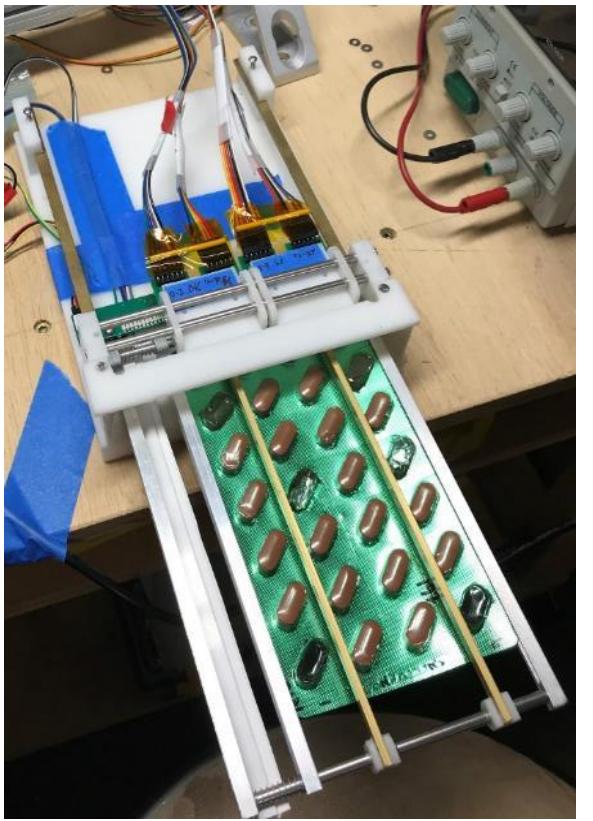


Andrew Miller

206-953-1287

andymiller@gmail.com



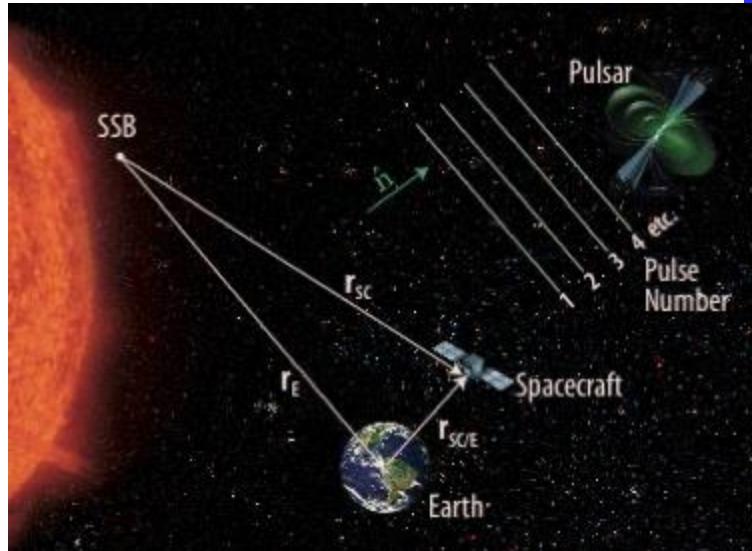
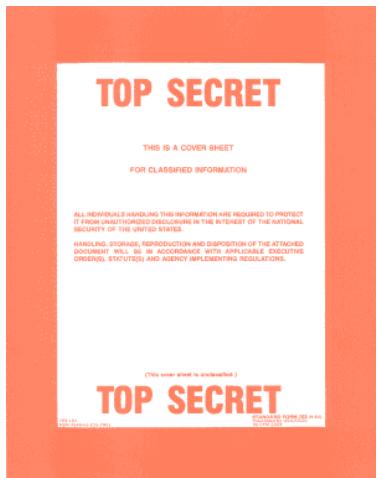


Lockheed Martin Space Systems Advanced Technology Center



Most of my time in Special Programs

Space Environmental Effects Group vacuum chamber operation and design
Atomic oxygen, proton accelerator, electron guns, solar simulation, thermal-vacuum



X-ray Timing from pulsars (DARPA XTIM)



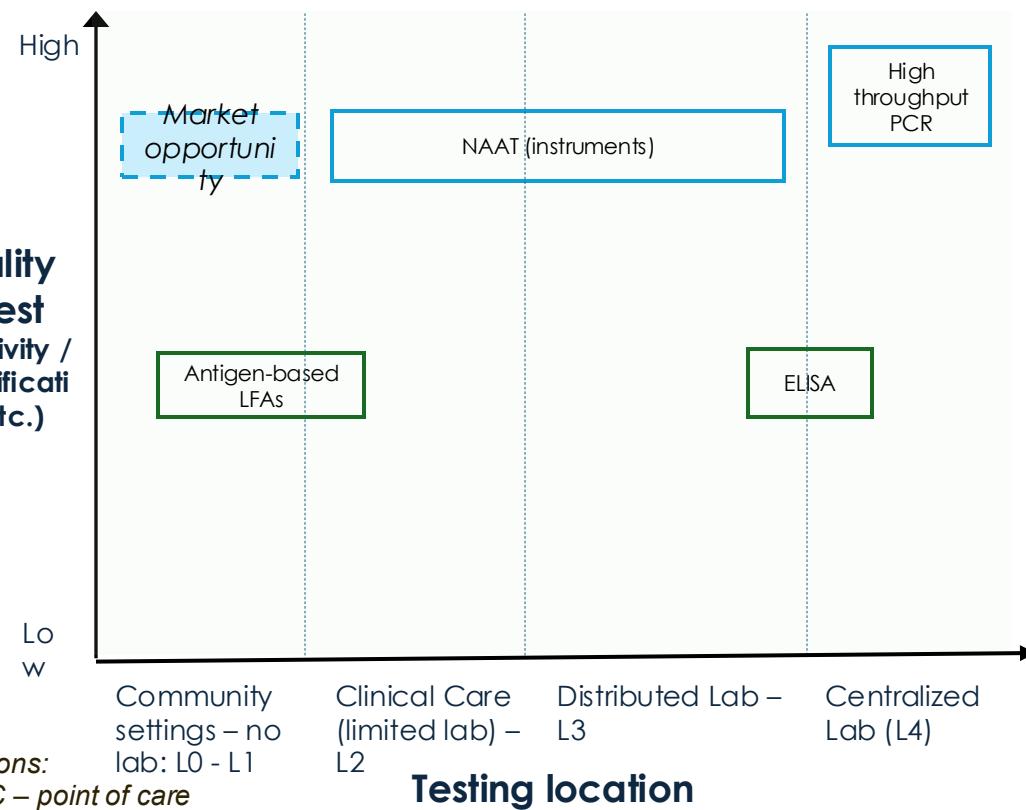
Cold weather evaluation for Army THAAD missiles
Thermal test rig design and operation

Community settings lack viable molecular test platform options

Diagnosis at community (no-lab) settings can support test and treat indications where today, no testing leads to:

- loss-to-follow-up (e.g. TB, HPV)
- ongoing transmission (e.g. STIs, TB)
- increased morbidity and mortality (e.g. asymptomatic malaria)

 Molecular test platforms  Immunoassay test platforms



Unlocks **molecular level sensitivity** for point of care setting



Test device assembled from plastic layers in reel-to-reel manufacturing

1. Low Price-per-test

- Reel-to-reel manufactured
- Compatible with **high-volume low-cost**

2. Availability

- Low cost, reusable instruments

3. Easy to use

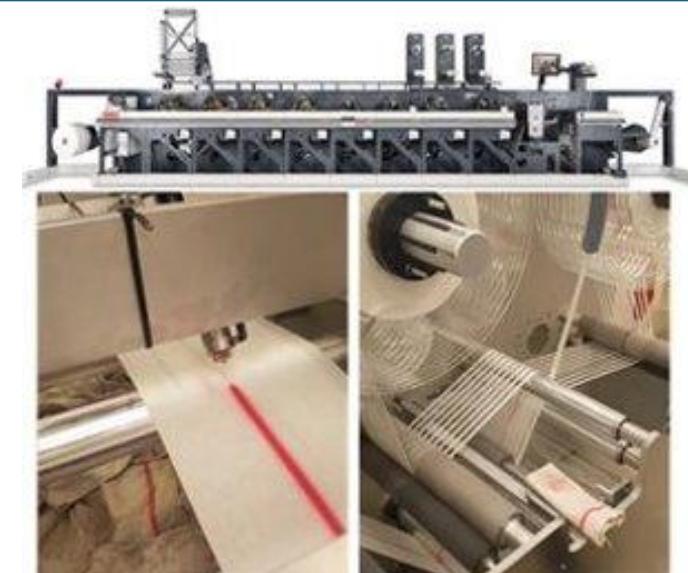
- User experience comparable to a **standard LFA**
- **Integrates** sample prep, isothermal nucleic acid amplification, detection,

4. Patient flow scalability

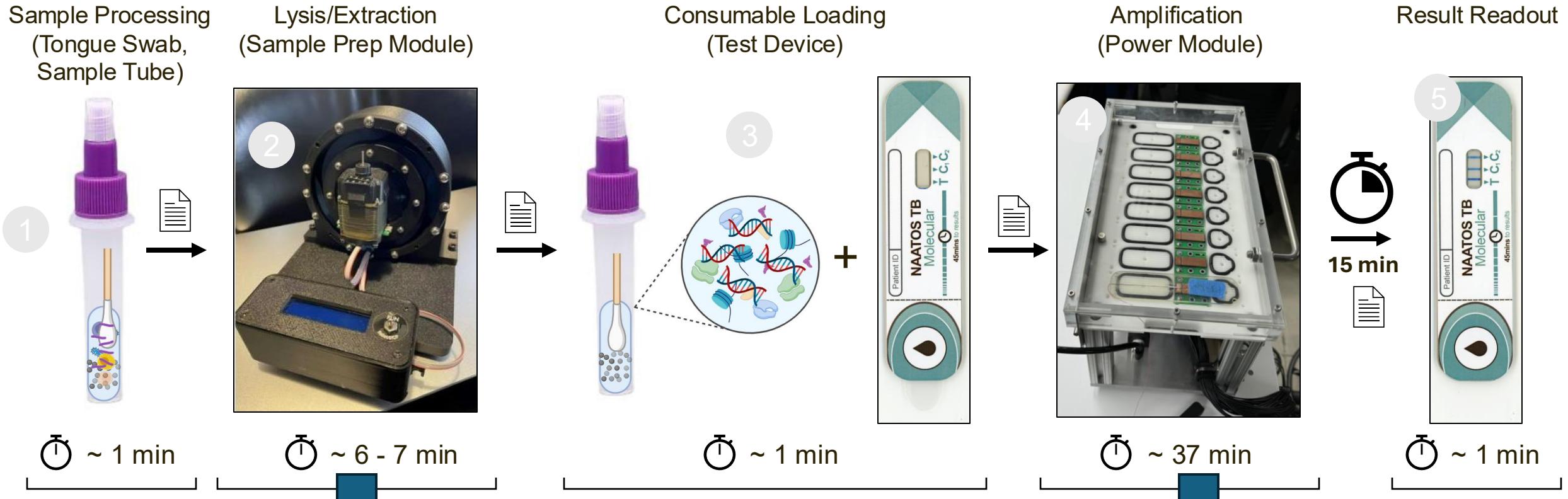
- Battery operated modules accommodate POC settings' throughput

5. Streamlined supply chain

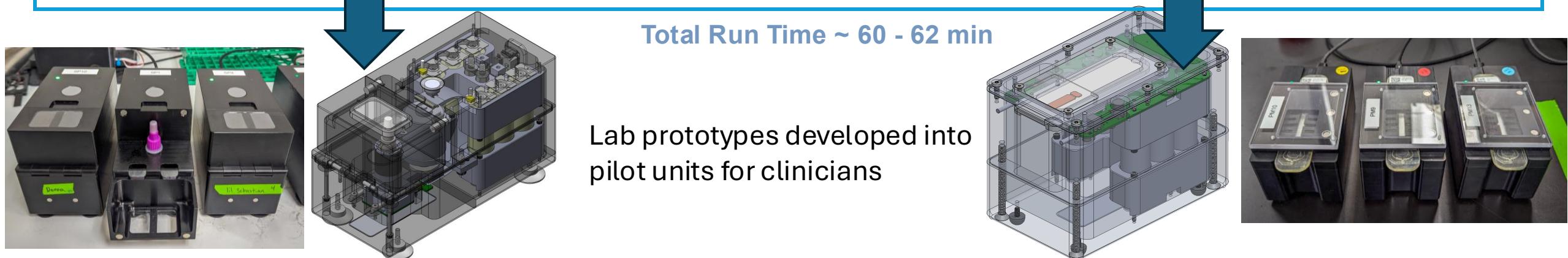
- Reel-to-reel manufactured
- Fits into **existing supply-chain**



NAATOS TB test Workflow and Test Procedure



Lab prototypes developed into pilot units for clinicians

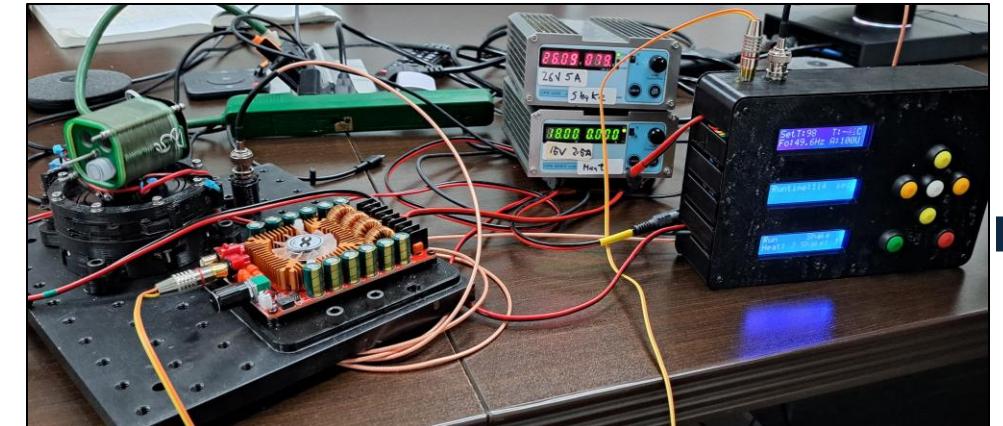


Sample prep

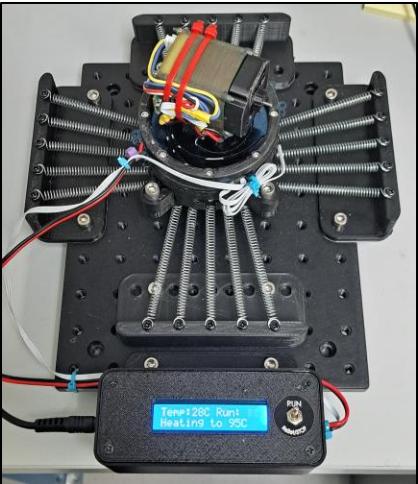
Heats and shakes the sample tube, lysing and inerting the bacteria

