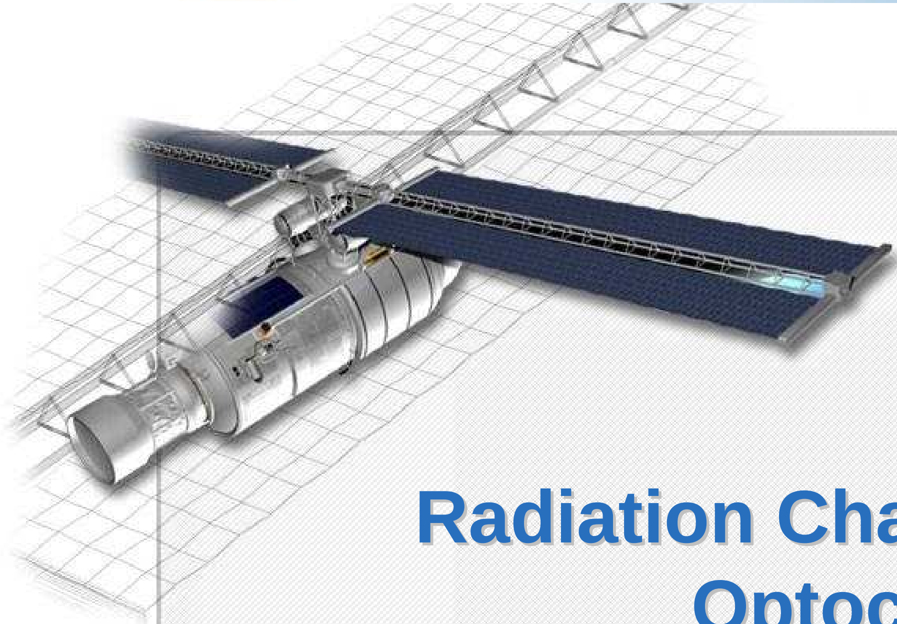
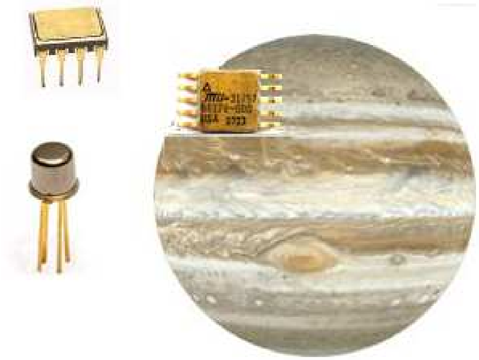


Radiation Characterization of Optocouplers for JUICE mission

Anne Samaras

Purpose of the study



Optocouplers Total Ionising Dose, Displacement Damage and Single Event Effects tests to propose potential candidates for the JUICE mission

Devices under test

Manufacturer	Part type	Date Code	LED Structure		Photodetector type	Structure[2]	Radiation information[3]
MICROPAC	66179-002	1124	GaAlAs[1]	660nm[1]	silicon planar NPN Output phototransistor	Lateral	High radiation immunity
	66193-002	1120	GaAlAs[1]	660nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant LED
	66221-103	1122	GaAlAs[1]	850nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant
	66224-105	1038, 1111	GaAlAs[1]	850nm[1]	silicon planar phototransistor	Lateral	Proton radiation tolerant
AVAGO	HCPL5431	1116	AlGaAs	850nm[1]	integrated high gain photon detector.	Sandwich	High Radiation Immunity
	HCPL5501	1105	GaAsP	-	integrated photodiode-darlington detector IC	Sandwich	High Radiation Immunity
	HCPL5701	1116	GaAsP	-	integrated high gain photon detector.	Sandwich	High Radiation Immunity
ISOLINK	OLH400	1048	AlGaAs double heterojunction [1]	700nm[1]	integrated photodiode-darlington detector IC	Lateral	Radiation Tolerant
	OLS0449	0949	AlGaAs double heterojunction[1]	830nm[1]	NPN silicon phototransistor	Lateral	Radiation Tolerant Phototransistor
	OLH7000-0010	0721	AlGaAs double heterojunction[1]	870nm[1]	two PIN photodiode detectors	Lateral	Displacement damage tolerant LED

[1] Missing information (not included in datasheets or manufacturer websites) concerning LED structure. No additional information was obtained from AVAGO. This information was provided by Isotope-electronics (MICROPAC parts) and by ISOLINK.
[2] As described in slide 6
[3] Information's given by the data-sheets provided by the manufacturers

Irradiation Test Conditions

Tests were performed:

- under **neutrons** (1MeV) to evaluate TNID degradation
- under several **proton** energies (30, 60, 190 MeV) to evaluate TNID and TID degradation
- under ^{60}**Co γ rays** to evaluate TID degradation
- under **protons** (up to 230MeV) to evaluate SET sensitivity

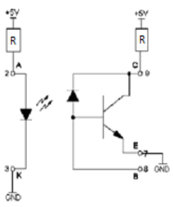
Neutron and proton steps were defined in order to obtain an equivalent of 10 MeV proton irradiation fluence steps in silicon.

After ^{60}Co irradiation, two annealing steps were performed:

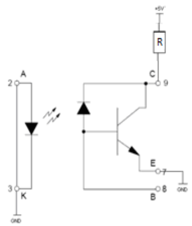
- **24 hours at +25°C**
- **168 hours at +100°C**

Irradiation Test Conditions

Bias conditions for TID and TNID tests:

