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Aging of Control and Service Air Compressors and Dryers Used in Nuclear Power Plants

Prepared by J. C. Moyers

Oak Ridge National Laboratory

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Prepared by
J. C. Moyers

Oak Ridge National Laboratory
Operated by Martin Marietta Energy Systems, Inc.

Oak Ridge National Laboratory
Oak Ridge, TN 37831

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SUMMARY

This report presents the results of a Phase I assessment of the time-related degradation (aging) of air compressors and dryers used to provide control and service compressed air in nuclear power plants. The assessment was sponsored by the Office of Nuclear Regulatory Research, Nuclear Regulatory Commission, as an element of the ongoing Nuclear Plant Aging Research (NPAR) Program. The objective of an NPAR Phase I assessment is to review operating experience and manufacturers' information, to identify failure modes and causes resulting from aging, and to identify measurable parameters that might provide a better indication of equipment condition.

The report briefly reviews typical compressors and dryers in nuclear power plants and identifies the nonlubricated reciprocating compressor as the type used in more plants than any other, for both service and control air; for this reason, the assessment focused on this type. Similarly, regenerative desiccant dryers are most often used and received primary emphasis in the assessment. A general description of the equipment is provided and includes illustrations, defined equipment boundaries, functional requirements, and materials of construction. Operational stressors are categorized, and a detailed stressor list is provided.

Operating experiences reported in data bases for nuclear power plants and in nuclear industry reports were examined. These data bases included the Licensee Event Report file as cataloged in the Sequence Coding and Search System maintained by ORNL's Nuclear Operations Analysis Center, the Nuclear Power Experience compilation maintained and published by Stoller Power, Inc., the In-Plant Reliability Data System containing maintenance records for one utility plant, and maintenance records obtained from a cooperating utility for a second plant. During the 1978-1988 decade covered by the LER data, which represents ~812 reactor unit-years, a total of 22 compressor-related and 16 dryer-related events that resulted in loss of control air supply were reported. Equipment failure causes were diverse, with no single type of failure dominating. The records available for the two utility plants indicate a significant preventative and corrective maintenance effort to correct for service wear and provide reliable equipment operation.

Maintenance recommendations included in operating and maintenance manuals provided by equipment manufacturers were reviewed and were compared to the preventative maintenance practices at one utility plant. The user-applied practices generally were in conformance with or exceeded the manufacturers' recommendations. One troublesome aspect is that of assuring operational readiness of auxiliary compressors that normally sit idle for long periods of time but that must provide backup service for critical needs if the main control air supply deteriorates. Manufacturer-recommended mothballing procedures do not appear practical for this application; such failure causes as permanent set of drive belts, corrosion of internal parts, and small internal water leaks may present a problem when the compressor is needed.

Measurable parameters were identified that have potential for enhancing capabilities for incipient failure detection and examining degradation trends in compressors and dryers. For compressors, these include periodic delivery capacity tests, trending of stage temperatures and pressures, and motor current signature analysis. For dryers, identified measurable parameters include moisture sensing within but near the exit of the desiccant column and periodic monitoring of the axial temperature profile within the column. Use of these measurable parameters in the surveillance and monitoring program might reduce the level of time-directed, out-of-service, inspection and maintenance, thereby increasing availability and improving overall system reliability.

Nuclear plant control and service air compressors and dryers are not usually considered as safety-related, because the air systems are not needed to bring the plant to a safe shutdown condition. An effective surveillance and monitoring program, with preventative and corrective maintenance, can provide reliable service from nuclear plant compressors and dryers. Instances where loss of air supply occurs due to compressor or dryer failure are rare, due both to rare occurrences of equipment failure to operate and to redundancy provided by most systems. For these reasons, it is recommended that no further consideration of aging of this equipment be included in the NPAR program.

AGING OF CONTROL AND SERVICE AIR COMPRESSORS AND DRYERS USED IN NUCLEAR POWER PLANTS

Volume 1. Operating Experience and Failure Identification

J. C. Moyers

ABSTRACT

This report was produced under the Detection of Defects and Degradation Monitoring of Nuclear Plant Safety Equipment element of the Nuclear Plant Aging Research Program. This element includes the identification of practical and cost-effective methods for detecting, monitoring, and assessing the severity of time-dependent degradation (aging) of control and service air compressors and dryers in nuclear power plants. These methods are to provide capabilities for establishing degradation trends prior to failure and developing guidance for effective maintenance.

The topics of this Phase I assessment report are failure modes and causes resulting from aging, manufacturer-recommended maintenance and surveillance practices, and measurable parameters (including functional indicators) for use in assessing operational readiness, establishing degradation trends, and detecting incipient failure. The results presented are based on information derived from operating experience records, manufacturer-supplied information, and input from plant operators.

For each failure mode, failure causes are listed by subcomponent, and parameters potentially useful for detecting degradation that could lead to failure are identified.

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1. INTRODUCTION

1.1 Background

The Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission (NRC) has an ongoing program, the Nuclear Plant Aging Research (NPAR) Program,[1] aimed at understanding the time-related degradation (aging) of nuclear power plant systems and equipment. It includes assessing the effectiveness of methods of inspection and surveillance that monitor such degradation and establishing guidelines for maintenance. The program is intended to provide technical bases for examining the ongoing operational safety of operating plants.

This report addresses the time-related degradation of air compressors and dryers. Other components being studied in the Nuclear Plant Aging Research (NPAR) Program include motor-operated valves, check valves, auxiliary feedwater pumps, diesel generators, snubbers, batteries, chargers, and inverters.

Compressors and dryers, which are vital components of the plant service and control air systems, are not normally classified as safety-related components because their continued operation is not required to bring the plant to a safe shutdown condition. However, a reliable supply of clean, dry, control air is required to maintain stable plant operation. Loss of that supply often results in a reactor trip and, on occasion, actuation of the plant's Engineered Safety Feature systems, thus presenting a challenge to the safety-related systems. Safety implications of outages of control air systems have been documented[2,3] and concern for those implications resulted in the assignment of a high priority to Generic Issue No. 43, "Air Systems Reliability".[4] An aging assessment of instrument air systems in nuclear power plants,[5] covering the total system but with less detail on compressors and dryers than included in this assessment, recently has been completed by Brookhaven National Laboratory.

1.2 Objective

The objective of this NPAR Program element is to review operating experience and manufacturers' information, to identify failure modes and causes resulting from aging of air compressors and dryers in nuclear plant service, and to identify measurable parameters which, if tracked in improved inspection, surveillance, and monitoring procedures, might result in improved system reliability.

1.3 Project Scope

This assessment covers the following information for air compressors and dryers used in plant air and control air systems of nuclear power plants.

1. Background information on compressors and dryers — boundary of equipment to be studied, types, uses, requirements, and materials of construction
2. Reviews of regulatory requirements, guides, and standards
3. Summary of operational and environmental stressors
4. Summary of operating experience
5. Manufacturers' input
6. State-of-the-art aging monitoring and assessment

Because the majority of the presently operating nuclear plants rely on nonlubricated reciprocating compressors and regenerative desiccant dryers, the assessment is focused primarily on these types of units.

1.4 Definitions

For the purpose of this report, the following definitions apply:

Failure mode – the way in which a component does not perform a function for which it was designed.

Failure cause – degradation (the presence of a defect) in a component that is the proximate cause of its failure; for example, bent shaft, loss of lubricant or coolant, and loosening of a fastener.

Failure mechanisms – the phenomena that are responsible for the degradation present in a given component at a given time. Frequently, several failure mechanisms are collectively responsible for degradation (synergistic influences). Where one major failure mechanism is identified, it has been called the "root cause." Generic examples of failure mechanisms (and of root causes) include aging, human error, and seismic events.

Aging – the combined cumulative effects over time of internal and external stressors acting on a component, leading to degradation of the component which increases with time. Aging degradation may involve changes in chemical, physical, electrical, or metallurgical properties, dimensions, and/or relative positions of individual parts.

Normal aging – aging of a component that has been designed, fabricated, installed, operated, and maintained in accordance with specifications, instructions, and good practice, and that results from exposure to normal stressors for the specific application. Normal aging should be taken into account in component design and specifications.

Measurable parameters – physical or chemical characteristics of a component that can be described or measured directly or indirectly and that can be correlated with aging. Useful measurable parameters are those that can be used to establish trends of the magnitude of aging associated with each failure cause, that have well-defined criteria for quantifying the approach to failure, and that are able to discriminate between the degradation that leads to failure and other degradation.

Inspection, surveillance, and condition monitoring (ISCM) – the spectrum of methods for obtaining qualitative or quantitative values of a measurable parameter of a component. The methods may be periodic or continuous, may be in-plant or may require removal and installation in a test stand or disassembly, and may involve dynamic or static measurements.

2. BASIC INFORMATION

2.1 Principal Types and Uses of Air Compressors and Dryers in BWRs and PWRs

The two principal applications of air compressors in pressurized-water reactor (PWR) and boiling-water reactor (BWR) nuclear power plants are to provide plant service air and control (or instrument) air. Plant service air is used for general plant maintenance purposes, such as in the operation of pneumatic tools, and the presence of small amounts of moisture and oil is acceptable. Control air is used as the motive power source for many pneumatically operated valves throughout the plants. Gross accumulations of oil, water, or solid contaminants in air lines and valve operators can result in valve operator malfunction. Even minute amounts of these liquid or solid contaminants can cause malfunctions in the solenoid-operated valves, check valves, and electronic-to-pneumatic converters used to direct and control the air supply to the pneumatically operated valves. Therefore, cleanliness and dryness are prime requirements for the control air system.

Compressors used to provide control air are usually of the nonlubricated, oil-free, type. The terms 'nonlubricated' and 'oil-free' pertain to the region of the machine in contact with the air being compressed; the running gear of this type unit is oil-lubricated but the design prevents migration of oil into the air-compression cylinder region. Cylinder lubrication in oil-lubricated machines is not by running gear oil but by controlled injection of cylinder oil.

Because the plant service air system is often considered as backup in the event of loss of the control air compressors, the service air compressors are often of the nonlubricated type also. In many plants, both service air and control air are provided by the same non-lubricated compressors, with control air taken from common headers passing through filter-dryers before being distributed to the using areas. When oil-lubricated compressors are used to provide service air, oil separators are installed to reduce oil carryover into the control air system during cross-connected operation. System pressure for both service and control air systems is nominally 100 psig. Capacity for the individual compressors providing service air and main control air usually lie in the range of 400-700 scfm.

Smaller control air compressors are used in some plants to provide air to isolatable segments of the control air system that serve the more vital control applications. These compressors are configured to operate only upon degradation of the main control air system, and often have capacities ranging from 10 to 80 scfm.

BWR plants frequently have separate drywell control gas systems in which small compressors take their suction from the drywell and supply the control devices located within the drywell. In this way, leakage from the air system does not introduce oxygen into the inert drywell atmosphere or cause buildup of drywell pressure.

Typically, two or more compressors, any one of which can provide normally required system capacity, are installed in parallel to ensure uninterrupted service in the event of malfunction of one of the units. One machine is usually assigned the lead role, operating continuously while meeting fluctuations in system capacity requirements by means of an unloading system that varies output in response to system pressure. The second machine is assigned an automatic standby role, ready to start if the lead machine cannot maintain system pressure. Additional machines, if installed, are available for use if the lead or standby unit is down for maintenance or repair.

Other air and gas compressors are used for the following applications in various power plants. These compressors are outside the scope of the present assessment.

1. Emergency diesel generator start air. In a Pacific Northwest Laboratory study of aging of nuclear station diesel generators,[6] start air compressors were found to cause only one percent of diesel generator failures. Brookhaven National Laboratory found that head gaskets for these compressors have a service life of approximately six years.[5]
2. Waste gas compressors which compress radioactive waste gas into decay tanks.
3. Control room compressors which ensure a reliable air source for environmental control under accident conditions.
4. Penetration pressurization compressors which provide positive buffer pressure between containment isolation valves and in weld channels in the containment liner.
5. Recombiner compressors which force radiolytic gasses through the recombiner.
6. Pumpback compressors which maintain desired differential pressure between the drywell and the torus in BWRs.
7. Miscellaneous compressors which provide control air at remote locations, such as raw cooling water intake facilities and cooling towers.
8. Refrigeration compressors which are a part of various HVAC systems and ice-bank pressure suppression systems.

Compressed air leaving the compressor aftercooler is warm and saturated with water vapor. Without drying, condensation in distribution piping and in the control devices themselves would occur during subsequent cooling to ambient temperature. All control air systems use air dryers located between the compressors and the distribution piping to lower the pressure dew point, defined as the dew point of the air at system pressure, to a level below any temperature encountered in the system piping or using equipment. The dryers are either refrigerated or desiccant types. The dryers often are installed with two units in parallel to provide redundancy for maintenance outages.

2.2 Compressors

2.2.1 Compressor Types

Service and control air compressor usage in each U.S. nuclear power plant, as described in safety analysis reports and other licensing documentation, is presented in Appendix A. Although the documentation is not specific as to equipment description in many cases, sufficient description is provided for the majority of the plants to permit determination of a fairly complete pattern for the use of different types of compressors and dryers. Incidence of use of the various compressor types for each application is summarized in Table 2.1. Of the types specified, reciprocating compressors are the most widely used of all types

Table 2.1. Incidence of use of various compressor types in U.S. nuclear power units[a]

Application and type	Non-lubricated	Oil lubricated	Not specified
Service air			
Reciprocating	42	4	12
Centrifugal	8	–	9
Screw	3	4	5
Liquid seal rotary	1	–	–
Unspecified	9	4	29
Main control air			
Reciprocating			
From service air	30	–	3
Dedicated	24	–	6
Centrifugal			
From service air	8	–	5
Dedicated	–	–	2
Screw			
From service air	3	–	4
Liquid seal rotary			
Dedicated	1	–	2
Unspecified			
From service air	6	–	6
Dedicated	7	–	7
Miscellaneous control air			
Reciprocating	18	–	3
Liquid seal rotary	1	–	2
Diaphragm	–	–	1
Unspecified	8	1	15

[a]As described in licensing documentation for 123 reactor units.

for providing service and control air, with nonlubricated or oil-free machines utilized for control air and either nonlubricated or oil-lubricated machines for service air.

Other types of compressors used in service and control air applications include oil-lubricated rotary screw, nonlubricated rotary screw, oil-free centrifugal, and liquid-seal rotary. Because of the relatively low incidence of use of these types, they are not included in this assessment.

Reciprocating compressors are usually double-acting, with compression occurring during both directions of piston movement. This results in a smaller machine for given capacity and provides a lower level of pulsation in the delivered air stream. Both single-stage and two-stage reciprocating compressors are used in service and control air applications. Two-stage compressors have water-cooled intercoolers between the two stages and provide lower discharge temperatures and higher efficiency. Aftercoolers followed by moisture separators are used with both single-stage and two-stage machines to cool the exiting compressed air and remove excess moisture. As a result, the air leaving the moisture separator is warm and saturated with water vapor.

A single-stage nonlubricated reciprocating compressor is shown schematically in Fig. 2.1. The running gear, consisting of the main frame and crankcase, crankshaft, connecting rod, crosshead, and oil wiper is identical to that of an oil-lubricated compressor. A filtered, force feed lubrication system supplies oil to the main bearings, the crankpin and crosshead pin bearings, and to the crosshead. The crosshead design absorbs side thrust from the crank-connecting rod mechanism

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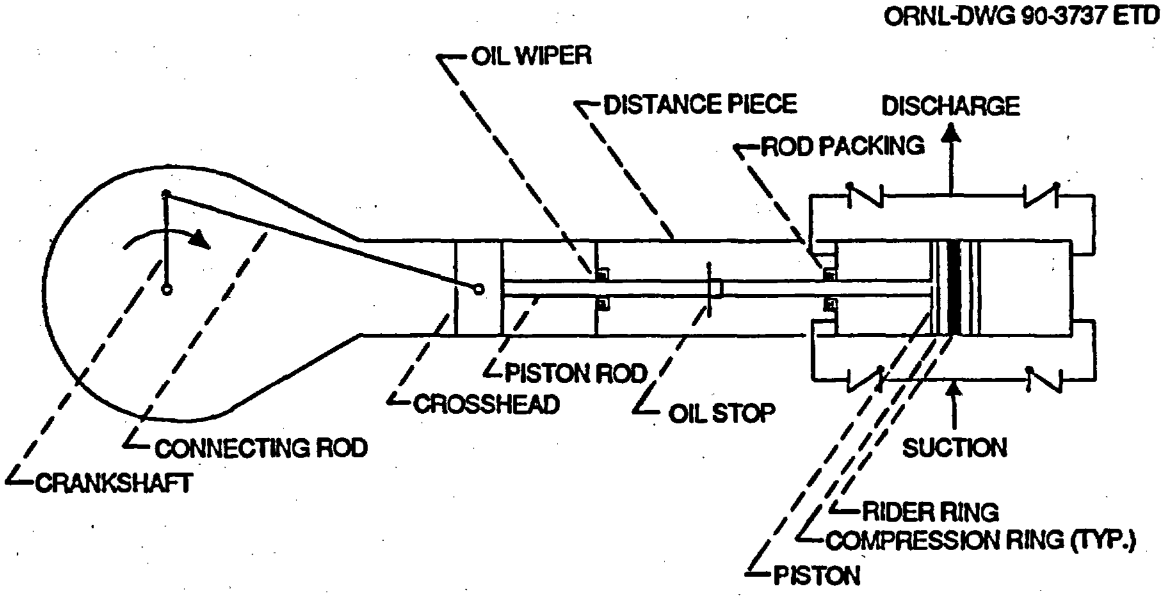

Fig. 2.1. Nonlubricated reciprocating compressor schematic.

and results in only axial forces and movement in the piston rod. The oil wiper prevents excessive oil migration from the running gear via the piston rod.

In the nonlubricated machine, the lengths of the distance piece, which connects the running gear frame to the compression cylinder, and the piston rod are adequate to assure that no point on the piston rod passes through both the oil wiper and the rod packing. In addition, an oil-stop baffle plate is installed on the piston rod between the oil wiper and rod packing to prevent oil migration along the rod.

The self-lubricating rod packing consists of segmented rings of carbon or tetrafluoroethylene (TFE), surrounded by garter springs, and contains system pressure. Self-lubricating compression rings and the broad rider ring, which supports the piston weight and prevents metal-to-metal contact, are made of TFE.

Nonlubricated reciprocating compressors are available from several manufacturers. Although the details of design differ with manufacturer and model, the basic principles of design and operation can be illustrated by reference to a single manufacturer and model. For this purpose, information for an Ingersoll-Rand Model PHE compressor is presented.[7] The Model PHE is a two-stage, horizontally opposed, machine having a 6-in stroke. Through the choice of low- and high-pressure cylinder bores and operating speed, it is available with rated capacities of from 409 to 667 actual cfm at a delivery pressure of 100 psig.

A cross-sectional view of the low-pressure cylinder is shown in Fig. 2.2, and a view of the high-pressure cylinder is shown in Fig. 2.3. The cylinder walls, heads, and rod packing region are cooled by water flow through the surrounding water jackets. In the low-pressure cylinder, suction and discharge valves are installed radially in each end of the cylinder. Valves in the high-pressure cylinder are installed in port plates that are parts of the head assemblies.

Details of the low-pressure cylinder valves are shown in Fig. 2.4. Design of the high-pressure valves is similar. The function of each valve is that of a spring-loaded check valve, with the spring-loaded valve channels lifting from the slotted seat plate, in response to pressure differential, to permit flow in the desired direction. Wear and friction are minimized by the use of TFE channel guides and spring wear strips.

The compressor accommodates variations in capacity requirements by means of unloaders that raise the suction valve channels off the seal plates in both the low-pressure and high-pressure cylinders. Staged half-capacity unloading or full unloading may be accomplished by opening either the valves on one end or on both ends of each cylinder. The unloaders are pneumatically operated, via a regulator that senses receiver pressure. A solenoid air valve is used to apply air pressure to the unloaders, thereby unloading the compressor, during startup.

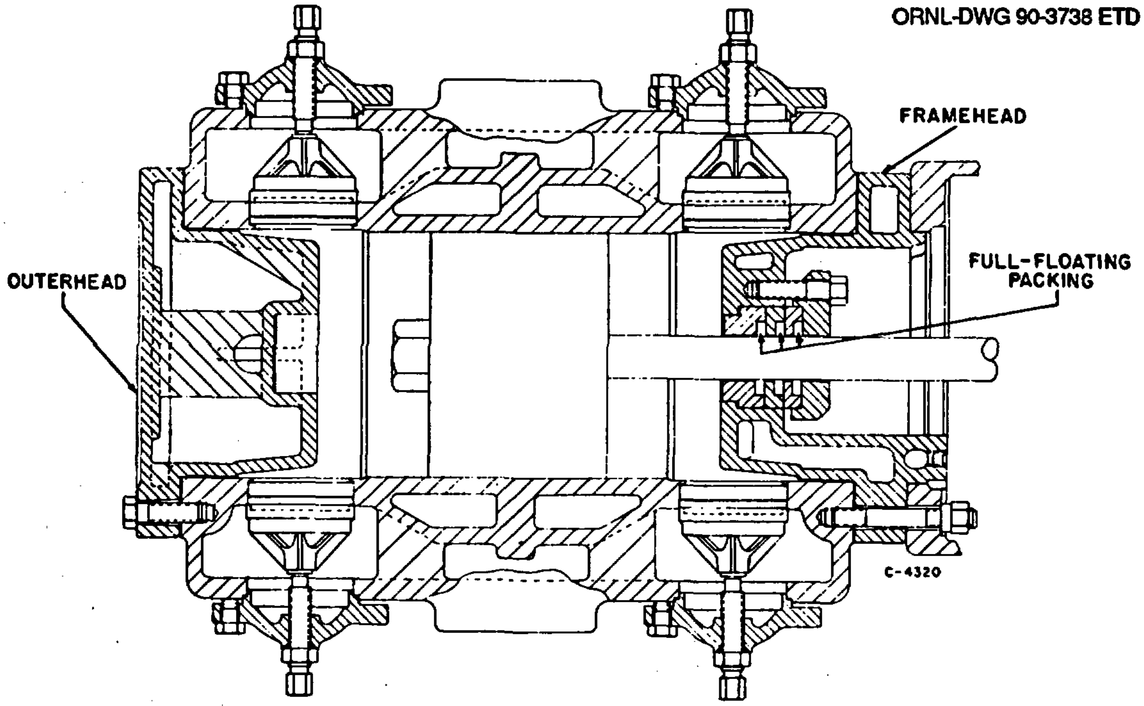

Fig. 2.2. Cross-sectional view of low-pressure cylinder. (From Ref. 7, by permission).

