

NISoC: An Integrated Solid-State Platform for Neutron Detection, Radiography, and Dosimetry

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Team and NISoC Overview:

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- **Patented**
- **Peer-Reviewed**
 - T. Hossain, et. al. *Thermal Neutron Measurements with an Unpowered, Miniature, Solid-State Device*, Nuclear Instruments and Methods in Physics Research A 165577 (2021).
- The **Neutron Intercepting System on a Chip (N/SoC)** is an integrated system-on-a-chip style platform capable of neutron detection, neutron radiography, and dosimetry.
- NISoC is manufactured using CMOS processes, allowing for a size, weight, power, and cost (SWaP-C) advantage.

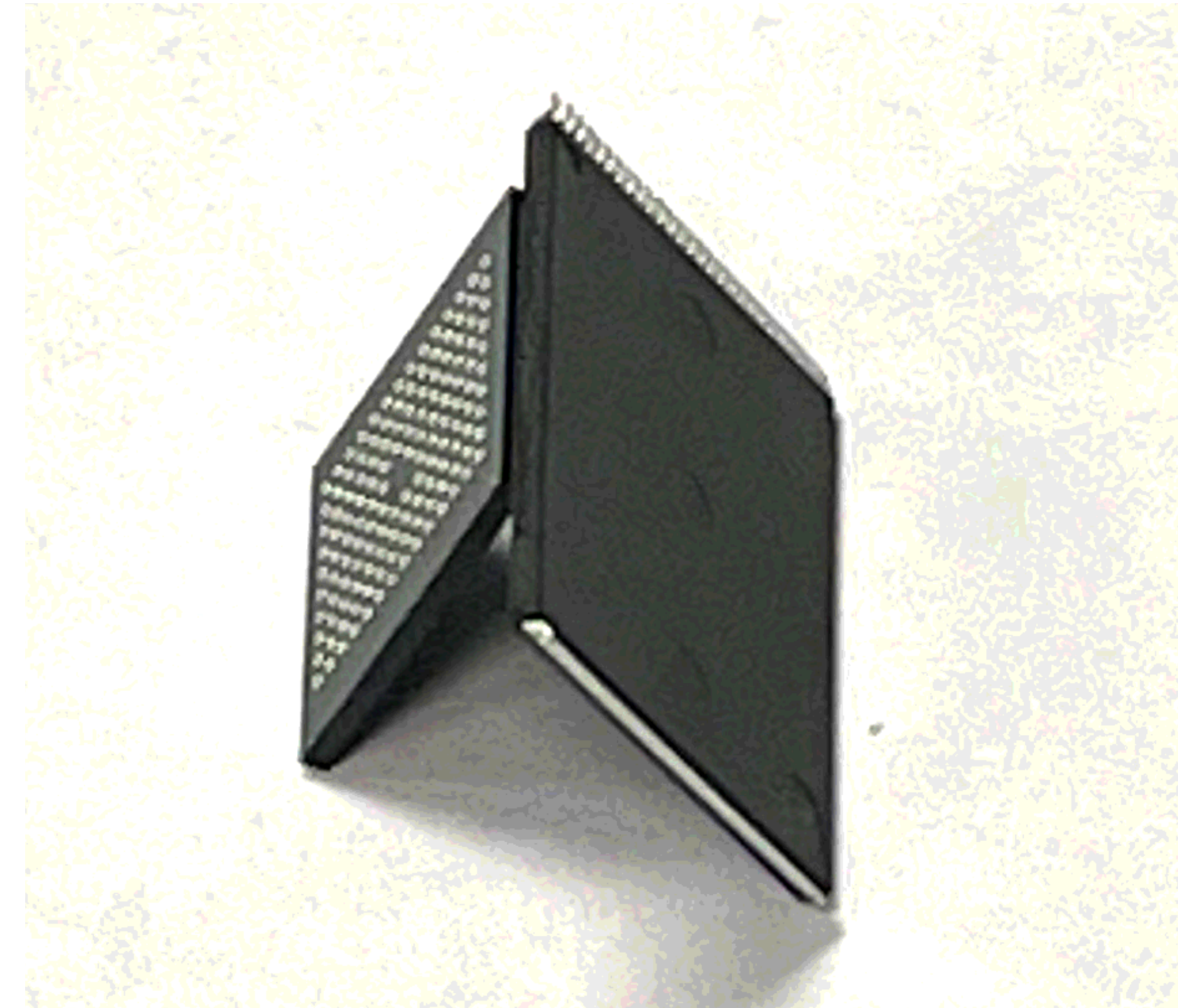
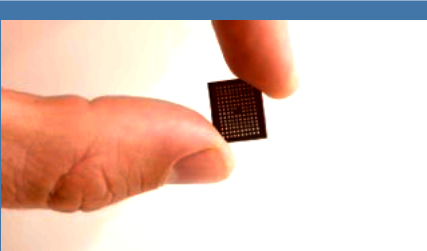


Fig 1: NISoC prototype devices packaged in BGA (left) and TSOP (right) packaging. Standard packaging allows for seamless integration into modern electronic systems.



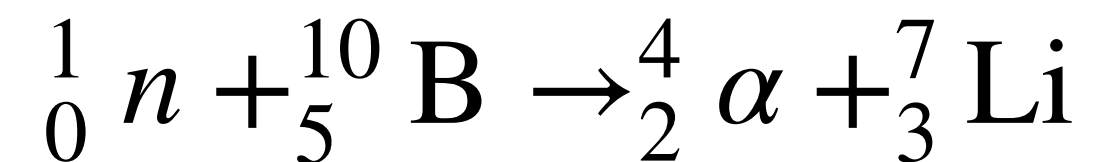
Named as 2020 Intelligence National Security Alliance Honoree “as a potentially groundbreaking solution to some of the most critical and high-priority challenges that the U.S. Intelligence Community (IC) faces.”

Other Neutron Detecting Technologies Compared:

Technology	Typical Voltage	Typical Deadtime	Spatial Resolution	Temperature Sensitivity	Vacuum / High Pressure	Invented before 1960	Analog or Digital	Photo w\o power, cables
³ He Proportional Detectors	10,000V	s	10mm	Moderate	Yes	Yes	Analog	
¹⁰ BF ₃ Proportional Detectors	10,000V	s	10mm	Moderate	Yes	Yes	Analog	
Boron-Lined Proportional Detectors	10,000V	s	10mm	Moderate	Yes	Yes	Analog	
Photomultiplier Tube Detectors	2,000V	ns-s	1mm	Moderate	Yes	Yes	Analog	
Silicon Photomultiplier Detectors	30V	ns-s	1mm	High	No	No	Analog	
Other Solid-State Technology	Various	Various	Various	Often Require Cryogenics	Often	No	Analog	
<i>NISoC</i>	<i>None or 3V</i>	<i>None</i>	<i>0.001mm</i>	<i>None</i>	<i>No</i>	<i>No</i>	<i>Digital</i>	

Neutron Intercepting System on a Chip (NISoC) Overview:

- NISoC's sensitive element is a MOSFET style transistor traditionally used in non-volatile memory applications, referred to as a “MirrorBit” or NROM transistor.
- Electric charge is stored in two bits per cell.
- Neutrons interact with ^{10}B in surrounding BPSG to create ionizing radiation via:



- This ionizing radiation depletes the stored charge in relevant cells, resulting in a measurable threshold voltage shift.
- Current prototypes contain over 1 billion sensitive elements.