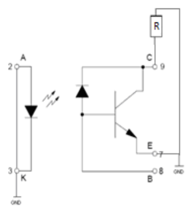


ON Bias1



ON Bias2

LED shorted



OFF

all leads shorted

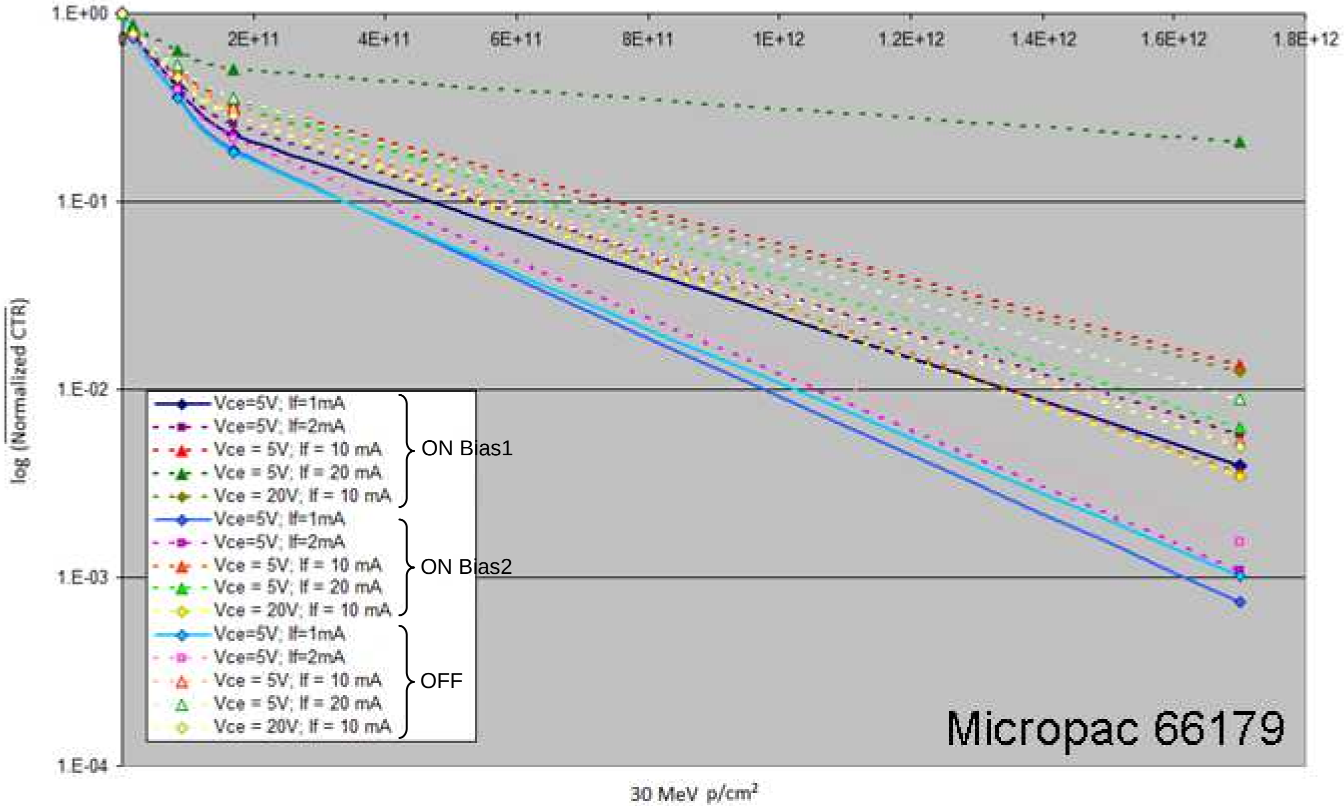
Different CTR configurations (Vce, If) were applied for measurement

RADIATION TESTING / PARTS SHARING OUT				
	ON Bias 1	**ON Bias 2**	**OFF**	**Total for 10 references**
TID	5	5	5	150
TNID neutrons			3	30
TNID protons				
30 MeV	5	5	5	150
60 MeV	5	5	5	150
200MeV	5	5	5	150
SEE protons*				
100MeV	3			9
175MeV	3			9
230MeV	3			9
Control parts				**30**
TOTAL				**687**

* three references (HCPL5431, OLH7000.001, 66193) were selected for SET evaluation

- Impact of Bias condition on CTR degradation
- Impact of electrical test on CTR degradation
- Impact of the irradiation type on CTR degradation
- SET test results
- Sensitivity Comparison Between All Part References
- Other observations

Impact of Bias condition on CTR degradation



Whatever the CTR configuration (Vce, If), ON Bias2 is the most sensitive mode and ON Bias1 exhibits the smallest average parameter drift.

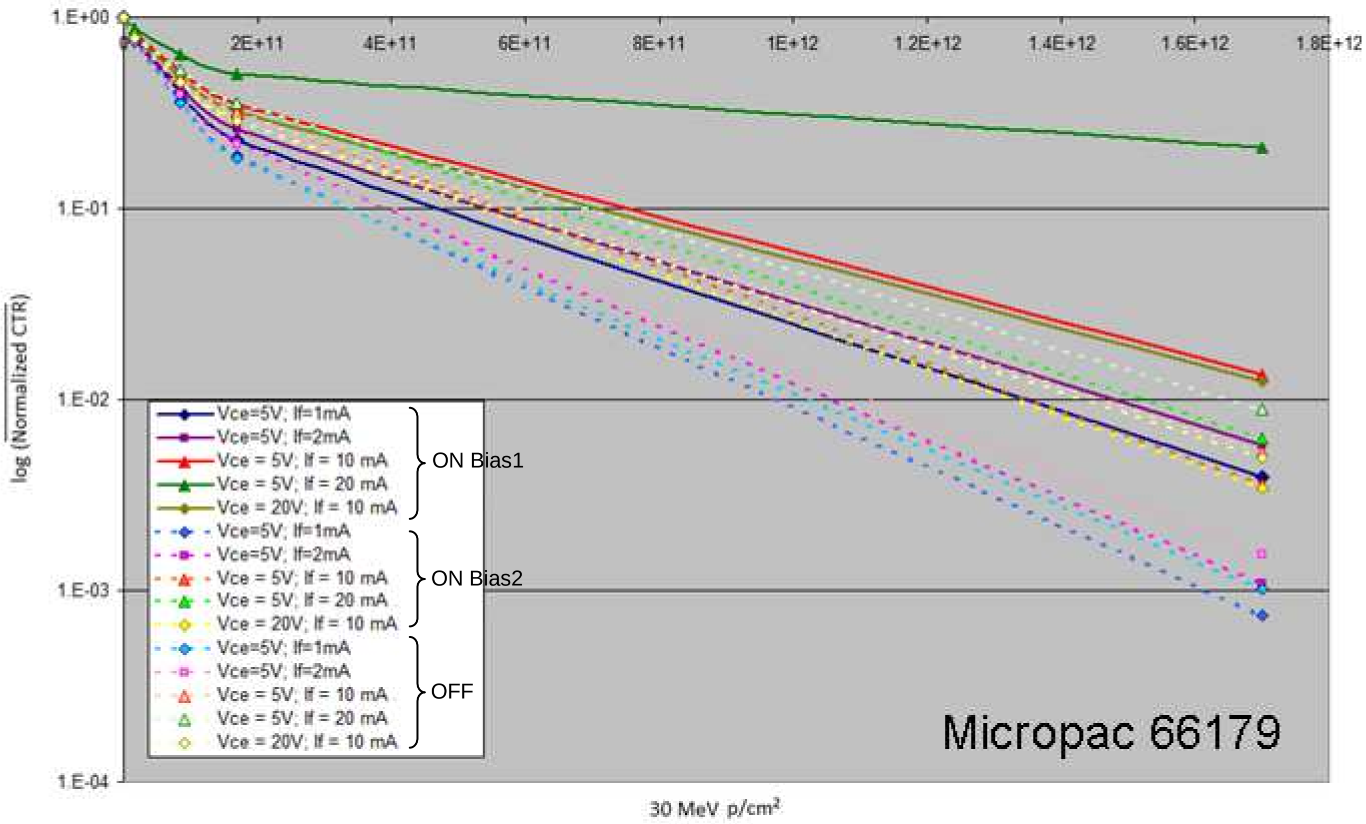
Impact of Bias condition on CTR degradation

		PROTON	^{60}Co
66179	☺	ON Bias 1	ON Bias1
	🛇	On Bias 2	OFF
66193	☺	ON Bias 1	ON Bias 1
	🛇	OFF	OFF
66221	☺	ON Bias 1	ON Bias 1
	🛇	OFF	OFF
66224	☺	ON Bias 1	ON Bias 1
	🛇	OFF	On Bias 2: CTR1, CTR2 & CTR4 OFF : CTR3 & CTR5
HCPL5431		No CTR measurement is performed due to the device construction	
HCPL5501	☺	ON Bias 1	ON Bias 1
	🛇	On Bias 2: CTR3 OFF : CTR1, CTR2, CTR4 & CTR5	On Bias 2
HCPL5701	☺	ON Bias 1	ON Bias 1
	🛇	OFF	OFF: CTR1, CTR4, CTR5 & CTR6 OFF & ON Bias2 :CTR2 & CTR3
OLH400	☺	ON Bias 1	ON Bias 1
	🛇	On Bias 2 (190 MeV) OFF (30 & 60 MeV)	OFF
OLH7000-0010		No CTR measurement is performed due to the device construction	
OLS0449	☺	ON Bias 1	ON Bias 1
	🛇	On Bias 2 (30 & 190 MeV) OFF (60 MeV)	OFF & On Bias 2

