CTC-028 JFET Radiation Resistance

Introduction:

The objective of this document is to provide information about radiation, the different kinds of radiation that a device could be subjected to, and the damage that different types of radiation can inflict on a silicon device. The results of radiation testing on various InterFET parts will be shown as well.

Types of Radiation and Damage

In various applications where Junction Field-Effect Transistors (JFETs) find use, they may encounter different types of radiation, each presenting unique challenges for their reliability and performance. The two primary types of radiation to consider are ionizing radiation and heavy ion radiation.

1. Ionizing Radiation: Ionizing radiation is a common and significant concern in many radiation-prone environments. It includes various types of radiation such as gamma rays and X-rays. These high-energy particles can penetrate materials and have enough energy to ionize atoms and molecules within a semiconductor device. When ionization occurs, it can lead to the creation of electron-hole pairs, which, in turn, may cause charge buildup and material damage within the JFET. This can cause the JFET to go out of tolerance as exposure grows, leading to behavior that is not expected / out of specification. As a result, JFETs used in applications like space exploration, nuclear reactors, and particle accelerators must be resistant to ionizing radiation.

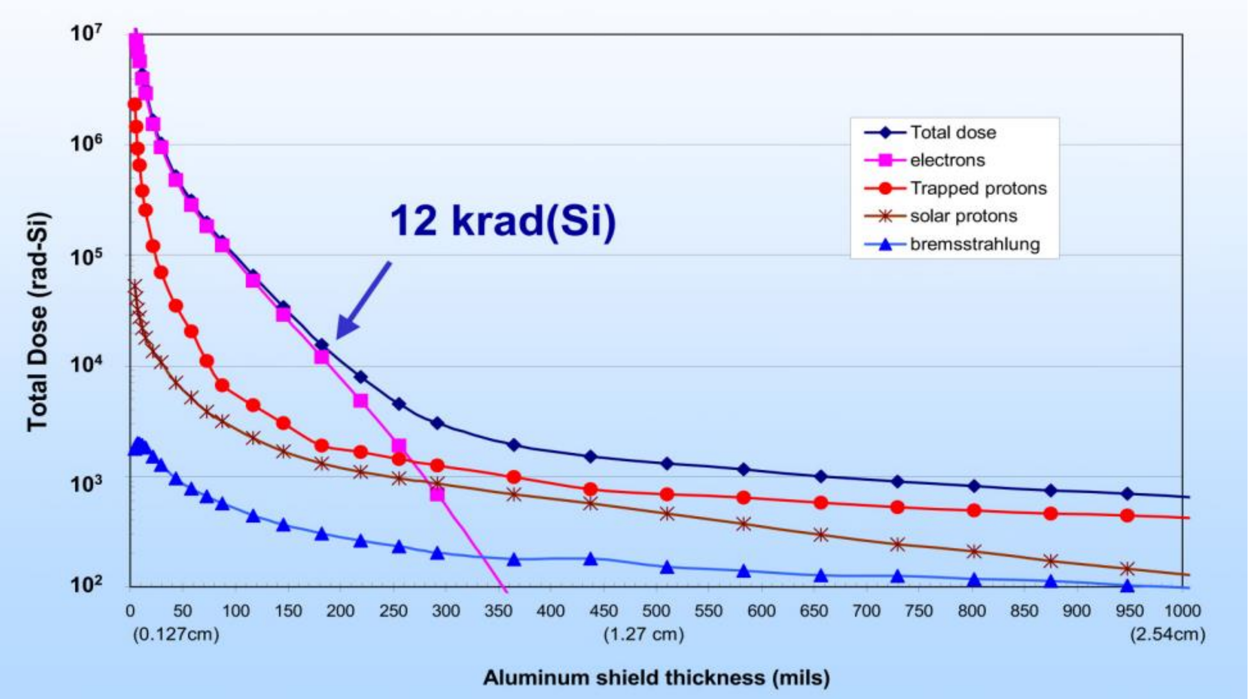
2. Heavy Ion Radiation: Heavy ion radiation involves the presence of relatively massive and charged particles, like heavy ions from cosmic rays or solar wind. When these heavy ions interact with the semiconductor material of a JFET, they can cause what are known as “Single Event Effects”. These events are typically seen as soft non-destructive errors like a bit flip in memory, however in semiconductors, they can cause displacement damage, ionization, and charge collection effects, which can affect the operating characteristics of a device. Worst case, these charged particles can cause a short that drives too much current through the JFET and burns it out. Heavy ion radiation can be particularly challenging in space environments, where these ions are prevalent, and there is nothing to protect devices against it. JFETs deployed in space applications need to withstand the effects of heavy ion radiation.

In harsh radiation environments such as outer space, JFETs are subjected to a combination of both ionizing and heavy ion radiation. Therefore, it is crucial for these devices to exhibit resistance to both types of radiation to ensure reliable and long-lasting operation. Achieving this resistance often involves specialized design considerations and materials that can mitigate the adverse effects of radiation exposure. Properly designed JFETs can continue to perform effectively in the presence of these radiation challenges, making them valuable components for critical applications.

Radiation Mitigation

To make devices more resistant to these kinds of radiation effect, special Rad Hardened MOSFETs are made, typically these are rated anywhere from 100kRad to 300kRad, they do go all the way up to 1MRad but they are very costly. Some issues arise with taking this approach however, in hardening the MOSFETs you typically sacrifice some operating characteristics / efficiencies to accomplish it. On top of this, Radiation Hardened device requirements can vary depending on the industry it is being used in, having to create a different product for each one gets very costly very quickly.

Shielding is another strategy that is used to try to mitigate the effects of radiation, this does help shield devices from ionizing radiation, lowering the total dose that they are exposed to.



(Figure 1: Aluminum shielding effectiveness)

JFET Radiation Resistance

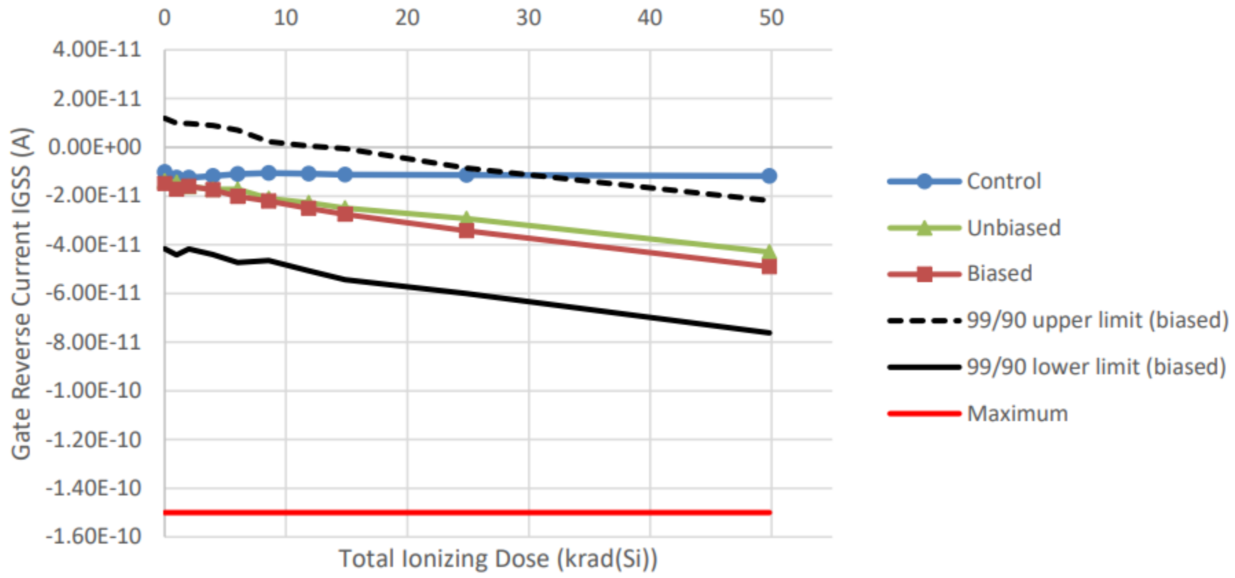
Because JFETs do not have a metal oxide layer, they are much more naturally resistant to radiation compared to MOSFETs. In testing, InterFET JFETs were able to stay within specification up to 300kRad without any radiation hardening. An essential characteristic of JFETs is their reliance on voltage control. Their operation is contingent on the voltage applied to the gate terminal. Unlike MOSFETs, JFETs do not depend on gate insulators, which can be susceptible to permanent radiation-induced damage and radiation-induced charge accumulation. Instead, JFETs operate though bulk semiconductor material, which both simplifies design, and increases radiation resistance.

