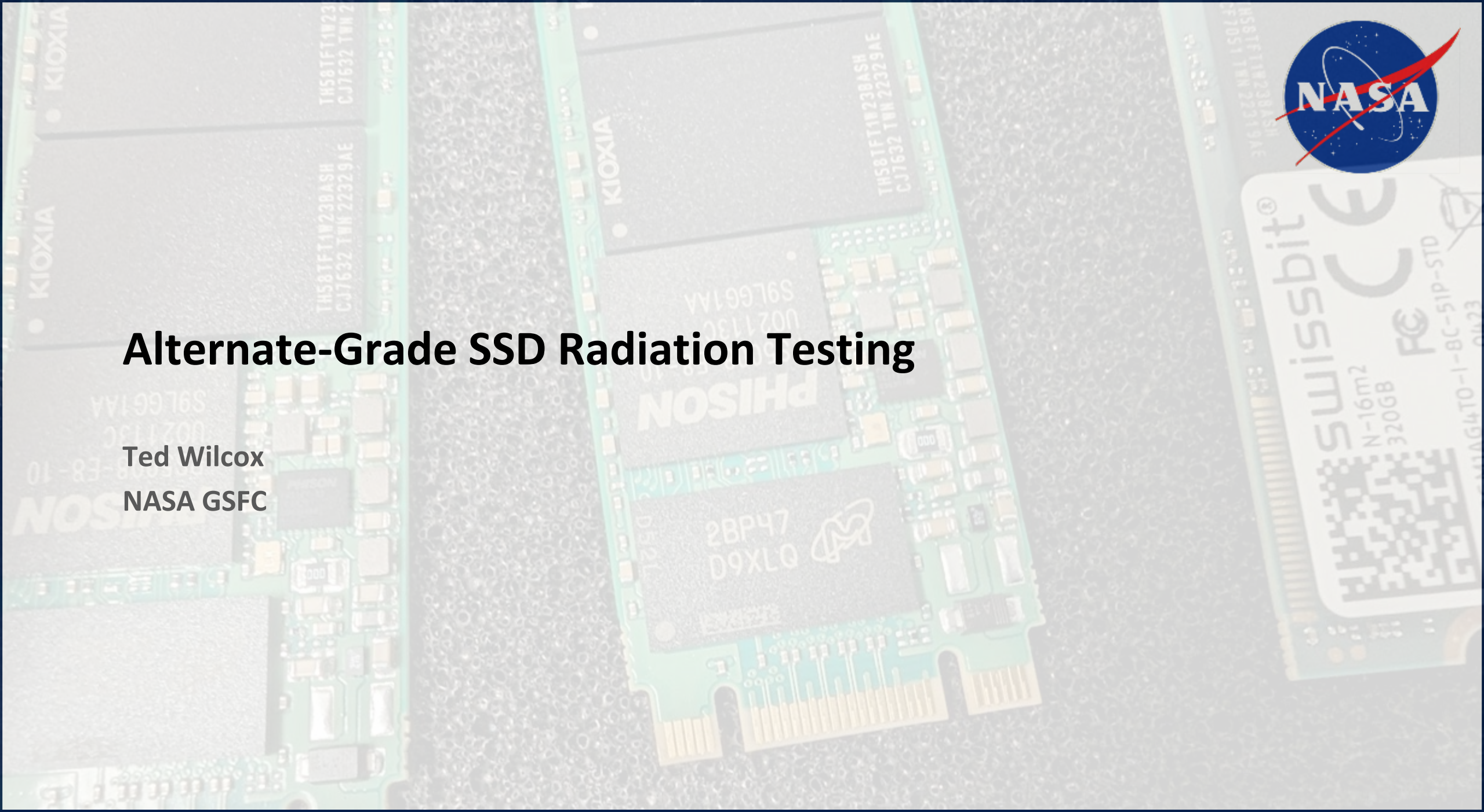


Alternate-Grade SSD Radiation Testing

Ted Wilcox

NASA GSFC

Alternate Grade?

- I'm talking automotive and industrial grade.
- There is momentum to adopt non-traditional parts across the NASA portfolio: Cubesats to Class D, C, and B missions.
- Clear cost & schedule advantages
- Radiation not *inherently* worse – many space parts are repackaged, qualified, and assured COTS – but with complexity grows the list of questions

Ex: Micron 2100AT
+105° C, Up to 1 TB in BGA
Configurable SLC or TLC

NEPP Flash Backstory

- We've tested numerous flash piece parts, including complex multi-Tb 3D NAND devices

ETW 2019

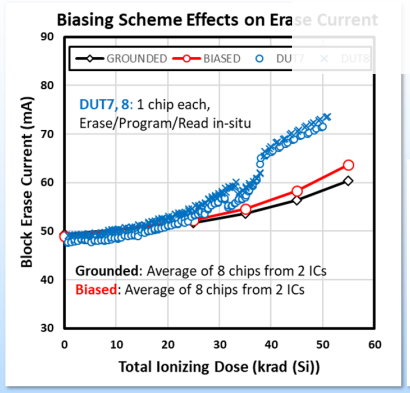
Recent Results -- 3D NAND Flash

- Three-dimensional ion track structure can be determined experimentally, and results look exactly as you'd expect:

3D NAND Flash – Biased vs. Unbiased

What if we dynamically operate device to keep our weak link operational?

Highly application-specific testing…

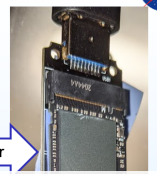


ETW 2021

Intel 760P NAND Flash SSD

- Intel's 760P is a mainstream consumer solid state drive (released 2018)
  - Silicon Motion's SM2262 controller
  - 256 Gb 64 layer TLC 3D NAND
  - Winbond DRAM
- Six devices prepared

