NITROGEN GAS AS A HALON REPLACEMENT

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INTRODUCTION

Under the Montreal Protocol the production of halon fire extinguishants has been phased out throughout the developed world. Recently Koatsu Co., Ltd. began developing, testing, and producing total-flood fire suppression systems containing nitrogen gas as the agent. The nitrogen gas is both the fire suppression agent and the cylinder pressurization agent. These systems are designed to replace Halon 1301 total-flood systems in a variety of applications. The nitrogen gas systems consist of an agent cylinder, discharge manifold, activation valves, distribution piping, nozzles, pipe hangers, and detection/control devices. There are no degradation byproducts resulting from the manufacture, processing, use, or disposal of nitrogen gas. When the agent is discharged in a fire situation the concentrations of carbon dioxide (CO_2) and carbon monoxide (CO) will increase. The increased concentration levels of these species are dependent upon the fire size and extinguishment time. Large-scale fire tests have been performed with Class A fuels (wood crib and PE cable), Class **B** fuels (heptane, fuel oil, toluene, and methanol), and Class C scenarios (energized circuits). Details of the tests and results are presented along with laboratory-scale cup-burner and inertion test data. Agent design concentrations range from 33.6 to **43.5** vol.%. The typical discharge time is 60 sec. Extinguishment times vary from 16 to 80 sec. The minimum measured oxygen concentrations after agent discharge vary from 11.7 to 14.2 vol.% (depending upon the design concentration). The use of the product requires installing new equipment (cylinder, valves, piping, controls, etc.). As with all halon replacements, retrofitting of existing equipment will not be acceptable.

BACKGROUND

The phaseout of halons sparked a renewed interest in developing new total-flood fire suppression systems. Of interest to this paper, a variety of inert gas systems have become commercially available (Table 1). The newest commercially available inert gas systems contain nitrogen gas, being used both as the fire suppression agent and the pressurization agent. Nitrogen gas has long been used in the fire suppression industry. Its primary use has been as a pressurization gas in total-flood fire suppression systems and in portable fire extinguishers. In early 1972 Carhart and Fielding with the U.S. Naval Research Laboratory (NRL) proposed using nitrogen gas as a fire suppression agent onboard submarines [1]. Again in 1994 Carhart advocated the development and **use** of nitrogen gas fire suppression systems as substitutes for halon systems [2].

In the mid-1990s Koatsu began testing, developing, commercializing, and selling nitrogen total-flood fire suppression systems in Japan. In Europe, nitrogen systems are being commercialized and sold by Cerberus. Nitrogen **gas** fire suppression systems will be included in the next revision of the National Fire Protection Association (NFPA) NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems 1996 Edition [3]. Nitrogen gas will also be listed as an acceptable fire suppression agent by the US Environmental Protection Agency (US EPA) Significant New Alternatives Policy (SNAP) Program [4]. Inclusion and listing will be available in 1999.

INERT GASES AS FIRE EXTINGUISHANTS

Combustion cannot occur when the oxygen concentration of air at normal pressures is reduced below approximately 15 vol.%, fires cannot be initiated; at lower concentrations, fires are extinguished. Thus, inert gases such as nitrogen, argon, etc., extinguish fires by diluting the air and decreasing the oxygen content. A limited amount of extinguishment is also caused by heat absorption [5].

The concentrations of inert gases needed for flame extinguishment range from 34 to 52 vol.% depending on the fuel and fire scenario. The extinguishing properties of all the inert gases are similar for Class A, B, and C fires; however, of particular importance, unlike nitrogen, pure argon is suitable for Class D fires involving metals that react with nitrogen (e.g., magnesium and lithium).

PHYSICAL PROPERTIES OF NITROGEN GAS

The physical properties of nitrogen gas are included in Table 2. Nitrogen gas, when used as a fire extinguishant will have the following purity specifications: (1) purity: 99.9 vol.% minimum, (2) moisture: 0.005 wt.% maximum, (3) oxygen: 0.1 vol.%. Other contaminants may include hydrocarbons, CO, NO, NO_2, CO_2, etc. Most are <20 parts per million (ppm). These minor contaminants would depend upon constituents found in the ambient air surrounding the agent manufacturing facility.

