



Arthur B. McDonald
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PICO-500 & Hydraulic Control Development

WNPPC Feb 2024

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Agenda

- ◇ PICO detectors: refresher
- ◇ Bubble formation
- ◇ Scale up for PICO-500
- ◇ Hydraulic control challenges
- ◇ New features in PICO-500

The PICO Experiment

- ◇ Bubble chamber technology using superheated fluids
- ◇ Holds the active fluid at a desired thermodynamic threshold
 - ◇ A tiny amount of energy deposition will cause boiling (a bubble!)
- ◇ Dark matter particles (WIMPS) could be that trigger
- ◇ Adjust the thermodynamic threshold to probe different areas of the WIMP mass-cross section parameter space

Bubble Formation

The necessary energy to deposit for bubble formation is given by the **Seitz threshold**

$$Q_{Sietz} = \underbrace{4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right)}_{\text{Surface Tension}} + \underbrace{\frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l)}_{\text{Phase Transition}} - \underbrace{\frac{4\pi}{3} r_c^3 (P_b - P_l)}_{\text{Expansion of Vapour}}$$

Bubble Formation

◇ $E_R > Q_{Seitz}$ must be deposited within a length scale of $r_l \sim 5-10$ nanometers

$$r_l = r_c \left(\frac{\rho_b}{\rho_l} \right)^{1/3}$$

Where r_c is the critical bubble radius

$$r_c = \frac{2\sigma}{P_b - P_l}$$

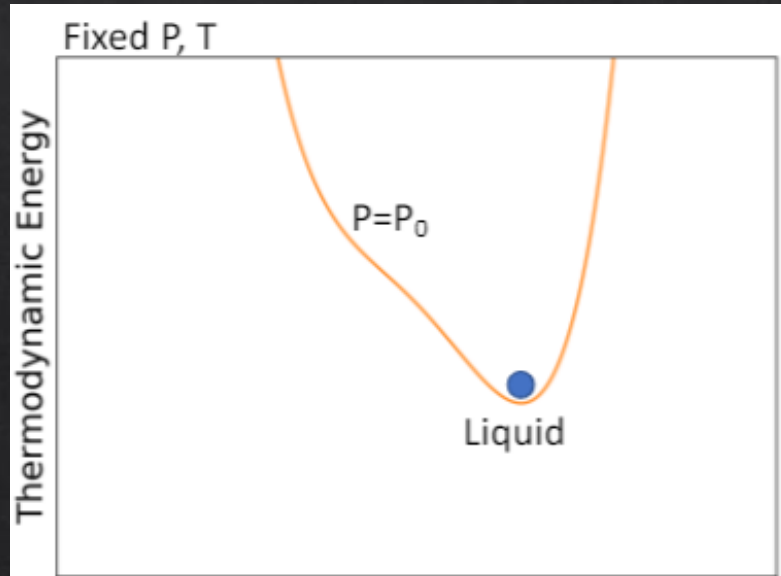
Minimum radius for
bubble to continue to
grow

For C_3F_8 in PICO: $r_c \approx 22.6nm$

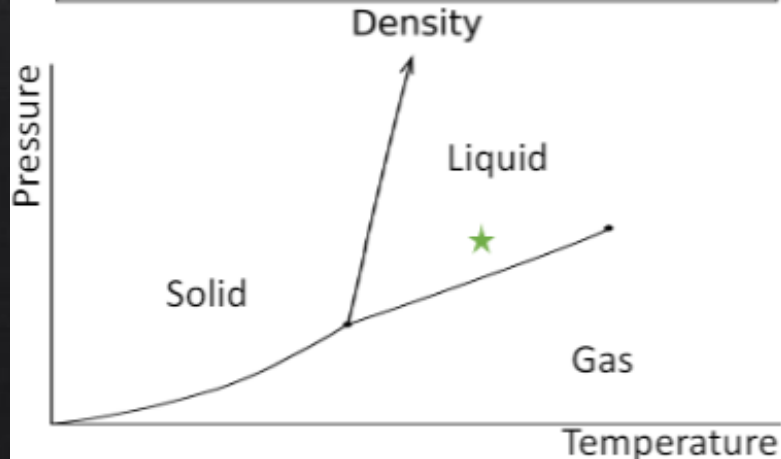
5

Bubble Chamber Dark Matter Search

Gibbs energy

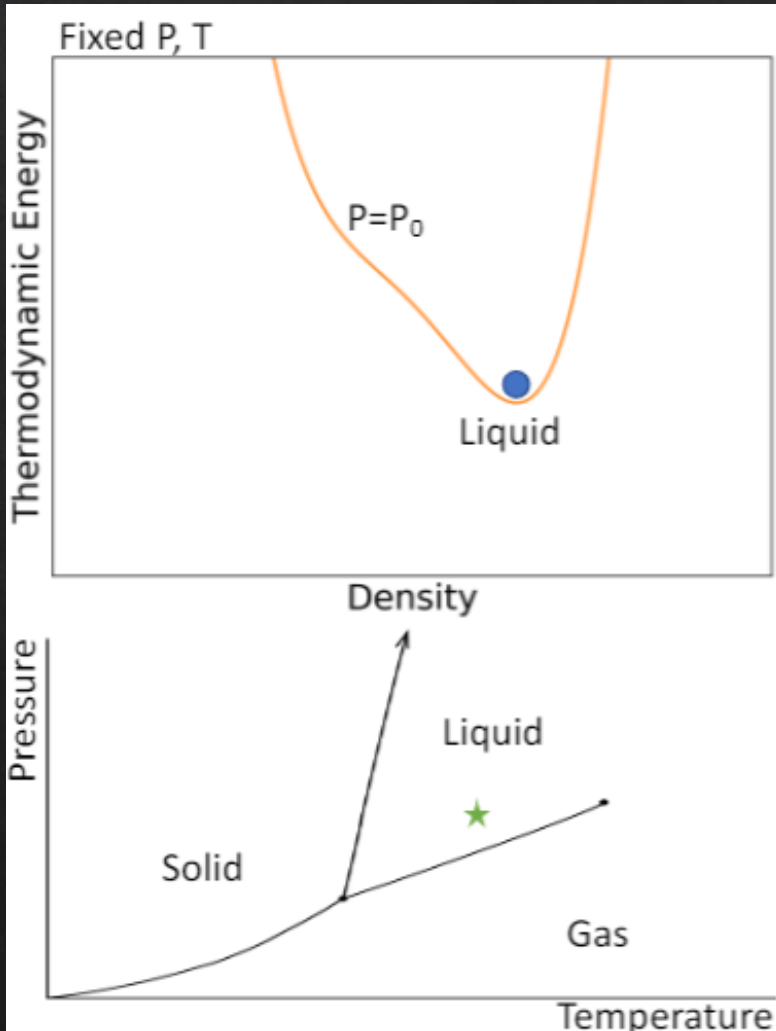


Phase diagram



Bubble Chamber Dark Matter Search

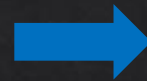
Liquid State



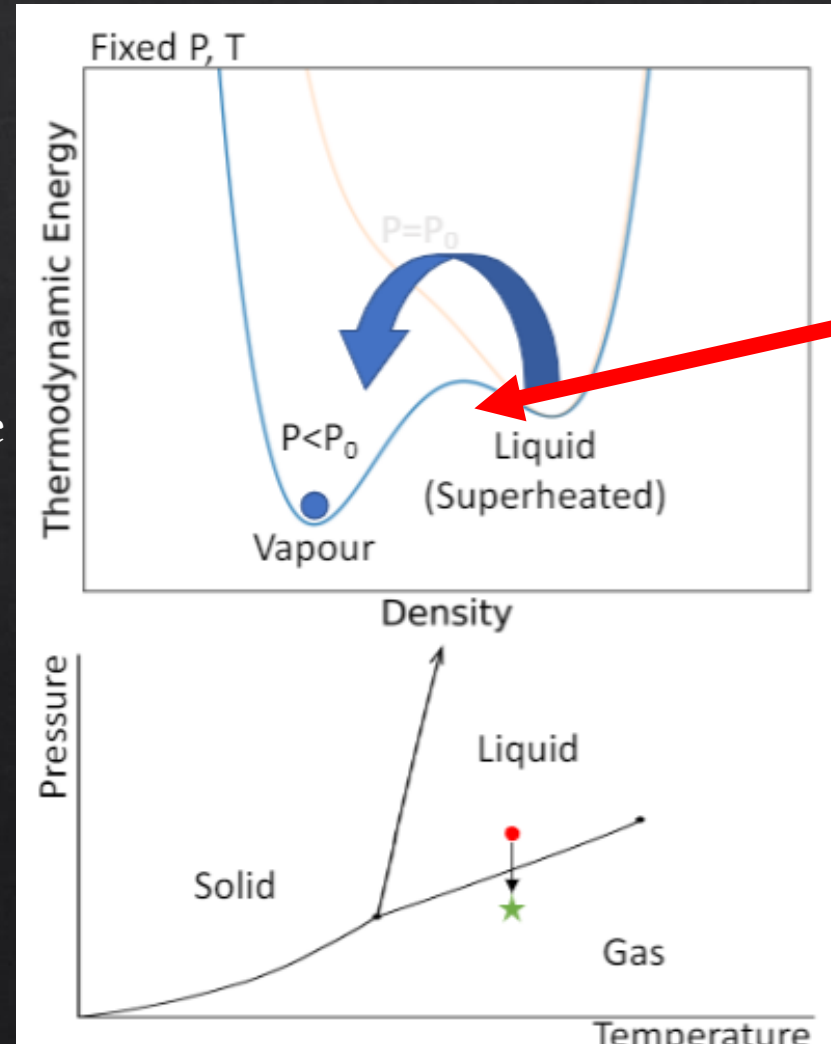
Gibbs Energy

Phase Diagram

Reduce pressure



Superheated Liquid State



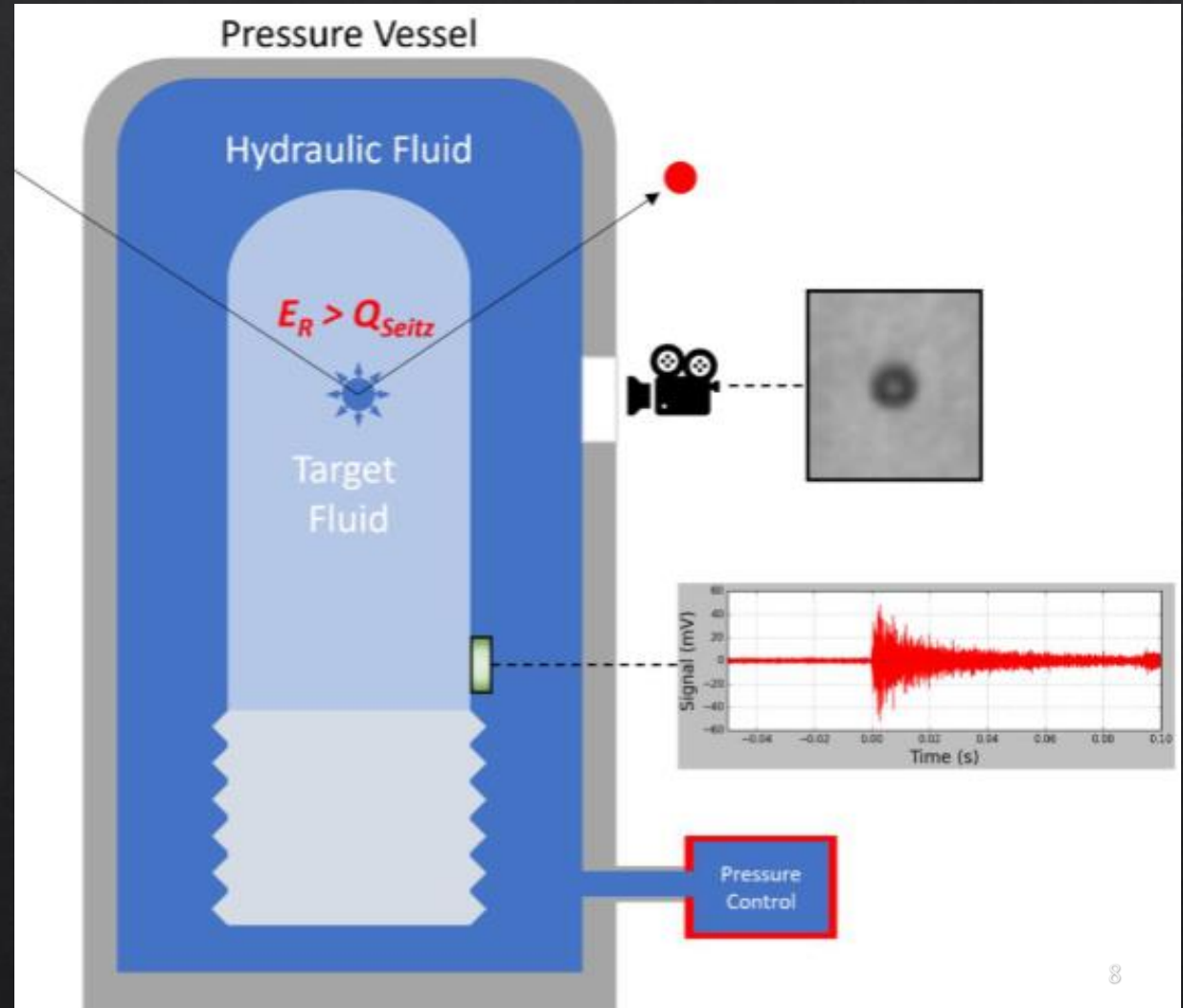
$$E_R > Q_{Sietz}$$

PICO Detectors

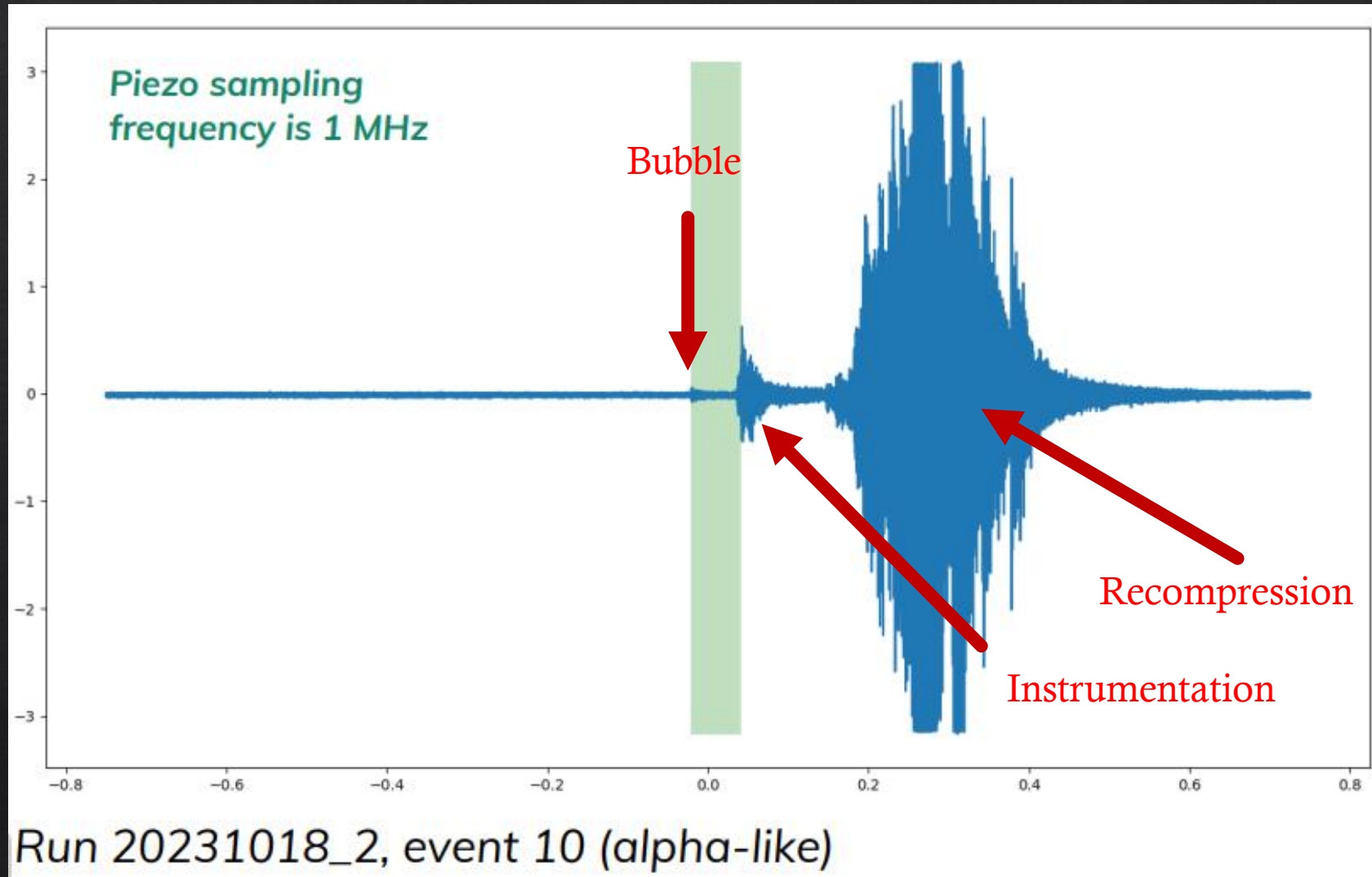
Triggers: pressure, optical

Data Saving:

