PMTurkeyCOLPEm Resource

From: Comar, Manny
Sent: Thursday, November 01, 2012 5:05 PM
To: TurkeyCOL Resource
Subject: FW: Hydrogen--single vessel
Attachments: FPL H2 ornl.pdf

From: Franzone, Steve [mailto:Steve.Franzone@fpl.com]
Sent: Thursday, October 11, 2012 10:02 AM
To: Comar, Manny
Cc: Burski, Raymond
Subject: FW: Hydrogen--single vessel

Here is some information that our vendor had provided to us which may be useful for our discussion next week:

“I was able to locate the document referenced in the EPRI guide that referred to the basis for considering a single vessel failure for a tube trailer. For context, I have included the paragraph below from the EPRI standard (Section 2.4, page 8) that was being discussed during the NRC call:

2.4 Gaseous Hydrogen Safety Considerations

The Guidelines are based on the safety analysis of the failure of single vessels and do not address simultaneous failure of multiple storage vessels. In the case of the Los Alamos tube trailer, hydrogen explosion of a single tube did not damage the adjacent hydrogen vessels. This event provides a technical basis for assuming only single vessel failure (Investigation Report, June 3, 1981). At two reactor sites hydrogen explosions and fireballs during filling operations occurred over the storage tanks but did not damage the adjacent cylinders (Reportable Event No. 07953, March 5, 1987, NUREG/CR-3551, May 1985)

From NUREG/CR-3551 (page 24) below is a description of the Los Alamos incident—emphasis added:

-On June 3, 1981, at Los Alamos National Laboratory, an explosion occurred after a hydrogen tube trailer and an oxygen tube trailer had been simultaneously connected to the same manifold. Insufficient barriers (only one shutoff valve) and incorrect purging procedures led to the damaging of the shutoff valve and a subsequent flow of higher pressure oxygen into one tube of the hydrogen trailer. Ignition was probably caused by contamination (sand) traveling through a valve at high velocity. ***The resulting explosion ruptured one of the tubes****, propelled tube fragments as far as 1250 ft away from the trailer, created a fireball of short duration that caused first- and second-degree burns over about 30% of the bodies of two employees and a small area of third degree burns on one of them, caused major damage to the hydrogen tube trailer, and caused minor damage to a portion of the facility. The incident was caused by the inadvertent mixing of the hydrogen and oxygen due to insufficient technical and safety training of the personnel involved, lack of management control of the operation, lack of standard operating procedures for the task being attempted, and inadequate and poorly maintained equipment.* [23]

I have attached NUREG/CR-3551 for reference.

I have also found a standard from ANSI and NFPA along with a hydrogen safety manual from NASA that supports our conclusions.”

Steve Franzone
NNP Licensing Manager - COLA
"When you blame others, you give up your power to change." Dr. Robert Anthony
561.694.3209 (office)

754.204.5996 (cell)

“This transmission is intended to be delivered only to the named addressee(s) and may contain information that is confidential and /or legally privileged. If this information is received by anyone other than the named addressee(s), the recipient should immediately notify the sender by E-MAIL and by telephone (561.694.3209) and permanently delete the original and any copy, including printout of the information. In no event shall this material be read, used, copied, reproduced, stored or retained by anyone other than the named addressee(s), except with the express consent of the sender or the named addressee(s).

Hearing Identifier: TurkeyPoint_COL_Public
Email Number: 698

Mail Envelope Properties (377CB97DD54F0F4FAAC7E9FD88BCA6D0B1656EF958)

Subject: FW: Hydrogen--single vessel
Sent Date: 11/1/2012 5:04:35 PM
Received Date: 11/1/2012 5:04:41 PM
From: Comar, Manny

Created By: Manny.Comar@nrc.gov

Recipients:
"TurkeyCOL Resource" <TurkeyCOL.Resource@nrc.gov>
Tracking Status: None

Post Office: HQCLSTR01.nrc.gov

Files	**Size**	**Date & Time**
MESSAGE	3617	11/1/2012 5:04:41 PM
FPL H2 ornl.pdf	4415475	

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:
Recipients Received:

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

3 4456 0054015 4

NUREG/CR-3551
(ORNL/NOAC-214)

Safety Implications Associated With In-Plant Pressurized Gas Storage and Distribution Systems in Nuclear Power Plants

Prepared by R. H. Guymon, W. R. Casto, E. L. Compere

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory
Commission

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this
report, send in name with report and
the library will arrange a loan.
UCN-7969 (3 9-77)

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555

2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082,
   Washington, DC 20013-7982

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations,* and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-3551
ORNL/NOAC-214

Safety Implications Associated With In-Plant Pressurized Gas Storage and Distribution Systems in Nuclear Power Plants

Manuscript Completed: April 1985
Date Published: May 1985

Prepared by
R. H. Guymon, W. R. Casto, E. L. Compere

Nuclear Operations Analysis Center
Oak Ridge National Laboratory
Oak Ridge, TN 37831

Prepared for
Office for Analysis and Evaluation of Operational Data
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN A9132

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0054015 4

FOREWORD

The work reported here was undertaken by the Nuclear Operations Analysis Center (NOAC) at Oak Ridge National Laboratory on behalf of the Office for Analysis and Evaluation of Operational Data (AEOD) of the Nuclear Regulatory Commission (NRC). The technical monitor for the project was H. L. Ornstein of the AEOD Reactor Operations Analysis staff.

NOAC performs analysis tasks, as well as information gathering activities, for the NRC. NOAC's activities involve many aspects of nuclear power reactor operations and safety.

NOAC was established in 1981 to reflect the broadening and refocusing of the scope and activities of its predecessor, the Nuclear Safety Information Center. It conducts a number of tasks related to the analysis of nuclear power experience, including summaries of operation for U.S. power reactors, generic case studies, plant operating assessments, and risk assessments.

NOAC has designed and developed a number of major data bases that it operates and maintains for the NRC. These data bases collect diverse types of information on nuclear power reactors from the construction phase through routine and off-normal operation. These data bases make extensive use of reactor-operator-submitted reports, such as the Licensee Event Reports.

NOAC also publishes staff studies and bibliographies, disseminates monthly nuclear power plant operating event reports, and prepares the *Nuclear Safety Journal*. Direct all inquiries to Joel R. Buchanan, Director, Nuclear Operations Analysis Center, P.O. Box Y, Oak Ridge National Laboratory, Oak Ridge, TN 37831, Telephone 615-574-0303 (FTS: 624-0393).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The hazards associated with the use of compressed gases in nuclear plants are similar to those associated with the same gases used in industrial plants. However, in nuclear plants the concern is that gas hazards do not create secondary nuclear hazards. Ten gases commonly used in nuclear power plants were selected for study to determine the safety implications associated with their storage and handling. The gases were air, acetylene, carbon dioxide, chlorine, Halon, hydrogen, nitrogen, oxygen, propane, and sulfur hexafluoride. The study was limited to the potential hazards from the time the gases were brought into the plant until they entered into the process, with special attention to the potential for subsequent events leading to secondary plant hazards.

All compressed gases are hazardous because of their stored energy, which could be released in case of equipment failures. Many of the gases have other unique hazards as well. The descriptions of each gas and the tabulation of physical properties in Chap. 2 give indications of other possible hazards. Hydrogen, acetylene and propane are flammable, and releases could lead to explosions. All except air and oxygen are either toxic or can cause asphyxiation. Sulfur hexafluoride, Halon, and chlorine are considerably heavier than air, which increases the hazards of toxicity or asphyxiation due to layering.

Gases can be shipped or stored in the compressed, dissolved, or liquified state as cryogenic liquids. Shipping and storage containers are built to comply with detailed specifications of the U.S. Department of Transportation and the ASME Boiler and Pressure Vessel Code, particularly Section VIII on unfired pressure vessels. Other regulations as listed in the references cover all other aspects of design, fabrication, operation, and maintenance of gas systems.

From a review of the methods used for the general containment and handling of each of the gases, it was found that the shipping containers vary from small portable cylinders to large tank trailers or tank cars. Gases are sometimes used directly from the shipping container or may be transferred to permanent on-site storage.

Available literature indicates that adequate rules and regulations are available for safe handling of portable gas cylinders, but these regulations are difficult to control administratively. Thus cylinders are susceptible to being overturned, dropped, or hit by other equipment such as cranes and motorized vehicles. If rupture occurs, the energy released from a 200-scf cylinder of gas pressurized to 2200 psig would be equivalent to a stick of standard dynamite. If the gas were hydrogen and an explosion occurred, the energy released would be equivalent to four sticks of standard dynamite. Portable cylinders can also become missiles and can travel long distances, causing considerable damage. The larger the gas container (for a given gas and pressure), the greater the energy released from a rupture or explosion.

Sources of safety-related information were reviewed to determine what type of accidents have occurred in industry or at nuclear power plants that were related to handling pressurized gases. A number of incidents which had serious consequences are described.

From a brief review of the safety analysis reports of several nuclear plants, it was concluded that pressurized gas storage, transfer, and control systems were designed using industry codes and practices as well as Nuclear Regulatory Commission (NRC) requirements. Descriptions and typical flowsheets of these systems are included in the report. Visits made to three nuclear power plants indicated that, in general, safe practices were being followed.

Based on the reviews, studies, and plant visits, several areas of concern were identified. These are discussed in Chaps. 8 and 9; recommendations are given in Chap. 10.

Of particular concern is the use of portable cylinders because they are used throughout the nuclear industry and serious accidents involving the cylinders have occurred. These accidents could result in a gas cylinder becoming a missile and causing unacceptable damage to safety-related equipment. Recommendations are presented to prevent such occurrences.

Another concern is the possibility of a hydrogen explosion which could damage safety equipment. One of the three plants visited did not have an excess flow device in the hydrogen supply line to prevent emptying of an entire trailer of hydrogen into the auxiliary building. Changes in applicable NRC regulations are recommended.

It is recommended that NRC regulations be issued requiring identification of high-pressure gas lines to prevent mix-ups during emergencies as well as during routine operation or maintenance.

Other areas were identified that could cause safety incidents. In some cases, adherence to existing policies seemed adequate. In others, a review of existing design or practices is recommended.

SAFETY IMPLICATIONS ASSOCIATED WITH IN-PLANT PRESSURIZED GAS STORAGE AND DISTRIBUTION SYSTEMS IN NUCLEAR POWER PLANTS

R. H. Guymon
W. R. Casto   E. L. Compere

ABSTRACT

Storage and handling of compressed gases at nuclear power plants were studied to identify any potential safety hazards. Gases investigated were air, acetylene, carbon dioxide, chlorine, Halon, hydrogen, nitrogen, oxygen, propane, and sulfur hexafluoride. Physical properties of the gases were reviewed as were applicable industrial codes and standards. Incidents involving pressurized gases in general industry and in the nuclear industry were studied. In this report general hazards such as missiles from ruptures, rocketing of cylinders, pipe whipping, asphyxiation, and toxicity are discussed. Even though some serious injuries and deaths over the years have occurred in industries handling and using pressurized gases, the industrial codes, standards, practices, and procedures are very comprehensive. The most important step one can take to ensure the safe handling of gases is to enforce these well-known and established methods. The following recommendations are made for further improving the safe handling of pressurized gases.

1. Provide protection to prevent damage to safety-related equipment from gas cylinder missiles.
2. Provide protection to prevent explosions from rapid releases of hydrogen in areas containing safety-related equipment.
3. Provide easily recognizable identification of lines and tanks containing hazardous gases.

1. INTRODUCTION

Many compressed gases are employed in a typical nuclear power plant. All compressed gases are potentially hazardous because of the stored energy in the compressed fluid. In addition many of the gases have other hazard potentials: fire, explosion, toxicity, and asphyxiation are the more common. None of these hazards are unique to nuclear power plants, and all have been addressed by codes and standards, the application of which is reviewed as part of the licensing process. Nuclear plants have broadly based safety programs, and personnel are well trained. Information relevant to the safety of handling pressurized gases is given in the operating procedures, safety manuals, and emergency planning documents for each plant. These documents are implemented by operator training, safety meetings, and emergency drills. However, no systematic review of hazard potentials of gases as applied to nuclear power plants had been undertaken. Accordingly, the Nuclear Regulatory Commission (NRC) Office for Analysis and Evaluation of Operational Data funded this study which was undertaken by the Nuclear Operations Analysis Center at Oak Ridge National Laboratory.

The intent of the study was to review the type, location, and potential failure modes associated with pressurized gas systems to identify and characterize potential concerns that might pose unrecognized safety problems should one of these failures occur in a nuclear power plant. *This study does not involve plant conditions or operations under accident conditions nor does it include evaluations of failures or performance of plant systems that use pressurized gas in performing their functions.* It does assess the potential for failures of pressurized gas systems to induce other failures in a nuclear plant. Specifically, objectives of the study were

1. to obtain data on past failures and hazards experienced in nuclear and fossil power plants and in other industrial activities that resulted from the on-site transportation, handling, storage, and distribution of pressurized gas;
2. to evaluate the adequacy of typical nuclear plant designs, procedures, and practices regarding the transportation, handling, storage, piping, monitoring, and inspection of pressurized gas systems in light of real and potential failure modes; and
3. to recommend improvements that would reduce the hazards to nuclear plant personnel and equipment associated with pressurized gas systems.

Ten gases used at nuclear power installations were selected: air, acetylene, carbon dioxide, chlorine, Halon, hydrogen, nitrogen, oxygen, propane, and sulfur hexafluoride.

Compressed air is used extensively for instrumentation, pneumatic valve operation, and leak detection. It is also used in self-contained breathing apparatuses where particular purity specifications are necessary. Special cylinders are normally used. These are often refilled using small on-site dedicated air compressors. Acetylene is used in nuclear plants in metal cutting and welding equipment. Carbon dioxide and Halon 1301 are used in fire extinguishers because they are nonflammable and heavier than air. Carbon dioxide is also used in power plants to purge hydrogen from generators and other equipment because it does not react with hydrogen. Chlorine is used in power stations as an additive to raw water to kill organisms in the water and thus inhibit fouling of heat transfer surfaces. However, because of the hazards involved in handling chlorine, many plants now use sodium hypochlorite. Hydrogen is used in large electrical generators to reduce windage losses and as a heat transfer agent. In some plants it is also used as a cover gas for the volume control tank to reduce corrosion in the primary water system. Because it is inert and relatively inexpensive, nitrogen is used in pressurized-water-reactor (PWR) pressurizers and accumulators and for filling boiling-water-reactor (BWR) containments, charging control rod accumulators, and purging equipment to establish an inert atmosphere. It is also used as a backup for instrument air for some critical applications. The main use for oxygen in nuclear plants is in oxy-acetylene welding and cutting equipment; however, it is also used in hydrogen recombiners. Propane is occasionally used in nuclear plants as an auxiliary boiler fuel and as a fuel for forklifts and other vehicles. Because of its high dielectric strength, sulfur hexafluoride is used as an insulating atmosphere in electrical equipment such as switchyard circuit breakers.

Argon and helium are also used at nuclear plants mainly for welding and purging. However, these two gases are not specifically addressed in this report because they are inert gases and have a safety significance similar to that of nitrogen (i.e., stored energy at high pressure and a potential asphyxiant if released). Freon gases are also used in air conditioners but are not included because of their similarity to the Halons. Note also that propane was selected as being representative of all liquified petroleum gases (primarily propane and butane).

In this study the physical properties of the gases and their associated industrial codes and practices were first reviewed; then the general hazards of handling gases with respect to safety at a nuclear power plant were evaluated. Consideration was given to the various failure modes that can be encountered in handling pressurized gases, such as ruptures, explosions, missiles, pipe whip, asphyxiation, and toxicity. So that the general failure modes could be better understood, a study was made of incidents involving pressurized gases in industry as well as at nuclear power plants.

Several nuclear installations were examined for possible deficiencies of selected systems. For example, attention was directed to the various types of pressurized stored gas systems to evaluate such items as the on-site transportation routes, the location and type of storage, location and type of distribution and handling, ventilation capability with and without normal power, and available monitoring and warning systems. Three nuclear power plants were then visited so that specific systems could be traced and plant design observed first hand. During the visits the installations were considered with the standard codes and practices, history of incidents, and nuclear plant designs in mind. The results of these evaluations can be found in Chaps. 9 and 10.

2. PHYSICAL PROPERTIES AND HAZARDS OF THE GASES

Selected physical properties of the ten gases included in this study are tabulated in Table 1, including chemical formula, molecular weight, boiling point, density, vapor pressure, ratio of specific heat, and heat of vaporization. Where applicable their combustion and detonation limits as well as their auto ignition temperature and net heat of combustion are listed. Reference 1 provided a basis for the information in the table and for the following sections, which give a brief description of each gas along with some specific hazards associated with the use of each. None of the selected gases are very corrosive if they are kept dry. However, a corrosive atmosphere could be created if a release occurs and moisture is present.

2.1 Compressed Air

Compressed air is about 78% nitrogen and 21% oxygen. It is, of course, nontoxic and nonflammable, and dry air is noncorrosive. The main hazards are those associated with elevated pressure. Compressed air can accelerate burning of combustible material, which elevates temperatures.

2.2 Acetylene

Acetylene is a colorless gas that is somewhat lighter than air. The garlic-like odor of commercial acetylene provides warning of its presence. It has a very wide range of flammability and detonation and a low ignition temperature. It produces a high-temperature flame and will decompose and explode at pressures greater than about 15 psig. Unstable, exothermic solid compounds are formed with silver or copper. It is not toxic but does act as an asphyxiator. Fortunately, because the gas density is close to that of air, it mixes well with air and does not concentrate in isolated cavities such as casements and tanks.

2.3 Carbon Dioxide

Carbon dioxide is a colorless, odorless gas that is relatively nonreactive and nontoxic. About 1.5 times heavier than air, it tends to accumulate in lower elevations and can cause asphyxiation.

2.4 Chlorine

Chlorine is a greenish yellow gas with a distinctive, pungent odor that painfully attacks nasal and lung tissues (see Sect. 4.7.1). The acceptable breathing concentrations established by the American National

Table 1. Physical properties of selected gases

Name	Chemical formula	Molecular weight	Boiling point (°F)	Liquid density (lb/ft^3)		Vapor pressure (psia)		Gas density at 1 atm and 70°F (lb/ft^3)	Ratio of specific heat[a]	Heat of vaporization (Btu/lb)	Combustion limits in air (%)	Detonation limits in air (%)	Auto ignition temperature (°F)	Net heat of combustion (Btu/lb)
				At boiling point	At 70°F	At 70°F	At 130°F							
Air[b]	$N_2 + O_2$	29.0	−318	54.9	[c]	[c]	[c]	0.0750	1.40	88.2				
Acetylene	C_2H_2	26.0	−103	38.6	24.0	650	[c]	0.0730	1.26	[c]	2.8–80	4.2–50	581	18,410
Carbon dioxide	CO_2	44.0	−109[d]	94.4	47.6	853	940	0.1140	1.30	100.8				
Chlorine	Cl_2	70.9	−30	[c]	87.7	85	214	0.2000	1.36	123.7				
Halon 1301[e]	$CBrF_3$	148.9	−72	[c]	97.8	214	449	0.3970	1.14	51.1				
Hydrogen	H_2	2.0	−423	4.4	[c]	[c]	[c]	0.0050	1.41	192.7	4–75	18–59	1085	51,500
Nitrogen	N_2	28.0	−320	50.5	[c]	[c]	[c]	0.0720	1.40	85.6				
Oxygen	O_2	32.0	−297	71.3	[c]	[c]	[c]	0.0828	1.40	91.7				
Propane	C_3H_8	44.1	−44	31.2	[c]	109.7	258.4	0.1160	1.13	183.1	2.2–9.5	[c]	920–1120	18,810
Sulfur hexafluoride	SF_6	146.1	−82.8[d]	[c]	86.1	325	765	0.4000	1.28	37.3				

[a] Ratio of specific heat at constant pressure per specific heat at constant volume.

