Pressure Safety in Vacuum Systems

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Outline

- Scope of SNS/HFIR pressure system review
- SEQUOIA detector tank overview
- Flapper vent valve overview
- SEQUOIA vent system calculations
- Flapper valve testing
- Current status & future plans

POWGEN sample tank

Background

- Due to recent pressure safety concerns by the Department of Energy, related ORNL policies and procedures changed
- These policy changes triggered internal reviews of all pressure and/or vacuum systems within SNS and HFIR to document safety and compliance
- Neutron instruments incorporate numerous unique pressure & vacuum systems that must be considered individually
- This presentation provides an overview of this on-going process and summarizes the attention given to the SEQUOIA detector vessel

Inside CNCS Detector Tank

Pressure System Classification Criteria

Exempt	Moderate Energy	High Energy
• Maximum pressure times system volume ≤ 7 psi-ft^3 (1.35 kPa-m^3) • Consumer items • Dewars • Etc.	• System volume ≤ 5.0 ft^3 (0.14 m^3) and the product of maximum pressure rating times system volume is ≤ 73 psi-ft^3 (14.2 kPa-m^3) • Maximum stored energy potential does not exceed 10,000 ft-lbs (13.56 kJ) in all credible scenarios	• Everything not meeting Exempt or Moderate Energy criteria • Must be designed to national standard such as ASME Boiler / Pressure Vessel Code • Weld certifications and inspections • Etc. • Very few SNS/HFIR pressure vessels can provide such levels of documentation and certification

All non-exempt systems are required to be protected against the hazards of overpressure by use of 1 or more of the following:

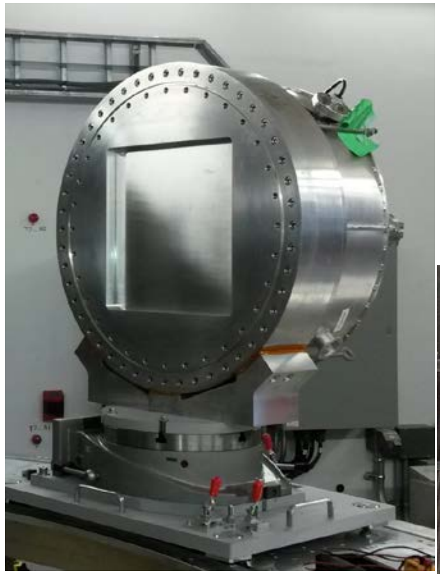
- System design
- Pressure relief
- Containment to protect from blast effects

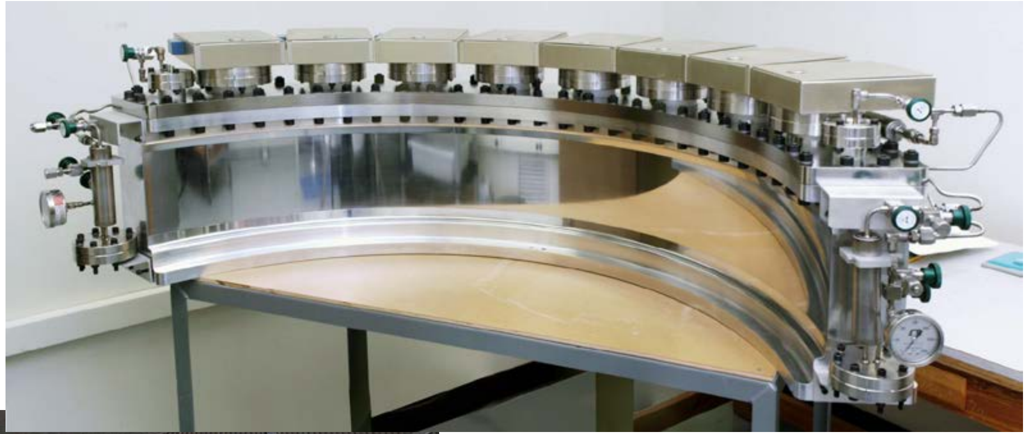
SNS/HFIR Pressure System Review

- Staff performed walkdowns of all SNS & HFIR beamlines to identify & inventory pressure/vacuum systems
  - Almost 500 systems were identified
- Facility pressure systems, Sample Environment, User Equipment not included
- Cross-cutting groups
  - Detectors
  - Choppers / Velocity Selectors
  - Optic Systems
  - Detector / Sample Vessels
  - Commercial Equipment

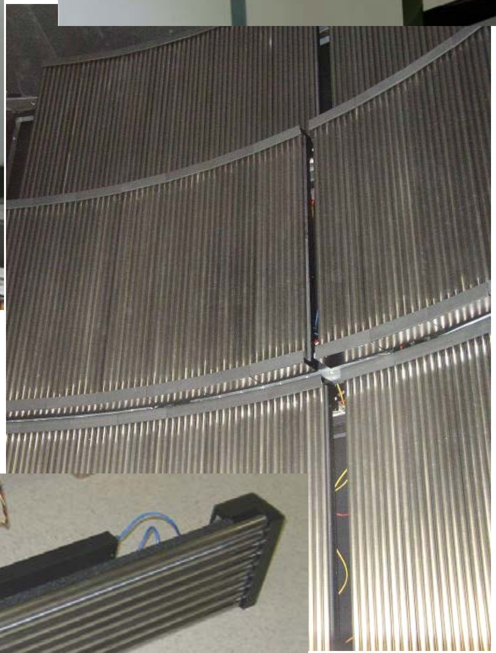
Pressure Systems: Detector Systems

- Static systems, filled by vendor with ORNL-supplied 3He
- 3He tubes – compliant with moderate energy requirements
  - Over 4600 at SNS, 600 at HFIR
  - 4 atm to 30 atm pressure
- Area detectors – reviewed case by case
- Beam monitors - exempt





WAND^2 area detector



CNCS 3He detectors

Beam Monitor

3He 8-pack module

Pressure Systems: Choppers

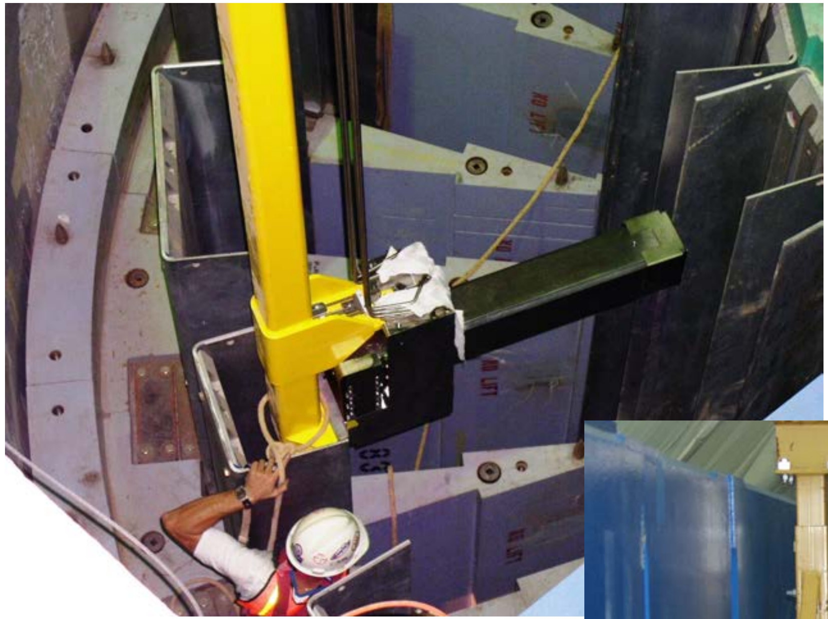
- Reviewed based on type
- Some choppers are connected to back-fill gas systems
- Concern with thin windows
- A fast-fill system implemented on some choppers was reviewed and subsequently removed
- Generally compliant with moderate energy requirements through the use of containment & pressure relief devices

