and TP2 was supplied at maximum voltage 3.6V.

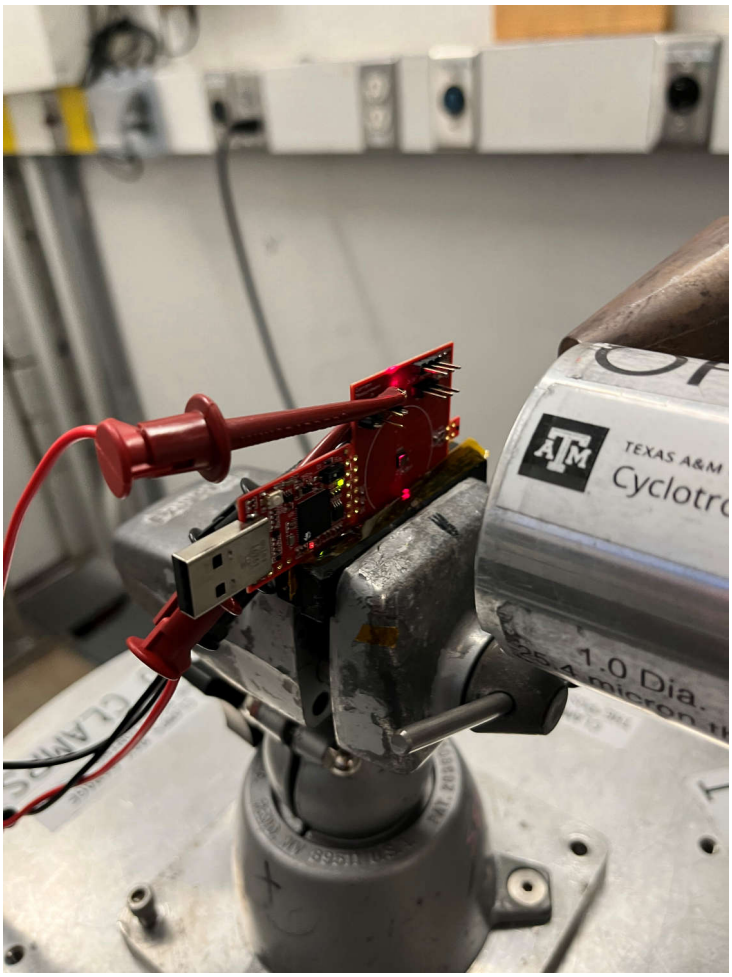

Figure 5-1. SEL Setup

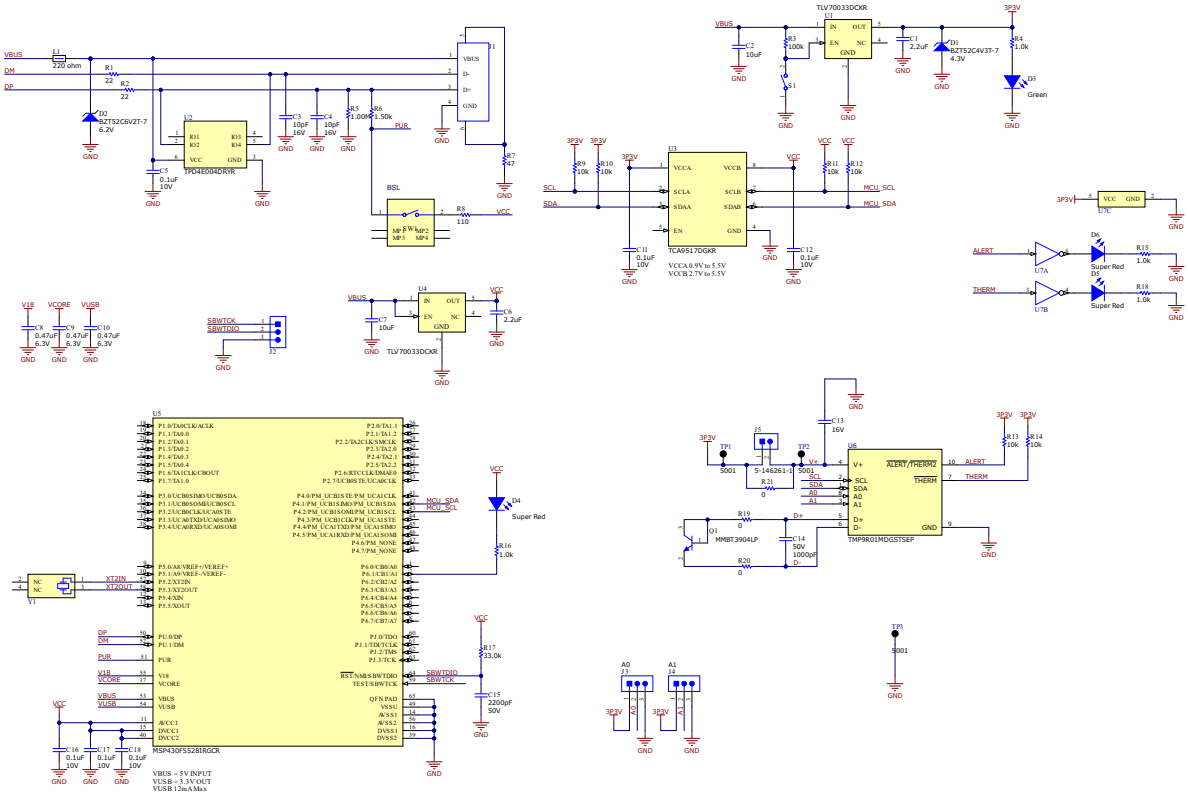

Figure 5-2. TMP9R01EVM Schematic

Table 5-1. TMP9R01 Current Specs

		TYP (µA)	MAX (µA)
Iq	Active conversion, local sensor	240	375
	Active conversion, remote sensor	400	600
	Standby mode (between conversions)	15	35
	Shutdown mode, serial bus inactive	3	8
	Shutdown mode, serial bus active, fs = 400kHz	90	
	Shutdown mode, serial bus active, fs = 2.17MHz	350	

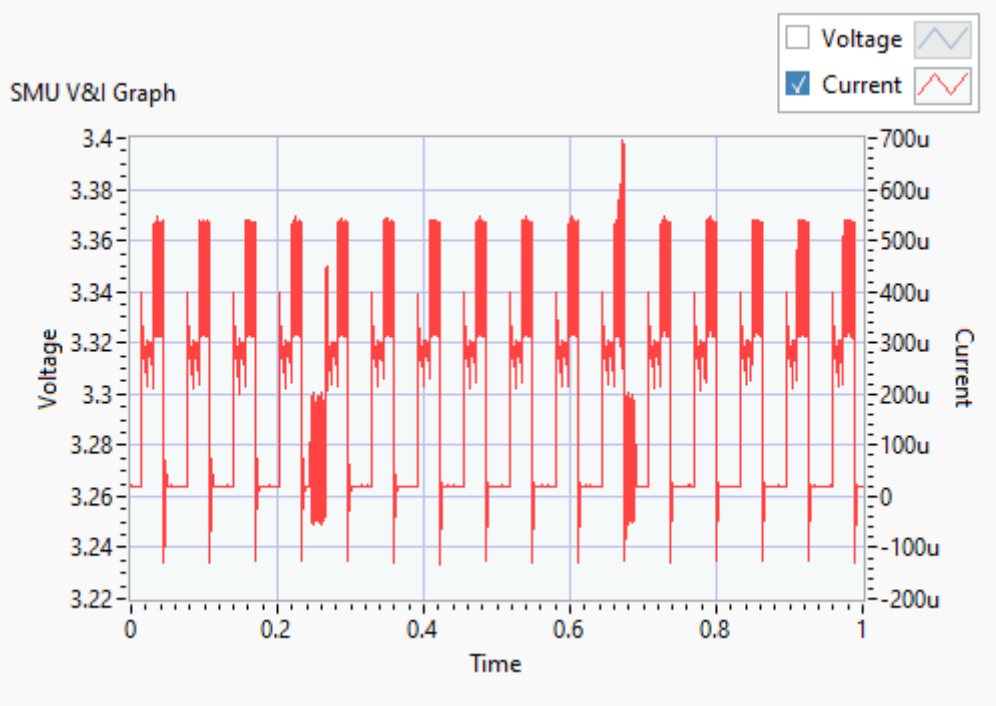

Figure 5-3. Expected Total Quiescent Current with Communication

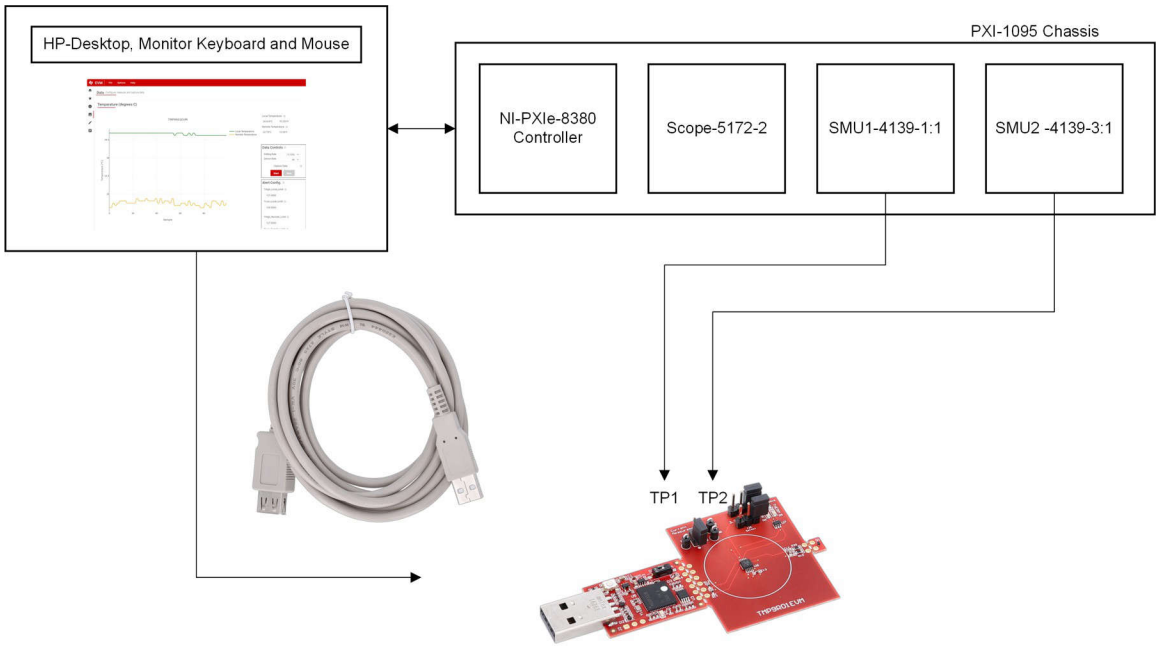

Figure 5-4. Full Lab SEL Set Up

SET testing for TMP9R01 has a separate board. The board was designed to capture transient data from the DUT and report the values in an excel sheet. More information about what was captured is presented in the Summary of SET Results Section. The board schematic, layout, and setup is shown below. TMP9R01 SET test setup was combined with other devices to multitask and only the TMP9R01 data is presented in this report.