[b] Approximately 78% nitrogen and 21% oxygen.

[c] Not found in abbreviated literature search.

[d] Sublimation point.

[e] Bromotrifluoromethane.

Standards Institute[2] are an 8-h time-weighted average concentration of 1 ppm, a ceiling concentration of 2 ppm, and an acceptable maximum for peaks above the acceptable ceiling concentration of 3 ppm for periods of 5 min. It is heavier than air and can accumulate at lower elevations. Its penetrating odor at low concentrations warns of its presence. Although nonflammable, its reactions are similiar to those of oxygen. Many organic chemicals react with it, in some cases with explosive violence.

2.5 Halon 1301 (Bromotrifluoromethane)

Halon 1301 is a stable nonflammable gas that is odorless at concentrations less than 20% in air. At higher concentrations it has a slight ether-like odor. It is relatively nontoxic (see Sect. 4.7.2) but is an asphyxiator. Because it is much heavier than air, it can accumulate in lower elevations, increasing the hazard of asphyxiation. However, this high density enhances its value for fire extinguishing — its main use in nuclear power plants. Its low boiling point can cause severe frostbite if contact is made with the liquid.

2.6 Hydrogen

Hydrogen is a colorless, odorless, tasteless, flammable, nontoxic gas about seven-hundredths as heavy as air. It diffuses rapidly through porous materials and through some metals at red heat, and it may leak out of systems that are leak tight to air. When it burns, the flame is pale blue and almost invisible. Because of the danger of explosive reignition, hydrogen fires should not be extinguished until the supply of hydrogen has been shut off.[3]

2.7 Nitrogen

Nitrogen makes up the major portion of the atmosphere. It is colorless, tasteless, nontoxic, nonflammable, and an almost totally inert gas. It has no odor to warn of possible asphyxiation.

2.8 Oxygen

Oxygen is a colorless, odorless, tasteless gas. Most chemical elements except the inert gases combine directly with oxygen. Some, such as phosphorus and magnesium, ignite spontaneously at ambient temperatures. Fire hazards are usually increased in oxygen-enriched atmospheres. The degree of hazard varies with the concentration of oxygen present, the concentration of any nonflammable gas present, and the total pressure.[4] Precautions should be taken to ensure that no oil or grease is present in oxygen distribution systems because organics burn with nearly explosive violence in oxygen. The inhalation of gaseous oxygen has a tonic effect on the human system rather than any toxic effect. Exposures to oxygen at higher pressures for prolonged periods have been found to adversely affect neuromuscular coordination and attentive powers.

2.9 Propane

Propane and other liquid petroleum gases are flammable, detonable, colorless, odorless, nontoxic, noncorrosive, chemically stable gases. However, the U.S. Department of Transportation (DOT) requires an odorant (mercaptan) be added to them so that leaks can be detected. Liquid petroleum gases are soluble in water. Prolonged inhalation of high concentrations has an anesthetic effect; also, due to the ability of these gases to displace oxygen in air, they can act as simple asphyxiants.

2.10 Sulfur Hexafluoride

Sulfur hexafluoride is a colorless, odorless, nontoxic, nonflammable, relatively inert gas. It is completely stable in the presence of most materials at temperatures up to 400°F. At atmospheric pressures it sublimes directly from the solid to the gas phase and does not have a stable liquid phase unless under a pressure of >15 psig. Because it is much heavier than air, leaks tend to accumulate in lower elevations and present an asphyxiation hazard. Its high dielectric strength makes it particularly suitable as an insulating atmosphere in electrical equipment such as switchyard circuit breakers.

3. GENERAL CONTAINMENT AND HANDLING OF GASES

Gases may be shipped and/or stored as compressed gases, dissolved gases, liquified gases, or cryogenic fluids. Shipping and storage containers are built to comply with detailed DOT specifications[5] and the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (particularly Sect. VIII on unfired pressure vessels).[6] New containers are inspected and tested by the manufacturer to ensure that they meet the intended requirements. Periodic tests and inspections are generally undertaken by the owner to ensure continued safe performance. The DOT periodically examines test equipment to ensure proper operability. Information on shipping containers used in nuclear reactor facilities and possible on-site storage and distribution systems for the ten selected gases is given in Table 2. Table 3 provides notes on applicable design specifications that are referenced in Table 2.

Almost all compressed gas containers are fitted with devices that allow gas to escape should surrounding conditions (primarily heat) cause the enclosed gas to overpressurize its container. The standards developed by the Compressed Gas Association, Inc.,[1] for pressure-relief devices for gas cylinders are given in Table 4, and a key to the symbols used in Table 4 are found in Table 5. The same general criteria as used to determine what relief devices are needed on tank trucks, tank trailers, tank cars, and in-plant storage tanks. However, because the size and configuration of these tanks may vary considerably, it is usually necessary to design each relief system separately. Design information on such systems is given in Refs. 1, 6, and 7.

Cylinders and other containers may be authorized for use with a number of different gases. However, the Compressed Gas Association has standardized cylinder valves used for different families of gases to prevent interchange of regulators and/or connecting equipment between gases that are not compatible.[1]

Some gases such as hydrogen and nitrogen, which were formerly shipped only in nonliquified high-pressure form, are increasingly shipped and stored as cryogenic fluids. Cryogenic storage systems often include vaporizing units for converting the very cold fluid to gas. In most cases the compressed gases are used directly from the shipping container. However, liquified or cryogenic gases are often transferred to an on-site storage tank. This is usually done by increasing the temperature in the shipping container, which increases the pressure due to vaporization, thus forcing the liquid through the pipe to the storage tank.

Visits to several nuclear plants, along with information from Ref. 1, provided much of the basis for the following discussion of each of the ten gases.

3.1 Compressed Air

Compressed air used in nuclear plants is usually produced by several on-site compressors with a combined capacity of around 3000 scfm.

Table 2. General handling methods for specific gases[a]

Gas	Shipping container			On-site storage and distribution systems		
	Description	Example		Description	Example	
		Size	Pressure (psig)		Size	Pressure (psig)
Air	On-site air compressors and receivers[1]	720 scfm	110	Distributed through carbon steel piping	2,200 scf	110
	Compressed gas cylinders[2]	200 scf	2,000	Transport cylinders to site of use		
Acetylene	Packed gas cylinders[3]	300 scf	250	Transport cylinders to site of use		
Carbon dioxide	Liquified gas tank trucks[4]	3–60 tons	830	Transfer to a storage tank	6–24 tons	360
	Liquified gas cylinders[5]	440 scf	830	Transport cylinders to site of use		
Chlorine	Liquified gas tank cars[6]	1 ton	85	Generally used from shipping containers		
	Liquified gas tank trailers[7]	30 tons	85	Generally used from shipping containers		
Halon 1301	Liquified gas cylinders[8]	250 scf	350	Transport cylinders to site of use		
Hydrogen	Cryogenic tank trailer	290,000 scf	230	Generally used from shipping containers		
	Compressed gas tube trailers[9]	35,000 scf	2,400	Generally used from shipping containers[10]		
Nitrogen	Cryogenic tank trucks	4,000 gal	25	Transfer to on-site cryogenic tanks		
	Compressed gas tube trailers[9]	35,000 scf	2,800	Generally used from shipping containers		
	Compressed gas cylinders[11]	225 scf	2,000	Transport cylinders to site of use		
Oxygen	Compressed gas cylinders[12]	245 scf	2,000	Transport cylinders to site of use		
Propane	Liquified gas tank trucks[13]	500 gal	15	Transfer to on-site storage tanks[1,14,15]	500 gal	15
	Liquified gas cylinders[16]	850 scf	110	Cylinders used for operating vehicles		
Sulfur hexafluoride	Liquified gas cylinders[17]	250 scf	320	Transport cylinders to site of use		

[a] Applicable design specifications are listed by number in Table 3.

Table 3. Notes for Table 2

1. ASME Boiler and Pressure Vessel Code, Sect. VIII.
2. DOT Specification 3A, 3AA, 3AX, 3AAX, 3B, 3C, 3D, 3E, 4, 4A, 4B, 4BA, 4BW, or 4C (continued use of DOT Specification 3, 25, 26, 33, or 38 is authorized).
3. DOT Specification 8 or 8AL.
4. DOT Specification MC-330 or MC-331 or requirements in Low Temperature Operation of ASME Boiler and Pressure Vessel Code, Sect. VIII, Unfired Pressure Vessels.
5. DOT Specification 3A 1800, 3HT 2000, 3AA 1800, 3E 1800, 3T 1800, 3AX 1800, 3AAX 1800, or 39.
6. DOT Specification 106A 500X, 106A 500, 27, BE 27, 105A 300W, 104A 300, 105A 500, or 105.
7. DOT Specification 106A 500X, 106A 500, 27, BE 27, MC 331, or MC 330.
8. DOT Specification 4DA 500, 3HT 900, 4DS 500, 3E 1800, 3A, 3AA, 4B, 4BA, 4BW, 4D, or 39.
9. DOT Specification 3A, 3AA, 3AX, or 3AAX.
10. Standards for gaseous hydrogen systems at consumer sites (Pamphlet 50-A), National Fire Protection Association.
11. DOT Specification 3A or 3AA is generally used; however, any cylinder approved for nonliquified compressed gas may be used.
12. Standard for the Design and Installation of Oxygen—Fuel Gas Systems for Welding and Cutting, NFPA 51, National Fire Protection Association.
13. DOT Specification MC-330 or MC-331.
14. Standard for the Storage and Handling of Liquified Petroleum Gases (Pamphlet No. 58), National Fire Protection Association (this is also American Standard Z106.1).
15. Standard for the Storage and Handling of Liquified Petroleum Gases at Utility Gas Plants (Pamphlet No. 59), National Fire Protection Association.
16. DOT Specification 3A 3AA, 3B, 3F, 4A, 4B, 4BA, 4B 240ET, 4B 240FLW, 4BW, 4F, 4, 9, or 41 (continued use of DOT-3, 4B 240X, 25, 26, or 38 is authorized).
17. DOT Specification 3A 1000, 3AA 1000, or 3E 1800 (continued use of DOT-3 is authorized).

Table 4. Approved relief devices for gas cylinders[a]

Gas	Form	Type of device[b]					
		CG-1	CG-2	CG-3	CG-4	CG-5	CG-7
Air	Compressed gas	A		G,B	B		G
Acetylene	Dissolved gas			C			
Carbon dioxide	Liquified gas	A					G
Chlorine	Liquified gas		E				
Halon 1301	Liquified gas	A					A
Hydrogen	Compressed gas	I			F	F	G
Nitrogen	Compressed gas	A		G,B	B		G
	Cryogenic liquid	D					
Oxygen	Compressed gas	A			B		G
Propane	Liquified gas			H			A
Sulfur hexafluoride	Liquified gas	A				B	A

[a] See Table 5 for key to symbols.

[b] CG-1: rupture disk; CG-2: fusible plug that uses a fusible alloy with yield temperature from 157–170°F, with 165°F nominal; CG-3: fusible plug that uses a fusible alloy with yield temperature from 208–220°F, with 212°F nominal; CG-4: combination rupture disk/fusible plug that uses a fusible alloy with yield temperature from 157–170°F, with 165°F nominal; CG-5: combination rupture disk/fusible plug that uses a fusible alloy with yield temperature from 208–220°F, with 212°F nominal; CG-7: pressure-relief valve.

Source: Adapted with permission from Compressed Gas Association, Inc., *Handbook of Compressed Gases*, 2d ed., Van Nostrand Reinhold Company, New York, 1981, Table 3, pp. 78–82.

Table 5. Key to symbols used in Table 4

A. Device is required in only one end of the cylinder regardless of length.

B. Device is required at both ends of cylinders over 65 in. long, exclusive of neck; for shorter cylinders, device is required in one end only.

C. Number and location of pressure-relief devices for cylinders of any particular size shall be proved adequate as a result of the fire test, and any change in style of cylinder, filler, or quantity of devices can only be approved if found adequate upon reapplication of the fire test. Fire testing shall be conducted in accordance with Compressed Gas Association Pamphlet C-12, Qualification Procedure for Acetylene Cylinder Design.

D. Device is required in one end of the cylinder only, regardless of length. A pressure-controlling valve as required in DOT Regulation 173.304 (b) note 2 of *DOT Regulation* must also be used. This valve must be sized and set so that cylinder pressure is limited to 1.25 times its marked service pressure less 15 psi if vacuum insulation is used. Insulation jacket shall be provided with a pressure-actuated device that will function at a pressure of not more than 25 psig and provide a discharge area of 0.00012 sq. in. per pound of cylinder water capacity. An alternate pressure-relief valve, with a marked set pressure not to exceed 150% of the DOT Service Pressure, may be used in lieu of the rupture disk device if flow capacity required by Sect. 5.9 of Ref. 1 is provided at 120% of marked set pressure. Installation must provide for (1) prevention of moisture accumulation at the seat by drainage away from that area, (2) periodic drainage of the vent piping, and (3) avoidance of foreign material in the vent piping.

E. When cylinders are over 55 in. long, exclusive of neck, this device is required in both ends, except for cylinders purchased after October 1, 1944, which must contain no aperture other than that provided in the neck of the cylinder for attachment of a valve equipped with an approved pressure-relief device. [Chlorine cylinders do not generally exceed 55 in. in length, because DOT Regulation 173.304 (a) note 2 requires that cylinders purchased after November 1, 1935, must not contain over 150 lb of chlorine.]

F. Device is required in only one end of cylinders having a length not exceeding 65 in., exclusive of neck. For cylinders over 65 in. long, device is required in both ends, and each device shall be arranged to discharge upward and unobstructed to the open air so that any impingement of escaping gas on the containers is prevented.

G. Device can be used up to 500-psig charging pressure.

H. Device may be used in addition to CG-7.

I. Device is for use only on cylinders over 65 in. long. It is required on both ends and shall be arranged to discharge upward and unobstructed to the open air so that any impingement of escaping gas on the containers is prevented.

Source: Adapted with permission from Compressed Gas Association, Inc., *Handbook of Compressed Gases*, 2d ed., Van Nostrand Reinhold Company, New York, 1981, Table 3, pp. 82–83.

These generally operate continuously and are provided with capacity control devices to match supply to demand; however, large receiver tanks holding 2000 scf or more are provided for each compressor to dampen pressure oscillations and to provide time for the redundant air compressors to start when necessary. Carbon steel and copper piping is used for distribution to the point of use. Small backpack cylinders or manifolds of standard 200-scf cylinders are provided as needed for emergency breathing air.

3.2 Acetylene

Gaseous acetylene under pressure above 15 psig may decompose with explosive force under certain conditions. Therefore, special cylinders are required which have a porous-mass packing material with minute cellular spaces so that no pockets of appreciable size remain where "free" acetylene in gaseous form can collect. This porous mass is saturated with acetone or other suitable solvent in which the acetylene dissolves. This technique allows for safe pressurization of the acetylene cylinders up to 250 psig. Normal cylinder capacity is 300 scf of acetylene. The maximum output setting of the pressure regulator at the cylinder is 15 psig. Because of this 15-psig limit on gaseous acetylene, it is usually necessary that the acetylene tanks be taken to the work site. When such containers are transported to and used at work sites of limited space (such as cutting and welding in primary containment), careful exact adherence to the established safety regulations must be enforced. In some welding shops a distribution manifold is used. Only steel or wrought iron pipe should be used for acetylene systems. Joints in piping must be welded or made up of threaded or flanged fittings. Leaks are indicated by the garlic-like odor characteristic of the gas.

3.3 Carbon Dioxide

Carbon dioxide systems are in standby condition most of the time. The carbon dioxide must be available for release in case of a fire, and it also must be available to purge the hydrogen from the generator and other equipment prior to maintenance. Therefore, it is generally purchased as a liquified gas in insulated tank trucks holding up to 60 tons and transferred to on-site insulated storage tanks. Refrigeration compressors are used as necessary to maintain the temperature around 0°F. Recommended in-plant distribution system piping is Schedule 80 threaded steel pipe with forged steel fittings or seamless Schedule 40 steel pipe with welded joints. Alternate recommendations include stainless steel, copper or brass pipe, and stainless or copper tubing. In some cases, liquified gas cylinders (440 scf) may be moved to the equipment where the gas is to be used.

3.4 Chlorine

Chlorine is shipped as a liquified gas by tank cars and tank trailers containing up to 30 tons of chlorine. To avoid the hazards of transferring it to a permanent storage tank, it may be fed directly from the shipping containers to the raw water treatment system. Carbon steel is a very satisfactory material for containing dry chlorine at temperatures below 300°F, as are iron, copper, nickel, and lead. Nickel and nickel alloys are used at temperatures up to 1000°F. Small amounts of moisture mixed with chlorine forms hypochlorous and hydrochloric acids, which are very corrosive to most metals. Ammonium hydroxide is commonly used in industry to locate small leaks in containers of chlorine; ammonium hydroxide and chlorine react to form an ammonium chloride cloud.

3.5 Halon 1301 (Bromotrifluoromethane)

Halon 1301 is shipped as a liquefied compressed gas in 250-scf cylinders. Its vapor pressure decreases from 199 psig at 70°F to 56 psig at 0°F. To flatten the pressure vs temperature curve and to provide higher average discharge pressure, the cylinders are overpressurized to 350 psig with nitrogen. Halon is used as a fire extinguishing gas and is generally used directly from the shipping cylinders. Schedule 40 pipe with screwed connections may be used in the distribution systems; however, welded joints are preferable. Copper piping (preferably type K) with silver solder fittings may also be used.[1] Leaks are indicated by the formation of frost on the pipe exterior. Usually the shutoff valve is located at the cylinder and is automatically opened in case of fire.

3.6 Hydrogen

Hydrogen is generally used directly from 35,000-scf compressed gas tube trailers or from large (~290,000-scf) cryogenic tank trailers in which the gas is shipped to the plant. Hydrogen is noncorrosive and can be contained at room temperatures by most common metals. It is used in electrical generators to reduce windage losses and as a heat transfer agent. In some plants it is used as a cover gas in the volume control tank to reduce corrosion in the primary water system.

Because of its ability to leak through very small openings (or through metal at elevated temperature), careful design and fabrication of distribution systems are required. In some plants, high-flow shutoff valves are provided to minimize the amount of hydrogen released in case of a ruptured line. Electronic instruments are manufactured and sometimes used in industry for leak detection. Detection of leaks is a continuing problem in electrical generating stations, both nuclear and fossile.

