IONIZED DOSE TESTING OF
COMMERCIAL DC|DC BUCK CONVERTERS FOR ePIC

July 30th 2024, BNL Gamma Ray Facility

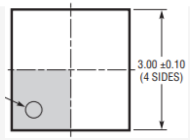
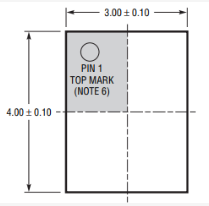
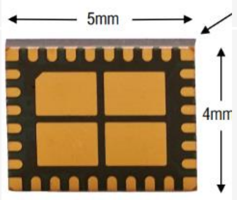
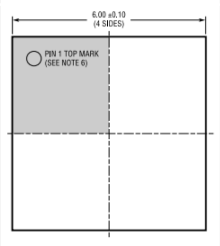
Presentation for DAQ & Electronics

Tim Camarda for BNL

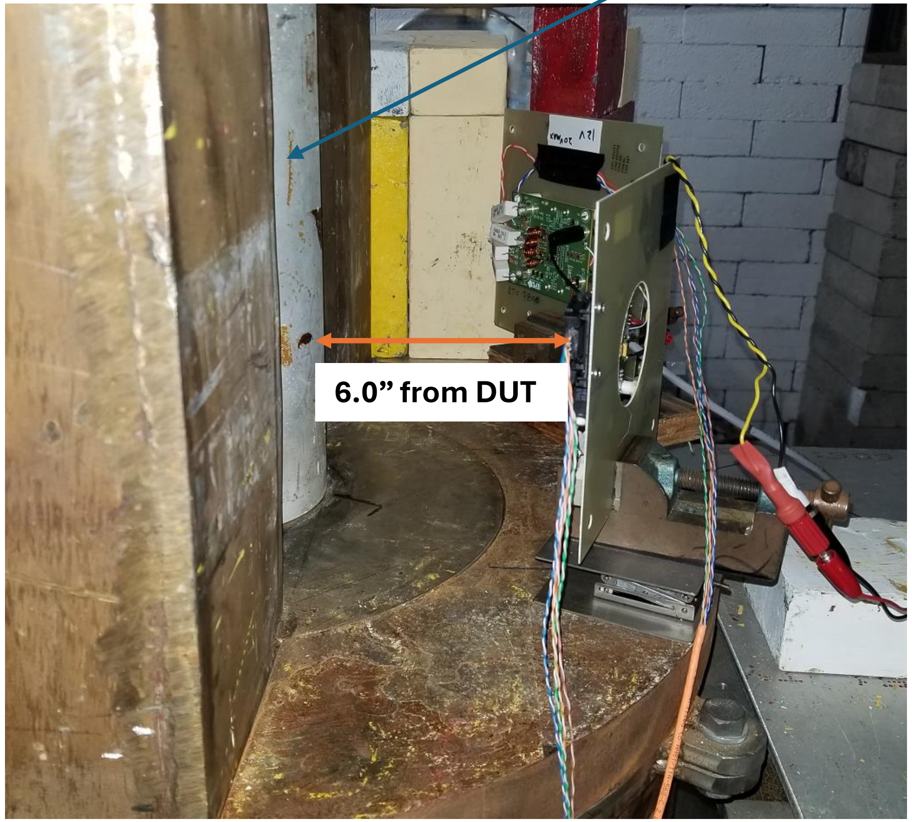
With Contributions from
Gerard Visser, IU
James Kierstead, BNL (Instrumentation Division)

Radiation Type	Facility	Comments
^{60}Co	BNL (SSIF)	5k rads/ hour
64 MeV proton	UC Davis Previous testing for reference	120k rads/ hour Only LTC7890 same DUT from proton beam was used for TID testing at BNL. All other DUTs are new but same PN was tested at UC Davis.

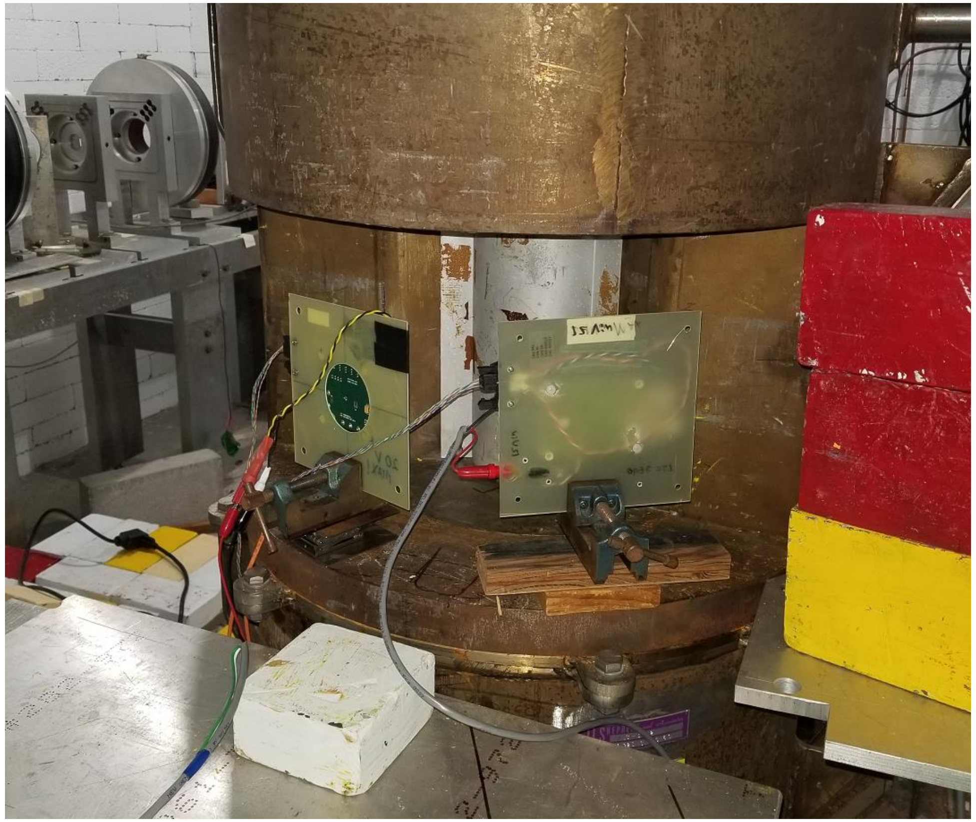
Tested Devices

Part Number	Description	Package	DUT condition Resistor Loads Ambient Temperature ~ 21°C
LTC 3600	**15V, 1.5A DC buck converter** **200kHz to 4MHz**	**3x3mm DFN** 	**V_{IN}: 14V** **Load: 1.5Ω** **V_{OUT}: 1.8V** **P_{OUT}: 2.16W** **Fsw: 1MHz**
LTC 3626	**20V, 2.5A DC buck converter** **500KHz to 3MHz**	**4x3mm QFN** 	**V_{IN}: 15V** **Load: 1.5Ω** **V_{OUT}: 1.8V** **P_{OUT}: 2.16W** **Fsw: 1MhZ**
LTC 7151	**20V, 15A DC buck converter** **400KHz to 3MHz**	**5x4 QFN** 	**V_{IN}: 12V** **Load: 0.68Ω** **V_{OUT}: 1.2V** **P_{OUT}: 2.12W** **Fsw: 1.5MHz**
LTC 7890	**2 channel synchronous GaN buck controller :** Wide VIN range: 4 V to 100 V Wide output voltage range: 0.8 V ≤ VOUT ≤ 60 V **100KHz to 3MhZ**	**6x6 QFN** 	**V_{IN}: 12V** **Load: 0.6Ω / channel** **V_{OUT}: 1.2V** **P_{OUT}: 4.8W (ch1 + Ch2)** **Fsw: 2MhZ** **Previously irradiated at UC Davis (27K rad dose @ 120k / hour)**