Horizontal T0

Bandwidth chopper

Pressure Systems: Neutron Optics Systems

- Neutron guides & evacuated flight tubes typically connected to back-fill gas systems
- Concern with thin windows
- Determined these are not safety concerns during operation because they are under shielding, no further action needed
  - Unshielded requires venting or other protection



Core Vessel Insert

BASIS Beam Guide

Pressure Systems: Sample & Detector Vessels

- Typically connected to facility gas systems for venting and backfilling
- Large volume vessels have increased pressure safety concerns
- Must be evaluated case-by-case
- Primary focus of this presentation

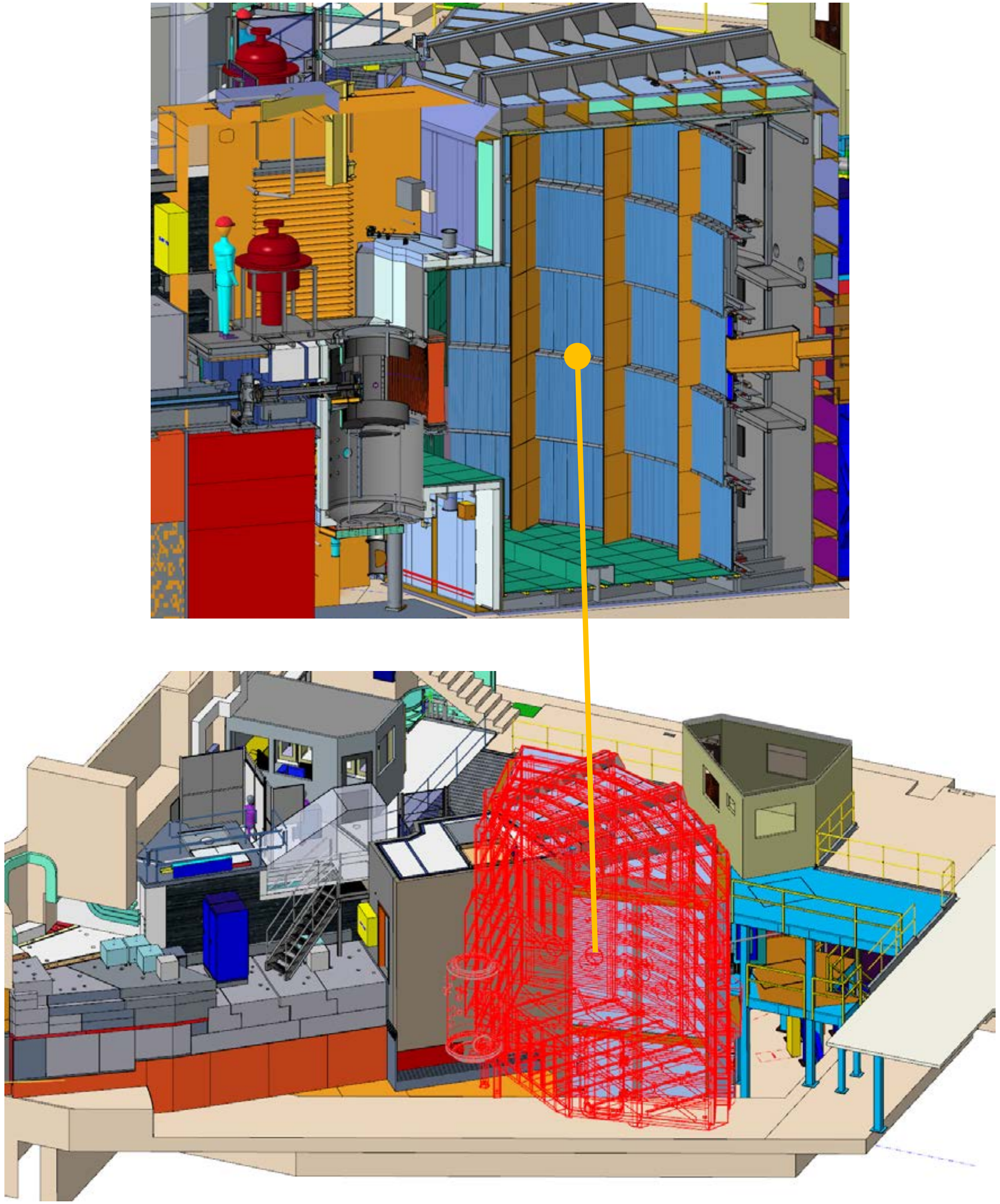
ARCS Detector Tank

Corelli Detector Tank

POWGEN Sample Tank

SEQUOIA Detector Tank

- 8900 ft^3 (250 m^3) volume
- Largest vacuum vessel at ORNL
- Sample vessel connected to detector tank through large gate valve
  - Separate sample and detector tank fill / vent operations
  - Allows quick venting of isolated sample tank



OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

SEQUOIA Vessel Installation

- One of the initial 2006 suite of SNS instruments

Complete Vacuum Vessel

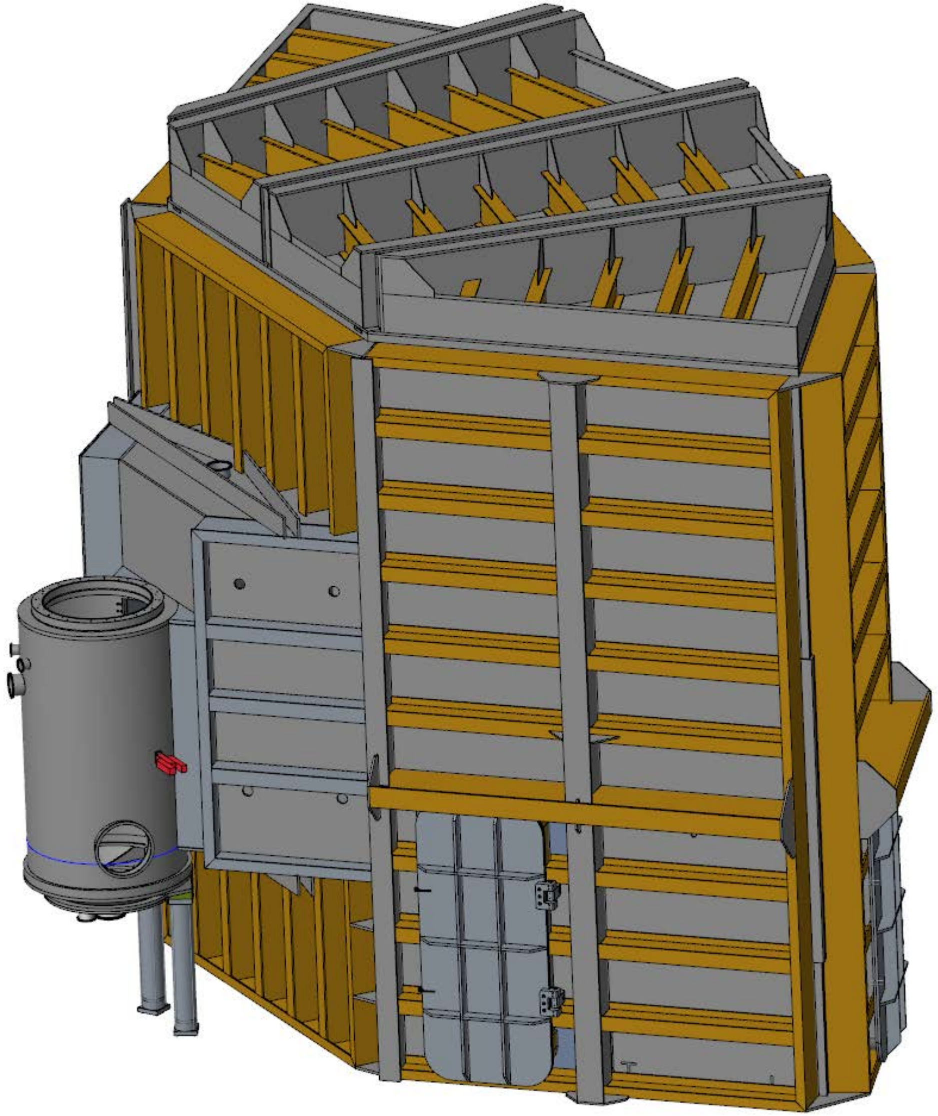
Detectors Inside Vessel

Detector Vessel Wall

Sample Vessel

SEQUOIA Detector Tank Design

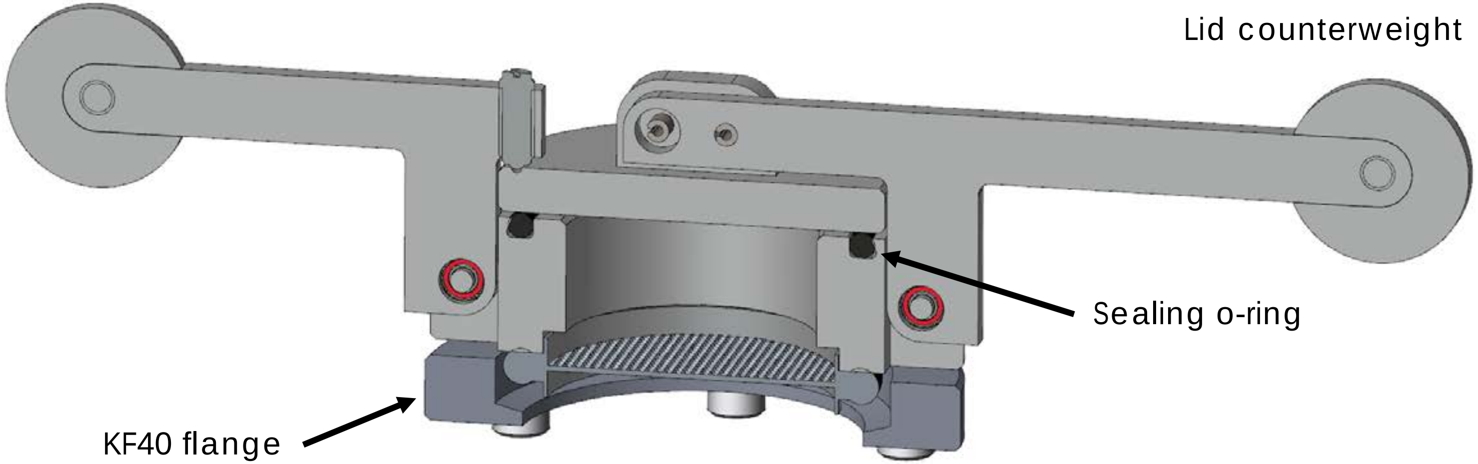
- Designed and fabricated by external company, limited documentation available
- Structure only analyzed for vacuum condition, not pressure
- Connected to facility's compressed air supply to decrease vent time and to minimize moisture creation during vent process
  - Vacuum control system monitors process, but an undetected failed regulator could allow a positive pressure condition
- Most vacuum vessels are also able to withstand at least 1atm pressure, but such assumptions on these large, flat vessels may not be defendable without analyses / documentation



SNS Flapper Vent Valve

- Designed by SNS Sample Environment team, provisional patent received
- Counterweight opens valve under slight vacuum
- Latch secures lid until tank evacuated, creating negative pressure that compresses o-ring and releases latch
- Current design sized with KF40 inlet flange

