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Puck Passive Loop Seal

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Topics

- Introduction and motivation
- Goals and objectives
- Seal concept and layout
- Seal body
- Oxygen-barrier plugs
- Wire self-capture
- Next steps

Introduction and motivation

- Tamper-indicating devices (TIDs, or seals) are used to ensure monitored items are not accessed without detection
- Regimes that utilize TIDs include:
  - International nuclear safeguards
  - Arms control
  - Domestic security
  - Commercial (though the security requirements are not nearly as stringent as for treaty verification)
- IAEA uses tens of thousands of passive loop seals per year (with most ubiquitous, metal cup seal, shown on upper right of slide) to maintain Continuity of Knowledge of material or items during inspector absence
  - For years, IAEA has requested a new seal that incorporates technical advances (especially tamper-indication, unique identification, wire self-capture, in-situ verification)
  - IAEA developed Field Verifiable Passive Loop Seal (FVPS), showcased during the IAEA Safeguards Symposium, November 2022

Metal cup seal (CAPS), image from IAEA

FVPS, image from IAEA

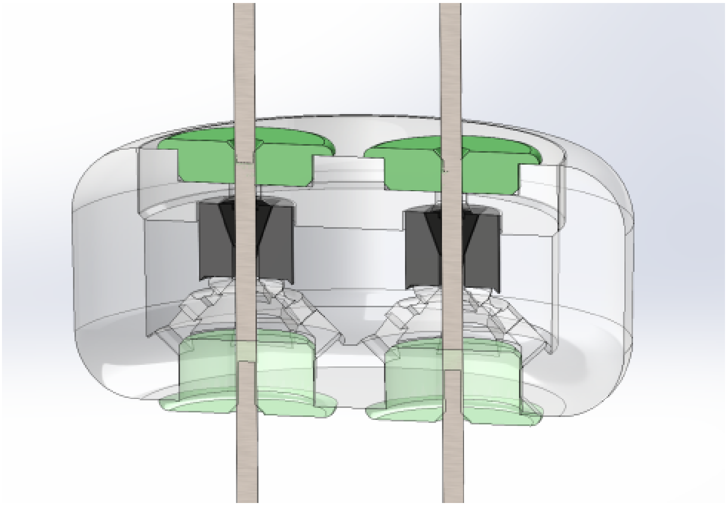
Goals and objectives

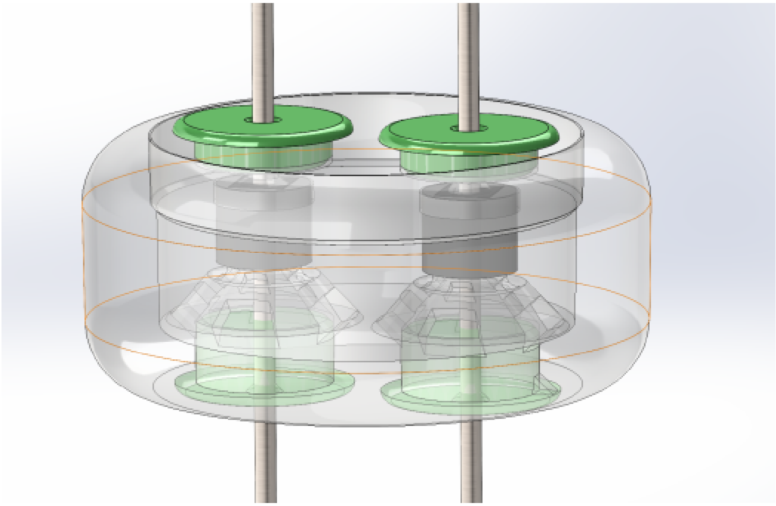
- Goal: to advance technical capabilities used in tamper-indicating devices (seals)
- Puck objective: design, develop, and test passive loop seal using published IAEA requirements [1] as guidelines
- Note that prototype design and development occurred in parallel with the IAEA's FVPS – Puck seal has several differentiating, value-added features

[1] "United Nations Global Marketplace: Field-Verifiable Passive Loop Seal," 23 June 2020. [Online]. Available: https://www.ungm.org/public/Notice/109997.

