Benefits of High Fault-Duty Submersible Transformer Tank Design

22nd Annual Electrical Network Systems Conference

Track #3 – April 25, 2023

1:00 PM & 2:15 PM

prolec®


xignux
Strong Alliance
Since 1995, Prolec GE has been a successful joint venture between two world class organizations.

Complete Line of Transformer Solutions for the Distribution, Transmission and Generation of Electrical Energy

Power Transformers (PT)

- **Monterrey:** 5 MVA up to 1,200 MVA and voltages up to 500kV
- **Waukesha:** 10 MVA up to 800 MVA and voltages up to 345kV
- **Goldsboro:** 2.5 MVA up to 112 MVA and voltages up to 230kV
- **Canoas:** 20 MVA to 750 MVA, voltages up to 765kV

Industrial (IT) & Renewables (REN) Transformers

- **Monterrey:** 225 kVA up to 15,000 kVA, voltages up to 69 kV

Distribution Transformers (DT)

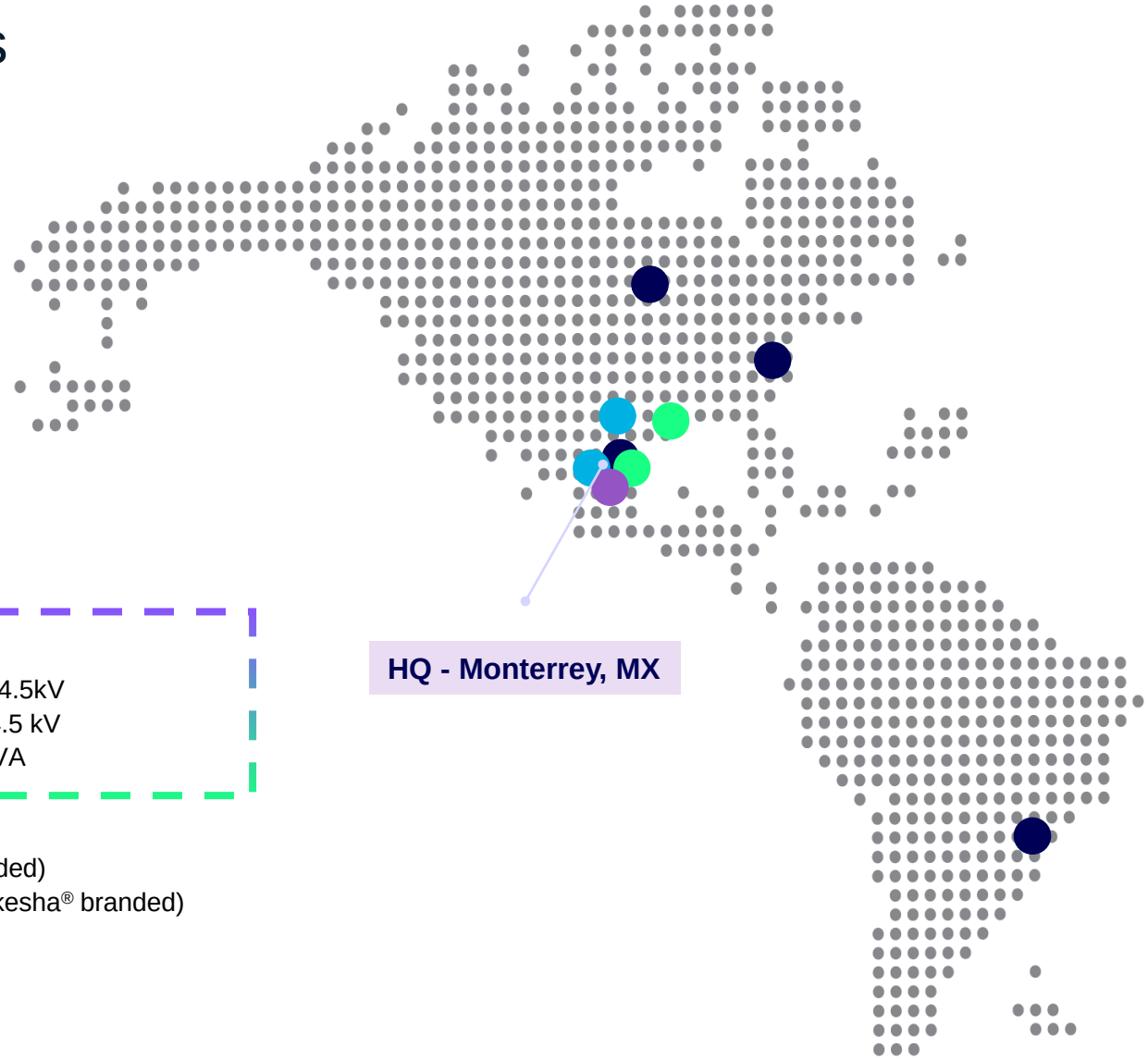
- **Monterrey:** Residential & Commercial - 5kVA to 3,750 kVA, voltages up to 34.5kV
- **Shreveport:** Network transformers - 300kVA to 2,500 kVA, voltages up to 34.5 kV
  Voltage Regulators - 38 kVA to 833 kVA, voltages up to 34.5 kVA

