SAND2024-07883C

Sandia National Laboratories

Exceptional service in the national interest

PUCK PASSIVE LOOP SEAL

INMM Annual Meeting 2024, Portland, OR

Stephanie White

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2024-XXXXC

ACKNOWLEDGMENTS

Project Team

Cody Corbin
Chemistry SME

Stephanie White
Postdoc - Chemistry

Clay Curtis
Postdoc - Chemistry

Heidi Smartt
SG C/S SME
Project PI

Rokwel Wade
Product Design Engineer

Photo

Sagan Cox
Intern

Funding

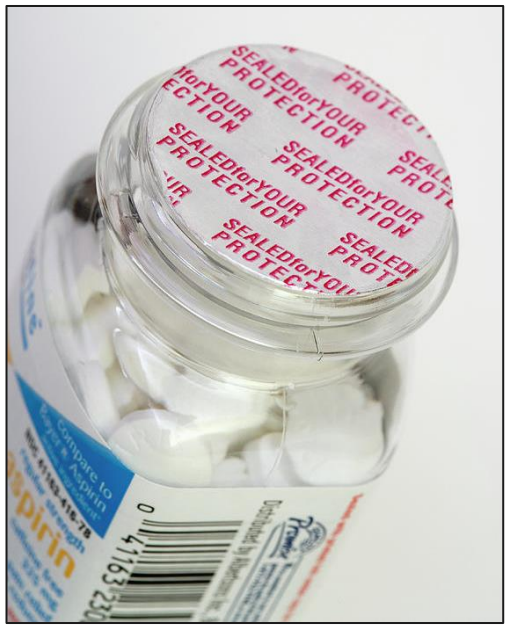
National Nuclear Security Administration

U.S. Department of Energy
National Nuclear Security Administration
Office of Defense Nuclear Nonproliferation

Safeguards Portfolio

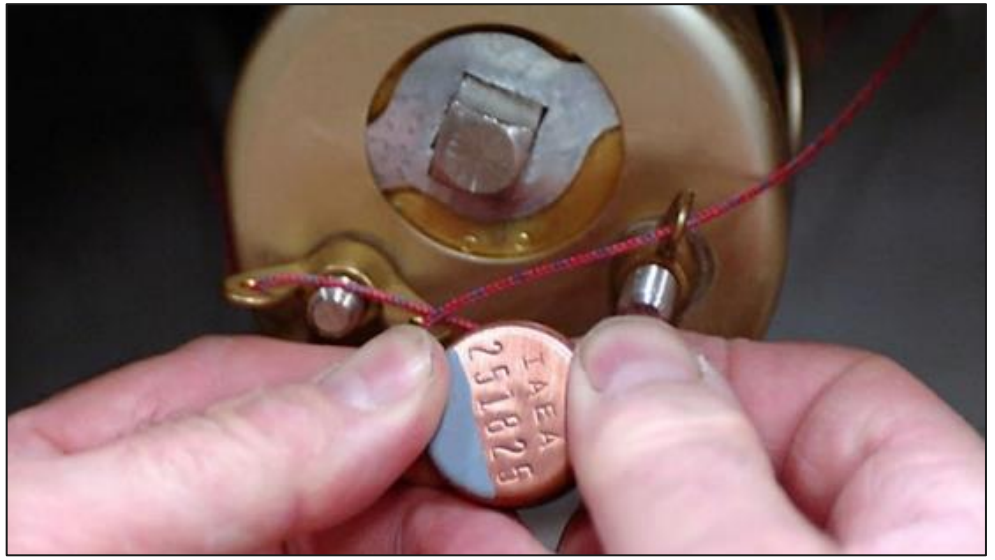
TAMPER INDICATING TECHNOLOGY

- Medications, food
  - Foils, shrink wraps, stickers
  - Indicate tamper event
  - Don’t inhibit access



TAMPER INDICATING TECHNOLOGY

- Medications, food
  - Foils, shrink wraps, stickers
  - Indicate tamper event
  - Don’t inhibit access
- International Atomic Energy Agency (IAEA)
  - Call to replace metal cup seal
    - Passive loop seal
    - Resource extensive
    - Dated technology
  - Stringent requirements
    - Anti-counterfeiting aspect
    - Unique identifier
    - Tamper indication
    - Difficult to repair
    - Quick & easy install, inspection

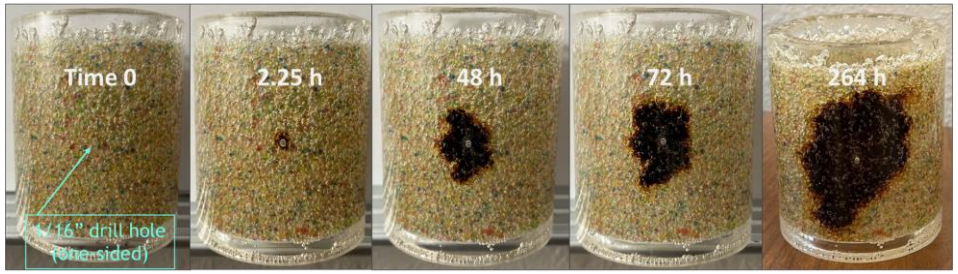


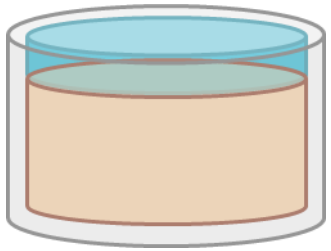
Metal cup seal

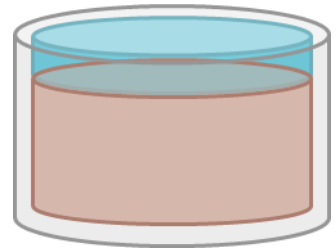
Field Verifiable Passive Loop Seal

VISUALLY OBVIOUS TAMPER INDICATION

- Simple preliminary coupons
  - 3D printed cup-shaped body
  - Sensing mixture
  - Sealed with epoxy layer
- Simulated tamper event
  - Drilled with 1/16” bit
  - Visually obvious color change from mixed/rainbow to black







Sensing mixture with silicone

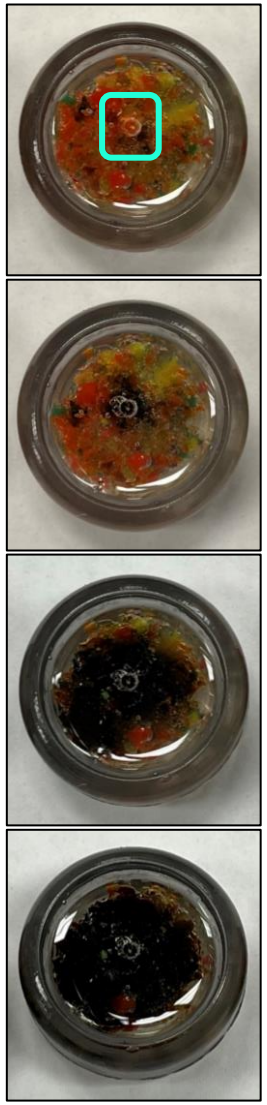
Sensing mixture without silicone

1/16” tamper

1.5 h

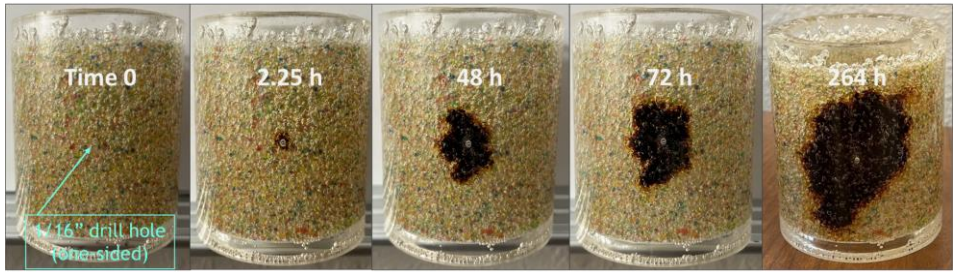
20 h

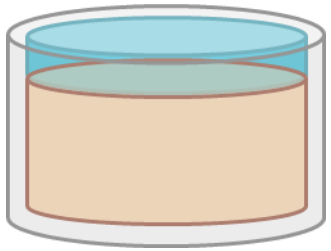
2 d



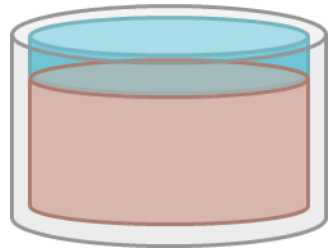
VISUALLY OBVIOUS TAMPER INDICATION

- Simple preliminary coupons
  - 3D printed cup-shaped body
  - Sensing mixture
  - Sealed with epoxy layer
- Simulated tamper event
  - Drilled with 1/16” bit
  - Visually obvious color change from mixed/rainbow to black





Sensing mixture with silicone



Sensing mixture without silicone

1/16” tamper

1.5 h

20 h

2 d

Technical Challenge:

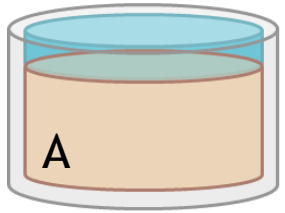
maintain air-tight seal

AND

allow wire puncture

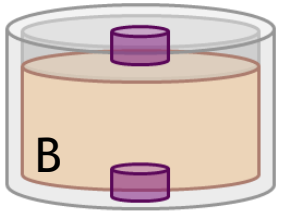
DESIGN DEVELOPMENT OF PUCK PROTOTYPES

3D printed body
Sensing mixture with silicone
Epoxy poured lid

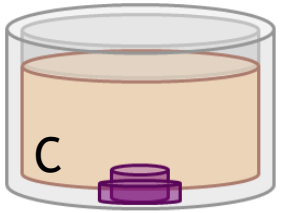


3D printed body
Sensing mixture with silicone
3D printed lid

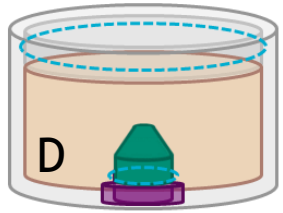
3D printed plug



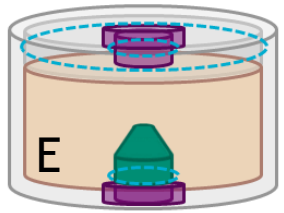
3D printed flanged plug

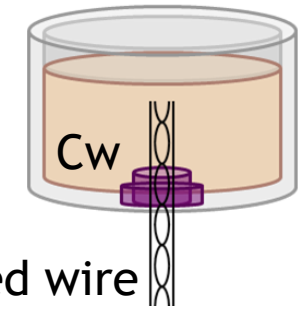


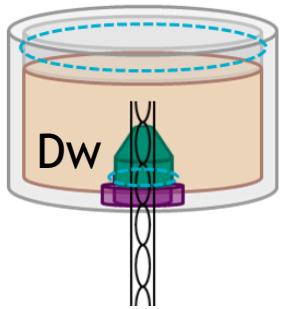
Epoxy trim
Volcano

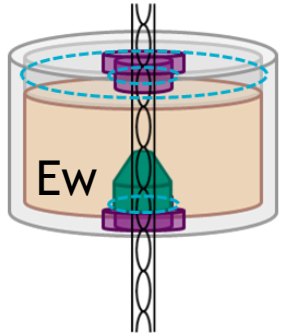


(2) 3D printed flanged plug



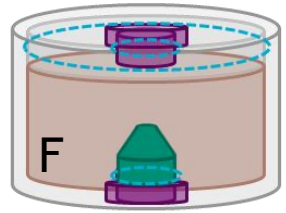


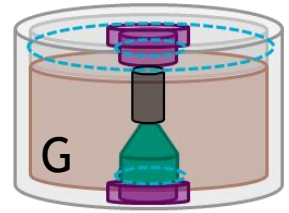


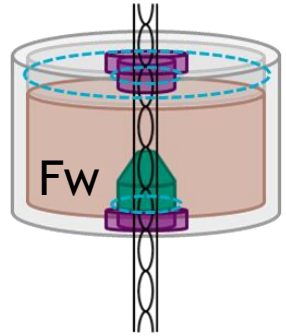


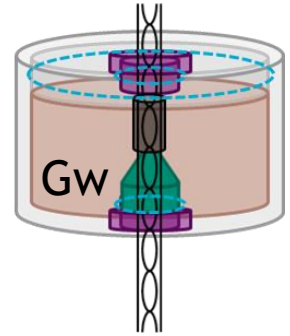
3D printed body
Sensing mixture without silicone
3D printed lid
(2)3D printed flanged plug
Epoxy trim
Volcano