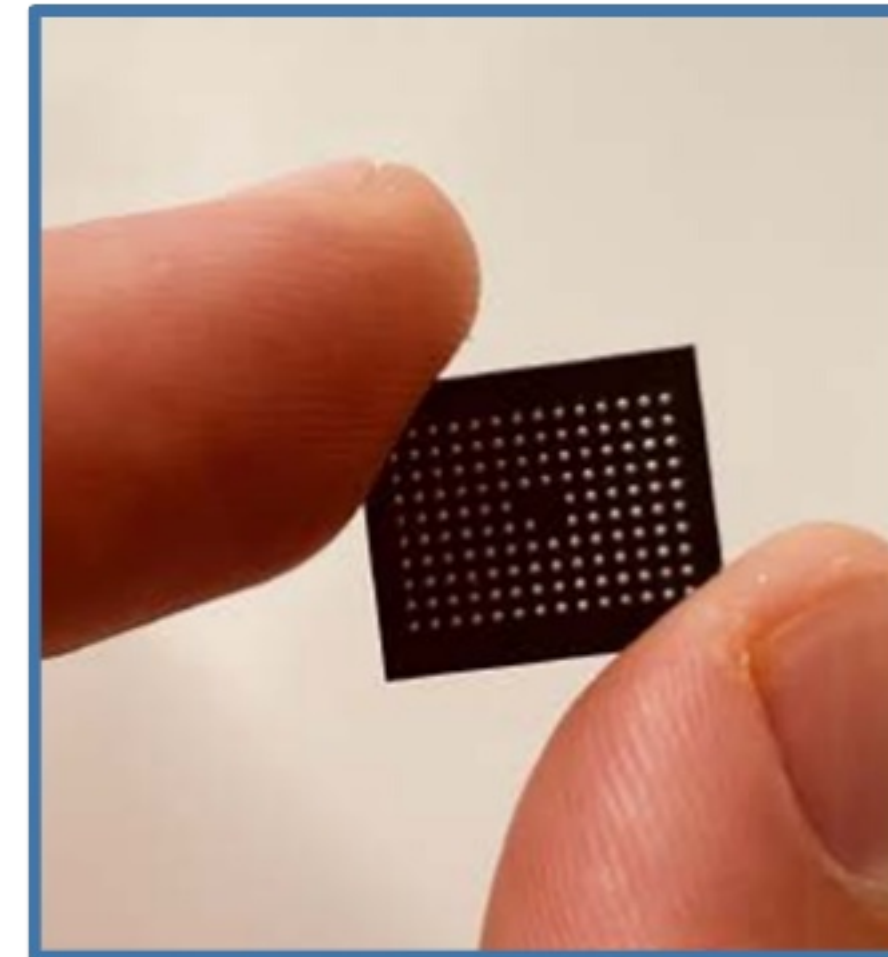


Fig 2: 1Gb, 65nm node size test device.

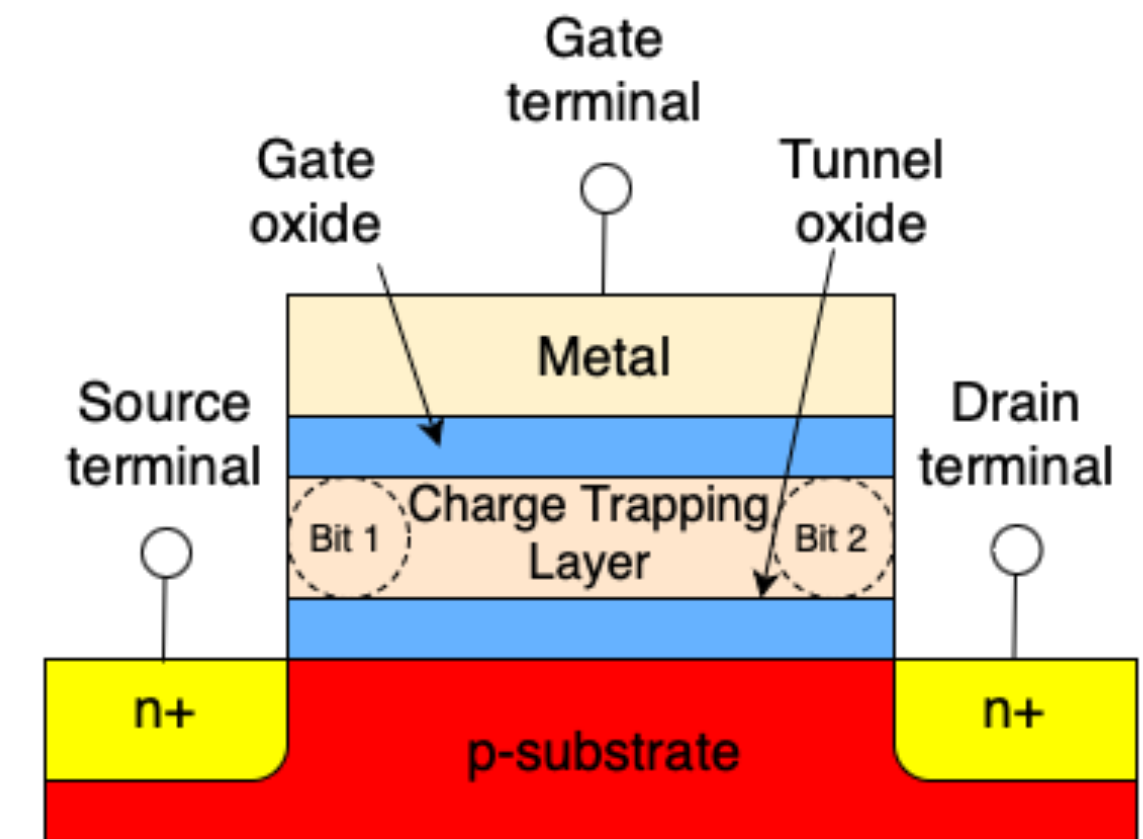


Fig 3: NROM transistor cross section.

