# Single Event Effect Testing of the Analog Devices ADV212

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## Introduction

The Analog Devices ADV212 was initially tested for single event effects (SEE) at the Texas A&M University (TAMU) Cyclotron Facility in July of 2013. Testing revealed a sensitivity to device hang-ups classified as single event functional interrupts (SEFI), soft data errors classified as single event upsets (SEU), and, of particular concern, single event latch-ups (SEL).

The sensitivity to SEL was in fact so high that the delay between observation of an SEL and commanding the beam run to end was substantial compared to the actual time it took the part to latchup. This resulted in poor data quality and low confidence in the estimated on-orbit rates.

To mitigate some of the risk posed by single event latch-ups, circuitry was added to the electrical design to detect a high current event and automatically cycle power and reboot the device. An additional heavy-ion test was scheduled to validate the operation of the recovery circuitry and the continuing functionality of the ADV212 after a substantial number of latch-up events. As a secondary goal, more precise data would be gathered by an improved test method, described below.

## Devices Tested

### ADV212 Background

The ADV212 is a single-chip JPEG2000 codec for video and image compression applications. It is built on a 180-nm complementary metal-oxide semiconductor (CMOS) process[1]. The devices tested are packaged in a 144-ball Ball Grid Array (BGA) package with gold bond wires. Further details on the device function, organization, and possible applications can be found in the full datasheet[1].

### Device Under Test (DUT) Preparation

Six devices were prepared and tested from two pre-selected Lot Date Codes (LDC) under consideration for use on a flight board. Table 1 lists the pertinent DUT information.

**Table 1. ADV212 Test Information**

| | |
|---|---|
| **Part Number:** | ADV212BBC2-150 |
| **Manufacturer:** | Analog Devices |
| **Lot Date Code:** | 1216 and 1220 |
| **Quantity Tested:** | 6 |
| **Part Function:** | Video Codec |
| **Part Technology:** | 180nm CMOS |
| **Package Style:** | 144 BGA |
| **REAG Identification** | 13-051, 13-053 |

A Nisene JetEtch machine[2] was used to de-encapsulate the plastic package and expose the silicon die for irradiation. A mixture of Nitric and Sulfuric acid was used at approximately 90˚C until the die was exposed (Figure 1) and most of the encapsulant removed. Devices were tested for functionality after etching.

