Radiation Hardening Electronics for Use in NIF

CEA-NNSA Joint Diagnostic Meeting

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June 30th, 2016

LLNL-PRES-XXXXXX

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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Rad hard diagnostic applications underway now

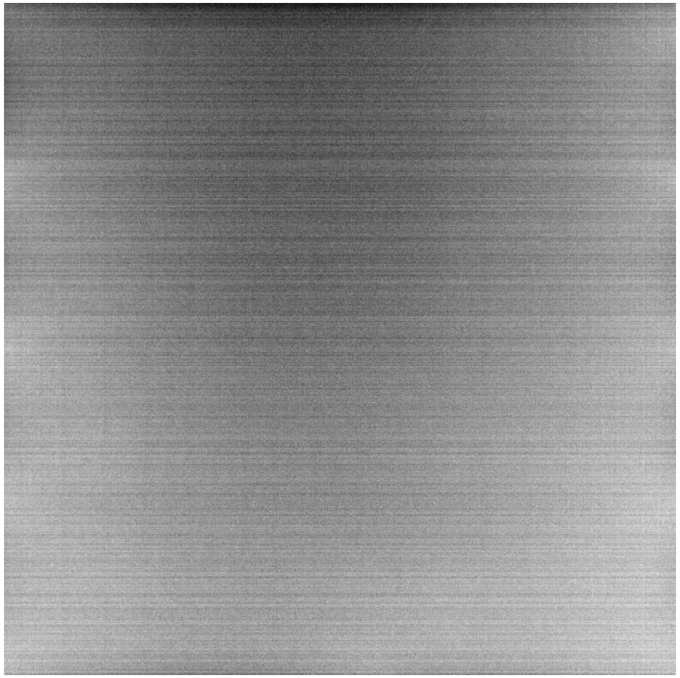
- Rad Hard SI-1050 Camera (aka Dump and Read)
- Real Time NAD
- Rad Hard DISC
- Rad Hard SLOS

Outline

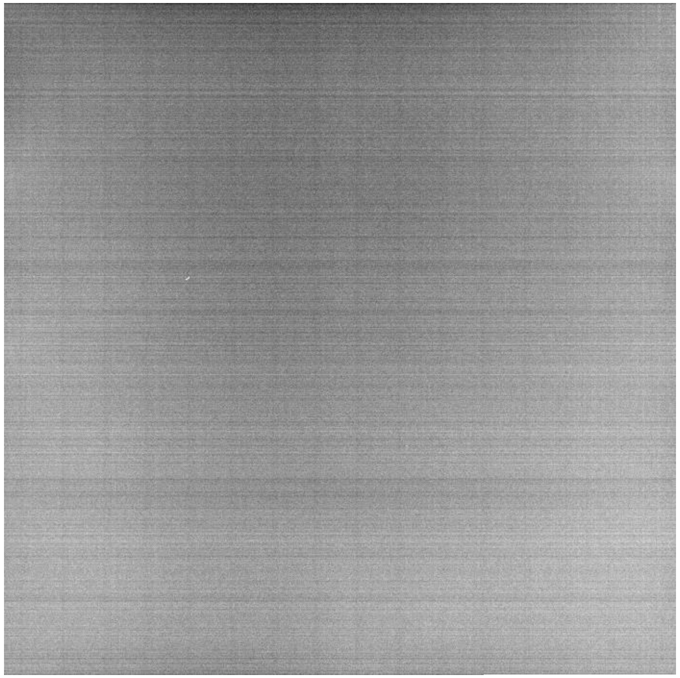
- Results from the SI-1050 Dump and Read Camera
- What are your requirements:
  - Total neutron yield?
  - Distance from TCC and location?
  - When will it be active?
- Simulations and Calculations
- System design, components level
- Electrical Test Plan
- Rad Testing Facilities
- Build it, field it, and learn