Wire capture mechanism







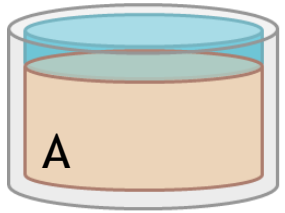


DESIGN DEVELOPMENT OF PUCK PROTOTYPES

3D printed body

Sensing mixture with silicone

Epoxy poured lid



3D printed body

Sensing mixture without silicone

3D printed lid

(2)3D printed flanged plug

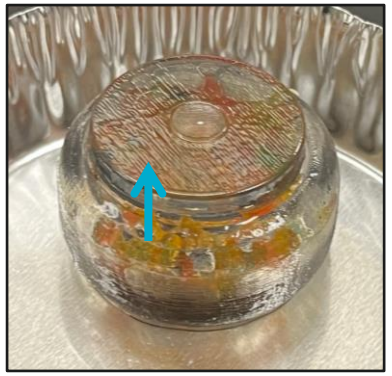
Epoxy trim

Volcano

Wire capture mechanism

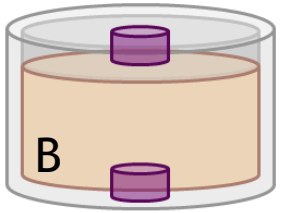
DESIGN DEVELOPMENT OF PUCK PROTOTYPES

3D printed body
Sensing mixture with silicone
Epoxy poured lid

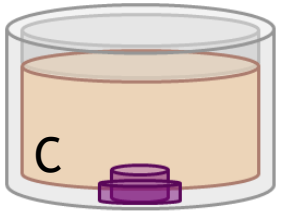


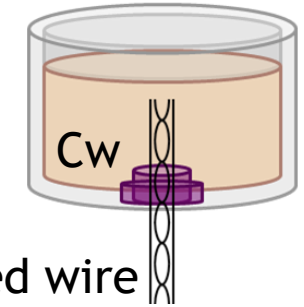
3D printed body
Sensing mixture with silicone
3D printed lid

3D printed plug

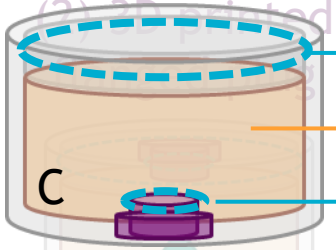


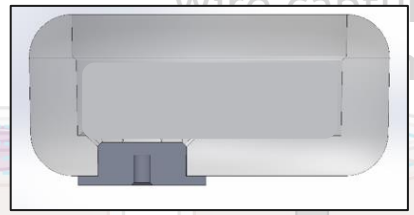
3D printed flanged plug





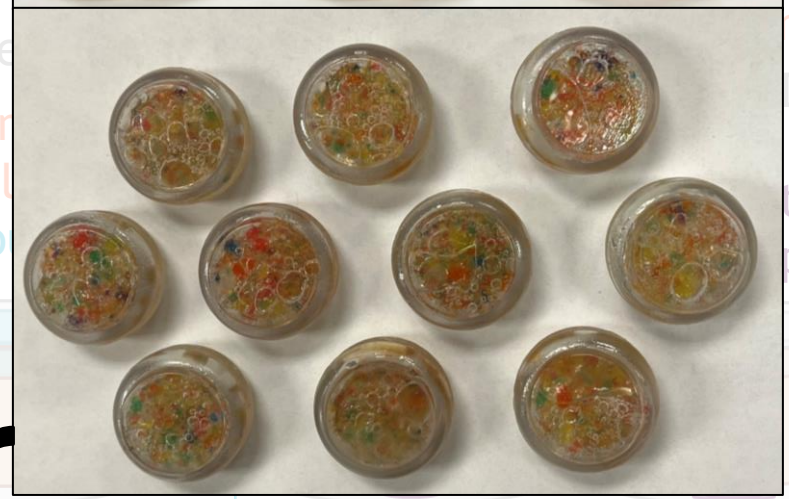
Epoxy trim
Volcano



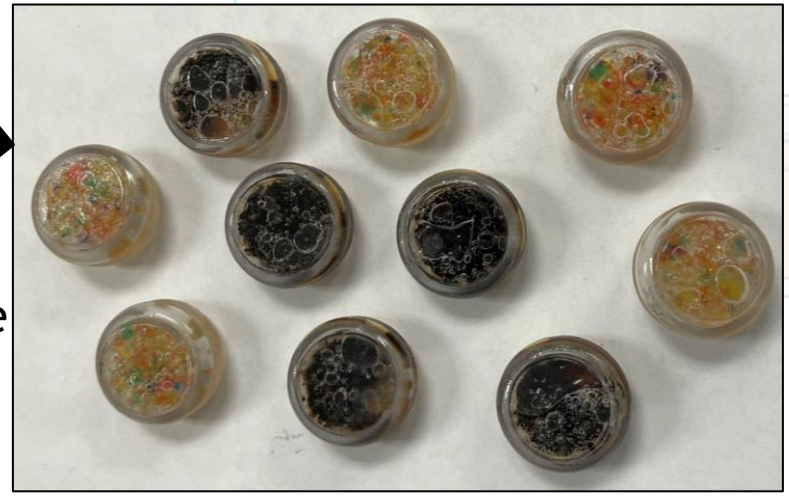


3D printed body
Sensing mixture without silicone
3D printed lid
(2)3D printed flanged plug
Epoxy trim
Volcano

DESIGN DEVELOPMENT OF PUCK PROTOTYPES

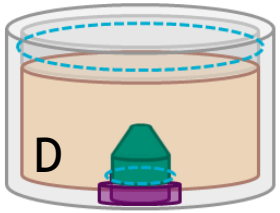


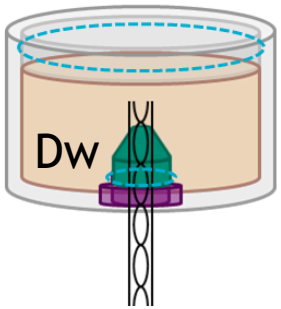
1 d after air exposure



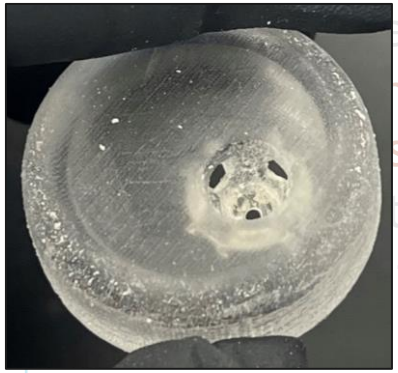
Epoxy trim

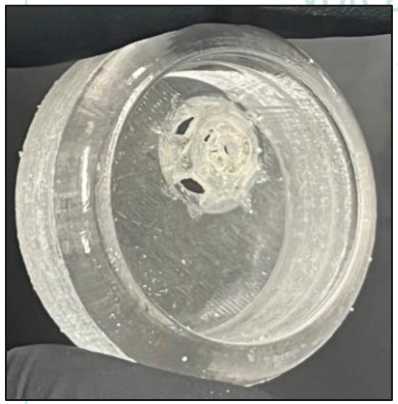
Volcano

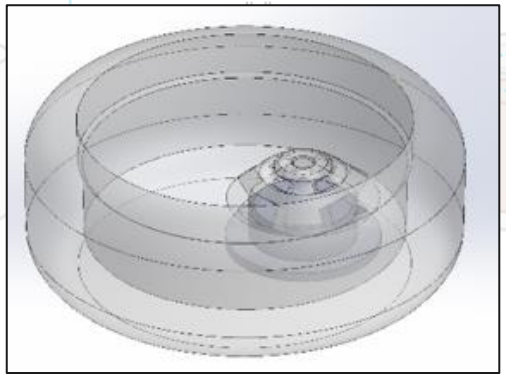




(2) 3D printed flanged plug







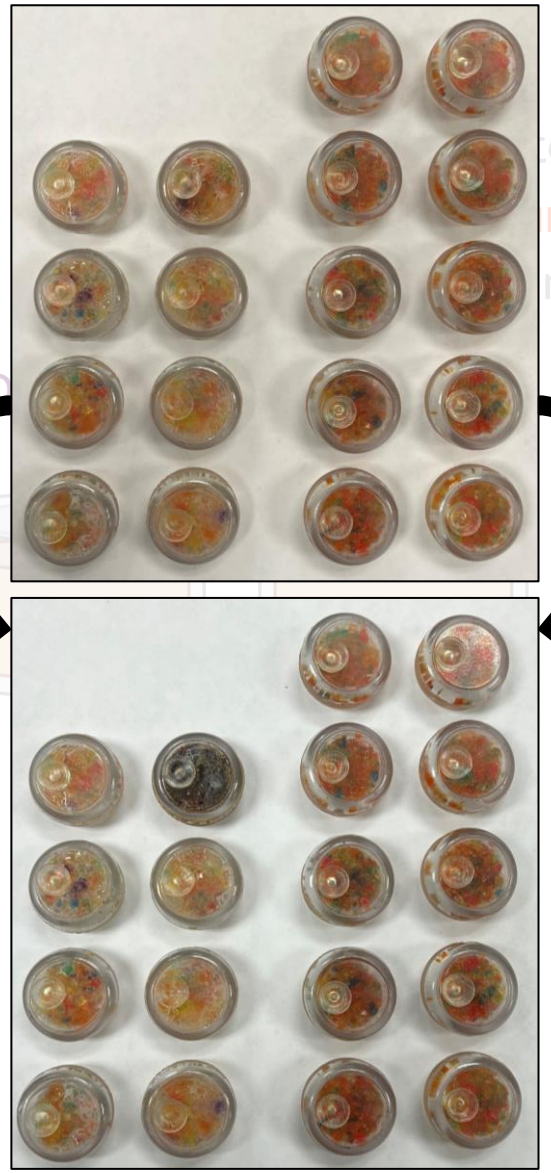
Wire capture mechanism

DESIGN DEVELOPMENT OF PUCK PROTOTYPES

3D printed body
Sensing mixture without silicone
3D printed lid
(2)3D printed flanged plug
Epoxy trim
Volcano