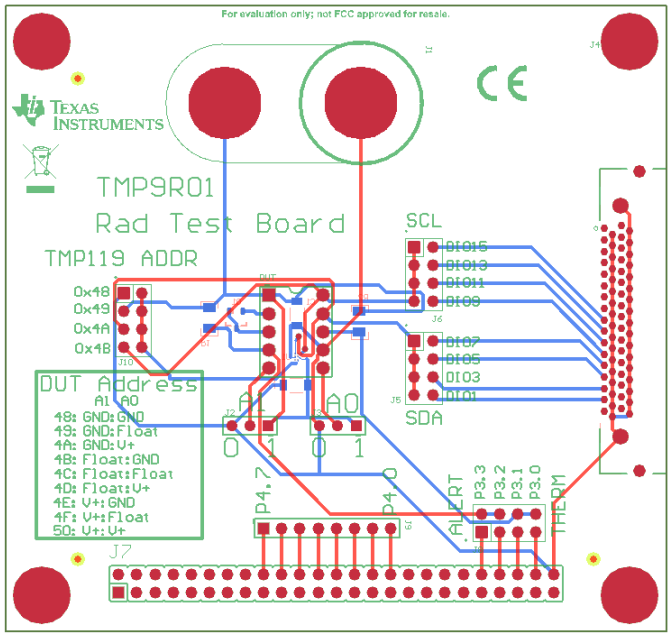

Figure 5-5. TMP9R01 SET PCB Layout

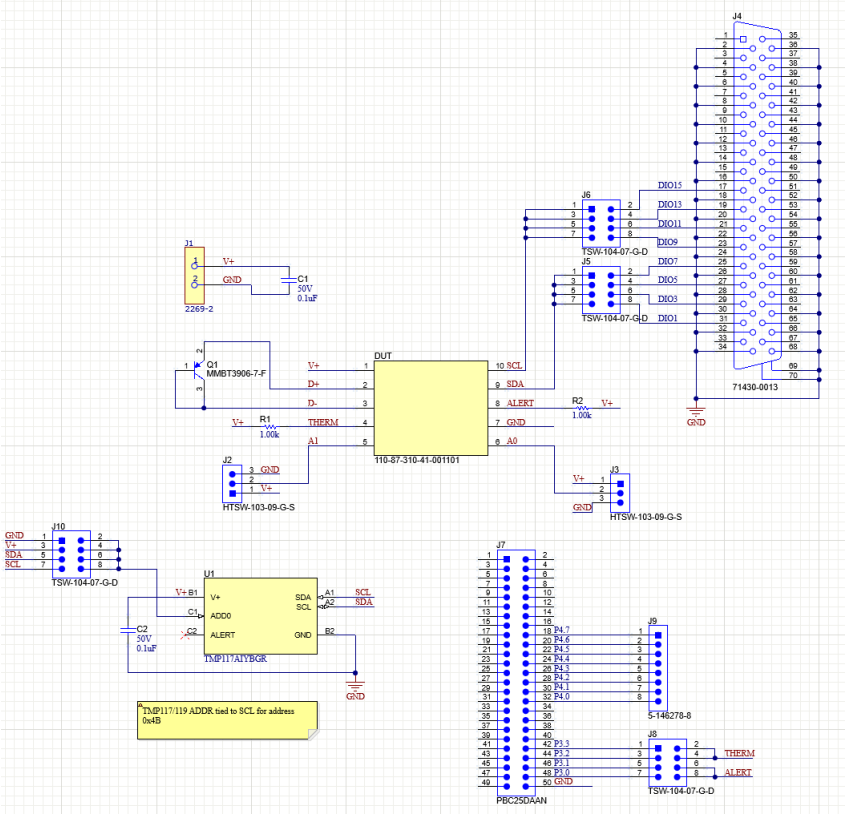

Figure 5-6. TMP9R01 SET Schematic

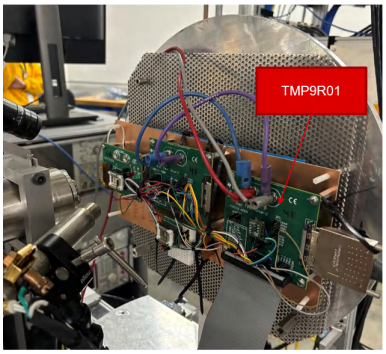

Figure 5-7. Full SET Test Setup

6 SEL Results

SEL detection is performed by monitoring the DUT supply current. An SEL event occurs when a device latches and the device current exceeds 600uA. During a latch up event, communication is interferd. A total of three devices were tested and verified at max temperature, max voltage, and at 75.1 MeV radiation exposure. Depending on the state the device is in, the output quiescent current can change. The beam start time and end time was taken at different states of the device. The device was heated using forced hot air, maintaining the die temperature at 125°C. All devices where tested before and after SEL exposure to verify the performance of the device. Table 6-1 below shows the details of each device passing with functional behavior after exposing.

6.1 TMP9R01-SP SEL Data

Table 6-1. TMP9R01-SP SEL data

Lot #	Device / Bias	Run #	Pass/Fail	Temp (°C) Thermo Camera	Uniformity %	Distance (mm)	Ion	Thetha Table Angle (°)	LETEFF (MeV·cm²/mg)	Target Flux (ions·cm²/s)	Actual Flux (ions·cm²/s)	Fluence (# of ions·cm²)	Actual Fluence (# of ions·cm²)	Dose (rad)	Elapsed Lifetime (sec)	VS (V)	Measured IS (mA) Before Beam	Measured IS (mA) Post Beam	Measured IS (mA) At Beam
TAMU	4	22	Pass	25	95	40	Ho	0	75.1	1.00E+05	1.10E+05	1.00E+07	1.00E+07	1.18E+04	91.416	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	4	23	Pass	125	95	40	Ho	0	75.1	1.00E+05	1.02E+05	1.00E+07	9.98E+06	1.17E+04	98.167	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	3	24	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.67E+04	1.00E+07	9.95E+06	1.20E+04	102.9	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	3	25	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.71E+04	1.00E+07	9.99E+06	1.20E+04	102.933	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	3	26	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.59E+04	1.00E+07	1.00E+07	1.20E+04	104.45	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-2.614e-6uA
TAMU	3	27	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.32E+04	1.00E+07	1.00E+07	1.20E+04	107.267	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	2	28	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.74E+04	1.00E+07	1.00E+07	1.20E+04	102.767	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	4	29	Pass	125	95	40	Ho	0	75.1	1.00E+05	1.07E+05	1.50E+07	1.50E+07	1.81E+04	139.917	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA
TAMU	4	30	Pass	125	95	40	Ho	0	75.1	1.00E+05	9.97E+04	1.50E+07	1.47E+07	1.81E+04	139.917	VS1 = VS2 = 3.6	-15uA to about 400uA	-15uA to about 400uA	-15uA to about 400uA

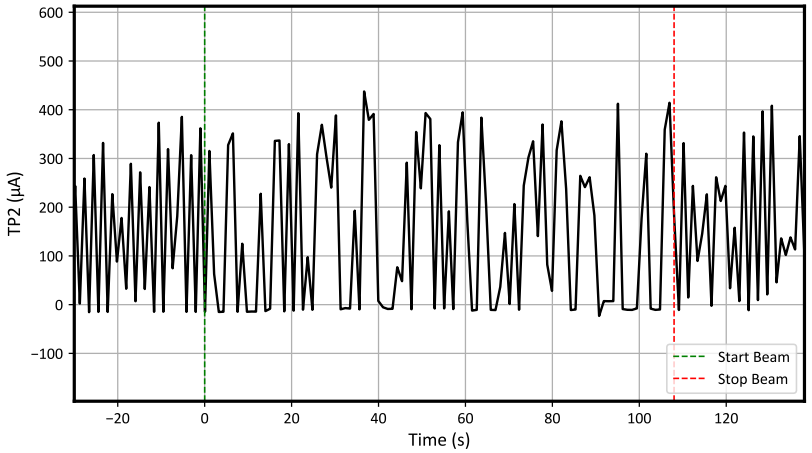

Figure 6-1. Run Passing SEL Run 27, DUT #3, TAMU, 125C, Ho (75.1MeV)

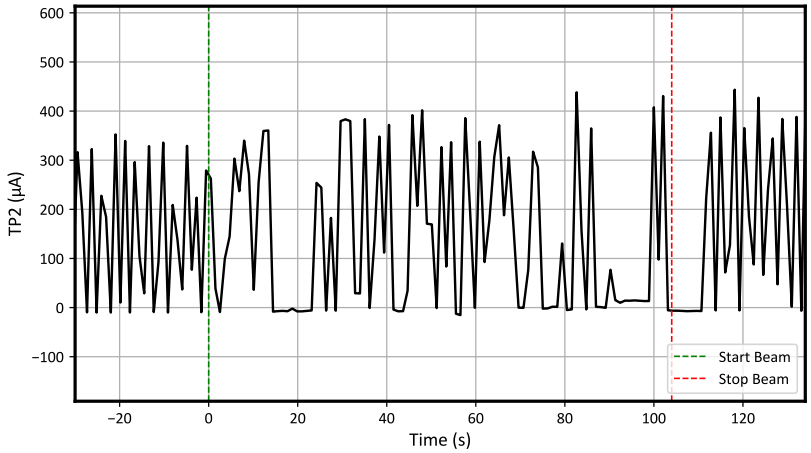

Figure 6-2. Run Passing SEL Run 28, DUT #2, TAMU, 125C, Ho (75.1MeV)

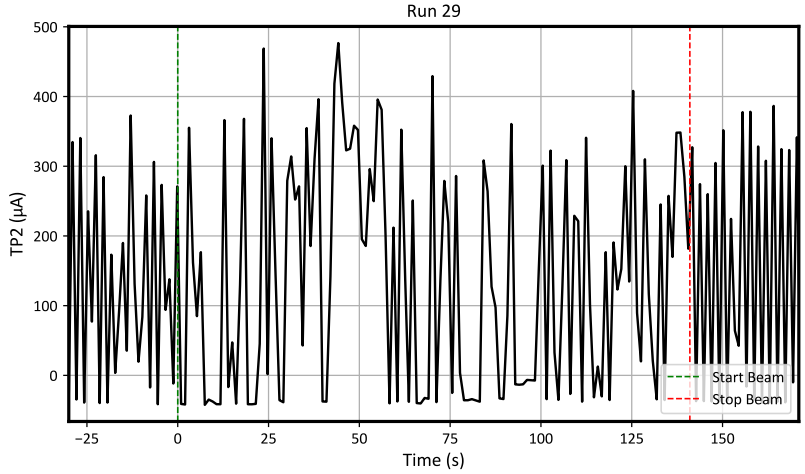

Figure 6-3. Run Passing SEL Run 29, DUT #4, TAMU, 125C, Ho (75.1MeV)

7 SET Results

Transient characterization data was captured while exposing the units to different levels of radiation. The cross-section plots were captured to provide information of the trend of how the device performs under radiation. Durring the exposure time, all I2C registers were continuously read. A device reset was taken before every read. The data collected in the registers and the alert pin signal was used to understand the complete functionally of the device and support the SET results presented in this report. Data captured in this report is labeled with reset or without resets.

TMP9R01 device supports reset using the two-wire general-call address 00h (0000 0000b). The TMP9R01 device acknowledges the general-call address and responds to the second byte. If the second byte is 06h (0000 0110b), the TMP9R01 device executes a software reset. This software reset restores the power-on reset state to all TMP9R01 registers and aborts any conversion in progress. The TMP9R01 device takes no action in response to other values in the second byte.