Cobalt 60 source inside

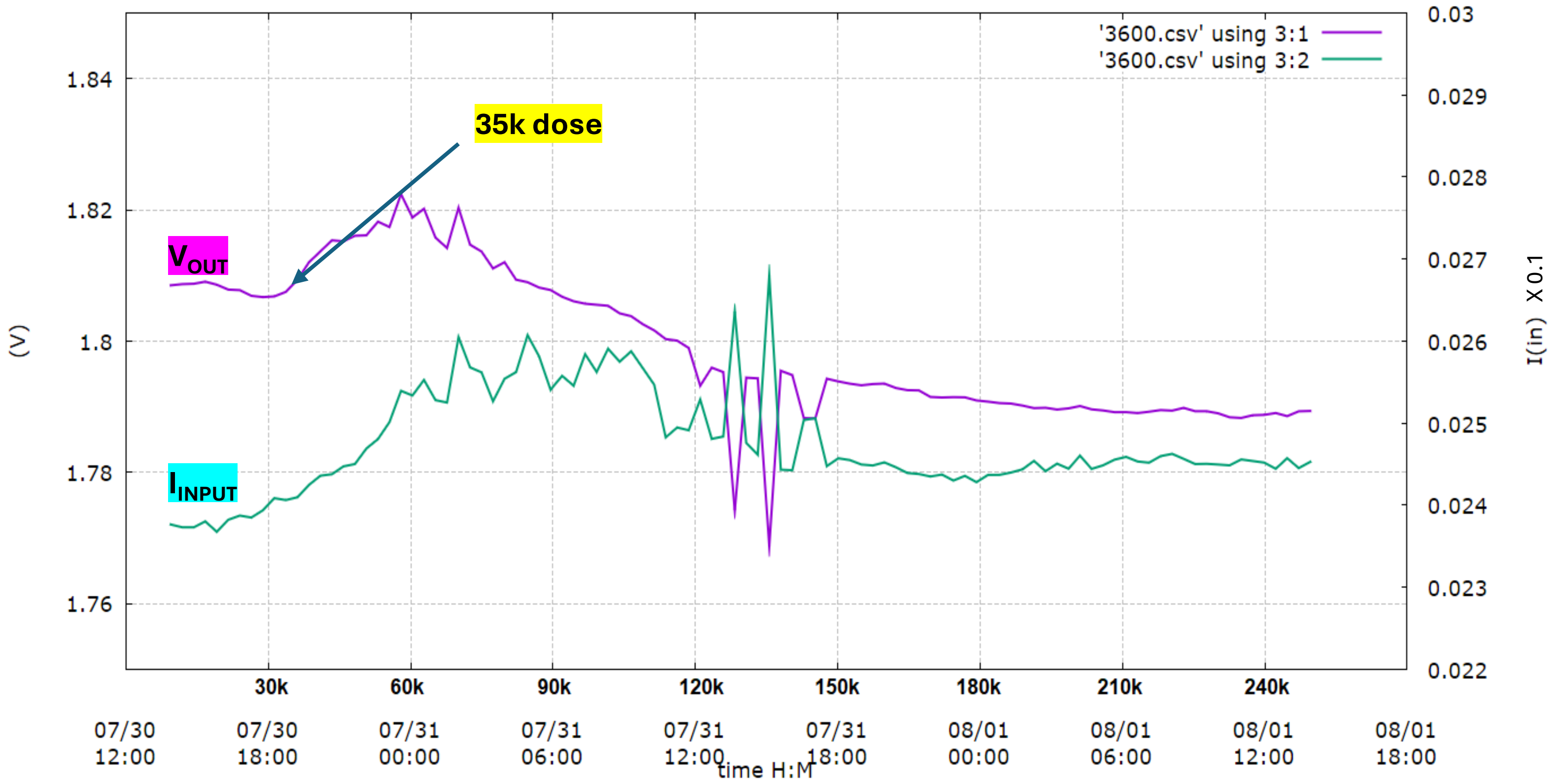


Source distant 6.0” (~5k rad/ hour)