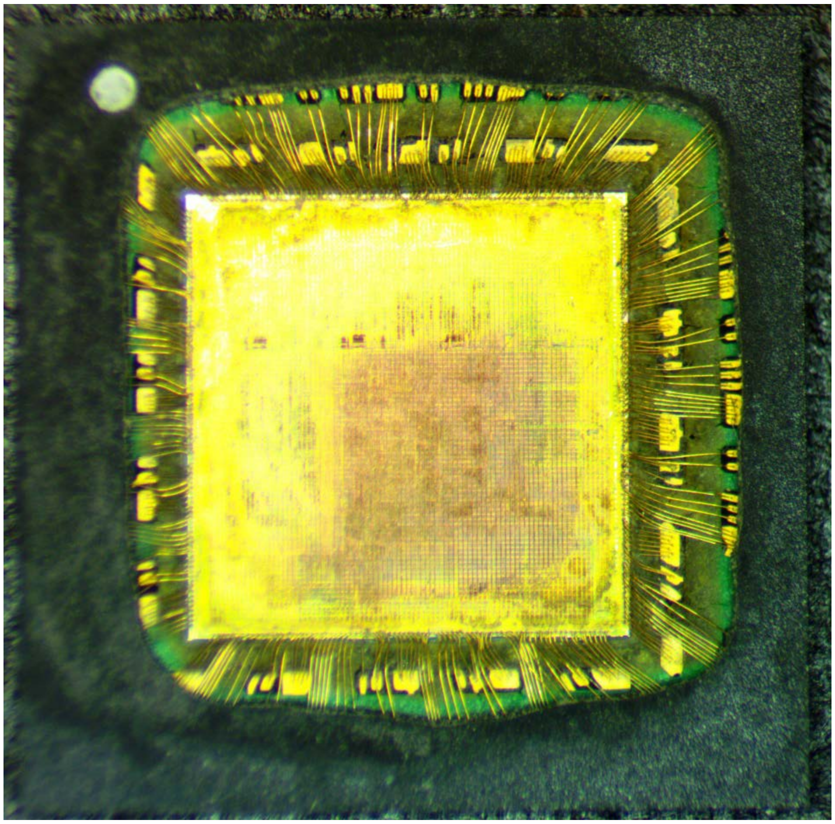

**Figure 1: ADV212 prepared for heavy ion irradiation**

## Test Method

<u>Test Description</u>

**Temperature:** Room temperature
**Test Voltages:** Core, 1.5V; I/O, 2.5V
**Over-current Limit:** 1.1A
**ADV212 Configuration:** 1000 x 1000 pixels, compression level 20, ~30 frames/sec

Raw data from a pseudo-random bit sequence (PRBS) generator was fed to the ADV212, which output compressed video data. That data was fed to an FPGA which generated a cyclic redundancy check (CRC) value for each video frame. The CRC value was compared to that of a known-good device running in parallel (outside of the beam). After 10 frames, the PRBS sequence was reset. Errors were captured by the test controller, a field programmable gate array (FPGA), and transmitted to a computer for logging.

Error Detection

Three types of errors were detected by the test hardware (Xilinx ML510 FPGA board). CRC errors resulting from data corruption in a video frame were logged. These soft errors represent single-event upsets somewhere in the hardware, and do not affect the continued operation of the device. Device hang-ups were logged whenever the ADV212 stopped processing video frames; these are considered single-event functional interrupts as they require a reset to resume normal operation. Finally, single event latch-ups resulted in a high-current situation which triggered a 1.1A limit and resulted in regulator shutdown.

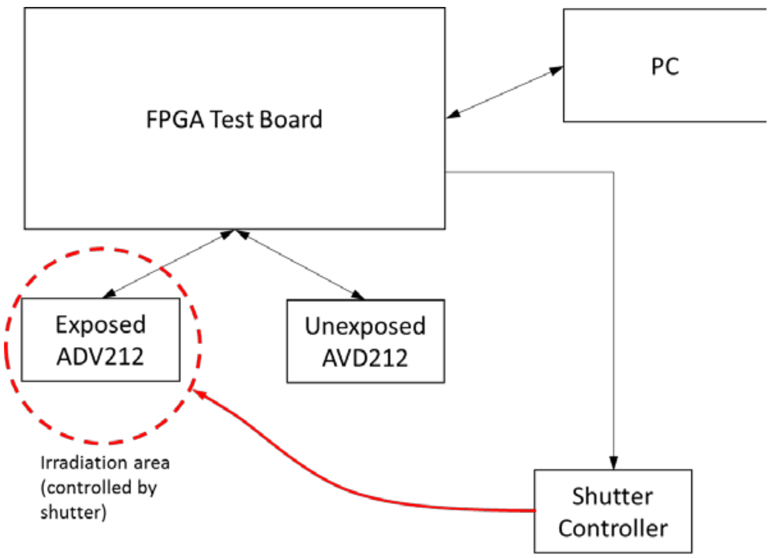


**Figure 2: Block diagram of test setup where the dashed line represents the area exposed to the heavy-ion beam.**

Error Recovery

No recovery was necessary from a CRC error as they are transient in nature. A hang-up (no device response but nominal current draw) or latch-up (no device response and high current limited by supply) required an automatic reboot process triggered by on-board circuitry. The power to the device was shutdown, a 1” diameter, 60-mil thick shutter (Thorlabs SH-1) was automatically closed to block the heavy ion beam (~20-30ms response), and the device was reset and reinitialized. Upon successful processing of clean data frames, the shutter was removed and testing resumed. The time spent in a shutter-closed mode was logged so that the total fluence of particles from the beam could be adjusted.

Typical latch-up tests are performed by irradiating until a pre-selected particle fluence is reached. If an SEL is observed, the irradiation is shut down and the total fluence-to-failure recorded. Manual observation of the SEL event and manual control of the irradiation beam (which closes in seconds, not milliseconds) both add error to the total recorded particle fluence. When sensitivity is low or non-existent, test runs may last several minutes, and a second or two of error is trivial (and the fact that SELs occurred at all is likely the most relevant result). However, when sensitivity is high, the device may latch almost immediately after activating the beam, making the additional error (post-latch) significant, and the SEL cross-section (events/fluence) may be unrealistically low. With the ADV212 setup, the 1” optical shutter mounted on the test board provided an automatically-triggered, faster method of blocking the beam to allow for a reset. By using this method, testing could proceed until hundreds or thousands of latch-ups were observed, and by accounting for the time spent with the shutter closed, an adjusted estimate of fluence calculated. Care was taken to minimize the time spent with the optical shutter closed to reduce any possible error in the fluence adjustments.