In addition InterFET uses proprietary start materials and processes to achieve the highest levels of radiation immunity for its products. No other JFET manufacturer presently in the industry uses these processes or achieves InterFET radiation tolerance levels.

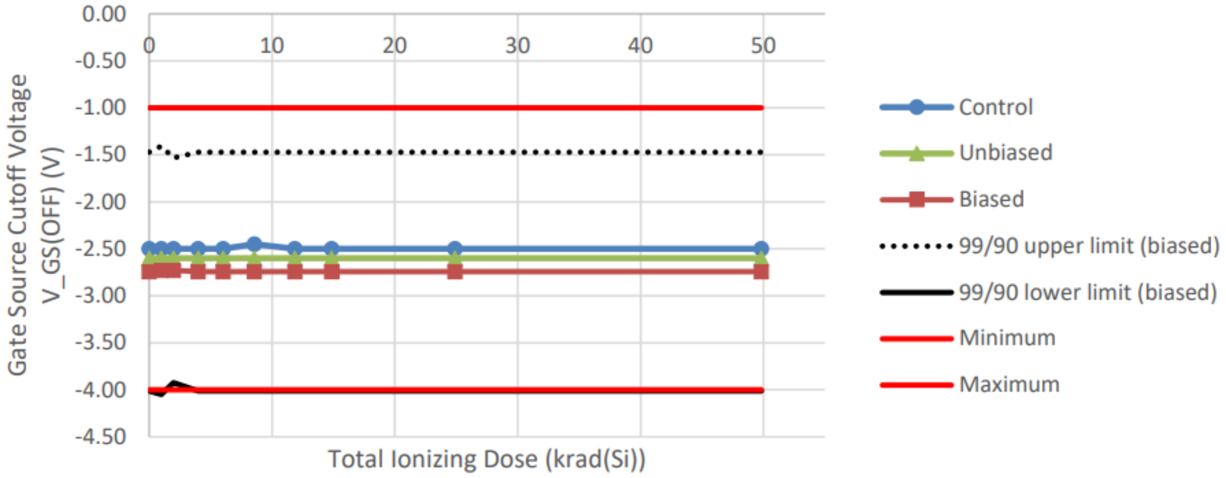
JFET Radiation Testing Results

In testing, InterFET JFETs proved to be quite stable under prolonged irradiation staying withing spec up to 300kRad (was not tested further). Over 90% of NASA missions only require around 100kRad of radiation resistance. Heavy Ion testing by NASA on IntferFET U309 showed no Single Event Effects up to 58.8 Mev-cm^2/mg. InterFET testing was done by ONERA Toulouse.

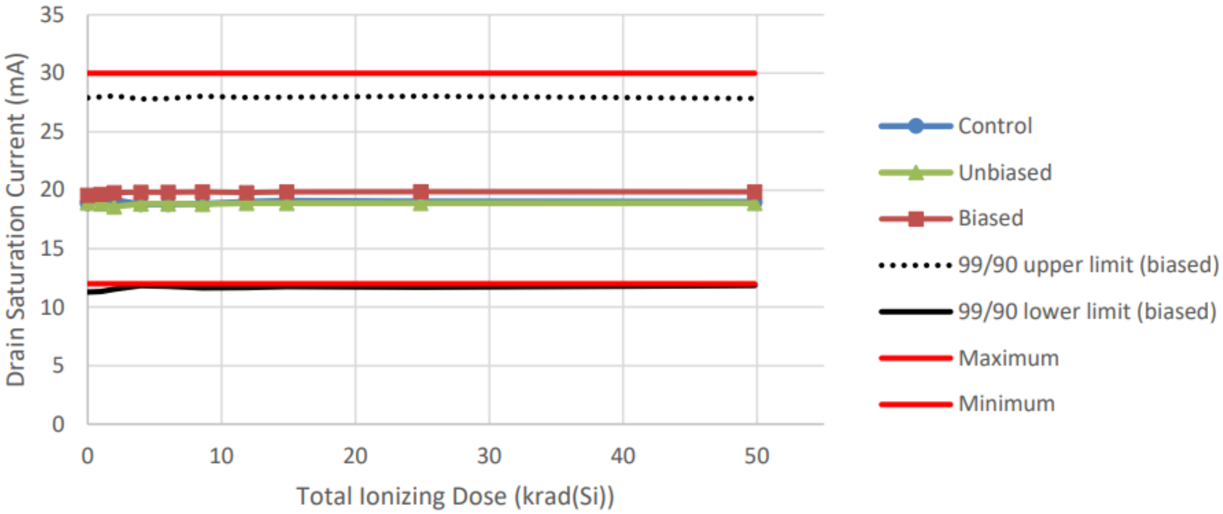
NASA Testing of U309



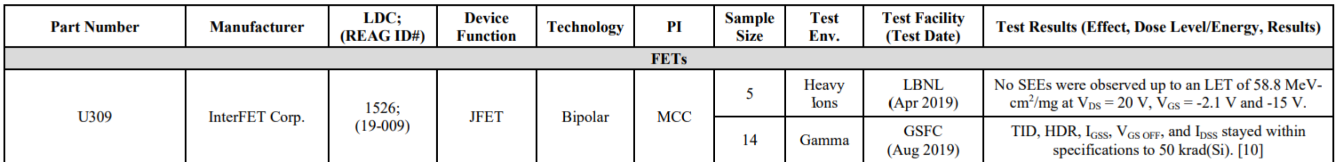
(Figure 2: IGSS testing of U309 by NASA)



(Figure 3: V_{gs} Off testing of U309 by NASA)



