AMD Radeon e9173 Low Power PCIE GPU Single Event Effects Test Report

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1. Summary of Results

The AMD Radeon Embedded e9170 Graphics Processing Unit (GPU), notably the e9173 Peripheral Component Interconnect Express (PCIE) variant, is of interest to Artemis generation programs with requirements for graphics rendering, compute, artificial intelligence (Ai) with a constraints-requiring piece-part procurement and power consumption of less than 50W.

In addition to collecting heavy ion data on this device, a secondary purpose of this test campaign was to validate video capture hardware and software workflows used with GPU, microprocessor and system-on-chip device testing. Five (5) test patterns from the NEPP Processor Enclave (NPE) test suite were used with the e9173. The test patterns covered the operating system's (OS) idle contribution towards the cross section, matrix math using tensorflow-rocm, two artificial intelligence models developed at NASA GSFC, and an industry standard GPU benchmarking application called Mesa GLXGears.

Test Patterns (More details in Appendix 5.6)
- o Ubuntu OS 20.04 –   Idle Test
- o *TensorFlow Matrix Math Test* –   *Math Test*
- o RApid Machine-learnEd Triage (*RAMjET*)[1] –   Ai Dynamic Test
- o *Sun vs Moon*[2] Classifier –   Ai Static Test
- o Mesa GLXGears Benchmark[3] –   Graphics Test

2. Test Article and Beamline Setup

A photograph of the DUT is provided to show the orientation of the AMD e9170 GPU chip in the center of the GPU circuit card.

Figure 1: AMD Radeon Embedded e9170 GPU (e9173 PCIE x8 variant)

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[1] https://github.com/golmschenk/ramjet
[2] https://ntrs.nasa.gov/citations/20205003132
[3] https://packages.debian.org/stretch/mesa-utils

Table 1: AMD e9173 Specification Information

	Chip	Memory	Shaders	Texture Map Units	Render Output Units	Compute Units
AMD Radeon e9173 PCIe	E9170	2 GB GDDR5	512	32	16	**8**

Base Clock	Boost Clock	Memory Clock	Memory Width
1124 MHz	1219 MHz	1500 MHz	64bit

One (1) AMD e9173, cannibalized and arbitrarily selected from a batch of Dell Wyse 5070 systems. The device was thinned by 225 microns for heavy ion testing. Another GPU from the same batch of Dell systems, was retained as the control sample and its COTS heatsink was left intact.

Test Vehicle: AMD 2200G and x64 Ubuntu 20.04.3
Software Frameworks: Vulkan, OpenGL, TensorFlow-ROCm version 2.3, OpenCL
Test Date: August 24, 2022, 4pm – 12am Pacific
Test Facility: Lawrence Berkley National Laboratory
Test Type: Single Event Effects – Heavy Ion
Test Chamber: In-air
Ion Species: 16 MeV/u ion cocktail (table in *Figure 2* below)

Ion	Cocktail (AMeV)	Energy (MeV)	Z	A	Chg. State	LET (Entrance) (MeV/mg/cm2)	LET (Bragg) (MeV/mg/cm2)	Range (Bragg) Vacuum (µm)	Range (Bragg) Window/Air (µm)	Range (Max) Vacuum (µm)
He*	16	43.46	2	3	+1	0.11	1.45	836.0	795.5	1020.0
B	16	190.22	5	11	+4	0.56	4.19			823.4
N	16	233.75	7	14	+5	1.16	6.04	503.0	464.0	505.9
O	16	277.33	8	17	+6	1.54	7.16	478.5	439.3	462.4
Ne	16	321.00	10	20	+7	2.39	8.95	337.5	299.2	347.9
Si	16	452.10	14	29	+10	4.56	13.99	269.5	230.7	274.3
Cl	16	539.51	17	35	+12	6.61	17.35	219.6	180.1	233.6
Ar	16	642.36	18	40	+14	7.27	18.65	242.2	203.1	255.6
V	16	832.84	23	51	+18	10.90	25.59	206.3	167.6	225.8
Cu	16	1007.34	29	63	+22	16.53	33.95	166.5	127.6	190.3
Kr	16	1225.54	36	78	+27	24.98	40.91	136.1	97.1	165.4
Ag*	16	1677.50	47	107	+37	39.17	59.27			153.6
Xe*	16	1954.71	54	124	+43	49.29	69.24	105.4	66.0	147.9

Figure 2: LBNL 16MeV/amu Cocktail

3. Test Setup and Wiring Procedure

The test bench is effectively a desktop computer without an enclosure, with all its peripherals placed ~18" away. The device itself is connected over a PCIE x8 extension bridge receiving power injected with a digitally monitored power supply. All points of interest in the test system are monitored electrically.

