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Short Course Agenda

- Part 1 8:45 – 10:30AM
  - Introduction
    - Safety and Cryogenic Fluids
    - Cryogens of Interest to SLAC
  - General Safety Topics
    - Physiological Hazards
    - Materials and Construction
    - Over-pressurization, Explosive and Flammability Hazards
    - Personnel and Operational Awareness
  - Material Safety Data Sheets
- Part 2 10:45 – Noon
  - Cryogenic Design and Safety Equipment
    - Design Considerations
    - Cryogenic Relief Valves
    - Rupture/Burst Devices
    - Venting of Facilities and Systems
    - System Monitoring
  - Problems of Interest
  - Summary

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Short Course on Cryogenic Safety
Part 2. - Cryogenic Design and Safety Equipment

- Design Considerations
- Cryogenic Relief Valves
- Burst Discs
- Venting of Facilities and Systems
- System Monitoring

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Cryogenic Storage System are Available in all Shapes and Sizes

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- **Cryogens require specialized storage containers to maintain any kind of shelf life (system boil-off time > minutes)**
  - **Commonly known as "Dewars"!**
- **Storage containers range in size from 1 Liter to 42,000,000 gallons**
- **Economics and <u>Safety</u> determine best container design**
  - **Rate Loss (Heat leak)**
  - **Weight**
  - **Materials of Construction (System Compatibility)**
  - **Insulation System (Dependent upon life requirements)**
  - **Specialized Requirements (dynamic environments, etc.)**
- **Many standard designs are available through a variety of suppliers and manufacturers**

Construction Features of a Conventional Cryogenic Dewars are Pretty Standard

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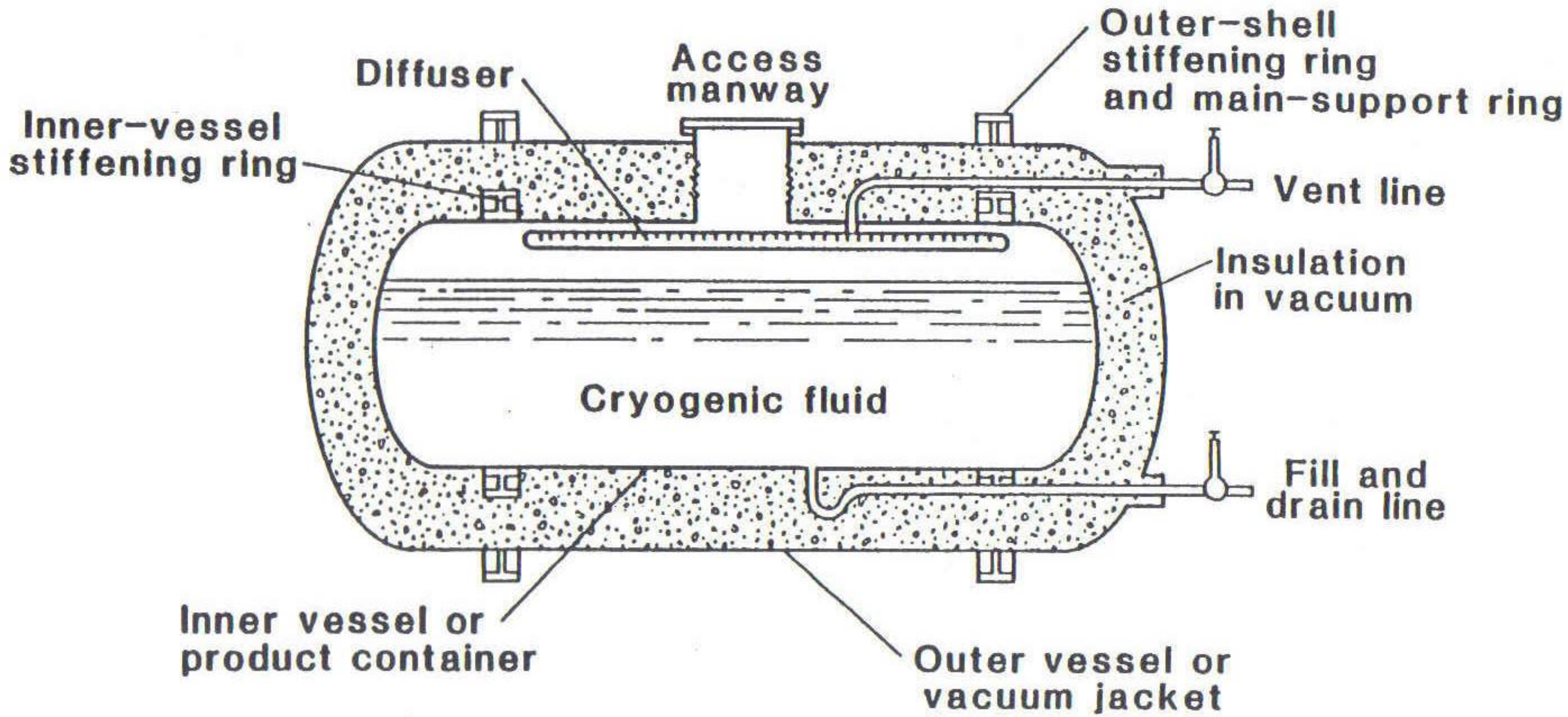