Flexures attempting to store energy and provide long life simultaneously

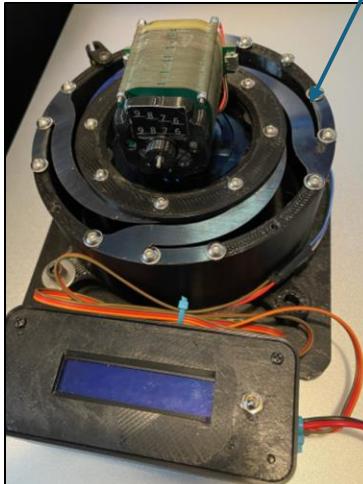
First heat-integrated lab version



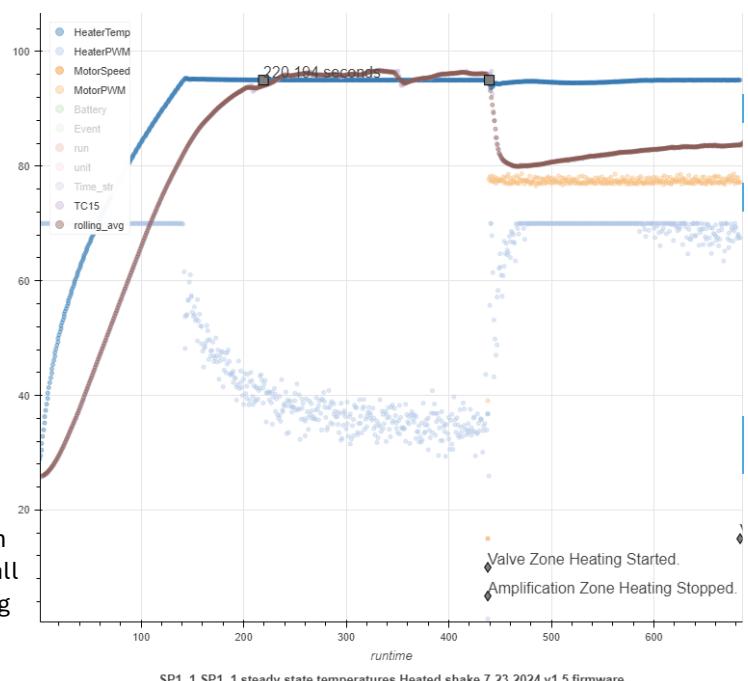
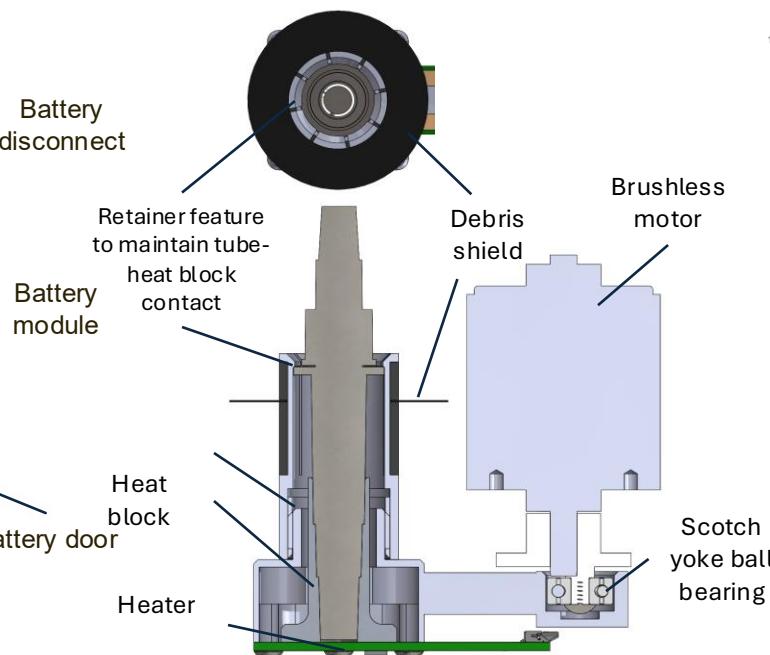
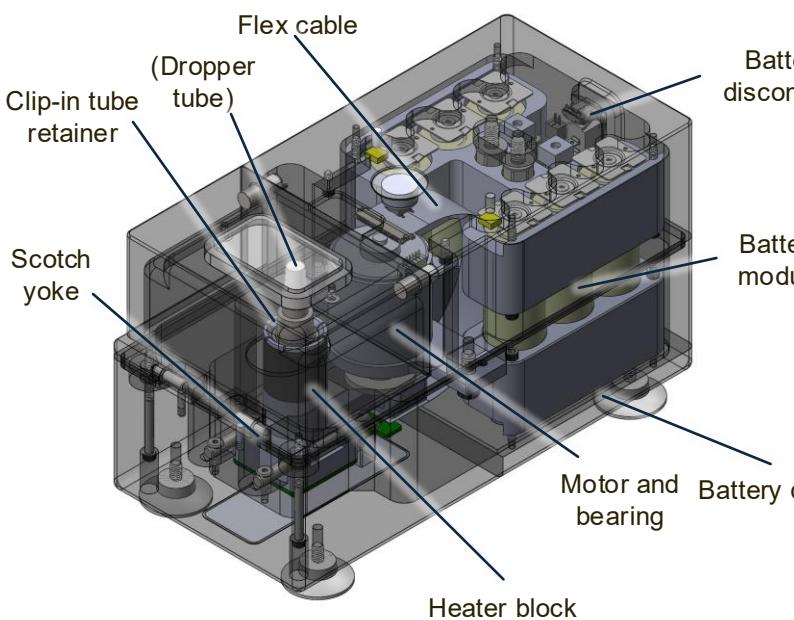
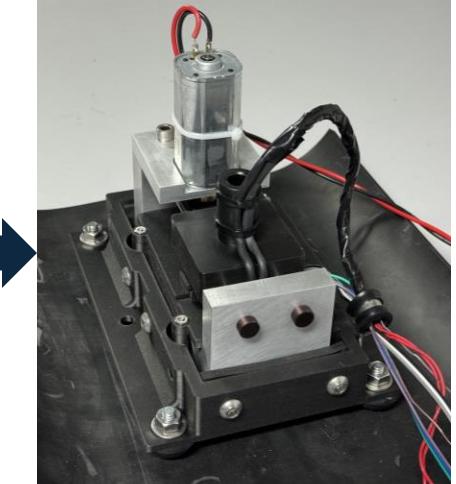
Uganda study (R1)



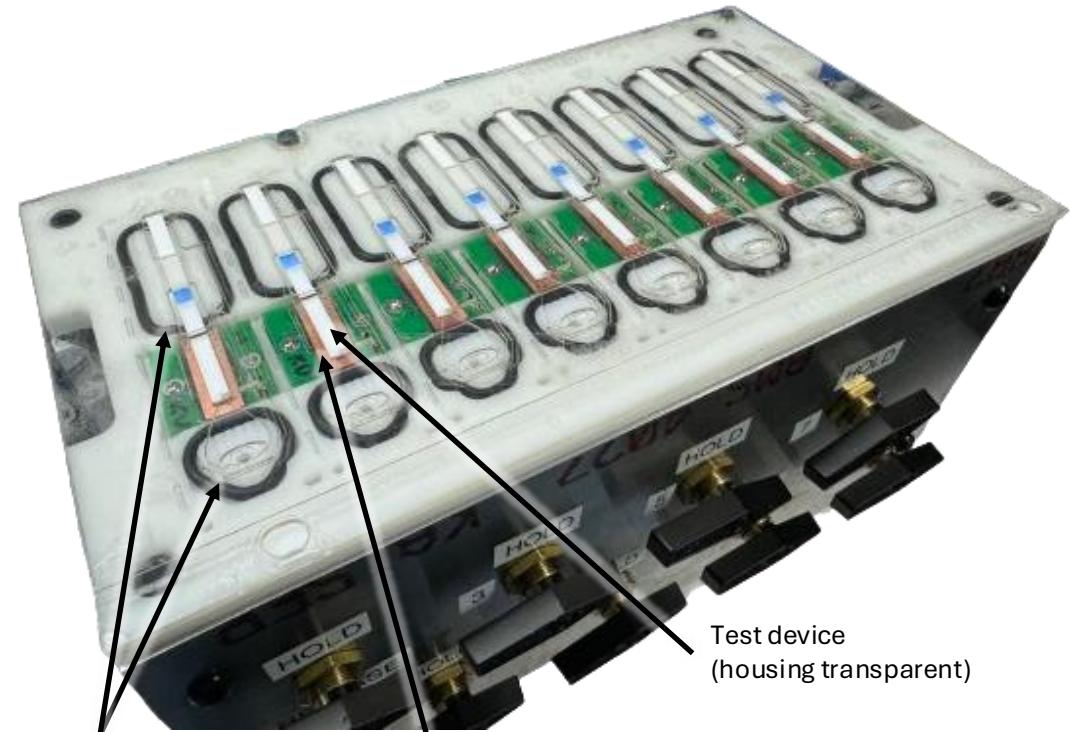
Current lab studies (R2)



Motor based design prototype



Testbeds and power module

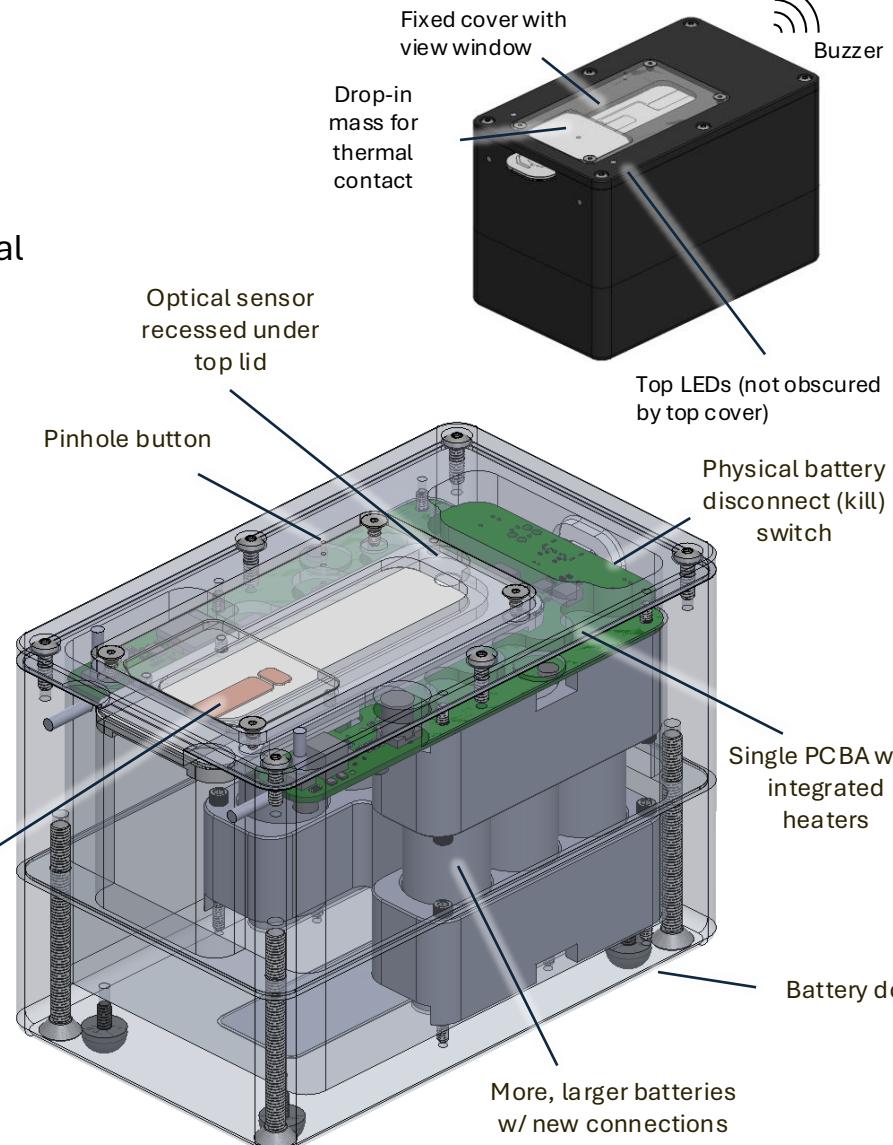


Vacuum chuck Heater module Controller



Testbeds provide stable thermal conditions for developing laminates, scaled to allow hundreds of tests per week.

Informed power module specifications once dialed in.

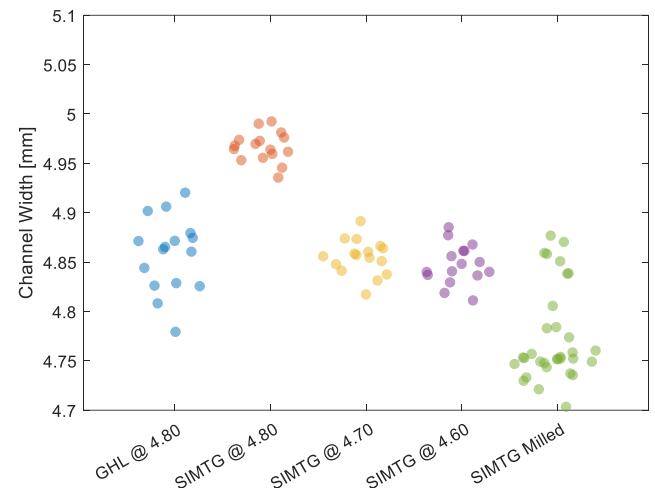
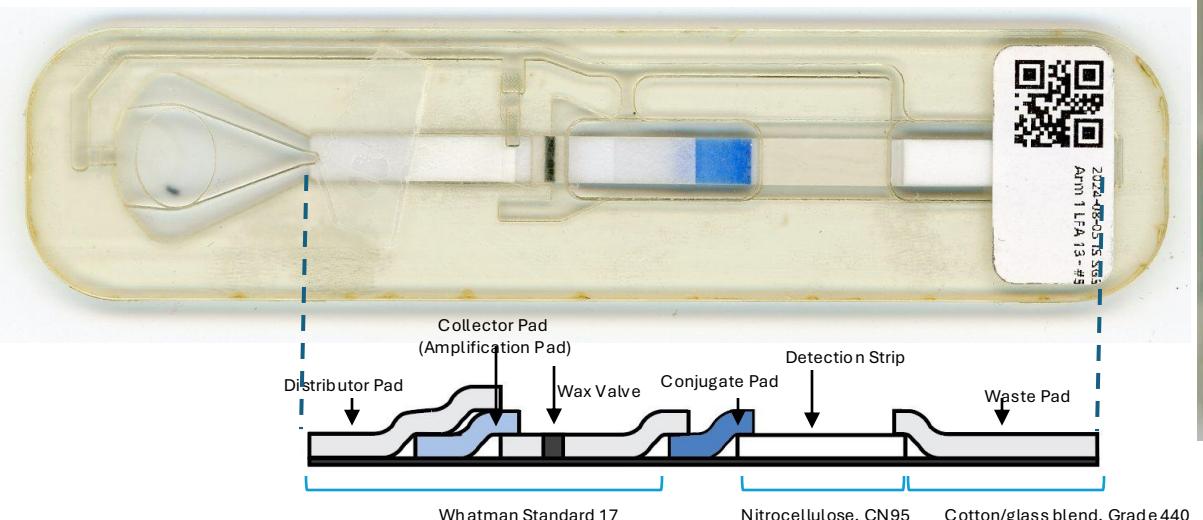


Power module provides heat to a single test device for clinical use, with automated processing and user interface

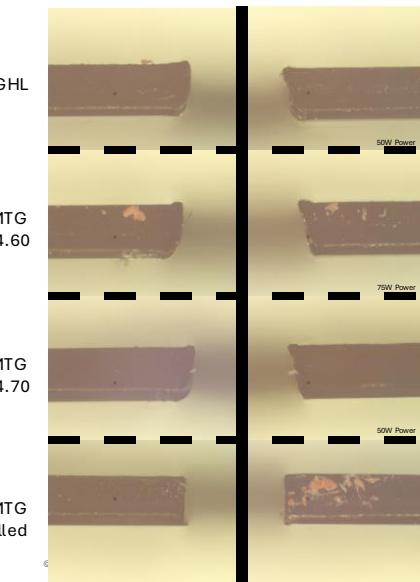
Test device

The test device consists of a laminate stack containing a lateral flow assay (LFA). It is sealed and has a recirculation channel to allow fluid flow.

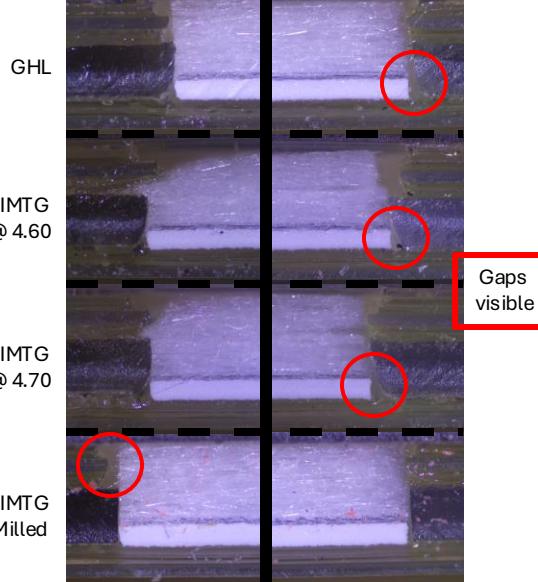
The amplification reaction occurs at 65C, then the wax valve is opened when its heater is set to 95C



Wax valve pinch tolerancing study



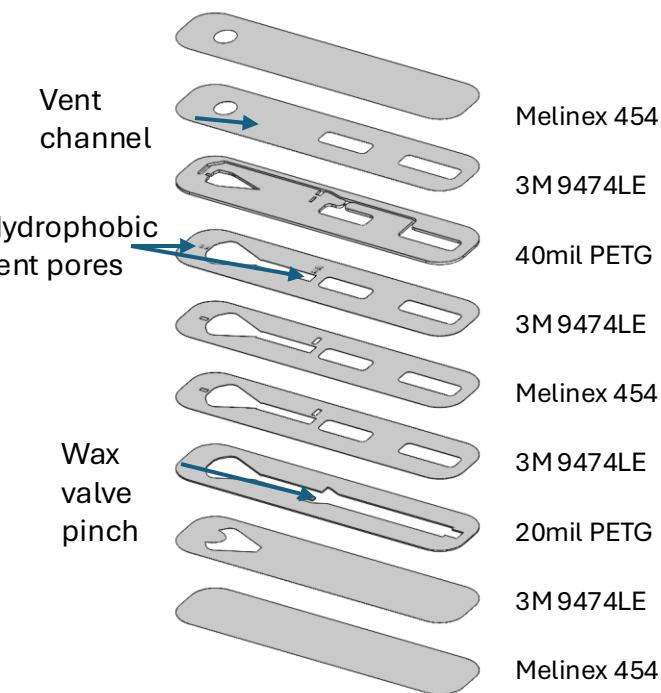
Layer cut profiles



Assembled devices

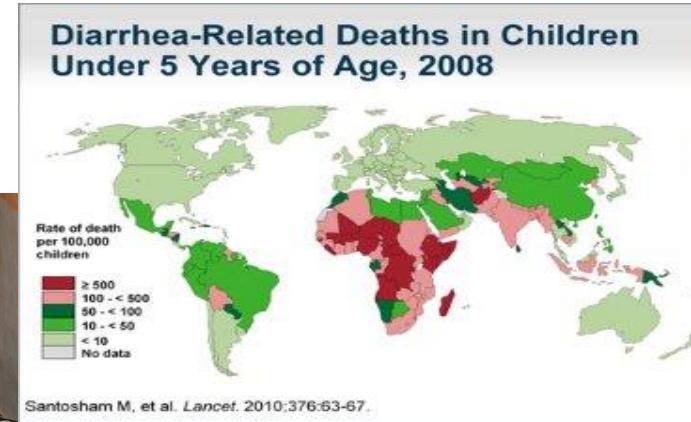
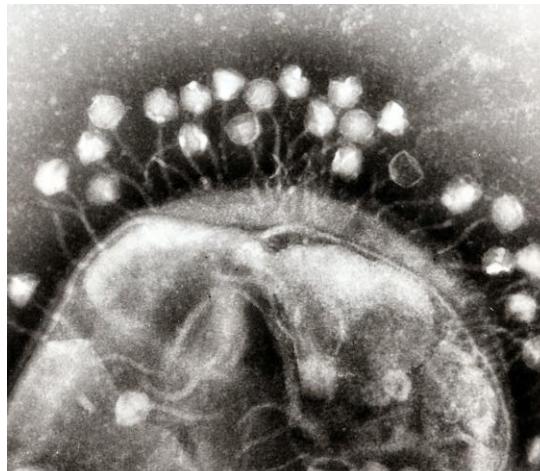