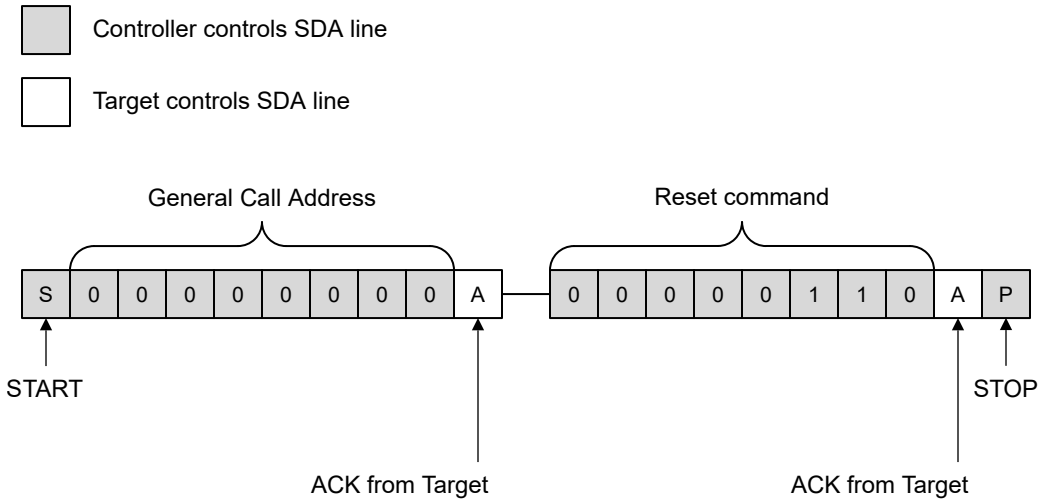

Figure 7-1. Reset Software Procedure

Data was read and captured every 50ms. With resets, the max time for the device to recover temperature is 50ms and no temperature value was seen to be stuck longer than 50ms during the exposure. The max time for the TMP461 to read all registers is shown in the following equation:

Where 36 is the number of clock cycles per communication cycle.

$$36 \times clock \;\; period \times \# \;\; of \;\; register \;\; reads \tag{1}$$

Without resetting the device, there is a large chance the device performs poorly. TMP9R01 is a digital I2C device and transient/upset events were defined in the following way:

- *A remote or local temperature output with an error larger than 1.5C* was recorded as a transient. Temperature delta was between the temperature readings during exposure and before. Data was read through I2C SCL and SDA lines and recorded through excel. Local and remote temperature is read through two bytes: high and low byte. The high byte represents the whole portion of the temperature result while the low byte represents the fractional portion of the temperature results. The amount of changed bits and location impact the overall accuracy of the device. The changes in the configuration registers can also affect the accuracy of the temperature result. The bits within the following registers impact temperature accuracy as shown in Table 7-1.

Table 7-1. Registers Impacting Accuracy Events

Pointer (HEX)	Register Description	Potential Accuracy Errors	Event Type
R 00h	Local temperature Register (high byte)	Reading Incorrect Measurement	SET
R 15h	Local temperature Register (low byte)	Reading Incorrect Measurement	SET
R 01h	Remote Temperature Register (high byte)	Reading Incorrect Measurement	SET
R 10h	Remote Temperature Register (low byte)	Reading Incorrect Measurement	SET
R 03h W 09h	Configuration Register	Changing the range from [-40C, 127C] to [-60C, 191C]	SEFI
RW 11h	Remote Temperature Offset Register (high byte)	An unwanted temperature offset is set	SET
RW 12h	Remote Temperature Offset Register (low byte)	An unwanted temperature offset was set	SET
RW 16h	Channel Enable Register	Disabled the temperature conversion of remote and local temperature sensors leading to inaccurate readings	SEFI
RW 23h	η-Factor Correction Register	An unwanted n-Factor calibration was set	SET

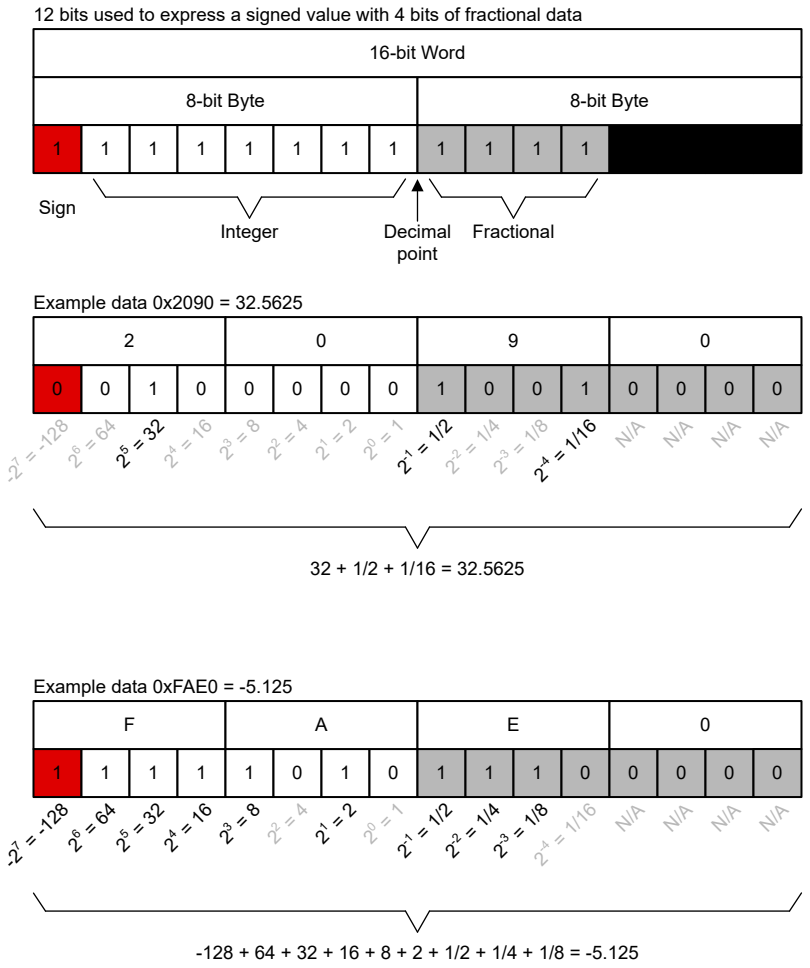

Figure 7-2. 12-bit Q4 Format

- *A SEFI was recorded when the alert/therm signal was tripped*. The device was programmed with default settings to where the alert stays off. If the alert is tripped, the number of assurances is recorded. Operation of the ALERT (pin 7) and THERM (pin 4) interrupts is shown in Figure 7-3. Operation of the THERM (pin 4) and THERM2 (pin 7) interrupts is shown in Figure 7-4.

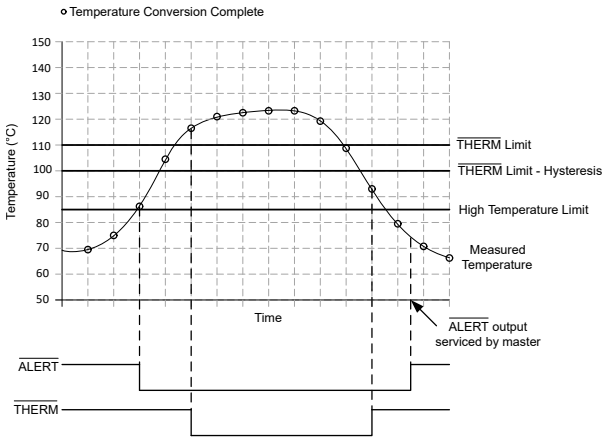

Figure 7-3. Alert and Therm Interrupt Operation

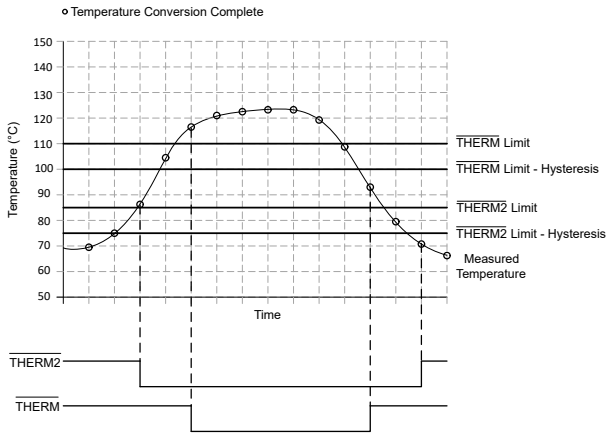

Figure 7-4. Therm and Therm2 Interrupt Operation

- *Any bit that was changed within any of the I2C registers* outside of the temperature reading registers was recorded as an upset. These events test if any of the configuration settings was changed during exposure. All events are SEU events. No MBU events were present.

The bits within the following registers impact the alert/therm signal as shown in Table 7-2.

Table 7-2. Registers Impacting Alert/Therm Events

Pointer (HEX)	Register Description	Potential Alert/Therm Errors	Event Type
R 02h	Status Register	Mismatch in Status of the Alert Signal	SEU
R 03h W 09h	Configuration Register	Unwanted mask of the alert signal and changing the mode from alert to therm	SEFI
R 05h W 0Bh	Local Temperature High Limit Register	Incorrect limit setting	SEFI
R 06h W 0Ch	Local Temperature Low Limit Register	Incorrect limit setting	SEFI
R 07h W 0Dh	Remote Temperature High Limit Register (high byte)	Incorrect limit setting	SEFI
RW 13h	Remote Temperature High Limit Register (low byte)	Incorrect limit setting	SEFI
R 08h W 0Eh	Remote Temperature Low Limit Register (high byte)	Incorrect limit setting	SEFI
RW 14h	Remote Temperature Low Limit Register (low byte)	Incorrect limit setting	SEFI
RW 19h	Remote Temperature THERM Limit Register	Incorrect limit setting	SEFI
RW 20h	Local Temperature THERM Limit Register	Incorrect limit setting	SEFI
RW 21h	THERM Hysteresis Register	Incorrect hysteresis setting	SEFI
RW 22h	Consecutive ALERT Register	Unwanted number of out-of-limit temperature measurements required for ALERT to be asserted	SEFI

A device reset was taken before every temperature read. All data captured in the report was taken with a temperature reset. *Data was read and captured every 50ms*. With resets, the max time for the device to recover temperature is 50ms and no temperature value was seen to be stuck longer than 50ms during the exposure. Without resetting the device, there is a large chance the device performs poorly. We have tested the results with and without resets and found that with resets the device preforms better.

The following table captures SET data with TMP9R01 in extended mode. Extended mode extends the temperature range to reach the range of -64C to 191C adding more bits to the temperature registers. The data below highlights the benefits of reseting the device before every temperature read.

Table 7-3. Data Comparing SET results with Resets and No Resets

LetEFF (MeV)	# Events (Reset)	# Events (No Reset)
8.7	24	22
48	26	324
56.36	33	643
76	41	369

7.1 Summary of SET Results

Table 7-4. Summary of TMP9R01-SP SET Results at 25C with Resets

Run #	Ion Type	Angle	LETEFF (MeV-cm²/mg)	Flux (ions-cm²/s)	Fluence (# of ions-cm²)	VS (V)	Temp (C)	Delta (C)	Total # of Events	Local Channel Temp Delta Events	Local Upper Bound X-Section (cm2)	Channel 1 Temp Delta Events	Channel 1 Upper Bound X-Section (cm2)	Bit Flip Events	Bit Flip Upper Bound X-Section (cm2)	Alert Trip Events	Alert Bound X-Section (cm2)
1	^{169}Tm	0	75	1E5	1E7	1.7	25	1.5	217	83	1.0576E-05	146	1.63743E-05	215	2.38932E-05	69	8.80086E-06
2	^{169}Tm	0	75	1E5	1E7	1.7	25	1.5	231	100		146		220		81	
4	^{169}Tm	0	75	1E5	1E7	3.6	25	1.5	157	71	8.26027E-06	106	1.19135E-05	135	1.58454E-05	40	6.19105E-06
5	^{169}Tm	0	75	1E5	1E7	3.6	25	1.5	171	69		102		147		62	
1	^{129}Xe	0	50.5	1E5	1E7	1.7	25	1.5	88	36	5.08918E-06	62	8.20614E-06	66	9.82442E-06	19	2.54998E-06
2	^{129}Xe	0	50.5	1E5	1E7	1.7	25	1.5	105	46		77		103		18	
4	^{129}Xe	0	50.5	1E5	1E7	3.6	25	1.5	64	34	3.80529E-06	44	5.64149E-06	64	6.68363E-06	12	1.84525E-06
5	^{129}Xe	0	50.5	1E5	1E7	3.6	25	1.5	61	25		48		47		13	
1	^{84}Kr	0	35.4	1E5	1E7	1.7	25	1.5	66	45	4.5336E-06	47	5.91659E-06	41	4.92288E-06	--	---
2	^{84}Kr	0	35.4	1E5	1E7	1.7	25	1.5	61	27		50		38		--	
4	^{84}Kr	0	35.4	1E5	1E7	3.6	25	1.5	39	23	2.89604E-06	29	3.46627E-06	24	2.83859E-06	6	1.04808E-06
5	^{84}Kr	0	35.4	1E5	1E7	3.6	25	1.5	34	20		24		18		6	
1	^{40}Ar	0	7.9	1E5	1E7	1.7	25	1.5	3	2	5.83417E-07	0	4.38364E-07	1	5.83417E-07	--	---
2	^{40}Ar	0	7.9	1E5	1E7	1.7	25	1.5	4	3		3		4		--	
4	^{40}Ar	0	7.9	1E5	1E7	3.6	25	1.5	1	0	1.84444E-07	0	1.84444E-07	1	2.78582E-07	--	---
5	^{40}Ar	0	7.9	1E5	1E7	3.6	25	1.5	0	0		0		0		--	