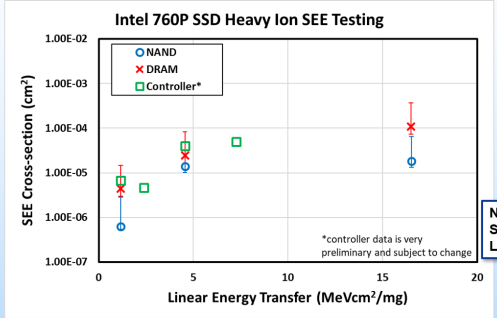
SM2262 Controller



Intel 760P SEE data

- The controller points must still be adapted to true surface-incident

LET



No unrecoverable SEE for Intel 760P to LET of at least 16.4

NSREC 2023

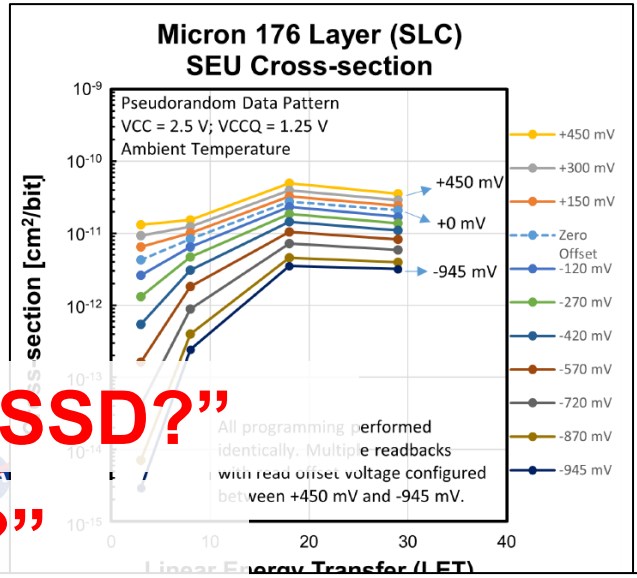


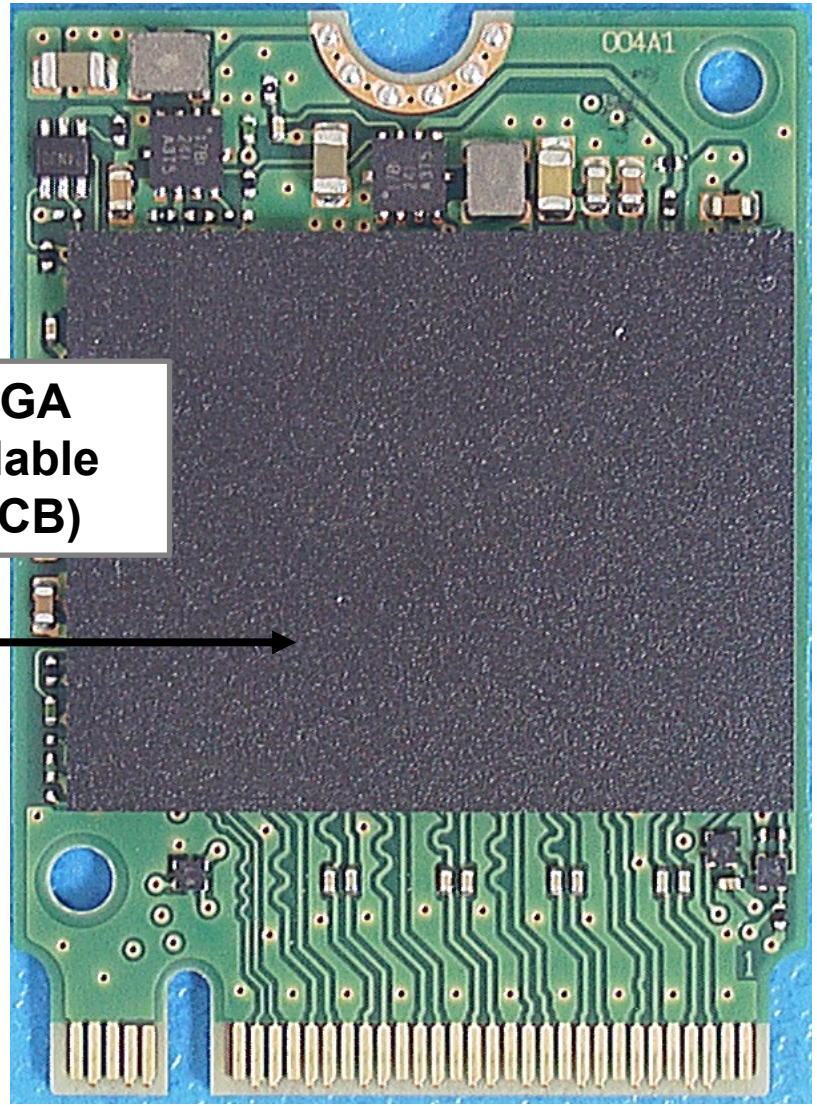
TABLE II
SEFI RECOVERY STEPS NECESSARY FOR MICRON 96-LAYER DEVICE

LET (MeV·-cm²/mg)	Fluence /cm²	Count of READID SEFI resettable by RESET	HARD RESET	Pow. Cycle
18.0	$2.01 * 10^6$	10 (77%)	3 (23%)	0 (0%)
29.0	$2.61 * 10^6$	10 (71%)	1 (7%)	3 (21%)
56.0	$8.58 * 10^6$	89 (77%)	20 (17%)	6 (5%)
79.2	$1.05 * 10^7$	132 (70%)	40 (21%)	16 (9%)

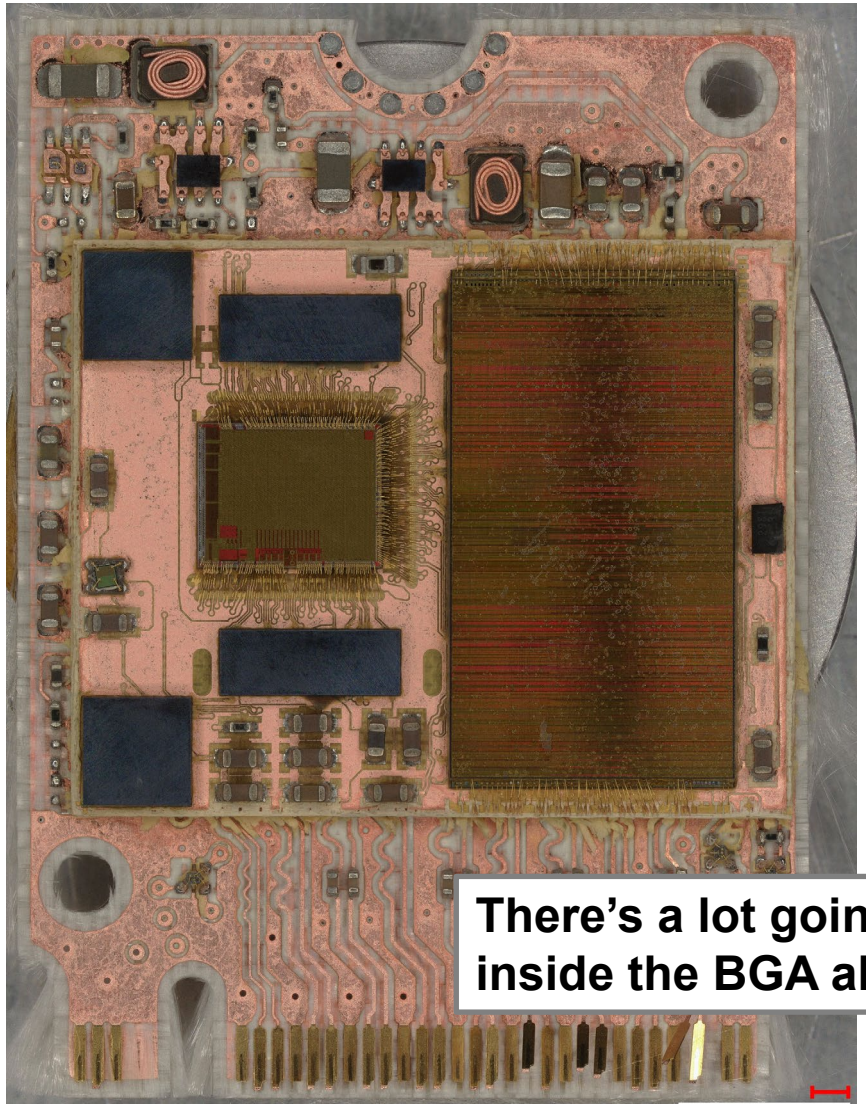
"Hey – can you recommend an SSD?"

