Title

Rules and Procedures for the Design, Installation, and Test of Hazardous Research Equipment

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Publication Date

1988-09-01

RULES AND PROCEDURES FOR THE DESIGN, INSTALLATION, AND TEST OF HAZARDOUS RESEARCH EQUIPMENT

Supplement to
Health and Safety Manual

Lawrence Berkeley Laboratory
University of California
Berkeley, California

September 1988

Prepared for the U.S. Department of Energy
under Contract No. DE-AC03-76SF00098

PUB-3000
Supplement

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Preface

This manual, Rules and Procedures for the Design, Installation, and Test of Hazardous Research Equipment, Supplement to PUB-3000, The LBL Health and Safety Manual, supplants PUB-3001, Rules & Procedures for the Design & Operation of Hazardous Research Equipment, which should be discarded.

The rules and procedures in PUB-3001 have been revised extensively to eliminate obsolete and/or duplicate material and have been made a part of the LBL Health and Safety Manual to make them more accessible.

CONTENTS

I. GENERAL INFORMATION AND SAFETY REQUIREMENTS FOR INSTALLATION OF RESEARCH EQUIPMENT

A. PROCEDURAL REQUIREMENTS AND RESPONSIBILITIES

1. Introduction

The Supplement to PUB-3000 (formerly PUB-3001) has been prepared for use by personnel involved in research experiments at the Lawrence Berkeley Laboratory. It contains rules and procedures for the design, installation, test, and operation of hazardous and nonhazardous research equipment. Hazardous research equipment is defined as equipment used in LBL-controlled research operations that requires an approved Operational Safety Procedure (OSP). The OSP and examples of operations that require an OSP are described in Chapter 1, Appendix B, of the LBL Health & Safety Manual (PUB-3000).

The hazardous nature of some research equipment requires that special attention and consideration be given to the design, test, approval, installation, and operation of such equipment and to the supervision of the associated experimental areas and activities. Experimental areas frequently are highly congested; contain heterogeneous assemblages of research equipment, some of which inherently may be potentially hazardous; have a high density of activities; and are under diverse management. In addition, the status of research equipment frequently changes.

Section I describes the responsibilities of experimenters for safety, describes the various Laboratory safety organizations, and contains specific rules for the installation of hazardous research equipment. Sections II, III, and IV give detailed design, fabrication, test, and emergency procedures for frequently encountered equipment.

The rules and procedures contained herein supplement the operational safety guidelines found in PUB-3000, issued by the Environmental Health & Safety Department (EH&S). The LBL Health and Safety Policy is found in LBL Policy and Procedures, Vol. VIII-19 (PUB-3000, Chapter I, Appendix E).

2. Laboratory Safety Organizations

The Laboratory has established various organizations to ensure safety in experimental areas. The general responsibilities of these organizations are to formulate safety policy; to establish review procedures and standards; to coordinate and review safety activities; to assist experimenters in the design, construction, test, setup, and operation of hazardous equipment; and to examine requests for variance.

Brief descriptions of the functions of these safety organizations are provided below. Complete information on these organizations is found in PUB-3000.

a. Safety Review Committee (SRC), advises the Director on all aspects of safety and safety policy. Its members are appointed by, and are responsible to, the Director of the Laboratory.

b. Subcommittees of the Safety Review Committee, formed by the SRC as necessary to act on safety matters that require special expertise and to develop safety standards and procedures for situations where no codes exist.

c. Environmental Health and Safety Department (EH&S), provides guidance regarding Federal health and safety standards and local environmental rules and formulates, subject to LBL management approval, LBL health and safety standards, monitors Laboratory compliance with those standards, and provides guidance and assistance to program and project organizations in their implementation of Laboratory health and safety policy.

d. Fire Department, maintains an emergency response program, reviews plans for new buildings and facilities, provides fire-pre-vention planning and inspections, and conducts training for emergencies.

e. Medical Services Department, establishes and maintains an occupational medical program for Laboratory employees.

f. Office of Health and Safety Liaison, performs a continuing assessment of the overall effectiveness of the Laboratory's health and safety program and provides advice and assistance, where needed, in the resolution of significant health and safety issues.

g. Emergency Preparedness Department, provides emergency-response planning and training and conducts test exercises in preparation for a major disaster or other hazardous conditions.

h. Building Managers, serve as the focal point for health and safety activities within their assigned areas and monitor compliance with applicable Laboratory health and safety requirements (see PUB-3000, Chapters 1-4 and Appendix C).

i. Division Safety Committees, typically provide specific safety guidelines and operating procedures relating to their activities. Each division has a safety coordinator, who provides the interface between his/her division and the LBL safety organizations.

3. Where to Get Help

The services of all the LBL safety and support organizations described in the previous section are available to experimenters. Help may be obtained from them in the design, construction, installation, and operation of experimental equipment and setups. In addition, the operations groups at any research area must be consulted regarding the design, installation, and test of experiments in that area.

The LBL safety organizations listed above provide inspections, technical review services, and advice on the design, installation, or test of hazardous equipment. Experimenters may work with these groups individually or through their Divisional Safety Coordinators.

4. Statement of Responsibility

The primary responsibility for proper design, for implementation of required procedures, and for safe operation of equipment resides with the Head of the division proposing the activity. This responsibility is often delegated by the Division Head to the Responsible User--defined as the Principal Investigator, Group Leader, or other person in charge of the research or of the Laboratory facility. A secondary responsibility rests with the Building Manager, who has authority to prevent or halt operations considered unsafe and who may insist on standards above the minimum established by this document. The responsibility of the Building Manager is to be regarded as supplementing, but not replacing, the basic responsibility of the Responsible User. Each experimenter, whether LBL employee or outside user, is responsible for becoming familiar with the safety requirements in this manual and for complying with them. The Responsible User must initiate special review meetings, when necessary, to identify hazards and to develop operational safety procedures. Work situations requiring special safety reviews include the following.

- New or modified experimental setups where unusual arrangements of equipment may result in a hazard to personnel, equipment, or the environment.
- Equipment found to deviate from Laboratory guidelines to the extent that it is considered a hazard to personnel or equipment.
- Any post-accident/incident situation where equipment has failed to operate as expected.

Hazardous experimental equipment (requires an OSP) must have a Design Review and a Preoperational Review before it is energized, filled, pressurized, or otherwise activated or tested.

5. Submission of Operational Safety Procedure (OSP)

An evaluation should begin during the design phase of a proposed activity involving the use of potentially hazardous research equipment (by the research division proposing the activity) to determine if an operational safety procedure (OSP) must be prepared (see PUB-3000, Chapter I, Appendix B).

6. Design Review

Design, fabrication, testing, and installation of hazardous research equipment must be reviewed by the appropriate SRC subcommittee. If the equipment is new and is being designed by an LBL engineering department, the review must include a representative from the design team. If, however, it is existing LBL equipment being put back into service (with or without modifications), or if the equipment comes from outside the Laboratory, the design and status of the equipment must be formally reviewed by the appropriate SRC subcommittee with the counsel and assistance of the responsible user.

7. Preoperational Review

If the research division proposing the activity determines that an OSP is required, in addition to the design review the activity must be reviewed and approved before the hazardous equipment may be activated or operated--for the first time or after any modification of the equipment. A formal review of the entire experimental setup and operation must be made. This review should be made jointly by a member of the appropriate SRC subcommittee, a member of the experimental group, the Building Manager, and a member of EH&S.

The Responsible User of the experiment or equipment is responsible for scheduling reviews. It is important that the various reviews be made early so that deadline pressures will not result in unsafe designs or operations. In all research activities the completed installation may differ significantly from the initially conceived experiment or project. Also, modifications to equipment or procedures that occur during design, construction, installation, or test and that affect safety must be immediately evaluated. These reviews must be made by the same groups that carried out the initial safety reviews.

The review should examine compliance with DOE, state, and Laboratory safety rules and policies, including the following requirements.

a. The equipment and the setup must comply with the provisions of this manual.

b. Hazard monitoring and warning devices must be approved and be operating properly.

c. Personnel access to, and traffic within, the hazardous experimental area must be controlled.

d. Adequate egress must be provided. Congestion around experimental equipment must be minimized.

e. Electrical equipment in and around blockhouses or other equipment enclosures must be inspected and be in compliance with all Laboratory requirements.

f. Interlock systems must be approved by appropriate LBL personnel and must be operating properly.

g. Blockhouse or other enclosures containing devices involving flammable fluids must be properly ventilated. Accumulation of flammable fluids, in general, must not be allowed to reach its lower explosive limit.

h. Vent systems and associated connections (including systems for nonflammable fluids) must be inspected and approved by appropriate LBL personnel.

i. High-pressure gas systems must be installed by qualified personnel and must be inspected and approved by an LBL Pressure Inspector, EH&S, or the Mechanical Safety Subcommittee.

j. Warning signs must be plainly visible from all approaches, including from overhead cranes. These signs must accurately represent the status of the equipment and must therefore differentiate between a safe and a potentially hazardous state of the equipment (see PUB-3000, Chapter 27, Warning Signs and Devices).

k. Personnel lists, phone numbers, schedules, and the names of shift supervisors must be posted at the control area of the equipment.

l. Copies of schematic diagrams of the equipment and copies of operating and emergency procedures must be on file or be posted at the control area of the equipment. Emergency procedures must consider utility failures, building fires, apparatus fires, or failures of the equipment.

m. Emergency lights must be in place and operational.

n. The relationship, responsibilities, and interface between the experimenter and the operations group must be established for normal and emergency conditions.

8. Shutdown Procedures

a. When an OSP operation is completed and equipment is shut down, either temporarily or permanently, the EH&S and the Building Manager must be advised regarding the status of the equipment.

b. Equipment that has been filled with flammable or toxic liquids or gases must be purged before it may be left unattended, and the proposed purging process must be approved in advance by the Industrial Hygiene Group of EH&S or the appropriate SRC Subcommittee.

c. Warning signs must be removed or changed to indicate correctly the status of the equipment.

9. Variances from Established Procedures

Requests for variances from established criteria, rules, or procedures must be submitted to the Safety Review Committee in writing by the experimenter. Variances from DOE-prescribed standards require DOE approval, obtained through EH&S.

Requests for variances must include the following:

o. an enumeration of the specific criteria, rules, or procedures with respect to which the variance is required;

o an explanation of the need to perform the experiment in the proposed manner;

o a description identifying the experimental apparatus;

o a description of the measures to be taken to ensure that the variance will not compromise safety; and

o a statement of the period of time during which the variance is to be in effect.

B. RULES GOVERNING ELECTRICAL AND MECHANICAL EQUIPMENT IN FLAMMABLE-FLUID HAZARDOUS AREAS

1. Definition of Flammable-Fluid Hazardous Area

The space surrounding research equipment that contains flammable fluid (liquid or gas) and that is located in an experimental hall (area) is defined as a flammable-fluid hazardous area; it is an area where flammable fluid may be present in the air in sufficient quantities to produce explosive or ignitible mixtures. Free flammable liquid or gas is not permitted in a flammable-fluid hazardous area. Flammable fluids are handled or used in confined, closed containers or closed systems from which they can escape only in case of accidental rupture, breakdown, or abnormal operation. The flammable-fluid hazardous area is further defined in the National Fire Protection Association (NFCA) National Fire Codes (1984), NFPA 70, Chapter 5, Article 500, Hazardous Locations.

At LBL (for operations covered in this manual) boundaries of a flammable-fluid hazardous area are defined as a cylindrical space extending 15 feet horizontally (radially) from the potential flammable source and extending vertically from the floor to the experimental-hall ceiling. The boundaries of an open flammable-fluid hazardous area without a ceiling are defined by a cylinder extending 15 feet horizontally (radially) from the potential flammable source and 60 feet vertically. The boundaries of an enclosed flammable-fluid hazardous area such as a room, laboratory, or blockhouse are defined by the inside surfaces of the enclosure.

2. Rules Governing Installation of Electrical Equipment in Flammable-Fluid Hazardous Areas

Electrical equipment must be explosion proof if it is a permanent part of a device containing flammable fluid or if it will routinely be used in association with such devices. Applicable guidelines for electrical equipment in hazardous areas are in the NFPA National Electrical Code 70, Chapter 5, Special Occupancies.

Sparking devices are not permitted in the hazardous area unless they are either sealed or enclosed, with a continuous flow of air purging the enclosure. A sparking device is defined as any apparatus that sparks during normal operation. Guidelines for purging may be found in NFPA National Fire Codes (1984), Volume 2, Standard 496, Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Areas.

All electrical equipment such as power supplies, motors, etc., and flammable-fluid-filled equipment, including fill lines and vent lines, must be grounded.

At the Bevatron or other areas with pulsed magnetic fields, liquid-hydrogen targets or other such hazardous systems must be grounded at one point only. Accidental double grounding of equipment can allow very high ground currents, which might result in sparking at or near the target. A liquid-hydrogen target is usually grounded through its vent line. An insulated section must be installed in the vent line and a shunt connected across the insulated section so that the ground current may be monitored. Thereby, excessive ground currents (representing accidental grounds) may be detected and may serve to actuate an alarm. The insulated section must be designed to withstand all possible temperatures and pressures to be encountered.

Care must be taken when vent lines or cryogenic-fluid transfer lines are disconnected in a varying magnetic field in the presence of flammable gas. These lines can be current loops and can cause a spark when they are opened.

Electrical wiring and equipment must be placed so as to minimize the chance of accidental damage or an accidental disconnect. Electrical connections must be properly fastened, and plug-in connections must be taped, or otherwise reinforced, to prevent the accidental breaking of connections.

All unused electrical equipment must be removed from the area. This includes drop cords, temporary lights, J-boxes, vacuum pumps, electrical tools, and oscilloscopes and other electronic test equipment.

Electrical equipment must conform to the standards of PUB-3000.

3. Rules Governing the Installation and Test of Mechanical Equipment in Flammable-Fluid Hazardous Areas

The physical layout of the equipment, piping, wiring, etc., must minimize congestion, and exits must not be blocked.

An explosimeter must be installed at a suitable location near the hazardous equipment containing flammable gas and checked daily to ensure that it is functioning properly. The controls and alarm must be located in the local control area. The explosimeter must be calibrated at least semiannually.

Emergency lighting designed for the environment must be installed, and explosion-proof flashlights must be available at the local control area.

All pressure vessels and lines must be tested at pressures approved by the mechanical engineer assigned to the pressure-vessel project or by the Mechanical Safety Subcommittee of the SRC.

Nonsparking (beryllium copper) tools should, if possible, be used for working on, or near, equipment containing flammable fluids.

Emergency equipment such as portable gas detectors, fire extinguishers, flashlights, etc., must be in well-identified and accessible locations. [It is good practice to have such equipment in more than one location.]

4. General Rules for Enclosed Flammable-Fluid Hazardous Areas

Ventilation of known direction and flow rates must be provided in enclosed flammable-fluid hazardous areas to dissipate any accidentally released flammable liquid or gas. Particular attention must be paid to the direction of flow of the ventilating air when the gases are heavier than air.

For heavier-than-air flammable gases, floor drains and trenches must be isolated from the hazardous equipment or must be ventilated. Trenches must be monitored with an automatic gas detector, and a warning sign that describes the hazard must be posted.

The number of areas in which flammable gas may accumulate (and the sizes of these areas) must be minimized by segregating work areas and following safe operating procedures. Ventilation must be used to keep flammable-gas concentrations below the flammable limit.

Alarms must be installed to give warning when powered ventilation devices or gas detectors become inoperable.

Where possible, flammable gases must be placed outside the building and piped directly to the apparatus. The amount of flammable gas or other flammable material in experimental areas must be minimized.

Appropriate flammable-gas warning signs must be posted inside the area and at entrances to the area when the equipment is filled with flammable fluid. The signs must be removed when the hazard no longer exists.

If a conducting floor is installed around hazardous equipment, the floor must be electrically connected to the hazardous equipment.

At least two exits from the hazardous area must be available. They should be remote from each other, and both should be less than 75 feet from any point within the area.

Emergency lighting must be provided.

All gas cylinders must be secured in an approved manner to prevent them from falling when shaken, as during an earthquake, or bumped. All gas cylinders must be grounded. All unnecessary gas cylinders must be removed from the area.

C. LIQUIFIED (CRYOGENIC) GASES: FLAMMABLE AND NONFLAMMABLE

1. <u>General</u>

Flammable cryogenic fluids may be transferred or used within buildings or near ignition sources only after a safety review by the SRC Mechanical Safety Subcommittee.

Cryogenic liquid-gas vessels (Dewars) must be safety vented and protected against mechanical shock and damage, and glass Dewars must be wrapped with fabric or fiber-glass tape, or otherwise protected, to prevent flying glass in the event of breakage. (For additional information on cryogenic safety see PUB-3000.)

All Dewars must be moved very carefully. Do not tilt, jar, bump, or roll the Dewar. Sloshing liquid into warmer regions of the container can cause sharp pressure rises. Before 150- and 165-liter industrial-type liquid-hydrogen Dewars are moved, the internal pressure must be reduced to 5 psig or lower. The relief valve must be set at not more than 10 psig.

Protect vents against icing and plugging. When all vents are closed, enough gas can boil off (vaporize) in a short time to explode the vessel. At LBL, liquid hydrogen is supplied only in double-vent vessels. Liquid helium is supplied in both single- and double-vent vessels. The single-vent helium vessels have a special large-diameter neck and are issued on special request. All helium and hydrogen Dewars in use at LBL are checked every few days by a member of the Mechanical Technician Department Liquid Gas Storage Office (Building 81), and a safety-check record is maintained at Building 81.

On liquid-nitrogen-shielded laboratory-type hydrogen or helium Dewars, keep the rubber tube caps on the vent and fill lines of the nitrogen circuit at all times to prevent oxygen condensation and freezing.

Liquid hydrogen and liquid helium may be transferred only into approved systems and only by personnel experienced in the handling of these liquids. Operators must avoid physical contact with any liquified gases because "burns" can occur. Face masks and gloves must be worn while transferring and handling cryogenic liquids.

The proper transfer equipment must be used when moving cryogenic liquids from one container to another. Liquid helium must always be transferred through well-insulated, vacuum-jacketed lines. Flammable cryogenic liquids may be transferred only when there is controlled ventilation.

Only helium gas may be used for pressurizing liquid-helium or hydrogen Dewars for liquid transfer.

When transferring liquid gases from laboratory-type Dewars, insert a properly purged tube slowly.

When insufficient knowledge exists regarding the potential hazards of cryogenic fluids, obtain assistance from the Mechanical Safety Subcommittee before proceeding to full-scale operations.

Plan for emergency conditions that may occur during operations by considering (1) the consequences of a malfunction or error, (2) all methods of preventing such malfunctions and errors, and (3) methods of minimizing their effects.

Cryogenic systems that require personnel and/or equipment protection must be barricaded and isolated.

Glass apparatus in cryogenic systems must be shielded.

Adequate personnel exits must be provided, and they must never be blocked.

All cryogenic equipment must be promptly and adequately maintained.

Procurement requests must be sent to, and all deliveries of liquid hydrogen and liquid helium must be made to, the Liquid Gas Storage Office, Building 81, extension 5676, or to the Mechanical Technology Office, Building 25, extension 5381. Procurement requests for other cryogenic materials (including liquid nitrogen, argon, and oxygen) must be sent to the Materiel Management Department.

2. Liquid-Hydrogen Dewars

The standard 150-liter industrial-type liquid-hydrogen Dewar with LBL modifications is shown in Figure I-1. Instructions for the use of this Dewar are available from the Mechanical Technician Department Liquid Gas Storage Office (Building 81), extension 5676 or 5381.

Air or oxygen must be excluded from hydrogen-filled Dewars. Ice plugs, of frozen water, air, or other impurities, rarely occur in hydrogen Dewars because of their closed-system fill and vent circuits and their warmup procedure before every refilling. Frozen oxygen, however, has caused explosions in liquid hydrogen.

Single-neck (single-opening) laboratory-type Dewars must not be filled with liquid hydrogen.

Dewars filled with liquid hydrogen must be stored outdoors in a controlled area and must be securely attached to the contact of a good electrical ground at all times to preclude build-up of a static charge that could ignite escaping gas.

The hydrogen Dewar cart must be electrically grounded, and the hydrogen venting system must be connected before filling or transferring takes place.

3. Liquid-Hydrogen Targets

Mechanical refrigerators with a 10-watt capacity and a 3-liter reservoir for liquid hydrogen are used at LBL for liquid-hydrogen targets. Safety rules that must be observed around targets filled with liquid hydrogen are summarized as follows:

- o Efficient ventilation must be provided around targets.
- o All equipment must be electrically grounded.
- o No smoking or open flames are allowed near the target.
- o Where possible, electrical equipment should be kept remote from the target and below the level of the target and its associated liquid-hydrogen piping, etc.
- o Electrical equipment located within 15 feet of the target must be explosion proof.

All vessels and piping must be properly purged with inert gas before and after their use with liquid or gaseous hydrogen. Great care must be taken during a run to prevent air from entering hydrogen spaces and forming an explosive mixture.

4. Liquid Helium

At LBL liquid helium is supplied to users in gas-shielded 30-, 60-, 100-, 250-, and 500-liter Dewars and in LN-shielded 10-, 25-, and 50-liter Dewars (see Figures I-2, -3, and -4). There are about 15 to 20 liquid-helium Dewars in use throughout the Laboratory at any time. All of the liquid-helium Dewars in normal use at LBL have dual coaxial necks to provide redundant venting.

LN-shielded Dewars normally have a primary relief valve set at 0.5 psi located on the removable 5/8-inch-outside-diameter, inner coaxial neck. The LN-shielded Dewar has a secondary relief valve normally set at 7 to 10 psig and a pressure gauge, both located on the outer coaxial neck, which is part of the Dewar venting and safety system and is not accessible to the user.

Gas-shielded liquid-helium Dewars have a variety of openings and neck sizes up to 2 inches. Venting on gas-shielded Dewars is by multiple relief valves and safety bursting discs.

LBL has one 10-liter liquid-helium Dewar with a single 1.5-inch-diameter neck and one 50-liter Dewar with a 2-inch-diameter neck. These Dewars are used only for special experiments.

Dewars containing liquid helium must be inspected by the user to ensure that they do not plug. Although modern dual-neck Dewars seldom plug, users are cautioned to determine the approximate heat-leak rate and bursting pressure of any Dewars they use. The greatest hazard associated with the use of liquid-helium-filled Dewars [caused by the extreme low temperature (4.2 K) of liquid helium] is a vent plugged with ice. In a plugged Dewar, the boil-off gas cannot escape, and pressure builds up in the Dewar and may burst it. Therefore, air,

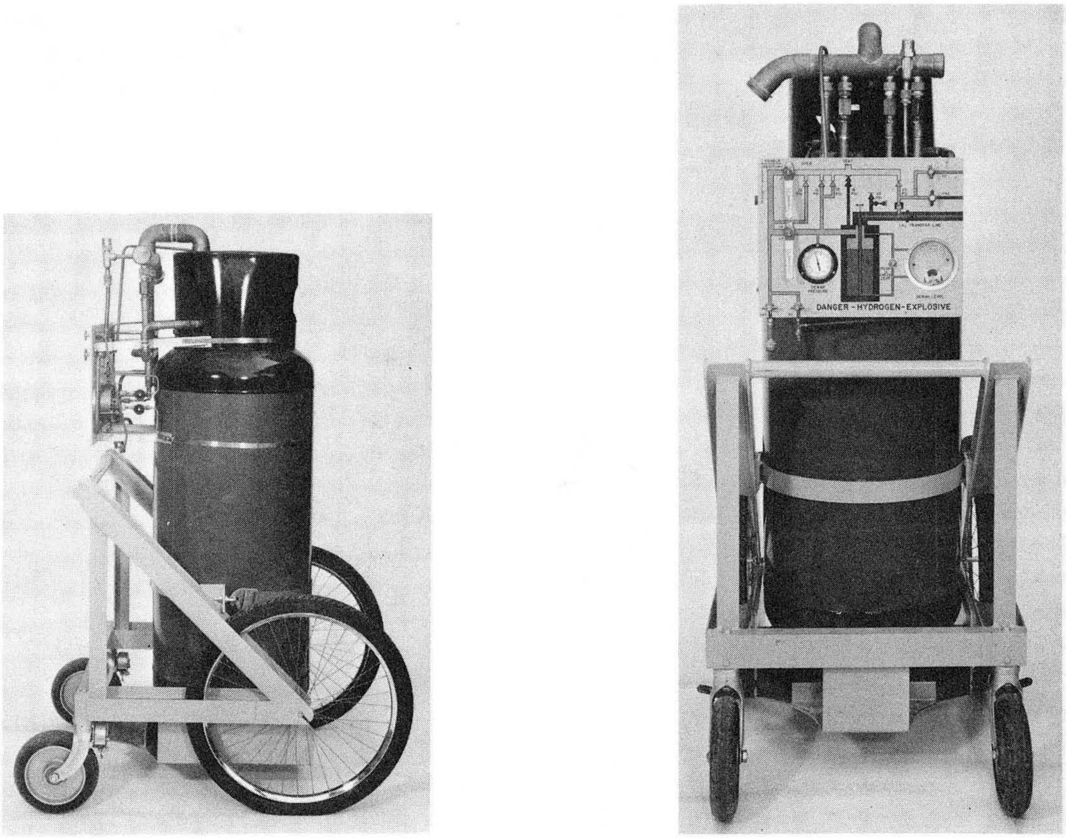
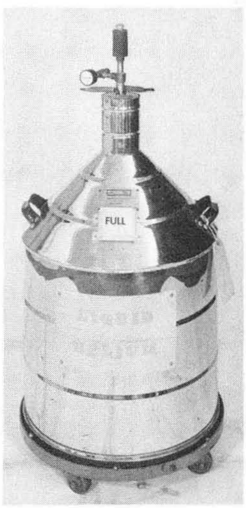


Figure I-1. Two views of a 150-liter industrial-type liquid-hydrogen Dewar with LBL panel attached.

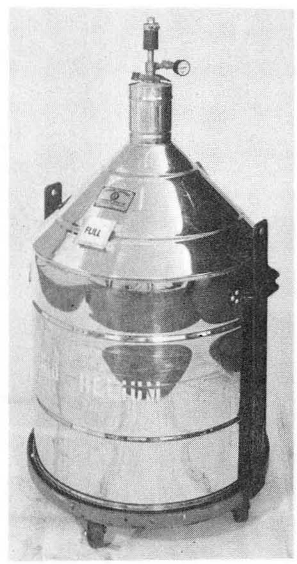
Figure I-2. Two 100-liter industrial-type liquid-helium Dewars with gas shielding.

Figure I-3. A 500-liter industrial-type liquid-helium Dewar with gas shielding.

10-liter, single-neck
(1.5 inch i.d.)



25-liter dual-safety neck



50-liter dual-safety neck

Figure I-4. Laboratory-type liquid-hydrogen/-helium Dewars with liquid-nitrogen shields and vacuum insulation.

water, and other impurities that can freeze solid and plug the vent must be excluded from the Dewar. Ice plugs can result when air is wiped into the Dewar neck as the fill tube is inserted or if air has entered because the positive-pressure relief cap was not in place.