with silicone

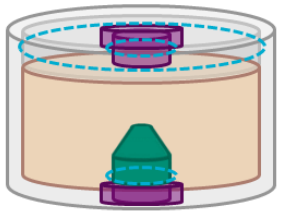
without silicone

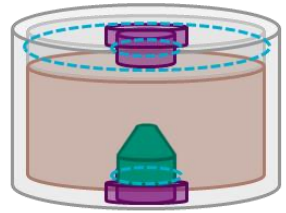


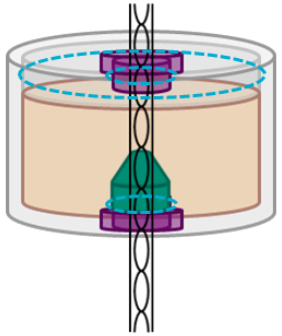
2 h after air exposure

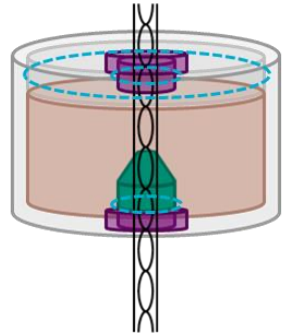
(2) 3D printed flanged plug

Wire capture mechanism

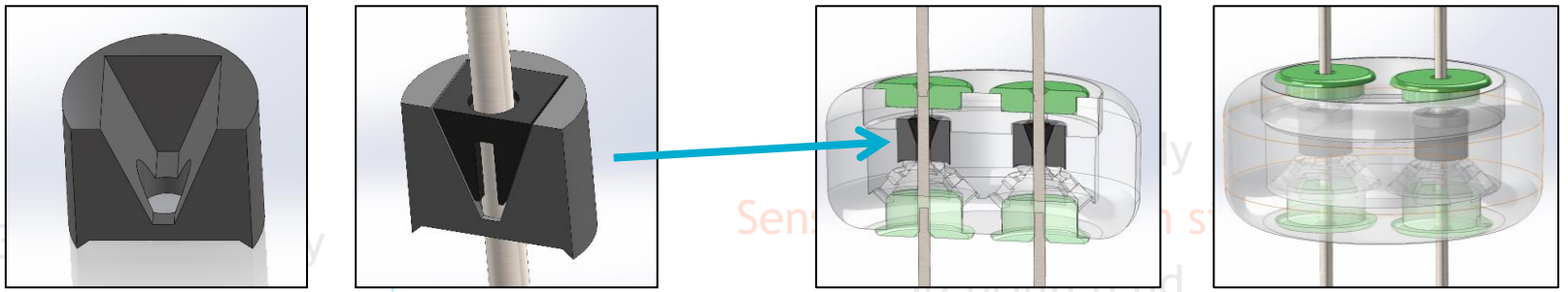


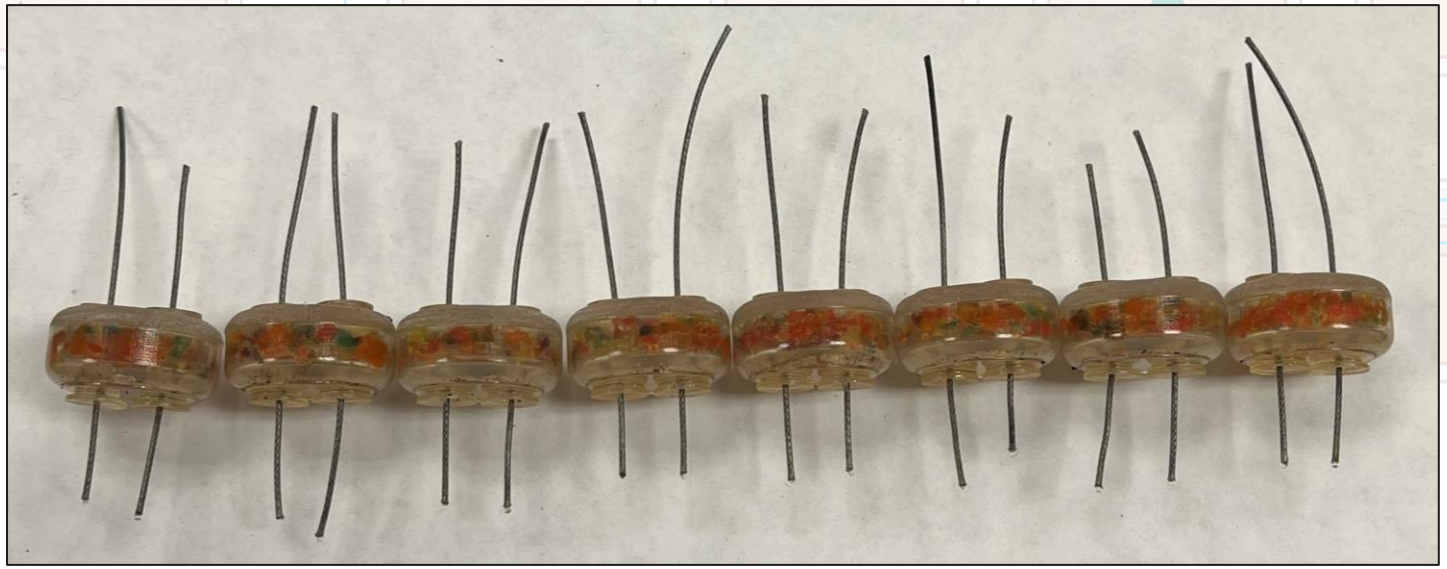






DESIGN DEVELOPMENT OF PUCK PROTOTYPES





3D printed body

Sensing mixture without silicone

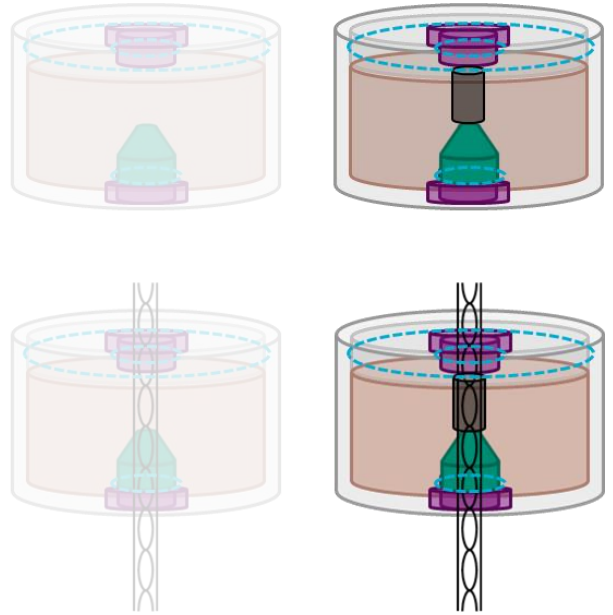
3D printed lid

(2)3D printed flanged plug

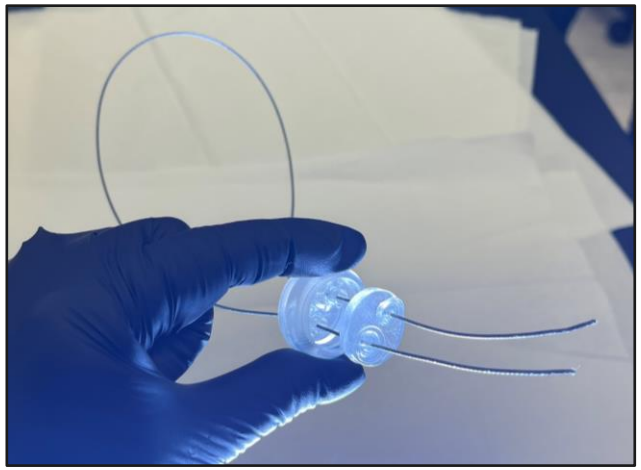
Epoxy trim

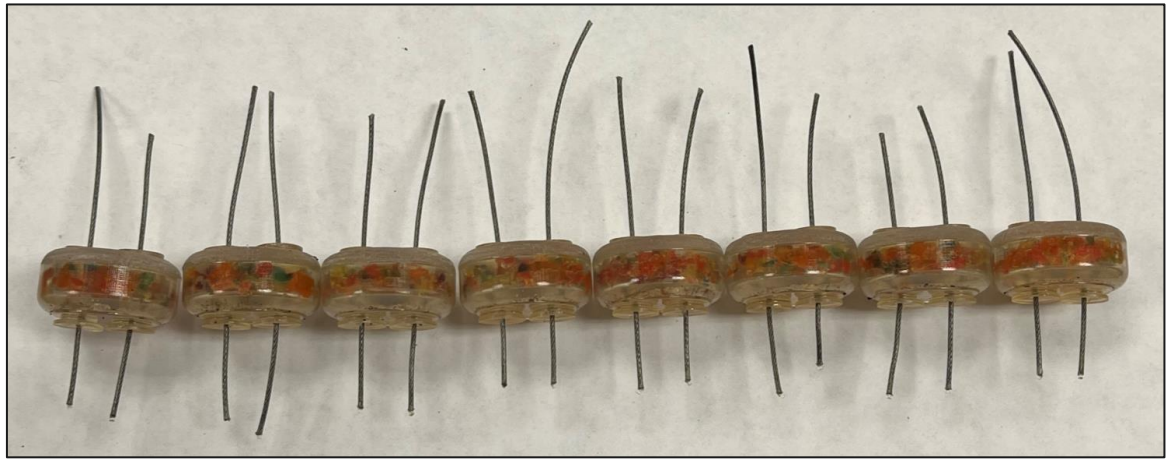
Volcano

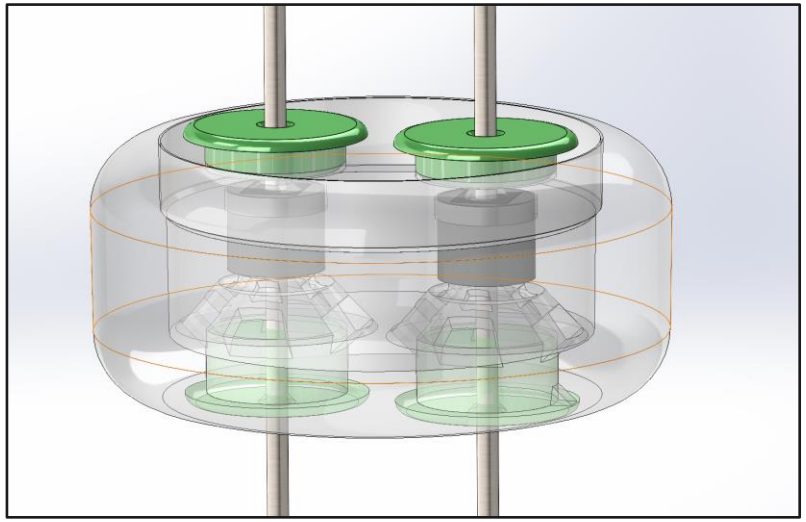
Wire capture mechanism

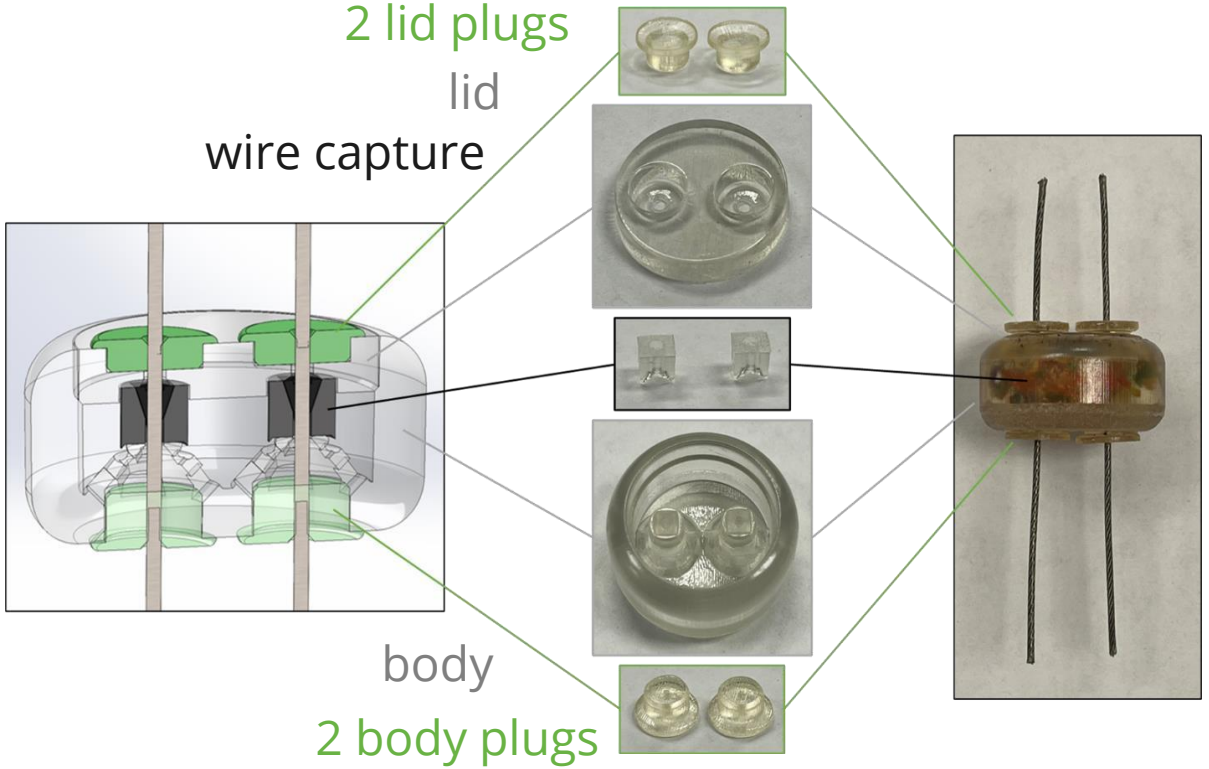


“FINAL” PUCK DESIGN

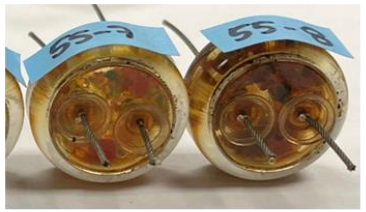
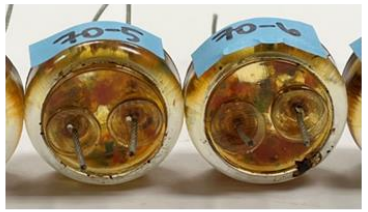
