Remote Camera for Reactor Latch Inspections

& Other Reactor Engineering Projects

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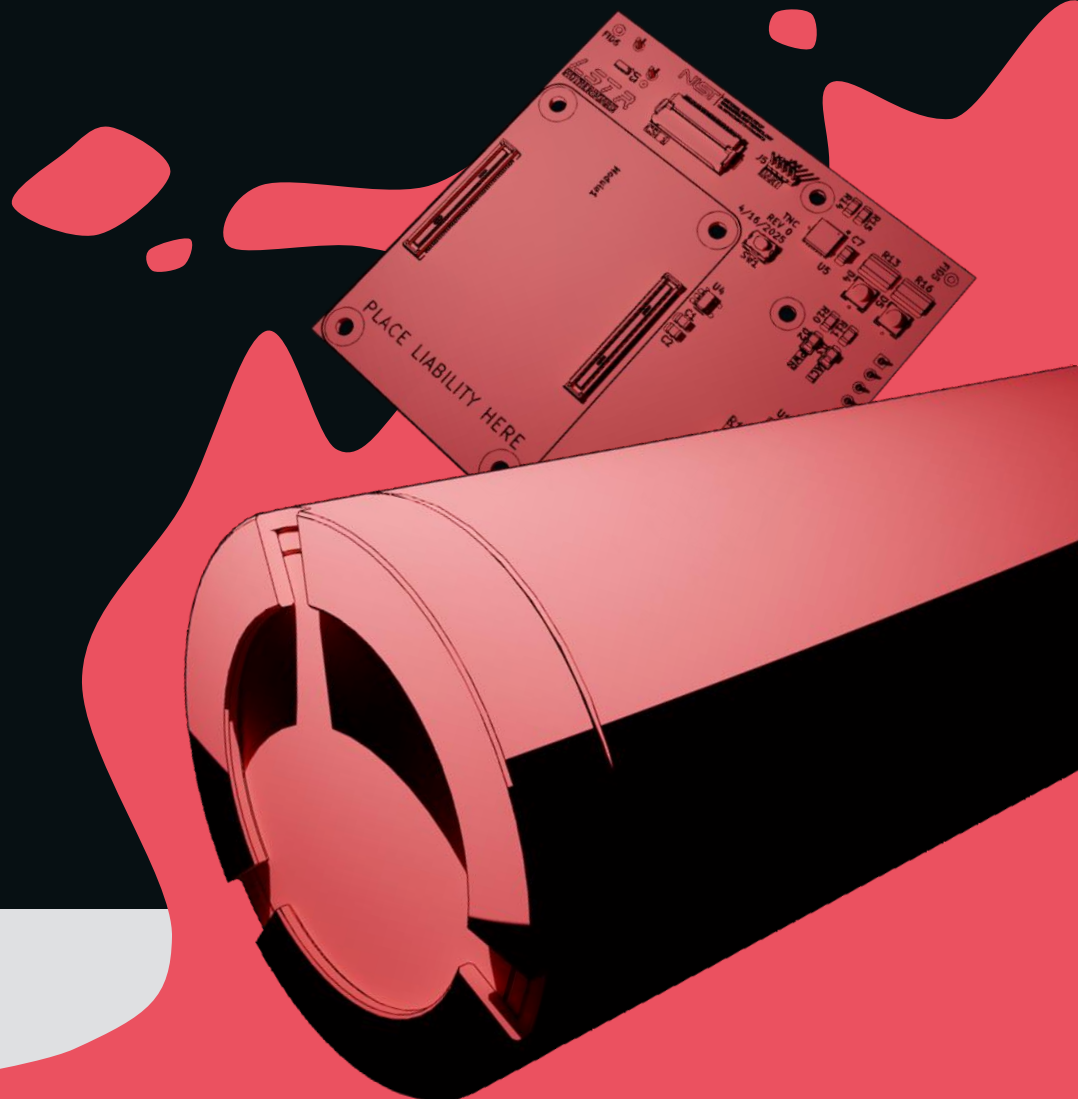
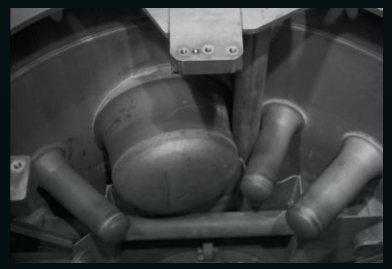
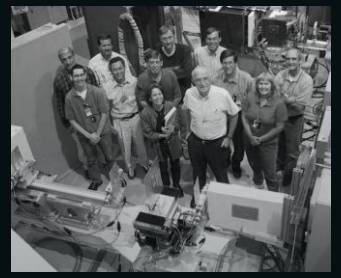
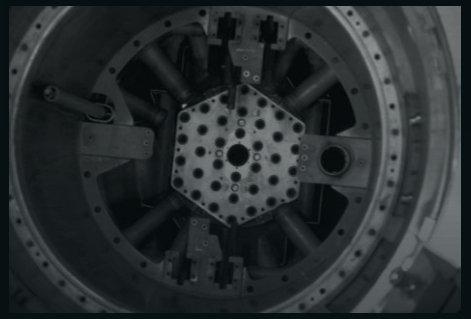
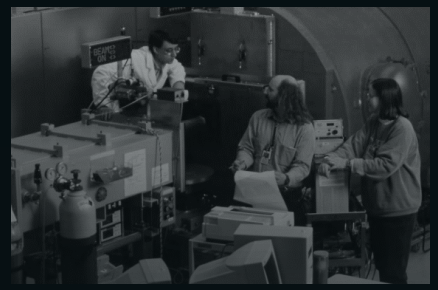


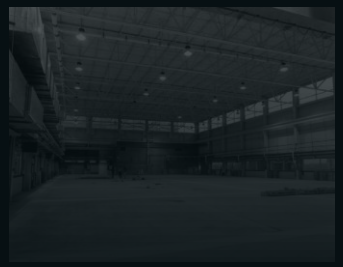
CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NIST

NIST CENTER FOR NEUTRON RESEARCH







1967 — First criticality

1985 — Upgraded from 10 MW to 20 MW

1987 — Cold neutron source

1995 — First neutron source upgrade

2003 — Second neutron source upgrade

2021 — Incident after refueling

Background

NIST Center for Neutron Research (NCNR)

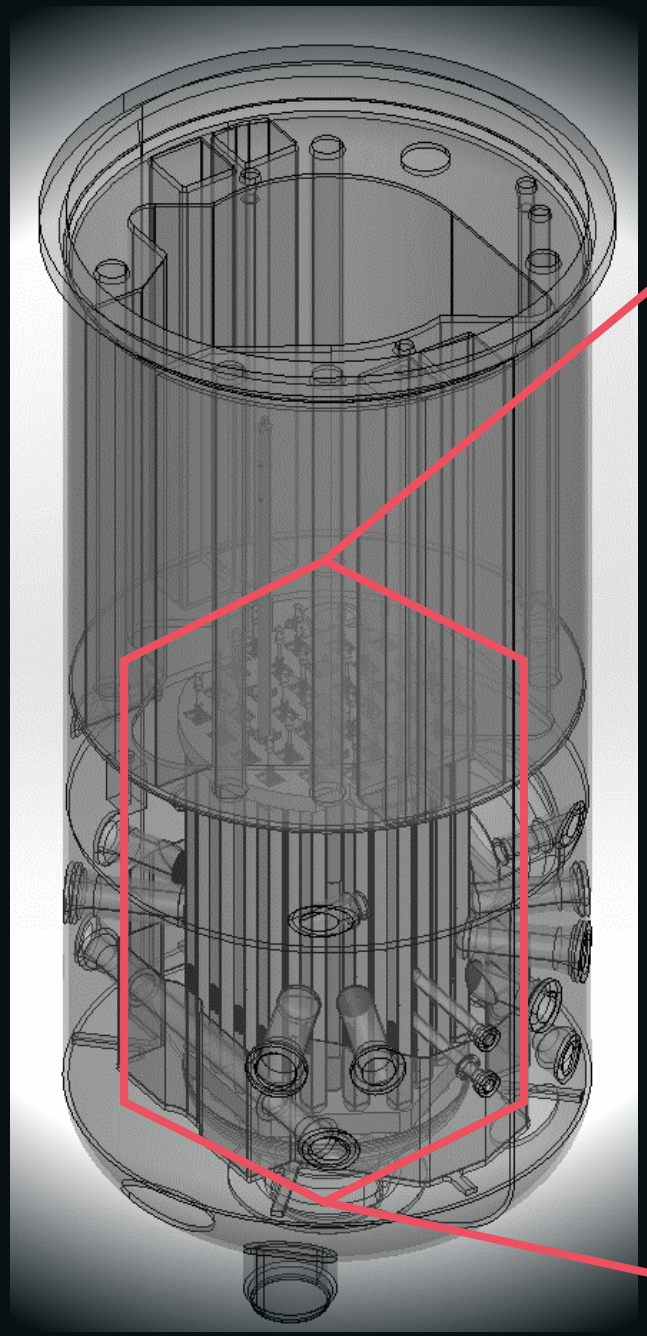
Supports: Neutron Scattering · Neutron Activation Analysis · Neutron Interferometry

The National Bureau of Standards Reactor (NBSR) research reactor is the NCNR's neutron source.

Exigence

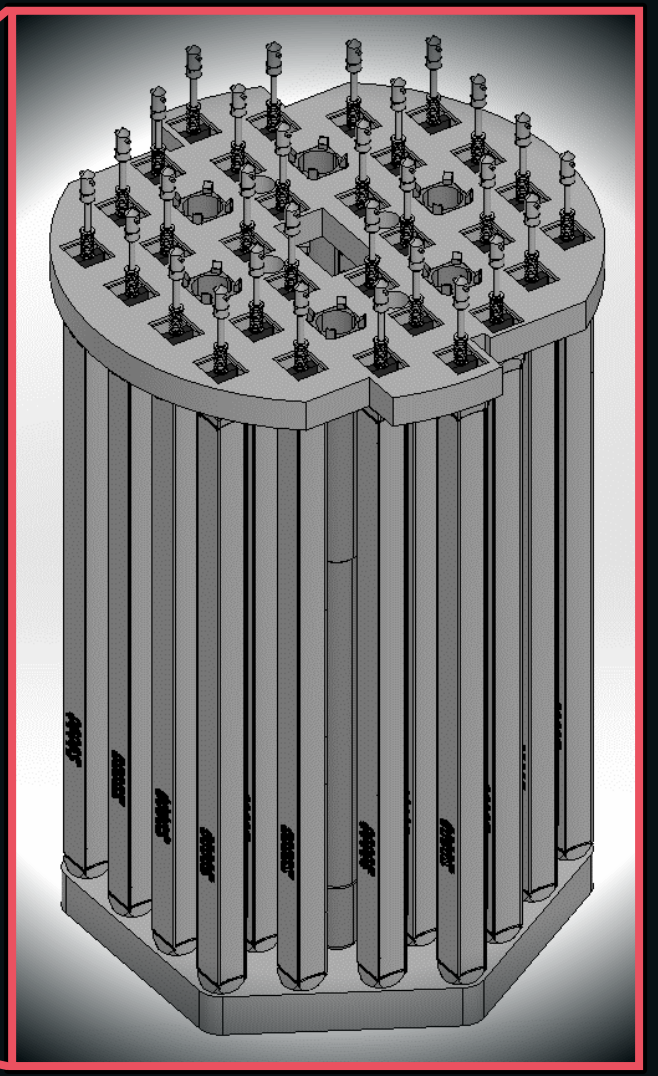
February 3rd, 2021
Partial Fuel Meltdown

Reactor Vessel



ⓘ
Refueling involves the removal of spent fuel elements, and insertion of fresh fuel elements.