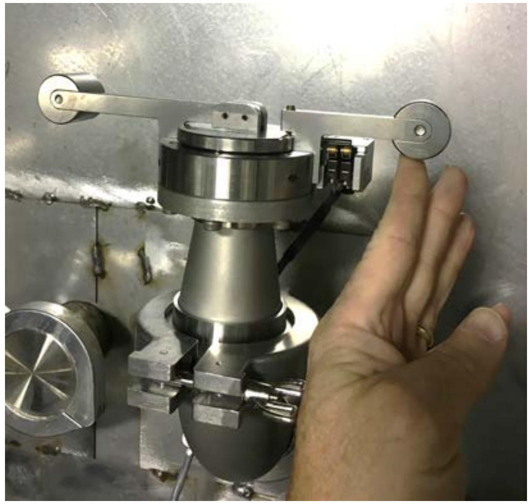
Flapper valve prior to tank evacuation



Design By: Mark Loguillo, SNS Sample Environment Team

Arming Flapper Valve

Step 1. Close lid and hold



Step 2. Close latch and hold

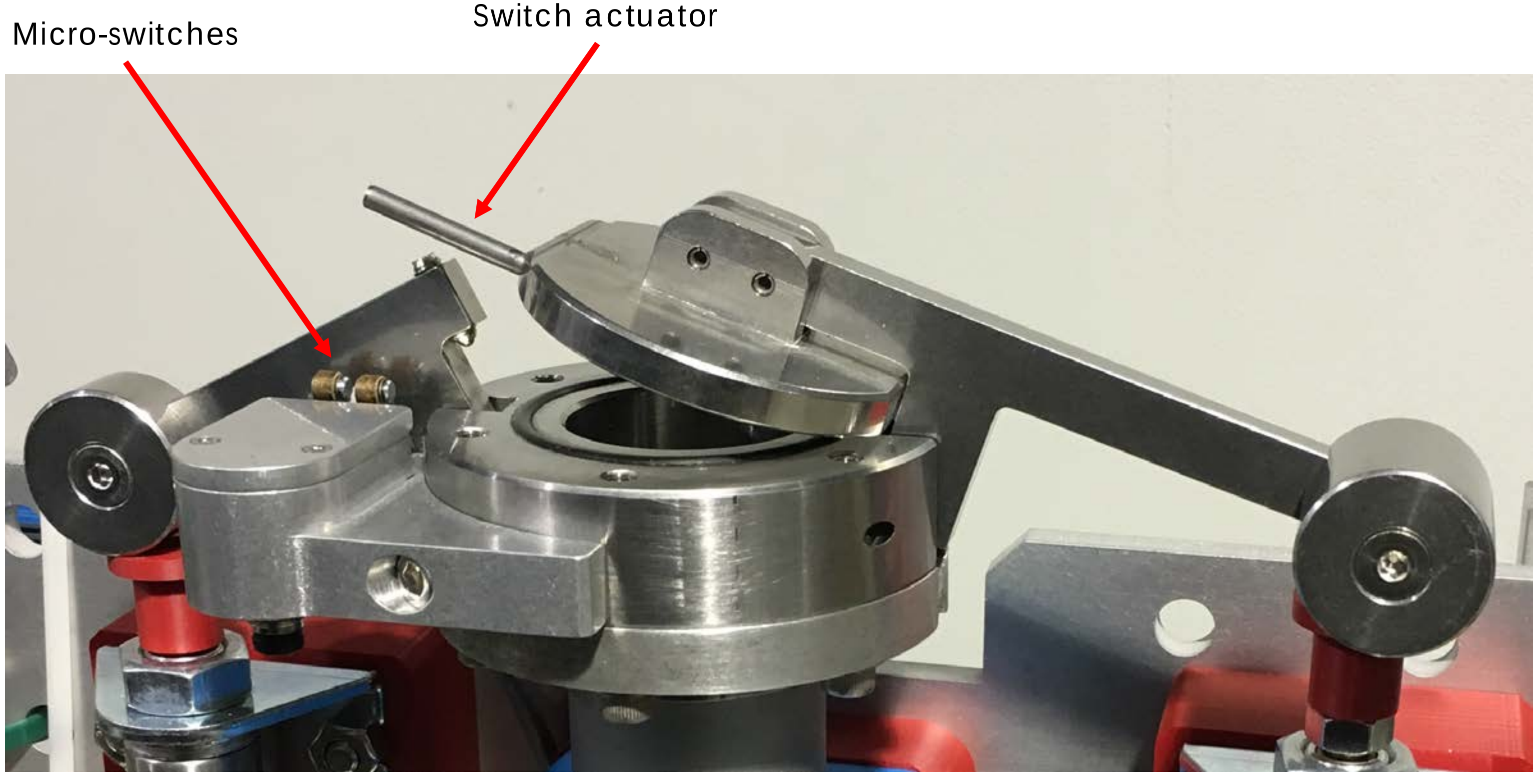
Step 3. Release lid, then release latch.
Both arms held in place by set screw.

Step 4. Evacuate vessel.
Latch releases automatically as o-ring compresses. Lid held in place by negative vessel pressure. Latch must release to create a safe configuration!

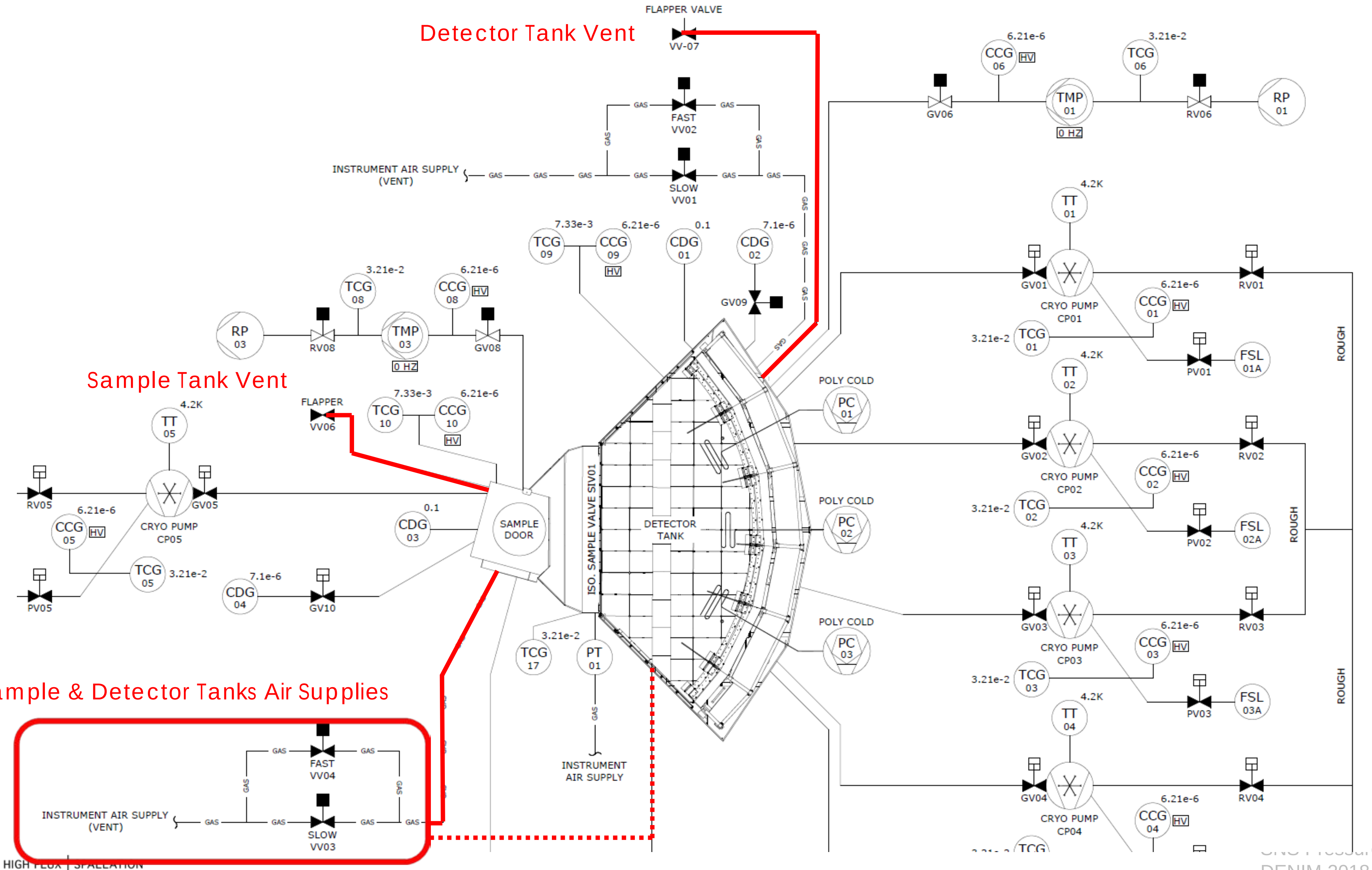
Negative tank pressure retains lid in closed position until venting occurs.