When approaching a Dewar suspected of being plugged, keep your face and body away from the top of the Dewar as much as possible. The pressure in a plugged Dewar depends on its heat-leak rate, how it has been handled, and how long it has been plugged. The pressure in a plugged 25-liter helium Dewar in good condition rises about 3 psi per hour.* The pressure in a Dewar in poor condition will rise faster. Also, the pressure will rise faster when a plugged Dewar is transported and the liquid helium sloshes against the warmer parts of the Dewar. The referenced paper, "Neck Plug Hazards in Liquid Helium Shipment," describes a burst test of a filled 25-liter liquid-helium Dewar and a heat-leak test. The test showed that the pressure in a filled 25-liter helium Dewar will rise less than 3 psi per hour when the Dewar has a closed vent. In a second test, a filled 25-liter helium Dewar was pressurized until it burst, at 400 psig. As an example based on this test data, if a 25-liter helium Dewar has been plugged for 72 hours and its pressure has been rising at 3 psi/hr, the Dewar pressure will be around 216 psig. A pressure of 216 psig is about half the burst pressure.

5. Detecting a Plugged Dewar

If a Dewar containing liquid helium is suspected of being plugged, first see if helium boil-off gas is coming out of the vent-cap check valve on a laboratory-type Dewar or the vent valve of an industrial-type Dewar. This may be detected by lifting the valve cap slightly. You will feel the gas flowing if the Dewar is not plugged. If no gas flows out of the valve, assume that the Dewar is plugged and immediately notify the Building Manager and call the Mechanical Technician Department Liquid Gas Storage Office:

Day shift: extension 5676 or 5381 (or radio page unit 190-214)
Night Shift and Weekends: Plant Maintenance Technicians, extension 5481

The Liquid Gas Storage Office will determine the Dewar's condition and will clear the Dewar if it is plugged or take other appropriate action. If a liquid-helium Dewar is plugged, all personnel must be evacuated from the area immediately.

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*Scott, L.E., "Neck Plug Hazards in Liquid Helium Shipment," Advances in Cryogenic Engineering, Vol. 9, 1963.

6. Purge Procedure

At LBL, the purging of hydrogen and helium Dewars is performed by the Mechanical Technician Department Liquid Gas Storage Office. All Dewars must be purged at least every 30 days to limit the buildup of contaminants. This procedure applies to LN_2-shielded Dewars used for either liquid helium or liquid hydrogen.

D. HIGH-PRESSURE CYLINDERS, MANIFOLDS, AND REGULATORS

Common Flammable Laboratory Gases

	Explosive limits* (% by vol. in air) Lower	Upper	Auto ignition* temp (°F)	Gas Specific Grav relative to air** (1 atm, 68°F)	Boiling point (K)
Hydrogen	4.0	75	1085	0.0695	20.4
Deuterium	5.3	75	----	0.140	23.6
Methane	5.0	14.0	999	0.553	111.7
Acetylene	2.5	81.0	571	0.897	189.0
Ethylene	3.1	32.0	842	0.975	169.3
Ethane	3.0	12.5	959	1.049	184.8
Propylene	2.0	11.1	927	1.48	226.1
Propane	2.2	9.5	871	1.56	230.8

*NFPA 325M Flammable Liquids, Gases, and Volatile Solids.
**Density of air 0.07528 lb/ft^3 at 68°F.

1. Hazards of Flammable or High-Pressure Liquids and Gases

The dangers associated with the handling and use of flammable or high-pressure liquids and gases are listed below.

- Asphyxiation by the gases themselves.
- Ignition or explosion of flammable gases, which can result in facility damage or personnel injuries such as radiation burns or burns from contact with hot or burning materials, wounds or fractures caused by flying objects accelerated by the explosion or pressure release, loss of hearing, and lung damage (almost always fatal) if a flammable mixture is inhaled and then ignites.
- Secondary accidents such as falls or electrical shocks.

2. Fire and Explosion Prevention--General Guidelines

In general, for fire, three elements are required: fuel, oxygen, and ignition. To reduce the risk of fire, eliminate two of these three elements whenever possible. Thus, for flammable gases, (1) eliminate ignition sources and (2) prevent mixing or accumulation of fuel with air. Contain or vent fuel.

Prevent the entrapment of flammable gas in closed pockets by providing good ventilation and air dilution. If the gas is lighter than air--hydrogen, for example--provide overhead ventilation to ensure proper dispersion. If the gas is denser than air, prevent it from entering trenches and manholes where it can collect.

Eliminate ignition sources in high-risk areas.

Minimize the use of oxygen in high concentration. Materials not normally considered combustible burn violently in high-oxygen atmospheres, and special precautions must be taken when working with high-oxygen environments.

3. High-Pressure Gas Cylinders

DOT Markings. High-pressure gases (over 150 psig) are usually stored in steel cylinders manufactured according to Department of Transportation (DOT) specifications. The Department of Transportation assumed responsibility for cylinder specifications, formerly issued by the ICC, when it was formed in 1969. DOT regulations require the following markings on all cylinders:

Type of cylinder and pressure rating
Serial number
Inspection date

For example:

DOT 3AA2065
973487
6-70

DOT 3AA = A seamless steel cylinder of definite prescribed steel, not over 1000-lbs water capacity, with at least 150-psi service pressure.
2065 = Service pressure at 70°F and maximum refill pressure.
973487 = Serial number of individual cylinder.
6-70 = Date of inspection and test.

Old cylinders (made before 1970) will have "ICC" in the markings, whereas those cylinders manufactured after 1970 will be marked "DOT." The remaining identification markings are unchanged.

<u>LBL Color Code</u>. The Laboratory owns cylinders for most of the common industrial gases and uses its own color code for contents identification. For non-Laboratory-owned cylinders, which may, or may not, have a non-LBL color code, the name (of the gas) painted on each cylinder, rather than the color code, should be used to identify the contents.

The Laboratory cylinder color code and some vendor color codes are shown in the table that follows.

<u>Compressed-Gas-Cylinder Color Code</u>

Gas (stenciled name)	Cylinder Owner	Color Code		
		Base	Center	Top
Acetylene	LBL	Yellow	Red	Red
Compressed air	LBL	Yellow	Gray	Gray
Ammonia	Vendor	Aluminum	---	---
Argon	LBL	Yellow	Brown	Brown
Carbon dioxide, Research	LBL	Yellow	Aluminum	Aluminum
Carbon dioxide, Fire	LBL	Red	Red	Red
Ethylene	Vendor	Aluminum with Blue & White top markings		
Freon 12	Vendor	White with decal (possible gray base)		
Freon 22	Vendor	Green with decal (possible gray base)		
Helium (extra pure)	LBL	Yellow	Orange	Brown
Helium (grade A)	LBL	Yellow	Orange	Orange
Hydrogen	LBL	Yellow	Red	Red
Methane	LBL	Yellow	Aluminum	Blue
Nitrogen	LBL	Yellow	Black	Black
Oxygen	LBL	Yellow	Green	Green
Magic Gas*	Vendor	Lt. Blue	Lt. Blue	Lt. Blue

*Magic gas is defined in Section II.I., Multiwire Proportional Counters Containing Flammable Gas.

Mixed-Gas Cylinder Markings. The supplier will furnish mixed-gas cylinders with an adhesive label placed on the shoulder of the cylinder. The label will contain a RED diamond for flammable gas or a GREEN diamond for nonflammable gas. The percentage of each gas component will be marked on the label and on a tag attached to the valve by the supplier. In addition, a circumferential white stripe will be painted near the shoulder of the cylinder as a visual indication of mixed gas.

Gas mixtures having only nonflammable components must have the outlet-valve connection determined by the component having the highest percent (by volume). Percentages of mixture components do not determine the choice of valve outlet connections.

Gas mixtures having a flammable component will have an outlet valve with left-handed threads (CGA 350), even though the gas mixture is nonflammable, unless EH&S has authorized otherwise.

Procurement. Procurement of all gases used at LBL is coordinated by the Materiel Management Department and is accomplished either on a blanket order for general use or on a special order from a user for a specific experiment. Most of the compressed-gas cylinders are stored in a designated area at Building 69. Some cylinders are kept in designated areas at various other buildings and project sites for immediate use.

When cylinders containing toxic gases are to be used in areas not previously established for such use, the gas-request forms must be sent to EH&S for approval.

All compressed-gas cylinders must be free of defects that could cause a failure. Cylinders shall be considered defective and rejected (or removed from service) if they contain

dents,
cuts, gouges, or digs over 3 inches long,
leaks (of any size),
fire damage, or
valve damage.

All defective cylinders (LBL or vendor-owned) must be sent back to the Materiel Management Department, which will send them to the manufacturer or vendor for test and repair.

All standard high-pressure cylinders (200 ft^3) that are used only at the LBL site, such as in fixed tube banks, must be pressure tested to 5/3 (1.67) of their DOT service pressure every 6 years.

Cylinder Storage. Cylinders not in use must be capped to protect the valves and secured in an approved manner to prevent falling when they are shaken, as during an earthquake, or bumped. All compressed-gas cylinders must be stored on solid, level footings in well-ventilated areas away from traffic lanes. Cylinders not actively in use inside of buildings must be stored outside in approved areas. Cylinders must be located well clear of traffic lanes, and cylinders stored in the open must be protected from continuous direct sunlight, extremes of weather, and moisture. To avoid uncontrolled pressure increases, they must not be stored near sources of intense heat such as furnaces, steamlines, or radiators. Cylinders containing oxygen must not be stored near highly combustible materials such as oil, grease, reserve acetylene supplies, or other flammable gases. Storage areas for cryogenic fluids and high-pressure gases must be separate.

Cylinder Handling. Compressed-gas cylinders are dangerous when handled incorrectly. If damaged, they can cause severe injuries, including lung damage from inhalation of toxic contents and physical trauma from explosion. A pressurized gas cylinder can become a dangerous projectile if its valve is broken off. Be very cautious in moving gas cylinders. Because of their shape, smooth surface, and weight, gas cylinders are difficult to move by hand. A truck or an approved cylinder handcart must always be used to move a cylinder. When a cylinder is not connected to a pressure regulator or a manifold, or is otherwise disconnected, it is extremely important that the safety cap be kept in place--the cap protects the cylinder valve.

Always assume that a cylinder is pressurized. Handle it carefully--avoid throwing, banging, tilting, or rolling. Cylinders must not be upset or dropped to the ground from a truck bed or any raised surface. If a standard cylinder must be lifted manually, at least two people must do the lifting. Cylinders must be secured in metal cradles or skid boxes before they are raised with cranes, forklift trucks, or hoists. Rope or chain lifting slings alone must not be used.

Oxygen cylinders must not be handled with greasy or oily hands or gloves. Note: the reaction between oxygen and hydrocarbons can be violent, even when minute quantities are involved. Prevent oxygen contact with oil or grease.

Gas cylinders, even empty ones, must never be used as rollers for moving materials or be used as work supports.

Inspection. Hoses, tubing, and manifolds must be inspected frequently for pressure integrity. Hoses and fittings that appear worn must be replaced before the equipment is put to further use. The Plant Maintenance Technician Regulator Shop (Building 76) can supply replacement hose, tubing, and fittings.

If cylinder valves are stiff, or if fittings leak, the cylinders must be marked and returned to the Materiel Management Department, Building 69.

If a cylinder is found to be leaking a toxic, irritant, or flammable gas or a gas of unknown composition, the Fire Department must be called immediately and the vicinity of the leak must be evacuated until the emergency crew arrives.

Precautions. Open flames must not be used to leak-check a cylinder; soapsuds or a leak-detection solution must be used.

Talc powder and dust must be blown from a new hose before it is connected to a cylinder.

Do not use white-lead, oil, grease, or any other nonapproved joint compound for sealing oxygen-system fittings. Fire or explosion could occur when oxygen contacts these materials. Threaded connections in oxygen piping must be sealed with joint compounds or Teflon tape approved for oxygen service. Litharge and water is recommended for service pressures above 2.0 MPa gauge (300 psig). Gaskets must be composed only of noncombustible materials. For additional information, contact the Plant Maintenance Technicians Regulator Shop (Building 76).

Always identify gas cylinder contents correctly. Do not use a cylinder if it is not clearly labeled.

Regulators and hoses used with one type of gas must not be used with another. Explosions can occur if flammable gases or other organic materials come into contact with oxygen under pressure.

Oxygen must never be used to purge lines, to operate pneumatic tools, or to dust clothing. Likewise, gas cylinders must never be used as hat racks, clothes hangers, etc., since leaky fittings can result in large accumulations of gas under the covering material. Clothing or other combustible material saturated with oxygen will burn explosively if ignited.

Gases must not be mixed at LBL sites in commercial DOT cylinders, and gases must not be transferred from one DOT cylinder to another. Commercial cylinder-gas mixtures are available through the LBL Materiel Management Department. Gases mixed at LBL must never be put into any compressed-gas cylinders--LBL or vendor owned.

Vendor-owned cylinders must not be used for any other purpose than as a source of vendor-supplied gas. Only the vendor may pressurize these cylinders.

Sparks, molten metal, or slag must never be allowed to fall on cylinders, pressure apparatus, or hoses. Welding, oxyacetylene-torch cutting, smoking, electrical arcing and arcing devices, lighting, electrostatic charges, pilot lights, and any other ignition sources must be kept away from flammable gases at all times.

Liquid nitrogen or other refrigerants must not be spilled on gas cylinders. Mild-steel gas cylinders may rupture due to thermal stress when they become cold because ferrous metals are extremely brittle at low temperatures.

High-pressure lines must be secured to prevent whipping in the event of mechanical damage or rupture.

Equipment must not be disassembled while it is under pressure. Be aware that any valved-off line may be under pressure; bleed the line or vessel before disassembly to ensure that there is not enough pressure energy stored in trapped gas or in piping distortion to propel loose objects.

Operation. Gas-cylinder valves can be "cracked" (opened slightly) momentarily before regulators are attached in order to blow dirt off the valve seats, but the valve outlet should always be pointed away from people or equipment. Be very careful with hydrogen because it can be ignited by static charge or friction heating and usually burns with an invisible flame. Closing the valve immediately stops the flame.

After the regulator is securely attached to the cylinder valve, fully release (turn counter-clockwise) the pressure-adjusting screw of the regular before opening the cylinder valve.

Open high-pressure valves slowly; for gas cylinders, this gives compression heat a chance to dissipate and prevents "bumping" the gauges. Never use a wrench on any cylinder valve that refuses to rotate when normal handforce is applied. Stand clear of pressure-regulator gauge faces when opening cylinder valves. Defective cylinder valves must be tagged, and the cylinder must be returned to the Industrial Gases Section of the Materiel Management Department.

Keep removable keys or handles on valve spindles or stems while cylinders are in service.

Never leave pressure on a hose that is not being used. To shut down a system, close the cylinder valve and vent the pressure from the entire system.

When a cylinder containing flammable gas is used in a laboratory or confined space, the room must be well ventilated, or the cylinder must be placed under a ventilated hood.

The number of active cylinders in an experimental area or room must be kept to the minimum approved by the Mechanical Safety Subcommittee or EH&S.

Empty Cylinders. About 0.2 MPa gauge (30 psig) of positive pressure must be left in "empty" cylinders to prevent air from getting into the cylinder and contaminating it; in the case of a hydrogen cylinder, air contamination would be extremely dangerous. Mark or tag empty cylinders with the letters "MT," and store them away from full cylinders. Empty cylinders should be returned promptly, via LBL Transportation, to the Materiel Management Department.

4. High-Pressure-Gas Manifolds

All high-pressure-gas manifolds must be approved by the Regulator Shop, by the Project Mechanical Engineer, or by the Mechanical Safety Subcommittee. Components of high-pressure-gas manifolds are available from the LBL Materiel Management Department, but their issue must be approved in advance by the Regulator Shop. Only Plant Maintenance Technicians are authorized to assemble compressed-gas-cylinder manifolds.

Manifold pigtails should not be left disconnected for more than a few minutes. Certain insects are attracted to pure gases and will quickly clog these lines. Insects in oxygen pigtails can ignite spontaneously and cause sufficient heat and overpressure to burst the pigtail, valve, or manifold.

5. Gas Pressure Regulators

General. The Laboratory stocks several models of cylinder-to-line gas regulators, each one designated for a particular gas as shown in the following table. Gas regulators are available from the LBL Materiel Management Department, Central Stores, with the advance approval of the Regulator Shop.

In-Stock Cylinder-to-Line Regulators for Compressed Gases

(Model) LBL Catalog No.	Type of Gas
6680-19991	CO_2
6680-19992	Acetylene
6680-19993	Explosive (hydrogen, methane, propane, etc.)
6680-19994	Nonexplosive, 0-150 psi delivery pressure (nitrogen, argon, helium, air, neon, etc.)
6680-19996	Oxygen
6680-19997	Nonexplosive, 0-1000 psi delivery pressure (nitrogen, argon, helium, air, neon, etc.)

Left-handed threads on regulator inlet connections are indicated by a groove on the hexagon nut.

Each regulator must be checked by the Regulator Shop to ensure that it is correctly specified for the particular application and is in safe working condition.

Regulator Diaphragms. Diaphram failure permits the cylinder gas to escape to the surrounding atmosphere through holes in the regulator body. To reduce the probability of diaphragm failure, regulators used for gases listed above are purchased with stainless-steel diaphragms. Regulators for use with flammable or toxic gases can be obtained with a bonnet fitting to conduct escaping gas to a vent.

Operation. All new regulators are stocked and issued at Central Stores (Building 7). Before installation, all regulators must be taken to the Regulator Shop for inspection, adjustment, and tagging.

When used regulators are temporarily stored, they must be sealed in plastic bags to keep them clean and free of insects.

Supervisors must make periodic surveys of regulators in their areas. All surplus regulators must be sent to the Regulator Shop, which will inspect, clean, adjust, and repair them, as required.

Only the Regulator Shop is authorized to alter or repair regulators, and the Regulator Shop must approve any adapter to be used on a regulator. The used regulators reapplied to oxygen service must be degreased in the Regulator Shop.

Immediately upon removal of regulators from flammable, toxic, or radioactive systems, all hazardous gas must be safely vented (and purged as required) from the entire regulator.

Use only regulators of the approved type and design for the specific gas-and-cylinder combination to be employed. Make sure that threads on regulators correspond to those on the cylinder valve outlet. Never force connections that do not fit perfectly. Do not use regulators with green-face gauges for anything except oxygen.

Damaged, unreliable, or otherwise defective regulators must be replaced immediately.

Regulators designed for use on gas lines must not be used on gas cylinders; single-stage regulators are for use up to only 1.0 MPa (150 psig) and must be used for in-line installation only.

Two-stage regulators for inert gases are equipped with two relief valves that protect the regulator diaphragms and gauges from excessive overpressure. Relief valves on regulators for use with flammable, toxic, or radioactive gases must be safely vented. The Regulator Shop will normally adjust the second stage of a two-stage regulator so that the low-pressure output can not exceed 67% of the highest reading on the low-pressure output gauge; they will set the low-pressure output relief valve to open at (or under) the highest readings on the low-pressure output gauge. Users are cautioned that additional pressure-relief valves may be required to protect downstream equipment.

Single-stage cylinder regulators (except acetylene regulators) are equipped with a single relief device that is set to open at (or under) the highest reading on the output gauge. The Regulator Shop adjusts these regulators to limit the output pressure to 67% of the highest reading of the output gauge.

If the piping and associated apparatus connected to the regulator discharge are rated at a pressure lower than the lowest possible setting of the low-pressure output relief valve on the regulator, a leak in the regulator valve seat may cause damage to the connected apparatus. Under this circumstance a separate relief valve must be installed in the experimental equipment to protect it from damage from overpressurization.

Vacuum Applications. When a regulator is used in a system in which piping on the high-pressure side of the regulator is to be evacuated through the regulator, the regulator must be modified for vacuum service to prevent damage to the diaphragms and pressure gauges. The Regulator Shop will modify regulators for proper operation under vacuum. Regulators so modified must be labeled to indicate the modification.

Flammable Gas. Whenever two or more cylinders containing flammable gas are used inside a laboratory or in a confined area, and are connected to a common manifold, the regulator must be modified. The existing relief valves on the regulator must be replaced with two special relief valves connected to a metal vent line that terminates outside the building. These regulator modifications must be made by the Regulator Shop.

The above practice is also recommended for permanent single-cylinder applications, where it is important to reduce the probability of accidental gas leakage.

Toxic Gas. Use of toxic gases must comply with EH&S requirements. If you are in doubt as to the hazards, toxicity, or safe-operating practices for any gases, please consult Industrial Hygiene, extension 5829.

E. COMPRESSED-AIR SAFETY RULES

Compressed air may be used to dry parts and to help accomplish many other jobs in the shop or laboratory more efficiently, but the following safety rules must be observed.

Never apply air pressure to the human body. Compressed air injected into the anus (posterior opening of the alimentary canal) can be fatal. In addition, compressed air must not be used to clean clothing. The air jet tends to drive particles into the fabric, where they can cause skin irritation and serious infections. Use a clothes brush or wear protective clothing.

When compressed air is used to dry parts, be sure that nobody is in line with the air stream and wear goggles or a face shield to protect your eyes.

Air pressure must not be used to transfer liquids from containers of unknown safe working pressure. A pressurized commercial drum of unknown pressure rating is a hazardous device; for example, a standard commercial 200-liter (55-gal) drum pressurized to 100 kPa (14.5 psig) has a force on the head of the drum of about 25 kN (almost 3 tons). A siphon with a bulk aspirator or a pump must be used instead. The transfer pressure for commercial LN Dewars must be less than 100 kPa (14.5 psig). For most laboratory-type LN systems, transfer pressures of less than 5 psig are adequate.

When a automatic shut-off coupling is not used, a short chain (or its equivalent) must be attached between the hose and the air-operated tool to prevent the hose from whipping in case it separates from the tool.

Whenever possible, the pressure should be vented from the air line before the nozzles or fittings are changed.

Compressed air must not be used for breathing unless it has been especially installed for this purpose and approved by the EH&S.

Compressed air for general shop or laboratory use must be restricted to 207-kPa (30-psig) maximum pressure by restricting nozzles. Compressed air at pressures up to 700 kPa (100 psig) may be used to operate pneumatic tools, certain control instruments, and research equipment with properly designed overpressure relief devices. Air-pressurized research apparatus must be reviewed and certified safe by the Mechanical Safety Subcommittee.

F. VENTING

1. Equipment-Venting Guidelines

Every vessel connected to research apparatus and containing flammable gas or liquefied flammable gas must be connected to a fixed venting system.

All flammable-gas vent lines or exhaust systems, including those for normal boil off, emergency dumping, and relief-valve and rupture-disk venting, must be unobstructed and must lead directly outside the building with no possibility of discharge inside the building.

The vent-system termination must be outside the building and must not be near the building air intakes or other openings in the building.

Vent lines, associated equipment, and experimental apparatus attached to the vent system must be designed not to fail when subjected to thermal changes caused by cryogenic (i.e., low-temperature) gases.

All vessels, piping, or other closed circuits must have positive relief devices connected to the building fixed-vent system.

The vent system must remain tight when subjected to fire or to temperatures and pressures expected during other emergencies.

Venting of toxic gases must comply with all EH&S regulations. If in doubt regarding the hazards or toxicity of gases or regarding safe operating practices consult the Industrial Hygiene Group of EH&S, extension 5829.

2. Building Piped-Vent Systems

A building piped-vent system is defined as a vent required for an experiment because a suitable building vent system did not exist. An example is the 3-inch metal-pipe vent systems used in accelerator experimental halls.

Only one flammable-fluid device may be connected to a piped vent. This keeps experimental devices isolated from each other and eliminates the danger of having a gas from one device enter another device through the vent.

Piped-vent lines used in operations or research areas normally must be made of metal and must have a design rating of 150 psig. Valves or other methods of blocking the vent, except approved full-size check valves, must not be installed between the relief device and the vent-line discharge.

Seals and gaskets in the vent line must be designed to be tight under vacuum test and at proof and emergency pressures and temperatures.

Quick-opening rubber gasket couplings are permitted in vent lines for research apparatus containing less than three liters of liquefied flammable gas; these couplings must not, however, be used within the "hazardous area."

The piped-vent line must have sufficient mechanical strength, must be sufficiently anchored, and must be protected or located so as to reduce the probability of mechanical damage. The vent line, where exposed in the building and when made of low-melting-point metal such as aluminum, must be insulated from heat when the research apparatus contains more than three liters of liquefied flammable gas. Soft-solder joints must not be used.

Mechanical vacuum pumps that, by design or accident, can pump flammable gas mixtures, or mechanical vacuum pumps of 50 SCFM (or greater) capacity that can pump oil vapors, must be connected to a separate metal exhaust line that vents outside the building.

Vent systems must be inspected monthly and before any use.

Vent systems must be designed so that they can be vacuum- and pressure-checked conveniently from the experimental area. Each vent system must have suitable identification, and the user must follow a written procedure to ensure that the vent system is both open to the atmosphere and gas tight.

3. Fume Vents

Fume vents have been permanently installed in some Laboratory buildings to exhaust permissible amounts of toxic chemical vapors and fumes. Such fume vents terminate outside and above the building with an exhaust blower that provides forced ventilation. The fume vent is a flanged and gasketed metal duct protected with corrosion resistant paint and is designed to the American Conference of Governmental Industrial Hygienists (ACGIH) specifications.

Limited amounts of flammable gas (such as from the relief valve of a system having a single high-pressure flammable-gas cylinder attached or from the bubblers on a multiwire proportional counter) may be released into a fume vent following review and approval by EH&S and the Mechanical Safety Subcommittee.

G. INSTALLATION AND TEST OF X-RAY MACHINES

An Operational Safety Procedure must be prepared and a System Safety Analysis must be performed for all x-ray machines under the administrative control of LBL, in compliance with LBL Policies and Procedures Memo, Vol. XIII, No. 2, October 28, 1986, as described below.

1. All x-ray machines within the administrative control of LBL must undergo a System Safety Analysis as follows:

New units--before operation.

Working units--at intervals no longer than every five years and following any modification.

Out-of-service units--before being brought back into service.

2. This System Safety Analysis must be performed by a qualified professional and must consist of at least the following:

Verification, updating, or production of schematic diagrams of the safety systems.

Identification of any modifications to the safety systems made since the last analysis.

Assessment of potential equipment failure modes and their possible consequences. Emphasis will be placed on the failure modes of interlocks and other safety devices.

Review of the detailed procedures for semiannual routine testing of safety devices.

Preparation of a written report of the findings of the analysis together with recommendations for action, if any. Copies of this report must be sent to the X-Ray Safety Officer, who will distribute it to the system supervisor and to the Division Safety Coordinator.

Because x-ray machine safety and control systems are mainly electrical, the qualified professional will usually be an electrical engineer with experience in failure-mode analysis. In those cases where some components of the safety system are mechanical, additional advice and consultation may be appropriate. Advice as to suitable qualified professionals may be obtained from the X-Ray Safety Officer (extension 5251) or from the Electronics Engineering Office (extension 4814). X-ray systems supervisors are responsible for ensuring that x-ray units under their control comply with the Laboratory policy. The X-Ray Safety Officer is responsible for monitoring the compliance of x-ray units with Laboratory policy.

H. RULES FOR SEISMIC SAFETY; PREVENTION OF EQUIPMENT OVERTURNING; AND EQUIPMENT HANDLING

1. Seismic Safety

Seismic Safety Subcommittee Functions. The Seismic Safety Subcommittee of the LBL Safety Review Committee provides guidance to program personnel by conducting Seismic Design Review meetings for structures and special LBL equipment involving state-of-the-art seismic design problems or for those cases in which the codes do not apply directly. These meetings are normally convened at the request of the person in charge of the equipment or experiment. The Seismic Safety Subcommittee determines whether dynamic-structural analyses are required or whether a static-structural analysis is sufficient. The Subcommittee provides a Design-Basis Earthquake (with time history and spectral-response data) if dynamic analyses are required.