"How do you test an SSD?"

Complex Devices



This is sold as a BGA piece part (or available mounted on m.2 PCB)

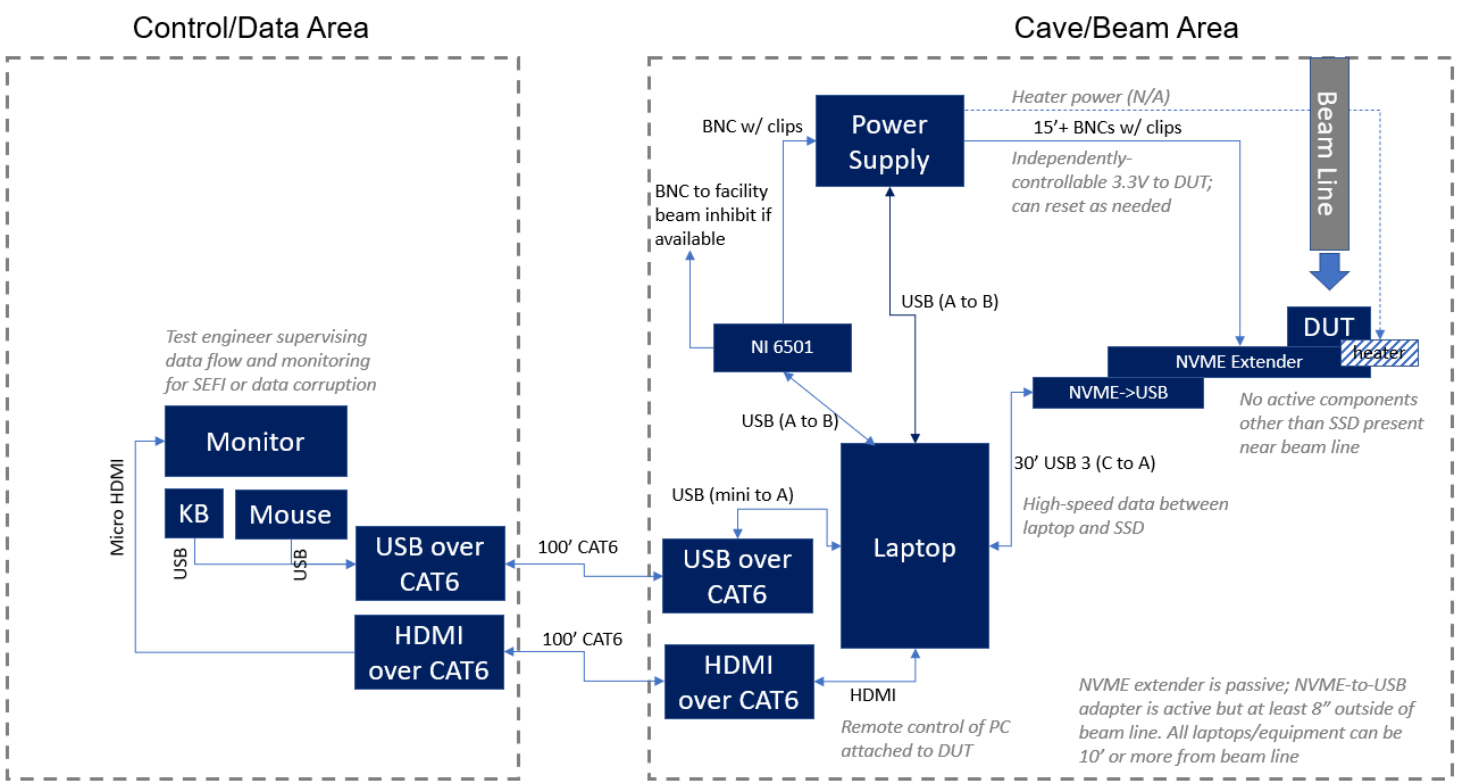


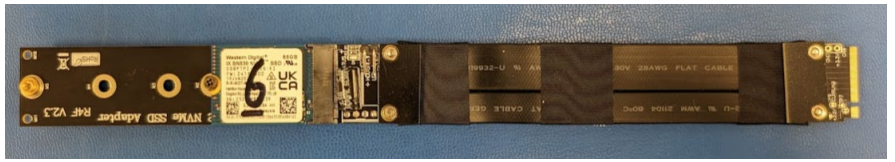
There's a lot going on inside the BGA alone

Micron 2100AT (teardown in collaboration with 562 PA Lab!)

Improved Test Setup

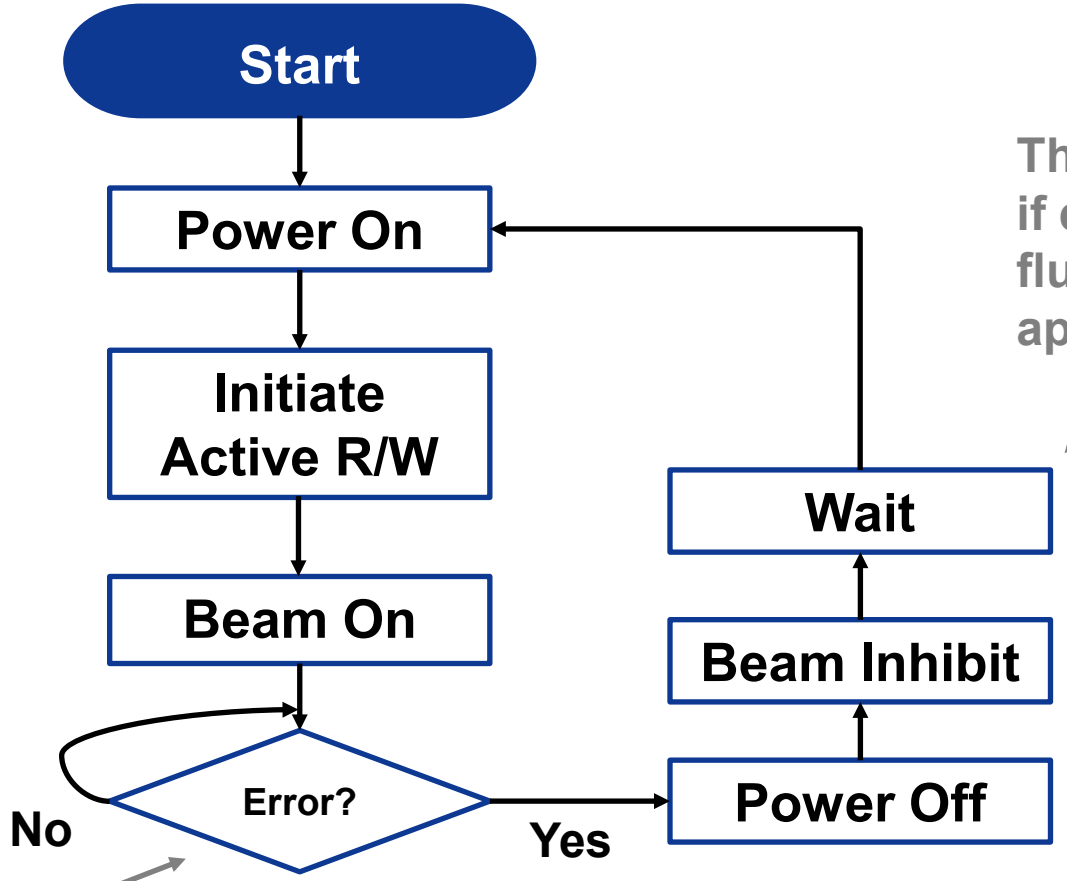
- NASA needed a way to automate SSD tests rather than test only until error
- NASA needed to operate these parts in beam to detect errors in real time