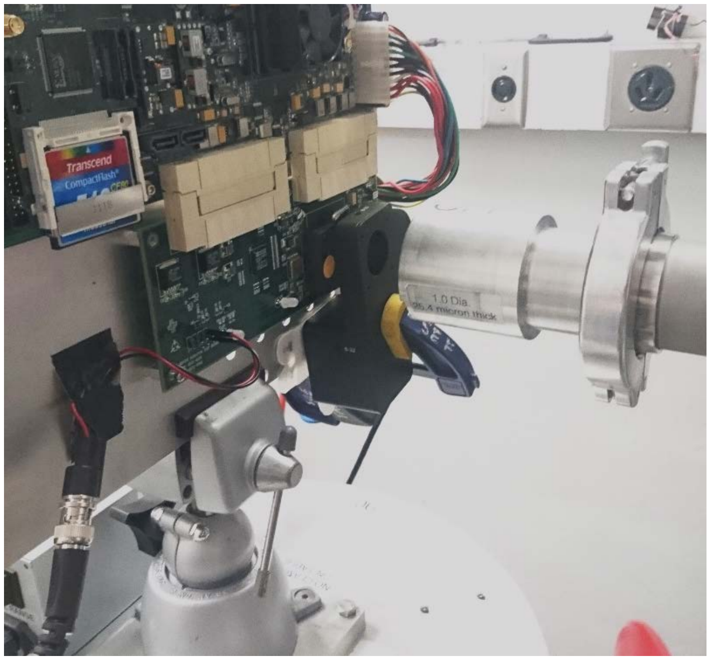


**Figure 3. Test board with shutter affixed and device under test aligned with beamline.**

## Test Facility

Heavy-ion testing was performed at the Texas A&M University Cyclotron Facility (TAMU), using their K500 cyclotron at the 15 MeV/amu configuration. The following ions were used for this test:

**Table 3: Ions Used**

| Ion | LET (MeV*cm$^2$/mg) After 1mil Aramica and 50mm air |
|---|---|
| N | 1.3 |
| Ne | 2.7 |
| Ar | 13 |
| Ag | 42.8 |

| | |
|---|---|
| Xe | 52.3 |
| Ho | 70 |
| Au | 86.3 |

**Flux:** Due to the high rate of single event effects observed with this part, most testing was conducted with the lowest reasonable flux obtainable with good beam stability, generally between 100-200 particles/$cm^2$/s. At very low LET, where SEL events were fewer, some runs were conducted up to 500 or 1000 particles/$cm^2$/s.

**Fluence:** Because the test setup allowed for the beam to be blocked while the part was rebooted, a large fluence was possible for each run, during which many single event effects could be observed. While a typical latch-up test might require $1x10^7$ particles/$cm^2$ to rule out latch-up sensitivity, this testing was unique in that latch-ups were expected and the run continued until several hundred latch-ups were counted. Typical runs were conducted to between $2x10^4$ or $5x10^5$ particles/$cm^2$. Longer runs were conducted until 1000 latch-up events were observed. An "adjusted fluence" was computed for each run, by taking the raw fluence provided by the facility and subtracting the particles "missed" while the shutter was closed, as calculated by multiplying the shutter-closed time by the average flux during the run.

## Results

### Single Event Latch-up

Single event latch-ups (high current events requiring a power cycle and device reset) were observed with LET as low as 1.3 MeV*$cm^2$/mg. No threshold was observed where the device could operate in the beam without latch-ups. A saturated cross-section was estimated to be $4.1x10^{-2}$ $cm^2$. A Weibull curve was fit to the data using a least-squares fit, and a graph of SEL cross-section vs. LET is shown in Fig. 4. The Weibull parameters for the curve are: threshold, 0.1; saturated cross-section, $4.126x10^{-2}$; shape, 2.415; and width, 10.99.