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Establishment of Allowable Working Pressures is Critical in the Safety Design

- **Know as Maximum Expected Operating Pressure (MEOP) or Maximum Allowable Working Pressure (MAWP)**
- **Design practices should follow the appropriate ANSI and ASME requirements**
  - **Departure from these requirements will affect how these units are to be used; research vs. aerospace vs. commercial**
- **All systems require testing**
  - **Hydrostatic (1.25 to 1.5 times MAWP)**
  - **Burst testing (minimum of 2.5 times MAWP)**
- **Appropriate inspections techniques**
  - **Leak checks (soap, decay, mass spec, etc)**
  - **NDI (X-ray, dye penetration, etc,)**

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Making Sure System is Tight Will Save Lives and Equipment.

- **Table below gives the open line thrust force as a function of tube diameter. To calculate the force acting on line opening, select the applicable diameter and multiply the right-hand column by the source pressure in psi.**

Diameter Opening, inches	Calculated force factor for each psi of source pressure
1/8	0.18506
1/4	0.2832
3/8	0.3814
1/2	0.4796
5/8	0.5777
3/4	0.6759
7/8	0.7741
1	0.8723

- **Example: 1" inch at 2000 psi has a thrust force of 1750 psi**
- **Note: "Empty" lines under pressure can be hazardous**
- **Oh yes, one other thing "Do Not Walk on Flex Hoses!"**

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Keep your systems in good shape!

- **All cryogenic systems should be inspected regularly to ensure that all components are in good working order and are not showing signs of wear or failure.**
- **Any questionable components should be removed from the system for checking and possible repair.**
- **New components or vessels and equipment taken out of service for maintenance (scheduled or unscheduled) should follow this suggested procedure during re-installation back into system:**
  - **Thoroughly clean**
  - **Perform cold-shock tests at nitrogen temperature**
  - **Perform leak checks after cold shock**
  - **Inspect all maintenance records**
  - **Verify component is still well within its usable life, including fatigue**
  - **Keep environment clean during installation**

Cryogenic Vessel/Dewar/Tank Safety Devices

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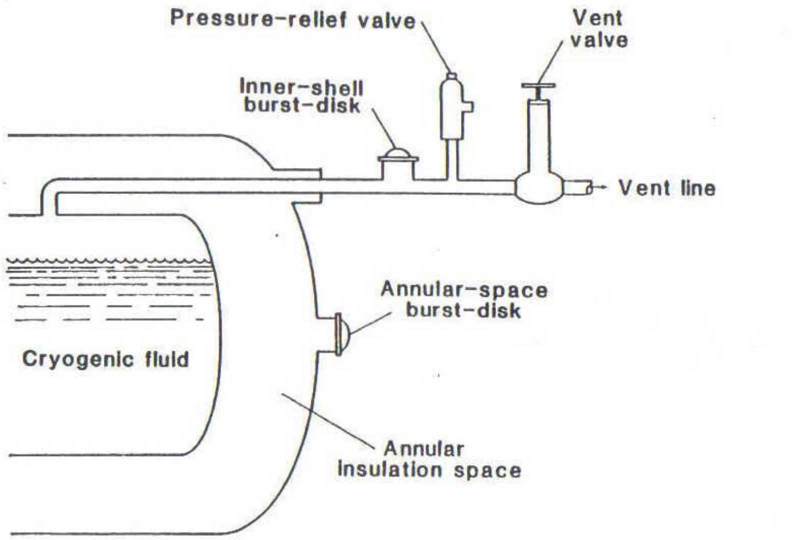
- **Most probable malfunction is overpressure of inner vessel or transfer line**
- **Every dewar that can be sealed off with valves, or somehow be isolated, must be equipped with at lest one if not two pressure relief devices**
  - **Safety devices provide necessary insurance against catastrophe**
  - **Inner vessel should be hydrostatically or pneumatically tested to 1.5 - 2.0 times working pressure**
- **ASME code requires two safety devices**
  - **Pressure relief set to 1.1 times working pressure**
  - **Rupture system to burst at 1.2 times working pressure**