3.7 Nitrogen

Depending on which is the most economical for the intended use at the particular reactor, nitrogen may be purchased as a cryogenic liquified gas or compressed gas. The liquified gas is usually transferred from the cryogenic tank truck to on-site insulated cryogenic tanks. It is used for purging equipment, for pressurizing BWR control rod drive accumulators, and in certain BWR plants for inerting containment. The compressed gas is often used directly from 225-scf compressed gas cylinders or 35,000-scf compressed gas tube trailers for the PWR pressurizers and core flooding accumulators. In some PWRs that have upper head injection systems, nitrogen is also used to pressurize these accumulators.

Because nitrogen is noncorrosive, distribution systems can be fabricated of most common metals. Because it is nontoxic and inexpensive, small leaks are relatively unimportant.

3.8 Oxygen

Oxygen is mainly used in cutting and welding operations on site. The 245-scf commonly used shipping cylinders are transferred to the site of use, and the cutting and welding hoses are connected directly to the pressure regulator on the cylinder. Occasionally steel or wrought iron pipe manifolds are used with a permanent distribution system in welding shops. In this case, care must be used to exclude oil and grease which can react violently with oxygen. It is sometimes used in recombiners to reduce the hydrogen concentration in gaseous effluents.

3.9 Propane

When propane or any other liquid petroleum gas is used for such purposes as firing auxiliary boilers or replacing gasoline for forklifts, it is received at the plant in the form of liquified gas in various sized tank trucks and is transferred to variously sized on-site storage tanks. Because it is noncorrosive, any common commercially available metals may be used for distribution systems. Leaks are indicated by odor or by the formation of frost on the exterior of the piping.

3.10 Sulfur Hexafluoride

Sulfur hexafluoride in the liquified gas form is used in electrical circuit breakers directly from the 250-scf shipping containers. It is noncorrosive to all metals, and most common gasket materials including asbestos, neoprene, and natural rubber may be used. Standard fluorocarbon detecting devices are available for locating leaks.

4. FAILURE MODES IN THE UTILIZATION OF GASES

Gases at high pressure have considerable stored energy which if suddenly released can cause extensive damage. If the gas is flammable, it can be ignited, possibly leading to a fire or explosion. Toxicity and asphyxiation can occur when some gases are improperly handled. Failure modes and possible hazards are discussed in the following sections.

4.1 Portable Cylinder Failures

Of the different methods employed to contain and handle gases, probably the most difficult to administratively control is the use of portable cylinders. These cylinders are stored in racks and are required to be chained or otherwise restrained. If the cylinders are not properly restrained, they may fall and become damaged. Although caps are provided for protecting the valves on the ends of the cylinders, these are sometimes left off and, of course, must be removed during use. The cylinders are usually transported from the storage racks to the point of use with two-wheel dollies. In some cases, such as welding and cutting, cylinders are left on the dolly during use.

These methods of handling make the cylinders susceptible to being overturned, dropped, or struck by other equipment such as cranes and motorized vehicles, which can damage the cylinders or create missiles (see Sect. 4.4). Compressed gases can escape from a puncture with sonic velocity. Bodily contact with such jets can cause gas to be injected into the flesh, with serious consequences. The National Safety Council reports, "Improper use of compressed air hoses and horseplay have caused severe injuries to the internal organs and eardrums."[8] The rubber distribution hoses used in welding and cutting can easily be severed, releasing oxygen and/or acetylene, which could cause explosions or asphyxiation.

Mixing of gases is undesirable and can cause considerable hazards (e.g., hydrogen and oxygen). Since cylinders are periodically replaced, it is possible to install one containing the wrong type gas. Cylinder valves have been standardized by the Compressed Gas Association[1] for different families of gases so that interchange between incompatible gases can be prevented. However, adapters are sometimes used, which defeats the purpose of standardizing the cylinder valves.

Air cylinders used for self-contained breathing apparatuses are sometimes pressurized to 4500 psig and may contain up to 87 scf of air. If these cylinders are dropped or impacted during use, they could become missiles; however, they are designed to minimize the chance of this occurring. The pressure gage is flush mounted, and a unique rubber guard protects it from damage if the cylinder is accidentally dropped.

4.2 Vessel Ruptures

The concern here is with the failure of equipment due to the increase in pressure beyond the strength of the equipment. Overpressure can occur from human errors, failure of pressure controls in the supply, failure of overpressure protection devices (see Sect. 3), or temperature increases such as those encountered during fires. When overheated, containers will also lose strength because of elevated metal temperatures, and they may rupture before the overpressure protection devices actuate. Temperature increases can cause tremendous stresses in liquified gas containers if they are full (or nearly full) or in isolated sections of the distribution system.

The energy released from ruptured gas containers by the reversible adiabatic expansion of a compressed gas is given by

$$U = \frac{P_1V_1}{k - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{k-1/k}\right] ,$$

where U is the energy released in ft•lb, P_1 and V_1 are respectively the original absolute pressure in lb/ft^2 and volume in ft^3, P_2 is the final absolute pressure in lb/ft^2, and k is the ratio of specific heats (ratio of the heat capacity at constant pressure to the heat capacity at constant volume).[9]

The energy corresponding to a diatomic gas ($k = 1.4$) compressed to 2000 psig in a 1.76-ft^3 cylinder is 9.7×10^5 ft•lb [the equivalent of 0.67 lb of TNT, or one stick of standard dynamite (1.25 in., 60% nitroglycerin)]. This can propel a 150-lb cylinder at a velocity of 640 ft/s.

4.3 Explosions

Explosions can occur following leaks of flammable gases or ruptures of their containers. The magnitude of the explosion depends mainly on the gas itself, the amount of gas released, and the concentration accumulated prior to ignition. Explosions can also occur when an igniter fails to function, as in gas-fired boilers. If the volume of a gas-air mixture actually involved in an explosion is known, good estimates of the maximum amount of available energy can be made. However, the destructiveness of the explosion depends on the time of the energy release, type of confinement, and other factors.

McCarty, Hord, and Roder have made some estimates of explosive yields of hydrogen.[10] The maximum available energy for hydrogen determined by computing the isothermal decrease in the Helmholtz free-energy function is 3.7×10^7 ft•lb/lb. Based on the high heat of combustion, it is 4.8×10^7 ft•lb/lb. Experimental data and computations indicate that 10% explosive yield factors are reasonable for hydrogen-air explosions. Thus, possible yields of approximately 3.7×10^6 to 4.8×10^6 ft•lb/lb could be expected. Based on this, the explosion resulting from the leakage of a 200-ft^3 (1-lb) cylinder of hydrogen would be equivalent to about four sticks of standard dynamite.

Based on the heat of combustion of acetylene, a 300-ft^3 (22-lb) cylinder of acetylene has about ten times the maximum available energy as a 200-scf (1-lb) cylinder of hydrogen. Even though the acetylene yield factor, rate of combustion, and other factors may be quite different from those of hydrogen, leakage and subsequent explosion of a cylinder of acetylene could cause considerable damage.

Instances where flammable liquified gas containers fail and break into two or more pieces are common enough to be considered separately. These are called boiling liquid—expanding vapor explosions (BLEVEs).[11] Most BLEVEs have been caused by container failures resulting from fire exposure. A few BLEVEs have occurred from corrosion or impact-type container failures. When the break occurs, the pressure is reduced to atmospheric pressure. Part of the liquid is vaporized very rapidly, and the heat of vaporization cools the remaining liquid. The large expansion due to vaporization can create missiles from pieces of the container. The explosion rapidly mixes the vapor in air and when ignited results in a fireball. The remaining cold liquid may be atomized and ignite as it flies through the air. The size of a BLEVE depends basically on how much liquid vaporizes when the container fails and what the container pieces weigh. This is analogous in many respects to the performance of rockets as far as propulsion of container parts is concerned. Most liquefied gas BLEVEs occur when containers are from slightly less than one-half to about three-fourths full of liquid. The ratio of liquid vaporization expansion energy to container piece weight is such that pieces are propelled for distances up to ~0.5 mile. Fireballs several hundred feet in diameter are not uncommon, and deaths from burns have occurred to persons as much as 250 ft from larger containers (e.g., 30,000-gal liquid propane gas tank car).

4.4 Missiles

Missiles can be generated from the energy released from ruptured containers and/or explosions. Some calculations of missiles are given in Refs. 12 and 13; examples of incidents are given in Chap. 5. The most common cause of missiles is unrestrained portable cylinders from which the valve assembly has been broken off,[7] frequently caused by a fall with the valve cover not in place. Missiles can also be produced when instruments fail. The weakest parts of a compressed gas system are usually its gages. Bourdon tubes on pressure gages often fail, usually due to fatigue caused by constant pulsing of the pressure. To prevent injury of personnel, high-pressure gages should have full-sized blowout backs with either multi-ply plastic or double-laminated safety-glass-gage face covers.

4.5 Pipe Whip

Pipe whip is a hazard related to inadequate fastening of pressurized gas lines — either flexible or rigid. The force of fluid escaping from a broken pipe can cause the pipe section to move, but the elastic stiffness of the pipe tends to return it to its original position. Additionally, long unsecured runs of piping can create a plastic hinge at some distance from the break. In either case, pipe whipping at high pressure can cause extensive damage to equipment and/or injuries to personnel. Generally gas distribution systems are operated at low pressure (i.e., <200 psig) to avoid this problem; some applications, however, require higher pressures.

4.6 Asphyxiation

Asphyxiants are substances that deprive body tissues of oxygen, causing hypoxia (i.e., oxygen starvation). Often there is no warning, loss of mental faculties begins within a few seconds, and unconsciousness occurs shortly thereafter. The normal oxygen content of air is 20.9%. Below about 16%, flames are extinguished and individuals breathing such air suffer loss of coordination and judgment masked by euphoria, giving the victim a sense of well-being and security. Exposure to atmospheres containing less than 12% oxygen can rapidly result in unconsciousness, brain damage, and death by asphyxiation. The minimum oxygen concentration in air required for short-term survival is 6–8%.

Except for air and oxygen, all of the selected gases can cause asphyxiation. Gases with different densities than air present the greatest hazards due to their potential for stratification. The heavier gases usually are more hazardous because they accumulate at lower elevations where personnel are more likely to be. Sulfur hexafluoride and Halon gases are about five times more dense than air.

Mitigation or prevention of asphyxiation includes limiting where possible the amounts of gas available to enter an enclosure, providing suitable ventilation, providing instrumentation that indicates low oxygen content of enclosure atmosphere, having portable and/or extended air supplies available to personnel entering enclosures that could have low oxygen concentrations, and using the buddy system (where two people work together but only one enters suspect areas while the other observes from a safe place).

4.7 Toxicity

In addition to asphyxiation, some gases have a toxic effect on the human system, either through inhalation, through high vapor concentrations, or by contact of liquified gas with the skin or eyes. Adequate ventilation and monitoring of susceptible areas as well as training of personnel serve as the chief precautions. Only two of the ten gases selected, chlorine and Halon 1301, are considered toxic.

4.7.1 Chlorine

Chlorine is the most toxic of the ten gases covered. The dose that will cause a 50% death rate for chlorine, LD_{50} is about 1000 ppm-min at concentrations of 30–60 ppm.[14] The effects of various concentrations of chlorine gas are given in Table 6.

Chlorine has a characteristic sharply penetrating odor above 3–5 ppm. At higher concentrations, the severely irritating and painful effects make it unlikely that any person would remain in the locale. Low concentrations irritate the mucous membranes, the respiratory system, and the skin. Large concentrations cause irritation of the eyes, coughing, and labored breathing.

Table 6. Physiological response to various concentrations of chlorine gas

Effect	Parts chlorine gas per million parts air by volume
Least amount required to produce slight symptoms after several hours of exposure	1
Least amount necessary to detect odor	3.5
Maximum amount that can be inhaled for 1 h without serious disturbances	4
Amount considered noxious, making breathing impossible for several minutes	5
Least amount required to cause irritation of throat	15.1
Least amount required to cause coughing	30.2
Amount dangerous in 30 min to 1 h	40–60
Amount that kills most animals in very short time	1000

Source: Adapted with permission from J. S. Sconce, ed., *Chlorine, Its Manufacture, Properties, and Uses*, American Chemical Society, Monograph Series, Reinhold Publishing Corporation, New York, 1962.

4.7.2 Halon 1301 (Bromotrifluoromethane)

Halon 1301 is mildly toxic.[15] Most concentrations required for fire extinguishing range from 4 to 6% by volume. Tests indicate minimal, if any, effect on the central nervous system with concentrations up to 7%. Between 7 and 10%, lightheadedness and reduced dexterity have been noted. High concentrations lead to dizziness, impaired coordination, and reduced mental acuity. There is no residual poisoning effect.

The decomposition products of Halon 1301 used on a fire are much more toxic. However, tests indicate that the amounts produced are small enough not to be a safety hazard. The odors from decomposition products in concentrations of only a few parts per million provide adequate warning.

5. INCIDENTS INVOLVING PRESSURIZED GASES

So that information could be obtained from incidents that have occurred during on-site transportation, handling, storage, and distribution of pressurized gases, a search of the literature was made for records of such incidents. Sources of information were National Safety Council Research and Development Newsletters;[16–18] Nuclear Safety Information Center (NSIC) RECON data base;[19] *The Risk of Catastrophic Spills of Toxic Chemicals;*[20] Nuclear Regulatory Commission Inspection and Enforcement Circular 80-03, Protection from Toxic Gas Hazards;[21] a presentation by H. L. Howe;[22] an investigation report from the Compressed Gas Facility at Los Alamos National Laboratory;[23] and a National Aeronautics and Space Administration report.[24] Following are descriptions of some of the more significant and/or relevant incidents that have occurred at nuclear and nonnuclear installations.

5.1 Missiles

Pressurized gas is a form of stored energy inherently seeking release. A particular hazard is the rocket effect of unrestrained portable gas cylinders when the valve has been broken, which frequently happens if the cylinder falls with the valve cover not in place. The literature contains many descriptions of such incidents. Some of the more illustrative ones have been chosen and are presented below.

— The National Safety Council Construction Section Newsletter[16] reported in March 1959 that a standard-sized cylinder traveled about 30 ft, struck the luggage compartment of an automobile and went through the roof just above the windshield. It then rocketed 1500 ft over the tops of two houses and made a hole in the foundation of a third building as it landed.

— The National Safety Council Power Press and Forging Section Newsletter[17] reported in March 1959 that one person was killed and two were injured by a standard heavy oxygen cylinder that ricocheted through a street. The cylinder fell from a truck and the valve broke off. The initial blast knocked a boy and girl through a shop window, inflicting serious injuries on both. The rocketing cylinder then hit a stone embankment, shot 100 ft into the air, killed a woman when it came down, then thundered down the street battering automobiles and parked bicycles until its gas supply was exhausted.

— An unsecured and uncapped standard-sized carbon dioxide cylinder fell from a jeep that was turning inside a hangar. After the valve smashed against the floor, the jet-propelled cylinder tore through several plane wings and fuselages, struck and broke the sprinkler system, which started a flood. The cylinder finally broke through a concrete block wall before stopping. Over a half-million dollars of damage resulted from the incident.[25]

— Standard-sized oxygen and acetylene cylinders being used in welding were not secured, and a pull on the hose caused the oxygen cylinder to fall, breaking off the valve. The rocketing cylinder tore out process lines and released flammable solvents, starting a raging fire.

The cylinder then tore through two brick walls and was airborne for some distance before it stopped.[26]

— This flying-cylinder incident[18] involved a cylinder filled with 65 lb of Halon 1211 liquid (bromochlorodifluoromethane), pressurized by nitrogen gas to 600 psig, which was being removed by a technician from an outdoor cylinder storage rack during the decommissioning phase of a project. The lever of the manual actuation cylinder valve had not been removed, and a safety pull-pin designed to prevent inadvertent manual actuation was not in place when the technician, holding the cylinder in a vertical position, rolled it on its base.

The technician stated that either his loosely rolled up shirt sleeve caught the lever or his forearm depressed it, causing a sudden discharge of the gas from the downward-turned discharge tube attached to the valve.

As the gas was being expelled, it created a cloud of Halon and dust. The technician's glasses were knocked off, and the unstable cylinder fell over and bounced around in the corner of the cylinder rack, where the brass valve broke off the cylinder. The cylinder then became airborne and rocketed upward. It struck the roof access platform at about 21 ft above grade and then ricocheted through a sheet metal wall into a nearby building. It continued upward smashing through the roof near the peak, ~48 ft above the floor. Three people working inside the building did not see the cylinder but reported hearing a rapid succession of noises, which were probably made by the cylinder as it crashed through the wall and then the roof.

The cylinder continued skyward until its contents were expelled, and then fell back through the roof to an unoccupied area about 140 ft from where it started. Fortunately, no one was injured and only minimal property damage occurred.

According to the manufacturer, there is no protective valve cap designed to fit over the valve head. To prevent similar occurrences, knowledgeable personnel should remove any electrical or mechanical actuation device prior to moving a cylinder, and then the nonoperable cylinder should be restrained within a wheeled cylinder cart before the cylinder is moved.

5.2 Gage Failures

Practically every system using pressurized gas has one or more gages in service, and workers frequently must read gages to determine or adjust pressure. For this reason proper concern must be expressed in the selection, use, and maintenance of gages. Two examples of gage failures follow.

— A technician at Los Alamos National Laboratory received first- and second-degree burns on the arms and face when a new gage ruptured at half its rated pressure and the hydrogen gas ignited. Damage was limited because the equipment was in a remote cell. The blowout feature of the gage back, which directed flames away from the operator, also prevented more serious injury.[27]

— Also at Los Alamos National Laboratory, the Bourdon tube of a 5000-lb gage failed at 4000 psi. An employee was injured by flying cover glass ejected from the dial of the unvented gage.[28]

5.3 Pipe Whip

When flexible piping breaks loose under pressure, danger exists for personnel or equipment within the range of the flailing pipe. The following two incidents are examples of pipe whip.

— A group at the Nevada Test Site was preparing to check a high-pressure actuator air line for leaks. The gage being used was connected to the pressure source by two 10-ft sections of 3/16-in. flexible line. The unsecured flexible line failed at the coupling and whipped. Fortunately, no one was injured and no essential equipment was damaged.[28]

In another incident reported by the Department of Energy, six gas-transport trailers had been positioned for discharging their cargoes, each connected to a common receiving manifold at the compressor station. The distance between the trailer end and the station manifold was 7 ft. The 20-ft high-pressure copper tubing connectors were for 0.840-in.-OD tubing, but fittings on the distribution system to which it was to be connected were for 0.875-in.-OD tubing. The contractor directed that the 0.840-in.-OD tubing ends be spread to fit the ferrule. Leaks occurred when the retaining nuts were tightened. While gas was being transferred from a trailer, the leak was noted. Valve operation then caused the tubing to blow out of the coupling. The tubing whipped, striking two men; one received skull and eye injuries and the other sustained a concussion and head laceration.[28]

5.4 Explosions

The following descriptions involve hydrogen explosions. Three incidents occurred at National Aeronautics and Space Administration (NASA) installations and were chosen for their similarity to problems that could occur at nuclear power plants. An explosion at Los Alamos National Laboratory involved a tube trailer similar to those used at nuclear power plants. Another incident occurred at a nuclear power plant and points up a very important problem with interfaces between hydrogen, nitrogen, and compressed air. The final three incidents describe explosions at nuclear plants.