When a dynamic analysis is required, the natural frequency of the structure must be computed and the maximum stress determined from the Design-Basis Earthquake specified in "Strong Seismic Motion for Design Purposes at the Lawrence Berkeley Laboratory," LBL-17377.

Many good references on response spectra are available; see, for example, "Response of Simple Structures to Earthquake Motions," Section 16.2, by N. M. Newmark in Earthquake Engineering, Robert L. Weigel, editor, Prentice-Hall (1970), in the LBL Engineering Library.

All structures and equipment at LBL, as a minimum requirement, must be designed and constructed to be in accordance with LBL PUB-3000, Health & Safety Manual, Chapter 23, "Seismic Safety," including the Design Requirements for Radioactive Containment Facilities.

Seismic protection must be provided to research equipment as soon as possible after its installation, and this protection must be maintained as much as possible during major maintenance or reassembly.

2. Prevention of Overturning

Lateral Restraint of Stationary Heavy Objects. If personnel can be injured, by being struck or trapped, by the lateral movement or upset (toppling) of any heavy object from any cause (such as self excitation in a machine tool with an eccentric work piece, seismic disturbance, wind gusts, impact by a moving vehicle, etc.), the movement or upset of the heavy object must be prevented, without reliance on friction, when the object is subjected to a horizontal acceleration of 0.7 g. If the object is provided with adjustments, it must resist 0.7 g when the adjustments are in the most unfavorable positions. In this context "heavy object" means any objects (such as cabinets or benches, machine tools or surface plates, laboratory apparatus, platforms, etc.) that if put in motion cannot be easily restrained by one person.

The maximum allowable stress in seismic restraining systems must not exceed that specified in LBL-3000, Chapter 23, Seismic Design Criteria for Radioactive Containment Facilities, Design Requirements.

In certain instances it may be undesirable to fasten objects securely to a floor, since normal settlement may cause unacceptable warpage or misalignment of sensitive elements. It is acceptable to supply the requisite restraint without initial hard contact by allowing a small movement before "motion stops" become effective.

In other instances, when it is not clear if the floor under a heavy object can withstand the horizontal earthquake force, it may be desirable to decouple the heavy object from the floor and allow an acceptable, but limited, horizontal motion. This decision may be made by the Project Engineer, with or without the assistance of the Mechanical Safety Subcommittee. The motion must be limited to a few inches and must not permit the heavy object to cause personnel injury or obstruct an escape route. In all cases, upset must be prevented.

For heavy equipment or other objects mounted on stands, the dynamic load during an earthquake may, due to amplification, greatly exceed the maximum ground acceleration. The Project Leader, or his or her designee, is responsible for ensuring that the stands have sufficient strength and ductility to withstand dynamic loads.

In certain cases, the Project Leader may request the Seismic Safety Subcommittee to review the dynamic analysis made by his or her group. In such cases the review procedure will be similar to that described in the section that follows on "Specific Seismic Design Criteria for Shielding."

<u>Research Apparatus Mounted on Wheels or Casters</u>. These guidelines cover apparatus mounted on wheels or casters while it is being intentionally moved.

- To reduce the risk of overturning when research apparatus mounted on wheels is moving, arrange the apparatus so that the center of gravity is low and the casters or wheels are far apart.

- When swivel casters are used, vertical stops must be provided adjacent to each caster to minimize the amount of tipping (and the risk of overturning) if a caster breaks.

- To reduce the risk of toppling when the research apparatus is mounted on casters, limit the rolling velocity to less than 4 feet per second (2.7 miles per hour).

- Roll research apparatus only on an unobstructed, smooth floors.

3. <u>Specific Seismic Design Criteria for Shielding</u>

The following requirements and guidelines apply to all LBL concrete-shielding block-houses, particle-beam shielding, or other structures consisting of large blocks.

Guideline--In view of the developing nature of seismic-design philosophy for concrete shielding structures and as a result of seismic-shake-table experiments, each concrete-shielding structure to be constructed, modified, or moved must be reviewed in a Seismic Design Review Meeting. The review committee must consist of the members of the Seismic Safety Subcommittee plus at least the following:

- the seismic representative of the LBL Mechanical Safety Subcommittee to act as Chairman;

- an engineer from the LBL Plant Engineering Department;

- a professional member of the project's staff;

- a member of EH&S; and

- an external seismic-engineering consultant, in complex cases.

Requirement--All shielding structures must be designed to resist static lateral loads applied to the center of gravity from any horizontal direction. The shielding structure must be designed to resist a horizontal acceleration of 0.7 g. Unless otherwise specified by the Seismic Safety Subcommittee, when moments resisting upset of a structure are calculated, vertical loads must be taken as the dead weight of parts. The intended system of restraint must be described in an Engineering Note, which must contain the supporting calculations. The maximum allowable stresses in the seismic restraining system must comply with PUB-3000, Chapter 23, Seismic Design Criteria for Radioactive Containment Facilities, Design Requirements.

Requirement--Elements of a shielding structure must be prevented from moving in any lateral direction with respect to one another by a positive physical interference, such as integral keys, metal plates with end stops, or their equivalent. This requirement does not include the shielding-to-floor interface.

The capacity of the floor to carry lateral loads must be ascertained. When it is not clear if the floor under a structure can withstand the horizontal earthquake force, it may be desirable to decouple the structure from the floor and allow an acceptable, but limited, horizontal motion. This decision must be made by the Project Engineer and the Seismic Safety Subcommittee. In all cases, upset (toppling, falling over) must be prevented. Engineering studies and shake-table tests can be conducted, if necessary, to determine optimal methods of absorbing the lateral load energy of concrete-shielding structures.

Requirement--When limited horizontal motion of the structure with respect to the floor is permitted during a seismic disturbance, the structure must be constructed such that the personnel escape routes will remain open.

Requirement--Moment arms for resistance against upset may be calculated from the edge of a block when the corner is formed by a metal angle adequately anchored to the concrete. When the corner is only concrete, or when the block rests on a substantial thickness of resilient material such as timber, the load line must be inset 5 inches from the edge of the block.

Requirement--The structural integrity of buildings and the continuity of plant services are Plant Engineering responsibilities. If shielding is in contact with building elements or is so close that contact is likely during a seismic disturbance, or if shielding is supported, restrained, or braced from the building structure, then Plant Engineering must participate in, and approve of, any design for the lateral restraint of the shielding. Buildings and shielding can be expected to have different motions in response to a seismic disturbance, and they should be made structurally independent whenever possible.

Requirement--Whenever dispersible residual radiation must be contained, for example, the material used in a radioactive-chemistry experiment, more stringent safeguards are necessary, and EH&S must be consulted regarding the appropriate requirements, including the seismic stability of shielding.

Guideline--The best seismic defense for shielding is to unify an assemblage of blocks into a single integral structure by use of keys, strap plates, tie rods, chain, etc.

Guideline--These requirements establish <u>minimum</u> criteria. In many cases lateral restraint can be significantly increased at very small increase in cost (1-2%) or loss in functional flexibility. Increasing the strength of restraints is to be encouraged and is left to the technical judgment and resourcefulness of the individual engineer.

4. <u>Design and Use of Handling Equipment</u>

The burden of verifying the strength and safety of a piece of handling equipment rests upon the person in charge of the project where the equipment is being used. For equipment designed at LBL, the Responsible Designer must provide the user with information required to use the handling equipment safely.

It is the responsibility of the supervisor to verify that the user knows how to use the handling equipment safely. If there are questions regarding safety, the supervisor is responsible for obtaining satisfactory answers before the equipment is used. The supervisor may obtain answers from the designer, the Project Engineer, or from the Mechanical Safety Subcommittee.

The design stress for handling equipment must not exceed one-fifth (1/5) the ultimate strength of the material being used at the operating temperature. If welded fabrication is used, the design stress must take into consideration any weakening effects of welding, such as those that occur in aluminum alloys.

If practical, avoid welding in the fabrication of handling equipment; however, if welding is used, design and fabrication must conform to the latest standards of the American Welding Society (AWS). Careful, thoughtful design and follow-up are required. The following rules apply when designing welded units:

> There must be no possibility of subjecting welds to tearing loads. Stresses in welds must be substantially uniform.

Where possible, design handling equipment so that the main loads are carried only by structural members, plates, or shear pins rather than by welds. Examine this possibility carefully.

Welded fabrications must be proof tested to twice the maximum rated load and then magnafluxed.

Eyebolts without shoulders must not be used for lifting. The use of single-bolt pickup devices, such as "Safety Hoist Rings" or equivalent carefully designed and maintained in-house units, is recommended.

Although the use of standard eyebolts with shoulders is discouraged, there may be cases where old designs will not permit substituting a Safety Hoist Ring. If it is necessary to use a standard eyebolt with shoulders, then the following rules apply:

The load must be in line with the axis of the eyebolt--<u>no side forces are permitted</u>.

Average stress on the root area of the thread must not exceed 5000 psi.

Thread engagement must be at least two bolt diameters.

Bolts used as part of "in-house" single-bolt pickup devices must be tested to two (2) times the rated load and then given a magnaflux test to ensure soundness. It is desirable to maintain a supply of tested bolts in case one is lost.

Once a fixture is in the hands of the user, it is the user's responsibility to see that it is used and maintained correctly, e.g., the proper bolt is inserted to the proper depth and correctly torqued.

The appropriate screw-thread engagement required for conservative development of the full strength of a screw fastner depends upon the materials involved. If the fastner is made of the same material into which the hole is tapped, e.g., a mild-steel bolt and a hole in mild steel, an engagement of 1-1/2 diameters is sufficient. A hardened hex-socket cap screw (Allen screw) in mild steel requires 2 diameters' engagement. Other material combinations must be checked.

All handling equipment, whether purchased commercially or designed at LBL, must be proof tested to twice the maximum rated load before it is placed into service. The capacity must be marked on the equipment so as to be clearly visible to the equipment operator.

The Responsible User must ensure that proof testing is performed and that adequate test records are kept.

I. REFERENCES FOR SECTION I

Compressed Gas Cylinder Valve Outlet and Inlet Connections, Compressed Gas Association, Pamphlet V-1, ANSI B57.1-1977.

Handbook of Compressed Gases, Compressed Gas Association, Reinhold Publishing Corporation, New York.

II. ACCELERATOR-RELATED HAZARDOUS RESEARCH EQUIPMENT

A. GENERAL GUIDELINES AND REQUIREMENTS

The following general guidelines and requirements apply to all equipment covered in this Section, including similar existing, or future, research equipment. These guidelines do not cover equipment that is a part of permanent plant or buildings (covered in PUB-3000) or pressure equipment (covered in Section III).

1. General

Equipment and its installation should be subject to early safety review. Consider safety in the conceptual-design phase of any project; consider possible interactions among various equipment components; and consider possible interactions between the equipment installation and the surrounding areas.

Equipment and all associated components and instruments must be designed to operate safely under both normal and emergency conditions. Consideration must be given to the effects of environment, e.g., working fluid, vacuum, pressure, temperature, and magnetic fields.

When new materials and techniques are used, a continuing review of the related technologies must be made. Such materials and techniques may be used only when a predictable safety factor can be determined or when any possible hazard arising from failure of components fabricated from these materials or by these techniques has been eliminated.

It is recommended that piping control panels be schematic. The piping control panel should show the connecting piping, valves, and instruments and the function indicated by each readout.

All equipment and controls must be designed so that the safety of the system is not jeopardized by failure of controls or utilities (electrical power, water, air, etc.).

All electrical apparatus must be designed, constructed, and installed in compliance with the National Electrical Standards and LBL Electrical Safety Standards, PUB-3000, Chapter 8, and be approved by the Electrical Safety Subcommittee.

For pressure vessels not within the scope of the ASME codes and not otherwise covered in this Section, the design stresses and the test procedure must comply with the ASME Boiler and Pressure Vessel Code: Section VIII, Pressure Vessels.

2. Documentation, Inspection, and Training

Documentation. A design file and other appropriate records should be maintained by the designer. In addition, an LBL Safety Note, a management-approved design document stating that every practicable precaution has been taken to control all significant hazards, may be required.

A Safety Note, when required, must be filed with the appropriate SRC subcommittee. A guide for pressure-equipment Safety Notes is shown in Section III.F.

In addition to the Safety Note, the design file should include test and material reports, sketches, schematic drawings, and major detail and assembly drawing numbers. The types of equipment requiring a Safety Note are shown in Tables II-2, II-3, and II-4.

Inspection. Equipment systems and components must be inspected to ensure that design specifications are met.

Training. Where test, operation, or emergency procedures are required, the operating personnel must be trained in these procedures, and the level of training must be maintained. Where system drawings or procedures are required, they must be available and must be current. A copy of current procedures and system schematic and assembly drawings must be available at the installation.

3. Installation

Any manned control panel or piping manifold required for operating hazardous equipment must be located as far as practicable from the equipment.

Alarm systems to warn of impending hazardous situations must be installed. These systems must be fail safe and must be tested periodically to ensure that they are functioning correctly.

Adequate measures must be taken to prevent asphyxiation of personnel in confined spaces in which toxic or inert gases are used.

Personnel must be able to leave the installation area rapidly--at least two exits must be maintained and must be clearly marked.

Emergency equipment must be provided, and its location must be clearly indicated.

Potentially hazardous activities may be carried out only by trained personnel.

Storage and use of combustibles must be minimized.

4. Equipment Containing Beryllium or Other Toxic Substances

Systems containing a toxic substance must bear a sign stating the name of the toxic substance and indicating that it is toxic. The installation and operation of any equipment containing a toxic substance must comply with PUB-3000, Chapter 5, Chemical Safety.

Beryllium and many of its compounds are highly toxic. Beryllium-containing materials likely to be encountered at LBL include beryllium copper and beryllium oxide ceramics (beryllia).

All drawings of parts made of beryllium or beryllium compounds or alloys, including beryllium copper, must include the note:

> "Beryllium alloy (or metal, oxide, etc.) used in this part (or assembly) is toxic and must be handled in accordance with PUB-3000, Chapter 5."

5. Pressure Definitions

Pressures as used in Section II are defined in Table II-1.

6. Required Reviews

General. An LBL mechanical engineer must review the design, fabrication, test, installation, and operational procedures for all pressurized research-equipment, piping, and pressure-relief devices and for all large vacuum vessels.

Hazardous Research Equipment. The Mechanical Safety Subcommittee must review the design, fabrication, test, installation, and operating procedures of all hazardous research equipment containing flammable or toxic fluid, such as cryogenic targets and counters; noncryogenic pressure vessels, counters, and piping; and pulsed pressure vessels.

A representative from EH&S must attend any major review meeting called by a Subcommittee member. When a change in plant facilities is expected, a representative from Plant Engineering must also attend.

Plant Engineering Facilities. All safety matters relating to plant facilities, including plant pressure vessels or boilers, buildings, outside structures, or earthworks, or any changes affecting LBL buildings or the LBL site, are to be referred to the Plant Engineering Department.

B. FLAMMABLE-FLUID CRYOGENIC TARGETS AND COUNTERS

The liquid-hydrogen target operating at 1 atm is the principal research apparatus covered by the rules of this section. Other cryogenic flammable-fluid low-pressure containers and storage Dewars are also covered by these rules.

Table II-1. Pressure definitions based on ASME Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels - Division 1 (1986 Edition) and this manual.

3000 psig

MAXIMUM PRESSURE FOR WHICH CODE RULES ARE CONSIDERED ADEQUATE

BURSTING PROOF-TEST PRESSURE, UG-101

For most materials: MAWP X 5 X Correction Factors for Variations in Material Properties, for Joint Efficiency, for Casting Quality Factors, and for Temperature.

YIELDING PROOF-TEST PRESSURE, UG-101

MAWP X 2 X Correction Factors for Variations in Material Properties and for Temperature

or

MAWP X 2.5 X Correction Factor for Temperature

STD. HYDROSTATIC TEST, UG-99

MAWP X 1.5 X Correction Factor for Temperature

PNEUMATIC TEST, UG-100

MAWP X 1.25 X Correction Factor for Temperature.

PRESSURE AT MAX. FLOW THRU PRESSURE-RELIEF DEVICES, UG-125

10% of MAWP max. (except 20% for pressure due to fire)

MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP), UG-98, Appendix 3.1 (a)

MAWP may be established higher than original design pressure if calculations are made to determine MAWP. Usually design pressure = MAWP.

Any desired fraction of MAWP but never higher than MAWP (except devices to protect against fire)

DESIGN PRESSURE, UG-21 & Appendix 3-1(b)

The pressure used in the design of a vessel for determining the minimum permissible thickness or physical characteristics of the different parts of the vessel

PRESSURE SETTING OF PRESSURE-RELIEF DEVICES, UG-134

Keep operating pressure enough below set pressure to prevent frequent opening or leakage of valves (usually 10% min.) or shortening fatigue life of rupture discs (usually 33% min.).

OPERATING PRESSURE, APPENDIX 3-1 (f)

At LBL for targets, counters, and pressure vessels: the pressure at which it normally operates. For bubble chambers or other pressure-pulsed devices: the highest instantaneous pressure that can be reached during any normal expansion and recompression of the chamber.

PROVISIONS FOR EXTERNAL PRESSURE SAME AS FOR INTERNAL PRESSURE

1. General Design Considerations

The low-temperature properties of materials to be used for cryogenic systems must be carefully considered. For example, the designer must consider the effects of differential contraction, embrittlement, and phase transitions in metals and the consequences of fatigue failures in equipment and associated piping during normal and emergency conditions. Efforts should be made to reduce stress concentration and to avoid brittle materials.

Hoses and seals that can embrittle at cryogenic temperatures must not be used in pressurized systems.

Procedures for pumping and purging must be followed to eliminate impurities, which can freeze and cause blockage.

All valves in contact with cryogenic liquid must be designed to operate at all expected temperatures.

Vessels normally operating at low pressure--such as vacuum tanks, heat exchangers, or switch housings--that enclose vessels or piping carrying high-pressure or liquefied gases must be protected from inadvertent rises in pressure.

Liquid-helium containers must have two independent and accessible means of venting.

The design and pressure-test criteria for flammable-fluid cryogenic targets and counters are summarized in Table II-2. A Safety Note is required for these devices.

2. Target Flasks

MAWP. Target flasks for operation at atmospheric internal pressure in an insulating vacuum vessel (15 psi internal differential) must have a MAWP of at least 20 psia at its operating temperature.

Pressure Tests. Flasks must be pressure tested three times to at least twice the maximum allowable working pressure (MAWP), but not less than 40 psi total differential pressure. The first test must be made at room temperature, the second must at liquid-nitrogen temperature or below, and the third at room temperature again.

There must be no noticeable permanent deformation resulting from these tests.

Newly Developed Nonmetallic Flasks. The MAWP for newly developed nonmetallic flasks can be established as follows:

Table II-2. Summary of Design and Test Criteria for Flammable-Fluid Cryogenic Targets and Counters.

Liquid-hydrogen targets normally operate at 1 atm and require a Safety Note.

Section	Title	Number of vents	Design Pressure	MAWP	Pressure-Relief Device Maximum setting	Pressure Test
III B 2	Target Flasks, to operate at atmospheric pressure.	2	Design to 5 psig (20 psia internal differential pressure).	5 psig (20 psia internal differential) at OT.	10 psig	Test to 2 times MAWP but not less than 40 psia internal differential pressure. Test 3 times: 1st at RT, 2nd at 77 K, & 3rd at RT.
II B 2	Target Flasks, newly developed nonmetallic.	2	Design to 5 psig (20 psia internal differential pressure).	See II B for procedure to establish MAWP.	MAWP	Test to 2 times MAWP but not less than 40 psi internal differential pressure.
II B 2	Target Flasks, reassembled and previously tested.	2	Previously designed to 5 psig (20 psia internal differential pressure).	5 psig (20 psia internal differential pressure).	MAWP	Test to 1.5 times MAWP at 77 K, or lower.
II B 3	Vacuum Vessels for targets containing more than 3 liters flammable liquid.	1	Design to 150 psig internal and 30 psi external differential pressure.	15 psi external pressure.	1 psig	Internal pressure test to 150 psig. External pressure test not required.
II B 3	Vacuum Vessels for targets containing less than 3 liters flammable liquid cooled by mechanical refrigerators.	1	Design to 75 psig internal and 22 psi external differential pressure.	7 psig (22 psi external differential pressure).	1 psig	Internal pressure test to 75 psig. External pressure test not required.
II B 3	Vacuum Piping Systems.	1	Design to 150 psig internal pressure.	0 psig (15 psi external differential presssure).	0.15 torr actuates alarm and isolates target; 1 psig internal pressure removes power.	Test to 150 psig internal pressure.
II B 4	Liquid Nitrogen Vessels.	1	Design to 2 times maximum operating internal differential pressure or 30 psi, if greater, and 1 atm external pressure.	Maximum operating internal pressure.	MAWP	Test to 2 times maximum operating internal differential pressure, or 30 psi, if greater, and 1 atm external pressure.
II B 5	Cryogenic Flammable-Fluid Reservoir with liquid connection to target.	2	Design to 2 times maximum operating internal differential pressure or 50 psi, if greater, and 30 psi external pressure at OT.	Maximum operating internal pressure.	MAWP	Test to 2 times maximum operating internal differential pressure, or 50 psi, if greater, at 77 K. External pressure test to 1 atm.
II B 6	Piping for flammable fluids.	1 (a)	Design to 2 times MAWP or 150 psig, if greater.	Maximum operating internal pressure.	MAWP	Test to 2 times MAWP or 150 psig, if greater.
II B 6	Piping for nonflammable fluids.	1 (a)	Design to 1.5 times MAWP or 150 psig, if greater.	Maximum operating internal pressure.	MAWP	Test to 1.5 times MAWP or 150 psig, if greater.
II B 7	Relief Devices.		As specified.	Maximum operating internal pressure.	MAWP	Pressure test relief valves to ensure set pressure. Rupture-disc assemblies must be certified by manufacturer, or rupture test 3 discs.

(a) Provide a relief device in cryogenic systems at any location where cryogenic fluids can be isolated or liquified.

At least two full-sized samples must be thermally cycled from room temperature to liquid-nitrogen temperature, or lower, and back to room temperature at least five times. Each time the flask is cold and each time it is warm, it must be pressure tested to at least twice the maximum allowable operating differential pressure, but not less than 40 psi differential. Succeeding models of the same materials, design, and construction must be tested according to this procedure.

At least one of the full-sized samples must be pressurized to destruction at near operating temperature.

When the data obtained from the rupture test agree with the expected results, the remaining parts may be used.

The setting of the pressure-relief device must not exceed the MAWP.

Previously tested reassembled flasks. These flasks must be pressure tested to a minimum of 1.5 times the MAWP at liquid-nitrogen temperature, or lower.

Venting. The target flask must have two independent and accessible vents, with a relief valve on each vent. The relief devices must comply with the section (II.B.7) on relief devices. Consideration should be given to making the two fittings such that they cannot be easily interchanged.

3. Vacuum Systems

Vacuum vessels for cryogenic systems containing more than three liters of flammable liquid, together with all cover plates, viewing ports and beam windows, must be designed and tested to an internal pressure of 150 psig and must be designed to withstand a differential external pressure (MAWP) of 30 psi without collapsing. Permanent deformation that relieves local stresses but does not continue at the maximum pressure is allowed.

Vacuum vessels for cryogenic systems operated by mechanical refrigerators and containing less than three liters of flammable liquid, together with all cover plates, viewing ports, and beam windows, must be designed and tested to an internal pressure of 75 psig and must be designed to withstand a differential external pres- sure (MAWP) of 22 psi without collapsing. Permanent deformation that relieves local stresses but does not continue at the maximum pressure is allowed. The vessel must be designed to have a test rating of 75 psig at the fluid temperature.

Whenever low-temperature fluids can come into contact with a vacuum-vessel optical window, normally or accidentally, the window and window gaskets must be designed and tested for these low-temperature conditions. Beryllium or other brittle materials must not be used as the material for vacuum-system beam windows. Deterioration of beam windows due to radiation or other environmental conditions must be considered.

Insulating vacuum systems for cryogenic fluids must have a pressure-relief device and vent (see Section I.F.2. for mechanical-vacuum-pump vents).

Vacuum piping systems must be designed for, and pressure tested at, 150 psig. At least one sample of each model of vacuum pump must be tested.

Vacuum-pump systems must be designed to isolate themselves from the vacuum system and trip an alarm, whenever the pressure rises above 0.15 Torr (20.0 Pa).

A major interlock system that activates an alarm and shuts off power to all equipment in the hazardous area when the vacuum-tank pressure exceeds 1 psig must be provided.

Glass vacuum ion gauges must not be used.

4. <u>Liquid-Nitrogen Vessels</u>

A liquid-nitrogen vessel in a cryogenic flammable-fluid system must be designed to withstand, and must be tested at, twice the operating internal differential pressure or 30 psi differential, whichever is greater. The vessel must be tested to an external differential pressure of 1 atm.

5. <u>Cryogenic Flammable-Fluid Reservoir</u>

Cryogenic flammable-fluid reservoirs with liquid connections to targets must be designed to operate at its operating temperature and must be tested at 77 K in a vacuum to an internal pressure of 50 psi differential, or twice the maximum operating internal differential pressure, whichever is greater, without permanent deformation. The vessel must be designed to withstand an external differential pressure of 30 psi and must be tested to an external differential pressure of 1 atm. All cryogenic flammable-fluid reservoirs must have two pipes connected to them and leading from the liquid compartment to the outside of the vacuum vessel. The pipes must not be connected inside the vacuum system.

6. <u>Piping</u>

Piping to be used for flammable-fluid cryogenic targets and counters must comply with Section II.C.3., Pressurized Flammable-Fluid Piping.

7. Relief Devices

All systems, system components, and piping subject to accidental overpressures must be equipped with relief devices. Particular attention must be given to those parts of a system in which cryogenic fluids can be isolated or gases can be liquefied.

Insulating vacuum systems for cryogenic fluids must have relief devices.

Shutoff valves must not be installed in series with a relief device.

All valves that can isolate a part of a pressurized system and thereby create a hazard must be bypassed with a relief valve.

Relief devices must have sufficient flow capacity to limit the pressure to 10% or less above the MAWP during any emergency condition.

All safety valves must be pressure tested to ensure that they lift at the set pressure. Rupture-disk assemblies must be certified by the manufacturer or pressure tested by rupturing three disks selected at random from disks made from the same sheet. Permanent test records must be kept.

Relief devices must be set (at the MAWP or lower), locked, and tagged with the date and set pressure.

The operation of primary relief valves must be ensured before each use or setup of the equipment.

Relief devices for atmospheric-pressure targets must be set at not more than 10 psig.

Relief devices and piping must be designed to handle emergency flow conditions.

8. Instruments

Components or vacuum pressure gauges exposed to the vacuum in flammable-gas systems must not be heated to temperatures exceeding 80% of the ignition temperature of the flammable gas unless interlocked to shut off their power whenever the pressure rises above 0.01 Torr (1.33 Pa).

Electrical liquid-level indicators located in flammable fluids must be intrinsically safe (i.e., the amount of energy that can be released by the indicator must be less than the energy required to ignite the most sensitive mixture).

Flow meters having plastic bodies for use with flammable gas must operate at ambient temperature, at less than 2 atm differential pressure, and at less than 15 scfh. The flow meters must have a safety factor of not less than 8 to rupture and must be tested to 2.5 times the operating pressure. The flow meter must be protected with a relief valve set at no higher than 1.25 times the operating pressure. The flow meter must be mounted so that exposure to mechanical damage and strains caused by the connected meter tubing are minimized.