SEE Test Flow

Ideal situation – test runs for a half hour, counting and recovering from errors several dozen times.

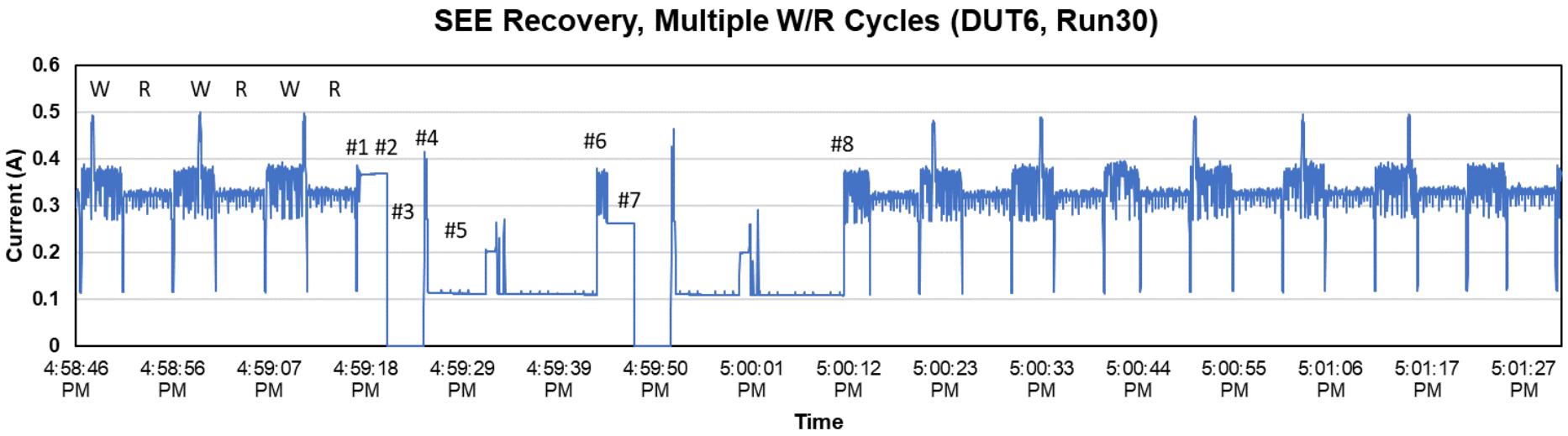


This time can be a problem if errors occur often, but fluence is not being applied to part

Most time spent here, reading and writing while waiting for an error.

Power and beam inhibit handled autonomously by digital I/O devices

SEE Automation Example – Micron 2100AT

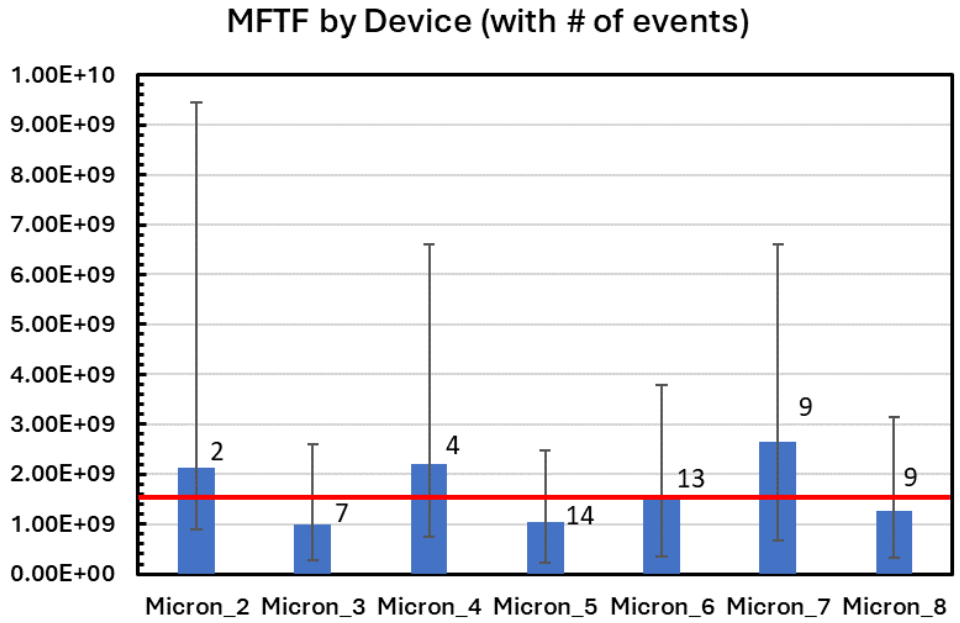


1. Initiation of a write command at 4:59:17 PM. The supply current elevates but is uncharacteristically flat.
2. Three seconds later the test software throws an exception when the write has failed to complete. This is classified as a timeout error.
3. The power supply is disabled for four seconds and the proton beam is inhibited.
4. At 4:59:24 PM power is restored.
5. The device is allowed 20 seconds to initialize, still without beam applied.
6. At 4:59:44 PM the beam is uninhibited and testing (the incomplete write) resumes.
7. Writing proceeds successfully for about 2 seconds until it again hangs for 3 seconds, triggering a timeout error and a repeat of the recovery in steps 3-6.
8. Writing resumes after the second recovery and completes. The subsequent read operation is successful, along with the depicted write and read cycles afterwards.