TABLE 1. COMMERCIAL INERT GAS FIRE SUPPRESSION SYSTEMS.

Inert Gas Agent	Inert Gas Designation		System Manufacturer
	NFPA/EPA	Trade Name	
Pure Gases			
Argon (Ar)	IG-01	Argotec™	Minimax GmbH
Nitrogen (N_2)	IG-100	NN100™	Koatsu Co. Ltd. and Cerberus
Gas Blends			
50% Ar and 50% N_2	IG-55	Argonite™	Unitor Denmark, A/S
52% N_2, 40% Ar, and 8% CO_2	IG-541	INERGEN™	Anusl, Inc., Tyco International, Ltd., and Fire Eater A/S

TABLE 2. PHYSICAL PROPERTIES OF NITROGEN GAS.

Physical Property	Value	Physical Property	Value
Mole Wt., g/mol.	28.01	Viscosity @ 20 °C, CP	0.017
Melting Pt., °C	-209.86	Critical Temp., °C	-146.9
Boiling Pt., °C	-195.81	Critical Pressure, psi	492.9
Odor Threshold	odorless	Flammability	none
Solubility in Water	2.35 cm^3/100g H_2O @ 0 °C	pH	neutral (7.0)

FIRE SUPPRESSION CAPABILITY

Cup-burner and inertion concentrations using nitrogen gas for a variety of fuels are shown in Tables 3 and 4. Weight and volume equivalent relative to Halon 1301 are shown in Table 5.

TABLE 3. CUP-BURNER EXTINGUISHMENT CONCENTRATIONS."

Fuel	Cup-Burner Ext. Conc., vol.%	Min. Design Conc., vol.% [b]
Acetone	28.5	34.2
Ethanol	36.8	44.2
Methanol	38.5	46.2
Heptane	33.6	40.3
Hexane	30.6	36.7
Pentane	32.4	38.9
Toluene	25.7	30.8
Transformer Oil	27.0	32.4

[a] Reference 6
[b] 120% above cup-burner concentration.

TABLE 4. INERTION CONCENTRATIONS.

Fuel	Inertion Conc., vol.%	Min. Design Conc., vol.% [b]
Butane	40.0	44.0
Propane	42.0	46.2
Methane	37.0	40.7

[a] Reference 7
[b] 110% above inertion concentration.

TABLE 5. WEIGHT AND STORAGE EQUIVALENTS RELATIVE TO HALON 1301.

Agent	Based Upon Typical Design Concentration			Based Upon Heptane Cup-Burner Conc.			Based Upon 120% above Heptane Cup-Burner Conc.		
	Conc., Vol.% [a]	Rel. to Halon 1301	Rel. to Halon 1301	Conc., Vol.%	Rel. to Halon 1301	Rel. to Halon 1301	plus 20%, Vol.%	to Halon 1301	Rel. to Halon 1301
IG-100 (150) [b]	40.3	1.8	11.9	33.6	2.5	16.1	40.3	2.6	16.4
IG-100 (180) [c]	40.3	1.8	9.9	33.6	2.5	13.4	40.3	2.6	13.7
Halon 1301	5.0	1.0	1.0	3.0	1.0	1.0	3.6	1.0	1.0

[a] 12 % above cup-burner heptane fuel ext. conc. for IG-100: 170% for Halon 1301.
[b] Agent cylinder pressurized to 150 bar (2205 psi).
[c] Agent cylinder pressurized to 180 bar (2646 psi).

FULL-SCALE FIRE SUPPRESSION TESTING

Koatsu has verified the fire suppression effectiveness of nitrogen gas through a variety of full-scale fire tests. The test chamber was 102 m^3 (3615 ft^3) in size. The first tests were area coverage tests at 33.6 vol.%, which equates to a measured minimum oxygen concentration of 13.9 vol.%. Ten (10) test cans placed in the comers of the test chamber were repeatably extinguished within 43 sec from the start of the agent discharge. Class A tests with wood cribs and polyethylene (PE) cable were also performed at 33.6 vol.% (13.9 vol.% O_2 conc.). These fires were extinguished within 44 and 71 sec, respectively, from the start of the agent discharge.

