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Compressed-Air and Backup Nitrogen Systems in Nuclear Power Plants

Prepared by E. W. Hagen

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory
Commission

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FOREWORD

The Nuclear Safety Information Center (NSIC), which was established in March 1963 at Oak Ridge National Laboratory, is sponsored by the U.S. Nuclear Regulatory Commission's Office for Analysis and Evaluation of Operational Data. Support for the technical progress review *Nuclear Safety* (see last page of this report) is provided by both the Breeder Reactor and Light-Water Reactor Safety Programs of the Department of Energy. NSIC is a focal point for the collection, storage, evaluation, and dissemination of operational safety information to aid those concerned with the analysis, design, and operation of nuclear facilities. The Center prepares reports and bibliographies as listed on the inside covers of this document. NSIC has developed a system of keywords to index the information it catalogs. The title, author, installation, abstract, and keywords for each document reviewed are recorded at the central computing facility in Oak Ridge.

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PREFACE

The Nuclear Regulatory Commission (NRC) Division of Safety Technology in the Office of Nuclear Reactor Regulation assigned the project entitled *Special Studies of Reactor Operating Experience* to the Nuclear Safety Information Center (NSIC) in the early part of FY-1981. The object of this project was to identify safety significant implications of current nuclear power plant operating experience by special studies of the following specific subsystems: compressed air and backup nitrogen, service water, decay heat removal, and boron dilution.

About two to three man-months of engineering assessment was devoted to each of the studies. The information used was basically that found in NSIC's files. The documents containing this information are available to the public in the NRC Public Document Room, 1717 H Street, Washington, DC 20555. The scope of the project did not include visits to the plants or meetings with inspectors of the NRC Office of Inspection and Enforcement.

Project personnel for the studies were

NRC Cognizant Manager	M. L. Ernst
NRC Technical Manager	R. L. Colmar
NRC Cognizant Branch Chief	M. L. Ernst
ORNL Program Director	A. L. Lotts
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COMPRESSED-AIR AND BACKUP NITROGEN SYSTEMS IN NUCLEAR POWER PLANTS

E. W. Hagen

ABSTRACT

This report reviews and evaluates the performance of the compressed-air and pressurized-nitrogen gas systems in commercial nuclear power units. The information was collected from readily available operating experiences, licensee event reports, system designs in safety analysis reports, and regulatory documents. The results are collated and analyzed for significance and impact on power plant safety performance.

Under certain circumstances, the "fail-safe" philosophy for a piece of equipment or subsystem of the compressed-air systems initiated a series of actions culminating in reactor transient or unit scram. However, based on this study of prevailing operating experiences, reclassifying the compressed-gas systems to a higher safety level will neither prevent (nor mitigate) the reoccurrences of such happenings nor alleviate nuclear power plant problems caused by inadequate maintenance, operating procedures, and/or practices. Conversely, because most of the problems were derived from the sources listed previously, upgrading of both maintenance and operating procedures will not only result in substantial improvement in the performance and availability of the compressed-air (and backup nitrogen) systems but in improved overall plant performance.

INTRODUCTION

Interest in process control system performance and safety implications for nuclear power plants has been extant for some time. One nuclear power plant service, the compressed-gas system, has on occasion triggered sequences of occurrences that resulted in reactor transients and even unit scrams. However, because of the nonsafety classification for these control systems, only limited attention has been given to this subject. More recently, both the Nuclear Regulatory Commission (NRC) and the Advisory Committee on Reactor Safeguards (ACRS) have directed that attention be given to this subject and to the role these systems play in causing reactor transients. In its August 1979 meeting, the ACRS made several recommendations based on studies to improve reactor safety.[1] One recommendation involved

> ...a systematic reevaluation of the common-mode failure potential of compressed-air systems used for control or service in both safety and nonsafety applications. Among the matters to be considered in such a review should be the effect of moisture and corrosion products and a total loss of air supply. Also of concern is any interconnection of compressed-air supplies to both safety and nonsafety devices and to other fluid systems. Consideration should be given to the adequacy of separation rules for air systems.

The NRC's Division of Safety Technology in the Office of Nuclear Reactor Regulation commissioned this limited-funded study of operating experiences for the compressed-air and nitrogen systems. The purposes of the review were to expeditiously identify and place in perspective any possible significant implications for reactor safety, to determine if the prevailing operating experiences warranted further safety considerations for these systems, and, if so, to determine what relative degree of safety classification would be appropriate for these systems. Systems identification and reported operating experiences that were readily available were systematically compiled, categorized, and evaluated. The period reviewed for the 79 units in 49 plants was from early 1970 or initial unit operation (whichever was first) through early 1981. Loss or impairment of air or nitrogen systems or sub-systems for various reasons including contamination (see Table 1) were studied to identify possible changes in design, operating procedures, or systems classifications that would improve reactor safety.

This study was based on information found in the files of the Nuclear Safety Information Center. The documents used are also available to the public in the NRC Public Document Room, 1717 H Street, Washington, DC 20555. Visits to the plants or meetings with inspectors of the NRC Office of Inspection and Enforcement were outside the scope of this study.

Computerized reference files of the Nuclear Safety Information Center (containing more than 24,000 LER descriptions plus abstracts of thousands of other operational and licensing documents) were systematically searched for those events associated with pneumatic systems and nitrogen backup or support for such systems. The computer selected and retrieved some 564 references, including replies to questions asked by the NRC during their

Table 1. Plant distribution of compressed air and backup nitrogen LERs per unit subsystem/system services and auxiliaries

Name of reactor	Reactor type[a] (designer)[b]	Automatic depressurization system	Air compression equipment	Boron system	Breathing air system	Component cooling system	Containment atmosphere	Containment isolation	Containment penetrations	Control room ventilation system	Diesel-generator air-start system	ECCS room ventilation	Electrical power breakers	Feedwater control valves	Floor/sump drain valves	Main cooling system valves	Main steam isolation valves	Nitrogen system	Pressure relief/ safety valves	Radwaste system isolation valves	Resin transfer valves	Scram discharge volume valves	Service water system valves	Shutdown cooling system valves	Standby gas treatment valves	Steam-generator isolation valves	Turbine service valves	Vacuum breaker system valves	Reactor building isolation valves
Arkansas 1	PWR (BW)								1		1												1						
Arkansas 2	PWR (CE)																												
Arnold	BWR (GE)										1								1										
Beaver Valley 1	PWR (W)		2								1						1												
Big Rock Point	BWR (GE)					1		2										1			1								
Browns Ferry 1	BWR (GE)										4																		
Browns Ferry 2	BWR (GE)																												
Browns Ferry 3	BWR (GE)							1																					
Brunswick 1	BWR (GE)						1	3								1													
Brunswick 2	BWR (GE)		1				1		1		2				1	1	1												
Calvert Cliffs 1	PWR (CE)										3	1																	
Calvert Cliffs 2	PWR (CE)		2								3																		
Cook 1	PWR (W)						1	1																					
Cook 2	PWR (W)		1								2																		
Cooper	BWR (GE)	1						1			4						2												
Crystal River 3	PWR (BW)																									1			
Davis-Besse 1	PWR (BW)									1						1	1												
Dresden 1	BWR (GE)										1																		
Dresden 2	BWR (GE)							3			10																		
Dresden 3	BWR (GE)							1			2											2							
Farley 1	PWR (W)		1					1			13						1												
Fitzpatrick	BWR (GE)										1				1														
Fort Calhoun 1	PWR (CE)										6			1									1						
Fort St. Vrain	HTGR (GA)																												
Ginna	PWR (W)																1												
Haddam Neck	PWR (W)																									1			
Hatch 1	BWR (GE)		2								2						1												
Hatch 2	BWR (GE)	1						1																				2	
Humboldt Bay	BWR (GE)													1															
Indian Point 1	PWR (BW)		1																										
Indian Point 2	PWR (W)		3								1							1											
Indian Point 3	PWR (W)		2																										
Kewaunee	PWR (W)						1	1			4		1																
LaCrosse	BWR (AC)																												
Maine Yankee	PWR (CE)		1																										
Millstone Point 1	BWR (GE)		1					2						1															
Millstone Point 2	PWR (CE)																		3				1						
Monticello	BWR (GE)		2					1			3								1			1							
Nine Mile Point 1	BWR (GE)																1												
North Anna 1	PWR (W)					1		1									1										1		
North Anna 2	PWR (W)																1	1											
Oconee 1	PWR (BW)																												
Oconee 2	PWR (BW)				1			1	1							2													1
Oconee 3	PWR (BW)																												
Oyster Creek	BWR (GE)		1														2					1			1				
Palisades	PWR (CE)							2			1				1									1					
Peach Bottom 2	BWR (GE)	1									1							1		1									
Peach Bottom 3	BWR (GE)						1	2			1		1					7											
Pilgrim 1	BWR (GE)																												
Point Beach 1	PWR (W)										1																		
Point Beach 2	PWR (W)									2										1						2			

Table 1 (continued)

Name of reactor	Reactor type[a] (designer)[b]	Automatic depressurization system	Air compression equipment	Boron system	Breathing air system	Component cooling system	Containment atmosphere	Containment isolation	Containment penetrations	Control room ventilation system	Diesel-generator air-start system	CCS room ventilation	Electrical power breakers	Feedwater control valves	Floor/sump drain valves	Main cooling system valves	Main steam isolation valves	Nitrogen system	Pressure relief/ safety valves	Radwaste system isolation valves	Resin transfer valves	Scram discharge volume valves	Service water system valves	Shutdown cooling system valves	Standby gas treatment valves	Steam-generator isolation valves	Turbine service valves	Vacuum breaker system valves	Reactor building isolation valves
Prairie Island 1	PWR (W)																1												
Prairie Island 2	PWR (W)						2									1													
Quad Cities 1	BWR (GE)										4				1		2												1
Quad Cities 2	BWR (GE)		1					3									4											1	
Rancho Seco	PWR (BW)							1			2																		
Robinson 2	PWR (W)		1							1														1					
St. Lucie 1	PWR (CE)		2					1			1						1											1	
Salem 1	PWR (W)					1					1						1												
Salem 2	PWR (W)																												
San Onofre 1	PWR (W)																						1						
Sequoyah 1	PWR (W)						2				1																		
Sequoyah 2	PWR (W)										1																		
Surry 1	PWR (W)		2		1	1																							
Surry 2	PWR (W)			1				2			1						1												
Three Mile Island 1	PWR (BW)																												2
Three Mile Island 2	PWR (BW)																												
Trojan	PWR (W)													2															
Turkey Point 3	PWR (W)																												
Turkey Point 4	PWR (W)													2			2												
Vermont Yankee	BWR (GE)	1	1				1	1			1						1								1				
Yankee Rowe	PWR (W)							1																					
Zion 1	PWR (W)		3				1	6			7						1									3			
Zion 2	PWR (W)						1	16	1		6						2												

[a] PWR = pressurized-water reactor, BWR = boiling-water reactor, HTGR = high-temperature gas-cooled reactor.

[b] BW = Babcock and Wilcox, CE = Combustion Engineering, GE = General Electric, W = Westinghouse, GA = General Atomic, AC = Alice Chalmers.

review of SARs. These references in turn led to the selection of certain system schematics as representative. Many plants have specific features, but these did not appear in the problem areas. Five systems generally common to all units were identified along with three interesting plant-specific systems. The initial premise was that a probability would be found to justify reclassifying the air systems to a safety grade. However, analysis of the available operating experiences did not produce such evidence. Only when accident scenarios were developed past the first stage of "what if's" following a failure could a potential be indicated for a serious accident.

Because compressed air is needed for process instrumentation and control and unit/plant services, this study begins with a review of the requirements for the air itself and the general concerns and problems with compressed air. Brief descriptions for five typical major compressed-gas systems are presented along with a few representative design problems encountered during the operation of these systems. Complete tabulations of operating experiences are found in the Appendixes. The safety relevance of these systems and the consequential inspection and testing requirements are reviewed; a discussion of observations and comments follows. Conclusions and recommendations conclude this study.

COMPRESSED-AIR CONTAMINANT PROBLEMS

Compressed air may be contaminated from several sources including (1) the ambient air, (2) the compressor itself, (3) drying equipment, and (4) corrosion products in the piping systems. Thus, compressed air must be cleaned and for many applications also dried. Service air for many applications such as tools, cylinders, brakes, and various machinery can carry dirt, water, and sludge into the equipment, causing corrosion and impending free movement of moving parts. On the other hand, instrument air must be of a higher grade to prevent clogging and corrosion inside tubing, instruments, and valves.

Air taken in by a compressor will contain a certain amount of water based on ambient air temperature and relative humidity. In addition, it may carry corrosive chemical vapors that could harm the compressor and equipment using air. If the air is for breathing purposes, contaminants such as carbon monoxide must also be removed.

Dirt and process material particles in the air sometimes damage compressors and equipment using air. Particles can mix with compressor lubricant or coolant to alter properties and also form a grinding compound that will cause excessive compressor wear. Oil, which would jeopardize pneumatic instrument performance, may be in intake air. Contaminant oil may be incompatible with the compressor lubricant. The compressor can itself add contaminants to the processed air. A reciprocating machine may put lubricant-breakdown products into the compressed air. Rotary-screw machines also may add oil during periods of upset. An oil-free reciprocating compressor can release small amounts of Teflon or graphite into the air. Compressors containing synthetic lubricants can add materials that are incompatible with oils entering in the intake air or from other compressors.

Downstream from the compressor, rust and scale from piping may enter the air. These contaminants can be in comparatively large fragments, capable of blocking instrument and tool orifices. Compressed air can contain particles from regenerative dryer and desiccant dryers. By far the worst contaminant is water in droplet and vapor form. Water droplets have a large total surface area and can pick up oil-like contaminants to form emulsions. A sludge will block lines to instruments and tools and clog close clearances in them. Acid-breakdown products may attack seals and gaskets.

Heat is not a contaminant per se, but it often is removed from compressed air to permit easier and cheaper removal of water. Heat is replaced in compressed air after water is removed in some aftercoolers and dryers. Air may be heated merely to prevent pipe sweating or, when heated to considerably higher temperatures, to help prevent freezing or water fallout futher down the air lines.

Generally, however, the trend is to use higher-quality air, with many decisions on auxiliary equipment being made on the basis of preventing trouble. The potential for damage and loss is real, and the cost of the auxiliary equipment is low in comparison with compressor capacity cost or reactor unit downtime.

GENERAL DESIGN BASES FOR COMPRESSED-AIR SYSTEMS

A compressed-air system is provided for normal nuclear steam supply instrumentation and valve operators, both of which are required for plant control. The objective of the compressed-air system is to ensure the availability of required air of suitable quality and pressure for instruments, controls, maintenance, and general power plant uses and operations.

The compressed-air system is generally divided into two subsystems, the service air system (SAS) and the instrument air system (IAS). The compressed-gas system (air and nitrogen) is not classified as safety grade except for those portions of the distribution system that penetrate the containment. The auxiliary building penetrations, the containment penetrations, and the drywell penetrations are of seismic category 1 (Ref.2) design and are equipped with sufficient isolation valves to satisfy the single-failure criteria.[3] In some cases, a separate and independent system called the containment instrument air system (CIAS) is located entirely within the containment structure to preclude any pressurization of the containment structure.