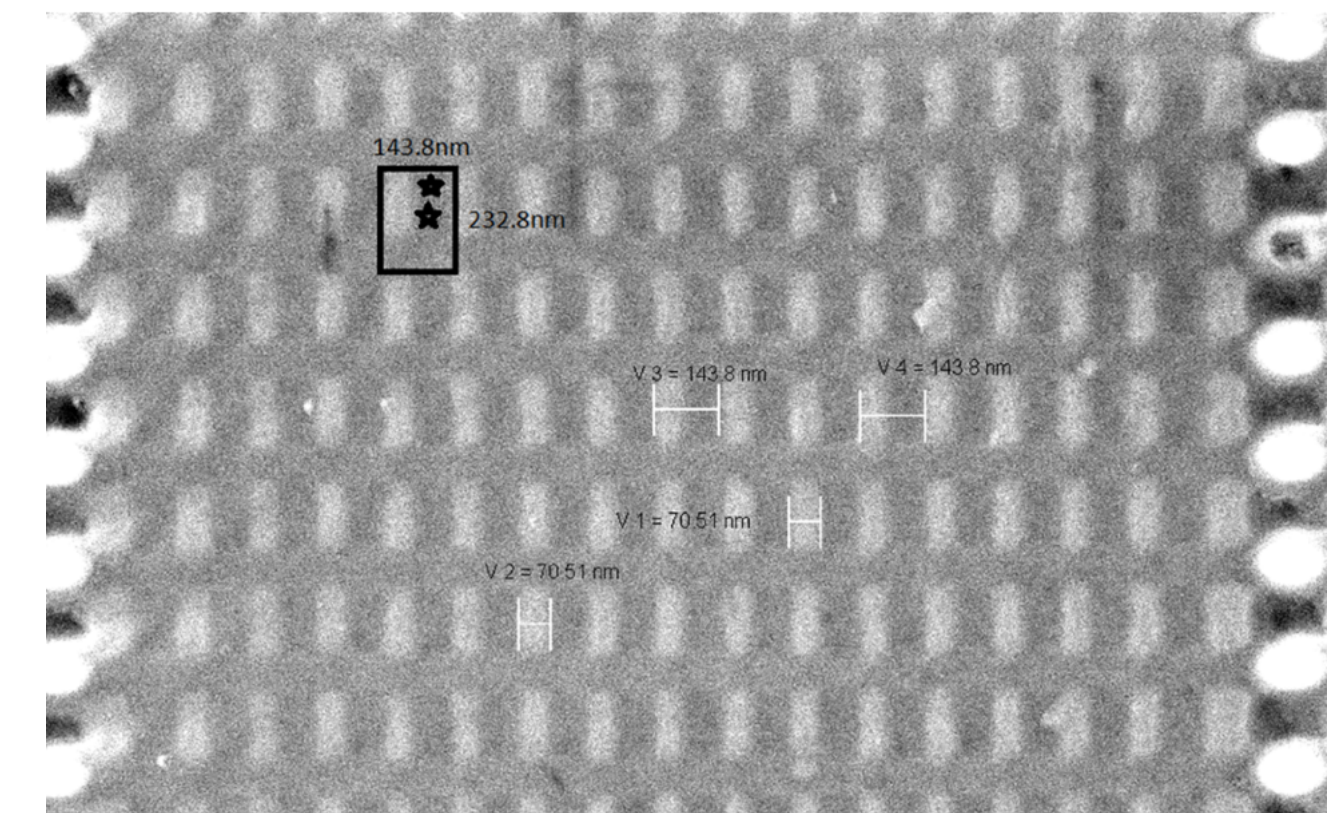


Fig 4: Top-down view of arrayed NROM cells.

NISoC Operation:

- Before irradiation, the threshold voltage is recorded for each bit (V_{th}).
- After irradiation, the *threshold voltage shift* (ΔV_{th}) is calculated on a **per bit basis**: $\Delta V_{th} = V_{th,Pre} - V_{th,Post}$
- A cutoff value is used to separate interacted bits (signal) from non-interacted bits (background).
- The recorded signal is the summation over all ΔV_{th} less than the cutoff value ($\sum \Delta V$).

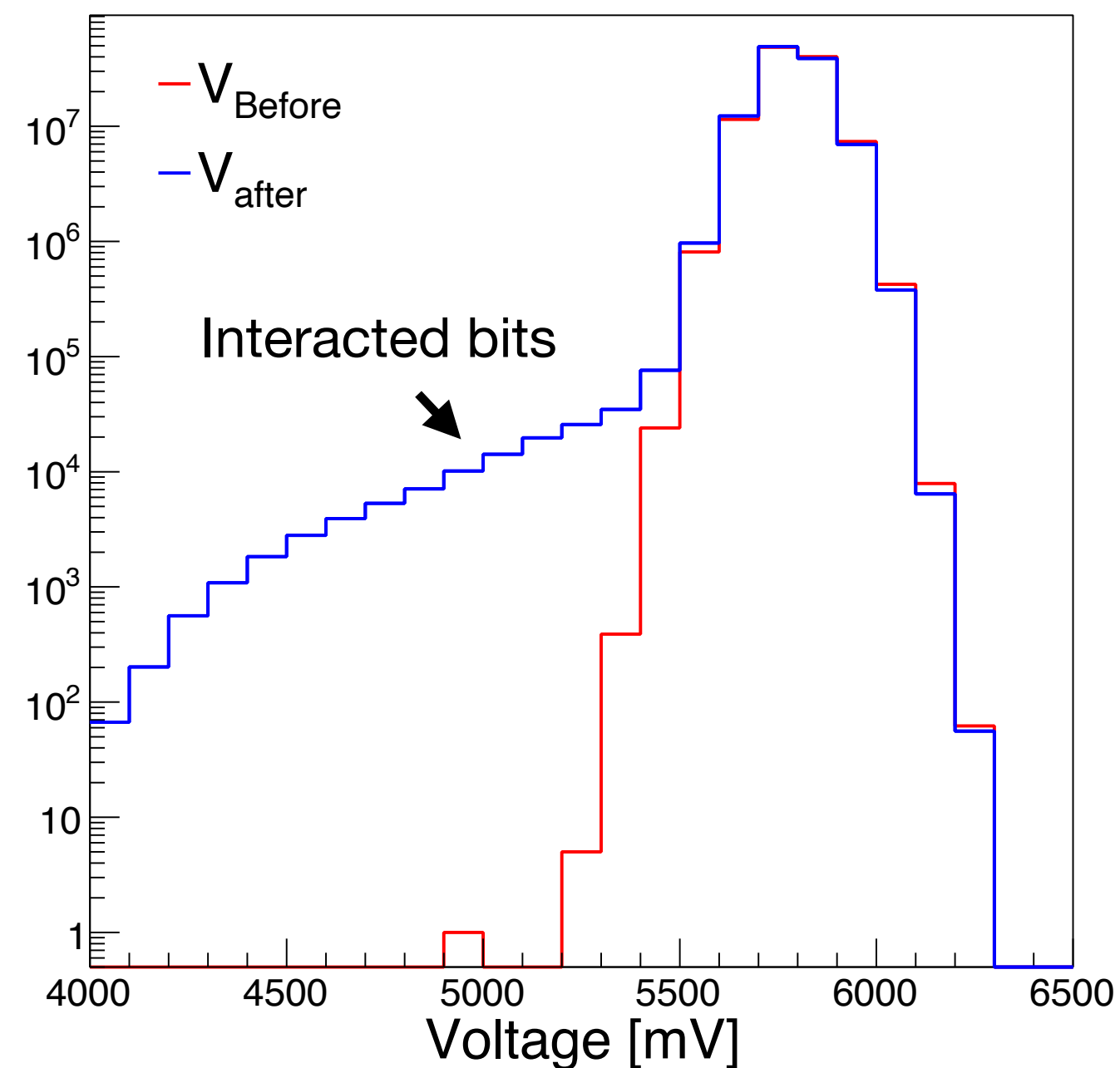


Fig 5: Threshold voltage distribution before (red) and after (blue) irradiation.