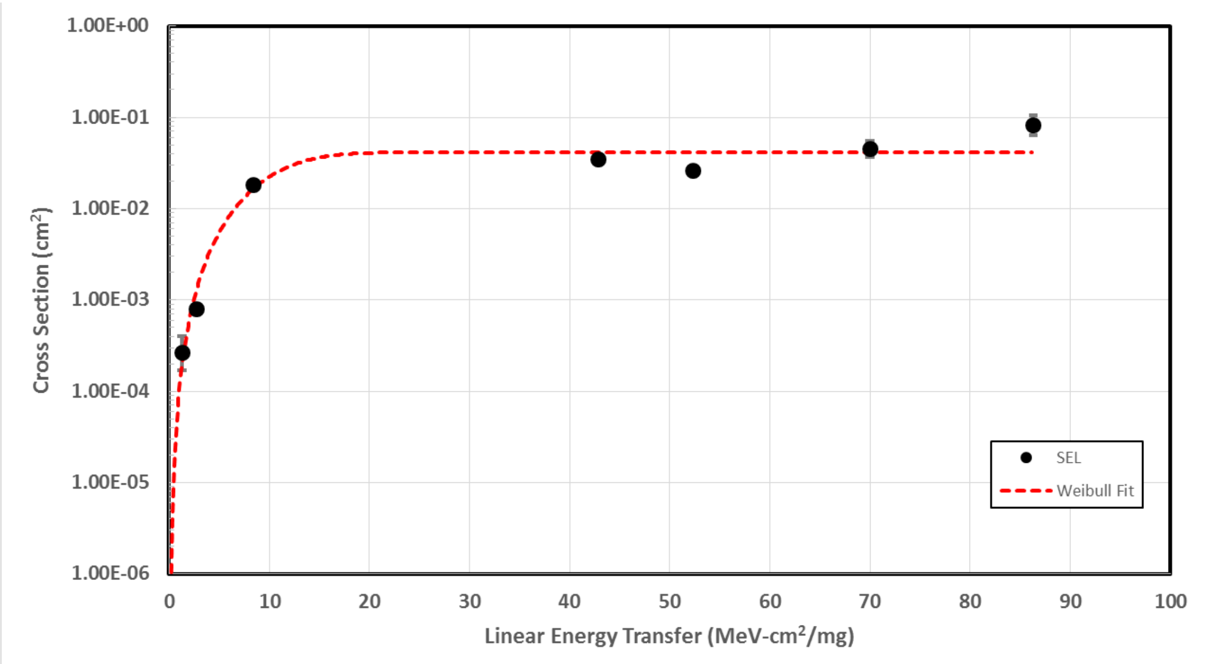


**Figure 4. Single event latch-up cross-section vs. heavy ion LET.**

## Destructive (Permanent) Device Failure and High-Cycle Test Verification

Up to (and including) an LET of 42.8 MeV*cm$^2$/mg, individual SELs were always recoverable with an automatic power cycle and reboot. At this LET, a device from each date code was tested until >1000 latch-ups were observed in a single run (in addition to latch-ups already encountered on these same parts at lower LET). For device 101 (LDC 1220), a run to an adjusted (shutter-open) fluence of $3.86x10^4$/cm$^2$ was completed with 1002 latch-up/recovery cycles. The device continued to function normally for one minute after the beam was turned off. For device 201 (LDC 1216), an adjusted fluence of $2.04x10^4$/cm$^2$ was sufficient to cause 1012 latch-up/recovery cycles. Again, the device was operated for one minute after the run ended to confirm normal function. No further reliability testing was performed on these parts beyond this functional verification.

For LET higher than 42.8 MeV*cm$^2$/mg, *destructive device failures were observed*. Following the tests with silver ions (42.8 MeV*cm$^2$/mg), testing moved to gold ions (86.3 MeV*cm$^2$/mg), the highest LET available at this facility. The first test recorded 105 latch-ups, events which happened so frequently that the shutter was only open for 5.8% of the run – an adjusted fluence of just $1.26x10^3$/cm$^2$. After testing, the part could not be recovered to normal operation without CRC errors. Other runs of less fluence resulted in additional device failures. Further testing with LET of 70 MeV*cm$^2$/mg resulted, again, in a failure after a run with 135 latch-ups.

Testing with LET of 52.3 MeV*cm$^2$/mg passed the 1000 latch-up test, but failed to operate after an additional test of 896 latch-up cycles.