The SAS is designed to provide air at a nominal pressure of 100 psig to various plant locations and equipment for operational and maintenance purposes. When used for cleaning purposes, the air does not exceed 30 psig. The SAS is also designed to back up the IAS during abnormal unit operations. The IAS is designed so that the instrument air shall be available under all normal and abnormal operating conditions. All essential systems requiring air during or after an accident are self-supporting, and after an accident the air system is reestablished. The IAS is designed to provide air that is clean, dry, oil free, and at a nominal pressure of 90 to 125 psig for pneumatic instruments, controls, valves, and actuators. The dewpoint should be -40°F at 100 psig, and no entrained particles larger than 10-μ nominal size should be present.

The standby diesel-generator air-starting system is designed in accordance with General Design Criteria Nos. 2, 4, and 5 (Ref. 4) and Regulatory Guides Nos. 1.26 (Ref. 5) and 1.29 (Ref. 2). The standby-generator air-starting system in general also meets the following specific requirements:

1. Each standby diesel generator is provided with two independent and redundant starting systems, consisting of air compressor, air receiver(s), injection lines and valves, and devices to crank the engine. Sufficient redundancy is provided to ensure proper operation of the system during a maintenance outage or failure of any component in the system.

2. Each of the redundant starting systems is capable of providing three automatic starts and two manual starts without recharging the receiver.

3. Alarms are provided to alert operating personnel if the air-receiver pressure falls below the minimum allowable value.

4. Provisions are made for the periodic or automatic blowdown of accumulated moisture and foreign material in the air receivers.

SYSTEMS DESCRIPTIONS AND OPERATING EXPERIENCES

During the review of the Safety Analysis Report (SAR), many questions are asked of the owner/operator by the NRC to obtain more information about specific aspects of the system design and performance. A retrospective search of the computerized files at the Nuclear Safety Information Center yielded 151 entries on questions by reviewers pertaining to pneumatic systems. Table 2 lists the systems/equipment of expressed interest and the percentage of the total number of responses compared with questions asked about each item. The responses to questions in the SAR review were concerned mainly with aspects of general systems analysis and tests (60%), which was four times greater than the second largest topic of interest, the dieselgenerator starting system (15%). Table 2 compares the systems/equipment reviewed during the licensing process to the operating experiences for the same systems/equipment. For example, the diesel-generator airstarting systems accounted for 15% of the reviewers' questions, whereas 30% of the LERs were concerned with these systems. Containment atmosphere, isolation, and purge accounted for 6% of the question but for 36% of the nitrogen-system-related LERs and 25% of the air-system-related LERs. System design accounted for 60% of the review questions, 52% of the nitrogen-system-related LERs, and 16% of the air-system-related LERs. It would appear that SAR reviewers should devote more effort to system/equipment functional operation and performance and less to design analysis and application.

Typically, all reactor units have at least two compressed-air systems although most have more compressed-air systems and a pressurized-nitrogen-gas service or system. The compressed-air system generally refers to the combination of the IASs and the SASs.

A compressed-air station provides pressurized air to the IAS for control instrument action, pneumatic controls, and actuation of valves, dampers, and similar devices and to the SAS for items such as portably maintained tools and equipment and air-generated equipment. Other major pressurized-gas systems are the CIASs, the automatic depressurization systems, the diesel-generator air-start systems, and the nitrogen systems. Some typical systems are briefly described, and some specific operational

Table 2. A comparison of responses to reviewers' questions to number of events reported

(Percent of total)

System/equipment	Responses to questions	Operating experiences for	
		Nitrogen systems	Compressed-air systems
Automatic depressurization system	6		1
Atmospheric steam dump	1		
Breathing air	0.5		0.5
Component cooling		1	0.5
Containment atmosphere		24	5
Containment isolation	3	12	15
Containment purge	3		5
Cover gas		2	
Diesel-generator starting	15		30
Drywell/suppression pool purge	7		7
Feedwater			3
Heating, venting, and air conditioning	0.5		1
Main steam isolation valve	4		10
Pressurizer		3	1
Safety relief		5	2.5
Scram discharge	0.5	1	1.5
Service water			1
Systems analysis and tests			
System, component/equipment	60	52	16

experiences relevant to system design are cited for those systems. Tabulations of operating experiences are found in Appendix B.

A compressed-air station consists of compressors plus the added equipment and devices selected to improve the quality of the air and to ensure reliable air delivery. Compressed-air quality requirements depend chiefly on the end use for the air. Reliable air delivery can be obtained by redundancy or especially high quality equipment if proper maintenance and operating procedures are preserved and followed.

The typical compressed-air station generally employs redundant, nonlubricated electrical-motor-driven air compressors. Usually located in the turbine room, air compressors can be operated manually from either a local control panel or remotely from some control rooms. Room air is drawn into each compressor through intake air-filter-silencers and discharged through a water-cooled aftercooler/moisture separator to air receivers where the air is stored. Generally, the compressors discharge into a common header. Cooling water for the compressors and aftercoolers is supplied by the unit service water system. The air receivers discharge through isolation valves and check valves into another common header. The check valves prevent the systems from discharging back through the receivers and/or compressors. However, on at least one occasion, this design failed. The event was reported as a complete loss of air at Monticello [LER 81-20, February 24, 1981 (Ref. 6)]. Monticello reported that a loss of plant compressed-air supply occurred when one of two operating air compressors was shut down. The check valve on the discharge side of the shutdown compressor was stuck in the open position, providing a path from the common header back through the check valve and compressor to the atmosphere. With that path open to the atmosphere, the operating compressor could not supply adequate air for normal plant operation, and the SAS and IAS pressures decayed to ~18 psig before the problem was discovered and corrected. Loss of SAS and IAS pressure caused the closing (fail-safe) of the condensate demineralizer control valves which resulted in a trip of feedwater pumps which caused a low-reactor-water-level trip of the reactor. Approximately 1 min after the compressor was shut down, a low air pressure annunciator signal was received in the control room with the reactor trip occurring ~1 min later from 98% power.

At Peach Bottom, the loss of an air compressor resulted in the loss of one offsite power source [LER 79-14, June 20, 1979 (Ref. 7)]. An offsite source breaker was feeding emergency busses in units 2 and 3 and one auxiliary bus in unit 3 (a normal electrical configuration) when the breaker tripped because of low air pressure. Loss of some auxiliary power loads in unit 2 and half isolations in both units resulted. A short circuit in the light socket on the auto transfer switch tripped the breaker for the air compressor.

A standby air compressor is usually available and is kept in an automatic mode to start whenever a low discharge header pressure condition is sensed. Also, a pressure control valve, or flow resistor, is generally used in the service air discharge header to isolate the service air header on low compressor discharge header pressure to allow more air for instruments and controls required for unit operation. This discharge header low-pressure condition is alarmed in the control room. To maintain uniform wear and to verify proper component operability, the operating modes of the air compressors are alternated through administrative control.

During the review of LERs, a problem concerning maintenance and use of IASs became apparent. An example taken from the operating reports for Zion 1 and 2 explains the problem (see Table B.1). LERs 74-38 (Ref.8) and 74-32 (Ref. 9) for units 1 and 2, respectively, were the first of 32 that began in September 1974. An isolation valve failed to close during tests in each of the first two occurrences. In the first, the operator freed the valve action; in the latter, the air solenoid valve had to be replaced. Through May 1980, 30 other LERs reported similar responses. The failure mechanism was described in the Zion 1 LER 76-46 [September 8, 1976 (Ref. 10)] as being a failure of an ASCO Series 8320 solenoid valve in the air supply to the operator caused by the valve's actuating piston being stuck. Previous failures had indicated that the pistons stuck because of varnish on their surfaces resulting from oil impurities in the IAS that collected on the piston and were broken down by the coil heat. Then, in October 1976, Zion 1 LER 76-61 stated that another ASCO Series 8320 solenoid valve failed because its actuating piston was stuck due to a varnish buildup on the pistons. The adhesion was broken by a slight tap. This varnish was thought to come from oil introduced into the IAS when it was cross-tied with the SAS.

By now the cause of the failure was inherent to the system and the problem was exacerbated whenever the cross-connection was made between the two compressed-air systems. Thus, the problem was reported in various LERs throughout the period covered by this study. A third instrument air compressor and filter was installed to minimize the need to cross-tie with the oil service air system. Filters were also installed in the cross-tie line. This ensured a fresh supply of good air but did not remove impurities previously introduced.

Because only some of the ASCO valve operators on the IAS header experienced failures, the station personnel tried to identify a common mode of failure for these valve operators. Areas investigated were (1) design tolerances, (2) ambient environment conditions, (3) mounting orientation, (4) drainage characteristics of air header, and (5) coil design.

A plant maintenance program is apparently underway to correct this problem because LER 80-018 [May 1980 (Ref. 11)] for Zion 2, entitled Air Isolation Valve Failed To Close, states that after maintenance unstuck the solenoid the valve was operable. ASCO solenoid rebuild kits will be installed during unit 2 outage.[11] Although such a program may result in fewer reported inoperative valves, the cause of the basic problem will still exist (i.e., dirty, oil-wet air piped through the IAS). If the system is not to be retubed, the approach taken by Indian Point 1 is one solution to this problem. Essentially, the instrument air distribution system was blown down to remove accumulations of water and oil, the valves were all disassembled and cleaned, and additional filters and dryers were installed. (See LER for Indian Point 1 dated May 6, 1971, Appendix A.[12]) None of the reported events at Zion were judged as having adversely affected the safe operation of the station, plant, or unit. Other LERs reported for the compressed-air station are listed in Table B.1 (Appendix B). Some events that resulted in a reactor transient are summarized in Appendix B.

Service Air System

The SAS furnishes compressed air for pneumatic tools, circulating-water-pump priming, and miscellaneous cleaning and maintenance purposes throughout the secondary and primary plants. This system is used for all indoor services where ambient temperature is not expected to drop below 50°F. Services used for outdoor equipment and for lines that leave the control house and/or turbine room and enter the yard area to serve the primary auxiliary building and containment building are served through a desiccant-type dryer, which further reduces the dewpoint to -40°F to be compatible with the lowest expected outdoor temperature.

The SAS distribution header is taken off the air receivers common discharge manifold (for example, see Figs. 1 and 2). The takeoff is made from the top of the manifold to reduce moisture carried through the line. The SAS header is connected to the IAS header through a normally closed, automatically actuated valve and check valve in series to preclude inadvertent use of instrument air by the SAS. This allows the SAS to back up the IAS, therefore ensuring priority for instrument air requirements. Whenever necessary throughout the unit, air for personal breathing apparatuses can be obtained from the SAS headers.

Interdependencies between systems and routine operating procedures under seemingly normal operating conditions can combine to produce unexpected results. For example, LER 78-71 [November 1, 1978 (Ref. 13)] for Salem reports that all three air compressors were rendered inoperable and low SAS pressure allowed air-operated fire protection deluge valves to open. LER 78-39 [October 4, 1978 (Ref. 14)] for Peach Bottom 2 reports that service air was used at times to supply breathing air for workers performing maintenance in areas with high airborne contamination. On September 4, 1978, and again on September 21, a backflow of radioactive liquid occurred from the radwaste system demineralizers to the SAS. At these times no work requiring air breathing service was in progress. Breathing air supply equipment filters were checked for contamination, but none was found. The problem was caused by valve leakage attributed to dirt deposits in the process valves and associated check valves between the SAS and the demineralizers in the radwaste system.

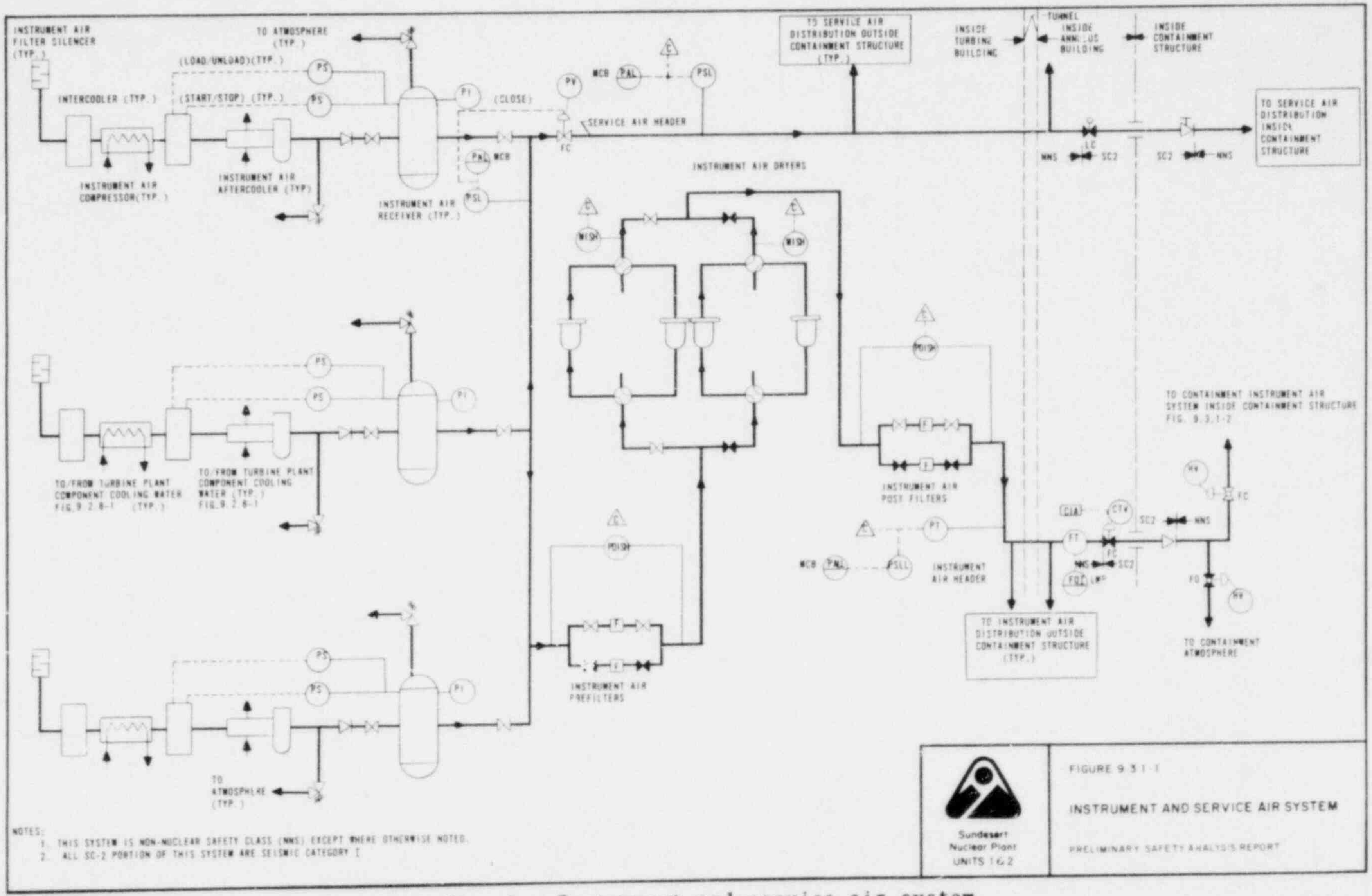

Fig. 1. Instrument and service air system.