Flapper Valve Operating Status

- Valve incorporates redundant micro-switches which convey lid position to vacuum control system
- Current version of valve provides no feedback of the latch position

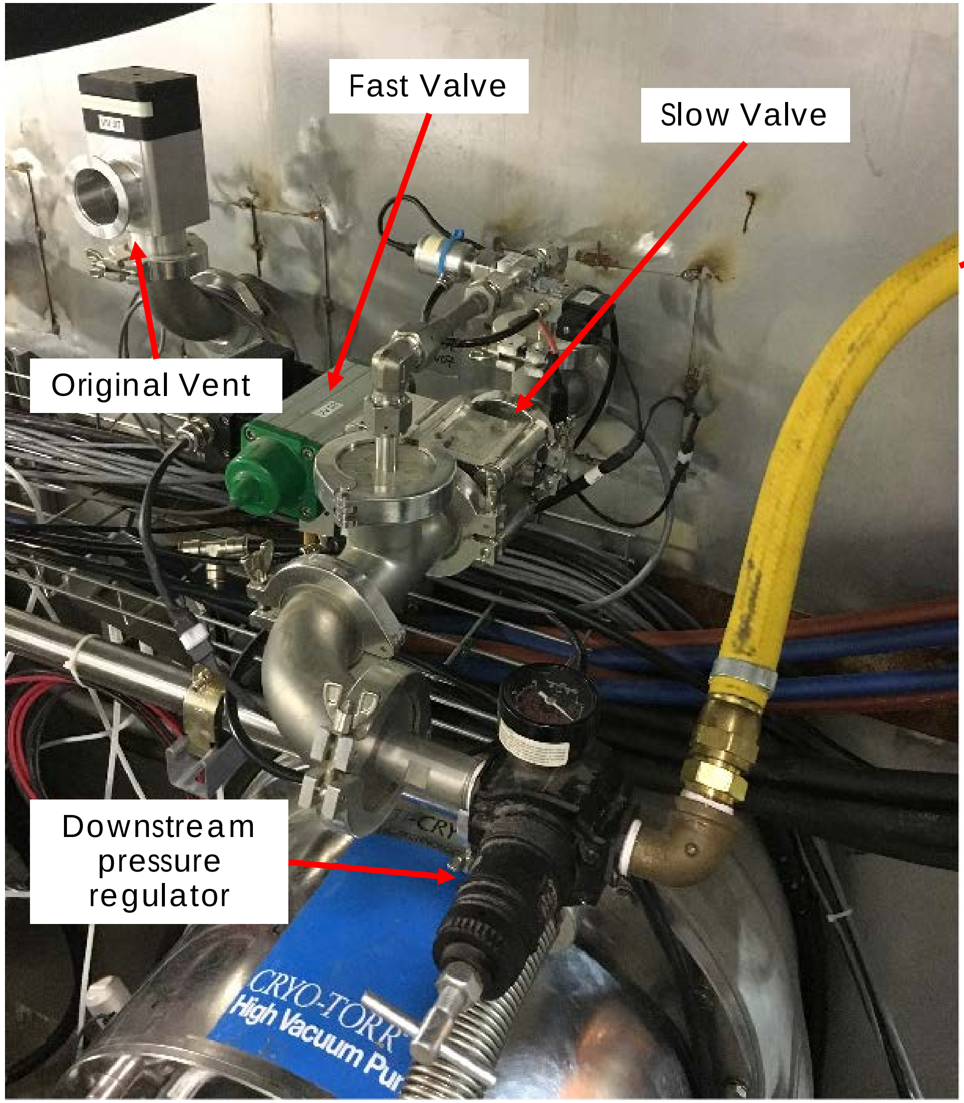


SEQUOIA Vacuum System Schematic



SEQUOIA Venting System

- Two regulators in series with slow- and fast-vent valves in parallel
  - Fast valve opened ~10 Torr
- Concerned with failed downstream regulator scenario
  - Downstream regulator can accommodate failure of upstream regulator
- Analysis of the SEQUOIA detector vessel and its venting system performed
  - Is there a safety problem with this vessel?
  - Is it compliant with pressure system guidelines?



Upstream pressure regulator

Allowable Tank Pressure

- What pressure is allowed in the detector tank within the Moderate Energy limit?

$$W = \frac{P_1 \cdot V_1}{k-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{(1-k)}{k}}\right]$$

Where:

W = Work Energy
k = Ratio of Specific Heats
P_1 = Initial Pressure
P_2 = 2nd State Pressure
V_1 = Initial Volume

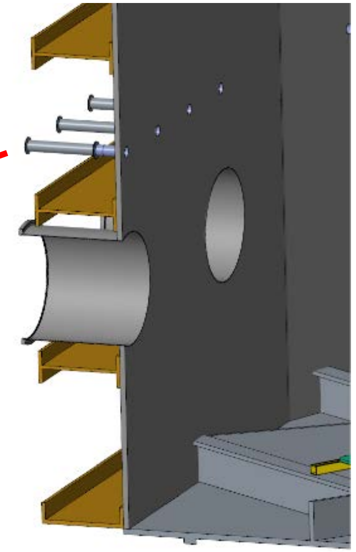
$W = 13560$ J	moderate energy limit
$k = 1.4$ (air)	
$P_1 = 1$ atm $= 1.0133$ bar	
$V_1 = 250\ m^3$	SEQUOIA tank volume
$P_2 = 1.0140$ bar	allowable pressure (varies with atmosphere)
$dP = P_2 - P_1 = 0.7$ mbar	tank gauge pressure (constant)
$= 0.011$ psi	available driving pressure to vent tank
$= 0.303$ inch H_2O	
$= 0.770$ mm H_2O	

Ref: PNNL-18696, Pressure Systems Stored-Energy Threshold Risk Analysis

Vent Path Capacity

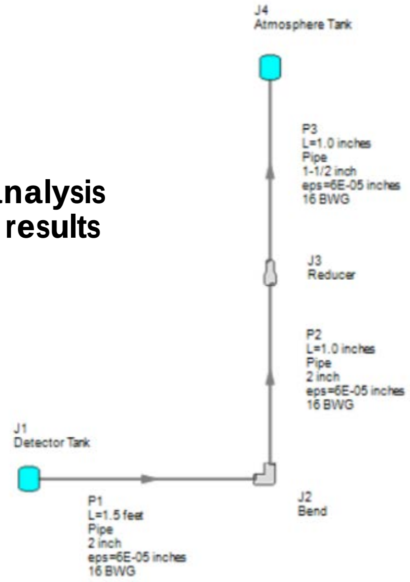
- Tank driving pressure used in compressible flow analysis program (Applied Flow Technologies Arrow) to calculate the steady-state pressure drop and flow distribution in the vent path
  - Software performs mass/energy balances, not finite element analyses
  - This is the vent path capacity
- Low driving pressure and higher frictional losses (inlet contraction & outlet expansion) result in reduced venting capacity
- Steady-state allowable vent flow rate
  - 0.54 m^3/min = 19 SCFM
- Steady-state allowable mass flow rate
  - 39.5 kg/hr = 87 lbm/hr