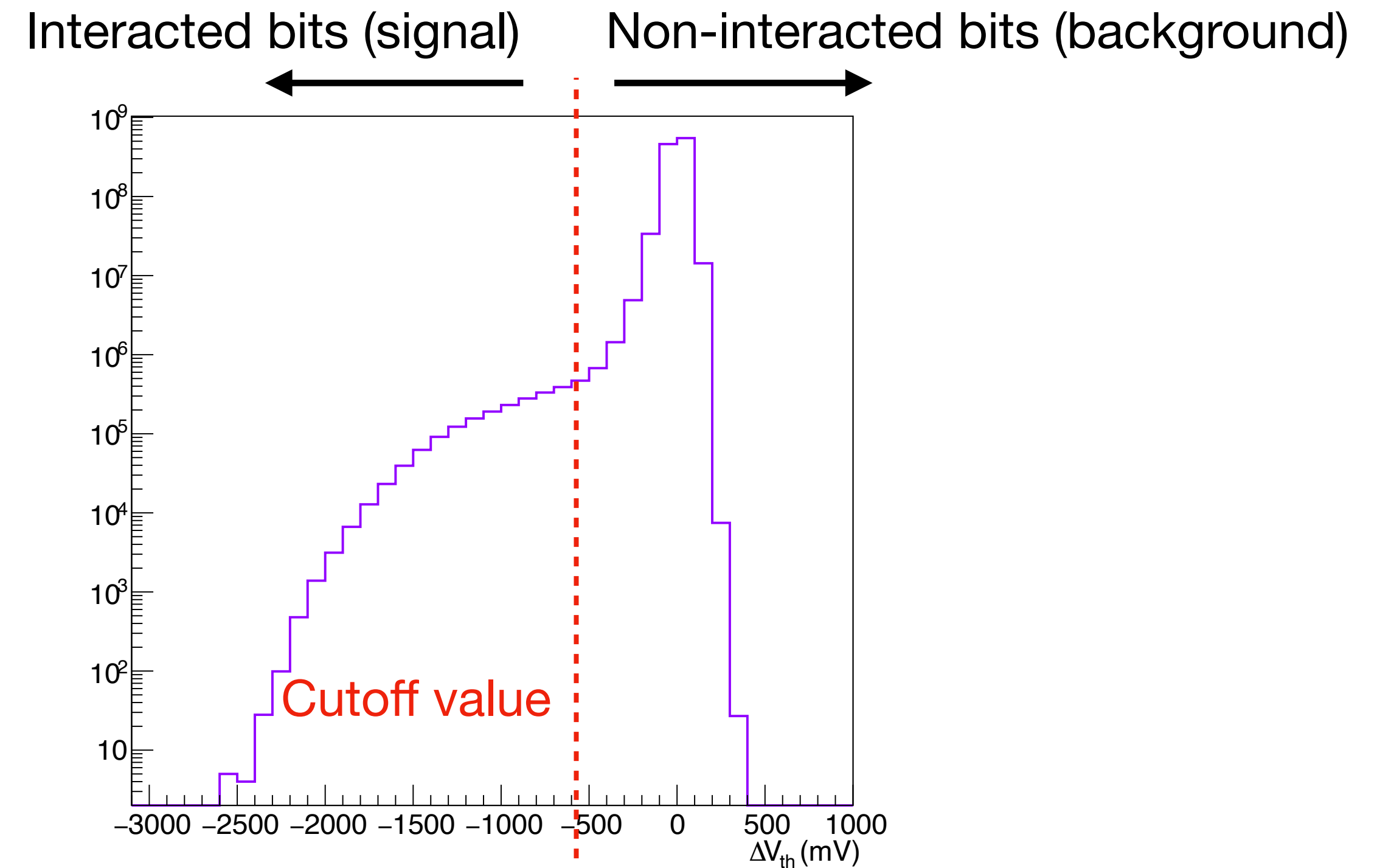


Fig 6: Threshold voltage shift distribution.

NISoC Thermal Neutron Dosimetry:

- Extensive thermal neutron irradiations have been performed at the UT-Austin NETL TRIGA reactor (Fig 5).
- Results from these irradiations currently demonstrate a power-law relationship across six orders-of-magnitude with respect to thermal neutron fluence.



Fig 7: 3D printed device holder (yellow), NISoC prototypes (black, labeled), gold foils & cadmium covered gold foils.

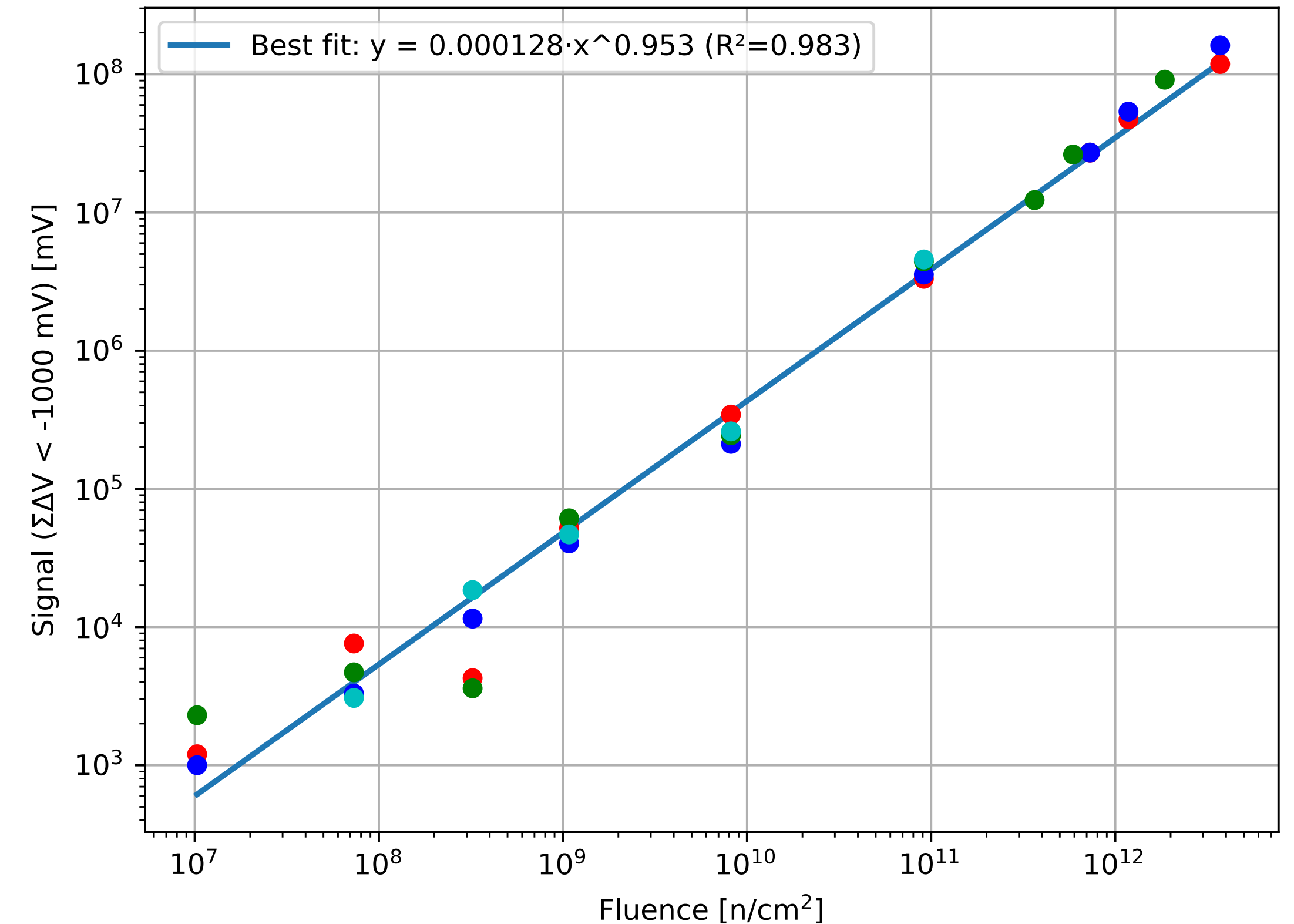


Fig 8: Recorded signal vs thermal neutron fluence for various irradiations.

NISoC Imaging Device Operation:

- The device can operate in two separate modes:
 - Sector mode: number of bit flips per sector.
 - Subsector mode: Threshold voltage shift per bit.

The "x-dimension" is
2 (2^1) regions wide where a
region is 16384 (2^{14}) bits
wide and 3.8mm wide...

Or you could say it is **128 (2^7)
sectors wide** where a sector
is 256 (2^8) bits wide and
0.06mm wide...

