NATIONAL ACCELERATOR LABORATORY

ENVIRONMENT, SAFETY & HEALTH DIVISION

Chapter 14: Pressure Systems

Design and Construction Requirements

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1 Purpose

The purpose of these requirements is to ensure that pressure systems are designed and constructed in strict adherence to the pressure systems requirements of Cal/OSHA (8 CCR), applicable codes and standards, and sound engineering principles. They apply to design engineers when they design a new *conventional* or *scientific* pressure system or modify or alter any existing system, including legacy systems; to persons responsible for determining design specifications; and to the Building Inspection Office (BIO), Purchasing, and pressure systems program manager.

When conformance to the requirements of national consensus codes is neither possible nor feasible, refer to the Pressure Systems: Alternate Pressure Systems Qualification Requirements to ensure an equivalent level of safety.

2 Requirements

2.1 Design Approval

2.1.1 Review

The design of any new pressure system and modification or alteration of an existing system, including legacy, used at SLAC must be approved by the pressure systems program manager. The design package may be submitted either to

- The pressure systems program manager directly for review before entering another process such as ESH design review or purchasing
- The Building Inspection Office (BIO) if the system requires ESH design review (see the General Policy and Responsibilities: ESH Project Review Procedure); BIO will then submit the package to the pressure systems program manager
- The Purchasing Department, in the form of a purchase requisition, for which approval is contingent on the design having been approved by the pressure systems program manager (see Pressure Systems: Procurement Procedure)

2.1.2 Design Package

In order to be approved, the design must meet all applicable codes and standards and the requirements of this chapter. The design documentation package must include the following:

1. System specifications and drawings identifying design conditions (such as temperature and pressure), material specifications, and fabrication details
2. Design calculations in accordance with the applicable codes, standards, or sound engineering principles
3. Fabrication drawings with details for welding, non-destructive examination, inspection, and testing
4. Stamping information (such as markings and other permanent means of identification)
5. Certification (American Society of Mechanical Engineers [ASME] manufacturer's data report or equivalent) requirements by the fabricator and inspector.
6. When ASME and other national consensus codes cannot be used, see Pressure Systems: Alternate Pressure Systems Qualification Requirements.

2.2 Design Standards

The following is an overview.

2.2.1 Conventional Pressure Systems

All pressure vessels, boilers, and air receivers and supporting piping systems must be designed in accordance with applicable ASME code, which includes the *Boiler and Pressure Vessel Code (BPVC)* Sections I though XII, including applicable code cases and applicable ASME B31 (*Code for Pressure Piping*) standards.

2.2.2 Scientific Pressure Systems

To evaluate and qualify components that were not manufactured under the required national consensus codes, or require modifications not possible within the scope of the approved code, or components that are used in a manner outside the applicability of the code under which they were designed or manufactured, see Pressure Systems: Alternate Pressure Systems Qualification Requirements.

2.2.3 Pressure Vessels

Pressure vessels, tanks, and storage systems are to be designed and installed to comply with applicable ASME, ANSI, and other US codes and standards. (Others will be treated as non-coded, which must meet equivalent safety requirements as provided by the ASME code and this program.)

All the designs will be submitted in accordance with Section 2.1 above for review and approval at the appropriate stages of design (such as conceptual, engineering, and procurement readiness reviews).

- ASME-authorized inspector (AI) required
- Application of ASME BPVC to the applicable equipment
- Non-ASME systems designs verified and approved

2.2.4 Pressure Piping

All piping must be designed, fabricated, tested, and inspected in accordance with the ASME B31 series of codes or other applicable consensus standards. Piping may be designed under other codes if necessary, based on sound engineering judgment and proven work experience.

The design specifications, drawings, lay-out plans, calculations, and stress analysis reports must be submitted for review in accordance with Section 2.1 above.

If a manufacturer or vendor refuses to submit this information on the basis of "proprietary item or trade secret", that manufacturer or vendor will submit documents to that effect, and secure prior approval from SLAC.

2.2.5 Pressure Relief Devices

Adequate relief valves must be installed for all vacuum and pressure vessels, piping and also for any cryogenic lines that have the potential to trap cryogenic fluids.