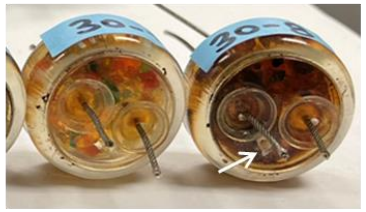
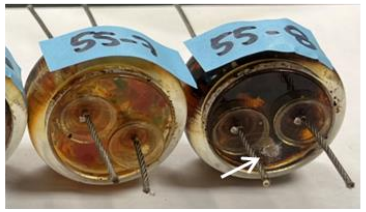




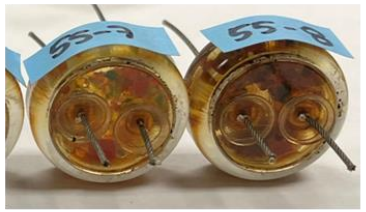
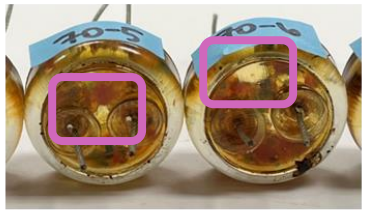
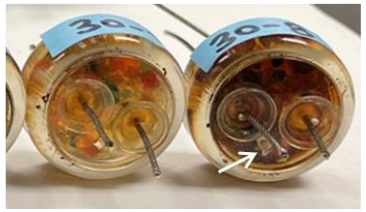
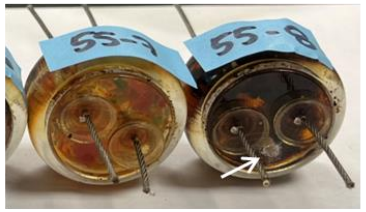




ENVIRONMENTAL TESTING

	-30 °C	30 °C	40 °C	55 °C	70 °C
t = 0 Before thermal treatment					
t = 4 d After thermal treatment					
t = 4 d After drilling (right)					

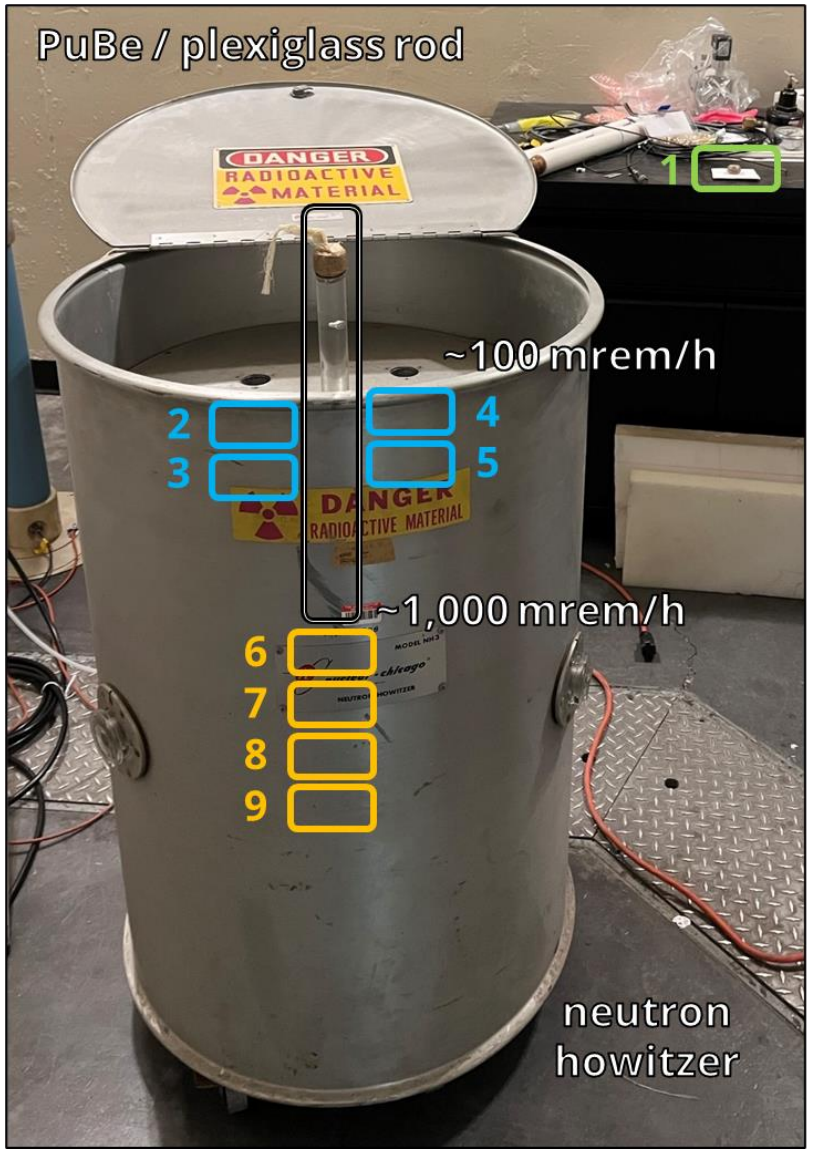
ENVIRONMENTAL TESTING

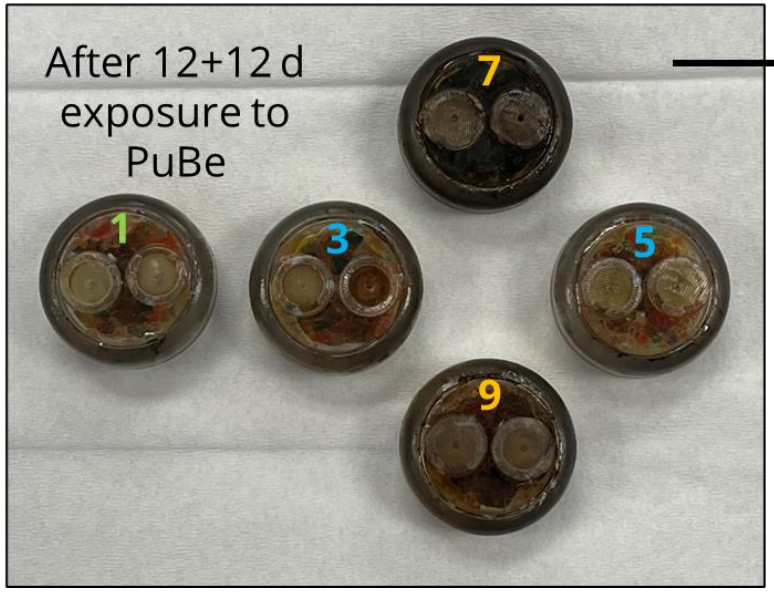
	-30 °C	30 °C	40 °C	55 °C	70 °C
t = 0 Before thermal treatment					
t = 4 d After thermal treatment					
t = 4 d After drilling (right)					

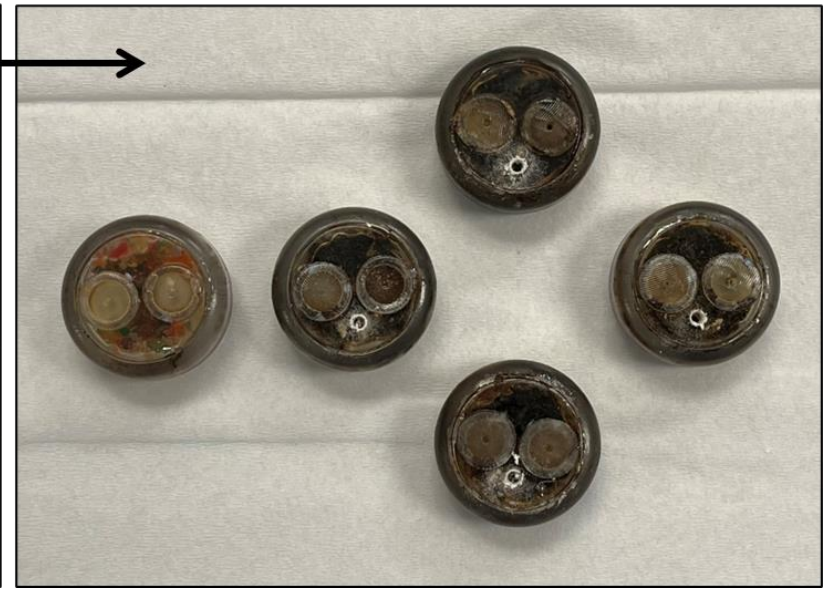
Aging Effect:

darkening, shrinkage

RADIATION TESTING





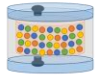
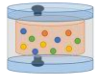
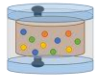