Other single event effects

Single event upsets were detected by means of a failed CRC check on a data frame. No threshold was measured, as CRC errors were observed at the lowest LET tested of 1.3 MeV*cm$^2$/mg. A saturated cross-section could not be properly calculated because the SELs overwhelmed the other data errors at higher LET.

Device hang-ups (functional failure without high current) were observed at the lowest LET tested of 1.3 MeV*cm$^2$/mg. Again, no saturated cross-section could be calculated because the SELs overwhelmed other error types at higher LET.

Fig. 5 below shows the cross sections of CRC data errors and device hang-ups (SEFIs). Only at very low LET are the data particularly relevant. At medium and high LET, SEL events dominate the device response entirely.

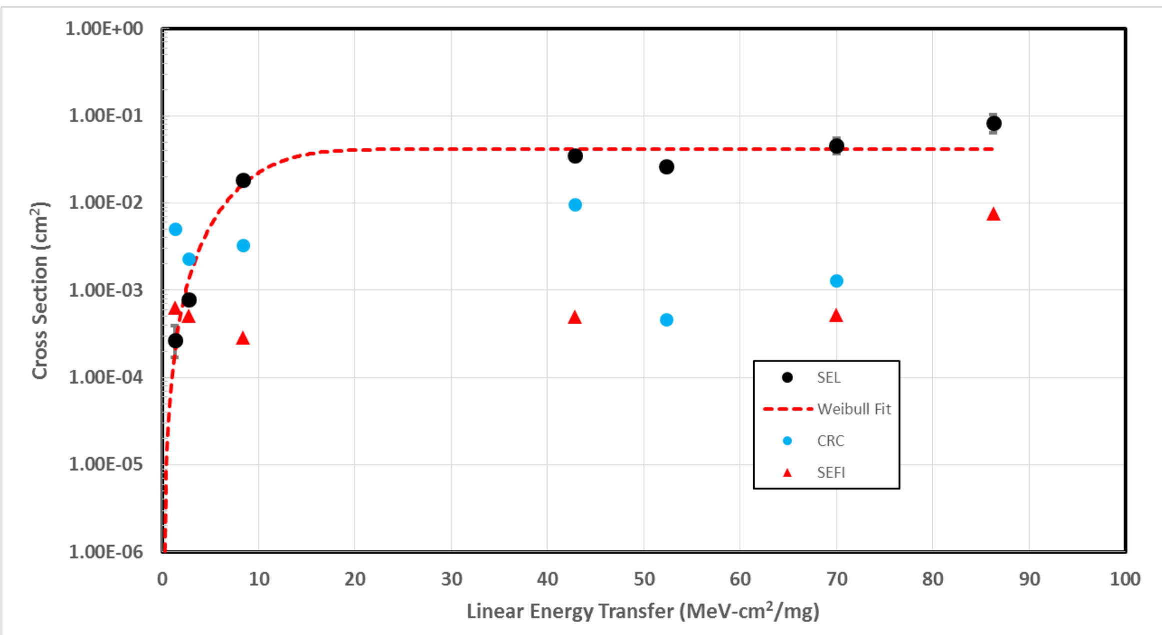


**Figure 5.** Chart of SEL, CRC, and SEFI events vs. LET

## Conclusions

*The ADV212 has an exceptionally-high sensitivity to single-event latch-ups*, even at very low (i.e., frequently-occurring in most space environments) LETs (<1.2 MeV*cm$^2$/mg). Because SEL cause a localized, high-current condition (effectively shorting the positive and negative supplies in the substrate), long-term effects on the device lifetime and reliability must be considered. Care must be taken to ensure events are properly detected and recovered at the hardware level. Rate estimates of on-orbit SEL are necessary to determine feasibility for a specific mission, based on orbital parameters, shielding, and mission timeline. It may be necessary to forbid operation of this device entirely in certain space weather conditions. As a reminder, complete device failure was observed on several devices when tested at high LET (>42.8 MeV*cm$^2$/mg). While particles at this LET are exceedingly rare for typical applications, the possibility of complete device failure cannot be ignored.