Wax valve actuation



Problem: water quality testing too slow & complex

- Current LMIC water quality testing is culturing water samples for 24+ hours and looking for growth
 - Complex processing steps, contamination concerns, unsuited for field use
- Contaminated water won't be detected until the culture is done, if it is done at all
- Solution: use novel phage detection chemistry and field deployable automated platform to detect water quality issues in <24 hours



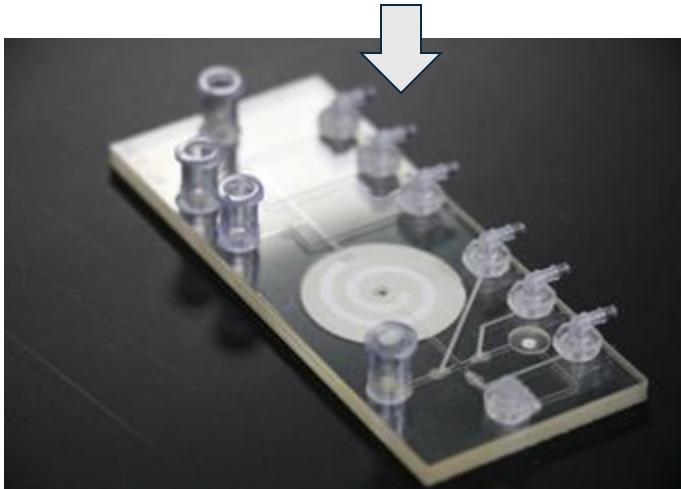
Unsafe drinking water, inadequate availability of water for hygiene, and lack of access to sanitation together contribute to **88%** of deaths from diarrheal disease.

E. Coli Phage water quality assessment

- Battery operated
- Automated
- Portable (size similar to carry-on)
- Results in 5 hours
- LOD 10 CFU/mL
- Semi quantitative



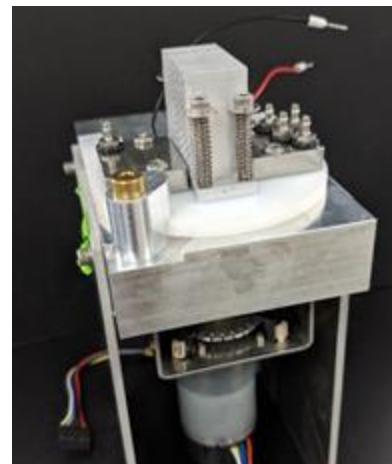
Conventional water quality assessment:
Complex process, 24+ hour incubation time



Phage based chemistry proven,
but internal pneumatic valves add
too much cost

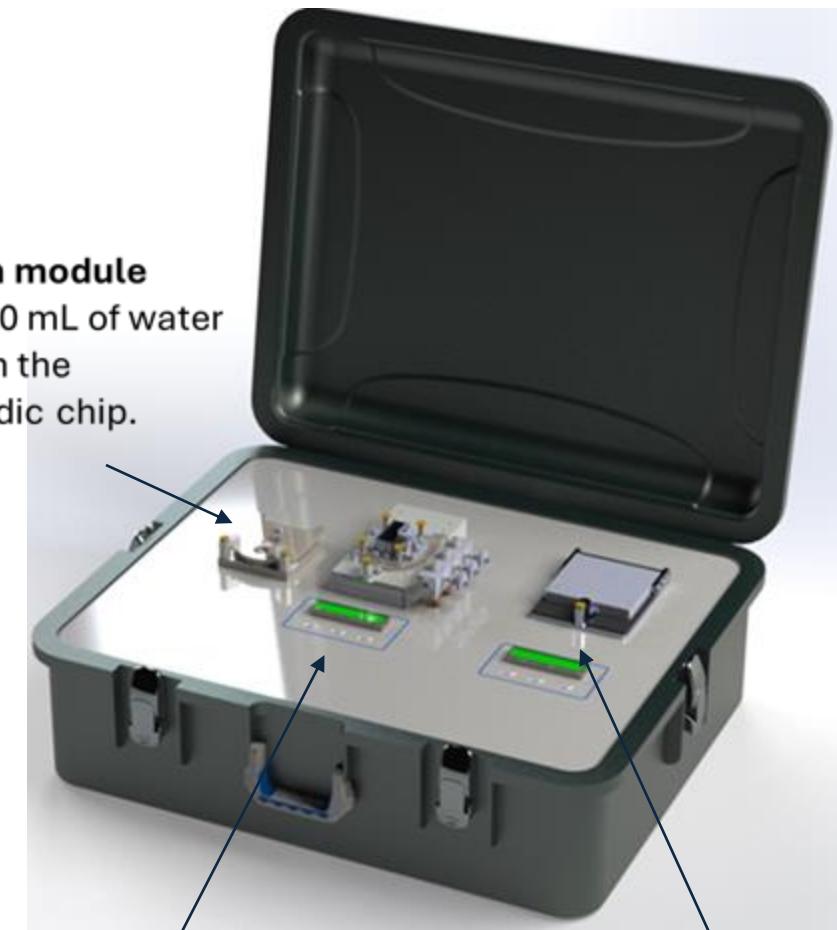
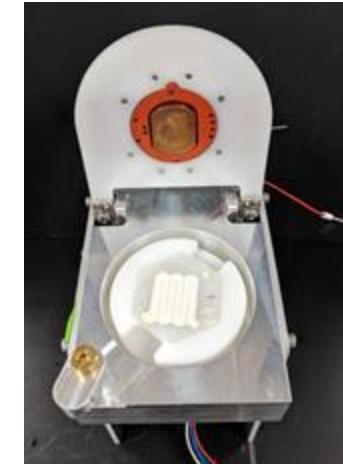


Valve-less microfluidic chip



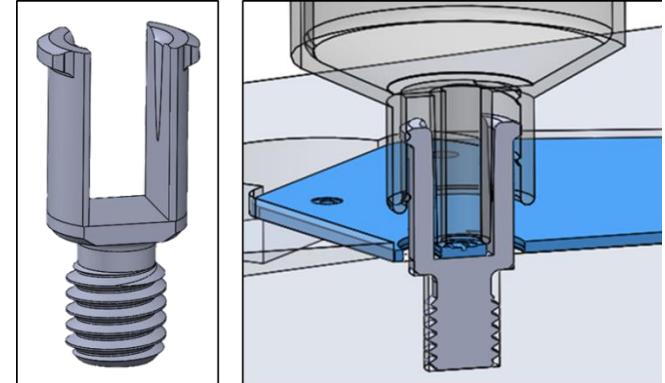
Novel valve-less microfluidic chip and
hardware architecture developed

Filtration module
Filters 100 mL of water
directly in the
microfluidic chip.

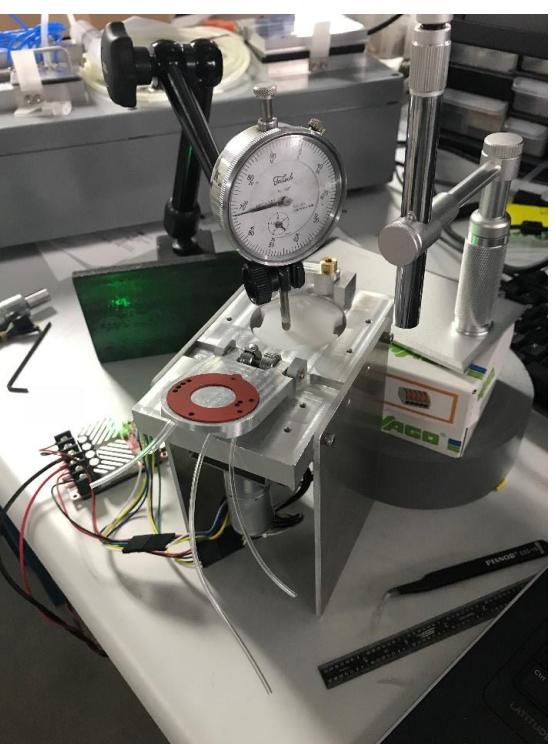


Fluid handling module
Connected to reagents,
delivers appropriate fluids to
the chip and keep
temperature constant at 37
°C.

Detection module
Contains a PMT to
detect very low levels of
light

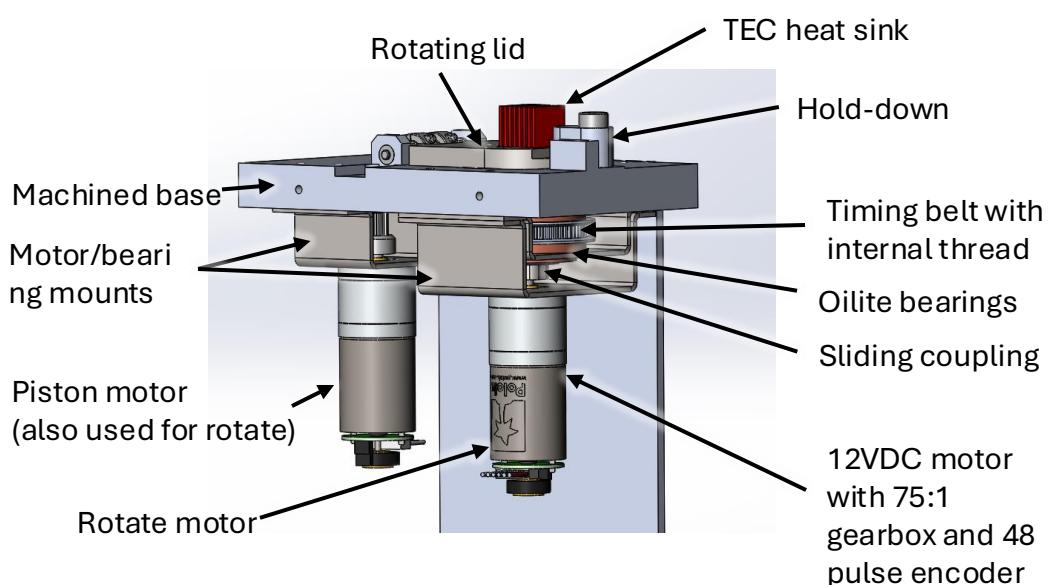
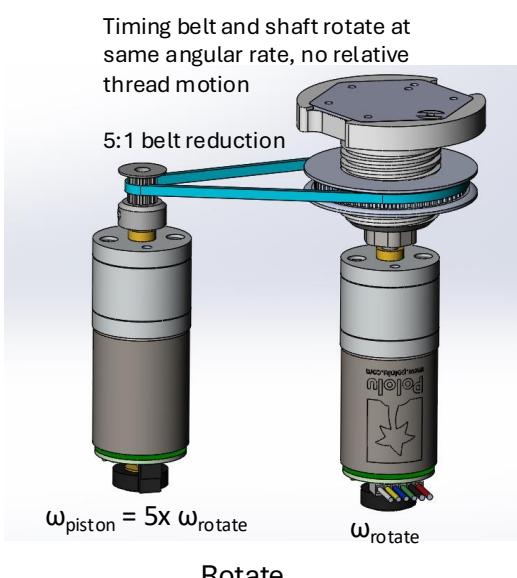
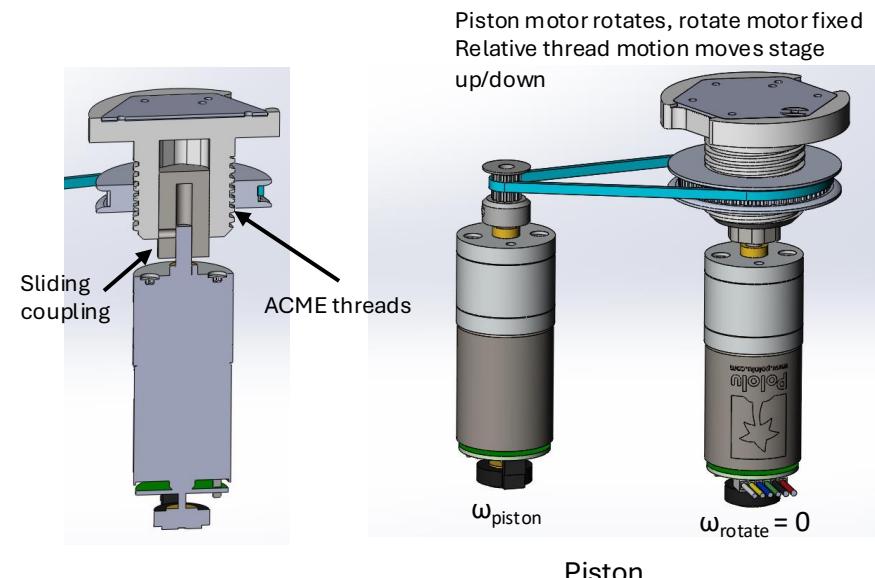
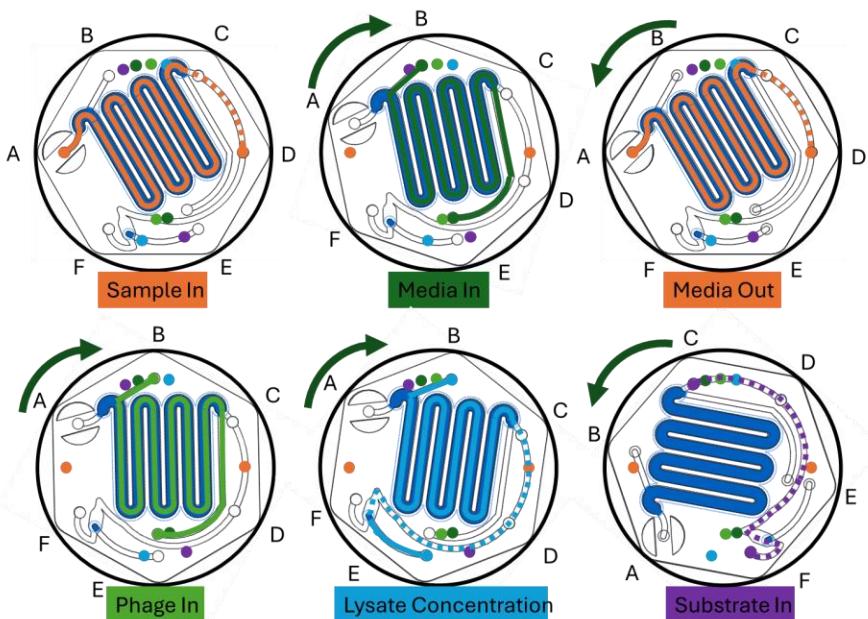


Luer lock based sample injection interface (no Luer lock on disposable, lower cost)



Rotation of microfluidic device to align inlet/outlet pairs.