Relief valves must be sized so that under worst-case failure conditions, the maximum potential pressure or vacuum reached in any system is below the maximum safe working pressure (MSWP) for the vessel, piping or components.

The worst-case failure condition is the maximum pressure or vacuum achievable from the source pumps, cylinders, dewars, and so on.

No fixed prescription can be given to determine valve sizing for all, or even most cases. Each system must be analyzed in detail to properly determine worst-case failure modes and the required relief valve sizing. Relief device calculations must be performed in according to ASME, American Petroleum Institute (API), or Compressed Gas Association (CGA) standards and appropriate published studies on vacuum failures on helium cryogenic systems.

2.3 Construction Specifications

The design engineer must specify construction requirements as follows.

2.3.1 Materials

The design engineer must follow ASME code material specifications for material type and grade (or supply equivalent specifications). Materials must be specified as new.

Material test reports for the following components must be specified:

- All pressure-containing parts
- All internal parts welded directly to a pressure containing part
- Main support material (skirt/lugs)
- Major supporting piping

Material test reports must be clearly identified with the part number for which the material was used and show cast or heat numbers, chemical analysis, and mechanical properties.

2.3.2 Fabrication

The design must specify fabrication requirements according to ASME code or its equivalent, including the following:

- All cylindrical parts must be round in accordance with the ASME *Boiler and Pressure Vessel Code* or ASME *Code for Pressure Piping*. Reforming for out-of-roundness must be performed before any assembly or radiography.
- Cleanliness (free from dirt, grease, paint, and other foreign matter) during hot forming, heat treating, or welding operations must be carefully monitored and maintained. Solvents used to clean or remove scale or oil must be free from organic and inorganic chlorides and sulfides.
- Level of qualification required to perform examinations and inspections of materials, in- process fabrications, non-destructive tests, and acceptance test
- Pressure testing requirements in accordance with the code under which the system was designed
- Vessels only: each plate must be legibly stamped or stenciled showing material grade number and plate number. When metal stamping is done on plate it will preferably be on the long edge of each component.

2.3.3 Stamping

The design engineer must specify stamping requirements according to the ASME code or equivalent as follows.

Each pressure vessel must be stamped with information required by the applicable code of construction. The information must include design pressure, design temperature, capacity, fabricator's name, year of manufacture, and manufacturer's serial number. In addition, the ASME certification mark must be stamped as shown in Figure 1 with the appropriate designator under the certification mark.

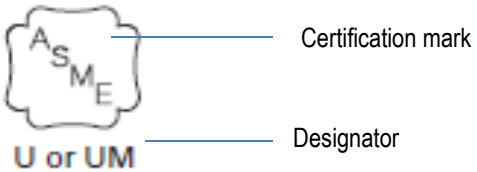

Figure 1 ASME Certification Mark with Designator U or UM

ASME certification marks will have the following designators for boilers and pressure vessels

- S power boiler
- E electric boiler
- H heating boiler
- HLW lined potable water heater

- U pressure vessel
- UM miniature pressure vessel

2.3.4 Certification

The design engineer must specify certification requirements according to the ASME code or equivalent as follows. A manufacturer's data report (MDR) is required for each pressure vessel.

- An ASME MDR is required if the vessel is designed and stamped under ASME code. ASME MDR forms include the following:
  - P-2 Manufacturer's Data Report for All Types of Boilers except Watertube and Electric (BPVC Section 1)
  - H-2 Manufacturer's Data Report for All Types of Boilers except Watertube and Those Made of Cast Iron (BPVC Section 4)
  - U-1 Manufacturer's Data Report for Pressure Vessels (BPVC Section 8, Division 1)
  - U1-A Manufacturer's Data Report for Pressure Vessels (Alternative Form for Single Chamber, Completely Shop- or Field-Fabricated Vessels Only) (BPVC Section 8, Division 1)
- For non-ASME pressure vessels, a fabricator's certificate of compliance confirming that the pressure system has been designed and constructed according to SLAC's specifications and stamping is required.