Redundant Relief Device Design Requirements

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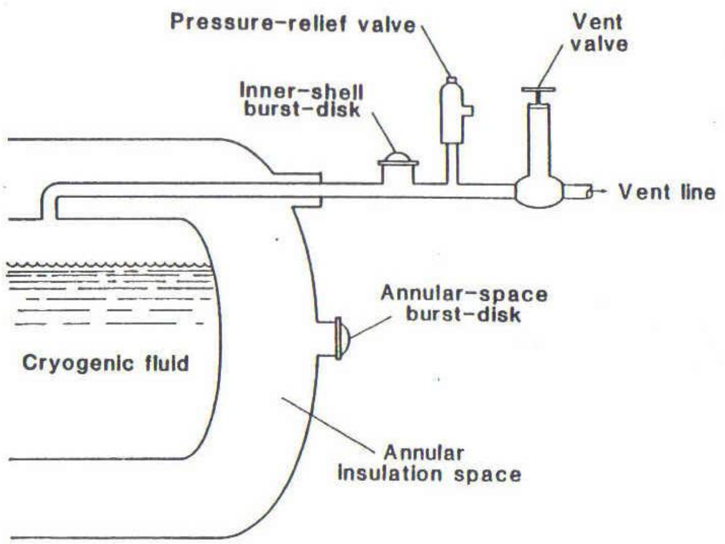
- **Relief valves and burst disks are often used in combination**
- **Each device must be sized to handle the flow requirements of the entire vessel**
- **Redundant relief valves are preferred for some test articles and flight hardware because they seal after relieving, minimizing hardware impacts**



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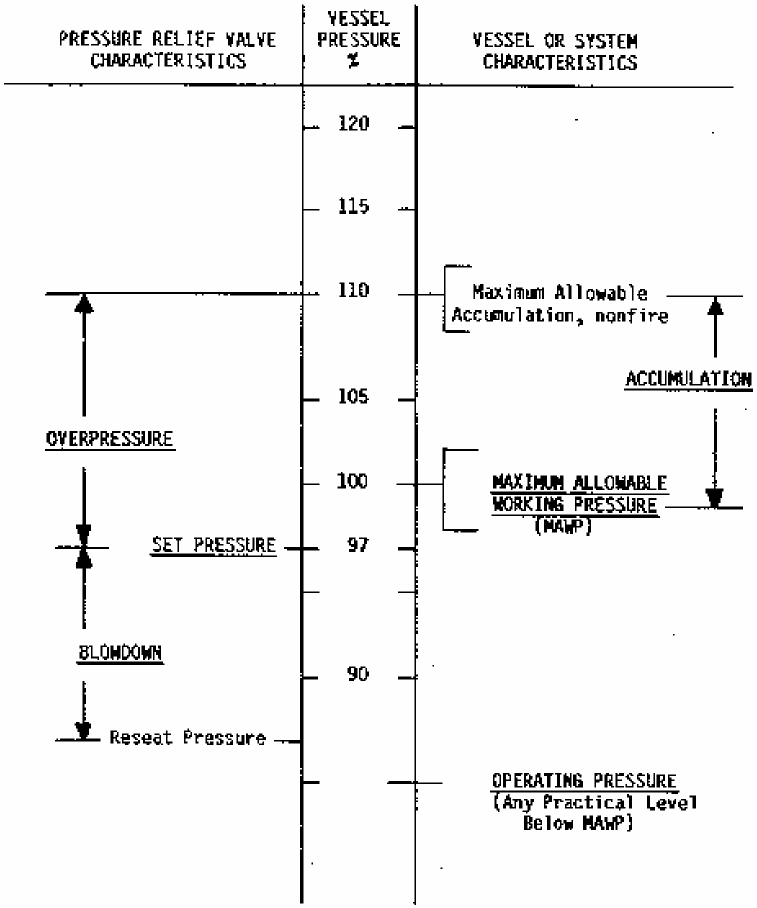
Relief Device Basics

- **Relief valves used as a safety device relieve overpressure conditions**
- **Cracking pressure can be set to meet customer requirements**
- **Will reseat after the pressure drops below the reseating pressure**
- **Can leak at cryogenic temperatures and may not reseat properly**
- **Types are:**
  - **Relief Valves**
  - **Rupture/Burst Discs**
  - **Rupture Pins (aka breaking or buckling pins)**



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The Requirements have been established and Tested Over Time

- **General Code requirements include:**
  - **ASME Boiler & Pressure Vessel Codes**
  - **ASME B31.3 / Petroleum Refinery Piping**
  - **ASME B16.5 / Flanges & Flanged Fittings**

The Code Requirements are Clear and for Your Safety

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- **All pressure vessels subject to overpressure shall be protected by a pressure relieving device**
- **Liquid filled vessels or piping subject to thermal expansion must be protected by a thermal relief device**
- **Multiple vessels may be protected by a single relief device provided there is a clear, unobstructed path to the device**
- **At least one pressure relief device must be set at or below the MAWP**

- **Relieving pressure shall not exceed MAWP (accumulation) by more than:**
  - **3% for fired and unfired steam boilers**
  - **10% for vessels equipped with a single pressure relief device**
  - **16% for vessels equipped with multiple pressure relief devices**
  - **21% for fire contingency**

<ins>All</ins> devices must be able to handle maximum expected flow rates for the case analytical condition of over-pressurization.