☺ **Best case**
🛇 **Worst case**

- **ON Bias 1 is the least sensitive bias configuration, regardless of radiation type (proton (30, 60 or 190 MeV) or 60Co)**
- **Worst case cannot be determined: OFF and ON Bias 2 modes exhibit the greatest parameter degradation, depending on the type of irradiation test or on the type of component.**
- **The off mode often leads to the greatest parameter degradation: point to be taken in account by designers**
  - **JUICE mission = 7.6 y cruise + 3.5 y Jovian system.**
  - **CTR degradation is to be expected at the power ON of the equipment.**
  - **This result must also be taken into consideration for cold redundancy equipment (or function).**

Impact of Irradiation on CTR degradation



Whatever the Biased mode, CRT1 (Vce = 5V; If = 1 mA) is the most sensitive configuration and CTR4 (Vce = 5V; If = 20 mA) exhibits the smallest average parameter drift.

Impact of Irradiation on CTR degradation

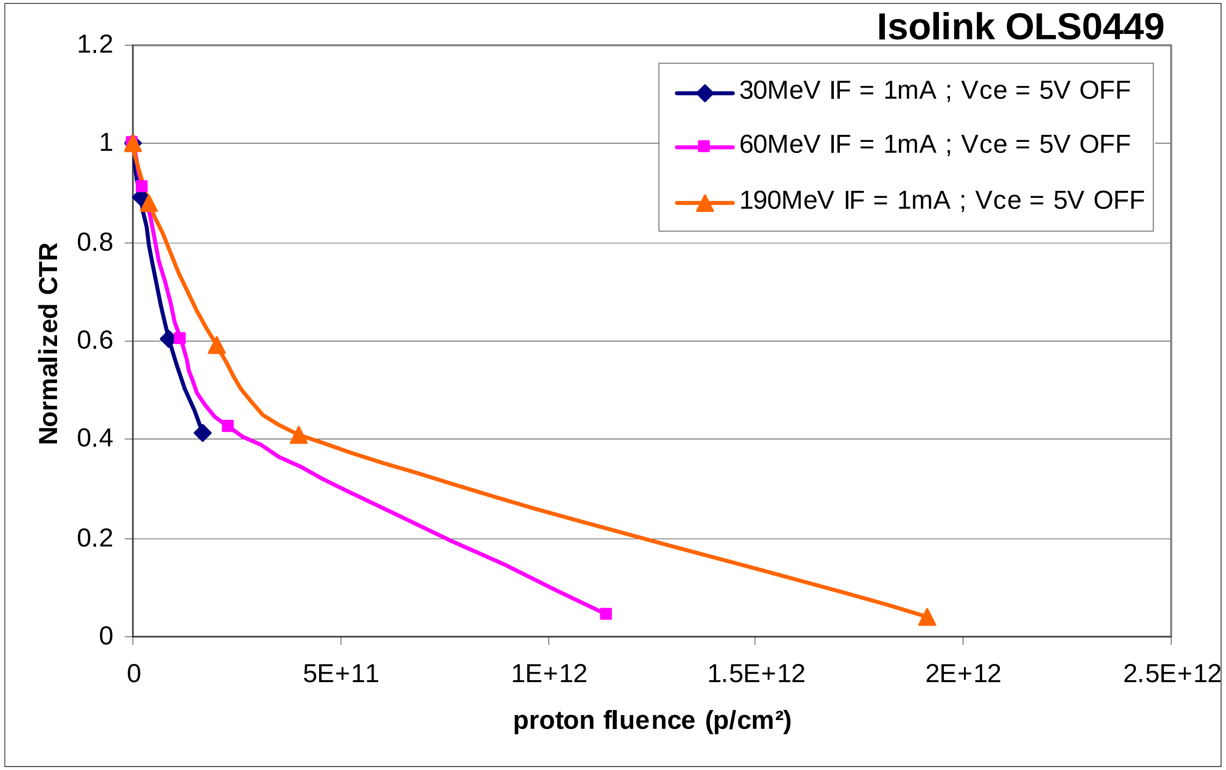
		NEUTRON	PROTON	^{60}Co
66179	☺	CTR4 (Vce = 5V; If = 20mA)	CTR4 (Vce = 5V; If = 20mA)	CTR3 (Vce = 5V; If =10mA) CTR4 (Vce = 5V; If = 20mA) CTR5 (Vce = 20V; If = 10mA)
	⊘	CRT1 (Vce = 5V; If = 1mA)	CRT1 (Vce = 5V; If = 1mA)	CRT1 (Vce = 5V; If = 1mA)
66193	☺	CTR4 (Vce=5V; If=20mA)	CTR4 (Vce=5V; If=20mA)	CTR3* (Vce=5V; If=10mA) CTR4 (Vce=5V; If=20mA) CTR5 (Vce=30V; If=10mA)
	⊘	CRT1 (Vce = 5V; If = 1mA)	CRT1 (Vce = 5V; If = 1mA)	CRT1 (Vce = 5V; If = 1mA)
66221	☺	CTR4 (Vce = 30V, If=10mA)	CTR4 (Vce = 30V, If =10mA)	CTR4 (Vce= 30V, If =10mA)
	⊘	*CTR1 (VCE = 5V, IF = 1mA)	*CTR1 (VCE = 5V, IF = 1mA)	*CTR1 (VCE = 5V, IF = 1mA)
66224	☺	CTR4 (Vce=5V; If=50mA)	CTR4 (Vce = 5V; If = 50mA) CTR3 (Vce = 5V; If = 10mA)	CTR5 (VCE = 30V, IF = 5mA)
	⊘	*CRT1 (Vce = 5V; If = 1mA)	*CRT1 (Vce = 5V; If = 1mA)	*CRT1 (Vce = 5V; If = 1mA)
HCPL5431		No CTR measurement is performed due to the device construction		
HCPL5501	☺	CTR5 (VO=0.4V, IF=40 mA, VCC=5V)	CTR4 (VO=0.4V, IF=20 mA, VCC=5V) : ON Bias 1 CTR5 (VO=0.4V, IF=40 mA, VCC=5V): ON Bias 2 & OFF	CTR5 (VO=0.4V, IF=40 mA, VCC=5V)
	⊘	CRT1 (VO=0.4V, IF=2mA, VCC=5V)	CRT1 (VO=0.4V, IF=2mA, VCC=5V)	CRT1 (VO=0.4V, IF=2mA, VCC=5V)
HCPL5701	☺	CTR5 (IF=10mA, VO=0.4V, VCC=5V)	CTR5 (IF=10mA, VO=0.4V, VCC=5V)	CTR5 (IF=10mA, VO=0.4V, VCC=5V)
	⊘	CRT2 (IF=0.5mA, VO=0.4V, VCC=5V)	CRT2 (IF=0.5mA, VO=0.4V, VCC=5V)	CRT2 (IF=0.5mA, VO=0.4V, VCC=5V)
OLH400	☺	CTR5 (IF=16 mA, VO=0.4V, VCC=5V)	CTR5 (IF=16 mA, VO=0.4V, VCC=5V)	CTR6 (IF=1.6 mA, VO=0.4V, VCC=20V)
	⊘	CRT2 (IF=0.16 mA, VO=0.4V, VCC=5V) CTR3 (IF=0.32 mA, VO=0.4V, VCC=5V)	CRT2 (IF=0.16 mA, VO=0.4V, VCC=5V)	CRT2 (IF=0.16 mA, VO=0.4V, VCC=5V)
OLH7000-0010		No CTR measurement is performed due to the device construction		
OLS0449	☺	CRT4 (If = 40mA, Vce = 5V)	CTR4 (IF=40mA, Vce=5V)	CTR5 (If =10 mA, Vce = 32V)
	⊘	*CTR1 (If = 1mA, Vce = 5V)	*CRT1 (IF=1mA, Vce=5V)	*CTR1 (If = 1mA, Vce = 5V)