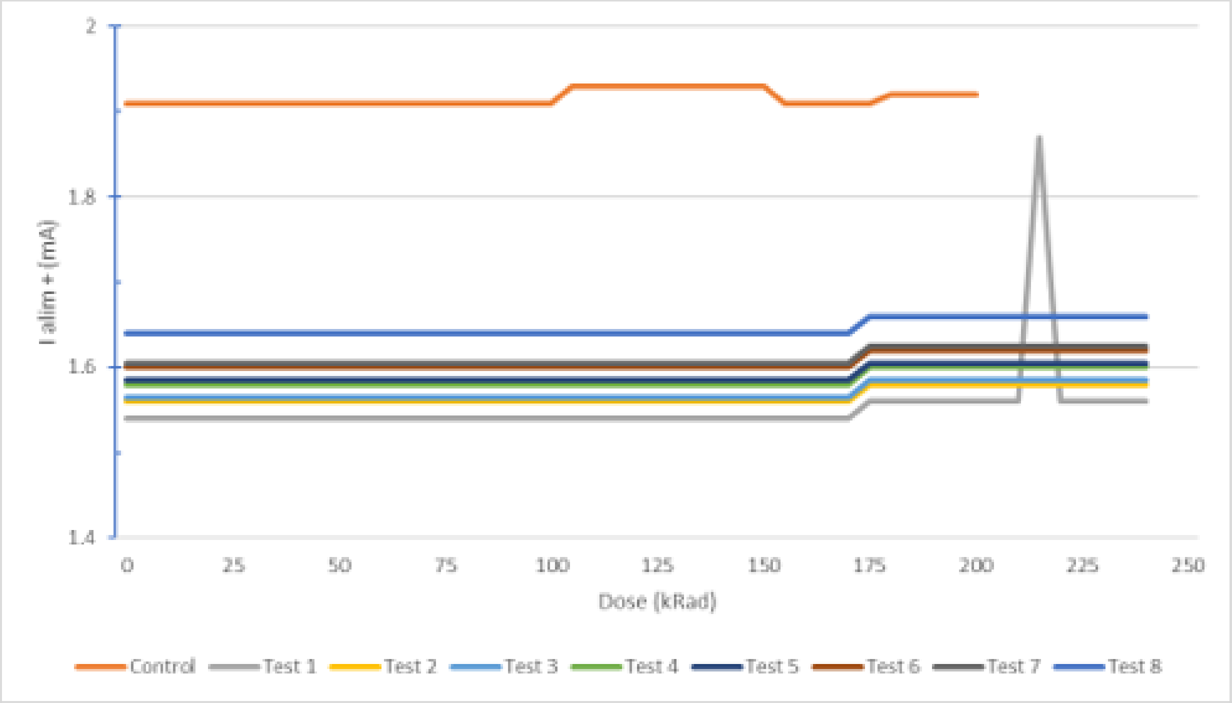
(Figure 4: Drain Saturation Current testing of U309 by NASA)



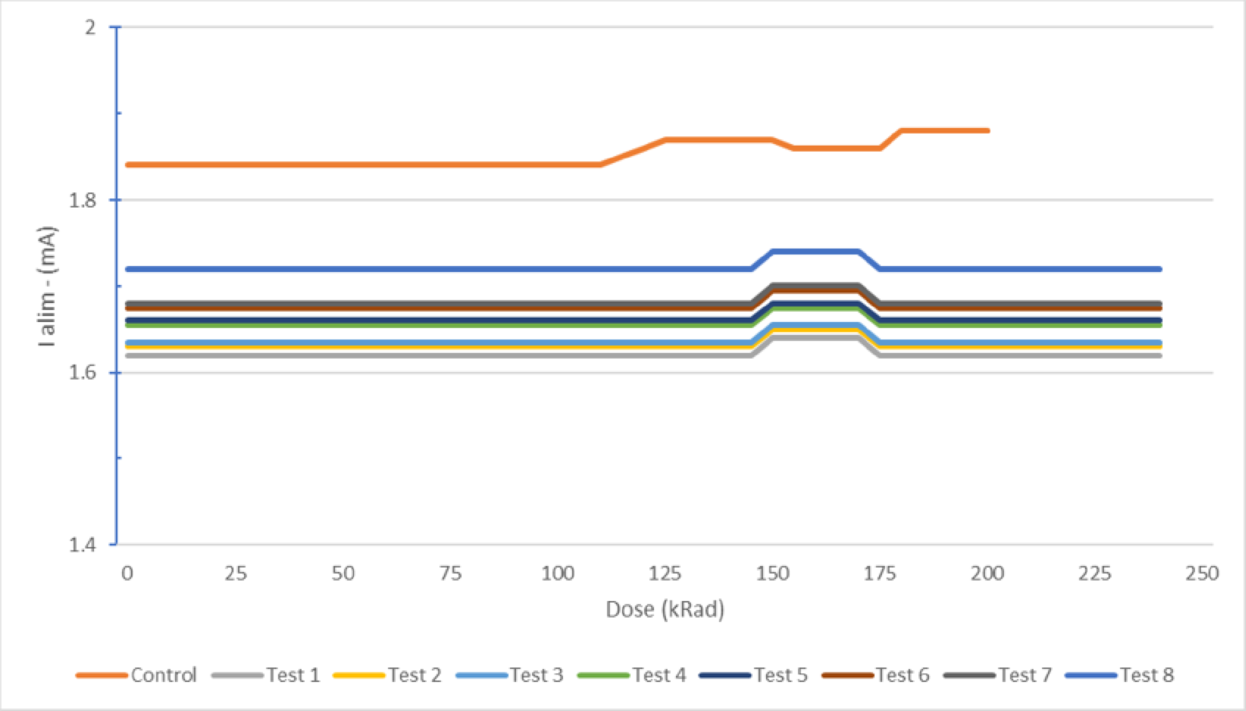
Part Number	Manufacturer	LDC; (REAG ID#)	Device Function	Technology	PI	Sample Size	Test Env.	Test Facility (Test Date)	Test Results (Effect, Dose Level/Energy, Results)
FETs									
U309	InterFET Corp.	1526; (19-009)	JFET	Bipolar	MCC	5	Heavy Ions	LBNL (Apr 2019)	No SEEs were observed up to an LET of 58.8 MeV-cm^2/mg at V_{DS} = 20 V, V_{GS} = -2.1 V and -15 V.
						14	Gamma	GSFC (Aug 2019)	TID, HDR, I_{GSS}, $V_{GS\ OFF}$, and I_{DSS} stayed within specifications to 50 krad(Si). [10]

Figure 5: NASA testing of U309

IF140



(Figure 6: I alim + of IF140)



