An Assessment of the Implications of 10CFR851 on Vacuum Systems at the NSLS

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Introduction to 10CFR851

- Section 10 of the Code of Federal Regulations, Part 851 specifies Worker Safety and Health Program regulations for U.S. DOE facilities. It requires that contractors must "Provide a place of employment that is free from recognized hazards,…"
- These new regulations may find their way into insurance reqmts, so although they apply to US facilities now, they may be coming soon to a synchrotron facility near you.

What is new?

- 10CFR851 defines pressure systems to include 'all pressure vessels and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum. Vacuum systems should be considered pressure systems due to their potential for backfill pressurization. Associated hardware (e.g. gauges and regulators), fittings, piping, pumps, and pressure relief devices are also integral parts of the pressure system.'
- "Contractors must ensure that all pressure vessels, boilers, air receivers, and supporting piping systems conform to:
  1. The applicable ASME Boiler and Pressure Vessel Code (2004); sections I through section XII including applicable Code Cases
  2. The applicable ASME B31 standards
  3. The strictest applicable State & local codes."

10CFR851 equivalence/enforcement

When National consensus codes are not applicable (because of pressure range, vessel geometry, use of special materials, etc), contractors must implement measures to provide equivalent protection and ensure a level of safety greater than or equivalent to the level of protection afforded by the ASME or applicable state or local code. Measures must include:

1. Design drawings, sketches, and calculations must be reviewed & approved by an independent design professional (i.e. professional engineer). Documented organizational peer review is acceptable.
2. Qualified personnel must be used to provide examinations & inspections of materials, in-process fabrications, non-destructive tests, & acceptance tests.
3. Documentation, traceability, & accountability must be maintained for each pressure vessel or system, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance.

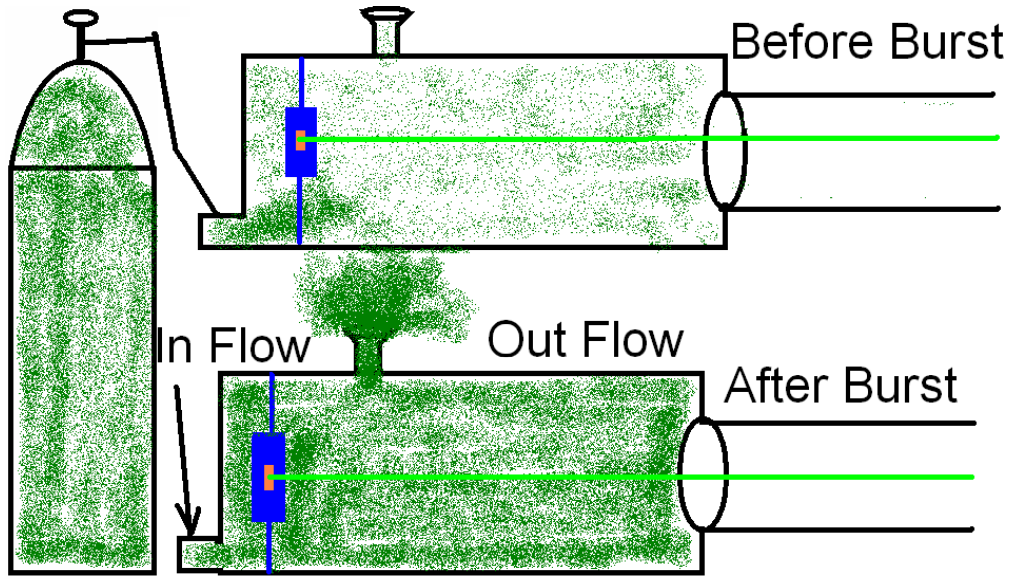
Enforcement Actions:

– DOE may assess civil penalties or up to $70,000 per violation per day & DOE may also seek contract fee reductions

What's an engineer to do??