Table 2: System Bill of Materials:

Item	Purpose
Corsair 750i Power Supply	Power supply & Rail monitoring of Motherboard
Corsair 750i Power Supply	Power supply & Rail monitoring of GPU DUT
AMD mATX motherboard, AMD 2200G microprocessor with eGPU, 8GB DDR4	Test Vehicle
Sewell USB 2.0 Extenders	KVM & Power Supply monitoring x2
Watts Up Meter	120VAC supply main monitoring
Digital Loggers, Inc' Switch	120VAC remote outlet switching
Intel HDMI Splitter 4k@60Hz	Test Vehicle monitoring before extension
SIIG 1x2 HDMI Splitter 4k	DUT monitoring before extension
Startech HDUSB3CAP	DUT video recording
JTECH 150M HDMI extender	HDMI extension from cave to operator area, DUT
JTECH 75M HDMI extender	HDMI extension from cave to operator area, external discrete GPU
Laptop 1	DUT power monitoring
Laptop 2	Test Vehicle power monitoring & Power Mains monitoring
Laptop 3	DUT video monitoring

Figure 3: DUT Control from Operator Area showing extenders, splitters, power switches, portable LCD monitors, and laptops

4. Results

Each test run was terminated when erroneous behavior of the system was recorded or observed in real-time. Electrical anomalies or graphical anomalies were recorded to csv files and video media files through components in the test bench. The entire test run was "played back" during post-processing to identify any additional errors not seen at the beam line in real-time. Each run terminated with a well-documented anomaly.