Puck concept

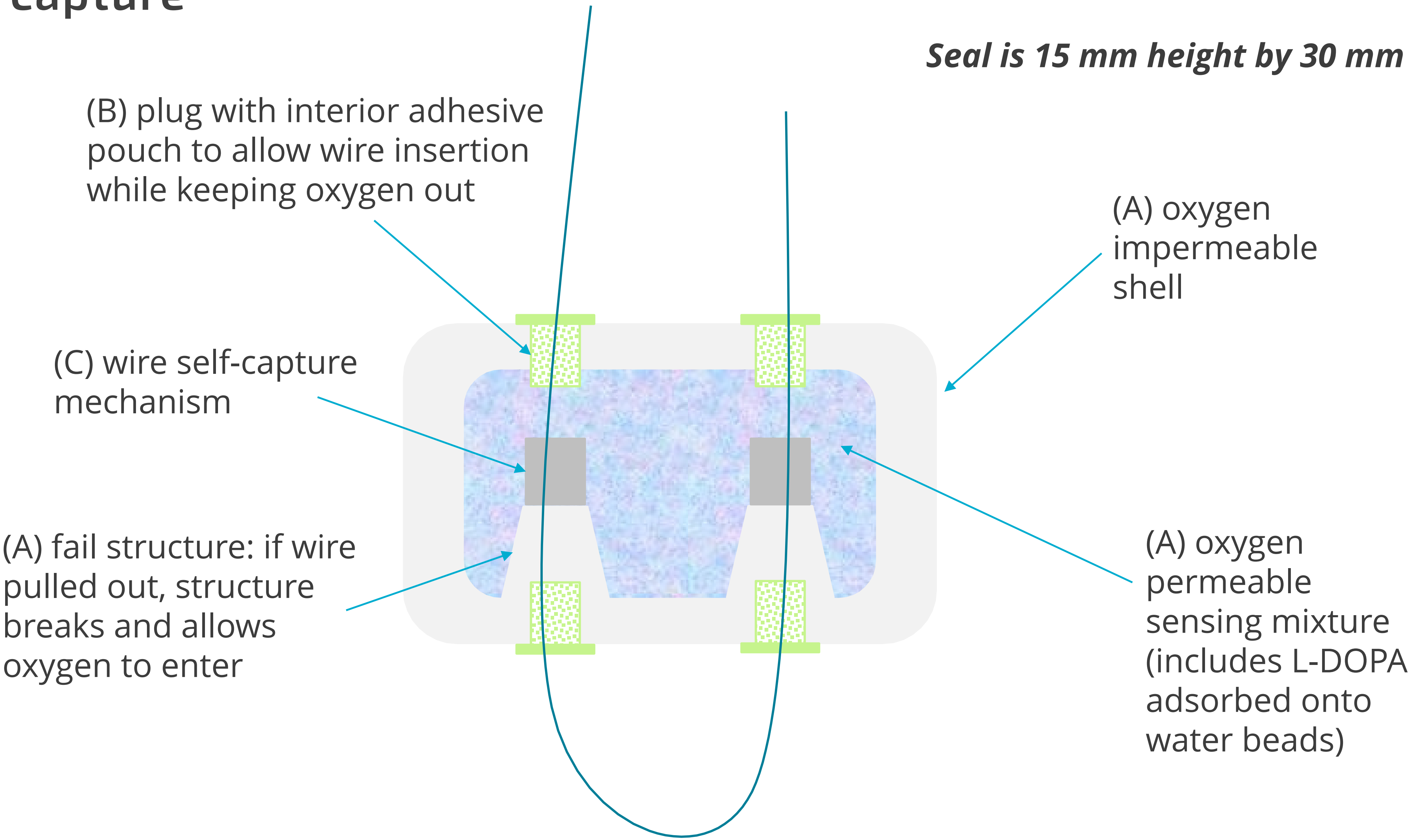
- Simple monolithic passive loop seal with wire self-capture, visually-obvious tamper-indication of seal body, inherent unique identifier
- Based on previously developed oxygen-sensitive material that irreversibly changes color upon tamper
- Meet as many requirements as possible from IAEA published guidelines while advancing R&D for application to tamper-indicating devices
    - IAEA requirements used as guidelines, but strict adherence is not necessary