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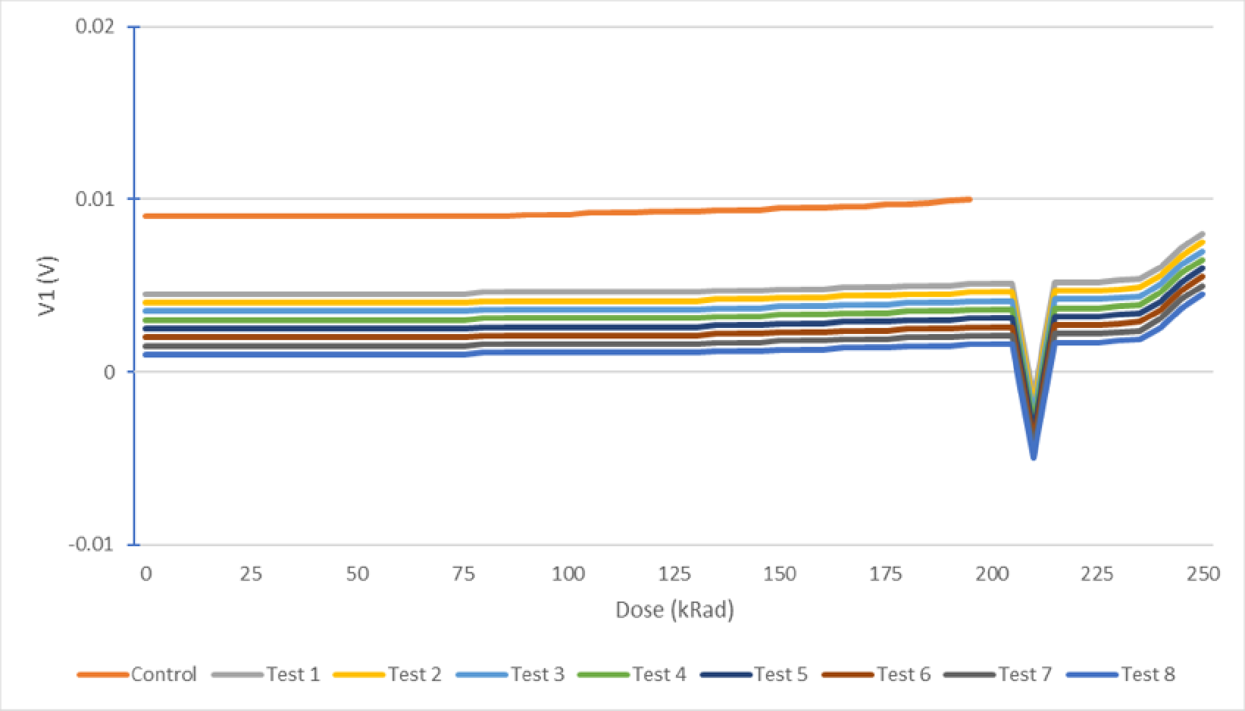
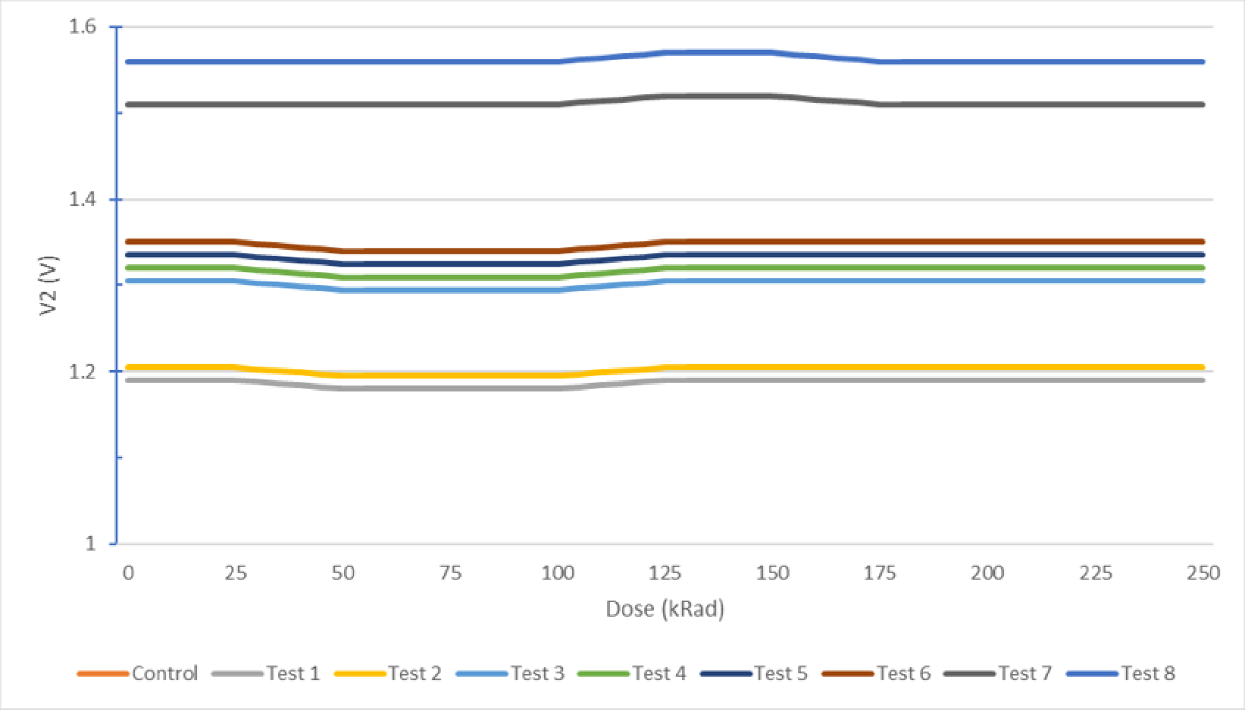
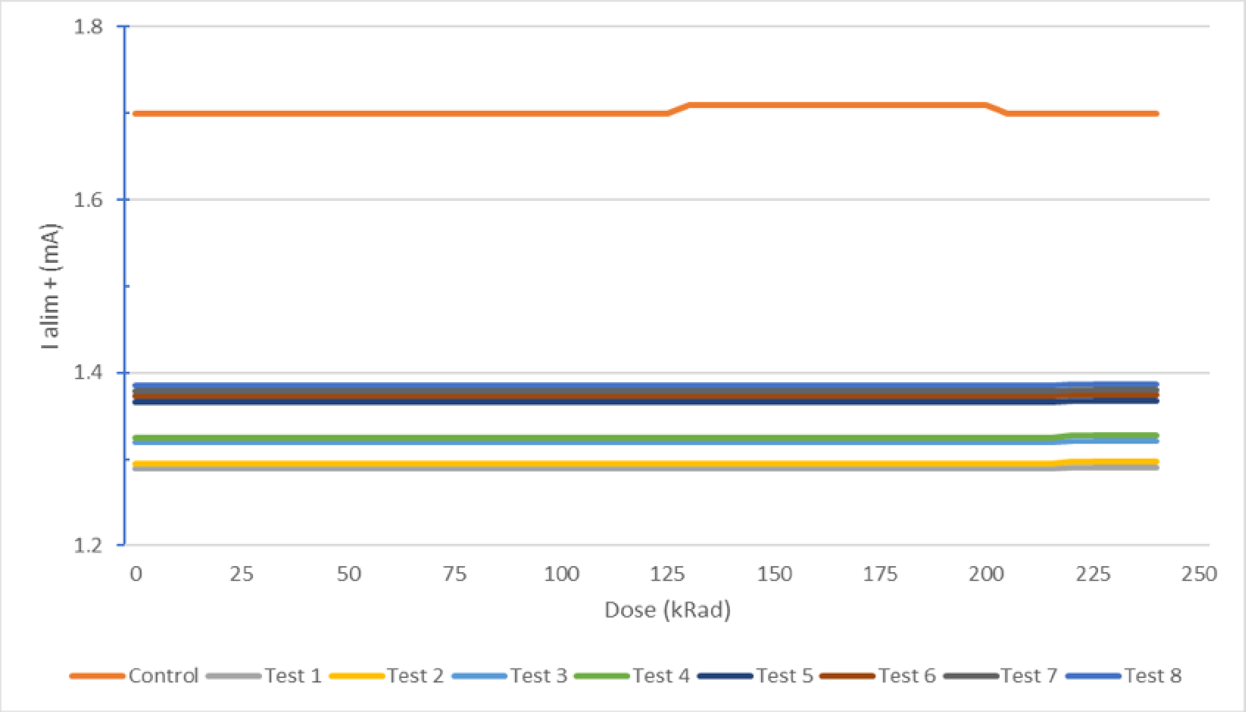


(Figure 8: V1 of IF140)