The electrical thresholds and visual signatures that the operator must identify to stop the test run are well documented. Since the typical SEFI condition is a fully crashed Linux OS, we check a basic keyboard interrupt with the system by toggling number-lock on the keyboard. Secondly, we check the system's response on the network using ping. Because networking hardware is not being irradiated, the system should reply even if the desktop environment has crashed. We are also able to see when the system automatically reboots itself. For electrical monitoring, we record the output of two system-health prognostics monitor programs running in Linux sensors and rocm-smi. Sensors uses the sensors on the motherboard while rocm-smi uses the sensors on the GPU. We watch this output for clock frequency hysteresis or abnormal readings that are well outside of the specified range. Here is an example screenshot of pixel artifacts but otherwise functioning Linux desktop. Section 5.5, NEPP Processor Enclave (NPE) Test Suite – Test Procedure, contains additional references to expected and unexpected behaviors of the system during test.
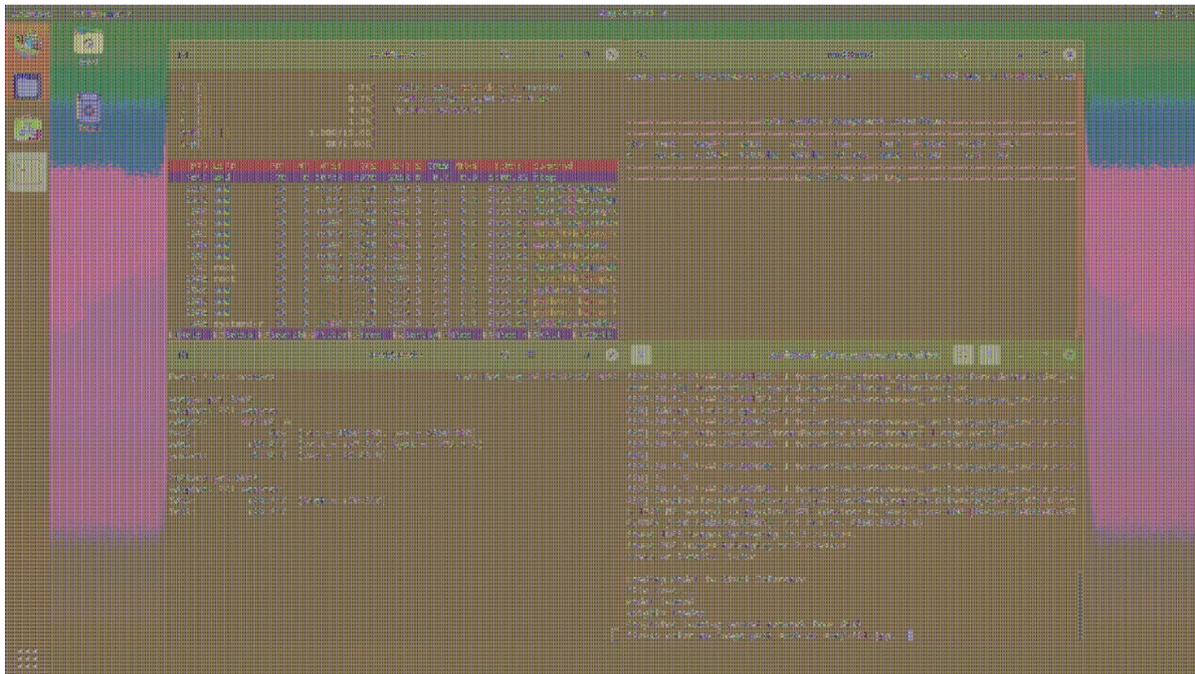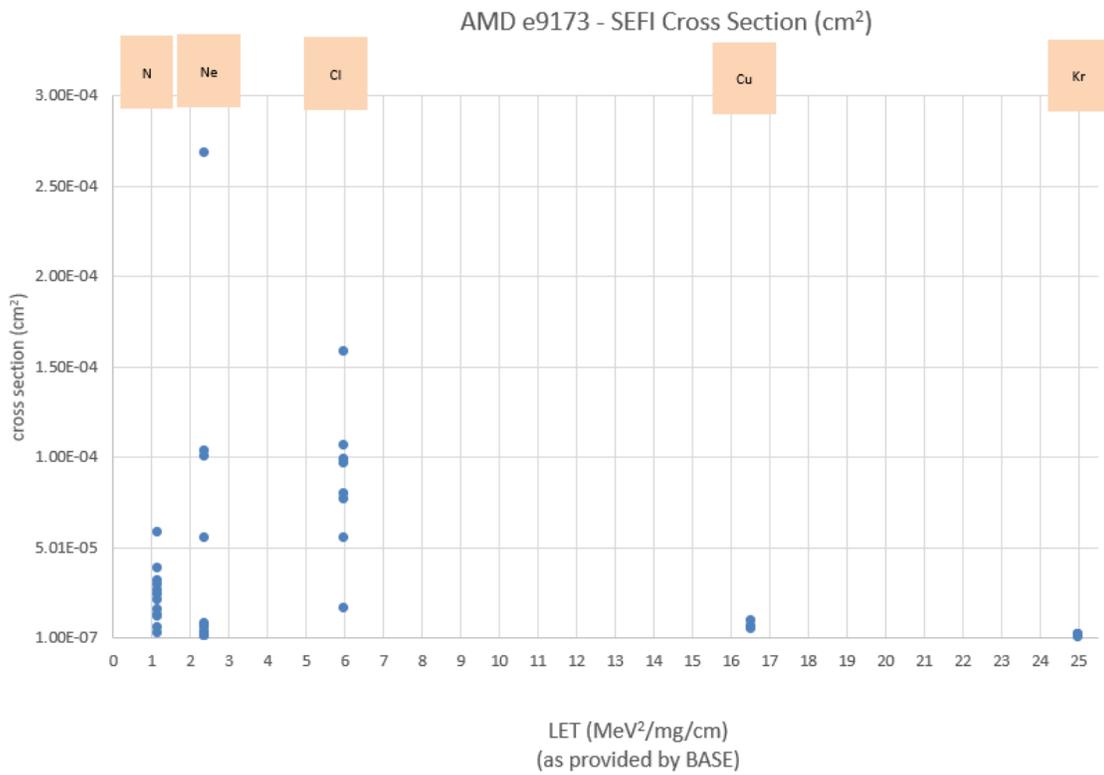

Figure 4: Pixel Artifacts

Figure 5: SEFI Cross Section Curve for AMD e9173 GPU

Each cross section was defined with an event-quantity of 1 since a SEFI end the test sequence. The run data is provided in *Table 3* and visualized in Figure 5. The cross sections were unexpectantly low on the copper and krypton ions. This is likely due the limitation in their range at the 16MeV/amu energy. While there is always a likelihood that a little more silicon can be removed during die thinning to promote further penetration of ions, it is more reasonable to continue this testing at the NASA Space Radiation Laboratory at Brookhaven National Laboratory where there are much higher energies available for testing.