Puck design, (A) seal body, (B) plug, (C) wire capture

Seal is 15 mm height by 30 mm diameter



Seal body

- Outer shell – began with molds but had issues releasing seal body off mold
  - To allow other R&D to continue, we've been 3D printing shells and either pouring epoxy on top or adhering a 3D printed top piece after sensing mixture poured inside
- Sensing mixture – concentration and processing studies (next slide)
  - Ensures consistency and mitigates false negatives
- Fail structure to allow increased oxygen flow if seal wire is pulled out

Coupon sets of the material (without oxygen plugs) fabricated. Tampered coupon turns black.

Seal body – concentration studies

- Processing studies to determine optimal material ratios and ensure consistency of Puck production

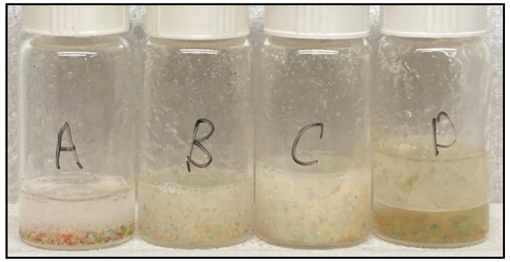
Optimizing bead size
Silicone amounts constant

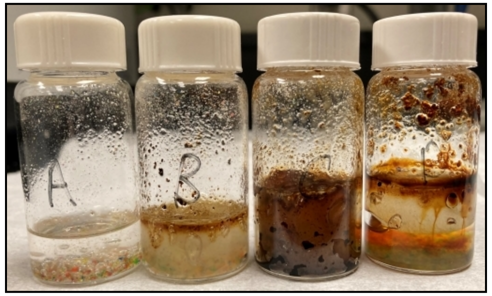
Bead size →

✗ ✓

Optimizing ratio of beads:L-DOPA
Beads & silicone amounts constant

