


«Elli fu amore, che, trovando nui,
meco restette che venia lontano,
a guisa d'un arcier presto soriano,
acconcio sol per uccider altrui.» G. Cavalcanti

# Spoke 8
# Total Ionizing Dose Tolerance of CNN-Enabled Microcontrollers for Space Applications


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## 1. Introduction

**Onboard Artificial Intelligence (AI) is crucial for autonomous space missions**, as it enables real-time data processing and decision-making in environments where communication and ground control are constrained. It is particularly important for robotic swarms, which require continuous coordination and collision avoidance. In space environments, electronic devices can be affected by ionizing radiation [1]. Most radiation reliability studies on AI systems rely on high-power GPUs, which are unsuitable for energy-constrained space missions [2].

**Our work investigates low-power edge AI systems based on MicroController Units (MCUs) implementing Convolutional Neural Networks (CNNs) and evaluates their radiation tolerance, starting from Total Ionizing Dose (TID) effects.**

## 2. Experimental Setup

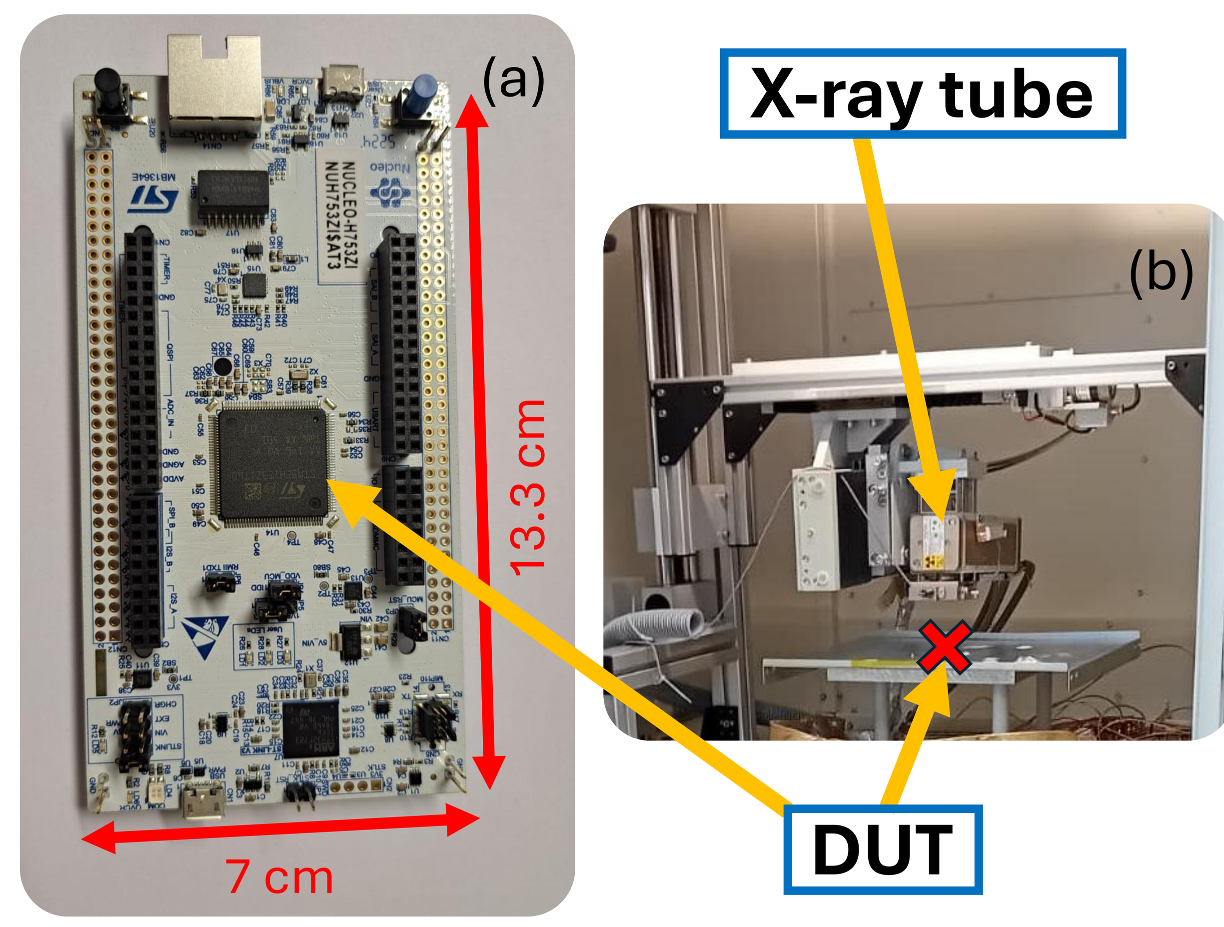
**STM32 (a):** widely known and commercially available on the market, characterized by low supply current requirements and native support for AI execution.