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What We Want to Work and Work Again

- **Cryogenic Relief Valves Basics**
  - Set points are adjustable
  - Can be reused and re-calibrated, if required
  - Are testable to verify operational requirements are met
  - Are required to be keep at ambient temperature (Code)
  - Must be sized to meet the full flow environment
  - Outlet must be equal to or greater than inlet to ensure that flow is not restricted
  - Installation should be made so as not to pool liquids

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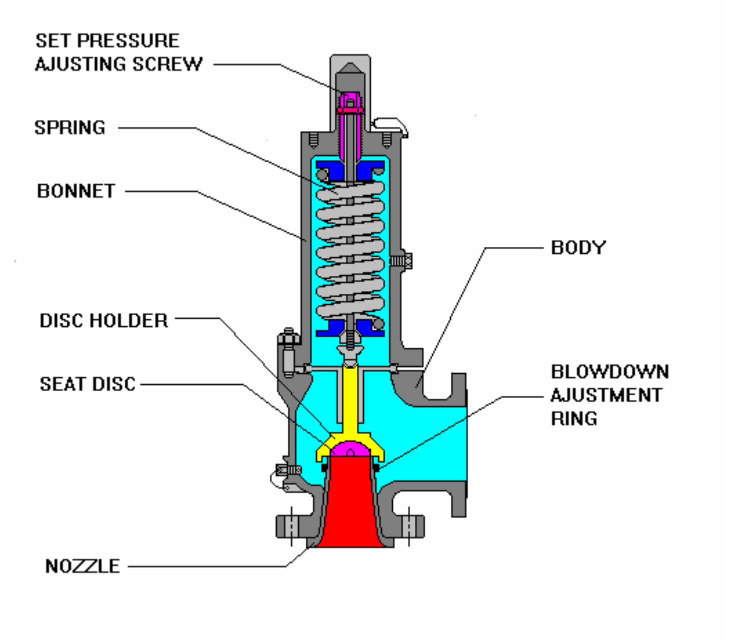
The Old Stand-by Is Still Carrying a Majority of the Load

- **Direct acting type**
  - **Oldest and most common**
  - **Kept closed by a spring or weight to oppose lifting force of process pressure**



Advantages

+ Most reliable type if properly sized and operated

+ Versatile -- can be used in many services

Disadvantages

- Relieving pressure affected by back pressure

- Susceptible to chatter if built-up back pressure is too high

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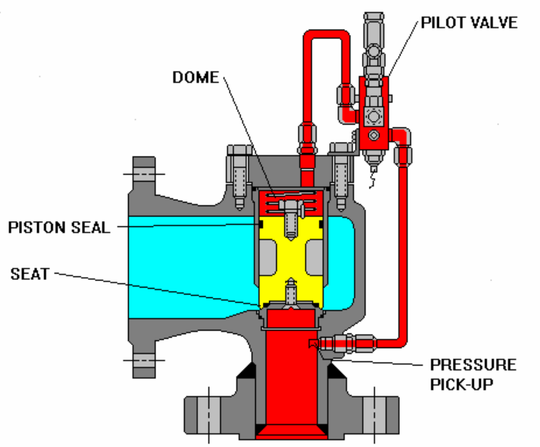
The Pilot Operated Relief Valve is a Close Second in Popularity

- Pilot operated type
  - Kept closed by process pressure



- Advantages
  - Relieving pressure not affected by backpressure
  - Can operate at up to 98% of set pressure
  - Less susceptible to chatter (some models)
- Disadvantages
  - Pilot is susceptible to plugging
  - Limited chemical and high temperature use by “O-ring” seals
  - Vapor condensation and liquid accumulation above the piston may cause problems
  - Potential for back flow

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What you have all Seen Before!

Conventional PRV

Piston Type Pilot Operated PRV

A Few Words about Relief Valve Chatter are Needed

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- What is it?
  - Chattering is the rapid, alternating opening and closing of a PR Valve.
  - Resulting vibration may cause misalignment, valve seat damage and, if prolonged, can cause mechanical failure of valve internals and associated piping.
  - Chatter may occur in either liquid or vapor services
- What causes it?
  - Excessive inlet pressure drop
  - Excessive built-up back pressure
  - Oversized valve
  - Valve handling widely differing rates

A Few Words about What Can We Do with Chatter?