Proton Results – Fluence Between Failure

- Micron 2100AT automotive (256GB variant)
- 200 MeV protons
- Francis H. Burr Proton Therapy Center (Massachusetts General Hospital)
- January 2024

- Two clear error signatures
  1. Interruption in read or write cycle, recoverable with power cycle
  2. Interruption with subsequent inability to write to device (appears to be write locked)
- No signs of elevated current nor any actual data corruption

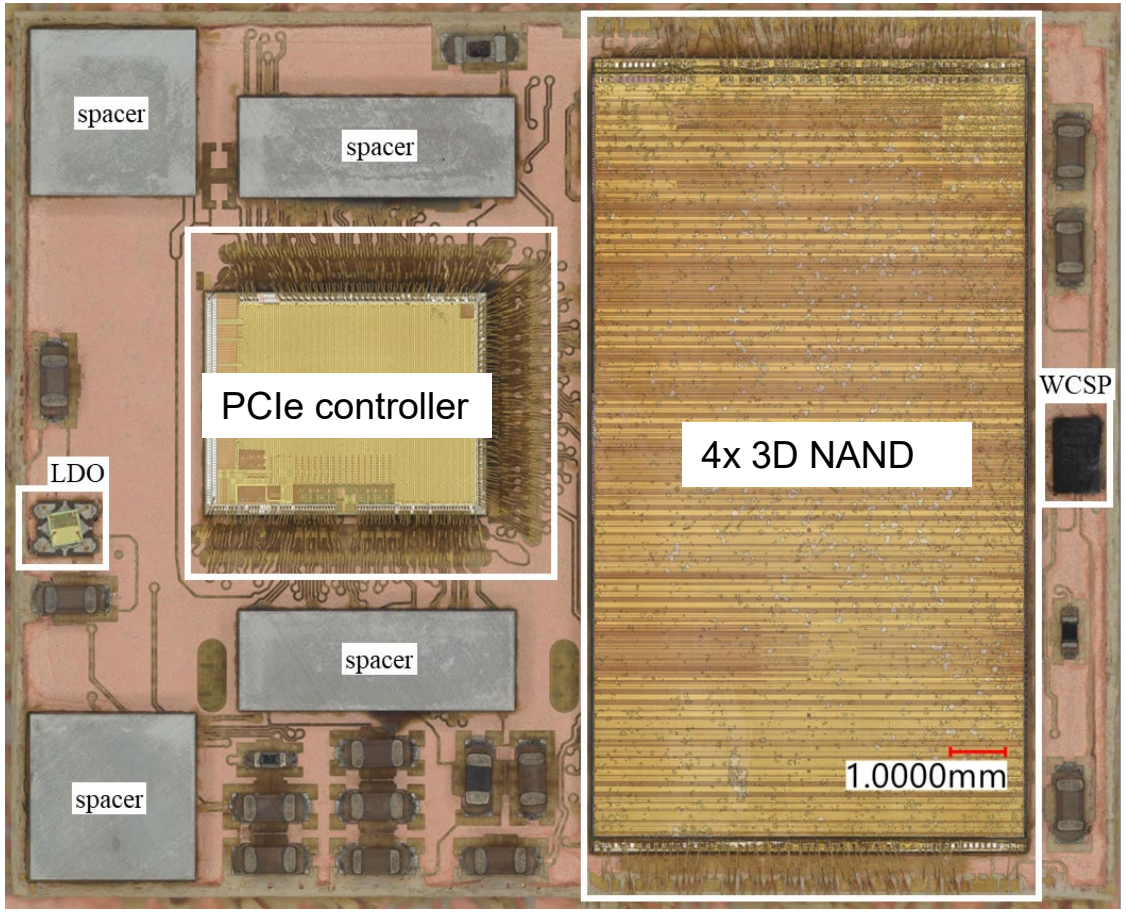


Device #	Total Timeout Events	Total Biased Fluence	MFTF	Tested until unrecoverable error occurred?
Micron_2	2	4.28E+09	2.14E+09	Yes
Micron_3	7	6.97E+09	9.96E+08	Yes
Micron_4	4	8.82E+09	2.21E+09	Yes
Micron_5	14	1.46E+10	1.04E+09	Yes
Micron_6	13	2.06E+10	1.58E+09	No
Micron_7	9	2.38E+10	1.98E+09	No
Micron_8	9	1.26E+10	9.42E+08	No
sum	*58*	*9E+10*	*1.56E+09*	

What about TID?

- Complex devices make a complex TID process
  - 4x Intel (Micron) B17A 64L TLC NAND Flash
  - 1x Silicon Motion SM2263A PCIe controller
  - TLV733A1P8 1.8V LDO
  - Unknown WCSP die
  - Numerous R & C

First cut – reuse SEE test setup to actively read and write at a distance.

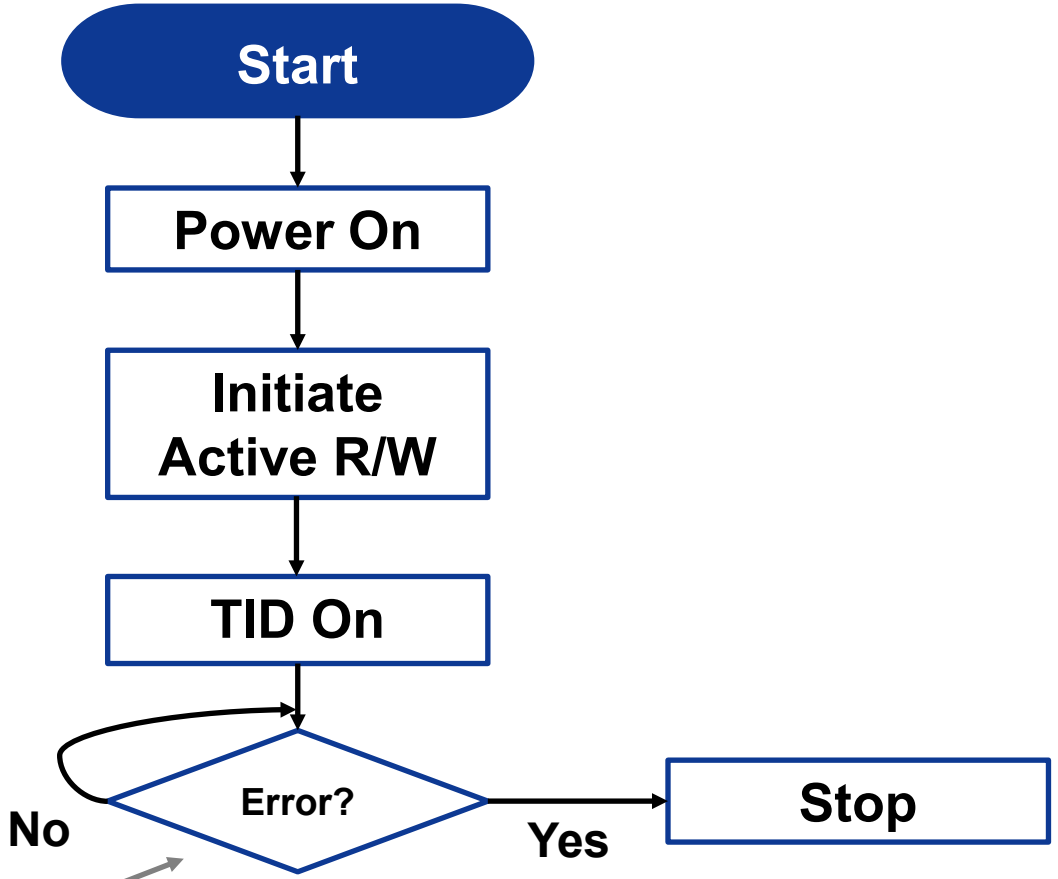


Micron 2100AT 256GB internal components (BGA only!)

