SOFT ROBOTICS IN RADIATION ENVIRONMENTS FOR SAFEGUARD APPLICATIONS

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BACKGROUND

Nuclear safeguards include the "institutional, legal, and technical mechanisms" that monitor and maintain the non-weaponized status of signatories to the Nuclear Non-Proliferation Treaty (NPT). This research looks specifically at the potential for one emerging technology, soft robotic systems, to contribute to the field of nuclear safeguards.

SOFT ROBOTICS

Robots have a long history in the nuclear field, from the incident at Three Mile Island in 1979 to the 2011 disaster in Fukushima. However, where "rigid" robots are composed of rigid materials like metals and plastics, soft robots are composed of soft materials like rubber and polymers. Being composed of soft materials confers these advantages to soft robotic systems:

1) potential for infinite degrees of freedom
2) "intrinsic" safety
3) little resistance against obstacles
4) adaptive and responsive to environment
5) relatively cheap and disposable

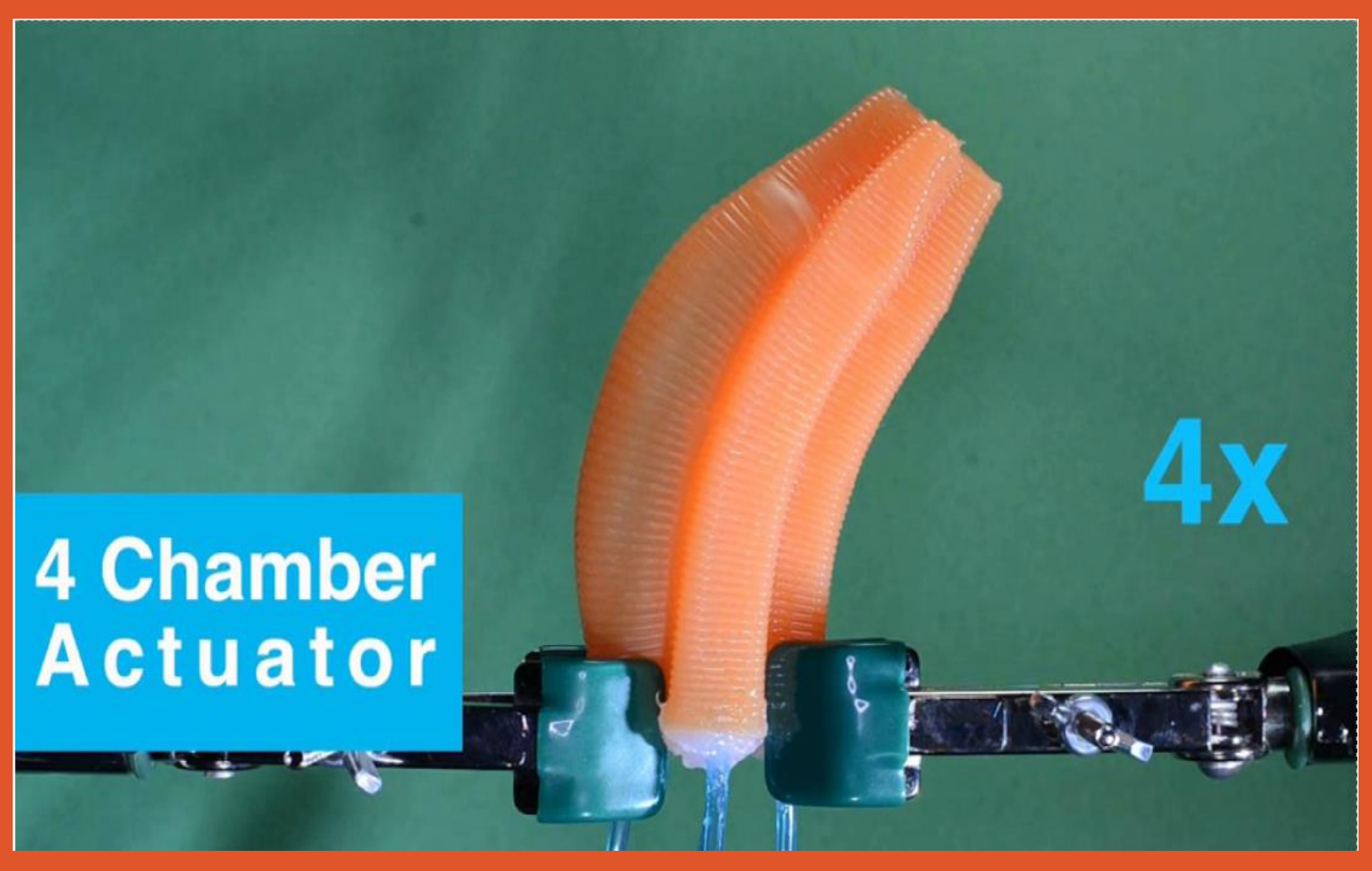


Figure 1. Example of a soft robotic actuator developed by OSU Robotics.

APPROACH

This evaluation is based on Vandergriff's "system design process to minimize radiation effects" (Figure 2). It focuses on the interaction between components and environments.