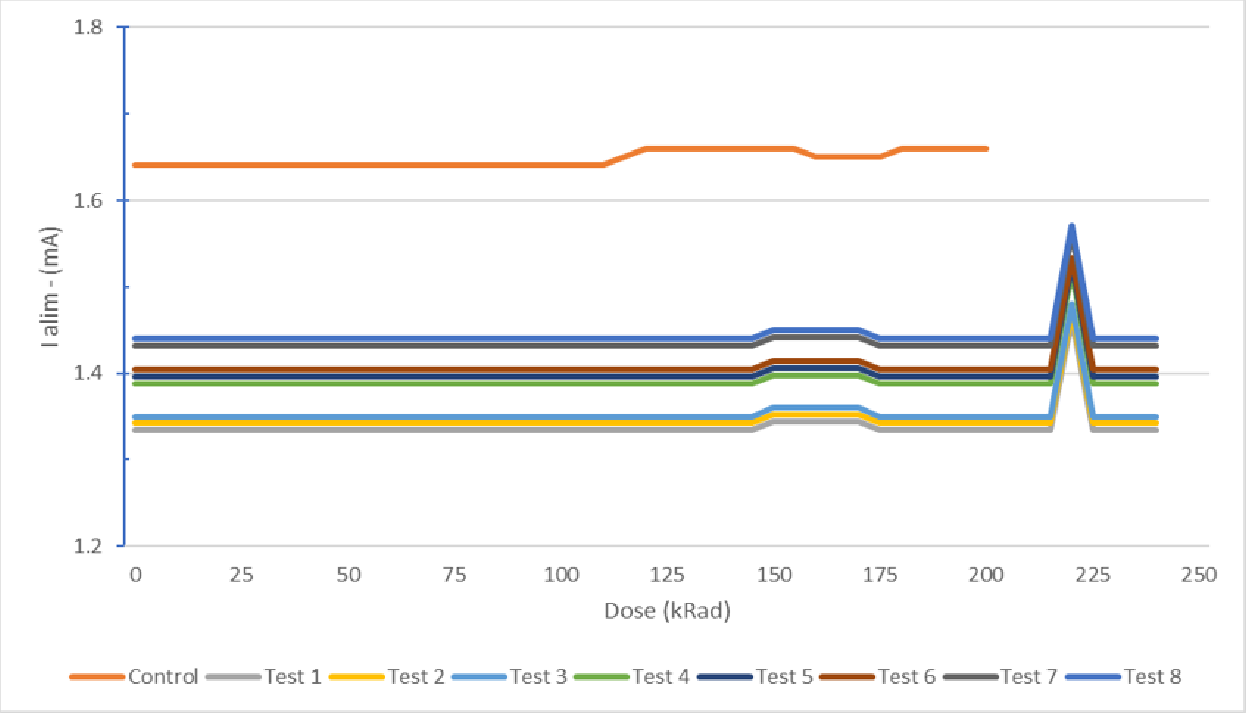


(Figure 9: V2 of IF140)

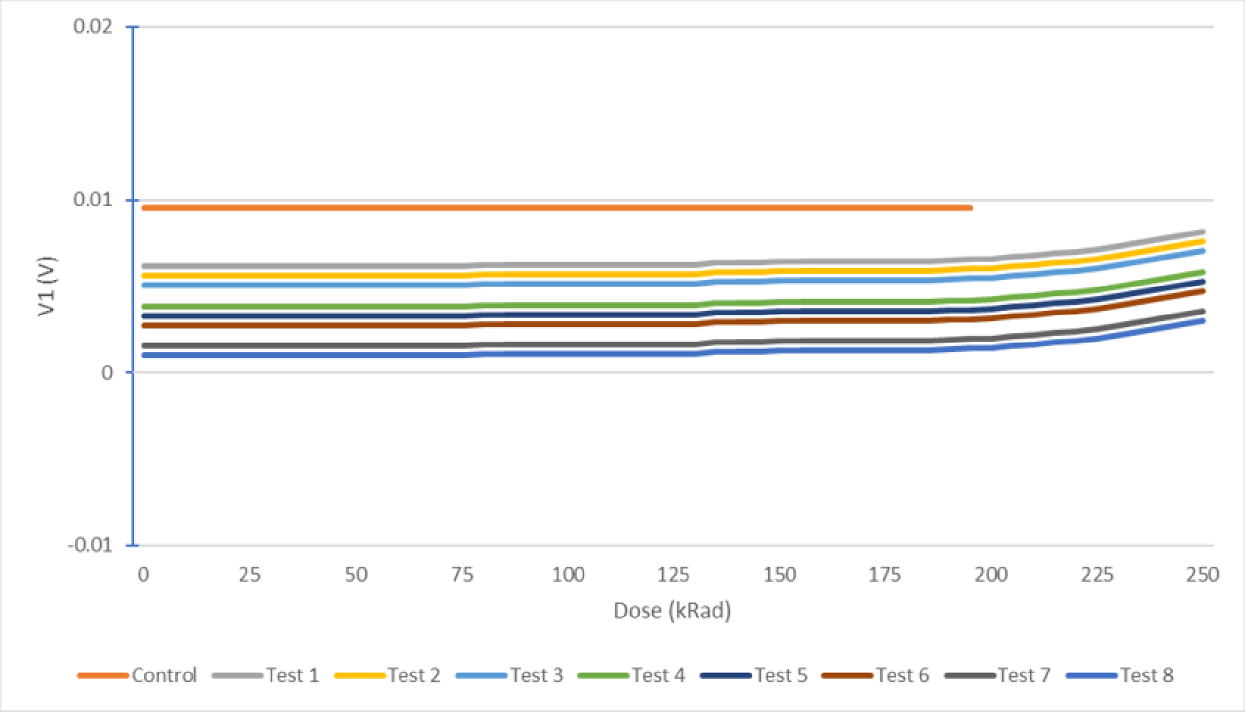
IF3601



(Figure 10: L alim + of IF3601)



(Figure 11: L alim – of IF3601)