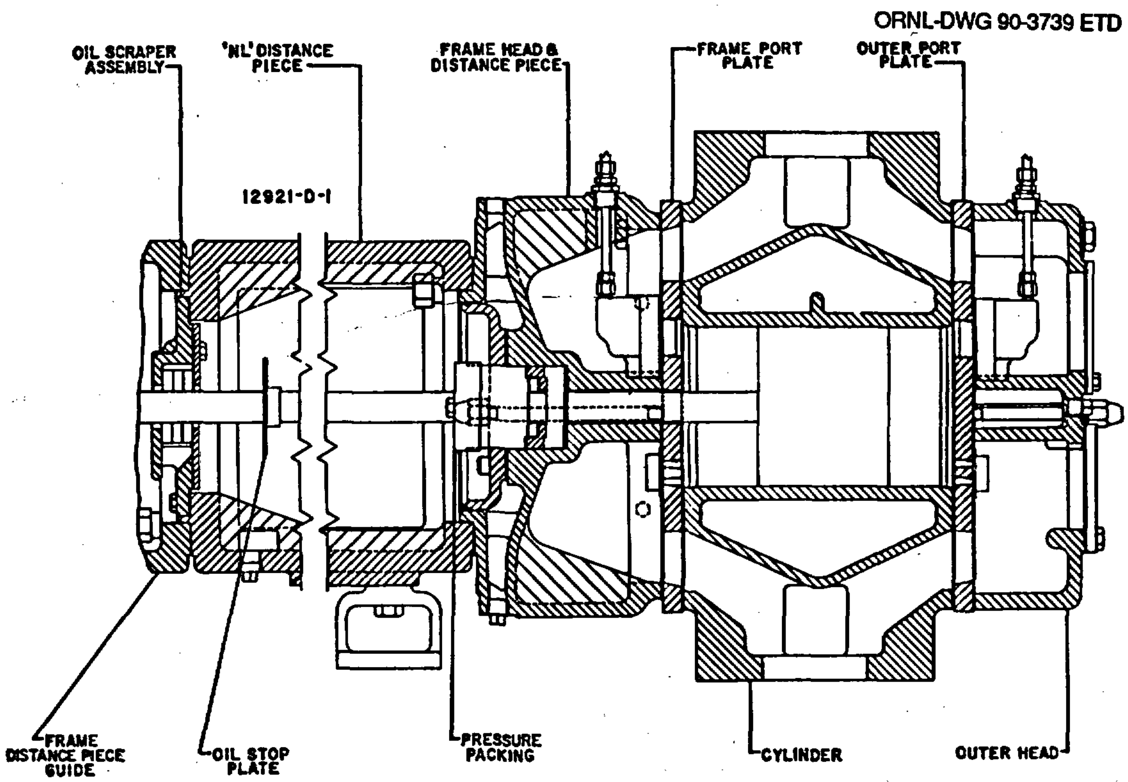

Fig. 2.3. Cross-sectional view of high-pressure cylinder. (From Ref. 7, by permission).

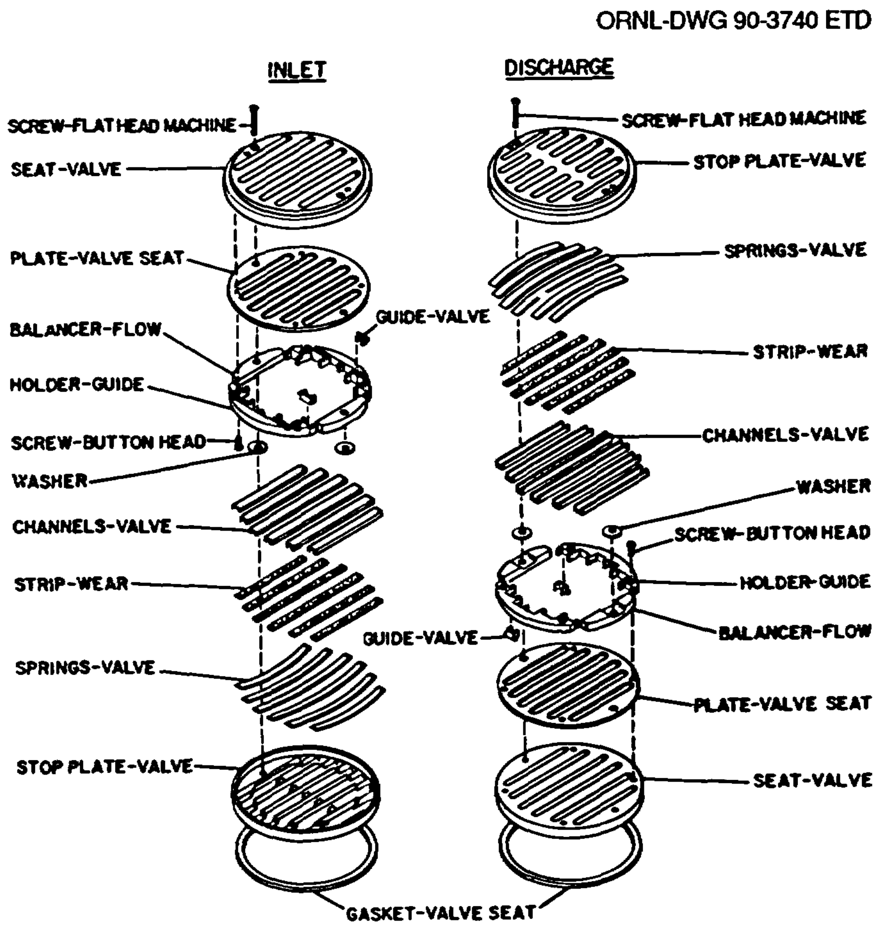

Fig. 2.4. Typical inlet and discharge channel valves. (From Ref. 7, by permission).

The compressor is driven either by a frame-mounted, direct-connected, motor or by V-belt drive from a separate motor. Usually, protective circuitry stops the motor on high cooling water outlet temperature, high outlet air temperature, high outlet air pressure, or low running gear oil pressure. A time-delay relay bypasses the low oil pressure switch and unloads the compressor for approximately 10 seconds during startup.

The intercooler, shown in Fig. 2.5, is a water-cooled shell-and-tube heat exchanger with provision for separating and automatically draining condensate. Admiralty brass tubes are used. The inside surface of the steel shell is coated with neoprene to retard rust. A filter in the air discharge line protects the high-pressure stage from any scale or particulates that may build up in the shell. A solenoid valve is often used in the cooling water supply to both the cylinder water jackets and the intercooler to interrupt water flow when the compressor is idle, thereby reducing any tendency for internal or external moisture condensation during idle periods.

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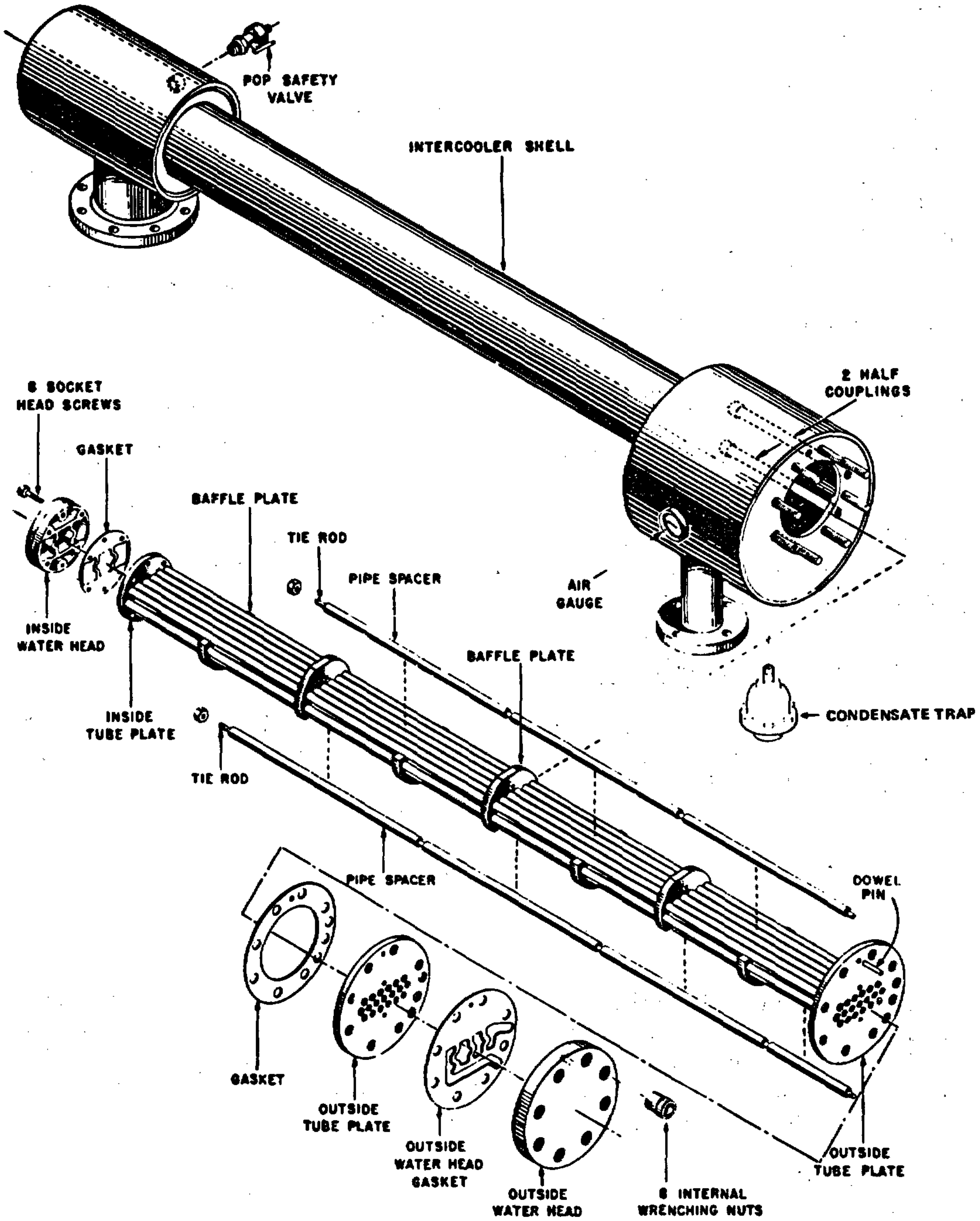

Fig. 2.5. Intercooler. (From Ref. 7, by permission).

2.2.2 Compressor equipment boundaries

For purposes of this report, the compressor is defined to include the following.

1. The main frame and running gear, including all internal parts.
2. The compression cylinders, including piston rods, rod packings, pistons and rings, valves, and unloaders.
3. The intercooler, in two-stage equipment.
4. Belt drive.
5. Protective circuitry.

Electric motors are not included in this assessment; they are included as another element[8] of the NPAR program.

2.2.3 Compressor functional requirements

The compressors, serving either as lead units or backup to the lead units, are required to provide highly reliable sources of compressed air for all plant uses. Required capacities are dependent on specific application, as shown in Appendix A. Delivery pressure is usually in the 100-125 psig range. Compressors providing control air are usually required to deliver oil-free air.

2.2.4 Compressor materials of construction

The materials of construction, as provided in catalogs by three manufacturers of nonlubricated reciprocating compressors (Ingersoll-Rand, Joy, and Worthington), are listed in Table 2.2.

2.3 Dryers

2.3.1 Dryer types

Refrigerated and desiccant type dryers are used in the control air systems of nuclear power plants. In a few cases, combination refrigerated/desiccant dryers are used, with the refrigerated section preceding the desiccant section to remove a large fraction of the excess moisture and thereby lower desiccant loading.

Refrigerated dryers cool the air stream to condense out a fraction of the contained water vapor, separate the condensed moisture, and then reheat the leaving air stream. Achievable pressure dew point can be no lower than a few degrees above the freezing point if ice formation in the dryer is to be avoided.

A refrigerated dryer is shown schematically in Fig. 2.6. Entering air is cooled in a regenerative shell-and-tube heat exchanger by the leaving air, with an appreciable fraction of the total moisture removal

Table 2.2. Compressor materials of construction

Component	Ingersoll-Rand	Joy	Worthington
Main frame	Cast iron	Cast semi-steel	Cast iron
Crank shaft	Forged steel	Not specified	Nodular iron
Connecting rod	Forged steel	Forged steel	Nodular iron
Main bearings	Full-floating aluminum	Spherical roller steel	Double roller steel
Crank bearings	Full-floating aluminum	Steel-backed copper-lead	Babbitt-lined steel
Crosshead	Aluminum	Tin-faced cast iron	Babbitted cast iron
Piston rod	Hardened steel	Chrome-plated hardened steel	Hardened steel
Rod packing	TFE	Carbon	TFE
L.P. piston	Aluminum	Nickel-plated cast iron	Aluminum
H.P. piston	Aluminum	Nickel-plated cast iron	Cast iron
Rings	TFE	TFE	TFE
Cylinders	Cast iron	Cast semi-steel	Cast iron
Cylinder liner	Not used	Flame-sprayed 420 stainless on cast iron	Not used
Valve elements	Stainless steel	Stainless steel	Stainless steel
Valve seats	Stainless steel	Not specified	Nodular iron

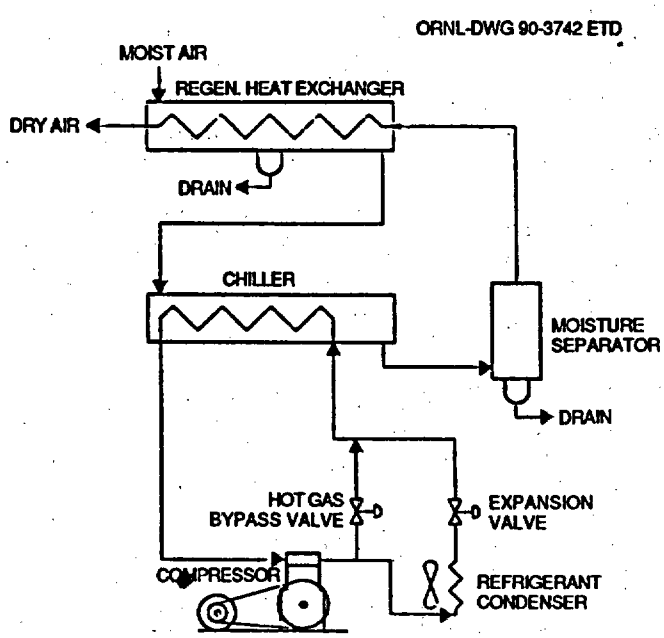

Fig. 2.6. Refrigerated air dryer schematic.

occurring in this heat exchanger. The air stream then flows to the chiller, where it is further cooled by evaporating refrigerant and additional moisture is condensed. The cold air and condensed moisture then passes through a centrifugal moisture separator, where the moisture is separated and removed via a trapped drain. The air stream, now saturated with moisture vapor at low temperature, then flows through the regenerative heat exchanger, where it is warmed by the incoming air. The leaving air dew point is controlled by the refrigerant thermostatic expansion valve setting. During low air flow conditions, hot refrigerant gas from the compressor discharge is added to the cold, low-pressure, refrigerant leaving the expansion valve by the hot gas bypass valve. This is done to limit minimum chiller temperature, preventing ice formation under the lightly loaded conditions.

Desiccant dryers pass the air stream through a column filled with granular desiccant material. Moisture in the air is adsorbed onto the desiccant in passage, resulting in a typical discharge pressure dew point of -40°F. The moisture-holding capability of the desiccant is limited, and means of regeneration must be provided. To provide for continuous drying service, dryers are constructed with two desiccant columns, with valving to permit one column to regenerate while the other is in active service. The regeneration process is automated, with a cycle timer controlling initiation and termination of regeneration.

One of two processes is used to regenerate the moisture-laden column. In the heat-regenerated process, a relatively small stream of air, electrically heated to approximately 400°F, flows in reverse direction through the regenerating column to remove the adsorbed moisture from the desiccant. The air then either is exhausted or is recirculated through a cooler/moisture separator and back to the heater by a small blower, as shown schematically in Fig. 2.7. Heat-regenerated dryers normally operate on an active-regeneration cycle of several hours duration.

In the heatless regeneration process, a relatively small stream of air from the exit of the active column is reduced in pressure and passed in reverse direction through the regenerating column. Moisture is retrieved from the desiccant by the low-humidity air, driven by the heat of adsorption remaining in the desiccant from the active phase of operation. A heatless dryer is shown schematically in Fig. 2.8. Heatless dryers typically operate on a much shorter active-regeneration cycle, usually only a few minutes in duration.

Desiccant dryers are protected from entrained free moisture and oil in the incoming air by prefilters. These filters use either ceramic or fiber elements to coalesce and drain off incoming liquid and to trap solid particulates, thereby preventing contamination of the desiccant material. Prefilters are not used universally for refrigerated dryers because incoming contaminants are collected and removed by the condensed moisture. Afterfilters are always provided for desiccant dryers, to trap any desiccant that may be carried from the dryer by the exiting dry air. Afterfilters are usually provided for refrigerated dryers to trap particulates and any entrained moisture or oil.

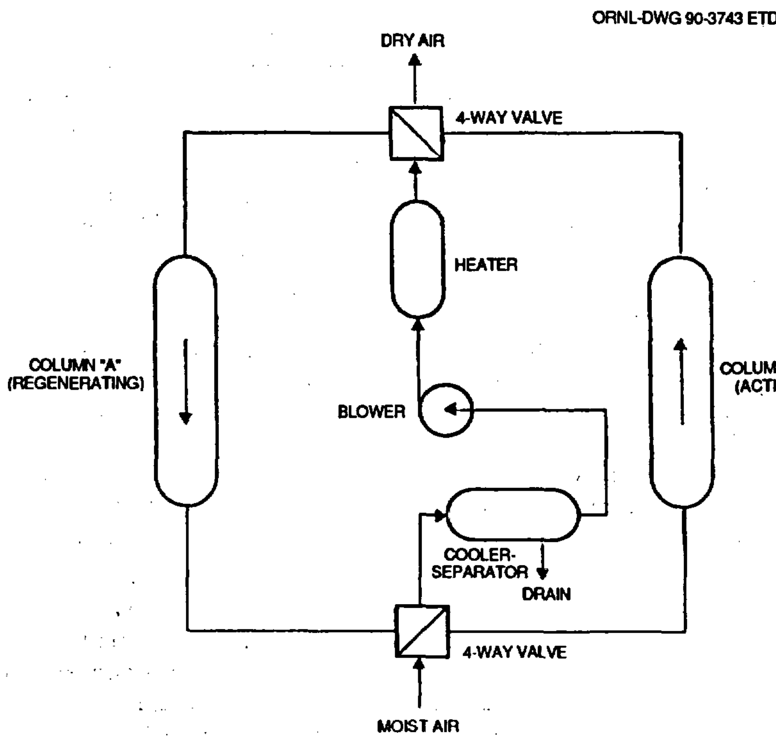

Fig. 2.7. Heat regenerated dryer schematic.

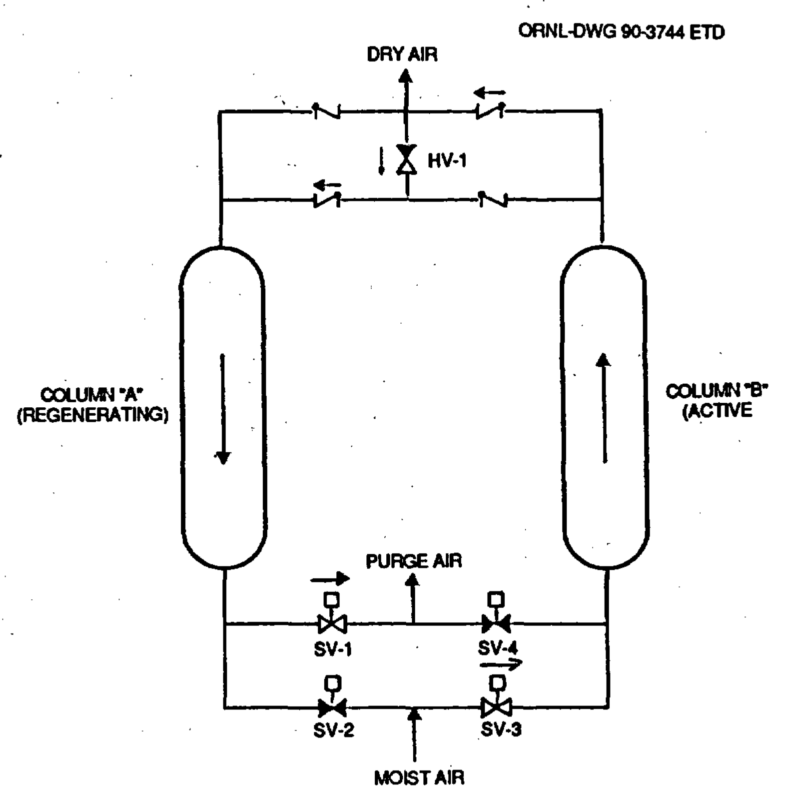

Fig. 2.8. Heatless dryer schematic.