2.4 Additional Requirements for Cryogenic Systems

A *cryogenic system* is considered a pressure system. Therefore, all of the above requirements for pressure systems, including for design packages, apply. The following are additional requirements specific to cryogenic systems.

Cryogenic hazards in cryogenic plants include the potential for oxygen deficient atmospheres due to catastrophic failure of the cryogenic systems, thermal (cold burn) hazards from cryogenic components, pressure hazards, and electrical hazards. Initiators could include the failure/rupture of cryogenic systems from overpressure, failure of insulating vacuum jackets, mechanical damage/failure, deficient maintenance, or improper procedures.

2.4.1 Cryomodules and Components

Cryomodules may be considered as a pressure system. The following describes a basic approach, with ramifications for design, manufacturing, and testing, that results in compliant pressure systems:

- Designate each circuit within a cryomodule as a pressure system
- Define a separate design pressure and temperature for each circuit
- Utilize material properties at 2 K (or other operating temperature) where appropriate
- Provide inspection that is conducted by an independent representative
- Apply ASME BPVC and/or B31.3 as appropriate. This results in components that comply with appropriate consensus standards but do not require an ASME code stamp.

In case of a non-ASME-compliant cryomodule, a complete traveler is required to be developed, documenting all stages of material inspection, cryomodule component fabrication, piping and weld inspection, cryomodule assembly, leak checking, and testing.

All the designs will be submitted in accordance with Section 2.1 above for reviews and approval at the appropriate stages of design (such as conceptual, engineering, and procurement readiness reviews).

2.5 Additional Requirements for Vacuum Systems

A vacuum vessel can pose a potential hazard to personnel and equipment from collapse, rupture due to back-fill pressurization, or implosion due to vacuum window failure. It is important to design, fabricate, and operate vacuum systems in accordance with applicable codes and sound engineering principles.

The above requirements for pressure systems, including for design packages, apply. The following are additional requirements specific to vacuum systems.

2.5.1 Vacuum System Classification

Any new or legacy vacuum system that must be brought into compliance, as described above, must be categorized as follows.

- Category I. Category I vacuum vessels include all vessels in which the differential operating pressure can never exceed 15 pounds per square inch (psi).
- Category II. Category II vacuum vessels include all vessels that can be protected from pressurization exceeding 15 psi through such engineering controls as pressure relief devices.
- Category III. Category III vacuum vessels include all vacuum vessels that are not or cannot be protected from pressurization exceeding 15 psi.

2.5.2 Shielding Requirements

The type of component most likely to fail catastrophically in a vacuum system is a brittle component such as a view port (window), glass bell jar, glass ion gauge, glass or plastic vessel, or glass or brittle plastic tubing. Component failure can be caused by, for example, an inadvertent blow or a scratch by a hard, sharp object and can produce sharp-edged shrapnel.

Protective barriers may be used to reduce the likelihood of injury to personnel and damage to equipment. Some common shielding strategies include

- Placing mechanical protective shielding around components such as glass or brittle plastic tubing and glass ion gauges
- Operating a system within a hood with the hood door down (size permitting)
- Operating the system behind or within a polycarbonate (for example, Lexan) or metal shield
- Wearing personal protective equipment (PPE) such as safety glasses or a face shield
- Glass viewports in Category III systems should be protected when not in use. A common strategy is to fasten a polycarbonate cover over the viewport. View ports in Category I and II systems may be protected with clip-on polycarbonate covers if desired.

2.5.3 Protecting the System from Overpressure

A second common cause of catastrophic vacuum vessel or system failure, particularly if there are brittle components, is the inadvertent application of internal pressure. Such pressure may be realized as a result of

- Failure of a valve or regulator that is connected to the backfill source
- Pressure generated by a chemical reaction involving reactive gases
- Pressure realized by the accidental connection of the exhaust port of a fore pump to the inlet of the vacuum system. The vacuum pump inlet and outlet should be labelled to avoid switched connections.