Two devices are tested at a time with both receiving the same dose

DUT LT3600: 5k rad/hour dose over 48hr period
V_{OUT} & I_{IN} Vs time/ dose



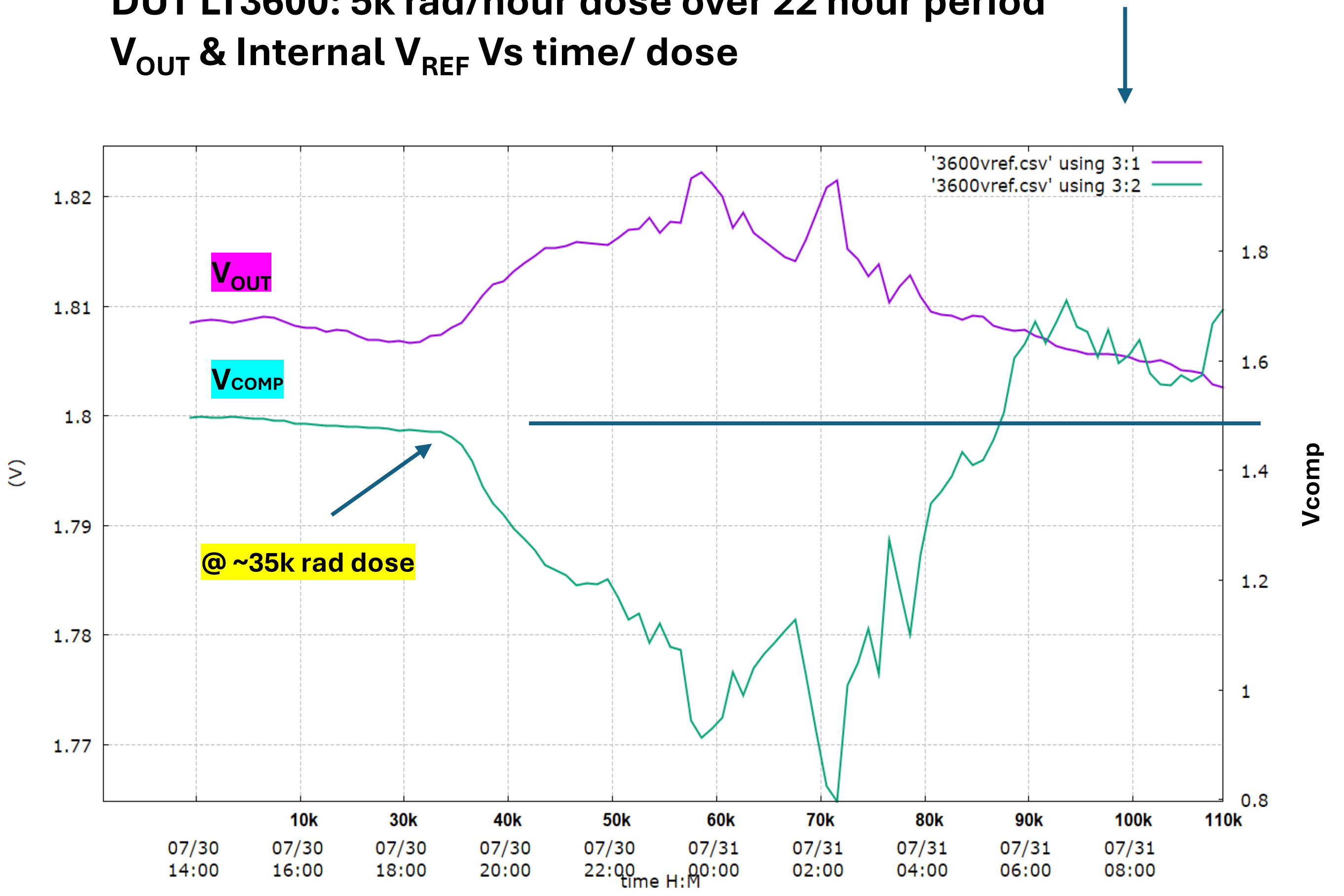
LT3600 DC:DC converter

- **1.5A Output Current**
- **Adjustable Frequency: 200kHz to 4MHz**
- **4V to 15V V_{IN} Range**

Bias Conditions:

V_{OUT} =	1.8V
I_{IN} =	190ma (logger adds +50mA)
I_{OUT} =	1.2A
P_{OUT} =	2.16W
V_{IN} =	14V
P_{IN} =	2.7W
P_{EFF} =	80%

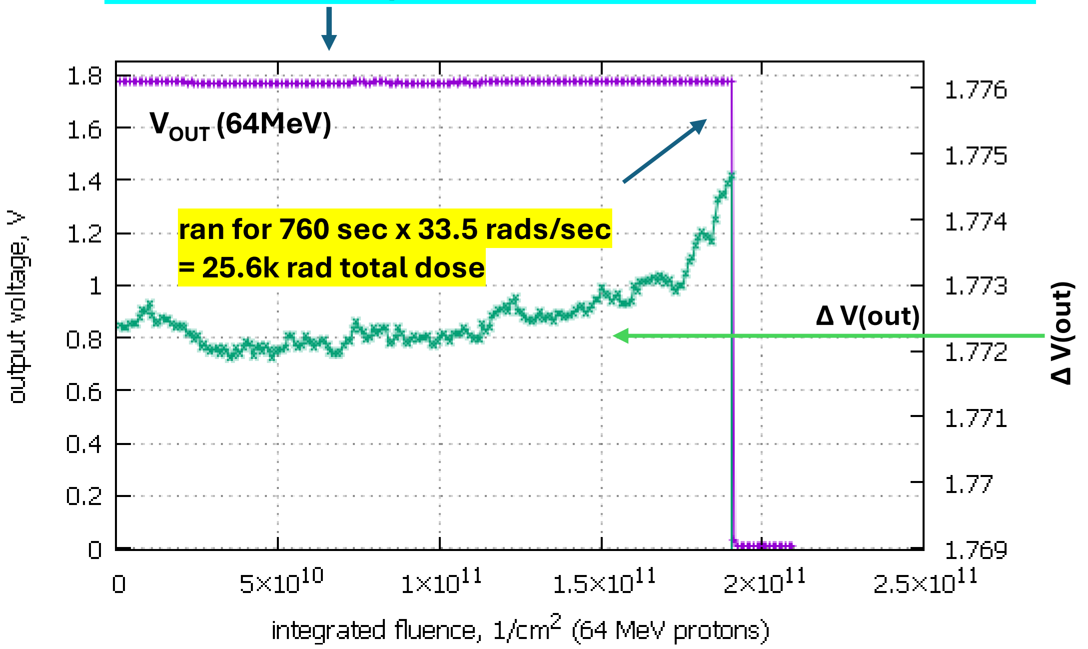
DUT LT3600: 5k rad/hour dose over 22 hour period
V_{OUT} & Internal V_{REF} Vs time/ dose