Reactor Core



ⓘ
The core is composed of an upper and lower grid plate, with slots that accommodate fuel elements.

30
Fuel Elements

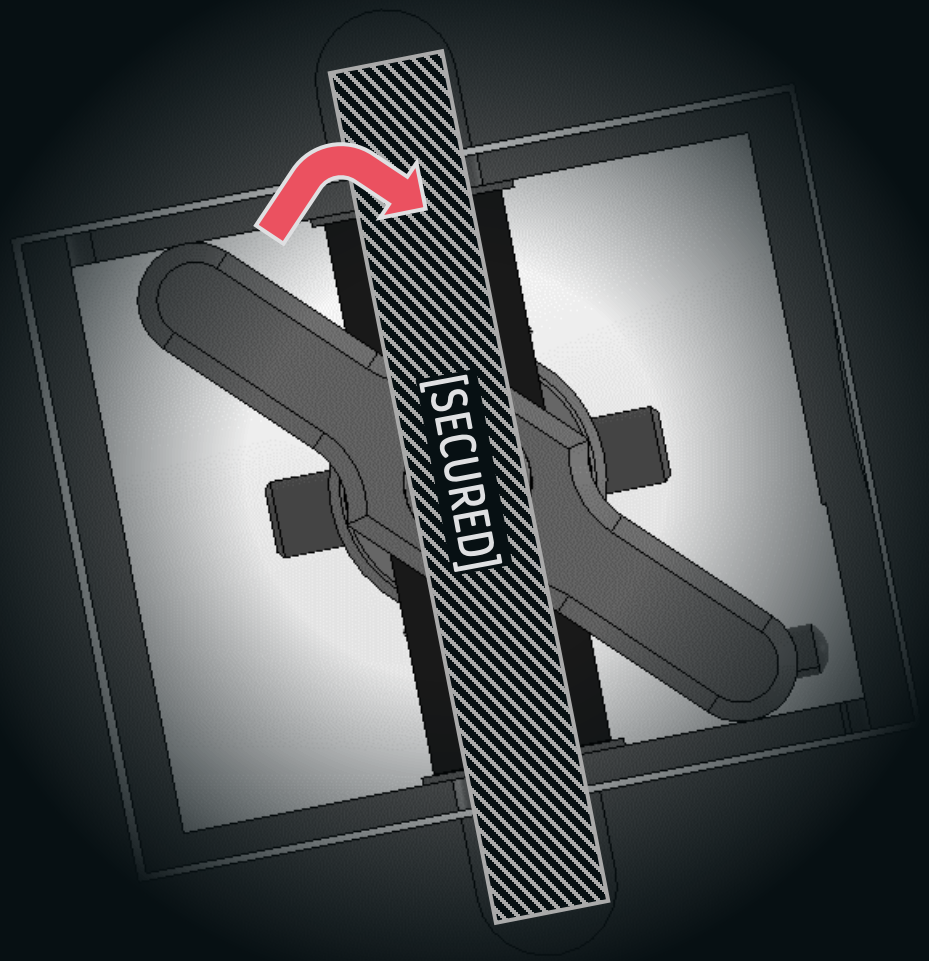
Exigence

February 3rd, 2021
Partial Fuel Meltdown

1.
The operator engages the element with a turning tool and presses down on the spring to release tension on the latch.

2.
The operator turns the latch to the “secured” position, aligning with the notches in the upper grid plate of the core.

3.
The operator disengages the turning tool from the element. The spring restores force onto the latch and keeps it in the secured position.



If the latch is not properly secured, the fuel element can become dislodged. This may restrict the flow of coolant and result in damage to the fuel element.

This is exactly what occurs on February 3rd of 2021, after the reactor was restarted.

Exigence

Lists are not exhaustive.
Before 2021, the NCNR had operated without incident for over 50 years.
The incident did not affect the surrounding community.

Response

- Major SCRAM, confinement sealed.
- Assessment of situation.
- Assessment of environmental contamination.
- Initial report to NRC.

Recovery

- Investigation into root causes.
- Cleaning of vessel and primary cooling loop.
- Repairs and testing.
- Vessel inspections.
- Reactor restart authorized and attempted in 2023.

Prevention

- Addressing vulnerabilities in latching mechanism of fuel elements.
- Implementing visual latch inspections as part of refueling procedures.

Research Operations Planned to Resume in Early 2026

nist.gov/ncnr/clean-run

February 3rd Incident

Proficiency Training

Procedure Improvements

ECR 1195

Fuelhead Latch Redesign

Corrective Action Program

Action

February 3rd Incident

ECR 1195

- Demand for visual inspection of latches before startup.
- Preventative control against similar incident

Initial Design

- First version of visual inspection tool.
- Designed to be inserted into reactor.
- Successfully deployed between 2022 and 2023.

Action

Action

February 3rd Incident

ECR 1195

Initial Design

ENGINEERING CHANGE REQUEST (ECR) — ECR No.: 1195

ECR Title:	Core Inspection Tool
System:	Fuel (elements, tools, storage, cannon)
Date:	08/04/2021

Introduction	
System or Equipment to be changed:	New Equipment for the refueling system
Purpose:	Provide tool for visual inspection to verify and document all fuel elements are in the proper fully latched position following fuel manipulations.

Description Summary

Discuss Design Functions, Planned Change, and Risk Management

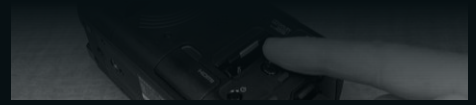
The visual inspection tool is to be used in response to the incident on February 3rd, 2021 at the NCNR where a fuel element was not properly latched when the reactor underwent startup. The function is to provide video evidence and confirmation that all fuel elements are properly latched after fuel manipulations and before startup to avoid any similar future incidents. Previously fuel latching was verified by rotational check per tech spec 3.9.2.1(2). This visual inspection tool provides an extra layer of redundancy by allowing a visual inspection per tech spec 3.9.2.1(3) to be performed after each refueling operation. Both the refueling and the rotational check are performed by feel. This visual inspection will allow us to see the condition of the element heads and latch bars prior to startup

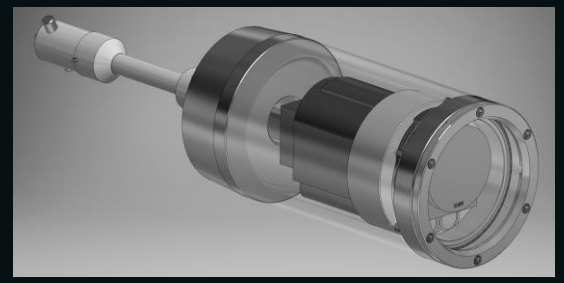
The tool is composed of a camera, lights, and an enclosure. The form of the system is designed to be very similar to a fuel element in terms of shape and weight to make use of an operator's muscle memory that is developed for moving fuel elements in the reactor. Use of unsecured fasteners is limited to avoid the tool leaking during usage and/or becoming dropped into the vessel. Additionally, the tool is designed out of aluminum, stainless steel and titanium for the body and fasteners with polycarbonate for the transparent face to ensure it is safe for use in a D2O environment. The tool is developed to be easy to decontaminate, using a smooth surface with minimal nooks, holes, and valleys that could trap contamination and/or make decontamination harder.

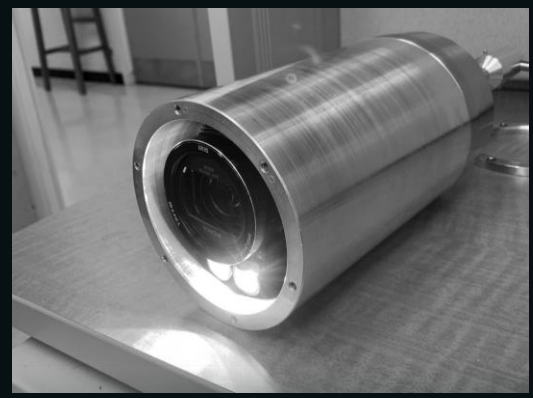
The tool must fit within the refueling tool plug and be manipulated with the same transfer tool. The buoyancy weight and movement of the tool are designed to be similar to a new element. This will allow insertion, movement through the transfer arms, and removal similar to a new element. This will also allow the reactor to stay on helium sweep with a raised vessel level, the same way a new element is put into the reactor. The transfer arms are by the nature of their normal use designed to move an element directly over each grid position with no obstructions. By designing our tool similar to a new element, it will be able to be moved over every grid position and look straight down on the fuel head, latching block, and latching bar assembly.

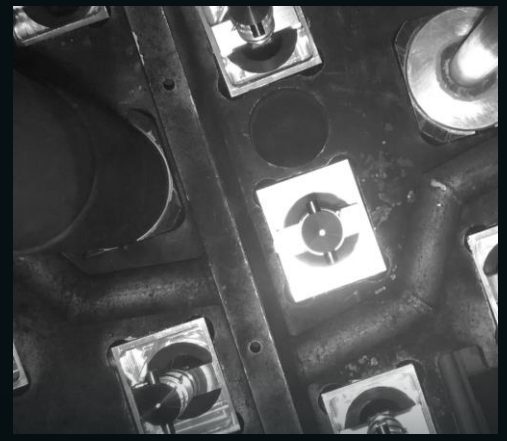
To avoid the possibility of tangling cables on core components, such as the poison hold-down tubes, the tool is designed to be completely wireless, containing within the enclosure its own battery and storage media. Our current design is for recording only with no live view feature. To be compatible with any computers in the NCNR both at present and in the future, the video format of the recorded video shall be a non-proprietary format.