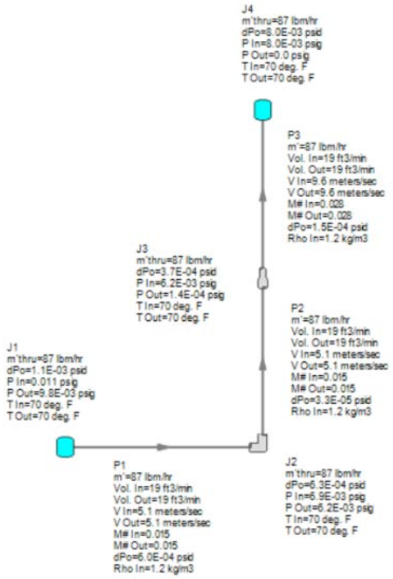
Vent valve on SEQUOIA detector tank



SEQUOIA vent path piping

AFT Arrow analysis model and results

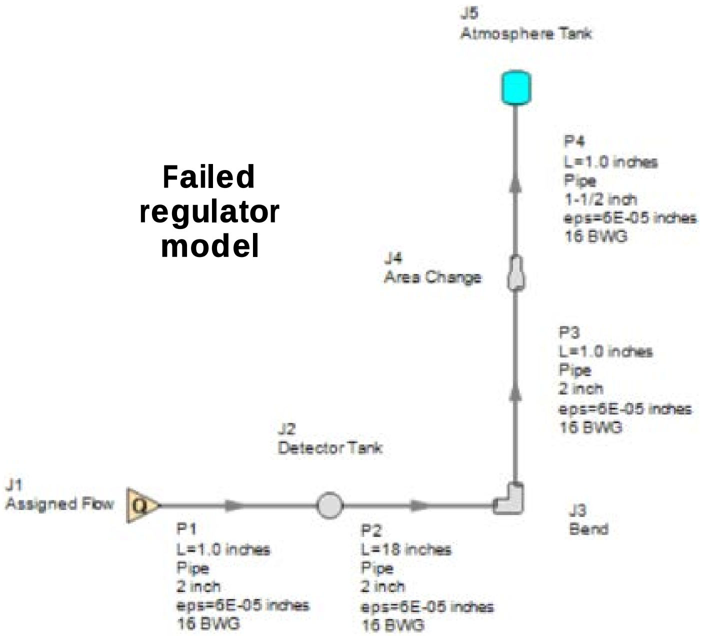




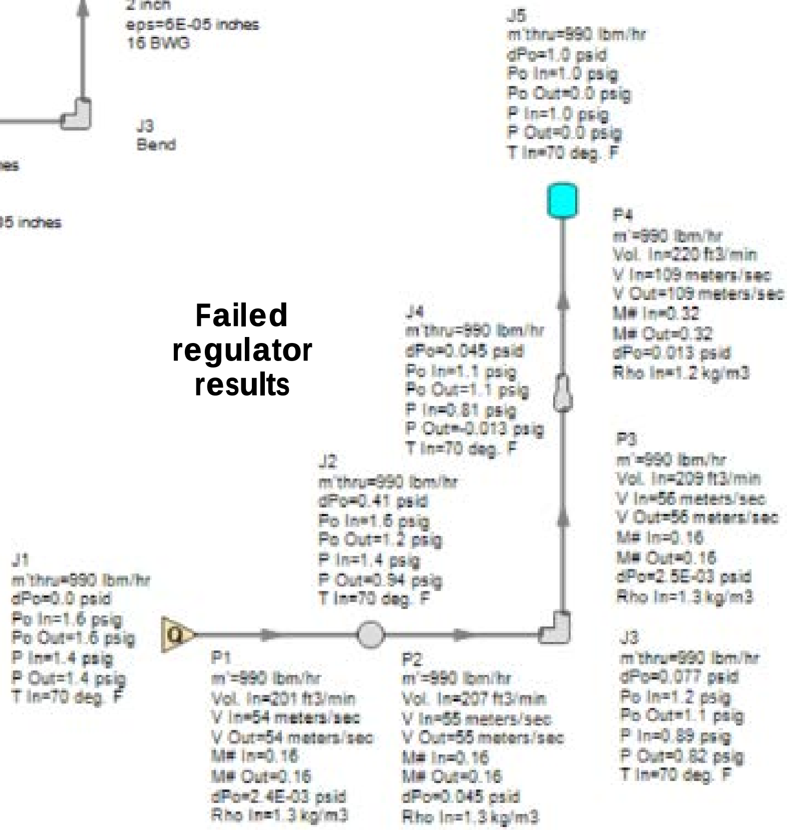
Failed Regulator Flow

- Assuming failed downstream regulator, the supply pressure is the regulated pressure from upstream regulator
  - P_{fail} = 5.5 barg = 80 psig
- Per regulator vendor information, calculate flow through downstream regulator
  - Q_{fail} = 6.1 m^3/min = 216 SCFM
- Create another flow analysis to determine steady-state tank pressure at the failed regulator flow
  - P_{tank} = 110 mbarg = 1.6 psig
- Compare to allowable tank pressure
  - P_{allow} = 0.7 mbarg = 0.011 psig
  - Steady-state tank pressure due to failed regulator exceeds allowable pressure by >100X!

Failed regulator model



Failed regulator results



What to do?

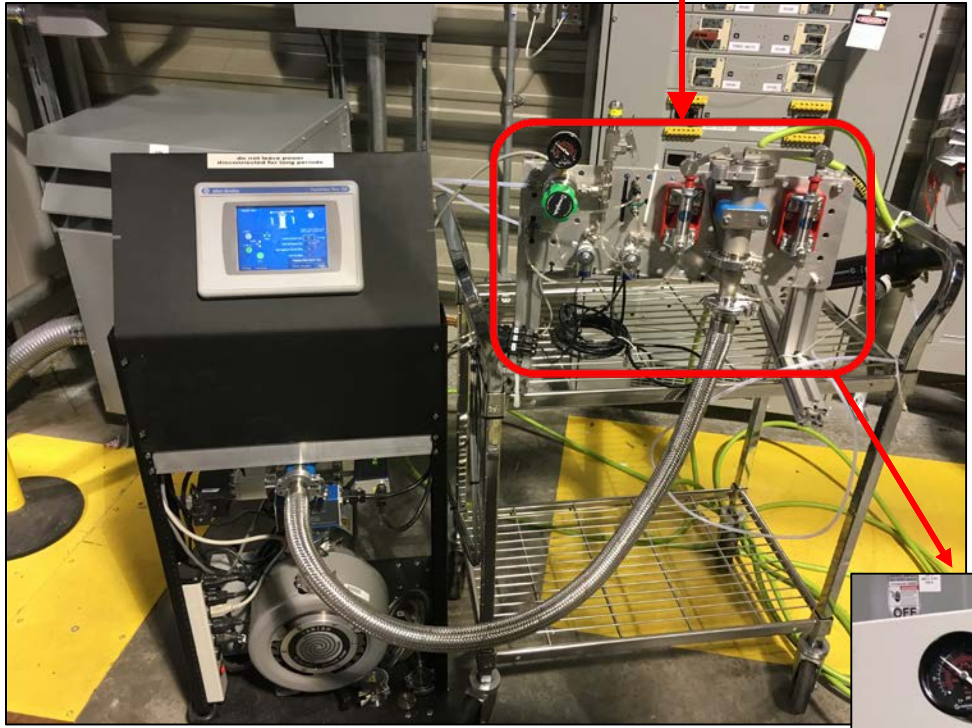
- 110 mbar (1.6 psi) not considered a safety problem in the detector tank, but we can't prove that without expensive structural analyses
  - Even with structural analyses, pressure still exceeds allowable limits
- Increase size of vent piping (and flapper valve) or add additional vent paths
  - Relying on flapper valve to protect the tank if a regulator failure goes undetected
- Introduce a fixed orifice into vent supply system or change regulators
  - Reducing vent flow will significantly increase vent time