- ◇ PT
- ◇ Piezos
- ◇ Cameras
- ◇ Dytrans



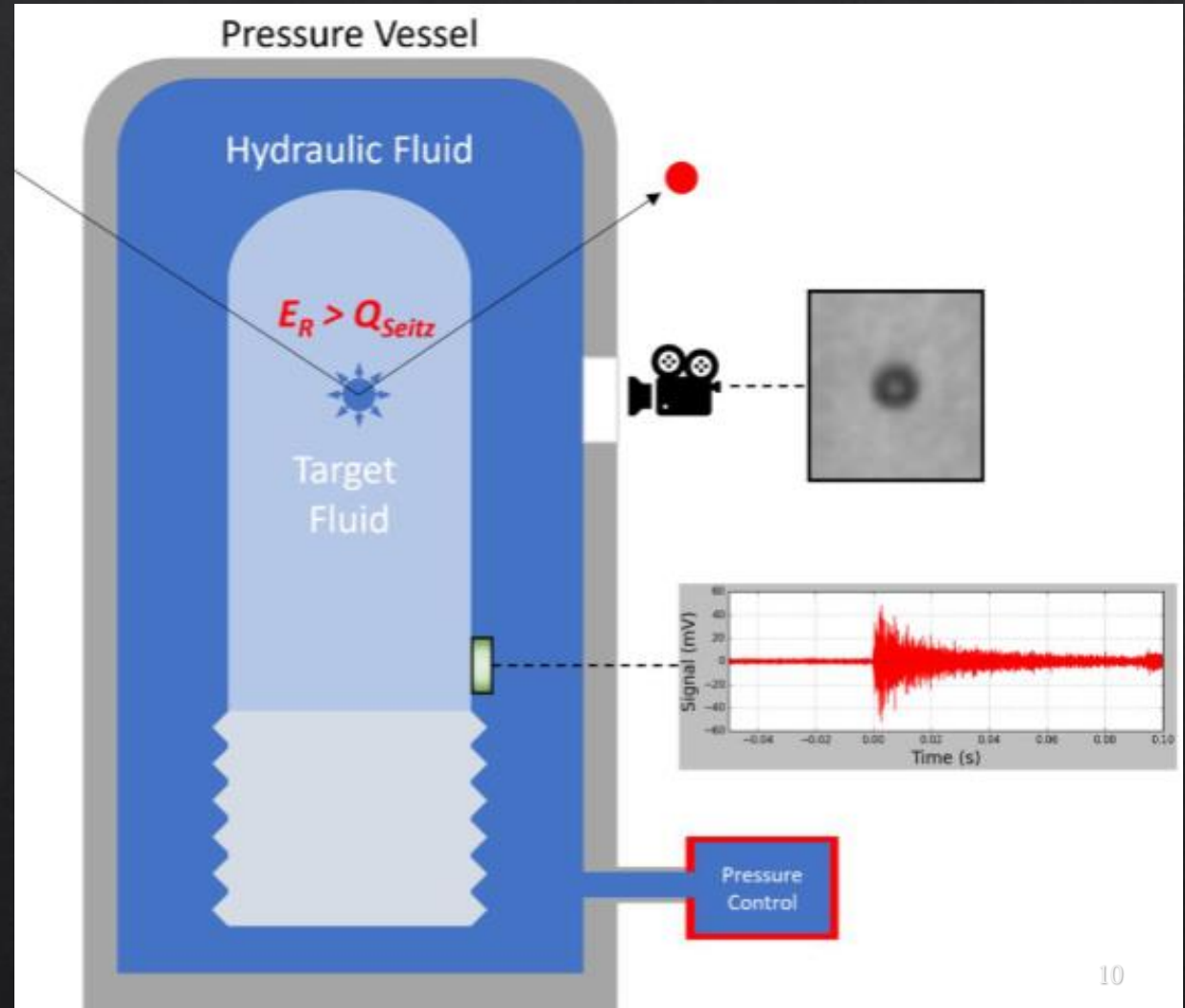
Acoustic Signal



PICO Detectors

WIMP-like events – physics analysis

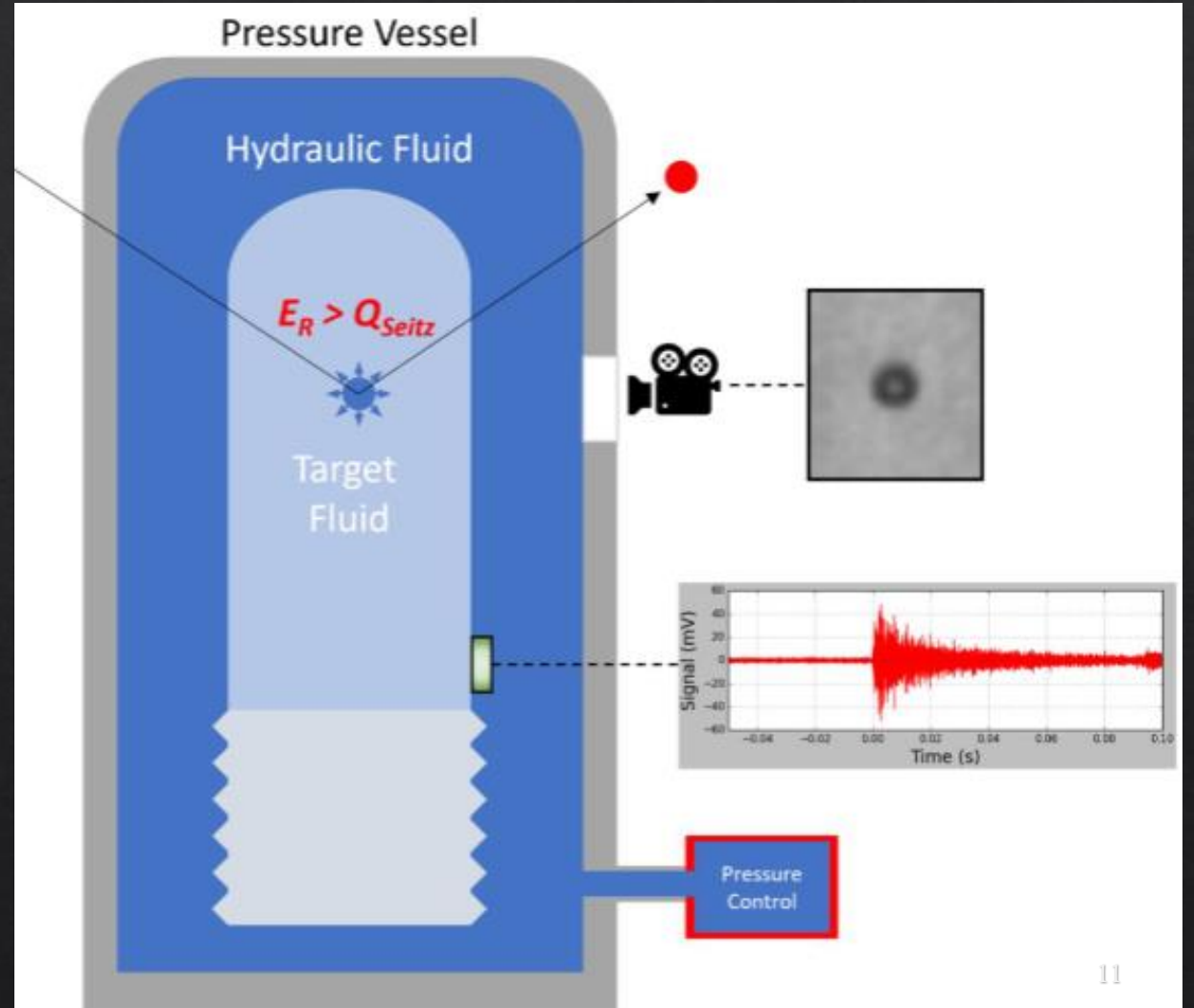
- ◆ Single bubble



PICO Detectors

WIMP-like events – physics analysis

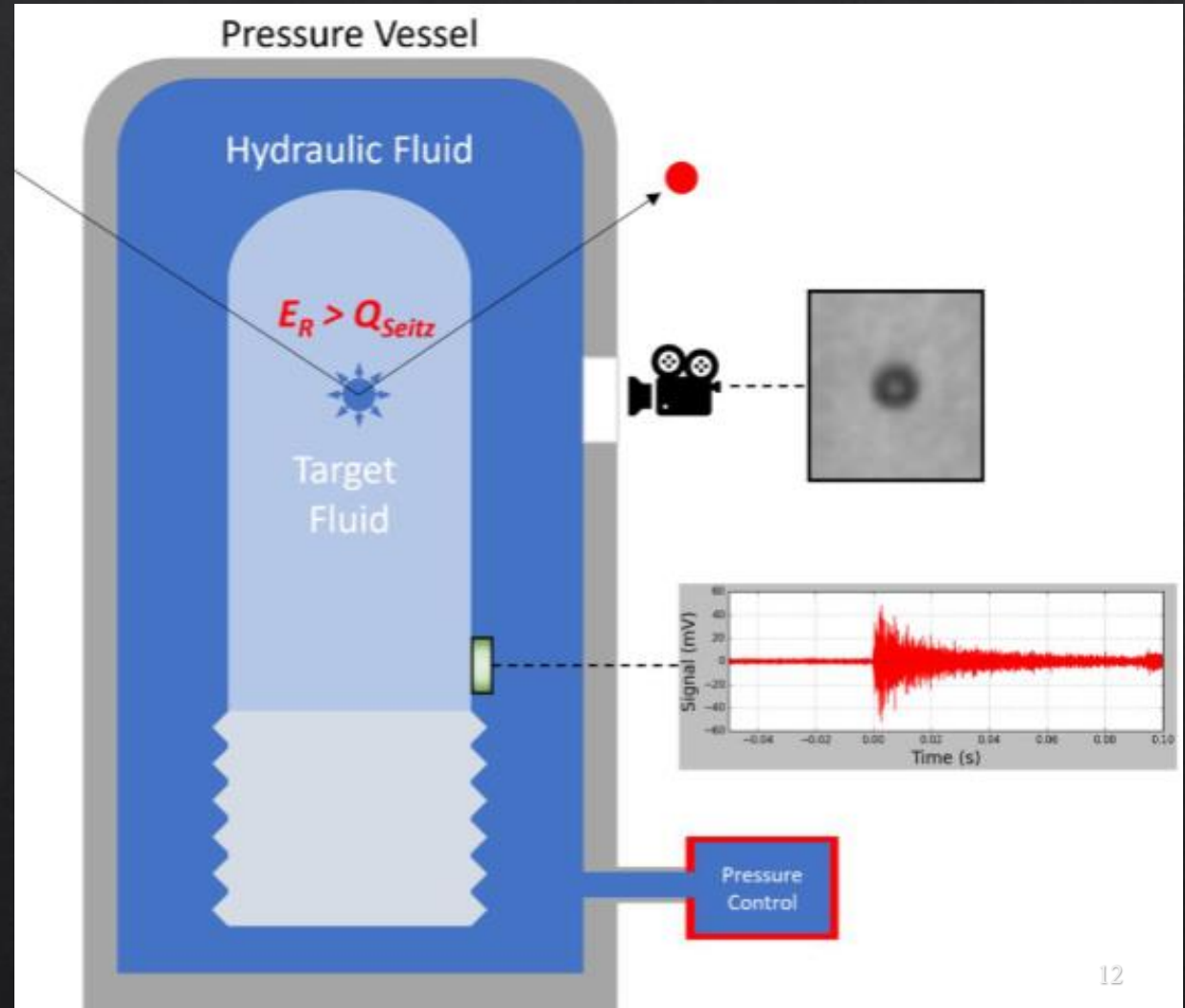
- ◇ Single bubble
- ◇ Position reconstructed in the bulk of the fluid



PICO Detectors

WIMP-like events – physics analysis

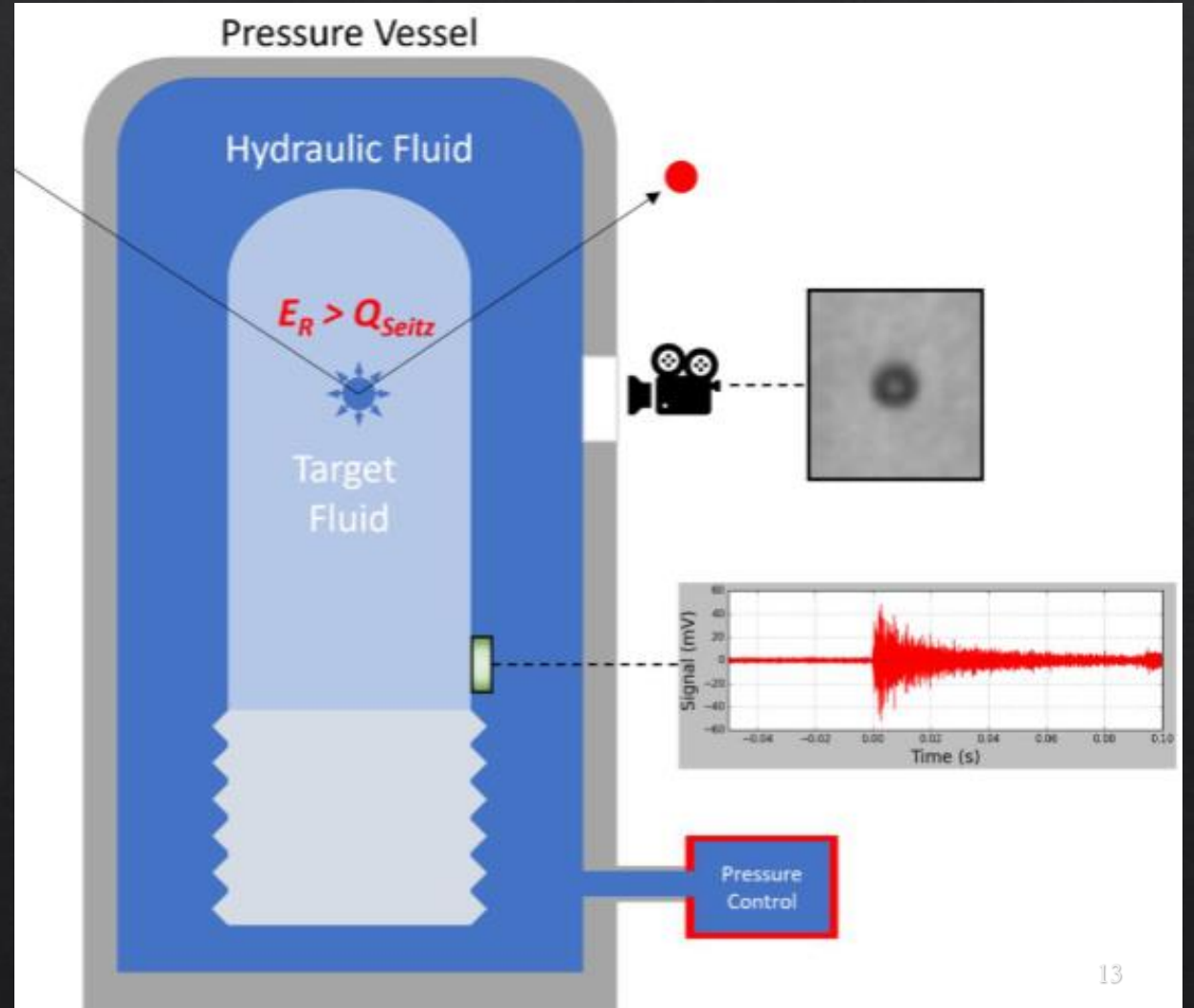
- ◇ Single bubble
- ◇ Position reconstructed in the bulk of the fluid
- ◇ Nucleate while detector is expanded