Components

- **Monterrey:** Distribution/Low voltage transformer components (Celeco® branded)
- **Dallas:** Power/High voltage transformer components & training center (Waukesha® branded)

Services:

- **USA Coverage:** Service centers, storage and field services



prolec® | GE

waukesha® by prolec ge

prolec® celeco

Overview

- Located in Shreveport, Louisiana
- Acquired by Prolec GE in 2020;
  GE facility since 1971
- 600,000 ft^2 facility on 200 acres of land
- Total employees: 250
- Currently manufacturing voltage regulators and network transformers

Shreveport Expansion

- With the objective to increase our production capacity and maintain our on-time delivery commitments, a $100 million investment has been approved for 2023
- Investment plan includes strengthening our supply chain and setting up new production lines
- Some customers may benefit from Buy American and IRA requirements
- Main upgrades to be performed include:
  - Increase internal components production
  - New production line for Industrial and Renewables
    - Expansion at Shreveport, Louisiana facility
    - Plan to increase current capacity by **30%**
    - Product capabilities to include pads and subs up to 5 MVA
    - Begin manufacturing in **June 2024**

600,000 ft² of manufacturing area

Products

NETWORK TRANSFORMERS

- 300 to 2500 kVA 3-phase, voltages up to 34.5 kVA
- ANSI LV network
- Patented tank technology…GRC
- Best-in-class product lifecycle 85+ years

VOLTAGE REGULATORS

- 38 to 833 kVA single-phase
- Substation and pole-mounted
- 20 year maintenance-free operation
- Best-in-class load tap changer/switch
- First to market: reverse power detect

Transformer Failures

Transformers fail for many reasons.

It is possible, at the end of a transformer's life, for an internal fault to develop, which may result in high-voltage arcing. This arcing may create large quantities of gases, some of which may be flammable, such as acetylene and hydrogen.

These gases can create high pressures inside the hermetically sealed transformer tank during this arcing event before the protective devices of the GRID system can disconnect the power to the transformer.

Transformer Failures (cont.)

End of transformer life events can have negative impacts:

- May impact the public space
  - Potential injuries
- May impact the working space
  - Potential injuries
- Exposed arcing to air (oxygen)
  - Potential fire and injuries
- High cost of transformer removal, transformer replacement and vault repairs

ONE
is too many!

10% fluid 35 ft. up 2.5 ms after first fluid exit

Ways Traditional Tanks Can Rupture

Internal Testing: Tanks tested using dynamic pressure from pressurized air in water-filled tanks; test energy ≤5 Megajoules (MJ)

Ways Traditional Tanks Can Rupture (cont.)

What if this was flaming oil?!

Internal Testing: Tanks tested using dynamic pressure from pressurized air in water-filled tanks; test energy ≤5 Megajoules (MJ)