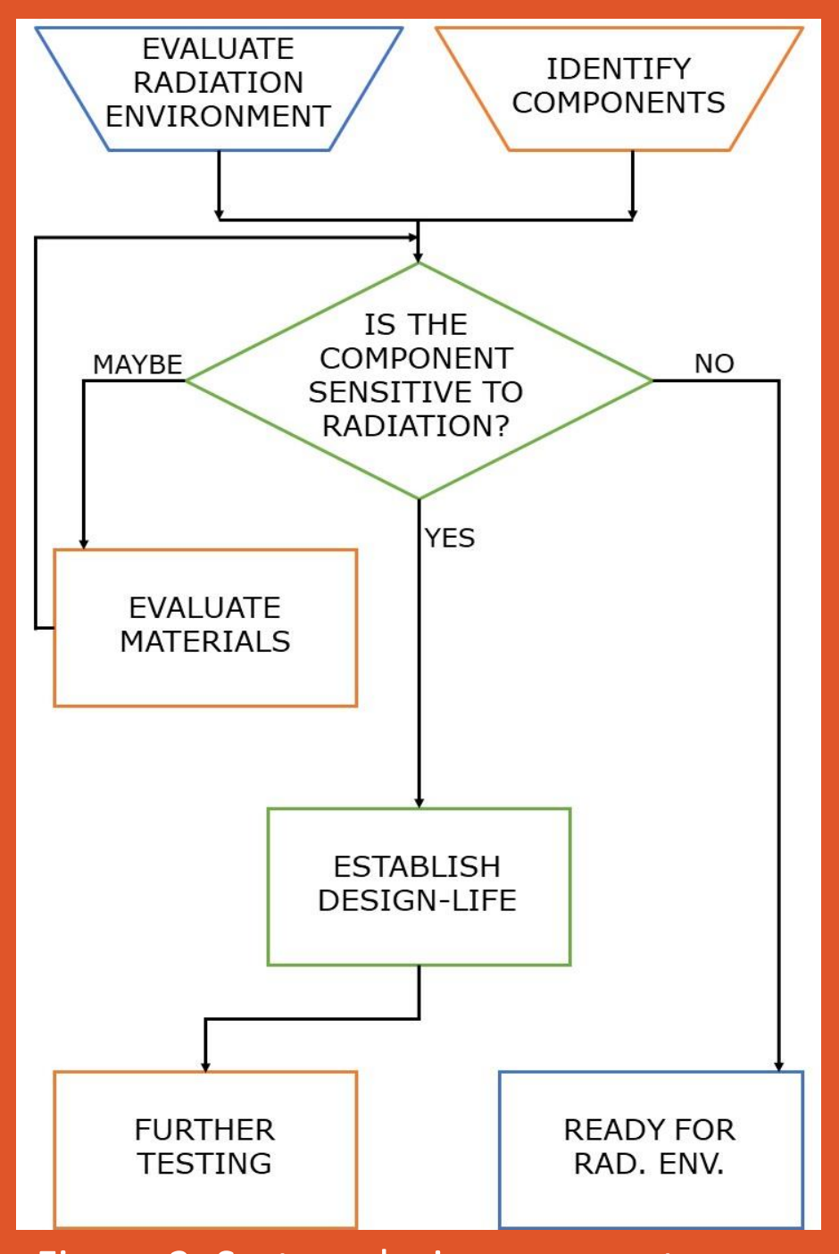


Figure 2. System design process to minimize radiation effects from Vandergriff (1990).

SELECTING ENVIRONMENTS

- Three environments were chosen from a paper on various robot prototypes in the nuclear industry (Figure 3, highlighted in blue) to represent the general diversity of potential applications (Houssay, 2000).
- Dose rate maximums or averages were extrapolated to a cumulative dose after 12 hours as a general estimate of robot task time.

Environment	Highest Avg/Max (kGy/hr)	Avg or Max?	Cumulative Dose over 12 hours (kGy)
Within fueling machine	100	Avg	1200
Storage Pond	10	Max	120
Vitrification	10	Avg	120
Vitrified Waste	1.8	Avg	21.6
Spent Fuel Stripping/Cutting	1	Avg	12
PWR deactivation	1	Max	12

Figure 3. Gamma radiation environments for robots in the nuclear industry from Houssay (2000).

IDENTIFYING COMPONENTS

- Actuator body: polydimethylsiloxane (PDMS)
- Microchannels: Gallium, Indium, Tin (Galinstan) + Nickel