Components that can protect a vacuum system that must be purged or backfilled with a high-pressure source capable of causing the system to exceed the *maximum allowable working pressure (MAWP)* include

- A safety manifold
- Relief valves
- Burst discs

A burst disk may be incorporated into a vacuum system design to limit the internal pressure to less than 15 psig following any equipment failure. Burst disks must be adequately sized for the credible identified failure mode and must be rated to fail at internal pressures of less than 15 psig in order to defend the system as intrinsically safe. The burst disk must be connected to the vacuum system and must not be isolated from the system by a valve.

2.5.4 Test and Inspection

Most vacuum systems are designed for external pressure and contain components that render an overpressure internal proof test inappropriate. Other means are necessary to document the safety of these systems, and the appropriate method must consider system type, system size (contained energy), system complexity (ease of making errors), and associated hazards.

The following is a partial list of inspection items of special concern:

- General inspection items
  - Check for leaks using the appropriate protocol
  - Ensure that brittle and fragile components are protected to prevent leaks from forming
  - When testing sub-systems, be mindful of unevaluated hazards that would be mitigated in the fully assembled system but may not be mitigated at the sub-system level
- Bellows systems
  - Verify that there is sufficient support at the points of connection so that vacuum force cannot result in an uncontrolled bellows compression and/or injury to personnel

    Vacuum sub-systems with bellows may require additional support against unbalanced atmospheric pressure loads unless the bellows with similar cross-section area are located on opposing sides.
- Kicker-magnet ceramic vacuum chamber
  - Testing before full assembly requires consideration of the overall design in which the fully assembled magnet provides the necessary protection for the fragile subcomponent

- Thin-walled ceramic beam pipes must be checked before installation in a kicker system
- Special care is required during assembly
- Ceramic chambers and metalized joints must never be put in tension or put under torque during assembly or while flanges are bolted

2.6 Additional Requirements for Compressed Gas Systems

A compressed gas system is a pressure system, therefore the above requirements for pressure systems, including for design packages, apply. The following are additional requirements specific to compressed gas systems.

There are two types of systems used at SLAC, compressed gas cylinder and tube trailer systems.

2.6.1 Compressed Gas Cylinder Systems

A compressed gas cylinder system consists of a cylinder and other associated parts such as regulator, pressure relief valve, valves, and fittings. A compressed gas cylinder system is shown in Figure 2.