Four step plan:

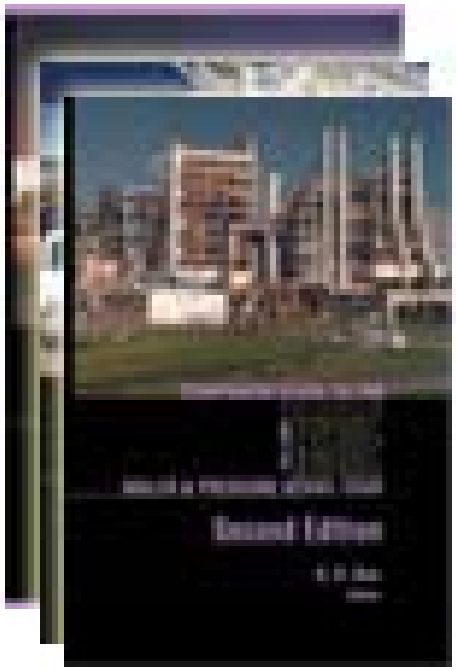
1. Review & understand ASME codes
2. Inspect NSLS systems & determine how to bring them into compliance
3. Develop & automate eng'g analyses



4. Get Ntl Bd-certified UHV-compatible burst disks (on CF flanges) in large enough sizes to protect vacuum vessels & windows & keep burst press < 15 psid

1. Research ASME codes:

- which codes apply?
- what exclusions apply?
- What are their implications?



ASME Boiler & Pressure Vessel codes:

- **I. Power Boilers**
- **II. Materials**
- **III. Rules for Construction of Nuclear Power Plant Components**
- **IV. Heating Boilers**
- **V. Nondestructive Examination**
- **VI. Recommended Rules for the Care and Operation of Heating Boilers**
- **VII. Recommended Guidelines for the Care of Power Boilers**
- **VIII. Pressure Vessels**
- **IX. Welding & Brazing Qualifications**
- **X. Fiber-Reinforced Plastic Pressure Vessels**
- **XI. Rules for In-service Inspection of Nuclear Power Plant Components**
- **XII. Rules for the Construction & Continued Service of Transport Tanks**

Still more codes!!

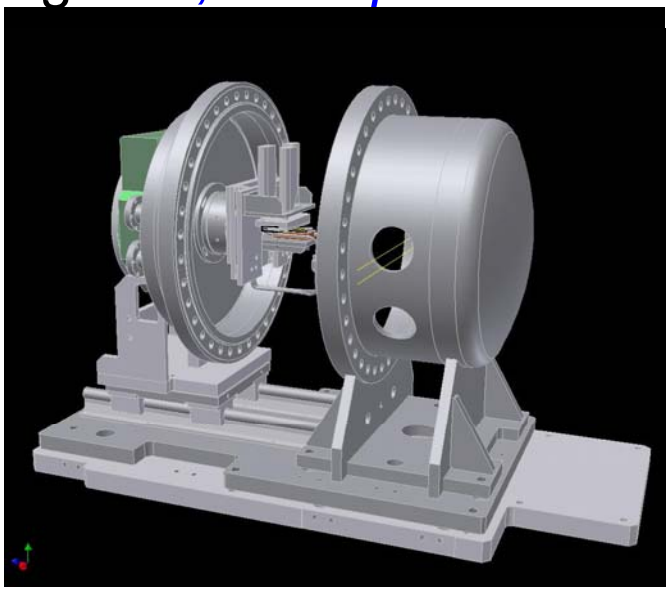
Which ones apply?