PICO Detectors

WIMP-like events – physics analysis

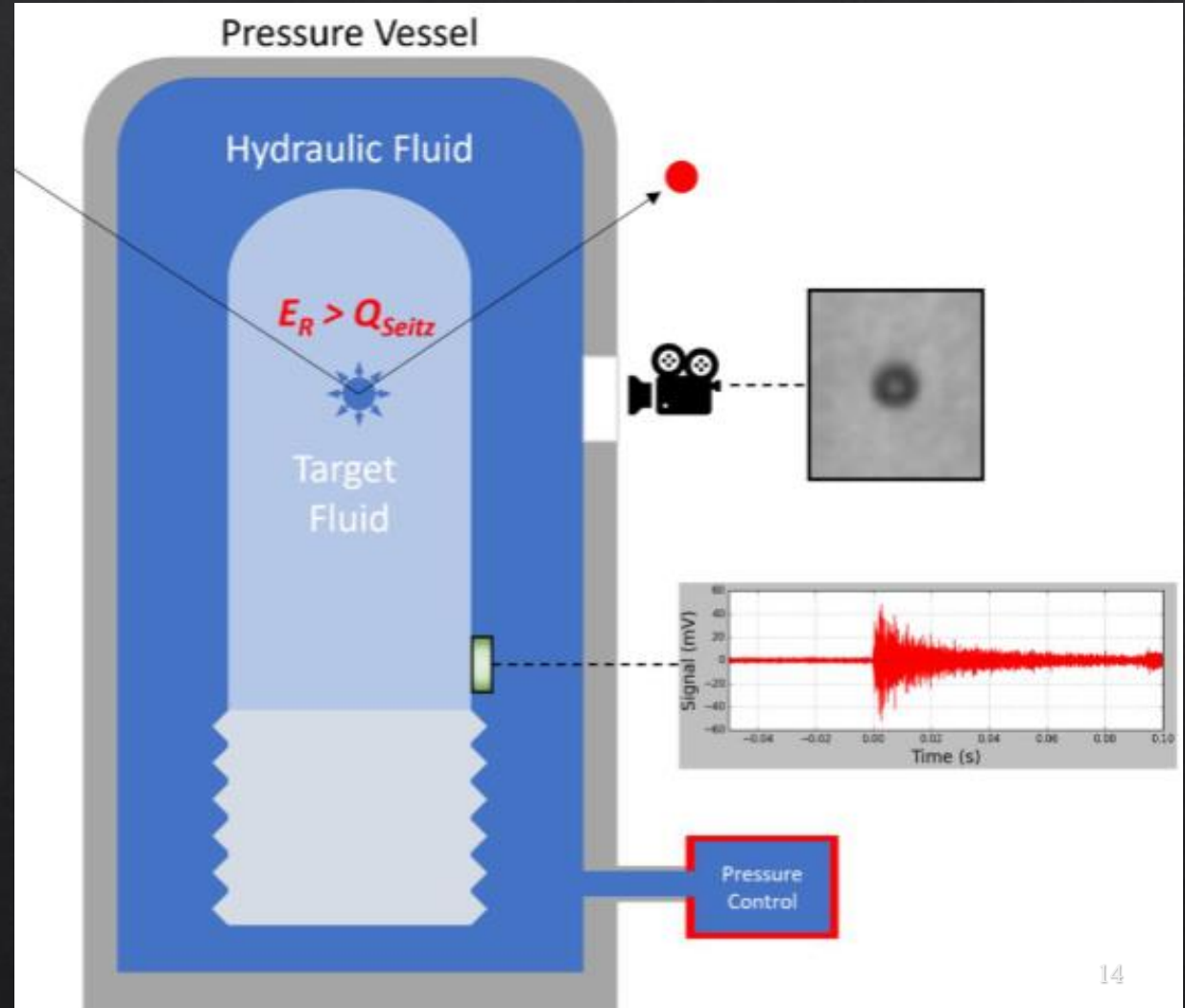
- ◇ Single bubble
- ◇ Position reconstructed in the bulk of the fluid
- ◇ Nucleate while detector is expanded
- ◇ Pressure is very close the desired set point



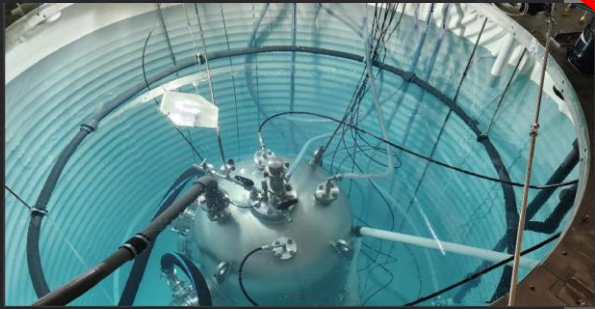
PICO Detectors

WIMP-like events – physics analysis

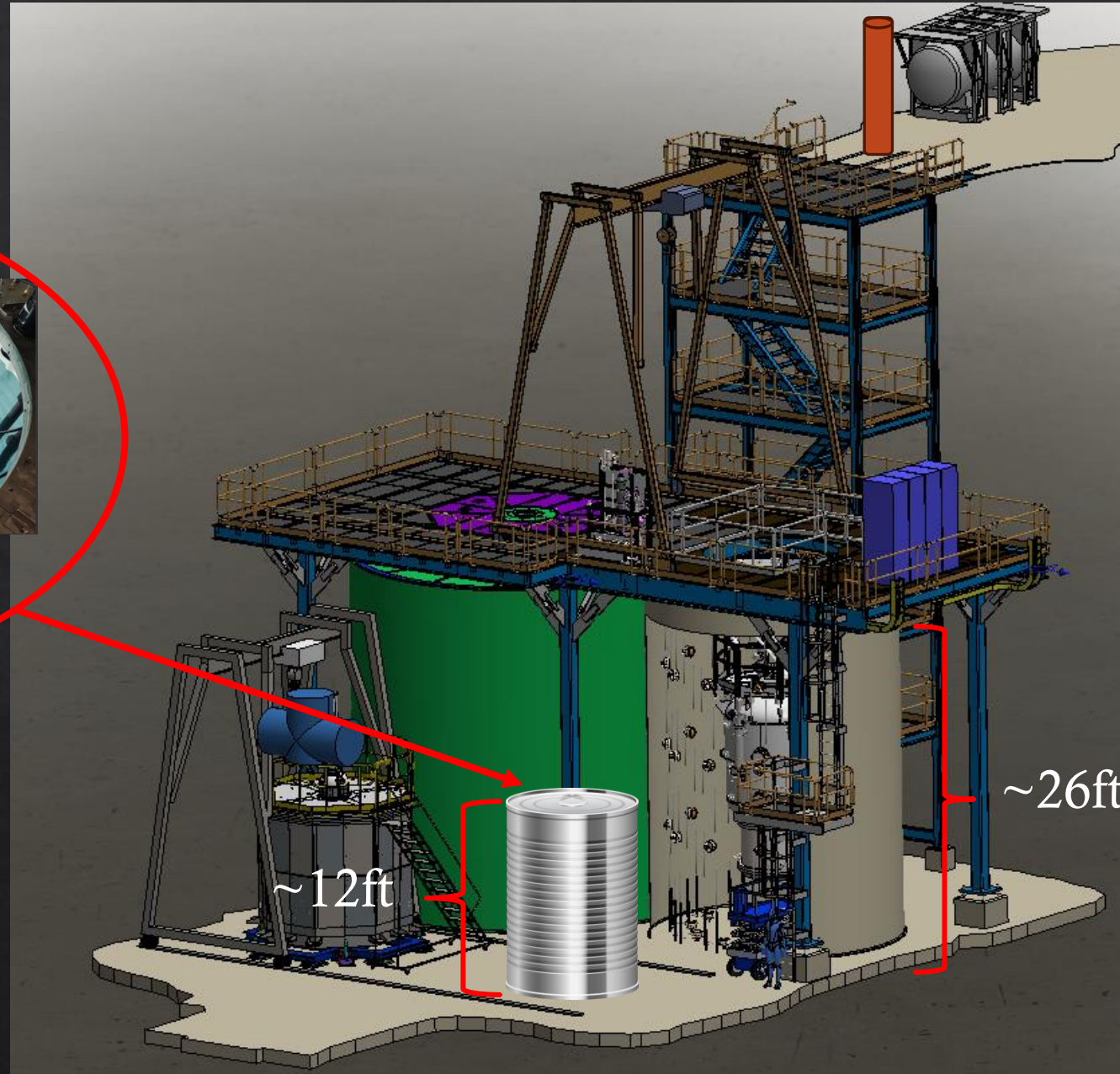
- ◇ Single bubble
- ◇ Position reconstructed in the bulk of the fluid
- ◇ Nucleate while detector is expanded
- ◇ Pressure is very close the desired set point
- ◇ Acoustic power (AP) discrimination



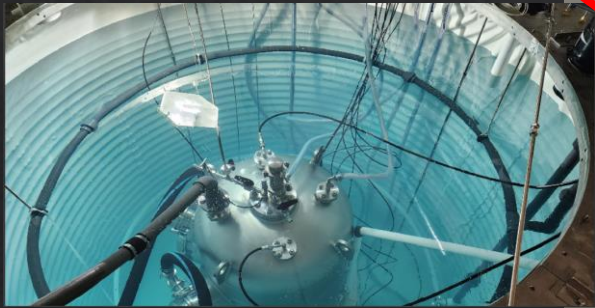
Scale up for PICO-500



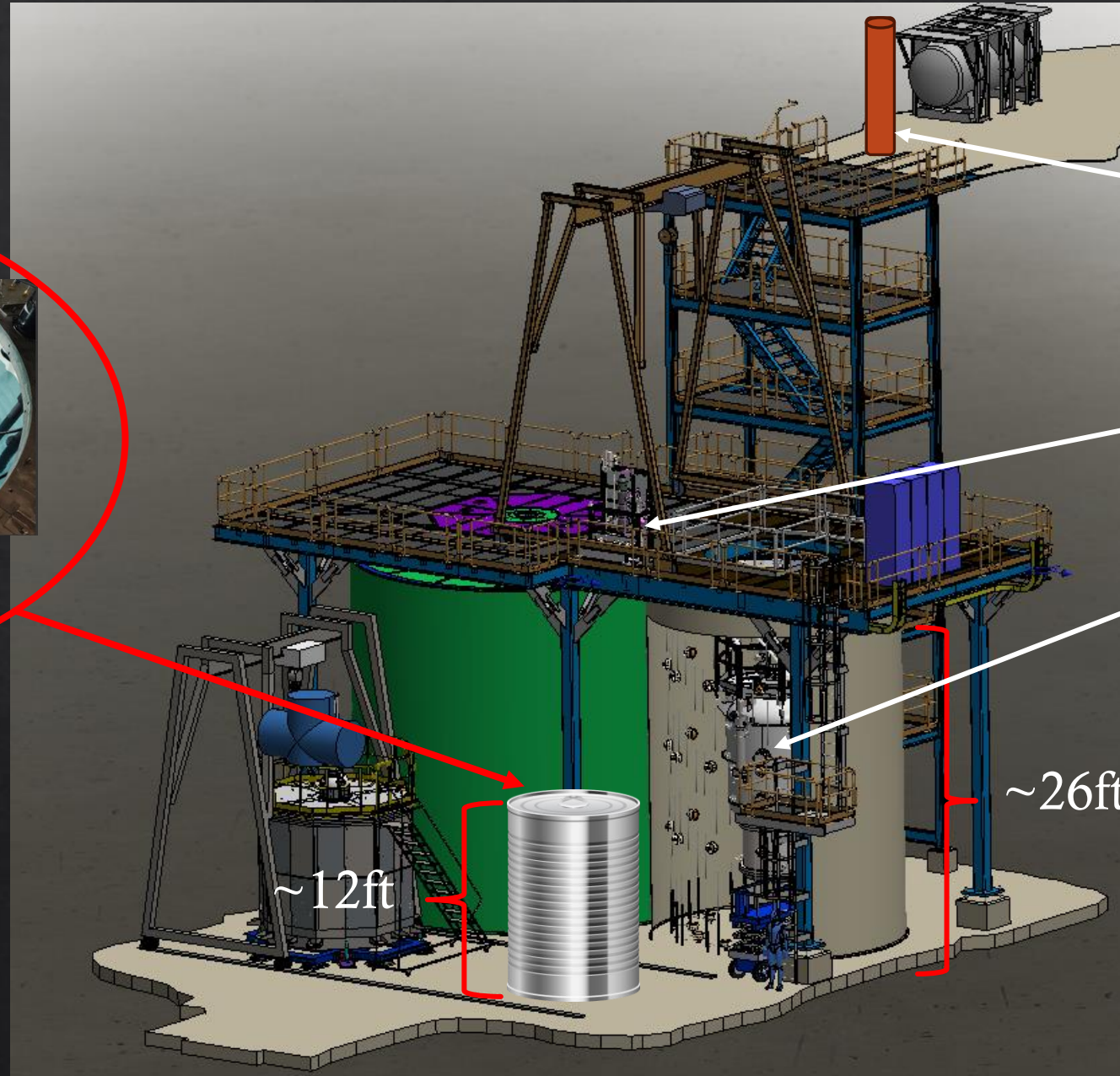
PICO 40L



Scale up for PICO-500



PICO 40L



Degassing Tank

Hydraulic Cart

Pressure Vessel

~26ft

~12ft

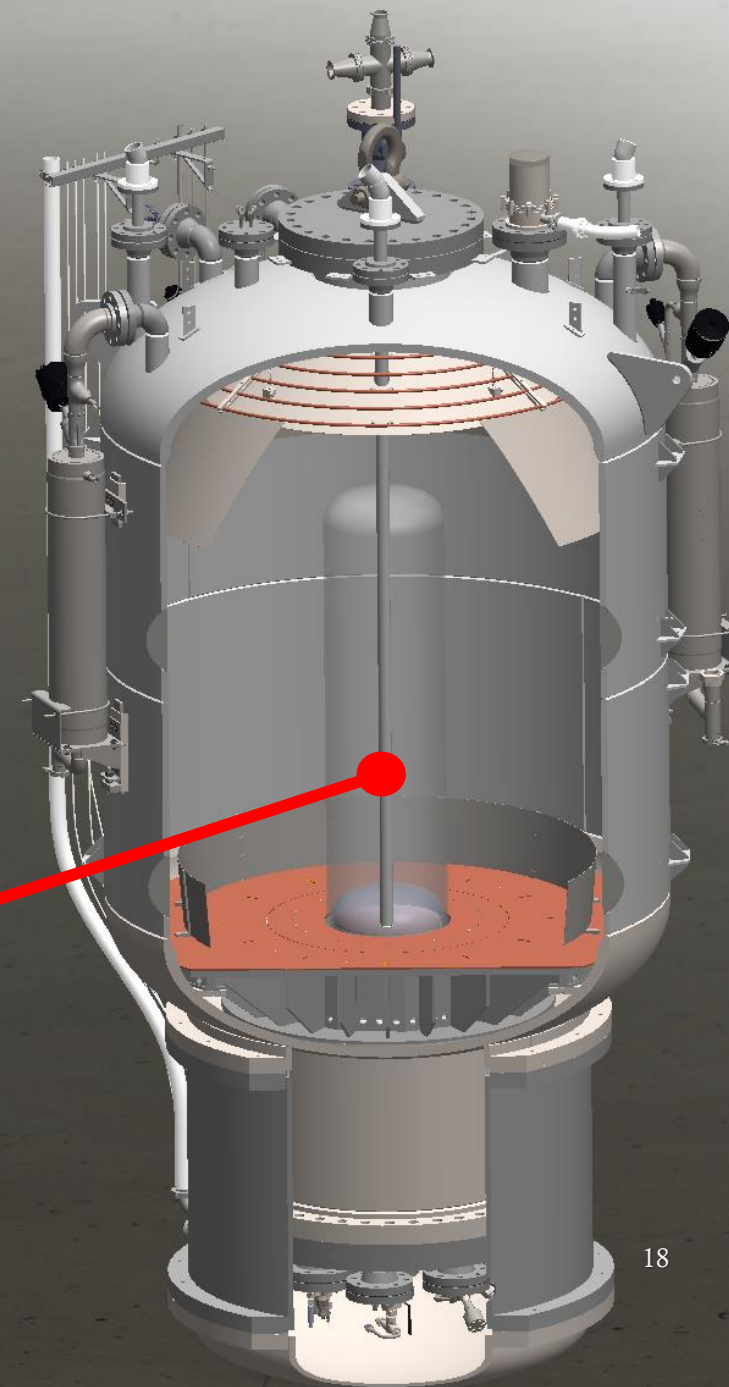
Bigger Pressure Vessel

40L

500



Big Jars!