Class B (heptane, toluene, and fuel oil) fires were extinguished within 16 to 53 sec using nitrogen gas at 33.6 vol.% (13.9 vol.% O_2 conc.). Methanol extinguishment was successful at 43.5 vol.% (11.8 vol.% O_2 conc.) within 65 sec after beginning of the agent discharge.

Class C energized (420 A, ***60*** sec-preburn, reduced to 320 A) fire test series have also been performed with nitrogen gas, IG-541, HFC-227ea, HFC-23, and CO_2. Both PE and polyvinyl chloride (PVC) cables were tested. PE results are shown in Table 6. Similar agent concentrations were used during similar PVC cable tests; no reignition occurred for the tested agents during the PVC tests.

TABLE 6. CLASS C ENERGIZED TEST RESULTS FOR POLYETHYLENE CABLE.

Agent	Agent Conc, vol.%	Ext. Time, sec	Reignition	Reburning Time, sec
Nitrogen	39.1	11	yes	3
IG-541	40.2	13	yes	6
FM-200	1.6	6	yes	several sec
HFC-23	15.9	6	yes	several sec

ENVIRONMENTAL AND REGULATORY CONSIDERATIONS

Nitrogen gas is not a global warming gas, thus, it does not have a global warming potential (GWP) [8,9]. It is not an ozone depleting compound either. Nitrogen gas is listed as IG-100 in the International Standard Organization (ISO), Technical Committee 21, Subcommittee 8, (ISO/TC21/SC8) Gaseous Media Fire Extinguishing Systems Standard, Part 13 as a firefighting systems extinguishant. Information on nitrogen gas has been submitted for inclusion into NFPA 2001 as a clean extinguishing agent (inert gas). Under Department of Transportation (DOT) regulations, nitrogen gas is regulated as a nonflammable compressed gas, hazard class, or division 2.2, UN1956. Under the Occupational Safety and Health Act (OSHA), nitrogen gas is regulated as a nonflammable compressed gas under Section 1910.101. Nitrogen gas is recognized in the SNAP Program as a pressurization gas for the various listed fire suppression agents. Information for listing nitrogen gas as a fire suppression agent has been submitted for SNAP listing. Nitrogen gas is not a byproduct of another manufacturing process. It is manufactured from ambient air, and at the end of its life **as** a fire suppression agent it will be returned back into ambient air. Nitrogen is not regulated under other environmental regulatory statutes. In fact, the air we breathe contains 78% nitrogen gas.

COST AND AVAILABILITY

Nitrogen is typically cryogenically extracted (liquefied) from atmospheric air. The estimated retail cost for nitrogen gas ranges from \$0.03 to \$0.05/ft^3 of gas. The typical cost range to protect a space with this agent will be \$2.00 to \$4.00/ft^3 of protected space. This cost includes the agent, piping, cylinder, and detection system costs. Nitrogen gas has been produced worldwide for several decades for a variety of applications. A partial list of worldwide agent suppliers is shown in Table 7. Nitrogen gas has been accepted and is currently being produced and distributed in

TABLE 7. PARTIAL LIST OF WORLDWIDE NITROGEN GAS SUPPLIERS.

Ekika Carbon Dioxide Co., Ltd.

Head Office
NS3 Building, 51-3
Akabane 2-chome
Kim-ku. Tokyo, Japan

Kobe Factory
2-1-3, Murodani, Nisi-ku
Kobe. Hyogo, Japan

Nagoya Factory
10-1, Syowa-cho, Minato-ku
Nagoya. Aichi, Japan

Kuki Factory
1-2, Kiyohisa-cho
Kuki, Saitama, Japan

Nippon Sanso Corporations--- Japan

Head Office
1-16-7, Nishishibashi
Minato-ku, Tokyo, Japan

Oyama Factory
498, Shinden, Yokokura
Oyama, Tochigi, Japan

Mie Oyamada Factory
2500, Kashiki, Oyamada-mura
Ayamagun, Mie, Japan

Kitakyushyu Factory
2-3-1, Higashiminato, Kita-ku
Kitakyushyu, Fukioka, Japan

Nippon Sanso Corporations --- North America

Nippon Sanso U.S.A.. Inc.
1105 North Market St., Suite 1300
Wilmington, DE 19801, USA