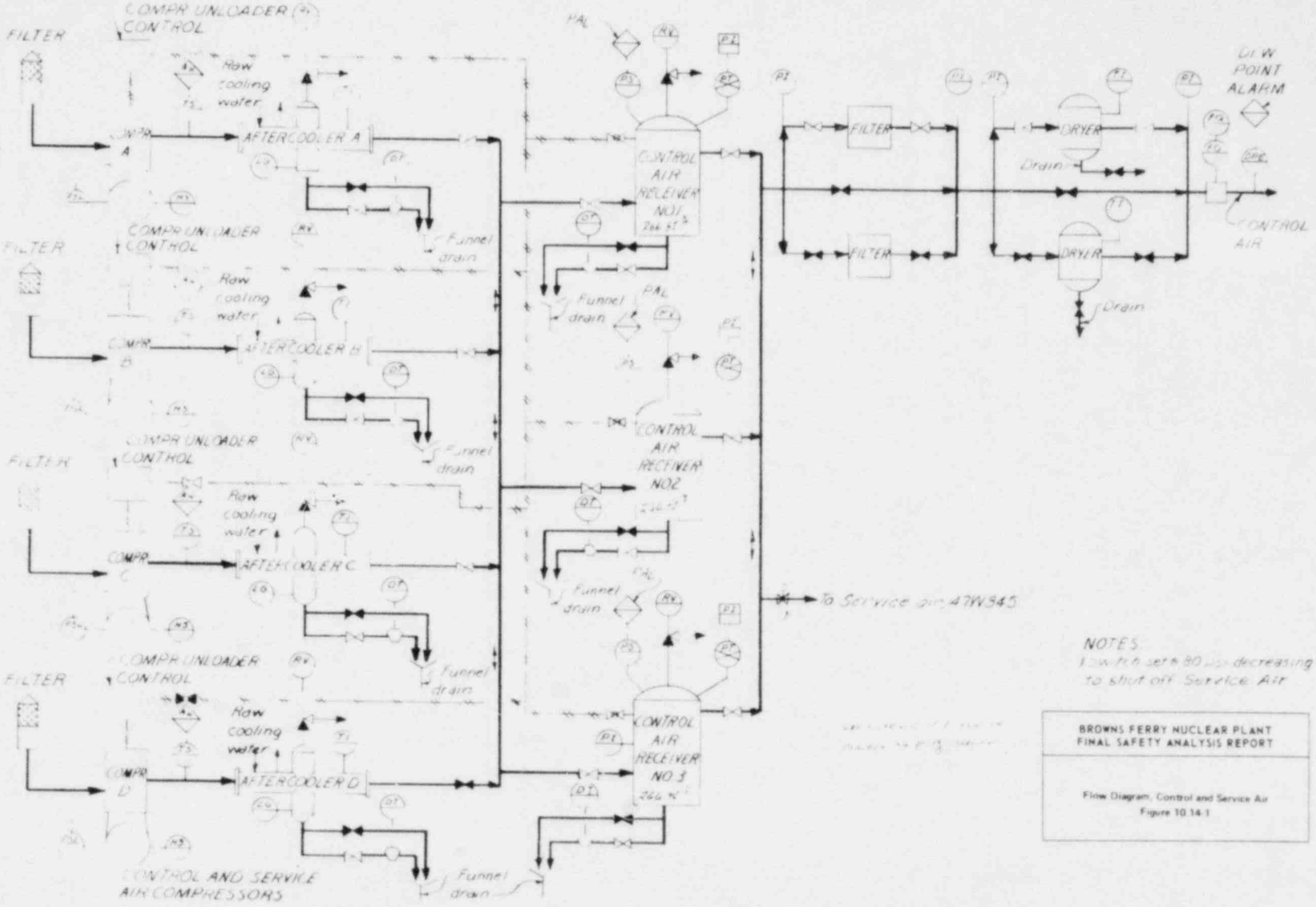

Fig. 2. Flow diagram for control and service air.

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Instrument Air System

The IAS is supplied from the air receivers discharge manifold through an arrangement of parallel connected equipment before being distributed throughout the unit (for example, see Figs. 1 and 2). Prefilters protect the dryers from gross carry-over of contaminants from the air receivers. The dryers are the regenerative desiccant type that reduce the dewpoint to −40°F; one air dryer is always being regenerated while the other is in service. Air flow is automatically alternated through each of the drying chambers. Air flow through one desiccant bed is dried and flows through redundant, 100% capacity, parallel connected after-filters to the common IAS header. Switchover for the after-filters is based on the pressure differential across the filters. A portion of the dried air is cycled through the other drying chamber to dry the desiccant and is then discharged to the atmosphere. An air filter set is provided on the discharge of these dryers to trap any desiccant that may be carried over by possible flotation of the bed. An automatic bypass around the dryer and filters ensures a connected supply of instrument air in the event of dryer failure and/or filter pluggage and also facilitates maintenance during operation. Air is supplied through takeoffs from the top of the IAS header to various users.

Sometimes the safe failure of a component can have a propagating effect, perhaps never considered by the designer. For example, LER 81-23 [March 19, 1981 (Ref. 15)] at the Sequoyah Nuclear Power Plant reports that river water was inadvertently introduced into all four steam generators. The occurrence began with the failure of an IAS line to the No. 3 steam-generator main feedwater regulating valve causing the valve to fail closed. This valve closure interrupted the feedwater flow to that steam generator. As a result of the low water levels following the reactor trip from 40% power, all three auxiliary feedwater (AFW) pumps started automatically. Starting of the three AFW pumps simultaneously caused the common suction header pressure to reduce momentarily to a point that allowed the automatic actuation of the suction water supply switchover feature. This switchover resulted in the automatic realignment of the steam-driven AFW pump suction valves from the condensate storage tank to the essential raw cooling water system. River water was injected into all four steam generators for a period of ~2 min before the operator could close the valve. This event was attributed to an inadequate setting of 1 s on the switchover time delay circuitry. Other problems reported for the IAS are described in Appendix C. Table C.1 lists those events relating to the main steam isolation valves; a few of the more interesting events are summarized.

Containment Instrument Air System

The CIAS is a separate air system provided for instrumentation, controls, and valves inside the containment. This system takes air from and discharges air to the containment, thus creating no pressure increase inside the containment. For example, two 100%-capacity nonlubricated air compressors, water-cooled air coolers, air recievers, air filters, and two 100%-capacity desiccant dryers are provided to ensure a reliable system (shown in Fig. 3). The CIAS equipment is located in an area of the containment isolated from any safety-related equipment. Such a location precludes the possibility that missile generation from a rupture-type failure of this equipment would cause damage to any safety-related components.

The SAS and IAS provide backups for the CIAS by a cross-tie. The SAS line penetrating the containment contains one locked closed isolation valve outside the containment and one check valve inside. It provides service air for use inside the containment. The IAS line penetrating the containment contains one air-operated isolation valve outside the containment structure and a check valve inside. This backup supplies air to the CIAS and for the containment leakage monitoring system. In addition, a limiting orifice is provided for each penetration should the penetration rupture.

Design for fail safe operation and/or accident prevention can never be foolproof. Human error accounted for a breach of containment integrity at Surry, reported as AO-S1-75-02 [January 23, 1975 (Ref. 16)]. The control room operator noted during startup of unit 1 (unit 2 was at power) that the CIAS pressure was the same as that for IAS instead of being about 10 psig lower, which is normal. Two containment isolation valves were

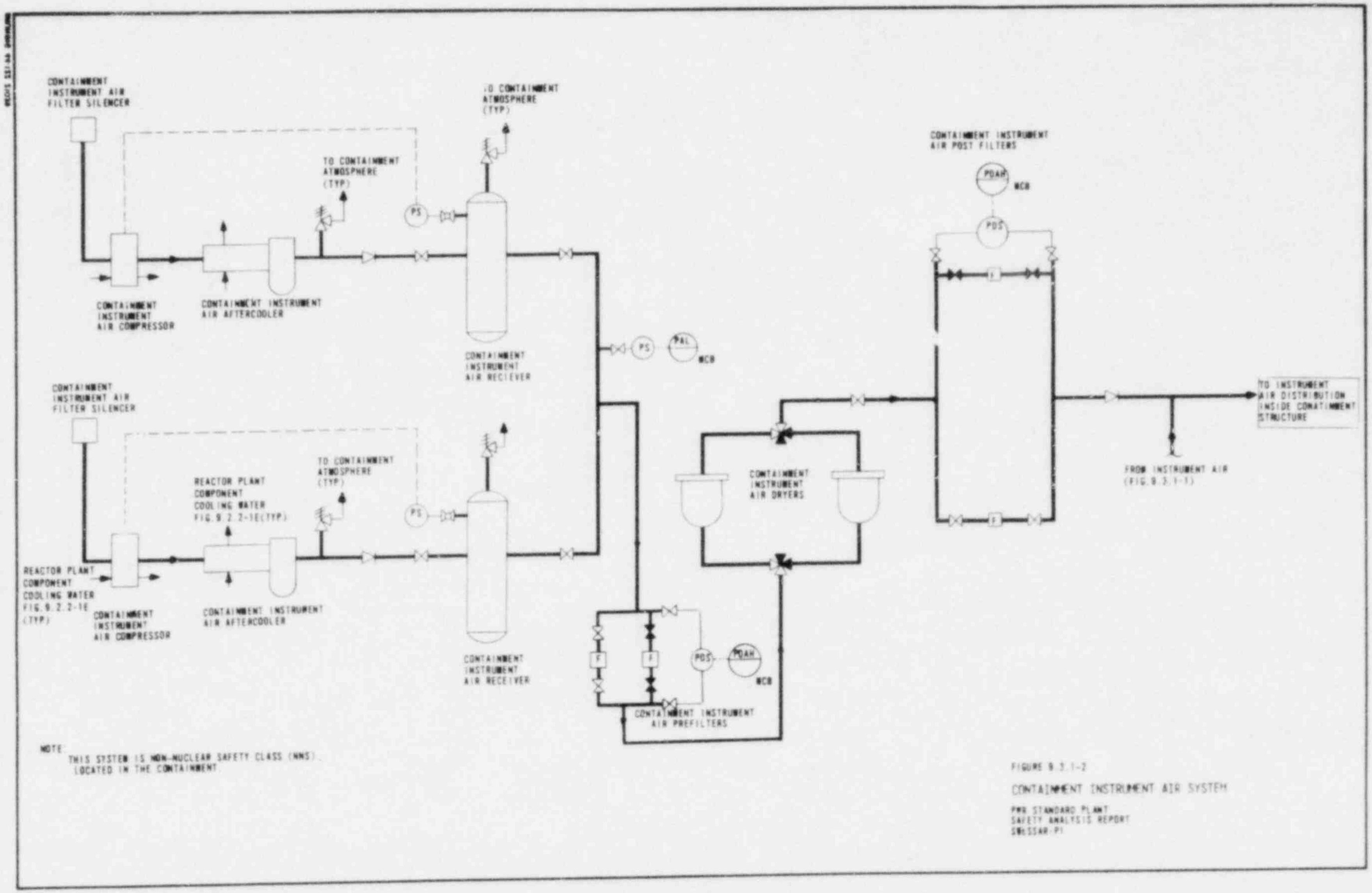

Fig. 3. Containment instrument air system.

found open. In establishing the valve lineups, the operator assumed that all valve numbers beginning with the number "2" were associated with unit 2, not realizing that there were two valves from unit 2 IAS connected to unit 1 containment. He assumed that these two valves with numbers beginning with "2" were at the unit 2 containment boundary and were therefore locked closed. He did not verify the valves by checking the valve taps.

Appendix D contains a tabulation of those LERs depicting the various effects and causes for violation of containment integrity by failures and problems in the CIAS. Three examples are summarized.

Diesel Engine Air-Start System

The two complete air-start systems for each standby diesel generator are an integral part of each diesel-generator package. Each starting system essentially consists of starting air compressors, aftercoolers, dryers, receivers, associated piping valves, and controls (for example, see Fig. 4). Either system is capable of starting the engine without offsite power, and they can be cross connected to ensure a sufficient supply of air for successful starting operation independent of normal plant power sources. Thus, sufficient redundancy is provided to ensure proper operation of the system during a maintenance outage or failure of any component in the system. The starting system for each diesel is completely independent of the starting system of other diesels. Consequently, failure of one starting systems could result in failure only of that one diesel.

Two more serious events [one each from a boiling-water reactor (BWR) and a pressurized-water reactor (PWR)], although caused by human error, help to show the extended influences of the compressed-air systems. These two unusual events are described further.