**Irradiation facility (b):** 10-keV X-ray tungsten irradiator (Department of Physics and Astronomy, University of Padova).

**CNN:** a simple 4-layer CNN for image recognition. It processes 28×28 pixel images of handwritten digits and outputs the probability associated with each digit class.

**Objectives:**

- Evaluation of the **STM32 tolerance to TID** for space applications and identification of **radiation-induced failures**
- Monitoring of key **parameters** under irradiation, including clock waveform and frequency, current consumption, ADC and DAC signals, internal voltage reference, memory integrity, and CNN inference.

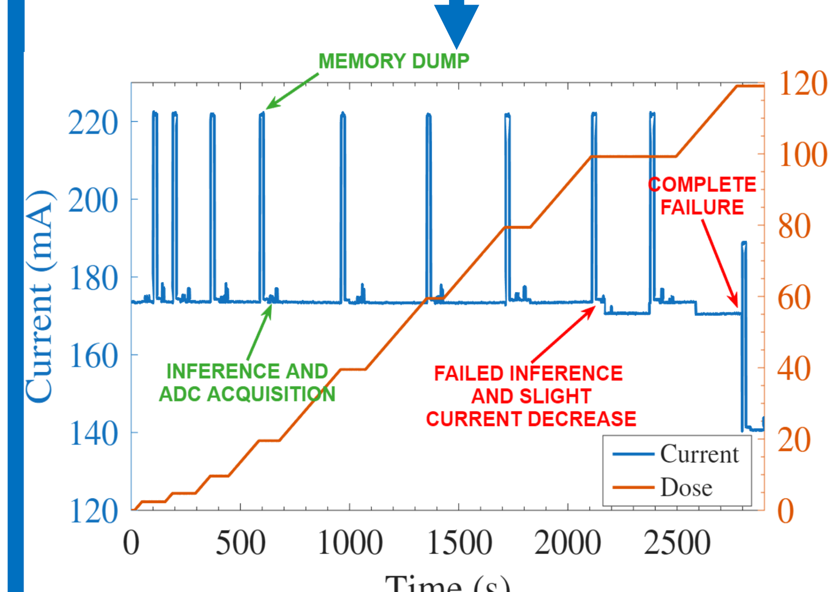



## 3. Results and Discussion

Proper MCU operation and stable CNN performance are observed **up to 100 krad($SiO_2$)**. Beyond this dose, failure occurs, causing the inference to produce no output, and the device under test enters a faulty state.

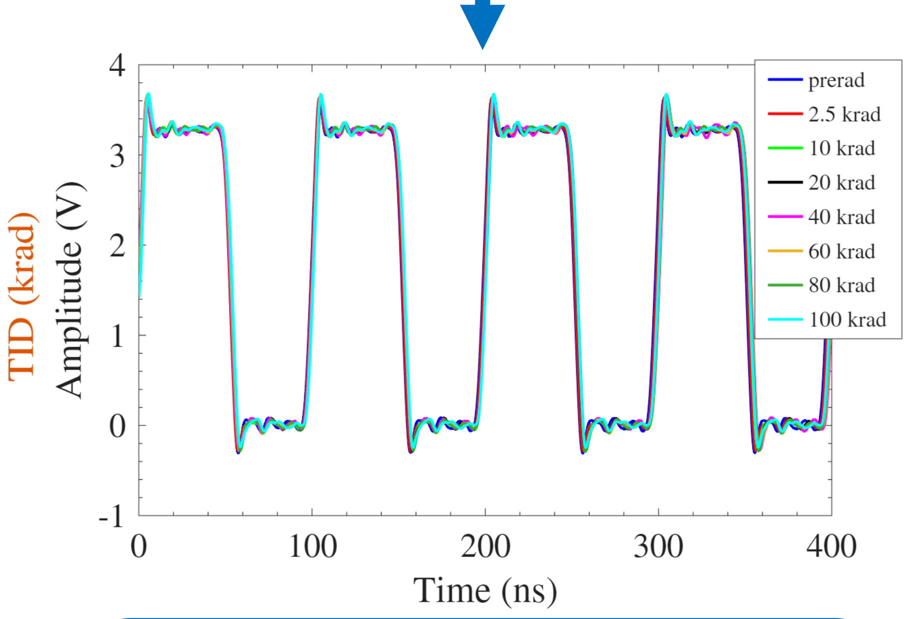
**Absorbed current**

Increasing TID leads to inference failure with a slight decrease in current consumption, followed by complete device failure at doses >100 krad($SiO_2$)