C. NONCRYOGENIC COUNTERS AND PIPING

The Time Projection Chamber and the Cerenkov counter filled with pressurized flammable gas at ambient temperature are the principal research devices covered by the rules of this section. Rules for such pressurized flammable-fluid counters, pressure vessels, piping, and relief valves, are described. Design stress values for these pressure vessels may be found in Section III and in ASME Pressure Vessel Codes. A Safety Note is required.

The pressure-test and design criteria for noncryogenic pressure vessels, counters, and piping are summarized in Table II-3.

1. Noncryogenic Flammable-Fluid Pressure Vessels and Counters

When the flammable-fluid counters and pressure vessels are made of known materials and the engineering information is adequate for proper design:

> Areas of the counter or vessel other than the beam-entrance windows, etc., must be designed according to the ASME Boiler and Pressure Vessel Code, Section VIII--Pressure Vessels. When possible, beam-entrance windows, etc., should adhere to the same design requirements. The counter or vessel must be pressure tested to twice the MAWP at room temperature and at the operating temperature.
>
> Calculated stresses in ductile-metal beam windows must be less than 40% of the yield stress at the MAWP. The windows must be pressure tested to twice the MAWP and held at that pressure for 6 hours at the operating temperature. The pressure must then be cycled between 1.8 and 2.0 times the MAWP four times and held at 2.0 times the MAWP for 1 hour at the operating temperature. Pressure-deformation measurements must be made.

When the flammable-fluid counters or pressure vessels are made of unknown new material or when engineering information is inadequate for proper design, the MAWP must be determined from prototype tests. At least two of the parts must be made. One of the prototype vessels must be pressure tested to destruction or tested to at least 10 times the MAWP at the operating temperature. When the data obtained from the rupture test agree with the expected or acceptable results, the

Table II-3. Summary of Design and Test Criteria for Noncryogenic Counters and Piping.

Cerenkov counters normally operate at ten's of atm and require a Safety Note.
Set pressure-relief valve no higher than MAWP.

Section	Title	Number of Vents	Design Pressure	Pressure Test
II C 1	**FLAMMABLE FLUID**			
II C 1	Vessels & Counters made of known material.	2	Design to ASME Sec VIII.	Test at 2 times MAWP at RT and OT.
II C 1	Beam Windows made of known ductile metal.		Design to 0.4 times yield stress at MAWP.	Test at 2 times MAWP at OT for 6 hours, cycle between 1.8 and 2 times MAWP 4 times, hold at 2 times MAWP for 1 hr.
II C 1	Vessels & Counters made of unknown material.	2	Test 1 prototype to destruction or to at least 10 times MAWP at OT. MAWP is 1/4 times rupture pressure, or less.	Test at 2 times MAWP at OT for 6 hours, cycle between 1.8 and 2 times MAWP 4 times, hold at 2 times MAWP for 1 hr at OT.
II C 1	Vessel & Counter Assemblies.	2		Test at 1.5 times MAWP at OT before first filling. After reassembly test to MAWP before filling.
II C 3	Flammable-Fluid Piping.	Connect to system vent; pressure gauge required.	Design for operating pressure and temperature. Guidelines ANSI B31.1 and B31.3.	Test at 2 times MAWP or 150 psig, if greater.
II C 2	**NONFLAMMABLE FLUID**			
II C 2	Vessels & Counters.	2	Design to ASME Sec VIII.	Test at 1.5 times MAWP.

remaining part may be used. The MAWP must be 1/4 the rupture pressure or less. Pressure-deformation measurements must be made. The part to be used must be pressure tested to twice the MAWP, and the pressure held for 6 hours at the operating temperature. The pressure must then be cycled four times between 1.8 and 2.0 times the MAWP and held at 2.0 for 1 hour at the operating temperature.

General design requirements include the following:

Materials must be suitable to the environment, i.e., the working fluid, pressure, temperature, and magnetic field. Radiation damage, corrosion, hydrogen diffusion, and alloying must be considered, where necessary. Minimize the use of brittle materials.

Any pressurized system must have two independent and accessible means of venting.

Pulsating pressure systems must be designed to withstand vibration and fatigue.

Any line or part of a pressurized system that may be isolated by valves must have a pressure gauge indicating the pressure in that part of the system.

Optical windows must be designed according to the guidelines of Section II.F., Glass Windows.

Equipment must be installed according to the following requirements:

Pressurized counters or vessels assembled and ready for use must be pressure tested to 1.5 times the MAWP at the operating temperature before being filled with flammable fluid. A pressure test to at least the MAWP must be performed before filling each time the counter is reassembled, with the same previously assembled and tested parts, or when the assembly is reactivated after 1 year or more of inactivity. The relief valve must be set at the MAWP or lower.

Vessels containing liquefied gases must be connected to a relief system.

Pressurized gas equipment must be secured against recoil forces in the event of a failure. Gas lines must be secured against whipping in the event of a failure.

The equipment must be protected from possible damage by external occurrences.

Windows must be protected from accidental mechanical impact.

Personnel must be protected against hazards resulting from the rupture of thin or brittle windows in vacuum and pressure vessels.

2. Noncryogenic Nonflammable-Fluid Counters

Noncryogenic nonflammable-fluid counters must comply with the rules for noncryogenic flammable-fluid pressure vessels and counters except that the pressure test may be reduced to 1.5 times the MAWP.

3. Pressurized Flammable-Fluid Piping

Pressurized flammable-fluid piping must comply with the following rules (additional guidelines for piping for flammable-fluid service can be found in the ASME Code for Pressure Piping B31, An American Standard, ANSI/ASME B31.1, Power Piping, and B31.3, Chemical Plant and Petroleum Refinery Piping.

Flammable-fluid piping must be designed for the pressure and temperature at which it is to operate and must be tested at 2 times the MAWP or 150 psig, whichever is greater. A Safety Note is required.

Piping to be used for nonflammable fluids must be tested to 1.5 times the MAWP or 150 psig, whichever is greater.

Piping for cryogenic fluids must be made of metal suitable for use at cryogenic temperatures.

Stainless steel welded piping is preferred because it has a high melting point.

Silver-brazed socket type joints are permitted.

Approved tube fittings are acceptable.

Soft solder must not be used for general service; it is acceptable to seal screwed threads for instruments.

LRL (Lawrence Radiation Laboratory) Standard Tubing Fittings are designed for use in vacuum systems and are normally made of brass. They are described in Design Data 98B, LBL Standard Tubing Fittings Outline Dimensions and Typical Applications, J. J. Dols, 12/6/71. LRL tubing fittings may be used in low-hazard pressure equipment (see page III-1) that will be used to contain fluids compatible with their gaskets. When used with metal tubing LRL tube fittings must be silver soldered. The MAWP for LRL brass fittings (weakest part is the nut) are as follows:

Size (in.)	MAWP (MPa/psi)
1/4	13.8/2000
3/8	13.8/2000
1/2	6.9/1000
3/4	3.5/500
1	3.5/500

National pipe thread is not recommended, except for instrument, gas-cylinder, or valve connections. Where possible, permanent pipe-thread connections should be soft-soldered.

Short lengths at flexible metal hose reinforced with metal braid may be used for when flexibility is required; they must be protected from mechanical damage.

Rubber, plastic, or other combustible hose piping or tubing must not be used for flammable gas. When an experiment requires a flexible gas connection and nonmetal in contact with the flammable fluid, short lengths of rubber or plastic tubing may be used if the flow rate of the flammable fluid through the system is limited by an orifice or if the rubber or plastic tubing is encased in a gas-tight flexible metal jacket. The system must be approved by the Mechanical Safety Subcommittee.

Quick-disconnect fittings must not be used for flammable gas or on sensitive secondary circuits such as insulating vacuums, critical instruments, or safety devices.

Instruments must be capable of withstanding the temperature and pressure rating of the system.

The pressure in any part of a pressurized system must be indicated on a pressure gauge with a range of at least 120% of the MAWP.

Gauges, switches, meters, and other devices that indicate system conditions must be calibrated through their full range, which must be 120% or more of their maximum allowed working points (i.e., the maximum allowed value of the quantity served by the device).

Manifolded flammable-gas cylinders to be used with research apparatus and located in an enclosed area must have their regulator and/or manifold relief valves discharge into a vent system that leads outside the building.

Manifolded flammable-gas cylinders must have check valves install between the cylinder valve and the manifold to prevent air from entering the cylinder to form a combustible mixture.

4. Relief Devices

Relief devices for noncryogenic counters and piping must comply with Section II.B.7., Relief Devices.

D. FLAMMABLE-FLUID PULSED PRESSURIZED CHAMBERS

1. General

Flammable-fluid cryogenic and noncryogenic pulsed pressure vessels and bubble chambers must comply with the rules of this section and with the rules of other sections as specified below. The rules of this section take precedence over rules of other sections except Section II.B.2., Target Flasks.

In Section II.C., Noncryogenic Counters and Piping--All rules except C.2., Noncryogenic Nonflammable-Fluid Counters.

Flammable-fluid pulsed pressure chambers must be designed with a sufficient factor of safety to ensure containment of the flammable fluid. Design considerations must include the cyclic operation and sharp impact of chamber pulsing; the thermal stress and differential expansion due to thermal cycling; the special requirements of optical windows and mountings; and unplanned changes in operation.

Interlock and alarm systems must be provided on flammable fluid systems, on the expansion system, and on any other pertinent system. All alarm systems must be arranged to indicate where the trouble exists.

Emergency procedures must be written for power failure, for other pertinent system failures, and for fire. These procedures must be detailed instructions, and the operating crew must be trained in their use.

A Safety Note is required in lieu of the LBL Pressure-Test Record and Label described in Section III.

The Pressure Test and Design Criteria for flammable-fluid pulsed pressurized vessels and bubble chambers are summarized in Table II-4.

2. Pulsed Pressure Chamber

The operating or design pressure in the pulsed pressure chamber is defined as the highest instantaneous pressure that can be reached during any normal expansion and recompression of the chamber.

The chamber must be designed for a MAWP of at least 1.5 times the operating (design) pressure. Guidelines for design stresses may be found in the ASME Pressure Vessel Codes.

Table II-4. Summary of Design and Test Criteria for Flammable-Fluid Pulsed Pressurized Chambers.

Pulsed pressurized (bubble) chambers normally operate at ten's of atmospheres and require a Safety Note.
The MAWP must not be less than 1.5 times the design pressure

Section	Title	Number of vents	Design Pressure	Pressure-Relief Device Maximum Setting	Pressure Test
II D 2	Pulsed Pressure Vessels and Bubble Chambers.	1	Highest instantaneous pressure during a normal cycle.	Preoperational test pressure (POTP).	Test to 1.5 times MAWP (2.25 times design pressure).
II D 2	Noncryogenic Pulsed-Pressure-Vessel and Bubble-Chamber Assemblies.	1	Highest instantaneous pressure during a normal cycle.	POTP. Test the relief device after each assembly at a pressure not more than POTP.	Test to 1.5 times design pressure (MAWP) near OT, before filling with flammable fluid.
II D 2	Cryogenic Pulsed-Pressure-Vessel and Bubble-Chamber Assemblies.	1	Highest instantaneous pressure during a normal cycle.	POTP. Test the relief device after each cool-down at a pressure not more than POTP.	Test to 1.1 times design pressure at less than 77 K, before filling with flammable fluid.
II D 3	Pulsed-Pressure-Vessel Beam Windows made of known ductile materials.	- - -	1/6 ultimate stress, or less.	- - -	Test to 1.5 times MAWP (2.25 times design pressure) at RT or OT, whenever the material strength is lower.
II D 3	Pulsed-Pressure-Vessel Beam Windows made of new and/or brittle materials.	- - -	1/6 rupture pressure, or less.	- - -	Test two windows to 1.5 times MAWP (2.25 times design pressure) at RT or OT, whenever the material strength is lower. Pressurize one window to destruction or to at least 10 times design pressure.

The chamber metal parts must be hydrostatically tested to at least 2.25 times the operating (design) pressures (1.5 times the MAWP) at room temperature. Optical and beam windows may be omitted for this test. Whenever the mechanical properties of the material are lower at the operating temperature, the test must be performed at the operating temperature.

Pre-operation tests must be made as follows:

A noncryogenic flammable-fluid pulsed pressure chamber assembled for use must be pressure tested near operating temperature to at least the MAWP (which is 1.5 times the operating pressure) before being filled with flammable fluid. Each time the chamber is assembled this test must be repeated before it is filled with flammable fluid.

Cryogenic flammable-fluid pulsed pressure chambers must be pressure tested at a temperature less than 77 K to at least 1.1 times the operating pressure following each cooldown and before being filled with flammable fluid.

Remotely operated valves that could vent the chamber fluid accidentally are not permitted.

The chamber relief system must be set to relieve at not higher than the preoperation test pressure.

3. Pulsed-Pressure-Chamber Beam Windows

Flammable-fluid pulsed-pressure chamber-beam windows must be designed and tested in accordance with the following:

When known ductile materials are used and when engineering information is adequate for the proper design of an internally pressurized thin window, the window must be pressure tested at 2.25 times the operating (design) pressure at room temperature. The design stress must not be more than one-sixth the ultimate strength. Whenever the mechanical properties of the material are inferior at the operating temperature, the test must be performed at the operating temperature.

When new or brittle materials are used, when engineering information is inadequate for proper design of the thin window, or whenever the window is externally loaded (buckling), at least two of the windows must be pressure tested to 2.25 times the operating pressure at room temperature. Whenever the mechanical properties of the material are inferior at the operating temperature, the test must be performed at the operating temperature. One of these windows must be pressurized to destruction or to at least 10 times the operating (design) pressure at the operating temperature. When the data obtained from the rupture test agree with expected or acceptable results, the remaining windows may be used. The operating pressure must be no more than one-sixth the rupture pressure. Pressure deformation measurements should be made.

When the endurance limit of the material is unknown tests must be performed to ensure that the probability of fatigue failure is acceptable.

E. EVACUATED BEAM PIPES OR LARGE VACUUM VESSELS

A Safety Note covering the major beam-pipe components and beam windows is required.

When the allowable differential internal pressure of a vessel exceeds 15 psi, the vessel must comply with the ASME Pressure Vessel Code.

Vacuum vessels that are subjected to a few pounds internal pressure during testing or when the vacuum is purged must be pressure tested to 1.5 times the maximum purge or test internal differential pressure, and the design internal pressure marked on the vessel as follows: "Maximum internal pressure _______ psig."

A relief device must be provided on vacuum vessels in which there is a possibility of overpressure. The relief device must be set no higher than the purge pressure and must comply with Section II.B.7., Relief Devices.

Deterioration of beam windows due to radiation or other experimental conditions must be considered, and a written log of window beam exposure must be maintained.

Thin windows having diameters greater than 6 inches must be designed for, and be externally pressure tested to, 2 atm differential pressure. Nonmetallic windows (more than 6 inches in diameter) that could be damaged by the 2-atm external pressure test can be proven by testing duplicate parts to destruction or to 5 atm.

Protection for thin windows against mechanical damage must be considered, especially when personnel injury can result or when the vacuum system is directly connected to research apparatus, an accelerator, or other critical vacuum systems.

Thin, easily damaged windows not located in a protected area should be protected when not in use by cover plates.

When the beam window is in a high magnetic field, remove or fasten down ferromagnetic objects.

Install warning lights or signs.

Exclude nonessential personal from the area of the thin window.

F. GLASS WINDOWS

1. General

Glass does not have a plastic range, and whenever a strain is imposed on the glass there is a corresponding stress, as determined by Young's modulus. When the glass is strained too far the rupture stress is exceeded, and the glass breaks. Glass fails only in tension. For example, a compressive load such as a ball pressing on a flat glass surface stretches the surface causing tension, which can lead to failure. The rupture stress for glass depends upon surface or internal flaws and many of the following parameters:

- The size, thickness, surface finish, and type of glass.
- The environment, temperature, and pressure.
- The mounting design, gasketing, and assembly procedure.
- The thermal and stress history.

2. Design Guidelines

The guidelines listed below apply to glass windows.

A Safety Note is required.

Tension stresses should be minimized.

The glass should be mounted so that bending moments in the glass are minimized when the mount or glass is strained.

The glass shape should be simple; avoid sharp corners, point loads, stress concentrations, and sudden changes in section.

The materials in contact with the glass should have a modulus of elasticity lower than that of the glass.

The glass and its mounting flanges should be parallel to each other and remain parallel. Loads should not distort the flange or cause bending moments in the glass.

Differential expansion between the glass and mounting must be considered.

Careful analysis should be made of thermal stresses caused by temperature gradients within the glass during temperature changes.

All glass edges should be radiused or beveled.

All nonoptical surfaces should be fine ground and etched.

Fiducials should be etched only on the compression side of the glass. The number of fiducials on the glass should be minimized.

The mechanical strength of the glass should be appropriate for the environmental conditions and operating temperature. The principal design maximum stress in the glass is usually one-tenth to one-fifth the ultimate strength. The choice depends on how well the stress pattern, the maximum stress, and properties of the glass are known.

The window should be pressure tested at about one-fifth the ultimate strength to prove the system, but the test pressure and the number of tests should be limited to avoid initiating cracks in the glass, which will grow as the stress cycle is repeated. A single test at high pressure proves the basic design, but the uncertainty in the use of glass windows is in the mounting and thermal stress history. The principal stress in the glass window can be determined with greater accuracy if simple shapes and a conservative design are used. Clear glass can be examined for cracks before installation. Each assembly has its own risk, however, and inspection after assembly is difficult.

G. BEAM SEPARATORS

Beam separators used at the LBL accelerators and operating at accelerator vacuum pressures generally employ very high voltages across rather small gaps; 400 to 600 kV across gaps of 2 to 4 inches are typical values. The electrical hazard associated with such equipment (high-voltage power supply, cables, connectors, and separator) must be considered by all who work with separators.

Separators can be sources of extremely high x-ray fields, particularly if they are sparking. Separators must be shielded with concrete, lead, or other heavy material. The entrance to the separator areas must be interlocked with the high-voltage power supplies; i.e., the power to the separator shuts off when the door or gate to the area is opened. The Bevatron Radiation Control Group and the Radiation Safety and Electrical Safety Subcommittees can provide advice and must review the separator system design and installation.

H. SPARK AND STREAMER CHAMBERS

This section is applicable to ordinary spark chambers and streamer chambers, i.e., those operating with noble gases at atmospheric pressure. The type of hazard associated with spark chambers and streamer chambers is electrical, and the general electrical safety rules of PUB-3000 and the guidelines listed below must be followed. These systems must be reviewed by the Electrical Safety Subcommittee.

Designs for chambers involving cryogenic and/or flammable, corrosive, or toxic fluids or pressures above or below atmospheric must be referred to the Safety Review Committee.

Cables connecting power supplies with capacitors must either be permanently connected at each end or be such that both male and female parts are safe when disconnected.

In the design of an experiment using spark or streamer chambers concern must be given to the flow of ground currents. Because of the very large instantaneous currents involved in these chambers, a considerable potential difference may develop between various parts of the apparatus normally considered at ground. This can constitute a hazard both to personnel and to equipment.

When spark or streamer chambers are used with targets or counters containing flammable fluids, the following additional rules must be observed.

All high-voltage electrical cables and other equipment must be securely fastened.

When a spark or streamer chamber is used close to a target containing liquid-hydrogen or other flammable fluids, the target frame must not carry any of the ground current to the chamber. An electrical shield must be placed between the chamber and the target. This shield must be grounded to the chamber power supply but must not carry the chamber ground current.

Where possible, all high-voltage dc power supplies and large storage capacitors should be placed outside the hazardous area.

Chamber capacitors and spark-gap assemblies that must operate in the hazardous area are classified as sparking devices and, therefore, must be either sealed or purged with argon, nitrogen, or air (see Section I.B.2.). If the chamber is purged with air, the blower suction must be placed low (for lighter-than-air gases) and at a safe distance from any possible sources of flammable gases (see NFPA No. 496).

The chamber trigger, clearing field, and high voltages must be interlocked with the 1-psi interlock of the hydrogen target.

All capacitors used in a chamber system must have bleeder resistors that will provide a discharge path with a time constant no longer than 1 second.

I. MULTIWIRE PROPORTIONAL COUNTERS CONTAINING FLAMMABLE GAS

1. Introduction

These rules apply to proportional counters or similar detectors operating with flammable gas mixtures such as "Magic Mix II" (magic gas) near atmospheric pressure. This particular mixture is denser than air and is composed of

Isobutane	23.52%
Methylal (dimethoxy-methane)	4.00% (nominal)
Freon 13-B1	0.48%
Argon	72.00%

The premixed gas is purchased in cylinders pressurized to nominally 35 psig. The liquid capacity of the Matheson 1F (Fat Boy) cylinder is 3.87 ft^3; its pressure rating is 300 psig; and at 35 psig it holds 13.2 ft^3 STP of gas, of which 9.3 ft^3 STP, the amount normally stored above atmospheric pressure, is used. The gas (Isobutane and Methylal) content in the cylinder is 3.63 ft^3 STP total, of which 2.56 ft^3 STP, the amount above atmospheric pressure, is normally used.

The magic-gas cylinders do not contain a large quantity of thermal or PV energy since the cylinder pressure must be low (nominally 35 psig) to prevent the gas from liquefying. If the valve on the cylinder breaks off, there is little danger that the cylinder will become a high-speed projectile, as is the case with cylinders having gas pressures in the range of 2000 psig.

The internal energy content of a 1F-sized cylinder charged to 35 psig with 28% isobutane and methylal (methylal is assumed to have the same specific heat energy as isobutane) and 72% inert gas is 13 MJ internal energy and 0.04 MJ PV energy. The enthalpy of a hydrogen cylinder is 79.0 MJ internal energy and about 0.6 MJ as PV energy. The energy of 20 magic-gas 1F cylinders is equivalent to about 3 high-pressure hydrogen-gas cylinders, or about one-tenth of a 1F butane cylinder.

The flammable limits of pure isobutane in air are 1.8 to 8.4% by volume. The addition of the other gases listed above will reduce the flammable limits to about to 7% in air (Engineering Note M4579A, "Multiwire Proportional Counter Chambers Estimated Combustible Limits of Magic Mix," Paul Hernandez, 23 Jan 73; Engineering Note M4931B, "Estimated Combustible Limits of Methane Gas Mixtures," Gerd Behrsing, 11 Mar 76). The flammability of the gas has been demonstrated. The gas was burned at the end of a 1/4-inch-i.d. tube at a line pressure of about 5 inches of water (0.2 psi) and gave a flame about 14 inches long. Methylal $[CH_2(OCH_3)_2]$ is a colorless liquid having an ambient-temperature density of 0.866 and a boiling point of 42°C at 1 atm. (Chemical Engineering Handbook, McGraw-Hill, 2nd Ed., pp. 143, 216, 226.)

2. Rules for Operation with Flammable Fluid

LBL Rules for High Pressure Cylinders, Manifolds, and Regulators, Section I.D., apply.

At the time of the safety review, the responsible user must submit a procedure describing how the magic-gas cylinders will be stored and how the deliveries will be made to the experimental area.

Magic-gas cylinders must be colored light blue; they may be stored with other flammable gases, but not with oxygen.

Not more than two magic-gas 1F cylinders may be stored in any enclosed experimental area. Not more than twenty filled magic-gas cylinders may be stored at any research location. Larger numbers of cylinders must be stored by the LBL Materiel Management Department.

Supply cylinders for magic gas (other than Matheson 1F cylinders) must not contain more than 5 SCF of flammable gas. Only one such cylinder may be connected to the system at a time; one additional cylinder, however, may be connected to the manifold on standby.

If the first-stage pressure gauge of the cylinder regulator is changed to a lower rating, a relief valve must be installed between the cylinder and the cylinder regulator and must be set no higher than the maximum reading on the pressure gauge. The relief-valve flow capacity must be greater than the cylinder-valve capacity.

Any modified regulator mounted on the magic-gas cylinder must be marked on the dial under the glass or on a metal tag attached securely to the regulator with the following statement: "REGULATOR MODIFIED FOR USE WITH MAGIC MIX. DO NOT USE ON OTHER CYLINDERS."

To ensure that a gas regulator is correctly specified for a particular application and is in safe working condition, it must be checked by the Plant Maintenance Technician Regulator Shop in Building 76 (see Section I.D.5.).

Regulators must be mounted so as to protect them from damage.

The output pressure of the last stage of regulation must not exceed 5 inches of water (0.2 psi).

Proportional-counter piping or tubing containing flammable gas must be metal up to the flow-control point to reduce the probability of accidental damage, unless this piping and the gas-supply cylinder are in a protected area and within a few feet of each other.

Plastic tubing may be used for magic gas (or similar gases) beyond the flow-control point but must be arranged to minimize its amount and must be securely fastened at each end.

The exhaust-gas flow must be monitored with a bubbler to indicate an open line or a leaking counter. (The bubbler also functions as a relief valve for the counter.)

Proportional counters must be leak checked and pressure tested to twice their working pressure expressed as a differential pressure above atmospheric pressure, i.e., if the working pressure is 5 inches of water (0.2 psi) above atmospheric pressure, test to 10 inches of water (0.4 psi).

Counter exhaust gas must be vented outside the counter room or outside any enclosed experimental area. The vents must terminate where air movement will quickly disperse the flammable gas. When the counter enclosure is in a large, high-ceilinged room, e.g., an accelerator experimental hall, the vents may terminate at a point 10 feet above the enclosure. Vents must terminate exhaust outside laboratory buildings such as Buildings 50, 62, and 70. Metal vent lines are required (0.5-in. I.D. metal tubing is acceptable).

Flammable gas must be removed from the counter at the completion of the experiment or before disassembly of the counter to protect personnel who may be unaware of the status of the counter.

Any blockhouse enclosing counters operating with flammable gas must be designed to have ventilation.

Forced-air ventilation must be used in the experimental enclosure when the volume ratio of the combustible component of the gas to the enclosure volume exceeds 1/400.

When counters are used with liquid-hydrogen targets, the plastic window of the hydrogen target must be protected from fire or mechanical damage.

J. HAZARDS ASSOCIATED WITH MAGNETS AND HIGH MAGNETIC FIELDS

1. Magnetic Fields

Very little information is available on the biological effects of either varying or static magnetic fields that are significantly higher than the natural background, i.e., "high magnetic fields." The literature indicates that, although high magnetic fields are not life threatening, these fields can cause a number of disturbances, e.g., headaches, fatigue, low blood pressure, and lowered red-blood-cell counts. Therefore, personnel must not expose themselves unnecessarily to magnetic fields greater than background. In addition, high magnetic fields can interfere with the operation of coronary pacemakers, and individuals with pacemakers must be excluded from all areas where they could be exposed to such fields. Call EH&S for additional information.

2. Mechanical Hazards Associated with Magnetic Fields

Equipment to be located in or near magnetic fields must be designed with magnetic-field environments in mind. Objects made of magnetic material must be securely fastened down. Objects of non-magnetic, but electrically conducting, material located in varying magnetic fields can also have large forces exerted on them, and all such objects must likewise be fastened down. Remember, a changing magnetic field results when dc electromagnets are turned on or off.

Working in high magnetic fields may be hazardous if you are handling equipment, tools, etc., of magnetic material. Therefore, when working near electromagnets, turn off the magnet power supply and keep the interlock key until you are finished.

Respect barricades or caution signs around magnets being tested or operated.

Specific rules for operating magnets having large stray fields are listed below:

Install warning signs or lights on magnets having large stray fields.

Fix a warning sign to any magnetic research apparatus that is designed to be moved during the experiment and located in a magnetic field. The warning must state, "SECURE AGAINST MAGNETIC FORCE," in letters at least 2 inches high.