Air dryer usage in each U.S. nuclear power plant, as described in safety analysis reports and other licensing documentation, is presented in Appendix A. Dryers are specified for the control air systems for all of the 114 reactor units having compressed air systems described in the documentation. The number of units using each of the various dryer types is shown in Fig. 2.9. Because some units use more than one type of dryer, the total for all types is greater than the number of units. Of the 114 units for which information is provided, 103 use desiccant dryers. Heat-regenerated and heatless types of dryers share almost equal status among the units for which type of desiccant dryer is specified; however, the large number of units having desiccant dryers without specified type (shown as "Regen." in the figure) prevents meaningful conclusions regarding the relative incidence of use of the two types. Similarly, the lack of specificity as to desiccant used (type of desiccant is only specified for one-quarter of the units using desiccant dryers) precludes determination of the relative use of silica gel and alumina.

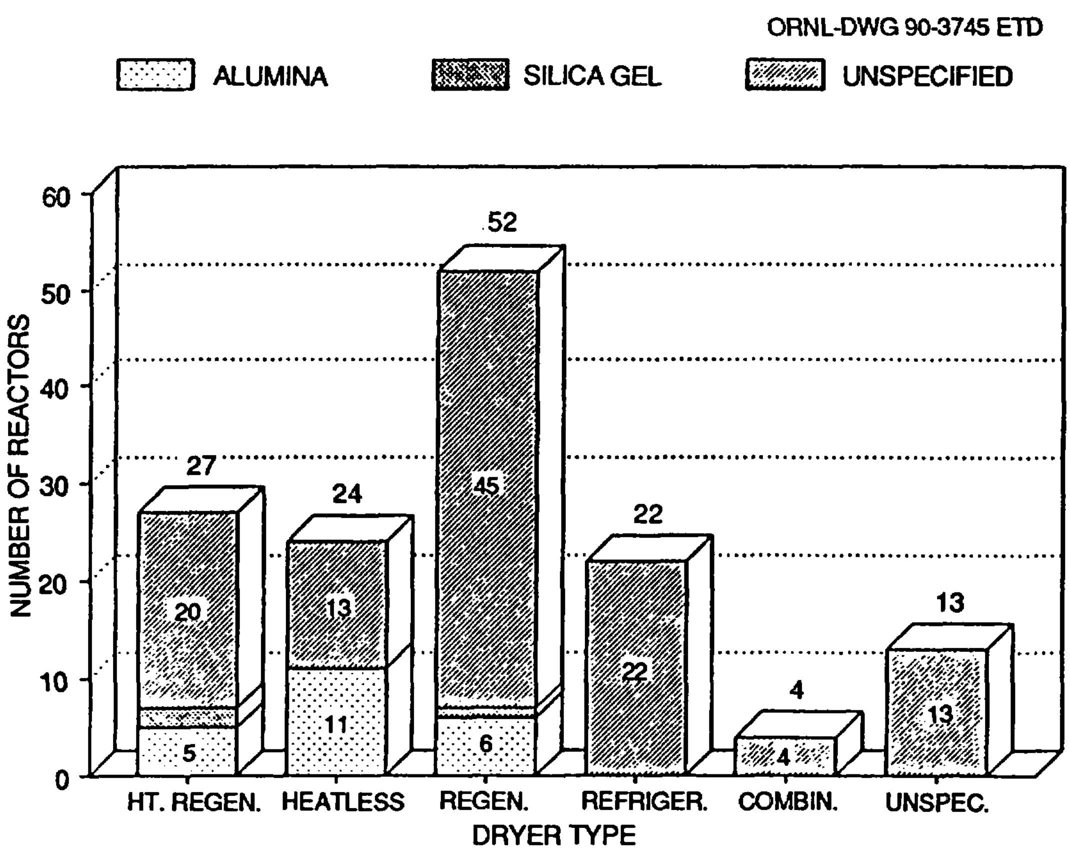

Fig. 2.9. Units using various types of air dryers.

2.3.2 Dryer equipment boundaries

For purposes of this report, the air dryer is defined to include the following.

1. For the refrigerated dryer:
   a. The refrigerant circuit equipment, including the compressor, the condenser, the evaporator (chiller), the expansion valve, the hot gas bypass valve, and associated controls.
   b. The regenerative air-to-air heat exchanger.

2. For the desiccant dryer:
   a. The desiccant-containing columns, including desiccant support structure and screens and the desiccant material.
   b. The air flow control valves and associated piping.
   c. The regeneration heater, cooler-separator, and blower, if used.
   d. The regeneration cycle control system.
   e. The prefilters and afterfilters.

2.3.3 Dryer functional requirements

The air dryers are required to provide a reliable supply of low-humidity air to the control air systems. System pressure is nominally 100 psig and dryer capacity is selected to meet system requirements. Refrigerated dryers are required to provide discharge air dew point, at pressure, in the range of 34-39°F. Regenerative desiccant dryers, either heatless or heat-regenerated, usually are required to provide -40°F discharge dew point.

2.3.4 Dryer materials of construction

Desiccant tower vessels are fabricated from carbon steel. Desiccant support screens are stainless steel. Main air piping is carbon steel. Valve bodies are usually steel, with stainless steel internals in some models. Valve control air piping is often copper. Desiccant is silica gel or activated alumina.

In refrigerated dryers, the shells of the regenerative air-to-air heat exchanger and the chiller are carbon steel. Heat exchanger tubing in both of these components is admiralty brass or copper.

3. TECHNICAL SPECIFICATION REQUIREMENTS

The Technical Specifications for each nuclear power plant establish requirements for surveillance testing of safety-related components to demonstrate operability of the components within specified limits. Compressed air systems are not usually considered to be safety-related because operation of these systems is not required to bring the plant to a safe shutdown condition. Therefore, the air systems are not usually referenced in the Technical Specification.

Plant service and main control air systems are required for startup and normal plant operation. Thus, their performance capability is demonstrated in the course of normal operation. Standby and emergency compressors are tested periodically to demonstrate their operational readiness if needed.

4. SUMMARY OF OPERATIONAL STRESSORS

In this section, the compressors and dryers are divided into subcomponents and parts and the significant stressors acting upon these parts are identified qualitatively under normal and accident conditions. Stressors have been divided into six categories: electrical, mechanical, thermal, chemical, radiation, and environmental.

Plant service air compressors and compressors and dryers providing main control air are usually located in the turbine building or the auxiliary building. They therefore are exposed to an environment not significantly different from that in normal industrial practice.

Smaller compressors and dryers serving to provide in-containment or emergency control air supply may be located within or adjacent to containment and can be exposed to a much harsher environment, especially under accident conditions. Although not normally expected to operate under accident conditions, some refurbishment may be required following an accident.

4.1 Compressors

4.1.1 Electrical stressors

4.1.1.1 Drive motor. An aging assessment of electric motors is reported in Ref. 8.

4.1.1.2 Protective switches. Protective switches used to detect and signal abnormal temperatures and pressures experience some arcing upon opening and closing of contact points, resulting in degradation of the contacts due to local vaporization of contact material. In addition, heat generation by the arcing and resulting increased contact resistance can affect the switch parts susceptible to thermal age degradation. Because 1) the current carried by these switches is small, 2) the frequency of switch actuation is low, and 3) Arrhenius aging data of polymeric materials normally used for insulating and structural parts in the switches indicate slow aging under normal conditions, switch degradation under normal conditions should not be a major factor in the aging characteristics of the total machine.

4.1.1.3 Solenoid valves. Solenoid valves are used to unload the compressor during startup and to stop the flow of cooling water when the compressor is idle. Aging characteristics of solenoid valves were assessed in Ref. 9.

4.1.2 Mechanical stressors

4.1.2.1 Running gear.

Main frame. The main frame serves to contain the lubricating oil, to support the static and dynamic loads imposed by the stationary and moving parts of the compressor, its drive system, and external piping, and to maintain the spatial relationships of the various parts of the compressor. Due to the robust design, the frame is competent to withstand the imposed loads over a long operating lifetime.

Main bearings and seals. Main bearings, which support the rotating crankshaft, either rolling element or hydrodynamic type, are stressed primarily by dynamic loads due to inertial forces from the reciprocating parts and the air forces on the piston faces. Rolling element bearing mechanical stressors include abrasion by dirt and wear particles in the lubricant, lubricant degradation, and surface fatigue from Hertzian contact stresses. Mechanical stressors for hydrodynamic bearings include abrasion by dirt and wear particles in the lubricant, lubricant degradation, and metal-to-metal contact between moving and stationary parts before the hydrodynamic film develops during startup. Elastomer seals, which prevent lubricant leakage and ingress of dirt, are subject to wear and to material properties deterioration with age.

Crankshaft. Mechanical stress in the crankshaft results from the transmitted torque and bending loads imposed by the drive system and cyclic forces from unbalance, inertial loads from the reciprocating parts, and work on the air being compressed. The main journals, in those machines using hydrodynamic main bearings, and the crank journals are exposed to tribological stressors, especially during startup. As in the case of the main frame, the robust design of the crankshaft provides competence to withstand the imposed mechanical stress. During normal operation, the journals are pressure-fed with filtered oil. During startup, the compressor is unloaded to reduce drive system and bearing loads. As a result, mechanical stressors on the crankshaft should not be a major factor in machine aging.

Connecting rod. Mechanical stress in the connecting rod results from cyclic compressive and tensile loading from gas forces and inertial forces of the reciprocating parts and cyclic bending forces due to inertial forces of the connecting rod itself. The connecting rod is normally capable of withstanding these stresses over a long lifetime.

Metal-to-metal contact in the crankpin bearing is prevented during normal operation by well-developed lubricant hydrodynamic film pressure and by squeeze-film pressure. The crosshead pin bearing, because of its oscillatory motion, depends upon squeeze-film pressure alone. Lubrication of both bearings is adequate to minimize tribological stress during normal operation. At startup, only boundary lubrication by lubricant remaining in the bearing clearances exists and wear during this brief period may be significant.

Crosshead. The crosshead serves to convert forces collinear with the instantaneous axis of the connecting rod to forces collinear with the compressor cylinder axis. With a short connecting rod, the side forces on the crosshead are appreciable during piston mid-stroke. Lubricant is pressure-fed to the crosshead sliding surfaces via drilled passageways through the crankshaft and connecting rod, thereby minimizing wear even though a hydrodynamic film does not develop fully. Again, lubrication during startup is marginal, with some wear to be expected during this phase of operation.

Oil wiper. The oil wiper serves to prevent excessive lubricant loss from the crankcase via the reciprocating piston rod. It consists of two or more metallic rings, which are segmented to accommodate some amount of radial wear while maintaining a close fit to the piston rod. Garter springs maintain radially inward pressure on the segments. The rings are lubricated by oil wiped from the piston rod surface. Wear of the wiper rings is expected; the rings are replaceable.

Belt drives. The V-belts used on a compressor that is belt-driven tend to assume a permanent "set", which can lead to premature belt failure, if the machine sits idle for a long period of time. Belts wear from contact with the sheave groove faces and from flexing, and periodic adjustment and replacement is expected.

4.1.2.2 Cylinder/Piston Assembly.

Piston rod. The piston rod transmits linear motion from the crosshead to the piston, while reciprocating through the oil wiper and the rod packing. Cyclic compressive and tensile stresses are imposed by gas forces and inertial forces from the reciprocating piston. Tribological stresses are imposed on the rod surface zones that pass through the oil wiper and the rod packing.

Rod packing. The rod packing seals the compressed air in the inboard compression chamber of the cylinder from the atmosphere. The packing consists of a series of TFE or carbon rings, segmented and radially loaded by garter springs to accommodate wear where the rings contact the reciprocating piston rod. The primary stressor is tribological. Wear is expected; the rings are replaceable.

Piston rider and compression rings. The piston rider ring is a broad TFE ring, contained in a circumferential groove midlength in the piston, that supports the weight of and centers the piston in the cylinder bore, thereby preventing metal-to-metal contact between the piston and cylinder. The primary stressor is tribological, with only the self-lubricating property of the ring material to provide acceptable wear rate.

The compression rings are relatively narrow TFE rings, contained in circumferential grooves near the two ends of the piston. These rings seal the piston to the cylinder bore to minimize blowby of high pressure air during the compression stroke. Adequate sealing even with a limited amount of radial wear is accomplished by a spring expander ring or by gas pressure that bears on the inside bore of the ring. As with the rider ring, the primary stressor is tribological.

Rider and compression ring wear is expected; they are replaceable. Wear rate is greatly accelerated by deterioration of the cylinder bore due to corrosion or by particulate matter in the incoming air. One manufacturer attributes a large fraction (90%) of the troubles with non-lubricated compressors to dirt and rust entering with the intake air and recommends that intake lines should be of a noncorroding material.[10]

Cylinder and heads. The cylinder and heads assembly provide the compression chambers, air flow passages, cooling water jacketing, mountings for the rod packing and valves, and connection points for external intake, discharge, and cooling water piping. Mechanical stressors include the mechanical stresses imposed by external piping loads, by vibration, and by the contained air pressure, and tribological stress from interaction with the reciprocating piston rings. Gasketted joints and their attendant fasteners are under continual mechanical and fluid stress, with relaxation through creep possibly causing air or water leaks.

Valves. The suction and discharge valves close at essentially zero flow, when the piston is at the extremes of the stroke and has zero velocity. As a result, closing is a gentle process with little impact. Suction valves open when piston velocity is approximately half maximum velocity and discharge valves open when the piston is essentially at maximum velocity, resulting in rapid movement of the moving valve parts during opening. Design features often are provided to cushion the opening action, either by springs or air cushioning, to prevent the valve channels (or strips or disks in other designs) from slamming against the valve stops. TFE inserts and guides are used as needed to prevent metal-to-metal wear of valve parts. Mechanical stressors include fatigue-inducing stresses in springs and sealing elements and erosion of the sealing surfaces from particulates in the air.

4.1.3 Thermal stressors

Elevated temperatures exist in the compressor, due to viscous friction in the running gear lubricant and to the compression process, during normal operation. Normal crankcase oil temperature is approximately 50°F above ambient.[7] Discharge air temperature from a single-stage, 100 psig, compressor is approximately 410°F, while a two-stage machine will have low-pressure and high-pressure stage discharge temperatures of approximately 225°F and 270°F, respectively. The materials of construction are compatible with these temperature levels; thermal stressors are not a significant factor in compressor aging.

4.1.4 Chemical stressors

Chemical stressors for compressors are limited to running gear lubricant deterioration and corrosion of the highly polished rubbing surfaces of the piston rod and the cylinder bore. Condensation of water in the crankcase can cause sludge formation and breakdown of the lubricant properties. Condensation of water in the cylinder and in the rod packing area during idle periods can cause deterioration of the surface finish, with subsequent accelerated wear of the packing or rings. Condensation is exacerbated if water flow to the cooling jackets is allowed to continue during idle periods. Exposure of in-containment compressors to high humidity during accident and post-accident conditions could also result in corrosion damage.

4.1.5 Radiation stressors

Compressors are normally installed in areas of low radiation exposure. This, coupled with the insensitivity of the materials of construction, should prevent any significant aging effects from radiation stressors.

4.1.6 Environmental stressors

Possible environmental stressors include dirt and high humidity in the inlet air and silt, biological organisms, or high mineral content in the cooling water. Ingestion of particulate material in the suction airstream would cause accelerated wear of piston rings and the cylinder bore. However, the compressors and their air intakes are usually located in relatively clean areas, and the intakes are equipped with particulate filters. High ambient humidity promotes condensation and subsequent corrosion in idle machines; it is also deleterious to idle belt drives. Poor cooling water quality can cause impaired cylinder cooling due to scale formation or flow blockage.

4.2 Dryers

4.2.1 Electrical stressors

Electrical components of refrigerated dryers include the refrigerant compressor drive motor, the compressor crankcase heater, low suction pressure and high discharge pressure cutout switches, dryer on-off switch and contactor, and miscellaneous indicator lamps. These components have widely-used counterparts that have demonstrated long lifetimes in all parts of the refrigeration industry. Actuation of the various switches is relatively infrequent and point degradation in the switches due to arcing should be minor. No appreciable aging effects due to electrical stressors are expected.

Electrical components of heatless desiccant dryers include the air flow control solenoid valves and the regeneration cycle sequence controller. Heat-regenerated dryers additionally have resistance heaters with associated temperature controller and, if closed-cycle, the recirculation blower drive motor.

An assessment of aging of solenoid-operated valves was reported in Ref. 9. Frequent cycling, as is the case for the control valves in heatless dryers where cycling periods of a few minutes are used, was pointed out as an abnormal stressor. Long-term energization of the coil, causing elevated coil temperatures especially where ambient temperature is high, was listed as as a significant stressor. However, the dryers are normally located in areas that do not have high ambient temperature, and although heat-regenerated dryer valves may be energized for several hours during the long regeneration cycle, high coil temperatures should not be a significant factor in the aging characteristics.

4.2.2 Mechanical stressors

The desiccant chambers are pressure vessels that undergo cyclic pressurization/depressurization and temperature changes during the active/regeneration cycles. Tensile and thermal stresses induced by these actions are the principal mechanical stressors for these components.

Frequent cycling of the air flow control valves, especially in heatless desiccant dryers, causes cyclic stresses and wear in the valve seats. Certain of the valves control the flow of air that may contain particles of desiccant, leading to erosive wear and possible sticking of the valve parts.

The desiccant itself is exposed to mechanical stress due to air flow. If repressurization, prior to resumption of active drying, and reestablishment of air flow as the active drying phase begins in a given chamber is abrupt, the desiccant may be levitated. This action results in particle degradation with dust generation and, ultimately, in impaired performance of the dryer.

4.2.3 Thermal stressors

Heat-regenerated desiccant dryers expose the desiccant to air temperatures of 400 to 550°F during the regeneration process. The desiccant does not suffer significant physical degradation due to these temperatures, but a loss of moisture retention capability may occur with time due to hydrocarbon impurities, such as oil vapor, baking onto the surface of the desiccant during regeneration.

4.2.4 Chemical, Radiation, and Environmental Stressors

There are no significant chemical, radiation, or environmental stressors that would cause accelerated aging of the air dryers.

5. OPERATING EXPERIENCE

5.1 Information Sources

Aging information for compressors and dryers was obtained from various sources of nuclear power plant operating experience documentation. These include Licensee Event Reports (LER), Nuclear Power Experience (NPE), In-Plant Reliability Data System (IPRDS), and maintenance records made available by a cooperating utility.

A summary of compressor and dryer problems delineated in LERs issued between 1978 and August, 1988, as identified from a search of the Sequence Coding and Search System (SCSS) maintained by ORNL's Nuclear Operations Analysis Center and supplemented by a manual search for the years 1978 and 1979 which are not included in the SCSS, is included in Appendix B. LERs are issued by plant operating utilities to inform the NRC of plant events having significant safety implications. Because compressed air systems are not usually considered safety-related systems, LERs are issued only for those air system problems that are precursors to safety-related events, such as reactor trips or actuation of Engineered Safety Features. As a result, the data base of LERs presents a far-from-complete portrayal of compressor and dryer problems encountered in plant operation.

Nuclear Power Experience, published by Stoller Power, Inc., is a compilation, derived from several sources, of operating experience in light water reactors. Summaries of events related to compressors and dryers not included in the LER data base that were detected in a search of the NPE data base are included in Appendix B.

The In-Plant Reliability Data System is a data base derived from detailed plant maintenance records provided by a cooperating utility. The plant for which the data was provided has a single boiling water reactor and utilizes three nonlubricated reciprocating compressors for service and control air and a single dryer. The data base includes information on each maintenance call, for scheduled preventative maintenance procedures and for response to perceived equipment problems. Information included, in varying degree of completeness, for each call includes the date, equipment identification code, the procedure or perceived problem, problem diagnosis, and corrective action. Information pertaining to the service and control compressors and to the dryers is summarized in Appendix C. Corrective maintenance calls and those few preventative maintenance calls from which problems were discovered are included.

A compilation of maintenance calls for the service/control and auxiliary air compressors and dryers for a second nuclear power plant was obtained from another cooperating utility. This is a two-unit pressurized water reactor plant. Service/control air is provided by four large nonlubricated reciprocating compressors and three desiccant dryers. In addition, there are two smaller auxiliary compressors and dryers to provide essential uses in the event of loss of the service/control air system. Data included for each call is similar to that included in the IPRDS records. This information is summarized in Appendix D.

It should be noted that the severity of problems reported in the various data sources may be quite different. Compressor or dryer problems reported in the LERs and, in most cases, in the NPE compilation are those that resulted in unplanned shutdown of the reactor or actuation of the plant's Engineered Safety Feature systems. They represent, in some cases, the result of aging effects that have not been adequately detected by surveillance methods and corrected by timely maintenance. Other problems occur as random, probably unpredictable, sudden failures of various components.

Problems as reported in the IPRDS and utility plant maintenance records, on the other hand, present a more accurate portrayal of aging. Included here are the day-to-day problems encountered with the machines, most of which are overcome by timely repair or reliance on redundant equipment such that loss of air supply does not occur. Many of these problems, if uncorrected, would result in a gradual loss of capability of the machines to meet volume delivery requirements at system pressure rather than a sudden and complete disablement of the unit.

5.2 Summary of Failure Modes and Causes

5.2.1 Compressors

Service/control and auxiliary compressor failures/problems reported in the data sources described above and delineated in the appendices are summarized by type of failure in Table 5.1. Information pertaining to the large service/control compressors and the smaller auxiliary compressors for the utility plant are presented separately to illustrate differences in operating experience with large, continuously operating machines and smaller, intermittent-service machines.