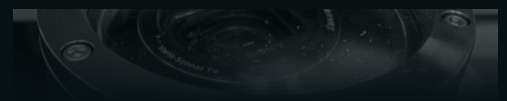
After the tool has recorded an entire trip around the core on each transfer arm over each element position, the video shall be moved off of the camera, reviewed by a qualified individual to verify all elements are fully latched, and then moved to the R drive for long term storage.











Inspection footage can only be viewed after the tool is recovered.

Charging and offloading data requires disassembling the tool for access to the camera.

Housing is susceptible to D_2O contamination.

Imperfect

Initial design is not practical for routine use.
New revision is needed to meet ECR 1195 requirements and satisfy operational needs.

Key Features for Revised Tool

New electronics and software will support a remote video feed.

Exterior hermetically-sealed connector will provide charging and data I/O.

Improved housing will reduce cavities for D_2O to collect in.

Imperfect

Initial design is not practical for routine use.
New revision is needed to meet ECR 1195 requirements and satisfy operational needs.

11 months later...

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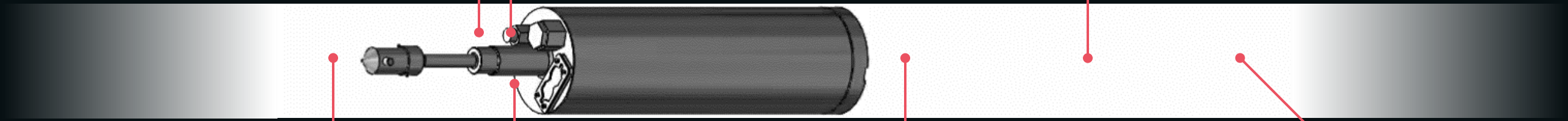
(Not)
Perfect
(But Good Enough)

PAVE PT4-SS-150-6-20-3112P-SOC
Docking Connector
Socket for charging and data transfer.

ContDisc Screw-Type ¼" NPT Muffled
Pressure Relief Valve
Burst-disc relief valve for excessive internal pressure.

TBD
Payload Assembly
Contains camera sensor, lens, and electronics.



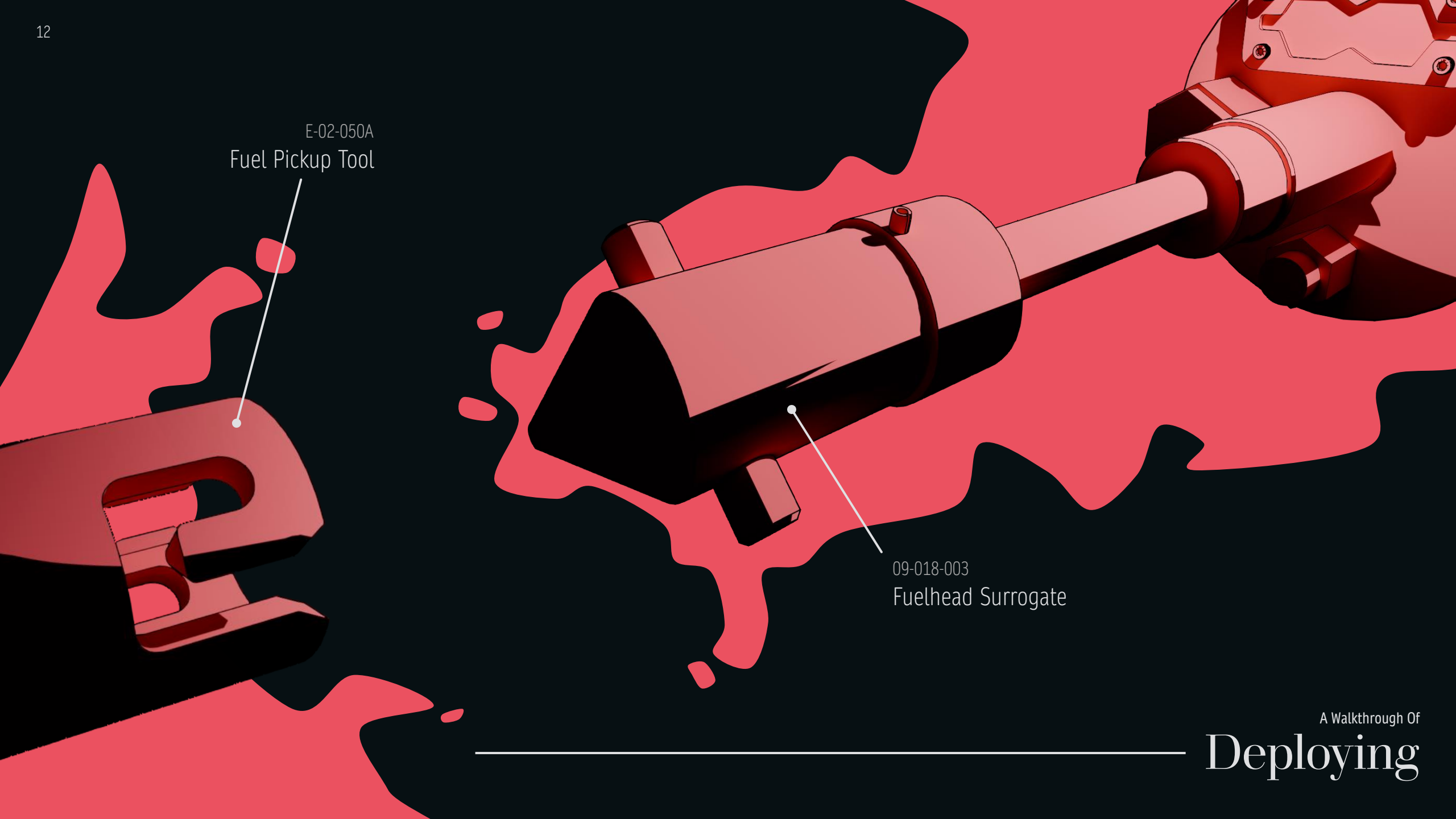
09-018-003
Fuelhead Surrogate
Interfaces with fuel management tools.
Reuses existing infrastructure and operator training.

TBD
Antenna Window
RF-transparent polycarbonate window for radio antenna for wireless communications.

Zeus Battery PC9-12S
Rechargeable SLA Battery
12 V with 9 Ah of capacity.
Allows tool to operate in the reactor without tethering.

TBD
Cover Assembly
Seals bottom of inspection tool.
Has a polycarbonate window for the camera to see through.

Latching Sighting Tool, Revised
(LSTR)


E-02-050A
Fuel Pickup Tool
09-018-003
Fuelhead Surrogate

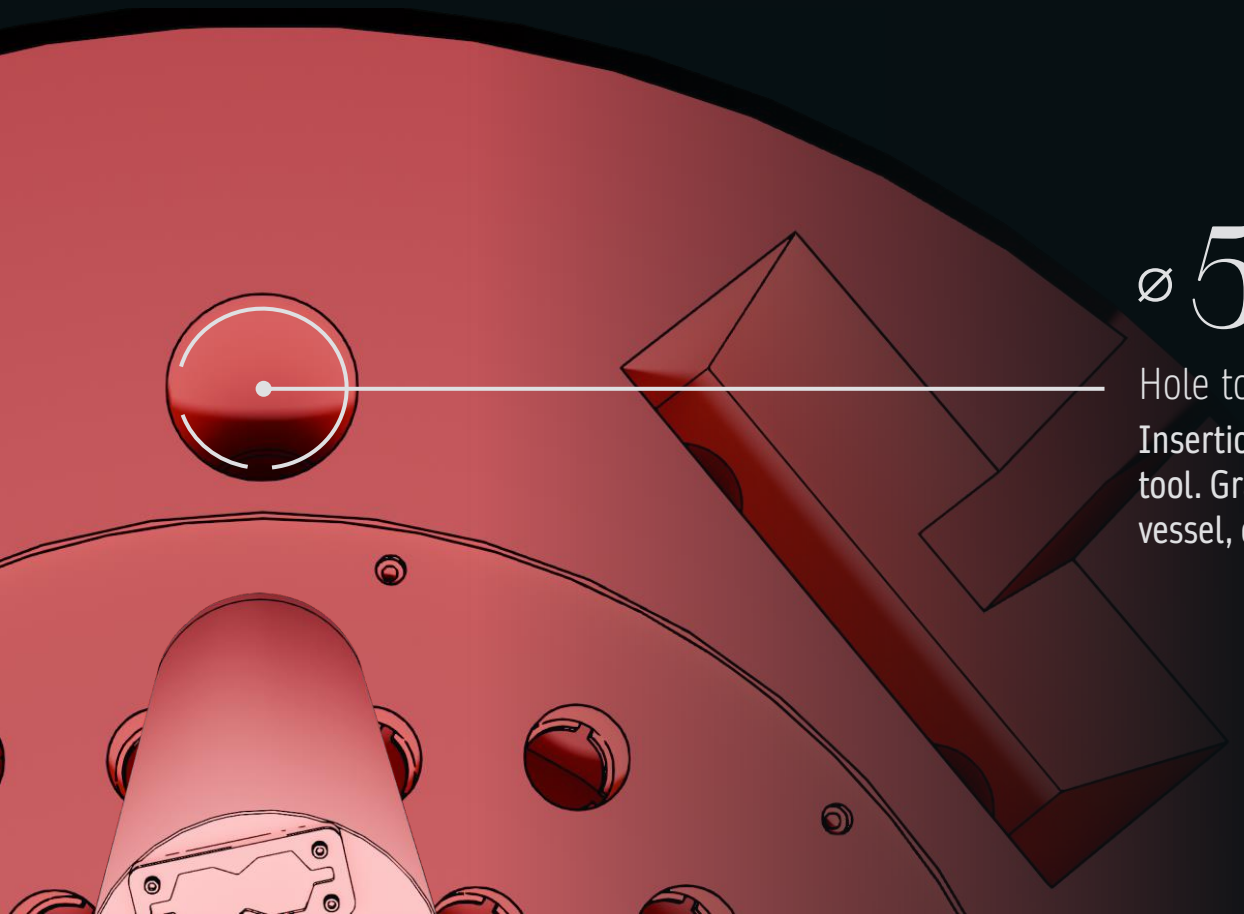
Restrictions

This introduces a lot of problems for the internals of the tool, because:

1. The tool is cylindrical.
2. 5” of diameter is not a lot to work with.
3. There’s even less space after accounting for the thickness of the hull.