Initial TID Test Flow

Repurposing the test-at-a-distance engineering to improve TID operations.

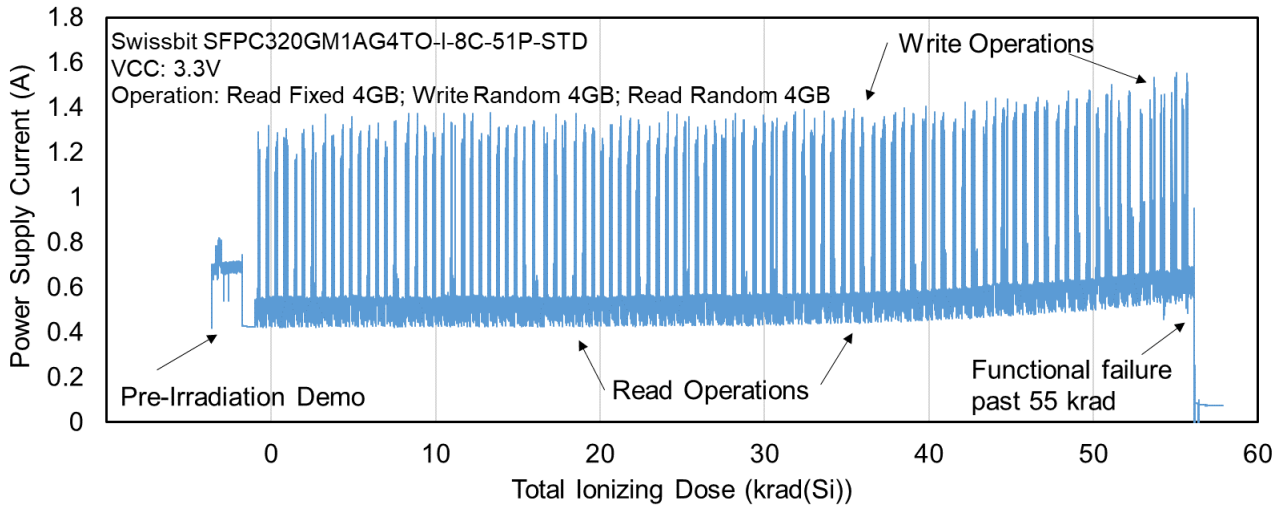
Plausible benefits of high-speed reading & writing in beam relative to classic biased and grounded tests include the activation of all internal circuit elements.



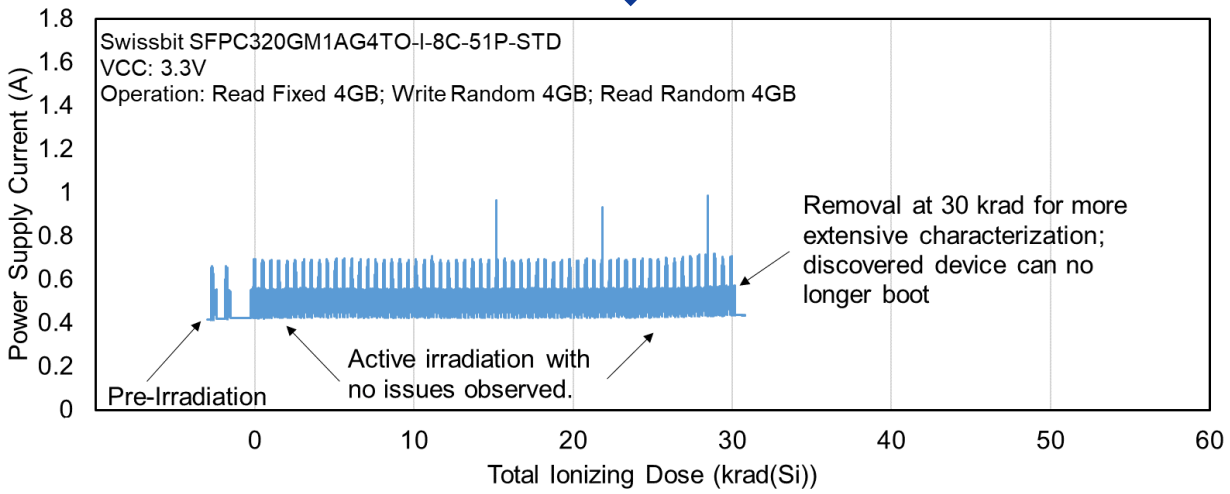
Most time spent here, reading and writing while waiting for an error.

TID RHA Issues Emerge

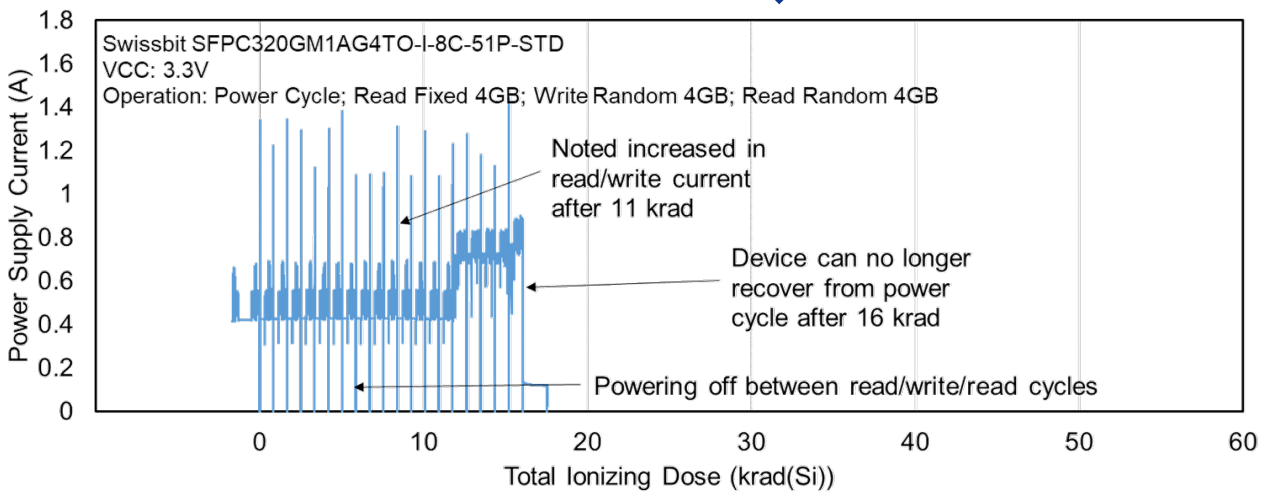
Continuous reading and writing – ensuring that all parts of the device are operating with radiation applied.