L-DOPA amount →



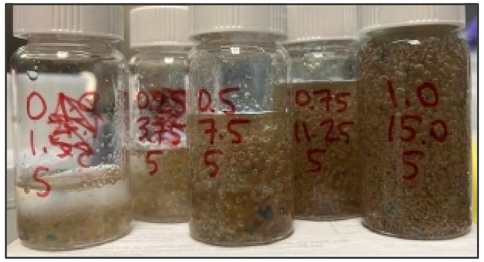


After 2 h of air exposure

✗ ✓ ✗

Optimizing ratio of (L-DOPA beads):silicone
Silicone amounts constant

Loaded beads amount →



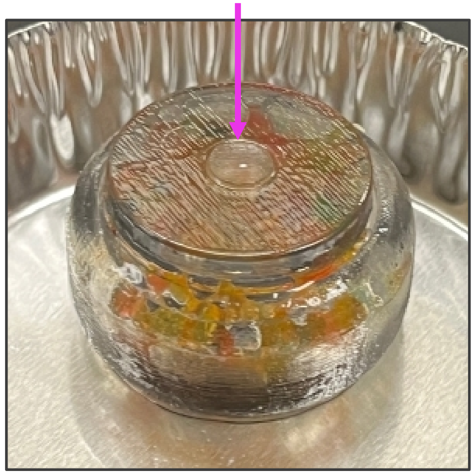
After 7.5 h of air exposure

✗ ✓ ✗

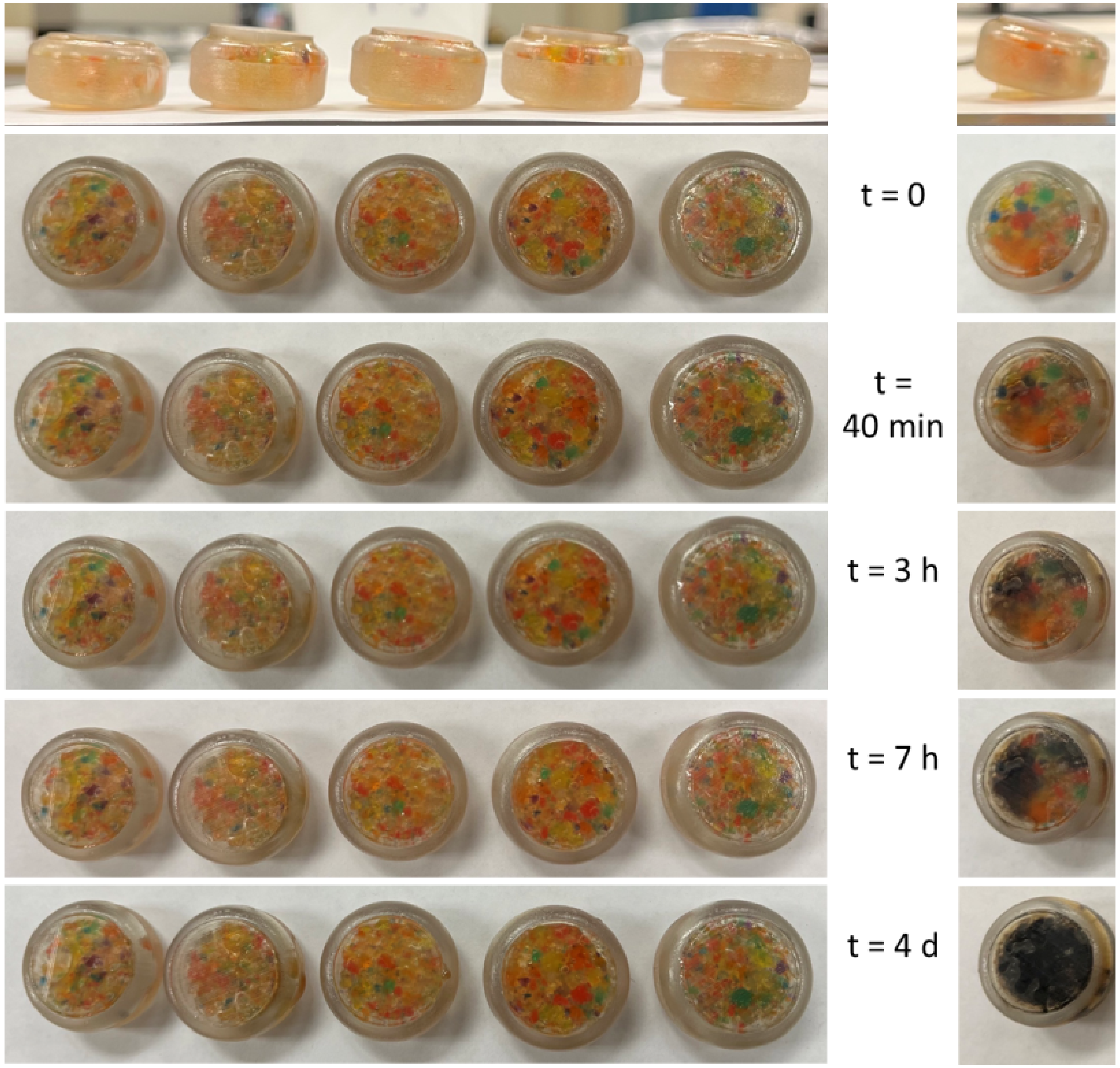
Plug or oxygen barrier

- Plug requirements
  - Allow wire insertion (like a pierceable membrane)
  - Mechanism to keep O_2 out – acrylate-based adhesive
  - Wire is inserted through viscous adhesive, then curing holds wire in place
- Adhesive curing studies performed using several acrylate monomers with four different photoinitiators
  - Down-selected formulation chosen due to quick curing at low irradiance power of handheld UV flashlight
    - Ethyl acrylate (EA)
    - Photoinitiator (BAPO)
    - 365 nm UV light exposure
    - UV penlight irradiance is 2 mW/cm^2
    - Shallow depth (~5 mm) of this formulation mixture cures solid quickly (~2 minutes)