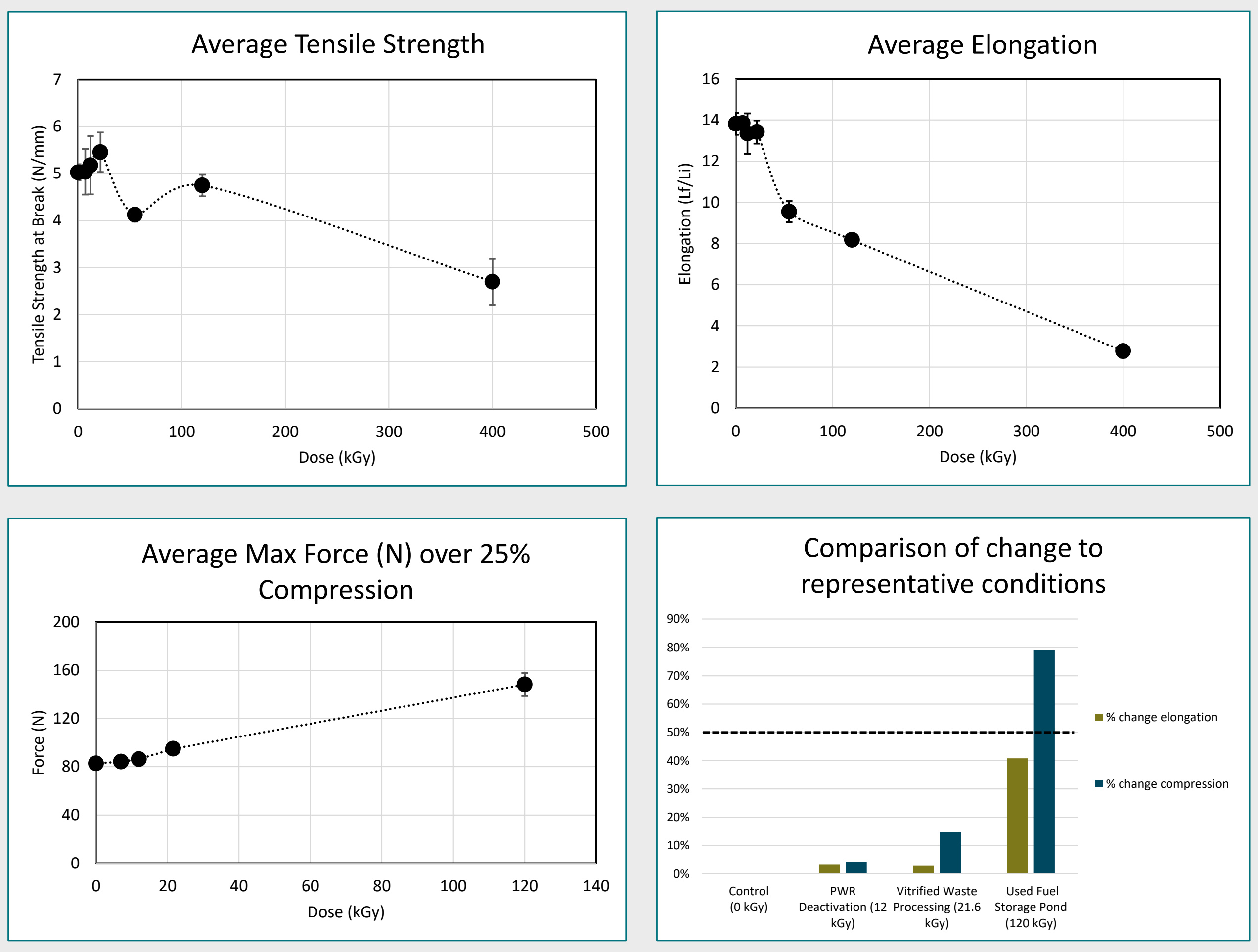
METHODS

- Gamma Testing: "dog bone" and cylinder PDMS samples were created from molds with Smooth-On Dragon Skin Fast brand silicone. Samples were irradiated in a GammaCell220 Co-60 irradiator. Irradiated samples were tested with a Mark-10 motorized stand.

Figure 4. A dogbone sample undergoing elongation and tensile strength testing in the Mark 10 machine.

- Neutron Analysis: A 2 g sample of PDMS was exposed to the rotating rack in Oregon State University's Triga Reactor (OSTR) for 7 hr (thermal flux: 3.85E12 ± 4.89E11 cm^{-2} s^{-1}); the NIST activation calculator was used to estimate activation in identical conditions.

GAMMA-INDUCED MECHANICAL CHANGES TO PDMS



Figures 5-7 (upper left/right; lower left). Results of mechanical testing for gamma-irradiated samples of PDMS. Figure 8 (lower right). Percent change to elongation and compression at representative environment doses. 50% change level marked as potential loss of function.

- Tensile tests: increased cumulative gamma dose led to decreased elongation and an initial increase followed by an overall decrease in tensile strength.
- Discs: increased cumulative gamma dose led to increased force needed to achieve the same level of compression (increased "stiffness"). Surpassed 50% change in highest dose environment.