#1

Tool Diameter



⌀5.5”

Hole to Drop-out Chute

Insertion point for inspection tool. Grants access into reactor vessel, overlooking the core.

Restrictions

ECR 1195

- 5 hours of uptime per inspection.
- Power source must be internal (due to other restrictions that will be discussed).

Technical Details

- Realistic estimate for power draw of tool was 25 W.
- Battery capacity expected to degrade over lifespan, need to over-spec capacity.

Initial Ideas

Can't fit larger battery sizes. Need power density or reduce power consumption!

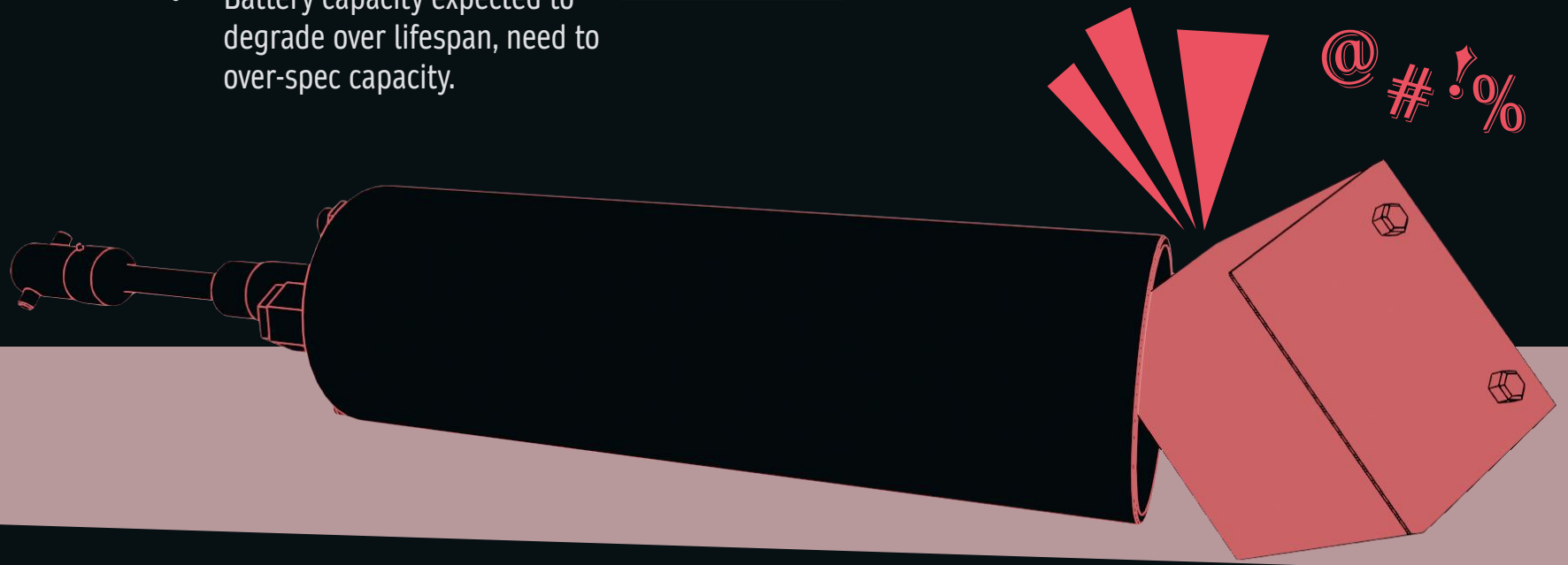
1. Lithium polymer (Li-Po) or lithium ion (Li-Ion) battery.
2. Lithium iron-phosphate ($LiFePO_4$) battery.
3. Lead-acid with power optimizations.

#1

Tool Diameter

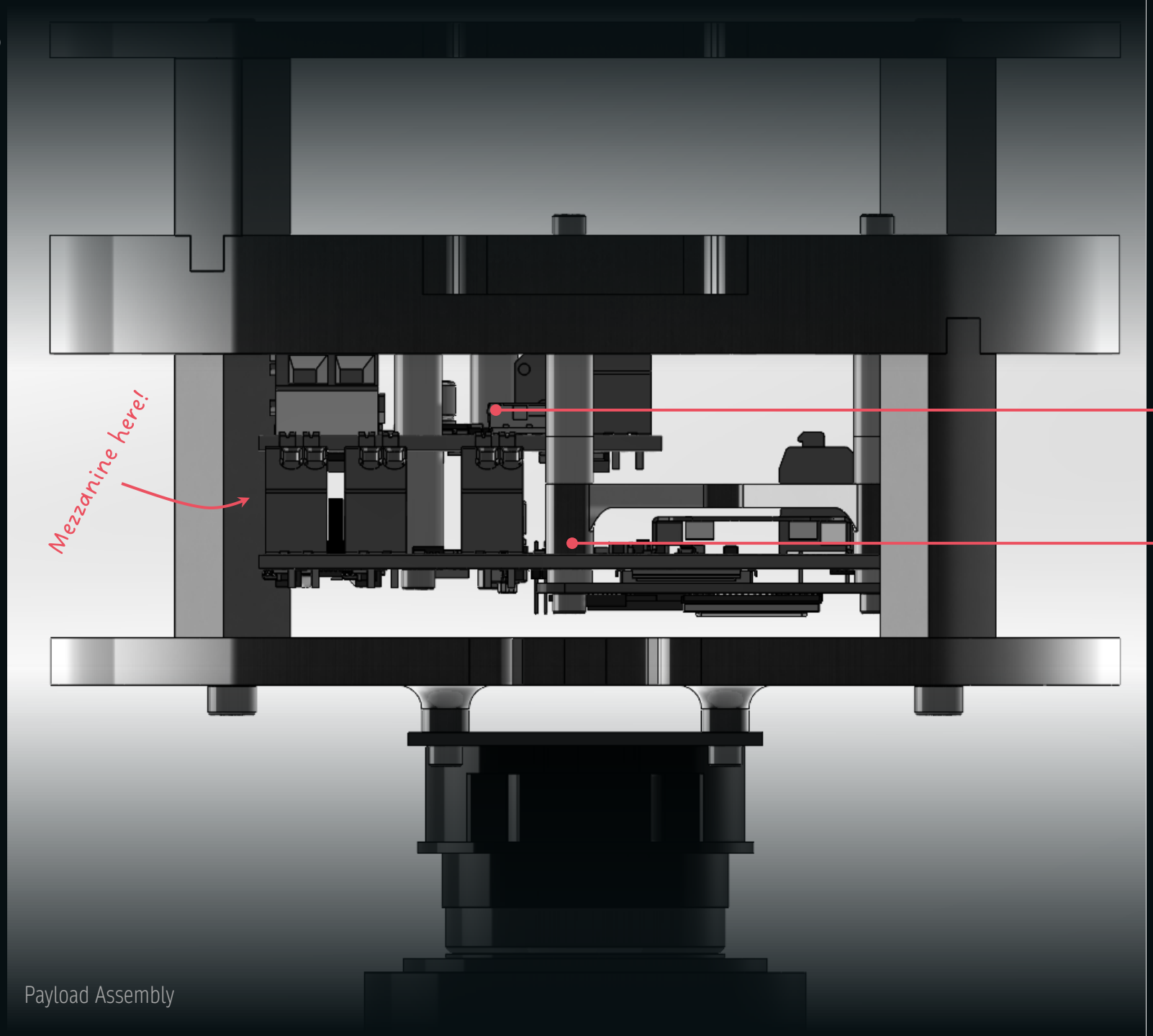
- Selected conveniently-dimensioned 12 V, 9 Ah (108 Wh) SLA battery.
- Replaced off-the-shelf camera with more integrated embedded camera, and separate optics (12.5 to 75 mm vari-focal lens).

No fire hazard while fulfilling ECR!



A lot of things just don't fit into a 5" tube.

Unfortunately, this includes many models of off-the-shelf rechargeable batteries.



Payload Assembly

Restrictions

#1

Tool Diameter

Power Management Daughterboard

Handles battery management, charging, and power regulation.

Motherboard

Carries embedded computer. Central hub for various sensing peripherals.

Not enough internal space for monolithic mainboard.

Motivates stacked design with daughterboard, connected to a motherboard through a board-to-board mezzanine connector.

Restrictions

#2

No Tether

Question

How do you move the tool to overlook different parts of the reactor?

Answer

By using transfer arms (part of fuel management infrastructure).

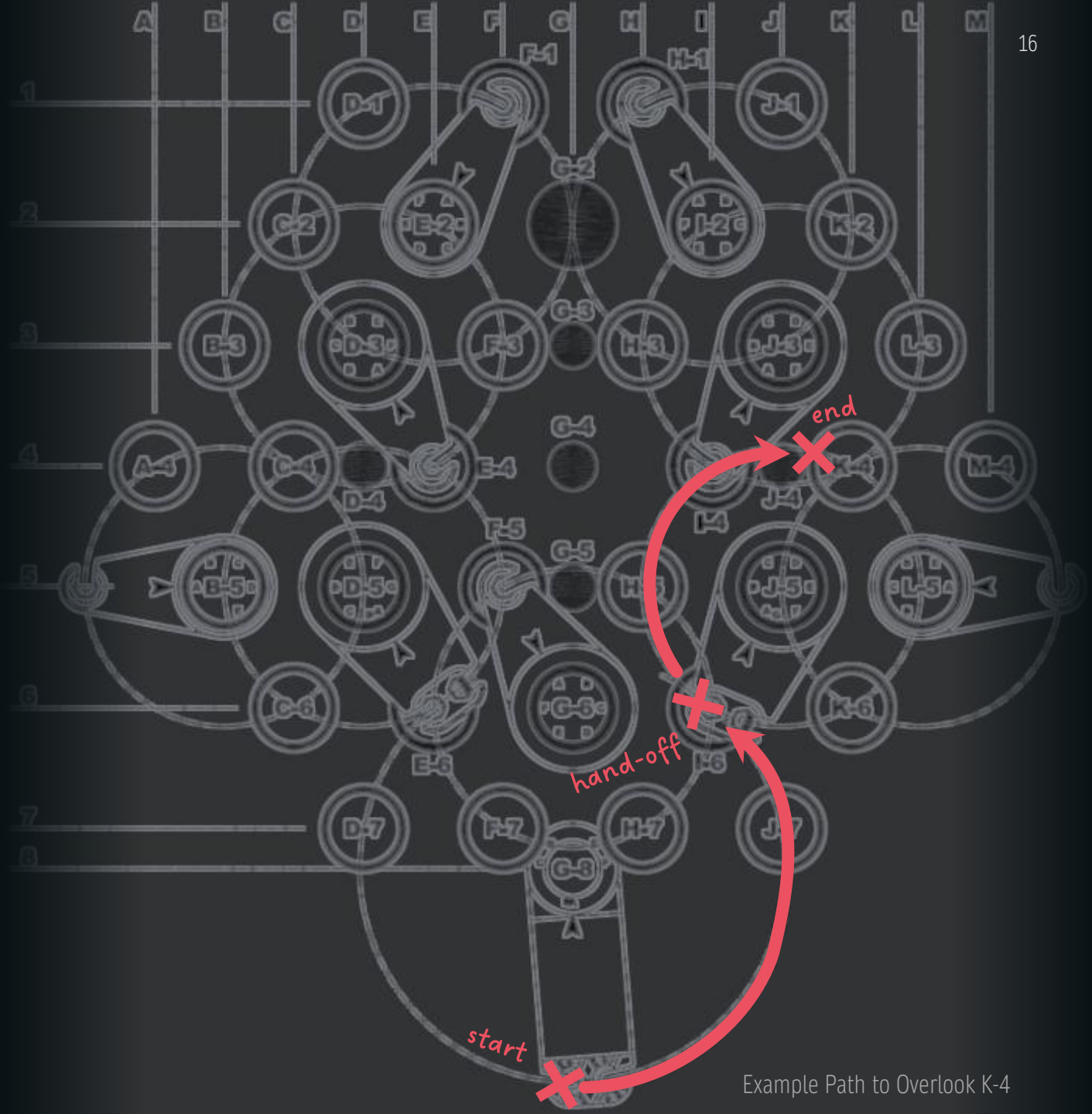
Cannot use umbilical cable for power and data. Would get tangled while tool moves between transfer arms.