Or you could say it is
32768 (2^{15}) bits wide
and **3.8+3.8mm wide**

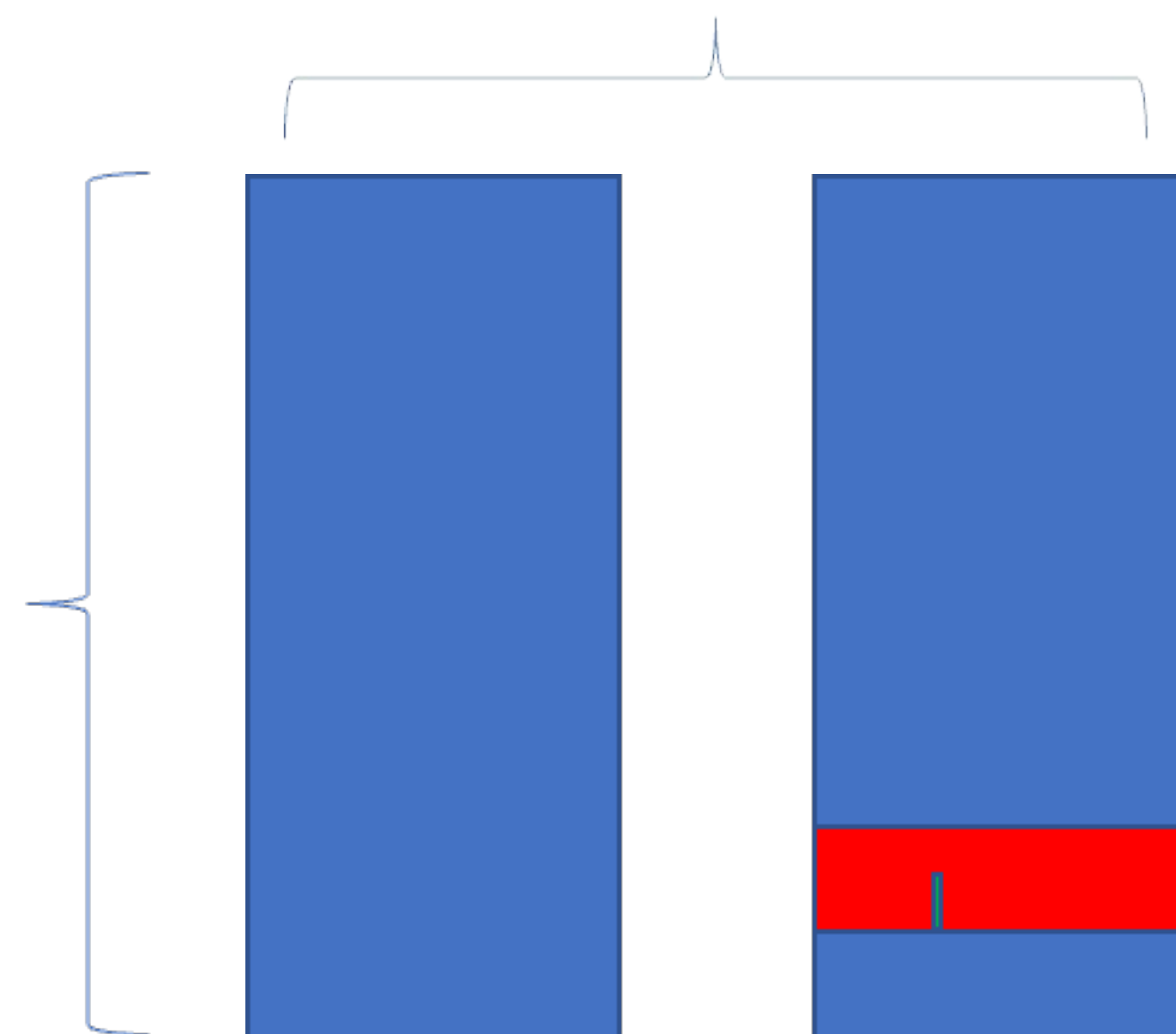
The "y-dimension" is
8 (2^3) regions tall
where a region is 8192
(2^{13}) bits tall and
1.12mm tall

...

Or you could say it is
16 (2^4) sectors tall
Where a sector is 4096
(2^{12}) bits tall and
0.56mm tall

...

Or you could say it is
65536 (2^{16}) bits tall
and **8.96mm tall**



Region (2^{27} bits)
16384 (2^{14}) by 8192 (2^{13}) bits
3.8 by 1.12 mm²



Sector (2^{20} bits)
256 (2^8) by 4096 (2^{12}) bits
0.06 by 0.056 mm²



**There are 2,147,483,648 (2^{31}) bits per chip.
Bits are separated by ~100nm.**

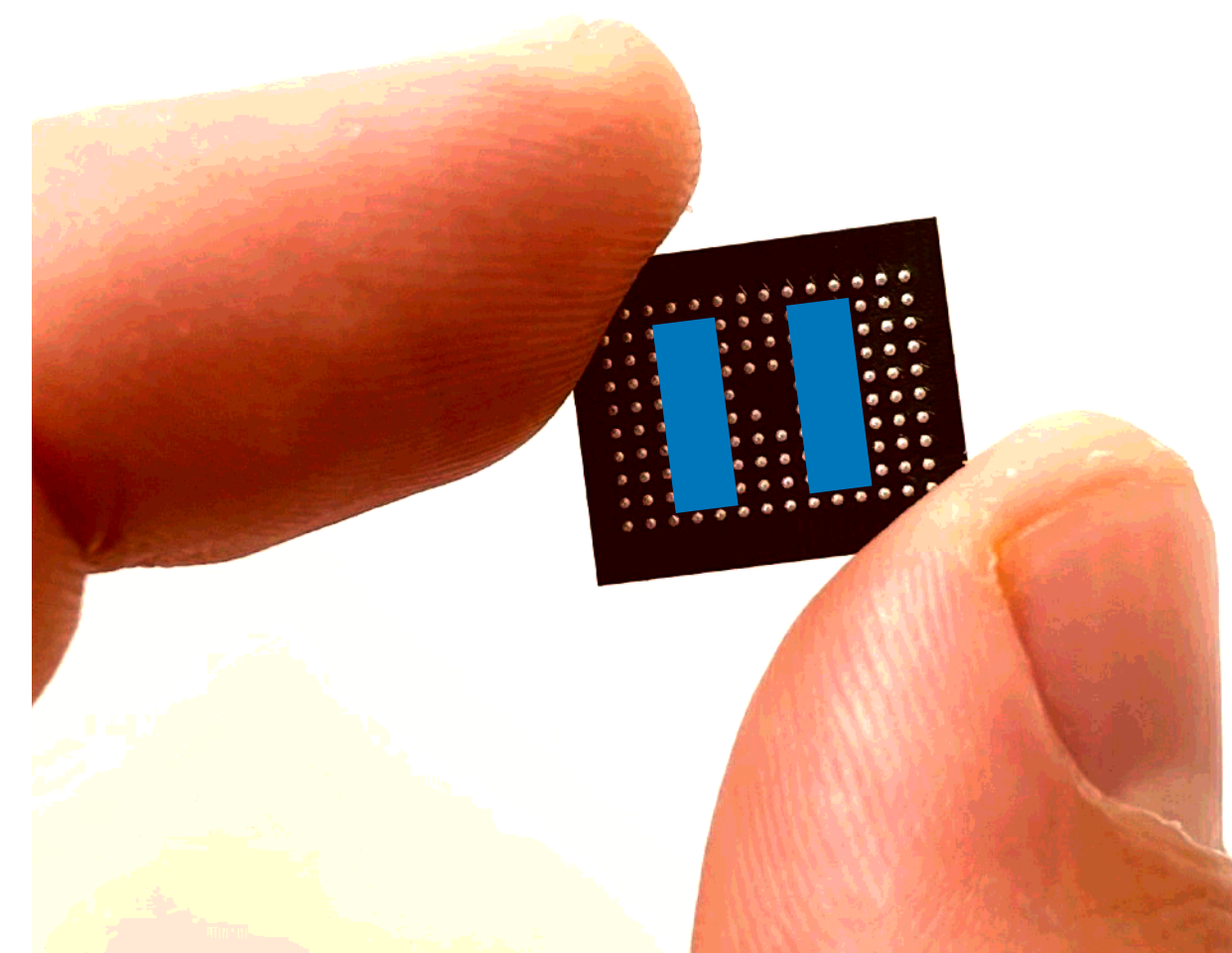


Fig 9: 1Gb prototype device with sensitive element locations overlaid.