1050 Camera before and after 3e10 n/cm^2

- Preimage mean 222 StdDev 13.6 max 322 min 84



- Post image mean 267 StdDev 6.6 max 1310 min 49

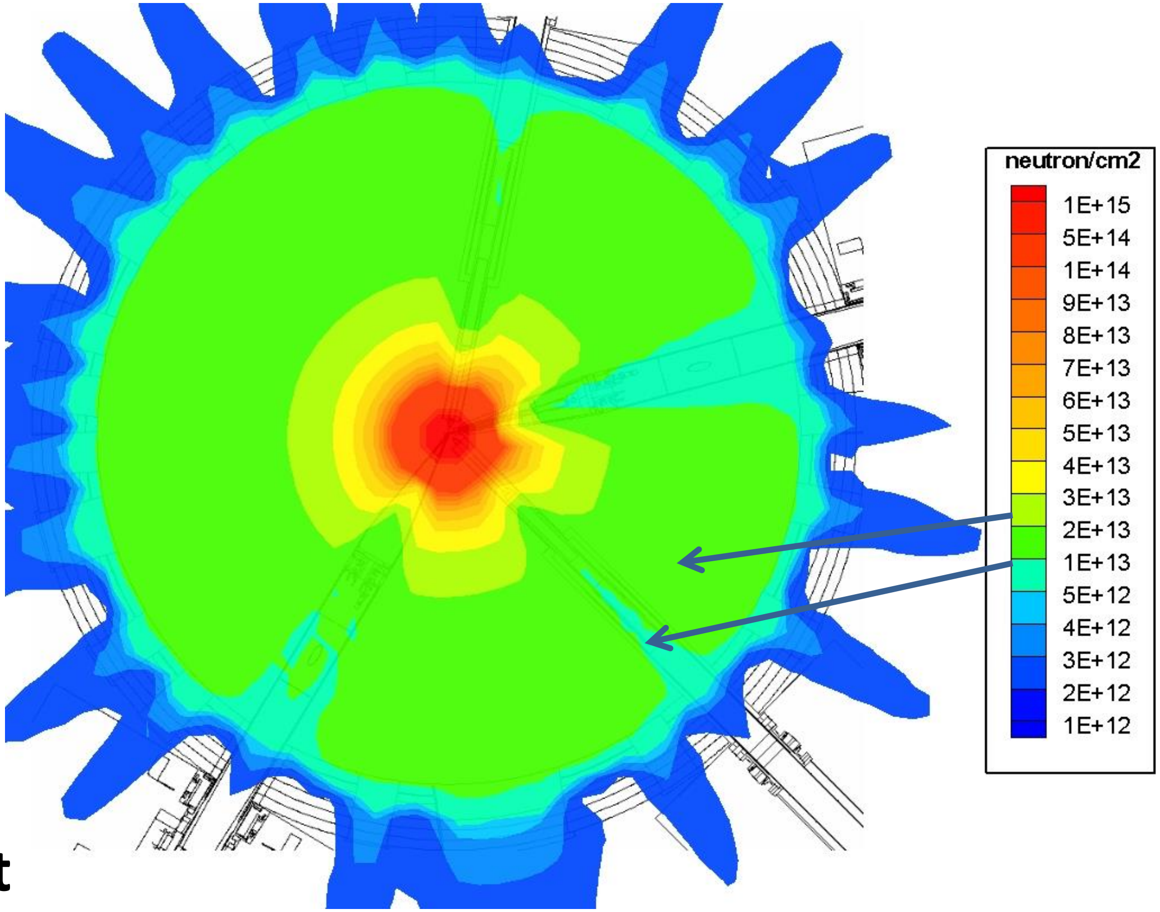


Neutron track

Determine neutron fluence:

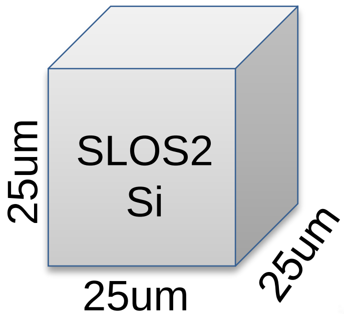
Target Bay neutron fluence map at equator

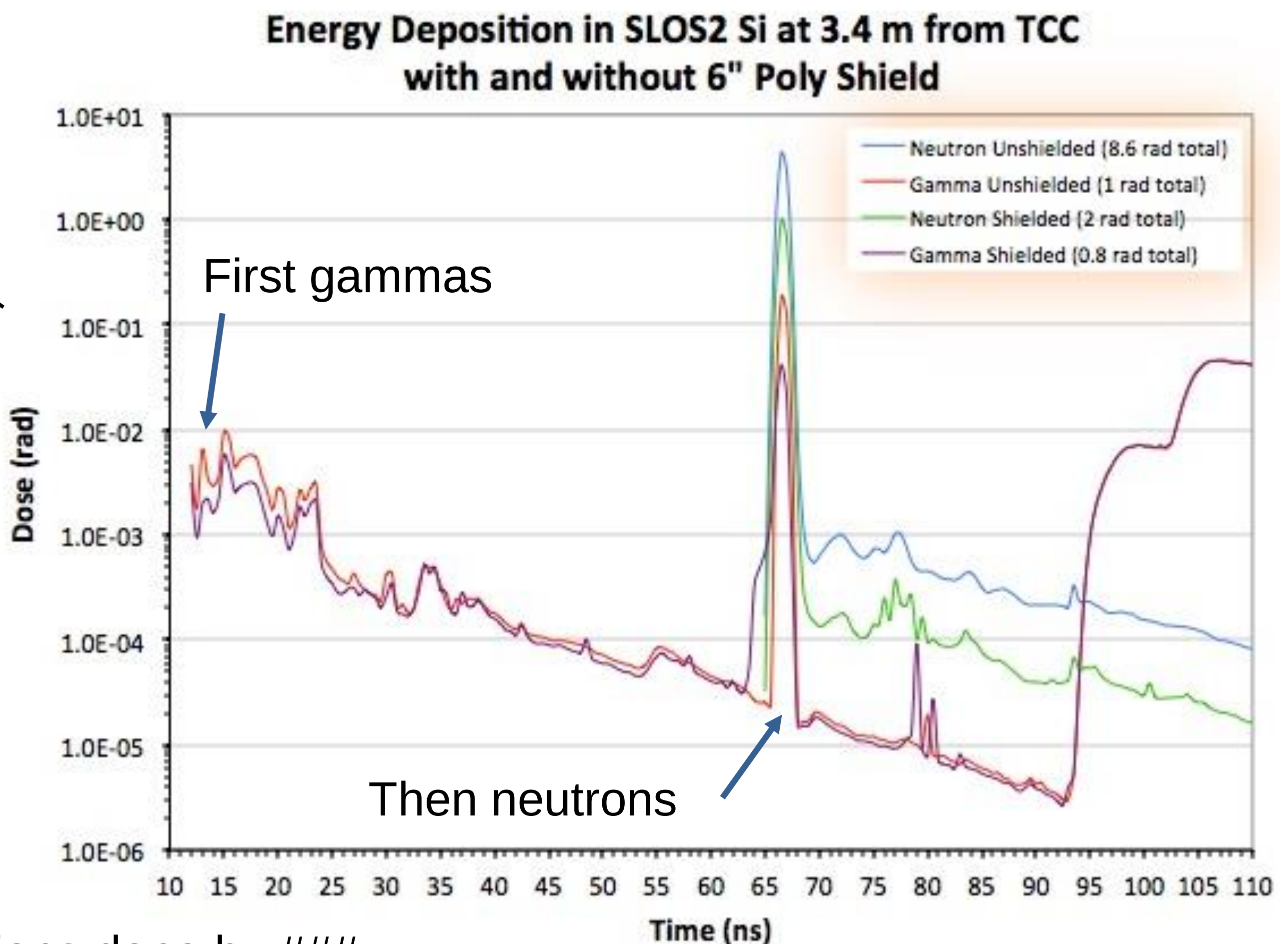
- Assuming some DIM self shielding: Yn=1e16 neutron fluence:
  - **~1.4e10 n/cm²**
  - **~10 Rad-SI @14MeV**
- Assuming no DIM self shielding: Yn=1e16 neutron fluence:
  - **~4.2e10 n/cm²**
  - **~40 Rad-SI @14MeV**
- **COTS Electronics fail at this fluence**