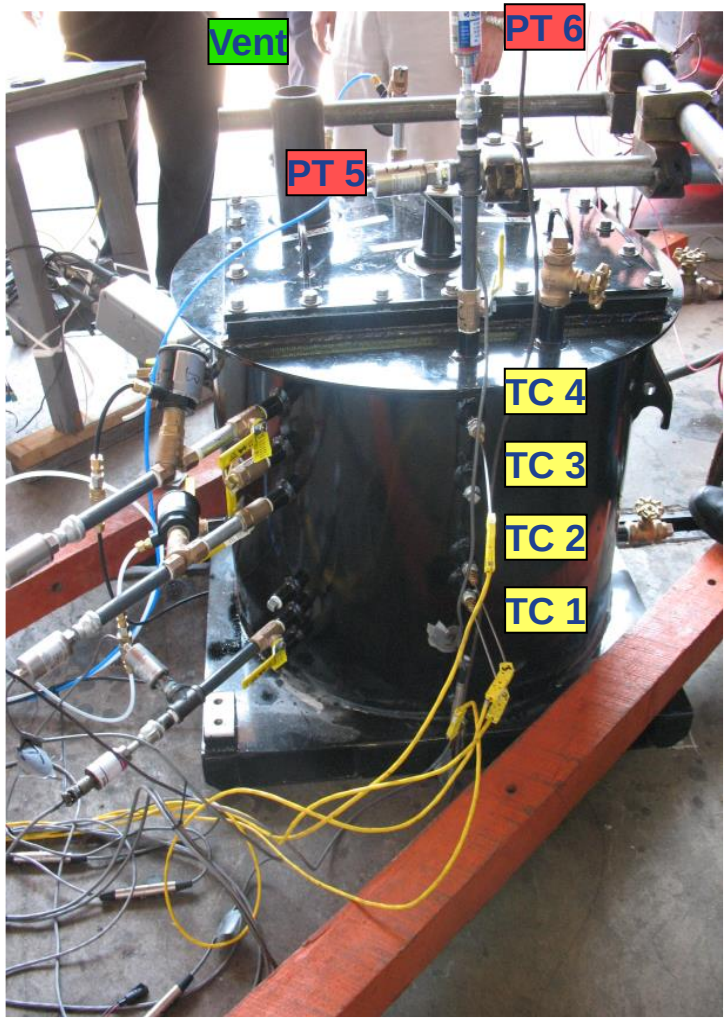
Arcing & Gas Generation

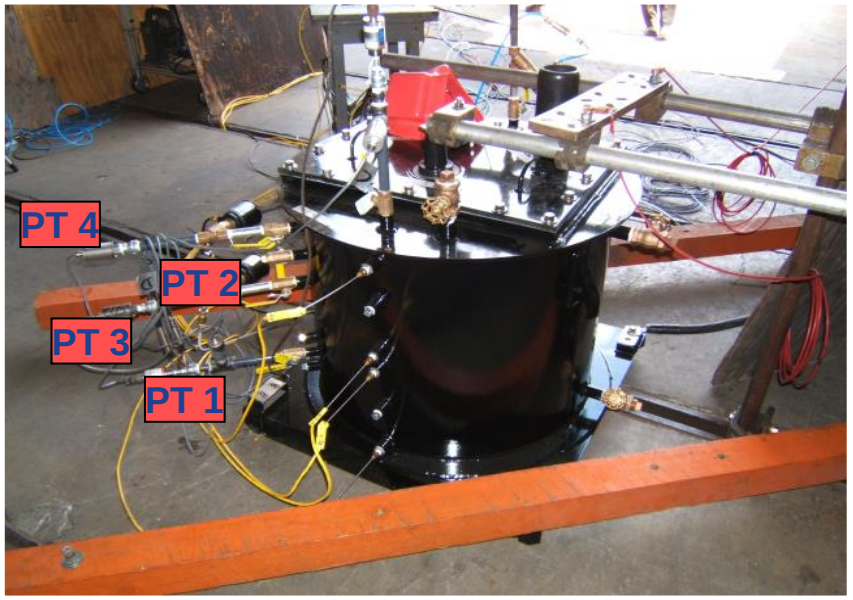
Variables

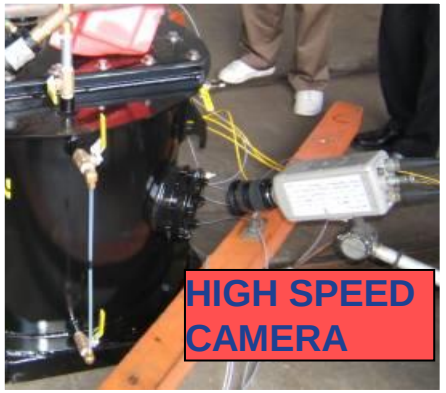
- Fluid type
- Voltage
- Amperage
- Time