References

(1) http://www.analog.com/media/en/technical-documentation/data-sheets/ADV212.pdf

(2) http://www.nisene.com/jetetch-pro

# Run Log

| RUN | Device | LDC | Ion | MeV/amu | Eff LET | Angle | Avg Flux | Fluence | Live Time | Shutter Closes | Shutter Close Time | Net Exposure Time | % Up time | Adjusted Fluence | CRC | Hangs | SEL | CRC CS | Lockup CS | SEL CS | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 101 | 1220 | Ne | 12.4 | 2.7 | 0 | 1.02E+03 | 5.00E+05 | 491 | 253 | 300.1 | 190.9 | 38.9% | 1.95E+05 | 326 | 61 | 183 | 1.67E-03 | 3.13E-04 | 9.39E-04 | |
| 2 | 101 | 1220 | Ne | 12.4 | 2.7 | 0 | 2.90E+02 | 2.00E+05 | 690 | 209 | 247.9 | 442.1 | 64.1% | 1.28E+05 | 377 | 76 | 126 | 2.94E-03 | 5.93E-04 | 9.83E-04 | |
| 3 | 101 | 1220 | Ne | 12.4 | 2.7 | 0 | 2.18E+02 | 1.00E+05 | 459 | 119 | 141.1 | 317.9 | 69.3% | 6.93E+04 | 235 | 56 | 56 | 3.39E-03 | 8.08E-04 | 8.08E-04 | |
| 4 | 201 | 1216 | Ne | 12.4 | 2.7 | 0 | 1.08E+03 | 5.00E+05 | 461 | 223 | 264.5 | 196.5 | 42.6% | 2.14E+05 | 351 | 91 | 122 | 1.64E-03 | 4.25E-04 | 5.69E-04 | |
| 5 | 201 | 1216 | Ne | 12.4 | 2.7 | 0 | 3.95E+02 | 2.00E+05 | 505 | 177 | 209.9 | 295.1 | 58.4% | 1.17E+05 | 313 | 82 | 88 | 2.67E-03 | 7.01E-04 | 7.52E-04 | |
| 6 | 201 | 1216 | Ne | 12.4 | 2.7 | 0 | 3.45E+02 | 1.00E+05 | 290 | 94 | 111.5 | 178.5 | 61.6% | 6.16E+04 | 207 | 38 | 49 | 3.36E-03 | 6.17E-04 | 7.96E-04 | |
| 7 | 201 | 1216 | Ar | 13 | 8.4 | 0 | 3.90E+02 | 2.00E+05 | 513 | 386 | 457.8 | 55.2 | 10.8% | 2.17E+04 | 6 | 0 | 385 | 2.77E-04 | 0.00E+00 | 1.78E-02 | |
| 8 | 201 | 1216 | Ar | 13 | 8.4 | 0 | 1.15E+02 | 5.00E+04 | 434 | 275 | 326.2 | 107.9 | 24.9% | 1.24E+04 | 38 | 5 | 269 | 3.07E-03 | 4.03E-04 | 2.17E-02 | |
| 9 | 201 | 1216 | Ar | 13 | 8.4 | 0 | 1.49E+02 | 5.00E+04 | 336 | 227 | 269.2 | 66.8 | 19.9% | 9.89E+03 | 28 | 3 | 222 | 2.83E-03 | 3.03E-04 | 2.25E-02 | |
| 10 | 101 | 1220 | Ar | 13 | 8.4 | 0 | 5.67E+01 | 5.00E+04 | 881 | 397 | 470.8 | 410.2 | 46.6% | 2.33E+04 | 144 | 10 | 381 | 6.18E-03 | 4.29E-04 | 1.64E-02 | |
| 11 | 101 | 1220 | Ar | 13 | 8.4 | 0 | 1.02E+02 | 2.00E+04 | 197 | 115 | 136.4 | 60.6 | 30.8% | 6.14E+03 | 21 | 1 | 114 | 3.42E-03 | 1.63E-04 | 1.86E-02 | |
| 12 | 101 | 1220 | Ar | 13 | 8.4 | 0 | 1.16E+02 | 2.00E+04 | 171 | 103 | 122.2 | 48.8 | 28.6% | 5.84E+03 | 22 | 4 | 98 | 3.77E-03 | 6.85E-04 | 1.68E-02 | |
| 13 | 101 | 1220 | Ar | 13 | 0 | 0 | 7.21E+01 | 2.00E+04 | 277 | 0 | 0.0 | 277.0 | 100.0% | 2.00E+04 | 0 | 0 | 0 | | | | SHUTTER INTENTIONALLY CLOSED (No errors noted, this shows shutter works) |