Table 3: Test Run Data and Cross Sections

Run#	DUT	Test Mode	ion	Time of run (s)	Flux	Effective Fluence	LET (MeV2/mg /cm)	SEFI Cross section (cm2)	tot fluence per condition	average cross section	#SEFI
1	1	IDLE	N	15.59	3.04E+03	4.74E+04	1.16	2.11E-05	1.02E+06	2.31E-05	1
2	1	IDLE	N	58.1	3.01E+03	1.75E+05	1.16	5.71E-06			1
3	1	IDLE	N	29.2	2.89E+03	8.44E+04	1.16	1.18E-05			1
4	1	TF Math	N	20.5	1.27E+03	2.61E+04	1.16	3.83E-05			1
5	1	IDLE	N	300	1.26E+03	3.79E+05	1.16	2.64E-06			1
6	1	IDLE	N	66.42	1.24E+03	8.23E+04	1.16	1.22E-05			1
7	1	RAMjET	N	26.59	1.28E+03	3.40E+04	1.16	2.94E-05			1
8	1	RAMjET	N	49.96	1.28E+03	6.41E+04	1.16	1.56E-05			1
9	1	SunMoon	N	33.45	1.23E+03	4.12E+04	1.16	2.43E-05			1
10	1	SunMoon	N	30	1.26E+03	3.78E+04	1.16	2.65E-05			1
11	1	SunMoon	N	30	5.70E+02	1.71E+04	1.16	5.85E-05			1
15	1	Graphics	N	57.33	5.60E+02	3.21E+04	1.16	3.12E-05			1
19	1	TF Math	Ne	30	5.27E+03	1.58E+05	2.39	6.33E-06	6.16E+06	3.76E-05	1
20	1	TF Math	Ne	30	5.23E+03	1.57E+05	2.39	6.37E-06			1
21	1	TF Math	Ne	30	5.23E+03	1.57E+05	2.39	6.37E-06			1
33	1	IDLE	Ne	60	2.37E+04	1.42E+06	2.39	7.04E-07			1
34	1	TF Math	Ne	41.58	2.16E+04	8.99E+05	2.39	1.11E-06			1
35	1	TF Math	Ne	30.99	2.11E+04	6.54E+05	2.39	1.53E-06			1
36	1	TF Math	Ne	30.57	1.98E+04	6.05E+05	2.39	1.65E-06			1
38	1	RAMjET	Ne	47.38	2.15E+04	1.02E+06	2.39	9.80E-07			1
46	2	IDLE	Ne	25	2.44E+04	6.09E+05	2.39	1.64E-06			1
47	2	IDLE	Ne	15.14	2.11E+04	3.20E+05	2.39	3.13E-06			1
48	2	IDLE	Ne	28.47	4.36E+03	1.24E+05	2.39	8.06E-06			1
50	2	TF Math	Ne	11.39	3.27E+02	3.73E+03	2.39	2.68E-04			1
53	2	RAMjET	Ne	31.21	3.11E+02	9.71E+03	2.39	1.03E-04			1
55	2	SunMoon	Ne	31.88	3.14E+02	1.00E+04	2.39	1.00E-04			1
58	2	Graphics	Ne	60	3.03E+02	1.82E+04	2.39	5.49E-05			1
60	2	IDLE	Cl	14.88	4.15E+03	6.17E+04	6.00	1.62E-05	1.42E+05	8.58E-05	1
61	2	IDLE	Cl	30.2	6.03E+02	1.82E+04	6.00	5.49E-05			1
62	2	IDLE	Cl	22.98	5.70E+02	1.31E+04	6.00	7.63E-05			1
63	2	Graphics	Cl	16.95	5.96E+02	1.01E+04	6.00	9.90E-05			1
64	2	Graphics	Cl	21.73	5.80E+02	1.26E+04	6.00	7.94E-05			1
65	2	Graphics	Cl	15.82	5.95E+02	9.41E+03	6.00	1.06E-04			1
66		Graphics	Cl	17.81	5.84E+02	1.04E+04	6.00	9.62E-05			1
67	2	IDLE	Cl	10.7	5.92E+02	6.33E+03	6.00	1.58E-04			1
70	2	IDLE	Cu	106.76	1.77E+03	1.89E+05	16.53	5.29E-06	6.63E+05	6.35E-06	1
73		Graphics	Cu	66.03	1.68E+03	1.11E+05	16.53	9.01E-06			1
75	2	Graphics	Cu	100.2	1.68E+03	1.68E+05	16.53	5.95E-06			1
76	2	Graphics	Cu	120	1.63E+03	1.95E+05	16.53	5.13E-06			1
77	2	IDLE	Kr	63.25	1.90E+04	1.20E+06	25.01	8.33E-07	6.88E+06	1.21E-06	1
78	2	IDLE	Kr	33.16	2.19E+04	7.25E+05	25.01	1.38E-06			1
79	2	IDLE	Kr	103.36	2.87E+04	2.97E+06	25.01	3.37E-07			1
80	2	Graphics	Kr	19.94	2.94E+04	5.86E+05	25.01	1.71E-06			1
81	2	Graphics	Kr	27.63	3.04E+04	8.39E+05	25.01	1.19E-06			1
82	2	Graphics	Kr	19.38	2.86E+04	5.55E+05	25.01	1.80E-06			1