Belts. Belt failures reported in the LER and NPE data bases consisted of belts either breaking or being thrown off, rendering the compressor inoperable. Belt problems included in the IPRDS and utility maintenance data bases were usually identified and corrected by belt replacement or adjustment before loss of operability.

Controls. Control failures include pressure switch malfunctions that prevent the compressor from starting on low pressure or cause short cycling due to insufficient dead band, faulty operation of time delay relays that keep the compressor unloaded during startup and that override the low-oil-pressure switch during startup, and spurious temperature or pressure signals. Control failures render the compressor inoperable.

Table 5.1. Summary of Compressor Failures/Problems

Failure Type	LER	NPE	IPRDS	Utility Serv/Contr.	Utility Auxil.	Total
Belts	2	1	12	0	5	20
Controls	4	1	9	3	7	24
Cooling	0	0	13	0	0	13
Heat Exchangers & Traps	3	0	7	8	2	20
Leaks	3	0	20	55	38	116
Low Output	2	0	0	0	0	2
Mechanical	1	0	14	19	24	58
Motor	1	0	4	0	0	5
Operational	2	4	1	0	0	7
Piston Rings	0	0	1	8	2	11
Seals & Packing	2	0	1	61	3	67
Valves & Unloaders	1	1	25	48	8	83
Total	21	7	107	202	89	426

Cooling. Cooling problems occurred with the compressors used in the plant covered by the IPRDS. This plant utilized well water containing sediment and dissolved minerals, resulting in scale buildup and blockage in the cooling water passages.

Heat Exchangers and Traps. Two instances of aftercooler tube failures that resulted in injection of high pressure air into the service water system, disrupting the operation of that system, occurred in one plant. The failure was attributed to faulty fabrication technique during manufacture. Tube leaks in the intercooler introduce cooling water into the shell side of the cooler; small leaks can be accommodated by the condensate trap. Trap problems include the trap sticking open, with air loss to the drain system, and the trap sticking closed, with buildup of condensate in the shell. Gasket leaks of air or cooling water to the environment also occurred in some cases.

Leaks. Leaks of air, water, or lubricating oil is the most common problem for the compressors. In most cases, these constitute a nuisance that is corrected by bolt tightening or regasketing. In two cases, leaks resulted in a reportable event — one in which air was injected into the cooling water and a reactor trip occurred as a result of an attempt to vent the water system, and another where a cover plate leak released chromate to the environment.

Low Output. Two instances of reduced compressor output, due to unexplained cause, were reported by LERs. Low output can result from wear or breakage of piston rings, rod packing, or intake or exhaust valves or from malfunction of the unloaders.

Mechanical. Mechanical problems primarily are related to the running gear of the compressors, but also include conditions requiring a general rebuild of the units. Only one mechanical failure, where the piston rod detached from the crosshead because of a broken locking washer in an auxiliary compressor while the backup compressor was down for maintenance, resulted in issuance of an LER.

Other mechanical problems identified in the IPRDS and utility maintenance records include:

a. unusual noise during operation (cause unexplained in 13 instances, 3 due to crankshaft or connecting rod problems, and 1 due to improper clearance adjustment);
b. low oil level or pressure (11);
c. broken components such as crankshaft (3), frame part (1), or valve mounting bolts (1); and
d. need for rebuilding the compressor (13 instances where causes were not identified, probably from worn internal parts, and 4 instances where water was found in the crankcase or in one of the cylinders, probably from an internal cooling water leak or from malfunction of the intercooler condensate trap).

A disproportionately large fraction of the mechanical problems with the utility plant compressors, including all occurrences of a broken crankshaft, were experienced in the two smaller auxiliary compressors. These compressors are operated only during quarterly serviceability inspections and in the event of loss of control/service air pressure in containment. Long idle periods may result in accumulation of water in a cylinder, either from condensation or small internal leakage, causing lockup and damage during subsequent startup.

Operational. Operational problems are those that arise from the imposition of improper operational requirements, rather than being inherent problems with the compressors themselves. In one LER incident, a centrifugal compressor surged and would not reload after a sudden change in load when the air systems for two reactors were cross-connected. In another LER incident, a compressor tripped due to high condensate level in the intercooler because of an improperly set trap bypass valve. In an NPR-reported incident, a scram resulted when a primary compressor tripped due to a faulty control and the backup compressor control was inadvertently in the "off" position. In three other incidents, water or oil in the instrument air system resulted in air system valve problems. Although not directly due to compressor malfunction, these incidents arose because of cross connection with the service air system which may have been necessitated by instrument air compressor problems. In an IPRDS-reported incident, a compressor would not load automatically because a manual valve in the unloader circuit was found to be closed when it should have been in the open position.

Piston Rings. No LER or NPE reports of piston ring problems were found. Rings usually do not fail catastrophically but undergo continual wear which is corrected by routine maintenance. Most of the maintenance calls for ring problems are found in the utility records for the large service/control compressors that provide a continuous supply of compressed air. The paucity of ring problem reports in the IPRDS data probably is due to routine ring replacement being accomplished during preventative maintenance procedures; details of these procedures are not available.

Seals and Packing. Two LERs resulted from seal failures — one from the loss of seal water in a liquid-seal rotary compressor, and the other from worn seals in the oil pump. The IPRDS data includes one seal problem, a worn oil seal on the crankshaft. Most of the seals and packing maintenance calls from the utility records were for replacement of the piston rod packing (49 calls for the four large compressors and 1 for the two auxiliary compressors). Oil wiper replacement was called for in 10 calls for the large compressors and 2 for the auxiliary machines. Two oil seal calls were recorded for the large compressors and none for the smaller units. As in the case for piston rings, seals and packing undergo gradual deterioration due to aging and wear and normally do not result in sudden failure of the compressor.

Valves and Unloaders. Only one LER-reported incident and one NPE-reported incident involved valve or unloader problems. In each case, a backup compressor failed to load upon startup, in one case due to a failed unloader system solenoid valve and in the other due to a sticking unloader valve.

Valve and unloader problems accounted for more maintenance calls (25) than any other compressor problem type in the IPRDS data. Seven valve problem calls are listed, with most due to leaking or noisy valve operation. In two cases, valves came loose from their mountings and broke apart with pieces entering the compression chamber and scoring the piston or cylinder wall. Unloaders were responsible for 18 calls, 14 of which involved unsatisfactory operation of the solenoid valves that control the unloaders.

In the utility plant record of maintenance calls, valves and unloaders tied with seals and packing for second ranking in number of calls. For the four large service/control compressors, which collectively provide full-time compressed air service, valves were involved in 40 maintenance calls. Valve leaks, usually detected by blowback through the intake filter or by abnormally high intercooler pressure, accounted for 21 of the calls, and noisy operation accounted for another four. One call each was due to a loose valve, broken mounting bolts, and a broken valve. Valves were replaced in 12 calls that were initiated for other causes, either due to possible damage from such events as water leakage into the compressor or to consolidate maintenance activities during other repairs.

The unloaders for the large compressors accounted for eight maintenance calls. Ambiguous references to components in the unloader system prevent positive identification of the malfunction causes. The records indicate a "stuck" unloader in four instances, a "bad" unloader in one instance, and "control valve", "pilot valve", or "3-way valve" problems in four instances. Rebuilding, cleaning, or unloader control valve replacement were the reported corrective actions.

The two smaller auxiliary compressors included in the utility plant records had a total of eight maintenance calls involving valves and unloaders. Leaky valves were the problem in two instances, and valve replacement was carried out in response to three calls for other events such as water leaks or a broken crankshaft. Unloader problems accounted for three maintenance calls; the records are inadequate to clearly define the nature of the problems.

5.2.2 Dryers

Air dryer failures and problems, for the dryers associated with service/control and auxiliary compressors, reported in the data sources described above and delineated in the appendices are summarized by type of failure in Table 5.2.

Table 5.2. Summary of Dryer Failures/Problems

Failure Type	LER[a]	IPRDS	Utility	Total
Controls	1	6	1	8
Desiccant and filters	6	4	7	17
Leaks	0	5	0	5
Operational	5	0	0	5
Valves	3	7	4	14
Water in system	3	0	0	3
Total	18	22	12	52

[a]Includes two citations in IEIN 81-38 and one in NPE.

Controls. One disruption of the compressed air system due to out-of-sequence operation of the solenoid valves during maintenance was reported in the LER data. The IPRDS data included five instances of problems with control of the regeneration heaters and one instance of malfunction of the high humidity alarm. A burned-out timer motor was the only reported control problem in the utility plant data.

Desiccant and Filters. Five events reported in the LER data base and one event in the IPRDS data base were due to desiccant carryover into the instrument air system. It would appear that failure of the afterfilter would be indicated in each of these events, possibly exacerbated by excessive dusting of the desiccant. Another LER event involved a plugged afterfilter as a result of improper replacement of desiccant in the dryer. The remaining problems reported in the IPRDS and utility plant data involve excessive pressure differential across either the dryer chambers (degraded desiccant) or the filters (dirty filters), or a call for desiccant replacement without explanation of the reason.

Leaks. There were five maintenance calls in the IPRDS data for repair of leaks in various parts of the piping and valves system associated with the dryer. Leaks were not an identified problem in either the LER or utility plant data.

Operational. The LER data included five operational problems that resulted in reactor trips or actuation of ESF systems. These included the failure of a soldered joint in an air line due to piping impact during a maintenance operation, improper valve alignment during the restoration of a dryer to service, two cases where a refrigerated dryer froze up due to misadjustment of the hot gas bypass valve, and one instance in which a restricted purge air outlet resulted in water in the air system due to poor regeneration of the dryer.

Valves. Valves accounted for a large fraction of dryer problems included in each of the data sources. Two solenoid valve failures and one 4-way switching valve failure were included in the LER data. The IPRDS data included maintenance calls for two valve actuator linkage problems, two 3-way valve problems, one purge regulator problem, one valve sticking problem, and one solenoid valve problem. The utility data included maintenance calls for two sticking purge valves, one call to clean check valves which were dirty and would not seat, and one undescribed valve problem requiring replacement.

Water in Air System. Three instances of water in the air system were included in the LER data, reflecting either poor operation of the dryers or operation of the system without the dryers being in service. In one of these instances, water had entered the system during maintenance; no explanation was provided for the other two.

5.3 Frequency of Failures

5.3.1 Compressors

Data from which the frequency of compressor failures can be determined are not available from the information sources used in this assessment. Events reported in the LER and NPE data bases, in which the compressed air system is degraded to the point where a reactor trip occurs or Engineered Safeguard Features are actuated, often represent a series of compressor failures involving inoperability of both the primary and backup compressors. Thus, mean time between failures calculated from these data sources errs on the high side. Conversely, mean time between failures determined from the maintenance call data from the two utility plants err on the low side because most of the maintenance calls are for correction of conditions that do not represent failures of the compressors to perform.

The LER data base covers the time period of 1978 through August 1988. During this period, U.S. power reactors accumulated a total of approximately 812 unit years of operation, 17 compressor-related LERs were submitted, and an additional 5 NPE-reported events occurred. From this, the mean time between failures of the compressor system (as reported by LERs plus the NPE) is 36.9 reactor-years.

Mean time between maintenance calls as derived from the IPRDS data base and the utility plant records are much shorter. Compressor maintenance calls data from IPRDS cover a period of about 5.7 years, approximately representing plant years 9 through 14.7, and include 107 calls. The average time interval between calls, for the three service/control air compressors, is approximately 19 reactor-days. The utility plant data cover approximately 7.2 years of air system operation and include 197 calls for the large service/control compressors and 89 calls for the smaller auxiliary compressors. The average time interval between calls is about 13 plant-days for the large compressors and 29 plant-days for the small compressors.

The numbers of maintenance calls occurring during each year represented by the IPRDS data are given in Table 5.3. Records for plant year 14 represent the first eight months of that year. There is no evidence of an increase in frequency of calls with increasing plant age.

The numbers of maintenance calls occurring during each year represented by the utility plant data are listed in Table 5.4. Records for

Table 5.3. Chronology of Maintenance Calls for IPRDS Plant Compressors

Plant Year	9	10	11	12	13	14
No. of Calls						
Belts	3	0	5	1	2	1
Controls	1	0	3	1	2	2
Cooling	2	6	1	3	1	0
Heat Exchangers	3	1	0	2	0	1
Leaks	3	3	3	5	5	1
Mechanical	1	5	6	2	0	0
Motor	0	0	2	1	1	0
Operational	0	0	0	0	1	0
Rings	0	0	0	0	1	0
Seals & Packing	0	0	0	1	0	0
Valves & Unloaders	7	3	6	2	6	1
Total	20	18	26	18	19	6

Table 5.4. Chronology of Maintenance Calls for Utility Plant Compressors

Plant year	1	2	3	4	5	6	7	8
Maintenance Calls for Large Compressors								
Controls		1			1	1		
HXs and Traps	1	1		1	2	1	2	
Leaks	3	9	5	10	8	5	14	1
Mechanical	3	3	3	1	2	5	2	
Rings				1	4	1	2	
Seals and Packing	1	5	3	14	18	4	14	2
Valves and Unloaders	7	2	4	9	9	6	9	2
Total	15	21	15	36	44	23	43	5
Maintenance Calls for Small Compressors								
Belts			2	1	2			
Controls		2	3				1	1
HXs and Traps					2			
Leaks	3	2	10	5	8	5	5	
Mechanical	1	5		7	4	2	4	1
Rings					1		1	
Seals and Packing					2		1	
Valves and Unloaders		1	1	1	3		2	
Total	4	10	16	14	22	7	14	2

plant year 8 represent the first eight months of the year. The high incidence of maintenance calls for the large compressors during plant years 4 and 5 was due to problems with seals and packing. The high incidence during plant year 7 was due to increases in the number of calls for seals and packing and for leaks. With the exception of these problem categories, there is no obvious trend toward increasing maintenance requirements with plant age. These two categories represent readily replaceable or repairable machine elements, with wear and time-related deterioration expected.

There is no evidence of an appreciable increase in frequency of calls with increasing plant age for the smaller auxiliary compressors.

5.3.2 Dryers

As was the case for compressor failures, mean time between failures for dryers as determined from LER data errs on the high side because only dryer failures that resulted in reportable events are included. Similarly, mean time between failures calculated from the IPRDS and utility plant maintenance data err on the low side because many of the maintenance calls included in that data do not represent dryer failures but are for correction of degraded component performance.

During the time period between 1978 and August 1988 covered by the LER data base, which represents approximately 812 reactor unit-years, 16 dryer citations are included in the LER, IEIN, and NPE data. From this, the mean time between failures of the dryers is almost 51 reactor-years.

The IPRDS data for dryers cover a period of approximately 5.7 years and include 22 maintenance calls. The resulting average time between maintenance calls is about 95 reactor-days. The utility plant data includes 12 dryer maintenance calls, occurring over a time period of approximately 7.2 years, yielding an average time between maintenance calls of about 218 plant-days.

The numbers of dryer maintenance calls occurring during each year represented by the IPRDS data are given in Table 5.5. Although the year-by-year number of calls fluctuate sharply, there is no indication of increasing maintenance requirements with age.

Dryer maintenance calls occurring during each year represented by the utility plant data are given in Table 5.6. The large number of

Table 5.5. Chronology of Maintenance Calls for IPRDS Plant Dryers

Plant Year	9	10	11	12	13	14
No. of Calls						
Controls	0	2	3	1	0	0
Desiccant & Filters	1	1	1	0	1	0
Leaks	0	1	1	0	3	0
Valves	1	0	4	0	1	1
Total	2	4	9	1	5	1

Table 5.6. Chronology of Maintenance Calls for Utility Plant Dryers

Plant Year	1	2	3	4	5	6	7	8
No. of Calls								
Controls	0	0	0	0	0	0	1	0
Desiccant & Filters	0	0	1	1	0	0	3	2
Valves	0	0	0	0	0	0	1	3
Total	0	0	1	1	0	0	5	5

calls in plant year 7 was due primarily to the need to clean the moisture trap and replace the afterfilter elements in each of the three large dryers. A spate of three valve problems in plant year 8 resulted in the high total for that year. It does not appear that any inherent increase in maintenance with plant age occurred.

5.4 Methods of Detection

The principal method for detecting compressor and dryer problems in the plants is by regularly scheduled system walkdowns by operations personnel. Other problems are detected by maintenance personnel working in the vicinity of the equipment. Incipient problems are also found during scheduled preventative maintenance procedures. Failures of the equipment that result in subnormal air system pressure or conditions that endanger the equipment, such as high dryer exit humidity or low lubricating oil pressure in a compressor are automatically detected and alarmed. No data are available to establish the incidence of problem detection by these various processes.

6. MANUFACTURER-RECOMMENDED AND USER-APPLIED MAINTENANCE AND SURVEILLANCE PRACTICES

Instruction or maintenance manuals provided by the equipment manufacturers contain recommended inspection, maintenance, repair, and replacement procedures. The frequency of these procedures is often not fixed by the manufacturer, but is to be determined by the owner from operating experience with the given installation.

Preventative maintenance procedures that include surveillance and inspection guidance are developed by the plant owner for each equipment item. These procedures are carried out on a regularly scheduled basis; the schedule may be modified as operating experience is gained with the installation.

The low frequency of serious problems with compressors and dryers, as evidenced by the operating experience cited in Section 5, indicates that these practices are effective in providing dependable service.

6.1 Manufacturer-Recommended Practices for Compressors

Recommended surveillance, maintenance, and inspection procedures and schedules for nonlubricated compressors, as included in an Ingersoll-Rand maintenance manual,[7] are as follows.

Daily

1. Drain receiver or check operation of automatic drain trap.

2. Adjust cooling water flow so that leaving cooling water is 10-15°F warmer than incoming air.

3. Check unloader control regulator and automatic devices.

4. Check oil level.

5. Drain intake piping (while unit is unloaded or shut down) as often as necessary.

Every 4000 operating hours or at least once per year

1. Change crankcase oil.

On a regular schedule, as established by experience

1. Check for rider and compression rings wear. During initial operation, check at 50, 200 and 500 operating hours, then at 500-hour intervals until approximate rate of wear is established. Piston-cylinder radial clearance must be greater than 0.005 inch at all times to preclude damage from metal-to-metal contact.

2. Check frame lubrication system, intake valves and unloaders, discharge valves, and packing.

3. Test safety valves to assure that they are free and in operating condition. Safety valves should be removed and calibration checked at least once per year.

4. Clean intake filter.

5. Clean the crankcase breather and change the oil filter.

6. Inspect water jacket and coolant passages for cleanliness.

7. Inspect intercooler tubes for cleanliness.

8. Change intercooler filter.

9. Inspect drive belts for general condition and tension.

Other

The unit should be protected from corrosion during extended shutdown or storage periods. Recommended protection measures for storage include:

Removal and protected storage of the oil scraper rings and piston rod packing.

Placing a small quantity of vapor phase corrosion inhibitor (VPI) crystals in the compressor cylinders.

Placing bags of VPI in the compressor inlet and discharge openings and sealing these openings.

Wrapping the piston rod and stuffing box with VPI paper and sealing with waterproof tape.

Removal and protected storage of drive belts to prevent their acquiring a permanent set that would greatly increase possibility of failure on restart.

6.2 User-Applied Practices for Compressors

Preventative maintenance and surveillance procedures for compressors were obtained from the utility operating the plant for which maintenance records are summarized in Appendix D and discussed in Section 5. The preventative maintenance procedures for the large control/service compressors and the smaller auxiliary compressors are summarized in Tables 6.1 and 6.2, respectively. In addition to these formalized procedures, plant operating personnel conduct a walkdown of

Table 6.1. Preventative Maintenance Procedures for Control/Service Compressors

No.	Frequency	Description
1	Weekly	Visual inspection of compressor and related equipment. Check oil level. Check proper operation of drain traps.
2	2 months	Change intercooler filter.
3	6 months	Check rings and pistons for wear. Check valves for wear. Check gaskets for condition. Check scraper rings for wear. Check seal condition. Check cylinder walls for wear. Clean water inlets. Change oil and oil filter. Replace all parts and gaskets as needed.

Table 6.2. Preventative Maintenance Procedures for Auxiliary Compressors

No.	Frequency	Description
1	12 weeks	Serviceability inspection.
2	Annually	Lubricate compressor drive motor bearings.
3	18 months	Calibration and test of low-oil-pressure switch.
4	18 months	Calibration and test of the compressor control time delay relays.
5	18 months	Similar to Procedure 3 for the control/service compressors. This procedure formerly was carried out semiannually, but the interval was increased because of the low accumulated run time for these compressors.

the compressor-dryer system and blow down the traps on a once-per-shift basis.

The auxiliary compressors, which operate in service only upon the event of subnormal pressure in the control air system, undergo a serviceability inspection every 12 weeks. In this inspection, the compressors are checked for proper lubricating oil level, for autostart capability, and for ability to maintain system pressure.

6.3 Manufacturer-Recommended Practices for Dryers

Recommended surveillance, maintenance, and inspection procedures for a heat-regenerated desiccant dryer are included in the installation, operating, and maintenance instructions[11] obtained from a supplier. Although this particular dryer relies on manual repositioning of the air flow valves for switching from active to regeneration mode, the procedures are similar to those for an automatically switching dryer using timer-controlled valves. The procedures are summarized as follows.

<u>Daily</u>

1. Monitor alarm lights. If an alarm light is lit, refer to Trouble Shooting Guide.

2. Monitor all pressure and temperature gauges. At no time should any temperature exceed 450°F.

<u>Weekly</u>

1. Check operation of drain system; entrained water in blower will damage blades.

<u>Monthly</u>

1. Check amp draw on all three phases of the blower and the heater.

<u>At six month intervals</u>

1. Check dryer outlet pressure dewpoint.

<u>Annually</u>

1. Clean and inspect all valves, inspect blower bearings and performance, inspect desiccant bed for oil fouling or other deterioration.