| 14 | 101 | 1220 | Ag | 11.3 | 42.8 | 0 | 1.23E+02 | 2.00E+04 | 163 | 113 | 134.0 | 29.0 | 17.8% | 3.57E+03 | 27 | 2 | 110 | 7.56E-03 | 5.60E-04 | 3.08E-02 | |
| 15 | 101 | 1220 | Ag | 11.3 | 42.8 | 0 | 1.26E+02 | 2.00E+04 | 158 | 110 | 130.5 | 27.5 | 17.4% | 3.55E+03 | 17 | 1 | 108 | 4.79E-03 | 2.82E-04 | 3.04E-02 | |
| 16 | 101 | 1220 | Ag | 11.3 | 42.8 | 0 | 8.82E+01 | 1.46E+05 | 1650 | 1027 | 1218.0 | 432.0 | 26.2% | 3.86E+04 | 307 | 19 | 1002 | 7.96E-03 | 4.93E-04 | 2.60E-02 | Verified running error free after beam for ~1 minute |
| 17 | 201 | 1216 | Ag | 11.3 | 42.8 | 0 | 4.41E+01 | 2.00E+04 | 453 | 282 | 334.5 | 118.5 | 26.2% | 5.24E+03 | 79 | 2 | 277 | 1.51E-02 | 3.81E-04 | 5.28E-02 | |
| 18 | 201 | 1216 | Ag | 11.3 | 42.8 | 0 | 4.39E+01 | 7.39E+04 | 1682 | 1027 | 1218.0 | 464.0 | 27.6% | 2.04E+04 | 259 | 12 | 1012 | 1.27E-02 | 5.88E-04 | 4.96E-02 | Verified running error free |
| 19 | 201 | 1216 | Au | 10.8 | 86.3 | 0 | 1.41E+02 | 2.00E+04 | 141 | 112 | 132.8 | 8.2 | 5.8% | 1.26E+03 | | 8 | 105 | 0.00E+00 | 6.36E-03 | 8.35E-02 | When run ended, part was continuously erroring, then had some reset cycles, then kept erroring. Nothing could fix the part. Considered dead. |
| 20 | 101 | 1220 | Au | 10.8 | 86.3 | 0 | 8.38E+01 | 1.00E+03 | 12.3 | 10 | 11.9 | 0.4 | 3.6% | 6.25E+00 | | 3 | 7 | 0.00E+00 | 4.80E-01 | 1.12E+00 | Same, but part seemed to recover (mostly). Had some reset and CRC well after beam. Power cycled everything and demonstrated part functional (at least it seemed that way), so will test again with Gold |
| 21 | 101 | 1220 | Au | 10.8 | 86.3 | 0 | 8.48E+01 | 1.00E+03 | 12.2 | 8 | 9.5 | 2.7 | 22.2% | 1.95E+02 | | 0 | 8 | 0.00E+00 | 0.00E+00 | 4.10E-02 | Same as before, where run ended with a bunch of CRC errors still happening. After full power cycle still giving CRC errors constantly. |
| 22 | 102 | 1220 | Au | 10.8 | 86.3 | 0 | 1.02E+02 | 1.00E+03 | 10.08 | 9 | 10.7 | -0.6 | -5.9% | -8.55E+01 | | 0 | 9 | 0.00E+00 | 0.00E+00 | -1.05E-01 | Constantly reseting, but ok after run at least - SHUTTER PROBABLY LEFT OPEN - too many errors to be useful data |
| 23 | 102 | 1220 | Au | 10.8 | 86.3 | 0 | 8.29E+01 | 4.10E+03 | 49.41 | | 0.0 | 49.4 | 100.0% | 4.10E+03 | | | | 0.00E+00 | 0.00E+00 | 0.00E+00 | Paused at 1e3 and 2e3 with all ok, paused at 4e3 and found a "dead" part with no good frames and constant resets. Full power cycle didn't help. SHUTTER PROBABLY LEFT OPEN!!! |
| 24 | 11 | 1216 | Ho | 11 | 70 | 0 | 8.67E+01 | 1.00E+03 | 11.88 | 9 | 10.7 | 1.2 | 10.2% | 7.50E+01 | 4 | 0 | 9 | 5.33E-02 | 0.00E+00 | 1.20E-01 | |