Table 7-5. Summary of TMP9R01-SP SET Results at 80C with Resets

Run #	Ion Type	Angle	LETEFF (MeV-cm²/mg)	Flux (ions-cm²/s)	Fluence (# of ions-cm²)	VS (V)	Temp (C)	Delta (C)	Total # of Events	Local Channel Accuracy	Local Upper Bound X-Section (cm2)	Channel 1 Accuracy	Channel 1 Upper Bound X-Section (cm2)	Bit Flip	Bit Flip Upper Bound X-Section (cm2)	Alert Trip	Alert Upper Bound X-Section (cm2)
7	^{169}Tm	0	75	1E5	1E7	1.7	80	1.5	282	113	1.32459E-05	169	1.95907E-05	262	2.87509E-05	140	1.55808E-05
8	^{169}Tm	0	75	1E5	1E7	1.7	80	1.5	291	120		184		266		137	
10	^{169}Tm	0	75	1E5	1E7	3.6	80	1.5	215	88	9.87817E-06	134	1.45739E-05	88	1.43617E-05	215	1.69555E-05
11	^{169}Tm	0	75	1E5	1E7	3.6	80	1.5	203	82		124		166		88	
7	^{129}Xe	0	50.5	1E5	1E7	1.7	80	1.5	136	56	5.91659E-06	77	9.23237E-06	136	1.48921E-05	51	6.62899E-06
8	^{129}Xe	0	50.5	1E5	1E7	1.7	80	1.5	148	41		81		128		59	
10	^{129}Xe	0	50.5	1E5	1E7	3.6	80	1.5	200	35	3.86159E-06	183	1.8169E-05	85	9.71688E-06	17	3.01068E-06
11	^{129}Xe	0	50.5	1E5	1E7	3.6	80	1.5	166	25		143		82		28	
7	^{84}Kr	0	35.4	1E5	1E7	1.7	80	1.5	79	36	4.3662E-06	59	6.46493E-06	53	5.86162E-06	--	---
8	^{84}Kr	0	35.4	1E5	1E7	1.7	80	1.5	61	33		48		43		--	
10	^{84}Kr	0	35.4	1E5	1E7	3.6	80	1.5	44	15	2.6079E-06	39	4.75627E-06	24	3.40955E-06	17	2.31721E-06
11	^{84}Kr	0	35.4	1E5	1E7	3.6	80	1.5	42	23		37		28		16	
7	^{40}Ar	0	7.9	1E5	1E7	1.7	80	1.5	2	1	4.38364E-07	1	5.12079E-07	1	5.12079E-07	--	---
8	^{40}Ar	0	7.9	1E5	1E7	1.7	80	1.5	4	2		3		3		--	
10	^{40}Ar	0	7.9	1E5	1E7	3.6	80	1.5	0	0	1.84444E-07	0	1.84444E-07	0	1.84444E-07	--	---
11	^{40}Ar	0	7.9	1E5	1E7	3.6	80	1.5	0	0		0		0		--	

Table 7-6. Number of Bit Flips within Registers 25C

Run #	Ion Type	Angle	LETEFF MeV-cm2/mg	Flux (ions-cm2/s)	Fluence (# of ions-cm2)	VS (V)	Temp (C)	Delta (C)	Config.	Remote Temp Offset (h)	Remote Temp Offset (l)	Ch. Enable	n-factor Correction	Local Temp High Limit	Local Temp Low Limit	Remote Temp High Limit (h)	Remote Temp High Limit (low byte)	Remote Temp Low Limit (high byte)	Remote Temp Low Limit (low byte)	Remote Temp THERM Limit	Local Temp THERM Limit	THERM Hysteresis	Consecutive ALERT
1	^{169}Tm	0	75	1E5	1E7	1.7	25	1.5	132	275	29	174	5	9	80	78	7	74	4	5	22	80	18
2	^{169}Tm	0	75	1E5	1E7	1.7	25	1.5	89	21	11	5	26	94	89	83	14	92	8	29	89	28	13
4	^{169}Tm	0	75	1E5	1E7	3.6	25	1.5	66	3	3	5	1	68	63	64	5	62	3	12	162	10	2
5	^{169}Tm	0	75	1E5	1E7	3.6	25	1.5	63	3	1	2	6	60	60	65	3	56	5	13	70	9	2
1	^{129}Xe	0	50.5	1E5	1E7	1.7	25	1.5	31	11	3	2	7	27	23	23	4	23	4	26	31	6	3
2	^{129}Xe	0	50.5	1E5	1E7	1.7	25	1.5	37	15	5	2	14	35	33	37	4	37	3	32	35	6	2
4	^{129}Xe	0	50.5	1E5	1E7	3.6	25	1.5	35	3	2	1	4	26	31	33	0	33	1	26	28	0	1
5	^{129}Xe	0	50.5	1E5	1E7	3.6	25	1.5	25	4	1	0	3	25	23	22	2	22	1	22	27	0	0
1	^{84}Kr	0	35.4	1E5	1E7	1.7	25	1.5	29	7	1	0	7	22	23	20	0	23	0	19	21	2	1
2	^{84}Kr	0	35.4	1E5	1E7	1.7	25	1.5	21	12	2	2	9	14	18	16	2	17	2	14	15	3	1
4	^{84}Kr	0	35.4	1E5	1E7	3.6	25	1.5	18	2	0	0	2	16	15	12	0	12	1	11	12	0	0
5	^{84}Kr	0	35.4	1E5	1E7	3.6	25	1.5	25	4	1	0	3	25	23	22	2	22	1	22	27	0	0
1	^{40}Ar	0	7.9	1E5	1E7	1.7	25	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	^{40}Ar	0	7.9	1E5	1E7	1.7	25	1.5	3	0	0	0	0	3	3	3	0	3	0	3	3	0	0
4	^{40}Ar	0	7.9	1E5	1E7	3.6	25	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	^{40}Ar	0	7.9	1E5	1E7	3.6	25	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7-7. Number of Bit Flips within Registers 80C

Run #	Ion Type	Angle	LETEFF MeV-cm2/mg	Flux (ions-cm2/s)	Fluence (# of ions-cm2)	VS (V)	Temp (C)	Delta (C)	Config.	Remote Temp Offset (h)	Remote Temp Offset (l)	Ch. Enable	n-factor Correction	Local Temp High Limit	Local Temp Low Limit	Remote Temp High Limit (h)	Remote Temp High Limit (low byte)	Remote Temp Low Limit (high byte)	Remote Temp Low Limit (low byte)	Remote Temp THERM Limit	Local Temp THERM Limit	THERM Hysteresis	Consecutive ALERT
7	^{169}Tm	0	75	1E+05	1E+07	1.7	80	1.5	110	34	11	20	21	119	105	109	21	99	17	108	116	42	9
8	^{169}Tm	0	75	1E+05	1E+07	1.7	80	1.5	114	36	9	12	36	121	110	117	12	104	10	114	125	36	11
10	^{169}Tm	0	75	1E+05	1E+07	3.6	80	1.5	85	7	4	3	9	86	72	67	3	67	7	75	76	16	4
11	^{169}Tm	0	75	1E+05	1E+07	3.6	80	1.5	78	11	1	1	12	85	77	77	1	73	1	75	79	12	2
7	^{129}Xe	0	50.5	1E+05	1E+07	1.7	80	1.5	48	9	6	48	4	48	47	51	5	41	128	48	17	4	14
8	^{129}Xe	0	50.5	1E+05	1E+07	1.7	80	1.5	47	18	4	2	10	48	40	48	8	39	7	45	47	17	5
10	^{129}Xe	0	50.5	1E+05	1E+07	3.6	80	1.5	29	7	3	2	10	37	28	33	4	26	2	38	36	9	2
11	^{129}Xe	0	50.5	1E+05	1E+07	3.6	80	1.5	24	7	3	1	7	26	26	29	2	21	3	31	28	4	3
7	^{84}Kr	0	35.4	1E+05	1E+07	1.7	80	1.5	25	10	1	1	11	22	22	23	2	20	1	22	21	3	0
8	^{84}Kr	0	35.4	1E+05	1E+07	1.7	80	1.5	27	8	2	0	8	20	22	14	0	17	1	14	13	2	1
10	^{84}Kr	0	35.4	1E+05	1E+07	3.6	80	1.5	16	3	0	0	2	17	17	17	0	16	0	15	15	1	0
11	^{84}Kr	0	35.4	1E+05	1E+07	3.6	80	1.5	23	3	0	0	1	17	17	17	0	17	0	16	16	1	0
7	^{40}Ar	0	7.9	1E+05	1E+07	1.7	80	1.5	1	0	0	0	0	1	1	1	0	1	0	1	1	0	0
8	^{40}Ar	0	7.9	1E+05	1E+07	1.7	80	1.5	2	0	0	0	0	2	2	2	0	2	0	2	2	0	0
10	^{40}Ar	0	7.9	1E+05	1E+07	3.6	80	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	^{40}Ar	0	7.9	1E+05	1E+07	3.6	80	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7-8. 25C Register Bit Flip Cross Section Summary

	# of Events	Fluence	LB	Mean	UB
SEL 75 MeV V+1.5 Config	221	20000000	9.64107E-06	0.00001105	1.26069E-05
SEL 75 MeV V+1.5 Remote Temp Offset L	296	20000000	1.31618E-05	0.0000148	1.65857E-05
SEL 75 MeV V+1.5 Remote Temp Offset H	40	20000000	1.42883E-06	0.000002	2.72343E-06
SEL 75 MeV V+1.5 Ch Enable	179	20000000	7.68685E-06	0.00000895	1.03615E-05
SEL 75 MeV V+1.5 N-Factor Correction	31	20000000	1.05315E-06	0.00000155	2.2001E-06
SEL 75 MeV V+1.5 Local Temp High Limit	103	20000000	4.2036E-06	0.00000515	6.24587E-06
SEL 75 MeV V+1.5 Local Temp Low Limit	169	20000000	7.22402E-06	0.00000845	9.82442E-06
SEL 75 MeV V+1.5 Remote Temp High Limit H	161	20000000	6.85456E-06	0.00000805	9.39398E-06
SEL 75 MeV V+1.5 Remote Temp High Limit L	21	20000000	6.49967E-07	0.00000105	1.60504E-06
SEL 75 MeV V+1.5 Remote Temp Low Limit H	166	20000000	7.08539E-06	0.0000083	9.66309E-06
SEL 75 MeV V+1.5 Remote Temp Low Limit L	12	20000000	3.10029E-07	0.0000006	1.04808E-06
SEL 75 MeV V+1.5 Remote Temp THERM Limit	34	20000000	1.1773E-06	0.0000017	2.37558E-06
SEL 75 MeV V+1.5 Local Temp THERM Limit	111	20000000	4.56567E-06	0.00000555	6.68363E-06
SEL 75 MeV V+1.5 Therm Hysteresis	108	20000000	4.42972E-06	0.0000054	6.51964E-06
SEL 75 MeV V+1.5 Consecutive ALERT	31	20000000	1.05315E-06	0.00000155	2.2001E-06
SEL 75 MeV V+3.6 Config	129	20000000	5.38504E-06	0.00000645	7.66393E-06
SEL 75 MeV V+3.6 Remote Temp Offset L	6	20000000	1.10095E-07	0.0000003	6.52974E-07