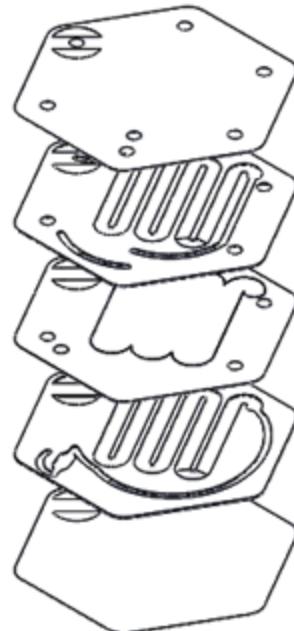
- *Liquid handling interface remains static
- *Solid lines represent channels on plane above the filter membranes
- *Dash lines represent channels on plane below the filter membranes



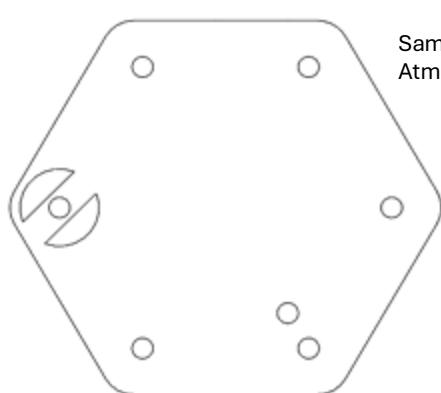
“rotary Vernier” system for port selection, using low cost PMDC motors



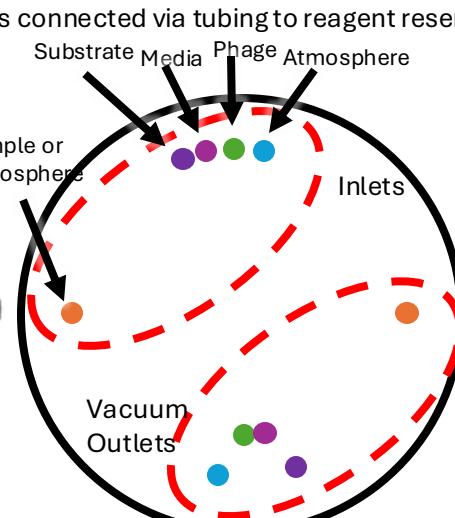
Microfluidic chip with only 5 layers, very low cost. Hexagonal shape reduces waste in reel to reel manufacturing



Very low CFU detection levels require use of photomultiplier tube (PMT) for single-photon readout of luminescent signal

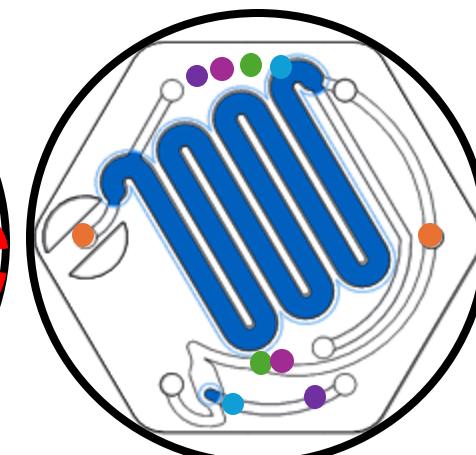


Top view of microfluidic device



Top view of liquid handling interface

*Matching colors show corresponding inlet/outlet pair



Top view of device in liquid handling interface

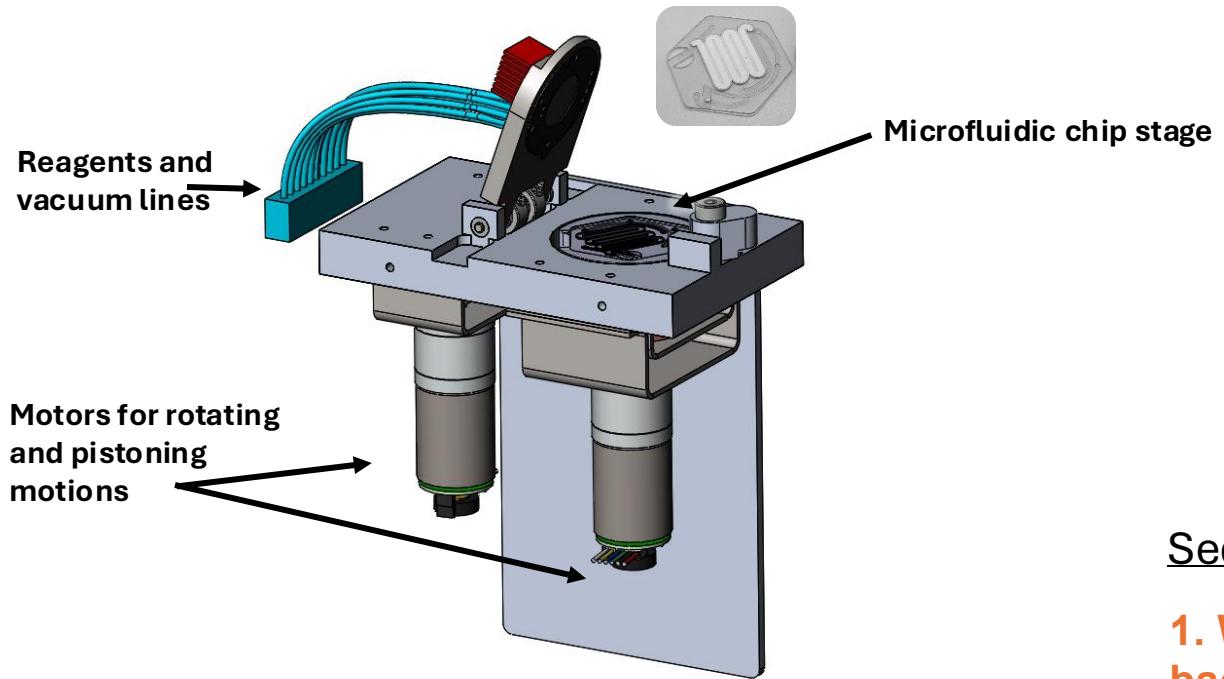
*Transparent interface view



Light tight readout chamber with PMT underneath integral shutter



- Platform performs assay in microfluidic cassette automatically

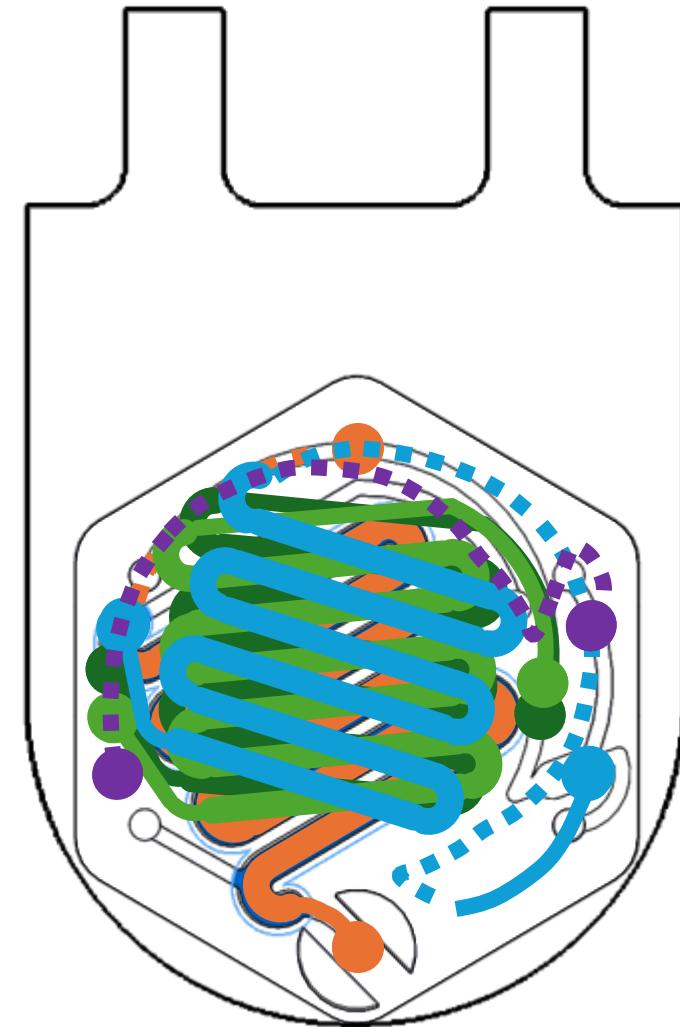


This module has 2 motors to:

1. Rotate the chip to align an entry port with an exit port.
2. Move the stage to connect and disconnect the chip from the access ports and allow for the rotation to the next position.

Sequence of actions:

1. **Water filtration (capture of bacteria – Done on filtration module)**
2. **Addition of growth media**
3. **Addition of phage solution**
4. **Capture of reporter enzyme**
5. **Addition of substrate**



Medication Adherence Tracking

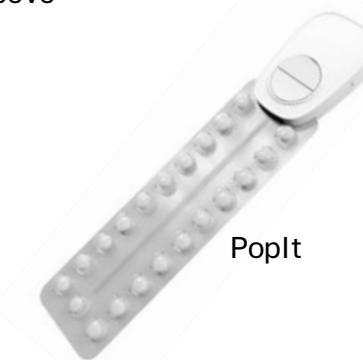
- Tuberculosis (TB) medications are long term (6 months), and very sensitive to missed doses
- Patients who stop taking it develop drug resistant TB, health authorities need to intervene to get them to adhere before that happens
- Existing attempts at solutions have had limited uptake, effective low-cost products for LMIC users haven't emerged in the market
- Solution: test portable storage form factors with integral telemetry



99DOTS sleeve



“smart” pill bottles



PopIt

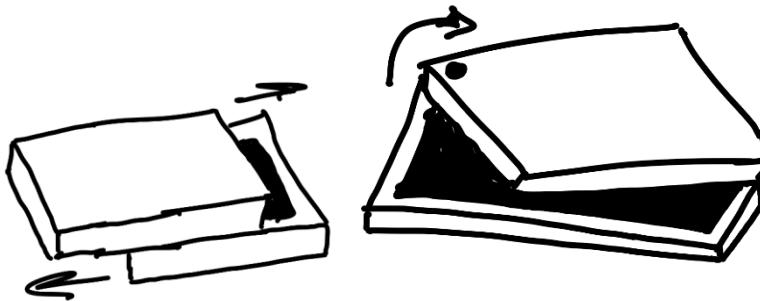


Wisepill evriMED (aka MERM)
~6x5x3", lunchbox sized

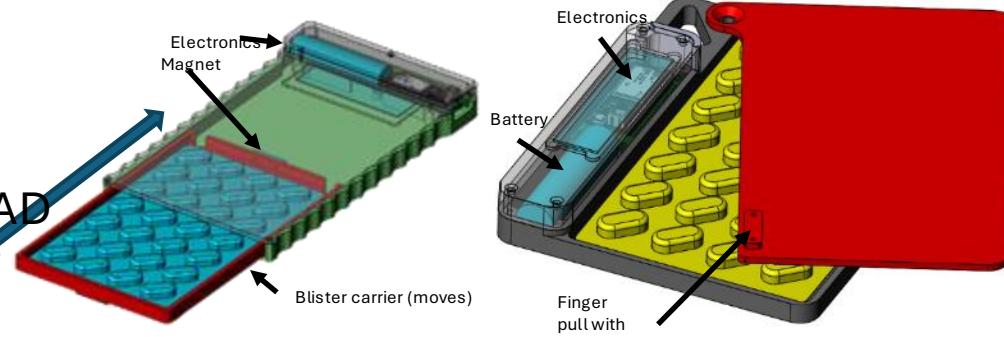
Existing approaches

Prototypes

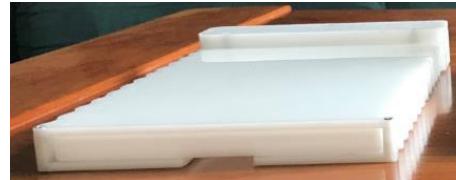
UCSF Better
Lab sketch
from ideation
sessions



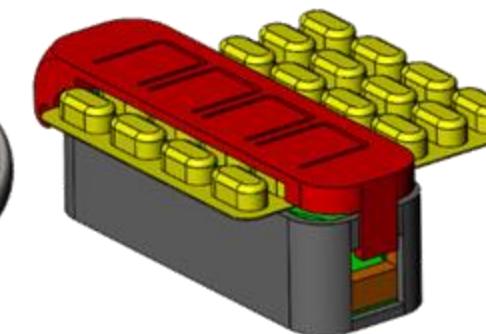
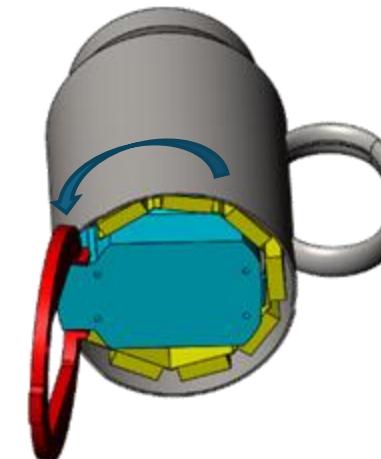
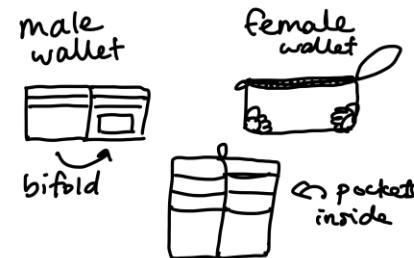
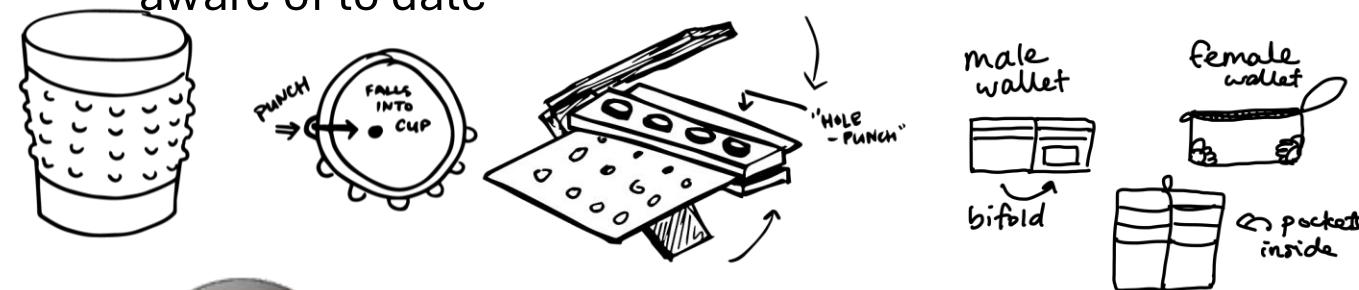
GHL CAD



GHL as
built



- Designed generate user preferences, not final products
- Sized to accommodate the largest blister pack we are aware of to date



(basement built during Spring 2020 lockdowns)

Field evaluations in Uganda and India

Magnetic sensor automatically logs and sends signal when medication is accessed.



Added utility via a personal storage space separate from medication

Space for 3 or more blister packs. Able to accommodate any size blister pack (not brand specific)



Medication instruction card (with motivational graphics)



GLOBAL
HEAL+H
LABS

&

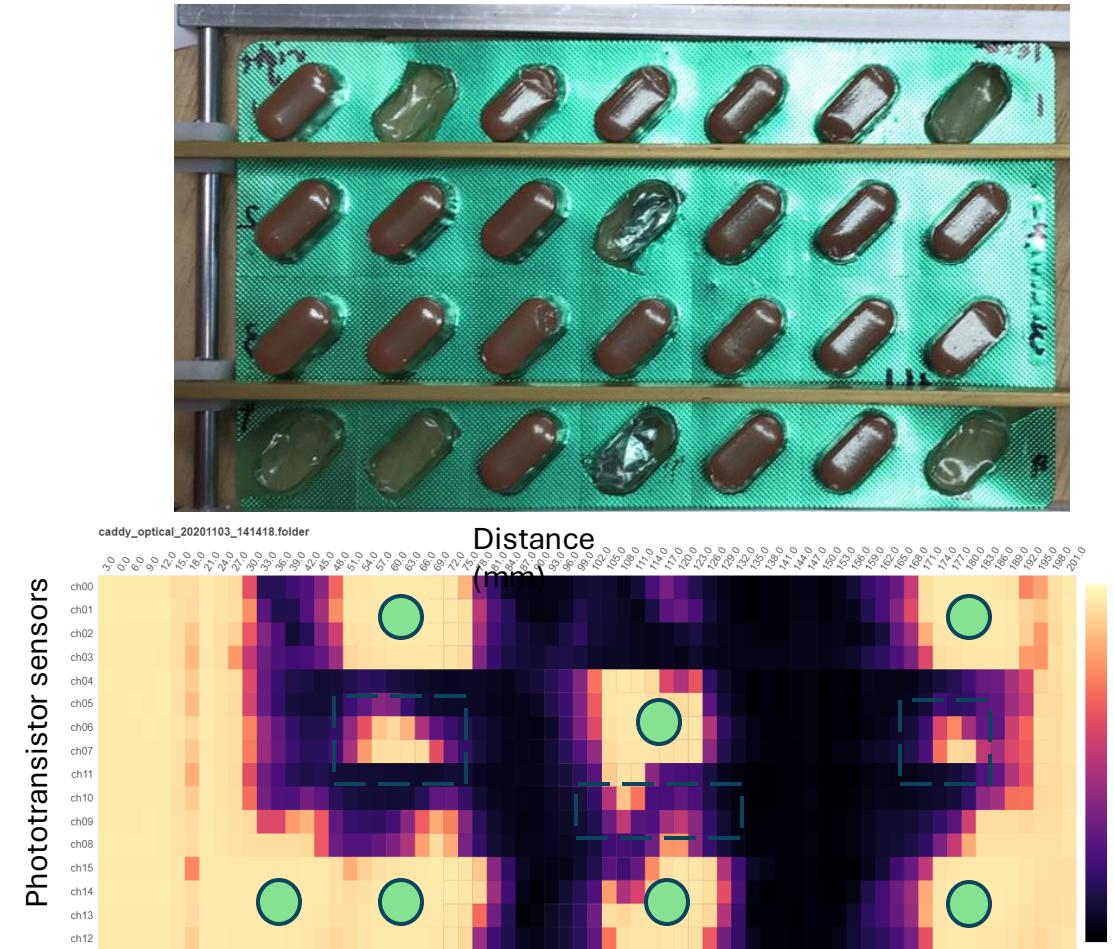
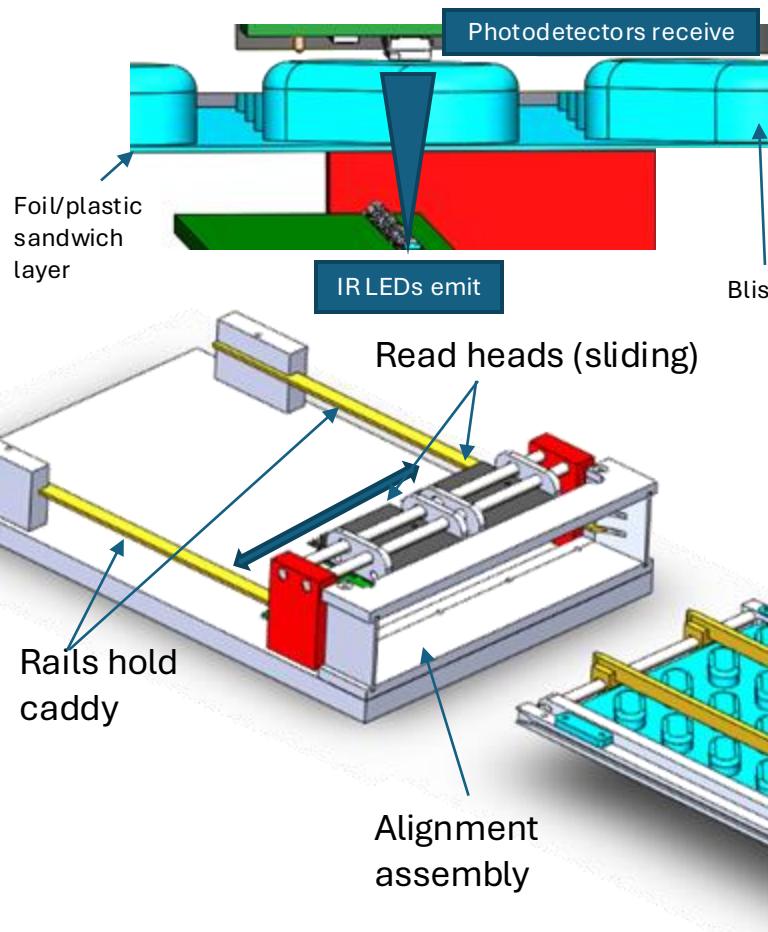
The BETTER LAB
BETTER HEALTH • BETTER SYSTEMS • BETTER DESIGN