LER 77-26 [June 30, 1977 (Ref. 17)] reported three of four diesel generators inoperable for 6 h at Peach Bottom 3. The E1 diesel generator was taken out of service and safety blocked for its annual maintenance outage. This blocking included venting of the starting air receiver tanks for this diesel. Later, the control room operator noticed a diesel trouble alarm on both the E3 and E4 diesels. The plant operator noted that

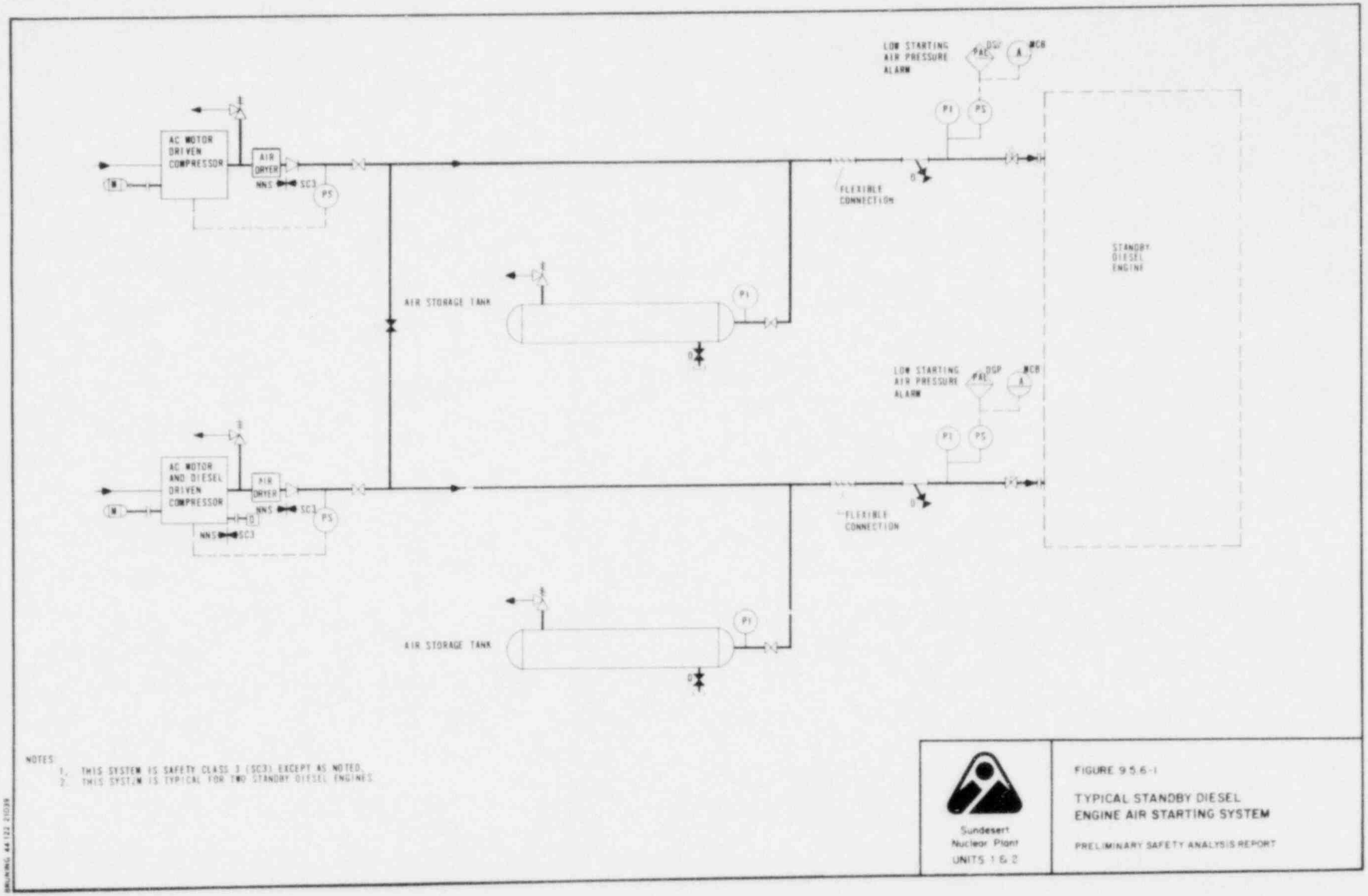

Fig. 4. Representative standby diesel engine air-starting system.

both air receivers on both diesels were essentially depressurized and that the associated compressors had tripped on thermal overload. He reset the overloads, returned the compressors to service, and established 70 psig in the starting air receiver tanks prior to informing the control room operator of his findings and corrective actions. The control room operator notified shift supervision, who in turn notified the plant staff. Because the air receiver tanks were by this time pressurized, no shutdown or power reductions were initiated. Another operator was dispatched to the diesel building to check on the status of the pressurization. He found that the receiver tanks were at ~170 psig and that air compressors were again tripped on thermal overload. He again reset the overload devices, returned the compressors to an operable status, and reported this information to shift supervision. As a result of additional plant staff investigation and discussions, the valves that interconnect the diesel starting air systems were checked. The E3-E4 sectionalizing valve was found to be partially open. This valve was then closed to isolate the starting air systems of the E3 and E4 diesels. Also, the check valves of the starting air receiver tanks failed to maintain the air pressure in the tanks, thus allowing the tanks to drain.

LER 78-37 [June 29, 1978 (Ref. 18)] reported that both diesel generators were removed from service for 3 h at Cook. This occurrence was not unique to the air-starting systems and has happened before when redundancy in equipment is employed. However, because maintenance was being performed on the air-starting system, degraded plant operations are charged to that system. This time neither diesel generator was capable of an automatic start. One diesel was removed from service for repair of a leaking injector. The auxiliary equipment operator inadvertently tagged and removed from operation the starting air pilot valve for the other diesel instead of the diesel requiring repair. Starting air pilot valves are closed to prevent manual start of the engine during maintenance. Shutting this valve prevents air from starting the diesel engine on any signal, manual or automatic. Tables E.1 and E.2 in Appendix E list LERs concerned with the air-starting systems for diesel engines in BWRs and PWRs, respectively.

Plant Gas Supply System (PGSS)

The PGSS is a composite of nitrogen, hydrogen, and oxygen compressed gases for various plant uses. Figures 5 and 6 are examples of PGSSs. The nitrogen portion is designed for use for example in the safety injection system, the pressurizer relief tank, the catalytic recombiner and waste-gas delay tanks, and the chemical and volume control tank and gas strippers in the boron recovery systems. Nitrogen is needed for pressurization, gas content control, purging and/or dilution, and operation of specific isolation valves.

Nitrogen supply to the accumulators is on an intermittent basis to maintain the pressure required for emergency operation of the accumulators. Usually a one-month supply is connected to each manifold with various additional storage facilities available to meet specific plant needs. A pressure regulator reduces the nitrogen bottle pressure, and each distribution manifold is equipped with a pressure relief valve to release excessive pressure to the atmosphere. Gas supply lines penetrating the containment have a locked closed containment isolation valve outside the containment structure and an automatic valve inside in accordance with General Design Criteria 54 and 57 (Ref. 19). However, as happens with the compressed-air systems, an open or malfunctioning relief valve will take a unit down. For example, LER 80-69 [October 20, 1980 (Ref. 20)] reports that reactor vessel relief valve opens at Pilgrim. The unit was in steady state operation at 96% power when a reactor safety relief valve (SRV) opened. Station procedures were followed — the unit was taken off line to cold shutdown, and the drywell deinerted. Excessive nitrogen supply pressure resulted in some leakage through the solenoid valve into the diaphragm of the SRV.

The design of the SRV is such that the air pressure on the diaphragm needed to open the SRV reduces as the main steam pressure increases. The design of the control valve will not allow it to close with either air or nitrogen pressure greater than 135 psi. Therefore, 160-psi nitrogen pressure caused the control valve to stay in the open position, thus preventing the SRV from closing. This event occurred again and was reported as

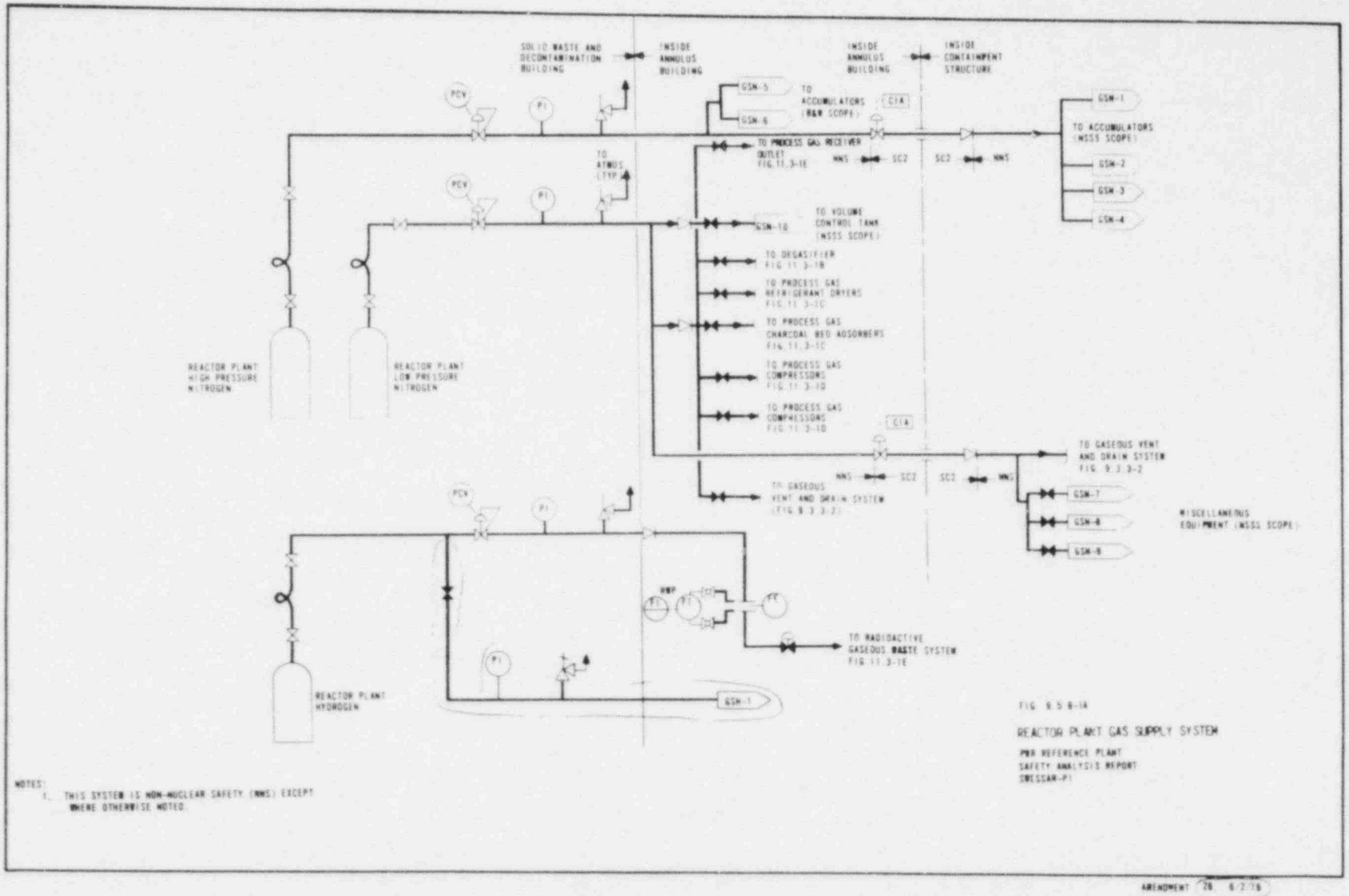

Fig. 5. Reactor plant gas supply system.

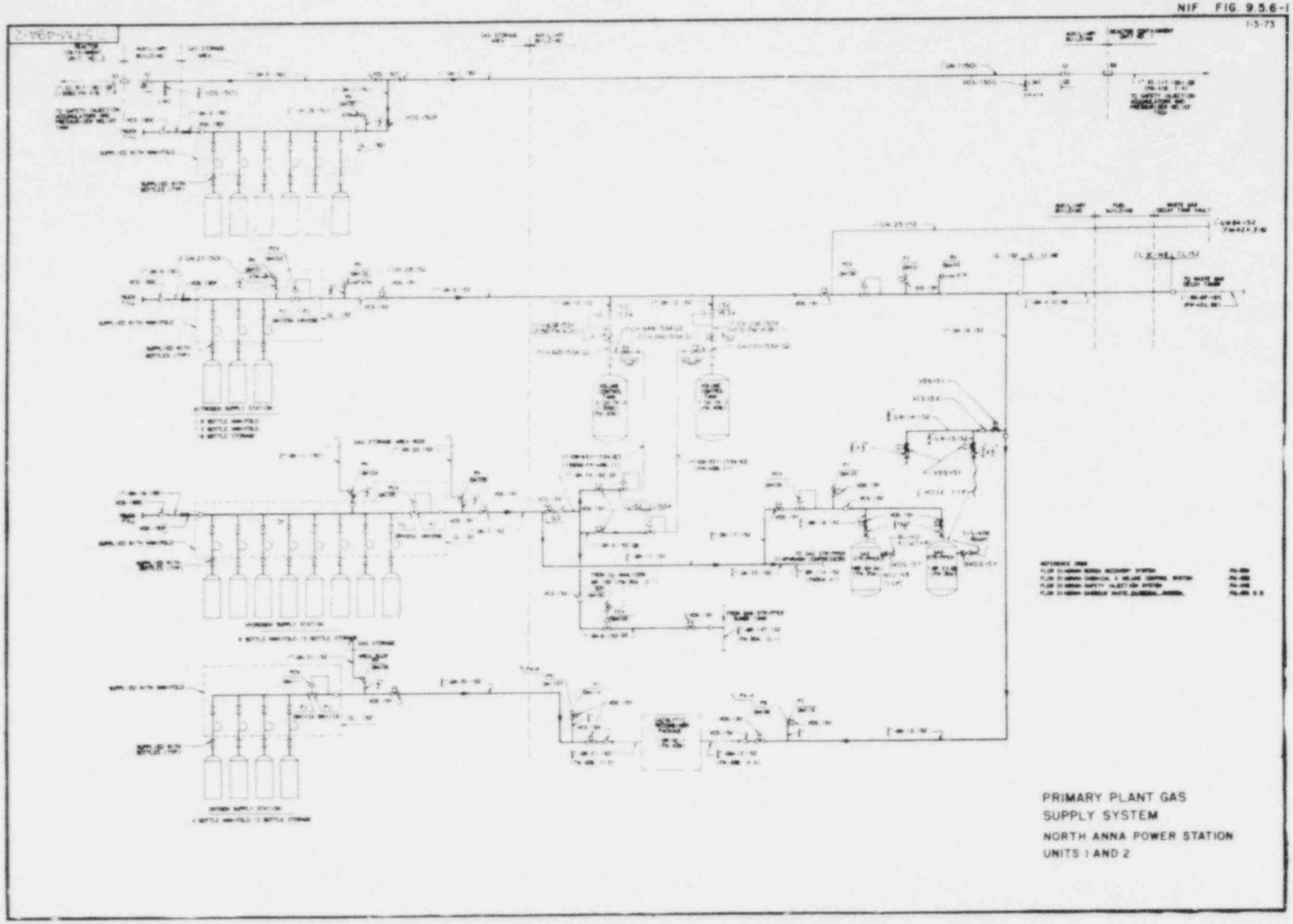

Fig. 6. Primary plant gas supply system.

LER 80-80 [November 14, 1980 (Ref. 21)]. An initial impulsive solution would be to add relief capability, but adding more equipment should be resisted. The valve should have been replaced with one of a different design. However, no changes were ordered or made.

An additional hazard associated with compressed nitrogen occurs when nitrogen is in a liquid form. One example was reported in LER 75-48 [October 17, 1975 (Ref. 22)] for Dresden 2, when a through-wall crack developed between the drywell and a purge line. A local leak-rate test was initiated on discovery of a cracked seat on a valve. The test failed, and the subsequent inspection revealed a through-wall crack on the piping.

The crack occurred at a tee connection of an 8-in. and an 18-in. line. It extended 180° around the 8-in. connection on the 18-in. line, across the welded intersection, and 7 in. down the 8-in. line. The crack apparently occured during an earlier drywell inerting process when the heating steam boilers, which vaporize the liquid nitrogen before its admission to the drywell, failed. The heating steam boiler alarm system did not activate because of a previous alarm that had not been cleared, and the boilers were inoperable for ~15 min before the problem became evident. During this interval, liquid nitrogen passed through the vaporizer and the nitrogen inerting line into the 18-in. line. The impingement of liquid nitrogen on the tee connection of the two lines caused rapid and uneven contraction, resulting in through-wall cracking. The immediate corrective action was initiation of an orderly unit shutdown. One month earlier a similar event occurred, during which a 20-in. section of the 18-in. line was cracked [see LER 74-29, September 24, 1975 (Ref. 23)]. Several other LER examples are summarized in Appendix F.