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 75 MeV V+3.6 Remote Temp Offset H	4	20000000	5.44933E-08	0.0000002	5.12079E-07
SEL 75 MeV V+3.6 Ch Enable	7	20000000	1.40718E-07	0.00000035	7.21134E-07
SEL 75 MeV V+3.6 N-Factor Correction	7	20000000	1.40718E-07	0.00000035	7.21134E-07
SEL 75 MeV V+3.6 Local Temp High Limit	128	20000000	5.33937E-06	0.0000064	7.60962E-06
SEL 75 MeV V+3.6 Local Temp Low Limit	123	20000000	5.11125E-06	0.00000615	7.33782E-06
SEL 75 MeV V+3.6 Remote Temp High Limit H	129	20000000	5.38504E-06	0.00000645	7.66393E-06
SEL 75 MeV V+3.6 Remote Temp High Limit L	8	20000000	1.72692E-07	0.0000004	7.88159E-07
SEL 75 MeV V+3.6 Remote Temp Low Limit H	118	20000000	4.88359E-06	0.0000059	7.06558E-06
SEL 75 MeV V+3.6 Remote Temp Low Limit L	8	20000000	1.72692E-07	0.0000004	7.88159E-07
SEL 75 MeV V+3.6 Remote Temp THERM Limit	25	20000000	8.08934E-07	0.00000125	1.84525E-06
SEL 75 MeV V+3.6 Local Temp THERM Limit	232	20000000	1.01552E-05	0.0000116	1.31927E-05
SEL 75 MeV V+3.6 Therm Hysteresis	19	20000000	5.71962E-07	0.00000095	1.48354E-06
SEL 75 MeV V+3.6 Consecutive ALERT	4	20000000	5.44933E-08	0.0000002	5.12079E-07
SEL 50 MeV V+1.5 Config	68	20000000	2.64023E-06	0.0000034	4.31031E-06
SEL 50 MeV V+1.5 Remote Temp Offset L	26	20000000	8.49203E-07	0.0000013	1.9048E-06
SEL 50 MeV V+1.5 Remote Temp Offset H	8	20000000	1.72692E-07	0.0000004	7.88159E-07
SEL 50 MeV V+1.5 Ch Enable	4	20000000	5.44933E-08	0.0000002	5.12079E-07

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 50 MeV V+1.5 N-Factor Correction	21	20000000	6.49967E-07	0.00000105	1.60504E-06
SEL 50 MeV V+1.5 Local Temp High Limit	62	20000000	2.37675E-06	0.0000031	3.97406E-06
SEL 50 MeV V+1.5 Local Temp Low Limit	56	20000000	2.11509E-06	0.0000028	3.63603E-06
SEL 50 MeV V+1.5 Remote Temp High Limit H	60	20000000	2.28932E-06	0.000003	3.86159E-06
SEL 50 MeV V+1.5 Remote Temp High Limit L	8	20000000	1.72692E-07	0.0000004	7.88159E-07
SEL 50 MeV V+1.5 Remote Temp Low Limit H	60	20000000	2.28932E-06	0.000003	3.86159E-06
SEL 50 MeV V+1.5 Remote Temp Low Limit L	7	20000000	1.40718E-07	0.00000035	7.21134E-07
SEL 50 MeV V+1.5 Remote Temp THERM Limit	58	20000000	2.20209E-06	0.0000029	3.74892E-06
SEL 50 MeV V+1.5 Local Temp THERM Limit	66	20000000	2.55222E-06	0.0000033	4.19841E-06
SEL 50 MeV V+1.5 Therm Hysteresis	12	20000000	3.10029E-07	0.0000006	1.04808E-06
SEL 50 MeV V+1.5 Consecutive ALERT	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 50 MeV V+3.6 Config	60	20000000	2.28932E-06	0.000003	3.86159E-06
SEL 50 MeV V+3.6 Remote Temp Offset L	7	20000000	1.40718E-07	0.00000035	7.21134E-07
SEL 50 MeV V+3.6 Remote Temp Offset H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 50 MeV V+3.6 Ch Enable	1	20000000	1.26589E-09	0.00000005	2.78582E-07
SEL 50 MeV V+3.6 N-Factor Correction	7	20000000	1.40718E-07	0.00000035	7.21134E-07
SEL 50 MeV V+3.6 Local Temp High Limit	51	20000000	1.89864E-06	0.00000255	3.35278E-06

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 50 MeV V+3.6 Local Temp Low Limit	54	20000000	2.02832E-06	0.0000027	3.52291E-06
SEL 50 MeV V+3.6 Remote Temp High Limit H	55	20000000	2.07168E-06	0.00000275	3.5795E-06
SEL 50 MeV V+3.6 Remote Temp High Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 50 MeV V+3.6 Remote Temp Low Limit H	55	20000000	2.07168E-06	0.00000275	3.5795E-06
SEL 50 MeV V+3.6 Remote Temp Low Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 50 MeV V+3.6 Remote Temp THERM Limit	48	20000000	1.76957E-06	0.0000024	3.18205E-06
SEL 50 MeV V+3.6 Local Temp THERM Limit	55	20000000	2.07168E-06	0.00000275	3.5795E-06
SEL 50 MeV V+3.6 Therm Hysteresis	0	20000000	0	0	1.84444E-07
SEL 50 MeV V+3.6 Consecutive ALERT	1	20000000	1.26589E-09	0.00000005	2.78582E-07
SEL 35.4 MeV V+1.5 Config	50	20000000	1.85555E-06	0.0000025	3.29594E-06
SEL 35.4 MeV V+1.5 Remote Temp Offset L	19	20000000	5.71962E-07	0.00000095	1.48354E-06
SEL 35.4 MeV V+1.5 Remote Temp Offset H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 35.4 MeV V+1.5 Ch Enable	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+1.5 N-Factor Correction	16	20000000	4.57269E-07	0.0000008	1.29915E-06
SEL 35.4 MeV V+1.5 Local Temp High Limit	36	20000000	1.2607E-06	0.0000018	2.49196E-06
SEL 35.4 MeV V+1.5 Local Temp Low Limit	41	20000000	1.47112E-06	0.00000205	2.78106E-06
SEL 35.4 MeV V+1.5 Remote Temp High Limit H	36	20000000	1.2607E-06	0.0000018	2.49196E-06

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 35.4 MeV V+1.5 Remote Temp High Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+1.5 Remote Temp Low Limit H	40	20000000	1.42883E-06	0.000002	2.72343E-06
SEL 35.4 MeV V+1.5 Remote Temp Low Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+1.5 Remote Temp THERM Limit	33	20000000	1.13578E-06	0.00000165	2.31721E-06
SEL 35.4 MeV V+1.5 Local Temp THERM Limit	36	20000000	1.2607E-06	0.0000018	2.49196E-06
SEL 35.4 MeV V+1.5 Therm Hysteresis	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 35.4 MeV V+1.5 Consecutive ALERT	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+3.6 Config	43	20000000	1.55597E-06	0.00000215	2.89604E-06
SEL 35.4 MeV V+3.6 Remote Temp Offset L	6	20000000	1.10095E-07	0.0000003	6.52974E-07
SEL 35.4 MeV V+3.6 Remote Temp Offset H	1	20000000	1.26589E-09	0.00000005	2.78582E-07
SEL 35.4 MeV V+3.6 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 N-Factor Correction	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 35.4 MeV V+3.6 Local Temp High Limit	41	20000000	1.47112E-06	0.00000205	2.78106E-06
SEL 35.4 MeV V+3.6 Local Temp Low Limit	38	20000000	1.34455E-06	0.0000019	2.6079E-06
SEL 35.4 MeV V+3.6 Remote Temp High Limit H	34	20000000	1.1773E-06	0.0000017	2.37558E-06
SEL 35.4 MeV V+3.6 Remote Temp High Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+3.6 Remote Temp Low Limit H	34	20000000	1.1773E-06	0.0000017	2.37558E-06

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 35.4 MeV V+3.6 Remote Temp Low Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+3.6 Remote Temp THERM Limit	33	20000000	1.13578E-06	0.00000165	2.31721E-06
SEL 35.4 MeV V+3.6 Local Temp THERM Limit	39	20000000	1.38664E-06	0.00000195	2.66571E-06
SEL 35.4 MeV V+3.6 Therm Hysteresis	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 Consecutive ALERT	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Config	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp Offset L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp Offset H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 N-Factor Correction	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Local Temp High Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Local Temp Low Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp High Limit H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp High Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp Low Limit H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp Low Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp THERM Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 7.9 MeV V+1.5 Local Temp THERM Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Therm Hysteresis	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Consecutive ALERT	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Config	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Offset L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Offset H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 N-Factor Correction	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Local Temp High Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Local Temp Low Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp High Limit H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp High Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Low Limit H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Low Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp THERM Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Local Temp THERM Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Therm Hysteresis	0	20000000	0	0	1.84444E-07

Table 7-8. 25C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 7.9 MeV V+3.6 Consecutive ALERT	0	20000000	0	0	1.84444E-07

Table 7-9. 80C Register Bit Flip Cross Section Summary

	# of Events	Fluence	LB	Mean	UB
SEL 75 MeV V+1.5 Config	224	20000000	9.78121E-06	0.0000112	1.27667E-05
SEL 75 MeV V+1.5 Remote Temp Offset L	70	20000000	2.72842E-06	0.0000035	4.42204E-06
SEL 75 MeV V+1.5 Remote Temp Offset H	20	20000000	6.10826E-07	0.000001	1.54442E-06
SEL 75 MeV V+1.5 Ch Enable	32	20000000	1.0944E-06	0.0000016	2.25872E-06
SEL 75 MeV V+1.5 N-Factor Correction	57	20000000	2.15856E-06	0.00000285	3.69251E-06
SEL 75 MeV V+1.5 Local Temp High Limit	240	20000000	1.05297E-05	0.000012	1.36181E-05
SEL 75 MeV V+1.5 Local Temp Low Limit	215	20000000	9.36099E-06	0.00001075	1.2287E-05
SEL 75 MeV V+1.5 Remote Temp High Limit H	226	20000000	9.87468E-06	0.0000113	1.28733E-05
SEL 75 MeV V+1.5 Remote Temp High Limit L	33	20000000	1.13578E-06	0.00000165	2.31721E-06
SEL 75 MeV V+1.5 Remote Temp Low Limit H	203	20000000	8.80168E-06	0.00001015	1.16464E-05
SEL 75 MeV V+1.5 Remote Temp Low Limit L	27	20000000	8.89659E-07	0.00000135	1.96418E-06
SEL 75 MeV V+1.5 Remote Temp THERM Limit	222	20000000	9.68778E-06	0.0000111	1.26602E-05
SEL 75 MeV V+1.5 Local Temp THERM Limit	241	20000000	1.05766E-05	0.00001205	1.36713E-05
SEL 75 MeV V+1.5 Therm Hysteresis	78	20000000	3.08279E-06	0.0000039	4.86738E-06
SEL 75 MeV V+1.5 Consecutive ALERT	20	20000000	6.10826E-07	0.000001	1.54442E-06