Motivates engineering requirement for internal battery and wireless communications.

Why IEEE 802.11 (Wi-Fi)?

5' of Reinforced Concrete	Conflict!	Live Video Feed Streaming
Wants Low-Frequency		Wants High-Frequency

Or just stick an antenna into the vessel and pick Wi-Fi, because it's the most ubiquitous and easiest to implement.



Example Path to Overlook K-4

Radiation

Counterintuitively not a problem.

1. High magnification optics, more separation distance.
2. D_2O provides inherent shielding.
3. Exposure not expected to affect tool, nor did it affect initial prototype.

Contamination

Of significant concern.

1. Tool is partially submerged in D_2O.
2. Need to resist D_2O from entering tool.
3. Need to reduce cavities for D_2O to collect in, mostly contributed by blind holes for screws.

Thermal

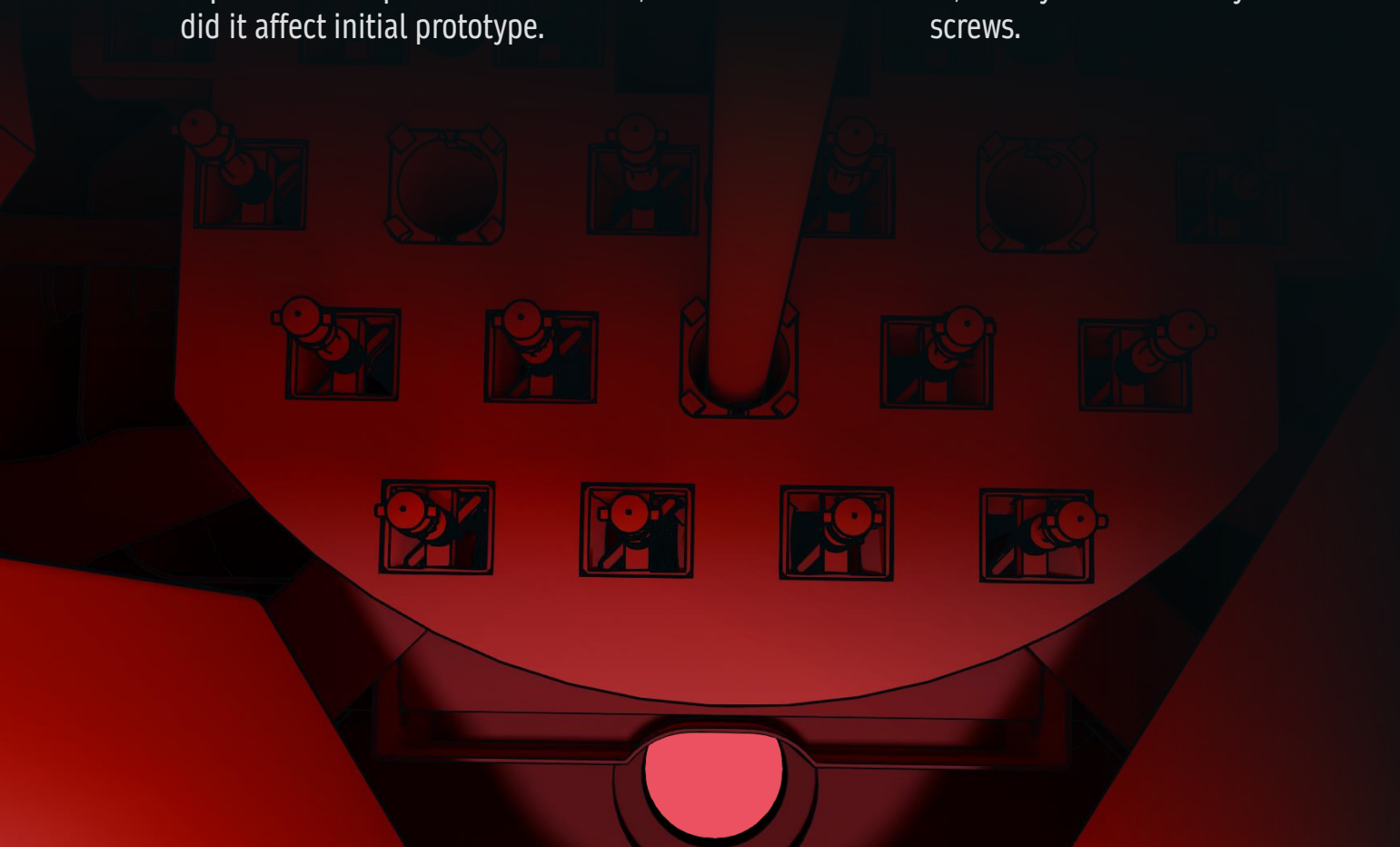
Of significant concern.

1. 21 to 38°C ambient D_2O temperature.
2. Tool generates waste heat, need heat capacity and dissipation.
3. Care to be taken around heat-sensitive components.

Darkness

Needs addressing.

1. No lighting installed inside of reactor vessel.
2. Like with initial design, new design needs onboard lighting.
3. IR is not a solution.



Conditions

Inside of a Reactor

New Design

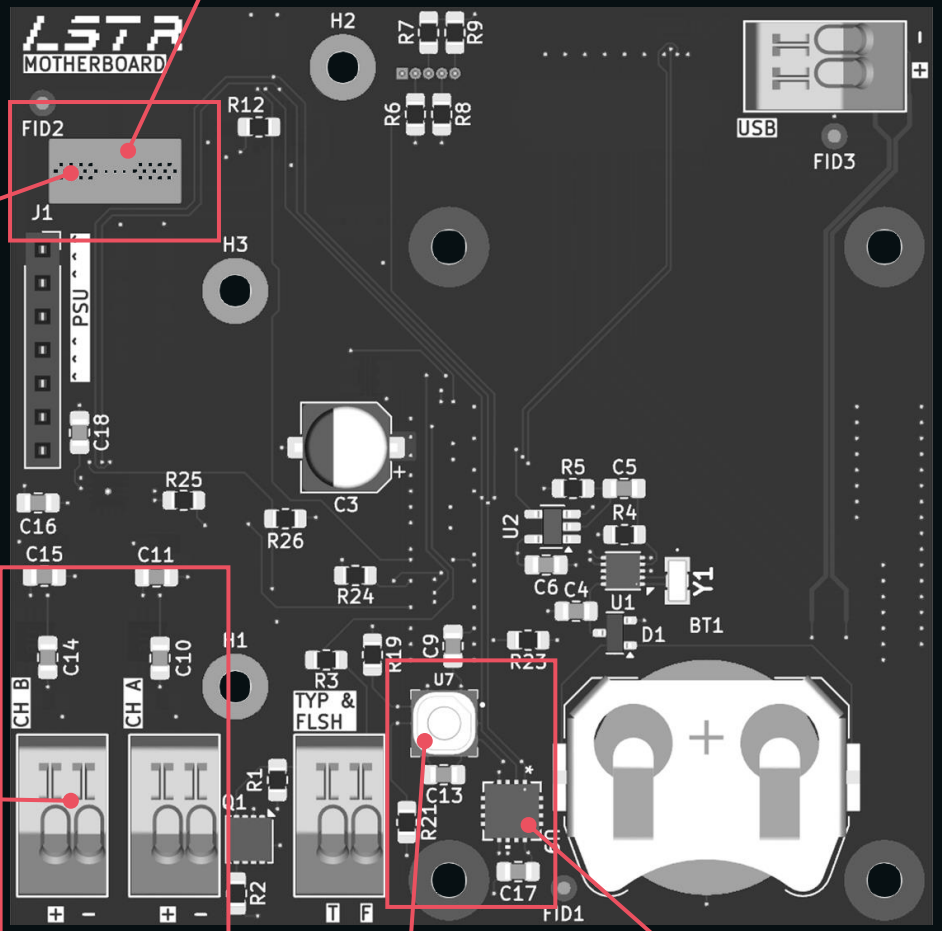
Initial Design

Screw-on design removes volume for D_2O by eliminating the usage of fasteners.

O-rings used in both designs are made from the same fluro-elastomer material for thermal and chemical resilience.