6.4 User-Applied Practices for Dryers

Preventative maintenance and surveillance procedures for dryers were obtained from the utility operating the plant for which maintenance records are included in Appendix D and discussed in Section 5. In addition to these formalized procedures, a once-per-shift system walkdown is performed by plant operating personnel. The procedures are summarized in Table 6.3.

Table 6.3. Preventative Maintenance Procedures for Dryers

No.	Frequency	Description
Control/Service Dryers		
1	6 months	Inspect sample of desiccant for fine particles, wetness, and discoloration by oil. Replace if any of these are present.
		Disassemble and clean all check valves.
		Blow down relief valves to assure they are not stuck.
		Remove and clean muffler and blowdown limiter.
		Remove prefilter elements and inspect for clogging or moisture. Reinstall or replace if necessary.
		Remove and clean moisture trap. Reinstall or replace if necessary.
		Remove afterfilter element and inspect for excessive powder. Clean and reinstall or replace if necessary.
		Inspect selector and purge valves for cleanliness and proper operation. Replace if excessively worn.
Auxiliary Dryers		
1	18 months	Test and calibrate cycle timer.
		Inspect desiccant and replace if badly broken up or contaminated with oil.
		Inspect and clean pilot operated valves and seats on check valves. Replace if worn or damaged.

7. AGING MONITORING AND ASSESSMENT

Failure modes and causes along with associated inspection, surveillance, and monitoring aspects are addressed in this section. The discussion is based on information derived from manufacturers' manuals, plant maintenance personnel, a U.S. Navy program dealing with serviceability of shipboard air compressors, and this study. The areas covered are failure mode detection, cause determination, and identification of parameters for degradation trending and incipient failure detection.

7.1 Failure Mode and Cause Determination

Failure mode detection is described in terms of currently used parameters and methods; suggested additions are also included. Failure cause determination embraces both methods for cause differentiation and use of measurable parameters for detailed evaluation. Methods for differentiation are discussed in this subsection, while measurable parameters are discussed in Subsect. 7.2.

The compressors and dryers included in this assessment are not normally considered as safety-related equipment and are not addressed in plant Technical Specifications or covered in the ASME Boiler and Pressure Vessel Code, Sect. XI rules for inservice inspection. The ASME Committee on Operation and Maintenance is preparing a standard, ANSI/ASME OM-17, Performance Testing of Nuclear Power Plant Instrument Air Systems, that will specify inservice performance tests to assure that the air system meets required specifications. It is expected that the standard will require periodic tests of the compressor to demonstrate that the compressor has adequate delivery capacity, bearing vibration levels are within acceptable limits, various temperatures and pressures are acceptable, and relief valves are properly operable. The standard is expected to require frequent measurement of dryer outlet dewpoint, pressure drops across the dryer chamber and filters, and contamination levels following prefilter and following afterfilter, as well as verification that the dryer is cycling properly.

Failure modes for the compressor include failure to operate, failure to operate as required, and external leaks. Failure to operate, the most serious of these, is reflected in the absolute failure of the machine to respond to a signal to initiate or continue delivery of air to the using system. Failure to operate as required includes both a.) failure types in which the machine operates but in a degraded state with reduced or no output, and b.) degradation of components that, if not corrected, will ultimately lead to loss of function of the unit.

Compressor failure modes, with identity of the responsible component, cause of the failure, and methods for differentiating between failure causes are listed in Table 7.1. Causes of many of the failures are identifiable only through machine disassembly and inspection; others are

Table 7.1. Methods for Differentiating Between Compressor Failure Causes

Failure Mode	Subcomponent	Failure Causes	Methods for Differentiation
Failure to operate	Drive belt	Broken or thrown drive belts	Visual inspection
	Running gear	Broken coupling	Visual inspection
		Broken crankshaft	Disassembly and inspection
		Broken connecting rod	Disassembly and inspection
		Piston rod disconnected from crosshead	Disassembly and inspection
	Pressure switch	Pressure switch inoperable	Removal and inspection
	Cylinder	Hydraulic lock due to leakage while idle	Disassembly and inspection
		Piston-head interference	Disassembly and inspection
	Time-delay relays	Failure to override low oil pressure switch or to unload compressor during startup	Inspection for operability and calibration
Failure to operate as required	Bearings	Worn or damaged main or crankpin bearings	Auditory, vibration, disassembly and inspection
	Lubricating oil	Lubricating oil contamination	Visual, sample analysis
	Pressure switch	Pressure switch inoperable or out of calibration	Removal and inspection
	Unloader	Unloader, regulator, or control valve stuck or inoperable	Disassembly and inspection

Table 7.1 (continued)

Failure Mode	Subcomponent	Failure Causes	Methods for Differentiation
	Packing	Rod packing blowthrough	Auditory, visual inspection
	Rings	Broken or excessively worn rider or compression rings	Disassembly and inspection
	Valves	Leaking, broken, or loose valves	Auditory, disassembly and inspection
	Cylinder	Scored or worn cylinder wall	Disassembly and inspection
	Oil wiper	Oil migration through oil wiper	Visual inspection
	Head gasket	Blown head gasket	Auditory, visual inspection
	Water jacket	Fouled water passages	Disassembly and inspection
	Water valve	Failure to open completely	Operational inspection
		Failure to close	Operational inspection
	Intercooler	Fouled heat exchange surface or restricted water passages	Disassembly and inspection
		Automatic drain malfunction	Operational inspection
External leaks	Main oil seals	Oil leaks at main seals	Visual inspection
	Gaskets and fasteners	Oil, water, or air leaks at gasketed joints	Visual inspection

obvious either through auditory and visual inspection while the machine is operating or visual inspection subsequent to the failure to operate.

Dryer failure modes, identity of the responsible component, cause of the failure, and methods for differentiating between causes are listed in Table 7.2. Many of the failure causes are identifiable by an operational inspection, with subsequent disassembly and inspection required in some cases.

7.2 Measurable Parameters for Establishing Degradation Trends

In the preceding subsection, failure mode determination and failure cause differentiation were considered. Measurable parameter use was also included in those considerations. As stated in the NPAR[1] strategy, a prime objective of this Phase I assessment is to enlarge on that use by introducing measurable parameters that have potential for being combined with those already identified to enhance capabilities for incipient failure detection and examination of degradation trends.

7.2.1 Compressors

Compressor failures to operate, as listed in Table 7.1, generally do not have measurable parameters that would indicate precursors to failure. These events usually are associated with sudden, catastrophic failure of a critical part in the machine that can be readily identified on inspection following failure, but which could be foretold only through periodic disassembly and nondestructive tests of the vulnerable component. In view of the infrequent nature of these failures and the redundancy provided, this type of inspection is not justified.

Failures to operate as required, listed in Table 7.1, often represent gradual time-dependent degradation of a component that is detectable by monitoring and trending of various measurable parameters. Measurable parameters associated with each of the failure causes are given in Table 7.3. Many of these are presently used in compressor diagnostics; others are not widely used but appear to offer potential for indicating degradation.

Periodic measurement of compressor capacity, at specified discharge pressure, can provide an overall assessment of compressor condition. Compressor duty cycle, determined from loaded and unloaded operating hours, provides an indication of capacity but is also affected by air usage rate and the leak tightness of the entire air system and its air-using equipment. Time-based trending of capacity and/or duty cycle may be used to detect degradation and to predict when refurbishment will be required.

Air temperatures at the suction and discharge of each compressor stage and stage discharge pressures are excellent indicators of the

Table 7.2. Methods for Differentiating Between Dryer Failure Causes

Failure Mode	Subcomponent	Failure Causes	Methods for Differentiation
<u>Desiccant Dryer</u>			
Failure to operate as required	Prefilter	Damaged filter element	Air sample, disassembly and inspection
		Clogged element	Pressure drop
	Valves	Valves stuck, leaking, or inoperative	Operational inspection, disassembly and inspection
	Desiccant	Desiccant attrition	Operational inspection, disassembly and inspection
		Desiccant fouling	Operational inspection, disassembly and inspection
	Heater	Heater inoperative	Operational inspection
	Blower	Blower inoperative	Operational inspection
	Afterfilter	Damaged filter element	Air sample, disassembly and inspection
		Clogged element	Pressure drop
	Controls	Improper operation of cycle timer	Operational inspection, in-bed moisture sensor
		Improper temperature control	Operational inspection

Table 7.2 (continued)

Failure Mode	Subcomponent	Failure Causes	Methods for Differentiation
<u>Refrigerated Dryer</u>			
Failure to operate as required	Gas bypass valve	Valve set improperly or inoperative	Operational inspection
	Drain traps	Traps leaking or stuck open	Auditory, visual inspection
		Traps clogged or stuck closed	Operational inspection

Table 7.3. Measurable Parameters for Compressors

Subcomponent	Failure Causes	Methods for Differentiation
Bearings	Worn or damaged main or crankpin bearings	Vibratory amplitude, velocity, and spectrum, dimensions, appearance, MCSA[a]
Lubricating oil	Lubricating oil contaminated	Visual for presence of water, analysis for bearing or crosshead wear particles
Pressure switch	Pressure switch inoperable or out of calibration	Bench test — pressure to open, pressure to close
Unloader	Unloader, regulator, or control valve stuck or inoperable	Loaded/unloaded hours, appearance, cleanliness, bench test
Packing	Rod packing blowthrough	Loaded/unloaded hours, noise, rod appearance, capacity, MCSA
Rings	Broken or excessively worn rider or compression rings	Loaded/unloaded hours, dimensions, appearance, capacity, air temperatures and pressures, MCSA
Valves	Leaking, broken, or loose valves	Loaded/unloaded hours, noise, air temperatures and pressures, appearance, capacity, MCSA
Cylinder	Scored or worn cylinder wall	Loaded/unloaded hours, dimensions, appearance, capacity, MCSA
Oil wiper	Oil migration through oil wiper	Rod appearance, oil consumption rate
Head gasket	Blown head gasket	Loaded/unloaded hours, noise, appearance, capacity, MCSA
Water jacket	Fouled water passages	Air and water temperatures
Water valve	Failure to open completely	Air and water temperatures, water flow rate
	Failure to close	Water temperatures, water flow rate

Table 7.3 (continued)

Subcomponent	Failure Causes	Methods for Differentiation
Intercooler	Fouled heat exchange surface or restricted water passages	Air and water temperatures, water flow rate
	Automatic drain malfunction	Condensate volume during manual blowdown

[a]Motor current signature analysis.

condition of valves, compression rings, and intercooler, and can often provide an early warning of component degradation.[12] Table 7.4, adapted from Ref. 12, shows the effects of faulty valves and rings on stage temperatures and pressures. Trending of these parameters as a function of time may provide guidance in the determination of need and scheduling for maintenance.

Table 7.4. Effects of Faulty Components on Stage Temperatures and Pressures

Faulty Component	Pressures		Temperatures			
			Stage 1		Stage 2	
	Stage 1	Stage 2	Suction	Discharge	Suction	Discharge
Valves						
Stage 1 suction	LOW	low	HIGH	low	low	high
Stage 1 discharge	LOW	low	–	HIGH	high	high
Stage 2 suction	HIGH	LOW	–	HIGH	high	low
Stage 2 discharge	high	LOW	–	high	high	low
Compression rings						
Stage 1	LOW	low	–	HIGH	high	low
Stage 2	high	LOW	–	high	high	HIGH

Tabulation indicates pressures or temperatures higher or lower than normal.

Capitals indicate location of most pronounced effect.

Analysis of lubricating oil samples for composition and size distribution of particulates can indicate wear of the running gear bearings and crosshead. Increasing concentrations of bearing material and increasing wear particle size are indications of distressed wear surfaces. Ref. 12recommends trending of these parameters against operating time.

Motor current signature analysis is a recently developed technique for detecting changes in the operating condition of electrically driven mechanisms.[13] The driving motor serves as the transducer to provide a current trace that, when examined both spectrally and in the time domain, can reflect small disturbances in motor torque indicative of mechanical degradation of mechanism components. If this technique can be adapted to reciprocating compressor application, it is conceivable that the equivalent of a pressure-volume indicator card for an operating compressor could be derived from the motor current. The indicator card is a traditional and highly valuable tool for diagnostics of this type machinery.

7.2.2 Dryers

Failures to operate as required, listed in Table 7.2, are usually detected either by system walkdowns, by inspections during operation, or by indicated elevated exit air dewpoint. Measurable parameters that can be used to identify any specific problem are presented in Table 7.5. These include the presently used parameters: pressure drops across the filters and the dryer chambers; process temperatures during the different phases of the operating cycle; and the dewpoint of the air leaving the dryer. Of these, only dewpoint appears to offer the opportunity for meaningful trending (to identify faulty regeneration cycle or degradation of the desiccant with time and use).

Use of a moisture-sensing probe, located within the desiccant bed near the dry-air exit end, could provide an indication of the adequacy of the active/regeneration cycle and the moisture retention capability of the desiccant charge. (Such a probe is used to control the active/regeneration cycle in the Pall Model DEA dryer.)

Another approach to monitoring for impending bed saturation and moisture breakthrough, as well as desiccant degradation, would be based on measuring the bed axial temperature profile (which indicates the position in the bed and the length of the active adsorption zone) during operation. As the drying process proceeds in the active column, the adsorption zone progresses from the inlet end toward the exit end, and the exothermic adsorption process causes an elevated temperature front to progress through the bed. Degradation of the adsorption capability of the desiccant, due to contamination or other aging deterioration, would be expected to result in an increase in the length of the adsorption zone. Periodic measurement of the temperature profile, by means of a series of temperature sensors in the bed, should provide an indication of the location of the saturation front and guidance on the need for cycle adjustment or desiccant replacement.

Table 7.5. Measurable Parameters for Dryers

Subcomponent	Failure Causes	Measurable Differentiation
<u>Desiccant Dryer</u>		
Prefilter	Damaged filter element	Filter pressure drop
	Clogged element	Filter pressure drop
Valves	Valves stuck, leaking, or inoperative	Noise, pressures, temperatures
Desiccant	Desiccant attrition	Dryer pressure drop, exit dewpoint, afterfilter performance, appearance
	Desiccant fouling	Exit dewpoint, in-bed moisture, bed axial temperature profile, appearance
Heater	Heater inoperative	Exit dewpoint, temperatures
Blower	Blower inoperative	Exit dewpoint, blower current, noise
Afterfilter	Damaged filter element	Filter pressure drop, air sample particulates, appearance
	Clogged element	Filter pressure drop, appearance
Controls	Improper operation of cycle timer	Exit dewpoint, temperatures, pressures
	Improper temperature control	Exit dewpoint, temperatures

8. SUMMARY AND RECOMMENDATIONS

The objective of this study was to identify failure modes and causes resulting from aging of control and service air compressors and dryers in nuclear plant service and to identify measurable parameters that are suitable for detecting and establishing time-dependent degradation trends prior to failure, as well as providing guidance for effective maintenance. To this end, operating experience information, nuclear industry reports, manufacturer-supplied information, and results from discussions with plant operators have been used.

Failure modes are of two types: complete failure to operate, and operation in a degraded condition that results in reduced capability or that, if uncorrected, will ultimately lead to complete failure to operate. Cause of complete failure to operate often is failure of a critical component or appurtenance of a compressor, an event for which there is little warning. Review of operating experience data revealed no dominant type of failure. No measurable parameters were identified to portend this type of failure.

Certain parts of a reciprocating compressor, principally rings, valves, and rod packing, undergo wear during service and are routinely replaced or refurbished when performance deteriorates or wear limits are reached. Operating experience data does not show any appreciable increase in required maintenance with increasing age. The degraded condition is often detected by either system walkdowns or periodic partial disassembly and inspection. Early detection and tracking of compressor degradation can be enhanced by the use of identified measurable parameters, including stage temperatures and pressures, compressor duty cycle, delivery capacity, and motor current signature analysis.

Dryer components that require periodic maintenance or replacement to provide dependable service include regeneration cycle controls, operating valves, the desiccant, and filter elements. Degradation of these components is presently detected by operational surveillance and performance (exit dewpoint). Identified measurable parameters that would enhance detection or tracking of dryer degradation include humidity measured within the desiccant bed a short distance from the dry-air exit end by means of a permanently installed probe, and measurement of the axial temperature profile within the bed by means of a series of temperature sensors.

Instances where loss of the air supply occurs due to compressor or dryer failure are rare, because equipment failures to operate are rare and redundancy is provided in most systems to preclude loss of system air supply from failure of a single machine. An effective surveillance and monitoring program, with preventative and corrective maintenance, can provide reliable service from the compressors and dryers. For these reasons, it is recommended that this equipment be deleted from further aging consideration in the NPAR program.

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APPENDIX A

AIR COMPRESSORS AND DRYERS IN U.S. NUCLEAR PLANTS AS DESCRIBED IN SAFETY ANALYSIS REPORTS

NOMENCLATURE

N/S	– Information not specified in reference document
NO.	– Number of compressors or dryers used. Where compressors or dryers are shared by more than one reactor, number is given as a fraction (e.g., 4/2 denotes four units shared by two reactors).
CFM	– Capacity of unit, ft^3/min
TYPE	– Type of compressor or dryer
Compressor:	
CENTR	– Centrifugal
DIAPH	– Diaphragm
LS ROT	– Liquid seal rotary
RECIP	– Reciprocating
SCREW	– Rotary screw
(SRVC)	– Instrument air provided by service air compressor
Dryer:	
HTLESS	– Heatless regenerative desiccant
HT REG	– Heat regenerative desiccant
REGEN	– regenerative desiccant (not specified whether heatless or heat regenerative)
REFRIG	– Refrigerated
COMBO	– Combination refrigerated and desiccant
LUB	– Type of air-side lubrication
N	– Nonlubricated
Oil	– Oil lubricated
APPLIC.	– Instrument air compressor application
AUX	– Auxiliary instrument air
ADS	– Automatic Depressurization System air
BACKUP	– Backup instrument air
CNTMNT	– Containment instrument air
DRYWELL	– Drywell instrument air
EMERGY	– Emergency instrument air
ESF	– Engineered Safety Feature air
IAN	– Noninterruptible instrument air
MAIN	– Provides main instrument air
NONINTR	– Noninterruptible instrument air
NSSS	– Nuclear Steam Supply System instrument air
NUCLEAR	– Same as NSSS
SHUTDWN	– Shutdown instrument air
DESIC	– Desiccant type
ALUMA	– Activated alumina
S GEL	– Silica gel

AIR COMPRESSORS AND DRYERS IN U.S. NUCLEAR PLANTS
AS DESCRIBED IN SAFETY ANALYSIS REPORTS

	COMPRESSORS									DRYERS		
	SERVICE AIR				INSTRUMENT AIR							
UNIT	NO.	CFM	TYPE	LUB	NO.	APPLIC.	CFM	TYPE	LUB	NO.	TYPE	DESIC.
Beaver Valley 1	3	350	RECIP	NL	0	MAIN		(SRVC)		1	HT REG	N/S
					2	CONTNMT	50	RECIP	NL			
Beaver Valley 2	2	728	SCREW	NL	0	MAIN		(SRVC)		1	HT REG	N/S
					2	CONTNMT	30	N/S	NL	2	REFRIG	
Bellefonte 1	4/2	720	RECIP	NL	0	MAIN		(SRVC)		1/2	REGEN	N/S
Bellefonte 2	4/2	720	RECIP	NL	0	MAIN		(SRVC)		1/2	REGEN	N/S
Big Rock Point	3	70	N/S	NL	0	MAIN		(SRVC)		1	REGEN	N/S
Braidwood 1	3/2	2190	CENTR	N/S	0	MAIN		(SRVC)		3/2	REGEN	ALUMA
Braidwood 2	3/2	2190	CENTR	N/S	0	MAIN		(SRVC)		3/2	REGEN	ALUMA
Browns Ferry 1	1/3	950	N/S	N/S	4/3	MAIN	610	N/S	N/S	4/3	REGEN	N/S
	1/3	590	N/S	N/S	2	DRYWELL	9	N/S	NL	2	REFRIG	
Browns Ferry 2	1/3	950	N/S	N/S	4/3	MAIN	610	N/S	N/S	4/3	REGEN	N/S
	1/3	590	N/S	N/S	2	DRYWELL	9	N/S	NL	2	REFRIG	
Browns Ferry 3	1/3	950	N/S	N/S	4/3	MAIN	610	N/S	N/S	4/3	REGEN	N/S
	1/3	590	N/S	N/S	2	DRYWELL	9	N/S	NL	2	REFRIG	
Brunswick 1	3	334	RECIP	NL	0	MAIN		(SRVC)		1	HT REG	N/S
					2	IAN	19.5	N/S	N/S			
Brunswick 2	3	334	RECIP	NL	0	MAIN		(SRVC)		1	HT REG	N/S
					2	IAN	19.5	N/S	N/S			
Byron 1	3/2	2190	CENTR	N/S	0	MAIN		(SRVC)		3/2	REGEN	ALUMA
Byron 2	3/2	2190	CENTR	N/S	0	MAIN		(SRVC)		3/2	REGEN	ALUMA
Callaway 1	3	525	RECIP	NL	0	MAIN		(SRVC)		2	HTLESS	N/S
Calvert Cliffs 1	1	616	RECIP	N/S	2	MAIN	470	RECIP	NL	1	HTLESS	ALUMA
Calvert Cliffs 2	1	616	RECIP	N/S	2	MAIN	470	RECIP	NL	1	HTLESS	ALUMA