PICO Detectors

Advantages

- ◇ Insensitive to electron recoils (depending on active fluid)
- ◇ Alpha rejection using acoustics
- ◇ Ability to change active fluid
 - ◇ Use different nucleus targets
 - ◇ Current target: Fluorine (SD WIMP-proton)
- ◇ Variable thresholds

Disadvantages

- ◇ Limited interaction energy information
- ◇ Large deadtime between events

PICO Detectors

Advantages

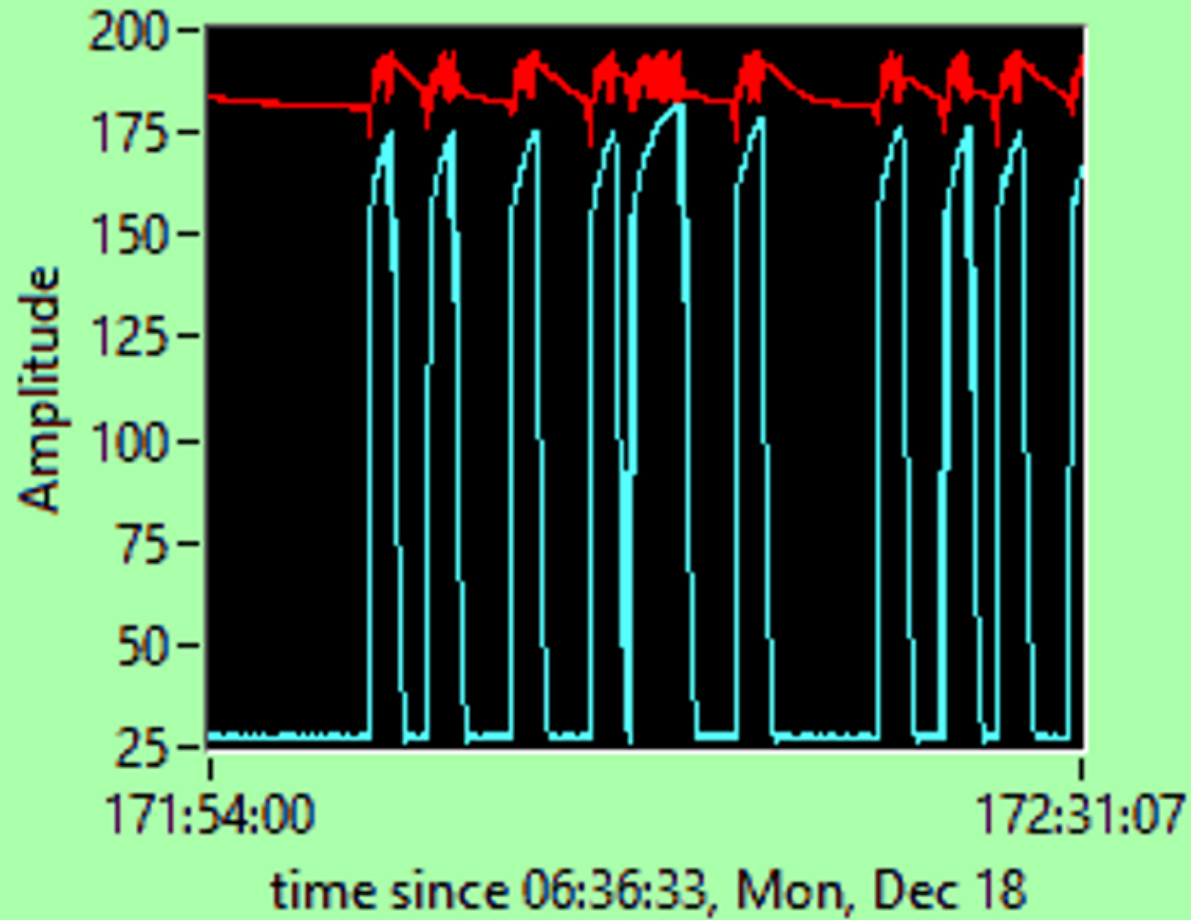
- ◇ Insensitive to electron recoils (depending on active fluid)
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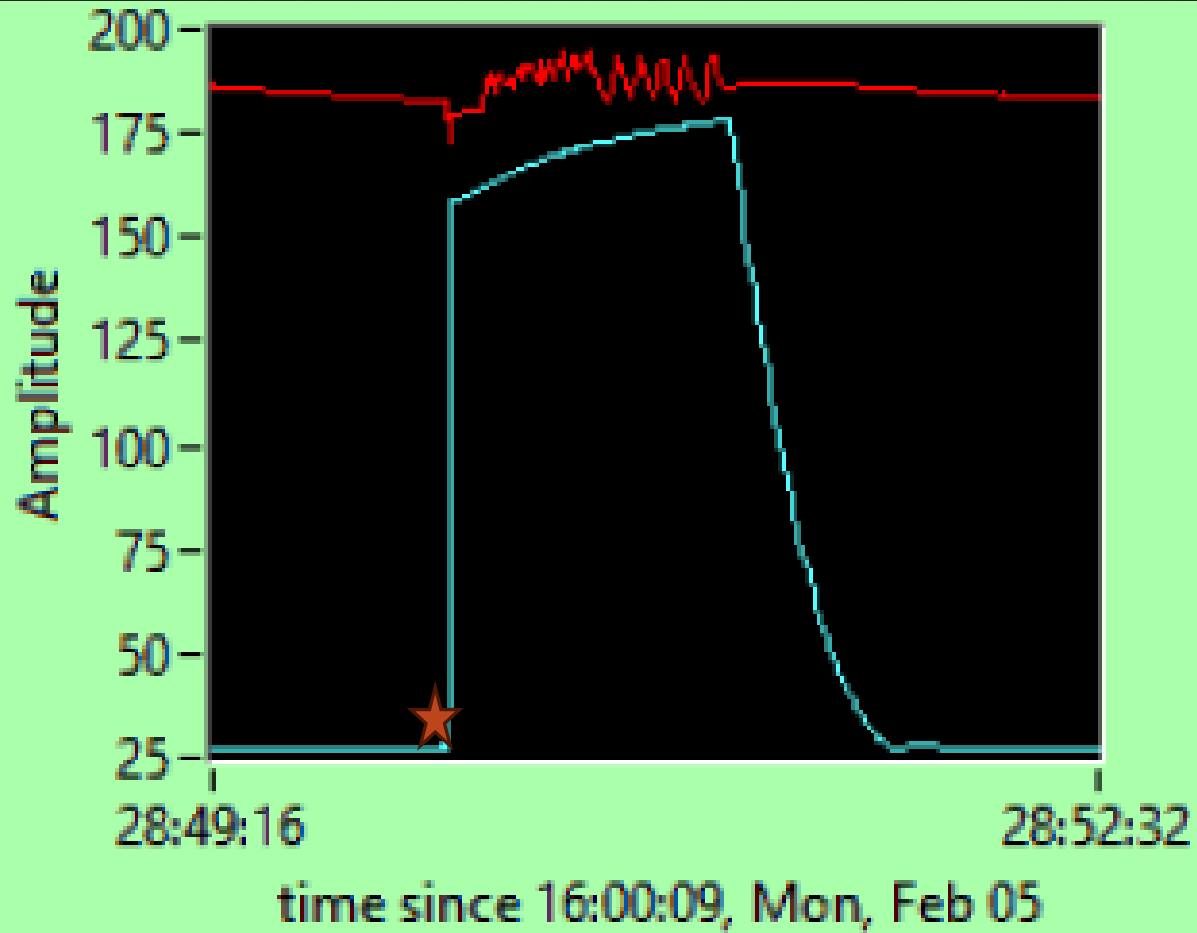
LOTS of cycles every day

PLC Chart



- ◇ Large deadtime
- ◇ Not all triggers provide good physics data
- ◇ Want to improve efficiency

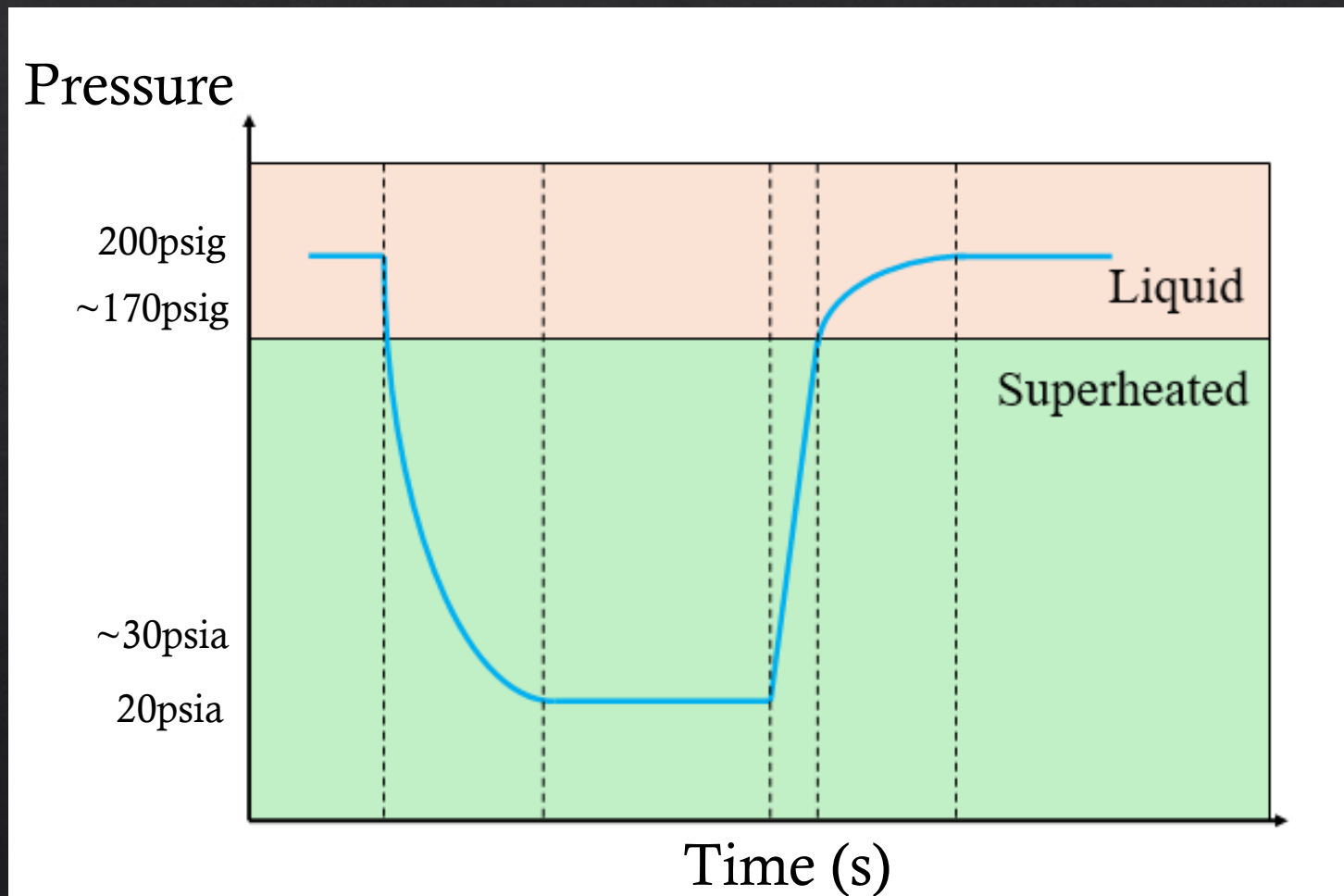
Compression Cycle (40L monitoring)



L to R

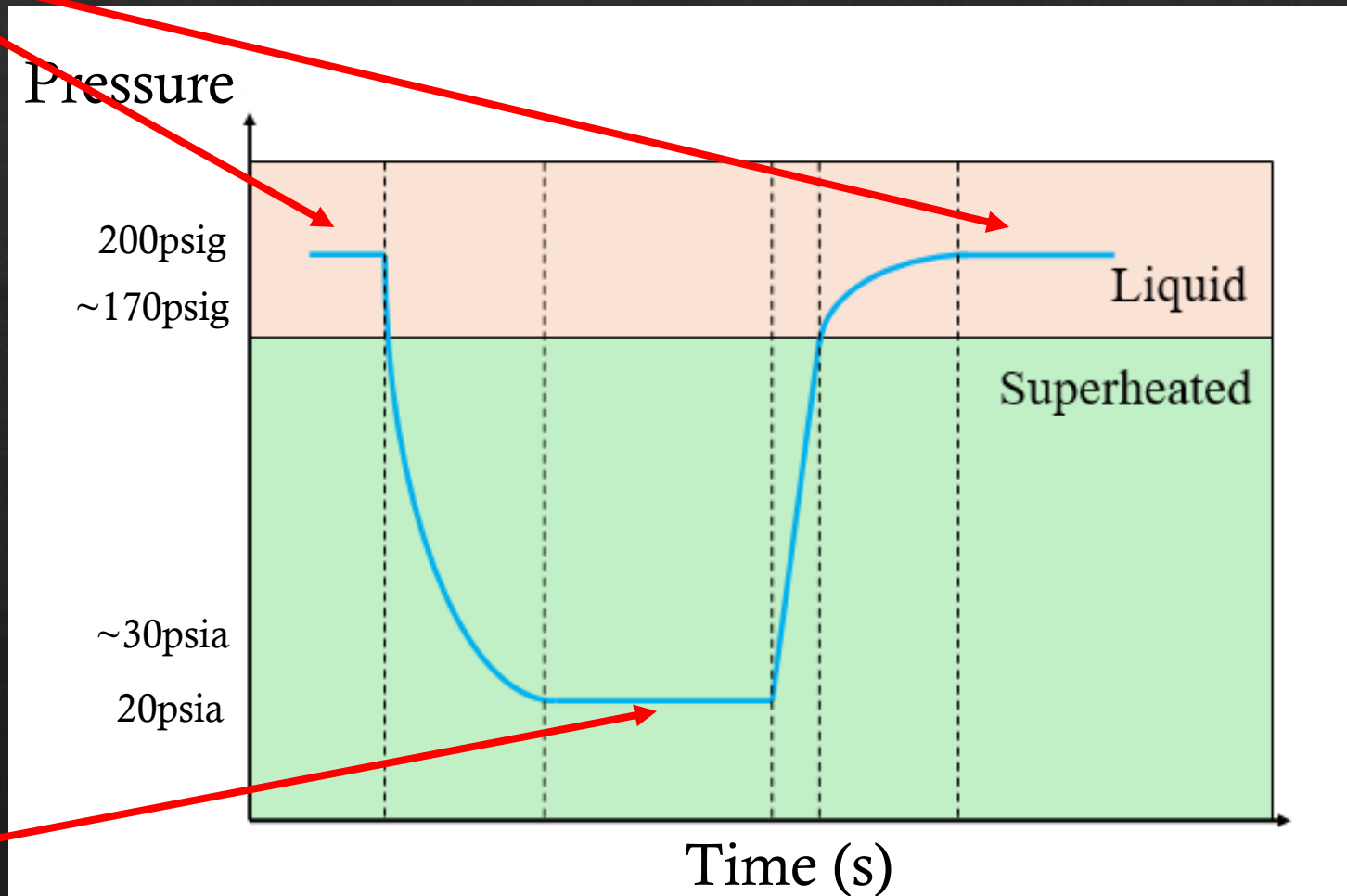
- ◇ Expanded state
- ◇ Bubble forms ★
- ◇ Fast compression
- ◇ Slow compression
- ◇ Expansion
- ◇ Back to Expanded state