Rubber plug inserted into Puck lid (does not contain adhesive in this photo)

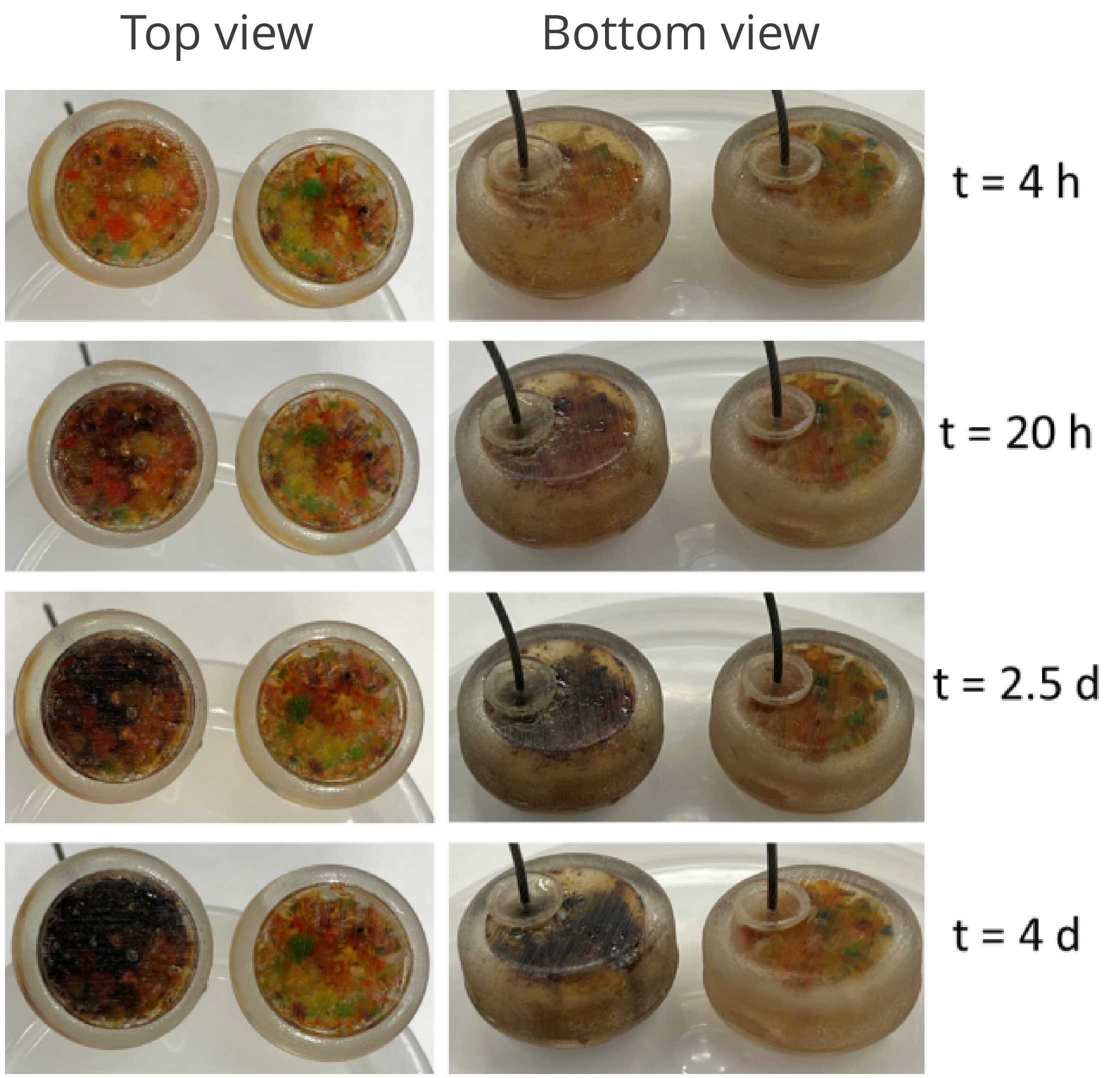


Initial plug testing



- Plug (without wire) is successful at keeping oxygen out when the plug is coated with epoxy
- Right side of this image shows a seal that did not have the plug coated with epoxy, resulting in oxygen entry to seal body