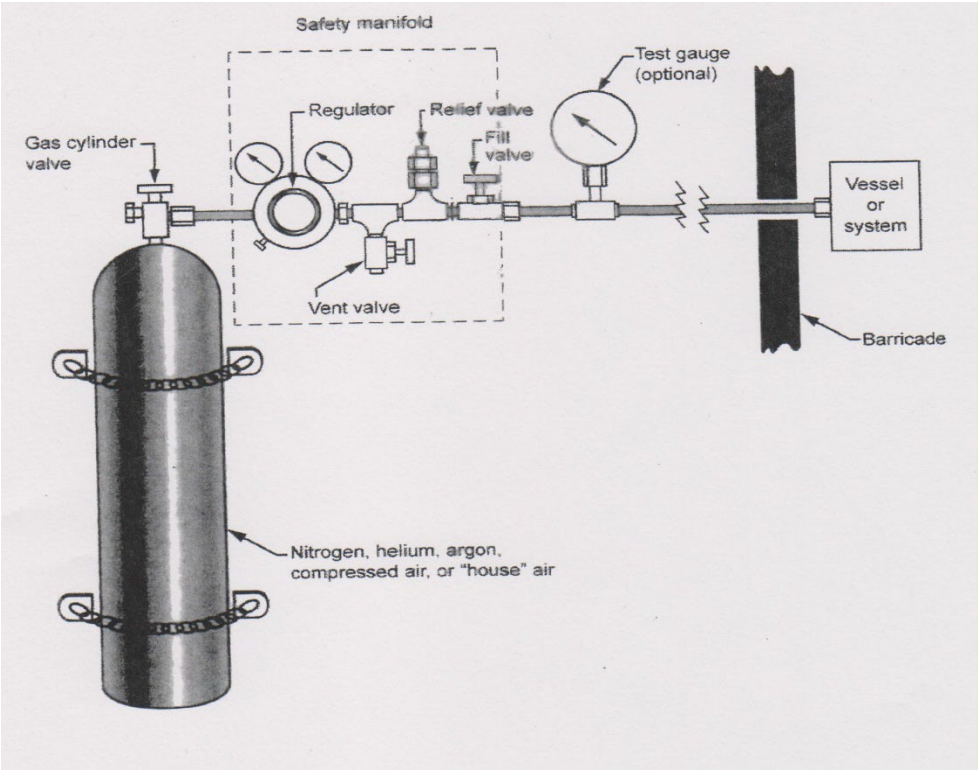

Figure 2 Example Compressed Gas Cylinder System

2.6.1.1 Cylinders

Cylinders for compressed gases are generally defined in US Department of Transportation (DOT) specifications (49 CFR 180.203) as containers having a maximum water capacity of 1,000 pounds or less. This is equivalent to 120 gallons. The DOT regulates the design, testing, filling, and transportation of commercially available gas cylinders.

Generally, cylinder types 3A or 3AA are used for compressed gas systems. Requalification of a cylinder is required every five years per Table 1 in 49 CFR 180.209. The requalifying means an internal inspection and hydrostatic testing of the cylinder at a pressure 5/3 the service pressure of the cylinder. A cylinder that is filled before retest may remain in service until it is emptied of its charge. In other words, a cylinder that currently has a charge when the five-year retest date occurs does not have to be drained of its charge and retested. The charge can be used and the cylinder retested after the charge has been used. (See Pressure Systems: Installation, Inspection, Maintenance, and Repair Requirements for details.)

Identification and Color Coding

Stencils, DOT shoulder labels, cautionary side-wall labels, or tags are used to identify the contents of all gas cylinders. Color codes are not used to identify contents.

Storage and Handling of Cylinders

The safe storage and handling of cylinders, return to vendor, disposing of damaged cylinders, and tags are covered in Chapter 40, “Chemical Lifecycle Management”.

2.6.1.2 Safety Manifolds

A safety manifold (see Figure 2) is required to reduce the pressure from a standard cylinder and provide relief protection (relief device) for the downstream system. The safety manifold consists of a regulator, a vent valve, a fill valve, and a relief valve.

Safety manifolds must

- Be assembled, inspected, and tested by a qualified pressure system mechanic
- Incorporate a means of shutting down or isolating the pressure source
- Address the safe venting of pressure from any and all parts of the system

Regulators

A regulator takes in gas from the cylinder and reduces the pressure to a low working pressure, simultaneously controlling the flow rate. It is important to obtain the correct regulator and ensure it is consistent with the gas involved and operation intended.

- Select a single-stage or double-stage regulator depending on your application.
- Store unused regulators in plastic bags to keep clean.
- Make sure that the threads on the regulator’s CGA connection correspond to those on the cylinder valve outlet.
- Do not lubricate any part of the regulator or cylinder valve.
- Properly label the regulators with the fluid being used.

- Use only oxygen regulators for oxygen service.
- Immediately replace damaged, defective, or unreliable regulators.
- Do not attempt to make repairs or modifications to regulators.
- Inspect regulators at regular intervals, as appropriate to the application.

Pressure Relief Devices

A pressure relief device is used to protect the down-stream system from over pressure. There are two types of pressure relief devices, spring loaded relief valves and rupture or burst discs.

- Whenever possible, use ASME-rated pressure relief devices.
- Never set a relief device above the MAWP of the lowest rated system component it is installed to protect.
- Install relief devices of adequate flow capacity. When the port is full open, the pressure must not exceed 110 percent of the MAWP.

2.6.2 Tube Trailer Systems

A tube trailer with its fittings and accessories is considered a pressure system. Tube trailers consist of 10 to 36 cluster high-pressure cylinders varying in length from 20 feet for small tubes to 38 feet on the jumbo tube trailers. Each tube may contain as much as 3,000 psig of gaseous product. Tubes may be operated as a unit or one at time.

Typical products stored in tube trailers are hydrogen, helium, and argon. All tube trailers are built to comply with DOT regulations for hazardous material safety, federal motor carrier safety, and national highway traffic safety.