Output

- Energy
- Pressure
- Temp Fluid
- Temp Gas
- Chemistry





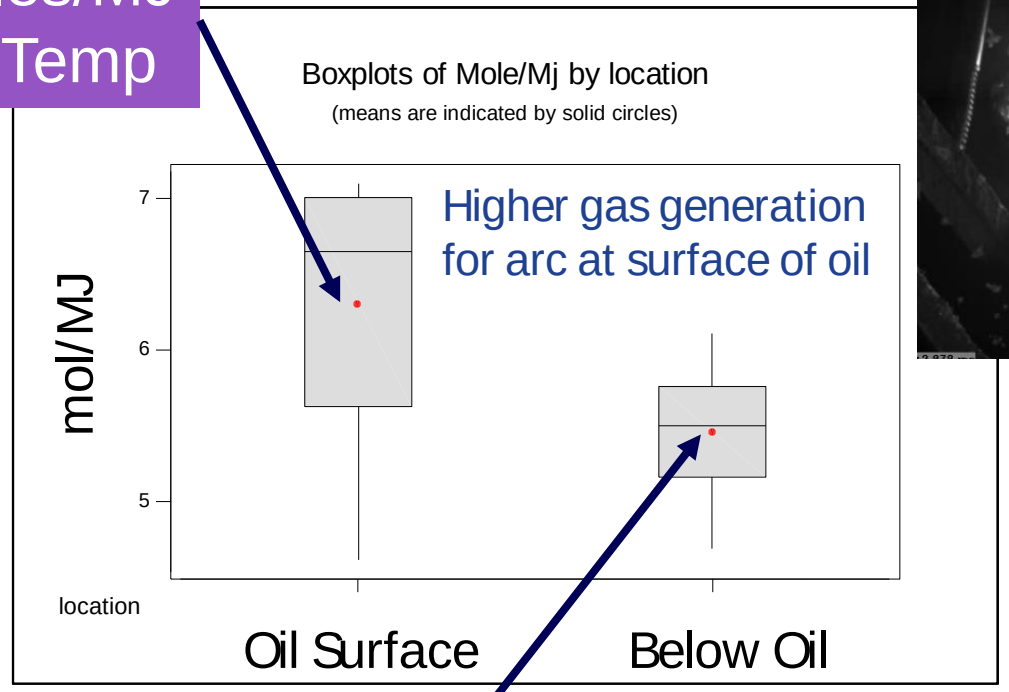


Arc Test Set-up

- 80 tests
- Two sessions
- Oil and natural ester fluid

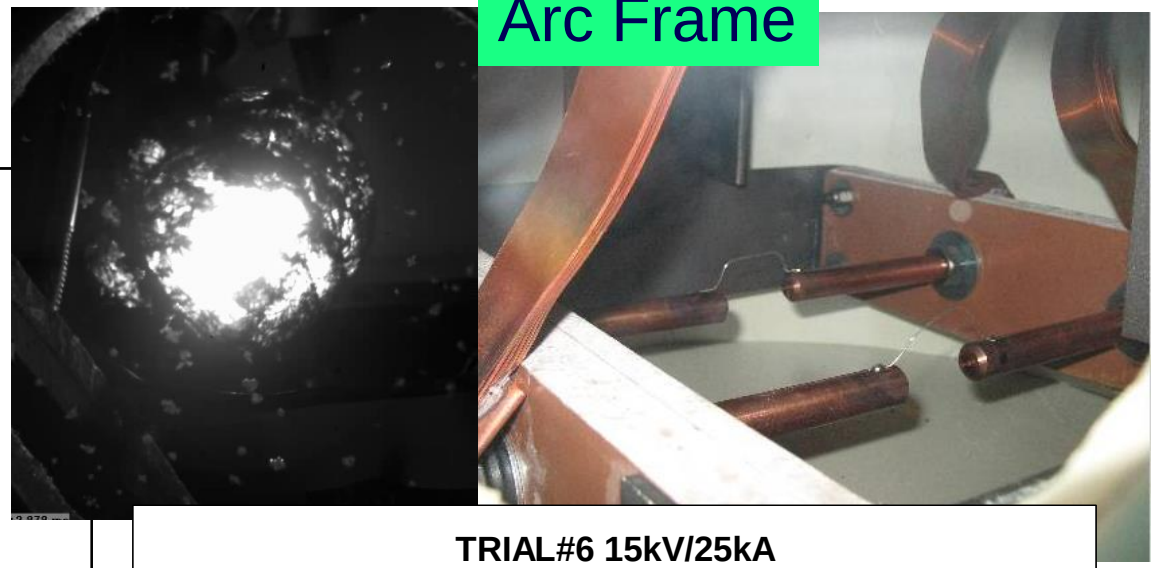
Arcing & Gas Generation (cont.)