background radiation = 150-350 mrem/year = 0.017-0.040 mrem/h

https://world-nuclear.org/images/articles/4_Background_Radiation(1).pdf

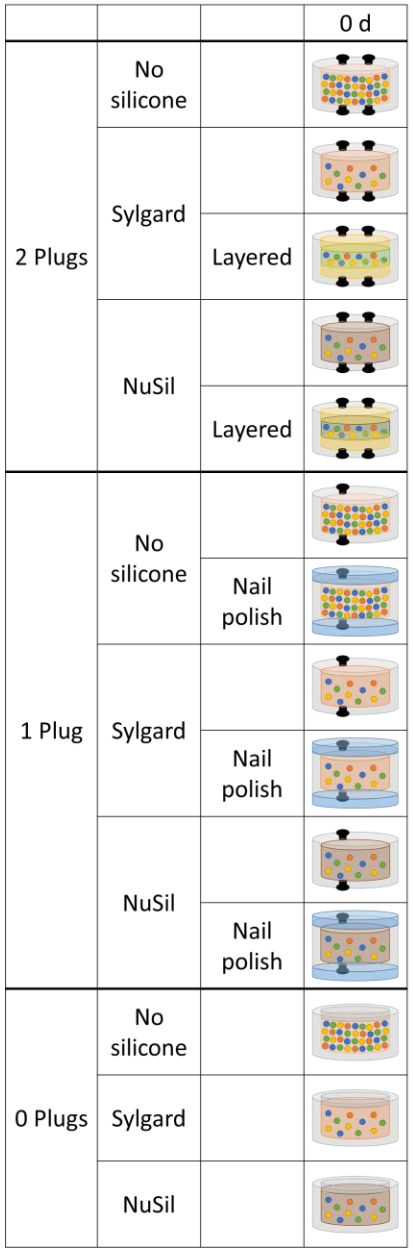
LONG-TERM AGING EFFECTS

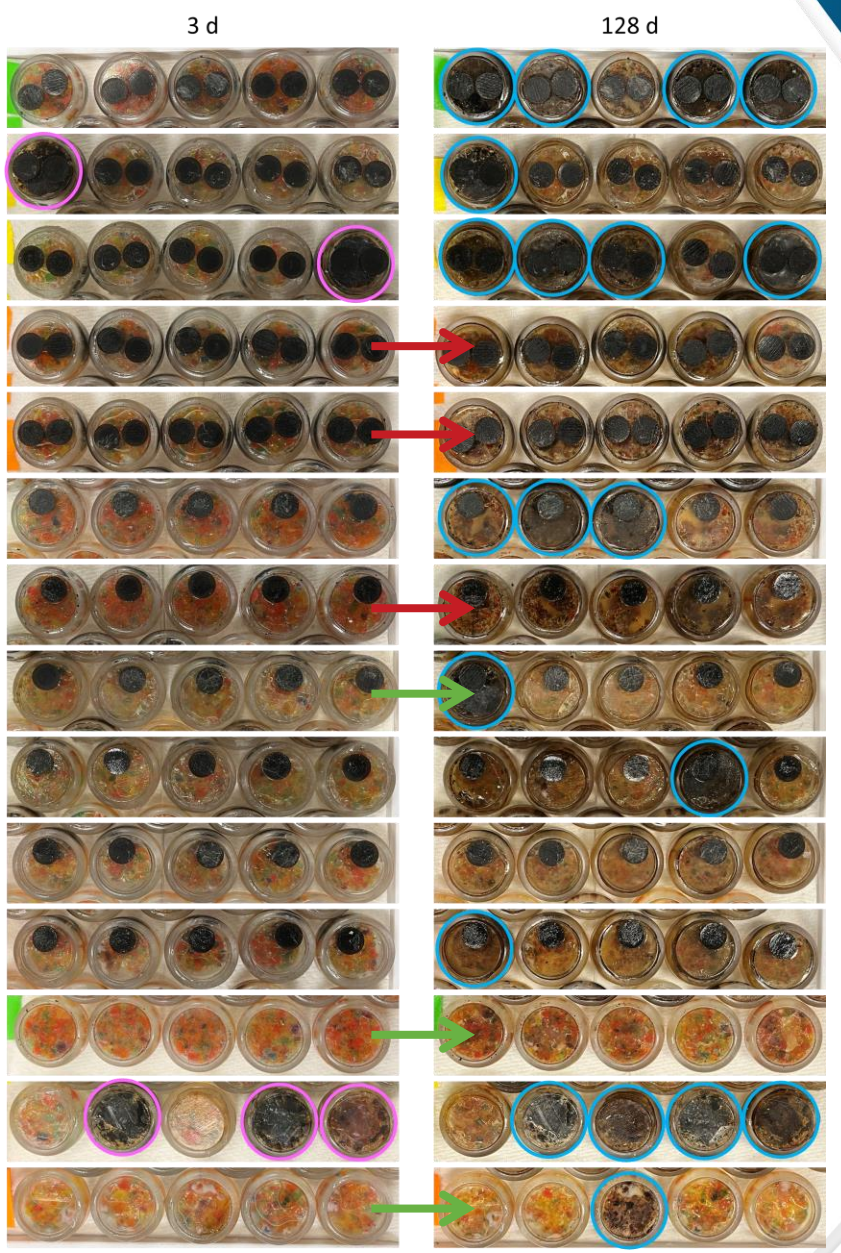
- Systematic aging study – 14 styles x 5 Pucks
  - 2 plugs vs 1 plug vs 0 plugs
  - No silicone vs Sylgard vs NuSil
  - Mixed vs layered
  - Post-assembly coating

			0 d
2 Plugs	No silicone		
	Sylgard		
		Layered	
	NuSil		
		Layered	
1 Plug	No silicone		
		Nail polish	
	Sylgard		
		Nail polish	
	NuSil		
		Nail polish	
0 Plugs	No silicone		
	Sylgard		
	NuSil		

LONG-TERM AGING EFFECTS

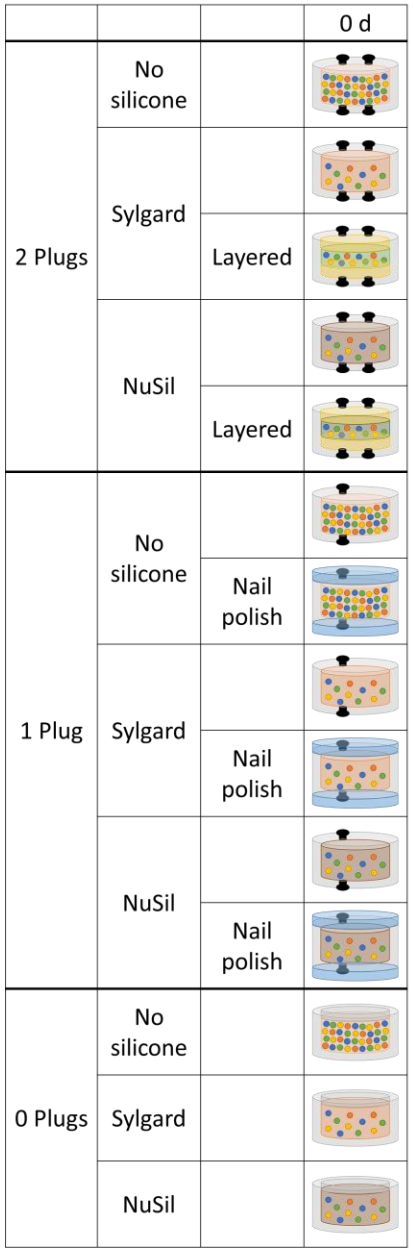
- Systematic aging study – 14 styles x 5 Pucks
  - 2 plugs vs 1 plug vs 0 plugs
  - No silicone vs Sylgard vs NuSil
  - Mixed vs layered
  - Post-assembly coating
- Observations
  - 5 false positives after 3 days
  - ~20 “false” positives after 128 days
  - Some samples look mostly unchanged after 128 days
    - Pucks with 0 plugs not very useful as loop seals
  - Some samples not black but noticeably darker