SAFETY ANALYSIS

The compressed-air systems are not characterized as nuclear safety and are not seismically designed except for those portions of the distribution system that penetrate the containment and those systems associated with safety-related valves (such as main steam isolation, drywell ventilation, and main steam relief valves) that are provided with accumulators, which permit reliable operation without compressor operation. Operation of the compressed-gas system is not required to initiate operation of engineered safeguards equipment. However, scenarios can be developed where after the storage accumulators are exhausted, failure of the compressed-gas system can be shown to influence performance of equipment in other service groups which after their subsequent failure can then adversely affect the performance of yet other equipment in engineered safeguards systems. The probability of such a common-cause failure happening is very low. Therefore, best engineering judgment is that a failure or malfunction of any system components or piping of the presently designed compressed-air system will not result in the loss of safety functions of another system.

All pneumatically operated valves are designed to assume their safety-related positions upon loss of a supply of compressed air. Even so, in the event of loss of normal power, individual air accumulators serve as a "reliable" source of compressed air for the main steam isolation valves, main steam relief valve, feedwater control valves, and containment air locks. If a compressed-air system fails, accumulator air is trapped by a check valve. Should an accumulator failure occur, the associated control valves will assume their safety-related positions.

The major components of the compressed-air system are located in the turbine building, which is remote from any safety-related equipment. This remote location precludes damage to safety-related equipment in the event of a postulated pipe rupture, equipment failure, or missile generation within the compressed-air system.

Loss of SAS does not present a hazard either during normal plant operation or in an accident situation. The SAS is not required for the operation of any nuclear safety feature and is not a safety system.

The availability of the IAS distribution system is improved by the use of the SAS distribution system as a backup supply. When IAS header pressure is low, the SAS is manually diverted by remote control to the IAS distribution system. This is a contingency situation: Even though it is recognized that "dirty" air is contaminating the system, the immediate need for the supply of air outweighs the prior consideration that that supply be clean.

A limiting orifice is provided in the CIAS for each penetration. Should the penetration rupture inside the containment, the limiting orifice restricts the flow before the air-operated valve closes. If the penetration ruptures outside the containment, the check valve isolates the compressed-air lines inside the containment.

Loss of compressed air to the BWR scram valves, scram volume vent drain valves, and control-rod-drive flow regulator will initiate a reactor scram. Consequently, a continuous supply of compressed air will not be required during emergency or abnormal operations. When unplanned events occur, the ensuing actions/reactions test the conservatism of the system design. Such an event was the loss of air pressure in the scram valve pilot header at Oyster Creek on September 28, 1972 (Ref. 24). This occurrence caused individual control rod insertions, which resulted in void collapse and a subsequent scram due to reactor low water level. The loss of air pressure was caused by the de-energizing of a backup scram solenoid valve in the reactor protection system. Until this event occurred, it was assumed that the failure of one such valve would not cause a loss of air pressure in the scram valve pilot header. However, for this particular application, this valve had an inherent flow restriction, and, coincidently with this occurrence, a large number of the scram pilot solenoid valves had minor air leaks. Such leakage is neither unexpected nor a problem during normal operation. Nevertheless, this event showed that only during an abnormal situation, when the backup scram solenoid is de-energized and the channel scram pilot solenoids are energized (as happened here), can the combination of leak in the scram pilot solenoids and restricted flow through the backup scram solenoid valve result in decreasing pressure in the scram valve pilot air header.

A safety concern of the NRC Office for Analysis and Evaluation of Operational Data is associated with pipe headers in the BWR scram system.

"The systems, including control air supply, upon which operation of the scram outlet valves is dependent have not been designed to assure reliable closure of these valves."[25] Because of the need for a reliable scram, the reactor protection and control air systems have been designed such that the numerous possible failure states of either of these systems would cause the scram outlet valves to open, which is in the "fail safe" direction for scram function reliability. Conversely, the same possible failure (loss of) modes of these two systems have the opposite impact on the reliability of the valves in the group closure sense. That is, the list of possible active and passive failure states of the reactor protection and control air systems that will cause the scram valves to open also represents the list of possible common-failure modes that will prevent group closure of the scram outlet valves when reactor coolant boundary integrity and containment isolation are needed. This dilemma is evaluated and assessed by the NRC staff in NUREG 0803 (Ref. 26).

Besides the loss of a compressed-gas supply, another concern is containment overpressurization brought about by a rupture in the pressurized-gas system. This postulated accident has been analyzed in the SARs, some examples of which are given below.

Douglas Point[27] — Assuming that all category 1 air lines located within the primary containment fail at the time of a design-basis loss-of-coolant accident (LOCA), the containment response to a flow of 500 scf/min is an increase of 0.6 psi/h, or 0.105 psi for a time period of 10 min. It is assumed that the operation is able to respond to a signal in the control room announcing a break in the non-category 1 lines with that time period.

Clinton[28] — At the time of an LOCA and after containment isolation, which secures air-supply lines, a failure of all category 2 air lines located in the containment releases 70 ft^3 of air at maximum of 160 psig. This release of air has been calculated to increase the peak pressure in the containment by <0.1 psi. Thus, the conservatism of the containment analysis is not affected.

Allens Creek[29] — The failure of the station air line (0.0332 ft^2), the instrument air line (0.0233 ft^2), and the ADS air line inside the containment building will result in the release of 12,200 scf of air during the first 10 min. The increase in containment pressure for the first

10 min of flow would be 0.0256 psi. The operator will respond to the air leak within 10 min by shutting down the air system; however, if the system is not shut down, air will continue to enter the containment at a rate of 900 scf/min. The calculations are conservatively based, assuming that the mass of air in the system at 100 psig (such as piping, air receiver, accumulators), together with the air continuously delivered by the air compressors, will enter the containment during the first 10 min. The second instrument air compressor automatically starts upon a low-low pressure signal. Therefore, it was conservatively assumed that both instrument air compressors plus the station air compressor are operating simultaneously. The containment response to such a flow is an increase of 1.08 psi/h in containment pressure. It may therefore be concluded from the 0.256-psi increase in 10 min that the break of non-category 1 air lines will not compromise the integrity of the containment.

The concern about containment overpressurization resulted in a study reported to the NRC in an LER for Palisades (LER 77-45, September 30, 1977, Subject: Potential Loss of Containment Integrity).[30] Investigations revealed that loss of the air supply to the containment building purge isolation valves would result in depressurization of the seal bladders, which could cause loss of containment integrity. The LER reported that this failure mode had not been considered in the Final Safety Analysis Report (FSAR).

The source of compressed nitrogen gas can be likened to the compressors for pressurized-air systems. However, while a loss of air pressure in an air system can be corrected by the startup of a standby/emergency air compressor, in a nitrogen system the supply of nitrogen depends on delivery from a commercial source. Therefore, a leak in the nitrogen storage system like that which occurred at Hatch 1 [LER 77-37 (Ref. 31); see Appendix F] could cause the unit to be shut down until the leak is repaired and the system recharged.

INSPECTION AND TESTING REQUIREMENTS

The ability of the compressed-air system to perform in accordance with its design bases is demonstrated by its continuous use during plant operation. During operation, periodic simulated-low-air-pressure tests are performed on the SAS and IAS to ensure proper starting of the standby compressor when required. Periodic tests are also performed on the auxiliary air system and isolation valves to ensure proper operation. Testing per se of the SAS and IAS is not a requirement because these systems are normally in continuous operation. Only preoperational testing of the IAS is specified [see Regulatory Guide 1.80 (Ref. 32)]. However, containment isolation valves do require testing because of their safety significance, and 60% of the 55 LERs retrieved on these valves resulted from the required testing.

The standby diesel-generator air-starting system is inspected periodically to ensure the quality of the air in the system and to ensure that automatic components of the system operate properly. These tests are normally accomplished during test runs of the diesel engines [see Regulatory Guide 1.108 (Ref. 33)]. Testing produced 70% of the 93 LERs retrieved concerning the air-starting systems for the standby diesel generators.

DISCUSSION

Many of the occurrences involving compressed-air systems illustrate an important precept in control technology for very large and complex systems. In this study the complex system is the nuclear-powered unit. While conventional control theory is applicable for individually controlled variables, it is not sufficient for complex systems where functional and performance interaction and interdependencies exist. In a similar way, what is fail-safe for a piece of equipment, subsystem, or system can produce, in complex systems under certain circumstances, loads, transients, or limiting conditions on other subsystems or systems, which in turn can sometimes lead to unintended and undesirable operating conditions for the unit.

Along with the fail-safe philosophy, the single-failure criterion can cause the propagation of events unforeseen by the designer. These events could be classified as one of numerous "what if's." Collectively or individually they rank with those rare events such as common-mode/common-cause failures that have a very low probability of happening and that must be accepted in this imperfect world. Seemingly small and simple happenings in the compressed-air systems sometimes disrupted the entire unit or plant. For example, (1) a head gasket failure on an air compressor started a sequence that culminated in a reactor scram due to a feedwater transient; (2) a stuck check valve on an air compressor culminated in a reactor trip because of the loss of cooling water for a coolant pump seal; (3) broken drive belts on an air compressor resulted in a reactor trip through the loss of SAS; (4) moisture freezing in an air line caused a coolant pressure transient; (5) the freezing of refrigerant dryers resulted in a rapid drop of water level in a plant's intake canal, almost to the unit trip point; and (6) the failure of a flexible connection on an air compressor caused a reactor scram through failure of some scram valves. Each of these six events was unique and unrelated. Even though the sequence of happenings was unexpected and unanticipated, none led to an accident nor could any one be designated as a potential accident precursor per se. Furthermore, during maintenance, startup, or shutdown, there is always the misoperation or element of human error that can trigger an undesired sequence of events when the wrong system is activated or deactivated. These events have been recited many times, and further examples are not needed here. The cascading of events — sort of a pseudo domino effect or just plain happenstance, as in common-mode failures — is very difficult to predict, let alone prevent. However, when recognized, these features can be altered through design. Dependencies in control system performance and responses are more subtle. Timing and circumstances are the elements that determine the extent to which a succession of events could lead to a reactor transient. Therefore, mitigation and defense in depth are the concepts that needed to be resorted to. However, during all abnormal operating conditions for the compressed-air systems, all systems and protective features functioned as designed; the concept of defense in depth has ensured plant protection and public safety during each of these occurrences. Consequently, for each of these events there was no adverse effect on the health or safety of the public or plant personnel. If the experienced fault warranted remedial action, this action should be pursued. Determination of such can be made through the use of safety goals and by prioritization of the safety concern by a probabilistic risk assessment.

The compressed-air systems in nuclear power plants experienced many of the usual and expected failures and malfunctions that occur in the process industries (see Table 1). LERs for the five principal compressed-gas systems were collated and tabulated as percentages of failure causes per system (see Table 3). At the air-compression stations, 32 LERs were generated; equipment failures and malfunctions accounted for 37% of the reported events, human error accounted for 25%, system contamination for 22%, and leaks for 16%. About 10% of the events were discovered during testing and inspection.

The IAS is used in controlling of the main steam isolation valves; 29 LERs were retrieved about this system, with testing and operator observation accounting for 38% of them. The CIAS services the containment isolation valves, and here 57% of the 31 LERs retrieved resulted from testing. Because the diesel generators require periodic testing, it was not unexpected that 70% of the LERs for the air-starting systems were the result of testing. Testing in the compressed-air systems appears to be adequate

Table 3. Distributions of failure causes

(Percent)

Cause	System				
	Compression station	IAS	CIAS	Diesel air starting	Nitrogen
Crud	22	34	47	30	4
Failure	25	24	16	19	20
Human error	25	7	16	16	34
Leaks	16	14	8	17	20
Malfunction	12	21	11	18	22

to uncover most of the random failures; this is predicated on the performance of the nitrogen-gas systems where no testing is conducted. Therefore, any significant increase in testing of the compressed-air systems would be difficult to justify based on the information available in the LERs to date.

The compressed-nitrogen systems experienced as many kinds of operational/maintenance problems as did the compressed-air systems. There were 110 LERs issued during the period reviewed (see Table 4). Two recurring problems associated with BWRs were noted. However, they were minor problems concerned with containment inerting levels and maintenance of adequate system capacity supply levels in accordance with Technical Specifications requirements.

Gas-operated mechanisms of necessity have small tolerances on the clearances between moving parts. Because of this, the gas supply must be kept clean, and the relative cleanliness of the supply depends on its use — whether for instrumentation and control or for activating equipment. (That essentially distinguishes the IAS from the SAS.) This review of operating experiences indicates that clean air is a necessary requirement, difficult to maintain, and an area where significant improvements can be realized. The equipment to do the job is available, but in too many instances it is improperly maintained (compare again the Zion and Indian Point examples given in the section titled Systems Descriptions and Operating Experiences). As a goal, see crud for the pressurized-nitrogen system in Table 3 where the supply of nitrogen is dry and clean.

In the compressed-gas systems, improvements could be realized in two areas: human errors and automation. Several of the human errors listed in Table 3 for the nitrogen systems were the result of late or short deliveries stemming from offsite commercial dependence. Nevertheless, the source columns (compression, nitrogen), which have a higher degree of man-machine interface, have a higher proportion of LERs than do the service columns (IAS, CIAS, diesel), which are more automated and thus require less operator interaction. Equipment failures, malfunctions, and leaks in a pressurized system are expected to occur throughout the normal life span of these system components, and the experience to date indicates no unusual trends or patterns.

Table 4. Number of LERs for nitrogen-supplied equipment

System component	PWR	BWR
Accumulator	8	5
Containment atmosphere	0	26
Containment isolation	5	9
Control rod drives	0	1
Cover gas	2	0
Penetration	1	0
Pressure-operated relief	2	4
Pressurizer	3	0
System (miscellaneous)	8	36

The compressed-gas systems have been designed to the point where further improvements or upgrading to safety classifications would be minimal, based on the reviewed operating experiences, and ultimate plant safety could even be lessened. Philosophically, a generic control problem exists. Increased unit safety, reliability, utility, and availability will best be served if the interaction and interdependencies of all "working parts" – mechanical, procedural, or human – are considered as acting simultaneously on the unit. Then the accident prevention/mitigation concepts for common-mode/common-cause failures should be applied.

Elevating or reclassifying the compressed-air and backup nitrogen systems to safety grade will essentially increase the design review, quality assurance documentation, equipment qualification, and testing, but it will not alleviate the obvious problem of inadequate maintenance and related operational procedures.

This study did not address either the subject of nitrogen supply to the containment penetrations and seals or the ensuing effects of losing this supply because of the constraints of time and dollars. Also, on a prioritized scale this subject was of lesser significance than those subjects chosen for analysis.

CONCLUSIONS AND RECOMMENDATIONS

Briefly, the compressed-air systems in nuclear power plants experienced most of the expected or usual problems encountered in the process industries. Also, during abnormal conditions, these unit service systems functioned as designed. Occasionally, the fail-safe philosophy and/or the single-failure criterion aggravated an equipment malfunction or failure event to cause a reactor transient or a unit scram. However, the concept of defense in depth ensured plant protection and public safety. During maintenance and/or operation of large and complex systems, there is always the element of human error, which can trigger an undesired sequence of events whenever the wrong equipment or subsystem is activated or deactivated. Nevertheless, the central problems in the compressed-air systems appear to be related to inadequate maintenance policies and operating procedures.