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 75 MeV V+3.6 Config	163	20000000	6.94685E-06	0.00000815	9.50166E-06
SEL 75 MeV V+3.6 Remote Temp Offset L	18	20000000	5.33397E-07	0.0000009	1.42239E-06
SEL 75 MeV V+3.6 Remote Temp Offset H	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 75 MeV V+3.6 Ch Enable	4	20000000	5.44933E-08	0.0000002	5.12079E-07
SEL 75 MeV V+3.6 N-Factor Correction	21	20000000	6.49967E-07	0.00000105	1.60504E-06
SEL 75 MeV V+3.6 Local Temp High Limit	171	20000000	7.3165E-06	0.00000855	9.93192E-06
SEL 75 MeV V+3.6 Local Temp Low Limit	149	20000000	6.30182E-06	0.00000745	8.74686E-06
SEL 75 MeV V+3.6 Remote Temp High Limit H	144	20000000	6.07207E-06	0.0000072	8.47668E-06
SEL 75 MeV V+3.6 Remote Temp High Limit L	4	20000000	5.44933E-08	0.0000002	5.12079E-07
SEL 75 MeV V+3.6 Remote Temp Low Limit H	140	20000000	5.88853E-06	0.000007	8.26027E-06
SEL 75 MeV V+3.6 Remote Temp Low Limit L	8	20000000	1.72692E-07	0.0000004	7.88159E-07
SEL 75 MeV V+3.6 Remote Temp THERM Limit	150	20000000	6.34781E-06	0.0000075	8.80086E-06
SEL 75 MeV V+3.6 Local Temp THERM Limit	155	20000000	6.57796E-06	0.00000775	9.07065E-06
SEL 75 MeV V+3.6 Therm Hysteresis	28	20000000	9.3029E-07	0.0000014	2.02339E-06
SEL 75 MeV V+3.6 Consecutive ALERT	6	20000000	1.10095E-07	0.0000003	6.52974E-07
SEL 50 MeV V+1.5 Config	95	20000000	3.84303E-06	0.00000475	5.80663E-06
SEL 50 MeV V+1.5 Remote Temp Offset L	27	20000000	8.89659E-07	0.00000135	1.96418E-06

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 50 MeV V+1.5 Remote Temp Offset H	10	20000000	2.39769E-07	0.0000005	9.19518E-07
SEL 50 MeV V+1.5 Ch Enable	50	20000000	1.85555E-06	0.0000025	3.29594E-06
SEL 50 MeV V+1.5 N-Factor Correction	14	20000000	3.82697E-07	0.0000007	1.17448E-06
SEL 50 MeV V+1.5 Local Temp High Limit	96	20000000	3.88802E-06	0.0000048	5.86162E-06
SEL 50 MeV V+1.5 Local Temp Low Limit	87	20000000	3.48417E-06	0.00000435	5.36571E-06
SEL 50 MeV V+1.5 Remote Temp High Limit H	99	20000000	4.02312E-06	0.00000495	6.02645E-06
SEL 50 MeV V+1.5 Remote Temp High Limit L	13	20000000	3.46098E-07	0.00000065	1.11152E-06
SEL 50 MeV V+1.5 Remote Temp Low Limit H	80	20000000	3.17175E-06	0.000004	4.97835E-06
SEL 50 MeV V+1.5 Remote Temp Low Limit L	135	20000000	5.65944E-06	0.00000675	7.98944E-06
SEL 50 MeV V+1.5 Remote Temp THERM Limit	93	20000000	3.75315E-06	0.00000465	5.69656E-06
SEL 50 MeV V+1.5 Local Temp THERM Limit	64	20000000	2.46439E-06	0.0000032	4.08633E-06
SEL 50 MeV V+1.5 Therm Hysteresis	21	20000000	6.49967E-07	0.00000105	1.60504E-06
SEL 50 MeV V+1.5 Consecutive ALERT	19	20000000	5.71962E-07	0.00000095	1.48354E-06
SEL 50 MeV V+3.6 Config	53	20000000	1.98503E-06	0.00000265	3.46627E-06
SEL 50 MeV V+3.6 Remote Temp Offset L	14	20000000	3.82697E-07	0.0000007	1.17448E-06
SEL 50 MeV V+3.6 Remote Temp Offset H	6	20000000	1.10095E-07	0.0000003	6.52974E-07
SEL 50 MeV V+3.6 Ch Enable	3	20000000	3.09336E-08	0.00000015	4.38364E-07

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 50 MeV V+3.6 N-Factor Correction	17	20000000	4.95156E-07	0.00000085	1.36093E-06
SEL 50 MeV V+3.6 Local Temp High Limit	63	20000000	2.42055E-06	0.00000315	4.03022E-06
SEL 50 MeV V+3.6 Local Temp Low Limit	54	20000000	2.02832E-06	0.0000027	3.52291E-06
SEL 50 MeV V+3.6 Remote Temp High Limit H	62	20000000	2.37675E-06	0.0000031	3.97406E-06
SEL 50 MeV V+3.6 Remote Temp High Limit L	6	20000000	1.10095E-07	0.0000003	6.52974E-07
SEL 50 MeV V+3.6 Remote Temp Low Limit H	47	20000000	1.72669E-06	0.00000235	3.125E-06
SEL 50 MeV V+3.6 Remote Temp Low Limit L	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 50 MeV V+3.6 Remote Temp THERM Limit	69	20000000	2.68431E-06	0.00000345	4.3662E-06
SEL 50 MeV V+3.6 Local Temp THERM Limit	64	20000000	2.46439E-06	0.0000032	4.08633E-06
SEL 50 MeV V+3.6 Therm Hysteresis	13	20000000	3.46098E-07	0.00000065	1.11152E-06
SEL 50 MeV V+3.6 Consecutive ALERT	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 35.4 MeV V+1.5 Config	52	20000000	1.9418E-06	0.0000026	3.40955E-06
SEL 35.4 MeV V+1.5 Remote Temp Offset L	18	20000000	5.33397E-07	0.0000009	1.42239E-06
SEL 35.4 MeV V+1.5 Remote Temp Offset H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 35.4 MeV V+1.5 Ch Enable	1	20000000	1.26589E-09	0.00000005	2.78582E-07
SEL 35.4 MeV V+1.5 N-Factor Correction	19	20000000	5.71962E-07	0.00000095	1.48354E-06
SEL 35.4 MeV V+1.5 Local Temp High Limit	42	20000000	1.5135E-06	0.0000021	2.83859E-06

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 35.4 MeV V+1.5 Local Temp Low Limit	44	20000000	1.59852E-06	0.0000022	2.9534E-06
SEL 35.4 MeV V+1.5 Remote Temp High Limit H	37	20000000	1.30257E-06	0.00000185	2.54998E-06
SEL 35.4 MeV V+1.5 Remote Temp High Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+1.5 Remote Temp Low Limit H	37	20000000	1.30257E-06	0.00000185	2.54998E-06
SEL 35.4 MeV V+1.5 Remote Temp Low Limit L	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+1.5 Remote Temp THERM Limit	36	20000000	1.2607E-06	0.0000018	2.49196E-06
SEL 35.4 MeV V+1.5 Local Temp THERM Limit	34	20000000	1.1773E-06	0.0000017	2.37558E-06
SEL 35.4 MeV V+1.5 Therm Hysteresis	5	20000000	8.11743E-08	0.00000025	5.83417E-07
SEL 35.4 MeV V+1.5 Consecutive ALERT	1	20000000	1.26589E-09	0.00000005	2.78582E-07
SEL 35.4 MeV V+3.6 Config	39	20000000	1.38664E-06	0.00000195	2.66571E-06
SEL 35.4 MeV V+3.6 Remote Temp Offset L	6	20000000	1.10095E-07	0.0000003	6.52974E-07
SEL 35.4 MeV V+3.6 Remote Temp Offset H	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 N-Factor Correction	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 35.4 MeV V+3.6 Local Temp High Limit	34	20000000	1.1773E-06	0.0000017	2.37558E-06
SEL 35.4 MeV V+3.6 Local Temp Low Limit	34	20000000	1.1773E-06	0.0000017	2.37558E-06
SEL 35.4 MeV V+3.6 Remote Temp High Limit H	34	20000000	1.1773E-06	0.0000017	2.37558E-06

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 35.4 MeV V+3.6 Remote Temp High Limit L	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 Remote Temp Low Limit H	33	20000000	1.13578E-06	0.00000165	2.31721E-06
SEL 35.4 MeV V+3.6 Remote Temp Low Limit L	0	20000000	0	0	1.84444E-07
SEL 35.4 MeV V+3.6 Remote Temp THERM Limit	31	20000000	1.05315E-06	0.00000155	2.2001E-06
SEL 35.4 MeV V+3.6 Local Temp THERM Limit	31	20000000	1.05315E-06	0.00000155	2.2001E-06
SEL 35.4 MeV V+3.6 Therm Hysteresis	2	20000000	1.21105E-08	0.0000001	3.61234E-07
SEL 35.4 MeV V+3.6 Consecutive ALERT	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Config	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp Offset L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp Offset H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 N-Factor Correction	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Local Temp High Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Local Temp Low Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp High Limit H	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Remote Temp High Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp Low Limit H	3	20000000	3.09336E-08	0.00000015	4.38364E-07

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 7.9 MeV V+1.5 Remote Temp Low Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Remote Temp THERM Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Local Temp THERM Limit	3	20000000	3.09336E-08	0.00000015	4.38364E-07
SEL 7.9 MeV V+1.5 Therm Hysteresis	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+1.5 Consecutive ALERT	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Config	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Offset L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Offset H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Ch Enable	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 N-Factor Correction	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Local Temp High Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Local Temp Low Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp High Limit H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp High Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Low Limit H	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp Low Limit L	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Remote Temp THERM Limit	0	20000000	0	0	1.84444E-07

Table 7-9. 80C Register Bit Flip Cross Section Summary (continued)

	# of Events	Fluence	LB	Mean	UB
SEL 7.9 MeV V+3.6 Local Temp THERM Limit	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Therm Hysteresis	0	20000000	0	0	1.84444E-07
SEL 7.9 MeV V+3.6 Consecutive ALERT	0	20000000	0	0	1.84444E-07

7.1.1 Summary of SET Results Continued

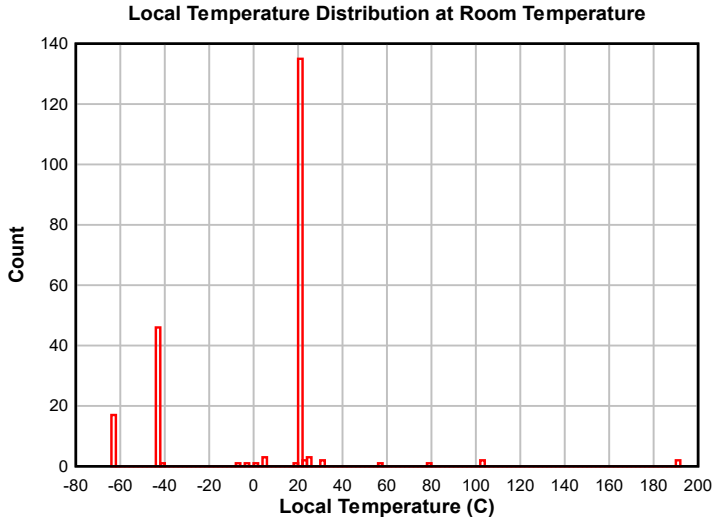

Figure 7-5. TMP9R01 Temperature Reads During 75MeV Exposure

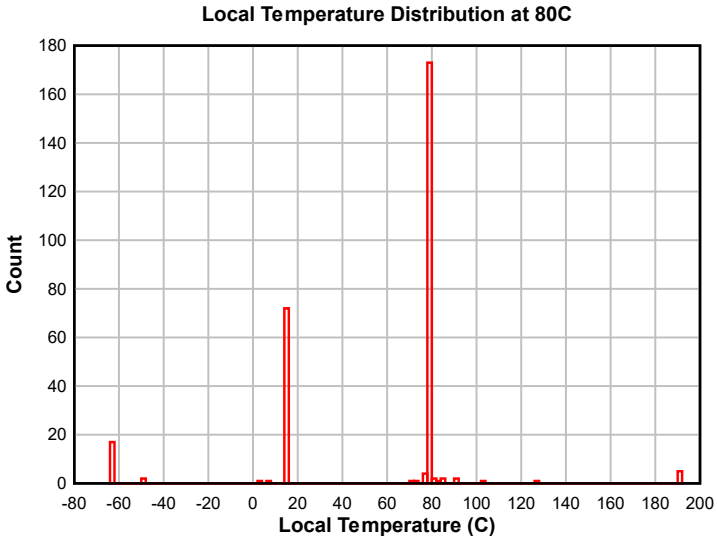

Figure 7-6. TMP9R01 Temperature Reads During 75MeV Exposure

Scope shots of the alert signal was captured during the exposure. There where 4 common transient captures. The following captures shown below was captured with no resets to highlight to worse case with the alert signal.