☺ Best case
⊘ Worst case
* CTR specified in the datasheet

- **For all component tested:**
  The lower the forward current (IF), the higher the degradation
  The contrary is not necessarily true
- **CTR configurations specified in the datasheets are leading to the least degradation as well as to the worst one**

Impact of the irradiation type on CTR degradation

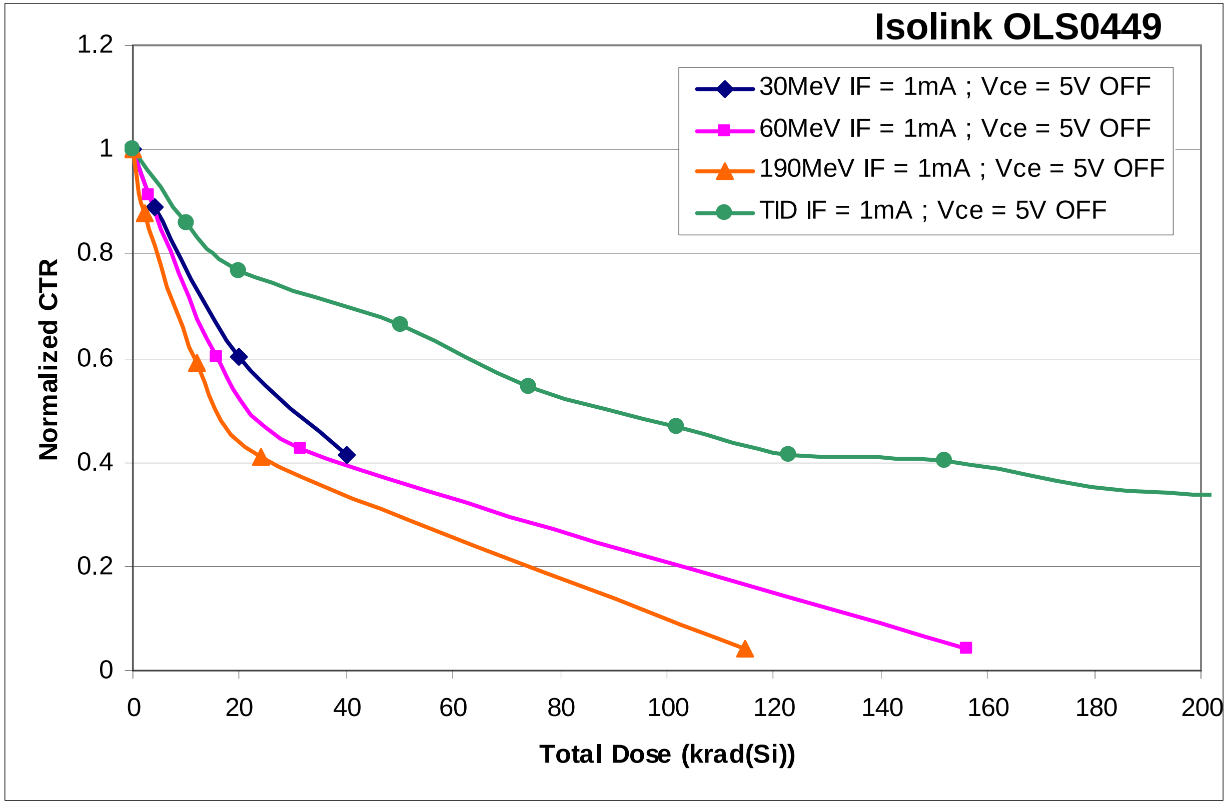
1. CTR degradation depending on Proton Fluence



⇨ **CTR damages are more important for the low-energy protons at low fluences**

Impact of the irradiation type on CTR degradation

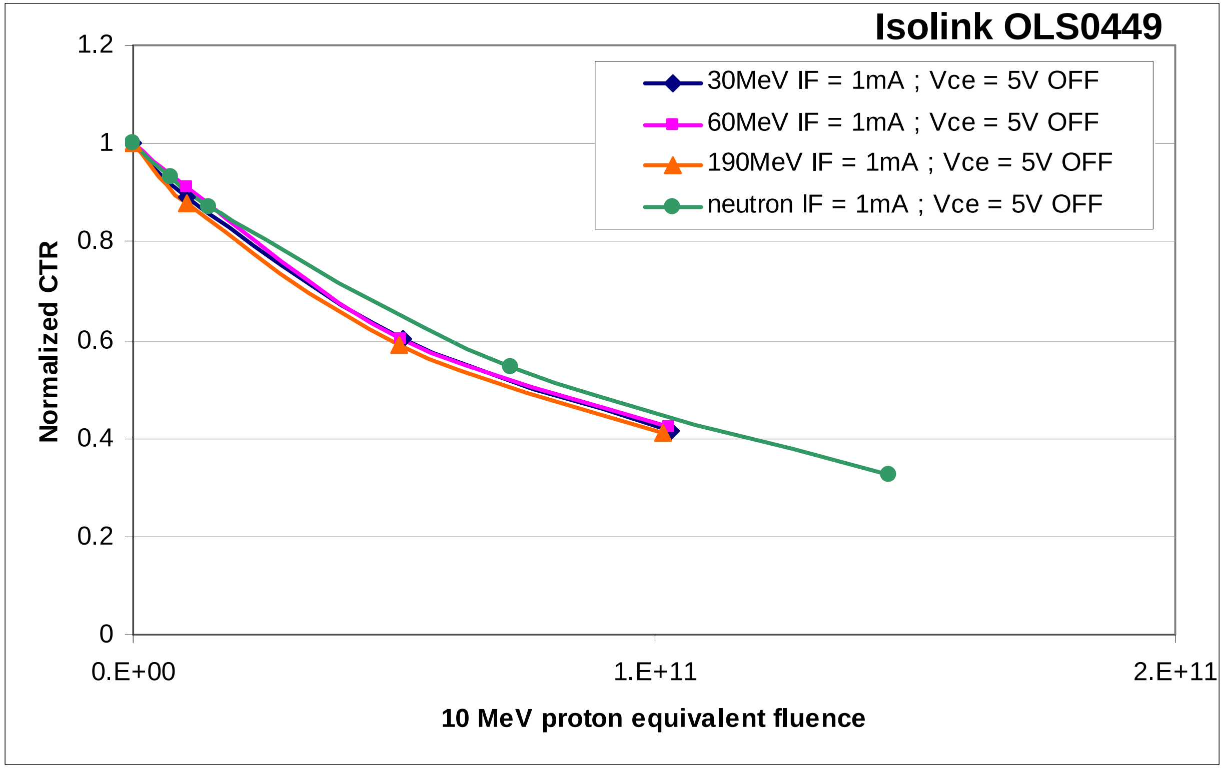
2. Comparison between protons and ^{60}Co CTR degradation