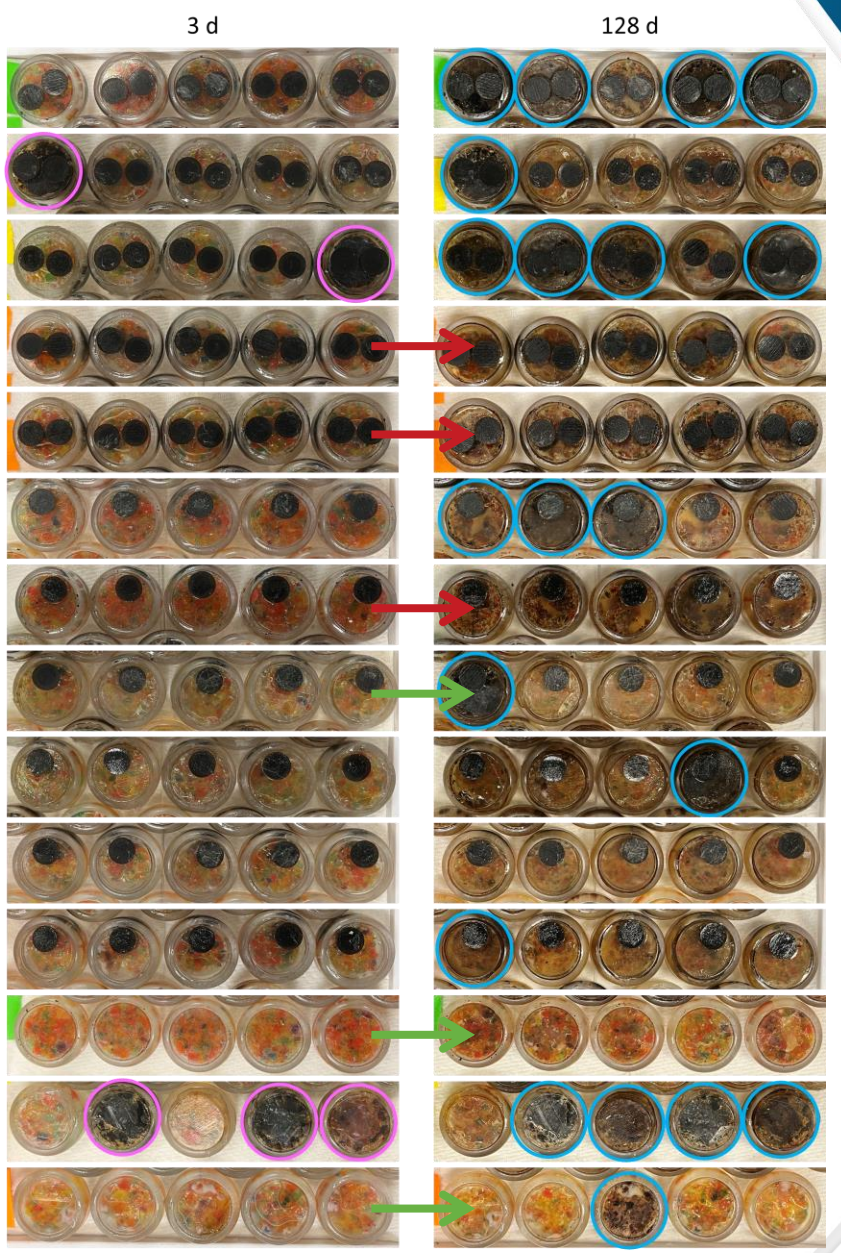




LONG-TERM AGING EFFECTS

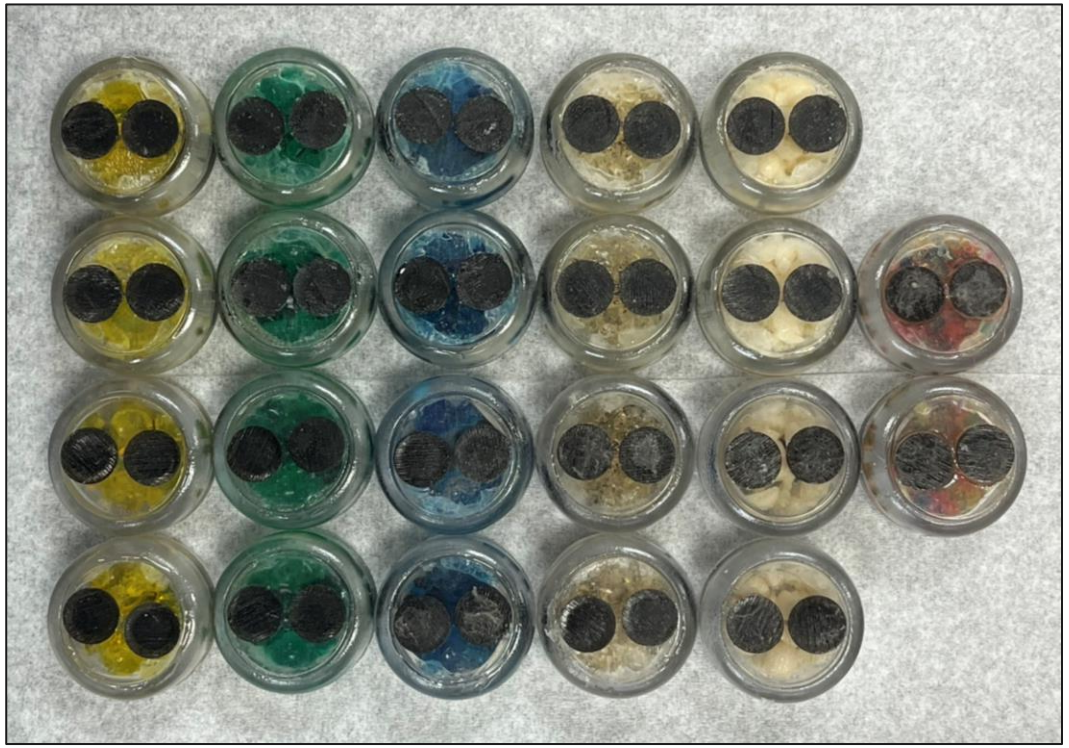
- Systematic aging study – 14 styles x 5 Pucks
  - 2 plugs vs 1 plug vs 0 plugs
  - No silicone vs Sylgard vs NuSil
  - Mixed vs layered
  - Post-assembly coating
- Observations
  - 5 false positives after 3 days
  - ~20 “false” positives after 128 days
  - Some samples look mostly unchanged after 128 days
    - Pucks with 0 plugs not very useful as loop seals
  - Some samples not black but noticeably darker
- Conclusions
  - Concern that aging effect will result in increased “false” positives over time
  - Layering and post-assembly coating do not seem to affect/minimize aging effects
  - **Aging likely due to changes in plug composition over time – can be mitigated by using alternative plug materials**
  - Aging effect may act as UID feature, difficult to counterfeit



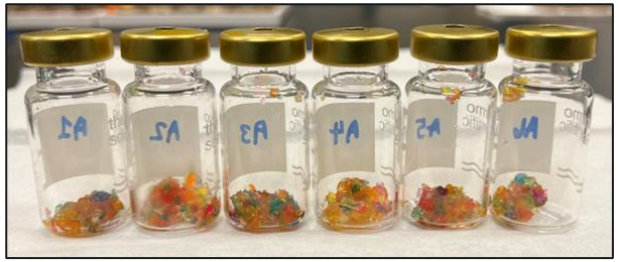


MITIGATIONS FOR AGING

- Evaluate alternative plug materials
  - COTS rubber
- Modify plug design/dimensions
- Evaluate single-colored beads for visual aging impact



A = PTFE/butyl



B = butyl

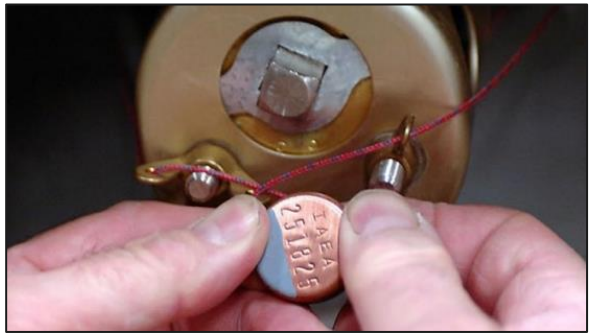
C = inert butyl

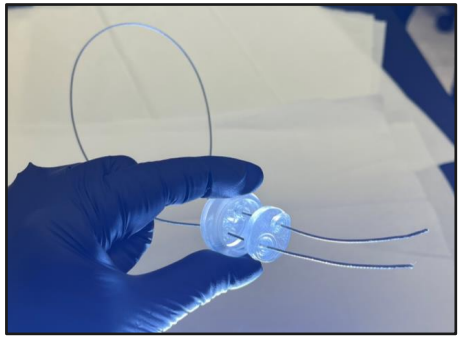
D = butyl

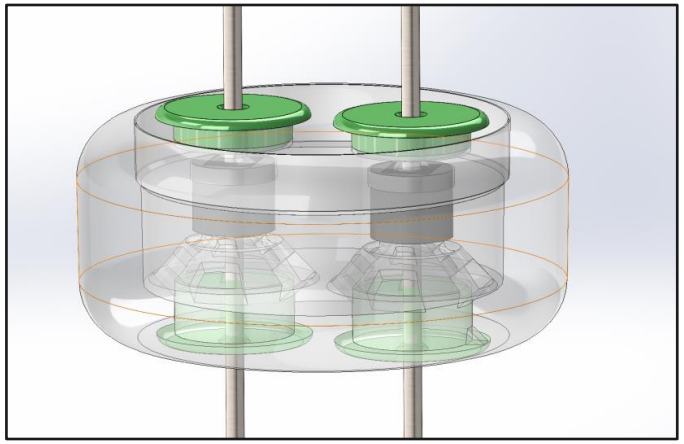
E = bromobutyl

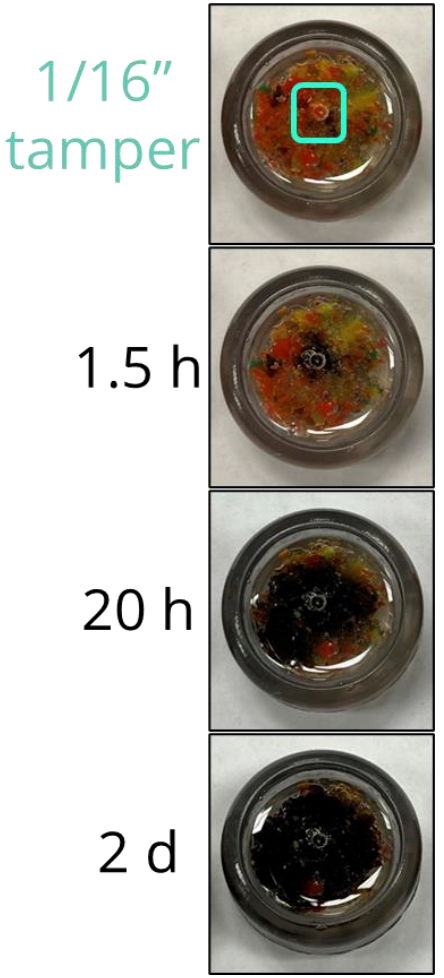
SUMMARY AND NEXT STEPS

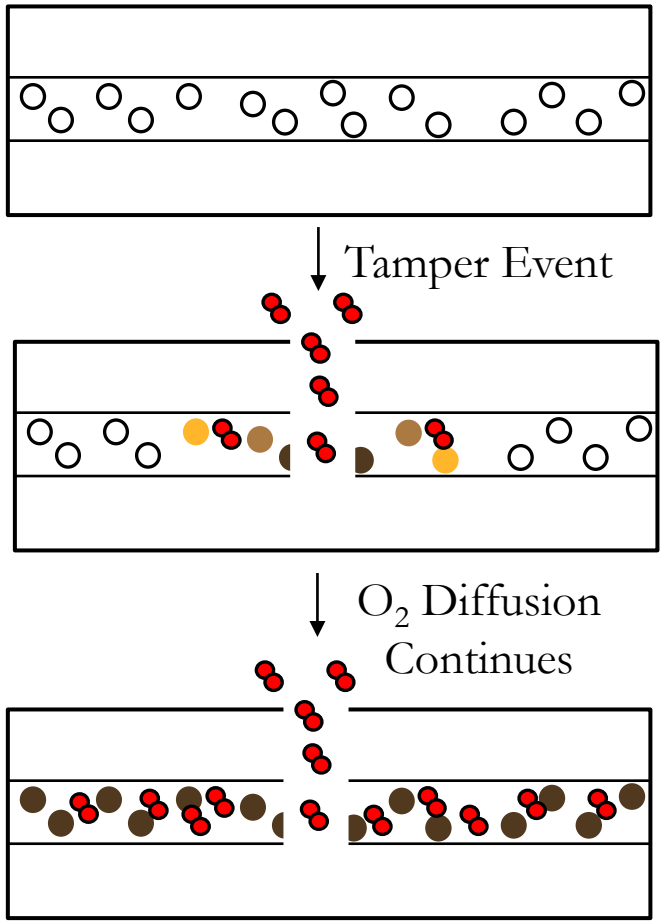
- Puck passive loop seal
  - Targeted as a replacement for IAEA metal cup seal
  - Incorporates novel and unique visibly obvious tamper indication
- Technical challenge: maintain air-tight seal and allow for wire puncture
  - Tested each design element individually and optimized for minimal false positives
  - Aging effects – long-term at ambient conditions; accelerated with thermal, UV, radiation exposure
- Mitigations for aging effects
- Collaboration with ORNL: Puck/SAW
  - Same features as Puck, larger geometry
  - Embeds SAW chip – monitors wire continuity