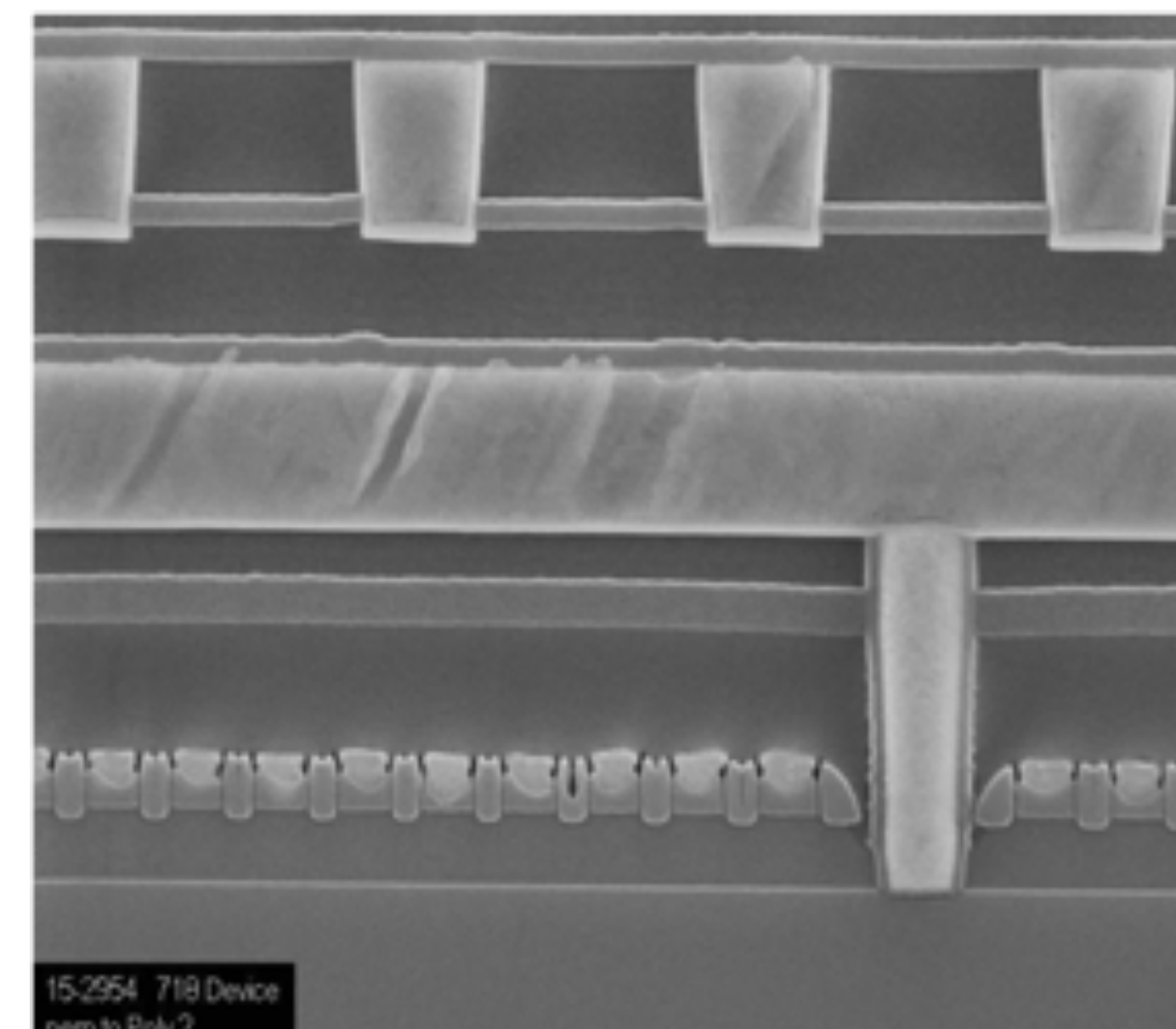


Fig 10: SEM cross section of individual sensitive elements.

NISoC Neutron Imaging & Radiography (sector mode):

- The following neutron radiography study was performed at the (UT-Austin) NETL reactor.
- 4x4 array of NISoC chips exposed to a collimated, thermalized neutron beam.
- Complete setup shown:
 - No cables
 - No power supply
 - No DAQ