⇨ **These results indicate that protons generate both ionizing and displacement damage, the latter being a significant contribution to the final degradation**

Impact of the irradiation type on CTR degradation

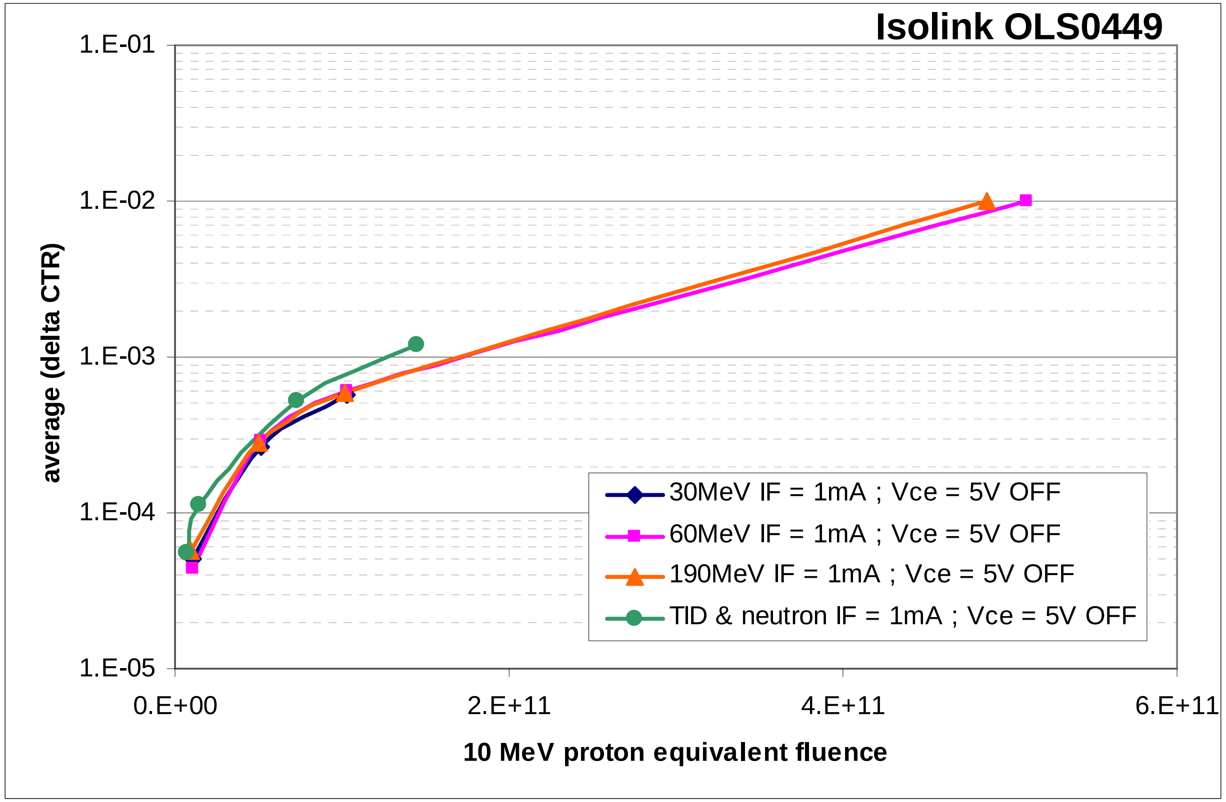
3. Comparison between protons and neutron CTR degradation



⇨ **These results indicate that protons generate both displacement and ionizing damage, the latter being a significant contribution to the final degradation**

Impact of the irradiation type on CTR degradation

4. Comparison between protons, neutrons and ^{60}Co CTR degradation



⇨ **Worst CTR degradations are observed under neutrons and ^{60}Co γ rays**

SET Test Results

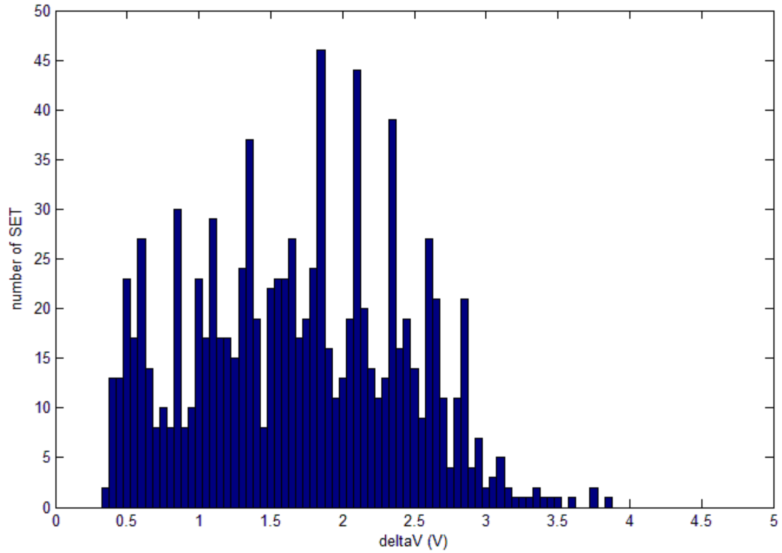
- **HCPL5431 reference is the only tested reference that is sensitive to SET**

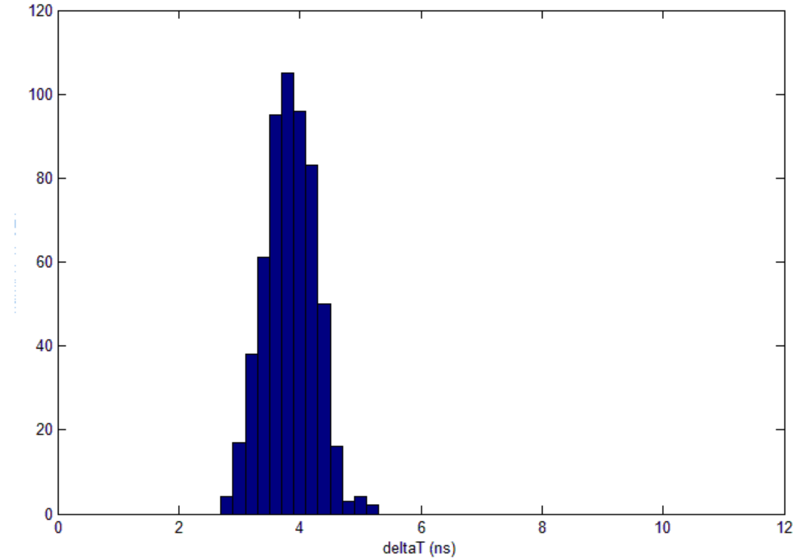
- **Four devices HCPL5431 were tested, under proton beam, up to 5E10 protons/cm², with energy of 230MeV**

- **One of the four devices tested (identified Part 2N) was previously irradiated with 1MeV neutron up to a total fluence of 7E12 neutrons/cm²**