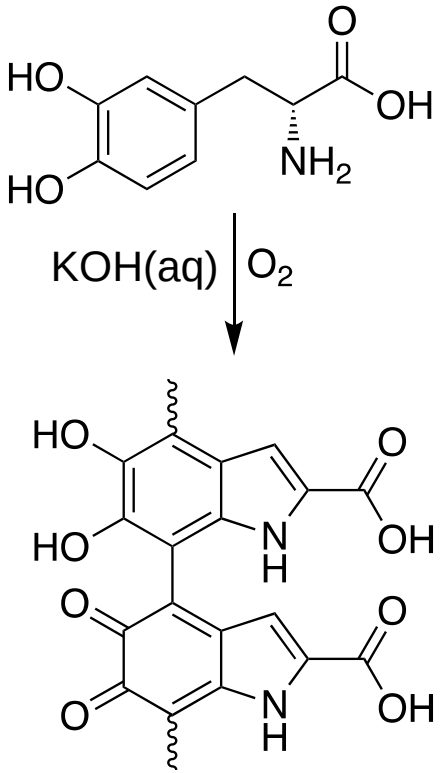




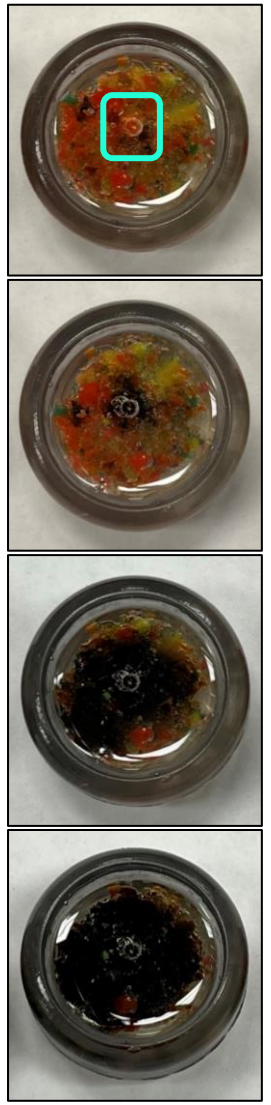








1/16" tamper



1.5 h

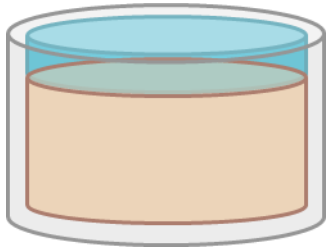
20 h

2 d

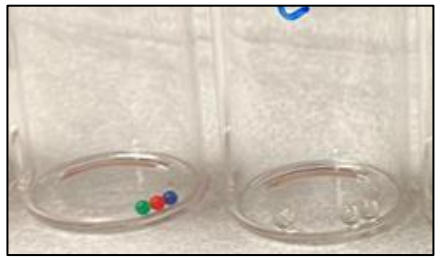
3D printed puck body

Epoxy poured lid

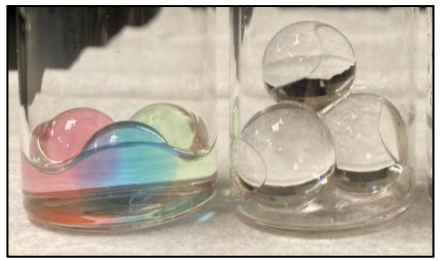
Sensing mixture with silicone



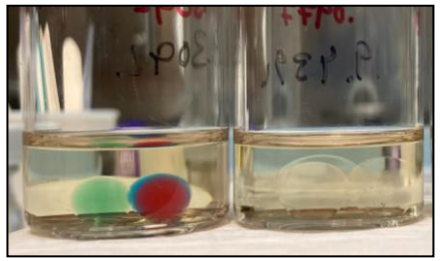
ACS Appl. Mater. *Interfaces,* **2016**, 8, 4314−4317