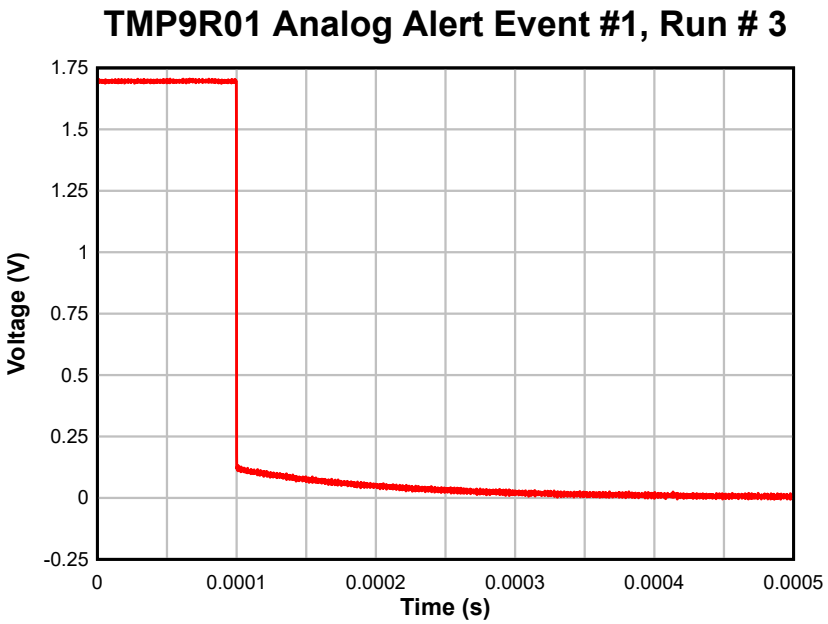

Figure 7-7. Possible Alert Signal Trip During Exposure

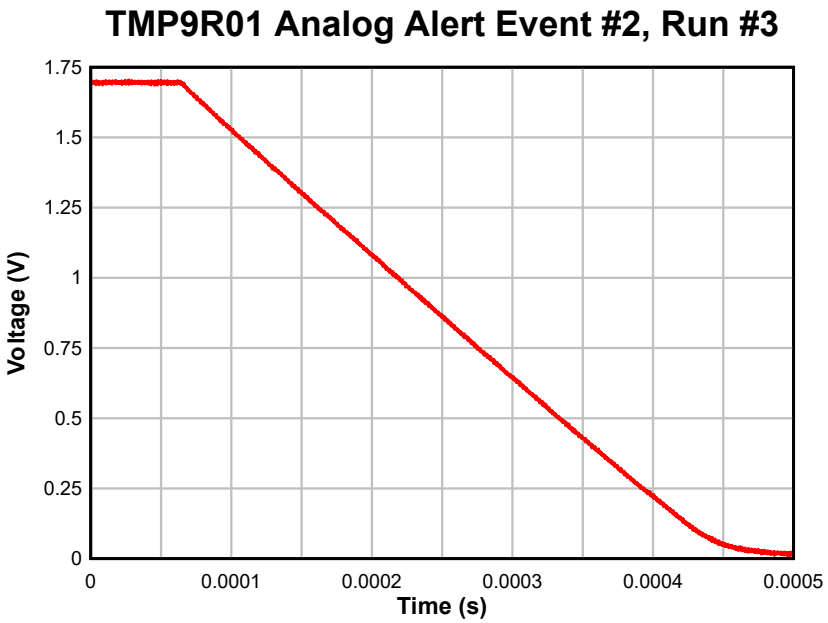

Figure 7-8. Possible Alert Signal Trip During Exposure

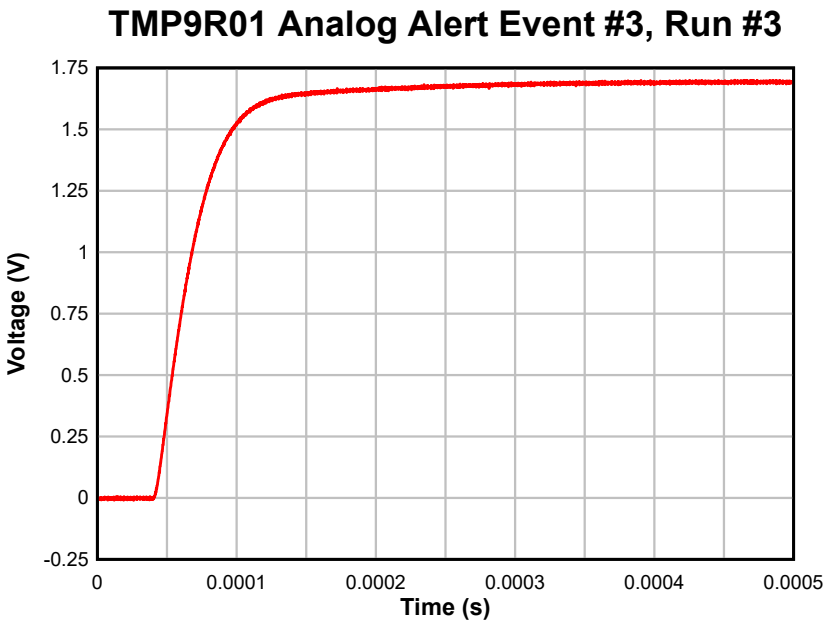

Figure 7-9. Possible Alert Signal Trip During Exposure

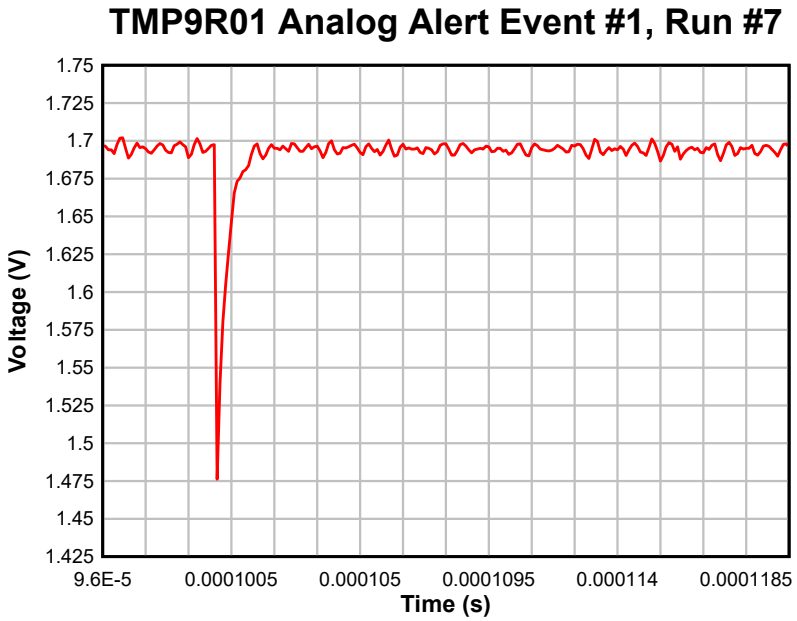

Figure 7-10. Possible Alert Signal Trip During Exposure

7.2 Cross Section Events and Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations. The Event Rate Calculations was calculated using the upper bound cross section.