NEUTRON-INDUCED ACTIVATION OF PDMS

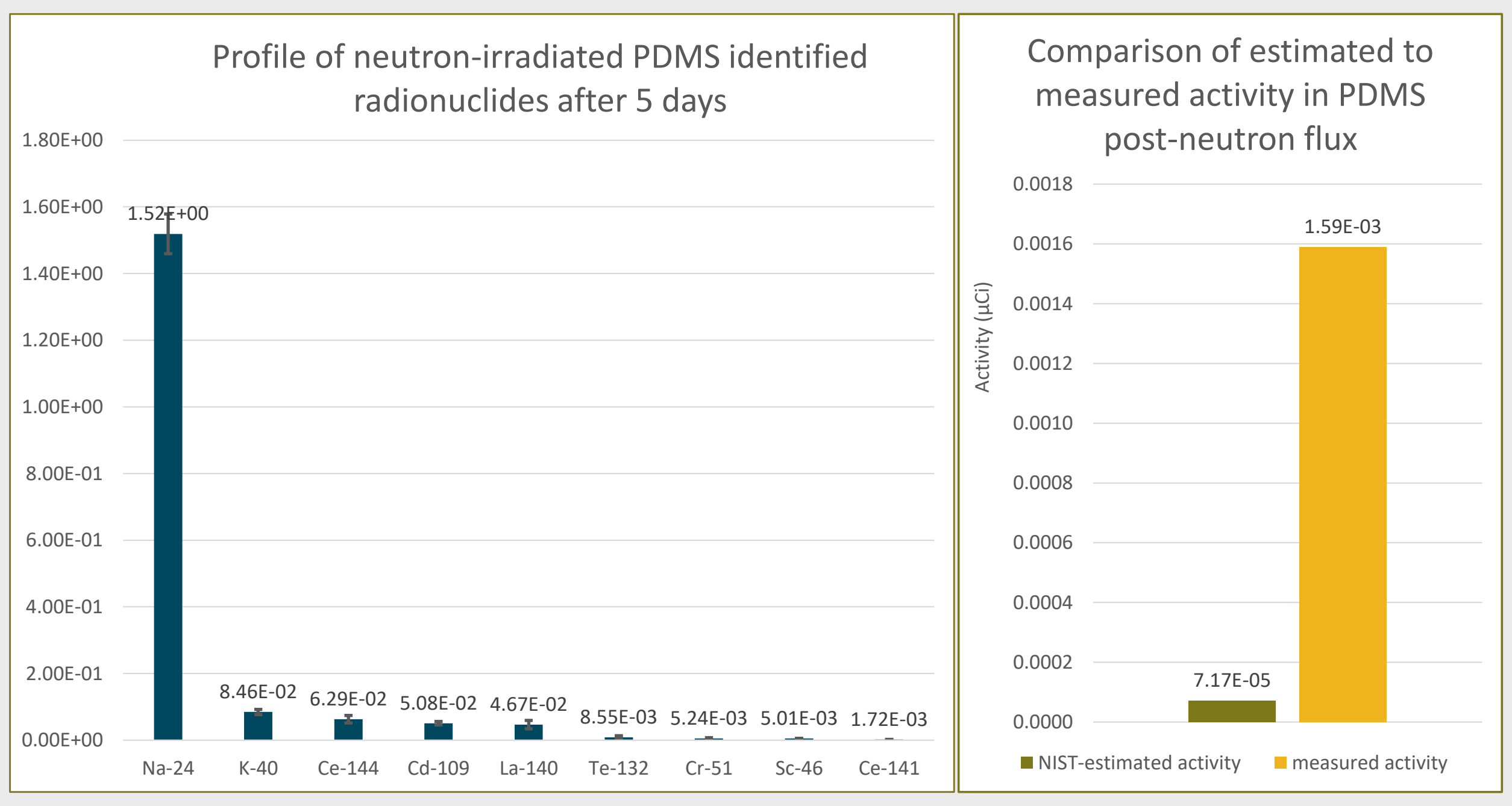


Figure 9 (left). Neutron activation profile of PDMS radionuclides from 7 hr exposure in OSTR Rotating Rack.
Figure 10 (right). Comparison of overall 5-day estimated activity to measured activity.

- Higher activity of measured sample suggests unexpected contaminants in PDMS.
- Profile of PDMS reveals the contaminants: Na-24 plays a major role along with some long-lived lanthanides.

CONCLUSIONS

- With increasing gamma dose: tensile strength initially increases, then eventually decreases; elongation decreases; and stiffness increases.
- In all but compression in the highest environment, PDMS remained within 50% mechanical change post-gamma irradiation.
- For activation of PDMS, contamination by Na-24 and lanthanides makes neutron activation difficult to predict.

NEXT STEPS

- For liquid metal sensors: determine electron liberation on sensor functionality.
- For overall assessment: compare magnitude of effects to soft robotic mechanical parameters.

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