UNIT	COMPRESSORS: SERVICE AIR NO.	CFM	TYPE	LUB	INSTRUMENT AIR NO.	APPLIC.	CFM	TYPE	LUB	DRYERS NO.	TYPE	DESIC.
Catawba 1	2/2	750	SCREW	OIL	3/2	MAIN	650	RECIP	NL	4/2	REFRIG	
Catawba 2	2/2	750	SCREW	OIL	3/2	MAIN	650	RECIP	NL	4/2	REFRIG	
Clinton 1	3	2000	N/S	N/S	0	MAIN		(SRVC)		3	HTLESS	ALUMA
Comanche Peak 1	2/2	1500	CENTR	N/S	3/2	MAIN	350	RECIP	NL	2/2	HT REG	ALUMA
Comanche Peak 2	2/2	1500	CENTR	N/S	3/2	MAIN	350	RECIP	NL	2/2	HT REG	ALUMA
Cooper	3	775	RECIP	NL	0	MAIN		(SRVC)		2	HT REG	N/S
Crystal River 3	2	335	N/S	N/S	2	MAIN	345	RECIP	NL	1	N/S	N/S
Davis-Besse 1	1	766	N/S	NL	0	MAIN		(SRVC)		1	HTLESS	ALUMA
	1	992	N/S	NL	1	EMERGCY	160	N/S	NL			
Diablo Canyon 1	2/2	650	SCREW	NL	0	MAIN		(SRVC)		2/2	HT REG	N/S
	4/2	334	RECIP	NL								
Diablo Canyon 2	2/2	650	SCREW	NL	0	MAIN		(SRVC)		2/2	HT REG	N/S
	4/2	334	RECIP	NL								
Donald Cook 1	1	1500	CENTR	NL	0	MAIN		(SRVC)		2	REGEN	N/S
					1	BACKUP	317	RECIP	NL			
Donald Cook 2	1	1500	CENTR	NL	0	MAIN		(SRVC)		2	REGEN	N/S
					1	BACKUP	317	RECIP	NL			
Dresden 2	1	600	N/S	N/S	1	MAIN	200	RECIP	N/S	1	N/S	N/S
					1	MAIN	400	RECIP	N/S			
Dresden 3	1	600	N/S	N/S	1	MAIN	200	RECIP	N/S	1	N/S	N/S
					2	MAIN	400	RECIP	N/S			
Duane Arnold	3	N/S	RECIP	NL	0	MAIN		(SRVC)		1	HT REG	N/S
Edwin I. Hatch 1	3	578	RECIP	NL	0	MAIN		(SRVC)		2	REGEN	N/S
					2	DRYWELL	5	N/S	NL	1	N/S	N/S
Edwin I. Hatch 2	3	527	RECIP	NL	0	MAIN		(SRVC)		2	REGEN	N/S
					2	DRYWELL	5	N/S	NL	1	REFRIG	
Fermi 2	3	1225	RECIP	NL	0	MAIN		(SRVC)		3	N/S	N/S
					2	NONINTR	100	RECIP	NL			
Fort Calhoun 1	3	710	RECIP	NL	0	MAIN		(SRVC)		1	REGEN	N/S

UNIT	COMPRESSORS: SERVICE AIR NO.	CFM	TYPE	LUB	INSTRUMENT AIR NO.	APPLIC.	CFM	TYPE	LUB	DRYERS NO.	TYPE	DESIC.
Fort St. Vrain	1	N/S	N/S	OIL	3	MAIN	N/S	N/S	NL	2	N/S	N/S
Grand Gulf 1	2/2	N/S	CENTR	N/S	1	MAIN	N/S	CENTR	N/S	1	HTLESS	N/S
					2	ADS	N/S	RECIP	NL			
Grand Gulf 2	2/2	N/S	CENTR	N/S	1	MAIN	N/S	CENTR	N/S	1	HTLESS	N/S
					2	ADS	N/S	RECIP	NL			
Haddam Neck	1	687	N/S	N/S	2	MAIN	168	RECIP	NL	2	REGEN	S GEL
					2	CNTMNT	N/S	N/S	N/S			
Hope Creek 1	2	3000	CENTR	NL	0	MAIN		(SRVC)		2	HTLESS	N/S
					1	EMERGY	500	RECIP	NL	2	HTLESS	N/S
					2	CNTMNT	35	RECIP	NL			
Indian Point 2	1	625	N/S	N/S	2	MAIN	225	RECIP	NL	2	REFRIG	
										1	REGEN	N/S
Indian Point 3	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
James FitzPatrick	3	500	RECIP	NL	0	MAIN		(SRVC)		3	HT REG	N/S
Joseph M. Farley 1	5	550	RECIP	N/S	0	MAIN		(SRVC)		2	REGEN	N/S
Joseph M. Farley 2	4	550	RECIP	N/S	0	MAIN		(SRVC)		2	REGEN	N/S
Kewaunee	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
LaSalle County 1	3/2	1750	CENTR	NL	0	MAIN		(SRVC)		4	REGEN	N/S
					2	DRYWELL	N/S	RECIP	NL			
LaSalle County 2	3/2	1750	CENTR	NL	0	MAIN		(SRVC)		1	REGEN	N/S
					2	DRYWELL	N/S	RECIP	NL			
Limerick 1	2	397	RECIP	N/S	2	MAIN	397	RECIP	N/S	2	REGEN	N/S
					2	CNTMNT	10	RECIP	NL	2	REFRIG	
Limerick 2	1	397	RECIP	N/S	2	MAIN	397	RECIP	N/S	2	REGEN	N/S
					2	CNTMNT	10	RECIP	NL	2	REFRIG	
Maine Yankee	3	317	RECIP	NL	0	MAIN		(SRVC)		2	HT REG	ALUMA
					2	CNTMNT	26	N/S	N/S	2	N/S	N/S
McGuire 1	2/2	750	SCREW	OIL	3/2	MAIN	650	RECIP	NL	4/2	REFRIG	
										1/2	REGEN	N/S
McGuire 2	2/2	750	SCREW	OIL	3/2	MAIN	650	RECIP	NL	4/2	REFRIG	
										1/2	REGEN	N/S

UNIT	COMPRESSORS									DRYERS		
	SERVICE AIR				INSTRUMENT AIR							
	NO.	CFM	TYPE	LUB	NO.	APPLIC.	CFM	TYPE	LUB	NO.	TYPE	DESIC.
Millstone 1	1	653	RECIP	NL	1	MAIN	653	RECIP	NL	1	REGEN	N/S
Millstone 2	1	323	RECIP	NL	2	MAIN	323	RECIP	NL	1	REGEN	ALUMA
Millstone 3	1	750	N/S	NL	2	MAIN	750	N/S	NL	3	REGEN	N/S
					2	SHUTDWN	150	N/S	N/S			
Monticello	1	376	N/S	NL	0	MAIN		(SRVC)		1	HT REG	N/S
	2	290	N/S	NL								
Nine Mile Point 1	1	500	RECIP	NL	1	MAIN	729	RECIP	NL	2	REGEN	N/S
					2	MAIN	485	RECIP	NL			
Nine Mile Point 2	3	N/S	N/S	N/S	0	MAIN		(SRVC)		2	REFRIG	
					1	ADS	N/S	N/S	N/S	1	REGEN	N/S
North Anna 1	1	373	N/S	NL	1	MAIN	373	N/S	NL	1	REFRIG	
					2	CNTMNT	25	N/S	N/S	2	REGEN	N/S
North Anna 2	1	373	N/S	NL	1	MAIN	373	N/S	NL	2	REFRIG	
					4	CNTMNT	25	N/S	N/S	2	REGEN	N/S
Nuclear One 1	2	100	N/S	OIL	3	MAIN	200	N/S	NL	2	REGEN	N/S
Nuclear One 2	1	100	N/S	OIL	2	MAIN	528	N/S	NL	1	REGEN	N/S
Oconee 1	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Oconee 2	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Oconee 3	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Oyster Creek 1	3	771	RECIP	NL	0	MAIN		(SRVC)		2	HT REG	N/S
Palisades	3	200	RECIP	NL	0	MAIN		(SRVC)		1	HT REG	S GEL
					3	ESF	22	N/S	OIL	3	REFRIG	
Palo Verde 1	3	500	N/S	N/S	0	MAIN		(SRVC)		1	REGEN	N/S
Palo Verde 2	3	500	N/S	N/S	0	MAIN		(SRVC)		1	REGEN	N/S
Palo Verde 3	3	500	N/S	N/S	0	MAIN		(SRVC)		1	REGEN	N/S
Peach Bottom 2	4	377	RECIP	NL	0	MAIN		(SRVC)		2	HTLESS	ALUMA
					2	DRYWELL	N/S	N/S	N/S	2	N/S	N/S
Peach Bottom 3	3	377	RECIP	NL	0	MAIN		(SRVC)		2	HTLESS	ALUMA
					2	DRYWELL	N/S	N/S	N/S	2	N/S	N/S

UNIT	COMPRESSORS: SERVICE AIR NO.	CFM	TYPE	LUB	INSTRUMENT AIR NO.	APPLIC.	CFM	TYPE	LUB	DRYERS NO.	TYPE	DESIC.
Perry 1	1	N/S	N/S	N/S	1	MAIN	N/S	N/S	N/S	2	COMBO	N/S
					1	ADS	16	RECIP	N/S			
Perry 2	1	N/S	N/S	N/S	1	MAIN	N/S	N/S	N/S	2	COMBO	N/S
					1	ADS	16	RECIP	N/S			
Pilgrim 1	2	655	SCREW	N/S	0	MAIN		(SRVC)		2	HTLESS	N/S
	3	160	RECIP	NL								
Point Beach 1	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Point Beach 2	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Prairie Island 1	3/2	405	RECIP	NL	0	MAIN		(SRVC)		2/2	REGEN	N/S
Prairie Island 2	3/2	405	RECIP	NL	0	MAIN		(SRVC)		2/2	REGEN	N/S
Quad-Cities 1	3/2	N/S	RECIP	OIL	2	MAIN	N/S	LS ROT	N/S	2	HTLESS	ALUMA
Quad-Cities 2	3/2	N/S	RECIP	OIL	2	MAIN	N/S	LS ROT	N/S	2	HTLESS	ALUMA
Rancho Seco	3	N/S	N/S	NL	0	MAIN		(SRVC)		1	HT REG	N/S
River Bend 1	3	N/S	N/S	NL	0	MAIN		(SRVC)		2	HT REG	N/S
Robert Ginna	1	N/S	RECIP	N/S	3	MAIN	N/S	RECIP	NL	2	HTLESS	N/S
Robinson 2	1	400	RECIP	OIL	1	MAIN	516	RECIP	NL	1	REFRIG	
					2	MAIN	200	RECIP	NL	2	REGEN	N/S
Salem 1	3/2	4000	CENTR	NL	0	MAIN		(SRVC)		2	HTLESS	N/S
					1	EMERGY	500	RECIP	NL			
Salem 2	3/2	4000	CENTR	NL	0	MAIN		(SRVC)		1	HTLESS	N/S
					1	EMERGY	500	RECIP	NL			
San Onofre 1	3	300	RECIP	N/S	0	MAIN		(SRVC)		1	HT REG	N/S
					1	EMERGY	98	RECIP	N/S			
San Onofre 2	3/2	800	RECIP	NL	0	MAIN		(SRVC)		2/2	REFRIG	
San Onofre 3	3/2	800	RECIP	NL	0	MAIN		(SRVC)		2/2	REFRIG	
Seabrook 1	3	N/S	RECIP	NL	0	MAIN		(SRVC)		2	COMBO	N/S
					2	CNTMNT	N/S	N/S	N/S	2	N/S	N/S
Sequoyah 1	4/2	610	RECIP	NL	0	MAIN		(SRVC)		5/2	REGEN	N/S
					2/2	AUX	78	RECIP	NL			

UNIT	COMPRESSORS: SERVICE AIR NO.	CFM	TYPE	LUB	INSTRUMENT AIR NO.	APPLIC.	CFM	TYPE	LUB	DRYERS NO.	TYPE	DESIC.
Sequoyah 2	4/2	610	RECIP	NL	0	MAIN		(SRVC)		5/2	REGEN	N/S
					2/2	AUX	78	RECIP	NL			
Shearon Harris	2	527	RECIP	NL	0	MAIN		(SRVC)		2	HT REG	N/S
Shoreham	3	N/S	CENTR	NL	0	MAIN		(SRVC)		1	HT REG	N/S
South Texas Project 1	2	N/S	RECIP	NL	2	MAIN	N/S	RECIP	NL	2	HTLESS	N/S
South Texas Project 2	2	N/S	RECIP	NL	2	MAIN	N/S	RECIP	NL	2	HTLESS	N/S
St. Lucie 1	1	518	RECIP	N/S	2	MAIN	162	RECIP	NL	1	COMBO	ALUMA
	1	665	SCREW	N/S	2	CNTMNT	48	LS ROT	NL	2	HTLESS	ALUMA
St. Lucie 2	1	518	RECIP	N/S	2	MAIN	231	RECIP	NL	1	HT REG	ALUMA
Surry 1	2	373	RECIP	NL	1	MAIN	373	RECIP	NL	1	REFRIG	
					2	CNTMNT	24	LS ROT	N/S	1	REGEN	N/S
Surry 2	1	373	RECIP	NL	1	MAIN	373	RECIP	NL	1	REFRIG	
					2	CNTMNT	24	LS ROT	N/S	1	REGEN	N/S
Susquehanna 1	2	440	N/S	N/S	2	MAIN	440	N/S	N/S	2	HT REG	N/S
					2	CNTMNT	40	N/S	N/S	2	REGEN	N/S
Susquehanna 2	2	440	N/S	N/S	2	MAIN	440	N/S	N/S	2	HT REG	N/S
					2	CNTMNT	40	N/S	N/S	2	REGEN	N/S
Three Mi. Island 1	2	N/S	N/S	OIL	2	MAIN	N/S	N/S	NL	1	N/S	N/S
					2	BACKUP	N/S	N/S	N/S			
Trojan	1	650	SCREW	N/S	0	MAIN		(SRVC)		1	HT REG	N/S
	3	337	RECIP	NL								
Turkey Point 3	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Turkey Point 4	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
Vermont Yankee	4	323	N/S	NL	0	MAIN		(SRVC)		3	HT REG	N/S
					2	CNTMNT	N/S	N/S	NL			
Virgil C. Summer 1	2	1298	CENTR	N/S	0	MAIN		(SRVC)		1	HT REG	ALUMA
					2	NSSS	150	RECIP	NL	2	REFRIG	
Vogtle 1	2	750	SCREW	N/S	0	MAIN		(SRVC)		3	REGEN	N/S
	2	885	RECIP	N/S								

UNIT	COMPRESSORS: SERVICE AIR NO.	CFM	TYPE	LUB	INSTRUMENT AIR NO.	APPLIC.	CFM	TYPE	LUB	DRYERS NO.	TYPE	DESIC.
Vogtle 2	2	750	SCREW	N/S	0	MAIN		(SRVC)		3	REGEN	N/S
	1	885	RECIP	N/S								
Waterford 3	3	280	LS ROT	NL	2	MAIN	280	LS ROT	NL	2	HTLESS	ALUMA
Watts Bar 1	4/2	610	RECIP	NL	0	MAIN		(SRVC)		3/2	HTLESS	N/S
					2/2	AUX	78	RECIP	NL	2/2	REGEN	N/S
Watts Bar 2	4/2	610	RECIP	NL	0	MAIN		(SRVC)		3/2	HTLESS	N/S
					2/2	AUX	78	RECIP	NL	2/2	REGEN	N/S
WNP-1	2	515	RECIP	NL	0	MAIN		(SRVC)		2	HTLESS	N/S
					2	NUCLEAR	N/S	DIAPH	N/S	2	HTLESS	ALUMA
WNP-2	3	450	N/S	N/S	0	MAIN		(SRVC)		2	REGEN	ALUMA
					2	CNTMNT	50	N/S	N/S			
WNP-3	1	N/S	RECIP	NL	2	MAIN	581	RECIP	NL	1	REGEN	N/S
Wolf Creek	3	525	RECIP	NL	0	MAIN		(SRVC)		2	HTLESS	N/S
Yankee	1	514	RECIP	OIL	2	MAIN	125	RECIP	NL	2	HT REG	S GEL
Zion 1	3/2	N/S	N/S	N/S	3/2	MAIN	N/S	RECIP	N/S	3/2	N/S	N/S
Zion 2	3/2	N/S	N/S	N/S	3/2	MAIN	N/S	RECIP	N/S	3/2	N/S	N/S

APPENDIX B

COMPRESSOR AND DRYER PROBLEMS FROM LER AND NPE SEARCHES

Table B.1
COMPRESSOR PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Belts				
BEAVER VALLEY 1	02/11/78		Containment IAS compressor tripped when 2 belts broke and other 3 jammed. Backup inoperable; cross-tie to outside IAS temporarily made but reactor was tripped when compressor restart failed.	NPE-P9H148
BEAVER VALLEY 1	/ /78	014	One containment IA compressor tripped; backup broke two belts and other three belts jammed on startup.	CR-2796
MILLSTONE POINT 1	/ /77	024	Backup IAS compressor threw its belts on startup.	CR-2796
FAILURE TYPE: Controls				
BRUNSWICK 1	02/24/80	012	Two of three service air compressors failed, due to bad air pressure switch.	SCSS-NOAC
MONTICELLO	09/11/71		Failed primary compressor control and standby compressor being in inadvertent "off" position resulted in scram. No compressor problem.	NPE-B16C47
YANKEE ROWE	10/04/86	012	Operating IAS compressor pressure switch failed so compressor would not load. First backup compressor would not load due to unloader solenoid valve failure. Reactor scrammed when second backup could not restore pressure quickly.	SCSS-NOAC
ZION 1	08/30/85	030	IAS compressor tripped on spurious high vibration signal; other on-line compressor could not maintain pressure. Penetr. pressurization compressors started (ESF.)	SCSS-NOAC
ZION 1	11/22/85	043	IA compressor tripped on spurious high oil temperature (switch out of tolerance.) Backup compressor still down for maintenance.	SCSS-NOAC

Table B.1 (cont'd)
COMPRESSOR PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Heat Exchanger				
CALVERT CLIFFS 1	05/20/80	027	Instrument air compressor aftercooler tube failure injected air into service water system, causing air binding and reactor trip.	SCSS-NOAC
CALVERT CLIFFS 1	08/12/80	041	IAS compressor aftercooler tube failure. Air leakage into service water system.	SCSS-NOAC
ZION 1	11/22/85	045	IA compressor trip due to high intercooler condensate level (trap bypass valve needed adjustment.) Penetr. pressurization compressor started (ESF).	SCSS-NOAC
FAILURE TYPE: Leaks				
GRAND GULF 1	02/13/85	008	System air compressor believed leaking air to cooling water. During venting, instrument air compressor tripped on low cooling water. Scram resulted. (Was SAS compressor leaking??)	SCSS-NOAC
INDIAN POINT 2	/ /79	001	Lo-press. cylinder cover plate corroded and leaked chromate to environment.	CR-2796
MILLSTONE POINT 1	/ /77	024	Station compressor head gasket failed, injecting air into cooling water system, causing IAS compressor to trip. Reactor scram.	CR-2796
FAILURE TYPE: Low Output				
BEAVER VALLEY 1	/ /76	061	Low compressor capacity - unexplained.	CR-2796
LA SALLE 2	08/31/88	010	Drywell compressor experienced reduced output while other compressor was out of service. No explanation for cause.	SCSS-NOAC

Table B.1 (cont'd)
COMPRESSOR PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Mechanical				
SEQUOYAH 1	07/09/84	045	Second aux. control compressor removed from service due to rod knock, after first compressor suffered broken crankshaft (something jammed a piston.) Knock due to broken lockwasher tab which allowed piston rod to detach from crosshead.	SCSS-NOAC
FAILURE TYPE: Motor				
MCGUIRE 2	09/06/87	016	Short to ground of IAS compressor motor lug (aging failure of tape) caused system upset and reactor trip. After retape, worn motor bearings caused high current draw.	SCSS-NOAC
FAILURE TYPE: Operational				
LA SALLE 1	02/13/84	011	Centrifugal compressor surged and would not reload after units were cross-connected.	SCSS-NOAC
MONTICELLO	09/11/71		Failed primary compressor control and standby compressor being in inadvertent "off" position resulted in scram. No compressor problem.	NPE-B16C47
TURKEY POINT 3	10/11/79		Water in IAS, due to temporary use of SAS air, caused an AFW pump turbine control valve to malfunction, disabling pump.	NPE-P6E246
ZION 1 & 2	01/11/81		IAS oil contamination from cross-tie to SAS caused solenoid valve problems. Third IAS compressor added to reduce need for SAS cross-ties.	NPE-P9H612

Table B.1 (cont'd)
COMPRESSOR PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
ZION 1	11/22/85	045	IA compressor trip due to high intercooler condensate level (trap bypass valve needed adjustment.) Penetr. pressurization compressor started (ESF).	SCSS-NOAC
ZION 2	05/09/80		Oil in IAS caused containment air sample valve to not close.	IEIN 81-38
FAILURE TYPE: Seals				
ST. LUCIE 1	04/15/77	023	Containment IAS compressor failed due to loss of seal water. Backup compressor started but its discharge blew back through failed compressor. Reactor trip to cold shutdown.	NPE-P9H117
ZION 1	11/15/85	042	IA compressor trip on low oil pressure due to worn oil seals in oil pump. Backup compressor down for maintenance. Third compressor couldn't maintain pressure. Penetr. pressurization compressor started (ESF actuation.)	SCSS-NOAC
FAILURE TYPE: Valves and Unloaders				
MILLSTONE POINT 1	06/10/87		Instrument air compressor started upon trip of active compressor but did not load, due to sticking unloading valve.	NPE-15A347
YANKEE ROWE	10/04/86	012	Operating IAS compressor pressure switch failed so compressor would not load. First backup compressor would not load due to unloader solenoid valve failure. Reactor scrammed when second backup could not restore pressure quickly.	SCSS-NOAC