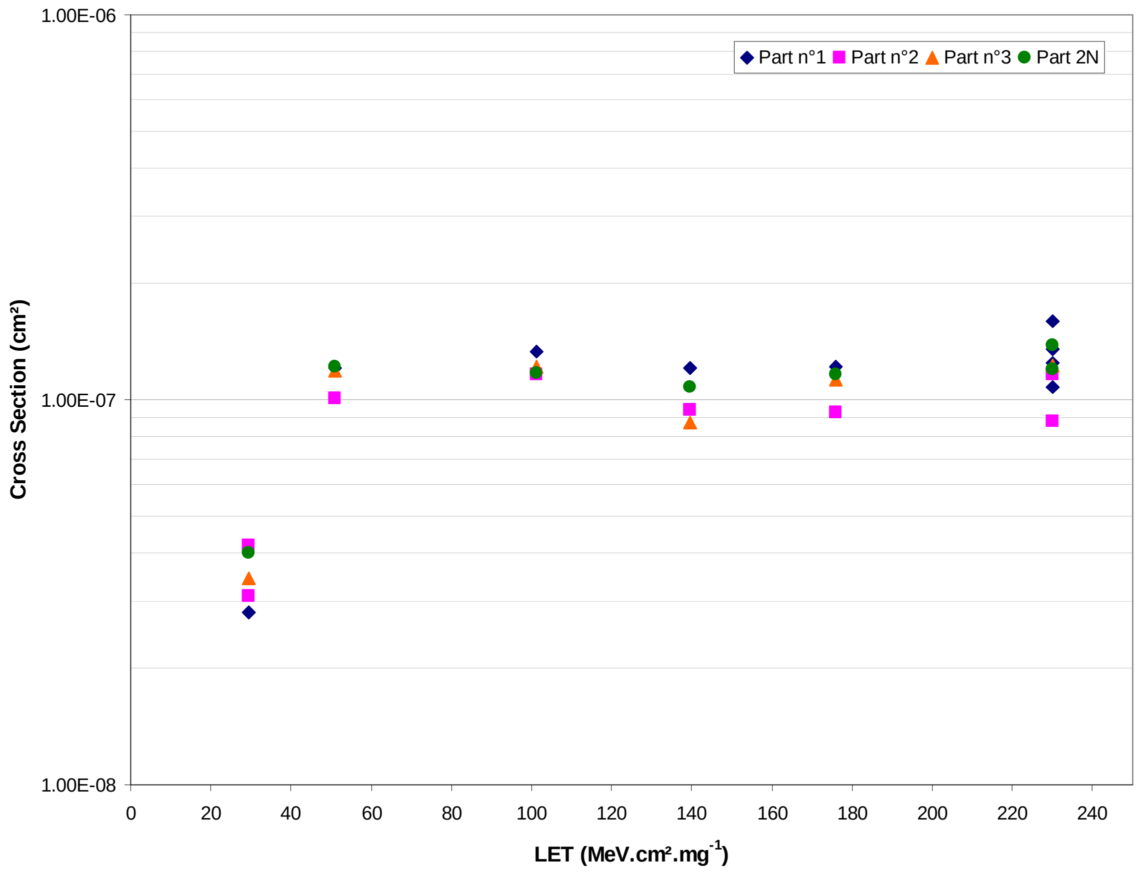
Observed SETs have:

- **a duration between 2.6ns to 10.4ns**
- **an amplitude between 0.33V to 4.38V**