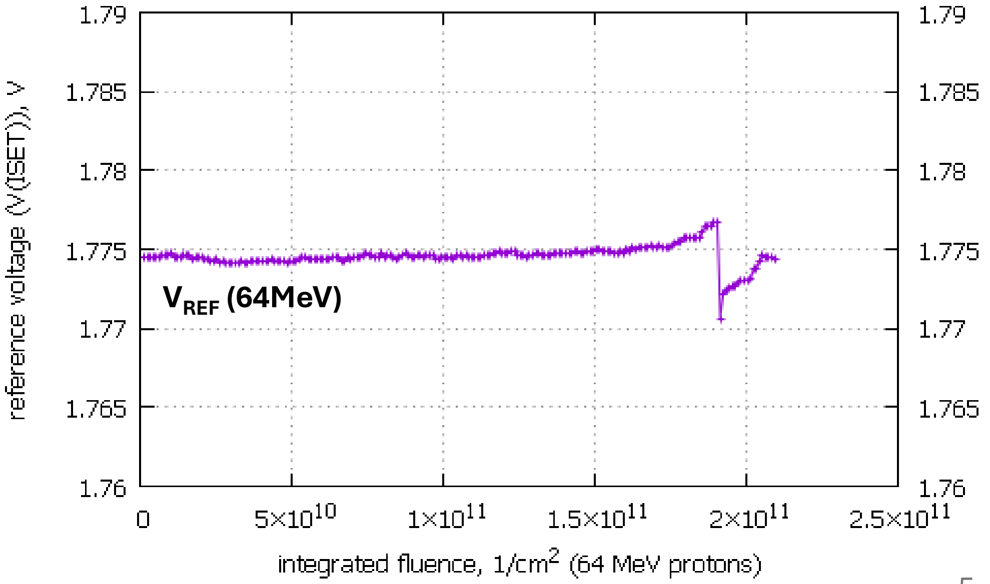


zoomed in on Vref fail LTC 3600 ~35k Rad dose

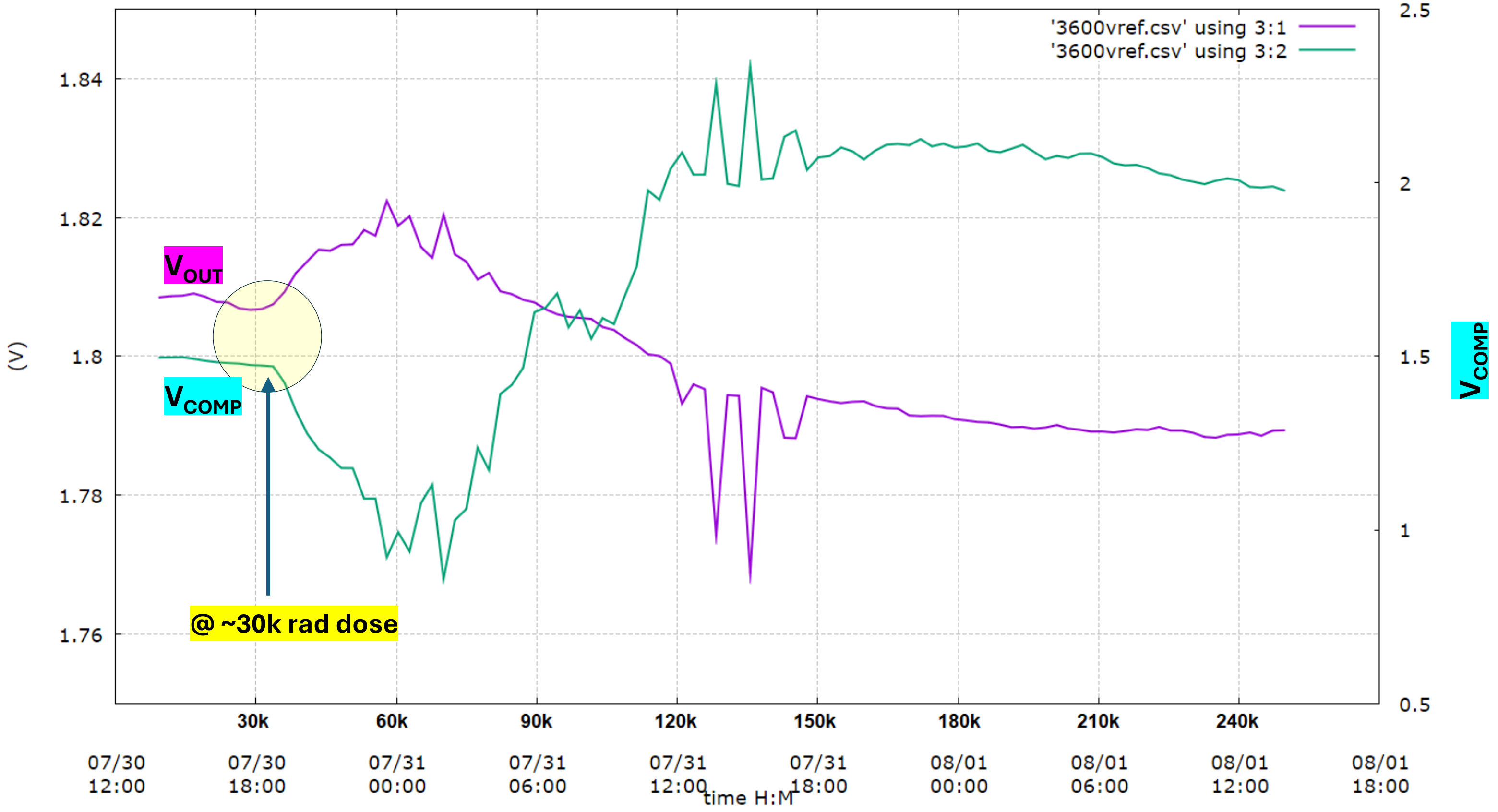
V_{COMP} = Compensation Amplifier

UC Davis 64MeV proton beam failed @ 12.8 min 26K TID



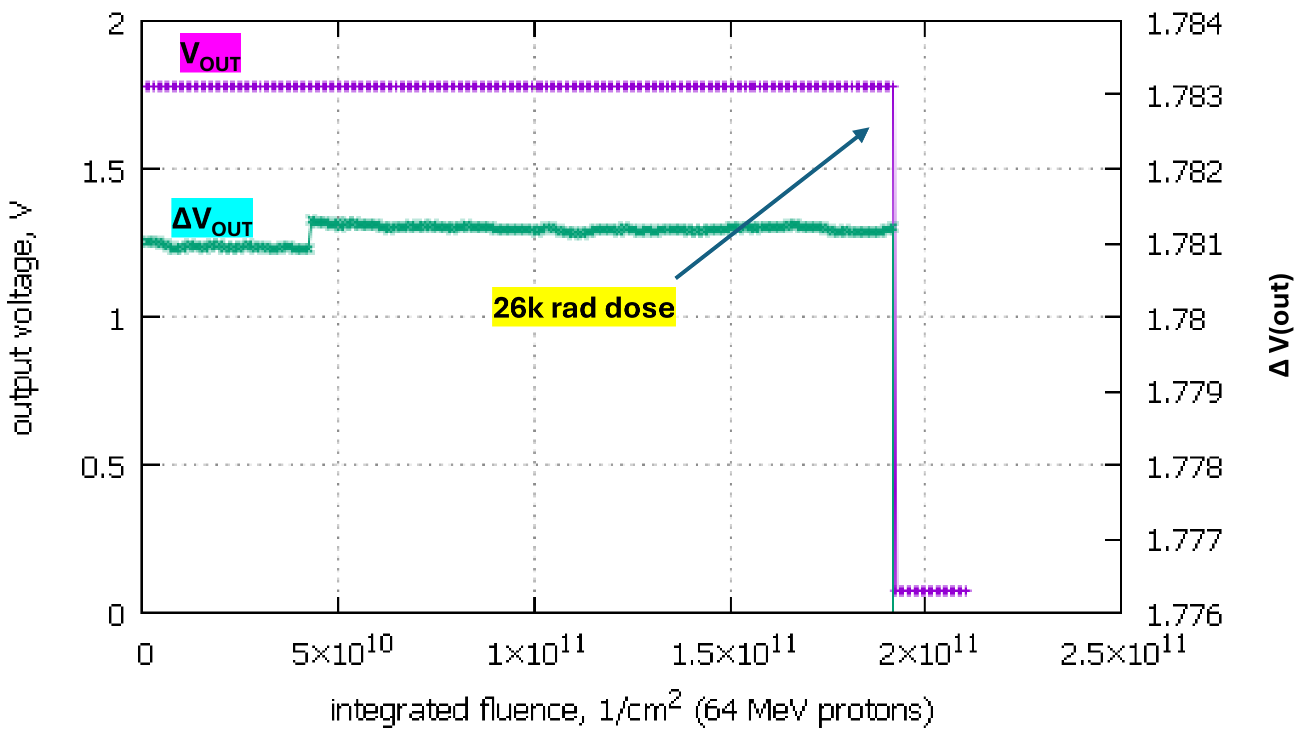


DUT LT3600: 5k rad/hour dose over 48 hour period
V_{OUT} & Internal V_{REF} Vs time/ dose