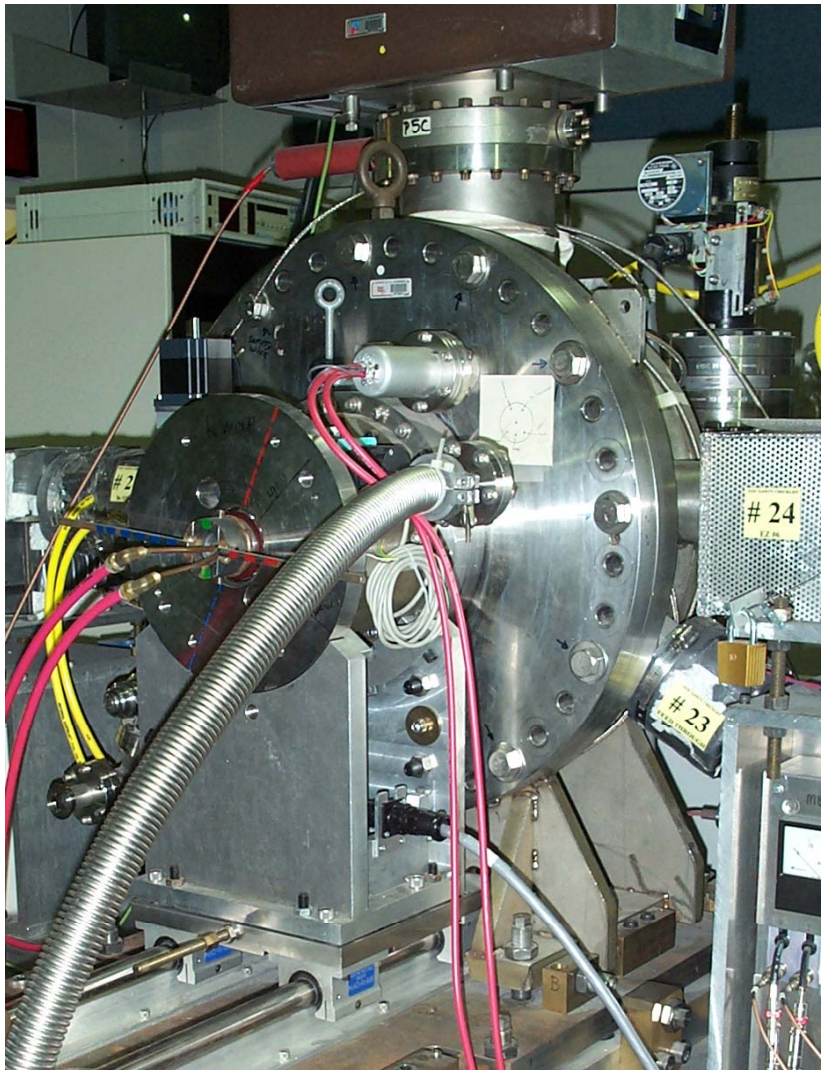
- B31.1 Power Piping
- B31.2 Fuel Gas Piping
- B31.3 Process Piping
- B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons & Other Liquids
- B31.5 Refrigeration Piping & Heat Transfer Components
- B31.8 Gas Transmission & Distribution Piping Systems
- B31.8S Managing System Integrity of Gas Pipelines
- B31.9 Building Services Piping
- B31.11 Slurry Transportation Piping Systems
- B31G, Manual for Determining Remaining Strength of Corroded Pipelines

2. Ck NSLS systems for compliance

When fluid lines enter vacuum chambers & a *failure* could allow internal press to rise above 15 psid, ASME Sect VIII applies !

- Vac systems are often assem'd from std compts, *few comply w/ Sect VIII*
- Beamlines often incl large vacuum vessels for mirrors, monochromators, & end stations, *none are U-stamped*
- Press sources incl cooling water (w/ unlimited make-up capacity) cryogenic & process gases, *most press relief >15 psi* !





NSLS systems review : More trouble!

Burst disks are non-NB cert'd & burst press can exceed 15 psi

Many GP valves at NSLS use sealed, concentric, axial bellows to apply sealing force. GP valves use non-ASME-compliant integral press relief. The GP valves are no longer mf'd & are slowly being replaced by Vat all-metal seal valves. The Vat valves do not use gas pressure for sealing. The replmt cost is high!

Still more trouble!

- Std UHV flanges & compts use continuous inner /stitch outer welds- they carry adequate loads for UHV service & assure no trapped volumes / virtual leaks, but aren't Sect VIII compliant!!
- t_{wall} on std vacuum compts doesn't meet Sect VIII reqmts
- Sect VIII requires full radiographic weld insp
- Sect VIII requires full mtl traceability & certs
- Sect VIII requires inspection by 3rd party AI's
- ASME certified mfr'r w/ U-stamp req'd
- Viewports & windows are not designed for internal press

Not done on Vacuum Vessels!

Conclusion: Std vacuum vessels & compts are NOT ASME Sect VIII compliant!

- Sect VIII compliance cannot easily be done retroactively
- new vacuum vessels could meet Sect VIII reqmts, but would be very costly & may perform poorly as vacuum vessels.