Map shows Yn = 7.1e18 ie 20MJ Shot

Simulations:
Rad dose time history of 25um cube of Si on DIM Axis



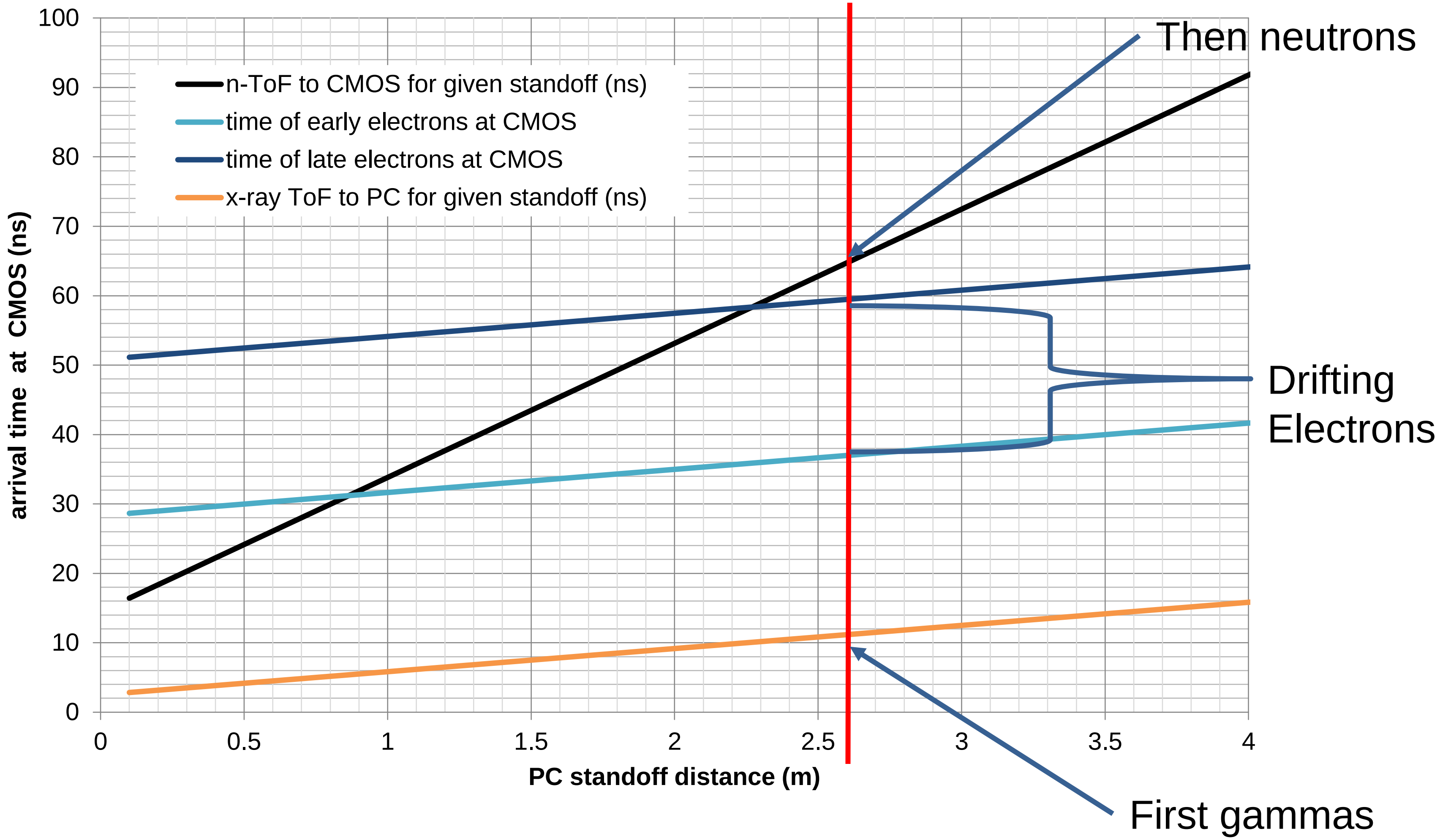


*MCMP Calculations done by ###

Calculations:

- Neutron Cross-section Method: This method uses the probability of an interaction and an assumed average energy deposited.
- Kerma Method: This is an imperially derived value of average energy absorption for a given material from a given radiation source at a given energy (statistical variations are not included)
- Both yield similar results, these are in imaging applications to determine degradation of image due to neutron interactions
- Niko Izumi and Sabrina Nagel are great resources