Compression Cycle (C_3F_8)



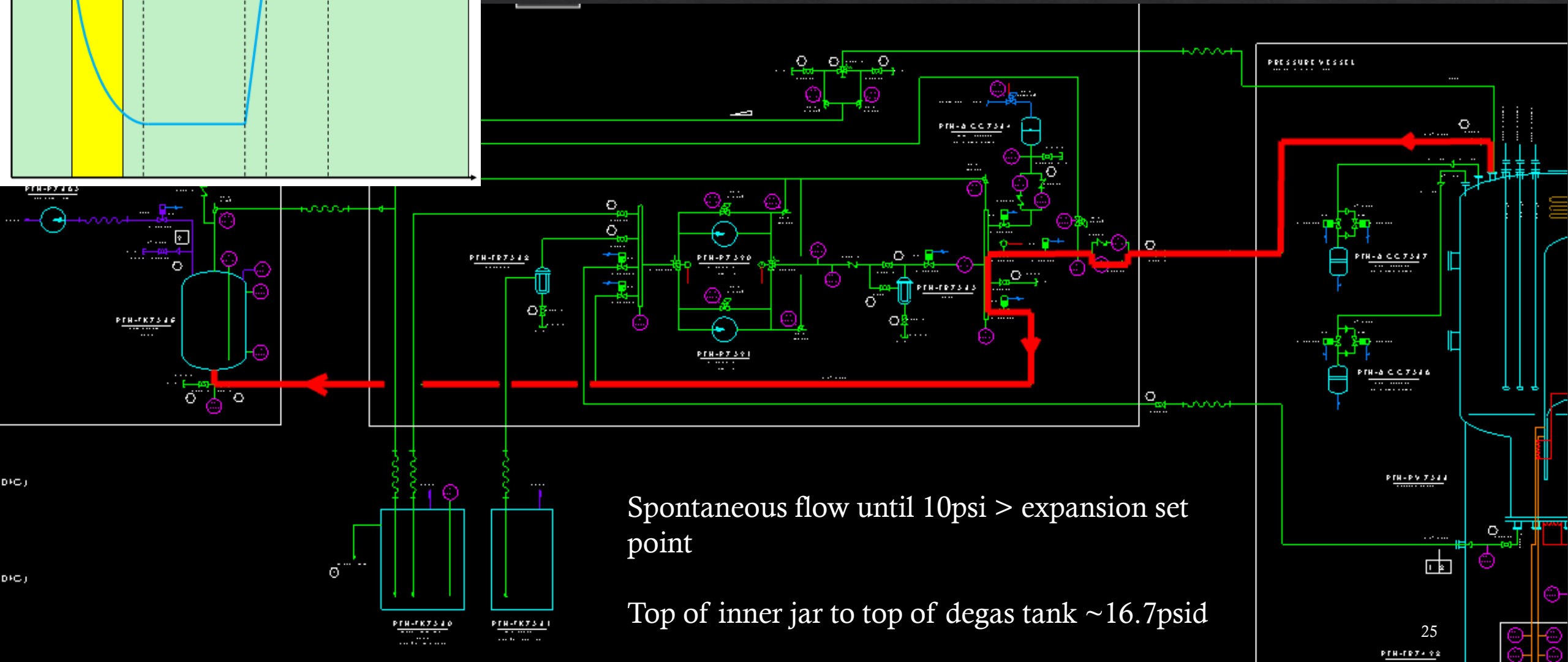
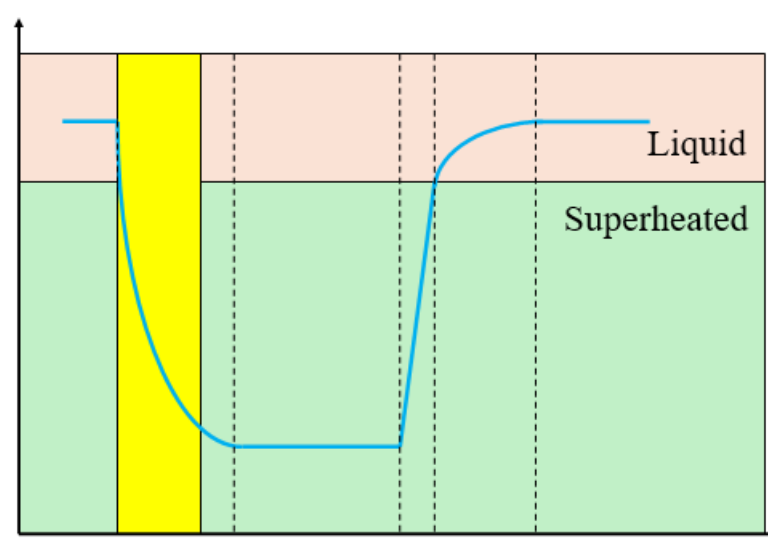
Compression Cycle (C_3F_8)

Idle



Taking data

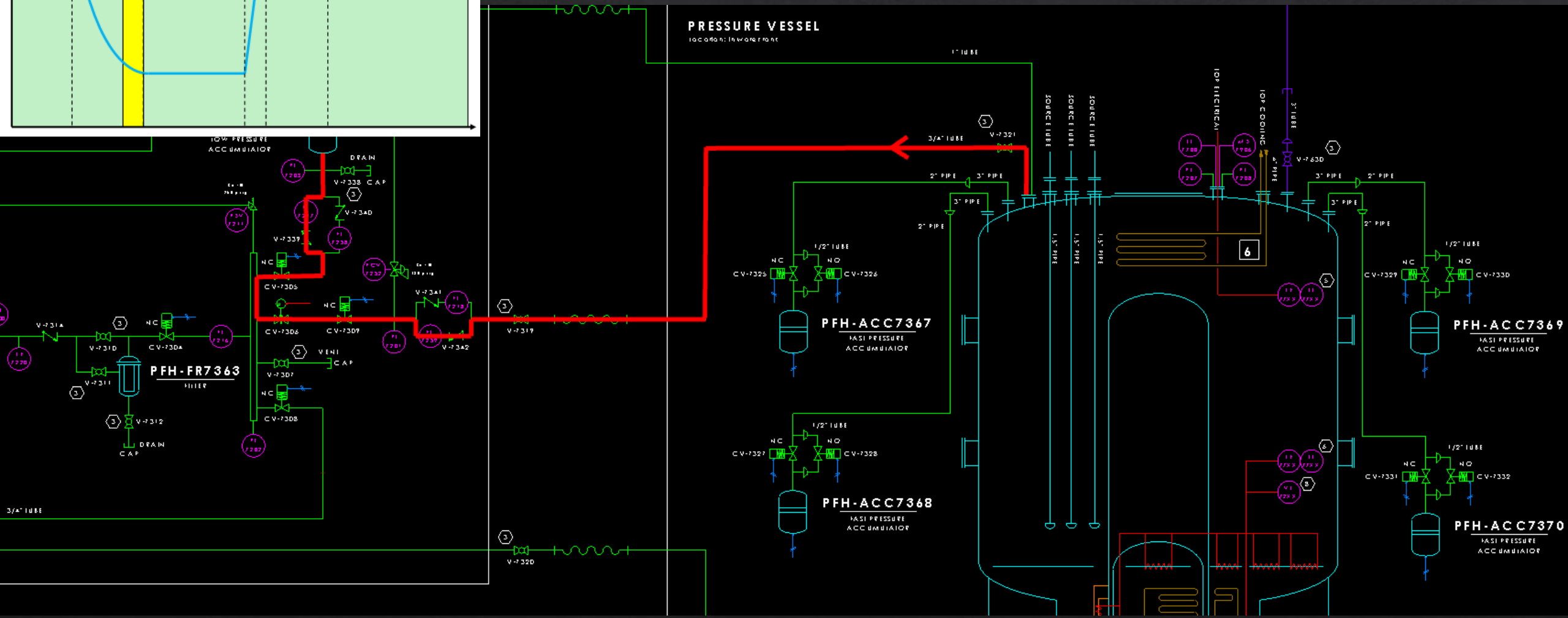
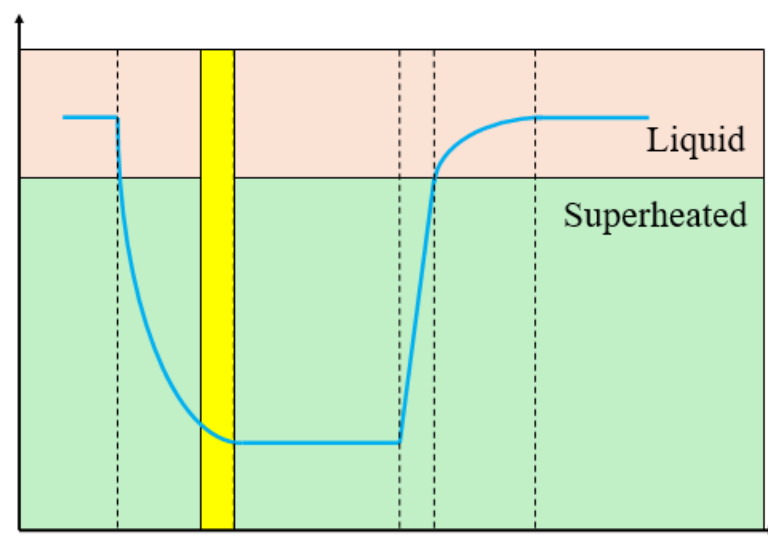
Expansion 1



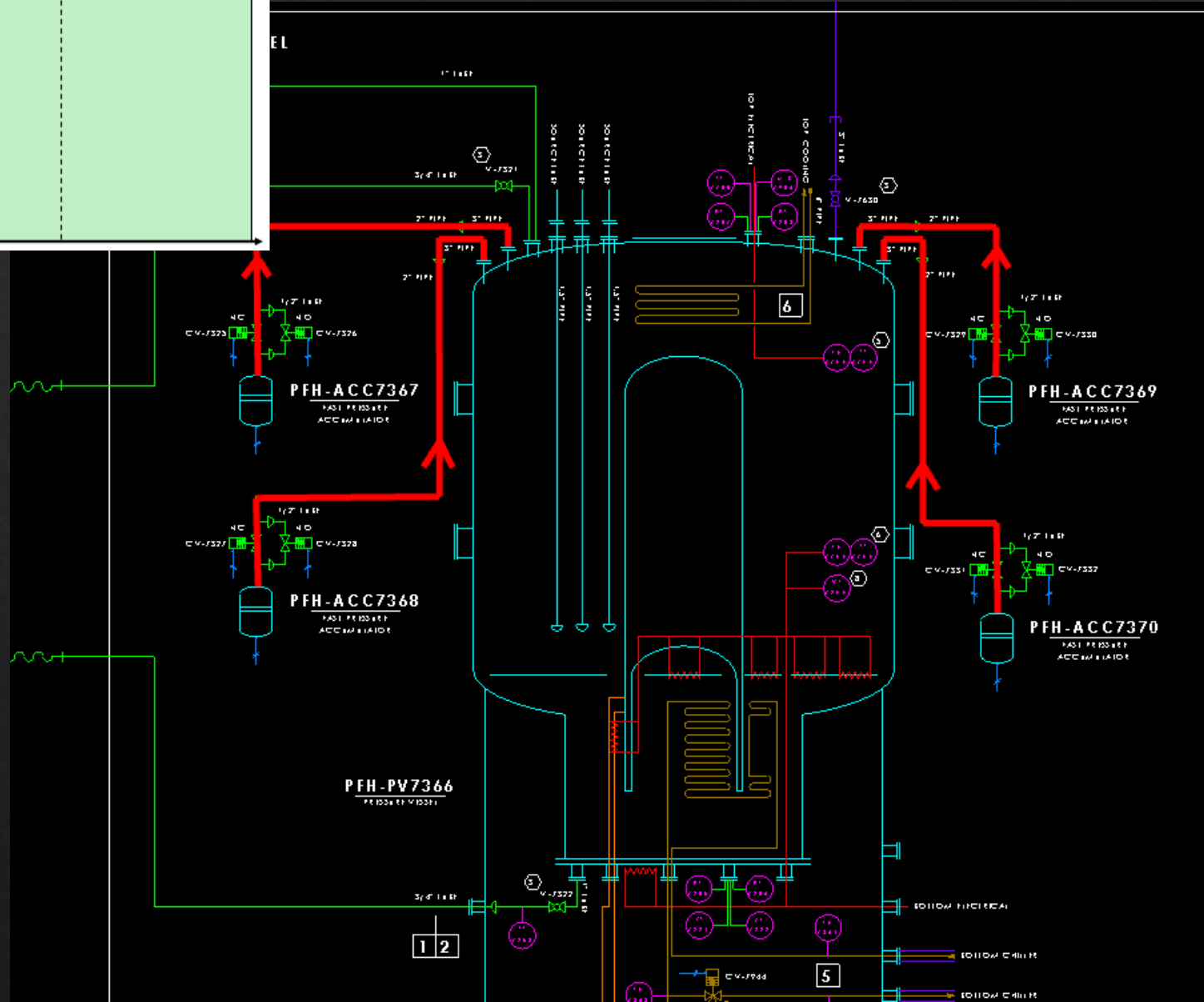
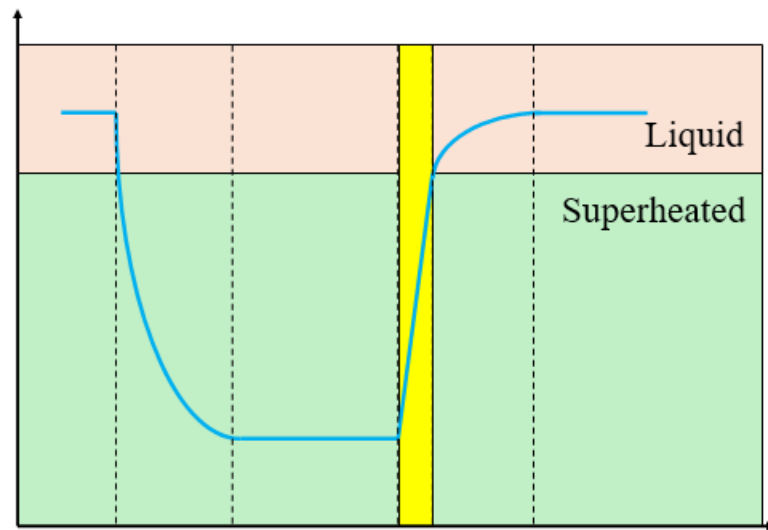
Spontaneous flow until 10psi > expansion set point