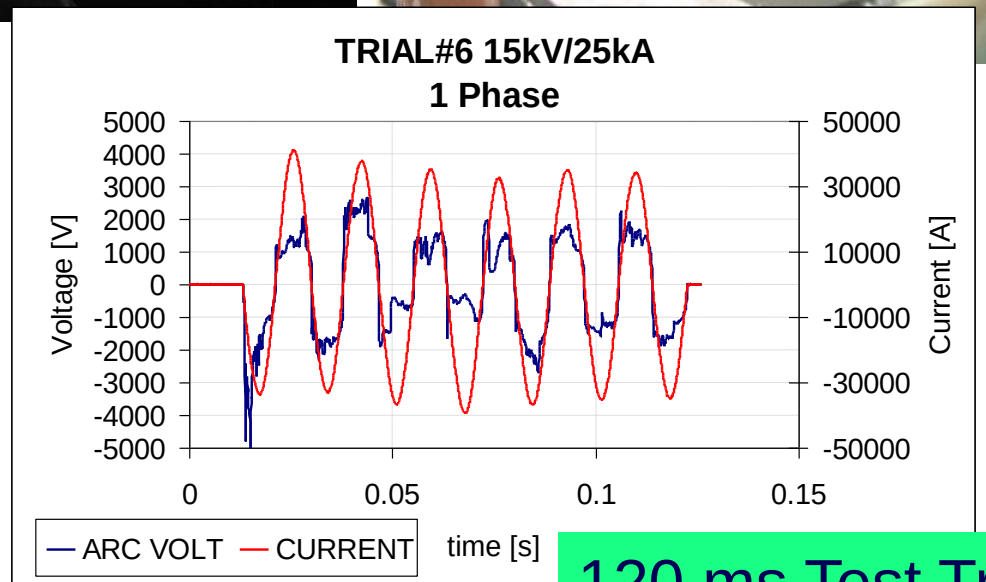
6.3 Moles/MJ at fluid Temp



5.8 Moles/MJ at fluid temp

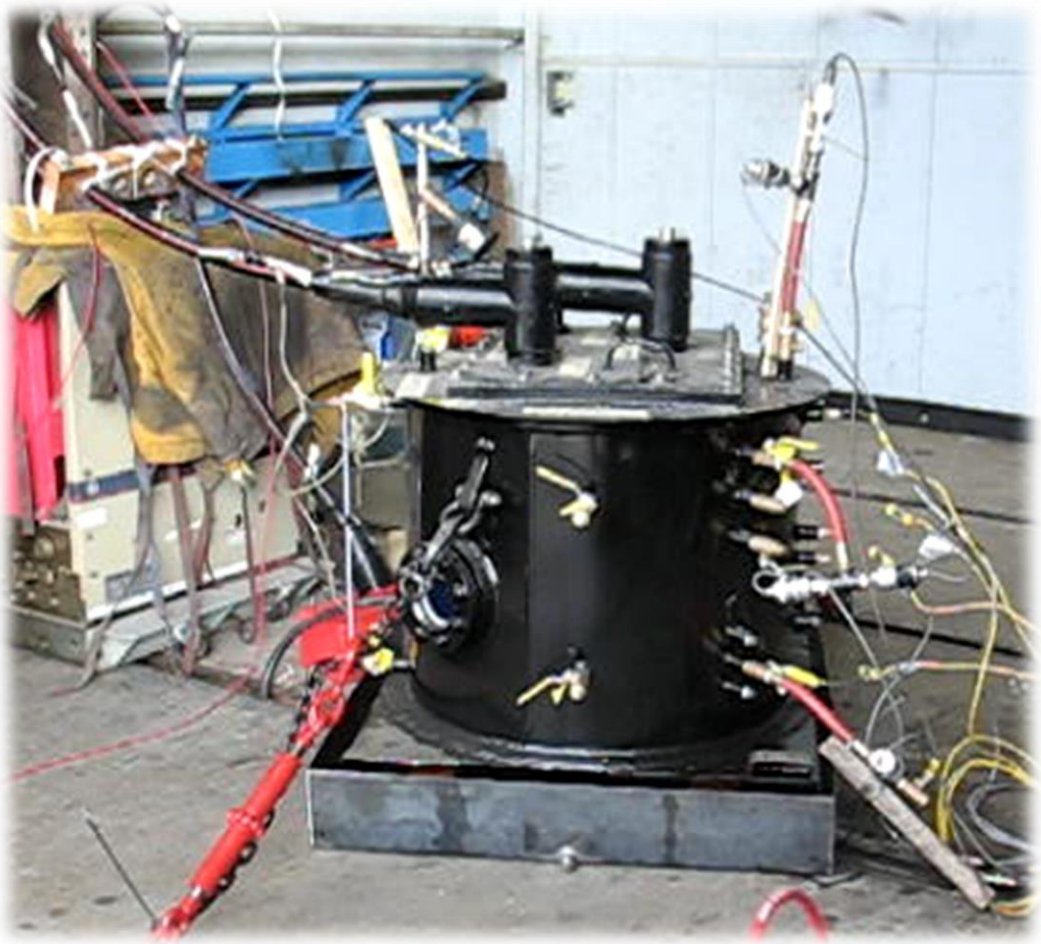
Arc Frame





120 ms Test Trace

Preliminary Testing

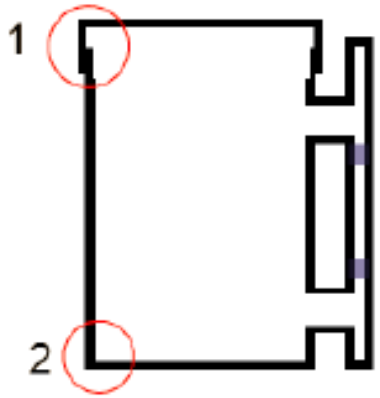


We tested the dynamic pressures and gases that are generated during an arcing event.

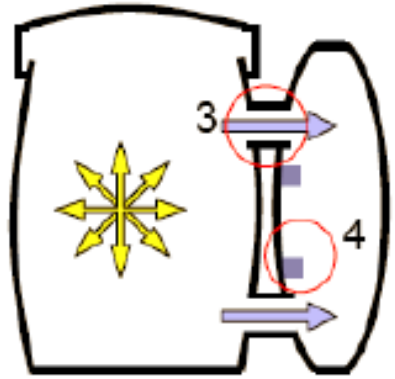
Preliminary Testing (cont.)

Then reproduced the dynamic pressures using air and water for rapid prototyping.