SLOS Drift Electron vs. Neutron Arrival Time



Evaluate your design

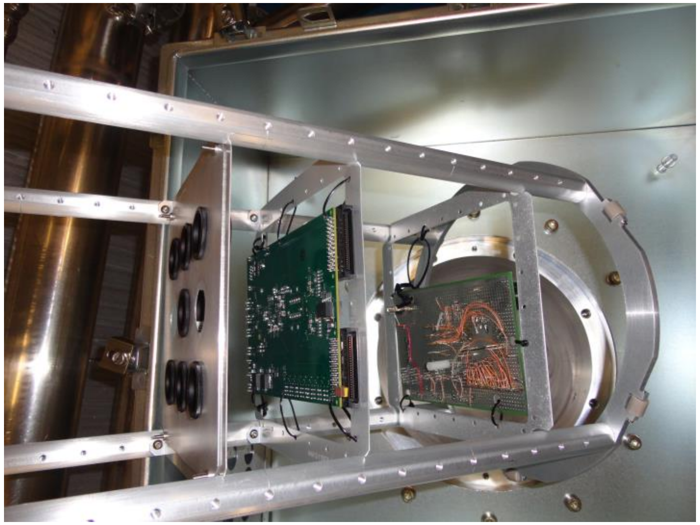
Component	Vendor	Part Number	RH Equivalent Part	Test plan
FPGA	Actel (Microsemi)	A3PE3000-FGG484	**Yes**	**Neutron testing**
SRAM	**Cypress**	**CY7C1470BV33-167AXI**	**No, but similar**	**Neutron testing**
Digital POT	**AD**	**AD5161BRMZ**	**No, use DAC**	**tbd**
Oscillator	ECS	ECS-3953M-400-BN-TR	**No, but similar**	**Neutron testing**
ADC	**TI**	**ADS8568**	**No**	**tbd**
ADC Driver	AD	ADA4896	**No, but similar**	**Neutron testing**
CH Link TX	TI	DS90CR287	**No, not needed**	**NA**
Diff TX/RX	TI	DS8921	**No, but similar**	**Neutron testing**
Diff TX/RX	TI	DS8922	**No, but similar**	**Neutron testing**
V-References	LT	LTC6655BHMS8−1.25#PBF	**No, but similar**	**Neutron testing**
+3.3V Power	National Semi	LM1086IS-3.3/NOPB	**No, but similar**	**Neutron testing**
+1.5V Power	National Semi	LMS1587CS-1.5/NOPB	**No, but similar**	**Neutron testing**
+5V Power	National Semi	LM1086IS-5.0/NOPB	**No, but similar**	**Neutron testing**
GigE	Orang Tree	ZestETM1	**No, not needed**	**Full testing**
+5V Power	LT	LT3042IMSE#PBF	**No, but similar**	**Neutron testing**
-5V Inverter	LT	LTC3261	**No, not needed**	**NA**
+/-5V ADC/Driver	LT	LT3032EDE−5#PBF	**No, not needed**	**NA**

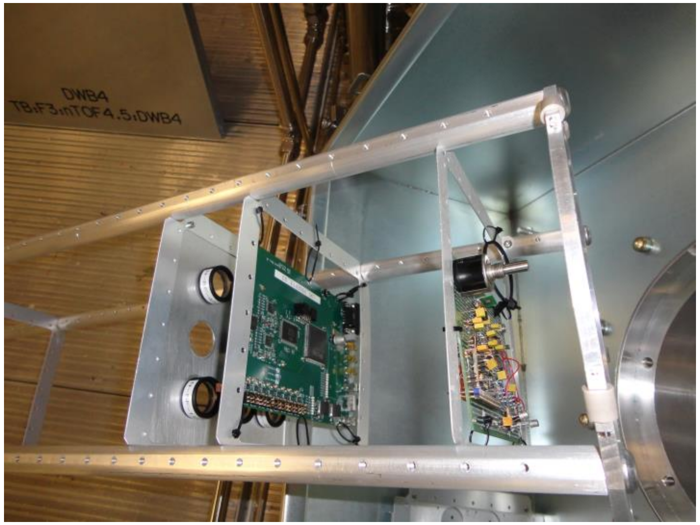
Rad Test Facilities

- NIF Test locations with 1e16 yield shot:
  - Test well, Ken Piston @4.5m, **3.9e9 n/cm²**
  - DIM Box , Dana Hargrove or Ben Hatch @1.5m, **3.5e10 n/cm²**
  - Snout NED, Charles Yeamans and Fred Allen @0.1m, **7.9e12 n/cm²**
- Cobham Rad (formally Aeroflex Rad Solutions)
  - Neutron source
  - Gamma Source
  - Flash X-ray Source
  - Proton Source
  - Other sources
  - UK office
- LBL Cyclotron
  - Broadband source peaking ~10MeV (Charles Yeamans)

Neutron Test Well 4.5m

- 4.5m from TCC in old nTOF well
- No cables at this time
- August upgrade adds, scopes, DGs, power, etc from mezz



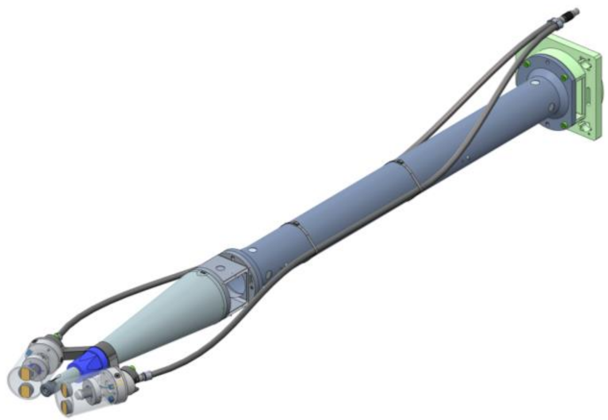


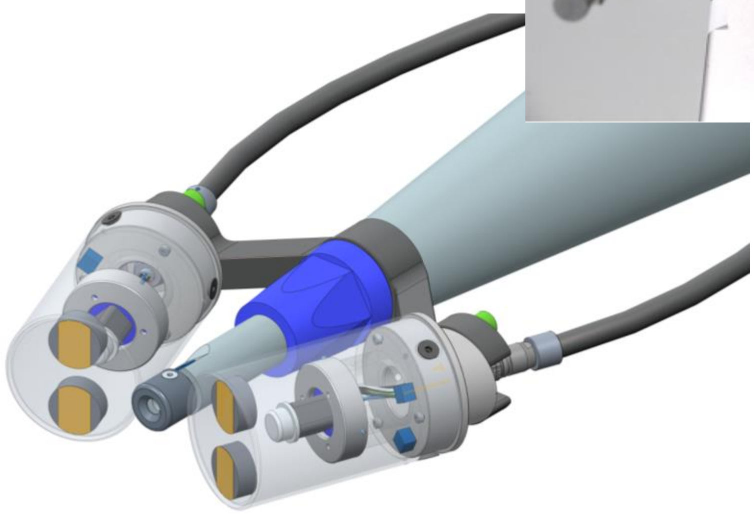
F1050 Camera Test Box

- 1.5m to 2m from TCC on back of DIM
- Similar in size to a 4ω fidu box
- Has cables to run a SI1050 camera
  - Optical Camera Trigger
  - OTxRx
  - 6 twisted pair
  - Water Lines