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- If you can't change the piping
  - Increase blowdown
  - Install smaller PRV
  - Install different type of PRV
- Excessive outlet pressure will also cause chatter.
  - Avoid
    - Long outlet piping runs
    - Elbows and turns
    - Sharp edge reductions
  - But if you must
    - Make outlet piping large!
- Oversized valve
  - Must flow at least 25% of capacity to keep valve open
  - Especially bad in larger sizes
- Valve handling widely differing rates
  - Leads to oversized valve case
- Use a number of PRVs and stagger set points

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Ok, Another Option are Rupture/Burst Devices, They Are?

- Burst (rupture) disks are non-closing relief valves
- They must all requirements the closing relief valves do
- Provide instantaneous unrestricted pressure relief
- They form a vacuum tight seal
- Several different types are available
- Installed in a warm zone to avoid temperature fluctuations
- Premature failure of rupture devices can occur from fatigue and creep
- Device failure can create a hazardous condition; replacement requires emptying and purging the vessel
- Installation considerations when upstream of PRV
  - Device operates at less than MAWP
  - Device failure of leakage detection is in place
  - Device failure cannot interfere with PRV operation
  - Sizing is correct for system

The Comparison of Rupture Devices to PRVs

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- Advantages
  - Protect against rapid pressure rise cased by sudden increase of heat into the cryogenic
  - Less expensive to provide corrosion resistance.
  - Less tendency to foul or plug.
  - Provide both over pressure protection and depressurizing.
  - Provide secondary protective device for lower probability contingencies requiring large relief areas.
- Disadvantages
  - Don’t re-close after relief.
  - Burst pressure cannot be tested.
  - Require periodic replacement.
  - Greater sensitivity to mechanical damage.
  - Greater sensitivity to temperature

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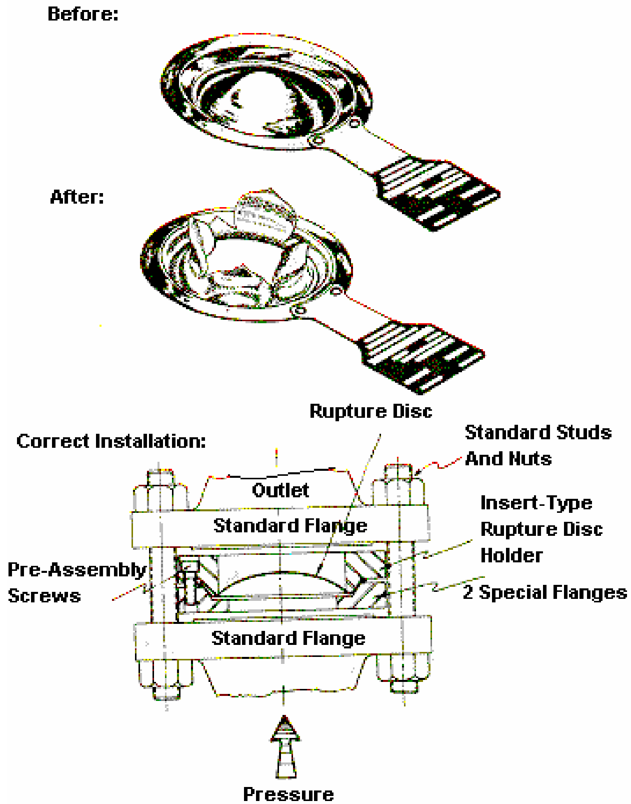
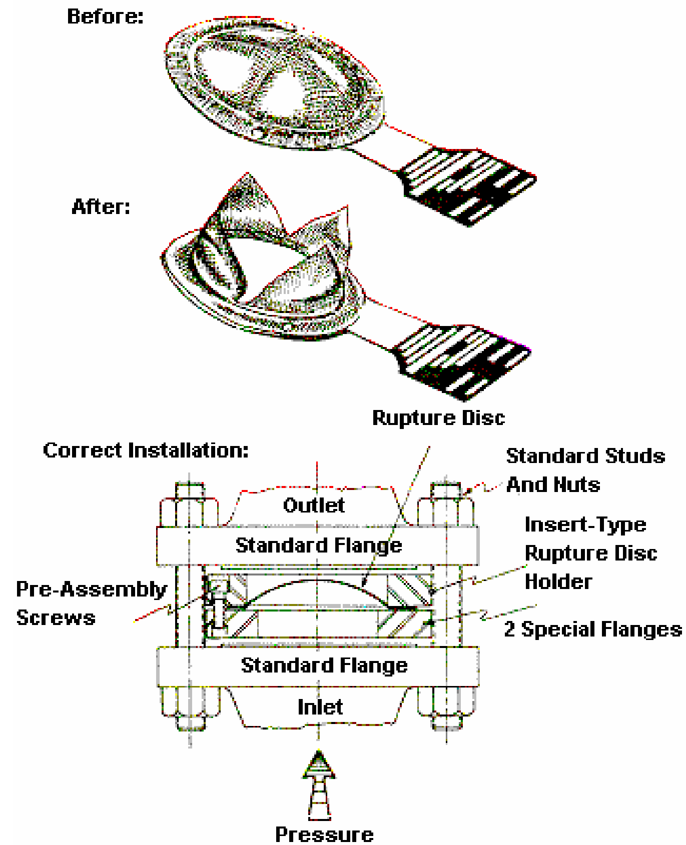
Conventional Tension-Loaded Metal Rupture Disc