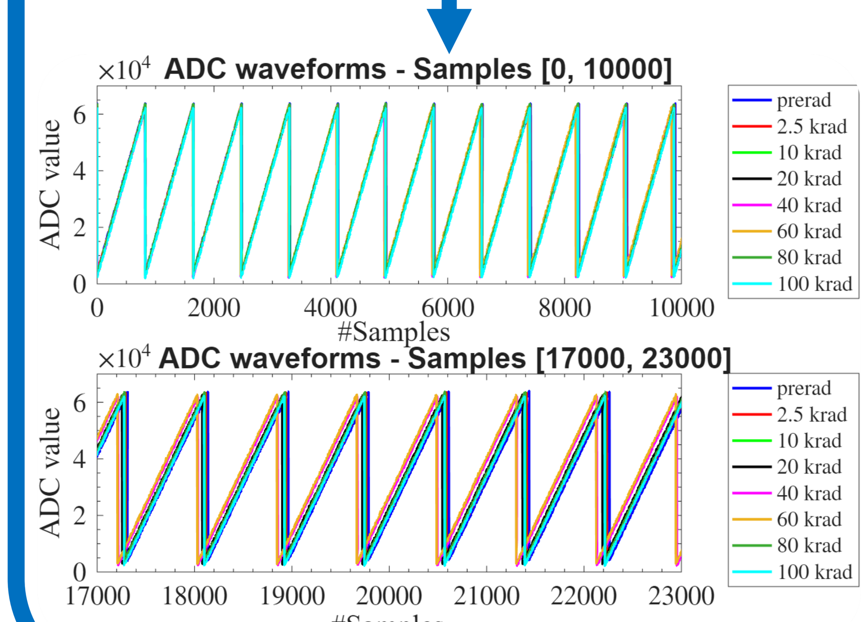

**Clock**

Measured clock waveforms show minimal distortion by increasing dose → stable clock amplitude and timing despite accumulated radiation dose



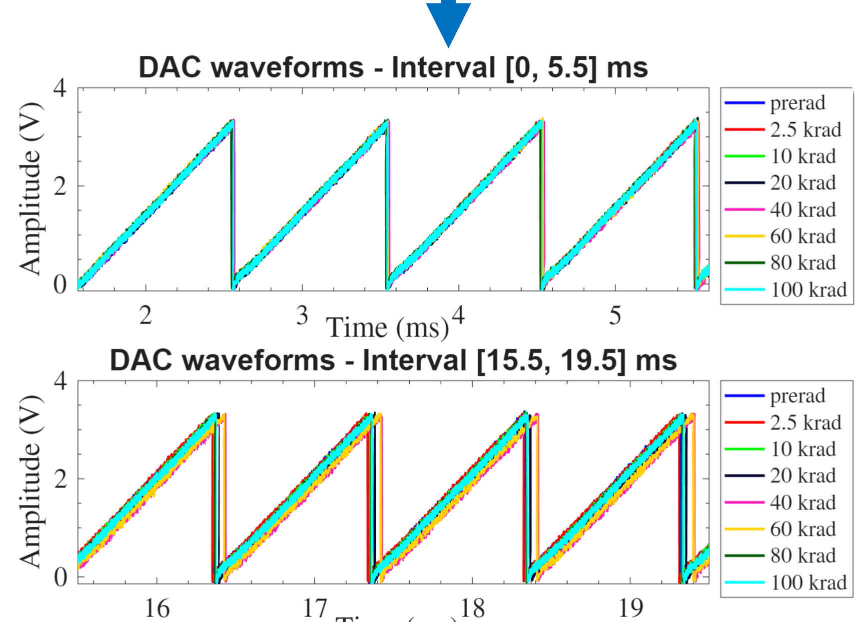

**ADC**

Progressive offset variations → small gradual leftward shifts were observed for increasing doses