Inherent to the common design of instrument-air systems is the requirement for a clean, oil-free supply of dry air to the control instrumentation. Anything less is a misapplication and should have been detected and corrected in the initial systems design and in the safety analysis reviews. Then, such built-in faults as the susceptibility for crud buildup would have been eliminated. To keep the air systems in their pristine conditions requires proper operation and maintenance, equipment design notwithstanding.

Some general conclusions can be drawn from this study of operating experiences.

1. There have been no adverse effects to the health or safety of the public or plant personnel due to the reported experiences.

2. All control systems and unit protective features functioned as designed.

3. The compressed-air and backup nitrogen systems in nuclear power plants encountered many of the expected or usual problems that are experienced in the process industries. Solutions are the same for either. Clean air is a necessary requirement, difficult to maintain, and an area where large improvements can be realized in nuclear power plants.

4. Two reoccurring problems were noted in the nitrogen system for BWRs. However, the problems were minor and concerned containment inerting levels and maintenance of adequate system capacity supply levels as per Technical Specifications requirements.

5. Human error is a major contributor to equipment and system malfunctions and faults and is the single most important area where system and unit availability can be increased.

6. The fail-safe philosophy and single-failure criterion when imposed on complex systems can initiate actions that result in reactor transients and/or unit scrams.

7. The initial premise of this study was to justify reclassification of the air systems to safety grade; however, analysis of the available operating experiences did not produce the evidence needed to support this premise. Each of the six events mentioned was unique and unrelated. Even though the sequence of happenings was unexpected and unanticipated, none of the events led to an accident nor could any one be designated as a potential accident precursor per se.

Based on these conclusions, the following recommendations are offered.

1. Elevation or reclassification of the compressed-air and/or nitrogen systems to a safety grade will not alleviate the obvious problem of inadequate maintenance and related operational procedures. Therefore, these systems should not be safety grade in toto.

2. Maintenance and administrative procedures need overhauling to ensure that cleanliness of the air supplies to instrumentation and controls is maintained at the highest practical level.

3. Gas-operated mechanisms of necessity have small tolerances on the clearances between moving parts. Therefore, the cleanliness of the systems' parts and pieces is equally as important as the cleanliness of the gas supplied to these parts.

4. Increased testing to improve safety or availability of these systems would be difficult to justify based on the information available in the operating reports to date. Therefore, increased testing is not recommended.

5. Increased availability of the compressed-air and backup nitrogen systems can be realized by decreasing the amount of direct operator and maintenance interface with the operating equipment (i.e., more automation and better maintenance and operating procedures).

REFERENCES

1. Letter from ACRS Chairman M. W. Carbon to NRC Chairman J. M. Hendrie, Aug. 14, 1979; Subject: Studies to Improve Reactor Safety; reprinted in *Nuclear Safety* 20(6), 751–53 (November–December 1979).

2. U.S. Nuclear Regulatory Commission, *Seismic Design Classification*, Regulatory Guide 1.29.

3. *Code of Federal Regulations*, Title 10, Energy, Appendix A – General Design Criteria for Nuclear Power Plants: Introduction, Definitions.

4. *Code of Federal Regulations*, Title 10, Energy, Appendix A – General Design Criteria for Nuclear Power Plants: Criterion 2 – Design Bases for Protection Against Natural Phenomena, Criterion 4 – Environmental and Missile Design Base, and Criterion 5 – Sharing of Structures, Systems, and Components.

5. U.S. Nuclear Regulatory Commission, *Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants*, Regulatory Guide 1.26.

6. Complete Loss of Plant Air, Preliminary Notification of Event or Unusual Occurrence, PNO-III-81-20, Feb. 24, 1981, for Monticello (Docket No. 50-263); Accession NBR 8103020591.

7. Loss of One Off-Site Power Source, LER 79-014, June 20, 1979, for Peach Bottom (Docket No. 50-278); Accession NBR 7906260294.

8. Service Air Line Isolation Valve Fails at Zion 1, AOR 74-38, Sept. 3, 1974 (Docket 50-295).

9. Containment Isolation Valve Inoperable at Zion 2, AOR 74-32, Sept. 5, 1974 (Docket 50-304).

10. Vent Header Isolation Valve Fails to Close at Zion 1, WRO 76-46, Sept. 8, 1974 (Docket 50-295).

11. Containment Air Sample Isolation Valve Fails to Close at Zion 2, LER 80-018, May 9, 1980 (Docket 50-304).

12. Pneumatically-Operated Containment Isolation Valves Failed to Function Properly, Event No. 70, May 6, 1971, at Indian Point (Docket 50-003).

13. No. 1 and 2 Fire Pumps Operated in Manual, LER 78-71, Nov. 1, 1978, for Salem (Docket 50-272); Accession NBR 7811070262.

14. Radioactive Liquid Backflows to Service Air System, LER 78-39, Oct. 4, 1978, at Peach Bottom 2 (Docket 50-277).

15. Inadvertent Introduction of River Water into Steam Generators, PNO-II-81-23, Mar. 19, 1981, for Sequoyah (Docket 50-327).

16. Station Instrument Air Supply to Containment Instrument Air Supply, AOR AO-SI-75-02, Jan. 23, 1975, for Surry (Docket 50-280).

17. Inoperability of Three of Four Diesel Generators, LER 77-26, June 30, 1977, at Peach Bottom (Docket 50-278).

18. Both Diesel Generators Removed from Service, LER 78-37, June 29, 1978, for Cook (Docket 50-316).

19. *Code of Federal Regulations*, Title 10, Energy, Appendix A — General Design Criteria for Nuclear Power Plants: Criterion 54 — Piping Systems Penetrating Containment and Criterion 57 — Closed System Isolation Valves.

20. RV203-3A Operation, LER 80-069, Oct. 20, 1980, for Pilgrim (Docket 50-293); Accession NBR 8010240410.

21. RV203-3A Operation at Pilgrim, LER 80-080, Nov. 14, 1980 (Docket 50-293); Accession NBR 8011190442.

22. Through-Wall Crack in Drywell/Torus Nitrogen Purge Line at Dresden 2, AO 75-48, Oct. 17, 1975 (Docket 50-237).

23. Torus/Drywell Nitrogen Purge Line Crack at Dresden 3, AO 74-29, Sept. 24, 1975 (Docket 50-249).

24. De-energizing of a Backup Scram Solenoid at Oyster Creek, File No. 215, Sept. 28, 1972 (Docket 50-219).

25. U.S. Nuclear Regulatory Commission, *Safety Concerns Associated with Pipe Breaks in the BWR Scram System*, NUREG-0785 (May 1981), draft.

26. U.S. Nuclear Regulatory Commission, *Generic Safety Evaluation Report Regarding Integrity of BWR Scram System Piping*, NUREG-0803 (August 1981).

27. Douglas Point Nuclear Generating Station PSAR Amend 5 Item 6.51, Jan. 16, 1974 (Docket 50-448).

28. Clinton Power Station PSAR Amend 11, Q6-40, Apr. 12, 1974 (Docket 50-461).

29. Allens Creek Nuclear Generating Station PSAR, Q1-9.23, Apr. 10, 1974 (Docket 50-466).

30. Containment Building Isolation Valves at Palisades, LER 77-45, Sept. 30, 1977 (Docket 50-255).

31. Entire Contents of Nitrogen Tank Lost at Hatch 1, LER 77-37, June 20, 1977 (Docket 50-321).

32. U.S. Nuclear Regulatory Commission, *Preoperational Testing of Instrument Air Systems*, Regulatory Guide 1.80.

33. U.S. Nuclear Regulatory Commission, *Periodic Testing of Diesel Generators Used As Onsite Electric Power Systems at Nuclear Power Plants*, Regulatory Guide 1.108.

Appendix A

EVENT NO. 70, MAY 6, 1971, AT INDIAN POINT

William E. Caldwell, Jr.
Vice President

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4 Irving Place, New York, N Y 10003
Telephone (212) 460-5181

DOCKET-50003--70

MASTER

May 6, 1971

RE Indian Point No. 1
Docket 50-3

Dr. Peter A. Morris, Director
Division of Reactor Licensing
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Dr. Morris:

By letter dated January 20, 1971, you were informed of a problem at the Indian Point Unit No. 1 facility whereby numerous pneumatically-operated containment isolation valves failed to function properly during a routine test conducted in accordance with the Technical Specifications. This letter, the purpose of which is to provide a follow-up report of the incident, describes: (1) the measures that have been taken to prevent recurrence of the problem and, (2) the results to date of the modified surveillance and testing program instituted as an outgrowth of the problem.

1. Remedial Measures

As indicated in the referenced letter, oil contamination of the air supplied to the air-operated containment isolation valves was the principal reason for the sticking of valve operators and the mal-functioning of valve solenoids. Accordingly, most of the remedial measures listed below had the elimination of this contaminant as a main objective. Several other measures were effected for the purpose of rendering the Instrument Air System free of water, a second contaminant found in the system contributing to the deleterious effects of the oil.

1.1 All of the containment isolation valve actuating solenoids were disassembled and cleaned.

1.2 Air supply lines to the isolation valves were free-blown to the greatest extent practicable to remove accumulations of water and oil.

1.3 The oil feed-rate for lubrication of the instrument air compressor cylinders was reduced to a minimum and is being maintained at that level.

1.4 The desiccant used in the Instrument Air System "Hydryer" was replaced. The "Hydryer" is an apparatus consisting of twin cylinders containing activated alumina as desiccative material, the function of which is to filter and dry air drawn from the instrument air receiver prior to its use. A heater and cooler/condenser are also provided, along with appropriate controls, to allow for automatic regeneration of the desiccant beds on a timed schedule.

1.5 The absorber beads contained in the "Oil Sorber", an in-line device located upstream of the Hydryer for the purpose of oil particle removal, were replaced.

1.6 Operations personnel have been issued a check-off list for use at regular intervals which will insure that sections of the instrument air system are free-blown at specified locations to prevent accumulations of oil and water.

1.7 A filter, designed specifically to remove oil particles from compressed air, has been installed in each of the two main air supply lines to pneumatically-operated isolation valves. The filters change color when no longer effective, thereby simplifying the matter of scheduling their replacement.

1.8 To more positively eliminate the potential for oil contamination of the air, we have decided to replace the existing air compressor with one that does not require cylinder lubrication. It is anticipated that this change will be effected before the end of the year.

1.9 A full-capacity refrigeration type dryer is presently being installed as a permanent part of the Instrument Air System. This will provide an additional means for oil and water vapor removal from the air. It is expected that the unit will be operational by mid-year, prior to the incidence of humid weather conditions.

2. Surveillance and Testing Results

2.1 In response to your Mr. J. Carter's request that we test a representative portion of the normally open containment isolation valves approximately one week after startup, and again one week later, forty-nine valves were tested for closure capability on February 16, 1971 and on February 22-23, 1971. All of these valves, which represent 33% of the total normally open, functioned properly during both tests.

2.2 Tests are being conducted the second Saturday of each month on all those containment isolation valves that can be tested without undue interference with plant operations. The results of the two such tests conducted thus far, during March and April, were completely satisfactory in that none of the one-hundred and fifteen valves tested failed to respond to a closure signal at either time. All or a portion of the remaining forty-four isolation valves not tested will be checked as the operating status of the unit allows.

2.3 As stated in our previous letter in this regard, a test of the entire Containment Isolation System will be performed at approximately six-month intervals, rather than annually as required by the Technical Specifications, until a level of confidence in the System has been re-established - at which time the frequency of testing will return to normal. The next full test is tentatively scheduled for July 1971.

2.4 Oil particle and water vapor analyses of the air supplied to containment isolation valves have been greatly increased with respect to frequency and scope as a direct result of the isolation valve problem. The results show that a marked improvement in the quality of the air has occurred since the previously cited remedial measures were effected. For example, no oil deposition is observed on 0.45 micron filter paper through which 30 standard cubic feet of sample has been passed, and the dew-point of the air leaving the Hydryer is now typically 35 F, where as it had been running as high as 70 F.

2.5 Other systems served by the Instrument Air System in the nuclear portion of the plant, and the Control Air System in the conventional portion, were evaluated with respect to the safety hazard potential oil/water contaminated air might offer. It was determined that no such potential exists mainly because the vital instruments and valves served are of such a design as to involve continuous air usage, rather than just static air pressure, and thus are inherently self-cleaning. Moreover, in each instance the air supplied is at a lower pressure by way of a pressure-reducing regulator equipped with a built-in filter and liquid trap.

In summary, it is our conviction that the cause of the containment isolation valve failures has been properly identified and that all necessary and appropriate action has been taken, or initiated, to insure the availability of this vital system, as well as any others that might have been similarly affected.

Our Nuclear Facilities Safety Committee shall continue to review the containment isolation and air supply systems surveillance and test program results. Should there appear to be a need for a course of corrective action other than described herein, or should the Committee decide that a change in the valve test frequency is warranted, you will be promptly informed.

.mmcl

William E. Caldwell, Jr.

Appendix B

OPERATING EXPERIENCE SUMMARIES FOR COMPRESSED-AIR STATIONS

Thirty-three malfunctions or failures of equipment or subsystems in the compressed-air stations at nuclear power plants are tabulated in Table B.1. Seven of the occurrences (21%) precipitated reactor transients or scrams/trips and are summarized. Those occurrences summarized include two coolant transients, one reactivity transient, two forced-shutdowns or trips, one scram, and one limited operating condition at reduced power.

Feedwater Coolant Injection System Low Flow Transient

(Millstone 1, LER 77-24, August 30, 1977)

A turbine building secondary closed cooling water (TBSCCW) system low discharge pressure alarm was received in the main control room during normal operation. The standby TBSCCW pump was started. An investigation revealed that the TBSCCW surge tank was overflowing although the makeup valve was closed. The instrument air compressor tripped, and the standby air compressor threw its drive belts on starting and tripped on overload. A reactor scram occurred due to a reactor low water signal, which was caused by the feedwater regulating valves locking up on a low air pressure signal.

A head gasket on the high-pressure end of the station air compressor had failed. This allowed compressed air, at a higher pressure, to enter the TBSCCW system, which provides, along with other components, the cooling water for the instrument and station air compressors. The air entering the TBSCCW system prevented it from providing adequate cooling to the instrument air compressor, and it tripped because of excessive temperature. The standby compressor was unable to assist in maintaining adequate air pressure, and the feedwater regulating valves locked up "as is" due to the decreasing air pressure. The feedwater regulating valves locked up in a position that caused the reactor water level to decrease, and a reactor scram occurred on receipt of a low reactor water level signal.