— At a test facility a hydrogen vent line exploded and destroyed about 150 ft of line because the line had not been properly purged. Ignition occurred either from the flare stack (effluent point for burning waste hydrogen) or from a static charge.[29]

— Fire erupted from a 3000-psi hydrogen line in the vicinity of an electrical junction box. The fire extinguishing system, Firex, came on, and attendants closed hand valves in the hydrogen bottle bank. About 15 min was required to bleed the line and header to ambient pressure and therefore to extinguish the flame. This incident was probably caused by a short in the electrical box, which caused sufficient heat to rupture a Bourdon tube in a nearby gage. Someone noticed black smoke coming from the junction box prior to the fire.[30]

— While a hydrogen header vent system was being welded, some hydrogen outside the header ignited. After the adjacent vessels and lines had been inerted with helium and checked for hydrogen, work on the header was resumed. When the arc was struck for welding, hydrogen again ignited. The hydrogen was found to be coming from a hole in the header. In this installation a common hydrogen venting system was used. There was an upstream hand-operated shutoff valve, but it was leaking.[24]

— On June 3, 1981, at Los Alamos National Laboratory, an explosion occurred after a hydrogen tube trailer and an oxygen tube trailer had been simultaneously connected to the same manifold. Insufficient barriers (only one shutoff valve) and incorrect purging procedures led to the damaging of the shutoff valve and a subsequent flow of higher pressure oxygen into one tube of the hydrogen trailer. Ignition was probably caused by contamination (sand) traveling through a valve at high velocity. The resulting explosion ruptured one of the tubes, propelled tube fragments as far as 1250 ft away from the trailer, created a fireball of short duration that caused first- and second-degree burns over about 30% of the bodies of two employees and a small area of third-degree burns on one of them, caused major damage to the hydrogen tube trailer, and caused minor damage to a portion of the facility. The incident was caused by the inadvertent mixing of the hydrogen and oxygen due to insufficient technical and safety training of the personnel involved, lack of management control of the operation, lack of standard operating procedures for the task being attempted, and inadequate and poorly maintained equipment.[23]

— On July 17, 1981, the radioactive-waste-gas decay tank was being vented through the cryogenic waste-gas treatment system at San Onofre Nuclear Generating Station Unit 1 (Ref. 31). Just before processing began on the north decay tank, the south decay tank was processed without incident. As processing began on the decay tank, difficulty was experienced in adjusting the flow rate through the system. A reducing valve that controls downstream gas pressure into the gas treatment system was cycling. While attempting to alleviate this problem, an operator noted "popping" noises, apparently originating in the piping downstream of the reducing valve. Sometime thereafter an ignition of the gas mixture in the decay tank occurred. Fire alarms were received in the control room, and operating personnel within the gas treatment system area were notified. They reported a loud noise, apparently from the gas-decay-tank area. Operating personnel reported the presence of smoke in the reactor auxiliary building. Local pressure indication on the decay tank read zero. Operating personnel entered the area in Scott Air Packs and inspected the north waste-gas decay tank. The area was clear of smoke and no fire was present. However, the tank manway cover bolts were found to be loose, and minor damage around the tank manway was noted. Investigation after this event revealed that damage to the tank was apparently limited to the manway area and the manway bolting.

The source of the ignition apparently was the oxygen recombiner located in the cryogenic waste-gas treatment system. At oxygen concentrations greater than 3%, the chemical reaction in the recombiner can generate temperatures above the ignition temperature for an oxygen-hydrogen combination. The manufacturer provides an oxygen analyzer with this system to detect oxygen levels exceeding this value. However, when this event occurred, this meter was inoperable, and its use was not required by the operating procedure. Local ignition of the hydrogen-oxygen atmosphere evidently created pressure spikes that caused the control valve to cycle, resulting in the popping noise heard by the operators. During one of the local ignitions the flame front flashed upstream and ignited the gas mixture in the tank.

Subsequent investigation into the cause of high oxygen concentrations within the waste-gas system revealed high oxygen concentrations in the station's nitrogen system. This had been discovered the day before the event and had led to sampling of the flash tank gas space (completed just prior to the ignition). This sample showed the presence of oxygen in the tank. Instrument air (maintained 10—20 psig above the nitrogen system pressure) was entering the nitrogen system at locations where nitrogen serves as a backup to instrument air. The backup function is for the following safety-related valves: pressurizer relief and pressurizer relief block valves, isolation valve on the nitrogen supply to the pressurizer, auxiliary feedwater system control valves and auxiliary feedwater turbine-driven pump, and steam control valve. The primary source of leakage was confined to those valves associated with the auxiliary feedwater system (insignificant leakage was found at the other locations).

The check valves isolating the instrument air and nitrogen systems had not been installed in accordance with manufacturer's recommendations during the recent Three Mile Island backfit modifications. As a result of this installation the valves failed to seat properly, providing a direct and rather large communication path between the two systems. This contaminated N_2 was subsequently used as a purge and cover gas in the waste gas system.

The following action was taken in regard to this incident:

1. The instrument air system and the station's nitrogen system have been physically separated. Bottled gas is now used in lieu of the station nitrogen system.
2. The procedure used to operate the waste-gas treatment system was revised to prohibit system use if oxygen concentrations above 3% are present (manufacturer's upper limit on oxygen concentration). Sampling the oxygen prior to release is now required.
3. The decay tank was examined with liquid penetrant, repaired, and pressure tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII (Ref. 6).
4. The pressure boundary components in the immediate vicinity of the decay tank were examined for indications of damage and repaired as needed.
5. In the cryogenic waste-gas treatment system, the oxygen recombiner and system filter were replaced, and the oxygen analyzer was repaired.

— In February 1974, a hydrogen explosion[32] occurred at the Three Mile Island Nuclear Station Unit 1 bulk hydrogen supply, which consists of twelve 12,000-scf cylinders arranged horizontally in a 3 × 4 array. The cylinders were being initially filled for subsequent main generator gas system testing by a commercial bulk hydrogen gas truck. One cylinder group (six cylinders) was at approximately 1500 psig when an explosion and a large fireball occurred about 100 ft above the cylinder bank, accompanied by the sound of gas rapidly escaping a tank rupture disk vent.

After several minutes, it was determined that no immediate risk of further explosion was present, so the other five cylinders were isolated from the leaking one and the gas was allowed to burn itself out. As the cylinder pressure dropped, the velocity of the escaping gas decreased to the point where combustion ceased and the remaining hydrogen gas dissipated into the air.

The hydrogen cylinder bank was installed at the Three Mile Island site approximately 2 years prior to the incident. During that time the vertically oriented rupture disk vent pipes apparently collected rain water because they were not capped. The ice plug formed by the freezing of the water in the pipes apparently weakened the rupture disk to the extent that its design burst pressure point (2500 psig) was affected.

Later investigation of the other 11 cylinder rupture disks indicated that all were subject to varying degrees of mechanical deformation inward, most likely due to ice, because water was found in the fittings and vent pipes.

— A similar event occurred at LaSalle County Nuclear Station on July 20, 1984.[33] Reserve hydrogen tanks were being filled from a tank truck when a rupture disk in one reserve tank failed and a hydrogen fire ensued.

— On March 20, 1984, a hydrogen explosion occurred in the main generator at Rancho Seco Nuclear Station.[34] The force of the explosion blew the doors off the generator enclosure. This was caused by the loss of the hydrogen seal oil pump that resulted in hydrogen leakage.

5.5 Incidents Involving Chlorine

Chlorine has long been used in water purification systems to kill living organisms. Initially the nuclear power industry adopted this standard method of treating condenser circulating water to kill organisms. As a result liquid chlorine was always on hand to be used as needed. As the nuclear industry matured, using elemental chlorine became recognized as tedious and time consuming because of the hazards involved in handling it. Now the trend is to use sodium hypochlorite, thereby avoiding the hazards of elemental chlorine. However, the following descriptions of typical incidents involving elemental chlorine are considered generally applicable.

In the past, the Chlorine Institute, a nonprofit trade association organized in 1924, has been the only group to maintain a comprehensive record of all accidents involving chlorine. More recently, the Department of Transportation also has begun to maintain both records and statistics of accidents involving transportation of chlorine.

Table 7 lists the more significant accidents, those involving loss of life or the release of large quantities of chlorine, as compiled by the Chlorine Institute as of May 1972 (Ref. 20). An interesting point is that in the United States more deaths have resulted from accidents with the smaller vessels, cylinders, and ton containers than with the larger ones. One may hypothesize that this is because of the smaller number of safety devices and the tendency to use such vessels indoors or in enclosures.

Catastrophic spills of chlorine must arise from accidents involving large vessels. Small vessels such as the 1-ton container and 150-lb cylinder simply contain too little chlorine to cover a large unconfined

Table 7. Significant chlorine accidents

Location	Date	Comments
		Storage tanks
St. Auban, France	12-13-26	Tank burst, 25 tons lost, 19 deaths
Near Baton Rouge, Louisiana	05-10-29	Tank burst, hydrogen-chlorine explosion, 25 tons lost, 1 death
Zarnesti, Romania	12-24-39	Tank burst, 25 tons lost, 60 deaths
Rauma, Finland	11-05-47	Tank burst from overfilling, 30 tons lost, 19 deaths
Walsum, Germany	04-04-52	Tank failed (a converted old boiler), 15 tons lost, 7 deaths
		Barges
	04-13-60	Loading hose ruptured, 1 death
	02-23-61	Wychem 112 sinking, no leak
Near Baton Rouge, Louisiana	09-12-65	Sunk during hurricane Betsy, no leak
	07-28-70	Pump break during unloading, 1 death
Near Louisville, Kentucky	03-19-72	Broke from tow and rested on dam, no leak
		Railroad tank cars
Niagara Falls, New York	02-28-34	Anchor failure, 16 tons lost
Griffith, Indiana	03-13-35	Anchor failure, 30 tons lost
Chicago, Illinois	02-04-47	Release caused by heat from a fire, 18 tons lost
La Barre, Louisiana	01-31-61	Train wreck, tank punctured, 30 tons lost, 1 death, 114 persons exposed to chlorine gas
Cornwall, Ontario	11-30-62	Anchor failure, 30 tons lost, 89 persons exposed to chlorine gas
Brandtsville, Pennsylvania	04-28-63	Valve sheared off in wreck, 9 tons lost
Philadelphia, Pennsylvania	08-09-63	Loading line broken when tank was rammed, >430 persons exposed to chlorine gas
Newton, Alabama	11-08-67	Tank punctured in wreck, 55 tons lost
		Truck tanks
		No significant accidents

Table 7 (continued)

Location	Date	Comments
	One-ton containers	
Asbokan, New York	07-07-28	Explosion, contamination with NCl
Asbokan, New York	07-13-28	Explosion, contamination with NCl
Cleveland, Ohio	05-08-69	Two deaths
	Pipelines	
Johnsonburg, Pennsylvania	11-12-36	Transfer line broken by housing, 3 tons lost, 1 death
Freeport, Texas	09-01-49	8-in. line burned in attempted welding, 5 tons lost
Mobile, Alabama	07-12-64	One death
Dominquez, California	09-12-66	Pipe accidently cut by welder, 500 lb lost
Dominquez, California	02-21-67	Pipe dug up accidently, 500 lb lost
Dominquez, California	02-22-67	Pipe dug up accidently, 500 lb lost

Source: J. A. Simmons, R. C. Erdman, and B. N. Naft, *The Risk of Catastrophic Spills of Toxic Chemicals*, UCLA-ENG-7415, May 1974.

area with a lethal dose. Because of the flow-limiting devices in the eduction lines of the larger containers, catastrophic spills will occur (under most circumstances) only by rupture or breaching of the vessel. Breakage of an attached transfer line or of one of the angle valves may result in a substantial release of chlorine, but the rate of the release is restricted so that a relatively small area is affected.

In addition to the events in Table 7, two incidents involving chlorine occurred at U.S. nuclear power plants. They were found by searching incidents contained in the NSIC data base of abstracted Licensee Event Reports. At Millstone Nuclear Power Station in March 1978, a leak of about 100 scf of chlorine, equal to about 1 gal of liquid, occurred during a 10-min period.[21] Fifteen people were hospitalized as a result of injury. In June 1979, a small leak from a diaphragm on a reducing valve caused injury serious enough to hospitalize five people including a control room operator.[21] This incident occurred at Browns Ferry Nuclear Power Station.

5.6 Asphyxiation

Various purge gases can cause asphyxiation. Nitrogen typifies the asphyxiant gases and is used extensively at nuclear power plants. For this reason the following incident was selected as a typical example of the hazards involved with using nitrogen.

The incident occurred in England some time ago.[22] Two construction workers were killed when exposed to an oxygen-deficient atmosphere as they worked on a vessel that was being purged with nitrogen. The first worker entered the vessel and when he passed out his fellow worker followed to rescue him. He lost consciousness and both men died. This type of accident has occurred repeatedly with various inert gases. The causes and cures are obvious.

Two people were killed at D. C. Cook Nuclear Plant in September 1976 as a result of asphyxiation from argon.[35] A purge of an 18-in.-diam stainless steel pipe had been established using a soft flexible rubber cover and duct tape. After several days, the welds were completed but the purge was not shut off. A pipefitter descended into the pit, without using the "buddy system," to remove the purge connections and was asphyxiated. Two other employees tried to rescue him; one of them was killed. Available oxygen analyzers were not used.

6. NUCLEAR PLANT DESIGN FOR HANDLING PRESSURIZED GASES

Pressurized gas storage, transfer, and control systems for nuclear power plants are designed and constructed to meet standard codes and practices as reviewed in Chap. 3 of this report. In addition, because of the potential for increased consequences of failures of equipment at nuclear power plants, the requirements given in Title 10 Part 50 of the *Code of Federal Regulations*[36] must be met. Although gas systems are not considered primary safety systems, the following parts of the Code are implemented in nuclear plant applications.

Title 10 Part 50 states that structures, systems, and components important to safety (1) shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiche without loss of capability to perform their safety functions; (2) shall be designed and located to minimize the probability and effects of fires and explosions; and (3) shall be protected from the effects of missiles, pipe whipping, and discharging fluids.

Before granting an operating license for a nuclear power plant, the NRC is responsible for determining that all safety requirements have been met. Guidance for this is given in the *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants* (NUREG-0800) (Ref. 37). Several requirements from this report relative to pressurized gases follow:

1. A review of possible effects of internally generated missiles (inside and outside containment) that could prevent safe shutdown of the plant or result in significant release of radioactivity.[38]
2. A review of high- and moderate-energy piping systems located outside containment to ensure that postulated piping failures are acceptable.[39] (All pressurized gas systems are considered moderate-energy piping systems.)
3. Review of the control room to ensure that it can be occupied at all times even if a toxic gas (such as chlorine) is released.[40] If compressed air bottles are used in emergencies to maintain the control room at a positive pressure, they should be protected from tornado missiles or internally generated missiles and should be placed where damage to vital equipment or interference with operation if they fail will not occur. Storage location of CO_2 or other fire fighting materials should be chosen to eliminate the possibility of significant quantities of gases entering the emergency zone.
4. Review of the systems that are important to safety or are required for safe shutdown to ensure that they will survive the effects of earthquakes, other natural phenomena, and missiles.[41] (The only gas system specifically mentioned is the compressed air system.) One nuclear power plant architect-engineer who was contacted advised that gas systems inside critical areas such as the reactor building, auxiliary building, diesel generator building, and control building are designed to seismic Class I L. Another architect-engineer advised that gas lines are designed for seismic events when they interface with safety systems.
5. Review bulk gas storage to ensure that it is not inside structures housing safety-related equipment.

6. Review storage of flammable gases such as hydrogen to ensure that containers are stored outdoors or in separate detached buildings. Two nuclear power plant architect-engineers who were contacted advised that hydrogen storage is located away from the building. The site was chosen so that hydrogen containers could not become missiles that would damage the plant. The other advised that the tanks are tied down but the structure is not tornado proof.

7. Review hydrogen lines to ensure that they are either designed to seismic Class I requirements, sleeved, or equipped with excess flow valves so that the hydrogen concentration in the affected areas will not exceed 2% in case of a line break.[42] As discussed in Chap. 7, one of the plants visited did not have excess flow valves, but the others did. Also, two nuclear plant architect-engineers, contacted by phone, advised that excess flow valves are used in their plants. One of these architect-engineers said that ventilation would probably prevent accumulation in case of a small leak. The other advised that no special precautions were taken in the turbine building but piping to the makeup tank in the auxiliary building is encased in a guardpipe and has an auto isolation system. In addition hydrogen analyzers are installed in various locations to warn of hydrogen accumulation. Other plants contacted advised that abnormal changes in supply pressures alert them of a leak. Portable hydrogen detectors are then used to locate the leak.

In addition to following standard codes and practices as well as NRC requirements in design and construction, special attention is paid to the hazards of gas systems during the NRC review of designs before a license is granted. An insight into some of the details of the design for mitigating the hazards associated with pressurized gases can be obtained by reviewing the licensee responses to some of the questions asked during the reviews. Between 1969 and 1981, most of these responses were abstracted by the NSIC and stored for retrieval in the computer. A search of these keyworded abstracts showed that over 600 responses pertained to gases used at nuclear power plants. The distribution of responses among the ten gases covered in this report is given in Table 8. From the number of questions asked about each gas, the gas considered the most hazardous by the reviewers can be deduced. No questions were asked about acetylene, which is understandable because acetylene is not used in the operation but only in maintenance. Some of these responses are included in the following descriptions of system design.

The following descriptions of designs cover only fixed systems. Portable cylinders will not be discussed nor will design of chlorine systems since most nuclear power plants now use sodium hypochlorite for water treatment. Guidance for handling chlorine gas in nuclear plants is given in Regulatory Guide 1.95 (Ref. 43).

The following examples of a system for handling compressed air, carbon dioxide, hydrogen, nitrogen, oxygen, and Halon were found in final safety analysis reports (FSARs), which were selected mainly because of availability. The descriptions are examples and are not presented as typical but can be considered similar to others in the industry. The plants are of new designs that fall under the purview of NRC's standard review procedures. Consequently the plants discussed here have probably been reviewed more stringently by NRC than have most other existing plants.

Table 8. Number of questions and responses concerning gases used at nuclear power plants

Gas	Number of questions and responses
Hydrogen	418
Chlorine	75
Nitrogen	41
Carbon dioxide	36
Oxygen	28
Air	26
Propane	9
Acetylene	0
Sulfur hexafluoride	0
Halon 1301	0

6.1 Compressed Air

The compressed air system for Sequoyah Nuclear Plant Unit 1 is shown in Fig. 1 and is described as follows.[44] Sequoyah's compressed air system is not typical of most plants because it has more redundancy of compressors and receivers; however, it can illustrate the compressed air system.

Figure 1 shows that building air is filtered, compressed, cooled, dried, and refiltered before it is used in the plant. The compressed air system is common to both units and is divided into three subsystems, the station control and service air system and two auxiliary control air systems for emergency use. The station control and service air system is designed to supply adequate compressed air capacity for general plant service, instrumentation, testing, and control. The auxiliary systems ensure that all vital equipment will have a continuous air supply to guarantee operation under all conditions, including safe shutdown, earthquake, and maximum possible flood conditions.