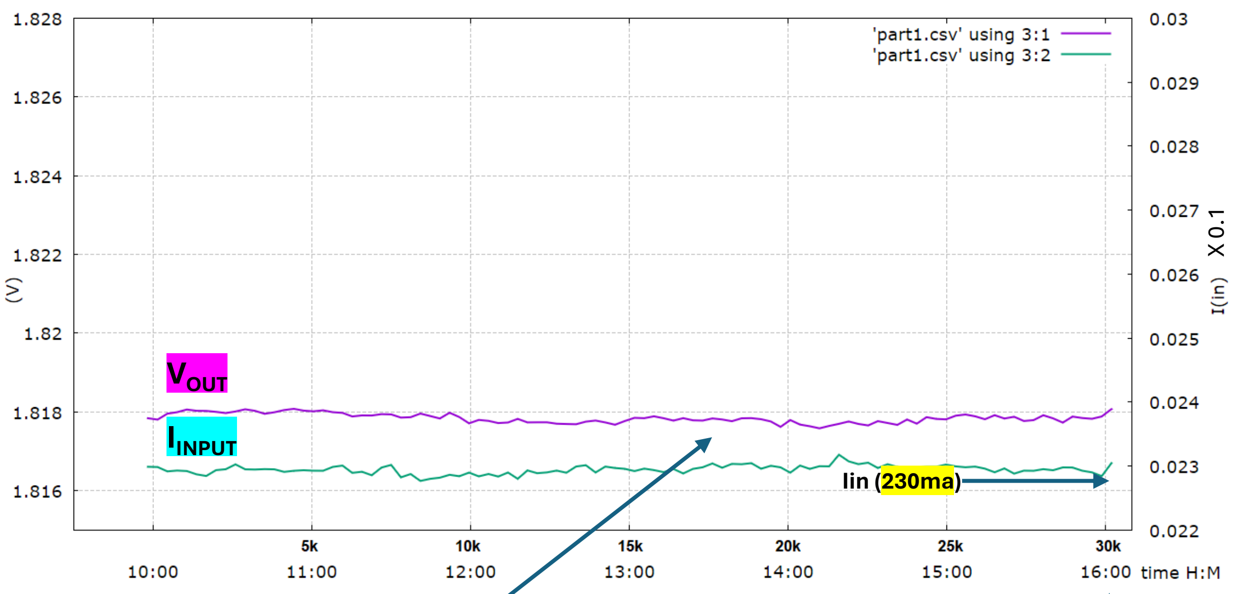


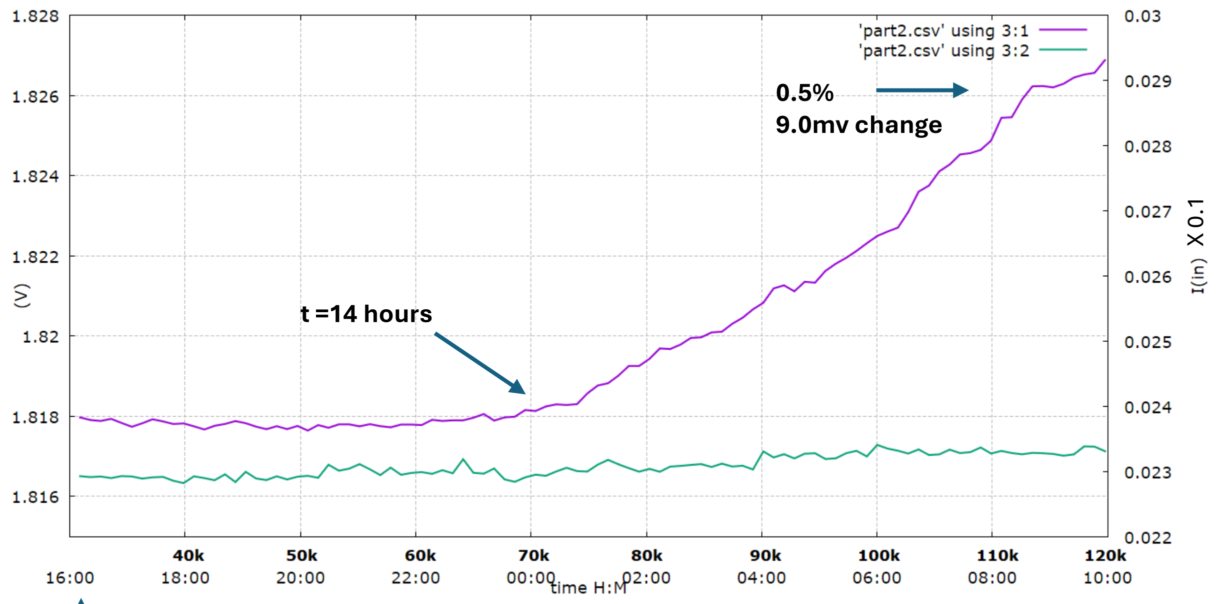
LTC3626 Irradiation Testing

64MeV proton, UC DAVIS May 2024, 120k rads / hour



LTC3626 V_{OUT} with I_{IN} (load 1.5A) over a 24hour period (120k TID)
V_{OUT} & I_{IN} Vs time/ dose





Very small change in V_{OUT} Vs I_{IN}

No loss in efficiency

Inadvertently turned of logger @ 4:00PM but quickly restarted hence the two separate plots

Bias Conditions:

V_{OUT} = 1.8V

I_{IN} = 180ma logger lower scale offset ~50mA => 230Ma

I_{OUT} = 1.2A

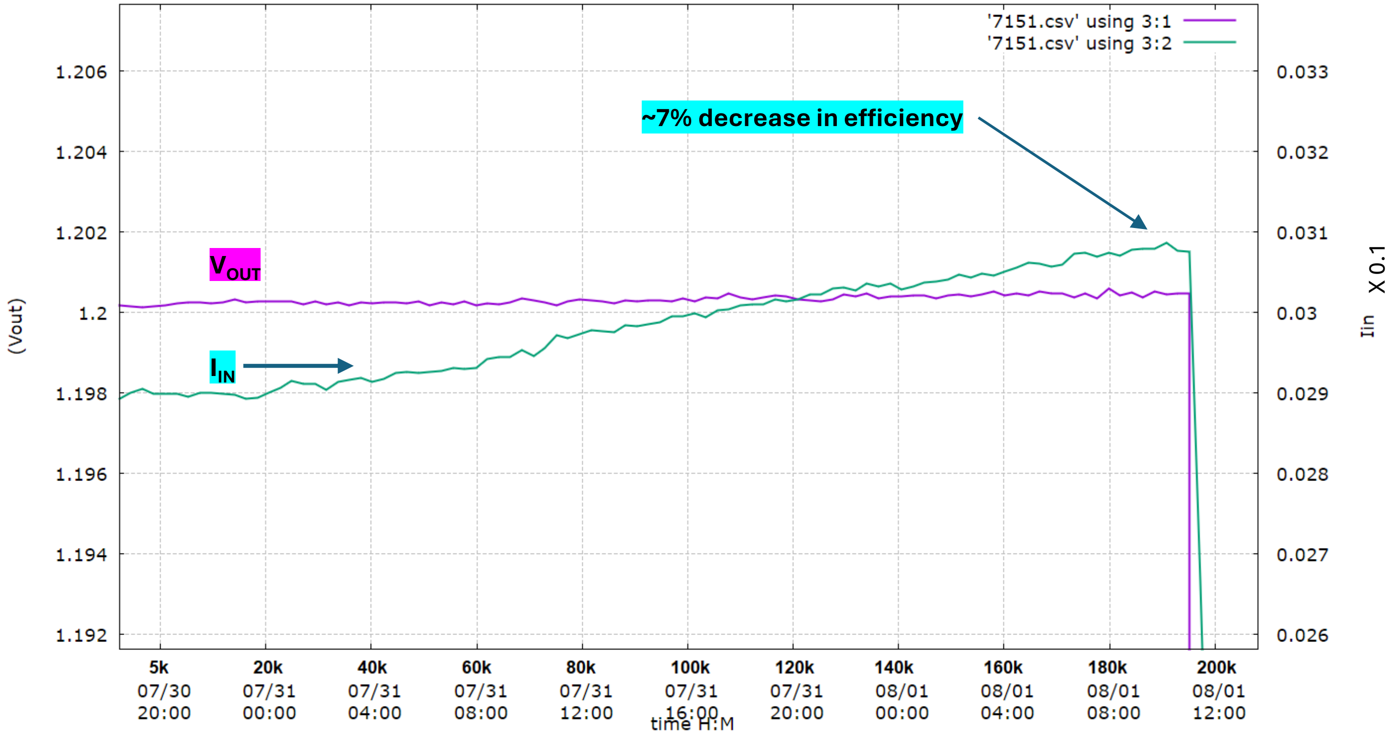
P_{OUT} = 2.16W

V_{IN} = 15V

P_{IN} = 2.7W

P_{EFF} = 80%

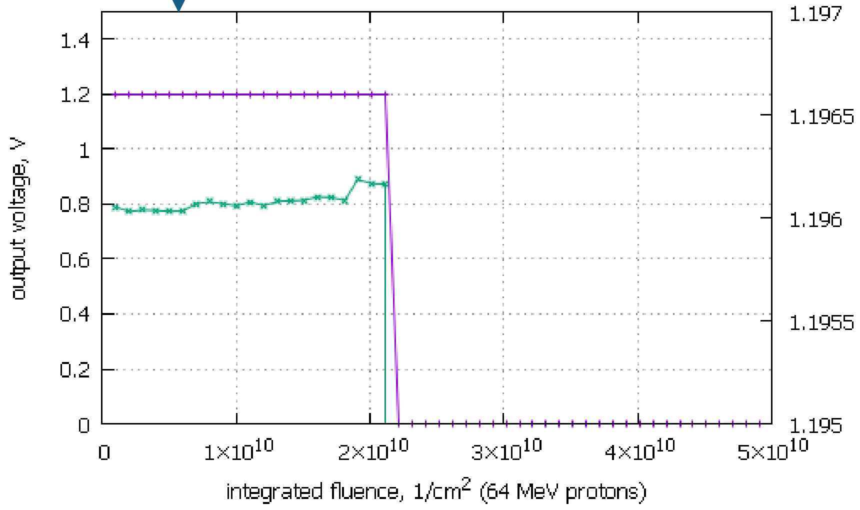
LTC7151 V_{OUT} with I_{IN} (load 1.8A) over a 40hour period (200k TID)
V_{OUT} & I_{IN} Vs time/ dose



After a TID of ~190K rad, the DUT Vout drops out to 0 Volts

The DUT was powered 48 hours later and Vout and original efficiency are recovered.

UC Davis 64MeV proton beam: DUT failed at 2.2E10 neutrons /cm² & 3k rad dose



Bias Conditions:

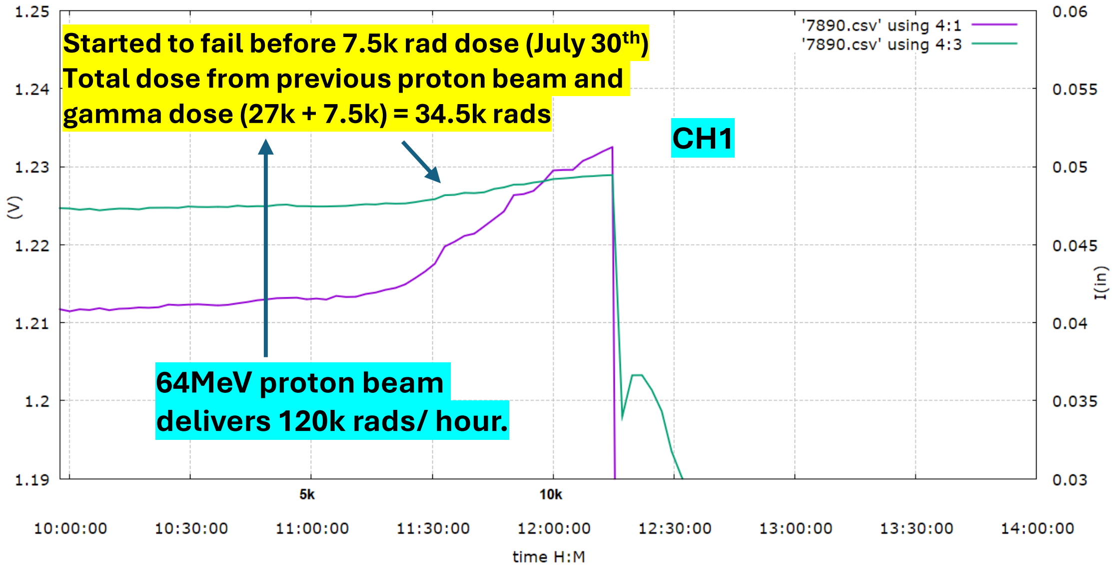
V_{OUT} =	1.2V
I_{IN} =	250ma logger lower scale offset ~40mA
I_{OUT} =	1.8A
P_{OUT} =	2.16W
V_{IN} =	12.0V
P_{IN} =	3.00W
P_{EFF} =	70%

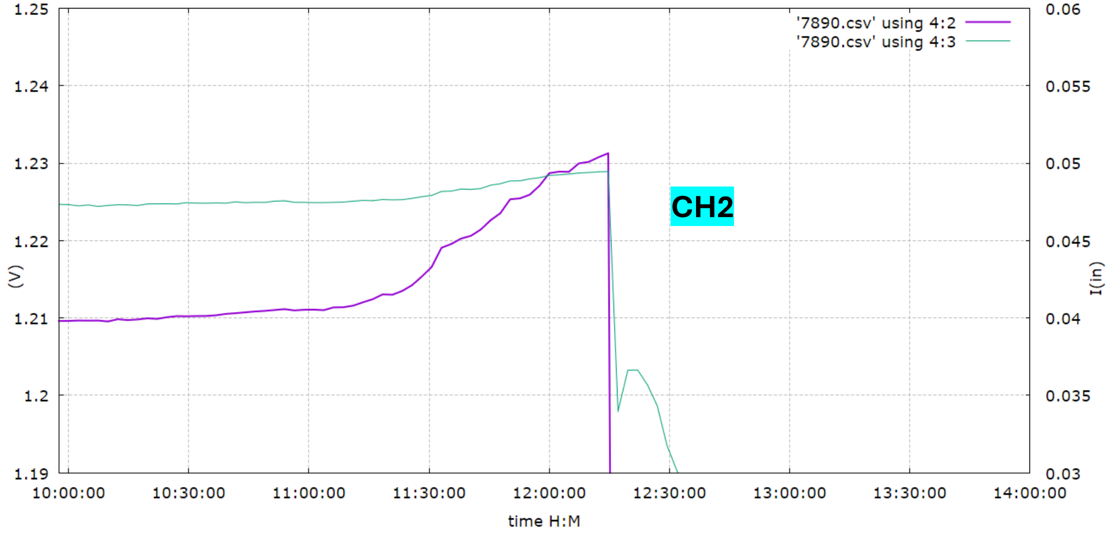
DUT: LTC7890 over a 24hour period (120k TID)
V_{OUT} & I_{IN} Vs time/ dose