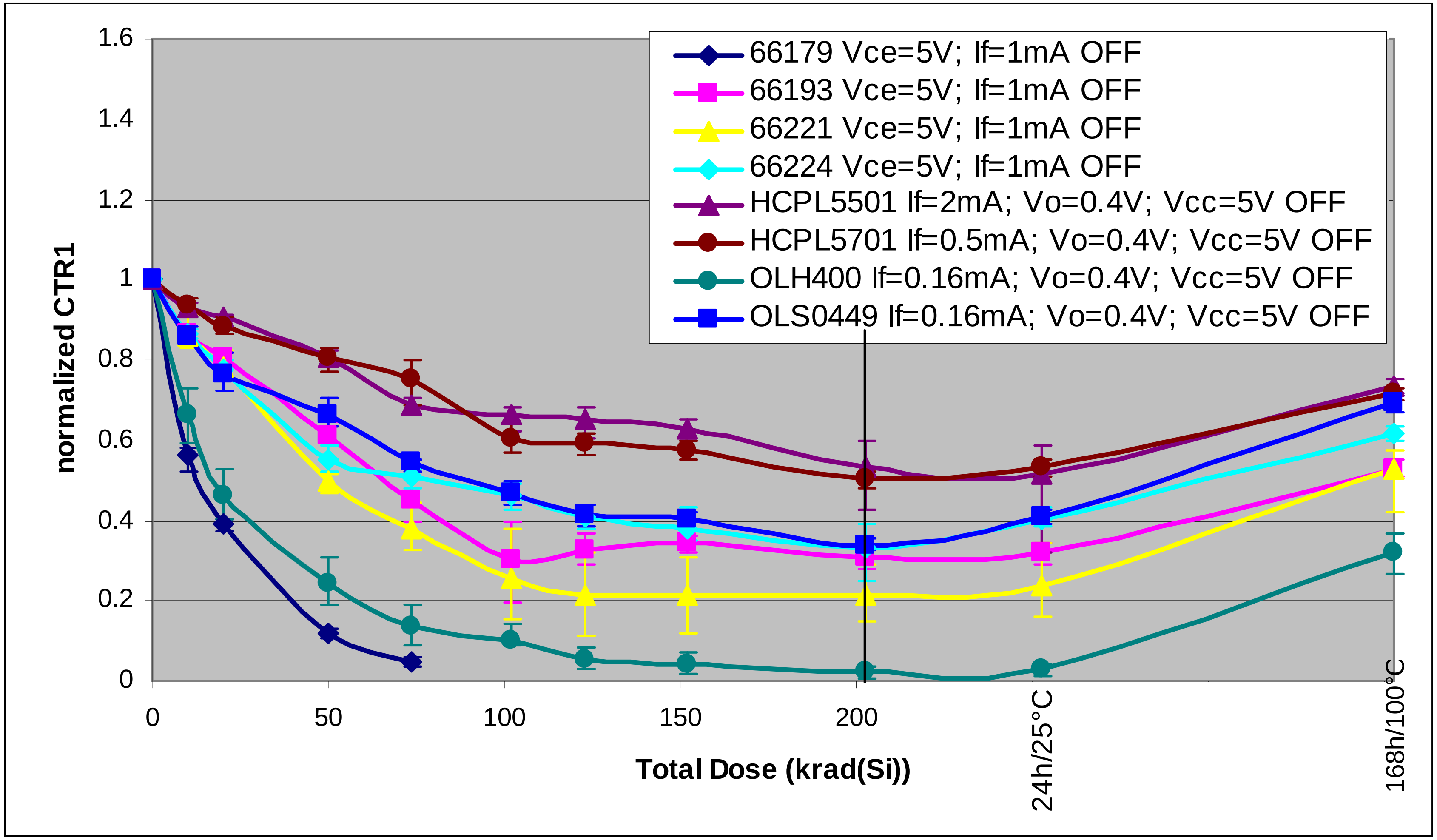


SET Test Results

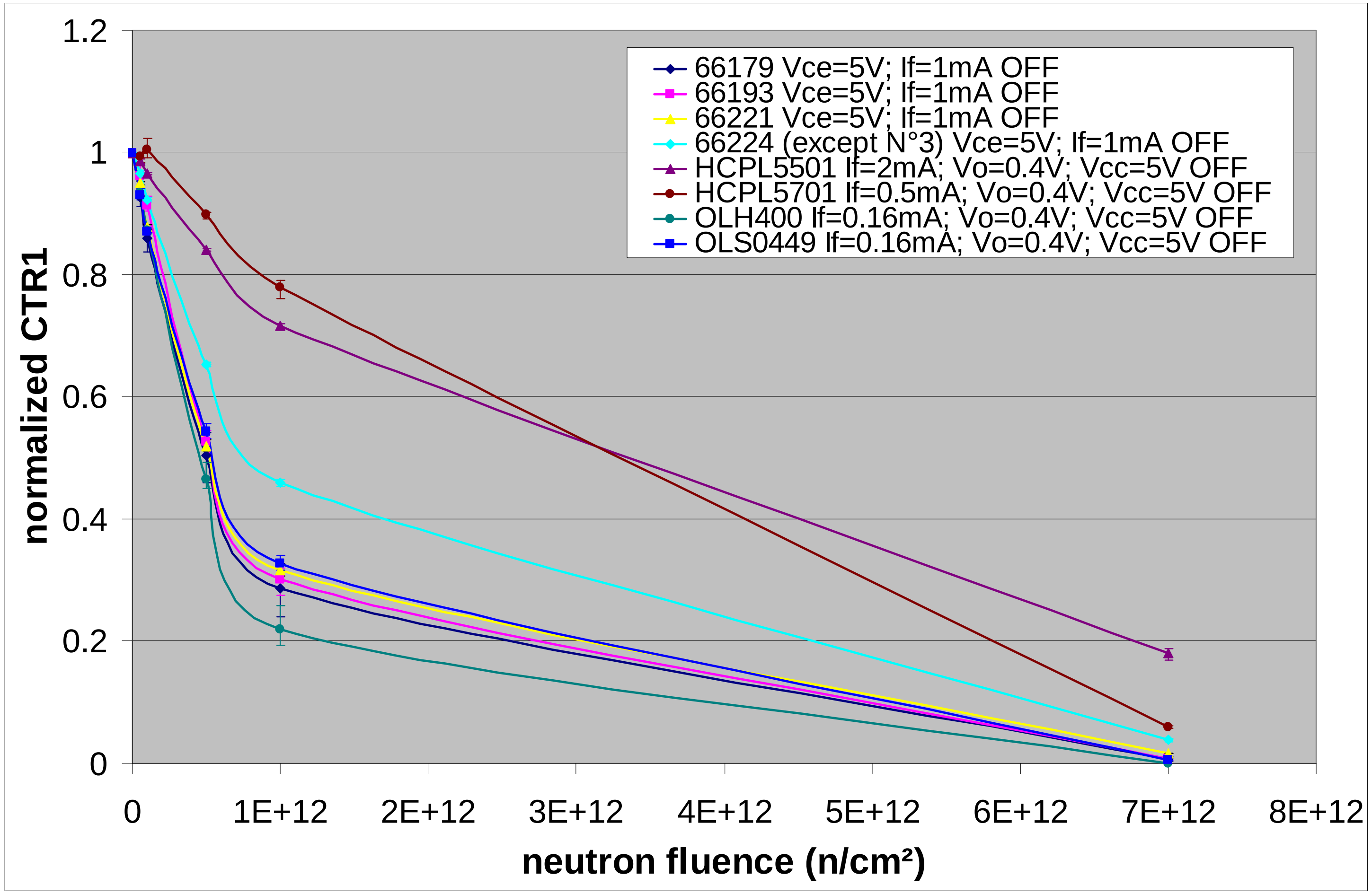


No susceptibility difference was identified between previously neutron irradiated device (PART 2N) and new parts (Part N°1, N°2 and N°3).

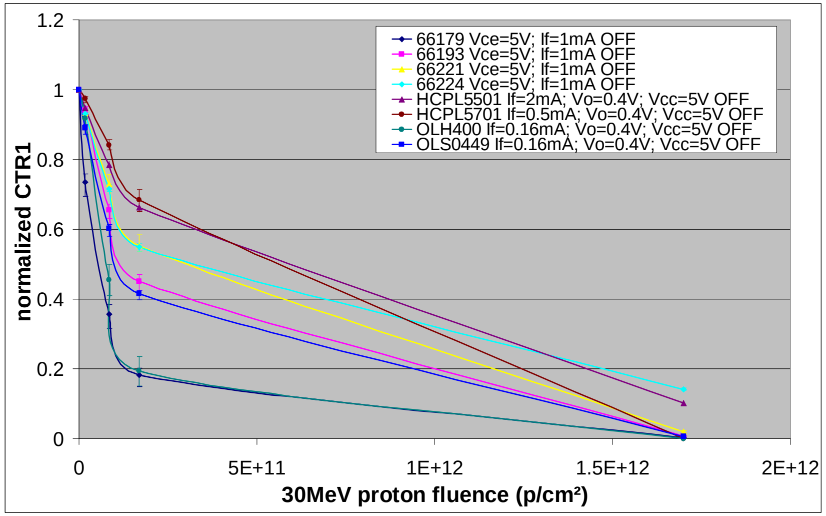
Sensitivity Comparison Between All Part References

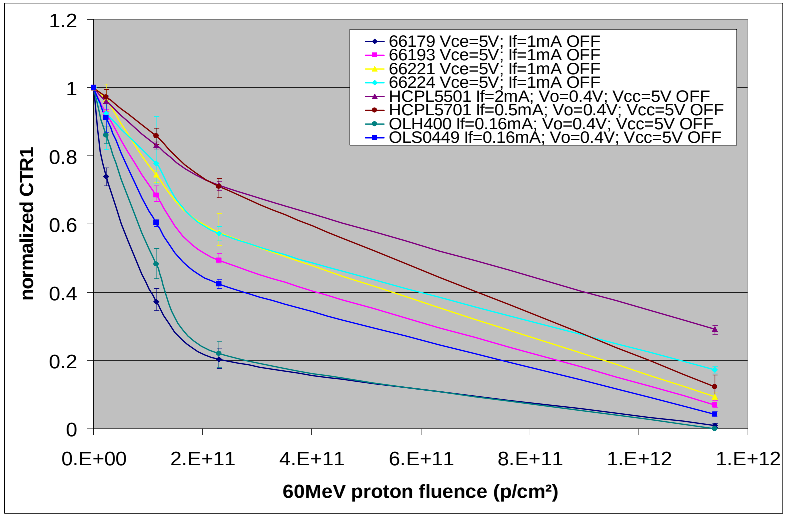


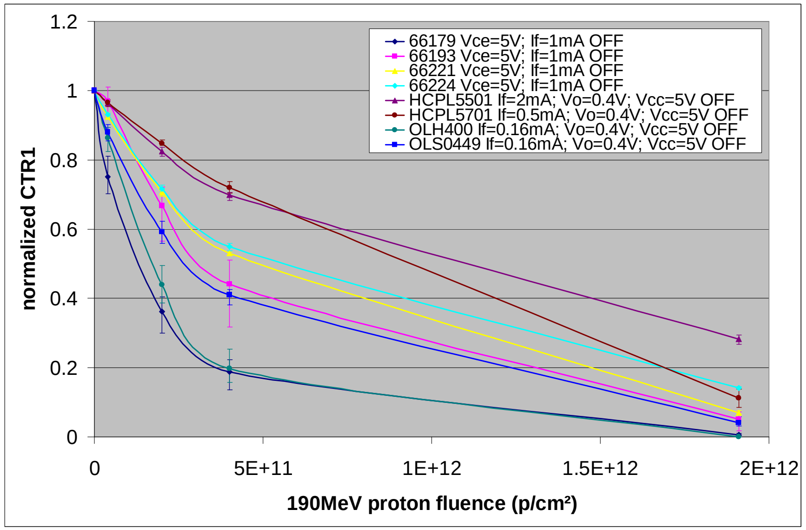
Sensitivity Comparison Between All Part References