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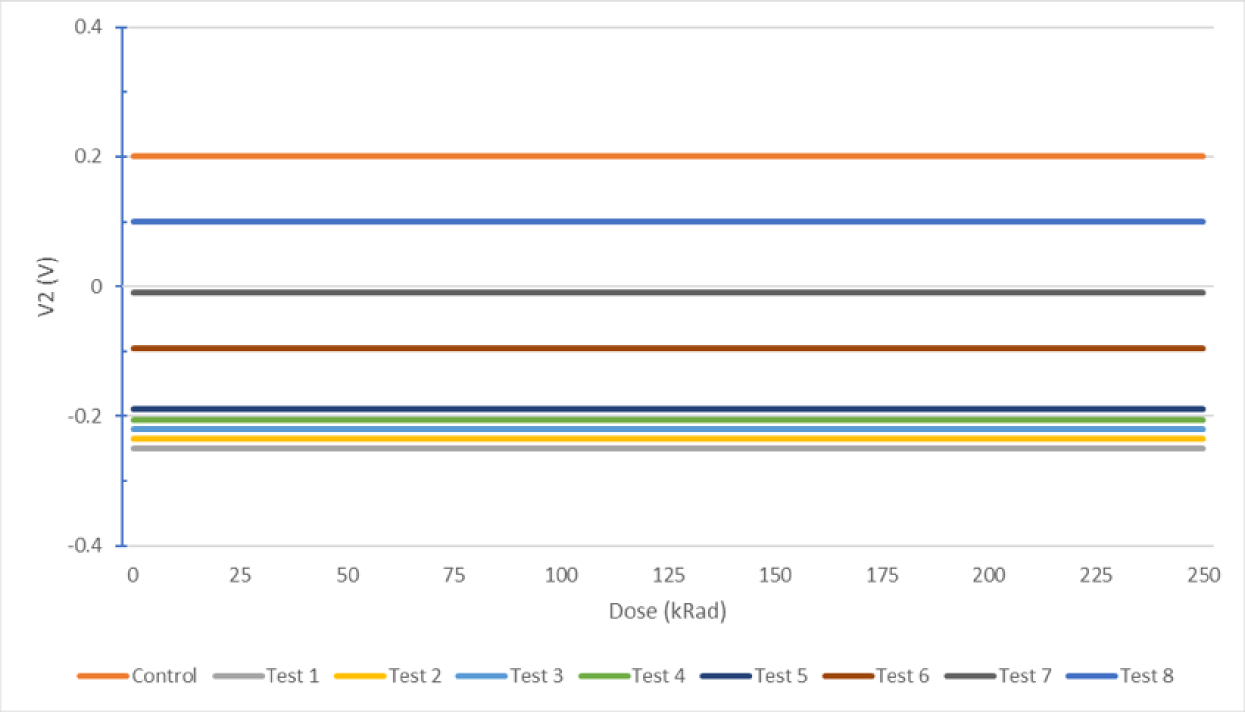
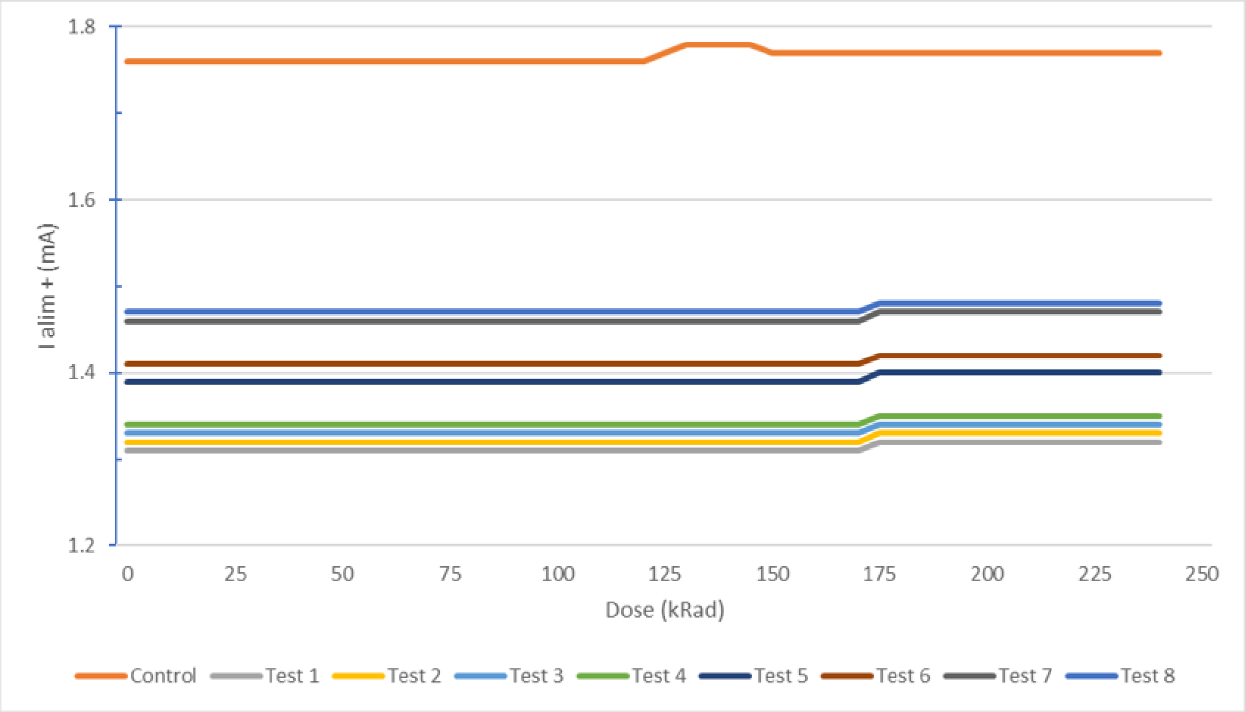
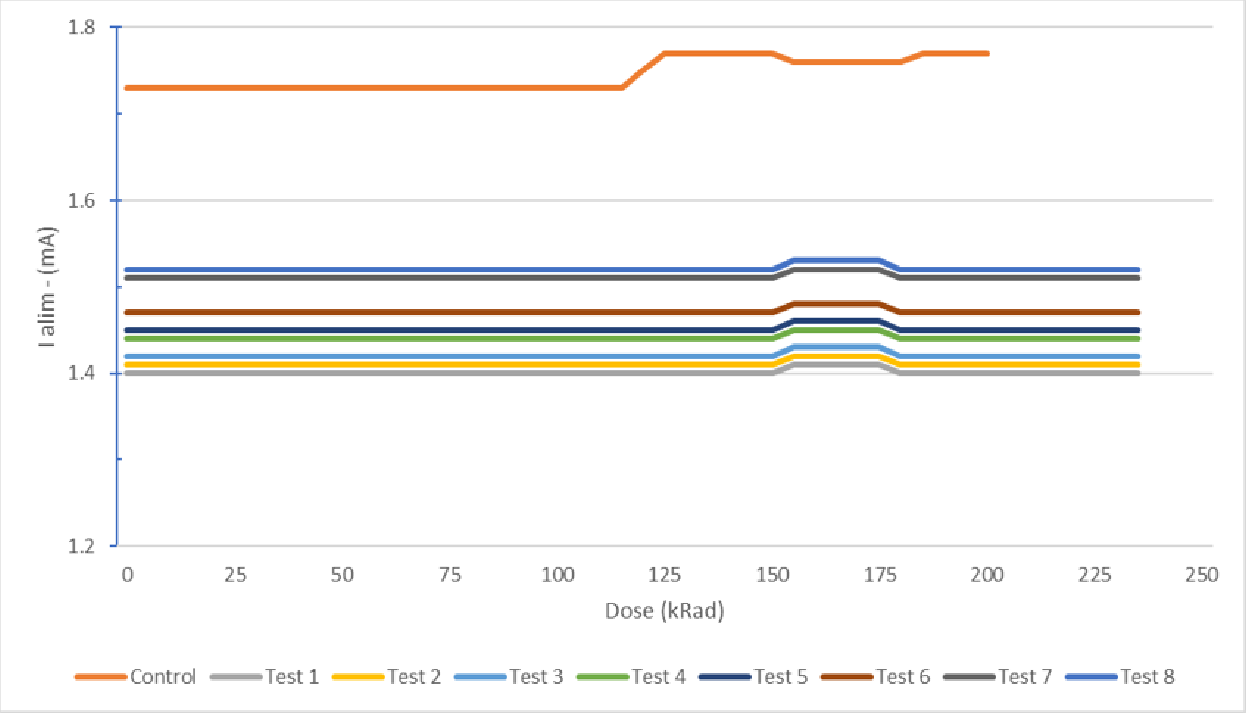


(Figure 13: V2 of IF3601)

IF9030



(Figure 14: I alim + of IF9030)