Neutron Effects Diagnostic

- 2x Twisted Pair Cable





Test Plan for SLOS

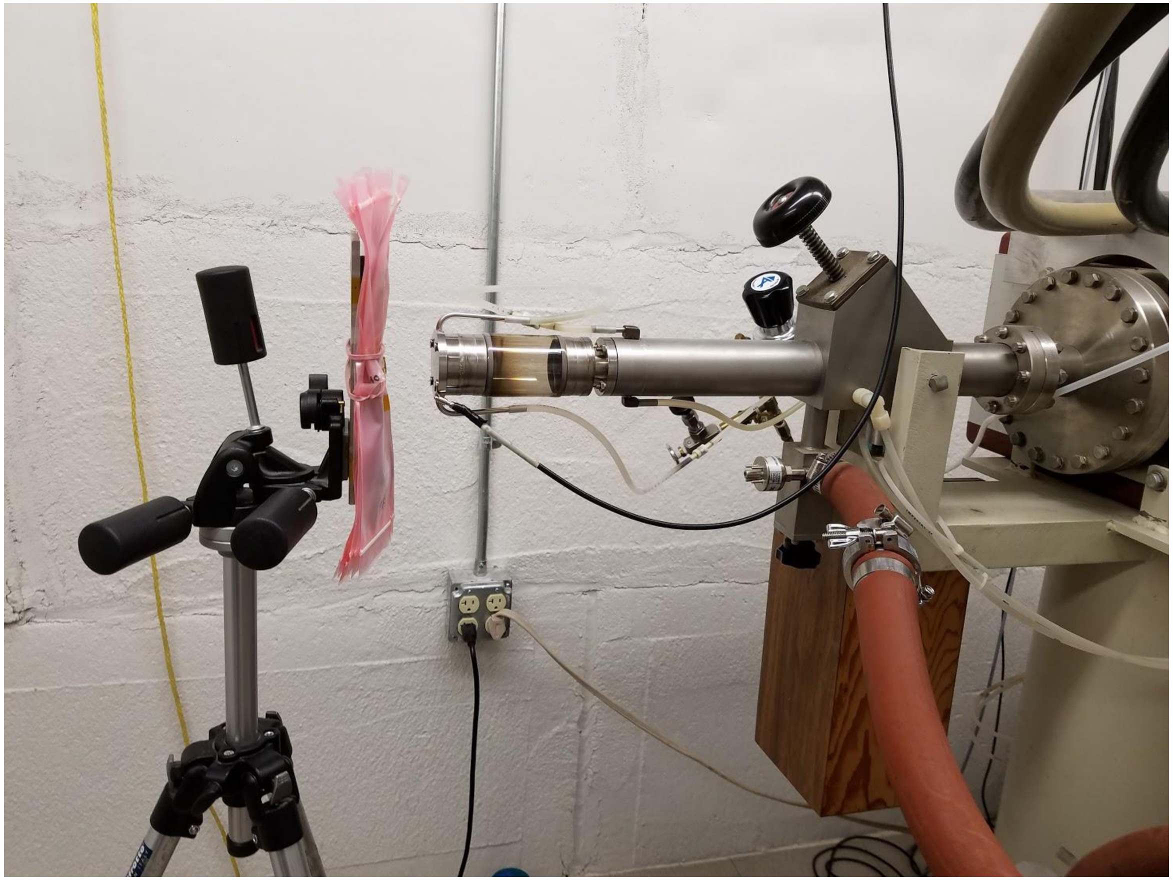
Name	Manufacturer	Part number	Test 2	Test 1	Optional Tests	Power On
RT FPGA	Microsemi	RT3PE3000L-CG484PROTO	1. Program FPGA with test code (see step 4) 2. Radiate 3. Read back FPGA program and compare. 4. Biderectional loopback of all available fpga pins. That is, in software assign half the pins as tx and half as rx. Run test pattern and check. Then reverse direction.	Monitor Current Before and After (test at 50kRad and 100kRad)		On
SRAM	Cypress	CYC7C1470BV33-16AXI	Read in and read out a test pattern and look for errors	Monitor Current Before and After		Off
ADC Driver	Analog Devices	ADA4896	measure offset	Monitor Current Before and After	GBP	Off
ADC	Texas Instruments	ADS8568	Read 3 known DAC input using internal and external voltage references	Monitor Current Before and After	INL, DNL, full voltage sweep	On, hold in "shut down"
Digital Pot	Analog Devices	AD5161BRMZ	shift in resistance values (3 values)	Monitor Current Before and After	all 255 desired	Off
Oscillator	ECS inc	ECS-3953M-400-BN-TR	drift, frequency change	Monitor Current Before and After		ON
Optical TX/	Avago	HFBR-0400Z	optical out amplitude change, rise time, jitter, delay,	Monitor Current Before and After		Off
GigE	Orange Tree	ZestETMI	tx/rx a signal, loop back	Monitor Current Before and After		Off
Differential TX/RX	Texas Instruments	DS8922	tx/rx a signal, loop back	Monitor Current Before and After		Off
Voltage Reference	Linear Technology	LTC6655BHMS8-1.25#PBF	stability, change	Monitor Current Before and After		On, hold in "not enable"
ADC	Maxim	MAX1304	Read 3 known DAC input using internal and external voltage references	Monitor Current Before and After	only perform test 2 if ADS8568 failes test 2	On, hold in "shut down"
Gig TX/RX	Texas Instruments	TLK 2501	tx/rx a signal, loop back	Monitor Current Before and After		Off
Opt TX/RX	Avago	HFBR-0542Z.	optical out amplitude change, rise time, jitter, delay, using ≥1GHz scope	Monitor Current Before and After	loop back test, ≥6GHz, DG645 trigge is fine	Off
Opt TX/RX	Avago	HFBR-0416Z	optical out amplitude change, rise time, jitter, delay, using ≥1GHz scope	Monitor Current Before and After	loop back test, ≥6GHz, DG645 trigge is fine	Off