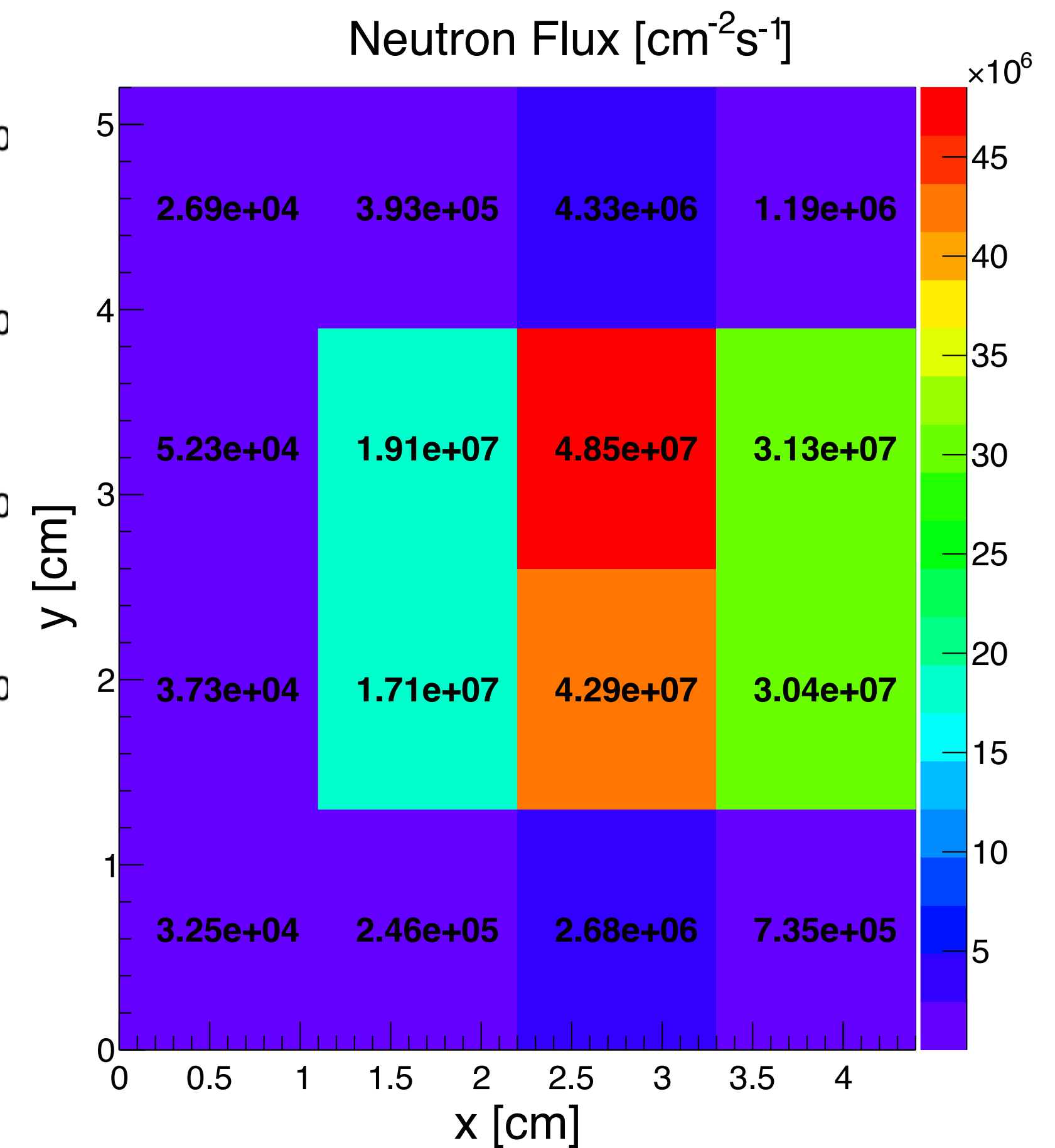
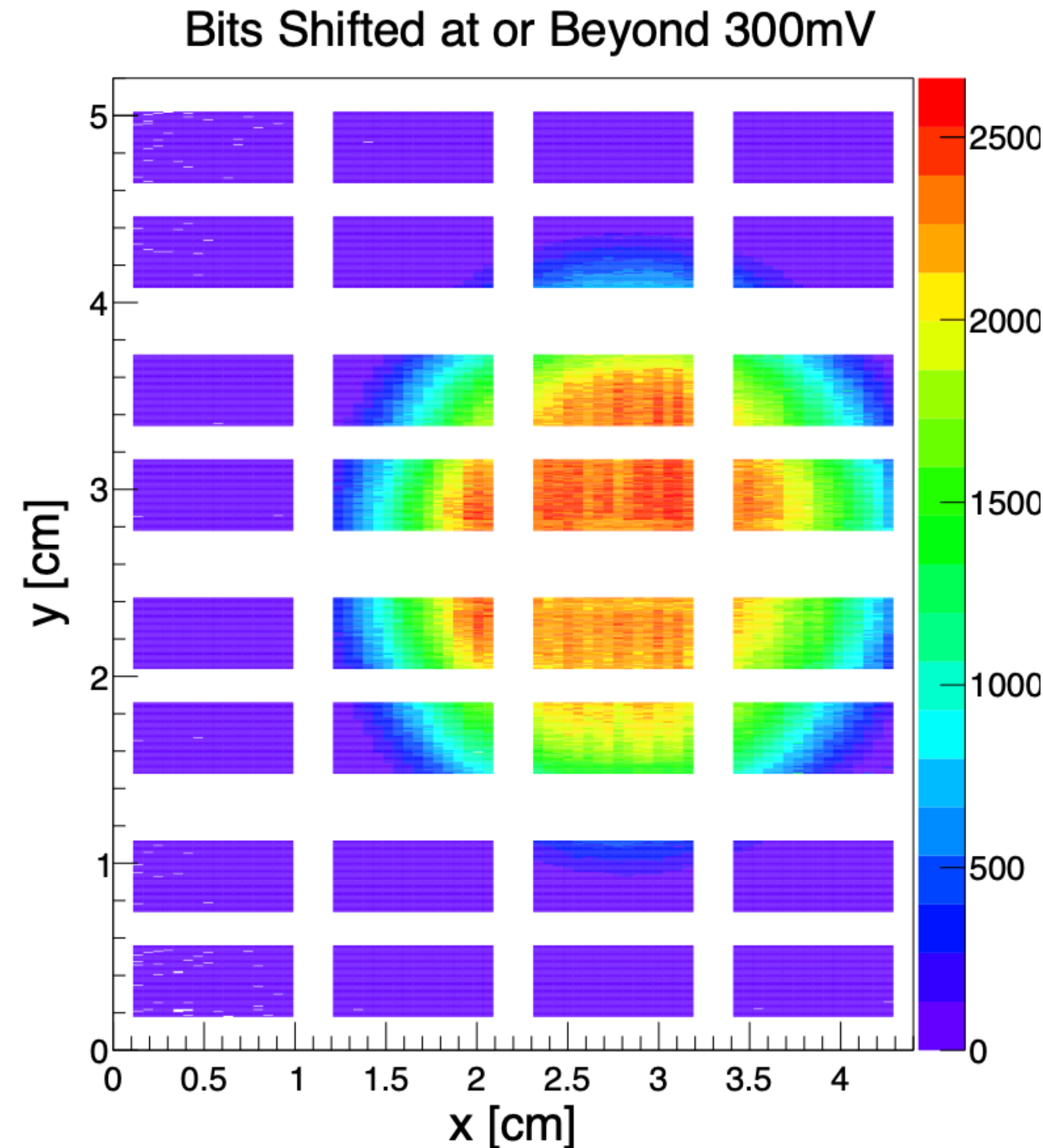


Fig 11: (Left to right) computer rendering of device holder. Physical device holder during irradiation. Resulting NISoC thermal neutron radiograph. Comparable radiograph produced with gold foils.

NISoC Neutron Imaging & Radiography (sub-sector mode):

- Thermal neutron exposure performed with Cadmium Siemens star overlaid.
- MTF formulation applied to multiple edges.
- Currently at $\sim 0.03 \text{ lp}/\mu\text{m}$ ($\sim 33\mu\text{m}$ resolution), however we can still go smaller!
- A past demonstration of this technology yielded **$<10\mu\text{m}$ resolution!**

Pixels are
 $64 \times 64 = 4096$
transistors in
these plots

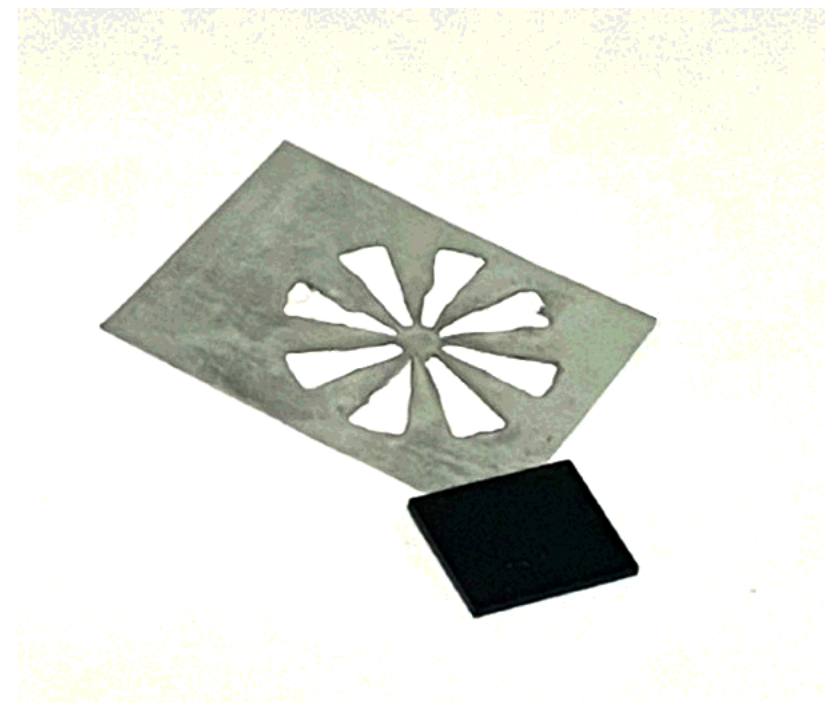


Fig 12: Cadmium Siemens star with NISoC prototype device.