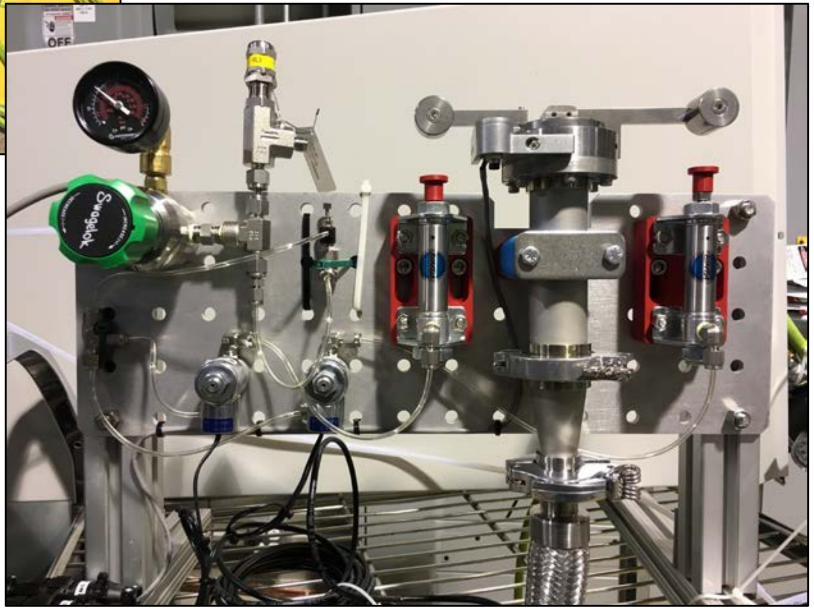
Flapper Valve Testing

- Custom design, no commercial certification
- Need higher confidence that the valve always opens under vacuum conditions
- How many cycles?
  - Worst-case for other vessels where it may be installed suggests a few thousand cycles over its lifetime
  - We chose 10,000 cycles
- How many students will it take to manually reset the valve that many times?

Flapper Valve Testing System

- Automated system replicates actual operation, resets the valve after opening, logs pressure data
- Connects to pre-existing vacuum testing system with pump, valves, controller, etc.



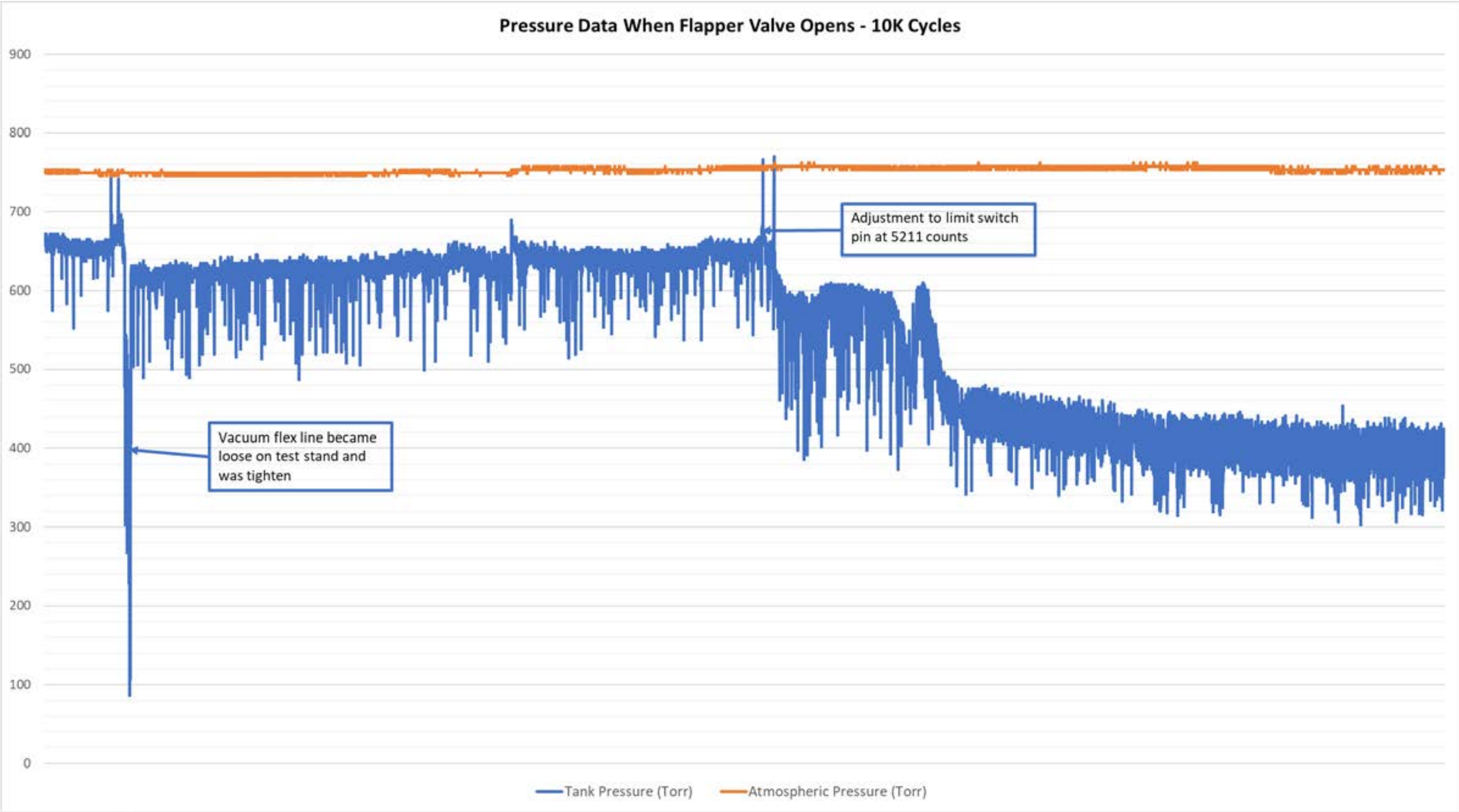


Cycle Testing

- Close lid
- Close latch
- Release lid
- Release latch
- Evacuate tank, latch falls away
- Vent tank, lid falls away
- Repeat thousands of times!