Matheson Gas Products, Inc.
30 Seaview Dr.
Secaucus, NJ 07096, USA

Matheson Gas Products Canada. Inc.
530 Watson St., East
Whitby, Ontario LIN 5R9, CANADA

Tri-Gas, Inc.
4545 Fuller Dr., Suite 200
Irving, TX 75038. USA

Doussan, Inc.
2525 St. Benard Ave.
New Orleans. LA 70119, USA

Nippon Sanso Corporations--- Europe

Nippon Sanso Netherlands B.V
Postbox 1469 Hoekenrode 6, 1102 BR
Amsterdam Zuidoost, The Neatherlands

Nippon Sanso corporations --- Asia & Oceania

Beijing Representative Office
Room No. 707 Beijing Fortune Bldg
5 Dong Sanhuan Bei-Lu
Chaoyang District, Beijing, China

Bangkok Representative Office
159 SERM-MIT Tower
11th Floor, Sukhumvit 21
Klongtoey, Bankok 10110

Jakarta Representative Office
Wisma Kyoei Prince 13th Floor, Room 1306
Jalan Jenderal Sudirman Kav.
3 Jakarta 10220, Indonesia

Hanoi Representative Office
3F 3 Story Building,
2A Nguyen Dinh Chieu St.
Hanoi. Vietnam

National Oxygen Pte, Ud.
21 Tanjong Kling Road
Jurong Town, Singapore 2262

Nissan-Industrial Oxygen Incorporated Sdn. Bhd
Lot 2, Persiaran Sabak Bernam
Section 26, HICOM Sector B
40000 Shah Alam
Selangor Darul Ehsan, West Malaysia

Tanaka (Thailand) Co.. Ud.
1/10 Moo 5 Rojana Road
Tambol Kamharm Utai
Ayutthaya 13210, Thailand

National Industrial Gases Pte. Ud.
1 Shipyard Road
Singapore 2262

Air Products Industry Co., Ltd.
35/9 Moo 5, Soi Petkasem 69
Bangborn III Road
Khaeng Laksong
Khet Nongkham, Bangkok 10160, Thailand

Dalian Nissan Guangming Gas Co., Ltd.
3 Nenjiang Road
Dalian Economic & Technical Dev. Zone
Dalian, China

Ingasco Inc
Columbian II Bldg.. 4th Floor
118 West Ave.
Q.C. Metro Manila 1104, Philippines

Shenyang Nissan Gas Co., Ud.
No. 50 North I West Road
Tiexi District
Shenyang, China

Japan by Koatsu as a fire suppression agent in commercially available systems (Figures 1 and 2). Nohmi Bosai, Ltd. has also developed a line of fire suppression detectors and control panels suitable for use with nitrogen based suppression systems (Figures 3 and 4). Fire suppression system distributors are also currently in place in many parts of the world. Table 8 summarizes the advantages and disadvantages of nitrogen as a fire extinguishant [2].

TOXICITY CONSIDERATIONS

Koatsu has sponsored two acute inhalation toxicity studies of nitrogen gas and IG-541 (INERGEN™) at the Hita Research Laboratories in Japan [10,11]. The purpose of these studies was to assess the acute toxicity of the test substances under low oxygen concentrations in rats during whole-body exposures. During the first study the rats were exposed to agent concentrations that generated nominal oxygen concentrations of 10 vol.% observation period. During the second exposure study nominal oxygen concentrations of 5.1 vol.% and 7.5 vol.% were used. The LC_{50} values of nitrogen and IC-541 were considered to be less than 5.57 vol.% of actual oxygen concentration in the nitrogen group and approximately 5.40 vol.% in the IG-541 group.

TABLE 8. ADVANTAGES AND DISADVANTAGES OF NITROGEN AS A FIRE EXTINGUISHANT.