Pre-Scored Tension - Loaded Rupture Disc



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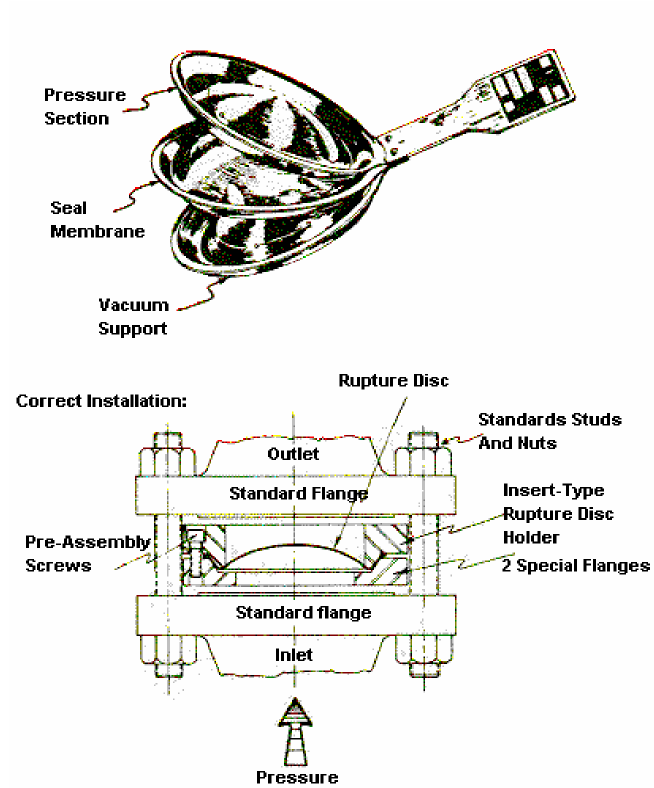
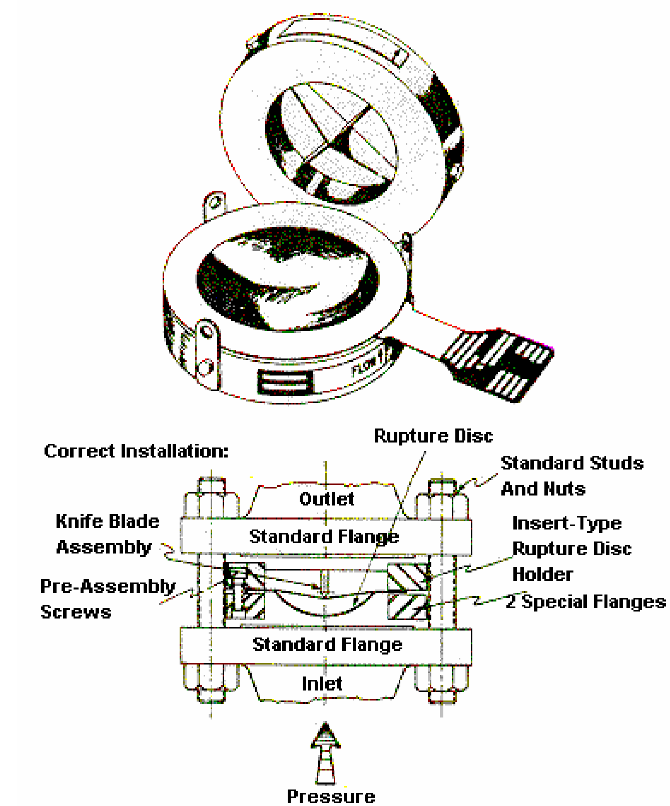
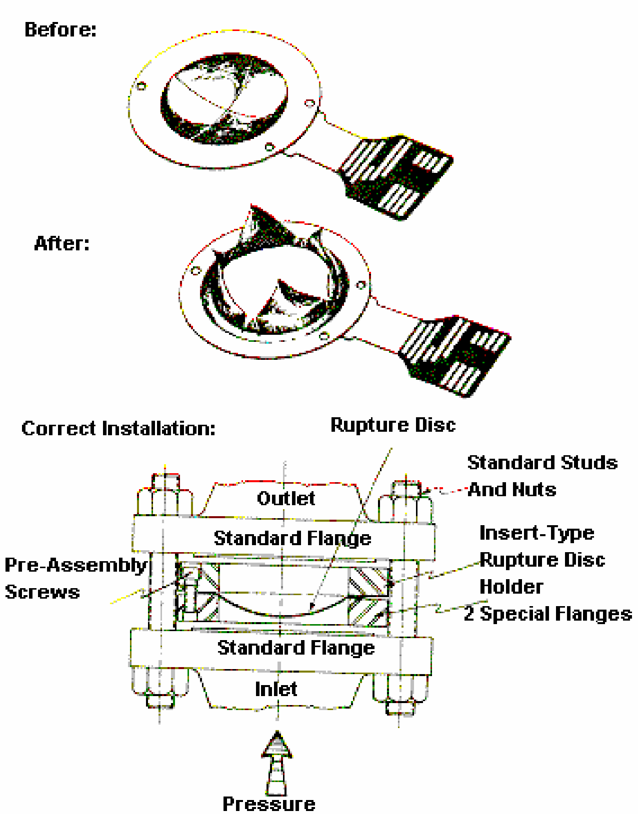
Composite Rupture Disc