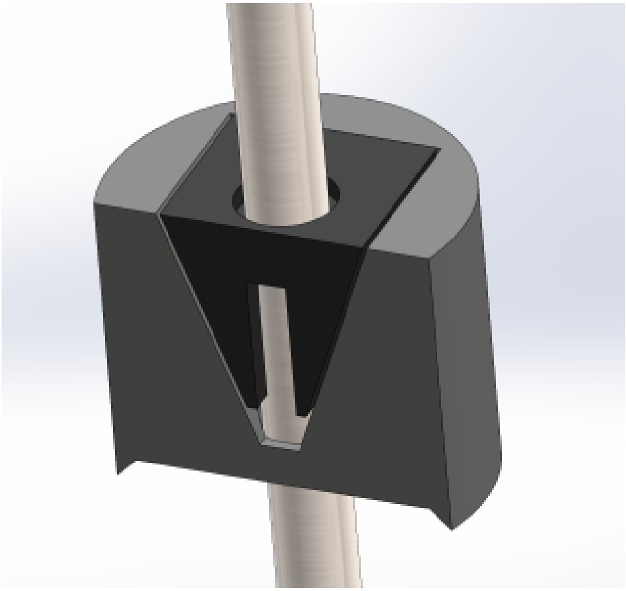
Plug with wire testing

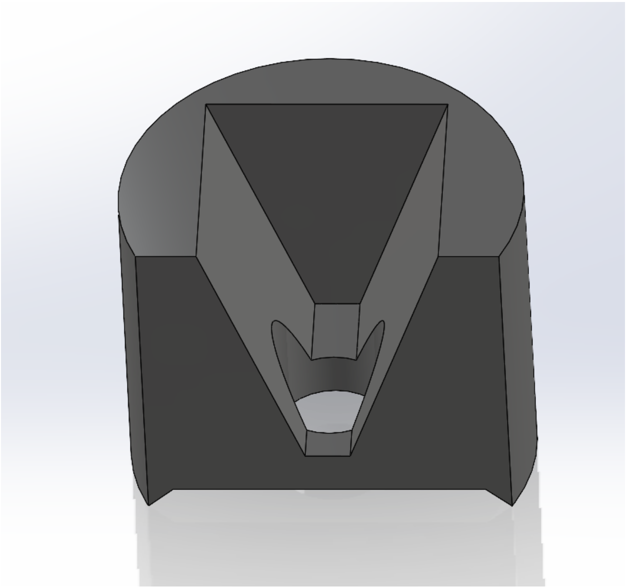


- Left seal: wire is not going all the way through seal body, potentially acting as a straw and allowing oxygen into inner mixture
- Right seal: wire still not going all the way through seal body, but making physical contact with 3D printed surface, potentially slowing oxygen straw effect
- Next step is to add exit plug and insert wire completely thru seal
- Adhesive pouch not yet integrated

Wire capture mechanism

- Originally, adhesive pouch would capture and hold the wire; however, team decided that adhesive would not hold enough weight against the IAEA required amount
  - "The sealing wire captured inside the seal body shall not be pulled out under the constant load up to at least 30 kg." [1]
- Two wire capture designs are being considered, one is shown below





Next steps

- SNL to continue developing prototype (wire capture, adhesive pouch within oxygen plug)
- Optimization and processing continuously addressed
- Test plan developed – testing will occur continuously throughout remainder of project
- Puck prototype to be completed and tested by 7/31/2023
- Work with Oak Ridge National Laboratory (ORNL) on another seal version, Puck/SAW
  - Passive
  - Uses same seal body (but enlarged)
  - Incorporates surface acoustic wave (SAW) chip that can provide a unique identifier upon standoff interrogation and monitor wire continuity