Station control and service air is supplied by three motor-driven, nonlubricated, two-stage, reciprocating compressors. Each of the three compressors is designed to handle control air requirements for the total plant under normal conditions with sufficient additional capacity to handle minimal service air requirements. The compressed air system includes normal accessory equipment such as cylinder cooling equipment, aftercoolers, and safety relief valves.

The station compressors discharge into two redundant headers that are provided with manual isolation valves. These headers feed the two control air receivers, which in turn supply air through redundant headers to the control air station. The control air station contains two complete trains of prefilters, dryers, and afterfilters. Each dryer train

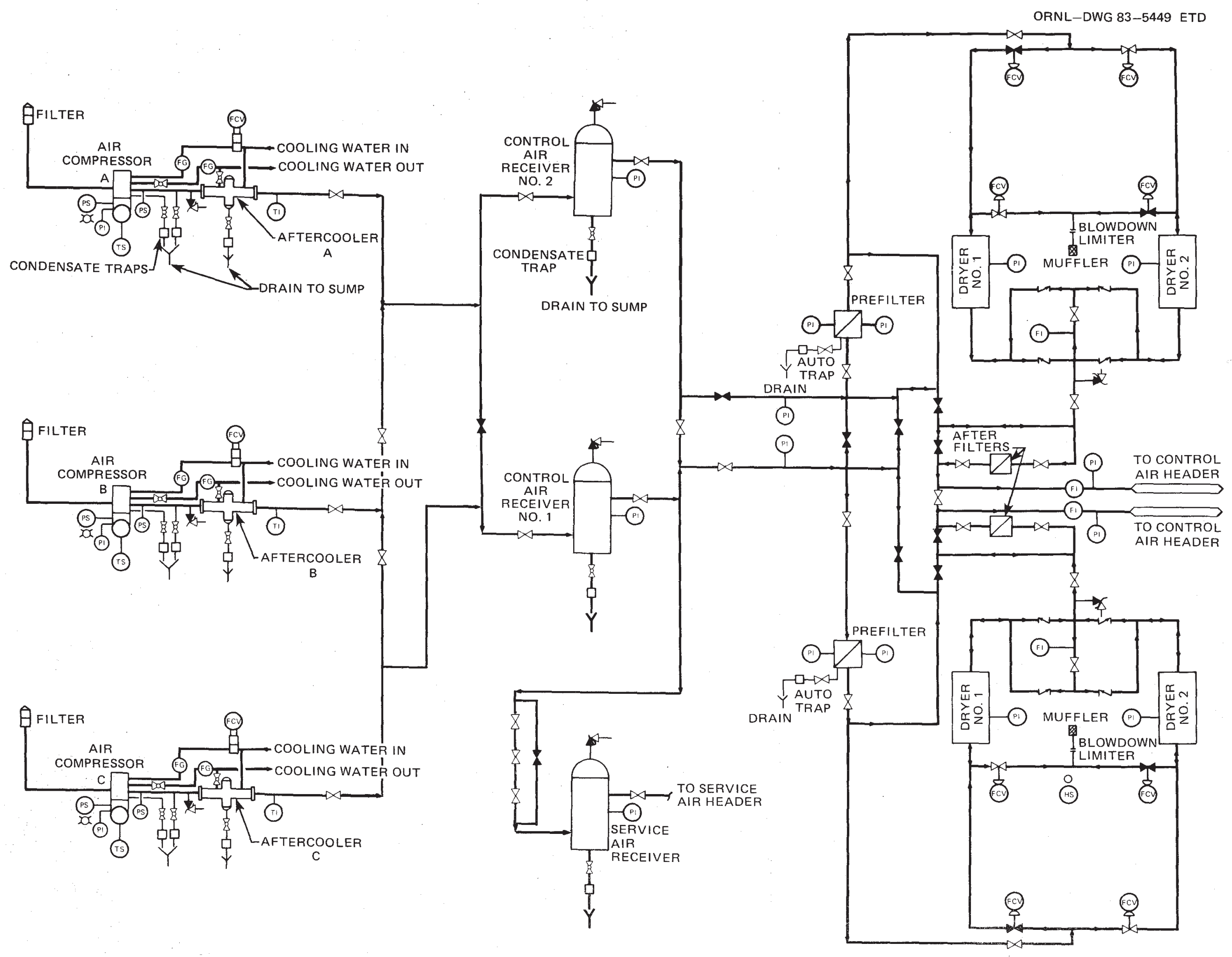

Fig. 1. Example of a compressed air system.

is sized to handle plant control air requirements. Manual bypasses are provided around each element for emergency operation. The control air is then piped through two independent headers to various valves, controllers, and instruments throughout the plant.

Service air, supplied to the service air receiver by a single header from the control air receivers, is supplied through a back-pressure valve that closes if control air pressure drops below 80 psig, thus ensuring that control air requirements take precedence over service air requirements. Service air is piped from the receiver to service outlets and miscellaneous equipment throughout the plant.

Auxiliary control air is supplied by two motor-driven, nonlubricated, two-stage, reciprocating compressors. Each compressor is sized to supply the total control air requirements in the event of an accident, flood, or loss of the station control air system. The auxiliary control air system is separated into two independent trains, each containing its own compressor, receiver, dryer, and filter. The auxiliary control air piping is arranged so that the auxiliary receivers are charged from the station control air system during normal operation. Electric power for the auxiliary systems is provided from both normal and emergency sources. The auxiliary control air system and all the station control air system components located in Class I structures are designed to seismic Class I requirements. The auxiliary air system is automatically isolated from the station air system upon loss of air from the station system.

The dryer and filter trains for both the station and auxiliary air systems are designed to give compressed air of high quality for instruments. The prefilters are designed to remove liquid water entrainment and other foreign matter from the compressed airstream down to 3-μm size. The air dryers dry the air to a dew point of —40°F. The discharge of the dryers is routed through an afterfilter which removes particles of desiccant and other foreign matter down to 5-μm size.

Additional information on compressed air and nitrogen backup systems and their performance in commercial nuclear power plants is given in Ref. 45.

6.2 Carbon Dioxide

Carbon dioxide is used in fire protection systems and for purging hydrogen lines and systems before they are opened for maintenance. The system design can vary from plant to plant. In the FSAR for North Anna Power Station, prepared by Stone and Webster,[46] a carbon dioxide system for fire protection is described as follows.

The low-pressure carbon dioxide system is shown in Fig. 2 and is used as the primary fire suppression agent in the following safety-related areas: cable spreading rooms, emergency switchgear rooms (including battery charger inverter room, control rod drive equipment room, motor generator room), and electrical tunnels. Total flooding carbon dioxide is also provided for the nonsafety-related cable spreading areas and normal switchgear rooms.

In these areas where greater combustible material concentrations may occur, physical separation prevents the spread of a potential fire

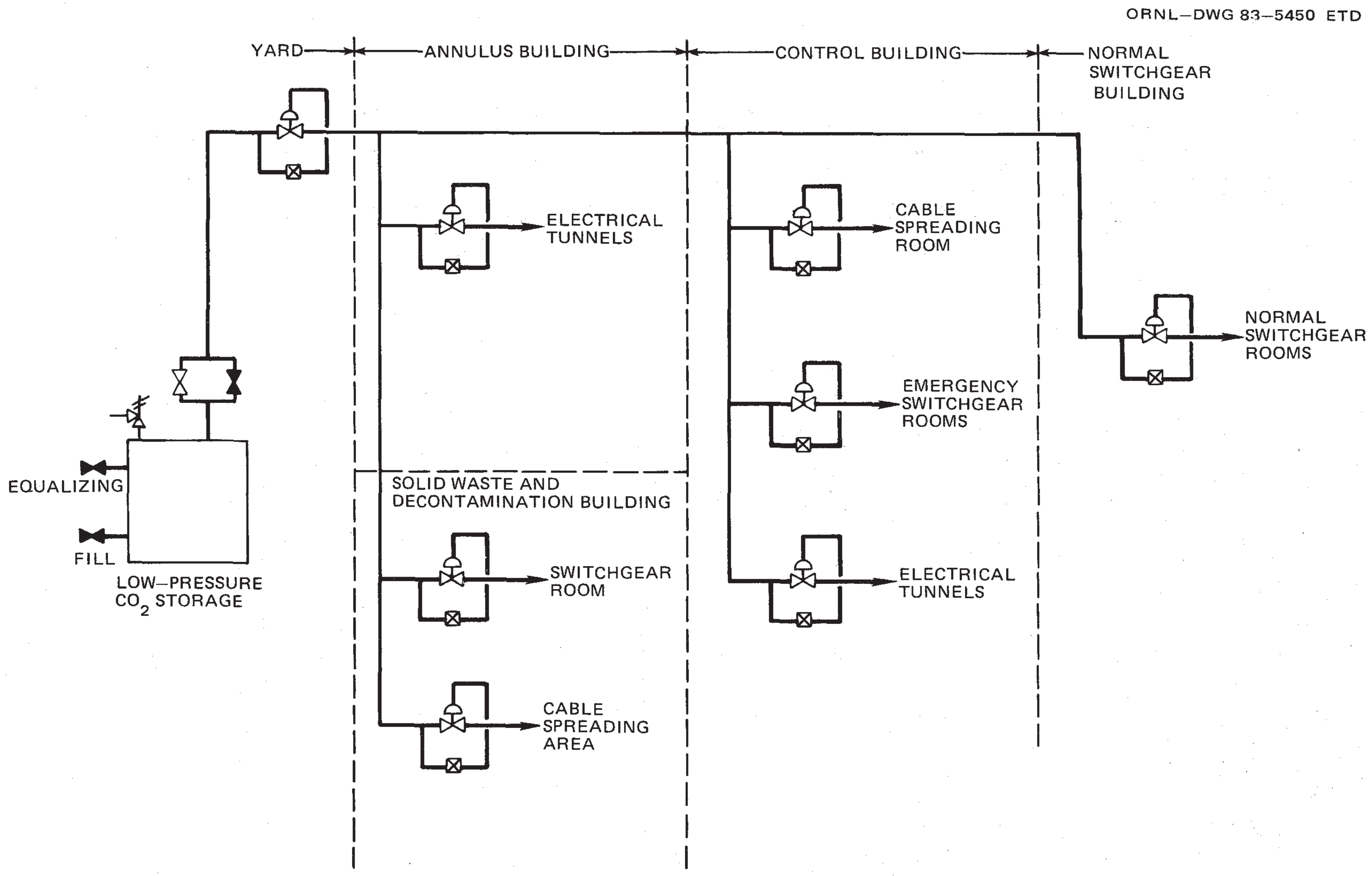

Fig. 2. Example of a carbon dioxide fire protection system.

and carbon dioxide provides suppression. Carbon dioxide is selected for its suppression capabilities and minimum cleanup requirements and because it does not cause electrical derating.

Low-pressure carbon dioxide fire protection systems using refrigerated carbon dioxide storage tanks, distribution piping, instrumentation, and controls for automatic and manual discharge are provided to meet the requirements of National Fire Protection Association Standard 12 (Ref. 47).

Liquid carbon dioxide for fire protection is supplied from a refrigerated, low-pressure storage tank at 0°F and 300 psig. The carbon dioxide storage tank has sufficient capacity to provide twice the amount of carbon dioxide required by the total flooding of the largest fire area served.

A fire detection and alarm system is installed in all carbon dioxide protected areas. A system of rate-compensated thermal and ionization detectors provides automatic actuation of the carbon dioxide extinguishing system. Carbon dioxide protected rooms and areas have local predischarge warning alarms, delayed operation, lockouts, and odorizing vials for personnel protection. Detection, actuation, and supervision of the wiring of the carbon dioxide system are annunciated and alarmed in the control room.

Safety lockout switches in the control circuit prevent accidental automatic carbon dioxide discharge when personnel are working in the area. These lockout switches, which are under strict administrative control, do not disable detection and supervisory circuits that annunciate and alarm in the control room. A push-button station outside each hazard area allows manual actuation of the system.

The carbon dioxide discharge nozzles are directed toward the floor of an enclosed space rather than at equipment to prevent direct impingement upon equipment. This arrangement permits only indirect or remote carbon dioxide gas flow within these areas and limits the deleterious cooling effects.

Carbon dioxide flooding is accompanied by the shutdown of fans and ventilation dampers. Pressure actuated relief devices for air displaced by carbon dioxide are installed as required to prevent structural damage.

Operation of the carbon dioxide system is in accordance with National Fire Protection Association Standard 12 and American Nuclear Insurors recommendations. Typically the system will discharge to attain 50% concentration within the first few minutes and then to maintain at least 30% concentration throughout the soak period (typically 20 min). Fire brigade personnel are expected to put on self-contained breathing apparatuses with portable equipment and hoses for entry into the affected area. This action ensures initial extinguishment and provides positive protection in the event of reflash on purging the carbon dioxide from the area.

Following is a response to an NRC question concerning the handling of carbon dioxide:

The carbon dioxide storage tanks have multiple safety devices: in the event of failure of the refrigeration compressors, an alarm sounds if the tank pressure increases to 325 psi.[48] If nothing can be done, a bleeder valve will relieve the pressure when it rises to 341 psi, causing the tank to self-refrigerate by boiling and thereby losing its charge intermittently until the supply is exhausted. If the pressure continues to rise beyond the capacity of the bleeder valve, a safety valve (one of two) will open at 357 psi. The storage tanks are designed and constructed in accordance with the ASME code on unfired pressure vessels.[6]

6.3 Hydrogen

A description of the hydrogen system for Sequoyah as contained in the FSAR for that plant follows.[44] The flow sheets for other plants are similar but can differ in some details.

Hydrogen provides a cover gas in the volume control tank to control the hydrogen concentration in the reactor coolant at 25 to 35 cm^3/kg of water (STP). Also it is used in the main electrical generator.

Hydrogen is supplied from the hydrogen trailer port through a secondary control cabinet outside the auxiliary building. The hydrogen pressure is reduced to 100 psig and fed through a shared header to the hydrogen control station at the volume control tanks at both Units 1 and 2. These control stations reduce the pressure to 15 to 20 psig and feed into the volume control tank as needed.

The safety of this system depends on two control valves, one of which is in the secondary control cabinet outside the auxiliary building and the other is just inside the auxiliary building. These control valves work in conjunction with a flowmeter and will close with a sudden increase in flow of hydrogen into the auxiliary building. The vent system is designed to pull an airflow of 7500 cfm through the volume control tank rooms and 28,400 cfm through the passageways where the header runs. With a major leak the maximum concentration of hydrogen would not exceed 1%, which is far below the 4% safe concentration in air.

The *Standard Review Plan* (NUREG-0800) states the following:

> Hydrogen lines in safety-related areas should be either designed to seismic Class I requirements, or sleeved such that the outer pipe is directly vented to the outside, or should be equipped with excess flow valves so that in case of a line break the hydrogen concentration in the affected areas will not exceed 2%.[42]

Periodical pressure tests and inspection ensure that there are no minor leaks. A major leak would automatically close down the hydrogen system.

The main instruments in this system are the control valves, which control the pressure and flow, and the pressure gages.

The flow diagram for this system is shown in Fig. 3.

Some of the responses given by utilities during the design review by the NRC follow.

— Hydrogen is supplied to the volume control tank for the purpose of maintaining the reactor coolant hydrogen concentration at 15 to 35 cm^3/kg at STP. Normal consumption is estimated to be 100 scf/d; startup from cold conditions will require 600 to 800 scf. The source of hydrogen for the volume control tank is the hydrogen supply manifold.

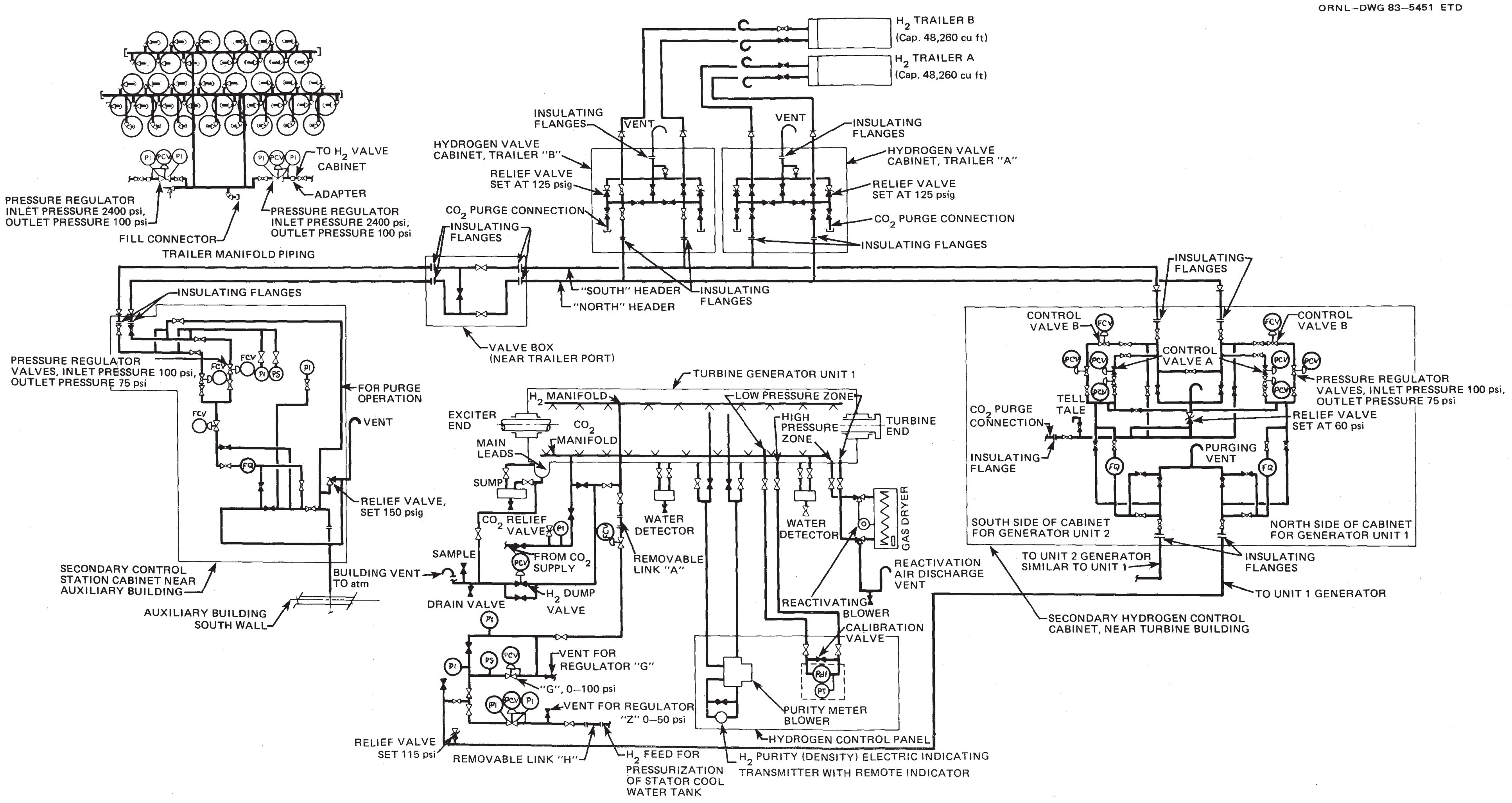

Fig. 3. Example of a hydrogen system.