The tubular cylinders of the trailers are made according to cylinder specifications 3A, 3AA, 3AX, 3AAX, or 3T. Specifications 3AX, 3AAX, and 3T are used for long, large containers approximately 22 inches in diameter instead of the older 9-3/8-inch tubes that were made to specifications 3A, and 3AA. Tube trailers have been built to carry as much as 180,000 square feet of helium.

Because of their length, pressure relief devices must be installed on both ends of a trailer tube. For flammable gases, each device must be arranged to discharge upwards, unobstructed to the open air, to prevent any impingement of escaping gas upon the other tubes.

Similar to a compressed gas cylinder, requalification of a tube trailer cylinder is required every five years per Table 1 in 49 CFR 180.209. The requalifying means an internal inspection and hydrostatic testing of the cylinder at a pressure 5/3 the service pressure of the cylinder. A cylinder that is filled before retest may remain in service until it is emptied of its charge. In other words, a cylinder that currently has a charge when the five-year retest date occurs does not have to be drained of its charge and retested. The cylinder can remain in service and the cylinder retested after the charge has been used. (See Pressure Systems: Installation, Inspection, Maintenance, and Repair Requirements for details.)

3 Forms

The following forms and systems are required by these requirements:

- An ASME MDR is required if the vessel is designed and stamped under ASME code.
- For non-ASME pressure vessels, a fabricator's certificate of compliance confirming that the pressure system has been designed and constructed according to SLAC's specifications and stamping is required.
- Pressure Systems Database. Database of pressure systems

4 Recordkeeping

The following recordkeeping requirements apply for these requirements:

- The pressure systems program manager retains approved design documents (specifications and/or drawings) (which are submitted to the pressure systems program manager directly or through a related design review process.)

5 References

SLAC Environment, Safety, and Health Manual (SLAC-I-720-0A29Z-001)

- Chapter 14, "Pressure Systems"
  - Pressure Systems: Alternate Pressure Systems Qualification Requirements (SLAC-I-730-0A21S-065)
  - Pressure Systems: Procurement Procedure (SLAC-I-730-0A21C-030)
  - Pressure Systems: Installation, Inspection, Maintenance, and Repair Requirements (SLAC-I-730-0A21S-053)
  - Pressure Systems Safety Program (SharePoint)
- Chapter 1, "General Policy and Responsibilities"
  - General Policy and Responsibilities: ESH Project Review Procedure
- Chapter 40, "Chemical Lifecycle Management"

Other Documents

- Title 10, *Code of Federal Regulations*, "Energy", Chapter 3, "Department of Energy", Part 851, "Worker Safety and Health Program" (10 CFR 851) (as described in SLAC Injury and Illness Prevention Program [SLAC-I-720-0A21B-001])
- Title 49, *Code of Federal Regulations*, "Transportation", Subtitle B, "Other Regulations Relating to Transportation", Chapter 1, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation", Subchapter C, "Hazardous Materials Regulations", Part 180, "Continuing Qualification and Maintenance of Packagings" (49 CFR 180)
- Title 8, *California Code of Regulations*, "Industrial Relations", Division 1, "Department of Industrial Relations", Chapter 4, "Division of Industrial Safety"
  - Subchapter 1, "Unfired Pressure Vessel Safety Orders" (8 CCR 450–560)
  - Subchapter 2, "Boiler and Fired Pressure Vessel Safety Orders" (8 CCR 750–797)

- Title 24, *California Code of Regulations,* "California Building Standards Code"
  - Part 4, "California Mechanical Code" Part 4 (24 CCR Part 4)
  - Part 5, "California Plumbing Code" Part 5 (24 CCR Part 5)
- American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code (BPVC)* (ASME BPVC), including applicable addenda and code cases
- ASME *Code for Pressure Piping* (ASME B31), including applicable addenda and code cases
- Brookhaven National Laboratory. *Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories* (BNL-81715-2008-IR)

Note *See Chapter 14, "Pressure Systems" for a complete list of applicable codes and standards.*