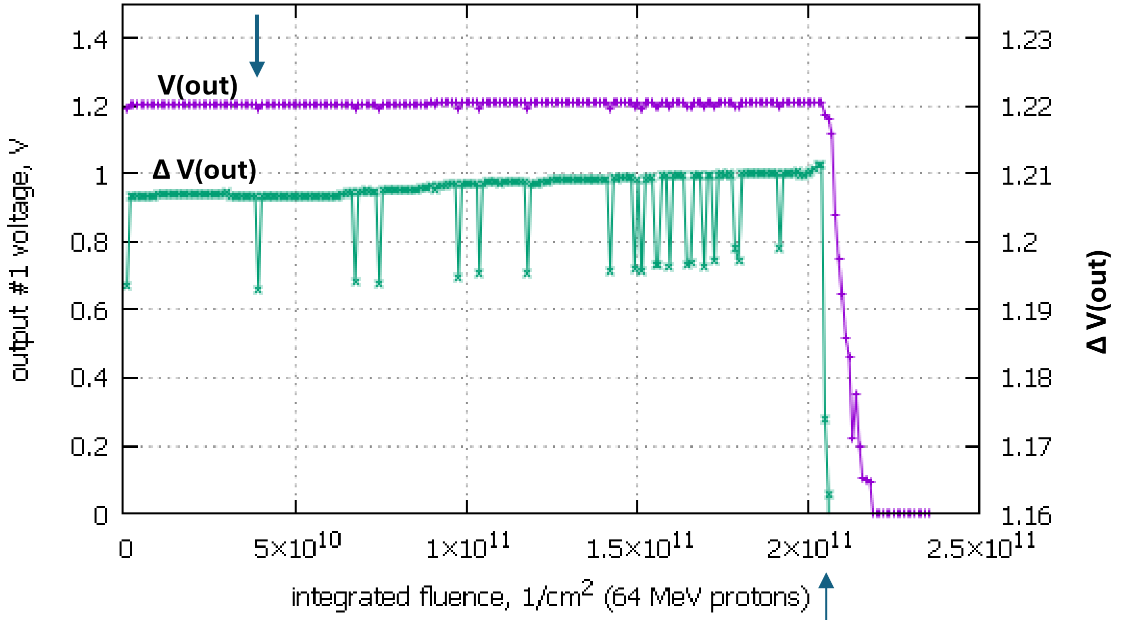
Same DUT from UC Davis 64MeV proton beam
DUT recovered after serval days
Before gamma facility test on July 30th, the DUT ran for 1 hour In lab with no measurable degradation

Started to fail before 7.5k rad dose (July 30th)
Total dose from previous proton beam and gamma dose (27k + 7.5k) = 34.5k rads

64MeV proton beam delivers 120k rads/ hour.







Ran for 806.5 sec * 33.5 rads/sec = 27k dose

Bias Conditions (DMM):

V_{OUT} =	1.2V
I_{IN} =	480ma
I_{OUT} =	2.0A / Ch
$P_{OUT\ ch1+ch2}$ =	4.8W
V_{IN} =	12.0V
P_{IN} =	5.82W
P_{EFF} =	82%
ΔP_{EFF} =	11%

The DUT was powered again 48 hours later. The output voltage is now ~ 1.23V => ~ 1.5% change.
Input current with $12V_{IN}$ increased to 600mA
Efficiency is now down to~73% => 9% change

Conclusions

LTC3600: Use at ePIC does not appear to be suitable

A different DUT was tested at UC Davis 64MeV proton beam in May 2024 (see slide# for beam conditions). The devices output failed at a fluence of 1.9E11 protons / cm^2 and an ionizing dose of ~26k rads. In that test the output dropped to 0 volts and the input current greatly increased. Several days later when the DUT was powered again, the input appears to be shorted.

A new DUT was tested in the gamma source @ 5k rads/ hour. The device seems to become unstable at 35k rad dose. Compared to the proton beam test the failure was not a complete dropout of Vout and shorted Vin. However, the failure of the DUT is evident by the steep change in internal V_{COMP}.

LTC3626: Device may be suitable for use at ePIC, pending our understanding of the dose rate effects & the displacement damage from the proton beam. Device failure under 64MeV proton beam may have been due to the higher dose rate of 120k rad/ hour Vs the gamma source 5k rad/ hour.

Device should be tested at Neutron facility.

A different DUT was tested at UC Davis 64MeV proton beam in May 2024 (see slide# for beam conditions). The devices output failed at a fluence of 1.9E11 neutrons / cm^2 and an ionizing dose of ~26k rads. In that test the output dropped to 0 volts and the input current greatly increased. Several days later when the DUT was powered again, the input appears to be shorted.

For the ionized rad exposure, the DUT showed no significant variation until Vout started to change after a 70k dose. From 70k rads to the end of the 24 hour test at 120k rads, V_{OUT} *changed only ~9.0mV with no significant change in efficiency.*

LTC7151: Devices failure under 64MeV proton beam may have been due to the higher dose rate of 120k rad/ hour Vs the gamma source 5k rad/ hour.

Device should be tested at Neutron facility.

A different DUT was tested at UC Davis 64MeV proton beam in May 2024 (see slide# for beam conditions). The devices output failed at a fluence of 2.2E10 neutrons / cm^2 and an ionizing dose of ~3.0k rads. In that test the output dropped to 0 volts and the input current greatly increased. Several days later when the DUT was powered again, the input appears to be shorted.

For the ionized radiation exposure, the V_{OUT} remained stable with no measurable change up to ~190k rads. At 190k rad the devices output dropped to 0 volts and I_{IN} dropped to 0 Amps. At ~ 40k rads, the input current started to increase. From 40k rads to 190k rads. I_{IN} increased from ~290mA to ~310mA (efficiency dropped to 67% from 72%) . After 48 hours the same DUT was powered and V_{OUT} is restored, and efficiency is ~70%.

LTC7890: Device may be suitable for use at ePIC pending our understanding of the dose rate effects.

Device should be tested at Neutron facility.