Advantages	Disadvantages
Will extinguish fire at life supporting O_2 concentrations.	Not as effective **as** halons.
Extremely environmentally friendly (benign).	Heavy steel cylinders and pipes required when
Wide range of applications.	compared to halon, equipment is similar to other inert gases.
Nontoxic.	Low cooling potential.
Nitrogen gas is by far the cheapest inert gas.	Anoxia potential, especially at high altitudes.
No halogen acid decomposition products.	
Acceptable for occupied areas.	
Readily available worldwide (existing infrastructure).	
Simple flow calculations.	
Available in solid form (additional research required).	

The US EPA in conjunction with a NFPA 2001 Standard Subcommittee on Toxicity convened a panel of toxicity experts to review the toxic effects of using inert gases as fire suppression agents for occupied spaces and the effects of low oxygen environments on human health. Their conclusion is that unneces-sary exposure to inert gas systems resulting in low oxygen environments should be avoided, specifically as follows [12]: (1) Inert gas systems designed to concentrations below 53 vol.% (corresponding to an O_2 concentration of 10 vol.% or greater) are permitted for occupied areas so long as exposures **of** 3 min are not exceeded. (2) Systems designed between 53 and 62 vol.% (corresponding to O_2 concentrations between 10 and 8 vol.%) are permitted for normally unoccupied spaces where exposures are less than 30 sec. (3) If systems are designed to above 62 vol.% (corresponding to 8 vol.% or less O_2 concentra-tion), personnel shall not he exposed to such oxygen depletion. The expert panel found no toxicological advantages of one inert gas over another

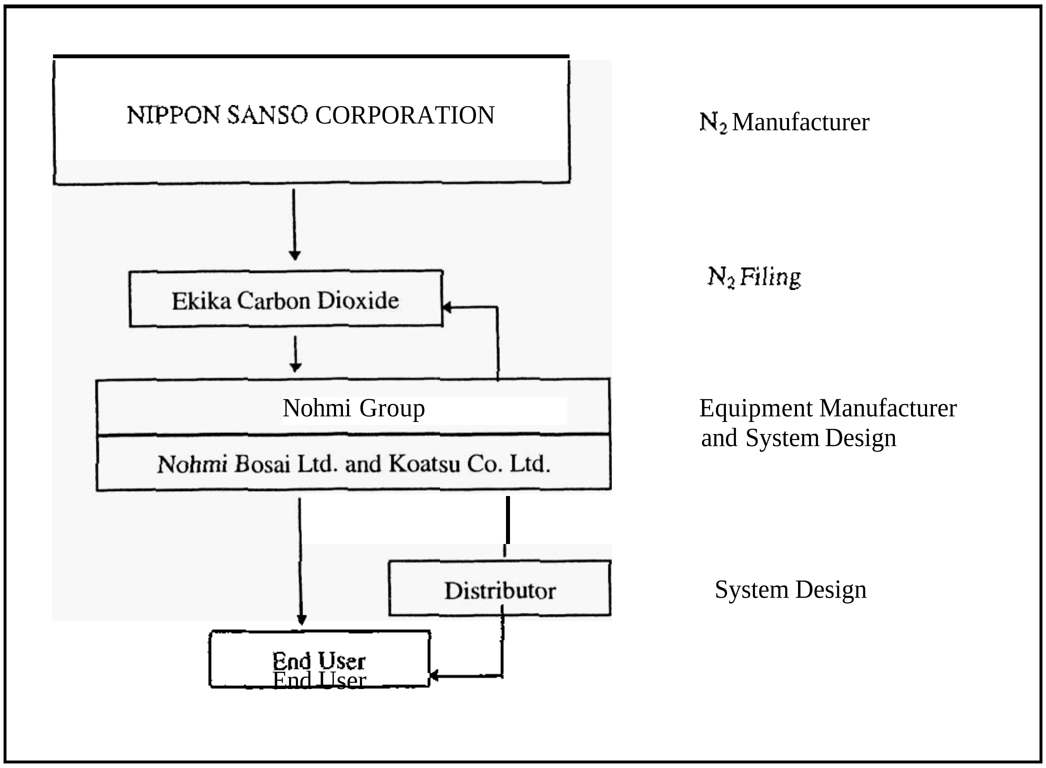

Figure 1. Koatsu *Co.* Ltd. Nitrogen Based Fire Suppression System Associations.