A pressure-reducing valve at the manifold reduces the hydrogen pressure to 100 psig in the supply header. The supply header to the volume control tank is also equipped with a pressure regulator to control downstream pressure at 15 psig.[49]

— Eight hydrogen cylinders, each containing 325.6 × 10^6 ft-lb of energy, have been relocated in an open-top concrete pit, below grade and ~500 ft from the transformers for engineered safety features. None of these transformers will be in line of sight of the hydrogen storage cylinder bank. Because of this change, the Class IE ac power system components will function following any potential fire or explosion involving the hydrogen in these eight storage cylinders.[50]

— The hydrogen bulk storage facility is located on the approximate centerline between Units 1 and 2 on the north side of the east-west road north of the station. The nearest safety-related structure, system, or component is more than 500 ft away. The hydrogen system is equipped with an automatic excess flow valve that prevents discharging hydrogen due to a leak or rupture in the distribution system. This valve must be manually reset if it is tripped.[51]

— Hydrogen for use as a generator cooling media is stored outdoors in commercial bottles.[52] The bulk hydrogen storage facility is located at grade level next to the access road off the northwest wall of the turbine generator building. The facility is ~100 ft from the condensate storage tank. Design and construction are in accordance with the specific requirements and design considerations of National Fire Protection Association No. 50A, Standards for Gaseous Hydrogen Systems at Consumer Sites.[3]

6.4 Nitrogen

The nitrogen system at Watts Bar Nuclear Plant, as found in the FSAR for that plant,[53] provides nitrogen for the spent resin storage tank, reactor coolant drain tank, pressurizer relief tank, volume control tank, gas stripper, boric acid evaporator and waste evaporator packages, and the BWR control rod accumulators. Nitrogen at 15 psig is furnished for the gas decay tanks and the holdup tanks. In addition, the nitrogen supply header has a truck fill connection for the direct filling of the safety injection system and upper head injection system accumulators.

Two headers are provided, one for operation and one for backup. The pressure regulator in the backup header is set slightly lower than that in the operating header. When the operating header is exhausted, its discharge pressure falls below the set pressure of the backup header, which comes into service automatically to ensure a continuous supply of gas. An alarm alerts the operator when one header is exhausted.

Figure 4 is a piping and instrumentation diagram for the nitrogen system. Diagrams for other plants are similar but can differ in some details.

ORNL–DWG 83–5452 ETD

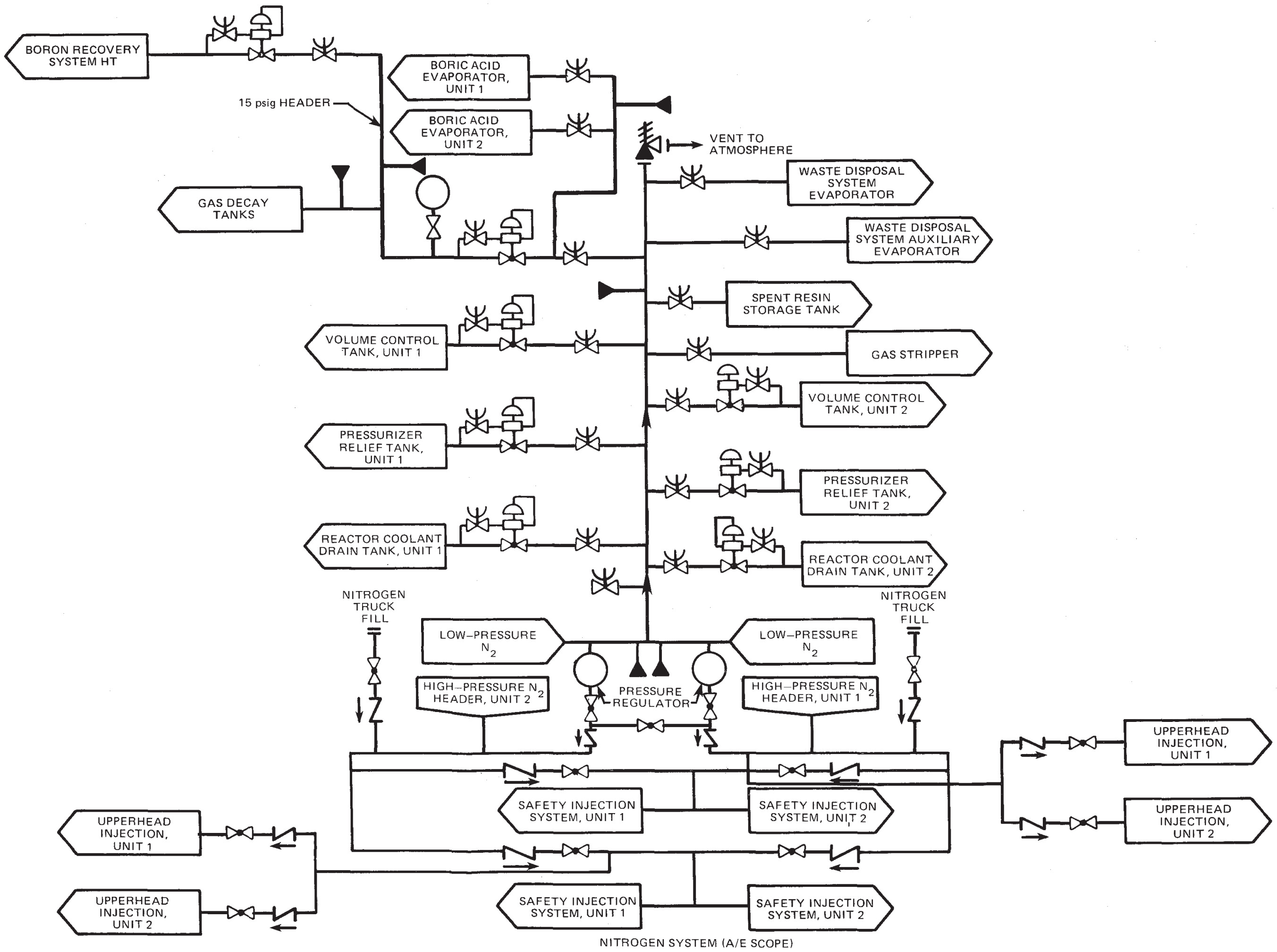

Fig. 4. Example of a nitrogen system.

6.5 Oxygen

Compressed oxygen from cylinders is used for welding and cutting at nuclear power plants. At some installations piping systems have been installed to supply oxygen to the shop for welding and cutting. Also some plants supply oxygen to a piping system at about 10 psig for use in a catalytic recombiner which serves the gaseous waste system. Such systems are equipped with a pressure relief valve that releases to the outside atmosphere. At North Anna the oxygen system piping for the recombiner within the auxiliary building has a seismic Class I design. Therefore, an earthquake will not result in conditions that could enhance the severity of a fire. Figure 5 shows the piping system at North Anna used to supply oxygen to the recombiner.[46]

6.6 Halon 1301 (Bromotrifluoromethane)

Following is the description of the Halon system for the North Anna Power Station Units 1 and 2. It came from the FSAR for the station.[46] Systems for other plants differ in some details but are generally similar.

At North Anna Power Station, a Halon 1301 (bromotrifluoromethane) system (Fig. 6) is provided for the underfloor area of the main control room.[46] The control room subflooring is relatively isolated from the control room air space. Cable penetrations through the subfloor boundaries are sealed with a room-temperature vulcanizing silicone foam material to maintain fire barrier integrity. The raised floor has removable panels that are firmly set on a grid support system. The grid support system is adjustable, which facilitates the leveling and proper seating of floor panels. Clearances between the edges of the panels are minimal, and the panels require suction-cup grip handles for removal.

The cable seals and panels are used to ensure a high degree of confinement of Halon. The removal of floor panels to verify that the fire is extinguished is easily accomplished with grip handles, several of which are available in the control room. Two cross-connected systems of temperature detectors are provided. Signals from one system cause an alarm only. Signals from two temperature detectors, one from each system, are required for automatic actuation. The system may be manually initiated. Manual or automatic actuation is indicated on the fire protection panel. A smoke detection system of the ionization type is provided for alarm only. The alarm is also indicated on the fire protection panel.

Two types of detection devices are used: rate-compensation-type thermostats and ionization-type smoke detectors. The only material in the underfloor area is control cables, which have flame-resistant insulation and jackets. The thermostat set point of 190°F is well below the ignition temperature of the cable insulation. The smoke detectors will annunciate an alarm in the main control room as soon as smoke enters the ionization path in the detector. Stratification does not occur, since the Halon is released only to the underfloor area, which is ~18 in. deep.

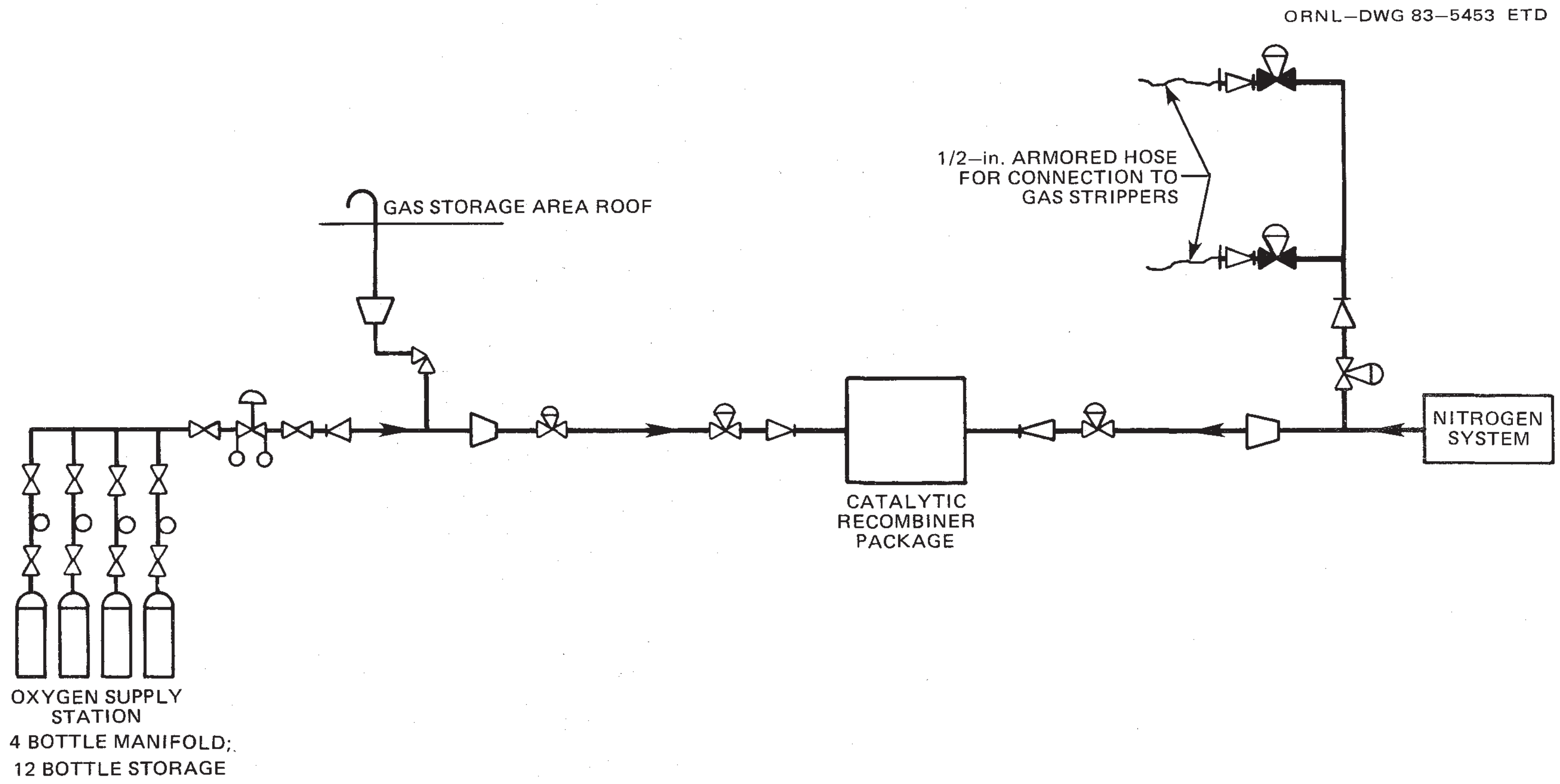

Fig. 5. Example of an oxygen system.

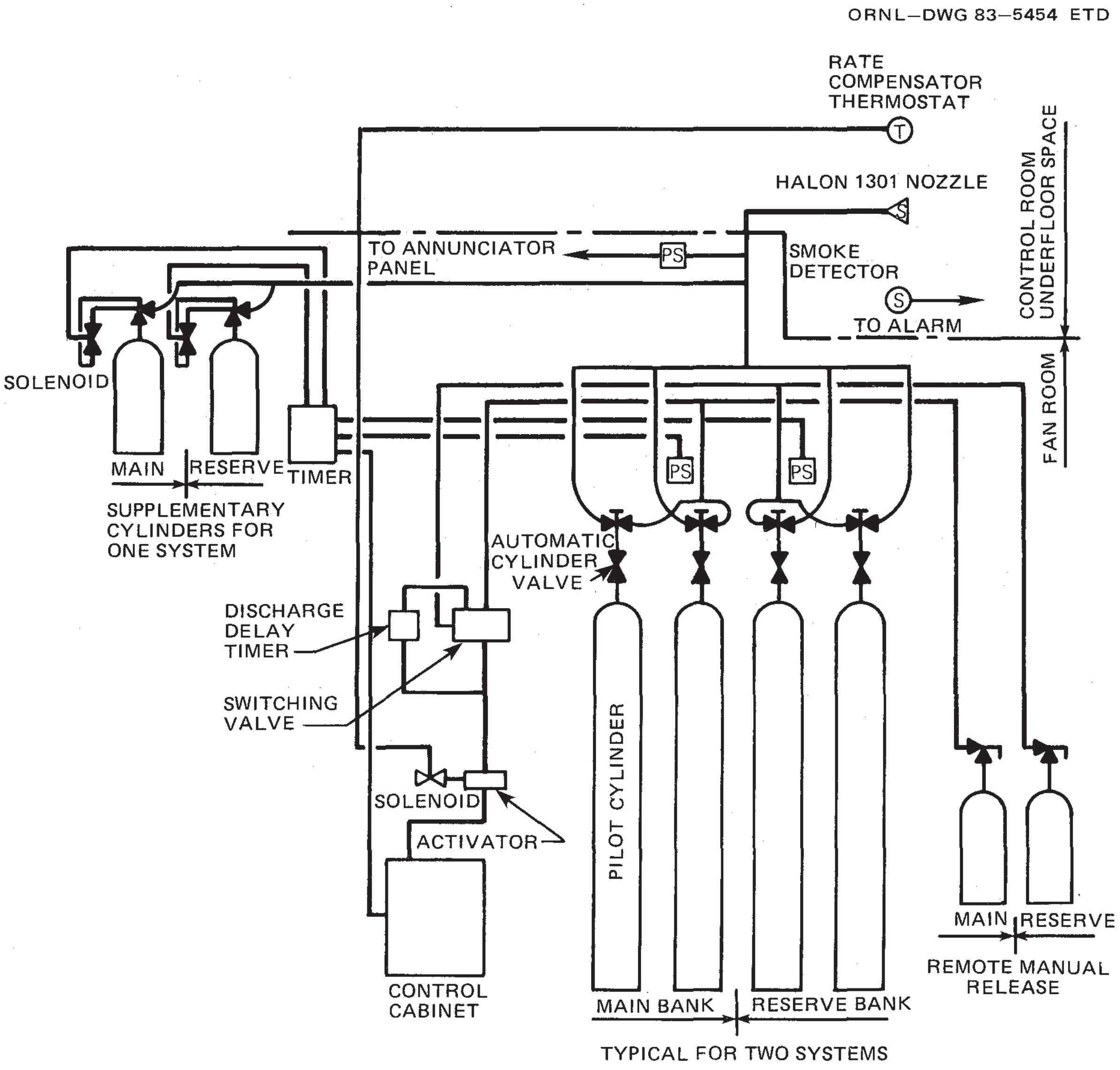

Fig. 6. Example of a Halon system.

The Halon system is a total-flooding system with a 100% reserve capability. Halon concentration in the underfloor area will remain high for a long period, as no air is circulated to this area. Therefore, the cooling time will be long enough to prevent rekindling.

Each system has six 50-lb Halon cylinders: two cylinders for the main bank initial discharge plus one cylinder for supplementary discharging and the same number for the reserve bank. Each bank of two cylinders is sized for sufficient capacity to provide two-shot total flooding at a 6% concentration for the underfloor volume. Each supplemental discharge cylinder is sized to maintain at least a 5% concentration for 10 min.

The Halon 1301 fire protection systems for the isolated underfloor area of the main control room are interlocked with the control room ventilation system. When either the Unit 1 or 2 system is actuated, the normal control room supply and exhaust and the corresponding unit's recirculation fans are shut down. The fans are turned on manually after extinguishment is certain.

A Halon 1301 system is provided for the records storage room located in the office building. Automatic actuation is initiated by any one of the temperature detectors in the area after a local annunciation to warn personnel. Automatic or manual actuation of the system is indicated on the fire protection panel. Actuation of a smoke detection system of the ionization type, which is for alarm only, is also indicated on the main control room fire protection panel.

A Halon 1301 system is provided for the following areas: (1) underfloor area of the monitor control room in the security building, (2) underfloor area of the security control center, and (3) north and south cable vaults of the security control center. Automatic actuation is initiated by ionization-type smoke detectors. Manual actuation is indicated on the main control room fire protection panel.

7. ON-SITE PLANT EVALUATIONS

As stated earlier, incidents involving pressurized gases still occur even though carefully prepared codes and standards exist for design and operation of pressurized gas systems. The low incident rate with pressurized gases may be acceptable in the nonnuclear industry, but in the nuclear industry the rate should be even lower because of potential consequences and public opinion. As a field check of safety in this area, three nuclear power plants were visited. These three were chosen for convenience and accessibility and were neither considered as typical nor as a cross section of the industry. Two of these were still under construction and the third had just started operation. A period of ~6 h was spent at each plant, during which questions were asked of plant personnel, gas lines were traced, and gas equipment was examined in order (1) to gain insight into how likely serious accidents related to pressurized gas systems are to occur and (2) to identify possible situations or mechanisms where a gas accident might initiate a more serious event in a nuclear plant.

The following potential problem areas were reviewed during the on-site plant evaluations.

7.1 Cylinder Storage and Handling

Areas for storing gas cylinders were checked to determine if the cylinders were capped, secured, identified, and segregated. Also housekeeping and ease of access to the cylinders were noted. No problems were found with gas cylinder storage facilities. Cylinder manifolds appeared to be adequately designed and properly maintained. However, while gas equipment was being examined, an acetylene cylinder was found in use with no restraint. The odor of acetylene indicated that a leak was present. Plant procedures require cylinders to be secured, especially when the cap is off.

Areas were noted where the closeness of equipment and piping would prevent positioning an oxygen-acetylene cart so that the work site could be reached with standard hoses. The lengths of these hoses are limited because the maximum regulated hose pressure of acetylene is 15 psig. None of the plants visited had specific procedures for handling this situation. Cylinders could be damaged using cranes or makeshift methods of moving them to the site of work.