Table B.2
DRYER PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Controls				
ZION 1	12/19/85	040	Dryer malfunction (vent to atmosphere due to sequencing solenoid valve opening out of sequence) during maintenance caused low IAS pressure. Penetration pressurization compressors started (ESF actuation.)	SCSS-NOAC
FAILURE TYPE: Desiccant				
NUCLEAR ONE 1	/ /76	032	Desiccant carryover caused valve malfunction.	NUREG-1275
NUCLEAR ONE 2	/ /84	014	Desiccant carryover caused feedwater flow control malfunction and reactor trip.	NUREG-1275
NUCLEAR ONE 2	10/08/85	022	Desiccant carryover fouled IAS, causing reactor trip (ESF actuated.)	SCSS-NOAC
RANCHO SECO	07/07/81		Desiccant in IAS caused air-operated globe valve to not close.	IEIN 81-38
FAILURE TYPE: Filter				
SAN ONOFRE 1	01/09/80	003	Failure of instrument air filter allowed desiccant into IAS, causing malfunction of service water isolation valve.	SCSS-NOAC
SHOREHAM	08/31/85	035	Low IAS pressure due to plugged dryer afterfilter, due to improper replacement of desiccant. Emergency shutdown.	SCSS-NOAC

Table B.2 (cont'd)
DRYER PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Operational				
BEAVER VALLEY 1	08/29/85	015	Failure of soldered fitting in air system, maybe due to impact during repair of faulty dryer heater control. Resulted in reactor trip and ESF actuation.	SCSS-NOAC
PALISADES	/ /78	003	Restricted regenerative purge outlet resulted in water in IAS. Caused shutdown cooling water valve to close.	NUREG-1275
SHEARON HARRIS 1	08/04/87	041	Improper valve alignment during restoring dryer to service caused low IAS pressure and reactor trip.	SCSS-NOAC
SURRY 1	11/21/85	022	Refrigerated dryer froze up, lowering IAS pressure and initiating ESFs. Freezeup problem not recognized until later recurrance.	SCSS-NOAC
SURRY 1	01/07/86	001	Refrigerated dryer froze up, causing low IAS pressure. Hot gas bypass valve out of adjustment. Reactor tripped.	SCSS-NOAC
FAILURE TYPE: Valve				
DAVIS-BESSE 1	12/07/87	015	Failure of solenoid valve in IAS dryer vented air to atmosphere. Reactor trip resulted, with ESF actuation.	SCSS-NOAC
INDIAN POINT 2	/ /76	015	Four-way inlet switching valve malfunctioned.	CR-2796
LA SALLE 1	12/31/82	178	Solenoid valves for drywell system dryer were stuck open (gummy), resulting in low IAS pressure.	SCSS-NOAC

Table B.2 (cont'd)
DRYER PROBLEMS FROM LER AND NPE SEARCHES
(BY FAILURE TYPE)

PLANT NAME	DATE	LER	REMARKS	SOURCE
FAILURE TYPE: Water in System				
CRYSTAL RIVER 3	03/23/83		Water in IAS caused FW valve air accumulator check valves to leak.	NPE-P6E444
PALISADES	/ /		Water in IAS caused air-operated control valve to fail to stay open, disabling both RHR trains.	IEIN 81-38
TURKEY POINT 3	09/26/80	018	Water entering IAS during dryer maintenance caused AFW control upset.	SCSS-NOAC

APPENDIX C

IPRDS SERVICE COMPRESSOR AND DRYER MAINTENANCE CALLS

Table C.1
IPROS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE*	CONCERN	PROBABLE CAUSE	ACTION TAKEN
COMPRESSOR "A"			
PROBLEM TYPE: Belt			
3787	CHECK COMPRESSOR FOR A LOOSE OR BAD BELT. WHILE RUNNING, SMELLS LIKE BURNT RUBBER.		
4445	BELTS SQUEAKING.	MOTOR SHAFT DRAGGING. HAD ROUGH SPOT WHEN TURNED BY HAND.	CHANGED BOTH BEARINGS ON MOTOR. CHANGED BELTS AND CHANGED SHEAVE - FOUND HEAD GASKET LEAKING.
4697	BELTS ARE SQUEAKING.	BELTS WERE LOOSE AND THE PULLEYS WERE MISALIGNED.	REALIGNED PULLEYS AND ADJUSTED THE BELTS.
PROBLEM TYPE: Controls			
3165	UNIT DOES NOT STAY LOADED.		
4706	TRIPPED ON APPARENT HI TEMP.	FOUND COMPRESSOR RUNNING, FOUND TRIP FUNCTION COMING IN BEFORE ALARM.	HAD OPS SHUT OFF COMPRESSOR WHILE WE INSTALLED A NEW TEMP SWITCH.
4904	PRESSURE INDICATOR ON 1C203 BROKE.	OVER PRESSURIZED.	RECALIBRATED GAUGE.
4908	SUPPLY BREAKER 1B3312 TRIPS WHEN THE COMPRESSOR IS TAKEN TO START.		MEG MOTOR A-B-C TO GROUND \ 500 MR PH TO PH-GOOD. CHECK STARTER AND HEATERS OHMED OUT GOOD.
PROBLEM TYPE: Cooling			
3005	AIR COMPRESSORS START OVERHEATING WHENEVER MAKE-UP DEMIN IS OPERATING.		

*Date is serial day after an arbitrarily selected starting date.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
3478	CHEMICAL CLEANING OF WATER JACKETS IS NEEDED ON AIR COMPRESSORS.		
4047	WATER JACKET FLOW PATHS NEED FLUSHED.		
PROBLEM TYPE: Leak			
3272	LEAK IN FLANGED CONNECTION AT AFTERCOOLER OF AIR COMPRESSOR.		
3299	THIS AFTERCOOLER HAS AN AIR LEAK AT OUTLET END.		
3362	WELL WATER PIPING TO AFTER COOLER ON AIR COMPRESSOR IS LEAKING.		
4024	AFTER COOLER IS LEAKING WATER AT FLANGE THAT ATTACHES TO MOISTURE SEPARATOR.		
4091	CRANKSHAFT AREA HAS OIL LEAK ON PLATE GASKET.		
4354	PREVENTATIVE MAINTENANCE INSPECTION.		OIL LEAKING FROM BOTTOM JOINT OF THE CENTER COLUMN.
4445	BELTS SQUEAKING.	MOTOR SHAFT DRAGGING. HAD ROUGH SPOT WHEN TURNED BY HAND.	CHANGED BOTH BEARINGS ON MOTOR. CHANGED BELTS AND CHANGED SHEAVE - FOUND HEAD GASKET LEAKING.
4446	HEAD GASKET LEAKS.	FOUND HEAD GASKET LEAKING WHEN COMPRESSOR WAS RUNNING.	REPLACED HEAD GASKET AND STARTED COMP. MADE A KNOCKING NOISE.
4569	CONNECTION ON AIR COMPRESSOR FOR AIRSENSING LINE IS LEAKING BY.	FOUND COMPRESSION FITTING LEAKING AND COPPER TUBING CRACK.	INSTALLED A NEW COPPER TUBING WITH NEW FITTINGS.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
4579	HAS AN AIR LEAK ON A DISCHARGE VALVE COVER.	LEAKING AROUND VALVE COVER GASKET?	TIGHTENED VALVE COVER BOLTS.
PROBLEM TYPE: Mechanical			
2982	OIL PRESSURE IS READING LOW.		
3361	COMPRESSOR HAS CHATTERING NOISE WHEN LOADING.		
3756	COMPRESSOR IS MAKING A KNOCKING NOISE WHEN UNLOADED.		
3761	COMPRESSOR IS MAKING INTER-MITTANT TAPPING NOISE (SOUNDS LIKE ROD LOOSENING).		
PROBLEM TYPE: Motor			
4445	BELTS SQUEAKING.	MOTOR SHAFT DRAGGING. HAD ROUGH SPOT WHEN TURNED BY HAND.	CHANGED BOTH BEARINGS ON MOTOR. CHANGED BELTS AND CHANGED SHEAVE - FOUND HEAD GASKET LEAKING.
PROBLEM TYPE: Rings			
4425	COMPRESSOR IS MAKING KNOCKING SOUNDS.	FOUND RIDER RING BROKE ON THE PISTON. FOUND BAD INTAKE VALVE.	REPLACE INTAKE VALVES. REMOVED PISTON & INSTALLED NEW PISTON RINGS AND RIDER RING. CLEANED PISTON UP.
PROBLEM TYPE: Seal			
4361	OIL LEAK. THE OIL IS RUNNING TO FLOOR DRAIN.	FOUND THE OIL SEAL LEAKING ON THE MAIN CRANK.	INSTALLED NEW OIL SEALS ON THE MAIN CRANK.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
PROBLEM TYPE: Unloader			
3198	LOADING VALVE STICKS PERIODICALLY AND DOES NOT ALLOW COMPRESSOR TO LOAD.		
3212	ELECTRIC LOADING SOLENOID TO LOADING VALVE STICKS AND DOES NOT LET COMPRESSOR LOAD.		
3258	SOLENOID VALVE DOES NOT WORK.		
4194	AIR COMPRESSOR DOES NOT UNLOAD PROPERLY.		
4424	SOLENOID NOT OPERATING. WILL NOT LOAD.	UNLOADING SOLENOID AND ASSOCIATED 3 WAY VALVE WERE BYPASSED.	REMOVED SOLENOID & 3 WAY VALVE AS A UNIT. DETERMINED SOLENOID TO BE BAD. REPLACED SOLENOID.
PROBLEM TYPE: Valve			
3724	POSSIBLE DISCHARGE VALVE KNOCKING.		
3853	COMPRESSOR WAS MAKING A TAPPING SOUND COMING FROM THE VALVE AREA.		
4425	COMPRESSOR IS MAKING KNOCKING SOUNDS.	FOUND RIDER RING BROKE ON PISTON. FOUND BAD INTAKE VALVE.	REPLACE INTAKE VALVES. REMOVED PISTON & INSTALLED NEW PISTON RINGS AND RIDER RING. CLEANED PISTON UP.
4447	CHECK PISTON CLEARANCE AT TOP AND BOTTOM OF COMPRESSOR.	FOUND UPPER EXHAUST VALVE (SOUTHWEST) TO HAVE SEGMENT OF VALVE BROKEN.	REPLACED ALL VALVES. PISTON END CLEARANCE TOP: .076, BOT .051. TEST RAN COMP FOR 15 MIN IN LAG POSITION.
4474	AIR COMPRESSOR FAILED.	FOUND A DISCHARGE VALVE HAD COME LOOSE CAUSING THE COPPER GASKET TO GO INTO CYLINDER.	INSTALLED NEW PISTON. REBUILT VALVES AND P.T. THE OUTER CYLINDER. FOUND NO CRACKS.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
COMPRESSOR "B"			
PROBLEM TYPE: Belt			
3793	BELTS NEED TO BE TIGHTENED OR REPLACED.		
3795	BELTS ARE LOOSE AND SLIP A LITTLE DURING LOADING.		
3893	DRIVE BELT ARE SQUEALING AND NEED TO BE ADJUSTED.		
4286	BELTS ARE LOOSE AND SQUEALING.		
4848	AIR COMPRESSOR IS MAKING A LABORED SCREACHING SOUND.	NORMAL BELT WEAR.	READJUSTED BELT TENSION. COMPRESSOR OPERATED SAT AFTER ADJUSTING.
PROBLEM TYPE: Controls			
3814	OIL PRESSURE GAUGE INDICATES 30 PSI WHEN COMPRESSOR IS SHUT DOWN.		
3997	CHECK TRS-2 (TIME DELAY SW WHICH SHUTS DOWN COMPRESSOR AFTER IT UNLOADS FOR 5 MIN.)		
4706	COMPRESSOR DID NOT START AND LOAD FROM THE LAG/AUTO POSITION.	FOUND UNIT TO TURN ON AND LOAD WHEN THE PRESSURE SWITCH WAS BLED OFF.	VALVED OUT PRESSURE SWITCH AND BLED OFF PRESSURE SLOWLY TO VERIFY COMPRESSOR WOULD LOAD WHEN SYSTEM PRESSURE DROPPED.
PROBLEM TYPE: Cooling			
3481	CHEMICAL CLEANING OF WATER JACKETS IS NEEDED ON AIR COMPRESSORS.		

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
3509	COMPRESSOR OVERHEATED SEVERLY. SUSPECT FAILURE OF SOLENOID VALVE FOR COOLING WATER.		
3612	COMPRESSOR IS RUNNING 15-30 DEGREES F HOTTER THAN EITHER OF OTHER COMPRESSORS.		
3997	THE COOLING WATER SUPPLY SOLENOID VALVE IS NOT SHUTTING OFF COOLING WATER.		
4047	FOUND WATER JACKET PATHS RESTRICTED. JACKETS NEED FLUSHED.		
4761	TEMPERATURE OF COOLING WATER HAS BEEN ABNORMALLY HIGH (APPROX 123F).	COOLING WATER LINES PLUGGED.	CROSS TIED WATER AND AIR AND FLUSHED AFTER COOLER, COMPRESSOR JUG, & DISCHARGE PIPE OUT. LOTS OF MUD BLOWN.

PROBLEM TYPE: Heat Exchanger

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
4391	INSTRUMENT AIR COMPRESSOR AFTER COOLER IS LEAKING 1 DROP/3 MIN FROM WEEP HOLE.		AFTERCOOLER TAKEN TO FAB SHOP. TUBE BUNDLE CLEANED. PACKING O-RINGS CHANGED. REPLACED GASKETS, REINSTALLED. OK.
4913	LEAKAGE ON AFTERCOOLER AT TELLTALE HOLE.	AGE & WATER PROBLEM.	EPOXY REPAIRED PITTED PLACES, MACHINED 1/8" OFF INSIDE TUBE PLATE. INSTALLED NEW O-RINGS, PRESSURE CHECKED.

PROBLEM TYPE: Leak

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
2937	OIL LEAKS FROM COVER PLATE.		
3351	SMALL OIL AND WATER LEAK CAUSES MESS ON FLOOR. IT IS FROM UNDETERMINED SOURCE.		

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
3797	COMPRESSOR HAS A SMALL AIR LEAK AT DISCHARGE GASKET.		
4059	VERY SMALL OIL LEAK WITH VERY SLOWLY LOWERING OIL LEVEL.		
4096	AFTERCOOLER HAS A LEAK AT THE FLANGE.		
4298	THE UPPER-CENTER DISCHARGE VALVE COVER IS LEAKING FROM GASKET.		
4700	AIR LEAK ON CYLINDER HEAD. PUT TACK TAPE ON THAT CYLINDER.	LEAKING AIR FROM LEAD SEAL AROUND VALVE BOLT.	REPLACED LEAD SEAL.
5023	INLET FLANGE TO GSW COOLING SV4747 IS LEAKING. TRIED TO TIGHTEN FLANGE.	BAD UNION SEALING SURFACES.	REPLACED UNION. CHECKED FOR LEAKS. NO LEAKS.

PROBLEM TYPE: Mechanical

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
5408	INSPECTION SHOWED WATER IN CYLINDER. NEEDS TO BE TORN DOWN FOR INSPECTION.		
3765	COMPRESSOR, WHEN LOADED, "POPS" ABNORMALLY FROM TOP AREA.		
3816	UNIT NEEDS OIL ADDED TO IT.		
4012	COMPRESSOR RUNS FREELY UNLOADED; HOWEVER WHEN LOADED IT RUNS HARD.		

PROBLEM TYPE: Motor

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
3760	COMPRESSOR MOTOR SOUNDS LIKE THERE MAY BE A BEARING GOING BAD.		
4109	MOTOR BEARING NOISY.		

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
PROBLEM TYPE: Unknown			
3115	WILL NOT RUN.		
5005	COMPRESSOR WILL NOT START IN 'HAND' POSITION, SUPPLY BREAKER KEEPS TRIPPING.		TOOK OHMS READINGS AT SWITCH. OK. MOTOR WINDINGS OK. MEG MOTOR > 1000 MOHMS - TURN POWER ON GOOD VOLTAGE 490 V.
PROBLEM TYPE: Unloader			
3005	LOADING SOLENOID VALVE IS NOT OPERATING PROPERLY.		
3130	LOADING SOLENOID ONLY WORKS OCCASIONALLY, NEEDS TO BE REPLACED OR REPAIRED.		
3135	LOADING SOLENOID STICKS SO COMPRESSOR WILL NOT LOAD.		
3153	UNIT MAKES WHISTLING SOUND AFTER IT UNLOADS. SUSPECT A BAD LOADING VALVE.		
3326	SOLENOID FAILED. COMPRESSOR WILL NOT LOAD BY ITSELF.		
3823	SOLENOID IS MAKING ABNORMAL NOISE WHEN COMPRESSOR LOADS. SOLENOID HAS QUIT WORKING.		
3997	UNLOADER SOLENOID IS GETTING HOT AND CHATTERING.		
4092	THE COMPRESSOR LOADING SOLENOID DOES NOT WORK.		
4569	LOAD VALVE BAD AND FITTING ON RIGHT SIDE LEAKS BY. LEAK IS EXCESSIVE.	FOUND UNLOADER SOLENOID TO BE CHATTERING.	REPLACED SOLENOID.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
COMPRESSOR "C"			
PROBLEM TYPE: Belt			
3178	COMPRESSOR HAS LOOSE BELTS.		
3198	BELTS ARE LOOSE.		
3257	BELTS ARE LOOSE AND FLAP WHEN COMPRESSOR IS LOADED.		
3893	DRIVE BELTS ARE SQUEALING AND NEED TO BE ADJUSTED.		
PROBLEM TYPE: Controls			
3814	OIL PRESSURE GAUGE INDICATES 30 PSI WHEN COMPRESSOR IS SHUT DOWN.		
4151	WHEN COMPRESSSOR UNLOADS THE LOADING PRESSURE INDICATED ON THE LOCAL GAUGE IS ABNORMAL.		
PROBLEM TYPE: Cooling			
2999	TEST AND REPLACE RELIEF VALVE ON COMPRESSOR WATER JACKET.		
3473	CHEMICAL CLEANING OF WATER JACKETS IS NEEDED.		
3485	UNIT COOLING JACKET NEEDS TO BE CHEMICALLY CLEANED.		
4055	WATER JACKET PATHS NEED FLUSHED.		

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
PROBLEM TYPE: Heat Exchanger			
3126	TRAP PASSES AIR THROUGH. DOES NOT WORK, SO IS ISOLATED.		
3291	AFTER COOLER LEAKED BACK INTO COMPRESSOR CYLINDER.		
3297	BAD RUBBER PACKING RINGS ARE CAUSING AIR LEAKAGE OUT OF TELL-TALE HOLES IN COOLER.		
3338	MOISTURE TRAP BLOWS AIR CONTINUOUSLY.		
4356	ABOUT 1 DROP/MIN LEAKAGE FROM UPPER WEEP HOLE ON AFTER-COOLER.		REMOVED AFTERCOOLER, REPLACED O-RINGS, INSTALLED WITH NEW GASKETS.
PROBLEM TYPE: Leak			
3611	SMALL WELL WATER LEAK ON PIPING DOWNSTREAM OF SV4752.		
3721	PIPE FITTING ON WELL WATER COOLING LINE UPSTREAM OF WATER SHUTOFF SOLENOID VALVE LEAKS.		
PROBLEM TYPE: Mechanical			
3310	COMPRESSOR MAKING UNUSUAL NOISES.		
3349	HAS VERY LOUD CHATTER.		
3597	UNIT MAKES LOUD HAMMERING NOISE WHEN IN OPERATION.		
3713	COMPRESSOR IS NOISY.		

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
4355	COMPRESSOR IS MAKING A LOUD TICKING/HAMMERING NOISE FROM THE INTAKE SIDE.		
4374	AIR COMPRESSOR FOUNDATION NUTS LOOSE AND AIR COMPRESSOR IS VIBRATING.		
PROBLEM TYPE: Motor			
3718	PULLEY END MOTOR BEARING IS MAKING NOISES LIKE IT WILL FAIL SOON.		
PROBLEM TYPE: Operational			
4488	COMPRESSOR WOULD NOT LOAD AUTOMATICALLY WHEN IT SHOULD HAVE.	UNIT WOULD NOT LOAD. FOUND V593 WAS SHUT, SHOULD BE OPEN.	HAD AUX OPERATOR OPEN V593.
PROBLEM TYPE: Unknown			
3710	FOUND SUPPLY BREAKER TRIPPED. LARGE ACCUMULATION OF WATER ON FLOOR.		
PROBLEM TYPE: Unloader			
3598	SOLENOID LOADING VALVE FOR COMPRESSOR IS ALLOWING AIR TO PASS THROUGH.		
3717	BREAKER WAS TRIPPED OFF. IT WOULD SEEM COMPRESSOR IS NOT LOADING PROPERLY.		
3718	TROUBLE-SHOOT PROBLEM WITH UNLOADING AIR CONTROL SYSTEM.		
4825	COMPRESSOR WAS CYCLING.	COIL OR CORE SPRING WEAKENED.	REPLACED LOADING SOLENOID.

Table C.1 (cont'd)
IPRDS SERVICE COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	PROBABLE CAUSE	ACTION TAKEN
PROBLEM TYPE: Valve			
3359	SUCTION CHECK VALVES ARE NOT OPERATING PROPERLY.		
4460	COMPRESSOR MAKING EXCESSIVE NOISE. SUSPECT SUCTION VALVE IS STICKING.	FOUND SUCTION VALVE HAS COME LOOSE & BROKE APART SCORING PISTON BEYOND REPAIR.	REPLACED PISTON, CLEANED CYLINDER, REPLACED RINGS(PISTON), VALVES(INTAKE & DISCHARGE), PACKING. SET PISTON CLEARANCE.