5. Appendix

5.1. Test Vehicle Wiring Configuration

- AMD mATX motherboard with AMD Ryzen 3 2200G microprocessor with eGPU
- Motherboard Power Supply (PSU) - Corsair 750i
  - connected to Sewell USB 2.0 Extender with red Micro-USB + 100ft CAT6
  - this connects to the 'Power Supply Monitor System'
  - ATX24, ATX4+4, SATA-L15 and SATA-L7 power supply cable extenders
- GPU DUT Power Supply - Corsair 750i
  - connected to Sewell USB 2.0 Extender with red Micro-USB + 100ft CAT6
  - this connects to the 'GPU Test Vehicle Laptop'
- Power Supply Line Voltage - Watts Up meter
  - connected to Sewell USB 2.0 Extender with long-plug Micro-USB + 100ft CAT6
  - this connects to the 'GPU Test Vehicle Laptop'
- Network Control for the Power Supplies using Web-based surge protector
  - Motherboard PSU and Watts Up Meter are plugged into Ports 1 and 2. These are color coded and should be noted in the network settings' page.
- Keyboard and Mouse for the DUT
  - connected to Sewell USB 2.0 Extender's USB Hub Side
  - Keyboard and Mouse with Operator, + 100ft CAT6
- eGPU video output from AMD Ryzen 3 2200G
  - connected to an Intel HDMI 1x2 Splitter, powered with USB AC Adapter (>2A).
  - one 'desk mount' monitor is connected to the splitter for 'node verification'
  - the other output connects to a JTECH 150M HDMI extender + 100ft CAT6
  - the JTECH connects to a Portable LCD monitor
  - the eGPU is mirrored with the test vehicle's GPU (AMD 2200G)

5.2. Video Capture Ground Support Equipment

- DUT GPU – AMD Radeon Embedded e9173
  - DP+ connects to a JTECH 150M HDMI extender
  - Extender connects to SIIG 1x2 HDMI Splitter 4K model
  - Splitter connects to LCD monitor and StarTech HDUSB3CAP's HDMI port
- Uses StarTech HDUSB3CAP video capture tool with HDMI in.
  - MUST plug into a USB 3.0 port that isn't a software-emulated USB bus and NOT have any other USB devices on that USB bus
- Open Broadcast Studio (OBS) is used as the software to capture and record the stream
  - The video input resolution must match the GPU DUT's resolution in order to match frames in post processing
  - The video compression MUST be lossless or better, the 'preview window' must be locked and so must the source, set the local recording folder
- Press 'Start Recording' to start the screen capture. Press 'Stop recording' to stop the screen capture.

5.3. Network Setup

ASUS 3 in 1 Router
- Reset device
- Route Test Vehicle, Video capture and Power supply monitor systems to Router
- Route web-ready surge strip

Shared folder on test bench
- Any computer with 100 GB of available space will be the scratch space to save our results and files
- Setup a shared folder and give it the 'everyone' permission
- Set a password on it
- Map this folder from all other computers

5.4. Prognostic Health Monitor
Setup continuous ping from any Windows-based PC for network health of test vehicle
- ping -t <IP Address>