GLOBAL
HEAL+H
LABS

The BETTER LAB
BETTER HEALTH • BETTER SYSTEMS • BETTER DESIGN
or
Surgo Foundation

Rapidly iterate in this loop (~4 months per cycle)

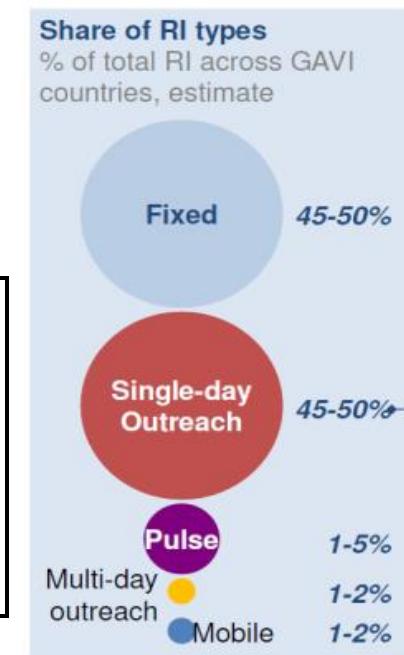
Developed concept to see-through scan the blister pack to determine quantitative pill count



(Also explored inductive measurement
but foil waviness confounded readout)

Problem: ice logistics for vaccine storage

- Without power and freezers available, trucks have to bring in ice to keep vaccines cold in coolers, ice melts quicker than vaccines get used typically (expensive logistics)
- Outreach with small coolers requires a supply of cold packs
- Steps to avoiding freezing of vaccines with subcooled ice necessary



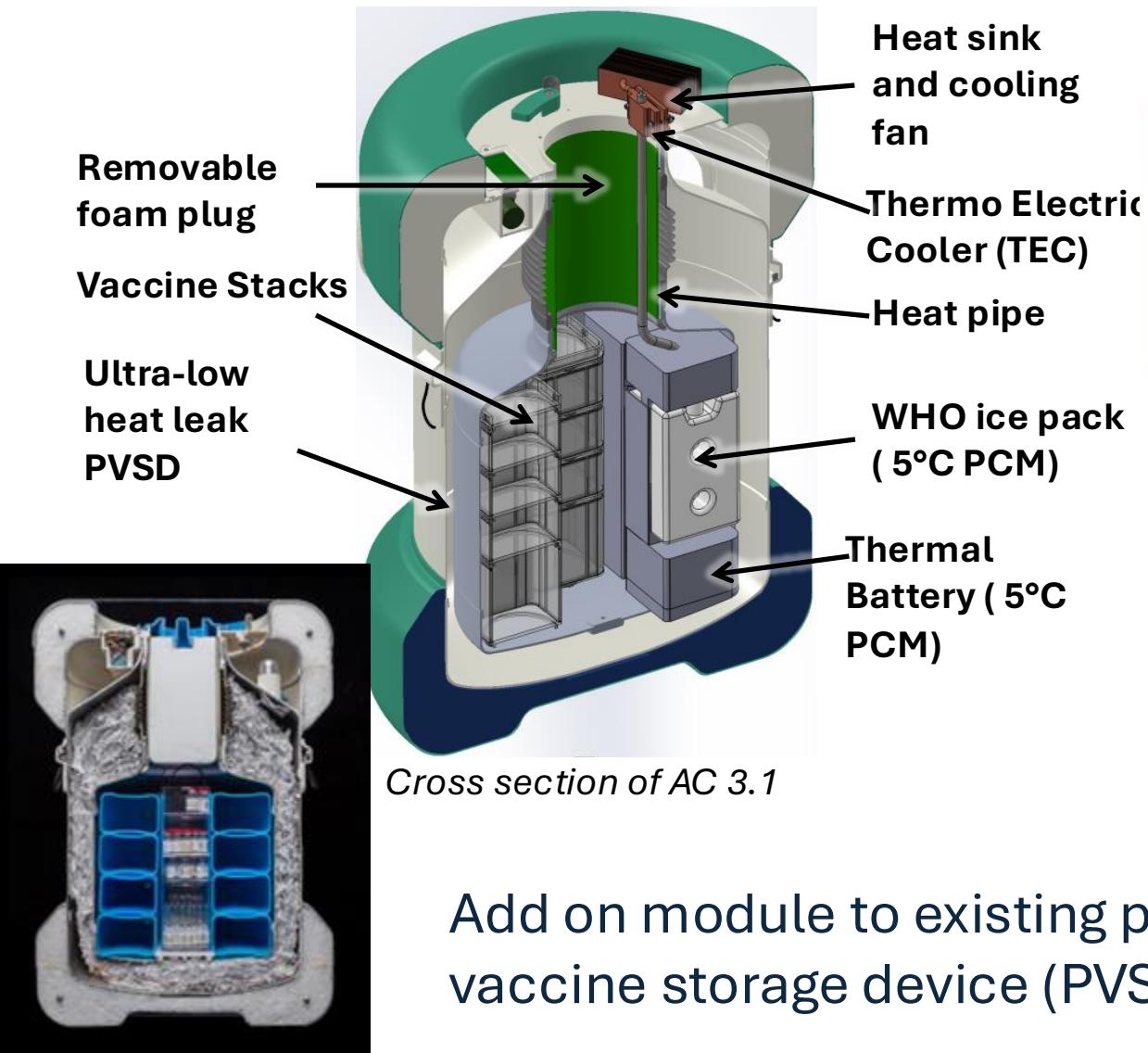
Challenges for Last Mile Cold Chain Equipment –

- In small off-grid villages
- Vaccine and ice logistics limitation
- Often a need for outreach (cold packs for portable coolers)
- Vaccine freezing protection

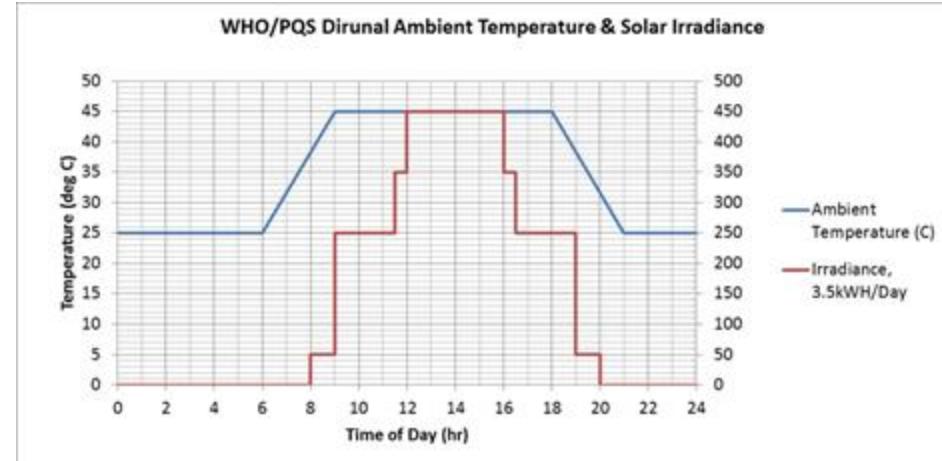
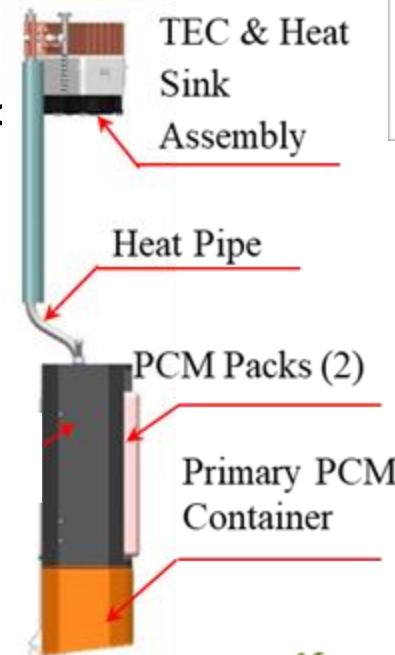
Arktek SDD Design Goals

- To work at off-grid
- To be certified as a combined device of vaccine refrigerator and PCM-pack freezer, under WHO hot zone conditions
- To support single-day vaccine immunization outreach a minimum of once per week
- To provide a user-independent freeze-free operation through outreach.
- Power harvesting for health workers

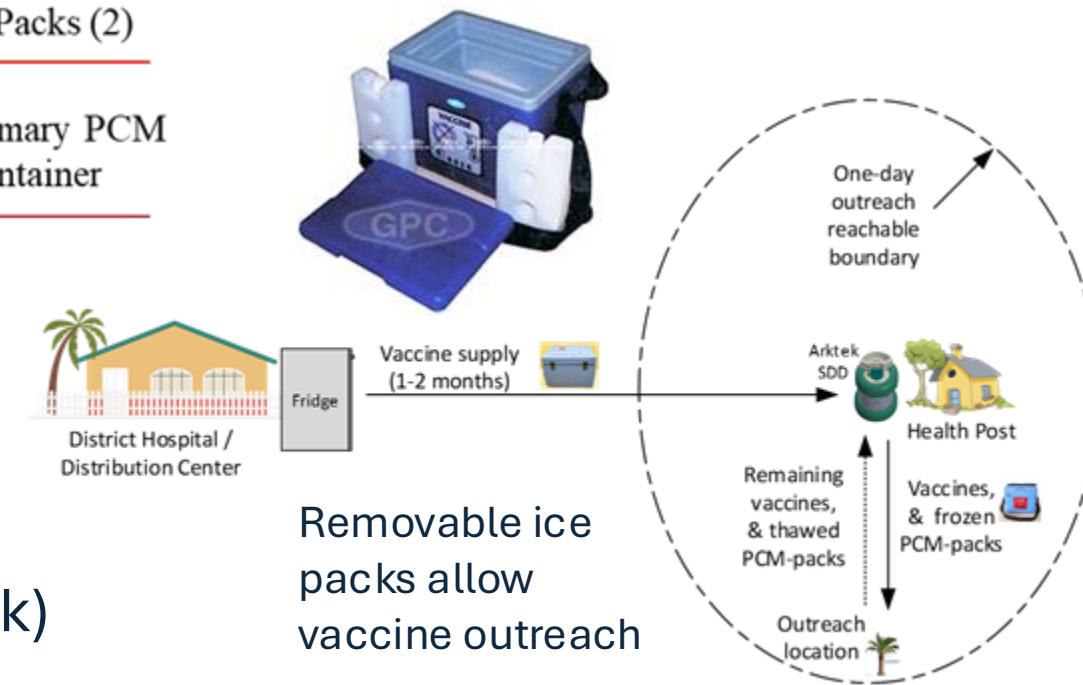
Solar Direct Drive cooling



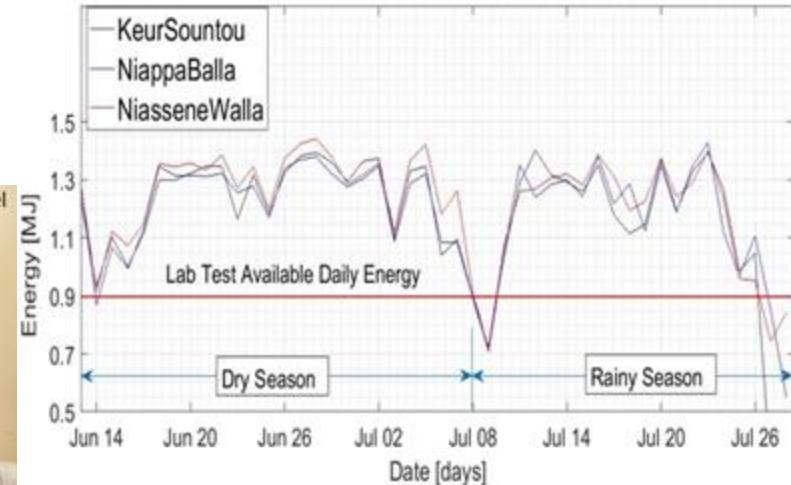
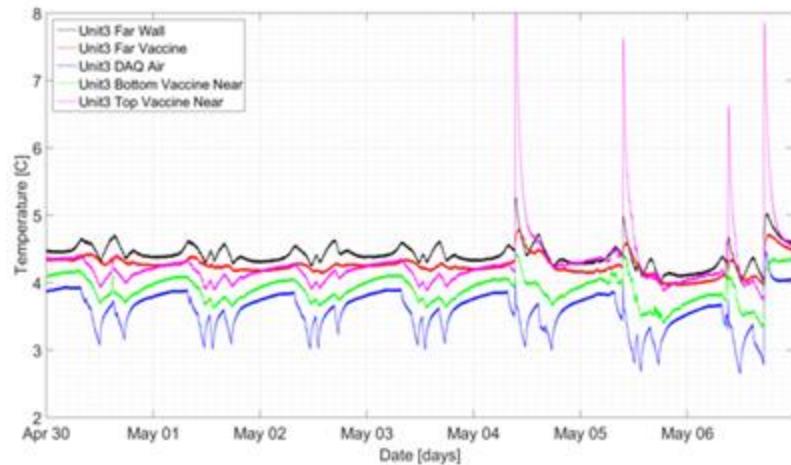
Add on module to existing passive vaccine storage device (PVSD/Arktek)



Challenging thermal environment, WHO “hot” zone (equatorial)

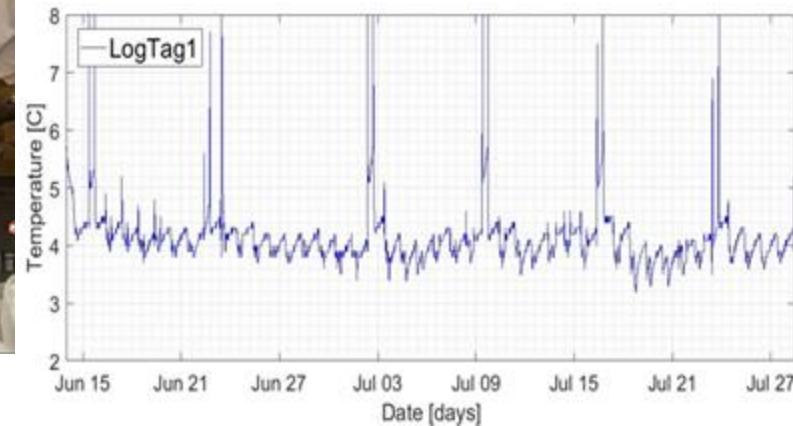


Solar Direct Drive cooling



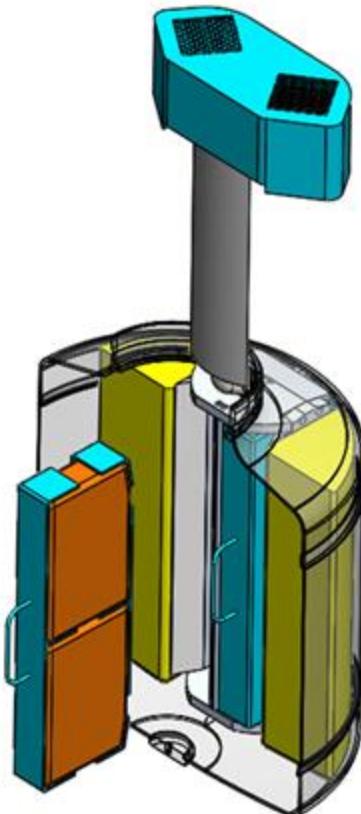
Field test in health outposts (Senegal)