Top of inner jar to top of degas tank ~16.7psid

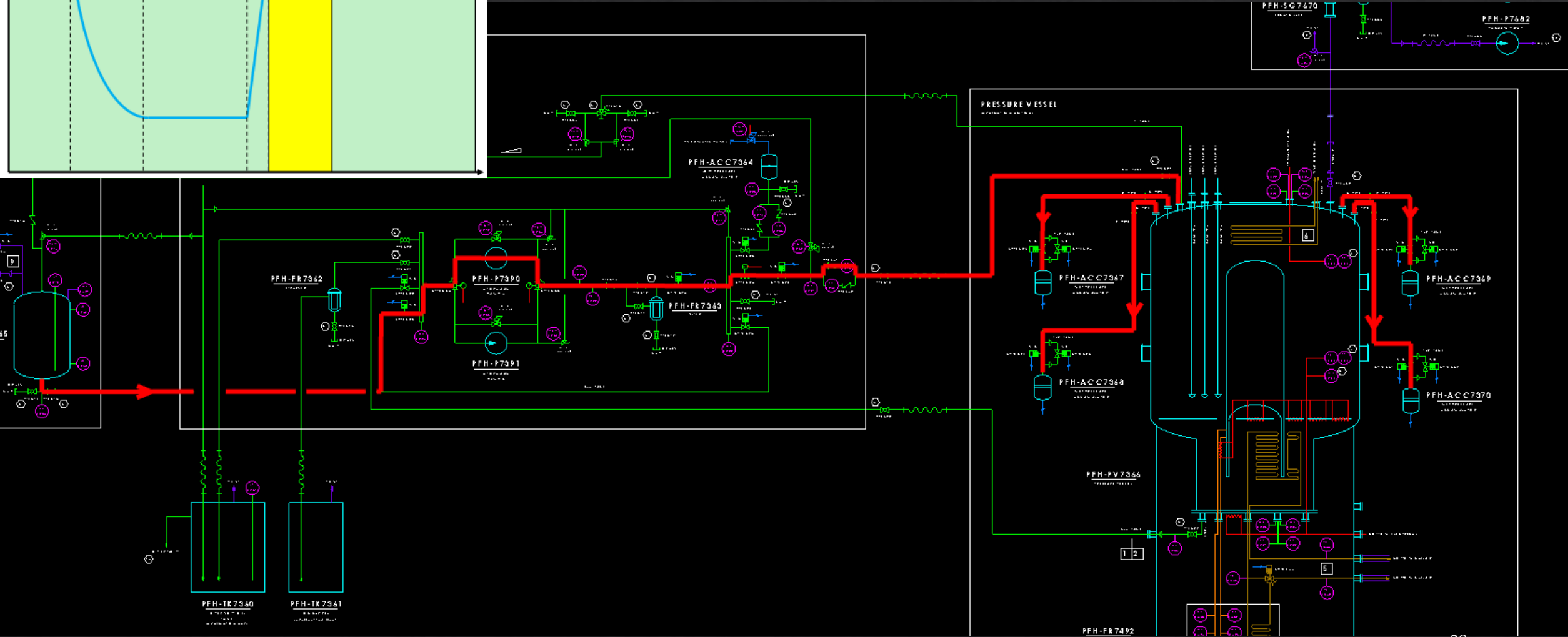
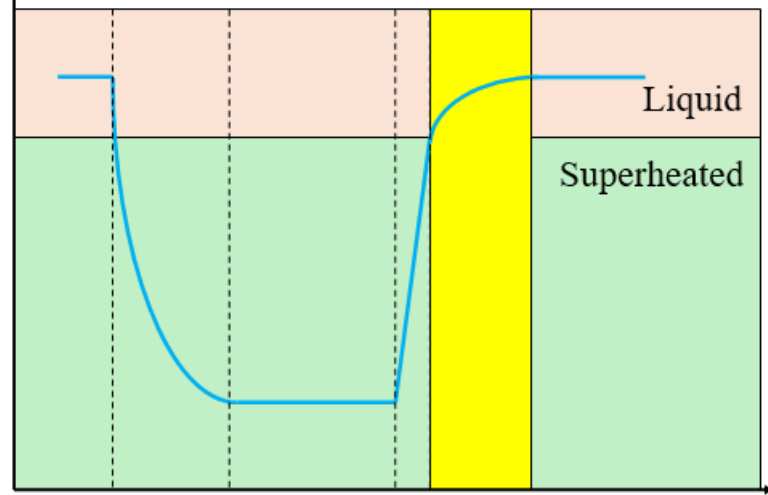
Expansion 2



Compression 1 (fast)



Compression 2 (slow)



PICO-500 Hydraulic Control System

Big components

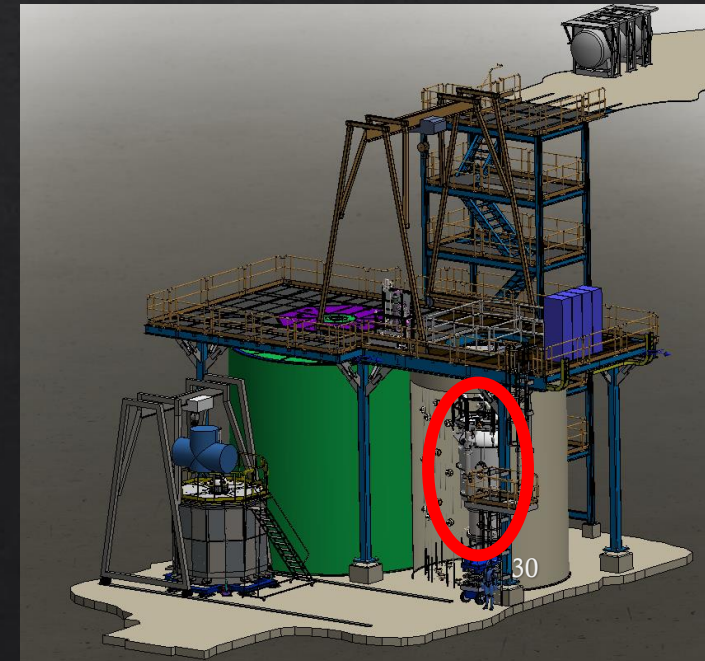
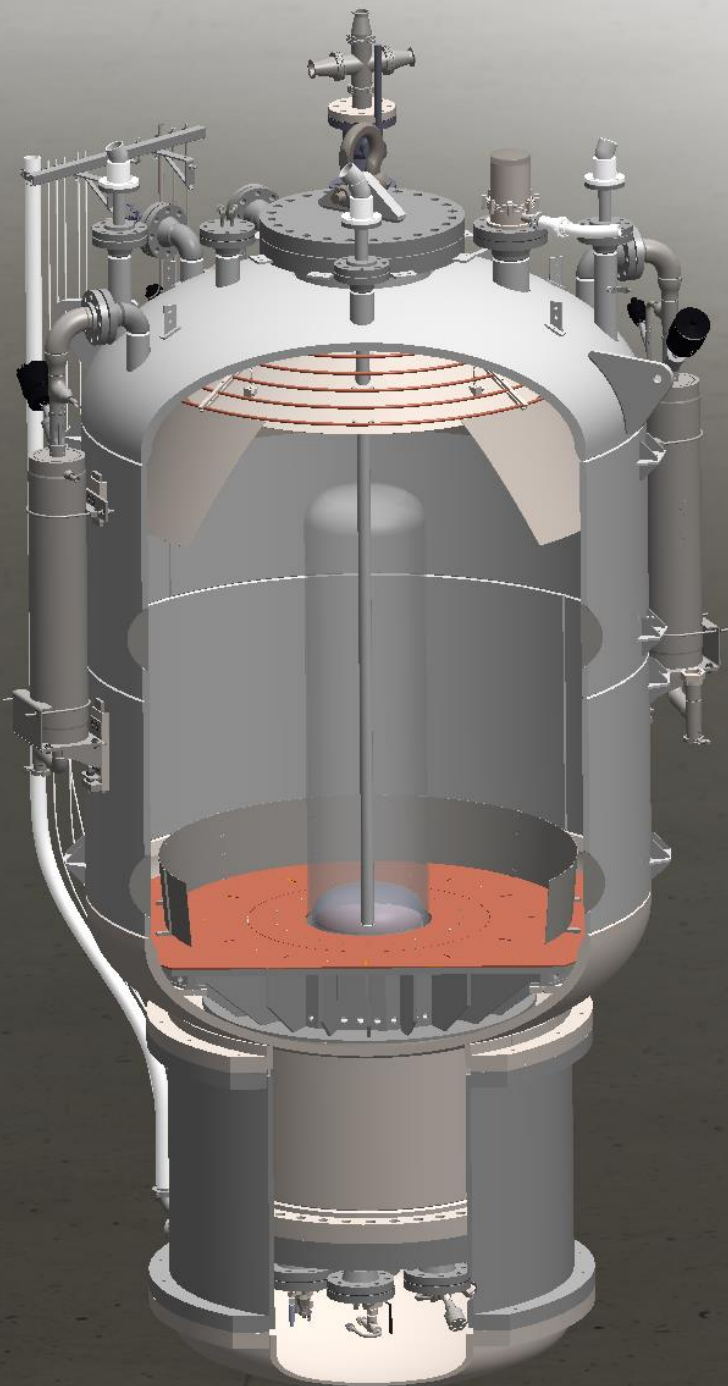
- ◇ Pressure Vessel
- ◇ Fast pressure accumulators (x4)
- ◇ Hydraulic Control Cart
- ◇ Pumps
- ◇ Low pressure accumulator (x1)
- ◇ Degassing Tank

Pressure Vessel

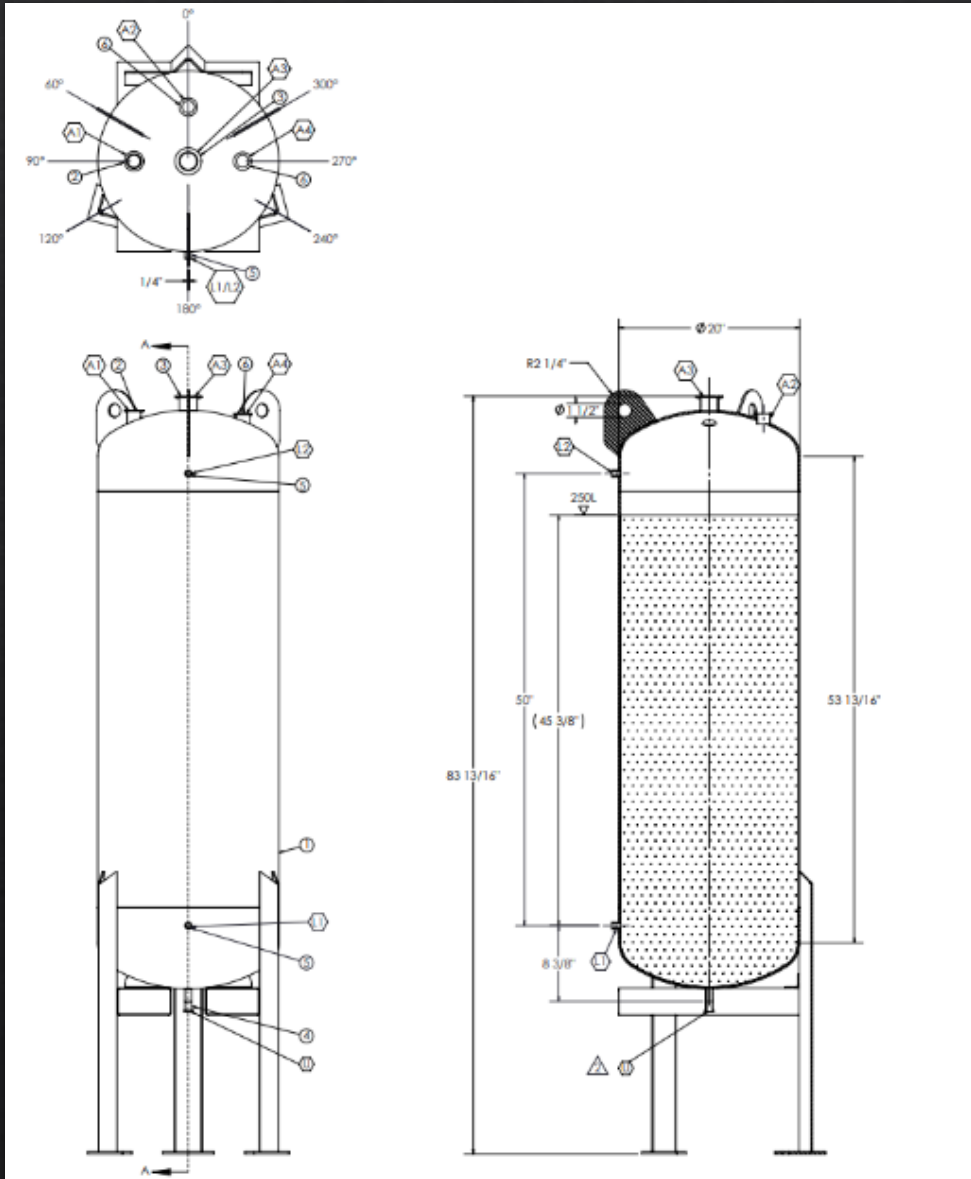
Housing for main detector components

- inner vessel
- instrumentation
- FPAs (x4)
- vacuum jacket
- cold plate (operating temp $\sim 13^{\circ}\text{C}$)

Its job: keep the inner vessel at the desired thermodynamic (P, T) threshold

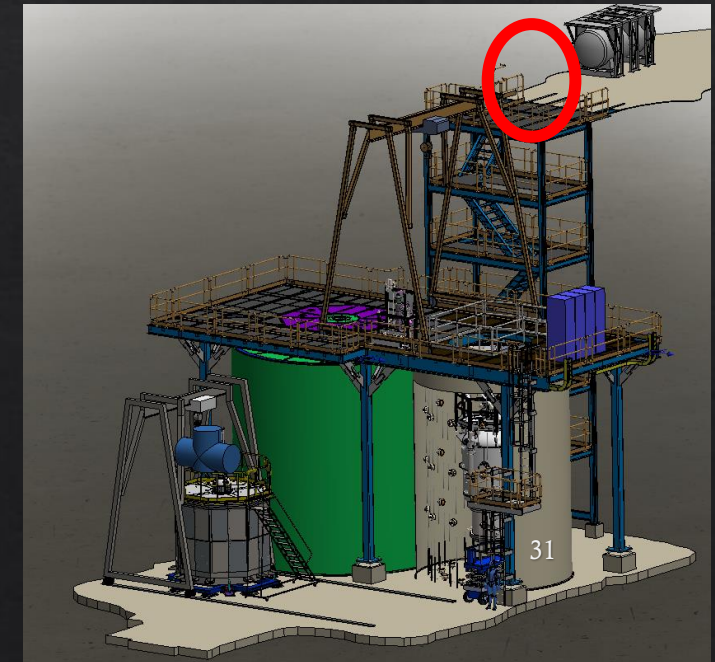


Degassing Tank



Dedicated oil degassing station

- ◇ Pull vacuum on the reservoir of oil to remove air bubbles
 - ◇ Reduce compressibility of the oil
- Better hydraulic control