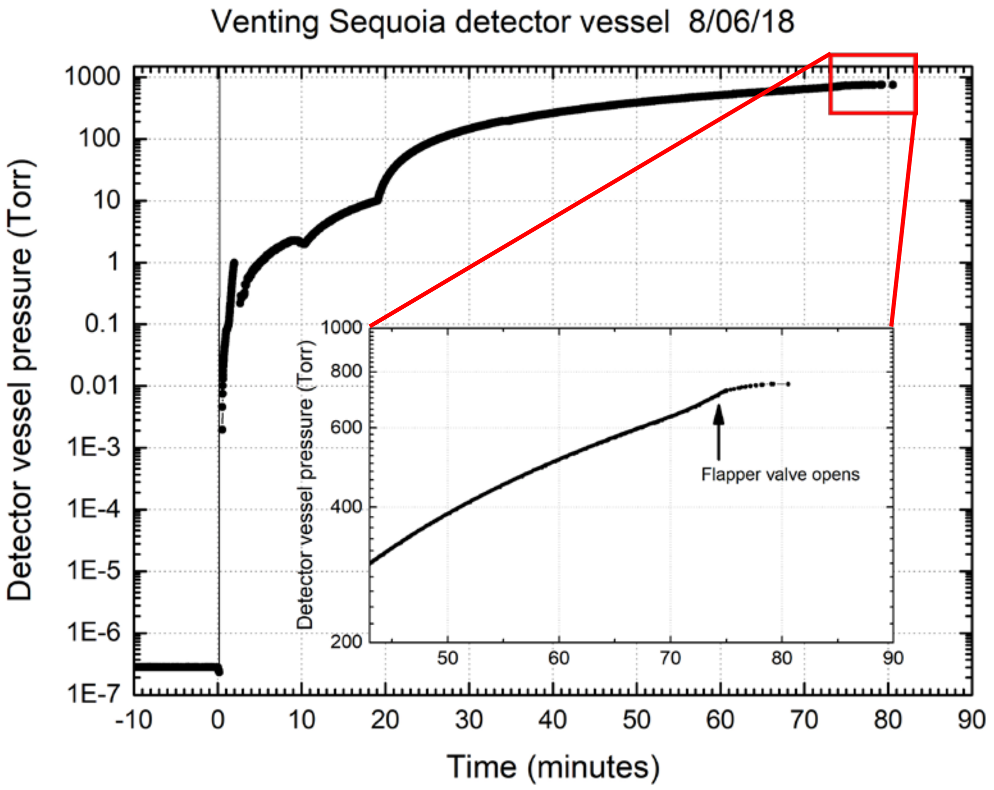
Flapper Valve Testing Results

- Valve always open below atmospheric pressure
- Testing took ~1wk, suspect o-ring got drier or dirty, leading to lower opening pressures
- We can now justify our claim that tank will not see positive pressure **during normal operation**



SEQUOIA Current Status and Future Plans

- SEQUOIA is operating with existing vent valve
- Design and implement latch switch to prevent venting process from initiating unless latch is opened
- Considering design of larger valve
- Considering introduction of a fixed orifice
  - Estimates suggest orifice will increase vent time by 9X
  - Plan to introduce fixed orifice into supply system and determine operational impact



Recent SEQUOIA detector tank vent test ~80 minutes (no orifice)

Final comments

- Pressure system safety concerns are real but have not been drivers in neutron instrument component designs
- Radiation shielding alleviates many of the safety concerns associated with pressure systems but not facility or equipment risks
- Consider future configuration changes in system design
- Require vacuum vessels to also be analyzed for pressure conditions
  - System documentation (analyses & calculations) is essential for future reference
- We are still executing our pressure system plan and considering engineering changes to improve instrument reliability & availability

Backup Slides

Regulatory Requirements

- ORNL is a Department Of Energy (DOE) facility and follows US Government / DOE rules and regulations (Code of Federal Regulations)
- DOE directive 10 CFR 851 covers Worker Safety and Health and includes Pressure Systems
- A 2017 review found that ORNL was not consistently applying 10 CFR 851 into its pressure systems design and associated work practices

Some Systems do not have Adequate Overpressure Protection

If <u>all components</u> in the system are not rated for the maximum pressure scenario, over-pressure protection is necessary.

- Over-pressure protection can consist of pressure relief valves, burst disks, etc.
- Over-pressure protection devices must relieve pressure at or below the maximum allowable working pressure for the lowest rated component.
- Regulators **are not** considered over-pressure protection.

Credit: Tim Gillespie, ORNL Senior System Safety Analyst

Pressure System Definition

- ***Pressure Systems:*** *all pressure vessels and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum.*
- ***Vacuum systems*** *are considered pressure systems due to their potential for catastrophic failure due to backfill pressurization.*
- ***Associated hardware*** *such as gauges, regulators, fittings, piping, pumps, and pressure relief devices are also integral parts of the pressure system.*
- ***Does not include*** *systems with volumetric capacity less than 5.0 ft^3 (0.14 m^3) and P*V < 73 psi/ft^3 (14.2 kPa-m^3).*
- ***Pressure System Classifications***
  - *Exempt*
  - *Moderate Energy*
  - *High Energy*

Pressure System Categories: Exempt

- Gas systems with a product of maximum pressure times system volume ≤ 7 psi-ft^3 (1.35 kPa-m^3), for which this threshold cannot be exceeded under any circumstance or failure and pressure is not limited by a pressure relief device
- Commonly available consumer products (tires, balls, inflatable boats, garden hoses, pressure washers, drinks, aerosol cans, etc.)
- Casings and machinery where pressure is not a significant design factor, which may include engines, pumps, lifts, and compressors
- Pressure system comprised of a self-contained assembly whose functional design and pressure safety considerations comply with nationally recognized standards (refrigerators, window air conditioners, water fountains, appliances, hydraulic/ pneumatic presses and jacks, etc.)
- Portable pressurized containers having a capacity not greater than five gallons (19 L) and primarily used for convenient storage, transport, or use of food, beverages, medicine, and consumer or industrial substances (paint, solvents, adhesives and cleaning agents, etc.)
- Portable double-walled pressurized cryogenic cylinders (also known as Dewars) used exclusively for storage and transport of cryogenic liquids with maximum allowable working pressure (MAWP) not exceeding 25 psi (172.4 kPa) and 120 gallons (454 L) - Piping and other components downstream of the cylinder are not exempt and must be categorized per this procedure.

Pressure System Categories: Moderate Energy (meet any of these criteria)

- **Gas** - System volume ≤ 5.0 ft^3 (0.142 m^3) and the product of maximum pressure rating times system volume is ≤ 73 psi-ft^3 (14.2 kPa-m^3)
- **Liquids** - System maximum operating temperature no greater than 2 °F (1.1° C) below the liquid's boiling point at 1 atm, volumetric capacity ≤ 120 gallons (454 L) with a product of maximum pressure times volume ≤ 800 psi-ft^3 (156.2 kPa-m^3)
- Pressure system with a system volume exceeding the limitations given above, but whose maximum stored energy potential does not exceed 10,000 ft-lbs (13,560 joules) in all credible scenarios
- Hydraulic and pneumatic systems not purchased in a self-contained assembly or designed and built by ORNL staff, where all components are rated by manufacturer for intended maximum pressure and service conditions
- Vacuum systems not exceeding the following:
  - Single wall chamber, tubing, or piping (i.e., no jacket commonly associated with cooling or insulation)
  - Internal design pressure, including backfill, cannot be greater than 15 psi (1 atm)
- **Note:** It is acceptable to provide pressure relief devices for the purposes of remaining under the 73 psi-ft^3 (14.2 kPa-m^3) and 800 psi-ft^3 (156.2 kPa-m^3) thresholds to maintain moderate energy classification.

Pressure System Categories: High Energy

- Any pressure system that is not exempt, pre-approved, or moderate-energy system
- Must be designed to national standard such as ASME Boiler / Pressure Vessel Code
- Weld certifications and inspections
- Etc.
- Very few SNS/HFIR pressure vessels can provide such levels of documentation and certification

Pressure Systems: Other

- Desiccant sample cabinets & gloveboxes are common, have no pressure rating, but incorporate gas ports
- Various other instrument-related pressure systems