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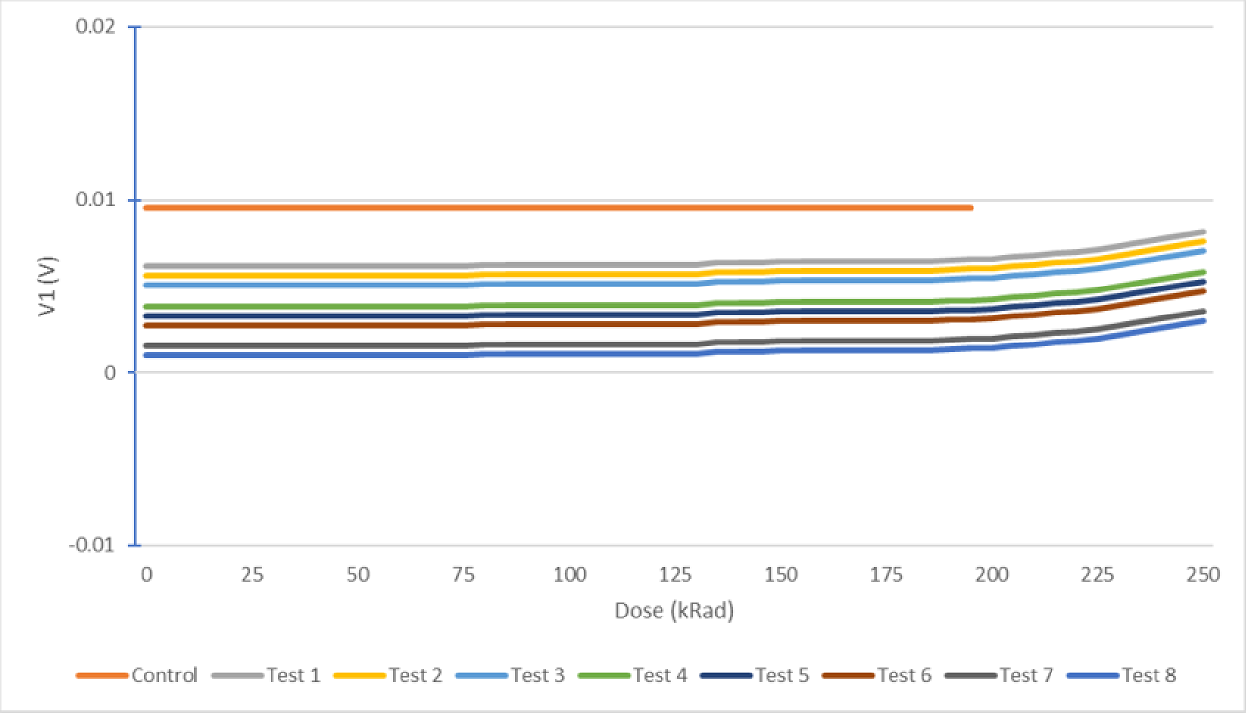
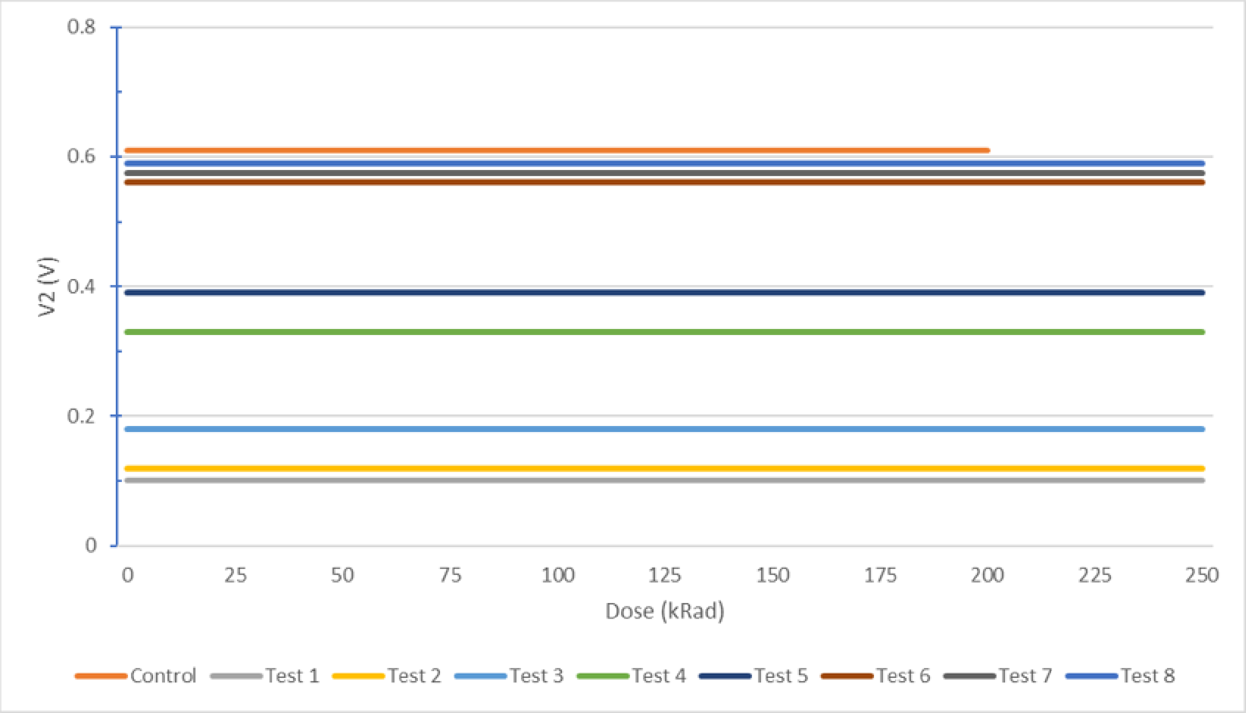
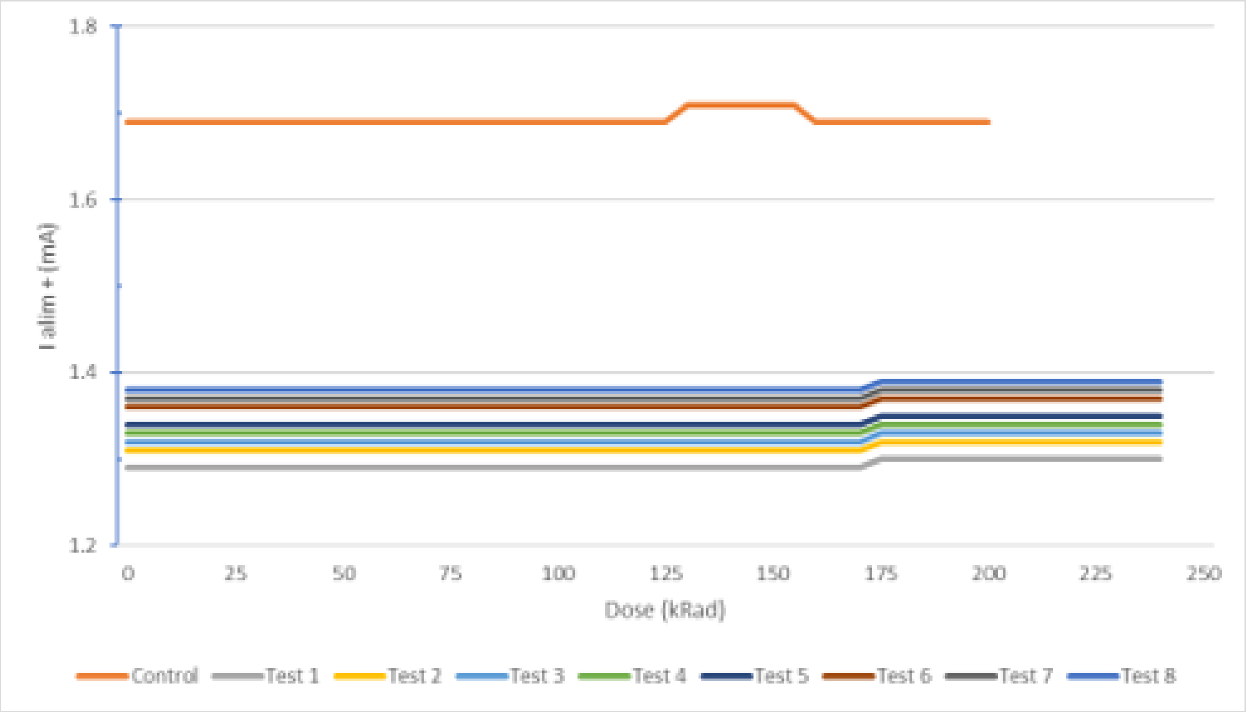


(Figure 16: V1 of IF9030)



(Figure 17: V2 IF9030)