7.2 Piping and Pipe Supports

Gas lines were inspected to see if they were protected from external forces and were adequately supported. Possible damage to other equipment from gas line failures was considered. Most of the gas lines were protected from floor level hazards by being routed near the ceiling. However, a few appeared to be susceptible to damage from heavy equipment; hydrogen lines were routed to lower levels to permit operation of valves and instrumentation. Installations were found where the hydrogen lines from the storage tanks had been run in below-ground concrete troughs with steel grating on top. The run of pipe was through the switchyard containing transformers using flammable liquid as the insulating fluid. An exploding transformer could expel flaming liquid into the trough. Although the piping might withstand the heat, a bad joint in a pipe too tightly restrained could break due to thermal expansion.

One plant had hydrogen and oxygen lines running in the same trench and entering the auxiliary building and running parallel inside the building for some distance. A forceful accident could sever both lines and result in a fire or possibly even an explosion under the proper conditions.

At two of the plants visited the hydrogen supply line was equipped with an excess flow device that initiated automatic isolation of the source of hydrogen in case of large leaks. No such protection was provided at the other plant. However, design of this was started while we were still visiting this plant.

No problems with pipe hangers were identified. Also, plant personnel at one plant as well as two architect-engineers contacted by phone advised that seismic design is used for gas lines in critical areas such as the reactor building and auxiliary building or when they interface with safety systems.

7.3 Gas Storage Tanks and Receiving Areas

Gas storage tanks and receiving areas were inspected to determine if they were adequately protected and to assess possible adverse effects on other equipment. High-pressure gas storage tanks and gas receiving areas appeared to be well protected and adequately isolated from other equipment. The hydrogen and oxygen trailer stations were placed in concrete block enclosures located a considerable distance from the main buildings. At one plant a 6-ton, 350-psig carbon dioxide storage tank was located in a separate room of the auxiliary building, and a 24-ton, 350-psig carbon dioxide storage tank was located in an underground pit. The instrument air receivers were not segregated but were located near the air compressors in the auxiliary building. This seemed acceptable because their operating pressure was only ~100 psig. A small air compressor and receiver tank were located in the reactor building.

7.4 Gas System Interfaces

Flow sheets and piping for the hydrogen, nitrogen, and oxygen systems were reviewed to evaluate the possibility of a series of failures resulting in an explosive mixture of hydrogen and oxygen. No interfaces were identified that could cause such an accident.

7.5 Personnel Safety

At one plant there were gages on one side of a diesel generator in an area confined by piping. To take readings from these gages, an operator would have to climb over the piping. If the carbon dioxide fire protection system were to be actuated while an operator was reading the gages, it is doubtful that he could safely exit during the 20-s warning period before carbon dioxide flooded the room.

7.6 Identification of Gas Lines and Tanks

In general the color coding and identification of gas lines and tanks was incomplete in the plants visited. The plants were not fully operational and were still under construction in some areas. However, some of the gas lines were already in use.

Subsequent information obtained through phone conversations with NRC inspectors and plant safety personnel indicated inconsistencies in identification practices. Valves were identified at all plants checked. At several reactors the design drawings were used to identify lines. One licensee stated that color coding would be very difficult due to insulation, penetration of walls, and closeness of lines. At one operating plant the licensee advised that they would start immediately to improve their identification methods.

8. DISCUSSION OF POTENTIAL HAZARDS

Although the gas systems used at nuclear power plants are not generally considered safety systems, some backup equipment may be provided, such as compressed air for critical instrumentation. The consequences of failures discussed here are related to the possible effect that a conceivable gas system failure would have on nearby plant equipment or systems. Although the review of plant histories did not reveal any major gas system failures in nuclear plants, such failures cannot be ruled out. Assessments of the possible consequences are given below.

8.1 Missiles

Under certain conditions vessels containing compressed gases have the potential to become missiles. Such pressurized vessels used in or around nuclear power plants include portable gas cylinders; shipping cylinders mounted on trucks, trailers, or railcars; and fixed storage tanks (listed in decreasing order of accident likelihood).

Of the potential missiles arising from the use of compressed gases, those caused by failure or misuse of portable gas cylinders are the most prevalent, both because of the large number of cylinders used in a typical plant and because of the relative ease with which a failure can be induced. Such accidents were discussed earlier (Sect. 5.1) and can conceivably occur at any place in the plant where these cylinders are used.

As a result of the plant visits and telephone discussions with personnel at two other operating plants, the following items were determined:

1. Compressed gases, including cutting and welding gases, can be used anywhere in the plant. Carts are used for these; however, personnel are allowed to replace empty cylinders in any area.
2. A work plan is generally required for cutting or welding in most areas. These activities are reviewed by safety, quality assurance, and engineering personnel, but no specific procedures were available for this review.
3. Welding and cutting permits, designed to ensure absence of combustibles and provide protection from sparks, are required.
4. Emergency breathing-air cylinders can be used in the control room or other safety-related areas if needed.

Given the above items, it is possible for portable compressed-gas-cylinder missiles to be created at any place in the plant. Depending on the location of the postulated accident, safety instrumentation or electrical lines could be damaged; small pipe lines could be broken; valve operators and other appendages of larger lines could be damaged; and pumps, valves, or other equipment could be made inoperable. In addition, personnel could be injured or killed.

It therefore seems that very serious consideration should be given to potential damages from portable compressed gas cylinder missiles. The extent to which this has been done is indicated by the following quotations from the FSAR of one nuclear power plant.

> The systems located both inside and outside containment have been examined to identify and classify potential missiles. The basic approach is to assure design adequacy against generation of missiles, rather than allow missile formation and try to contain their effects . . . .
>
> In the unlikely event that a missile should be generated, separation of redundant safety-related systems should prevent a compromise of plant safety.[54]

The report listed and analyzed modes and components considered to have a potential for missile generation. In each case it was concluded that missiles could not be generated. However, portable compressed gas cylinders were not specifically considered.

The FSAR of another plant states that there are no internal sources of missiles in such areas as the control building, cable spreading room, or auxiliary instrument room. Prevention of failures of redundant safety channels is provided by locating components in separate control cabinets and providing spatial separation between cable trays.[55]

As indicated in Sect. 5.1, compressed-gas-cylinder missiles have traveled several hundred feet and have gone through brick walls, airplane wings, and fuselages. It therefore seems inadequate to depend on a control cabinet or spatial separation for protecting redundant safety channels.

The appendix contains NRC inspection reports from two reactor sites where unrestrained or inadequately restrained compressed gas cylinders were found. In both reports, concern was expressed that an inadequately restrained cylinder could become a missile and damage safety-related equipment. In one case it was postulated that a coolant system boundary break could have occurred outside primary containment. In one case the NRC reviewers in the Auxiliary Support Branch confirmed the inspector's concern that temporary or transient high-pressure gas cylinders were not analyzed.

Shipping cylinders mounted on trucks or trailers constitute a movable hazard potential wherever these vehicles are employed inside the plant. An accident could occur as a result of a failure of the pressurized vessel itself or as a consequence of external events (e.g., mishandling of the transporting vehicle). However, shipping cylinders and their transporting vehicles are designed to meet Interstate Commerce Commission regulations to minimize the possibility of damage occurring, particularly at the reduced speeds commonly enforced within the plant. Another favorable factor is that most receiving stations are located in somewhat remote areas, thereby minimizing the potential for serious damage should a missile be created.

The permanent on-site storage tanks are remotely located because of their hazard potential, which is sufficiently great that the complete disruption of the tank site must be considered. In some plants, space and logistics have apparently dictated that these on-site storage systems be located adjacent to the main electrical switchyard, which places the switchyard in jeopardy. Gas storage sites can be and have been the source of explosions and fires that are lethal as well as disruptive. Although some of the resulting missiles may have sufficient range to reach the plant, the use of remote sites minimizes the likelihood of serious damage to the plant.

8.2 Vessel Ruptures

Conservative design is used for gas containers, and relief devices are provided to prevent rupture by overpressurization. However, as indicated in Sect. 4.2, failures do occur and the energy released can be considerable (a standard 225-scf gas cylinder at 2000 psig is equivalent to one stick of standard dynamite).

Gas system and gas storage facilities are not included in the list of structures, systems, and components of light-water reactors given in Regulatory Guide as needing protection against tornados.[56] However, because receiving stations are located outside and distant from the buildings, the effect on a plant of any rupture of shipping trailers and trucks or on-site storage vessels would be minimized. On the other hand, carbon dioxide used for fire extinguishing systems is sometimes stored as a liquified gas close to the point of use and loss of the refrigeration compressor could allow the tank pressure to increase. The tank could rupture if it had been weakened (as by fire) or if the pressure relief valves failed to operate. This could result in damage in such areas as the diesel generator room, computer room, or auxiliary instrument room. One plant had a 6-ton, 350-psig storage tank in a separate room of the auxiliary building which provides missile protection. If such protection is not provided, vessel rupture failure can cause damage to other plant systems and equipment.

8.3 Explosions and Fires

Hydrogen is mainly used in the main generator, and at some plants in the volume control tank. In one plant visited a hydrogen line was routed through the auxiliary building. Because no excess flow device was provided, a line rupture could empty an entire trailer of hydrogen in the area of the rupture at a flow rate determined by the pressure-reducing valve. The release of hydrogen could result in an explosion in confined areas of the building.

As indicated in Chap. 6, architect-engineers treat these possible hazards differently. One provides a guard pipe, autoisolation system, and hydrogen detectors in the auxiliary building but no special precautions in the turbine building. Another provides no special protection in either the auxiliary building or the turbine building, except for the ventilation systems. In some plants, changes in supply pressures provide indication of leaks. These are then located using portable hydrogen detectors.

Undetected small leaks of flammable gases can accumulate in confined areas and cause explosions and/or fires. Small leaks from outside storage tanks would probably be dispersed without problem. However, a rupture of a hydrogen shipping trailer (Sect. 8.2) could result in a serious explosive accident. This could possibly cause damage to nearby switchyard equipment.

At two of the plants visited, the hydrogen line from the supply trailer was routed in a concrete trough through the electrical switchyard. Oil from failed switchyard equipment could ignite in the trough and heat the hydrogen line. Any hydrogen leak would add to the fire and increase the damage to other switchyard equipment. OSHA requires that gaseous hydrogen systems be located above ground but not beneath electric power lines.[57]

The principal hazard from the use of propane-powered vehicles is fire.[58] This is minimized by the size of the fuel tanks, which are normally limited to less than 45 lb of gas.[59] In addition, contacts with several authorities did not locate any plants that used propane-powered vehicles in areas containing safety equipment. However, no NRC requirements were found that prohibited their use.

8.4 Toxicity and Asphyxiation

Except for air and oxygen, all of the selected gases are either toxic or can cause asphyxiation. The gases can be released by leaks from or ruptures of storage vessels or gas lines. Carbon dioxide and Halon can also be released automatically upon indication of a fire in areas provided with this type fire extinguishing system. Release of either toxic or asphyxiating gases could cause personnel to be incapacitated, and prevent entrance to important areas. In one plant the emergency generator room, computer room, and auxiliary instrument room have a carbon dioxide fire protection system that requires prompt evacuation if the system activates. Because lines for many of the gases are routed throughout the plant and gas cylinders are used in many locations, leaks or ruptures could cause other areas to be inaccessible.

Chlorine is still used for water treatment in some plants, and chlorine releases have occurred in these plants that caused personnel, including a control room operator, to be hospitalized (Sect. 5.5). As indicated in Sect. 6, NRC requires the control room to be operable at all times. To ensure this, redundant chlorine detectors are used to warn the operators and activate the control room emergency ventilation system. The detectors are periodically tested and are sometimes found to be inoperable. No record of a chlorine release was found when the detectors were inoperable.

8.5 Pipe Whip

Pipe whip can cause damage in case of a rupture of inadequately supported pressurized gas lines. However, pipe whip should not occur in critical areas because (1) gas lines generally are at relatively low pressure and (2) according to plant personnel at one of the plants visited and two architect-engineers contacted by phone, gas lines meet seismic design criteria in the reactor building, the auxiliary building, and areas where they interface with safety systems.

9. SUMMARY AND CONCLUSIONS

The storage and handling of any compressed gas is hazardous because of the high pressures (and stored energy) involved. Some of the gases considered are also flammable, which could cause explosions, and others are toxic or can cause asphyxiation. Although industry has developed codes and standards to reduce or eliminate these hazards, serious accidents do occur (Chap. 5). Nuclear plants are also designed and operated in accordance with these accepted codes and regulations as well as with NRC-imposed regulations. Lines and equipment located in the reactor building, auxiliary building, or areas where they interface with safety systems must meet seismic design criteria. Reported incidents relating to compressed gases are rare in nuclear power plants, indicating that the nuclear industry is generally using safe practices and following recommended safety rules. Continued good design and careful maintenance and operation will help to limit compressed gas incident rates to general industrial levels. On the other hand, compressed gas system-related accidents are possible which would have serious consequences on nuclear power plants. This chapter summarizes findings relative to the safe (or unsafe) use of compressed gases in nuclear power plants. Recommendations regarding those that could have potentially serious safety significance are given in Chap. 10.

9.1 Cylinder Handling and Storage

Portable gas cylinders are subject to damage that could cause the cylinders to become missiles and in some cases cause the release of flammable or toxic gases. Therefore, approved codes and standards for the design and handling of compressed gas cylinders (including the practice of securing cylinders, especially those in use without caps) must be enforced.

Portable gas cylinder missiles represent the most serious potential for damage from the use of compressed gases in nuclear power plants. From the plant visits and subsequent telephone contacts with personnel at additional plants, it was determined that gas cylinders can be taken into any area of the plant if needed. Gases used for cutting and welding are often needed by maintenance personnel. Although carts are used, personnel are allowed to replace empty cylinders anywhere in the plant, and no specific procedures are provided for their use. Serious damage to cylinder valves could create missiles in sensitive areas. This could result in damage to critical equipment, safety instrumentation, or electrical lines and equipment. Prevention of failures of redundant safety channels is provided by locating components in separate control cabinets and providing spatial separation between cable trays. However, compressed-gas-cylinder missiles have sufficient force to damage these as well as redundant safety channels and other critical equipment. NRC inspectors at two plant sites have reported finding inadequately secured cylinders that could damage safety-related equipment.

As indicated in Sect. 8.1, the FSARs of some plants state that there are no internal sources of missiles in safety areas; however, the effect of compressed-gas-cylinder missiles on safety equipment had not been analyzed. This same conclusion was reached by the NRC inspectors.

Based on these findings, there appears to be a lack of continuity between FSAR assurance statements and actual conditions. Protection from portable gas cylinder missiles is considered to be inadequate.

During the plant visits, areas were noted where the closeness of equipment would prevent positioning an oxygen-acetylene cart so that the work site could be reached with standard hoses. No specific procedures were available for handling this situation. Handling these cylinders with cranes or using makeshift methods is risky. Therefore, it was concluded that better maintenance control is needed.

No problems were found with in-plant portable gas cylinder storage facilities. Cylinders were capped, secured, identified, and segregated. Also, all cylinder manifolds appeared to be adequately designed and properly maintained. Except for one acetylene cylinder, all gas cylinders being used in the plants were properly secured.

From Sect. 8.3, it appears that although the hazards from propane-powered vehicles are not great, plants do not find it necessary to use them in safety-related areas. This cautious approach should be continued.

9.2 Piping and Pipe Supports

Compressed gas pipe runs, because of their number, length, and accessibility, constitute a potential hazard. However, the potential is recognized and is accommodated in the plant design. Installation of most of the gas lines at the plants visited was adequate, although some lines were susceptible to damage that would cause failures of other equipment such as the main electrical switchgear. As indicated in Sect. 8.8, the Occupational Safety and Health Act does not permit hydrogen lines to be located below electric power lines. Therefore, it was concluded that hydrogen lines should not have been routed through the switchyard as was done at two of the plants visited. This suggests that a review should be made of the location and protection of all gas lines, especially the hydrogen lines.

The consequences of a gross leak from a hydrogen line into a safety-related area are unacceptable. Excess flow prevention devices are installed in the hydrogen supply lines at some plants to prevent this from occurring. These should be installed at all plants. The NRC requires that hydrogen lines in safety-related areas be either designed to seismic Class I requirements, sleeved so that the outer pipe is directly vented to the outside, or equipped with excess flow valves so that in case of a line break the concentration in the affected areas will not exceed 2% hydrogen.[42] The NRC requirements should be strengthened.

Detection of and protection from small hydrogen leaks varied considerably among plants (see Chap. 6). It was concluded that this problem should be specifically addressed at all plants. Hydrogen detectors should be used in areas where hydrogen could accumulate.

No reports of failures of pipe supports were found in the review. Plant personnel at one plant advised that seismic design is used for gas lines in critical areas such as the reactor building, auxiliary building, or when they interface with safety systems. Two architect-engineers contacted by phone confirmed this design approach. Therefore, it was concluded that pipe supports were adequate.

9.3 Gas Storage Tanks and Receiving Areas

Gas storage tanks and receiving areas are normally isolated from other equipment and are well protected. They do not generally constitute a serious risk to the nuclear plant itself, although an explosion resulting from a rupture of a hydrogen trailer could release the equivalent energy of several sticks of dynamite. However, it was concluded that even if an explosion occurred due to a rupture of a hydrogen trailer, the remote location of the receiving station would prevent serious jeopardy to plant safety. However, at one plant, damage to other equipment would occur because the hydrogen storage tank was located near the main switchyard.

In the plants visited, it was noted that some carbon dioxide storage tanks were located near the point of use, such as those for fire protection of the emergency diesel generators. These tanks were in a separate room and had overpressure protection devices. Similarly, instrument air receiver tanks had overpressure protection devices, and their operating pressure was only ~100 psig. Thus, these do not present an unacceptable hazard.

As was clearly shown by the February 1974 event at Three Mile Island (Sect. 5.4), rupture disk and relief valve vent lines need to be designed to prevent moisture accumulation.

9.4 Gas System Interfaces

No interfaces were found that could result in an explosive mixture of hydrogen and oxygen, nor were such interfaces evident in the reports studied; therefore this was not considered to be a problem.

The use of hydrogen to reduce windage losses in generators is common to the power industry, both nuclear and nonnuclear. Therefore standard practices have been developed to ensure safety. However, hydrogen-air interfaces are possible if carbon dioxide purging is inadequate prior to maintenance. Strict adherence to approved procedures must be followed.

9.5 Personnel Safety

In any plant using gases that are toxic or can cause asphyxiation, there is danger to personnel from potential equipment rupture or leaks. Carbon dioxide or Halon, when used in fire protection systems, has an added hazard because the gas may be automatically released in case of a fire. An alarm is actuated and a time delay is provided to allow personnel time to evacuate. However, at one location a person could become asphyxiated before he could get out of an affected area. It was concluded that this did not constitute a threat to the plant.

The annunciation and automatic actuation of the control room emergency ventilation system in case of a chlorine release allows the control room to remain staffed to control the reactor. There is some hazard to other personnel, but evacuation can be initiated via the public address system from the control room.

In either of the above cases, if licensed operators were asphyxiated, a personnel safety problem could be upgraded to a plant safety problem. In areas where stratification of gases is possible, the oxygen concentration should be checked before entering the area. The buddy system should be used with caution to prevent both persons from being asphyxiated.