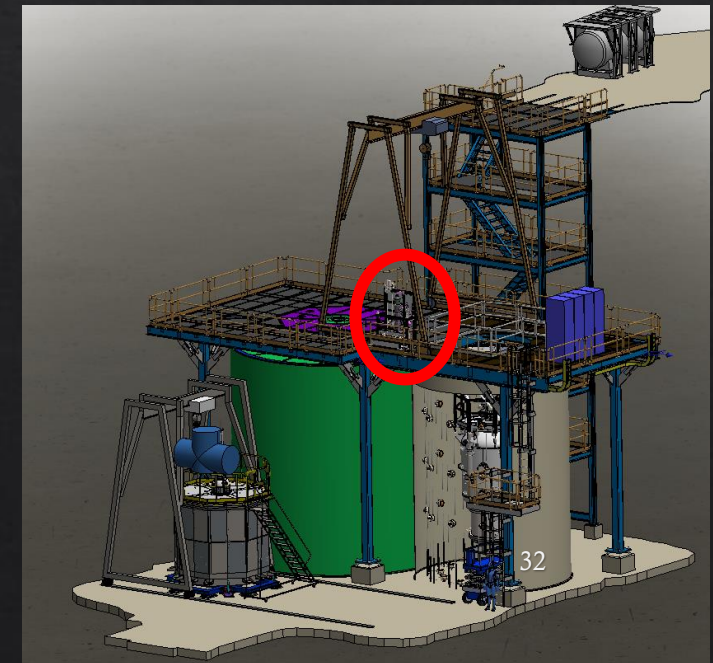


Hydraulic Control Cart



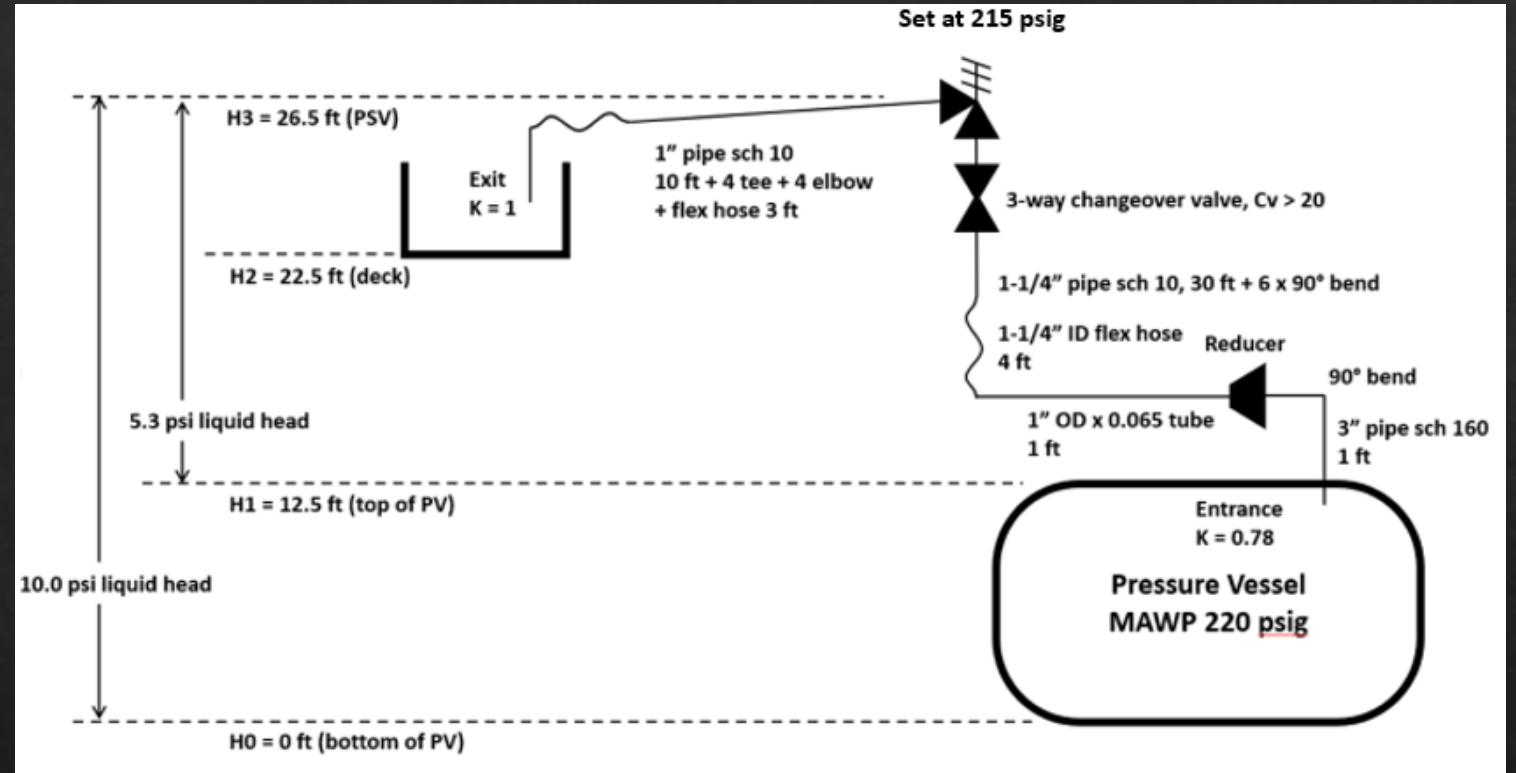
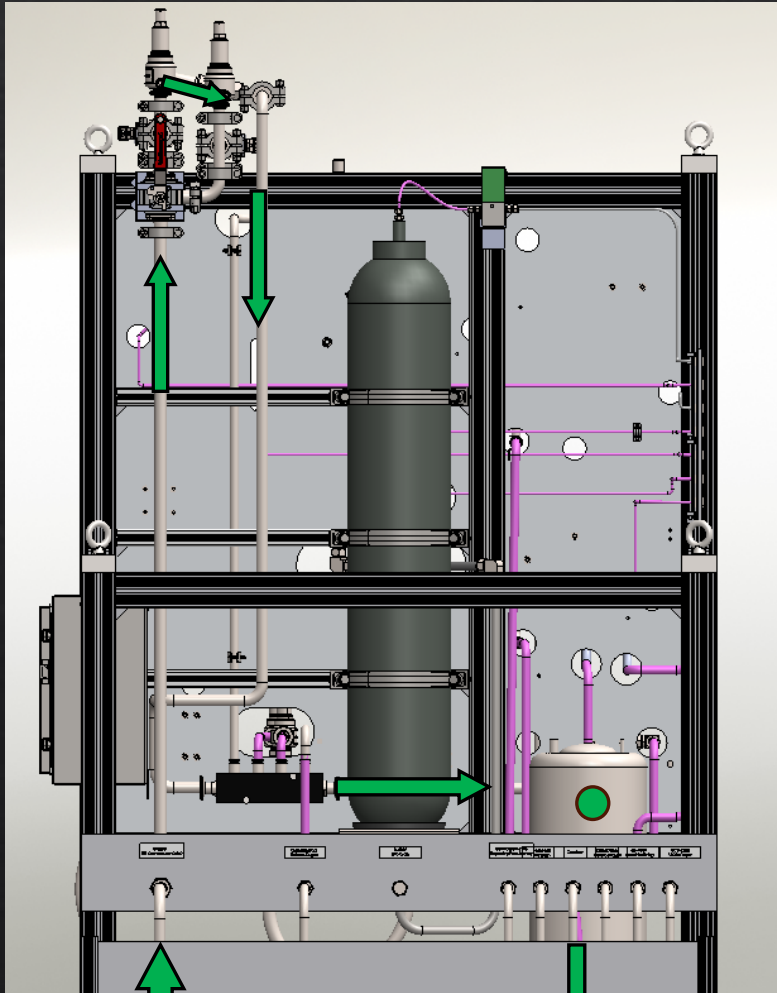
Improvements for PICO-500

- ◆ Dual redundancy for critical systems
- ◆ Engineered for minimal pressure loss
- ◆ Serviceability
- ◆ Vibration damping
- ◆ Oil sampling port
- ◆ Oil recirculation
- ◆ Materials of high radiopurity
- ◆ Oil pressure range 20-200psig



Overpressure Relief

Dual overpressure relief at
~215psig



Overflow
collection
reservoir

K Derring

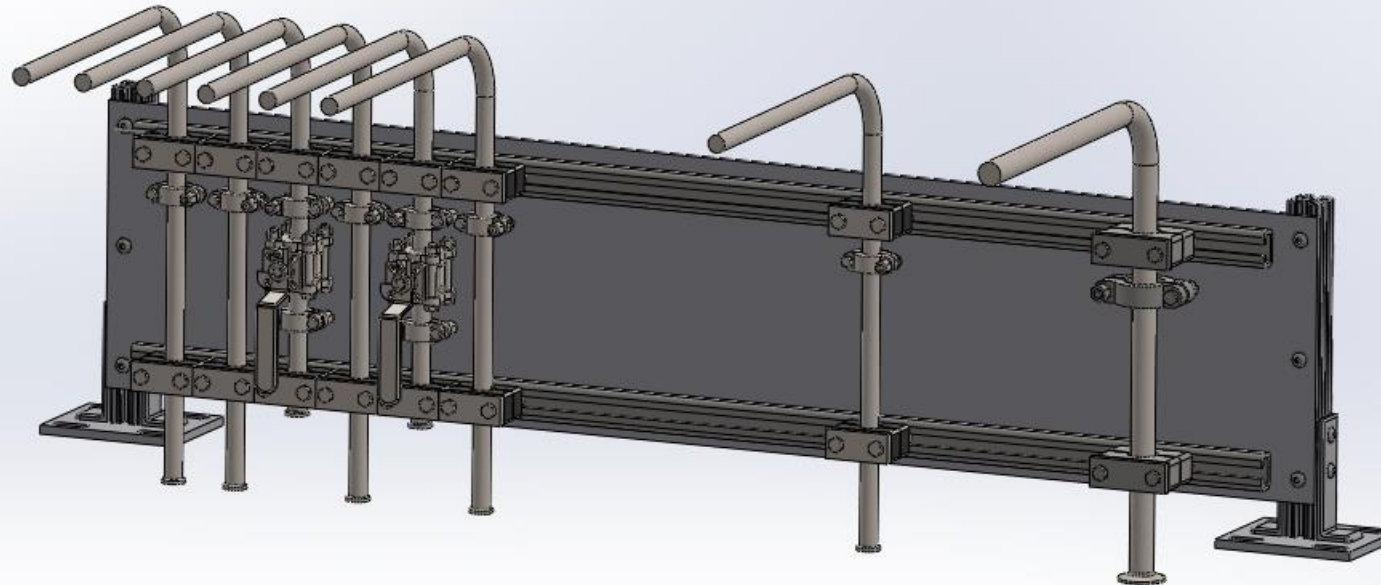
From PV

Excess overflow

Hydraulic Isolation Bulkhead

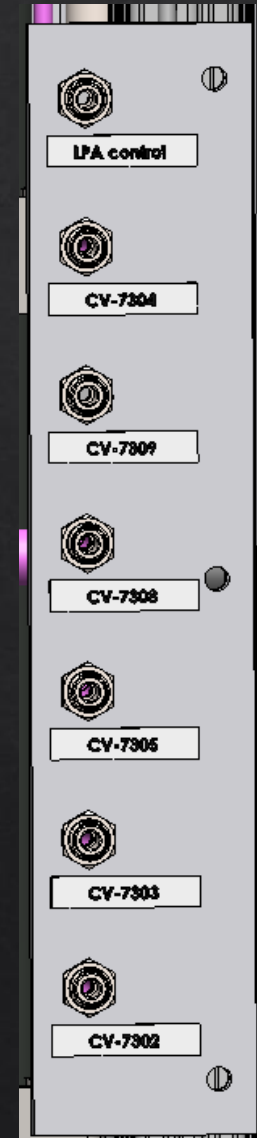
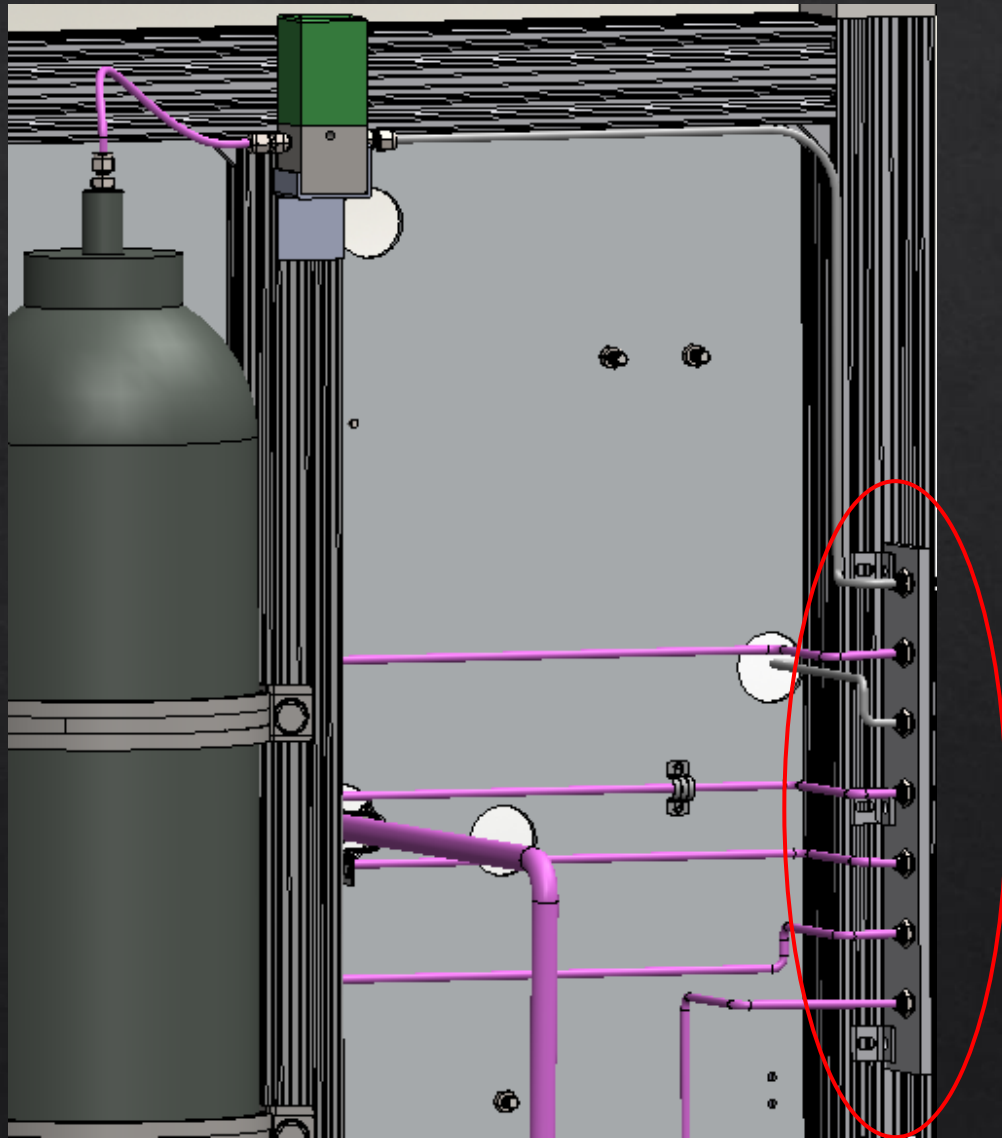


Mounted to cart



Fixed to deck

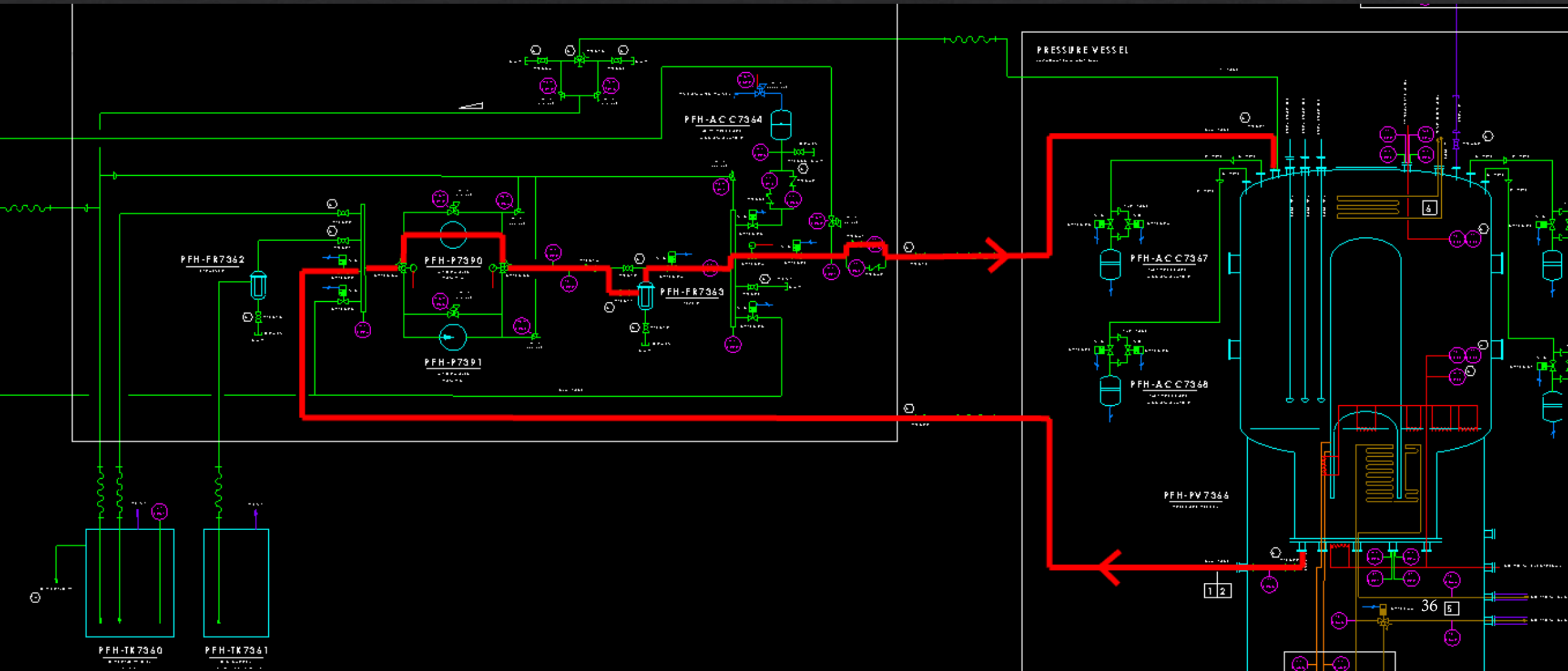
Pneumatic Isolation Bulkhead



PCV-7522
(LPA control)