| 25 | 11 | 1216 | Ho | 11 | 70 | 0 | 1.07E+02 | 4.02E+03 | 37.55 | 28 | 33.2 | 4.3 | 11.6% | 4.67E+02 | 1 | 0 | 28 | 2.14E-03 | 0.00E+00 | 6.00E-02 | |
| 26 | 11 | 1216 | Ho | 11 | 70 | 0 | 1.03E+02 | 2.00E+04 | 193 | 137 | 162.5 | 30.5 | 15.8% | 3.26E+03 | | 2 | 135 | 0.00E+00 | 6.13E-04 | 4.14E-02 | Part had tons of CRC errors after beam ended, then did some resets too. After power cycle still lots of CRC, then eventually a reset and more CRC |
| 27 | 23 | 1220 | Xe | 11.2 | 52.3 | 0 | 1.25E+02 | 1.00E+03 | 7.73 | 6 | 7.1 | 0.6 | 7.9% | 1.08E+02 | 0 | 0 | 6 | 0.00E+00 | 0.00E+00 | 5.57E-02 | |
| 28 | 23 | 1220 | Xe | 11.2 | 52.3 | 0 | 2.08E+02 | 1.00E+04 | 48 | 35 | 41.5 | 6.5 | 13.5% | 1.39E+03 | 2 | 0 | 35 | 1.44E-03 | 0.00E+00 | 2.52E-02 | |
| 29 | 23 | 1220 | Xe | 11.2 | 52.3 | 0 | 1.90E+02 | 2.62E+05 | 1376 | 1004 | 1190.7 | 185.3 | 13.5% | 3.53E+04 | 32 | 0 | 1004 | 9.06E-04 | 0.00E+00 | 2.84E-02 | Part functional after 1000 latchups |
| 30 | 23 | 1220 | Xe | 11.2 | 52.3 | 0 | 1.65E+02 | 6.26E+04 | 379 | 896 | 156.8 | 222.2 | 58.6% | 3.67E+04 | | | 896 | 0.00E+00 | 0.00E+00 | 2.44E-02 | Adjusted to faster shutter time - 175ms. Paused around 200 SELs and saw a few CRCs that kept coming, then went away. Paused again at 400 (?) and at 500 and part was fine. Paused at 896 and saw tons of CRC with some resets. Power cycled and still CRC errors. |
| 31 | 103 | 1220 | N | 14.1 | 1.3 | 0 | 1.85E+02 | 1.00E+04 | 54 | 6 | 7.1 | 46.9 | 86.8% | 8.68E+03 | 40 | 3 | 1 | 4.61E-03 | 3.45E-04 | 1.15E-04 | |
| 32 | 103 | 1220 | N | 14.1 | 1.3 | 0 | 5.00E+02 | 9.99E+04 | 220 | 62 | 73.5 | 146.5 | 66.6% | 6.31E+04 | 160 | 39 | 18 | 2.54E-03 | 6.18E-04 | 2.85E-04 | |
| 33 | 103 | 1220 | N | 14.1 | 1.3 | 0 | 2.27E+02 | 1.00E+05 | 441.6 | 81 | 96.1 | 345.5 | 78.2% | 7.82E+04 | 566 | 52 | 21 | 7.23E-03 | 6.65E-04 | 2.68E-04 | |
| 34 | 103 | 1220 | N | 14.1 | 0 | 0 | 4.74E+02 | 1.00E+05 | 211 | 0 | 0.0 | 211.0 | 100.0% | 1.00E+05 | 0 | 0 | 0 | | | | SHUTTER INTENTIONALLY CLOSED (No errors noted, this shows shutter works) |
| 35 | 103 | 1220 | Au | 10.8 | 86.3 | 0 | 1.02E+02 | 2.43E+04 | 238.6 | | | 238.6 | 100.0% | 2.43E+04 | | | | 0.00E+00 | 0.00E+00 | 0.00E+00 | Changed shutter parameters to close for at least 10 seconds after the last SEL. After ~7th SEL it never opened bc the part kept getting errors with shutter closed. Tried power cycle, and similar happened after another SEL. Power cycled again with beam off and had CRCs. |