IF1320



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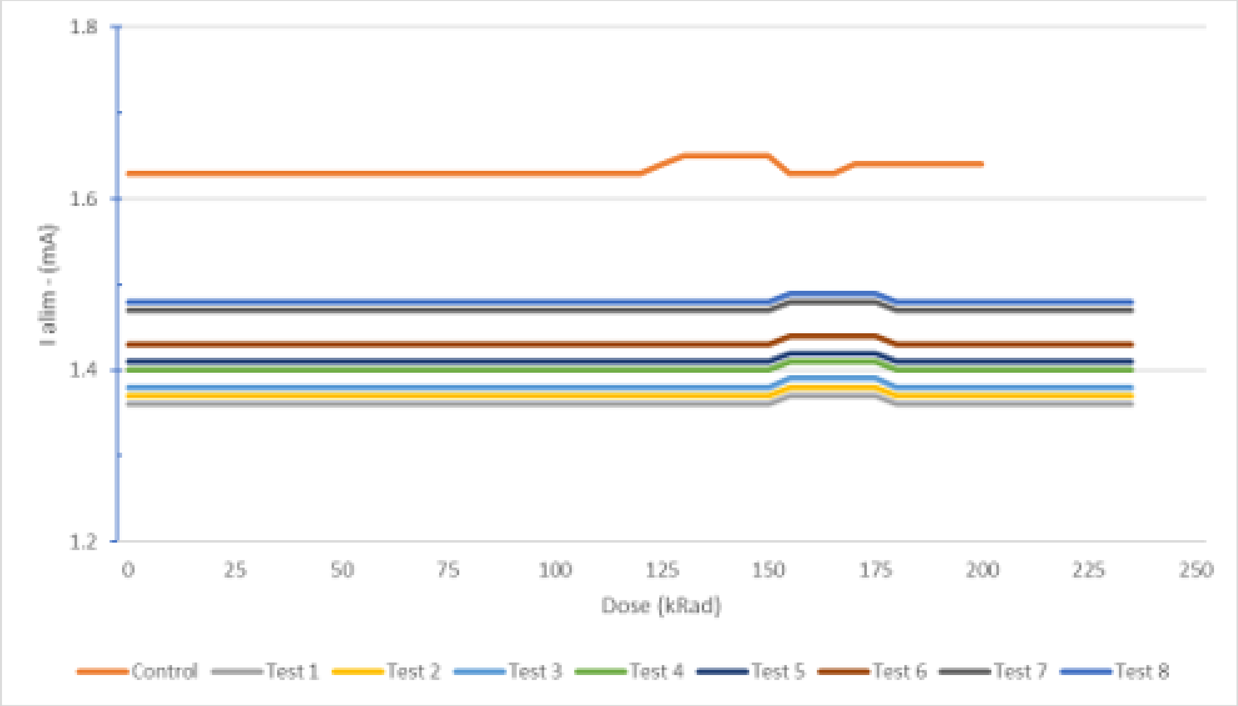

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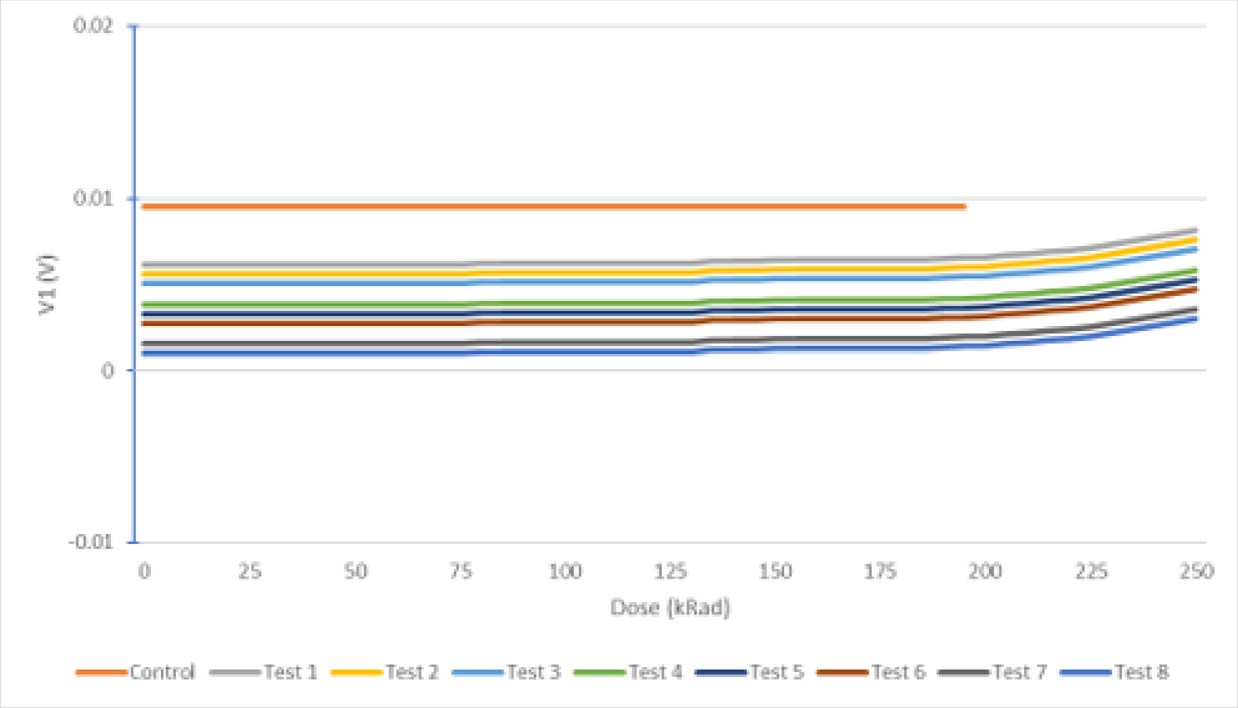

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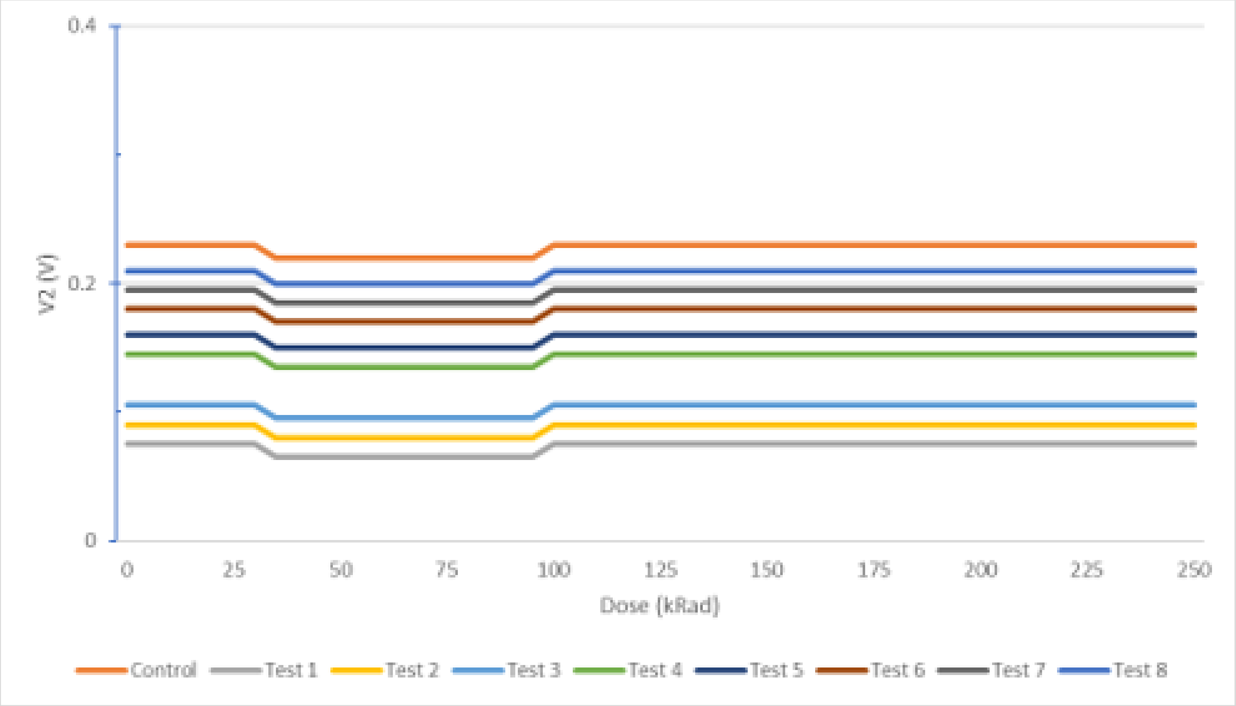

(Figure 21: V2 of IF1320)

Citations

Figure 1: Radiation Effects on Electronics 101 (sharepoint.com)

Figure 2-4:U309 N-Channel Silicon Junction Field Effect Transistor Total Ionizing Dose Characterization Report (nasa.gov)
Figure 5: NASA Goddard Space Flight Center's Compendium of Radiation Effects Test Results

Figure 6-21:jfet-radiation-tolerance-ctc-028-interfet.rx1.pptx