Remove unneeded magnetic materials from the area.

Make a magnet search for loose magnetic material before turning on the magnet and before increasing the field to a higher level. The search must also be made at the beginning of each shift during the period of magnet operation.

3. High-Field Pulsed Magnets

The design of high-field pulsed magnets and associated power equipment and the experimental arrangements using such magnets must be reviewed by the Mechanical and Electrical Engineering Departments or an appropriate SRC subcommittee before setup of such equipment.

4. Superconducting Magnets

Superconducting materials presently being used in the fabrication of magnets are known to become superconducting only at temperatures below 18 K. In most cases, the appropriate coolant in this temperature range is helium, although a flammable refrigerant such as hydrogen might be used in the cool-down process.

One characteristic of the superconducting materials being used in magnet technology is the rapidity of the transition from the superconducting to the normal (resistive) state when certain thermal or electromagnetic instabilities occur. Excessive values of the electric current, the magnetic-field intensity, or the temperature at the superconductor may cause a transition from the superconducting to the normal state. A normal (resistive) region, once initiated, may propagate quickly throughout the magnet. In the design of a superconducting magnet system, there should be recognition of the hazards that may arise from release of the magnetic-field energy if the superconductor goes into the normal state. These hazards and the measures used to guard against them are directly related to the amount of energy stored in the magnetic field and, hence, depend on the size of the magnet and the intensity of the field.

The development of various configurations of superconducting conductor has made feasible the construction of magnets capable of generating high magnetic-field intensities over large volumes.

These technological advances carry with them additional problems resulting from the interaction of the magnetic field with associated and/or nearby equipment, instrumentation, and structures.

Some guidelines for designing superconducting magnets are shown below.

Provide adequate means of protecting the system from the release of magnet energy in the event the coil goes normal. Consideration should be given to the possibility of induced high voltage and gas overpressures resulting from the dissipation of some magnetic-field energy in the magnet and its cryostat. Large amounts of stored energy should be dissipated in external circuits.

Design all components of the system, including the magnet conductor, to withstand the thermal and electromagnetic forces that occur under abnormal as well as normal conditions.

When superconducting magnets are located in confined areas, provide safety systems to protect personnel against asphyxiation if the magnet system fails and releases large amounts of nonbreathable gases, e.g., helium or nitrogen.

K. REFERENCES FOR SECTION II

ASME Code for Pressure Piping, B31, An American National Standard, ANSI/ASME B31.1, Power Piping, and B31.3, Chemical Plant and Petroleum Refinery Piping.

ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels, Divisions 1 and 2, American Society of Mechanical Engineers, New York.

ASME Boiler and Pressure Vessel Code, Section X, Fiberglass-Reinforced Plastic Pressure Vessels, American Society of Mechanical Engineers, New York.

Chemical Engineering Handbook, 2nd Edition, McGraw-Hill, New York, pp. 143, 216, 226.

Estimated Combustion Limits of Methane Gas Mixtures, G. Behrsing, Engineering Note M4931B, March 11, 1976.

Health and Safety Manual, PUB-3000, Chapter 13, Gases, Flammable and Compressed.

LBL Standard Tubing Fittings Outline Dimensions and Typical Applications, J. J. Dols, Design Data 98B, December 6, 1971.

Multiwire Proportional Counter Chambers, Estimated Combustion Limits of Magic Gas, Engineering Note M4579A, P. Hernandez, January 23, 1973.

National Fire Protection Association Technical Committee Report NFPA No. 496, Purged Enclosures for Electrical Equipment.

Related Publications Not Cited in the Text

American Petroleum Institute, API RP-500, API recommended practice for classification of areas for electrical installations in petroleum refineries.

Compressed Gas Association, Safe Handling of Compressed Gases, Pamphlet P-1.

Compressed Gases, Safe Practices Pamphlet No. 95, National Safety Council.

Fire Protection of AEC Electronic Data Processing System, Safety and Fire Protection Technical Bulletin 12, 1968.

Handbook of Compressed Gases, Compressed Gas Association, Reinhold, New York.

Handbook of Hydrogen Handling equipment (PB 16 183 5), U.S. Department of Commerce, Office of Technical Services, Washington, D.C.

High Pressure Safety Equipment, S. Hickman, Engineering Note, 4610-02, M2, 34 pages, March 18, 1959.

Instrument Society of America RP-12.1, Electrical instruments in hazardous atmospheres.

Instrument Society of American RP-12.1, Instrument purging for reduction of hazardous area classifications.

Instrument Society of America RP-12.2. Intrinsically safe and non-incendiary electrical instruments.

Interstate Commerce Commission Regulations, Tariff No. 19.

National Fire Protection Association, National Electrical Code, Article 500, Hazardous Locations.

National Fire Protection Association, Vol. 1, Flammable Liquids, and Vol. 2, Gases.

National Fire Protection Association, No. 493-PT, Intrinsically Safe Process Control Equipment for Use in Hazardous Locations.

National Fire Protection Association, No. 50B-T, Liquefied Hydrogen Systems at Consumer Sites.

National Fire Protection Association, No. 68, Guide for Explosive Venting.

Safety Instructions and Safety Guide for Handling Gaseous and Liquid Hydrogen at the Boulder Laboratories, Memorandum Report No. CM-4, January 1960, National Bureau of Standards.

Safety Guidelines for High Energy Accelerator Facilities, prepared by National Accelerator Committee, USAEC Division of Operational Safety, Health Safety Report TID 23992, 1967.

III. PRESSURE VESSELS AND PRESSURE SYSTEMS

Definitions

Low Pressure — Gas pressure less than 1 MPa gauge (150 psig) or liquid pressure less than 10 MPa (1500 psig).

Intermediate Pressure — Gas pressure from 1 to 20 MPa gauge (150 to 3000 psig) and liquid pressure from 1 to 35 MPa gauge (150 to 5000 psig).

High Pressure — Gas pressure greater than 20 MPa gauge (3000 psig) and liquid pressure greater than 35 MPa gauge (5000 psig).

Low-Hazard Pressure Equipment — Pressure equipment for use where the hazard is so low that an OSP and approval of design criteria and operational controls by a Department Head (or equivalent) and the Mechanical Safety Subcommittee are not required. See paragraph A.2. of this Section for pressure/energy limits and PUB-3000 (Ref. 1) for OSP requirements.

High-Hazard Pressure Equipment — Pressure equipment for use where the hazard is high enough to require an OSP and approval of design criteria and operational controls by a Department Head (or equivalent) and the Mechanical Safety Subcommittee. See paragraph A.3. of this Section for pressure/energy limits and Ref. 1 for OSP requirements.

Maximum Allowable Working Pressure (MAWP) — The maximum differential pressure (at the specified operating temperature) at which a vessel is designed to operate safely. The pressure setting of the pressure-relieving devices protecting the vessel and/or system must not exceed the MAWP (see Fig. III-1).

Operating Pressure (OP) — The pressure at which a vessel is normally operated; the OP must never exceed the MAWP of the vessel and is normally kept sufficiently below the settings of relief devices to prevent their frequent opening (also called working pressure).

Working Pressure (WP) — See Operating Pressure.

Pressure Test	A test to ensure that a vessel or a system will not fail or permanently deform and will operate reliably at the test pressure.
Proof Test	Pressurizing prototypes of a pressure component or vessel to determine the actual yield or burst pressure. This pressure is then used to calculate the MAWP of the vessel or component. See Ref. 2, Division 1, paragraph UG-101, for acceptable proof-test procedures.
Safety Factor	The ratio of the calculated failure pressure (or actual failure pressure when known) to the MAWP. A safety factor (SF) related to other than the failure pressure should be identified with an appropriate subscript, e.g., SF_y for a safety factor based on the yield strength of the material and SF_u for a safety factor based on ultimate strength.
Leak Test or Leak Check	A pressure or vacuum test to determine the existence, rate, or location of a leak.
Pressure Vessel	A relatively high-volume pressure component [such as a spherical or cylindrical container that has a cross section larger than the associated pipe or tubing or a coil (three or more full turns) of pipe or tubing]. Any operating pressure above or below atmospheric pressure qualifies the vessel as a pressure vessel. A vacuum vessel is a special case of pressure (external) vessel.
Ductile Vessel	A pressure vessel fabricated from materials that yield extensively before failure when overstressed at any temperature within the specified working-temperature range of the vessel. Materials that exhibit greater than 5% plastic strain to rupture are generally considered ductile. Some of these materials are listed in Ref. 2, Division 1, Subsection C.

Brittle Vessel	A pressure vessel fabricated from materials that do not yield extensively before failure when overstressed at any temperature within the specified working-temperature range of the vessel. Materials that exhibit less than 5% plastic strain to rupture are generally considered brittle.
Pressure System	Any mechanical system, containing vessels, manifolds, or piping, that operates above or below atmospheric pressure. A vacuum system is an external-pressure system.
Manned-Area Vessel	A pressure vessel or pressure system that has been approved for operation (within specified limits) with personnel present.
Remote-Area Vessel	A pressure vessel or pressure system that contains a high risk of personal injury in the event of failure. Remote-area vessels must be installed in test cells or behind certified barricades (concrete blocks, steel plates, etc.) or be operated from a safe location.
Inert Fluid	A liquid or gas that is nonflammable and nontoxic and has a low chemical-reaction-hazard potential.
Reactive Fluid	A liquid or gas that is flammable, toxic, or radioactive or is a strong oxidizer and has a high radiation-hazard or chemical-reaction-hazard potential.
SI (Metric) Pressure Units	Pa (pascal), the basic SI pressure unit, equals 0.000145 psi.
Additional Terms	See Ref. 1, Chapter 20, for additional definitions of pressure terms and pressure documentation.

A. INTRODUCTION

1. General

All pressure vessels and pressure systems designed or operated by LBL personnel fall within the scope of these rules, except for pressure vessels covered in Section II.* (Pressure-vessel and pressure-system design and test criteria are summarized in Table III-1.) For convenience in describing the required controls, pressure vessels and pressure systems have been divided into two hazard categories:

- Low-hazard pressure equipment--equipment with a low hazard level or that is satisfactorily covered by existing regulatory standards.
- High-hazard pressure equipment--where operational risk is high, and special approvals and controls are necessary.

Documentation requirements (including specific requirements for Safety Notes) are given in Section II.A. of this Manual, and a Documentation Guide for Pressure Equipment is shown in Fig. III-2.

2. Low-Hazard Pressure Equipment

The following systems are either of relatively low hazard or are so adequately controlled that they do not normally require an OSP.

Air and inert-gas systems for working pressures up to 1 MPa gauge (150 psig) and inert-liquid systems for working pressures up to 10 MPa gauge (1500 psig), provided that the energy stored in the pressurized gas does not exceed 100 kJ (75,000 ft-lb).

Utility systems for maximum allowable working pressures up to 2.0 MPa gauge (300 psig), including cold-water, hot-water, low-conductivity-water, compressed-gas, natural-gas, butane and propane (LPG), and steam systems that strictly comply with applicable Plant Engineering standards and that are inspected and maintained by the Construction & Maintenance Department.

Compressed-gas-cylinder manifolds assembled with compound-thread fittings by the Plant Maintenance Technician Regulator Shop in compliance with Section I of this Manual.

Manifolds on tubebanks and tubetrailers that consist of components rated at 20.7 MPa gauge (3000 psig) or higher and that are periodically retested.

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*This Section is largely based on LLNL's Health & Safety Manual and Mechanical Engineering Design Safety Standards.

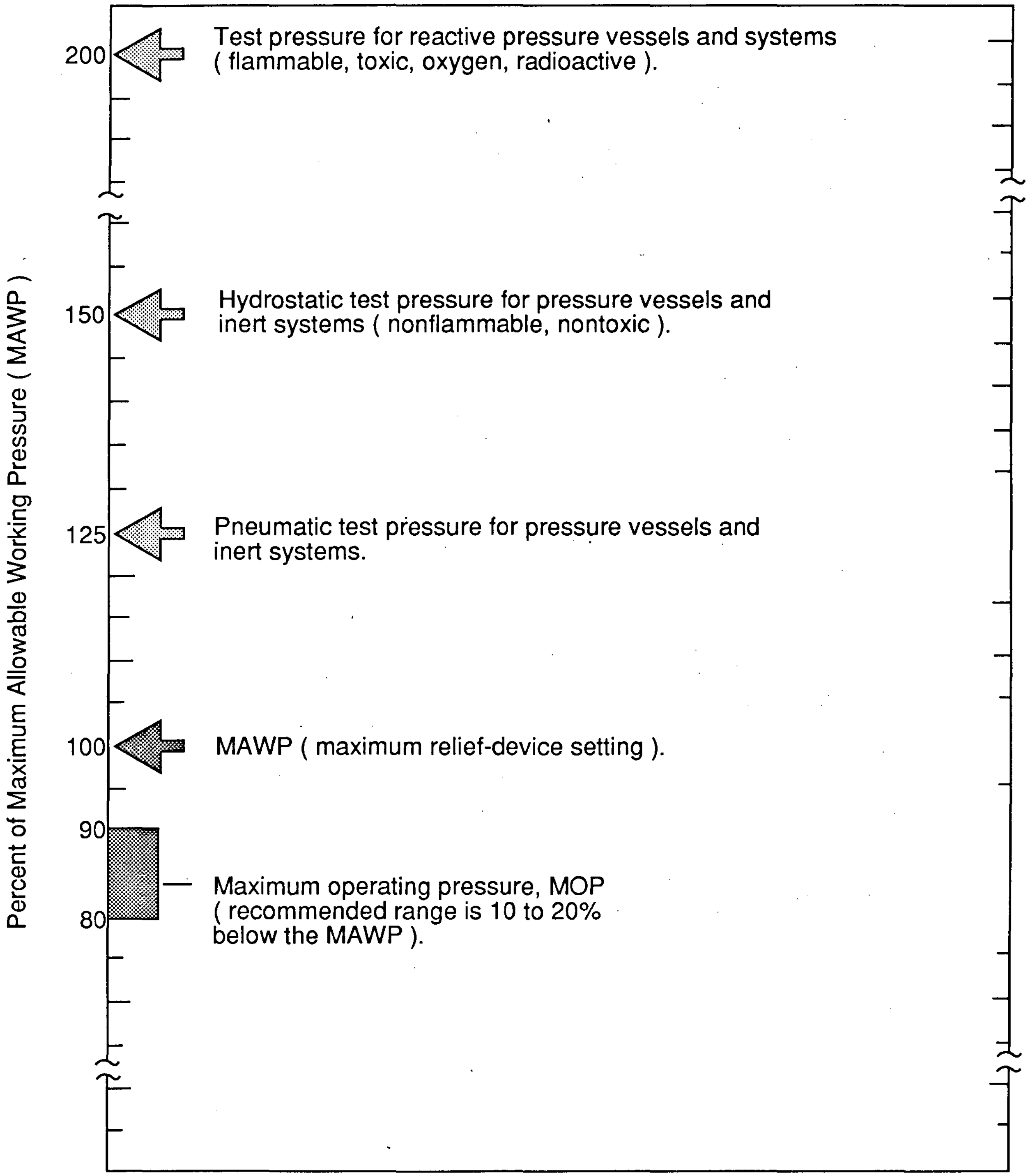
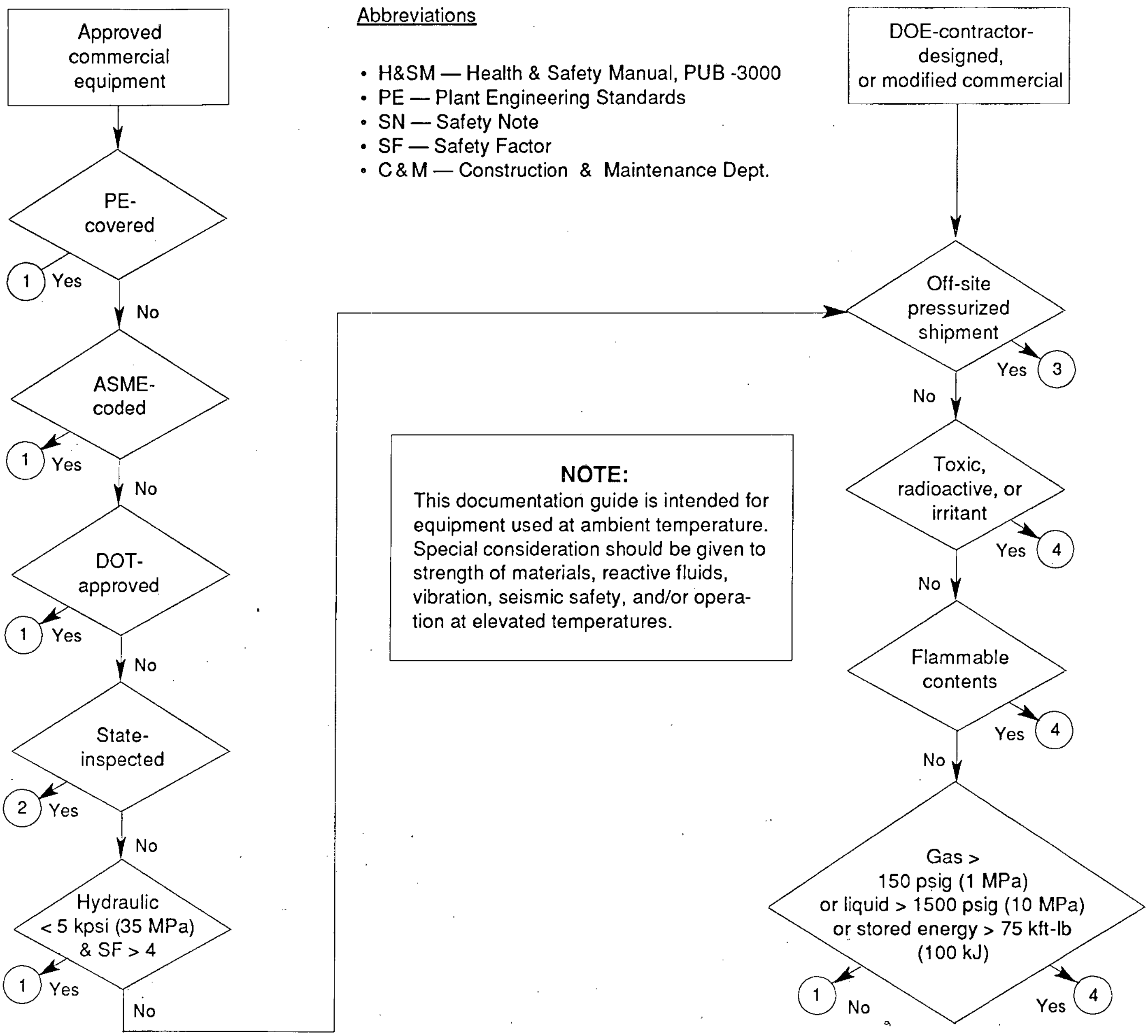


Figure III-1. Relationships of defined pressure terms.

Table III-1. Summary of Design Criteria for Pressure Vessels and Pressure Systems.

Pressure vessels in pressure range of 15 to 3000 psig.
See Table III-4 for Pressure Testing Summary.

Sec	Title	Design Notes	Safety Note Required
III A	**INTRODUCTION**		
III A 2	**Low-Hazard Pressure Equipment**		
	Air and inert gas systems.	MAWP up to150 psig.	No.
	Inert liquid systems.	MAWP up to1500 psig and energy < 100 kJ.	No.
	Utility systems: water, gas, butane, propane, and steam are to be designed to Plant Eng. and C&M Standards.	MAWP up to 300 psig.	Refer design to Plant Engineering Dept.
	Compressed-gas cylinder manifolds assembled by the regulator shop.	Comply with section I-D of this manual.	No.
	Manifolds on tube banks and tube trailers.	Periodic retest required if rated at 3000 psig or higher.	Yes if, > 3000 psig.
	Unmodified ASME pressure vessels that are ASME code stamped.	Inspect and test before pressurizing and inspect every 6 years if Safety Note required, unless state inspected.	Yes if, > 150 psig gas, > 1500 liquid, or if > 100 kJ.
	Refrigeration Systems that comply with ASME and Air Conditioning and Refrigeration Institute (ARI) codes.	---	No.
	Pressure Vessels DOT stamped used to supply and transport fluids.	Retest per Federal Regulation, CFR-49, Transportation, parts 100-199.	No.
	Air pressure tanks, LPG tanks, anhydrous-ammonia tanks, and fired steam boilers (C&M inspects LBL air pressure tanks and boilers. Materiel Management, Industrial Gas Section, ensures that vendor-owned LPG and anhydrous-ammonia tanks are inspected).	Inspect periodically in accordance with Unfired Pressure Vessel Safety Orders or Boiler and Fired Pressure Vessel Safety Orders of State of California.	Responsible user must notify C&M before installing.
	Unmodified, commercially manufactured hydraulic systems (used on hydraulic presses, motorized vehicles, machine tools, and the like).	MAWP up to 5075 psig. Periodically inspected and maintained by user.	No.
III A 3	**High-Hazard Pressure Equipment** Operated in manned areas and containing hazardous materials or pressures.		
	Vessesls and systems containing irritant, toxic, and/or radioactive fluids.	---	Yes. EH&S approval required.
	Vessels and systems containing flammable fluid and operated in manned areas.	---	Yes.
	Vessels and systems operated in manned areas at gas pressures over 150 psig or liquid pressures over 1500 psig or for systems that contain more than l00 kJ isentropic energy, including structurally modified ASME-coded vessels.	---	Yes.
III B	**PRESSURE VESSEL DESIGN**		
III B 1	**Design Criteria** Applies to all vessels listed above in this table. Pressure vessels within the scope of ASME codes must comply with ASME codes.	Use a design safety factor (SF) of 4 to ultimate strength. Lower SF allowed where permitted by ASME. Use higher SF for shock, vibration, corrosion, or thermal cycling.	Yes.
III B 2	**Material Selection**		
	Wall thickness > 2 inches and WP > 14,500 psig.	Confirm material identity. Impact test vessel material at OT, or -7 C, if lower.	Yes.
III B 3	**Design Considerations**		
	Wall thickness > 2 inches in manned area.	Ultrasonic inspection of vessel required.	Yes.
	Gas presssure vessels with wall thickness > 2 inches.	Prepare a fracture control plan.	Yes.
III C	**CONTAINMENTS FOR PRESSURE VESSELS** Outer protective vessel enclosing gas pressurized vessels containing hazardous fluids.		
III C 3	**Design Safety Factors**		
	Contained pressure vessel.	MAWP of at least the maximum pressure to which it could be subjected in use.	Yes.
	Containment vessel for a contained pressure vessel made of ductile material approved for manned-area operation.	Design for SF of 4 to ultimate stress.	Yes.
	Containment vessel for a contained pressure vessel not approved for manned-area operation.	Design for SF of 8 to ultimate stress.	Yes.
III C 5	**Testing and Labeling**	Pressure test to 1.5 times the maximum permissible equilibrium pressure. No leak > 1.0 E-08 atm cc/sec permitted.	Fix label showing working pressure and OT range.
III D	**PRESSURE SYSTEM REQUIREMENTS**	Show MAWP on all assembly drawings. Use ASME-approved or LBL-stocked relief devices.	
III D 3	**Pipe and Tubing**	Design to ANSI B31.1 or B31.3.	Yes, if to be used above pipe rating.
	Piping for nonflammable fluid.	Pressure Test to 1.5 times MAWP or 150 psig, whichever is greater.	---
	Piping for nonflammable cryogenic fluid surrounded by a vacuum jacket.	Test to 1.5 times maximum allowable differential working pressure.	---
III D 4	**Flexible Nonmetallic Hose**	Design to 0.25 times rated minimum burst pressure.	---
III D 7	**Pressure Gauges**		
	Gauges for gas systems.	Use gauges calibrated to about 2 times MAWP.	---
	Gauges for liquid systems.	Use gauges calibrated to at least 1.2 times MAWP.	---
	Safety-type gauges for gas systems.	Use safety-type gauges when gauge is over 100 mm in diameter and graduated to over 200 psig.	---
	Safety-type gauges for liquid systems.	Use safety-type gauges when gauge is over 100 mm in diameter and graduated to over 20,000 psig.	---



Abbreviations

- H&SM — Health & Safety Manual, PUB -3000
- PE — Plant Engineering Standards
- SN — Safety Note
- SF — Safety Factor
- C & M — Construction & Maintenance Dept.

NOTE:
This documentation guide is intended for equipment used at ambient temperature. Special consideration should be given to strength of materials, reactive fluids, vibration, seismic safety, and/or operation at elevated temperatures.

Documentation requirements

1. No SN required (documented or hazards are low).
2. No SN required but notify C & M .
3. Requires DOT approval or DOE-SAN exemption.
4. SN required by H & SM .

Figure III-2. Documentation guide for pressure-equipment safety notes.

Unmodified pressure vessels designed in accordance with Refs. 2, 3, 4, ASME Boiler and Pressure Vessel Codes and ASME-code stamped. If the contained fluid exceeds 1 MPa gauge (150 psig) gas pressure, 10 MPa gauge (1500 psig) liquid pressure, or 100 kJ (75,000 ft-lb) stored energy, a Safety Note (SN) is required, and the vessel must be inspected and labeled by the Pressure Inspector before pressurization, and every 6 years thereafter, unless it is inspected periodically by the State of California.

Refrigeration systems that comply with the ASME Boiler and Pressure Vessel Codes (Refs. 2 and 3) and applicable Air-Conditioning and Refrigeration Institute (ARI) standards (Ref. 5).

Pressure vessels stamped with a Department of Transportation (DOT) rating, used to supply and transport fluids. These vessels are subject to retesting requirements of Ref. 6, Code of Federal Regulations, CFR 49, Transportation, Parts 100-199 (current issue).

Air-pressure tanks, liquefied-petroleum-gas tanks, anhydrous-ammonia tanks, and fired-steam boilers inspected periodically in accordance with Ref. 7, "Unfired Pressure Vessel Safety Orders," or Ref. 8, "Boiler and Fired Pressure Vessel Safety Orders" of the State of California. The responsible designer must notify the Plant Maintenance Technicians whenever such a vessel is to be installed.

Unmodified, commercially manufactured hydraulic systems with a safety factor of 4 or higher for working pressures to 35 MPa (5075 psi) on hydraulic presses, motorized vehicles, and machine tools that are periodically inspected and maintained by the using Department.

3. High-Hazard Pressure Equipment

These are pressure vessels and systems containing hazardous materials or employing pressures that involve relatively high levels of hazard. For the applications itemized below, the responsible designer must prepare a Safety Note or its equivalent, and normally an OSP is required (see III.F., Guide for Writing Safety Notes...).

All vessels and systems that contain irritant, toxic, or radioactive fluids at any pressure and that operate in manned areas.

All oxygen or flammable-gas or -liquid vessels and systems operating in manned areas.

All vessels and systems operating in manned areas at gas pressures over 1 MPa gauge (150 psig) or liquid pressures over 10 MPa gauge (1500 psig) or that contain over 100 kJ (75,000 ft-lb) of stored energy, including ASME-coded vessels that have been structurally modified.

> Caution
>
> If an ASME-Coded vessel is modified, the Code stamping must be obliterated, and the Mechanical Safety Subcommittee must be so notified.

B. PRESSURE VESSEL DESIGN

1. Design Criteria

The following criteria apply to the design of liquid-pressure or gas-pressure vessels.

Use a safety factor of 4 to the ultimate strength when designing for normal manned-area operation. Use a higher factor if operation involves detrimental conditions, such as vibration, corrosion, shock, or thermal cycling. Never use a safety factor of less than 4 when designing a vessel unless the design conforms to the ASME Code (Refs. 2 and 3).