Lab testing existing prototype

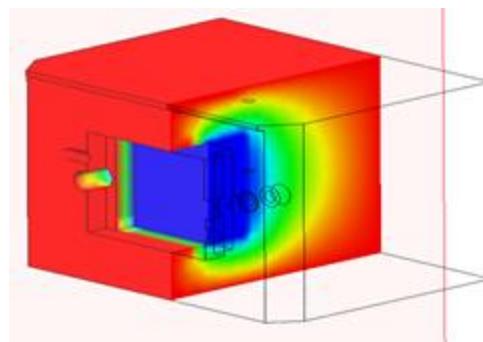
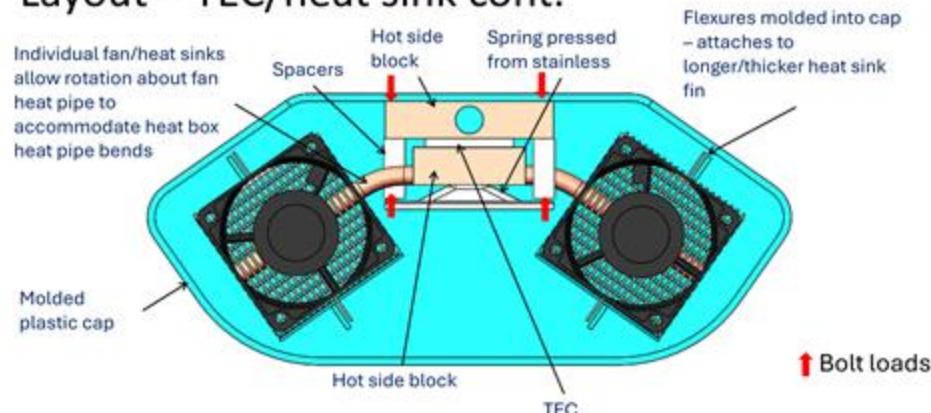


Maintained temperatures during field test, reality less conservative than WHO requirements in this case

SDD redesign and production

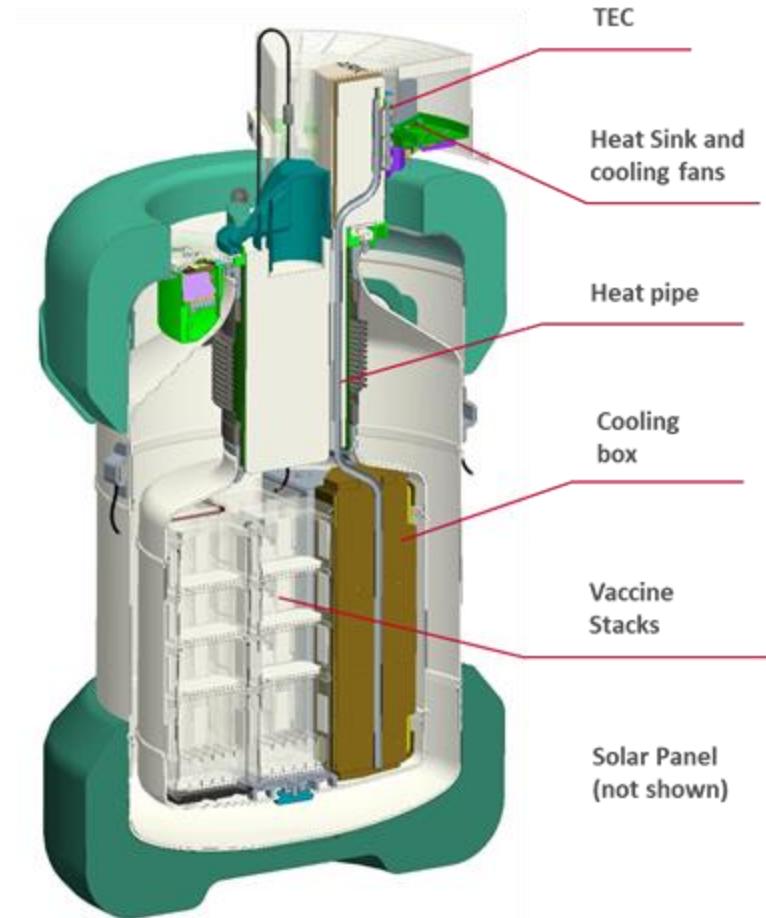


Layout – TEC/heat sink cont.



Redesigned for
4 packs, major DFM/DFA
improvements

Thermal modeling,
insulation efficiency



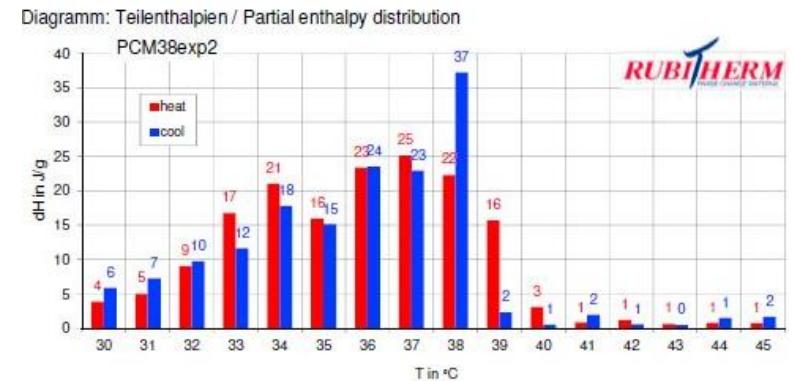
Design transfer, testing of
pre-production units

Problem: power outages disrupt culture incubators

- Incubation for culture based diagnostics
 - Is this sample sterile or growing bad things?
 - Is this sample antibiotic resistant?
- Incubators are widely available commercially
 - But without reliable power they aren't very useful (except as storage cabinets)
- Without reliable power, no way to confirm samples have had the requisite time at 37C
- Batteries are life limited and often stolen/repurposed
- Solution: use paraffin as a phase change material to buffer temperature against hot and cold excursions, using time-of-flight measurement to maintain in "slushy" state

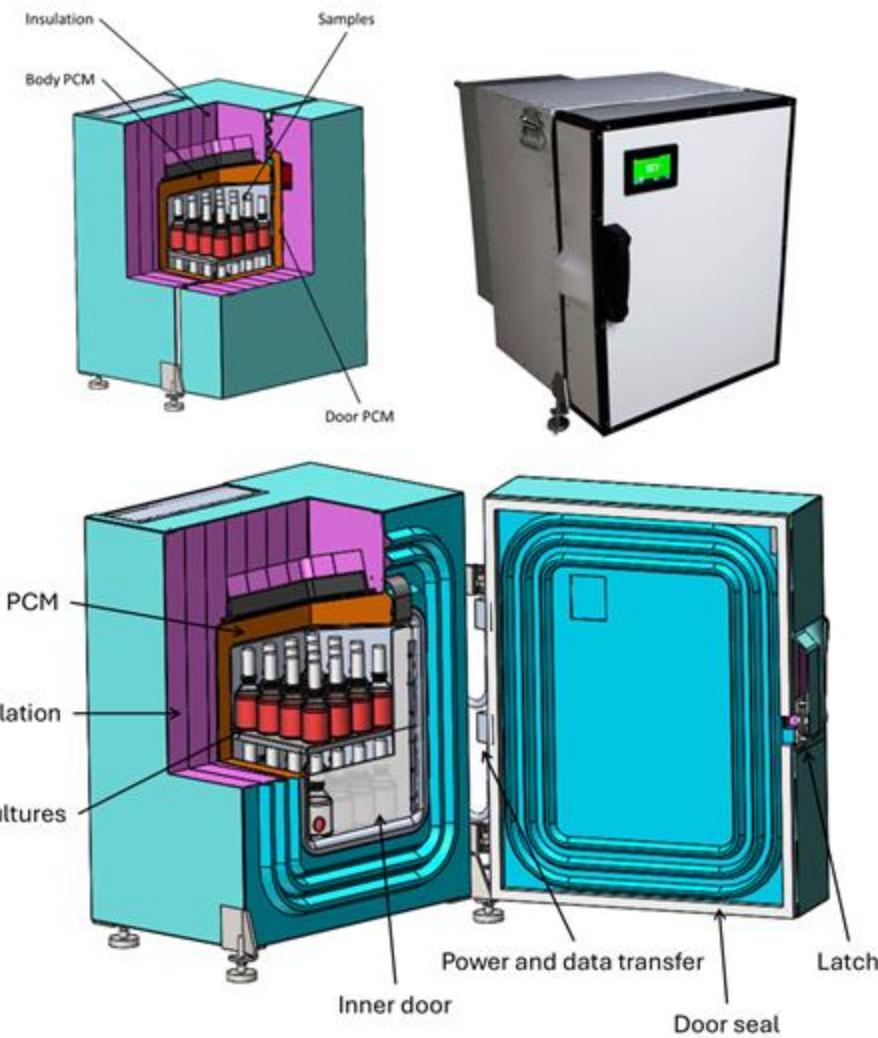
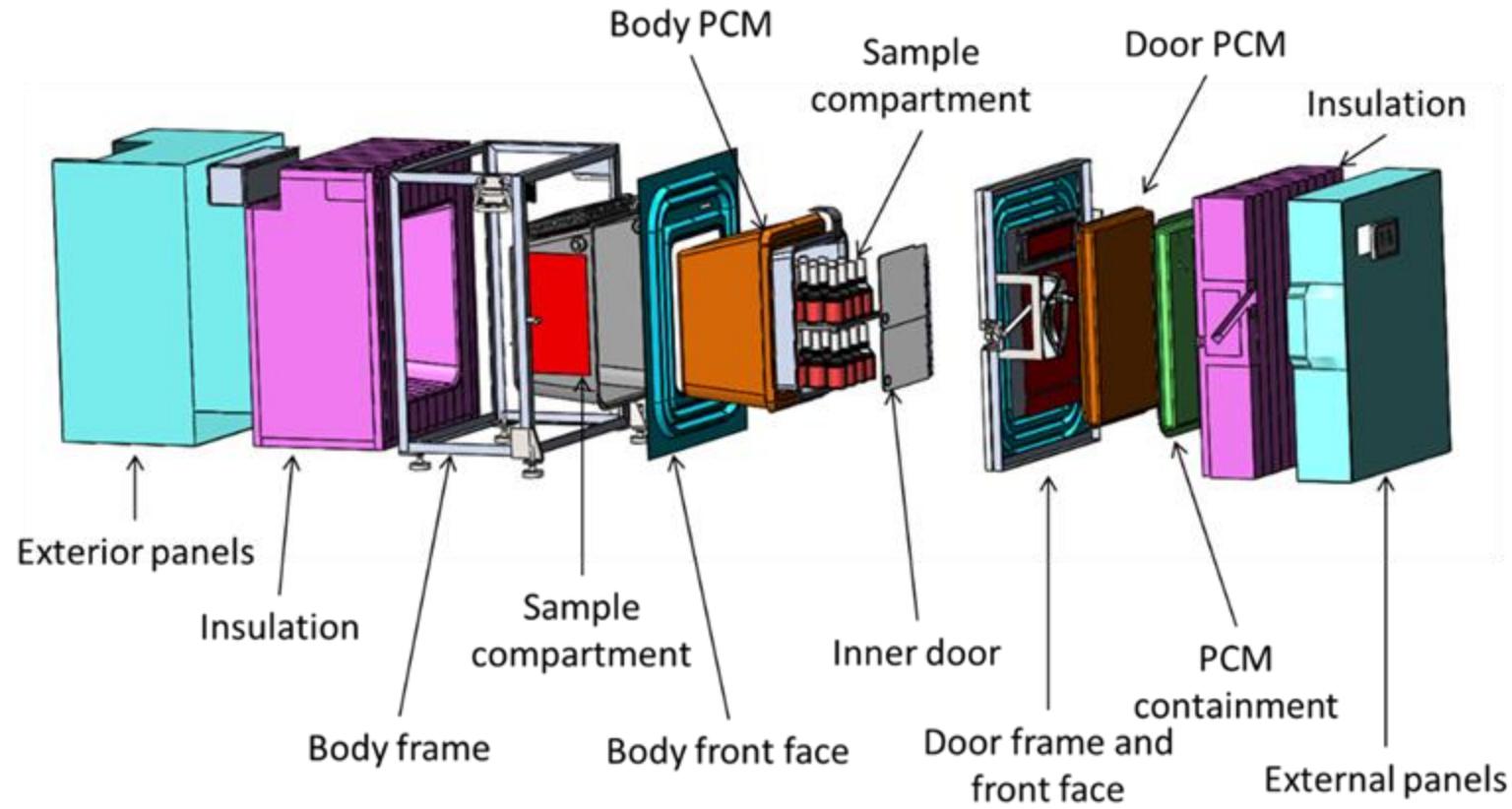


Well-made, expensive storage cabinet observed *in situ* in Senegal



Phase change material enthalpy curve

Low Cost Low Resource Incubator

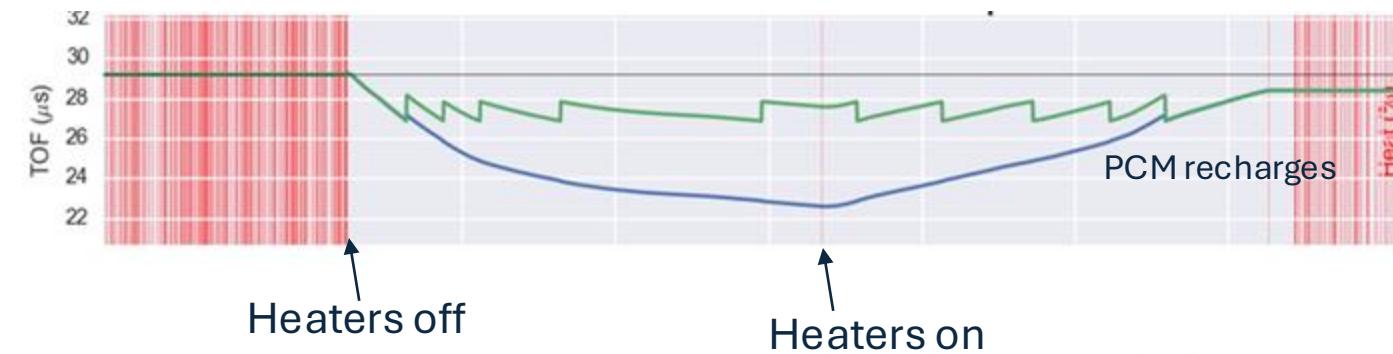
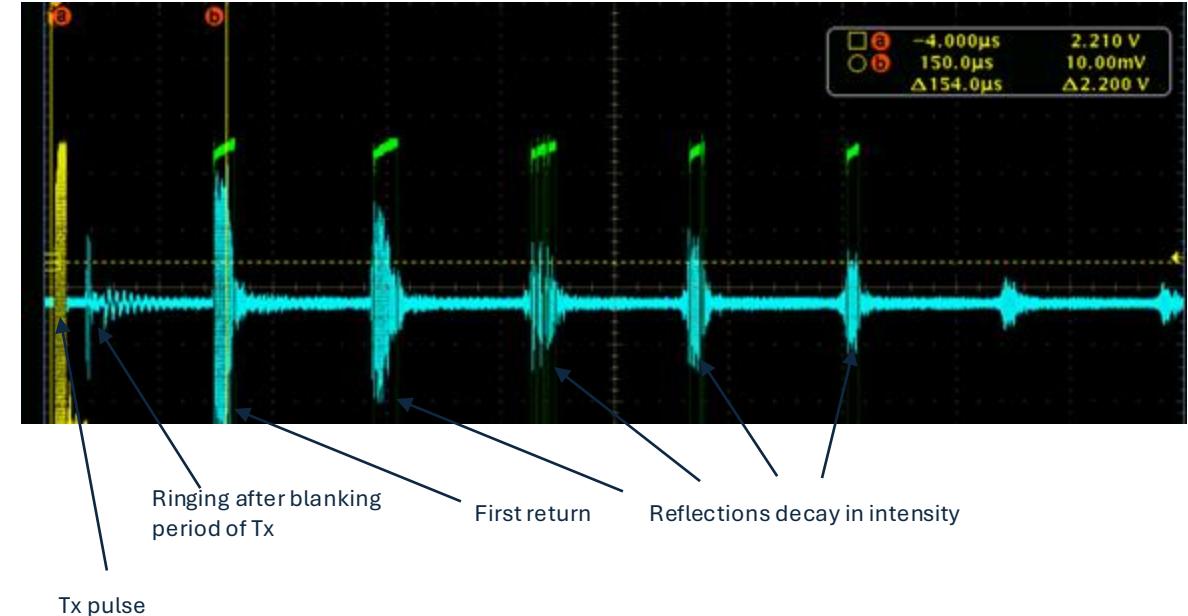
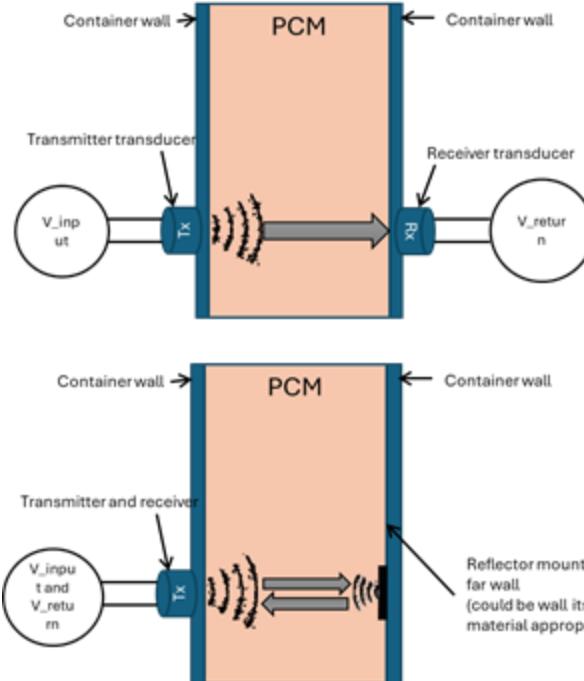