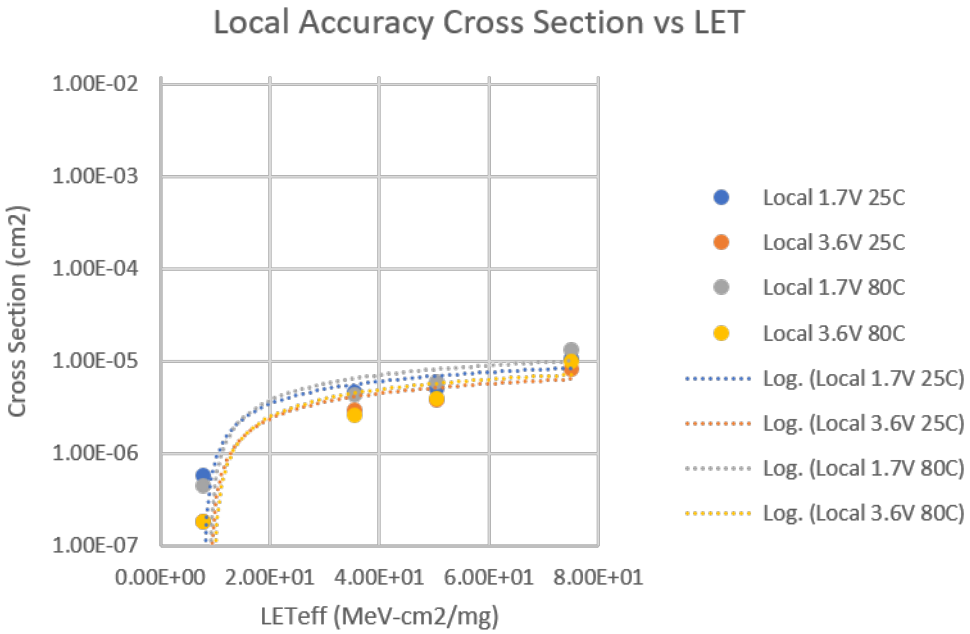

Figure 7-11. Weibull Plot for Local Temperature Accuracy Events

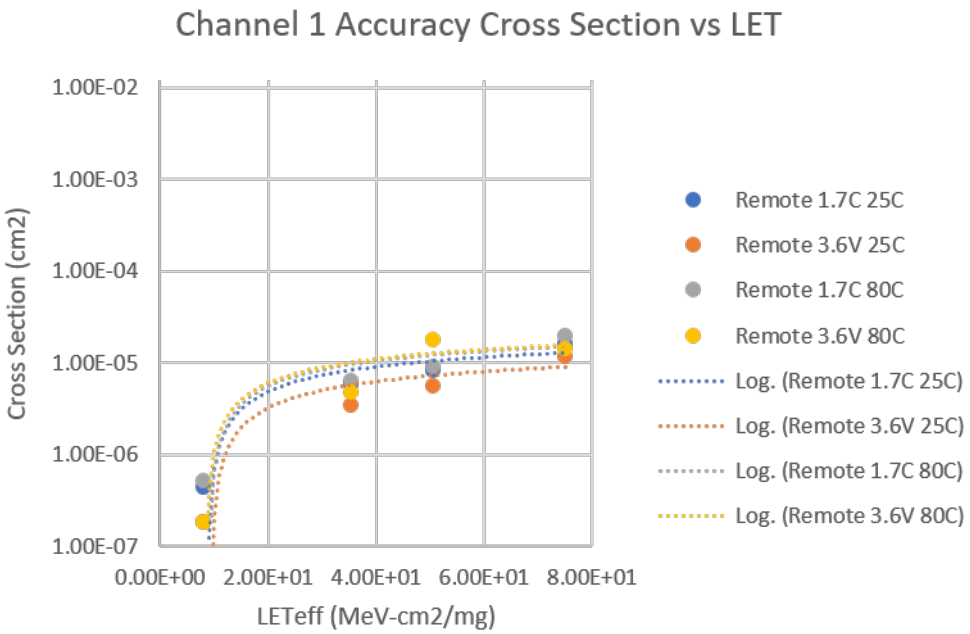

Figure 7-12. Weibull Plot for Remote Temperature Accuracy Events

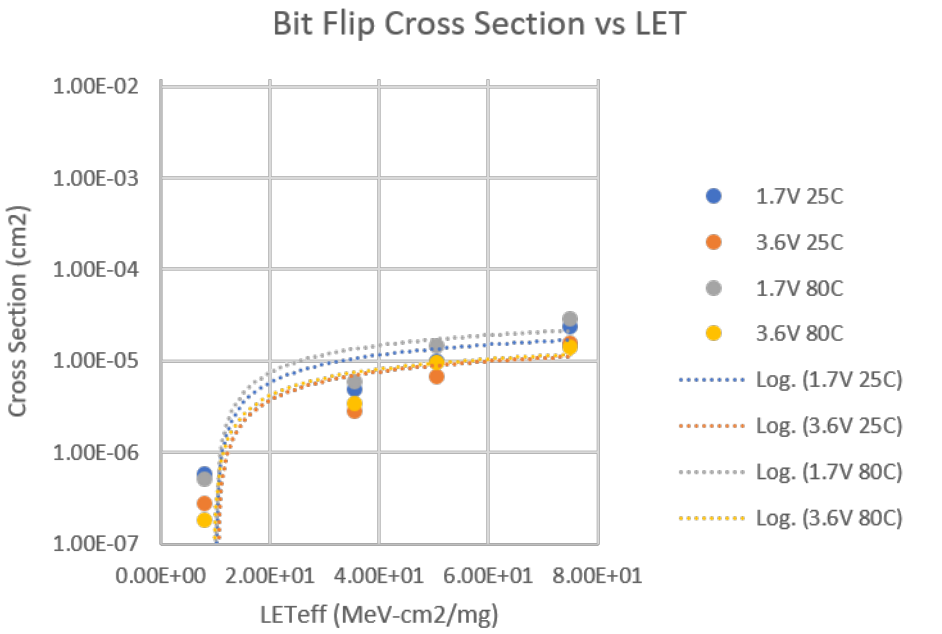

Figure 7-13. Weibull Plot for Bit Flip Events

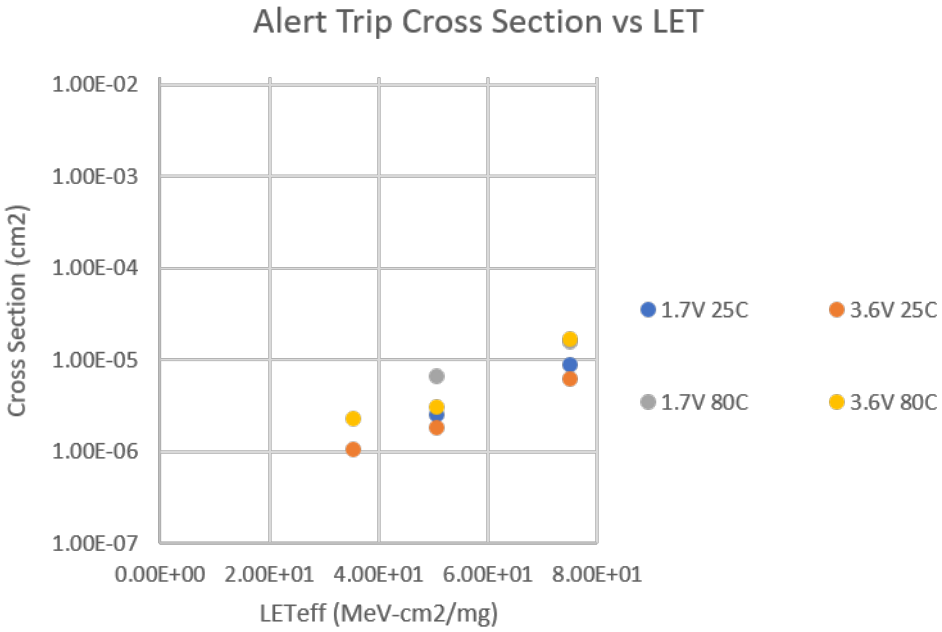

Figure 7-14. Weibull Plot for Alert Trip Events

Table 7-10. 25C SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Local 1.7V 25C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.0576E-05	0.000583153	24298.03146	4.69811722
GEO	7.9	465.6507132	1.0576E-05	0.00492473	205197.1005	0.556318777
Local 3.6V 25C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	8.26027E-06	0.000455465	18977.69147	6.015220565
GEO	7.9	465.6507132	8.26027E-06	0.003846403	160266.78	0.71228111
Channel-1 1.7V 25C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.63743E-05	0.000902865	37619.38782	3.034472558
GEO	7.9	465.6507132	1.63743E-05	0.007624706	317696.0782	0.359321401
Channel-1 3.6V 25C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.19135E-05	0.0006569	27370.82769	4.170681329
GEO	7.9	465.6507132	1.19135E-05	0.005547525	231146.8931	0.493863441

Table 7-11. 80C SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Local 1.7V 80C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.32459E-05	0.000730366	30431.91256	3.751160883
GEO	7.9	465.6507132	1.32459E-05	0.006167947	256997.7832	0.444186711
Local 3.6V 80C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	9.87817E-06	0.000544674	22694.75817	5.030016145
GEO	7.9	465.6507132	9.87817E-06	0.004599779	191657.4427	0.595619969
Channel-1 1.7V 80C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.95907E-05	0.001080216	45008.98496	2.536271371
GEO	7.9	465.6507132	1.95907E-05	0.009122431	380101.2945	0.300327838
Channel-1 3.6V 80C						
Orbit Type	Onset LETeff	CREME96 Integral FLUX	Cross-Saturation	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO	7.9	55.13915962	1.45739E-05	0.000803595	33483.12233	3.409329598
GEO	7.9	465.6507132	1.45739E-05	0.006786367	282765.2779	0.403709398

8 Detailed Results Per Run

The data that was captured per run is listed below. Only Events that were considered transients were captured.

- *Elapsed Time (s):* Total Time of Run
- *Initial Local (C):* Local Temperature of DUT without radiation exposure before run
- *Initial Remote (C):* Remote Temperature of DUT without radiation exposure before run
- *Temp Delta Threshold (C):* Set temperature error threshold to be considered an event for both local and remote channels
- *Current Local (C):* Current local temperature during exposure
- *Current Remote (C):* Current remote temperature during exposure
- *Number of Delta Events:* Number of events counted
- *Number of Reset Events:* Number of resets with general-call address
- *TMP119 Temp:* TMP119 was placed on the backside of the board for reference
- *Therm Pins:* Alert and THERM Pin signal captured during the exposure. Data came in as binary values indicating if the alert or THERM signal was turned on
- *Register Map:* Local Hi Byte (0x00), Remote Hi Byte (0x01), Status (0x02), Configuration (0x03), Conversion Rate (0x04), Local Hi Limit (0x05), Local Low Limit (0x06), Rem Hi Limit (0x07) , Rem Low Limit (0x08), Remote Low Byte (0x10), Rem Offset Hi Byte (0x11), Rem Offset Low Byte (0x12), Rem Hi Limit (0x13), Rem Low Limit (0x14), Local Low Byte (0x15), Channel Enable (0x16), Remote THERM Limit (0x19), Local THERM Limit (0x20), THERM Hysteresis (0x21), Consecutive ALERT (0x22), n-factor correction (0x23), Digital Filter (0x24), Manuf. ID (0xFE).

8.1 Detailed Run Raw Data

Table 8-1. Detailed Run Raw Data

Time (s)	Initial Local (C)	Initial Ch1 (C)	Temp Delta (C)	Current Local (C)	Current Ch1 (C)	# Delta Event	# Reset Event	Therm Pins	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07	0x08	0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x19	0x20	0x21	0x22	0x23	0x24	0xFE
0	21.37	21.93	1.5	21.37	21.93	0	0	4	85	85	128	36	8	200	0	200	0	224	0	0	240	0	96	3	200	200	10	1	0	0	85
0.10	21.37	21.93	1.5	21.37	22.31	1	1	4	85	86	0	36	8	200	0	200	0	80	0	0	240	0	96	3	200	200	10	1	0	0	85
10.18	21.37	21.93	1.5	21.37	21.75	2	97	4	85	85	0	36	8	200	0	200	0	192	0	0	240	0	96	3	200	200	10	1	0	0	85
20.21	21.37	21.93	1.5	21.31	21.75	3	193	4	85	85	0	36	8	200	0	200	0	192	0	0	240	0	80	3	200	200	10	1	0	0	85
30.04	21.37	21.93	1.5	149.4	21.5	4	287	4	213	85	0	36	8	200	0	200	0	128	0	0	240	0	96	3	200	200	10	1	0	0	85
30.22	21.37	21.93	1.5	21.37	22.06	5	288	4	85	86	0	36	8	200	0	200	0	16	0	0	240	0	112	3	200	200	10	1	0	0	85
36.73	21.37	21.93	1.5	136.4	21.62	6	350	4	85	85	0	36	8	200	0	200	0	160	0	0	240	0	112	3	200	200	10	1	0	0	85
40.22	21.37	21.93	1.5	21.5	21.81	7	383	4	85	85	0	36	8	200	0	200	0	208	0	0	240	0	128	3	200	200	10	1	0	0	85
50.23	21.37	21.93	1.5	21.5	21.81	8	479	4	85	85	0	36	8	200	0	200	0	208	0	0	240	0	128	3	200	200	10	1	0	0	85
60.29	21.37	21.93	1.5	21.37	21.93	9	575	4	85	85	0	36	8	200	0	200	0	240	0	0	240	0	96	3	200	200	10	1	0	0	85
70.32	21.37	21.93	1.5	21.37	22	10	671	4	85	86	0	36	8	200	0	200	0	0	0	0	240	0	96	3	200	200	10	1	0	0	85
80.35	21.37	21.93	1.5	21.31	21.81	11	767	4	85	85	0	36	8	200	0	200	0	208	0	0	240	0	64	3	200	200	10	1	0	0	85
90.40	21.37	21.93	1.5	21.37	21.56	12	863	4	85	85	0	36	8	200	0	200	0	144	0	0	240	0	96	3	200	200	10	1	0	0	85

9 Summary

This report summarizes all data collected on the TMP9R01-SP. This document provides the understanding of how the device would preform under radation. The data shows the TMP9R01-SP is SEL free up to 75MeV. A SET study was done by monitoring the temperature readout of the remote and local channels and recording events greater than ±1.5°C from the initial recorded temperatures.

10 Glossary

Most of the definitions here below are from JEDEC standard JESD89A.

- *DUT:* Device under test.
- *Fluence* (of particle radiation incident on a surface): The total amount of particle radiant energy incident on a surface in a given period of time, divided by the area of the surface. In this document, Fluence is expressed in ions per cm2.
- *Flux:* The time rate of flow of particle radiant energy incident on a surface, divided by the area of that surface. In this document, Flux is expressed in ions per cm2*s.
- *Single-Event Effect (SEE):* Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic particle strike. Single-event effects include single-event upset (SEU), multiple-bit upset (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latch-up (SEL).
- *Single-Event Transient (SET):* A soft error caused by the transient signal induced by a single energetic particle strike.
- *Single-Event Latch-up (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. SEL can 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. An example of SEL in a CMOS device is when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground. Single-Event Latch-up (SEL) cross-section: the number of events per unit fluence. For chip SEL cross-section, the dimensions are cm2 per chip.
- *Error cross-section:* the number of errors per unit fluence. For device error cross-section, the dimensions are cm2 per device. For bit error cross-section, the dimensions are cm2 per bit.
- *Tilt angle:* tilt angle, rotation axis of the DUT board is perpendicular to the beam axis; roll angle, board rotation axis is parallel to the beam axis
- *Weibull Function:* F(x) = A (1- exp{-[(x-x0)/W]s})
  - x = effective LET in MeV-cm2 /milligram;
  - F(x) = SEE cross-section in square-cm2/bit;
  - A = limiting or plateau cross-section;
  - x0 = onset parameter, such that F(x) = 0 for x < x0;
  - W = width parameter;
  - s = a dimensionless exponent

11 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (April 2025) to Revision A (June 2025)	Page
• Added 25C and 80C Register Bit Flip Cross Section Summary tables	19
• Added more description of data collection method and timing	19
• Removed SET calculation tables for bit flips and alert signals	19

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