Pressure vessels within the scope of the ASME codes (over 6 in. in diameter and 15 to 3000 psi for unfired pressure vessels) must be in compliance with these codes.

Pressure vessels and systems made of commercial pipe or pipe fittings, or both, must not be used above their rated ANSI working pressure and must comply with all the rules of this Manual.

2. Material Selection

Select materials that remain ductile throughout the operating temperature range of the vessel. If you cannot avoid the use of a brittle material for the vessel body, the SN must be approved by the Mechanical Safety Subcommittee.

Select materials that are physically and chemically compatible with the fluid(s) to be contained in the vessel.

Beware of hydrogen embrittlement. High-pressure hydrogen gas drastically degrades the ductility of highly stressed, high-strength, pressure-vessel materials. This problem can be solved as follows:

> Use lower-strength materials such as type 304, 316, 321, 347, or 21-6-9 stainless steel; 2024 or 6061 aluminum alloy; oxygen-free copper; phosphor bronze; or beryllium copper or other materials recommended by the Mechanical Engineering Department.

Include an inner liner (or bladder vessel) made of one of the above hydrogen-resistant materials. When designing such a liner, ensure that it will withstand the working and testing stresses. Consider positive venting of the space between the liner and the vessel so that any hydrogen that penetrates this liner cannot subject the high-strength vessel body to high-pressure hydrogen. Also, provide means for periodically verifying that this vent is open.

Consider the creep characteristics of the material. This is an important consideration when pressure is to be contained for extended periods at elevated temperatures.

Ensure that vessel material is of acceptable fracture toughness throughout its working-temperature range. For pressure vessels of wall thickness greater than 50 mm (2 in.) and working pressures over 100 MPa (14.5 kpsi), specify impact testing of vessel specimens at the lowest vessel working temperature or -7°C (+20°F), whichever is lower.

Confirm material identity by verifying it to be of a particular specification by x-ray diffraction, chemical analysis, metallography, radiography, or sample testing, as required.

The design stresses must be as specified in Refs. 2 and 3, Division 1 or Division 2.

Materials listed in Subsection C of Ref. 2, and the alloys listed in Table III-2 are normally satisfactory for pressure-vessel fabrication. The strength values listed in Table III-2 apply between -30°C (-20°F) and +95°C (+200°F). At working temperatures below -30°C, the possibility of brittle behavior must be considered; at temperatures over +95°C, reduction in strength usually becomes significant. The tabulated information is from Refs. 9, 10, and 11.

3. Design Considerations

Specify that all purchase-fabrication welding be performed per approved ASME procedures by ASME-certified welders.

Avoid longitudinal welds in vessels less than 0.15 m (6 in.) in diameter. Seamless tubing or pipe, or bar stock, is usually available in these smaller diameters.

Avoid stress concentrations. This is most critical when vessel-material elongation and toughness are relatively low. Stress concentrations are more important in materials that become brittle below 20°F.

Adjust the design and the allowable stresses to compensate for such environmental conditions as vibration, pressure cycling, temperature fluctuation, temperature extremes, shock, and corrosion.

Table III-2. Specifications of materials (alloys) used in pressure vessels.

Grade or type	Hardness (Rockwell)	Minimum ultimate tensile strength MPa	(ksi)	Minimum yield strength Mpa	(ksi)	Remarks
		LOW CARBON STEELS				
ASTM SA-30	—	380	(55)	210	(30)	
ASTM SA-129	—	275	(40)	150	(22)	
ASTM SA-201	—	380	(55)	210	(30)	
ASTM SA-299	—	500	(75)	275	(40)	
ASTM SA-414	—	310	(45)	165	(24)	
		LOW ALLOY, LOW CARBON STEELS				
ASTM SA-202	—	500	(75)	310	(45)	
ASTM SA-203	—	450	(65)	255	(37)	
ASTM SA-225	—	485	(70)	275	(40)	
ASTM SA-353	—	620	(90)	415	(60)	
ASTM SA-357	—	415	(60)	210	(30)	
ASTM SA-387	—	415	(60)	240	(35)	
USS "T-1"	—	800	(115)	620	(90)	
HY 80	—	~725	(105)	620	(90)	
HY 100	—	~860	(125)	760	(110)	
HY 180	—	~1380	(200)	1240	(180)	
		ALLOY STEELS [all tempered at 370°C (700°F) or higher]				
4130	25-30 R_C	860-1000	(125-145)	710	(103)	
	32-36 R_C	1035-1170	(150-170)	910	(132)	7.5 mm thick max.
8630	25-30 R_C	860-1000	(125-145)	710	(103)	
	32-36 R_C	1035-1170	(150-170)	910	(132)	7.5 mm thick max.
4340	25-30 R_C	860-1000	(125-145)	710	(103)	
	32-36 R_C	1035-1170	(150-170)	910	(132)	
	39-43 R_C	1240-1380	(180-200)	1125	(163)	beware of low
	43-46 R_C	1380-1515	(200-220)	1210	(175)	fracture toughness
		TITANIUM ALLOYS (beware of brittle welds)				
Ti-5 Al-2.5 Sn	—	800	(115)	620	(90)	RS-110C, A-110 At
Ti-6 Al-4 V	—	900	(130)	830	(120)	RC-128, C-120 AV
		AUSTINITIC STAINLESS STEELS (resistant to hydrogen embrittlement)				
	annealed	655-690	(95-100)	310	(45)	Enhanced properties
21-6-9 VIM/ESR	96 R_B	770	(112)	470	(68)	result from warm High
(ASTM A-276)	34 R_C	1000	(145)	900	(130)	Energy Rate Forging
304	70-90 R_B	485-620	(70-90)	170-345	(25-50)	
	10-35 R_C	700-1240	(100-180)	345-1035	(50-150)	
316	70-85 R_B	500-620	(75-90)	210-415	(30-60)	
	10-30 R_C	700-1035	(100-150)	345-860	(50-125)	
321, 347	70-90 R_B	500-655	(75-95)	210-380	(30-55)	
	10-35 R_C	700-1035	(100-150)	345-860	(50-125)	

Specify inspection by appropriate nondestructive detection methods (such as radiographic, ultrasonic, dye-penetrant, or magnetic-particle inspection) when designing a high-strength, high-pressure vessel. Specify appropriate ultrasonic inspection of all manned-area pressure vessels of wall thickness over 50 mm (2 in.). Maximum permissible defects should be based upon the capability of the vessel material to resist crack growth under the specified operating conditions. Contact the Materials Test and Evaluation Section of the Mechanical Engineering Science Division at LLNL for guidance in determining the allowable defect size and the Nondestructive Testing Section of the same Division for assistance in properly specifying ultrasonic inspection.

Prepare a Fracture Control Plan for all gas-pressure vessels of wall thickness over 50 mm (2 in.). Such vessels must be periodically (or possibly continuously) monitored by appropriate nondestructive inspection techniques to ensure that no cracks approach critical size. Contact the Materials Test and Evaluation Section at LLNL for assistance. A plan should be prepared for vessels of thinner wall thickness that are intended to contain radioactive, toxic, explosive, and/or flammable materials.

When specifying welding of pressure-vessel components, consider the following:

A weld might be brittle, and welding might embrittle the materials in the heat-affected zone. Consider checking a weld cross section for toughness.

Weld penetration might not be to the full thickness of the parent materials, so include realistic joint efficiencies in your calculations (see Ref. 2, Table UW-12).

Welding normally anneals the material in the heat-affected zone; consider the degradation of the properties of this zone when calculating the overall strength of the vessel.

Welding reduces resistance to hydrogen embrittlement of some materials; consult the Mechanical Engineering Department when planning to weld a vessel that is to contain high-pressure hydrogen.

Consider relieving stress in the weldment.

Select a realistic MAWP as the basis for design calculations, that is, 10 to 20% above the highest anticipated operating pressure. This permits relief protection against overpressure without degrading the dependable, leak-tight functioning of the vessel and its pressure-relief devices at the operating pressure. The MAWP must be indicated on all pressure-vessel drawings.

Provide positive protection against over pressure by providing an appropriate relief device set at a pressure not exceeding the MAWP of the vessel (see Ref. 2).

4. Calculation Guide (for ductile vessels)

Equations (1), (2), (3), and (4) below are based on maximum allowable circumferential (hoop) stress and not on the true combined-stress condition of the vessel. The actual stress near a weld joint or in any area of stress concentration will be higher than the "average" stress obtained from these equations. However, proper application of these equations will result in a vessel of ASME-Code-equivalent safety (for additional guidance, see Section III.K., References).

The following notations apply to all of the equations listed in this section.

σ_a = allowable stress, Pa (psi)

σ_y = yield strength, Pa (psi)

σ_u = ultimate strength, Pa (psi)

SF = safety factor, based on elastic/plastic failure (see Eq. 6)

SF_u = safety factor, based on ultimate strength (see Eq. 5)

d = internal diameter of vessel, m (in.)

t = wall thickness, m (in.)

r_i = inner radius, m (in.)

r_o = outer radius, m (in.)

r_m = mean radius, $\frac{r_i + r_o}{2}$, m (in.)

R = r_o/r_i

p = MAWP, Pa (psi)

E = joint efficiency factor, usually 1, except for welded vessels (see Ref. 2, Table UW-12)

h_G = radial difference between bolt circle and pressure-seal circle on a bolted-end closure, m (in.)

W = total bolt load for circular heads, (pressure force plus required gasket-sealing force), N (lb)

C = attachment coefficient (see Fig. III-3)

U = energy, J (ft-lb)

v = volume, m^3 (in^3)

γ = ratio of specific heats, c_p/c_v

For thin-wall vessels, where R is less than 1.1, use Equations (1) or (2) below to calculate p, the MAWP (Ref. 12, Ch. 5).

For Cylinders

$$p = \frac{\sigma_a Et}{r_m} \quad \text{or} \quad p = \frac{\sigma_u Et}{r_m SF_u} \tag{1}$$

For Spheres

$$p = \frac{2\sigma_a Et}{r_m} \quad \text{or} \quad p = \frac{2\sigma_u Et}{r_m SF_u} \tag{2}$$

For medium-wall vessels, where R is between 1.1 and 1.5, use Equations (3) or (4) below to calculate the MAWP (Ref. 2, par. UG-27).

For Cylinders

$$p = \frac{\sigma_a Et}{r_i + 0.6t} \quad \text{or} \quad p = \frac{\sigma_u Et}{SF_u(r_i + 0.6t)} \tag{3}$$

For Spheres

$$p = \frac{2\sigma_a Et}{r_i + 0.2t} \quad \text{or} \quad p = \frac{2\sigma_u Et}{SF_u(r_i + 0.2t)} \tag{4}$$

For thick-wall vessels, where R is between 1.5 and 2.0 use Eqs. (5), (6), (7), or (8) below to calculate the MAWP (Ref. 12, Ch. 5 and Ref. 2, Appendix 1).

For <u>Cylinders</u>

$$p = \sigma_a \frac{\left(r_o^2 - r_i^2\right)}{\left(r_o^2 + r_i^2\right)} \quad \text{or} \quad p = \frac{\sigma_u\left(r_o^2 - r_i^2\right)}{SF_u\left(r_o^2 + r_i^2\right)} \tag{5}$$

$$p = \frac{2\sigma_y}{\sqrt{3}\ SF} \left(2 - \frac{\sigma_y}{\sigma_u}\right) \ln R \tag{6}$$

For <u>Spheres</u>

$$p = 2\sigma_a \frac{\left(r_o^3 - r_i^3\right)}{\left(r_o^3 + 2r_i^3\right)} \quad \text{or} \quad p = \frac{2\sigma_u\left(r_o^3 - r_i^3\right)}{SF_u\left(r_o^3 + 2r_i^3\right)} \tag{7}$$

$$p = \frac{2\sigma_y}{SF} \left(2 - \frac{\sigma_y}{\sigma_u}\right) \ln R \tag{8}$$

For <u>thick-wall vessels</u>, where R is over 2.0, use Eqs. (5) and (7), only, to calculate the MAWP.

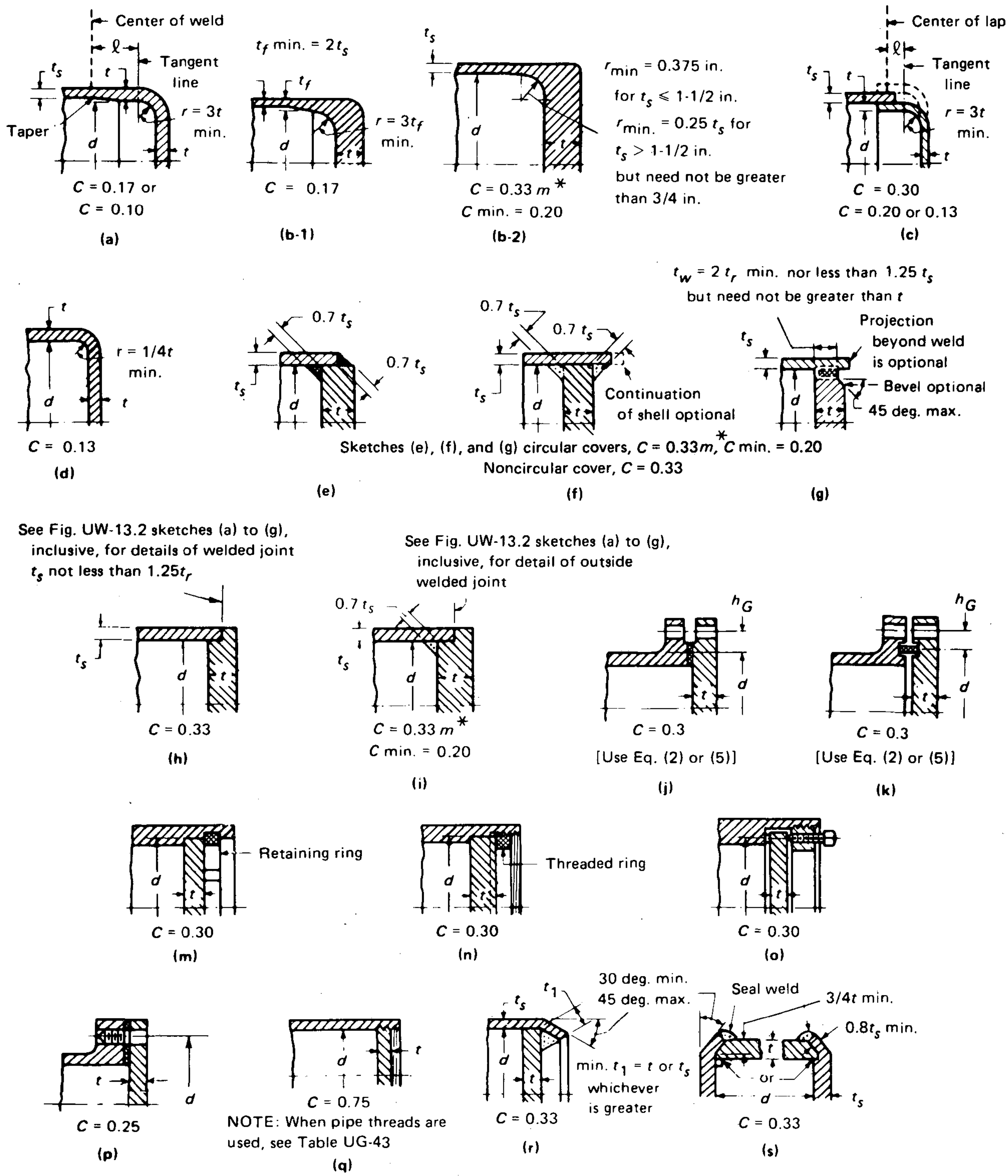
For <u>flat circular end closures</u> use Eqs. (9) or (10) below to calculate the required thickness. (See Ref. 2, par. UG-34 for design details; Fig. UG-34 of Ref. 2 is reproduced as Fig. III-3.) If no bending moment is imposed on the end closure when it is secured [welded, integral, ring retained, or other method; see Fig. III-3, (a) through (i) and (m) through (s)], use

$$t = d\sqrt{\frac{C\ p}{\sigma_a}} \quad \text{or} \quad t = d\sqrt{\frac{C\ SF_u p}{\sigma_u}} \tag{9}$$

If a bending moment is imposed on the end closure when it is being secured [bolted, i.e., Figure III-3, (j) and (k)], use

$$t = d\sqrt{\frac{C\ p}{\sigma_a} + \frac{1.9\ Wh_G}{\sigma_a d^3}} \quad \text{or}$$

$$t = d\sqrt{\frac{C\ SF_u p}{\sigma_u} + \frac{1.9\ Wh_G SF_u}{\sigma_u d^3}} \tag{10}$$



This figure was reproduced from Fig. UG-34 of Ref. 2 with the permission of the American Society of Mechanical Engineers. Minor portions of the printed material have been deleted.

*See Ref. 2. par. UG-34. The symbol "m" here is the ratio t_r/t_s, where t_r is the required shell thickness and t_s is the actual shell thickness, exclusive of corrosion allowance.

Figure III-3. Some acceptable types of unstayed flat heads and covers.

For other vessels, such as multiwall cylinders, and other end-closure designs, see Section K., References. Where imposed stresses in a large high-pressure vessel appear to be complex and excessive, contact the Mechanical Engineering Department for assistance in performing a finite-element analysis.

Calculate the energy contained in the fully pressurized vessel and include it in the SN. Compare this value with the 4.63 x 10^6 J (3.42 x 10^6 ft-lb) potential energy of 1 kg (2.2 lb) of TNT.

$$U = \frac{P_1 V_1}{(\gamma - 1)} \left[1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \right] \qquad (11)$$

Example: From the above equation (Ref. 12, Chapter 4), a 1.5-ft^3 standard Size-1 cylinder of nitrogen gas charged to 2500 psi contains energy equivalent to about 0.25 kg (0.5 lb) of TNT. This calculation is based upon the work performed on the surroundings during the reversible adiabatic (isentropic) expansion of the confined gas.

Use Ref. 13 to calculate the MAWP of LBL-owned DOT cylinders that are to be used in stationary installations.

C. CONTAINMENTS FOR PRESSURE VESSELS

1. Scope

This section covers protective containments designed, specified, or used by LBL personnel to enclose gas-pressurized vessels (including those that contain toxic, radioactive, and/or flammable materials) to protect personnel from the pressure-vessel-failure hazards of blast pressure and flying fragments and to prevent release to the atmosphere of any hazardous materials leaked from the pressure vessel. Containment vessels may be required by the Mechanical Safety Subcommittee, for example, to enclose research equipment during its development or to enclose vessels used to transport highly toxic and/or radioactive substances.

2. Special Shipping Requirements

Only containers approved by the Department of Transportation (DOT) or by the DOE may be used for off-site shipment of pressure vessels containing radioactive materials. Contact EH&S for approval for transporting radioactive material on or off site.

3. Design Safety Factors

When the contained vessel is made of ductile material and has been LBL approved for use in manned areas, the containment vessel must be designed with an ultimate (burst) safety factor of at least 4.

When the contained vessel has not been approved for manned areas, the containment vessel must have an ultimate (burst) safety factor of at least 8 for manned-area operations.

The contained vessel must, of course, have a MAWP of at least the maximum pressure to which it could be subjected in use.

4. General Design Requirements

The following requirements apply to all gas-pressure containment vessels.

Design the containment vessel using the appropriate safety factor specified above in paragraph 3. above. Base the design upon the maximum equilibration pressure expected if the contained vessel fails and its contents enter the containment vessel heated to the highest temperature expected within the containment vessel, or to 55°C (130°F), whichever is higher.

Containment-vessel materials must have satisfactory fracture toughness at an operating temperature of -40°C (-40°F), unless a lower temperature is required and specified.

If off-site transportation is to be permitted, design the containment vessel to withstand the normal conditions of transport, including heat, cold, pressure, vibration, water spray, free drop, corner drop, penetration, and compression. The contained vessel must be mounted securely inside the containment vessel.

Include a compound pressure/vacuum gauge to allow monitoring of the internal pressure of the containment vessel. This gauge must be graduated to at least 120%, but not over 200%, of the highest credible equilibration pressure.

Include two separate valves and gas lines for safely introducing, exhausting, and monitoring flushing gases.

Include suitable covers and shields to protect all valves and gauges from damage. Cap or plug all terminal valve ports. Provide accommodations for locking or wiring valve handles closed, or have valve handles removed during shipment, to prevent unauthorized operation or tampering.

5. Testing and Labeling

Pressure test the containment vessel at 1.50 times the maximum possible equilibration pressure as defined in paragraph 4. above. No detectable plastic strain is permitted, as determined before and after testing by measurements made to within 0.025 mm (0.001 inch).

After successful pressure testing leak check the containment vessel at its maximum possible equilibration pressure with a leak detector capable of detecting leakage of 1 X 10^{-8} atm cm^3/sec. No detectable leakage is permitted.

The responsible designer should specify contained-vessel rupture testing of the containment vessel if she/he deems it advisable.

After a successful test, the LBL Pressure Inspector will label the containment vessel with the working-pressure that was the basis for the design calculations and will also label it for an operating-temperature range of -29 to +55°C (-20 to +131°F), unless a wider temperature range is required and specified.

D. PRESSURE-SYSTEM REQUIREMENTS

1. General

The MAWP must be stated on all pressure-system (and pressure-vessel) assembly drawings.

The following precautions must be observed when you design, install, or operate a pressure system (or vessel).

2. Relief Devices

Limit pressure sources to the MAWP of the lowest-rated system component. Do not consider a pressure regulator by itself as satisfactory overpressure protection.

When pressure sources cannot be limited to less than the MAWP of every system component, include pressure-relief devices (relief valves or rupture-disc assemblies) to protect those components that are rated at less than the system-supply pressure. All pressure vessels, pressure-system components, and piping subject to accidental overpressure must be protected by a relief device that is set at a pressure not exceeding the MAWP of the lowest-rated component of the system.

A shutoff valve must not be installed between a relief device and the component it protects.

A relief device must not be set above the MAWP of the lowest-rated component of the system it is installed to protect.

Locate and orient relief devices so that their discharge is not hazardous to personnel.

Install relief devices and lines of total flow capacity such that when all supply ports are open, the pressure will never exceed 110% of the MAWP.

Insulating vacuum systems for cryogenic fluids must have relief devices. Particular attention must be given to those parts of a system in which cryogenic fluids can be isolated or gases can be liquified.

All valves that can isolate a part of a pressurized system and thereby create a hazard must be bypassed with a relief valve.

When evacuated vacuum vessels are raised to atmospheric pressure with a pressurized-gas source, a relief device must be installed between the gas source and vacuum vessel.

Do not reset relief devices unless you are specifically authorized to do so. LBL personnel are <u>not</u> permitted to set, seal, or stamp relief devices on utility water boilers, steam boilers, and compressed-air receivers that are under the jurisdiction of the State of California. Only authorized Plant Maintenance Technicians are permitted to set and seal relief devices on noncoded pressure vessels and systems.

Use ASME code-approved or LBL-stocked relief devices whenever possible. The use of any other non-ASME pressure-relief device on high-hazard pressure equipment must be specifically approved by the Mechanical Safety Subcommittee.

Have all component relief devices rechecked before the end of the contract guarantee period if the pressure equipment was installed by an outside contractor.

All relief valves must be pressure tested to ensure that they lift at the set pressure before each setup or use of the equipment.

Rupture-disk assemblies must be certified by the manufacturer or tested by rupturing three disks made from the sheet from which the operational disks were made. All test records must be kept for the life of the equipment.

After they are set, relief devices must be locked and tagged with the date and set pressure.

3. <u>Pipe and Tubing</u>

Metal pipe and tubing rated at or above the MAWP must be used unless approval is obtained from the Mechanical Safety Subcommittee. If you plan to use pipe or tubing at pressures above those indicated in the references listed, include calculations in the SN to justify your selection.

Use the American National Standard Code ANSI-B31.1 (Ref. 14), ANSI-B31.3 (Ref. 15), or refer to the LBL Stock Catalog to determine the MAWP for intermediate- and low-pressure pipe and tubing.

Use LLNL Standard Specification MEL 63-000681 (Ref. 16) or MEL 71-001150 (Ref. 17) to determine the acceptable MAWP for high-pressure tubing.

Piping to be used for nonflammable fluid must be tested at 1.5 times the MAWP or 150 psig, whichever is greater.

Piping for a nonflammable cryogenic system surrounded by a vacuum pipe must be tested at 1.5 times the MAWP (differential) with an inert fluid.

Soft-solder joints must not be used in pressurized piping systems, except that soft solder may be used to seal threaded joints, and soft-solder joints are permitted for nonflammable-gas piping operated at 1 atm gauge pressure or less or nonflammable-liquid piping operated at 10 atm gauge or less.

4. Flexible Nonmetallic Hose

Use flexible nonmetallic hose only when it is impractical to use metal pipe or tubing. Any use of nonmetallic hose in pressure systems must be approved by the Mechanical Safety Subcommittee. Any plans to use hose at pressures above the manufacturer's recommended maximum must be justified in the SN; however, never use hose at pressures over 25% of its rated minimum burst pressure as stated by the hose manufacturer.

Keep hose lengths as short as possible, protect them from mechanical damage, and anchor the ends to prevent whipping in case of a hose or hose/fitting failure.

Avoid sharp hose bends. In any case, do not bend hoses more sharply than recommended by the manufacturer.

Replace or repair any hose showing leaks, burns, wear, or other defects.

Do not use hose on flammable, toxic, or radioactive gas systems. (Gases tend to permeate through nonmetallic hose.)

5. Valves and Fittings

Use proper valves and fittings. Use valves and fittings that are rated at or above the MAWP and the maximum, or emergency, operating temperatures and are compatible with the system fluid. On liquefied-gas systems, ensure that all terminal-block valves (valves where users could attach to the system) are rated above the 38°C (100°F) vapor pressure of the liquefied gas or that a properly set relief valve is permanently installed on the outlet side of each terminal-block valve.

Ensure that all valve-stem packing nuts are kept properly adjusted and locked.

Ensure that there is no oil or other organic material in valves or fittings used on gas (especially oxygen) systems.

Open all internal-system valves when pressure testing a system.

6. Installation of System Components

All work on pressure equipment requiring a SN must be performed by trained personnel under the direction of a Responsible Designer or Responsible User.

Securely fasten all components of a pressure system by using adequate machine screws (or bolts and nuts). Wood screws are not considered adequate.

Support and fasten hose and tubing at least every 2 m (7 ft) in manned areas. Support and fasten pipe according to Table III-3 in manned areas. Position supports to limit strain on fittings and minimize overhang at bends. Consider the thermal expansion/contraction of pipe and tubing.

All systems must be adequately secured against seismic forces (see Section I-H of this Manual).

7. Pressure Gauges

The pressure in every part of a pressurized system must be indicated on a pressure gauge. For gas systems use gauges graduated to about twice the MAWP of the system; for liquid systems use gauges graduated to at least the test pressure.

Calibrate pressure gauges, switches, and other devices through 120% of their maximum operating points. They must be capable of withstanding the operational, and emergency, temperatures of the system, and their material must be compatible with the system fluid.

Use safety-type gauges (with shatterproof faces, solid fronts, and blow-out backs) or protect operators with a tested, LBL-approved gauge-safety shield. This applies to all gas-pressure gauges over 100 mm in diameter graduated to over 1.4 MPa (200 psi) and to all liquid-pressure gauges over 100 mm in diameter graduated to over 140 MPa (20,000 psi). Safety-type gauges may be required for other combinations of diameter and pressure.