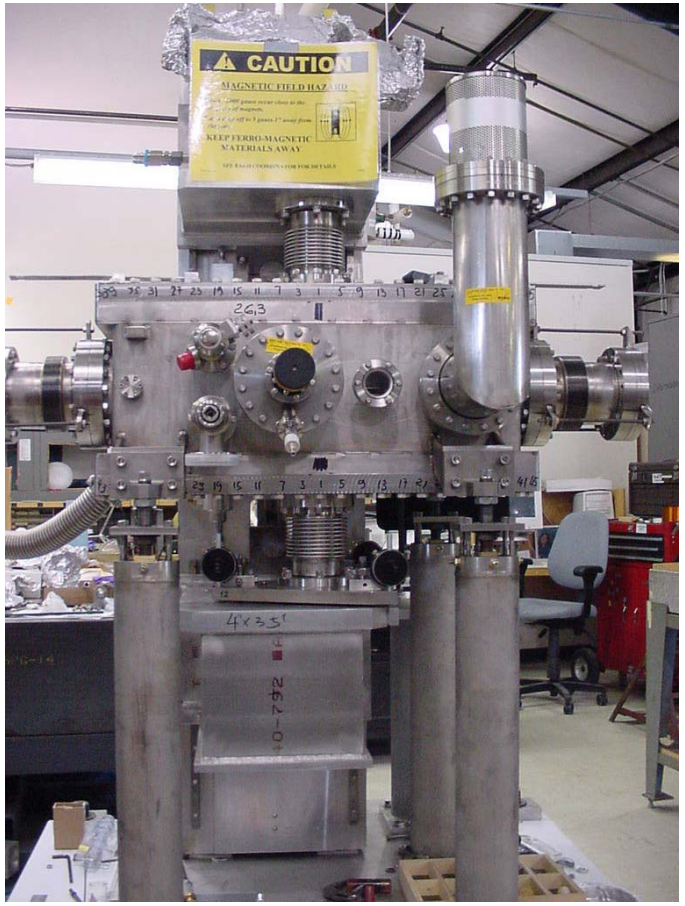
Actions needed to bring NSLS systems into compliance:

Good news:

- Sect VIII exempts vacuum/ press vessels w/ max Δp <15 psi or <6" diagonal but exemption requires <15 psid Ntl Bd press relief!

& more bad news

- 1-2 psig press relief valves presently used for gas/bleed-up systems (but unfortunately they are not ASME-compliant & no UHV / <15 psi press relief valves or burst disks were available*!!)



The Plan:

- **Develop automated analysis for press relief**
- **Get UHV compatible < 15 psid press relief**

*** prior to 10/1/2007**

3. Analyze vacuum vessels

Fluid mechanics basics for analyzing vacuum vessels:

Equation of State: $PV=mRT$

where

P = pressure (psi)

V = volume (in^3)

T = temperature (°R)

m = mass (lb_m)

R = Universal gas constant = 1545 ft lb_f/[lb_{mole}°R]/MW or for air 53.3 ft lb_f/[lb_m°R] in US customary units

For choked flow:

$$W = PC_dA\sqrt{\frac{Kg}{RT}\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

where

P = inlet press (psi)

C_d = coefficient of discharge

A = inlet area (in^2)

K = specific heat ratio (c_p/c_v)

g = gravity

Object: Develop equations for vacuum vessel pressure versus time

I. If a press regulator fails, flow from the tank into the vacuum vessel is choked:

1. Taking the derivative of the eqn of state with respect to time:

   dP/dt = dm/dt RT/V

   where R, T, & V all remain constant, and

   dm/dt is the change in mass per unit time (lb_m/s) or W, the rate of flow out of the tank.

$$W = PC_dA\sqrt{\frac{Kg}{RT}\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

2. Substituting, moving around the variables and solving for P this equation becomes

$$\int \frac{dP}{P} = \int \frac{C_dACRT}{V}\,dt$$

3. Solving this integral from initial pressure P_i to final pressure P_f, and from the initial time, zero to the final time, t, we get

$$P_f = P_i\, e^{\frac{C_dACRT}{V}t}$$

This expression govern tank pressure. Assuming a worst-case scenario where a press regulator fails open & no flow resistance from the regulator is encountered, the only flow resistance is from the connecting tubing.

Vacuum vessel pressure however increases with time until the burst disk opens.

Fluid mechanics calculations (cont'd)

Flow into vacuum chamber:

- Taking d/dt[**PV** = **mR**T]:

  where V_2 = vacuum chamber volume (not pressurized tank volume)

  $dP/dt = dm/dt\ (RT/V_2)$

  substituting **dm/dt = W** & integrating from initial pressure in the chamber, zero, to final pressure $P_{chamber}$ and from time zero to final time t for P

results in $P_{chamber} = \frac{P_i C_d V}{V_2}\left(1 - e^{-\frac{C_d A C R T}{V} t}\right)$

As you can see from this equation, as time goes on, the pressure will increase only up a maximum,

$$\frac{P_i C_d V}{V_2}$$

When the burst disk ruptures, the flow rate out of the tank has to be calculated and compared to the flow rate into the chamber. This is done iteratively using an Excel spreadsheet.