Layout Test Boards

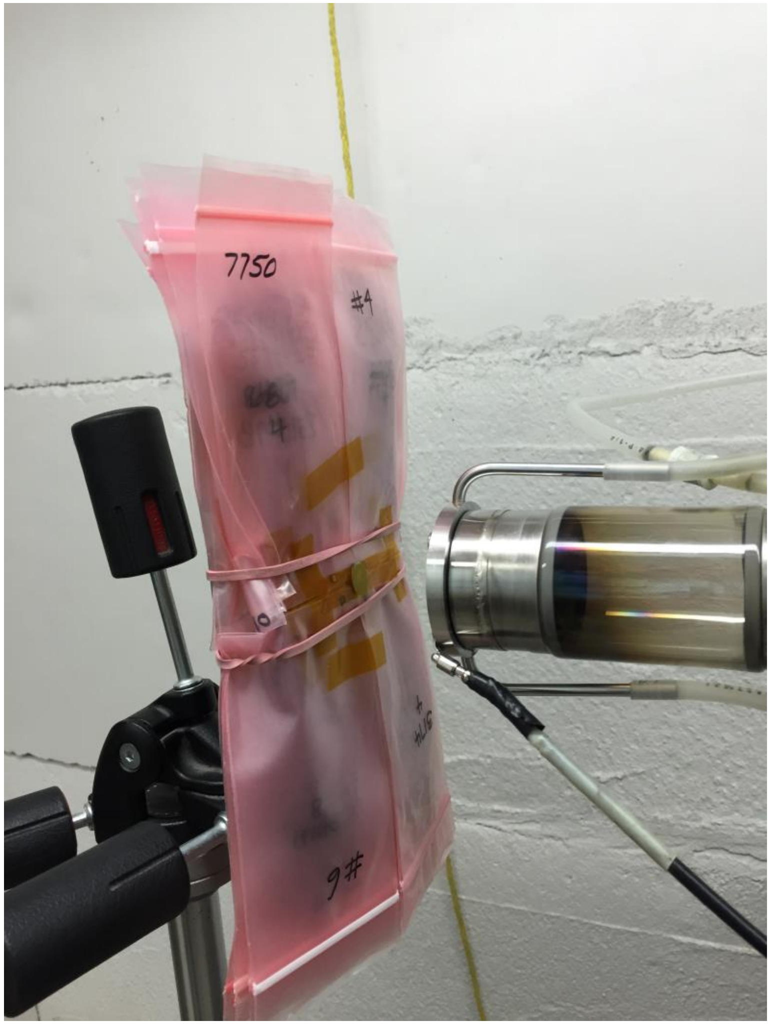
- Design Test System
- Cobham can do this if desired
- Can take entire system to facility

14 MeV Neutron Source

- 2x10^11 n/s (14 MeV) into 4pi



Neutron Yield (D-T) 2x10^11 n/s (14 MeV) into 4 pi



Total Integrated Dose (TID) Testing Co60
50 to 300 rads/sec

- Photon Energy 1.17 and 1.33 MeV

Preliminary Results from Cobham Testing

- Preliminary Results from testing at Cobham are encouraging
- Neutron testing is still underway

Name	Manufacturer	Part number	Co60 100kRad-SI	Co60 120kRad-SI	Neutron Test	Neutron Flux
RT FPGA	Microsemi	RT3PE3000L-CG484PROTO	All, Failed	All, Failed	Passed	1.91E+11
SRAM	Cypress	CYC7C1470BV33-16AXI	Passed	Passed		
ADC Driver	Analog Devices	ADA4896	Passed	Passed	Passed	
ADC	Texas Instruments	ADS8568	Passed	Passed		
Digital Pot	Analog Devices	AD5161BRMZ	2500->2450	2500->2460		
Oscillator	ECS inc	ECS-3953M-400-BN-TR	Passed	Passed	Passed	
Optical TX/	Avago	HFBR-0400Z	Passed	Passed		
GigE	Orange Tree	ZestETMI	Passed	Passed	Passed	
Differential TX/RX	Texas Instruments	DS8922	Passed	Passed	Passed	
Voltage Reference	Linear Technology	LTC6655BHMS8-1.25#PBF	Failed	Failed		
Voltage Reference	Linear Technology	LTC6655BHMS8-1.25#PBF	Passed	Passed	Passed	
ADC	Maxim	MAX1304	Passed	Passed		
Gig TX/RX	Texas Instruments	TLK 2501	Passed	Passed		
Opt TX/RX	Avago	HFBR-0542Z.	Passed	Passed	Passed	
Opt TX/RX	Avago	HFBR-0416Z	Passed	Passed	Passed	