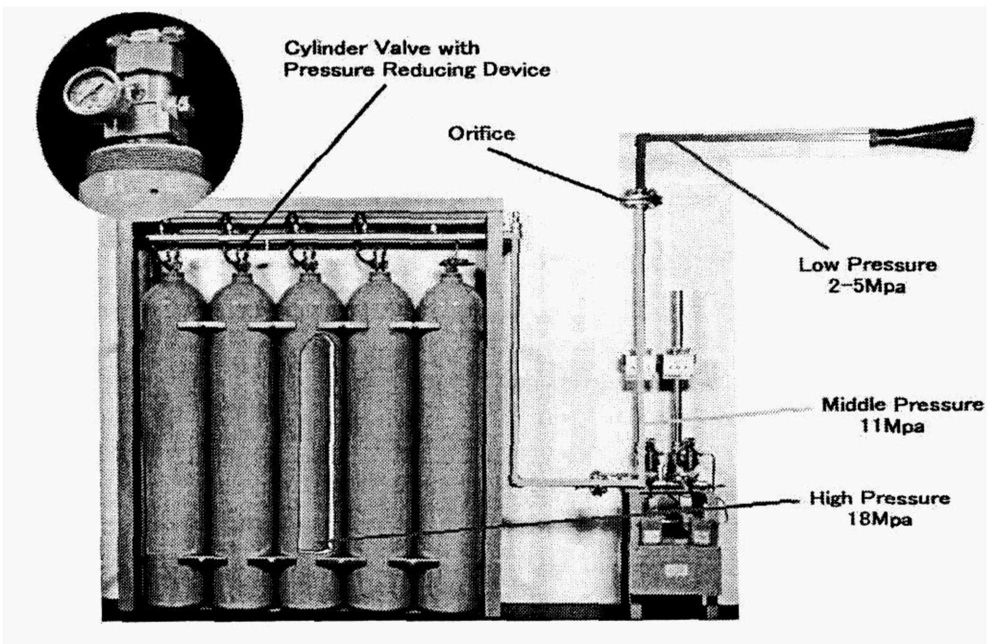

Figure 2. Typical Components of a Nitrogen Gas Total-Flood Fire Suppression System.

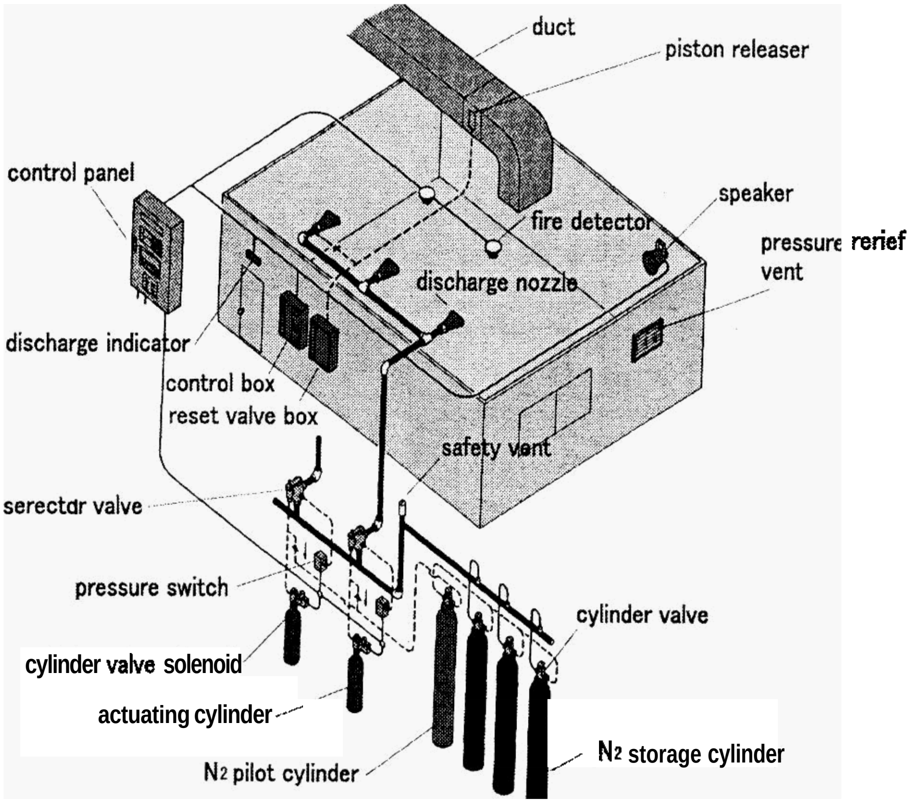

Figure 3. Typical Nitrogen Total-Flood Fire Suppression System Layout.