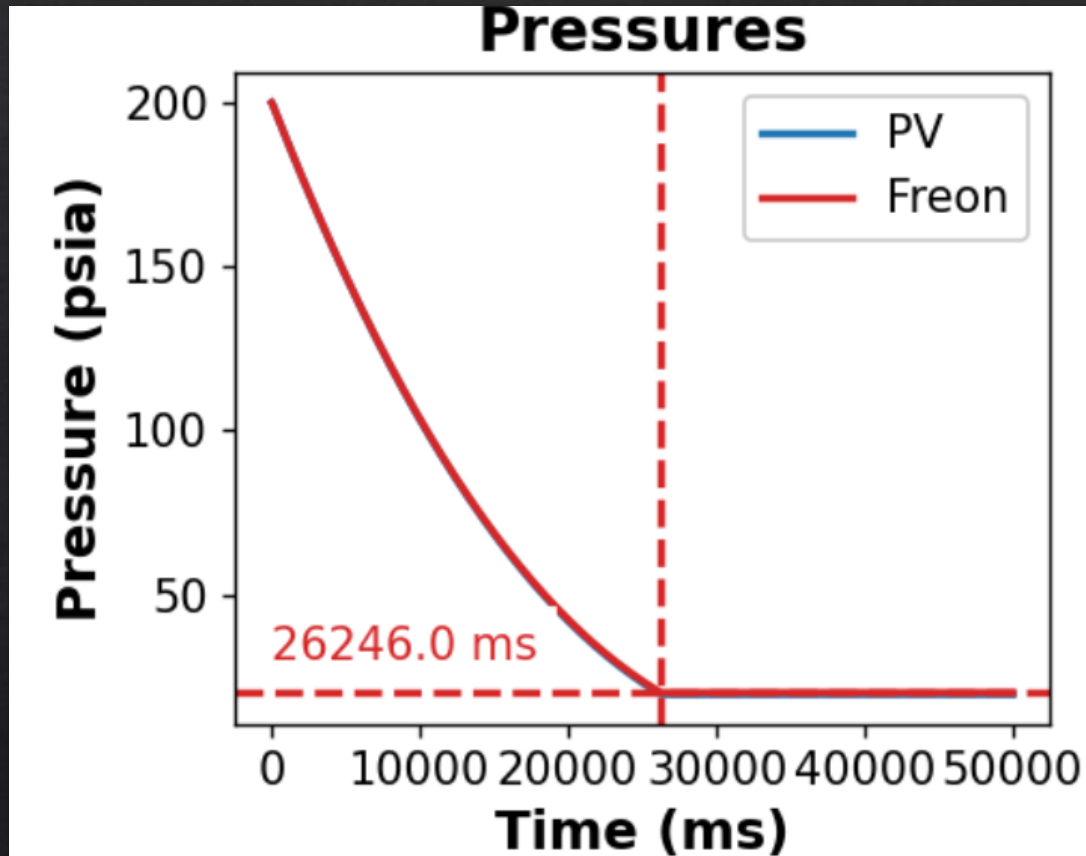
Pneumatic
Actuation

Oil Circulation

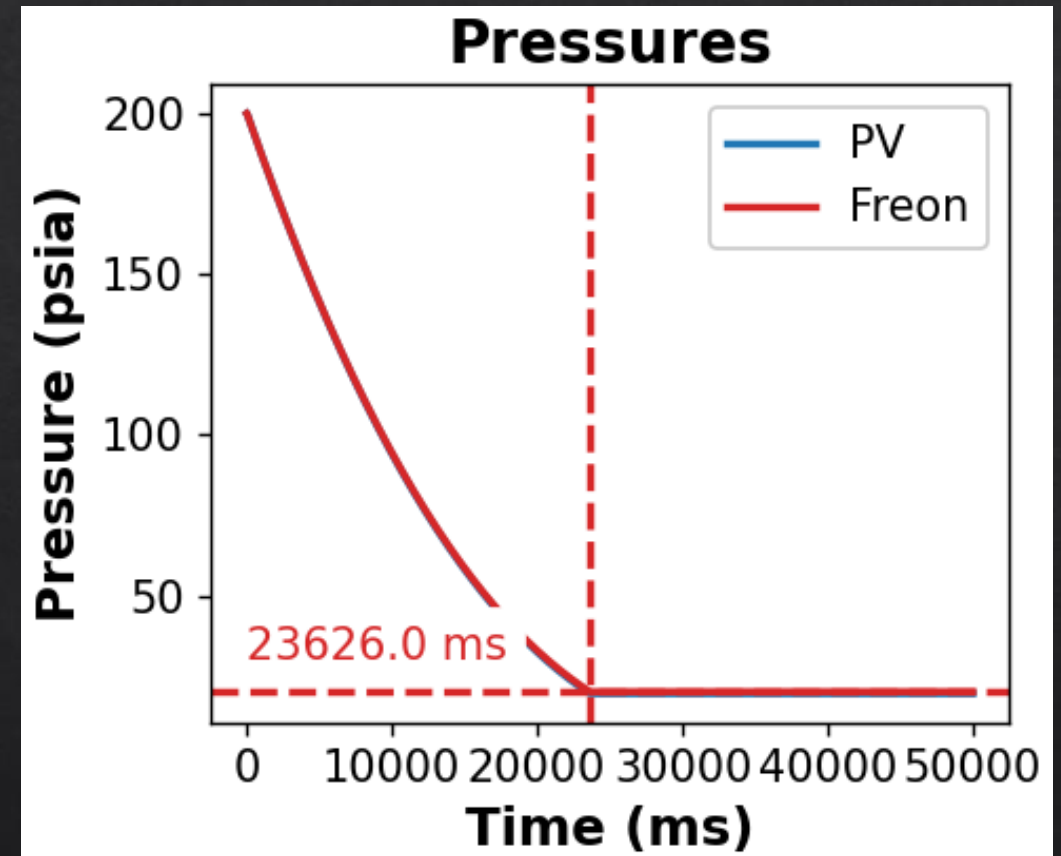


Scale up motor control needle valve

Old $C_v \approx 6.3$



New $C_v = 8.865$



Removes ~ 3 seconds of deadtime per cycle

~ 420 cycles per day \rightarrow

extra ~ 20 min of live time per day!

Thank You!



R. Filgas, D. Mamedov,
E. Rukhadze, I. Stekl



D. Priya, S. Priya, Y. Yan



C.E. Dahl



P. Grylls, A. Mathewson,
I. Lawson, S. Sekula



O. Harris



P.S. Cooper, M. Crisler,
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M. Baker, S. Fallows,
C. Krauss, Q. Malin, S. Miller,
M. Rangen, C. Rethmeier,
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NATIONAL LABORATORY

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B. Loer



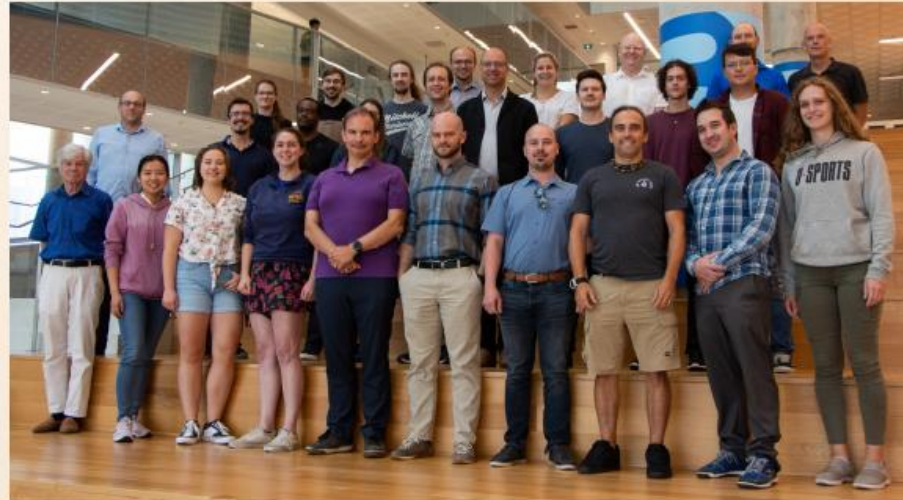
E. Adams, M. Bai, K. Clark,
D. Cranshaw, K. Dering,
G. Giroux, H. Herrera,
C. Moore, A. Noble, M. Robert



I. Brooklyn Varela, L. Desmmarais,
P. Frédéric, M. Laurin, V. Monette,
H. Nozard, A. Robinson, J. Savoie,
N. Starinski, V Zacek, C. Wen Chao



J. Farine, A. Le Blanc,
C. Licciardi, U. Wichoski



J. Basu, M. Das,
V. Kumar



INDIANA UNIVERSITY
SOUTH BEND

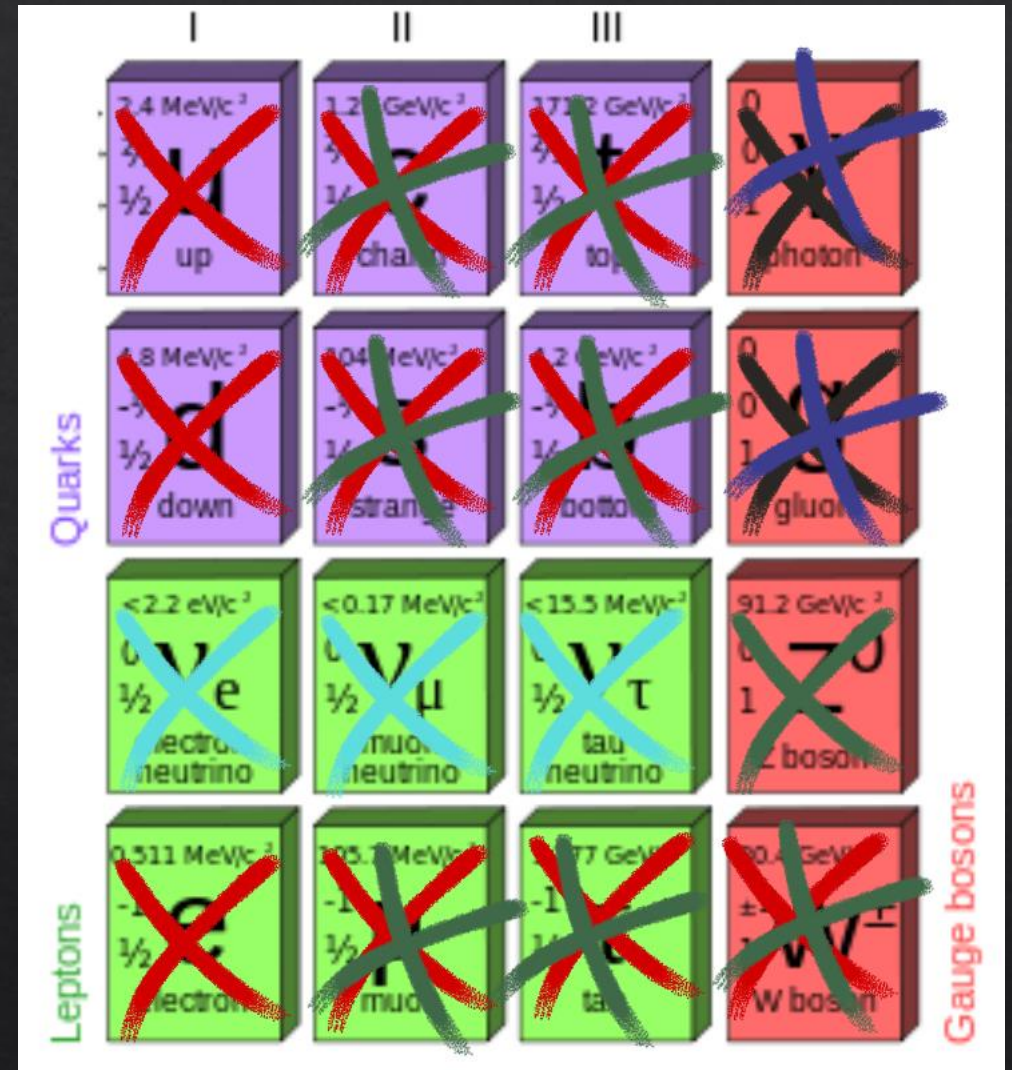
E. Behnke, C. Cripe,
I. Levine,

Properties of Dark Matter

- **Neutral** (or we could see it)
- **Weakly Interacting** (or it would be seen)
- **Massive** (it interacts through gravity)
- **Long lived** (or it would be gone)
- **Slow moving** (needed to form galaxies)

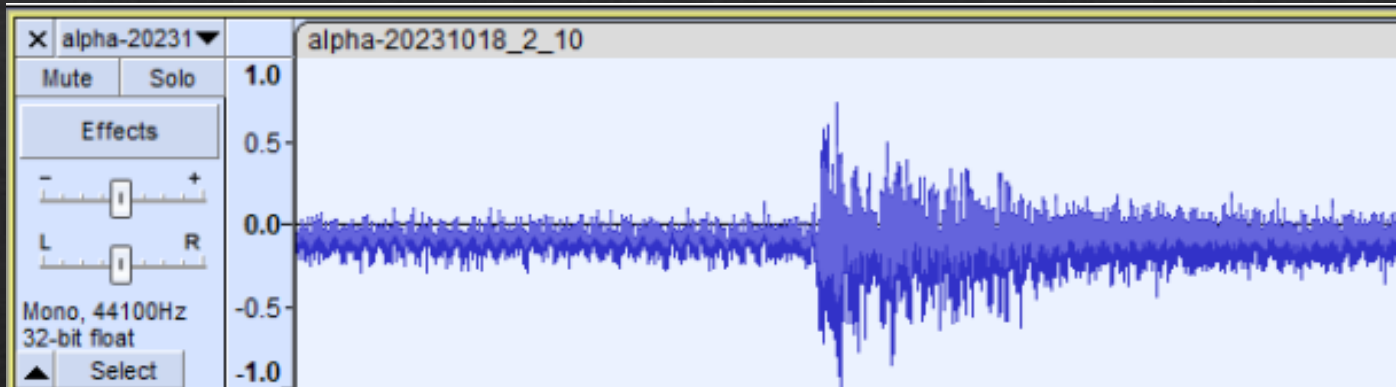
Dark Matter must be something completely new!

It is not part of the Standard Model

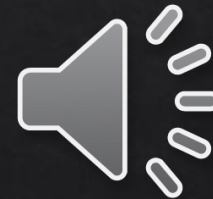
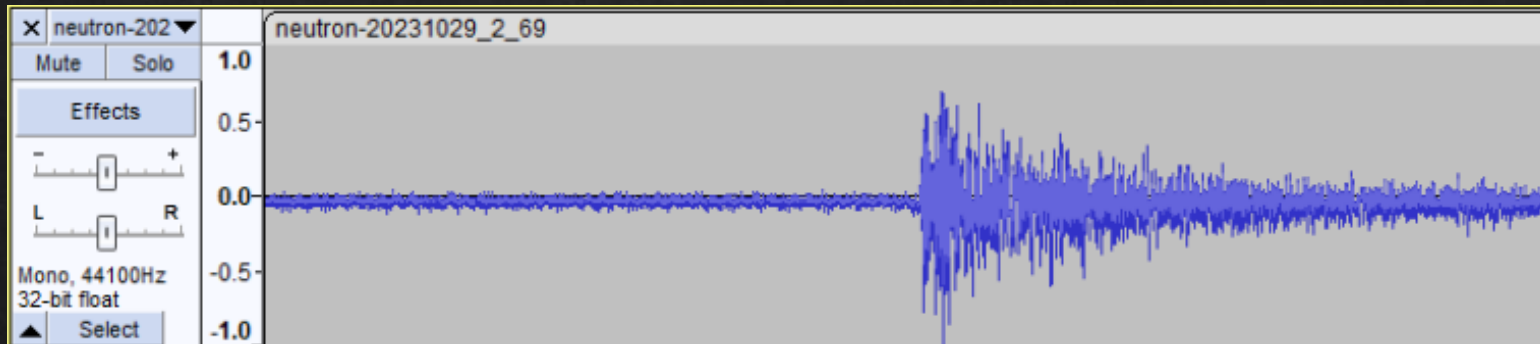


What do bubbles sound like?

Alpha



Neutron



S. Sekula