Darkness

Front



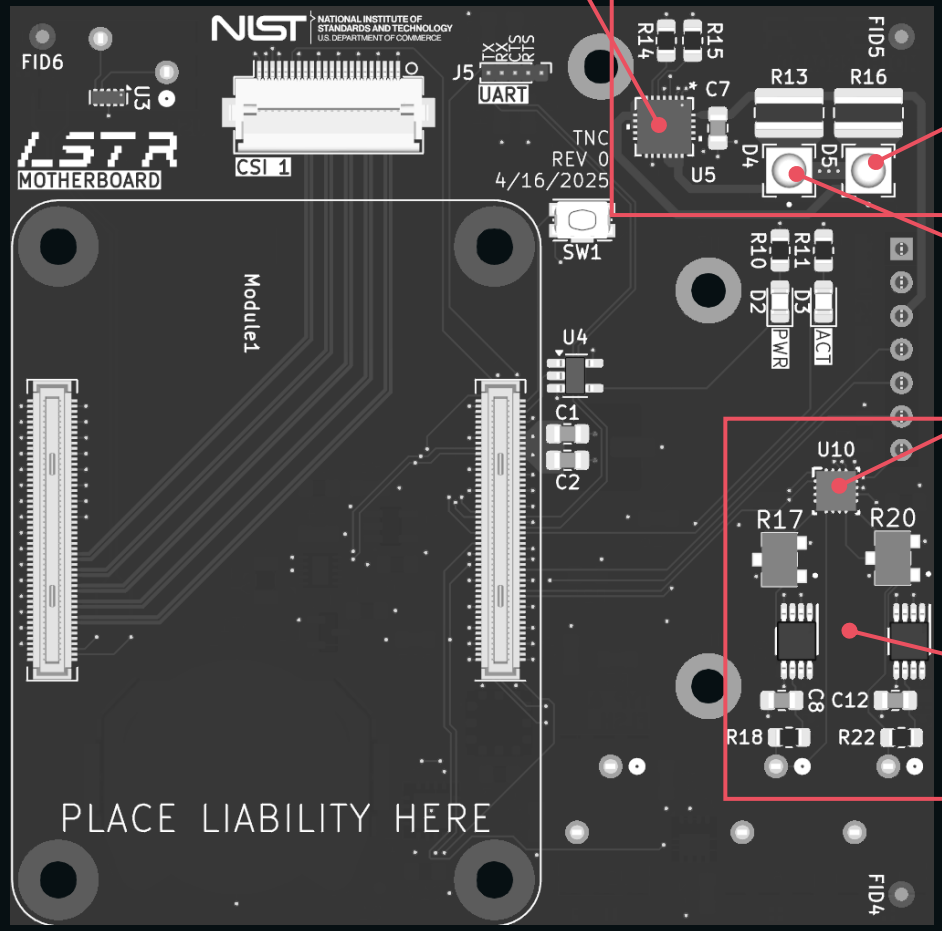
Exposed Copper Pad for Heatsinks

Thermal Vias

Wire-to-Board Interfaces for RTDs (External Temperature Sensors)

Absolute Pressure Sensor

Ambient Temperature Sensor



LED Driver IC

Illumination LED

Illumination LED

ADC

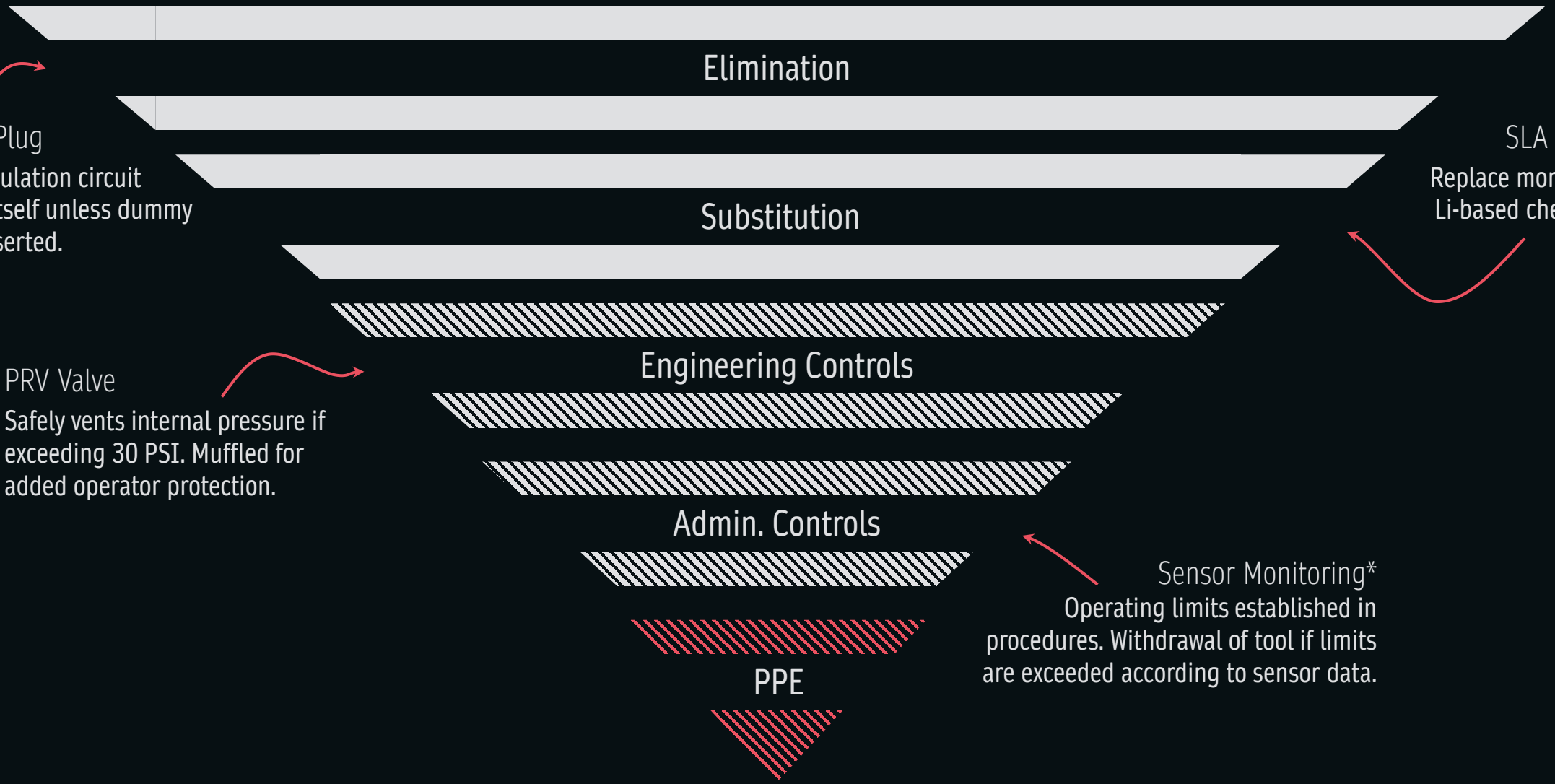
Voltage References & Bridges

Back

Thermal

Conditions

Inside of a Reactor



Dummy Plug

Power regulation circuit disables itself unless dummy plug is inserted.

SLA Battery*

Replace more volatile Li-based chemistries.

PRV Valve

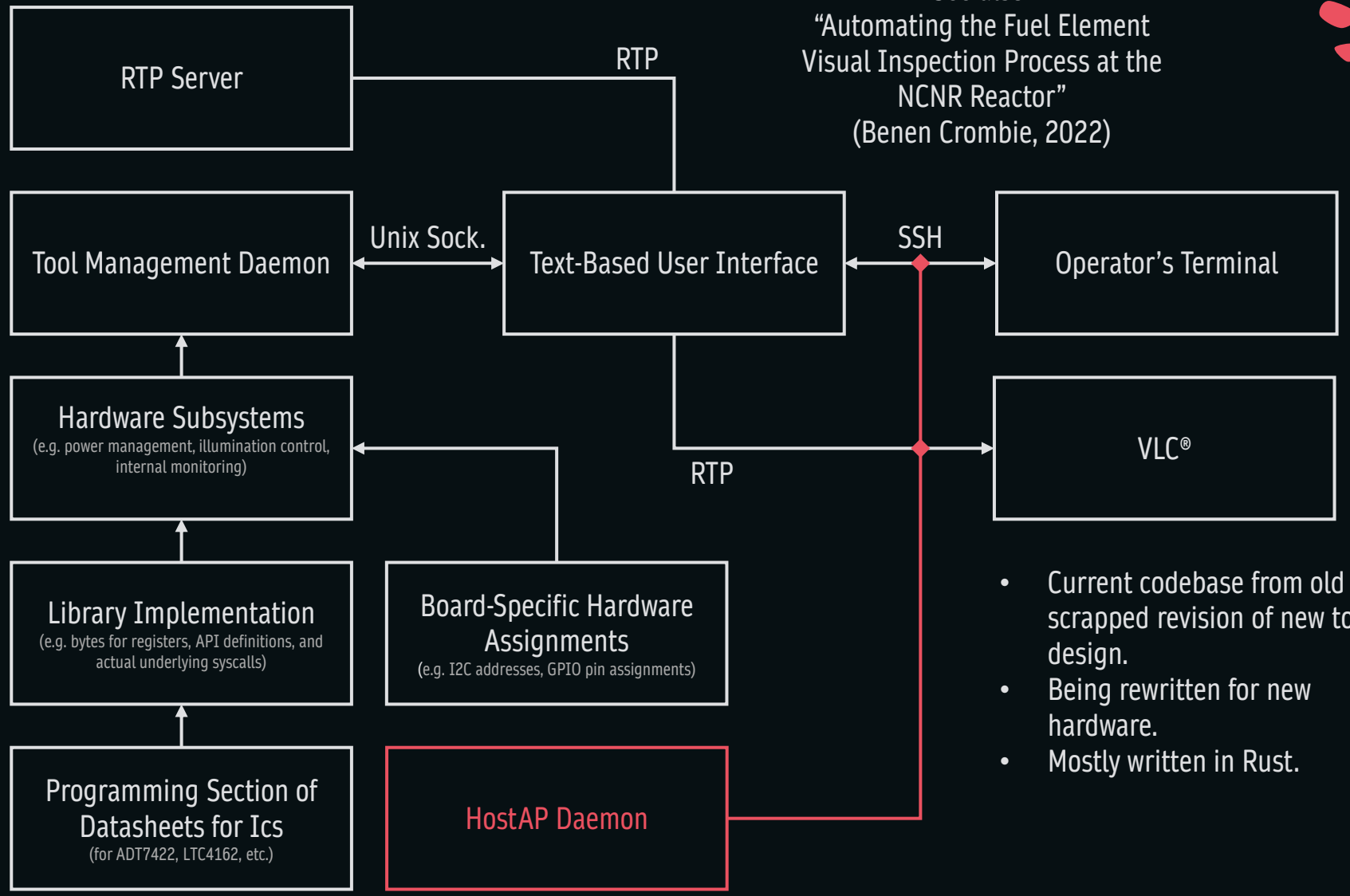
Safely vents internal pressure if exceeding 30 PSI. Muffled for added operator protection.