Desire for battery-less biological culture incubator, maintain 37C temperature over 12 hour power loss. Used phase change material (PCM, wax) as thermal buffer

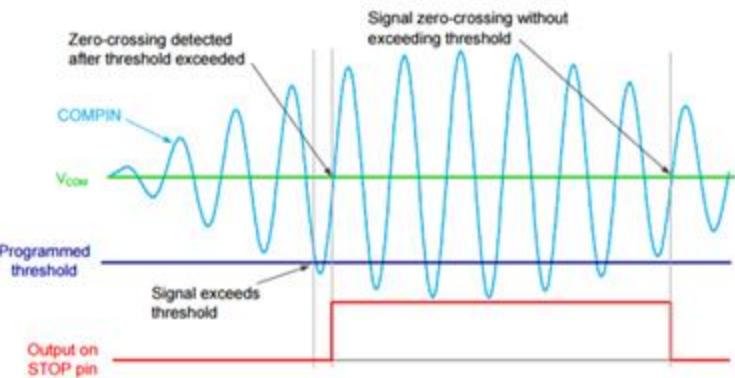
Wax state assessment

Since the temperature is buffered by phase change, can't use temperature to control the state of the wax

Time of flight across the wax solves this, integrating the change in speed of sound between liquid and solid across a cross section



Track raw returns (green) with 1Mhz/1 microsecond overflows as pulse signal strength changes (look on threshold)



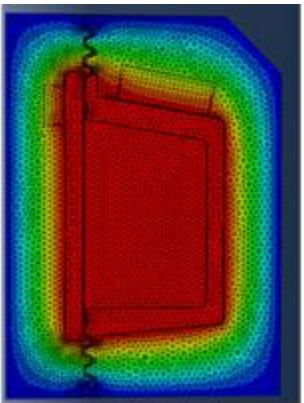
LCLRI features



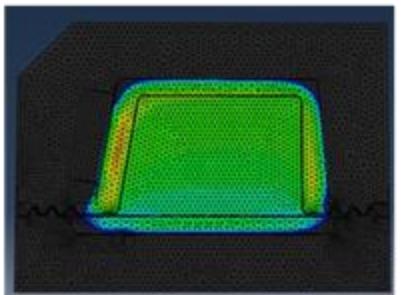
Wax crystallization - had to find additive to force microcrystallization and remove cleavage planes



Uniform microcrystalline structure with additive

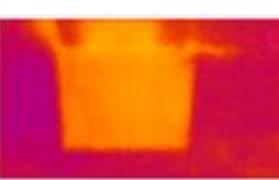


Full scale: interior 37C, exterior 5C



Incubation scale: black 36C, red 37C

Thermal modeling to predict hold time and uniformity in sample compartment



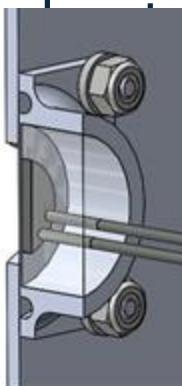
IR image - uniform to within (poor) resolution of camera



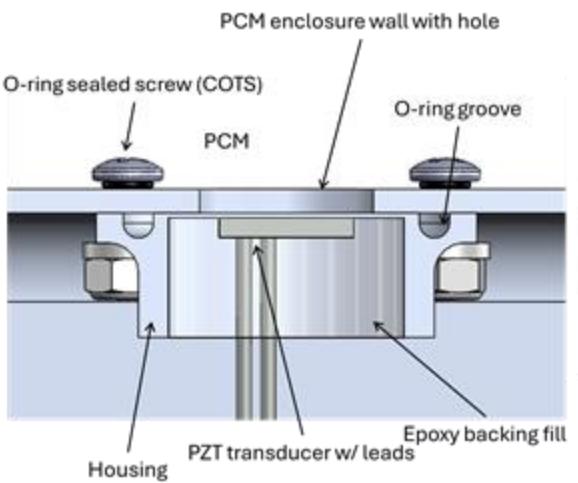
(shape is parallelogram - keystone removed by camera)



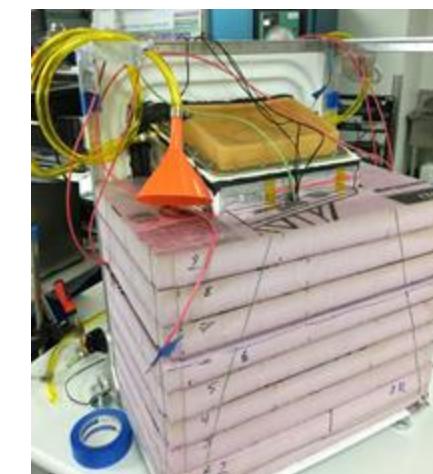
Prototype heaters to avoid lead time for custom silicone heaters



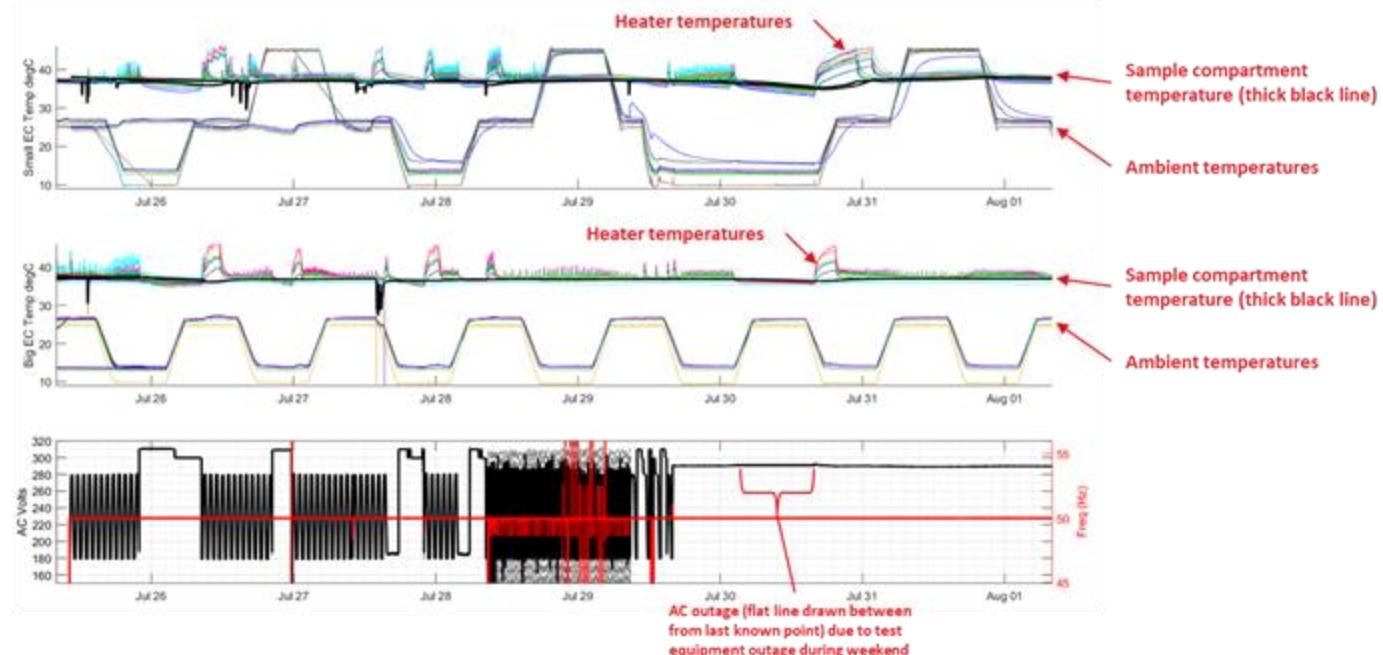
Hands on fun with assembly



Transducer assembly, low cost: pot it with epoxy in a housing



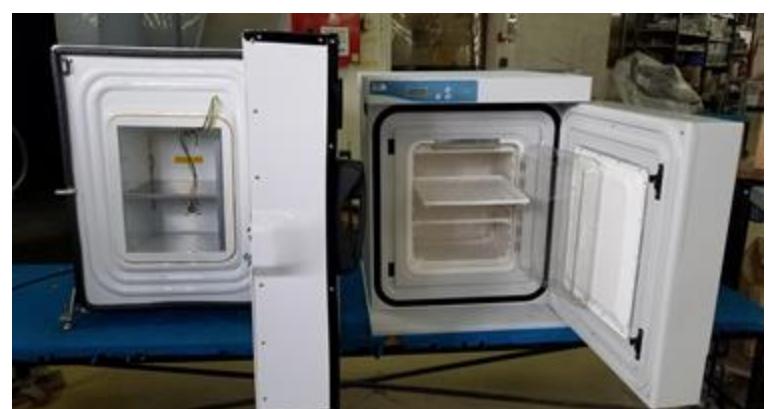
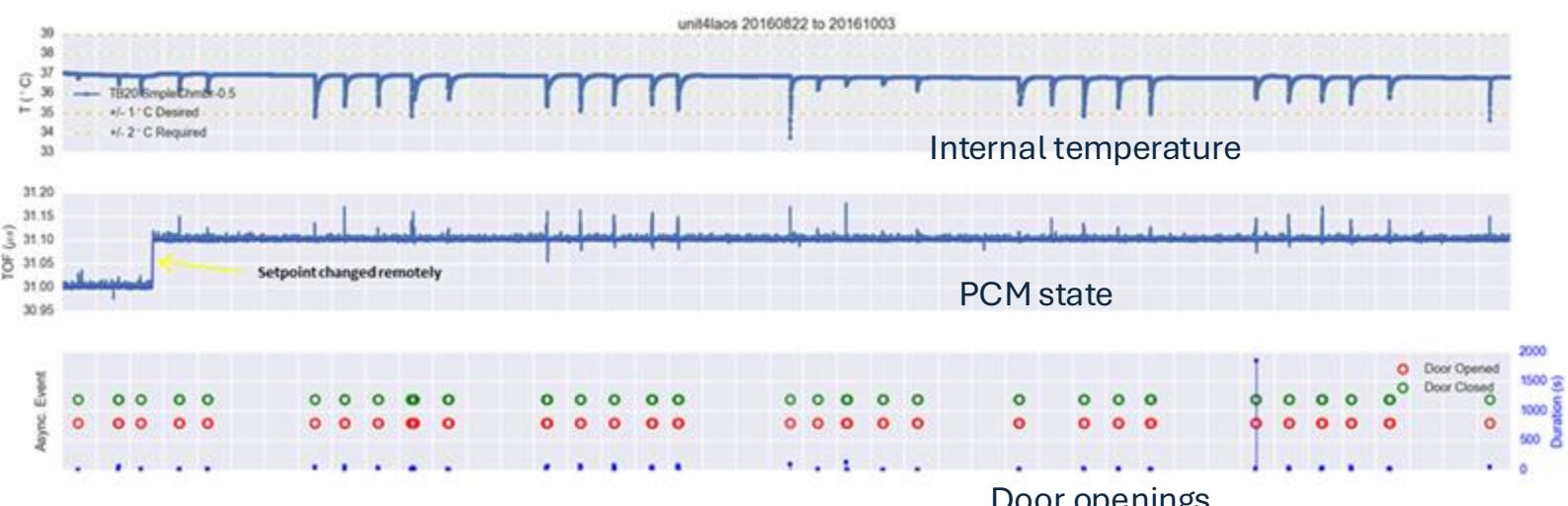
Lab test results



Environmental
chamber testing

Field test in Laos

Field test results



Prototype (left) with
commercial pilot unit (right)



Problem: QC check of dewar takes a long time

Problem: the factory producing our vacuum dewar needs a better method to assess the level of heat leak of the dewar after sealing

Existing hot water test protocol

- Record water temperature 5 and 24 hours after filling
- Compute delta T
- Determine pass/fail based on lookup table (in protocol)
- Ambient temp: 23 ± 2 C
- Issue causing inconsistency:
 - Measurement across shift changes
 - Room temperature not controlled



Performed at factory



Dry ice is more consistent, but takes 4 days to read out and is more costly, susceptible to ambient temperature and still requires multiple people to take measurements

Production continues during the testing, shorter test times would reduce scrap

ARKTEK™ Mini

Description

Arktek Mini is a double-vacuum-insulated-layer container that cryogenically stores vaccines using dry ice between -60 °C to -78.5 °C. The interior is configured to hold vaccines in one, two, or three cups with dry ice pellets positioned above in a refillable bag. Arktek Mini has been successfully used in East Africa to store bull semen at cryogenic temperature for artificial insemination applications.

| Configuration | Dry ice mass | Est. Vial capacity* | Hold time (at 43 °C ambient)** | Hold time (at 25/43 °C ambient)** |
|---------------|--------------|---------------------|--------------------------------|-----------------------------------|
| 2 vial cups | 1.6 kg | 40 | 5.5 days | 6.5 days |
| 3 vial cups | 1.4 kg | 60 | 4.5 days | 5.0 days |

* Based on vial size Ø16 mm x 35 mm (Pfizer COVID vaccine)

** Evaluated based on vaccine temperature reaches -60 °C

Specifications

| | |
|----------------------|-------------|
| Dimension | Ø20 x 56 cm |
| Weight (empty) | 3.4 kg |
| Max dry ice capacity | 2 kg |



Vaccine cups



Arktek Mini QC system

Goals

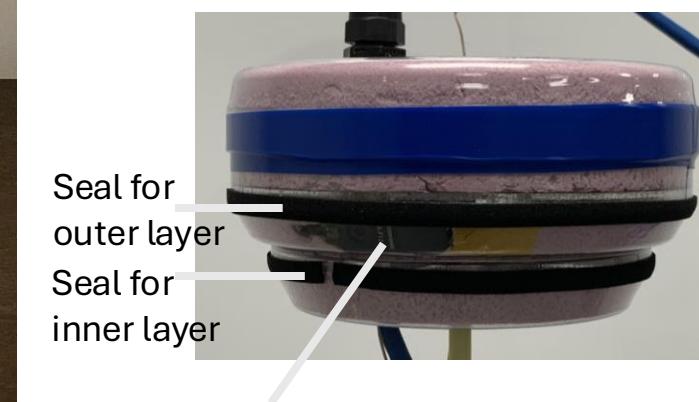
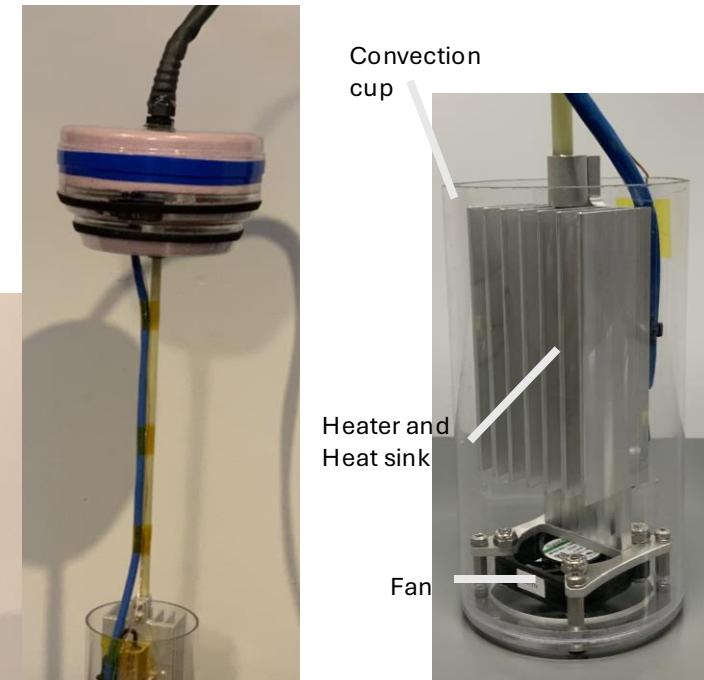
- Reduce run time from 4 days to <4 hours
- Eliminate the use of dry ice
- Reduce human error
 - Automatic heater control
 - Display pass/fail status via LED light
 - Automated data recording and calculation

Methods

- Active heating inside flask
- Fan to circulate air flow
- Temperature feedback control
- Acceptance based on heater duty cycle at steady state temperature.