Sensitivity Comparison Between All Part References

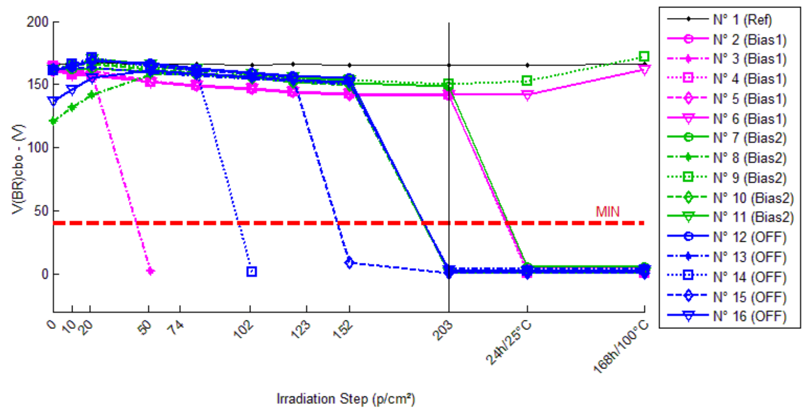






Other observations

MICROPAC test results indicate important part to part variations even with the same Optocoupler date code.



66179 V(BR)cbo parameters function of TID irradiation steps

A sufficient number of samples should be required to perform radiation lot testing

Other observations

No part to part variation on AVAGO devices

- visually present a very good workmanship
- built using the sandwich structure.

The medium coupling quality used in lateral structures and its potential degradation under radiation could also contribute to these overall variations.

Other observations

Potential inhomogeneity of dice lots could explain part to part variations

For space application components, with drawing configuration control:

- ISOLINK says: "only one LED lot is used for each assembly lot"
- MICROPAC says: "only one LED lot and one photodetector lot are used for a unique Optocoupler date-code, upon request by the customer through its purchase order."

- Consequently, it is essential to specify that a unique lot is required for each type of die assembled into the Optocoupler when procuring hi-rel parts

Other observations

It should be noted that all the tested devices are defined as radiation tolerant by their manufacturers.

Radiation tolerant information defined in the datasheet is only considered as qualitative information as no value, nor guaranty, is given by the manufacturer.

CONCLUSION

- **ON Bias 1 appears to be the less sensitive configuration whatever radiation testing performed (proton or 60Co γ rays) or proton energy applied (30, 60 or 190 MeV).**
- **CTR degradation is higher when tests are performed with a lower forward current (IF).**
- **CTR degradation is higher under neutrons and ^{60}Co γ rays than under protons.**

CONCLUSION

Considering all irradiation test results

HCPL5431, HCPL5501, and HCPL5701 Optocouplers from AVAGO are the best candidates for the JUICE mission.

All the detailed radiation test reports are available on ESCIES (https://escies.org)

NSREC 2013:

"Compendium of Total Ionising Dose, Displacement Damage and Single Event Transient test data of various Optocouplers for ESA"

Marc Poizat and all

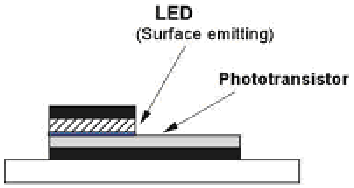
Radiation Characterization of Optocouplers
For JUICE mission

QUESTIONS

???

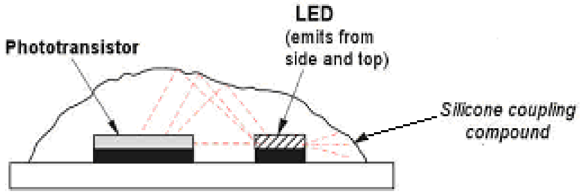
Optocoupler construction

Sandwich structure



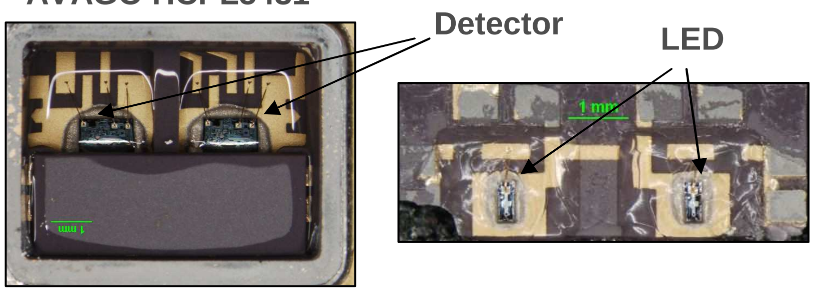
Surface-emitting LED placed directly over the photodetector.
A thin layer of optical coupling material placed between the LED and the photodetector.

Lateral structure



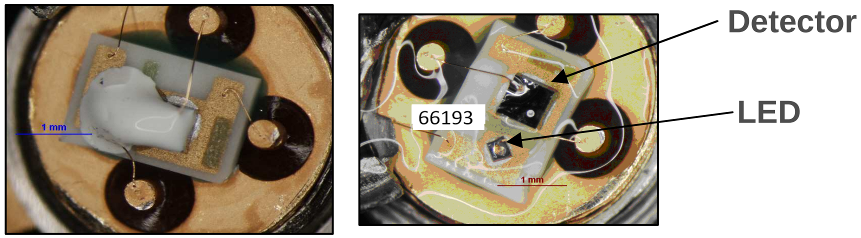
Internal reflection from a medium coupling that is placed over the LED and detector / amplifier.

AVAGO HCPL5431



Opened structure

Micropac 66193



Without medium coupling

Comparison between protons, neutrons and ^{60}Co CTR degradation

To combine neutron and gamma degradation, CTR was treated like a transistor gain: [1]

$$\overline{\Delta\frac{1}{CTR}} = \frac{\sum_{tested\_device\_number}\left(\frac{1}{\mathrm{CTR}\ \ (\mathrm{X\ particle}_{\mathrm{XMeV}}\ /\mathrm{cm}^2)} - \frac{1}{\mathrm{CTR}\ \ (0\ \mathrm{particle}_{\mathrm{XMeV}}\ /\mathrm{cm}^2)}\right)}{\mathrm{tested\_device\_number}}$$

The change in inverse-gain is computed by simply adding the shifts from gamma and neutrons:

$$\overline{\Delta\frac{1}{CTR}}_{TID\&neutrons} = \overline{\Delta\frac{1}{CTR}}_{TID} + \overline{\Delta\frac{1}{CTR}}_{neutrons}$$

[1] Proton, Neutron, and Gamma Degradation of Optocouplers; Jerry L. Gorelick, Member, IEEE, and Raymond Ladbury, Member, IEEE IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 6, DECEMBER 2004