Sensor Monitoring*

Operating limits established in procedures. Withdrawal of tool if limits are exceeded according to sensor data.

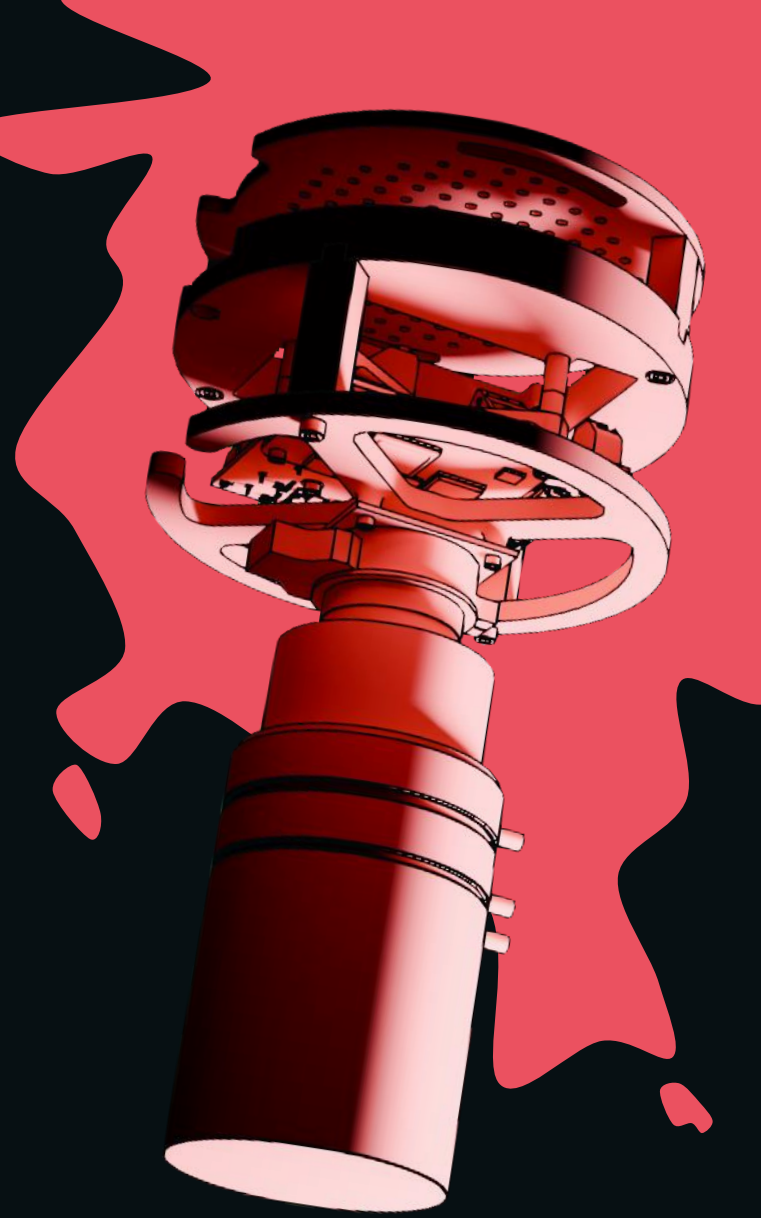
Controls

* Mentioned in previous slides.



See also:
"Automating the Fuel Element Visual Inspection Process at the NCNR Reactor"
(Benen Crombie, 2022)

- Current codebase from old scrapped revision of new tool design.
- Being rewritten for new hardware.
- Mostly written in Rust.



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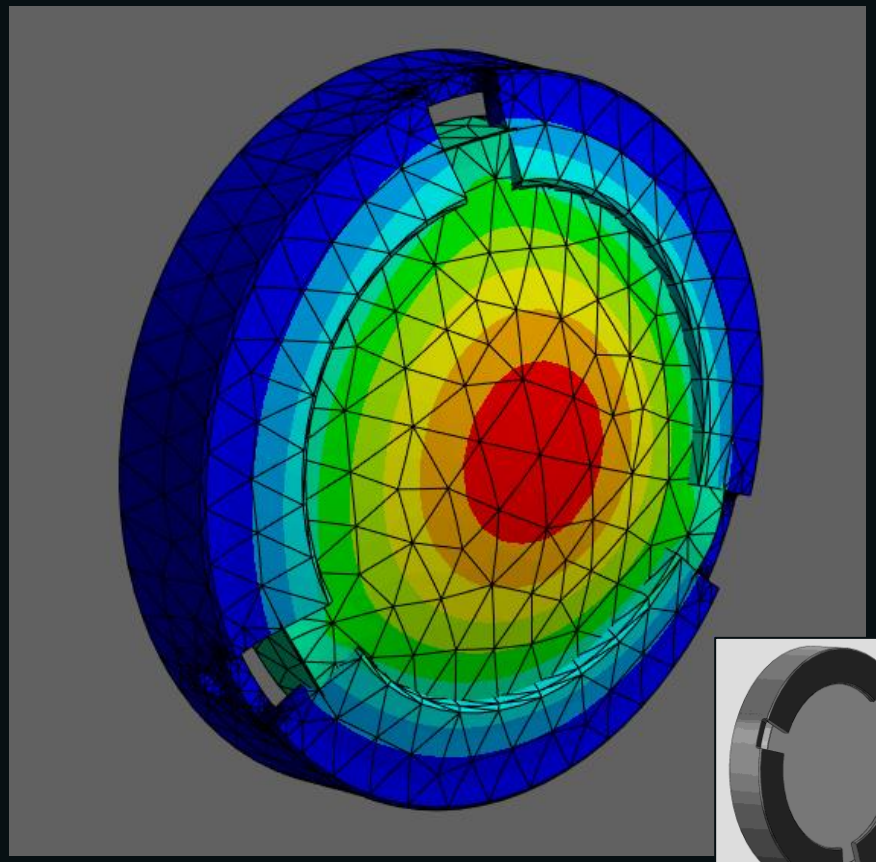
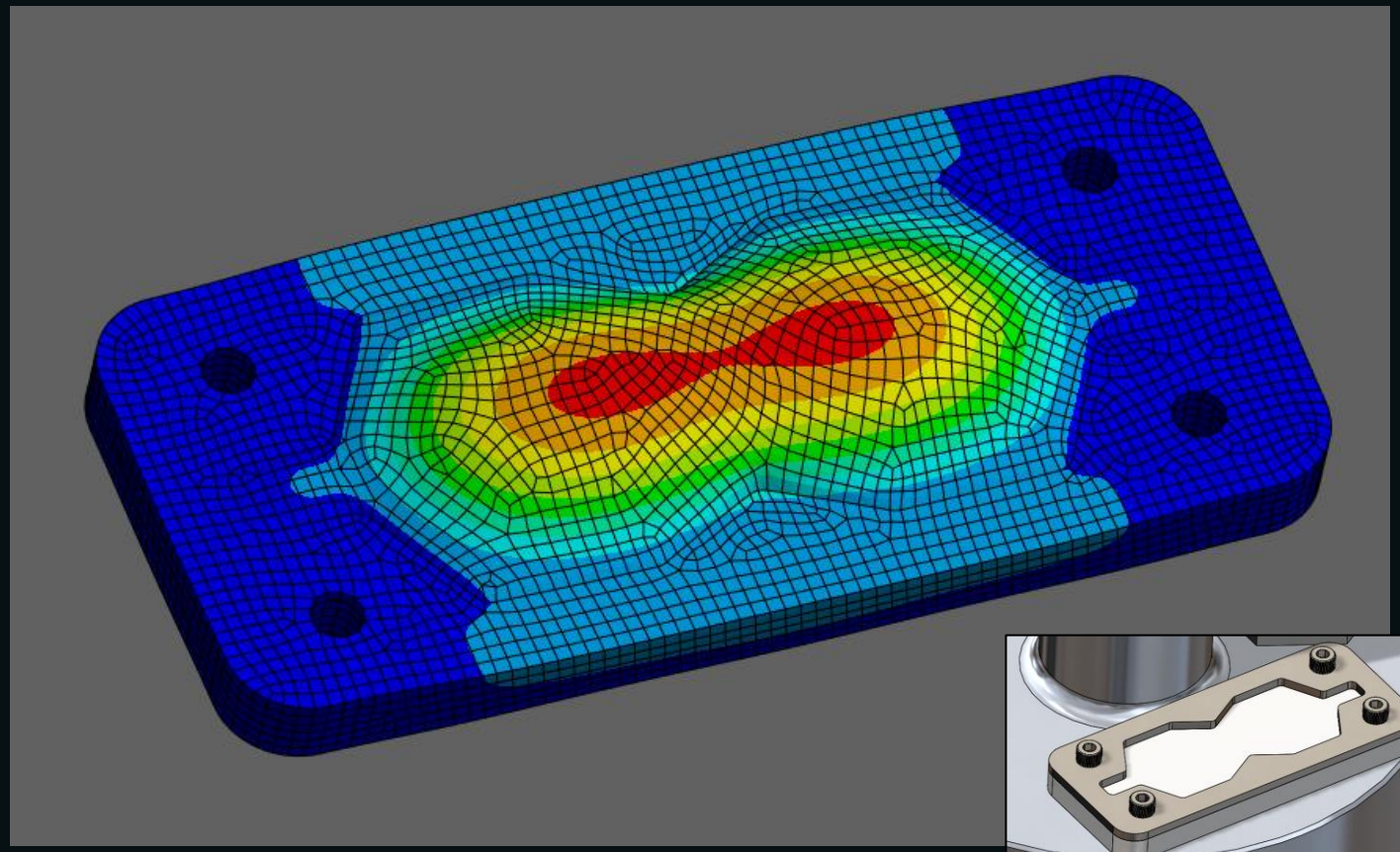
(Brief Overview Of)
Software

Analysis
(Glances At)

Preliminary finite-element modeling of polycarbonate windows.





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Future

RA 20h 37m 12s
DC +42° 0.1' 48"

Mechanical & Integrity

- Assess seal integrity.
- Assemble prototype.
- Order prototype parts.
- Review of mechanical design and preparing drawings.
- Package and deploy basic operating system, for testing and developing payload.
- Assemble motherboard, power supply daughterboard, and overall payload prototype.
- Procure parts for internal electronics and optics.
- Full integration of prototype and technical writing for ECN and procedures.
- Test optics against target setup that simulates separation distance within reactor.
- Out-of-reactor dry-run inspection.
- Develop software systems.

Payload & Software

PAC Room Reorganization

Addressing Corrective Action Program Report 694

- For the Process Automation and Control (PAC) Room.
- Rearrange hardware by subsystem.
- Restructure power distribution.
- Meet standards for workspace clearances.
- Cable management and labeling.
- Implement controls against undocumented modifications.