9.6 Indentification of Gas Lines and Tanks

At all plants visited, color coding and identification of piping, cylinders, and storage tanks were considered inadequate. Adequate labeling is important to prevent confusion among plant personnel during startup, maintenance, or operation.

10. RECOMMENDATIONS

Nuclear power plants have good safety records regarding the storage and handling of compressed gases. Good design and safe handling practices have been generally followed, as indicated by the relatively few accidents related to gas systems. Because of the serious consequences of some possible accidents and the intense public interest in failures that occur at nuclear plants, this safety record must be maintained.

A review of the potential hazards in Chap. 8 and the summary and conclusions in Chap. 9, show that in most cases present practices in storing and handling pressurized gases in nuclear plants are adequate. In some instances the adverse consequences warrant emphasizing that adherence to these must be continued. A number of potential accidents involving gas systems were identified; however, most are only of interest from an industrial-safety point of view and would not affect reactor safety systems.

This section focuses on the few potential events that could affect reactor safety systems. Recommendations are given for each potential event.

10.1 Gas Cylinder Missiles

Recommendation

Provide protection to prevent unacceptable damage to safety-related equipment from portable gas cylinder missiles.

Basis for Recommendation

1. Portable gas cylinders are susceptible to damage that can cause them to become missiles (Sects. 4.1 and 4.4).
2. Considerable energy is available to propel the missiles (Sect. 4.2).
3. Accidents involving portable gas cylinder missiles have occurred (Sect. 5.1).
4. Nuclear plants contacted indicated that portable gas cylinders can be used anywhere in the plant (Sect. 8.1).
5. Adequate protection from portable gas cylinder missiles is not provided for redundant safety channels (Sect. 9.1).
6. Some plants have not analyzed the effect of portable gas cylinder missiles on safety equipment (Sect. 8.1).

Suggested Method of Implementation

Plant procedures should require that gas cylinders be allowed in areas containing safety equipment only if (1) analysis indicates that portable gas cylinder missiles would not damage safety equipment to the extent that its safety functions were compromised or (2) procedures are developed to protect the cylinders and prevent them from becoming missiles. Standard Review Plan 3.5.1.1 and 3.5.1.2 should be revised accordingly.[38]

10.2 Hydrogen Explosions

Recommendation

Provide protection to prevent an explosion and/or fire from the rapid release of hydrogen in areas containing safety-related equipment or in other areas if unacceptable damage to safety equipment could occur.

Basis for Recommendation

1. Hydrogen lines are routed through the auxiliary building and some are susceptible to damage from heavy equipment (Sects. 7.2 and 8.3).
2. At one plant, no means have been provided to prevent a rapid release of large amounts of hydrogen in case of a line break (Sect. 8.3).
3. Numerous hydrogen explosions have occurred at industrial and nuclear plants causing extensive damage (Sect. 5.4).

Suggested Method of Implementation

Install excess flow valves in all hydrogen lines that enter areas containing or close to safety-related equipment. Standard Review Plan 9.5.1 should be revised to require this addition where not already provided.[42]

10.3 Identification of Lines and Tanks

Recommendation

Provide easily recognizable identification of all high-pressure gas lines and tanks as well as those containing especially hazardous gases such as hydrogen or chlorine, even at low pressures.

Basis for Recommendation

1. A misidentification could cause a hazardous condition.
2. Some plants have inadequately identified pipes and tanks. Whereas some nuclear plants have voluntarily provided identification (Sect. 7.6) and this is often done in nonnuclear plants.
3. Although not a justification, the cost of identification should be relatively small.

Suggested Method of Implementation

Utilities should be required to follow an identification scheme that meets or exceeds the one developed by American National Standards Institute.[60]

REFERENCES

1. Compressed Gas Association, Inc., *Handbook of Compressed Gases*, 2d ed., Van Nostrand Reinhold Company, New York, 1981.

2. American National Standards Institute, Standard Z 37.25 — 1974, Toxic Dusts and Gases, 1974.

3. National Fire Protection Association, Standards for Gaseous Hydrogen Systems at Consumer Sites, NFPA 50A, 1978.

4. G. P. McKinnon, ed., Sect. 5: Chap. 6, "Oxygen-Enriched Atmospheres," in *Fire Protection Handbook*, 14th ed., National Fire Protection Association, Boston, 1976.

5. *Code of Federal Regulations*, Title 49: Transportation, Parts 100 to 177, Office of the Federal Register, Dec. 1, 1980.

6. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, An American National Standard.

7. R. M. Graziano's Tariff No. 29, *Hazardous Materials Regulations of the Department of Transportation Including Specifications for Shipping Containers*, Dec. 15, 1974.

8. National Safety Council, Accident Prevention Manual for Industrial Operation, 7th ed., 1974, p. 904.

9. Theodore Baumeister, ed., *"Marks" Standard Handbook for Mechanical Engineers*, 8th ed., McGraw Hill Book Company, New York, 1978, pp. 4–19.

10. R. D. McCarty, J. Hord, and H. M. Roder, *Selected Properties of Hydrogen (Engineering Design Data)*, National Bureau of Standards, February 1981.

11. W. L. Walls, Sect. 4, Chap. 5, "Gases," in *Fire Protection Handbook*, 15th ed., G. P. McKinnon, ed., National Fire Protection Association, Boston, September 1981.

12. B. L. Greenstreet, M. A. Salmon, and N. A. Weil, "Shock and Missile Protection," Chap. 6.6 in *U.S. Reactor Containment Technology*, by W. B. Cottrell and A. W. Savolainen, ORNL-NSIC-5, Oak Ridge National Laboratory, August 1965.

13. R. C. Gwaltney, *Missile Generation and Protection in Light-Water-Cooled Power Reactor Plants*, ORNL-NSIC-22, Oak Ridge National Laboratory, September 1968.

14. J. S. Sconce, ed., *Chlorine, Its Manufacture, Properties, and Uses*, American Chemical Society, Monograph Series, Reinhold Publishing Corporation, New York, 1962.

15. G. P. McKinnon, ed., Sect. 13, Chap. 4, "The Halogenated Extinguishing Agents," in *Fire Prevention Handbook*, 14th ed., National Fire Protection Association, Boston, 1976.

16. National Safety Council, Construction Section Newsletter, Chicago, March 1959.

17. National Safety Council, Power Press and Forging Section Newsletter, Chicago, March 1959.

18. National Safety Council, Research and Development Newsletter, March—April 1982.

19. Nuclear Regulatory Commission, *Energy Data Base DOE/RECON Users Manual*, DOE/TIC-4586-R1, Technical Information Center, May 1981.

20. J. A. Simmons, R. C. Erdman, and B. N. Naft, *The Risk of Catastrophic Spills of Toxic Chemicals*, UCLA-ENG-7415, May 1974, p. 22.

21. Nuclear Regulatory Commission, *Protection from Toxic Gas Hazards*, IE Circular 80-03, March 6, 1980.

22. D. J. Scott, "Specialty Gases and Hazardous Chemical Wastes," p. 97 in *Hazardous Chemicals Handling and Disposal 1971, The Proceedings of the Second Symposium on Hazardous Chemicals, Handling and Disposal*, R. H. L. Howe (ed.), Noyes Data Corporation, Ridge Park, N.J., 1971.

23. Los Alamos National Laboratory, *Investigation Report, Hydrogen-Oxygen Explosion in a Tube Trailer, Compressed Gas Facility, June 3, 1981*, September 1981.

24. P. M. Ordin, *Review of Hydrogen Accidents and Incidents, in NASA Operations*, NASA TM X-71565, National Aeronautics and Space Administration, 1974.

25. Mechanical Inspection Department, Technical Services Division, *Pressure Safety Training Manual*, Y/TS-13, Oak Ridge Y-12 Plant, Jan. 4, 1982, p. 87.

26. Ibid., p. 88.

27. Ibid., p. 83.

28. Ibid., p. 84.

29. P. M. Ordin, *Review of Hydrogen Accidents and Incidents, in NASA Operations*, NASA TM X-71565, National Aeronautics and Space Administration, 1974, p. 26.

30. P. M. Ordin, *Review of Hydrogen Accidents and Incidents, in NASA Operations*, NASA TM X-71565, National Aeronautics and Space Administration, 1974, p. 29.

31. Letter from J. G. Haynes, Manager of Nuclear Operations, San Onofre Nuclear Generating Station Unit 1, Docket 50-206, to Nuclear Regulatory Commission, July 31, 1981, Subject: LER 80-018.

32. R. H. Guymon, Oak Ridge National Laboratory, personal communication to G. A. Murphy, Oak Ridge National Laboratory, Jan. 14, 1983.

33. Nuclear Regulatory Commission, *Region V Preliminary Notification of Event or Unusual Occurrence*, PNO-V-84-16, March 1984.

34. Nuclear Regulatory Commission, *Region III Preliminary Notification of Event or Unusual Occurrence*, PNO-III-84-59, July 1984.

35. E. L. Spitzer, Donald C. Cook Nuclear Plant, letter to H. Ornstein, Nuclear Regulatory Commission, April 17, 1984.

36. *Code of Federal Regulations*, Title 10, Part 50, Domestic Licensing of Production and Utilization Facilities, Appendix A: General Design Criteria for Nuclear Power Plants.

37. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, NUREG-0800, July 1981.

38. Ibid., pp. 3.5.1.1-3 and 3.5.1.2-3.

39. Ibid., p. 3.6.1-7.

40. Ibid., Sect. 6.4.

41. Ibid., Sect. 3.5.1.4.

42. Ibid., p. 9.5.1-34.

43. Nuclear Regulatory Commission, Regulatory Guide 1.95, *Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release*, Rev. 1, January 1972.

44. Tennessee Valley Authority, Sequoyah Nuclear Plant Unit 1 Final Safety Analysis Update Report, Docket 50-327.

45. E. W. Hagen, *Compressed-Air and Backup Nitrogen Systems in Nuclear Power Plants*, NUREG/CR-2796 (ORNL/NSIC-206), Oak Ridge National Laboratory, July 1982.

46. Virginia Electric & Power Company, North Anna Power Station Unit 1, Final Safety Analysis Report, Docket 50-338.

47. National Fire Protection Association, Standard NFPA 12-1977, Standard on Carbon Dioxide Extinguishing Systems, 1977.

48. Public Service Electric & Gas Company et al., Salem Nuclear Generating Station Unit 1 License Application, p. 9.28-1 of Amendment 38, Question 241, Docket 50-272, June 1976.

49. Consolidated Edison Company of New York, Inc., Indian Point Station Unit 2 Final Safety Analysis Report, p. 09.11.2-1 of Amendment 22, Question 51, Docket 50-247, Aug. 25, 1972.

50. Mississippi Power & Light Company, Grand Gulf Nuclear Station Unit 1 License Application, p. R9.36-1 of Amendment 15, Docket 50-416, Nov. 2, 1973.

51. Illinois Power Company, Clinton Power Station Unit 1 License Application, p. 10-3 of Amendment 13, Question 43, Docket 50-461, May 1, 1974.

52. Washington Public Power Supply System, Washington Nuclear Project Unit 1 License Application, p. Q10-4 and Q10-5 of Amendment 9, Question 38, July 31, 1979.

53. Tennessee Valley Authority, Watts Bar Nuclear Plant Unit 1 Final Safety Analysis Report, Docket 50-390, 1976.

54. Duke Power Company, Catawba Nuclear Station Unit 1 Final Safety Analysis Report, p. 3.5-1.

55. Tennessee Valley Authority, Watts Bar Nuclear Plant Unit 1, Final Safety Analysis Report, Docket 50-390, 1976, pp. 3.5-3 and 8.3-4.

56. Nuclear Regulatory Commission, Office of Standards Development, Regulatory Guide 1.117, *Tornado Design Classification*, Rev. 1, April 1978.

57 General Industry Safety and Health Regulations, Part 1910, OSHA 2206, Occupational Safety and Health Administration, U.S. Department of Labor, June 1974.

58. National Safety Council, Data Sheet 1-653-Rev. 82, Paragraph 64, Chicago, 1982.

59. National Fire Protection Association, NFPA 58, *Standard for Storage and Handling of Liquified Petroleum Gases*, Subparagraph 3561b, 1976.

60. American National Standards Institute, Standard A13.1, *Scheme for Identification of Piping Systems*, 1981.

Appendix

EXCERPTS FROM US NRC INSPECTION REPORTS

US NRC Inspection Report No. 50-293/83-03

On February 4, 1983, the inspector observed, in Fan Room No. 5 (located on the 74' elevation of the reactor building), a high pressure nitrogen cylinder with a regulator attached (this precludes the use of a protective cylinder cap). The cylinder was contained in a transport cart. When questioned about the status and use of the cylinder, the licensee informed the inspector that the bottle was not being used for any current activities and was probably last used during the refueling outage that ended in March, 1982.

On February 16, 1983, the inspector observed, at the west bank Hydraulic Control Units (HCU) on the 23' elevation of the reactor building, a high pressure nitrogen bottle in a vertical position on a concrete pedestal (about 6" off the floor) without it's safety chain being used. The cylinder, which is used to routinely pressurize accumulators for the control rod HCU's, was connected by a small metalic hose between its regulator and the charging station piping. If this nitrogen bottle had become a missle, its close proximity to the HCU insert and withdrawal lines could possibly have caused a reactor coolant system boundary break outside primary containment.

Station Procedure 1.4.8, Section III.A, requires that "when cylinders are not in use, they will be valved off and the protective cylinder caps will be installed. Cylinders containing gaseous elements shall be contained in approved carts or cylinders shall be securely held by safety chains when in the upright position." The licensee initiated corrective actions following each observation by the inspector.

The inspector also held discussions with the licensee pertaining to an apparent lack of guidance available to plant personnel concerning the quantity, approved location within process buildings and storage conditions for high pressure gas cylinders. Additionally, the procedural requirements appeared to need clarification for use, transport and storage conditions. The licensee acknowledged the inspector's concerns and indicated that a review of this area will be performed and Procedure 1.4.8 will be revised to include clear guidance for the control of gas cylinders.

The failure to control hazardous material in accordance with station Procedure 1.4.8 is considered a violation (83-03-04). NRC Inspection Report 81-38, dated February 4, 1982, described a similar violation relating to the control of high pressure gas cylinders.

US NRC Inspection Report Nos. 50-338/84-01 and 50-339/84-01

The resident inspectors have identified a concern with the control of high pressure gas cylinders in areas that contain safety related equipment. Specifically, the concern involved the potential for damage of safety related equipment from a missile generated by a high pressure gas cylinder that has been damaged, i.e., nozzle valve broken off as a result of the bottle falling. At the North Anna Station there is no present program to control non-flammable high pressure gas bottles and the prevalent practice is to loosely secure the cylinder with a rope.

General Design Criterion 4 of 10 CFR requires equipment important to safety be protected against all dynamic effects of missiles that could cause damage to the equipment. Standard Review Plan (SRP) 3.5.1.1 and 3.5.1.2 specify the criteria used by NRR to evaluate an applicant's design or administrative controls to combat the affects of internally generated missiles. These SRP's do not specifically address a high pressure gas cylinder as a credible missile, however, a conversation between the inspector and the NRR reviewer in the Auxiliary Support Branch (ASB) confirmed the inspector's concern that temporary or transient high pressure gas cylinders were not analyzed. Additionally, the ASB reviewer indicated that had he known that high pressure gas cylinders would remain unattended for extended periods in areas that contained safety related equipment, his conclusion on the adequacy of the applicant's design or controls may have been altered.

ACKNOWLEDGMENTS

The authors wish to acknowledge the valuable contribution of the many individuals who reviewed this report in one or more of its draft stages. These reviewers provided additional insights, and the authors are grateful for their helpful assistance. A special word of thanks is due to the technical monitor for this project, H. L. Ornstein, NRC Office for Analyses and Evaluation of Operational Data, who carefully reviewed every draft of the report and was a never failing source of guidance.

Every comment and suggestion of each reviewer was carefully considered, and most of them were incorporated into the final report. Some comments were not included because they were outside the scope of work or because they were not considered to add significantly to the report. In a few instances they were not included because the authors did not agree with the suggestions.

We also wish to acknowledge the cooperation of the personnel at the plants visited. Their assistance in our on-site evaluations was invaluable.

A list of the technical reviewers follows.

Cole, T. E., Oak Ridge National Laboratory, Oak Ridge, TN

Denton, H. R., Nuclear Regulatory Commission, Washington, D.C.

DeYoung, R. C., Nuclear Regulatory Commission, Washington, D.C.

First, M. W., (ACRS Consultant) Harvard University, Boston, MA

Hamrick, T. P., Oak Ridge National Laboratory, Oak Ridge, TN

Kois, J. P., Martin Marietta Energy Systems, Inc., Engineering, Oak Ridge, TN

Martin, R. D., Nuclear Regulatory Commission, Washington, D.C.

Minogne, R. B., Nuclear Regulatory Commission, Washington, D.C.

Moeller, D. W., Advisory Committee on Reactor Safeguards, Washington, D.C.

Murley, T. E., Nuclear Regulatory Commission, Washington, D.C.

O'Reilly, J. P., Nuclear Regulatory Commission, Washington, D.C.

Pate, Z. T., Institute of Nuclear Power Operations, Atlanta, GA

Reed, G. A., Advisory Committee on Reactor Safeguards, Washington, D.C.

NRC FORM 335
(2-84)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE.

1. REPORT NUMBER *(Assigned by TIDC, add Vol. No., if any)*
NUREG/CR-3551
ORNL/NSIC-214

2. TITLE AND SUBTITLE
Safety Implications Associated with In-Plant Pressurized Gas Storage and Distribution Systems in Nuclear Power Plants

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
April	1985

5. AUTHOR(S)
R. H. Guymon, W. R. Casto, E. L. Compere

6. DATE REPORT ISSUED

MONTH	YEAR
May	1985

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Nuclear Safety Information Center
P.O. Box Y
Oak Ridge National Laboratory
Oak Ridge, TN 37831

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
A9132

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Office for Analysis and Evaluation of Operational Data
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

11a. TYPE OF REPORT
Topical

b. PERIOD COVERED *(Inclusive dates)*

12. SUPPLEMENTARY NOTES

13. ABSTRACT *(200 words or less)*

Storage and handling of compressed gases at nuclear power plants were studied to identify any potential safety hazards. Gases investigated were air, acetylene, carbon dioxide, chlorine, Halon, hydrogen, nitrogen, oxygen, propane, and sulfur hexafluoride. Physical properties of the gases were reviewed as were applicable industrial codes and standards. Incidents involving pressurized gases in general industry and in the nuclear industry were studied. In this report general hazards such as missiles from ruptures, rocketing of cylinders, pipe whipping, asphyxiation, and toxicity are discussed. Even though some serious injuries and deaths over the years have occurred in industries handling and using pressurized gases, the industrial codes, standards, practices, and procedures are very comprehensive. The most important safety consideration in handling gases is the serious enforcement of these well-known and established methods. Recommendations are made concerning compressed gas cylinder missiles, hydrogen line ruptures or leaks, and identification of lines and equipment.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS

Nuclear Power Plants
Compressed Gases
Gas Cylinders
Gas Storage
Gas Distribution Systems

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17. NUMBER OF PAGES

18. PRICE