rocm-smi gpu
- watch /opt/rocm-3.7.0/bin/rocm-smi

Motherboard sensors prognostics monitor
- watch -n 5 sensors

Process/Task Manager prognostics monitor
- htop

5.5. Cold-Plate Conversion for AMD e9173 GPU

- GPU is an x16 PCIE variant using the standard form factor slot
- It is connected to the test vehicle using a crypto-mining riser and a shielded x16 PCIE extension cable.
- Device is half-enclosed in an Aluminum clamshell to sink the heat away from the BGA, GDDR5, and power regulators; empty space in the macroenvironment of the card is backfilled with thermal interface material (TIM) which is seen as blue in the image below.
- Cold plate clamshell is held with a vice at end of beam line and secured with tape
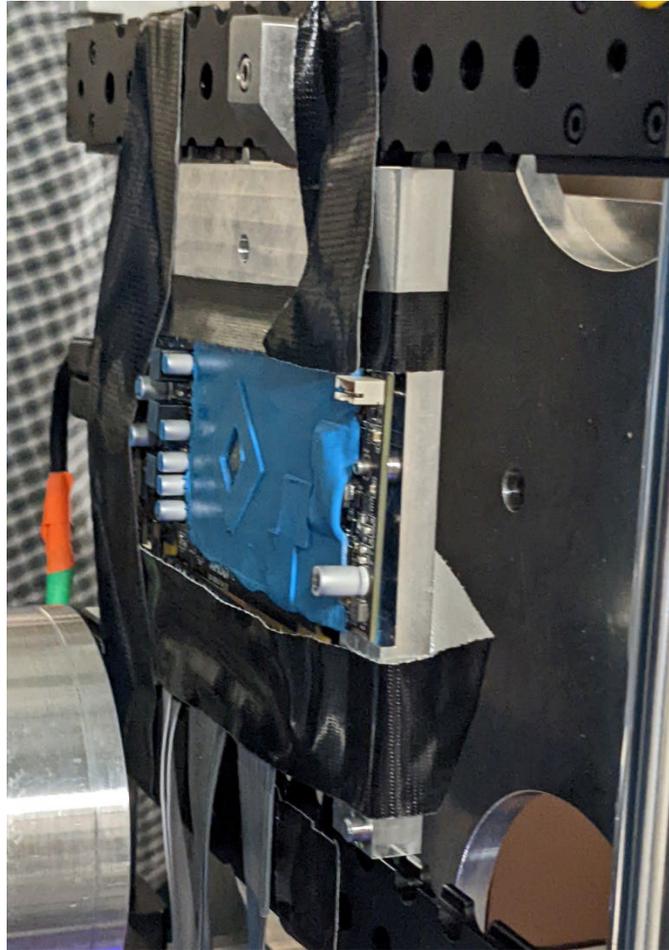
Figure 6: Device-under-test as installed for testing

5.6. NEPP Processor Enclave (NPE) Test Suite – Test Procedure

5.6.1.   Test Pattern: Ubuntu OS 20.04 - Idle Test

- Synchronize time stamps
- Run until fluence is met
- No stressors except Linux kernel operations
- Monitor electrical data from both Motherboard and GPU PSUs and Line meter
- Monitor performance counters and save kernel logs
- Record screen capture video
- Iterate five (5) times
- Pass/Fail Criteria: Successful or Not. Record behavioral notes.
- Expected result:

Figure 7: Test Pattern: Ubuntu OS 20.04 - Idle Test Expected Result

5.6.2. Test Pattern: *TensorFlow Matrix Math* - Math Test

- From home directory/AMD test:
  - source ./env/bin/activate
  - cd Downloads
  - python3 tensorflow-math-test.py
- Run until fluence is met or crash occurs
- Monitor electrical data from both Motherboard and GPU PSUs and Line meter
- Monitor performance counters and save kernel logs
- Record screen capture video
- Iterate five (5) times
- Pass/Fail Criteria: Successful or Not. Record behavioral notes.
- Expected result:

```
tf.Tensor(
[[8192. 8192. 8192. ... 8192. 8192. 8192.]
 [8192. 8192. 8192. ... 8192. 8192. 8192.]
 [8192. 8192. 8192. ... 8192. 8192. 8192.]
 ...
 [8192. 8192. 8192. ... 8192. 8192. 8192.]
 [8192. 8192. 8192. ... 8192. 8192. 8192.]
 [8192. 8192. 8192. ... 8192. 8192. 8192.]], shape=(8192, 8192), dtype=float32)
```