Protect a gauge that is subject to pressure surges or cyclic pulses by installing a throttling device such as a pulsation dampener (preferred), a pressure snubber, a gauge saver, or a restricting orifice or use a gauge equipped with a throttle screw in the tube socket.

Table III-3. Maximum span for various pipe sizes.

Nominal pipe size (inches)	Maximum unsupported span (meters)	(feet)
1	2.0	7
1-1/2	2.7	9
2	3.0	10
2-1/2	3.4	11
3	3.6	12
3-1/2	4.0	13
4	4.3	14
5	4.9	16
6	5.2	17
8	5.8	19
10	6.7	22
12	7.0	23

Ensure that there is no oil in gauges used on gas systems. This is important on oxygen systems since hydrocarbons and oxygen can combine explosively. Clean all gauges to be used on high-purity gas systems.

Protect the gauge with a relief device as required to prevent the static pressure from exceeding the full-scale pressure of the gauge.

8. Flash Arresters and Check Valves

Equip every flammable-gas drop or regulator/hose connection with a flash arrester or a check valve. If the flammable gas is to be (or could be) cross connected with oxygen or compressed air, a flash arrester must be installed in the flammable-gas line and a check valve in the oxygen- or compressed-air line.

Equip all oxygen drops with a check valve. This applies to all single- and multiple-station installations and portable equipment.

9. Pressure-System Inspection

The responsible designer must review the inspection report for all completed pressure vessels to ensure that they are free from manufacturing defects that might affect their use. (See Sections III.I. and III.J. for information on testing pressure vessels and systems.)

10. Safety Markings and Signs

Experimental pressurized gas equipment operating at pressures greater than 500 psig must be painted yellow, must have the operating pressure clearly marked thereon, and must bear a sign, "DANGER, HIGH-PRESSURE EQUIPMENT."

11. Pressure-System Operation

The responsible user may authorize only trained persons to operate pressurized equipment. (Refer to Ref. 1, Chapter 20, for information on personnel authorized to operate pressure equipment.) If the equipment will be used under hazardous conditions, an OSP may be required (see Ref. 1, Chapter 1, Appendix B). Use of personnel or equipment shields may be necessary when there is a probability of damage from blast; see Ref. 18.

The responsible user must ensure that the following safety precautions are taken:

A system or vessel must not be operated until the operator reads and understands all applicable Safety Notes, Operational Safety Notes, Operational Safety Procedures, and other related documentation.

Flammable, radioactive, irritant, or toxic gases or liquids or oxygen must not be used in systems that are not specifically designed for their use.

Flammable gas must <u>not</u> be used in combination with oxygen or compressed air unless there is a flash arrestor in the flammable-gas line and a check valve in the oxygen or air line. Oxygen and air, because of its oxygen content, can combine explosively with organic materials and flammable gases. Acetylene-gas pressure must be limited to 15 psig since acetylene is unstable and will explode spontaneously around 30 psig at room temperature.

Before connecting a pressure source, such as a compressed-gas cylinder to a pressure system, the source valve should be gently cracked open to expel any foreign material. For pressure sources that are toxic or flammable (including oxygen), vent the purging gas safely or use vacuum to clean the valve port.

The pressure source must be limited to the MAWP of the pressure system, or a properly set pressure-relief device of sufficient flow capacity must be installed between the source and the system. Refer to Section III.D.2. above for detailed relief-device requirements.

No work may be performed on pressurized components unless the method has been approved via a SN or is specifically authorized by the responsible user or her/his designated alternate.

12. <u>Remote Operation</u>

Remote-area pressure vessels do not qualify for manned-area operation because of the high risk of personal injury. They may be pressure vessels that operate above the MAWP under a variance, or they may contain highly toxic or radioactive fluids. All remote-area vessels must individually be reviewed for safety. Conspicuous warning signs bearing operational restrictions and an approved OSP must be posted at such vessels. A member of the Mechanical Safety Subcommittee and the responsible user must inspect the installation before operation.

13. <u>Pressure-System Maintenance</u>

The responsible user must ensure that operating personnel can correctly service and maintain pressure equipment under his/her control. Pressure-relief devices must be operational and properly labeled with the set pressure, the date, and the tester's name. Any relief device that is activated must be immediately checked and reset by the Plant Maintenance Technicians Group.

When worn or defective components have been repaired or replaced the equipment must be inspected by the Pressure Inspector.

If the equipment is modified (any change other than repair or replacement with identical or equal components) the responsible designer must approve the modification and revise the SN to reflect the change. The system must then be retested by the assembly shop or the Plant Maintenance Technicians, in the presence of the Pressure Inspector or the Mechanical Safety Subcommittee.

The equipment must be reinspected in accordance with Section III.H. of this Manual.

14. Deactivated Pressure Equipment

Whenever practical, a system or vessel that is not being used must be depressurized. When a vessel or system is stored under pressure the pressure, fluid, and date pressurized for storage must be clearly indicated on the vessel.

E. PLANT-FACILITY PRESSURE SYSTEMS

1. General

As well as being covered by the safety requirements previously defined in this Section, Plant-Facility utility unfired or fired pressure vessels and boilers, which are the responsibility of the Plant Engineering Department, are also covered by Ref. 16, DOE Order 6430.1A, General Design Criteria (1988), and by the State of California Administrative Codes as described below.

2. Unfired Pressure Vessels

Reference 7: State of California Administrative Code
Title 8. Industrial Relations
Part 1. Department of Industrial Relations
Chapter 4. Division of Industrial Safety
Subchapter 1. Unfired Pressure Vessel Safety Orders.

These Safety Orders establish minimum standards for the following:

The design and construction of all unfired pressure vessels for Plant-Facility pressure systems.

The installation, operation (including issuance of permits), inspection, and repair of air-pressure tanks and liquefied-petroleum-gas (LPG) tanks.

The installation, use, and repair of anhydrous-ammonia tanks.

The design and construction of pressure vessels for storing and dispensing natural gas for motor fuel and of motor-fuel tanks installed on vehicles not licensed to travel on highways.

The installation, use, and repair of natural-gas vessels and systems that are not a part of hazardous research equipment.

The design, construction, repair, or alteration of storage tanks for liquefied-natural gas (LNG) at 15 psi or less.

These Safety Orders are not applicable to the following:

Pressure vessels that are under the jurisdiction and inspection of the United States Government and that are specifically exempted by the Labor Code.

Pressure vessels, except for LNG tanks, subject to an internal or external pressure of not more than 15 psi, with no limitation on size, and vessels having an inside diameter not exceeding 6 inches, with no limitation on pressure. However, vessels excluded in this section must be designed and constructed in accordance with recognized standards, when applicable, or in accordance with good engineering practices concerning pressure-vessel design, with a factor of safety of at least 4, and must be fitted with controls and safety devices necessary for safe operation.

Natural-gas vessels and installations subject to the jurisdiction and inspection of the California State Public Utilities Commission, Department of Transportation, or Highway Patrol; air-brake tanks installed on units of transportation, including trucks, buses, trains, and streetcars, that are operated by any person, firm, or corporation subject to the jurisdiction and inspection of the Public Utilities Commission, the Department of Transportation, or the Highway Patrol.

The following vessels must be constructed, inspected, and stamped in accordance with the appropriate ASME Boiler and Pressure Vessel Code (Refs. 2 and 3):

Air-pressure tanks

LPG tanks

Anhydrous-ammonia tanks

All Plant-Facility pressure vessels

LNG tanks for low-temperature storage at 15 psi or less must be designed, constructed, inspected, and certified in accordance with API (American Petroleum Institute) Standard 620 (Ref. 20).

LPG vaporizers having a volume greater than one U.S. gallon must be constructed in accordance with the Boiler and Fired Pressure Vessel Safety Orders, Title 8, Subchapter 2 (Ref. 8).

State of California Permits to Operate are required for LPG tanks and air tanks larger than 1.5 ft^3 with relief valves set to open above 150 psi.

3. Boilers and Fired Pressure Vessels

Reference 8: State of California Administrative Code
Title 8. Industrial Relations
Part 1. Department of Industrial Relations
Chapter 4. Division of Industrial Safety
Sub-Chapter 2. Boiler and Fired Pressure Vessel Safety Orders.

These Safety Orders establish minimum standards for the design, construction, installation, inspection, operation, and repair of all (1) power boilers, including nuclear, (2) all low-pressure boilers and high-temperature-water boilers, and (3) any other fired pressure vessels in California not specifically exempted from these Orders.

These Safety Orders are not applicable to (1) boilers and fired pressure vessels under the jurisdiction of, and inspected by, the United States Government, (2) boilers and fired pressure vessels used in household service, and (3) boilers used exclusively to operate highway vehicles, including automobiles.

4. Design and Construction

All new power boilers and high-temperature water boilers must be constructed, inspected, and stamped in full compliance with the ASME Boiler and Pressure Vessel Codes (Refs. 21 and 22) unless the design and construction of the boiler are accepted by the Engineering Division as equivalent to Code.

All fired pressure vessels must be constructed, inspected, and stamped in accordance with the ASME Code insofar as applicable. Those vessels not included in the scope of the ASME Code must be designed and constructed in accordance with good engineering practice regarding pressure-vessel design for the pressure and temperature to be expected in service, with a factor of safety of at least 4. Good engineering practice (as used in this Manual) must be construed to require details of design and construction as safe as otherwise provided by the rules in the ASME Code, including shop inspection.

All new low-pressure boilers must be constructed, inspected, and stamped in accordance with the ASME Code, unless the design and construction are accepted by the Engineering Division as equivalent to Code.

State of California Permits to Operate are required on all boilers and fired pressure vessels except for:

Low-pressure boilers

Miniature boilers

High-temperature water boilers

Boilers, including forced-circulation boilers, in which none of the following is exceeded: 100 ft^2 of heating surface, 16-in. steam-drum inside diameter, 100-psi MAWP, 35-gal. normal water capacity, and 400,000-Btu/hr burner power input.

5. Code Definitions

Code: The ASME Boiler and Pressure Vessel Codes and the ANSI Standards (Refs. 2, 3, 4, 14, 15, 21, and 22).

Low-pressure boiler--a boiler that does not operate at steam pressure or with steam-safety valve settings exceeding 15 psi (low-pressure boiler) or (2) operate at water pressures exceeding 160 psi or water temperatures exceeding 250°F (hot-water-heating boiler). [This definition is not intended to include domestic-type water heaters, provided the heater does not have a water capacity of more than 120 gal and is used only for heating service water.]

Miniature boiler--a boiler that has (1) an inside shell diameter of 16 in. or less and (2) a gross volume of 5 ft^3 or less, exclusive of casing and insulation. (This volume includes the total volume of the steam- and water-containing parts of the boiler plus the volume of the combustion space and gas passages up to the point of attachment of the smokestack or chimney breeching.)

High-Temperature Water Boiler: a fired or unfired pressure vessel used to heat water to temperatures above 212°F at pressures exceeding 160 psi or to temperatures exceeding 250°F regardless of pressure.

Power boiler: a steam boiler operated at pressures exceeding 15 psi.

F. GUIDE FOR WRITING SAFETY NOTES (SN) FOR PRESSURE VESSELS AND SYSTEMS

Refer to Section II.A. and to Fig. III-2, Documentation Guide for Pressure Equipment Safety Note, to determine if a Safety Note is required for your vessel or system. The following guidelines have been prepared to assist those writing Safety Notes for pressure vessels and systems.

In the preparation of a Safety Note consider the following:

- Description.
- Hazards.
- Calculations.
- Pressure Testing.
- Labeling.
- Associated Procedures.
- References.
- Signature Authority.
- Distribution (see sample title page).

SAMPLE TITLE-PAGE FORMAT

MECHANICAL ENGINEERING SAFETY NOTE

TITLE

Engineering Note Serial Number
Safety Case File Number

Date:

Prepared by: ______________________________
Responsible Designer

Reviewed by: ______________________________
Project Mechanical Engineer

Approved by: ______________________________
Mechanical Safety Subcommittee

Distribution:

Author
Project Mechanical Engineer
Mechanical Safety Subcommittee
Responsible User
Mechanical Engineering Department Safety Case File

1. Description

What is it, its configuration, its size?

What will be its use?

What are its pressure ratings, MAWP, and OP*?

Is it an ASME-coded vessel?

What are its operating temperature and environment?

Is it DOT approved?

Are there drawing numbers or sketches you can cite?

Where will it be located? Building________ Room________.

Who will be the responsible experimenter or user?

From your description, could you find this vessel or system several years from now?

2. Hazards

What are the hazards?

What is the stored energy (in gas-filled vessels)?

Stored energy can be calculated using this formula:

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

Marks Handbook 7th Edition (pp. 4-25),

where

P_1 = MAWP, MPa (1 MPA = 145 psi)

P_2 = atmospheric pressure, MPa

k = specific heat ratio (1.4 for N, 1.66 for He, 1.67 for A, 1.41 for H)

V_1 = volume, cm^3

E = stored energy, joules (equivalent energy 2.1 MJ per lb of TNT)

---

*MAWP--relief-device setting; OP (operating pressure) 10 to 20% below MAWP.

Is it located in a manned area; is a flammable and/or cryogenic, radioactive, or toxic/corrosive material involved?

What happens in a loss of power, coolant, instrument air, etc.?

What will you do to eliminate or lessen the hazards, e.g., hood, barricades, protective clothing, special operating procedure?

3. Calculations

What are the design specifications?

What are the material specifications?

Are material certifications required?

Include calculations for the MAWP (see Ref. 2, UG-98).

Where applicable, show calculations for parameters such as

weld shear stress,
tensile stress on bolts, plates,
hoop stress,
thread shear, and
safety factors.

All components rated at or above MAWP do not require calculations.

Cite manufacturers' ratings, stores-catalog ratings, and identifications.

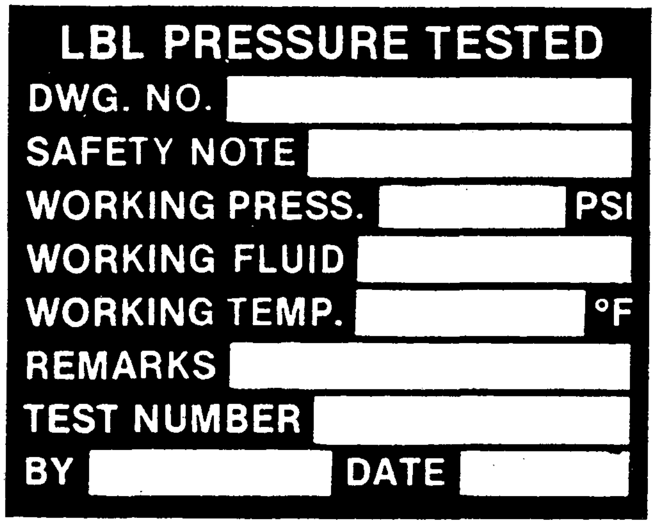
Show calculations for barricades or shields if used.

4. Pressure Testing

All pressure testing requires a procedure. Use this section to write the test procedure. Specify: test sequence, test pressure, test fluid, test temperature, hold time, and acceptance leak rate. Record actual test procedure and results.

Is a retest procedure required? Is it different from the original procedure? Should the frequency of inspection or retest be specified?

5. <u>Labeling</u>



6. <u>Associated Procedures</u>

List all procedures to be read and understood by all personnel operating the equipment, such as

Building Procedure,

Operating Procedure, and

Special Instructions.

7. <u>References</u>

List the references you have cited in your Safety Note.

8. <u>Signature Authority</u>

Prepared by: ______________________________
Responsible Designer

Reviewed by: ______________________________
Project Mechanical Engineer

Approved by: ______________________________
Mechanical Safety Subcommittee

9. Distribution

Mechanical Safety Subcommittee.

Project Mechanical Engineer.

Responsible User(s).

Responsible Designer(s).

Others concerned, such as Building Manager, Division Safety Coordinators, Area Operations Management, and EH&S.

Mechanical Engineering Department Safety Case File.

G. PRESSURE TESTING, GENERAL

This Section covers the pressure testing of research equipment, pressure vessels, and systems. Whenever practical, pressure vessels and systems should be sent to the Assembly Shop or the Plant Maintenance Technician Shops for pressure testing. When this is not practical, the vessel or system must be tested in accordance with the two standard procedures described in this Section. All pressure tests must be conducted by a Plant Maintenance Technician, a Physical Plant Mechanic, or an Assembly Shop Machinist and must be observed (or conducted) and certified by a member of the Mechanical Safety Subcommittee (or designate) or a Pressure Inspector.

A Summary of Pressure-Vessel and Pressure-System Testing is given in Table III-4.

The Mechanical Safety Subcommittee member (or designate) or Pressure Inspector who certifies the test must complete the "Pressure Test Record" form (Fig. III-4) and then attach, or have attached, an "LBL Pressure Tested" label (Fig. III-5) to the vessel or system, if it passed the test.

Pressure test and pressure inspection records must be maintained in a permanent file by the organization that certifies the test or inspection (Mechanical Safety Subcommitttee or Construction and Maintenance Department).

For definitions of pressure terms used in this Section, refer to the list at the beginning of this Section and to Ref. 1, Chapter 20.

1. Pressure Vessels

Pressure vessels must be tested in accordance with the rules in this Section, using an inert fluid.

Pressure vessels for low-hazard inert systems for operation with nonflammable, nontoxic fluids must be hydrostatically tested to 1.5

Table III-4. Summary of Pressure-Vessel and Pressure-System Testing.

Pressure vessels and systems in pressure range of 15 to 3000 psig.
Set pressure-relief device no higher than MAWP.
Pressure Test Record and Label required.

Section	Title	Pressure Test
III G 1	**Pressure Vessel (Testing)**	
	Pressure Vessels for low-hazard inert systems containing nonflammable or nontoxic fluids.	Hydrostatic test to 1.5 times MAWP or pneumatic test to 1.25 times MAWP. Pneumatic test only if electrical or research requirements prohibit hydrostatic test. Use an inert fluid.
	Pressure Vessels for high-hazard reactive systems containing oxygen or flammable, toxic, and/or radioactive fluids.	Test to 2.0 times MAWP with inert liquid (preferred) or gas and correct results to OT.
III G 2	**Pressure Systems (Testing)**	
	Pressure Systems (containing low-hazard inert substances) that will operate with nonhazardous liquid, inert gases, or compressed air.	Hydrostatic test to 1.5 times MAWP (preferred) or pneumatic test to 1.25 times MAWP. Pneumatic in-place testing is limited to 3000 psig maximum. Use an inert fluid.
	Pressure Sytems (containing high-hazard reactive substances) that will operate with oxygen or with flammable, toxic, and/or radioactive fluids.	Test to 2 times MAWP using an inert liquid (preferred) or gas and correct results to OT. Pneumatic in-place testing is limited to 3000 psig maximum.

LAWRENCE BERKELEY LABORATORY
PRESSURE-TEST RECORD

Date: ____________

Location of vessel (or system): Bldg ____________ Rm ________

Description: ______________________________

____

____

Pressure Vessel ☐ Pressure System ☐ (check box)

"Pressure-Tested" Label attached ☐

LBL PRESSURE TESTED			
DWG. NO.			
SAFETY NOTE			
WORKING PRESS.		PSI	
WORKING FLUID			
WORKING TEMP.		°F	
REMARKS			
TEST NUMBER			
BY		DATE	

TEST INFORMATION :

1. Test Pressure ________ Pa (________ kpsi)
2. Testing Fluid (oil, He, etc.) ________
3. Test Temperature ________ °C (________ °F)
4. Design Temperature ________ °C (________ °F)
5. Safety Case ________
6. Responsible Designer — Name: ________
7. Responsible User — Name: ________

   Dept: ________

   Divn: ________

8. Diameter measurements (for pressure-vessel tests only)

Location (marked)	Before testing	After testing	Difference (+ or –)

Remarks: ______________________________

Test by: ________________
C&M, Mech. Shop

CERTIFICATION:

The vessel identified above has been pressure tested and is approved for operation within these test conditions.

Certified By: ________________

RL - 6546 - Revised
(7/88)

Figure III-4. Pressure Test Record.

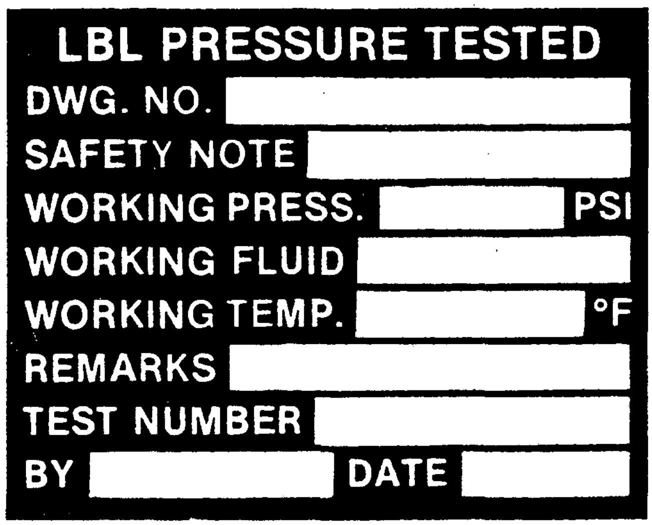


Figure III-5. "LBL Pressure Tested" label.

times the MAWP or pneumatically tested to 1.25 times the MAWP (only when safety considerations or research requirements do not permit a hydrostatic test). Any special temperature conditions or temperature cycles to which the vessel will be subjected in use must be reproduced as closely as possible during the test. Allowance must be made for temperature effects as described in Ref. 2, Division 1, UG-99, 100.

Pressure vessels for high-hazard reactive systems for operation with oxygen or flammable, toxic, or radioactive fluids must be tested to 2.0 times the MAWP with an inert liquid (preferred) or gas. This result must then be multiplied by the lowest ratio of the vessel-material stress value, S_1 (at vessel-test temperature), to the corresponding design-temperature stress value, S_2 (see Ref. 2, Division 1, UG-99, 100). Any special temperature conditions or temperature cycles to which the vessel will be subjected in use must be reproduced as closely as possible during the test. In addition, consider the need to inspect any vessel ultrasonically or to check the vessel surface for cracks using the magnetic-particle test or (for nonmagnetic vessels) the fluorescent-penetrant test.

During tests of pressure vessels in which the yield strengths of their construction materials is approached, strain-gauge measurements must be made at high-stress locations. Diameter measurements accurate to within ±0.025 mm (0.001 in.) must also be taken both before and after testing to determine whether detectable plastic yielding has occurred during pressurization.

In cases where the strength of the vessel is questionable (old or unknown design), strain-gauge measurements must be made during testing, and diameter measurements must be taken before and after testing. The MAWP for ASME Pressure Vessels (see Ref. 2) made of the acceptable ductile materials listed, must not exceed 0.4 times the test pressure and must comply with UG-101.

2. Pressure Systems

Inert-substance (low-hazard) pressure systems that will operate with nonhazardous liquids, inert gases, or compressed air must be tested hydrostatically (preferred) at 1.5 times the MAWP or pneumatically at 1.25 times the MAWP using an inert fluid.

Reactive-substance (high-hazard) pressure systems that will operate with oxygen or with flammable, toxic, or radioactive fluids must be tested at 2.0 times the MAWP using an inert liquid (preferred) or gas. This result must then be multiplied by the lowest ratio of the vessel-material stress value, S_1 (at vessel-test temperature), to the corresponding design-temperature stress value, S_2 (see Ref. 2, Division 1, UG-99, 100).

3. Leak Testing

Pressure vessels and systems must be leak tested at their MAWP after successful pressure testing. Gross leakage can be detected by observing the drop in pressure on the test gauge during pressure testing and can be pinpointed with leak-detection fluid. Small leaks can be located with commercial leak detectors.

Caution:

- Open flames must not be used for leak-testing.
- Remote-operation vessels and systems must be remotely leak tested.
- Manned-area leak testing of pressure-tested remote-operation vessels and systems (or of non-pressure-tested or undocumented pressure vessels or systems) must be limited to a maximum of 20% of the test pressure (or proposed test pressure).

4. Repairs

If a leak is detected during pressure testing of a manned-area vessel or system, and it is decided to locate the leak before completing the test, the pressure must be reduced to not over one-half the immediately preceding test pressure while the leak is being located.

Caution:

- For safety reasons, a system or vessel must not be repaired while it is pressurized unless this is specifically authorized by an approved OSP or by the Mechanical Safety Subcommittee.

5. Modifications

Any modification to a vessel or system that requires an SN or OSP, other than repair or replacement (with an exact duplicate) of existing components, must be recorded in a revision to the applicable engineering drawing and to the SN or OSP. The initial pressure test must be repeated before any further use of the modified vessel or system.

When pressure equipment has been modified for use at a pressure below the original design pressure, all modifications (e.g., use of fewer bolts in flanged joints) must be approved by the responsible designer. All safety requirements for the lower pressure must be met, and the reduced working pressure and the number of bolts or other supports required must be clearly marked on the equipment. If high-strength or other special bolts are required, this must also be clearly marked on the equipment near the bolt holes.

Instructions on the precautions to be taken when the modified equipment is operated must be sent to all personnel concerned, and one copy must be filed in the Safety Note file of the Mechanical Engineering Department.

6. Reinspection and Retesting

All high-hazard pressure vessels and systems must be reinspected at least every three years and retested remotely at least every six years, unless otherwise specified on the SN or OSP. Low-hazard pressure equipment need not be periodically reinspected and retested, unless otherwise specified in a SN or OSP.

Pressure reinspection is performed by a Pressure Inspector or by the Mechanical Safety Subcommittee and is recorded on a "Pressure Inspection Record" form (Fig. III-6). The completed form must be signed by the Responsible User and sent to the Construction and Maintenance Department or the Mechanical Safety Subcommittee for filing as a permanent record.

Pressure vessels and systems must be retested at the MAWP unless otherwise specified in the SN or OSP.

The result of the retest must be certified on the "Pressure Test Record" form (Fig. III-4) to be filed by the testing organization, and an "LBL Pressure Tested" label (Fig. III-5) must be fixed on the vessel or system as described earlier in this Section.

H. IN-PLACE PRESSURE TESTING, GENERAL

If it is impractical to pressure test a vessel or system at the Mechanical Shop, Construction and Maintenance Shop, or some other approved location, pressure test it in place, in accordance with the provisions of this Section and Sections I (gas) and J (liquid).

The responsible designer must prepare the required test procedure, direct the test personnel, and witness in-place pressure testing of vessels and systems for which he/she is responsible. The responsible user must be similarly responsible for in place retesting of pressure equipment for which he/she is responsible. Although other individuals may be designated to observe and direct testing or retesting, responsibility for safe conduct of the test and safe functioning of tested pressure equipment cannot be delegated.

LAWRENCE BERKELEY LABORATORY
PRESSURE INSPECTION RECORD

Date:______________

Location of vessel (or system): Bldg. __________ Rm. ______________

Is vessel or system still in use? Yes ________ No ________

If not in use, refer to EH&S Engineering Services for disposition.

Pressure Vessel ☐ Pressure System ☐ (check box)

LBL PRESSURE TESTED
DWG. NO.
SAFETY NOTE
WORKING PRESS. PSI
WORKING FLUID
WORKING TEMP. °F
REMARKS
TEST NUMBER
BY DATE

INSPECTION INFORMATION:

Inspect the following and check (✓) appropriate column, explaining as reqiured. (Enter N/A under Remarks if item is not applicable.)