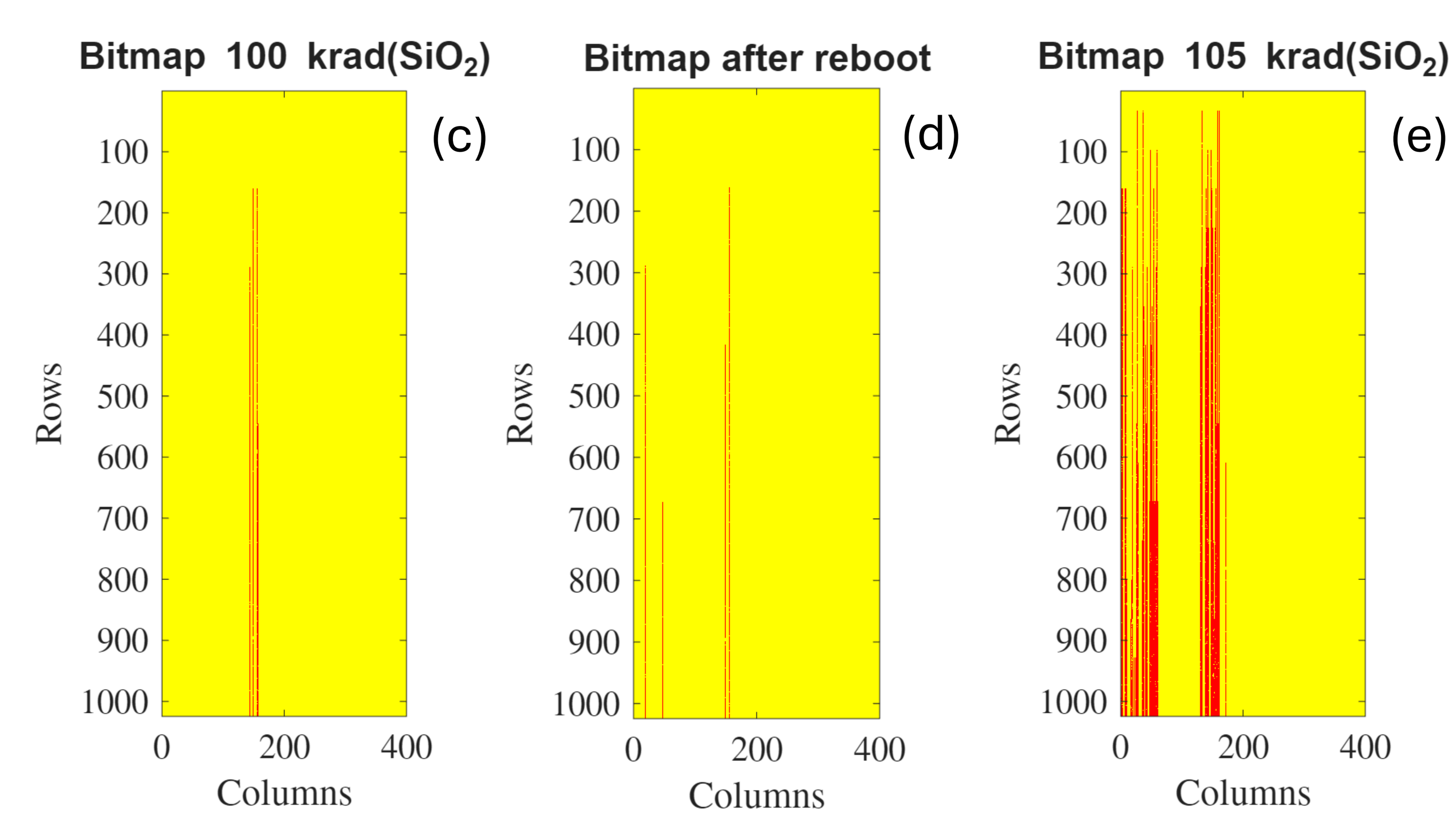



**DAC**

Progressive offset variations → small gradual rightward shifts were observed for increasing doses




**Flash memory:** At 100 krad($SiO_2$), the bitmap column-patterned memory differences are highlighted in red (c), partially reappearing after reboot (d). At 105 krad($SiO_2$), many more columns with differing bits are observed (e). This error pattern suggests **a malfunction in the memory read circuitry** rather than isolated bit corruption.




**CNN output:** CNN output probabilities **remain identical** across all dose steps up to 100 krad($SiO_2$); beyond this point, the system enters a faulty state and no probabilities are recorded nor given as output.

## 4. Summary

- Failure observed **only at doses >100 krad($SiO_2$)**, possibly due to a malfunction in the memory read circuitry.
- Encouraging level of **radiation tolerance** of low-power MCUs → suitability for future space edge AI applications
- Further investigation required to assess Single Event Effects (SEEs)

## References


[1] D. M. Fleetwood, "Radiation Effects in a Post-Moore World ," *IEEE Trans. Nucl. Sci.*, vol. 68, no. 5, pp. 509-545, May 2021

[2] P. Rech, "Artificial Neural Networks for Space and Safety-Critical Applications: Reliability Issues and Potential Solutions," *IEEE Trans. Nucl. Sci.*, vol. 71, no. 4, pp. 377-404, April 2024