Figure 8: Test Pattern: TensorFlow Matrix Math - Math Test Expected Result

5.6.3. Test Pattern: *RAMjET* Microlensing Ai - Dynamic Test

- From home directory/RAMjET Experiment: run python3 infer.py 45
  - edit integer argument to adjust number of inference batches (1 batch = 100 inferences)
- Run until fluence is met or crash occurs
- Monitor electrical data from both Motherboard and GPU PSUs and Line meter
- Monitor performance counters and save kernel logs
- Record screen capture video
- Save RAMjET results files for post processing
- Iterate five (5) times
- Pass/Fail Criteria: Successful or Not. **Save the CSV file to the network.** Record behavioral notes.
- Expected result:
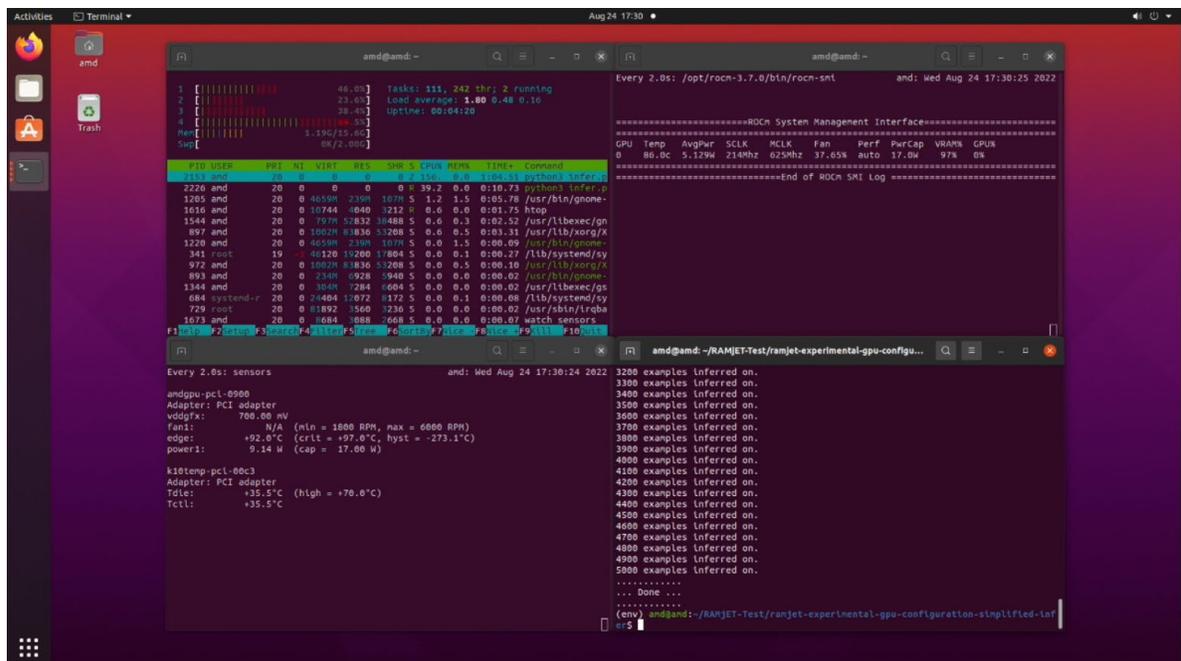
Figure 9: Test Pattern: RAMjET Microlensing Ai - Dynamic Test Expected Result

5.6.4. Test Pattern: *Sun vs Moon* Classifier Ai - Static Test

- from home directory/sun_vs_moon: run python3 keras_image_neuralNet.py, and follow the menu directions to start an inference
- the test operator will start the application, wait for the software framework to load, and then wait for the prompt.
- while the prompt is shown on the screen, irradiate the part to a fluence threshold
- if the DUT is still functioning, provide the prompt with the image of a moon located here: sun/-273.jpg
- the result should be [0,0] to indicate the photo is NOT an image of a sun.
- Monitor electrical data from both Motherboard and GPU PSUs and Line meter
- Monitor performance counters and save kernel logs
- Record screen capture video
- Iterate five (5) times
- Pass/Fail Criteria: Successful or Not. **Did it accurately identify the image?** Record behavioral notes.
- Expected results:
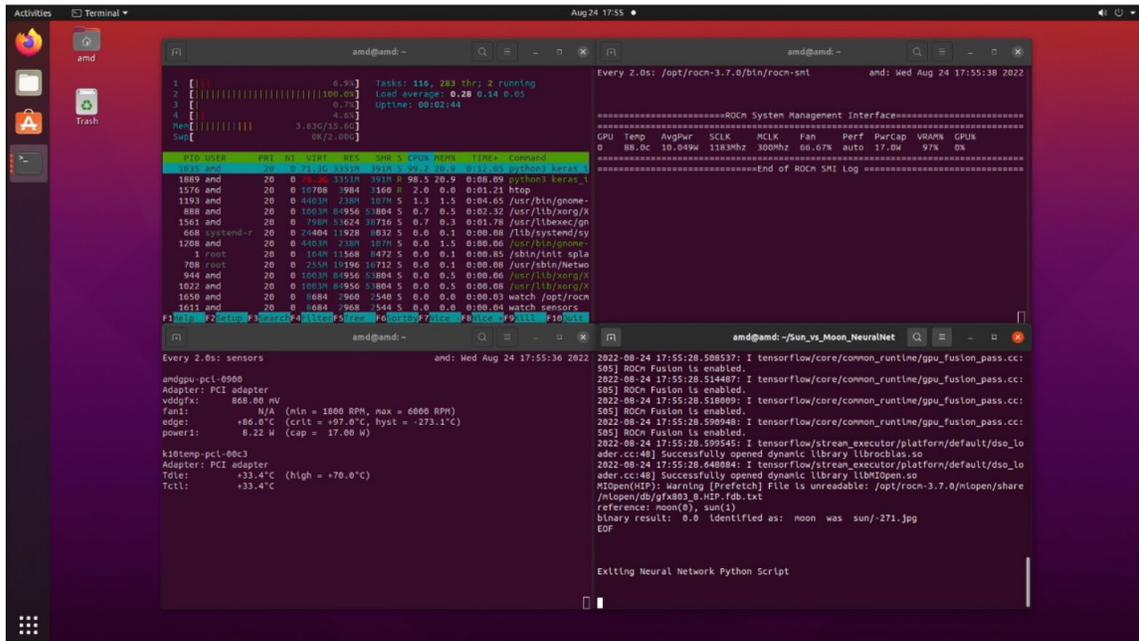
Figure 10: Test Pattern: Sun vs Moon Classifier Ai - Static Test Expected Result