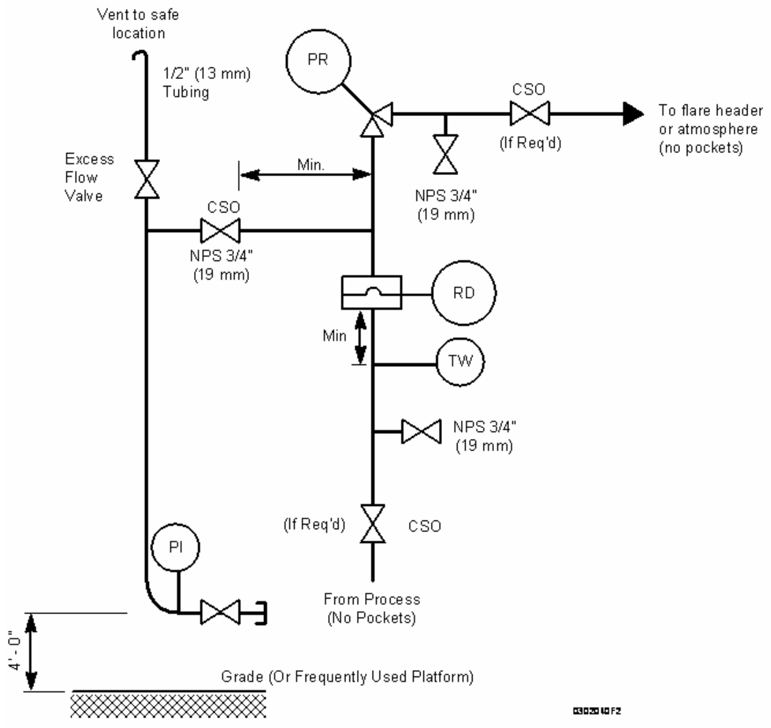
Reverse Buckling Rupture Disc With Knife Blades



Pre-Scored Reverse Buckling Rupture Disc



Typical RD/PRV Installation



Vacuum Jacket Burst Disc Placement

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Rupture Pins are One of the Devices in This Category

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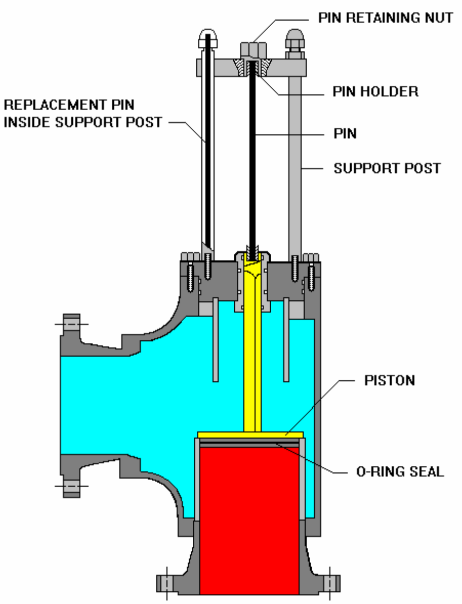
Advantages

- Not subject to premature failure due to fatigue
- Can be operated closer to its set point
- Set point is insensitive to operating temperature
- Available as balanced or unbalanced device
- Capable of operating as low as 0.1 psig
- Suitable for liquid service
- Resetting after release usually requires no breaking of flanges
- Replacement pins are 1/3 to 1/4 the cost of replacement discs



Disadvantages

- The elastomer o-ring seal limits the maximum operating temperature to about 450ºF (230ºC)
- Initial cost of installation is greater than for a rupture disc
  - twice as costly for 2” carbon steel
  - up to seven times as costly for 8” stainless steel

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Typical Cryogenic Industrial Station