Flow out of the vacuum chamber is subsonic:

$$W = C_d A P_1 \sqrt{\frac{2Kg}{(K-1)TR}\left(\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}\right)}$$

Therefore the total change in pressure is **$dP/dt = (W_{in}-W_{out})RT/V_2$**.

This equation is solved iteratively by incrementing the time interval dt

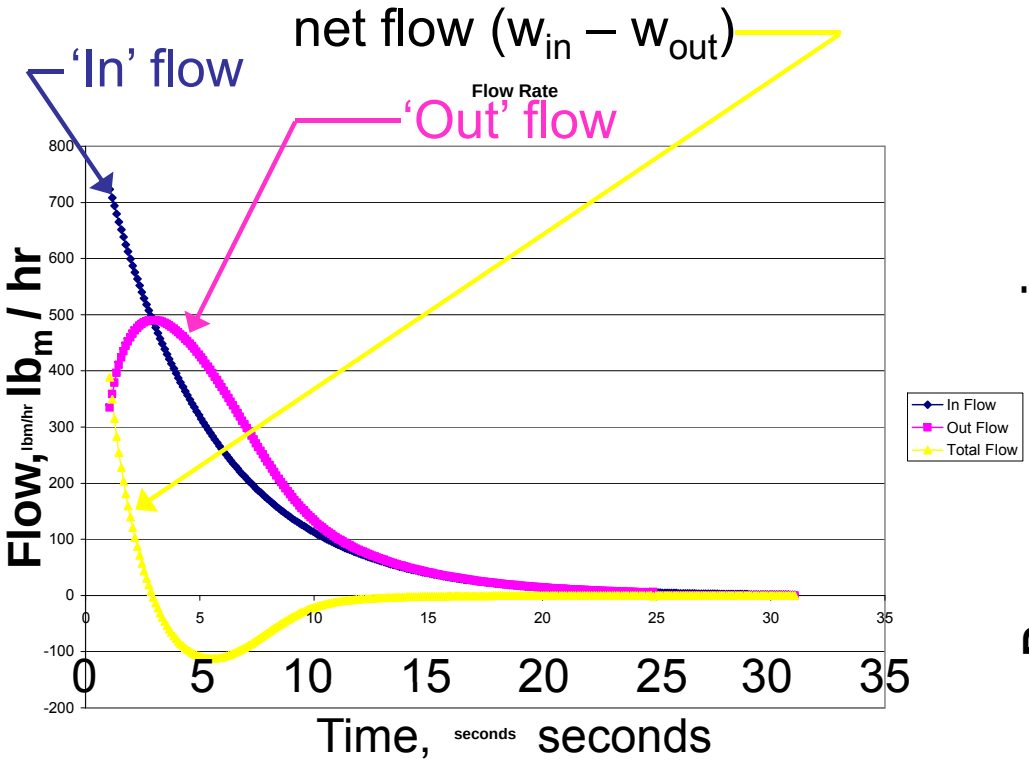
Excel output

Example:

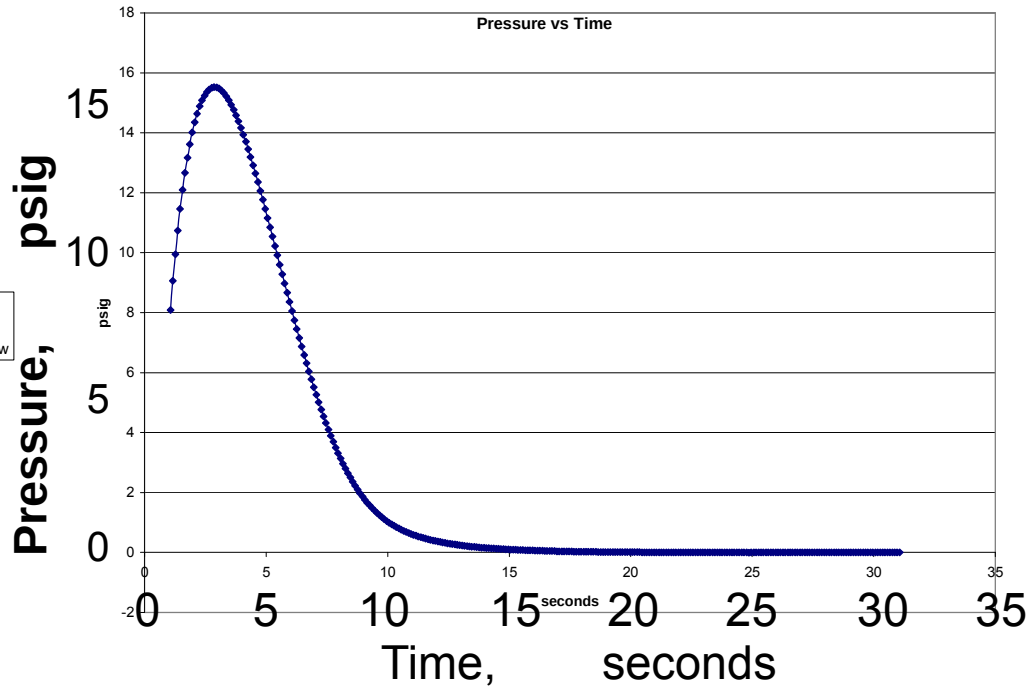
Burst disk opens at ~1 second after tank pressure regulator fails