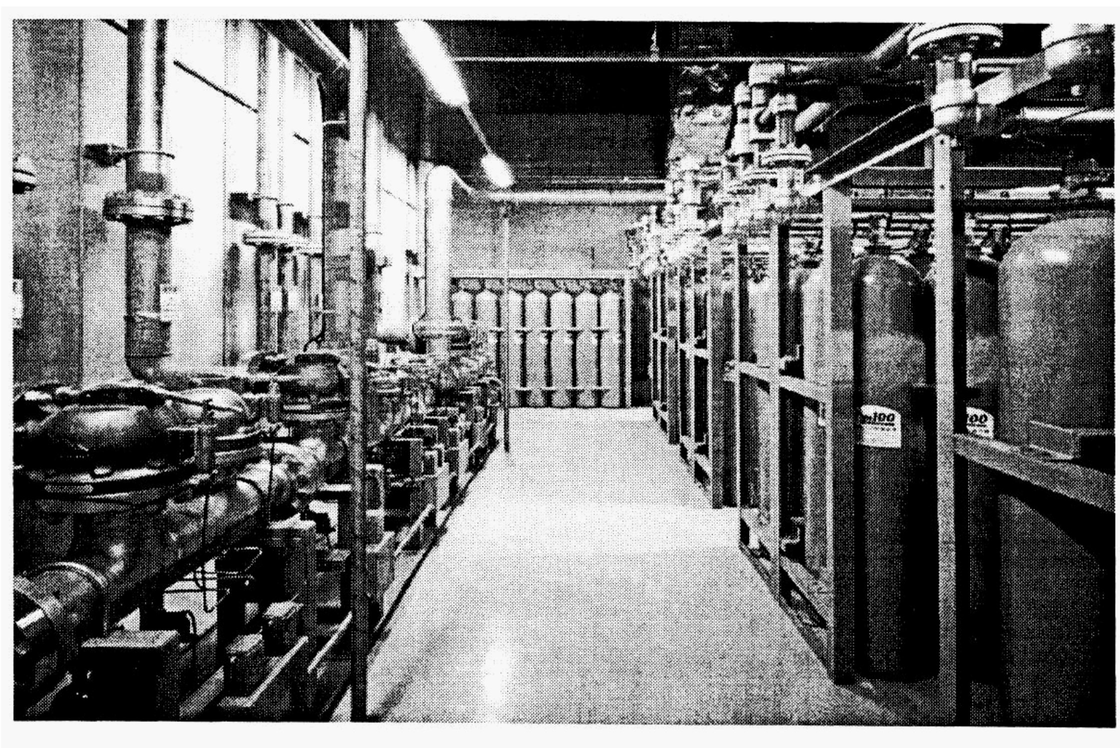

Figure **4.** Typical NN100 Total-Flood Fire Suppression System Installation.

(including INERGEN'"). The critical factor for occupied space protection was to maintain an O_2 concentration above 10 vol.% and egress time under 3 min.

CONCLUSIONS

Koatsu Co., Ltd. has developed, tested, and is manufacturing total-flood fire suppression systems containing nitrogen gas as the agent and the cylinder pressurization compound. These systems are designed to replace Halon 1301 total-flood systems in a variety of applications. The nitrogen gas systems consist of an agent cylinder, discharge manifold, activation valves, distribution piping, nozzles, pipe hangers, and detection/control devices, similar to existing halon systems. The agent cylinders are available in two different pressurizations (150 and 180 bar). Nitrogen gas is the cheapest agent available, effective as the other inert gases, non-toxic, suitable for occupied spaces and, is being listed and approved by the NFPA, ISO, and the US EPA, the system hardware is available today.

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