Placement and Handling of Cryogenic Vents

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- **Never vent large systems into a closed space.**
  - Always route to outside in an unoccupied area
  - Smaller laboratory dewars and transfer are generally OK however you should always be aware.
- **Due to leakage considerations, always maintain a positive flow of "clean" air into a facility using cryogenic fluids**
- **Always design vents with protection from rain/weather into the vent system**
  - Rain water will collect in vents and when used freeze vent shut!
- **Establish facility HVAC requirements for operations which occur; e.g. over-pressurization in laboratory, rupture of a transfer line or burst disc, etc.**

Vent from LN2 Heat Exchanger on Sea Launch Vessel

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LH2 Vent System

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System and Valve Health and Well Being

- **How do you want valves to fail? Open or closed?**
  - Latching versus non-latching
- **What is system doing?**
  - Position indicators
  - Temperature sensors
  - Heater currents
  - Accelerometers
  - Others?
- **Determining the maximum operations tempo of system and components is important**
- **Remotely operated components require a monitoring**
  - Many types of controller options, too many for this class
- **Got to table top and get buy in from all on procedure/operations**

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Short Course on Cryogenic Safety
Part 2. – Problems of Interest

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One Relief Valve Discharge Area Calculation Method

The basic minimum safety devices used on larger cryogenic-fluid storage vessels include: (1) the inner-vessel pressure-relief valve, (2) the inner-shell burst-disc assembly, and (3) the annular-space burst-disc assembly.

The inner-vessel pressure-relief valve is generally a spring-loaded safety valve set so that the gauge pressure within the inner vessel can never exceed the design gauge pressure by more than 10 percent, where the gauge pressure is equal to the absolute pressure minus atmospheric pressure. This safety device is installed so that excessive pressures within the inner vessel may be relieved before damage to the inner vessel can occur. The capacity of the safety valve is determined from the rate of vapor boil-off that would occur if the annular-space vacuum were lost. The required size of the safety valve is determined by the ASME Code by

$$A_v = \dot{m}_s (R_u T / g_c M)^{1/2} / C K_D p_{\max}$$

where A_v = discharge area of valve

$\dot{m}_s$ = maximum mass flow rate through valve

R_u = universal gas constant

T = absolute temperature of the gas at the inlet to the valve

M = molecular weight of gas flowing through the valve

g_c = unit conversion factor in Newton's Second Law = 1 kg-m/N-s²

K_D = discharge coefficient determined by test

$p_{\max}$ = (set gauge pressure)(1.10) + (atmospheric pressure)

$$C = \left[\gamma \left(\frac{2}{\gamma + 1} \right)^{(\gamma+1)/(\gamma-1)} \right]^{1/2}$$

$\gamma = c_p / c_v$ = specific heat ratio of gas

Another Approach to Determining Discharge Area

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$$\Delta P_{system} = \left(Q^2 \left(G \left(\frac{\left(\frac{12fL}{D}\right) + N}{\left(890.6\, D^4\right)} \right) \right) + \left(\frac{Q^2 G}{\left(1444\, Kd^2\, A^2\right)} \right) \right)$$

and

$$\Delta P_{piping} = \left(Q^2 \left(G \left(\frac{\left(\frac{12fL}{D}\right) + N}{\left(890.6\, D^4\right)} \right) \right) \right) \leq 0.15 \Delta P_{system}$$

Where:

ΔP = Differential pressure from inner vessel to relief discharge (psi)

Q = Capacity of filling equipment (US GPM)

G = Specific gravity (G for water = 1.0)

f = Piping friction factor (0.02 is reasonable)

L = Piping length (ft)

D = Piping inside diameter (in)

N = Number of velocity head losses for all fittings and valves

Kd = Coefficient of discharge (0.62 for disks)

A = Relief device orifice area (in^2)

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Setting of Pressure Relief Points as Well as Flow Rating of PRD

In U.S. customary units:

Set or flow rating pressure in psig where MAWP shall be in psig =

$$\frac{(\%\,\text{Factor})(\text{MAWP})}{100} + \frac{(\%\,\text{Factor})(14.7)}{100} - 14.7$$

In metric units:

Set or flow rating pressure in kPa where MAWP shall be in kPa =

$$\frac{(\%\,\text{Factor})(\text{MAWP})}{100} + \frac{(\%\,\text{Factor})(101)}{100} - 101$$

Example: Let MAWP = 200 psig (1379 kPa); set pressure = 110% of MAWP; and flow rating pressure = 121% of MAWP for a PRD on a vacuum-insulated container.

Then in U.S. customary units:

Set pressure, psig $= \frac{110}{100}(\text{MAWP}) + \frac{110}{100}(14.7) - 14.7$

$= \frac{110}{100}(200) + 16.17 - 14.7$

$= 221.47$

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Part 2. – Summary