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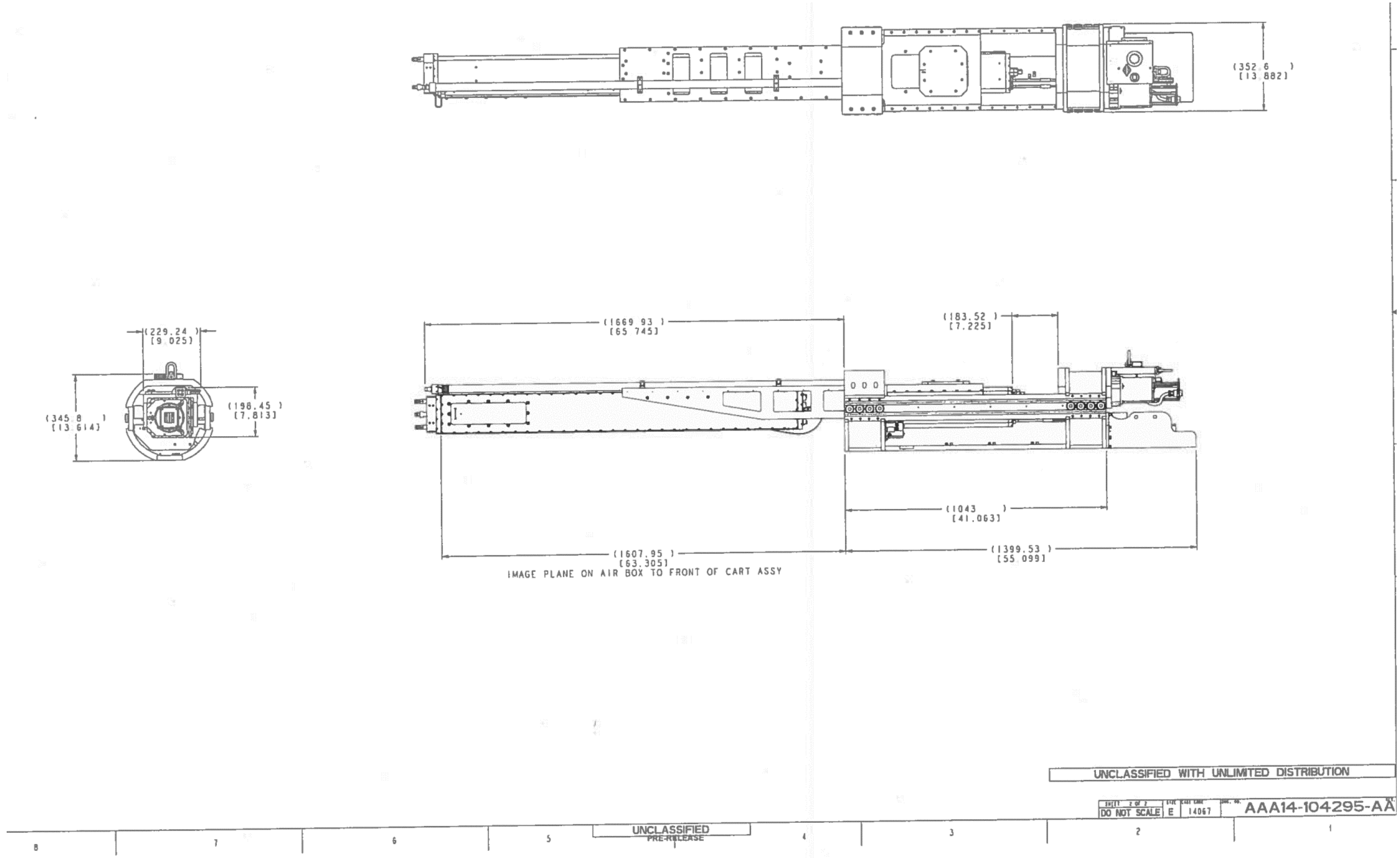
Backup Slides

Rad Hard Component Vendors

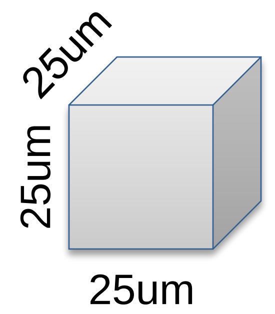
Company	Web Site
Linear	http://www.linear.com/products/Space_Qualified_Products
Intersil	http://www.intersil.com/en/parametricsearch.html?g=space-and-harsh-environment&sg=rad-hard-analog&f=rh-interface#g=space-and-harsh-environment&sg=rad-hard-analog
Aeroflex	http://ams.aeroflex.com/pagesfamily/fams-hirel.cfm
TI	http://www.ti.com/lsds/ti/high-reliability/space/overview.page
ST	http://www.st.com/web/en/catalog/sense_power/FM137/CL1945
Microsemi	http://www.microsemi.com/product-directory/high-reliability/3239-radiation-hardened-devices
Honeywell	http://www51.honeywell.com/aero/common/documents/myaerospacecatalog-documents/Space/Rad_hard_Microelectronics_Products_and_Services.pdf
Maxwell	http://www.maxwell.com/products/microelectronics
AD	http://www.analog.com/en/products/application-specific/militaryaerospace/aerospace.html
Atmel	http://www.atmel.com/products/rad-hard/default.aspx

F1050 Camera box mounted behind an HGXD

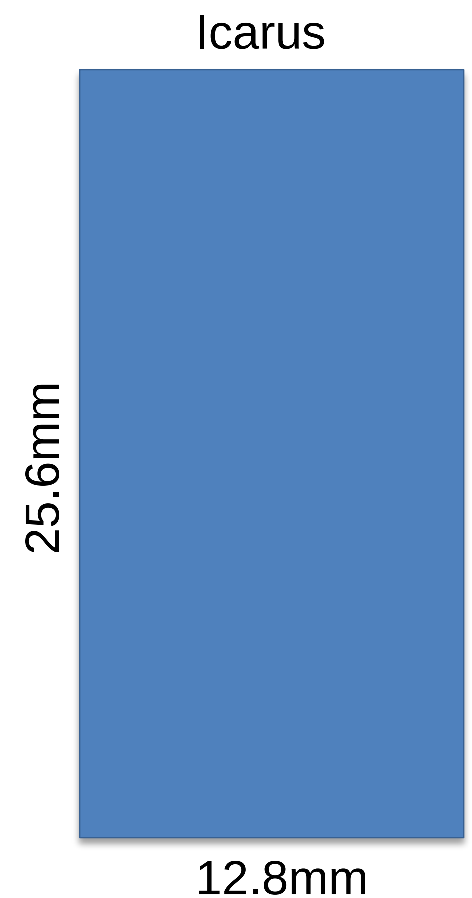


SLOS1-LLE: CDR Action Item
SLOS Neutron Pixel Flux and Charge

- Pixel/Sensor Properties:
  - Material: Si
  - Array Size: 1024x512 pixels
  - Pitch: 25um (25umx25um)
  - Thickness: 25um (fully depleted)