5.6.5. Test Pattern: *MESA GLX Gears Benchmark* - Graphics Test

- Install GL Benchmark using sudo apt install mesa-utils
- Run *glxgears* from the terminal
- Monitor electrical data from both Motherboard and GPU PSUs and Line meter
- Monitor performance counters and save kernel logs
- Record screen capture video
- Iterate five (5) times
- Pass/Fail Criteria: Successful or Not. Record behavioral notes.
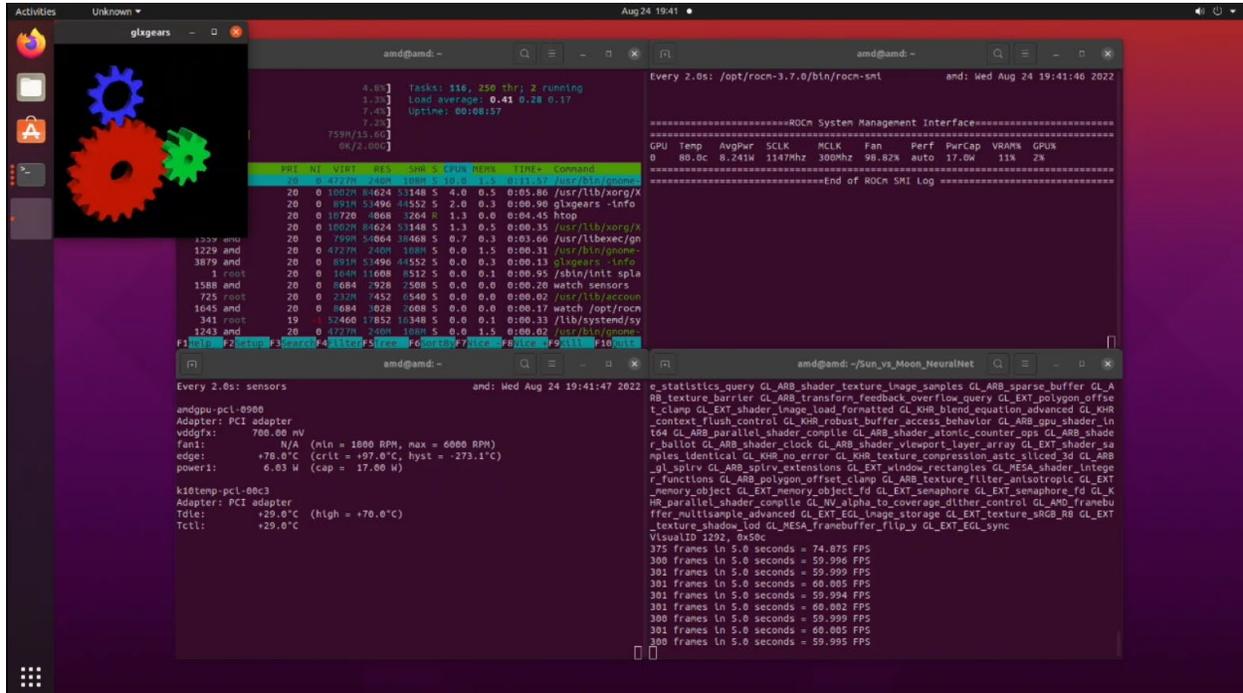- Expected results:

Figure 11: Test Pattern: MESA GLX Gears Benchmark - Graphics Test Expected Result

5.6.6.   Erroneous behavior while operation is "good"

- Power reporting is beyond specification

Figure 12: Erroneous Power Parameter Anomaly

- Framerate slow down below the anticipated 60fps

Figure 13: Erroneous Frame Rendering Speed Anomaly

- Inability for any payload to save its results on current iteration of script, but subsequent iteration was successful.

Figure 14: Failure to Save Results to Disk Anomaly