Table B.1. LERs for compressed-air stations

Unit	LER No. or report date	Event descriptions	Cause
Beaver Valley 1	78-14	Both containment air compressors inoperable	Broken belts
	78-7	Sealing air feeding ventilation dampers failed to actuate	Air pressure adjustment; sticky air supply system
	76-61	Containment air temperature exceeds limit	Air compressor capacity low
Bellefonte	6/26/78	Service and control air systems isolated from essential air systems	Setpoint drift
Brunswick 2	80-12	Two instrument sensing line isolation valves closed	Loss of two or three air compressors
Calvert Cliffs 1	80-41	Service water system head tanks went from normal to full indicator	Air compressor cooler tubes failed
	80-27	Service water system failed	Air bound due to instrument air cooler tube leak
Cook 2	78-99	Pressurizer pressure dropped below limit	Instrument air circuit breaker tripped
Farley 1	78-77	1B diesel-generator declared inoperable	Desiccant from air dryers lifted and would not permit relief valves to reseat
Hatch 1	80-86	Instrument air pipe support missing	Design error, IE bulletin 79-14 (service)
	79-65	Section of instrument air system seal seismically supported	Installation error, IE bulletin 79-14

Table B.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Indian Point 1	5/6/71	Improvements to air supply system to isolation valves	Oil- and water-contaminated air supply
Indian Point 2	79-1	Chromate released to river	Leak on air-compressor cover plate from corrosion
	76-2	Pressure transient in main cooling system	Loss of instrument air from malfunction of desiccant dryer switching valve
	5/31/74	Reactor trip from spurious high steam line delta-P safety injection signal	Isolation valve closures from leak in instrument air line
	7/23/73	Air dryer malfunction	Blockage of flow resulting from improper setting of refrigerator expansion valve
	5/25/73	Pressure transient in reactor coolant system	Air-operated valves in letdown system closed from low air supply
Maine Yankee	11/72	Unscheduled trip	Leaks in pneumatic system piping
Millstone Point 1	77-24	Feedwater system degraded	Air compressor head gasket failed
Monticello	80-22	Excessive oxygen concentration in containment	Service air isolation valve found open
	80-16	Safety/relief valve air line support not seismically qualified	Design deficiency, IE bulletin 80-01
	80-20	Complete loss of air	Check valve stuck open

Table B.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Oyster Creek	12/17/71	Loss of station air system	Rupture of 6-in. stainless steel flexible connection on discharge of air compressor
Quad Cities 2	3/21/74	Containment oxygen concentration high	Air inleakage into the drywell pneumatic system, loose fitting
Robinson 2	77-7	Penetration pressurization system for containment purge valves inoperable	Air line isolation valves closed rather than opened on system alignment
St. Lucie 1	77-41	Quality control documentation for seismic category 1 air-supply valves and piping lost	Contractor had not included piping certificate
	77-23	Reactor coolant system flow lost	Containment instrument air compressor failed
Surry 1	80-13	Accumulator level and pressure drop below limits	Moisture in valve operator lines
	7/19/73	Water level in intake canal dropped rapidly	Freezing flow-level-intake instrumentation
Vermont Yankee	78-25	Total primary containment leak rate exceeds limit	Leaking check valves in compressor discharge piping
Zion 1	78-9	Diesel-generator control air system low pressure	Bearing high-temperature trip valve seal leak
	76-19	Penetration pressurization air compressor failed	Unloader valves stuck open by crud and rust
	74-38	Service air line isolation valve fails to close	Spurious binding

Pressurizer Pressure Transient

(Cook, RO 78-99, December 28, 1978)

Pressurizer levels pressure increased during normal operation when the letdown valves closed. A circuit breaker controlling instrument air to the container tripped causing the valve to close; this loss of air left none available to open the pressurizer spray valves. When instrument air was restored, the spray valves opened wide because of the high-pressure signal and the pressurizer pressure rapidly declined. Spray valves were placed on manual control until the pressurizer heaters recovered the pressure.

Loss of Reactor Coolant System Flow

(St. Lucie 1, LER 77-23, May 13, 1977)

During normal plant operation, the containment instrument air system failed due to a loss of seal water. The backup air compressor started, but because the operating air compressor discharge check valve stuck in the open position, air from the backup compressor blew back through the failed compressor. The loss of air resulted in the loss of seal cooling water to the reactor coolant pumps, and the reactor was tripped.

Containment Temperature High

(Beaver Valley 1, LER 76-61, October 7, 1976)

During an air fluff of the mixed-bed demineralizer for water treating, the IAS air pressure dropped allowing the cooling water containment isolation valve to shut. The cause was an apparent design deficiency of the station's air compressors. The plant was in normal operation.

Loss of Containment Air Supply

(Beaver Valley 1, LER 78-14, March 7, 1978)

During manual operations, the 1A containment air compressor tripped. The 1B compressor was inoperable. A power reduction was begun, and the reactor later tripped when air service could not be restored. The 1A compressor tripped because of two broken drive belts. The remaining three belts were bound up on the drives.

Reactor Coolant System Pressure Transient
(Indian Pt. 2, AO 3-2-5, May 25, 1973)

The reactor coolant system was in the process of being heated up so that a hydrostatic test could be conducted. At the time, four reactor coolant pumps were in service with reactor coolant system conditions of approximately 440 psig, 130°F, 1980 ppm boron, and all control rods inserted. The reactor had not yet been brought to initial criticality.

A pressure transient within the reactor coolant system was experienced beause certain air-operated valves in the reactor coolant letdown system closed. Closure of the valves resulted in reactor coolant system pressure increasing to ~575 psig. An investigation revealed that moisture in an air supply line at the refrigerant dryer of the IAS had frozen and the refrigerant expansion valve had been improperly set.

Intake Canal Water Level Transient
(Surry, AO SI-73-08, July 16, 1973)

During normal operation at rated power, a rapid 1.5 ft drop in the intake canal water level caused an immediate load reduction of 200 MW in both units until the level stabilized after an additional 1 ft drop, 7 in. above the plant trip level.

The loss of water to the intake canal was caused by a failure of the low level intake IAS dryers and an immediate reduction in the intake water flow to the intake canal. On loss of instrument air, the vacuum breaker associated with each of the eight 96-in. intake lines to the canal from the circulating-water pumps failed open allowing air to be introduced into the lines, subsequently causing a reduction in flow.

The intake canal provides a reservoir of water for safeguards equipment requirements. Because of this, a low canal level of 18.0 ft trips both units and closes (1) condensor water box inlet and outlet valves,

(2) component cooling supply valves, and (3) bearing cooling-water supply valves. The remainder of the canal water, therefore, is available for recirculation spray heat exchangers, control room air conditioning, and high head safety-injection-pump (charging pump) service water.

The air systems for the controls consist of two compressors and two refrigerant dryer units. These two complete air systems operate in parallel for backup purposes. The failure of the IAS was apparently caused by freezing of two refrigerant dryers in the air system.

Reactivity Transient

(Oyster Creek, December 17, 1971)

A rod drift alarm during normal operation alerted the operator that individual control rods were scramming. A loss of the station air system caused the scram valves to fail (safe) open. The operator scrammed the reactor.

The cause of the air system failure was the complete rupture of a 6-in. stainless steel flexible connection mounted on the discharge side of air compressor 1-2. When the flexible connection failed, it struck the compressor high-temperature trip switch, which caused the compressor to trip. Air compressor 1-1 started automatically but was unable to keep up with the air loss.

Appendix C

OPERATING EXPERIENCE SUMMARIES FOR MAIN STEAM ISOLATION VALVES

The IAS has many uses, from fluffing resin columns to operation of main steam isolation valves (MSIVs). Because of the significance of the latter use, the 29 LERs identified with the MSIVs are tabulated in Table C.1; some of those occurrences that had the potential for more serious consequences are summarized.

Partial Failure to Scram at Browns Ferry 3

A partial failure of the scram system of Browns Ferry 3 occurred on June 28, 1980, while the reactor was being shut down for a scheduled feedwater system maintenance. The failure occurred when the control room operators manually scrammed the reactor from low power, which was the next step in the normal shutdown procedure. All of the control rods on the west side of the core inserted properly. However, most of the rods on the east side of the core failed to fully insert.

Following the event, the U.S. NRC Office of Inspection and Enforcement issued Bulletin 80-17 and Supplements 1, 2, and 3. Supplement 3 was issued in response to the concerns raised by the Office for Analysis and Evaluation of Operational Data report which identified degraded air pressure in the control air system as a mechanism that could rapidly fill the scram instrument volume. This event is summarized with references in *Nuclear Safety* 22(2), pp. 226-229, March-April 1981.

Crud Buildup on Fuel Assemblies
(Calvert Cliffs 1, February 1, 1980)

The cause of the crud buildup was a small air inleakage into the purification system via the instrument air header through two leaking isolation valves. This air source is normally used to assist in spent resin transfer. Crud deposits could increase the core differential pressure resulting in reactivity effects.

Table C.1. LERs for main steam isolation valves

Unit	LER No. or report date	Event descriptions	Cause
Beaver Valley 1	77-33	Partial closure (i.e., valve flutter)	Leak in air supply line
Brunswick 2	75-111	Fast closing time	Pinched packing rings permitted oil to be blown into air cylinder
Cooper	77-48	Would not open	Incorrect installation of sensing lines on eight main steam isolation valves
	75-8		Solenoid-operated air pilot valve partially grounded by heat and moisture from steam relief valve
Davis Besse 1	77-55	Closed	Loss of instrument air due to leak in valve operator moisture trap
Farley 1	78-22	Made inoperable for maintenance	Leaking fitting on the actuator air supply line needed repair
Ginna	75-4		Air supply solenoid did not trip due to fault on latching pin trip mechanism
Hatch 1	75-46	Failed to close	Dirt in air supply solenoid valve
Nine Mile Point 1	80-07	Failed to close	Rust buildup in pilot valves
North Anna 1	79-16	Failed to open completely	Air control valve out of adjustment
North Anna 2	80-52	Failed to close	Stuck solenoid valve

Table C.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Oyster Creek	77-9	Failed to close	Deformed gasket blocked air vent in solenoid valve
	10/1/73	Failed to close	Sticking pilot-operated power valves due to red dust
Prairie Island 1	5/22/75	Failed to open	Valve operator air leakage
Quad Cities 1	80-05	Failed to close	Blockage of exhaust restrictor on the pilot valve
	79-26	Failed to close fully	Stuck pilot valve
Quad Cities 2	78-32	Failed to open	Broken air line to air operator
	78-18		Air pilot valve temperature exceeds technical specifications
St. Lucie 1	76-12	Closing time too slow	Needle valve out of adjustment, air accumulator undersized
Salem 1	77-14	Inadvertent closure	Maintenance error - vented wrong valve
Surry 2	75-12	Spurious closure	Faulty O-ring in operating cylinder and air-supply solenoid valve contained trash
Turkey Point 3	79-38 78-18 79-5	Failed to fully close	Air solenoid binding due to high temperature and moisture in area
	78-8	Failed to fully close	Two air supply valves had open circuits

Table C.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Vermont Yankee	74-13	Failed to close	Air pilot valve failure
Zion 1	75-25	Failed to open	Setpoint drift in electronic controller
Zion 2	76-4	Inoperable	Two failed relays in manual/auto valve pneumatic controller
	75-45	Lifts at regular intervals	Set point drift in electronic controller

Resin Plug
(Three Mile Island 2, March 28, 1978)

Just prior to the accident, two operators had been working to unclog a resin plug in the secondary cooling system from the feedwater demineralizers to the resin regeneration tank. Transfer of resin is a normal practice, but occasionally the resin becomes packed and clogs the pipe. When this happens, the resin must be "fluffed" back up with blast of compressed air. Air from the IAS bubbled through the water into the packed beads. At TMI 2, this type of a plug had been frustrating the crew for over an 11-h period.

Erratic Steam Generator Level Control
(Yankee LER 80-22, December 26, 1980)

During steady state power operation, instrument air problems resulted in erratic steam-generator level control.

Air-Operated Outside MSIVs Fail Open
(Nine Mile Point, LER 80-7, March 18, 1980)

While shutdown for maintenance, attempts to close both air-operated outside MSIVs failed. Rust buildup had occurred in the pilot shuttle. A new instrument air system is being installed which should eliminate the moisture problem.

Partial Closure of MSIVs
(Beaver Valley 1, LER 77-33, May 20, 1977)

During normal operation, MSIV 1A partially closed and alarmed in the control room. Then MSIV 1B partially closed, resulting in a high steamline differential pressure safety injection and reactor trip. Partial closures were caused by valve flutter attributable to low air pressure caused by an air leak in the supply line to MSIV 1A.

Inadvertent Closure of MSIV
(Salem, LER 77-14, March 8, 1977)

Maintenance was in process of changing intervals of an emergency closure vent valve for No. 14 MSIV. The cause of this occurrence was personnel error. A performance technician was sent to vent the control air piping from 14MS169, an emergency closure vent valve for No. 14 steam-generator MSIV. He unintentionally went to the wrong valve and vented the control air from 12MS169, the emergency closure vent valve for No. 12 steam-generator MSIV. When the control air that normally keeps 12MS169 shut was vented, 12MS169 opened and initiated an emergency closure of No. 12 MSIV and caused a reactor-turbine trip due to No. 12 steam-generator low level and flow mismatch.

MSIVs Fail to Close
(Oyster Creek, October 1, 1973)

On two occasions, the outboard MSIVs failed to close on receiving an isolation signal. These failures are attributed to the sticking of pilot-operated power valves. On inspection, a small amount of fine red dust was found on the sleeve O-rings of these valves.

The outboard MSIVs are presently air operated; the inboard MSIVs are nitrogen-gas operated with air as a backup supply, and they have not exhibited any similar failures.

The cleanliness of the MSIVs nitrogen-gas supply is governed by the cleanliness of the "boil-off" from the nitrogen supply tank, which can be considered pure.

Additional case histories of operating experiences for malfunctioning MSIVs can be found in ROE 73-1, pp. 78-83, February 9, 1973.

Appendix D

OPERATING EXPERIENCE SUMMARIES FOR CONTAINMENT INSTRUMENT AIR SYSTEM

A total of 55 LERs depicting the various effects and causes for violation of containment integrity by failures and problems in the CIAS are tabulated in Table D.1. Three examples are summarized to show the implications for "limited conditions for operation" that a single malfunction or failure can impose on an operating unit.

Component Cooling Lost to a Reactor Coolant Pump

(North Anna 1, LER 79-29, April 27, 1979)

During steady state operation at 97% power, component cooling was lost to a reactor coolant pump. The containment isolation valve in the component cooling system failed closed when the coil in its air solenoid valve burned out.

Containment Pressure Exceeds Limited Conditions for Operation

(Kewaunee, LER 78-36, January 10, 1979)

Recent operating history has shown that containment pressure slowly increases over a period of weeks until venting is necessary. The probable cause is an air leak.

Containment Oxygen Concentration Exceeds Limit

(Peach Bottom 2, LER 78-20, November 1, 1978)

With unit 3 at full power and unit 2 being made inert, the operator observed that the unit 3 containment oxygen concentration had increased above the Technical Specifications limit. IAS backup valves were open because instrument nitrogen compressors were inoperable. This caused the oxygen level to increase at a greater than normal rate. When this increase was discovered, shutdown was initiated and purging was begun.