- Constants Used in Calculations:
  - Kerma_Si: 1.28 fGy * m^2
  - Si Density: 2.34 gm/cm^3
  - Si Atomic Density: 5e22 (cm^{-3})
  - Si Neutron Cross section: 1.8 Barn
  - Average energy per interacting neutron: 2MeV
  - Electron hole pair production (3.65eV)
  - Joules to eV conversion: 1.602e-19



Calculation Method 1: Neutron Cross section

- Probability of Neutron Interaction in a pixel:
  - (n/pix)*(Si Atomic density)*(neutron cross section)*(L of depletion region)
- Average Charge Generated in a pixel:
  - (probability of detection)*(average energy of interacting neutron)/(electron hole pair creation energy)
- Note: When an interaction does occur the charge collected in the pixel from any other source cannot be determined

Total Neutron Yield: 4e13

TCC-PC (m)	TCC-hCMOS (m)	Neutron flux (cm^{-2})	Probability of Neutron Interaction	Charge generated (e-)
2	2.8	4.2E+07	0.0571	3.128E+4
2.5	3.3	3.0E+07	0.0411	2.252E+4
3	3.8	2.3E+07	0.0310	1.697E+4

Calculation Method 2: Kerma

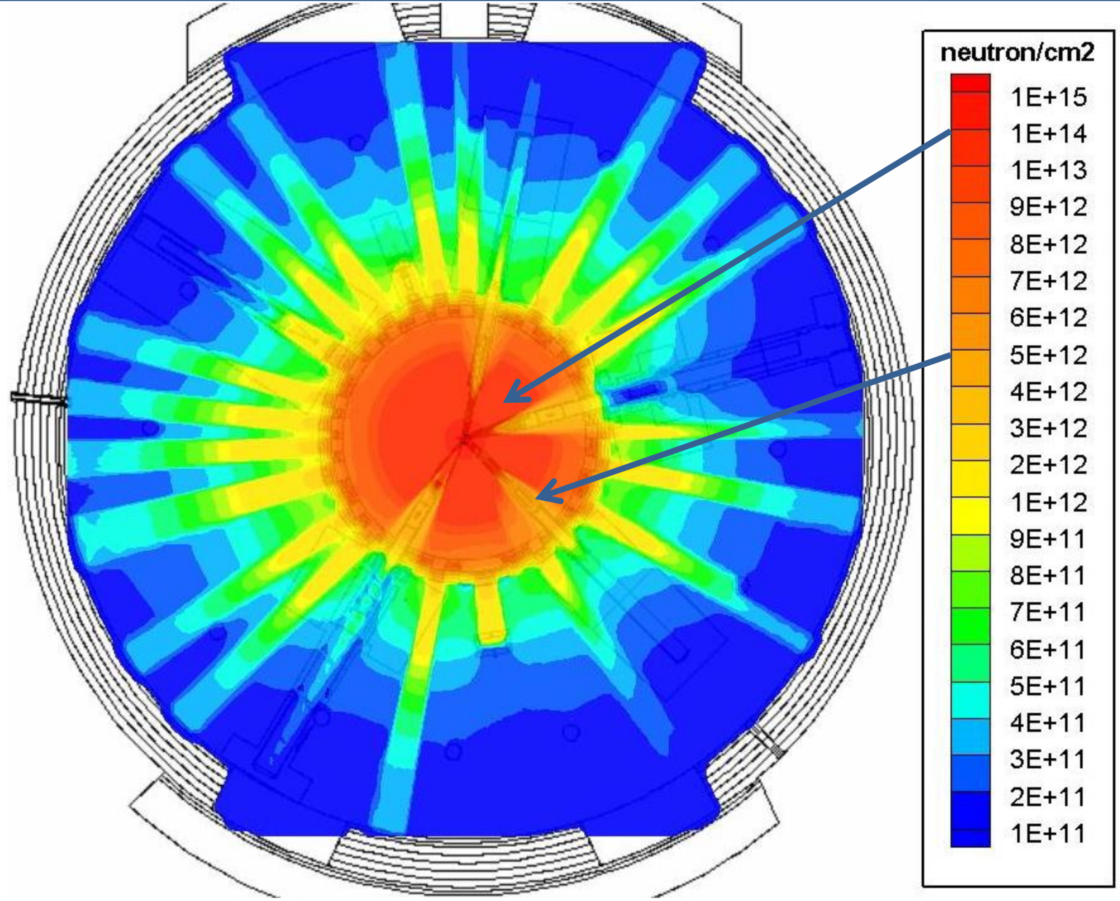
- Energy Absorbed in pixel from 14.1 MeV neutron:
  - (n/pix)*(kerma for Si)*(Si density)*(L of depletion region)
- Average Charge Generated in a pixel:
  - (probability of detection)*(average energy of interacting neutron)/(electron hole pair creation energy)
- Note: Kerma is an imperially derived value of average energy absorption (statistical variations are not included)

Total Neutron Yield: 4e13

TCC-PC (m)	TCC-hCMOS (m)	Neutron flux (cm^{-2})	Average Energy Absorbed (J)	Charge generated (e-)
2	2.8	4.2E+07	1.900E-14	3.249E+04
2.5	3.3	3.0E+07	1.368E-14	2.339E+04
3	3.8	2.3E+07	1.032E-14	1.764E+04

Determine neutron fluence: Target Bay neutron fluence map at equator

- Assuming some DIM self shielding: Yn = 1e16 neutron fluence:
  - **~7e9 n/cm²**
- Assuming no DIM self shielding: Yn = 1e16 neutron fluence:
  - **~1.4e11 n/cm²**
- Camera Electronics located 3.3m from TCC



Map shows Yn = 7.1e18 ie 20MJ Shot