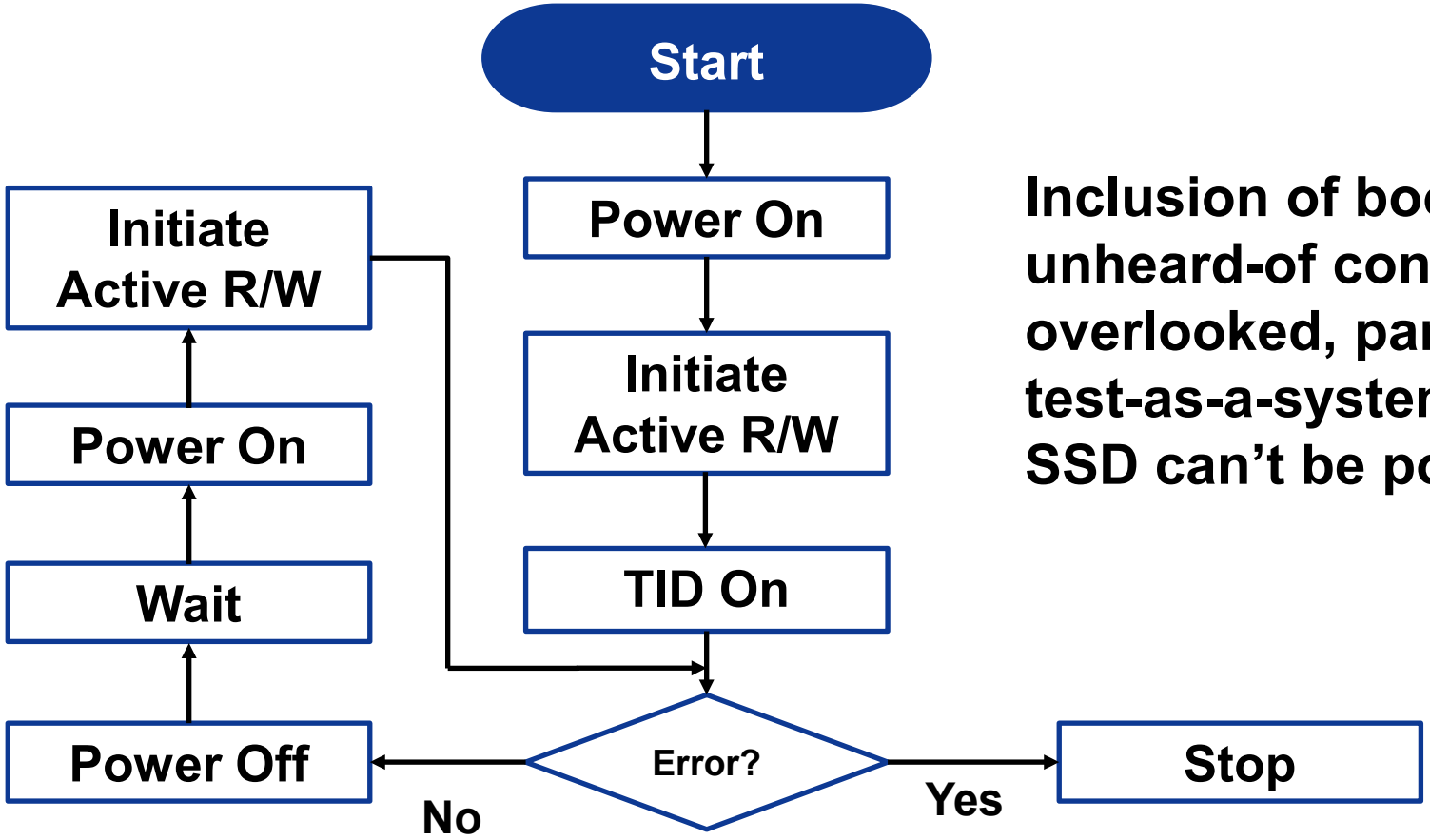
Let's do a more thorough test at 30 krad rather than taking it all the way to failure.



We should have been testing the power cycling all along.