Item	Satis-factory	Unsatis-factory	Remarks
1. General appearance of system (or vessel)			
2. Relief devices are a. properly set (have checked; reset as required).			
b. properly sealed.			
c. pointed in safe direction or safely vented.			
3. All fittings are tight.			
4. Replaced or added fittings, gauges, valves (and piping *) are properly rated			
5. All system components are adequately secured.			
6. Valve packing nuts are tight and locked (if locking type).			
7. Oil is not apparent on or in* gas (especially oxygen) systems.			
8. The outside surface of the vessel shows no evidence of strain, damage, or corrosion.			
9. The inside surface of the vessel shows no evidence of strain, damage, or corrosion.			
10. Lined-vessel vent path is unobstructed; check with helium.			
11. Vessel or system seals are leaktight. Have replaced as required.			
12. The vessel or system is safe for continuing operation.			
13. Vessel or system was pressure tested within the last 6 years, or as required by the Safety Note. (If not, and vessel is to be certified for manned-area operation, retest it and submit a Pressure Test Record in place of this Pressure Inspection Record).			

Inspected by: ______________________________
C&M, Mech. Eng., EH&S

____
RESPONSIBLE USER

Send this completed form to EH&S Engineering Services.

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* Consider assurance by the Responsible User as satisfactory verification.

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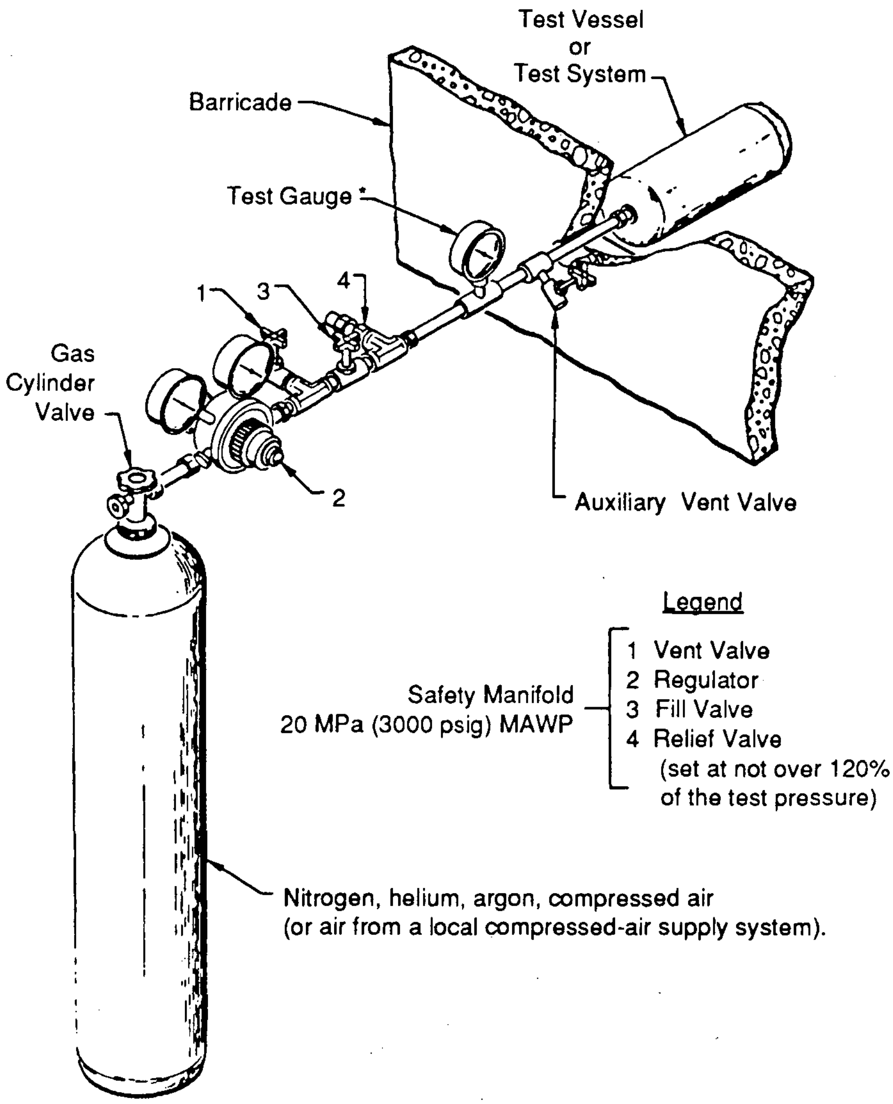
Figure III-6. Pressure Inspection Record.



* Test gauge must have a solid front, blow-out back, and a securely attached plastic face if over 100-mm (4-inch) diameter and graduated to over 1.4 MPa (200 psi). The scale should be about double the test pressure and never less than 1.2 times the maximum test pressure.

Figure III-7. Setup for pressure testing in place with gas.

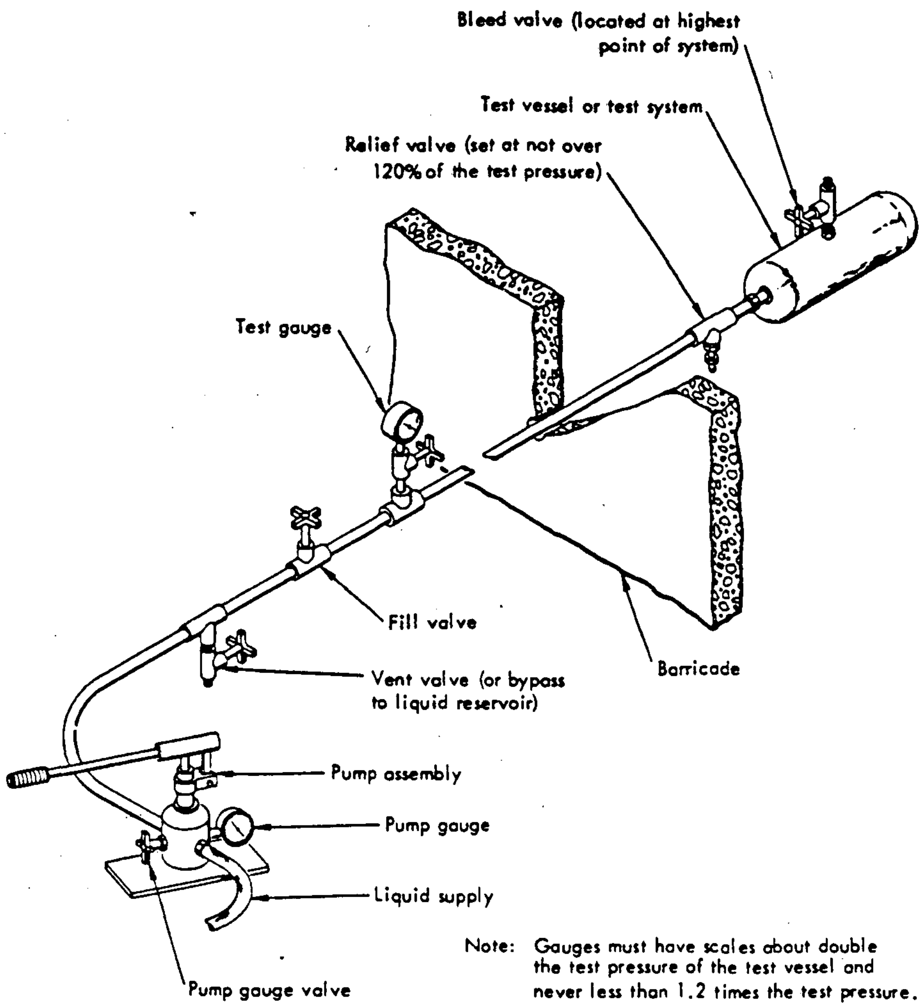


Figure III-8. Setup for pressure testing in place with a liquid.

1. Test Procedure

A written test procedure must be prepared for every high-hazard pressure test conducted in the field. If only a safety manifold or equivalent (see Figs. III-7 and III-8) is employed, use the applicable Standard Procedure for pressure testing in place. Since the condition requiring that testing be conducted in place is usually apparent to the responsible designer, the test procedure should normally be included in (or appended to) the SN or OSP.

2. Test-Procedure Approval

Procedures for in-place testing of high-hazard vessels and systems must be approved by the Mechanical Safety Subcommittee, which maintains a complete file of all approved in-place testing procedures.

The Building Manager or Area Supervisor must be advised of pressure tests planned to occur in his/her facility, and EH&S must be notified if toxic or radioactive material is involved.

3. Test Personnel

All pressure tests must be conducted by a person designated by the responsible designer or conducted by a Plant Maintenance Technician, a Physical Plant Mechanic, or a Machinist in the Assembly Shop and must be observed (or conducted) and certified by a member of the Mechanical Safety Subcommittee (or designate) or a Pressure Inspector.

4. Precautions

Pressure testing with a gas is more dangerous than testing with a liquid. Therefore, tests must be conducted with liquids, whenever practical.

Barricade the equipment being tested or shield the controls and operators and evacuate all unauthorized personnel from the area. Shielding against possible projectiles and liquid jets may be required.

Signs reading "Danger--High-Pressure Test in Progress--Keep Out" must be posted at all approaches to the test area.

For in place testing with liquids, all air must be removed from both the testing system and the equipment to be tested. Compressed air will expand violently in case of vessel failure. Spongy action of pumping equipment usually indicates the presence of trapped air.

I. STANDARD PROCEDURE FOR PRESSURE TESTING IN PLACE WITH GAS

1. Applicability

This standard procedure may be used for conducting low- and intermediate-pressure in-place gas tests with the safety manifold, shown in Fig. III-7 at pressures up to 20 MPa gauge (3000 psig). Pressure Testing services are available from the Plant Maintenance Technicians, Building 76.

2. Pretest Procedure

The following actions must be taken before actual pressure testing is started (see Fig. III-1).

- o Obtain the appropriate safety manifold from the Plant Maintenance Technicians in Building 76.
- o Barricade the test vessel or system or install shielding and post the required warning signs.
- o Attach the safety manifold to the test vessel or system with adapters and tubing rated at, or above, the testing pressure.
- o Back off (turn counterclockwise) the Regulator Adjusting Screw, open Vent Valve (1), close Fill Valve (3), and connect the regulator to the supported compressed-gas cylinder.

The test system must be checked in advance by a member of the Mechanical Safety Subcommittee (or designate), who is authorized to prohibit testing if, in his/her opinion, the test setup is unsafe, the components of the system have not been properly identified, or all precautions in this procedure have not been observed.

3. Test Procedure

People not directly involved in the test must leave the area. A member of the Mechanical Safety Subcommittee (or designate) or a Pressure Inspector must witness the test, which must consist of the following steps (see Fig. III-7).

a. Measure and record test-vessel dimensions as indicated on the test procedure. (Omit this step and Step m. below when only a system is being tested.)

b. With Fill Valve (3) closed, Vent Valve (1) open, and the Regulator Adjusting Screw (2) backed off (turned counterclockwise), slowly open the Gas-Cylinder Valve.

c. Close Vent Valve (1).

d. Turn the Regulator Adjusting Screw (2) until about 110% of the test pressure is indicated on the regulator low-side pressure gauge.

e. Open and close Vent Valve (1) to confirm accurate regulator setting; then close Vent Valve (1).

f. Close the Gas-Cylinder Valve, open Fill Valve (3), and confirm by the low-side regulator-gauge reading that the flow path is open to the test vessel or system. Then close Fill Valve (3) and slowly open the Gas-Cylinder Valve.

g. Slowly open Fill Valve (3).

h. When the test vessel or system has reached the specified test pressure, close Fill Valve (3) and the Gas-Cylinder Valve and open Vent Valve (1).

i. Periodically check the test gauge for signs of vessel or system leakage during the specified pressure-hold time.

j. If unacceptable leakage is observed, open the Auxiliary Vent Valve to reduce the system to the lowest-possible pressure for locating the leak. This leak-test pressure must never exceed one-half the immediately preceding pressure applied to the system. Locate the leak, reduce the pressure to zero, repair the leak, and repeat Steps a-i.

Caution:

This vessel or system has not yet been proven safe for manned-area operation. If leakage is minor, complete the pressure test remotely and leak test later (after Step m) at a pressure (not exceeding the MAWP) that you have by then established as safe. Reduce the pressure to zero before repairing any leaks.

If a leak is detected past a test-vessel seal, as distinguished from a minor fitting leak, repair as required and repeat the entire pressure test.

k. If the leak rate is acceptable, hold the test pressure for the required time, then release the pressure by opening Fill Valve (3) or the Auxiliary Vent Valve.

l. Verify that the Gas-Cylinder Valve is closed and that both regulator gauges read zero.

m. After 30 minutes, remeasure and record diameters to confirm that the vessel has not permanently expanded.

4. Leak Testing

After pressure testing, leak test (as required by the SN or OSP) the manned-area gas vessel or system at its MAWP.

5. Labeling

When the vessel or system passes the pressure test, a member of the Mechanical Safety Subcommittee (or designate) or the Pressure Inspector must complete and file the permanent Pressure Test Record and must label (Figs. III-4 and III-5) the tested equipment, as described earlier in this Section.

J. STANDARD PROCEDURE FOR PRESSURE TESTING IN PLACE WITH LIQUID

1. Applicability

This procedure must be used for conducting in-place hydrostatic pressure tests.

2. Pretest Procedure

The following actions must be taken before actual testing is started (see Fig. III-8).

- Signs reading "Danger--High Pressure Test in Progress--Keep Out" must be posted at all approaches to the test area.

- Fill the Pump Gauge and Test Gauge with testing liquid, close the Pump-Gauge Valve, close the Test-Gauge Valve, and assemble as shown in Fig. III-8 using components rated at, or above, the test pressure.

- Remove, or fill with liquid, any test-system gauges and plug openings as required. Caution: If gas pressure is required to operate any test-system valves or other components, the responsible designer (or responsible user) must include instructions for operating such components in the pretest or test procedure and must be present whenever such components are tested. These components must be tagged with their rated MAWP before being operated.

- Close the Vent Valve, open the Fill Valve, open the Bleed Valve, and fill the system with liquid using (or through) the pump.

- Close the Bleed Valve, open the Pump-Gauge Valve, open the Test-Gauge Valve, and and close the Fill Valve.

3. Test Procedure

Persons not directly involved in the test must leave the area. The responsible designer, responsible user, a member of the Mechanical Safety Subcommittee (or designate), or a Pressure Inspector must witness the test, which must consist of the following steps (see Fig. III-8):

a. Measure and record test-vessel dimensions (usually mid- and quarter points on cylindrical vessels) as indicated on the test procedure. (Omit this step, and Step g below, when a system is being tested.)

b. Open the Fill Valve and slowly pump to the test pressure.

c. Close the Fill Valve.

d. Periodically check the test gauge for signs of vessel leakage during the specified pressure-hold time.

e. If unacceptable leakage is observed, open the Vent Valve and the Fill Valve to reduce the system pressure to zero, then locate and repair the leak. Remove all air from the system, close the Vent Valve, then slowly pump again to the test pressure and hold for the required time.

f. If the leak rate is acceptable, hold the test pressure for the required time by opening the Fill Valve, pumping as required, and then closing the Fill Valve. Then open the Vent Valve, Fill Valve, and Bleed Valve to release pressure and drain the liquid from the system.

g. After 30 minutes, remeasure and record diameters to confirm that the vessel has not permanently expanded.

4. Leak Testing

After pressure testing, leak test (as required by the SN or OSP) manned-area gas vessels or systems at the MAWP. Leak test vessels and systems that operate with liquids to the extent necessary (but no higher than the MAWP) to ensure the functional reliability required, as specified on the SN or OSP.

5. Labeling

When the vessel or system passes the pressure test, the Mechanical Safety Subcommittee member (or designate) or the Pressure Inspector must complete and file the permanent Pressure Test Record and must label (Figs. III-4 and III-5) the tested vessel or system.

K. REFERENCES

1. LBL Health and Safety Manual, PUB-3000.

2. ASME Boiler and Pressure Vessel Code, Section VIII, "Pressure Vessels," Division 1, American Society of Mechanical Engineers, New York (current edition).

3. ASME Boiler and Pressure Vessel Code, Section VIII, "Pressure Vessels," Division 2, American Society of Mechanical Engineers, New York (current issue).

4. ASME Boiler and Pressure Vessel Code, Section X, "Fibreglass-Reinforced Plastic Pressure Vessels," American Society of Mechanical Engineers, New York (current edition).

5. ARI Standards, Air-Conditioning and Refrigeration Institute, Arlington, VA.

6. Code of Federal Regulations 49, Transportation, Parts 100 to 199, General Services Administration (current issue).

7. State of California Administration Code, Title 8, Industrial Relations, Part 1, Department of Industrial Relations, Chapter 4, Division of Industrial Relations, Subchapter 1, Unfired Pressure Vessel Safety Orders (latest edition).

8. State of California Administration Code, Title 8, Industrial Relations, Part 1, Department of Industrial Relations, Chapter 4, Division of Industrial Relations, Subchapter 2, Boiler and Fired Pressure Vessel Safety Orders (latest edition).

9. ASTM Standards, Vol. 03.01, Metals, American Society for Testing and Materials, Philadelphia, PA (current edition).

10. Strength of Metal Aircraft Elements, Spec. MIL-HDBK-5 Armed Forces Supply Support Center, Washington, D.C., (current edition).

11. Steel Forging: Alloy, High Yield Strength, Spec. Mil-S-23009 Bureau of Ships, Department of the Navy, Washington, D. C., (April 1965).

12. T. Baumeister, Marks' Mechanical Engineers' Handbook, McGraw-Hill, New York (1958).

13. W. A. Burton, Stationary Installation and Use of DOT Cylinders, M. E. Safety Note EN M 70-905, Lawrence Livermore National Laboratory, September 11, 1970.

14. American National Standard Code, ANSI-B31.1, Power Piping (current edition).

15. American National Standard Code, ANSI-B31.3, Chemical Plant and Refinery Piping (current edition).

16. W. Burton and F. Locke, Tubing, Seamless, Stainless Steel, for General High-Pressure Applications, Lawrence Livermore National Laboratory Standard Specification MEL 63-000681, January 7, 1963.

17. W. Burton et al., Tubing, Seamless, Stainless Steel, Certified for Ultra-Reliable High-Pressure Systems, Lawrence Livermore National Laboratory Standard Specification MEL 71-001150, June 18, 1971.

18. Design Safety Standards, Manual M-012, Mechanical Engineering Department, Lawrence Livermore National Laboratory (current edition).

19. DOE Order 6430.1, General Design Criteria, (latest version).

20. American Petroleum Institute, Standard 620 (latest edition).

21. ASME Boiler and Pressure Vessel Code, Section I, Power Boilers, American Society of Mechanical Engineers, New York (latest edition).

22. ASME Boiler and Pressure Vessel Code, Section IV, Heating Boilers, American Society of Mechanical Engineers, New York (latest edition).

Related Publications, Not Cited in the Text

J. F. Harvey, Pressure Vessel Design: Nuclear and Chemical Applications, Nuclear Science Series TS-283-H2, Van Nostrand Company, Princeton, N.J. (1963).

S. Timoshenko, Strength of Materials Part II, "Advanced Theory and Problems" Van Nostrand Company, Princeton, N.J. (1956).

R. J. Roark, Formulas for Stress and Strain, McGraw-Hill, New York, (1954).

J. H. Faupel, Engineering Design, John Wiley and Sons, Inc., New York (1964).

F. B. Seely, Advanced Mechanics of Materials, 2nd ed., John Wiley and Sons, Inc., New York (1952).

E. W. Comings, High Pressure Technology, McGraw-Hill, New York (1956).

N. L. Svensson, The Bursting Pressure of Cylindrical and Spherical Vessels, ASME J. Appl. Mech. 25, 89 (March 1958).

T. J. Dolan, "Significance of Fatigue Data in Design of Pressure Vessels," Welding J. 35, 255s (1956); also, ASME Paper No. 57-A-15 (1957).

G. Geroard, Structural Significance of Ductility in Aerospace Pressure Vessels, College of Engineering, New York University, Tech. Rept. SM-60-8 (1960).

G. R. Irwin, "Fracture of Pressure Vessels," in Materials for Missiles and Spacecraft, E. R. Parker, Ed., McGraw-Hill, New York (1963) pp. 205-299.

Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petroleum Plants, American Petroleum Institute, API Publication 941, July 1970.

G. H. Bhat and D. V. Lindh, "Evaluation of Ultra-High Strength Steels for Thin Walled Pressure Vessels and Rocket Motor Cases," ASME Paper No. 62-MET-16 (1962).

A. Hurlich and J. Balsch, "Titanium Pressure Vessels," J. Metals 12, 136 (1960).

D. A. Wruck, "Titanium Pressure Vessels," Machine Design 33, 144 (1971).

R. Gorcey, "Filament Wound Pressure Vessels," Rocketdyne Division, North American Aviation, Design News (January 1962).

R. Chuse, Unfired Pressure Vessels, Nuclear Science Series TS-283-A, F. W. Dodge Corporation, N.Y. (1960).

H. Thielsch, Defects and Failures in Pressure Vessels and Piping, Reinhold, New York (1965).

J. P. Den Hartog, Advanced Strength of Materials, McGraw-Hill, New York (1952).

Health & Safety Manual, Supplement 32.03, Pressure Vessel and Pressure System Design, and Supplement 32.05, Pressure Testing, Lawrence Livermore National Laboratory (current edition).

L. E. Brownell and E. H. Young, Process Equipment Design, Wiley, New York (1959).

IV. HYDROGEN FURNACES

Before the purchase or construction of a hydrogen furnace the responsible user must submit the furnace specifications to the Mechanical Safety Subcommittee and EH&S for review.

In addition to the general flammable-gas safety rules shown in Sections I.B., I.C., and I.F. and II of this manual and in PUB-3000, Chapter 13 (Ref. 1), the following special guidelines must be observed for hydrogen furnaces:

A. CONSTRUCTION

All hydrogen furnaces must be constructed of material resistant to impact and heat shock and not subject to hydrogen embrittlement.

The furnace and associated equipment must be vacuum tight at 40 Pa (0.3 Torr) at all operating temperatures.

Personnel shields must be placed around all hot outside surfaces on the furnace to prevent injuries.

If the hydrogen furnace is to be operated in a location where the hydrogen content of the space surrounding the furnace can exceed 10% of the Lower Explosive Limit (LEL) then all electrical equipment and wiring attached to the furnace and to the system must be explosion proof, i.e., Class I, group B, Division 2 (NFPA 70-NEC, Ref. 2) or intrinsically safe, i.e., NFPA No. 493-PT (Ref. 3).

In lieu of explosion-proof equipment, all electrical devices (switches, relays, etc.) on the furnace or system must be totally enclosed, and the enclosure must be purged with nitrogen at a positive pressure of not less than 0.1 inch of water when power is on. Other requirements regarding purge-gas flow rate, alarms, and other items, are stated in NFPA 496, Type Z Purging, Ref. 4.

B. INSTALLATION

Hydrogen furnaces must be installed and operated only in rooms having automatic-sprinkler protection, and the room may only be heated by steam, hot water, or any other <u>indirect</u> means.

A forced-air ventilation system, with the room exhaust duct located near the ceiling, must be installed and operated in rooms containing operating hydrogen furnaces. The capacity (ft^3/min) of the exhaust blower must be sufficient to ensure that the maximum concentration of H_2 does not exceed 10% of the LEL based on the maximum expected leak rate of H_2 over a period of 8 hours. In most cases the blower capacity may be calculated through the following formula (Ref. 4):

$$\log_{10}\left(1 - \frac{QC}{G}\right) = - \frac{Qt}{2.3V}$$

where

C = concentration of H_2 expressed as a fraction at any time, t (min)

V = room volume (ft^3)

G = rate of generation of H_2 (ft^3/min)

Q = ventilation rate (ft^3/min).

Consideration must be given to deviations from the ideal conditions for the location of air inlets and outlets, room baffling, and hoods and to any other factors affecting exhaust efficiency.

The exhaust fan must be explosion proof or use a three-phase motor without sparking devices.

Hydrogen supply cylinders must be located at least 10 feet away from the furnace.

An orifice that limits the hydrogen flow to less than 10% of the LEL when the room exhaust system is operating must be located in the high-pressure hydrogen-gas supply line at the hydrogen cylinder.

A solenoid valve must be installed in the high-pressure section of the hydrogen-supply line at the hydrogen cylinder and must be interlocked with the room combustible-gas detectors to shut off the hydrogen flow when an alarm is activated, a loss of blower air occurs, or power fails. After a power failure, both the solenoid valve in the hydrogen supply line and the furnace must be manually reactivated.

A solenoid valve must be located in the inert-gas supply line and must be interlocked with the combustible-gas detectors to purge the furnace with helium, argon, or nitrogen gas when the hydrogen alarm is activated. Preferably, the inert-gas supply should be located outside the furnace room.

Installation of a check valve in the inert-gas supply line is recommended to prevent hydrogen gas from backing into the inert gas.

Tubing used for supplying hydrogen to the furnace must be metal and must be protected from physical damage.

The furnace and associated equipment must be electrically grounded and bonded (all non-current-carrying metal parts connected by a solid electrical conductor) to minimize voltage-, capacitive-, and electrostatic-spark hazards.

Flammable-gas detectors must be mounted above the furnace and above the hydrogen-supply cylinder if the cylinder is located inside the building. Gas detectors must be set to give an alarm at 10% of the LEL for hydrogen.

Approved fire extinguishers must be easily accessible and located within a few feet of the furnace.

C. OPERATION

An OSP must be prepared by the responsible user in charge of the furnace operation. (See PUB-3000, Chapter 1, Appendix B.)

The hydrogen-furnace system, and its piping diagram, must be approved by a member of the Mechanical Safety Subcommittee and the EH&S Department before furnace operation can begin. The piping diagram must be posted at the furnace.

Only trained personnel thoroughly familiar with the hydrogen furnace may be authorized to operate it, and a list of authorized operators and their phone numbers must be posted at the hydrogen furnace.

The furnace must be pressure tested for leaks with inert gas at about 5 psig at room temperature before each use.

The furnace must be evacuated to less than 0.3 torr and purged with an inert gas to remove air before the introduction of hydrogen, and during operation a positive hydrogen pressure must be maintained in the furnace to exclude air from the system (the autoignition temperature for hydrogen in air is 585°C).

Other flammable gases located in the furnace room must be confined while the furnace is in operation since the hot surface of the furnace may ignite these gases.

At the end of each experiment the furnace heater must be turned off, the hydrogen flow shut off, and the furnace flushed with inert gas.

All safety devices on the furnace and associated equipment must be inspected at least every 6 months to ensure that they are operating properly, and the responsible user must file an inspection report with his/her Division Safety Coordinator.

Any modification to an existing hydrogen-furnace system requires a safety review by a member of the Mechanical Safety Subcommittee and the EH&S Department, and the modification must be shown in a corrected OSP prepared by the responsible user.

D. REFERENCES FOR SECTION IV

General guidelines for equipment can be found in the following documents.

1. Health and Safety Manual, PUB-3000, Chapter 13, Gases, Flammable and Compressed.

2. National Fire Protection Association, National Fire Codes, NFPA 50A, Hydrogen Systems, Gaseous, at Consumer Sites.

3. National Fire Protection Association, National Fire Code, NFPA 493-PT, Intrinsically Safe Process Control Equipment for Use in Hazardous Locations.

4. National Fire Protection Association Technical Committee Report OFPA No. 496, Purged Enclosures for Electrical Equipment.

5. "Protection of Laboratories and Buildings from Hydrogen Explosion," Hazards-Control Progress Report No. 26, UCRL 50007-66-2.

6. National Fire Protection Association, National Fire Code, NFPA 70, Electric Code, National.

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