Bits Shifted at or Beyond 300mV

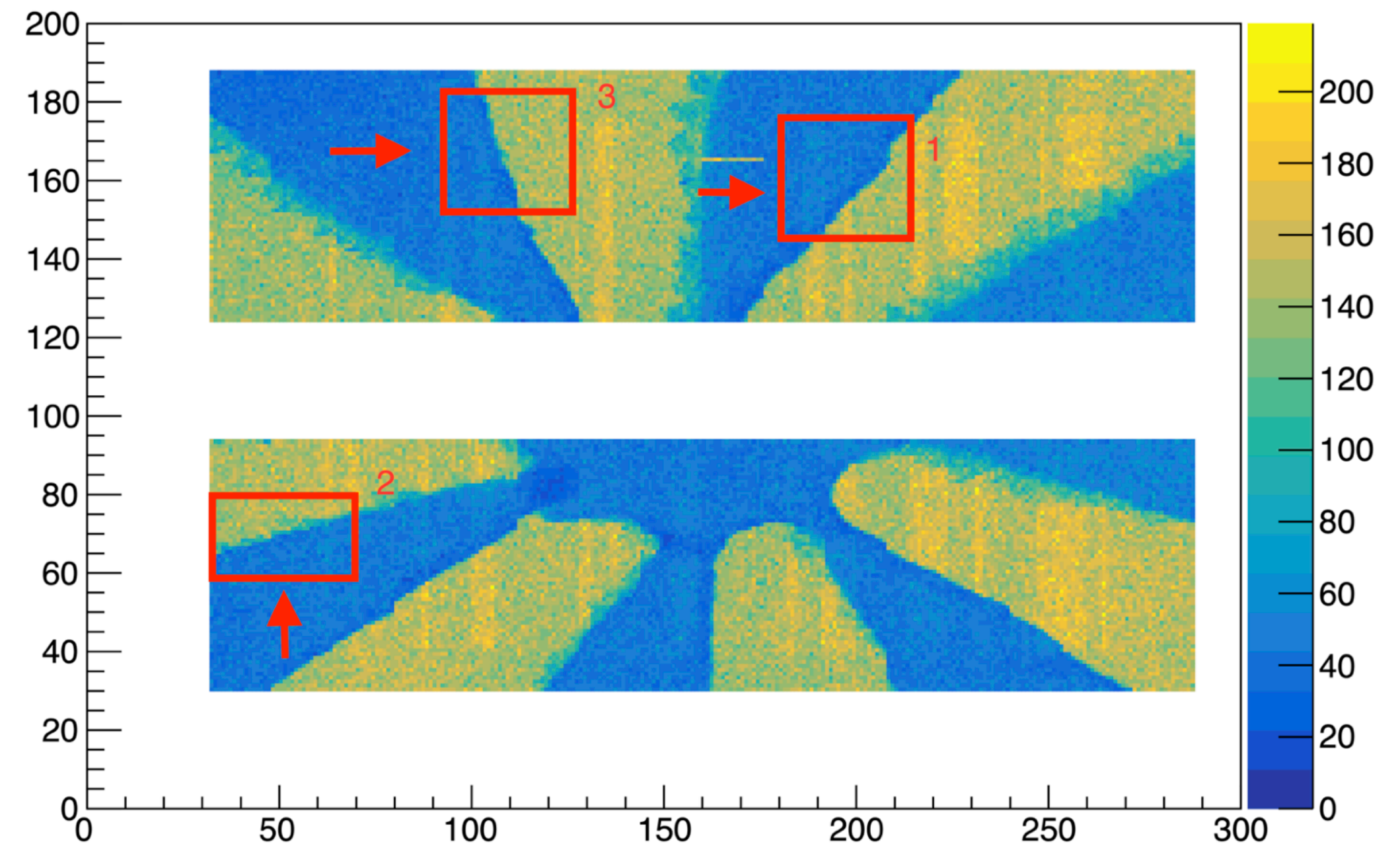


Fig 13: Recorded image after thermal neutron exposure.

Thank you!

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Thermal neutron measurements with an unpowered, miniature, solid-state device

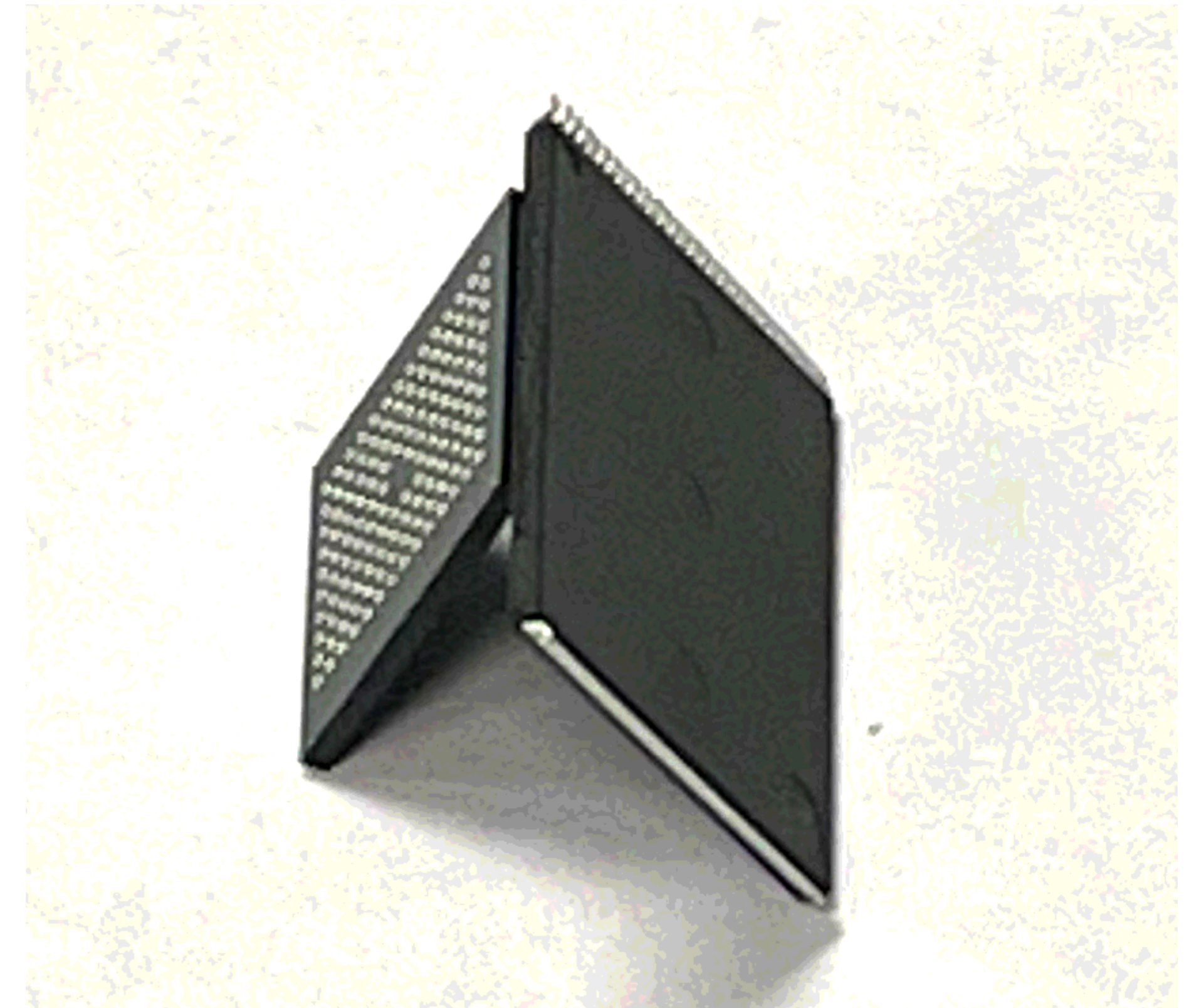
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Neutron Intercepting System on a Chip (NISoC)

The world's first entirely digital neutron detector on a single chip.



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