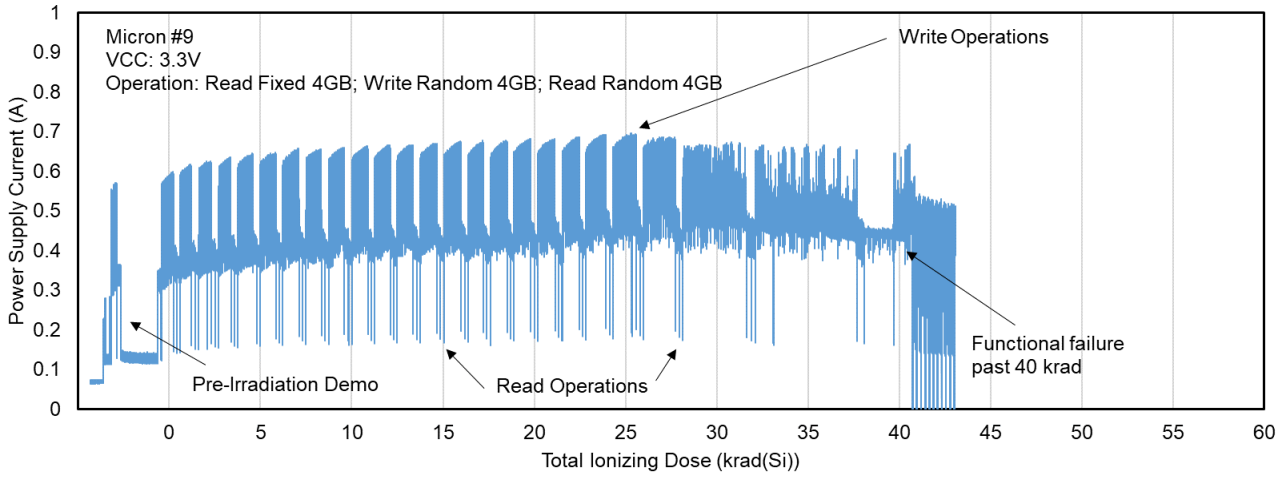
Revised TID Test Flow



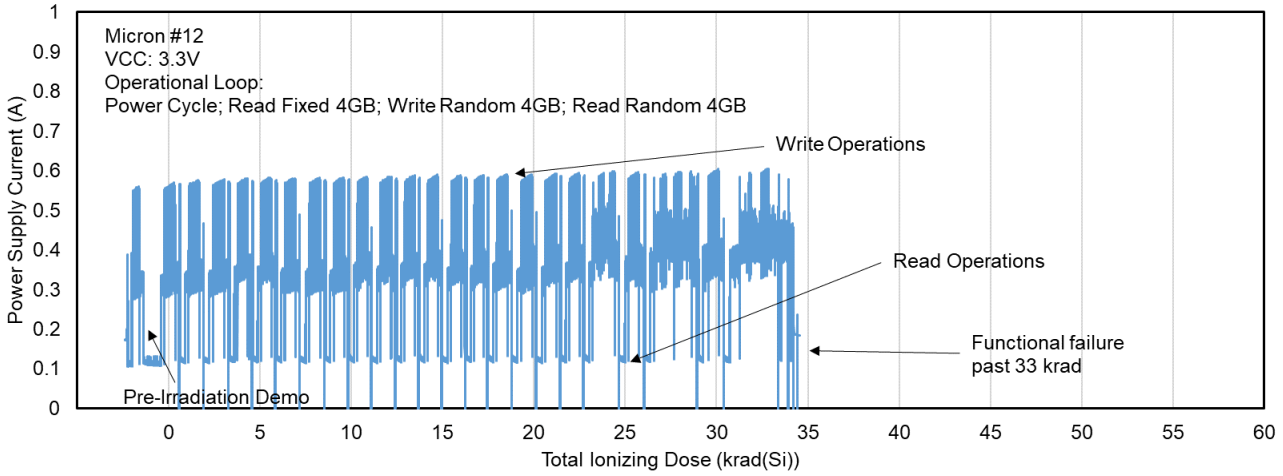
Inclusion of bootability testing is not an unheard-of concept, but it is easily overlooked, particularly in an even larger test-as-a-system experiment (perhaps the SSD can't be power cycled)

More Complex TID Behavior

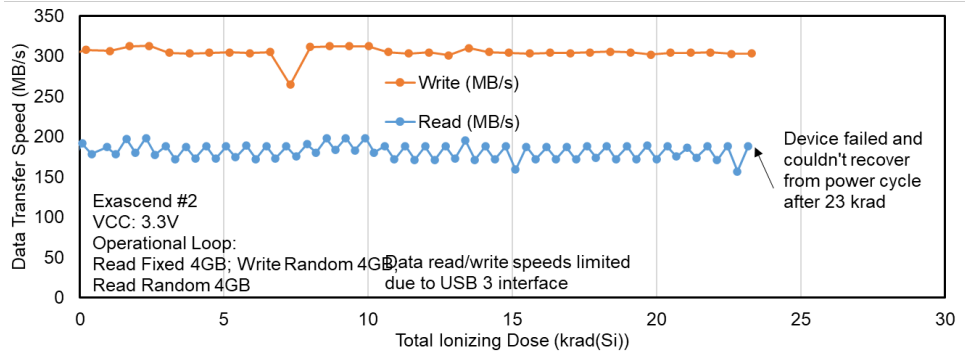
Micron Automotive SSD (Read/Write)



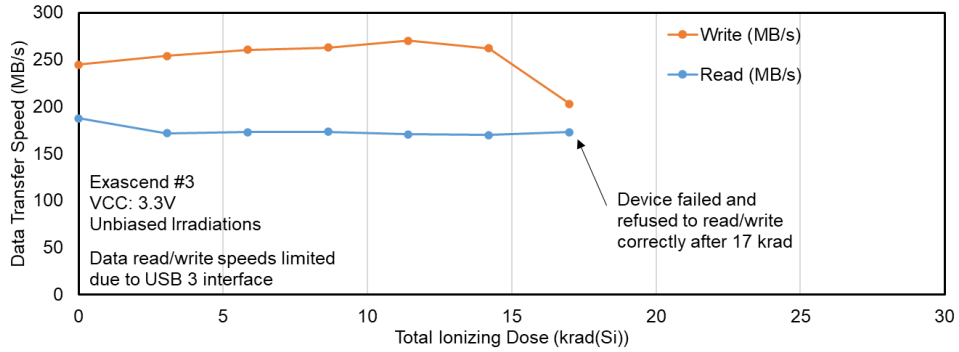
Micron Automotive SSD (Read/Write + Power)



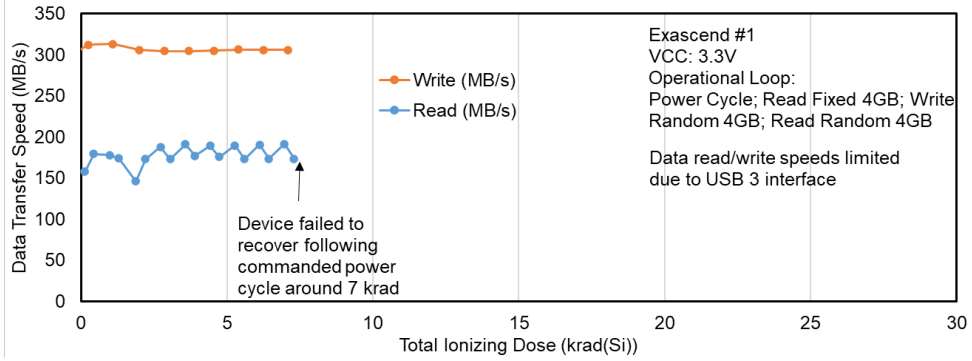
Exascend 960GB Industrial PCIe SSD



Read & Write



Warm Spare



Read & Write & Power Cycle

Key Considerations with SSDs

- SEU are not the problem – these devices are designed to correct errors constantly, even on Earth
- Don’t expect perfect SEE resilience. However, evaluate the reliability of your mitigation to some degree.
- NAND flash is often the dose-limiting component for a rad-hard space computer. It is not likely the dose-limiting component for a COTS SSD.
- Test behavior is (seemingly) more deterministic at the board level rather than trying to play with individual components, especially if decapsulating.
- SEL is fair game, but may not be the predominant risk to reliability or availability
- Biggest problem may be the controller’s own inability – or unwillingness – to recover from events that should be recoverable

Upcoming tests

- NASA Space Radiation Lab Testing of PCIe SSDs:
  1. **Micron** 2100AT 256 GB TLC/SLC Automotive SSD – Limited proof of concept at NSRL March 2024 (confirmed proton error signatures with LET ~ 5.3 MeV·cm^2/mg)
  2. **Western Digital** SN530 85 GB SLC Industrial SSD
  3. **Swissbit** 320 GB SLC Industrial SSD
  4. **Exascend** 960 GB Industrial SSD

Trade space includes SLC vs TLC; multiple PCIe controllers; DRAM vs DRAM-less