Blatant stock photo.
It's a security issue if I publicly distribute images of the PAC room.
Just imagine some CAT6 spaghetti for me, alright?

Tritium Monitoring System Overhaul

Restoration of H-3 Monitoring at the NCNR

- Airborne tritium is a weak beta radiation source.
- Monitoring is of interest for the sake of ALARA.
- Overhaul seeks to resolve maintenance and operational issues.
- Engineering requirements being developed.
- Health Physics and Reactor Operations included in discussion.

Others

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PAC Room Project Owner
James Whipple

Tritium Mon. Project Owner
Sahar Rubin

SURF Directors
Leland Harringer
Susana Teixeria
Julie Borchers
Julie Keyser

CORE
CHRNS OUTREACH AND RESEARCH EXPERIENCE

SUPPORTED BY

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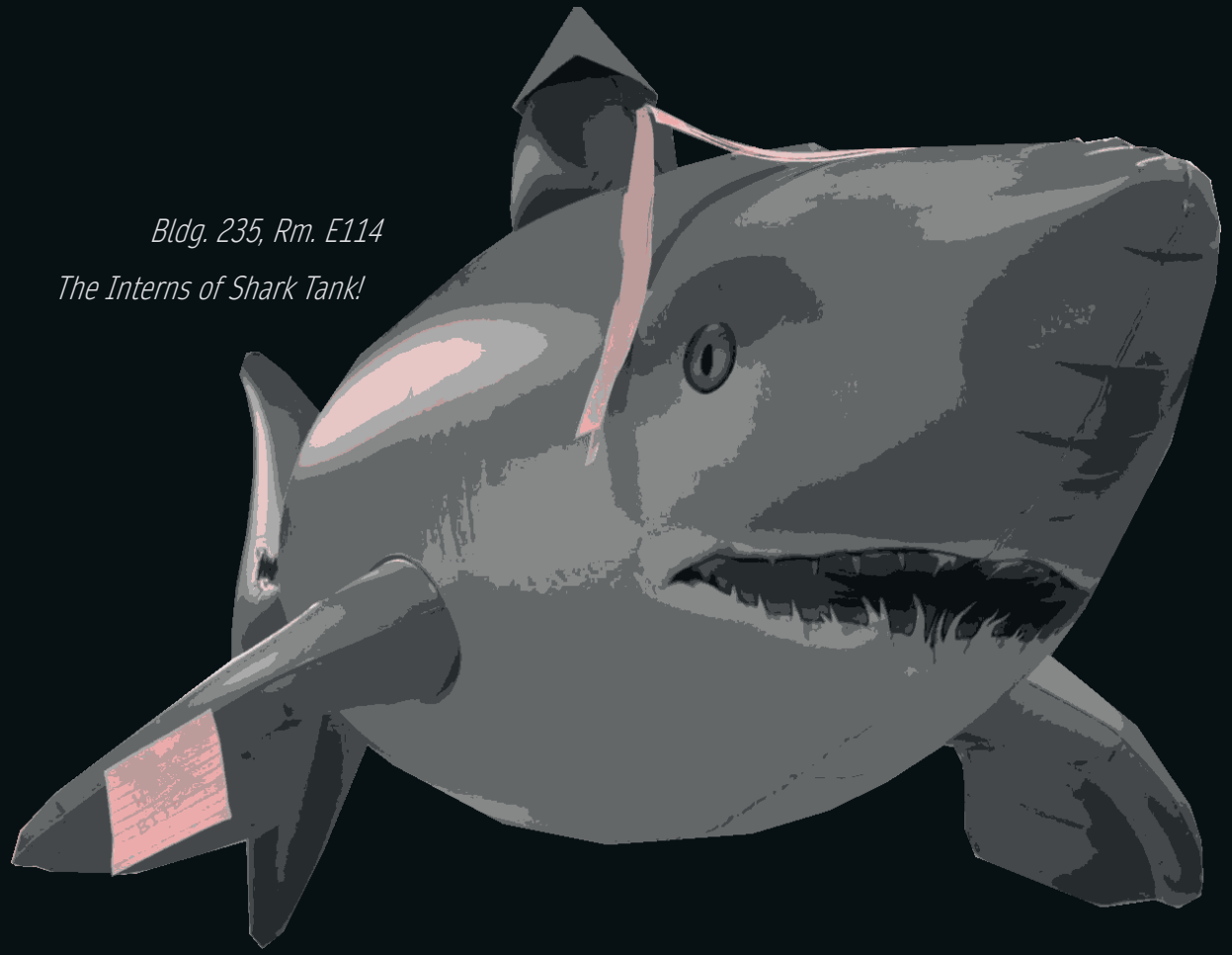
NIST CENTER FOR NEUTRON RESEARCH

Bldg. 235, Rm. E114

The Interns of Shark Tank!



Questions?

Static Structural
Total Deformation
Type: Total Deformation
Unit: in
Time: 1 s
Deformation Scale Factor: 90 (2x Auto)
10/30/2024 2:04 PM

0.0079094 Max
0.0070306
0.0061518
0.005273
0.0043941
0.0035153
0.0026365
0.0017577
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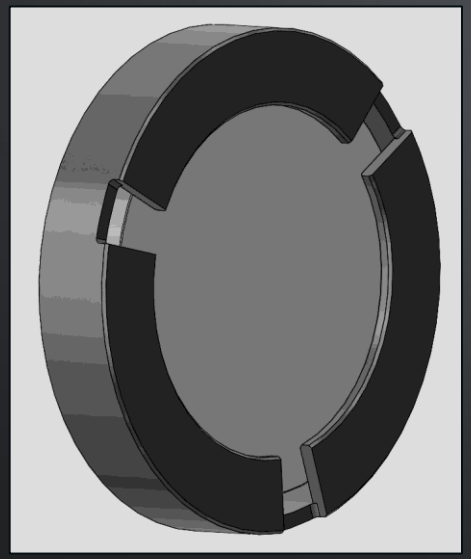
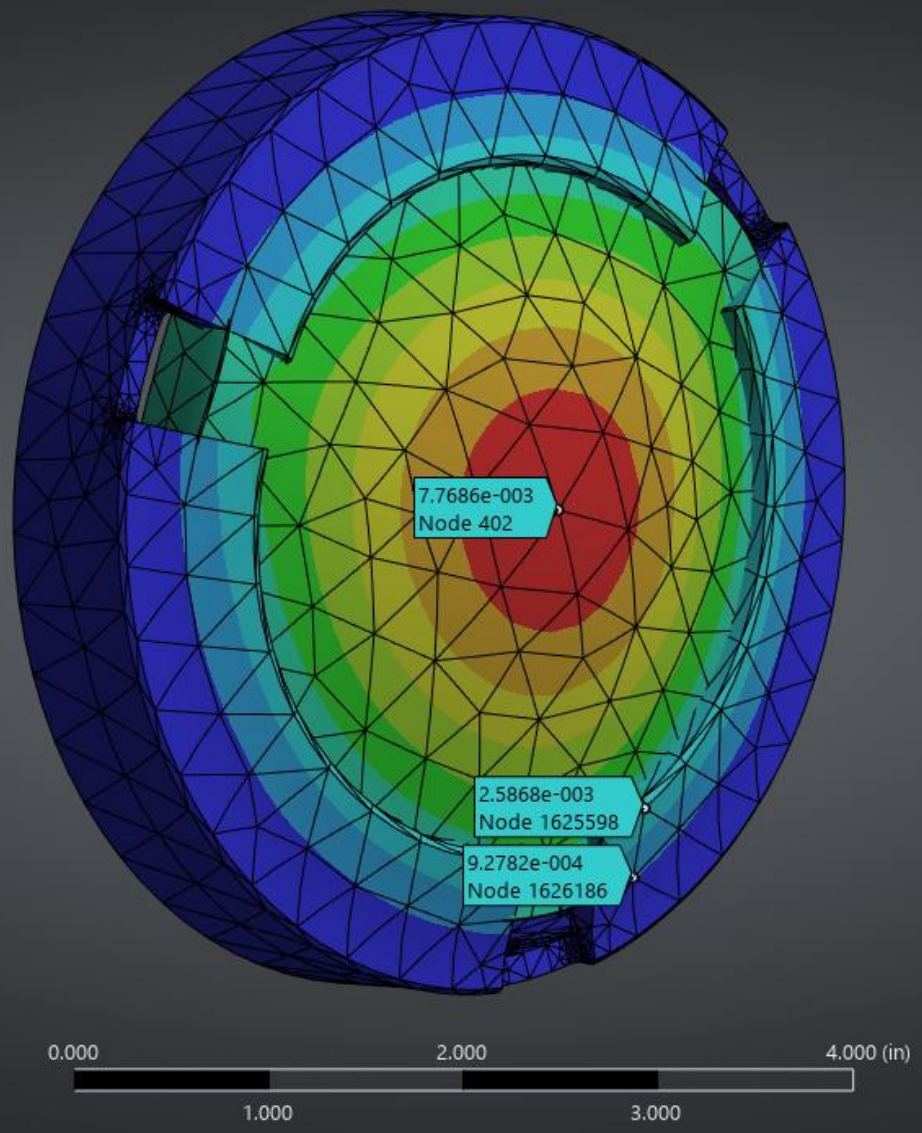
0 Min



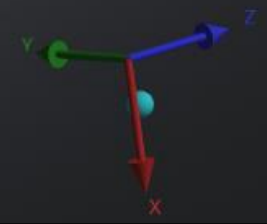


Ansys
2024 R2

CYLINDRICAL SUPPORT ON OUTER RING WHERE CONTACTING COVER BASE.

~60 PSI INTERNAL PRESSURE.
O-RING COMPRESSION FORCE OF ~1011 LBF.

NO HYDROSTATIC PRESSURE OR GRAVITY CONSIDERED.



Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1 s
Deformation Scale Factor: 4.2e+002 (Auto Scale)
7/23/2025 1:18:54 PM

9.5293e-6 Max
8.4705e-6
7.4117e-6
6.3529e-6
5.2941e-6
4.2353e-6
3.1764e-6
2.1176e-6
1.0588e-6
0 Min

Ansys
2025 R1

FULLY SUPPORTED. ASSUMES SURROUNDING COMPONENTS ARE RIGID.

~60 PSI INTERNAL PRESSURE.
O-RING COMPRESSION FORCE OF ~369 LBF.

NO HYDROSTATIC PRESSURE OR GRAVITY CONSIDERED.