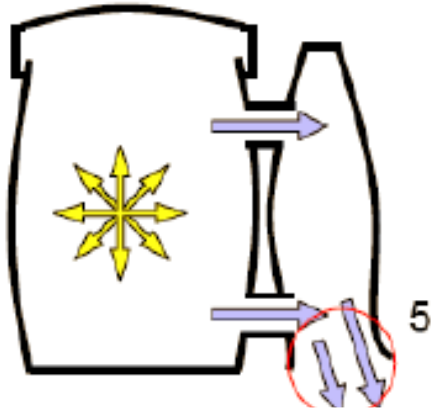
High Fault-Duty for High Fault Event (HFE)



Operating



Arcing



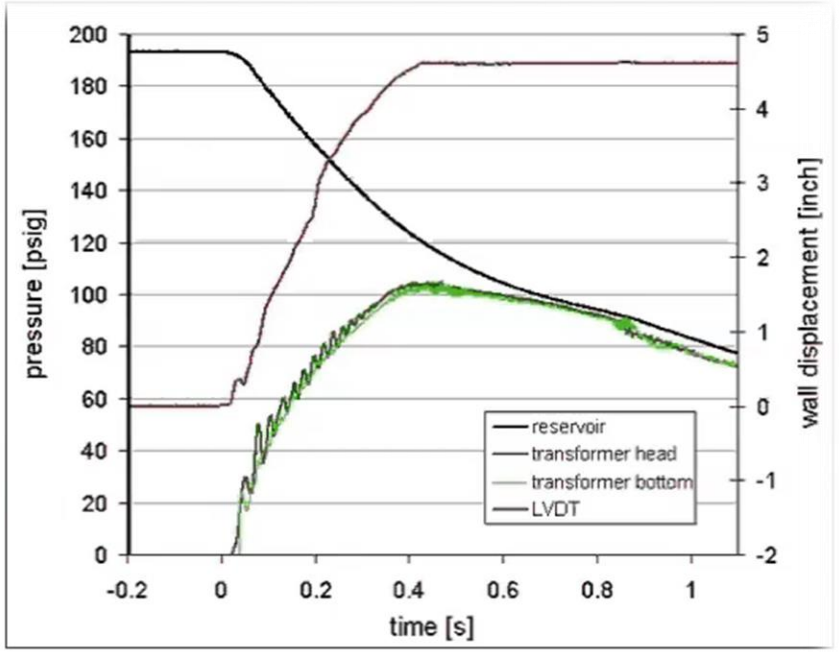
Failure

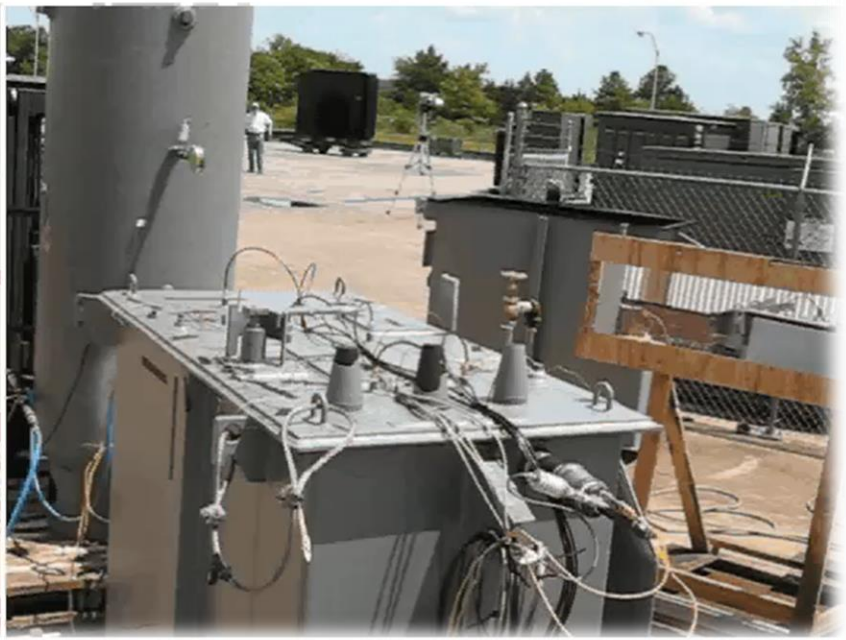
1 cover stronger
2 base stronger
3 larger bottom headers
4 weaker spacer pattern
5 weaker bottom radiator weld

- 200%+ fault energy capacity ... design + weld differentiation
- Transformer expands under severe pressure
- Cooling panel acts as relief point
- Flammable gases not exposed to arc + oxygen