Table D.1. LERs for containment isolation

Unit	LER No. or report date	Event descriptions	Cause
Big Rock Point	77-3	Containment building ventilation flow decreased	Leaking air supply line to discharge damper on standby fan
	9/26/72	Fuel-pool reactor drain line valve failed to close	Defective solenoid valve in control system
Browns Ferry 3	77-17	Drywell floor drain sump pump discharge valve inoperable	Air supply line oil cracked
Brunswick 1	79-105	Four rip valves failed to operate properly	Air isolation valve not fully open
	79-66	Drywell purge vent valve failed to close	Solenoid valve dirty and sticking
	79-11	Drywell vent line valve failed to close	Pneumatic flow restrictor closed
Cook 1	75-28	Containment pressure relief fan isolation valve closes too slowly	Design error - vent through instrument air reducer eliminated
Cooper	77-28	Containment isolation valve failed to close	Leaking air solenoid valve
Dresden 2	80-23	Torus vent failed to open	Closed instrument air supply valve
	79-55	Drywell/torus vent valve failed to close	Corrosion and dirt in air switching valve
	78-61	Containment vent valve failed to close	Dirt in solenoid valve

Table D.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Dresden 3	12/16/74	Torus vent valve failed to close	Drift in pressure switch setpoint for low instrument air pressure
Farley 1	78-73	Containment isolation valve blocked open for maintenance	Control air supply regulator diaphragm failure
Hatch 2	80-158	Drywell pneumatic return isolation valve leak	Valve seal scratched
Kewaunee	77-1	Containment valves for service air left open	Personnel error
Millstone Point 1	78-22	Drywell vent bypass valve failed to fully close	Dirt in air operator
	77-4	Drywell vent bypass valve failed to fully close	Dirt in air operator
Monticello	80-10	Torus IAS isolation valve leaking	Dirt on seat
North Anna 1	78-72	Instrument isolation air valve unattended	Administrative control fault
Oconee 2	76-6	Two manual containment isolation valves left open	Administrative control fault
Palisades	78-28	Containment building purge valve not pressurized	Incorrect assembly of air supply
	77-45	All containment purge isolation valves could fail if low air supply failed	Design deficiency, no redundant air supply

Table D.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Peach Bottom 3	80-21	Containment ventilation isolation valve failed to close	Stuck solenoid valve
	80-7	Backup air supplies to containment vent valves failed	Defective procedure
Quad Cities 2	78-38	Drywell vent valve failed to open	Solenoid air supply valve failed
	78-16	SJAC suction valve failed to isolate	Sticking pilot solenoid valve
	77-12	Drywell and suppression chamber vent valves failed to close	Solenoid pilot valve seat leaks
Rancho Seco	75-1	Containment isolation valve failed to operate	Water in air lines
St. Lucie 1	77-38	Conflict in valve closing time, containment isolation	Procedure not changed after modification
Surry 1	73-4	Failure of containment isolation valve to close	Stem scoring and foreign material in actuation cylinders
	75-2	Containment instrument air system not properly isolated	Startup operational error
Vermont Yankee	9/29/72	Two torus sampling isolation valves failed to close	Construction dust caused binding of actuation cylinders
Yankee Row	11/2/72	Four vapor container isolation valves failed to close	Solenoid latch was rough

Table D.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Zion 1	78-17	Nonfiltered vent header isolation valve failed to close	Stuck air solenoid valve
	2/8/77	IAS isolation valve failed to close	Oil in air supply
	75-32	Containment isolation valve failed to close	Jammed solenoid pilot valve
	76-61	Containment isolation valve failed to close	Piston stuck in solenoid actuation valve
	76-46	Vent header isolation valve failed to close	Sticking solenoid valve
	75-5	Service air containment isolation valve failed to close	Sticking solenoid valve
Zion 2	79-20	Isolation valve failed to close	Stuck solenoid valve
	79-11	Isolation valve failed to close	Stuck solenoid valve
	78-86	Three containment isolation valves failed to close	Oil in IAS causes solenoid valve to stick
	78-124	Two containment isolation valves failed to close	Oil in IAS causes solenoid valve to stick
	78-94	Two containment isolation valves failed to close	Oil in IAS causes solenoid valve to stick
	78-39	Containment valves failed to close	Oil in IAS causes solenoid valve to stick
	78-45	Three containment valves failed to stroke	Oil in IAS causes solenoid valve to stick

Table D.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Zion 2	78-51	Containment isolation valve failed to close	Oil in IAS causes solenoid valve to stick
	78-30	Nonfiltered vent heads isolation valve failed to close	Oil in IAS causes solenoid valve to stick
	77-36	Instrument air isolation valve failed to close	Oil in IAS causes solenoid valve to stick
	77-30	Containment isolation valve failed to close	Oil in IAS causes solenoid valve to stick
	75-42	Containment purge isolation valve failed to close	Loose fitting on air solenoid valve
	75-11	Two containment isolation valves failed to close	Hang-up of solenoid valves
	75-10	Containment isolation valve failed to close	Hang-up of solenoid valves
	74-51	IAS isolation valve failed to close	Solenoid failure
	74-32	IAS isolation valve failed to close	Solenoid failure

Appendix E

MALFUNCTION AND FAULT OPERATING EXPERIENCES FOR THE DIESEL ENGINE AIR-START SYSTEM

Table E.1. LERs for BWR diesel-generator air-start system

Unit	LER No. or report date	Event descriptions	Cause
Arnold	3/7/74		Air-start system contaminated with rust
Browns Ferry 1	4/12/74	Failed to start	Rust in air supply
	3/7/74	Failed to start	Rust in air supply system found in starters
	1/25/74	Failed to start	Rust in air supply system found in starters
	5/30/75	Failed to start	Rust in air-start motors
Brunswick 2	75-149	Failed to start	Check valve stuck closed
	76-158	Failed to start	Control air check valve rusted closed
Cooper	12/20/74	Declared inoperable	Air compressor failed from improper lubrication
	75-12	Failed to adequately respond	Control air line leaking fittings
	75-25	Tripped during test	Low air pressure from damaged air supply lines
	79-37	Failed to start	Silencer bypass solenoid inoperative due to low air pressure
Dresden 1	78-19		Low starting air pressure from leaking pilot valve

Table E.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Dresden 2	5/23/75	Failed to start	Air-start motor pinion gears jammed
	75-44	Failed to start	Improper seal ring installed in main air relay valve
	75-44 suppl.	Failed to start	Improper O-ring in air relay valves
	75-39	Failed to start	Burred areas on ring gear in air-start system
	76-33	Failed to start	Undetermined
	77-71	Failed to start	Air regulator diaphragm ruptured
	78-20	Failed to start	Damaged power lug in air-start solenoid
	78-52	Failed to start	Air-start motors engaged but failed to turn engine
	79-24	Failed to start	Air lines to start motor were reversed
	79-34	Failed to start	Lower air-start gear failed to engage
Dresden 3	11/6/73	Failed to start	Partial plugging of air supply line
	80-49	Declared inoperable	Failed air seal in air-start regulator valve

Table E.1 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Fitzpatrick	79-20		Air commpressor did not load
Hatch 1	1/16/75	Failed to start	Booster on the governors rusted on air side
	77-86	Failed to start	Stuck governor booster servomotor from air piston corrosion
Monticello	10/13/72	Failed to start	Rust particles restricted bleed orifice on air relay
	75-21	Failed to start	Loose air line fittings
	76-22	Failed to start	Rust particles in air relay
Peach Bottom 2	78-35	Slow start	Leaking check valve in air booster relay
Peach Bottom 3	77-26 (3)	Inoperable	Air compressor failure
Quad Cities 1	74-31	Failed to start	Air valves from air supply accumulators found closed
	76-5	Failed to start	Dirty solenoid valve
	79-5		Pilot solenoid failed to operate
	79-37		Starting air supply valves found in locked closed position
Vermont Yankee	77-18	Failed to start	Air-start solenoid valves binding from debris

Table E.2. LERs for PWR diesel-generator air-start system

Unit	LER No. or report date	Event descriptions	Cause
Arkansas 1	78-70	Declared inoperable	Piston bolt loosened allowing combustion vapors to enter air-start lines and burn off paint
Beaver Valley 1	79-23	Failed to start	Sticking pinion on air motor
Calvert Cliffs 1	7/8/74	Failed to start	Solenoid clogged with magnetic rust particles
	79-47		Air-start system pipe hangers not as per IE Bulletin 79-14
	79-61		Air-start system pipe hangers need seismic modification
	76-18	Failed to start	Air-start valves plugged
	79-34		Air system not seismically qualified as per IE Bulletin 79-14
	79-39		Air-start system pipe hangers need seismic modification
Cook 2	78-13	Declared inoperable	Air-start check valve breaks in two pieces
	78-37	Rendered inoperable	Operator closed wrong starting air valve
Farley 1	77-15	Tripped after starting	Air-start valve failed to close
	77-23	Tripped on overspeed	Air-start valve failed to close

Table E.2 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Farley 1	77-26	Tripped on overspeed	Main air-start valve failed to close
	77-27	Tripped on overspeed	Main air-start valve failed to close
	77-35	Failed to start	Main air valve/mechanical booster problem
	78-2	Declared inoperable	Both air compressors inoperable from unloader seat leakage
	78-16	Failed to attain rated speed	Rust clogged air-start solenoid valves
	78-18	Failed to start	Air-start valve stuck due to rust particles
	78-23	Failed to reach rated speed	Deficient maintenance on air-start control valve
	78-66		Air-start system air reservoir pressure low, relief valve leak
	78-76	Declared inoperable	Air-start valve stuck open following test
	78-77	Declared inoperable	Desiccant from air dryers lifted inner stage relief valve
Ft. Calhoun	7/18/73 (2)	Failed to start	Water plugged strainers in supply line to air motors

Table E.2 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Ft. Calhoun	11/13/73	Failed to start	Water and oil in air motor
	75-19	Failed to start in <10 s	Pressure regulator on primary air-start motor sticking
	75-20	Failed to start in <10 s	Air-start motors sluggish
Indian Point 2	78-37	Declared inoperable	Air-start motors needed cleaning
Kewaunee	77-28	Declared inoperable	Air-compressor failure, blown head gasket
	79-4	Failed to start	Air-start motor failure
	80-27	Failed to start	Water and crud in air-start solenoid valve
	80-106	Failed to start	Air motors malfunctioned
Palisades	77-18		Cracked pipe nipple
Point Beach 1	80-4	Failed to start	Broken vane in starting air motor
Rancho Seco	80-13		Leaking hose in air-start system
	76-10	Failed to start	Air-start motor gearing jammed
Sequoyah 1 and 2	2/11/77		Starting air piping system not installed as per seismic design
St. Lucie	76-21		Air-start solenoid valve and air lines clogged with dirt
Surry 2	4/18/73	Failed to start	Water in air receiver tanks carried over to air motors

Table E.2 (continued)

Unit	LER No. or report date	Event descriptions	Cause
Zion 1	8/24/73	Tripped during starting	AMOT safety trip valve set too high
	8/31/73	Erratic operation	Air supply fitting to AMOT master trip device was loose
	8/30/74	Declared inoperable	Control air filter's plastic shell cracked
	78-9	Declared inoperable	Control air system pressure low because of compressor bearing trip
	78-72	Failed to start	Leak in starting air pilot valve
	78-132	Failed to start	Control air leak at fittings on AMOT valve
	80-17	Failed to continue running	Loose air system fitting on master shutdown valve
Zion 2	74-49	Tripped while being loaded	Control air system leaks bled off the fuel rack shutdown cylinder
	75-23	Failed to start	Control air leaks
	77-20	Tripped from full load testing	Air line to shutdown valve leaks
	77-69	Tripped master shutdown switch	Pipe nipple on control air system split
	78-87	Failed to start	Shift in air-start timing mechanism
	79-34	Declared inoperable	Starting air valve leaked down air receivers

Appendix F

OPERATING EXPERIENCE SUMMARY FOR THE BACKUP COMPRESSED-NITROGEN SYSTEM

Although the general problems with a nitrogen system were like those for a compressed-air system and on occasion could cause a limited condition for operation status for the unit, the nitrogen system is different. The onsite supply capacity for nitrogen is limited, and nitrogen in a liquid form causes problems of its own. Four LERs are summarized; two are typical and two atypical of general compressed-gas-system problems in nuclear power plants.

Inoperative Pressurizer Relief Valve

(North Anna 2, LER 80-43, August 27, 1980)

During Mode 5 operation, the pressurizer power operated relief valves (PORVs) were required to be operable for over-pressure protection. In this condition, nitrogen is used as the cycling medium for the PORVs. The nitrogen supply pressure dropped to below the pressure necessary to maintain the PORVs in an operable status.

The PORV became inoperable because the nitrogen supply tank pressure dropped below the pressure necessary to provide this protection function. The low nitrogen supply in this system was created by excessive usage of nitrogen throughout the station, by excessive usage of nitrogen to cycle the PORVs to reduce the reactor coolant system pressure to atmospheric during the shutdown of the unit, and an inadequate method for replenishing this supply. This event was repeated on December 31, 1980 (see LER 81-02, January 15, 1981).

Containment Isolation Valve Fails Open

(Indian Point 2, LER 80-08, July 30, 1980)

During normal operation, one of the redundant containment isolation valves in the nitrogen supply header would not fully close following adjustment of accumulator nitrogen pressure. A plant shutdown was initiated. The valve jammed due to gaveling of the valve plug and cage.

CRD Accumulators Declared Inoperable

(Hatch 1, LER 80-58, July 8, 1980)

During steady state power operation with one control rod drive (CRD) hydraulic control unit inoperable, three additional CRD accumulators were declared inoperable due to their inability to maintain required pressure of 955 ± 15 psi. The CRD hydraulic control units could not maintain nitrogen pressure because of leaking cartridge valves. Problems of the same nature are expected on unit 2 with increasing age of the operating unit.

An event of the same nature occurred June 20, 1980, with another group of accumulators.

Entire Contents of Nitrogen Tank Lost

(Hatch 1, LER 77-37, June 20, 1977)

During steady state power operations, operations personnel observed a leak at a flange in the nitrogen supply line to the ambient vaporizer. This leak caused the nitrogen in the tank to be reduced to zero. The Technical Specifications limit is 2000 gal. The flange gasket was replaced, and the tank was refilled in 12 h.

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This report reviews and evaluates the performance of the compressed-air and pressurized nitrogen gas systems in commercial nuclear power units. The information was collected from readily available operating experiences, licensee event reports, system designs in safety analysis reports, and regulatory documents. The results are collated and analyzed for significance and impact on power plant safety performance.

Under certain circumstances, the "fail-safe" philosophy for a piece of equipment or subsystem of the compressed-air systems initiated a series of actions culminating in reactor transient or unit scram. However, based on this study of prevailing operating experiences, reclassifying the compressed-gas systems to a higher safety level will neither prevent (nor mitigate) the reoccurrences of such happenings nor alleviate nuclear power plant problems caused by inadequate maintenance, operating procedures, and/or practices. Conversely, because most of the problems were derived from the sources listed previously, upgrading of both maintenance and operating procedures will not only result in substantial improvement in the performance and availability of the compressed-air (and backup nitrogen) systems but in improved overall plant performance.

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