Complete system (plus software)



Proximity sensor – To determine when outer layer is being tested

Problem: Smallholder farmers can't determine optimal insemination conditions

- Cows are an important source of income and food for smallholder farmers, and can produce more if bred
 - Estrous cycle repeat every 21 days, when the cows are fertile
- In developed world commercial farms assessing estrous is key to determining when to artificially inseminate (AI) cows
 - Performed with ultrasound systems, and with synchronization of herds with removable hormone devices
 - Herds also exhibit behaviors when in heat
- In smallholder farms where they may only have one or two cows these methods are unavailable, and AI or bringing in a bull is costly
 - A low cost, quick method of assessment in the literature is to measure vaginal electrical resistance which drops several hours before estrous



Draminski

Heat detector, Insemination instruments, Ultrasound units, Obstetric instruments



Hauptner Herberholz



Emkavet

EMKAVET



Ovatec

Commercial devices on the market, too costly for LMIC

Estrous detection through vaginal resistance measurement

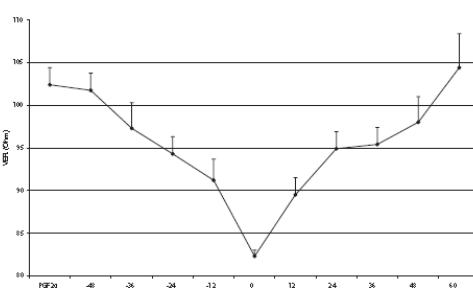
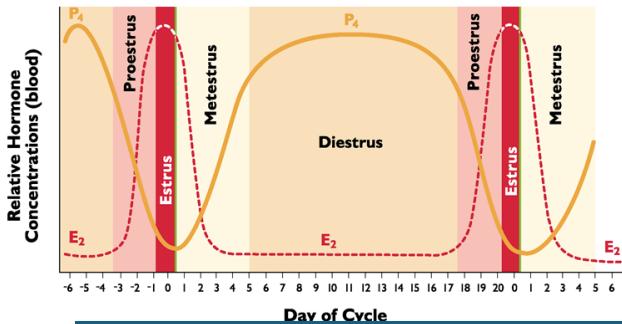
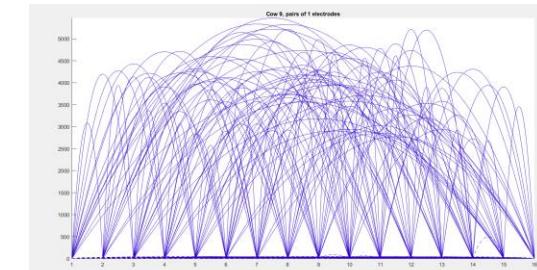
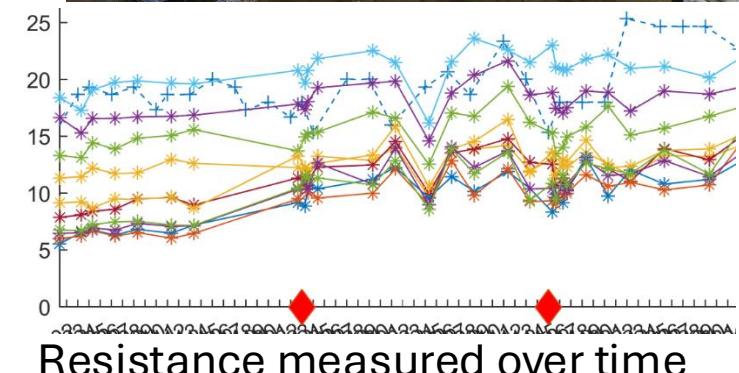
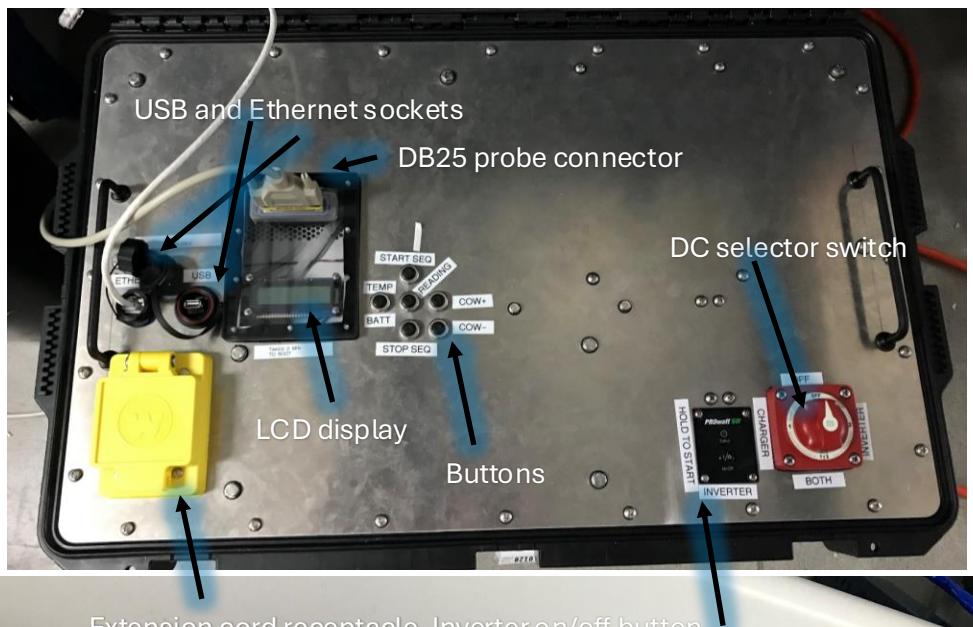


Figure 1 Change in VER around estrus after PGF_{2α} injection in dairy cows synchronized with GnRH+PGF_{2α} (0 = day of estrus). The vertical bars indicate the standard error.

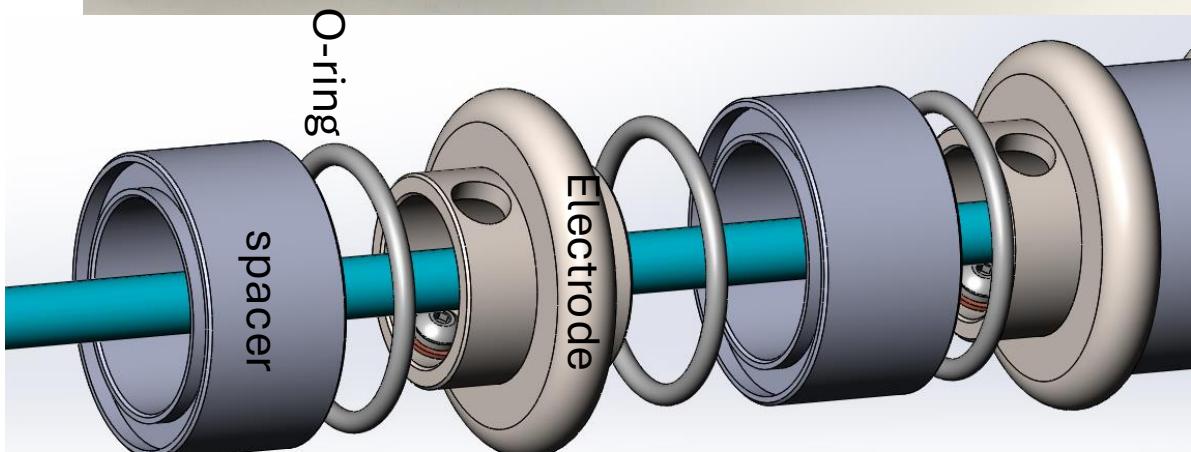
Resistance changes when hormones change during estrus



Combinations of electrodes,
4 wire measurements

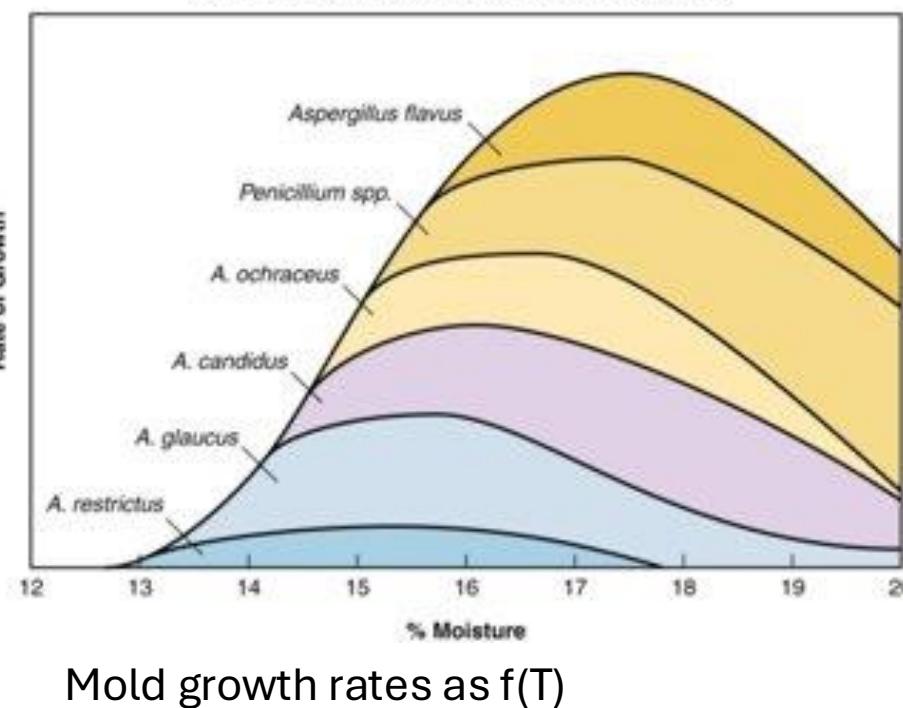


Position and frequency sweeps



Problem:

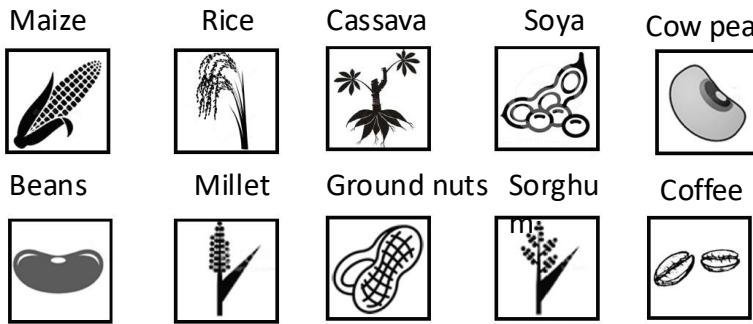
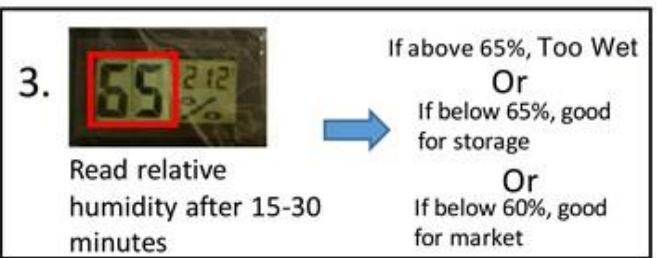
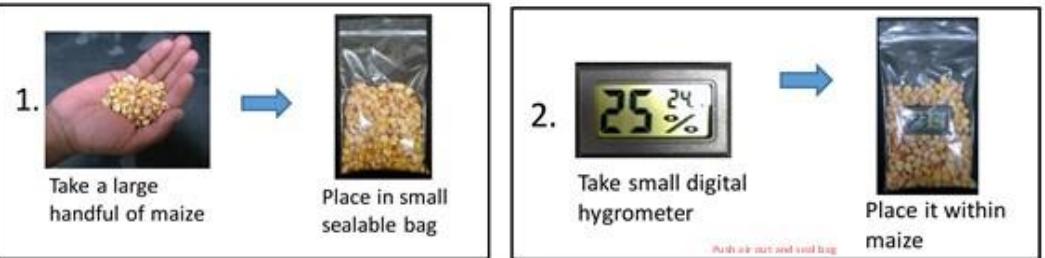
- Grains must be dried to be stored or mold can occur, spoiling the grain or making them become toxic (aflatoxin)
- Smallholder farmers are paid by weight at the grainaries
- Smallholder farmers get the most economic benefit by selling at the maximum acceptable moisture level, avoiding over-drying
- Commercial grain moisture meters are too expensive for smallholder farmers (\$hundreds), a <\$5 device would provide benefits



| Temperature (°C) | Relative Humidity (%) | | | | | | | |
|------------------|-----------------------|------|------|------|------|------|------|--|
| | 50 | 55 | 60 | 65 | 70 | 75 | 80 | |
| 15 | 11.9 | 12.6 | 13.3 | 14.1 | 14.9 | 15.8 | 16.8 | |
| 18 | 11.6 | 12.3 | 13.0 | 13.8 | 14.6 | 15.5 | 16.6 | |
| 21 | 11.4 | 12.0 | 12.8 | 13.5 | 14.3 | 15.3 | 16.3 | |
| 24 | 11.1 | 11.8 | 12.5 | 13.3 | 14.1 | 15.0 | 16.1 | |
| 27 | 10.8 | 11.5 | 12.3 | 13.0 | 13.9 | 14.8 | 15.9 | |
| 30 | 10.6 | 11.3 | 12.0 | 12.8 | 13.6 | 14.6 | 15.6 | |
| 33 | 10.4 | 11.1 | 11.8 | 12.6 | 13.4 | 14.4 | 15.4 | |
| 36 | 10.2 | 10.9 | 11.6 | 12.4 | 13.2 | 14.2 | 15.2 | |

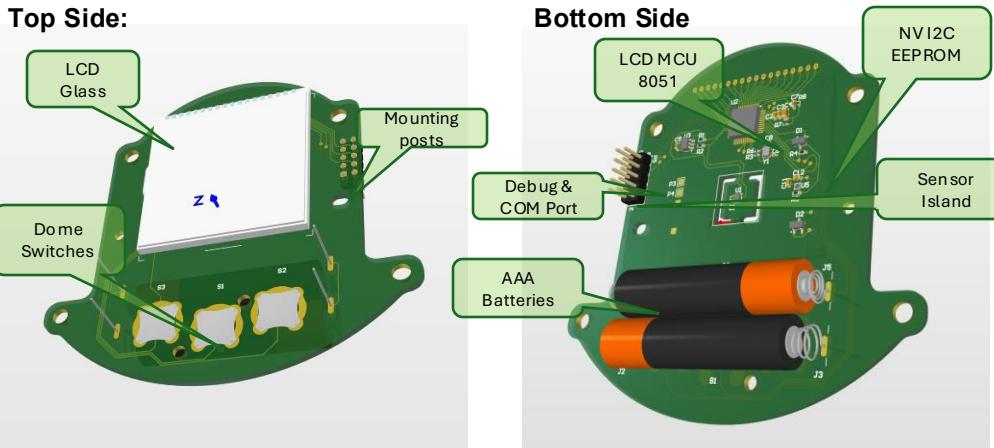
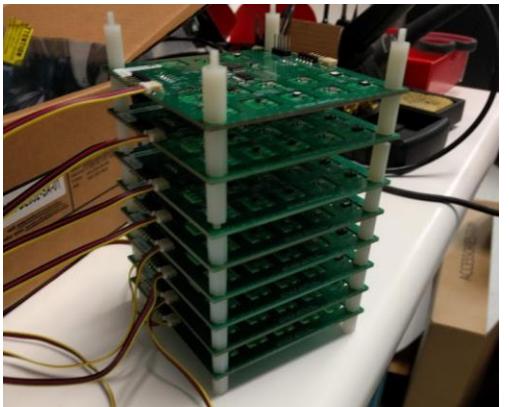
Empirical temperature/relative humidity to grain moisture percent table

Grain Moisture Measurement



Goal: Provide a low cost means for LMIC farmers to assess their grain dryness, reducing losses and increasing prices paid.

Place grain in a sealed volume, measure temperature and humidity to get moisture %



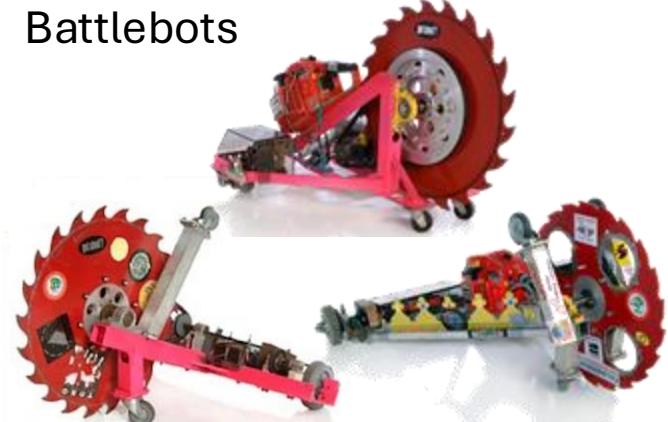
Lots of time exploring humidity sensor stability

Andrew Miller

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- andymiller@gmail.com



Battlebots



I built a Farrier 22 trimaran
Carbon fiber, fiberglass, foam core



4 bar linkage allows folding onto trailer

Built a CNC
router



Wood and
nonferrous
metals



Make your own plaques and save!