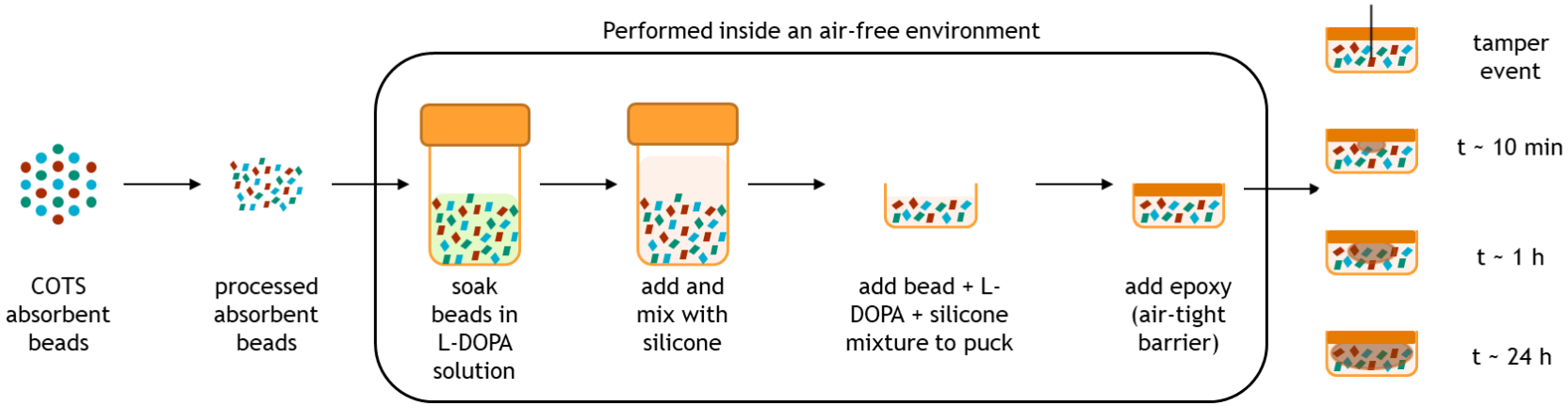
Dry

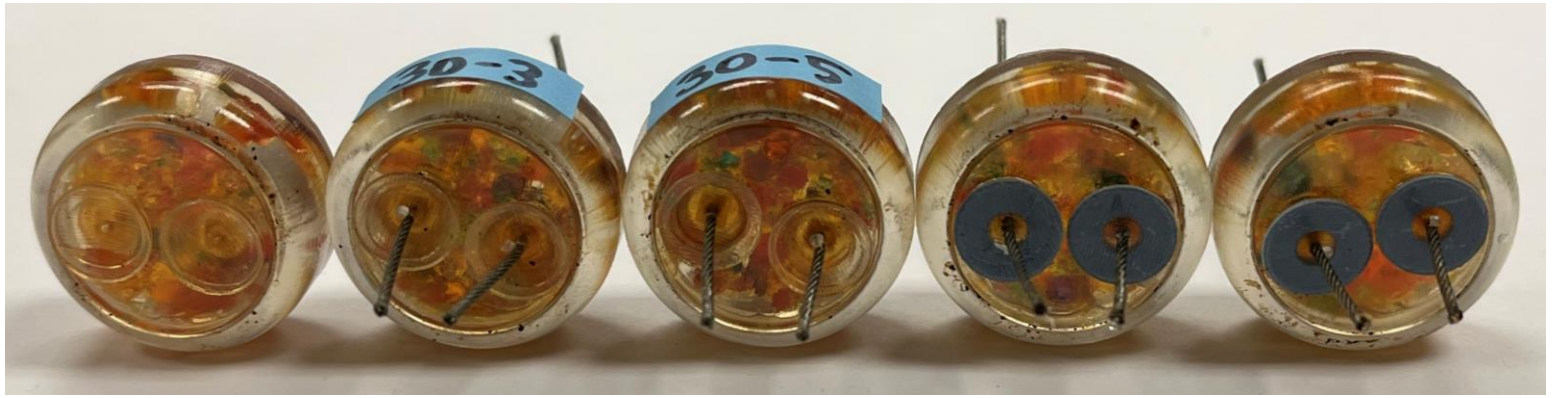


Soaked in water

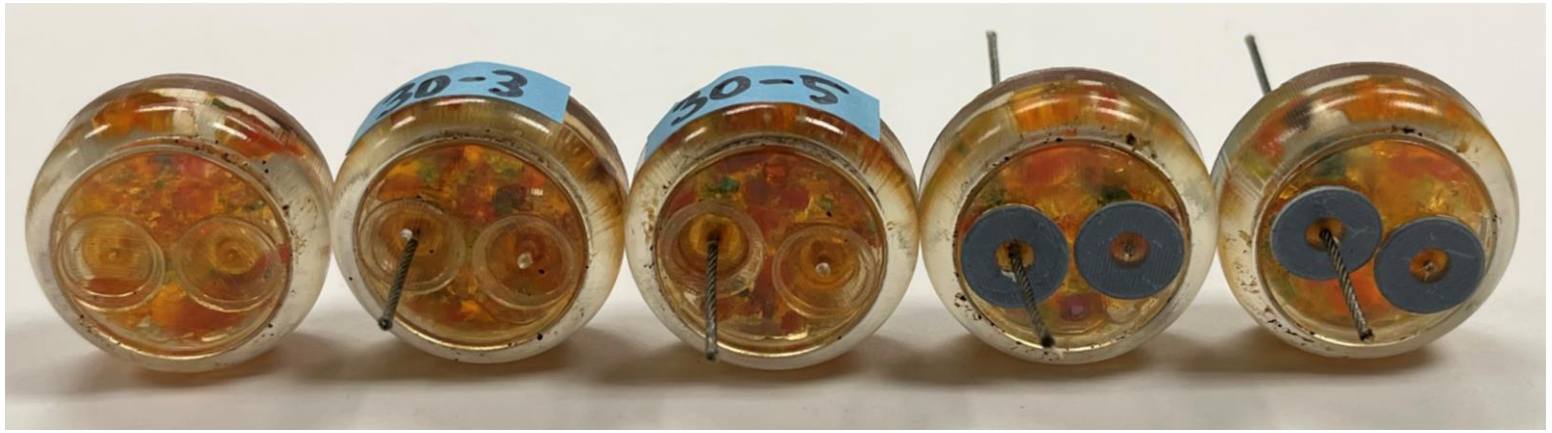


Soaked in O_2-responsive solution

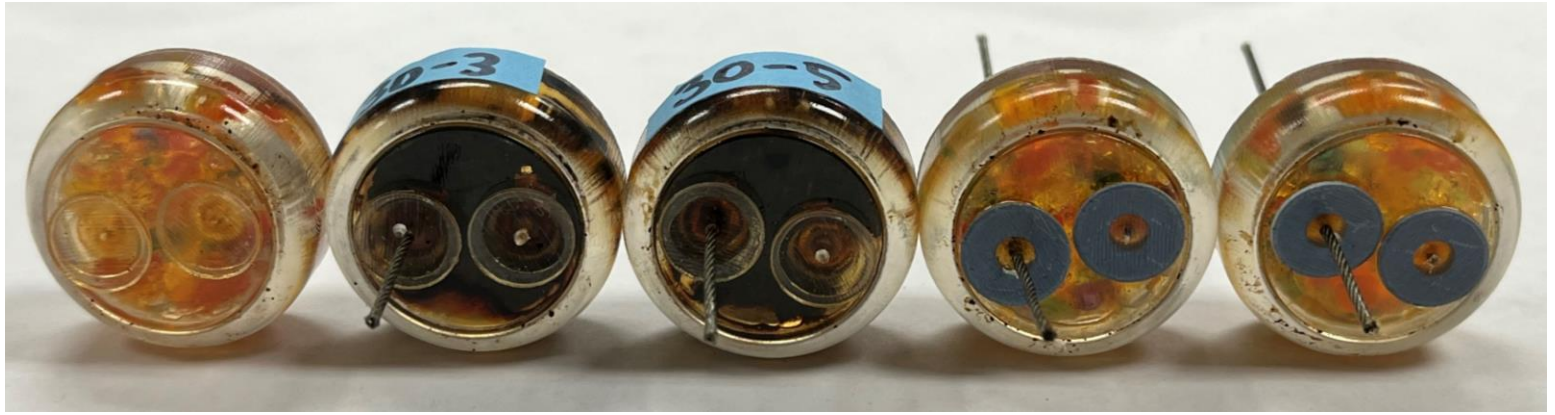




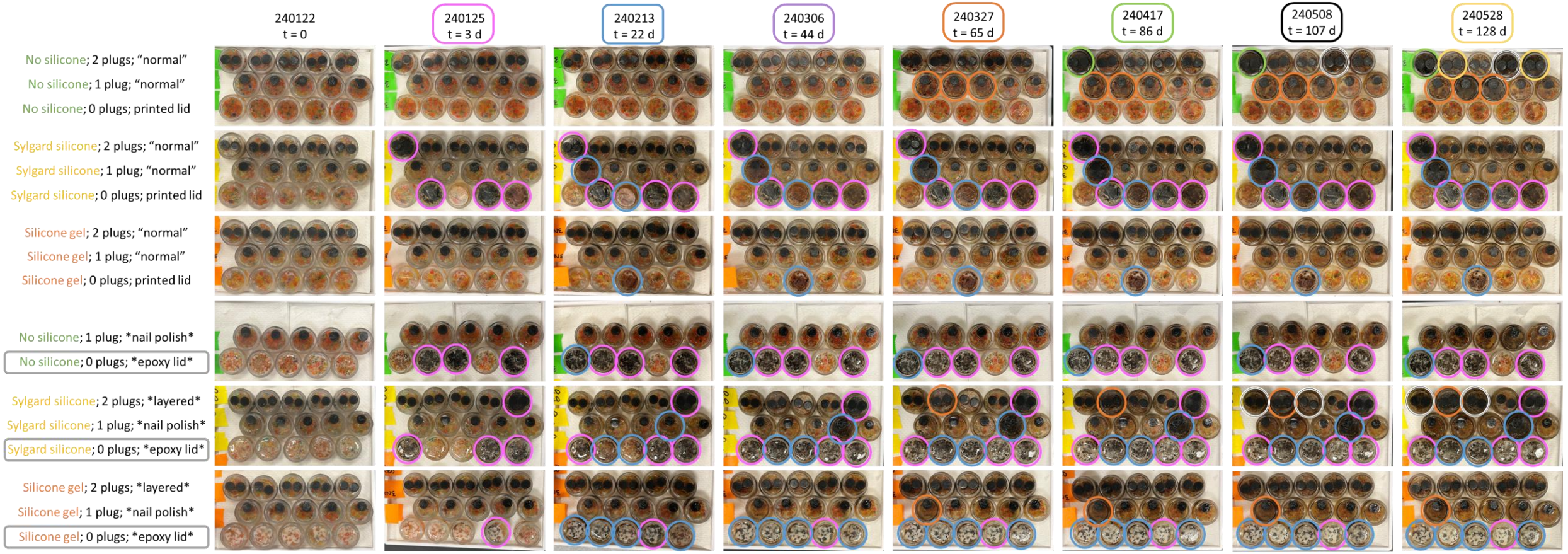
230807
1:15
Before wire removal

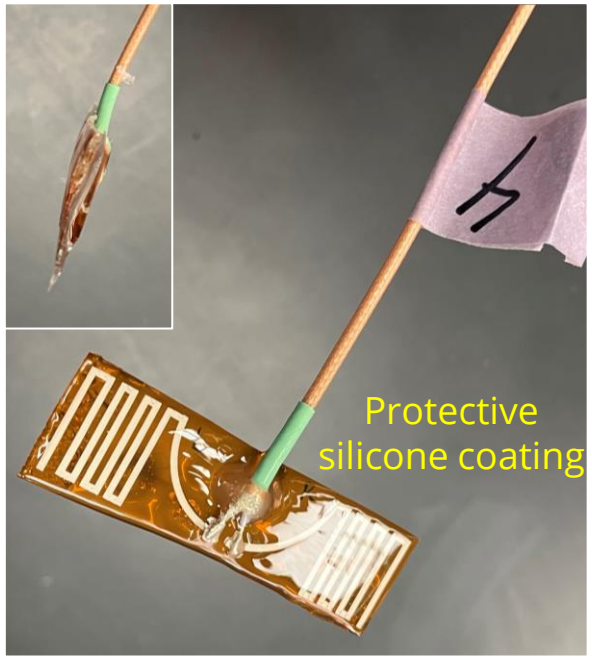


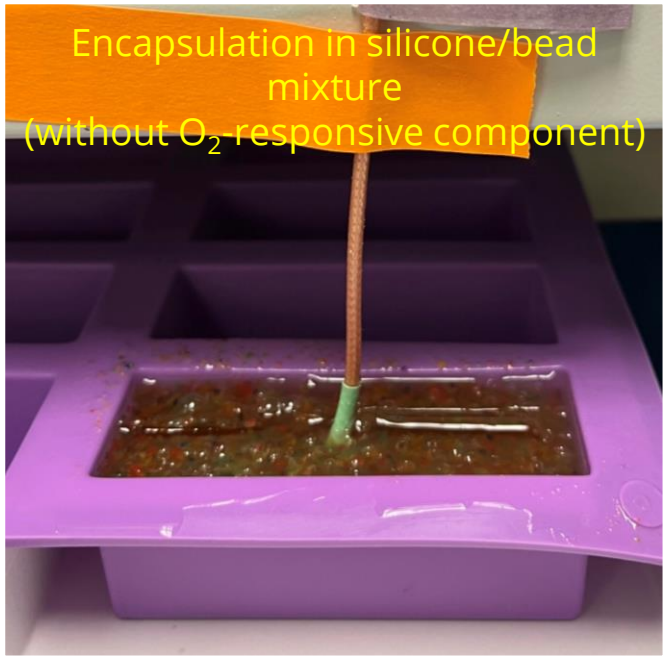
230807
1:20
After wire removal

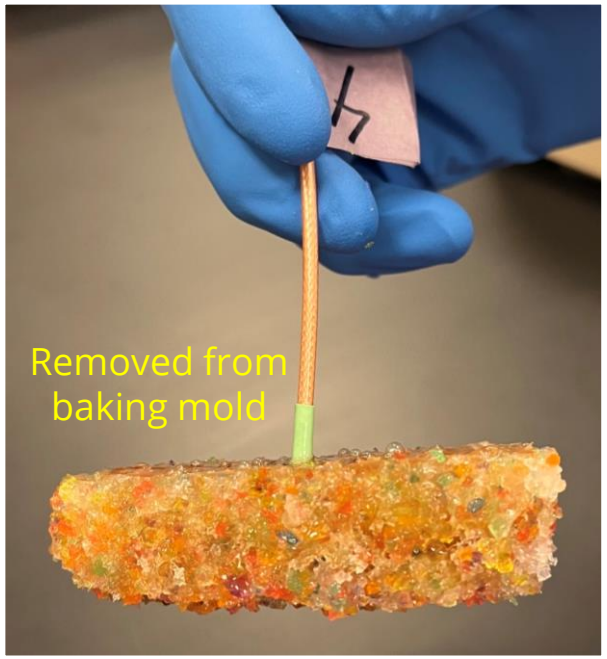


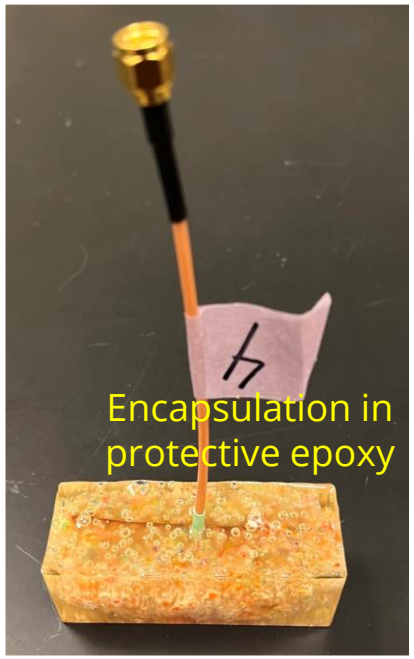
230807
4:10
3 h after wire removal

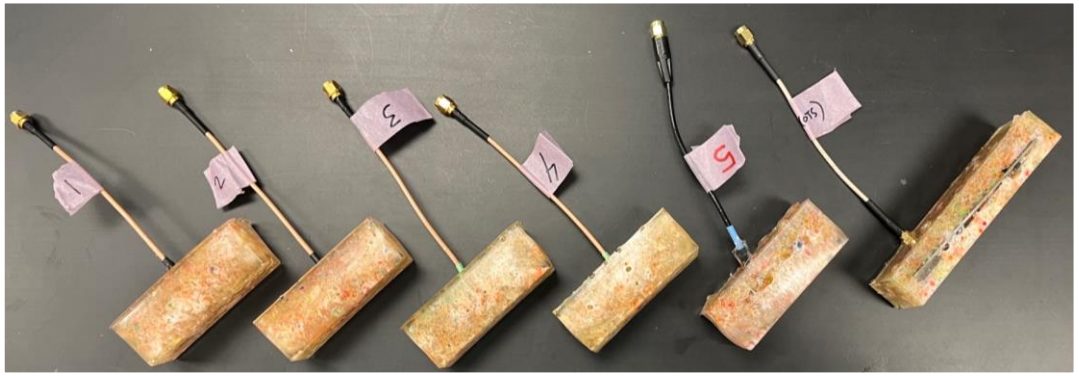

240122
t = 0
240125
t = 3 d
240213
t = 22 d
240306
t = 44 d
240327
t = 65 d
240417
t = 86 d
240508
t = 107 d
240528
t = 128 d
No silicone; 2 plugs; “normal”
No silicone; 1 plug; “normal”
No silicone; 0 plugs; printed lid
Sylgard silicone; 2 plugs; “normal”
Sylgard silicone; 1 plug; “normal”
Sylgard silicone; 0 plugs; printed lid
Silicone gel; 2 plugs; “normal”
Silicone gel; 1 plug; “normal”
Silicone gel; 0 plugs; printed lid
No silicone; 1 plug; *nail polish*
No silicone; 0 plugs; *epoxy lid*
Sylgard silicone; 2 plugs; *layered*
Sylgard silicone; 1 plug; *nail polish*
Sylgard silicone; 0 plugs; *epoxy lid*
Silicone gel; 2 plugs; *layered*
Silicone gel; 1 plug; *nail polish*
Silicone gel; 0 plugs; *epoxy lid*

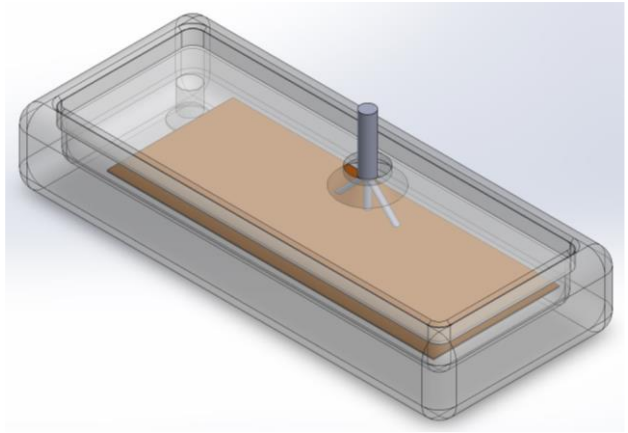

Protective
silicone coating

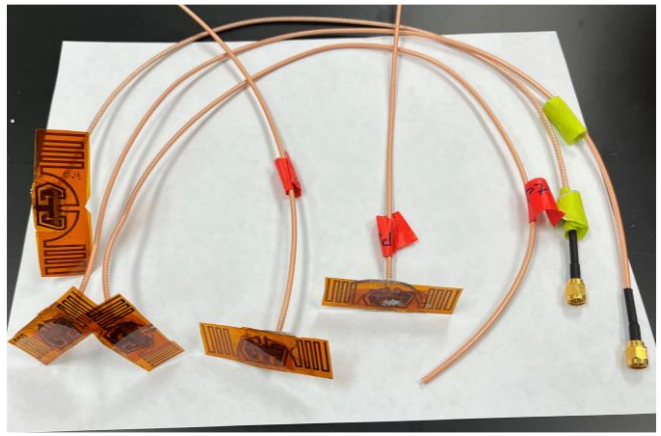

Encapsulation in silicone/bead
mixture
(without O_2-responsive component)

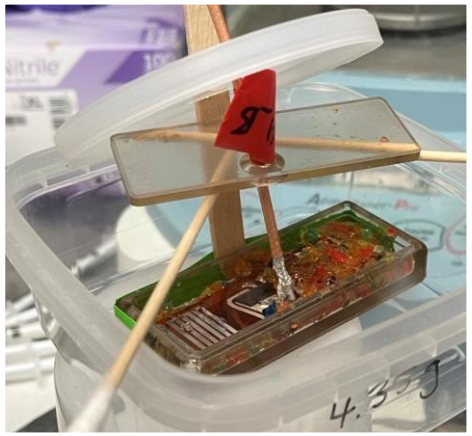

Removed from
baking mold


Encapsulation in
protective epoxy









With 3D printed lid

without silicone

with silicone

With epoxy poured lid

without silicone

with silicone