Time	Flow Rate In	Flow Rate Out	Total Flow	Change in Pressure	Pressure in Vessel	Gage Pressure
s	lb_m/hr	lb_m/hr	lb_m/hr	dP	psia	psig
1.0609933	723.14719	334.47303	388.67416	1.0886475	23.088648	8.0886475
1.1609933	708.25631	358.65351	349.6028	0.9792116	24.067859	9.0678591
1.2609933	693.67207	378.90852	314.76355	0.8816294	24.949488	9.9494885
1.3609933	679.38814	396.12494	283.2632	0.7933992	25.742888	10.742888
1.4609933	665.39834	410.89918	254.49917	0.7128333	26.455721	11.455721
1.5609933	651.69662	423.65499	228.04163	0.6387277	27.094449	12.094449
1.6609933	638.27704	434.70619	203.57085	0.5701869	27.664636	12.664636
1.7609933	625.13379	444.29274	180.84105	0.5065224	28.171158	13.171158
1.8609933	612.26118	452.60299	159.6582	0.4471908	28.618349	13.618349
1.9609933	599.65365	459.80525	139.8484	0.391705	29.010054	14.010054
2.0609933	587.30572	466.0987	121.20703	0.3394919	29.349546	14.349546
2.1609933	575.21207	471.55324	103.65882	0.2903407	29.639886	14.639886
2.2609933	563.36744	476.21809	87.149348	0.2440989	29.883985	14.883985
2.3609933	551.76671	480.13998	71.626733	0.2006212	30.084606	15.084606
2.4609933	540.40486	483.36332	57.041545	0.1597691	30.244376	15.244376
2.5609933	529.27697	485.93029	43.346679	0.1214108	30.365786	15.365786
2.6609933	518.37823	487.88098	30.49725	0.0854205	30.451207	15.451207
2.7609933	507.70391	489.25341	18.450495	0.0516785	30.502885	15.502885
2.8609933	497.24939	490.08372	7.1656705	0.0200705	30.522956	15.522956
2.9609933	487.01015	490.40619	-3.396039	-0.009512	30.513444	15.513444

Flow Graphs



Flow rate vs. time



Vacuum vessel pressure vs. time

4. Get Ntl Board-certified, UHV compatible press relief

MDC Introduced certified UHV Burst Disks:

- UHV compatible all-metal construction
- ASME UD certified
- 10CFR851 compliant
- Pressure relief range 9 to 11.5 PSIG
- Leak tight to 2 x 10^{-10} std. cc/sec He
- 316 Stainless steel body & membrane
- Bakeable to 450°C
- Compact design w/ no moving parts
- Calculated Flow rates
  - 107 SCFM on 1.33” flange
  - 435 SCFM on 2.75” flange

Further Actions

Ad-hoc Intra-Lab committee formed by W. Casey to develop 10CFR851 interpretation

Issues:

- Vacuum/Press vessels categorized
  - Type 1: vacuum vessel w/ no internal press sources
  - Type 2: vacuum vessel w/ <15psi press relief
  - Type 3: others (incl those exempt from ASME code)
- Equivalence- what is req'd?
  - Inspection & QA
- Lower bound threshold for stored energy
  - 100,000 joules (~35 ft^3) proposed
- Interpretation S/B submitted to U.S. DOE soon

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