Preliminary HFE Tank Testing

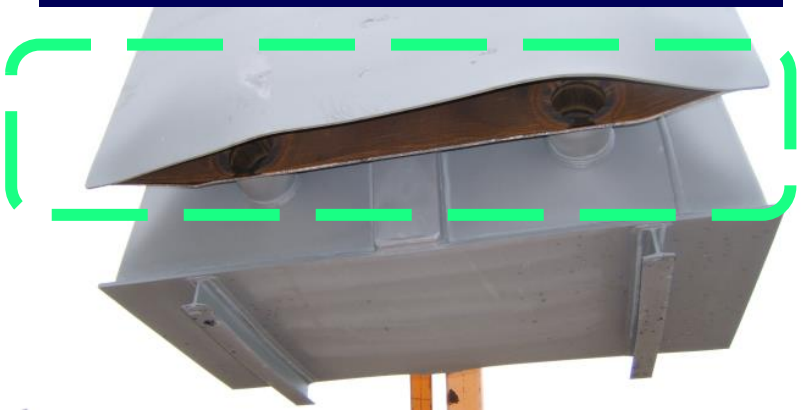
No quick and easy answers…

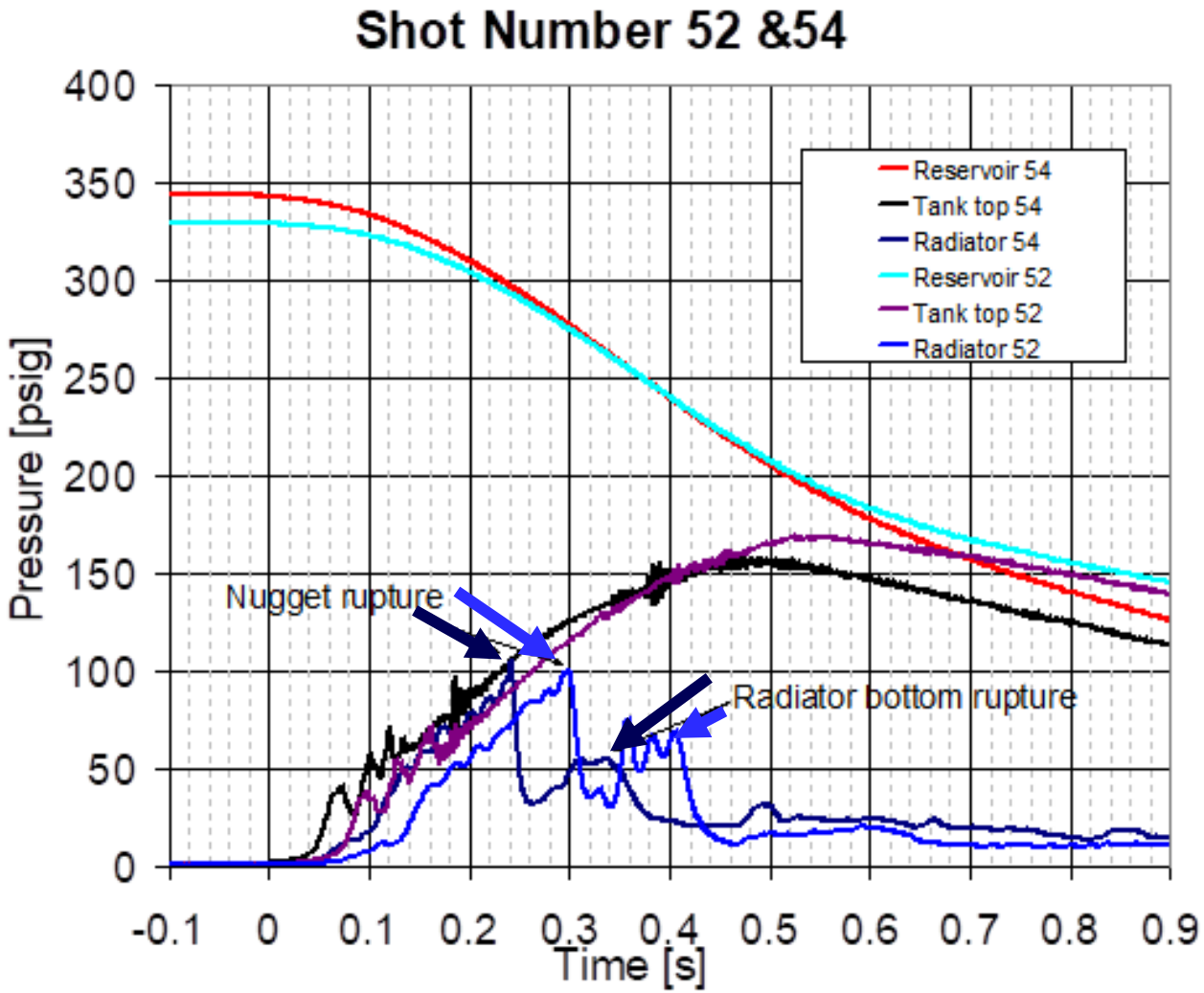




HFE Air & Water 18MJ Test

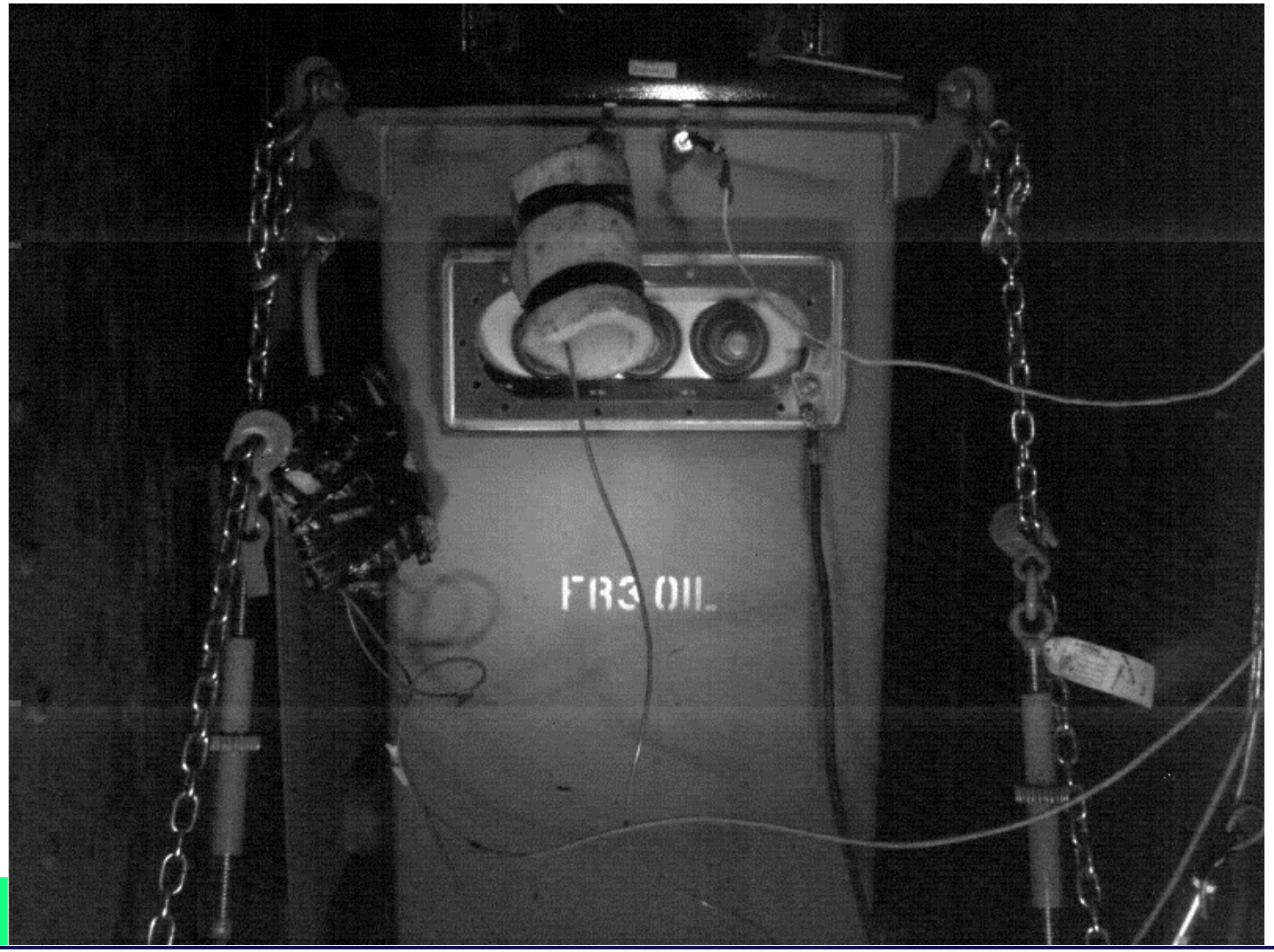
Bottom Radiator Pressure Relief Opening





HFE KEMA USA 18MJ Test

93% of study transformers had ≤ 12 MJ Potential Energy **HFE**



80 ms shown

Learnings

- **Top rupture at 4 MJ to 5 MJ can impact public space**
- HFE tank just expanded in tests through 12.7 MJ: **NO RUPTURE**
- HFE tank radiator bottom ruptured at 18 MJ (12MJ target)
- Fault voltages were much higher that expected
- Expected fault currents during testing ±10%
- **93% of HFE of potential events (≤ 12 MJ potential energy) contained without rupture; transformer volume increases and irreversible plastic deformation of transformer**
- 100% of HFE contained in original KEMA USA tested design margin of 18 MJ

Learnings (cont.)

- Bottom radiator rupture had no ejected fluid into the public space; secondary vault cover used during KEMA tests did not have any liquid splatter when it was inspected after 18 MJ test.
- **Gas did not release during fault event, therefore volatile gases when generated by arcs were not exposed to oxygen in air**
- Tank pressure <50 psig after 1.0 second from event start