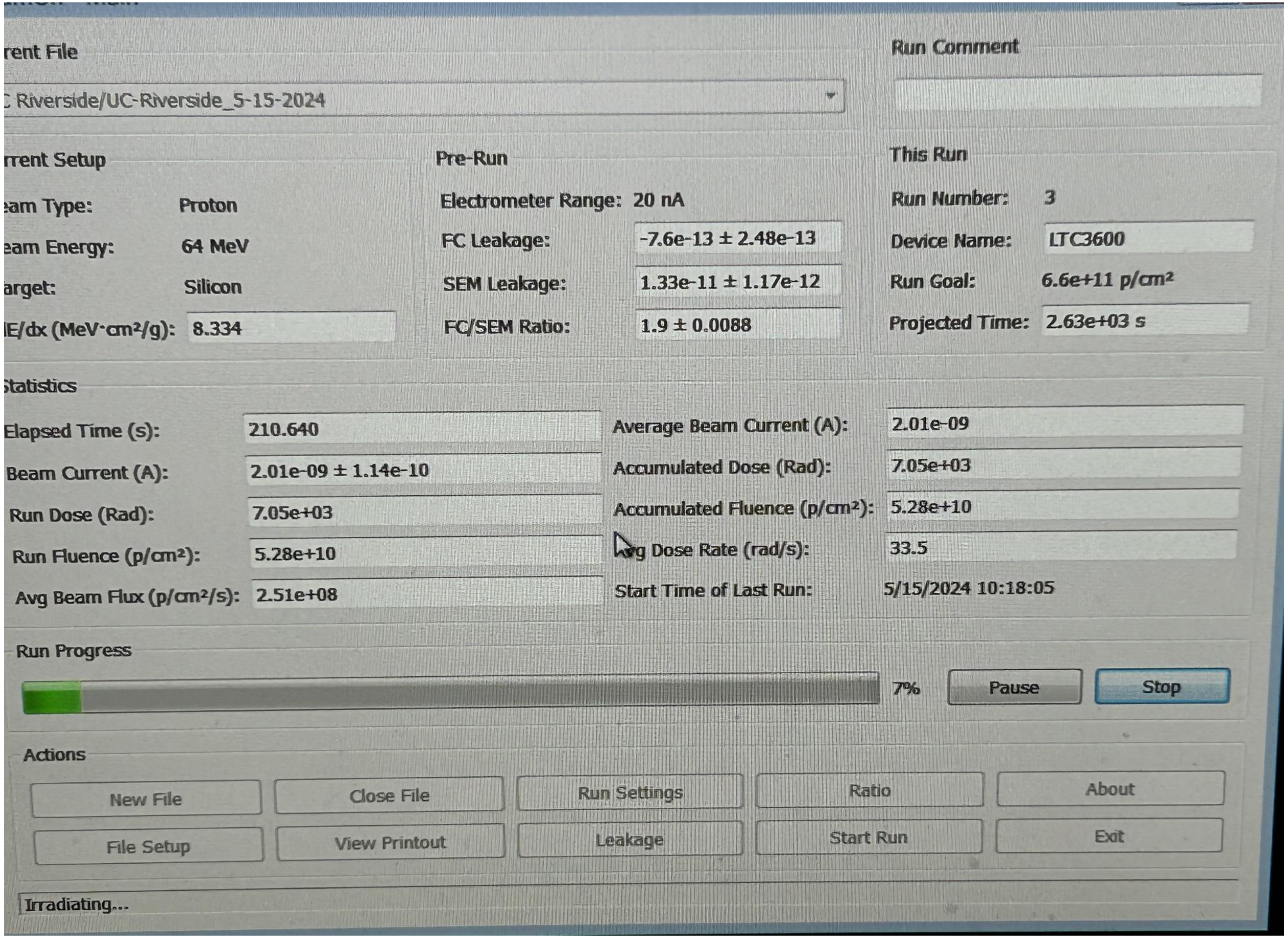
The same DUT was previously exposed in May 2024 at UC Davis 64MeV proton beam with a flux of 2.48E8 protons / CM^2 (120k rads/ hour).

The DUT failed (Vout dropped to 0) at a fluence of ~2.0E11 p/ cm^2 and a dose of ~27k rads.

After several days, the device was powered and Vout was recovered (~1.2V and efficiency was back to normal > %80).

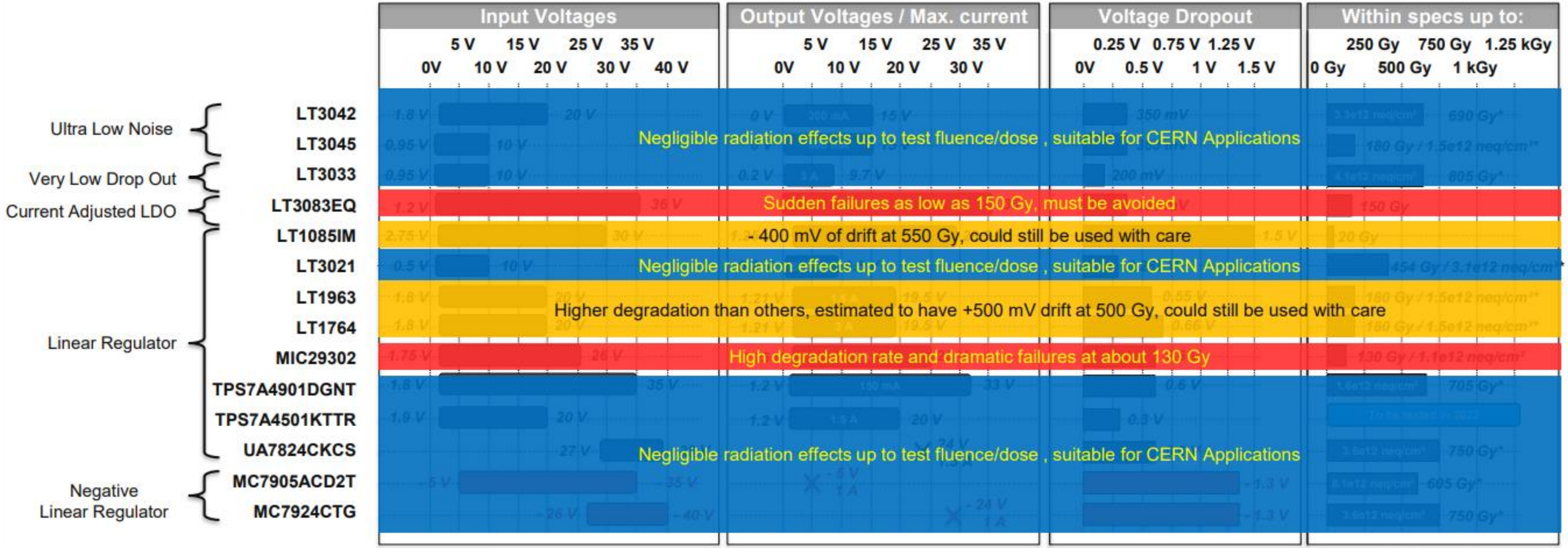
During the July 30th gamma test, Vout dropped to 0 volts after ~ 7.5k rad dose (total dose from proton beam was ~ 34.5 k rads).

Efficiency decreased from 82% to 73%.


rent File
Run Comment
C Riverside/UC-Riverside_5-15-2024
rrent Setup
Pre-Run
This Run
eam Type: Proton
eam Energy: 64 MeV
arget: Silicon
lE/dx (MeV·cm²/g): 8.334
Electrometer Range: 20 nA
FC Leakage: -7.6e-13 ± 2.48e-13
SEM Leakage: 1.33e-11 ± 1.17e-12
FC/SEM Ratio: 1.9 ± 0.0088
Run Number: 3
Device Name: LTC3600
Run Goal: 6.6e+11 p/cm²
Projected Time: 2.63e+03 s
Statistics
Elapsed Time (s): 210.640
Beam Current (A): 2.01e-09 ± 1.14e-10
Run Dose (Rad): 7.05e+03
Run Fluence (p/cm²): 5.28e+10
Avg Beam Flux (p/cm²/s): 2.51e+08
Average Beam Current (A): 2.01e-09
Accumulated Dose (Rad): 7.05e+03
Accumulated Fluence (p/cm²): 5.28e+10
vg Dose Rate (rad/s): 33.5
Start Time of Last Run: 5/15/2024 10:18:05
Run Progress
7%
Pause
Stop
Actions
New File
Close File
Run Settings
Ratio
About
File Setup
View Printout
Leakage
Start Run
Exit
Irradiating...

Overview of Radiation-Tolerant Voltage Regulators

➢ **Are presented only the devices tested in representative LHC radiation environments (i.e. CHARM)**



Fixed Value X
Acceptable Range *min* ■ *max*

** = stayed within manufacturer specifications when specified or within 1% of degradation up to the end of the test*