Table C.2
IPRDS DRYER MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	ACTION TAKEN
PROBLEM TYPE: Controls		
3312	REQUEST CHECK OF INSTRUMENT AIR DRYER. HEATERS APPEAR TO BE OFF.	
3599	RIGHT CHAMBER OUTLET TEMP READS >550°F.	
3717	GOT HI TEMP ALARM WHILE RIGHT DESSICANT CHAMBER WAS IN HEATING MODE.	
3830	CHECK CALB. OF TI-3045 (RIGHT CHAMBER INLET TEMP). READS 50F LESS THAN LEFT CHAMBER.	
3914	RIGHT CHAMBER OUTLET TEMP READS >550 DEGREES. NEEDS NEW STARTING UNIT.	
4069	THE HIGH HUMIDITY ALARM KEEPS COMING IN AND OUT RAPIDLY.	
PROBLEM TYPE: Desiccant or Filter		
3139	8-10 PSI ACROSS AIR DRYER AFTER FILTER AND ALSO STANDBY FILTER.	
3493	EVALUATE EXCESSIVE P ACROSS THE INSTR AIR DRYER.	
3810	PREV. MAINT. PROCEDURE	REPLACED AIR FILTER CARTRIDGE.
3817	PREV. MAINT. PROCEDURE	DESICCANT CHANGED.

Table C.2 (cont'd)
IPRDS DRYER MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	ACTION TAKEN
3887	INSPECT AFTER FILTER CARTRIDGES FOR CAUSE OF DESSICANT LEAKAGE.	
3977	PREV. MAINT. PROCEDURE	AFTER FILTERS WERE BAD - NO REPLACEMENTS - CLEANED THE OLD ONE - CHANGED FILTERS.
	PROBLEM TYPE: Leak	
3305	1/4 INCH COPPER TUBING HAS A HOLE IN IT - BLOWING OUT AIR.	
3745	ON RIGHT CHAMBER, LOWER PIPE HAS A SMALL AIR LEAK.	
	PROBLEM TYPE: Valve	
2999	INST AIR DRYER PISTON & LINKAGE ASSEMBLY DOES NOT MOVE AS SIGNALED.	
3738	THE LOWER 3-WAY VALVE THAT SELECTS THE CHAMBERS HAS AN AIR LEAK.	
3748	THE SECOND SOLENOID VALVE FROM THE TOP ON THE LEFT SIDE... (Data base truncated text.)	
3864	1T-53 INSTRUMENT AIR DRYER, BOTTOM 3-WAY VALVE BETWEEN THE TWO DESICANT .... (Data base truncated text.)	
3985	PURGE FLOW ADJUSTMENT REGULATOR WILL NOT CHANGE PURGE RATE.	

Table C.2 (cont'd)
IPRDS DRYER MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	CONCERN	ACTION TAKEN
******		
4399	COMPLETE INSTALLATION AND TESTING OF NEW INSTRUMENT AIR DRYER.	
******		
PROBLEM TYPE: Desiccant or Filter		
4539	THE LEFT CHAMBER OF DRYER APPEARS TO BE CLOGGED.	CHANGED DESSICCANT PER VENDOR MANUAL.
4937	PREV. MAINT. PROCEDURE	REPLACED BYPASS AND MAIN AFTER FILTERS.
PROBLEM TYPE: Leak		
4413	BOTTOM 4-WAY CV ON BACK OF OLD INST AIR DRYER HAS AIR LEAK AROUND STEM.	SNOOPED PACKING GLAND, NO LEAKAGE FOUND. SNOOPED FLANGES AND FOUND LEAKS ON TWO OF THE FOUR FLANGES. TIGHTENED.
4476	THERE IS AN AIR LEAK ON THE PIPING GOING INTO THE AIR DRYER HEATER.	REPLACED PIPING AND FITTING.
4685	IT APPERAS THAT THE INLET VALVE MANIFOLD IS LEAKING AT THE LEFT CHAMBER.	NOTHING.
PROBLEM TYPE: Valve		
4747	TROUBLESHOOT AND REPAIR THE INLET AND/OR OUTLET VALVES FOR STICKING.	CLEANED VALVES UP, POLISHED CYLINDER BORES, PISTONS AND RODS. WORKING SAT NOW.
4780	INLET AND PURGE EXHAUST VALVES HAVE DAMAGED CYLINDERS, RODS, ETC.	REPLACED INLETS & EXHAUST VALVES.

APPENDIX D

UTILITY NUCLEAR PLANT AIR COMPRESSOR AND DRYER MAINTENANCE CALLS

Table D.1
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
SERVICE/CONTROL COMPRESSOR "A"		
PROBLEM TYPE: Controls		
09/29/85	Repair or replace hour meter.	Replaced hour meter.
PROBLEM TYPE: Heat Exchangers and Traps		
12/18/84	Moisture trap, and possibly line to it, appears to be clogged.	Removed and cleaned trap.
03/25/85	Excessive amount of water inside intercooler.	Checked tube bundle for leaks and replaced.
PROBLEM TYPE: Leaks		
06/07/81	High pressure end plate gasket blown.	
07/21/81	Blown gasket on high pressure head.	
11/13/81	Air leak on high pressure cylinder.	
04/13/82	Leaking inspection plate gasket.	
04/18/82	Oil leak from motor housing.	
06/17/82	Gasket leaking oil between casing and motor.	
08/01/82	Valve cover gasket on high pressure head is leaking air.	
08/14/82	High pressure head gasket leaking.	

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
08/27/82	High pressure gasket needs replacing.	
04/25/83	Air leak on high pressure head.	
11/16/83	Oil filter leaking.	
05/31/84	Crankcase seals leaking.	Replaced crankshaft seal, leaking gaskets, and oil sight glass.
02/21/85	Oil leak on top of crankcase.	Replaced gasket.
10/31/86	Low and high pressure seals blown. Compressor was filled with water.	Installed new seals, oil filter, and port plate.
03/07/87	On startup, compressor tripped on low oil pressure. Water spurting from connecting rod cover vent hole on high pressure end.	Installed new oil filter, gaskets and intake and exhaust valves.
08/23/87	High pressure head has blown gasket.	Cleaned, inspected and reassembled compressor.
12/20/87	Low pressure side filled with water.	Replaced intercooler filter. Installed new oil filter, stuffing box piston head valves oil and air packing. Filled with new oil.

PROBLEM TYPE: Mechanical

DATE	PROBLEM	ACTION TAKEN
11/06/81	Install sleeves in high pressure heads.	
01/15/82		Compressor was rebuilt.
12/18/84	Repair rip in copper air line.	Replaced copper air line.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
09/23/85	Coupling broken.	Fabricated and installed hubs.
PROBLEM TYPE: Piston Rings		
10/31/87	Blowthrough at high pressure shaft seal.	Rebuilt low pressure valve and unloaders. Replaced gaskets, o-rings, and oil filter. Installed new high pressure cylinder.
PROBLEM TYPE: Seals		
06/07/81	Bad oil seal on high pressure end.	
01/19/84	Repair high pressure shaft seal.	
02/15/84	Compressor uses excessive amount of oil and has unusual amount of air in oil.	
05/31/84	Crankcase seals leaking.	Replaced crankshaft seal, leaking gaskets, and oil sight glass.
11/24/84	High pressure shaft seal is blown.	Replaced bad low pressure valves, unstuck unloader, replaced air filter.
01/19/85	Air leak at high pressure seal.	Installed new packing.
02/01/85	High pressure rod seal leaking through.	Replaced seal.
05/27/85	High pressure seal leaking.	Repacked component.
06/11/85	Large amount of air bubbles in crankcase oil.	

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
09/21/85	Packing leaks.	Repacked.
10/31/85	Air leak around shaft packing.	Installed new packing.
10/31/86	Low and high pressure seals blown. Compressor was filled with water.	Installed new seals, oil filter, and port plate.
01/21/87	High pressure seal leakage.	Installed new packing.
10/18/87	Second stage air blowby from weep hole.	Replaced high pressure packing.
10/31/87	Blowthrough at high pressure shaft seal.	Rebuilt low pressure valve and unloaders. Replaced gaskets, o-rings, and oil filter. Installed new high pressure cylinder.
12/20/87	Low pressure side filled with water.	Replaced intercooler filter. Installed new oil filter, stuffing box piston head valves oil and air packing. Filled with new oil.
07/07/88	High pressure end leakage into crosshead area - seal leaks.	Installed packing.

PROBLEM TYPE: Valves

DATE	PROBLEM	ACTION TAKEN
06/07/81	Bad valves on high pressure end.	
10/08/82	Intercooler safety valve is relieving, indicating bad high pressure valves.	
02/05/83	Low pressure valve making noise.	
10/03/83	High pressure reed valves are leaking through.	

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
10/30/84	High pressure side making unusual noise.	Replaced valve.
11/24/84	High pressure shaft seal is blown.	Replaced bad low pressure valves, unstuck unloader, replaced air filter.
12/02/84	Intercooler relief valve lifting.	
01/25/85	Air is leaking out the intake filter. Replace valves.	Replaced intake valves on low pressure end.
06/11/85	Intake valves on low pressure side need repair.	
09/23/86	Valves on high pressure cylinder leaking through, causing relief valve to lift.	Installed 2 intake valves with unloaders and 2 exhaust valves.
03/07/87	On startup, compressor tripped on low oil pressure. Water spurting from connecting rod cover vent hole on high pressure end.	Installed new oil filter, gaskets and intake and exhaust valves.
10/31/87	Blowthrough at high pressure shaft seal.	Rebuilt low pressure valve and unloaders. Replaced gaskets, o-rings, and oil filter. Installed new high pressure cylinder.
12/20/87	Low pressure side filled with water.	Replaced intercooler filter. Installed new oil filter, stuffing box piston head valves oil and air packing. Filled with new oil.
01/31/88	Compressor will not follow load.	Removed and replaced unloader "B".

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
SERVICE/CONTROL COMPRESSOR "B"		
PROBLEM TYPE: Heat Exchangers and Traps		
09/26/81	Suspect intercooler leak in rod oil collection tank.	
09/15/86	Pressure test intercooler tube bundle for leak.	
02/06/87	Water leaking into high pressure side.	Rebuilt compressor and cleaned out moisture trap.
PROBLEM TYPE: Leaks		
06/16/82	Oil leaking from motor housing.	
07/14/83	Oil leaking from compressor through motor vents.	
11/16/83	Oil leak at compressor crankcase below oil filter.	
03/14/84	Oil leaks through both high pressure and low pressure sides.	
09/21/84	Water leak around high pressure side flange.	
11/29/84	High pressure air leak.	
01/14/85	Water leak at high pressure head piping.	Tightened nipple. Repaired leak in solder joint.
03/28/85	Leak at discharge flange on high pressure end.	
06/28/85	Oil leaks in crankcase.	Replaced gasket.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
09/21/85	Replace gasket on second stage.	Replaced gasket.
04/09/86	Flange leaks at valve covers and intercooler inlet.	Installed new gaskets and rod packing. Added 1 gal oil.
PROBLEM TYPE: Mechanical		
11/06/81	Install sleeves in high pressure heads.	
03/26/82	Overhaul compressor.	
02/05/83	Rebuild compressor and replace high pressure head.	
07/08/85	Blown seal on high pressure side.	Installed new valves and cylinder. Replaced oil scraper rings and piston rod packing.
05/01/86	High pressure valves leaking back, causing intercooler relief valve to lift.	Broken mounting bolts; debris in valves. Installed new high pressure intake and exhaust valves.
05/22/86	Replace warped port plate on high pressure end.	Installed new port plate, inner cylinder assembly, piston rings, intake and exhaust valves, packing, and gaskets.
11/09/86		Rebuilt compressor.
02/06/87	Water leaking into high pressure side.	Rebuilt compressor and cleaned out moisture trap.
05/27/87	Low pressure end has excessive oil leakage and noisy valves.	Installed main bearing housing oil pump motor bearing housing seals and piston packing. Added oil.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
PROBLEM TYPE: Piston Rings		
05/22/86	Replace warped port plate on high pressure end.	Installed new port plate, inner cylinder assembly, piston rings, intake and exhaust valves, packing, and gaskets.
PROBLEM TYPE: Seals		
04/05/82	Excessive leakage from high pressure seals.	
10/08/82	High pressure shaft seal leaking air.	
01/26/84	Repair high pressure shaft seal.	
07/18/84	Excessive oil usage. Leaks past ring seal in both high and low pressure ends.	Replaced packing.
09/12/84	Repair high pressure air seal.	Replaced packing.
02/21/85	High pressure rod seal leaking through.	Repacked.
05/29/85	High pressure seal leaking.	Replaced packing.
07/08/85	Blown seal on high pressure side.	Installed new valves and cylinder. Replaced oil scraper rings and piston rod packing.
04/09/86	Flange leaks at valve covers and intercooler inlet.	Installed new gaskets and rod packing. Added 1 gal oil.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
05/22/86	Replace warped port plate on high pressure end.	Installed new port plate, inner cylinder assembly, piston rings, intake and exhaust valves, packing, and gaskets.
05/27/87	Low pressure end has excessive oil leakage and noisy valves.	Installed main bearing housing oil pump motor bearing housing seals and piston packing. Added oil.
PROBLEM TYPE: Valves		
06/06/81	Bad valves on high pressure end.	
09/23/81	High pressure feather valves allow air to flow through when compressor unloaded.	
09/26/81	Intercooler relief valve relieving intermittently.	
05/20/85	Intake valves are bad.	Replaced unloader control valve and low pressure valves.
07/08/85	Blown seal on high pressure side.	Installed new valves and cylinder. Replaced oil scraper rings and piston rod packing.
05/01/86	High pressure valves leaking back, causing intercooler relief valve to lift.	Broken mounting bolts; debris in valves. Installed new high pressure intake and exhaust valves.
05/22/86	Replace warped port plate on high pressure end.	Installed new port plate, inner cylinder assembly, piston rings, intake and exhaust valves, packing, and gaskets.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
08/11/88	Compressor will not build pressure when full loaded.	Broken intake valve on low pressure end. Replaced 6 intake and 6 discharge valves on low pressure end.

SERVICE/CONTROL COMPRESSOR "C"

PROBLEM TYPE: Controls

DATE	PROBLEM	ACTION TAKEN
01/15/82	Charging motor appears to be bad.	

PROBLEM TYPE: Leaks

DATE	PROBLEM	ACTION TAKEN
04/13/82	High pressure valve cover gaskets leaking air. Need to replace seals.	
04/14/82	High pressure section leaking air.	Replaced gasket.
05/05/83	Air leak on high pressure head.	
06/14/86	High pressure cylinder head has air leak.	Replaced worn gaskets and packing.
07/29/87	Discharge head has blown gasket.	Replaced gaskets. Installed new intake and discharge valves and oil and air packing.
08/22/87	Suspect water leak into high pressure end; lots of water from moisture trap on aftercooler.	Disassembled high pressure end for inspection. Replaced inner portplate and gasket. Cleaned trap.
11/20/87	Air leak on distance piece cover plate.	Replaced high pressure side cover gasket.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
12/07/87	Air leak on high pressure unloader valve.	Tightened fitting on unloader line.
PROBLEM TYPE: Mechanical		
11/06/81	Install sleeves in high pressure heads.	
03/05/82	High oil temperature; high oil pressure.	
05/06/83	Compressor noisy when starting up or shutting down.	
PROBLEM TYPE: Piston Rings		
08/26/85	Compressor will only half-load.	Installed new piston rings and rod seals.
PROBLEM TYPE: Seals		
04/13/82	High pressure valve cover gaskets leaking air. Need to replace seals.	
11/12/82	Packing blown on discharge.	
11/07/83	High pressure shaft seal is leaking.	
01/20/84	Repair high pressure shaft seal.	Replaced Grafoil packing.
09/12/84	Repair high pressure shaft seal.	Replaced packing.
12/03/84	High pressure shaft seal is blown.	
08/26/85	Compressor will only half-load.	Installed new piston rings and rod seals.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
09/21/85	Packing leaks.	Installed new packing.
06/14/86	High pressure cylinder head has air leak.	Replaced worn gaskets and packing.
03/11/87	Bad seal on high pressure cylinder.	Installed new packing in high pressure end.
07/29/87	Discharge head has blown gasket.	Replaced gaskets. Installed new intake and discharge valves and oil and air packing.
10/27/87	Loading valve is sticking open.	Replaced inlet and discharge valves and piston rod packing. Cleaned unloader valves.
PROBLEM TYPE: Valves		
09/20/81	Intercooler relief valve relieving on high pressure.	
09/20/81	High pressure feather valves stuck, causing intercooler relief valve to lift.	
09/30/81	High pressure reed valves are apparently stuck open.	
11/12/82	Suspect low pressure end needs valves.	
02/05/83	Low pressure valve making noise.	
05/09/84	Compressor makes loud knocking noise when half loaded.	Replaced low pressure valve.
09/23/84	Intercooler pressure is low and erratic.	Replaced intake valve.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
01/18/85	Intake valve problem.	Replaced low pressure intake and exhaust valves.
06/14/85	Air blowing back through intake filter when loaded.	Replaced gaskets and installed new pilot valve.
09/15/86	Suspect reed valve is hanging open, causing over-pressure in intercooler.	Replaced 2 worn high pressure discharge valves.
10/29/86	When unloaded or half-loaded, it appears that high pressure valves are leaking back, causing intercooler relief valve to lift.	
07/29/87	Discharge head has blown gasket.	Replaced gaskets. Installed new intake and discharge valves and oil and air packing.
08/31/87	Unloader on high pressure end blowing water and sticking open.	Unloader valves disassembled and cleaned.
10/27/87	Loading valve is sticking open.	Replaced inlet and discharge valves and piston rod packing. Cleaned unloader valves.

CONTROL/SERVICE COMPRESSOR "D"

PROBLEM TYPE: Controls

DATE	PROBLEM	ACTION TAKEN
06/10/86	Charging spring motor does not work; spring must be manually charged to close ACB.	Resurfaced contacts and lubricated gears on charging spring motor.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
PROBLEM TYPE: Heat Exchangers and Traps		
11/10/82	RCW leakage into aftercooler shell.	
12/10/85	Air and water leak at intercooler tube bundle inspection plate.	Cleaned trap. Installed new low pressure discharge valves and new pilot valve.
03/17/87	Aftercooler head gasket blown; suspect blown tube.	Installed upper and lower tube bundles with gaskets.
PROBLEM TYPE: Leaks		
02/16/84	Air leak where discharge pipe bolts to compressor.	
06/19/84	High pressure chamber has leak.	Replaced gasket.
08/30/84	High pressure side panel leaking air.	Replaced gasket on high pressure discharge cover.
09/12/84	High pressure discharge flange leak.	Replaced gasket.
09/14/84	High pressure reed valve has blown gasket.	Installed new valves and cover gaskets.
11/08/84	Air leak around flange.	
06/09/85	Low pressure side leak at intercooler flange.	Replaced gaskets.
06/25/85	Oil leak at oil filter.	Replaced oil filter seal.
08/20/85	Water leak in low pressure head.	Cleaned trap. Cleaned valves. Replaced rings, seals, and wipers. Set piston clearance.
09/24/86	Air leak at intercooler.	

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
10/31/86	High pressure head has bolt leaking air.	Installed new discharge gasket and packing and tightened bolts.
03/24/87	Oil leaking from breather cap above oil filter.	Changed oil and oil filter, tightened all bolts around oil pump.
04/22/87	Compressor dirty and has oil leak.	Cleaned compressor and replaced some parts.
05/29/87	Oil loss. Suspect rod packing not correctly broken in.	Replaced oil scrapers. Replaced gaskets.
07/01/87	Blown high pressure head gasket.	Replaced gasket.
07/14/87	Water dripping from suction header after compressor idle for 8 hours.	Installed new head gasket and intercooler gaskets. Cleaned and tested trap. Replaced rusty high pressure discharge valves.
10/31/87	Wrong type of gasket material on inner port plate. Gasket blew out.	Rebuilt valves and cleaned all parts. Replaced high pressure piston and head, discharge valves, and cover plates. Replaced gaskets.
10/31/87	Oil leak.	Replaced intercooler gaskets and oil pump cover plate.
08/01/88	Blown high pressure cylinder head gasket.	Replaced High pressure discharge valve cover gasket and pipe gasket.
PROBLEM TYPE: Mechanical		
04/25/83	Loud knocking in suction end of compressor.	
09/24/86	Worn internals.	Air compressor rebuilt.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
10/06/86	Loud knocking noise on low pressure end.	
PROBLEM TYPE: Piston Rings		
05/31/84	Oil leak from piston rod housing.	Replaced rings and packing.
08/20/85	Water leak in low pressure head.	Cleaned trap. Cleaned valves. Replaced rings, seals, and wipers. Set piston clearance.
08/20/85	High pressure shaft seal leaking.	Replaced rings, seals and wipers. Set piston clearance.
08/20/85	High pressure reed valve leaking.	Replaced rings, seals and wipers. Set piston clearance.
10/31/87	Wrong type of gasket material on inner port plate. Gasket blew out.	Rebuilt valves and cleaned all parts. Replaced high pressure piston and head, discharge valves, and cover plates. Replaced gaskets.
PROBLEM TYPE: Seals		
12/08/82	High pressure seal appears bad.	
04/25/83	High pressure seal replacement.	
11/05/83	High pressure rod seal is leaking.	
01/19/84	High pressure shaft seal leaking.	Replaced packing.
02/18/84	Repair high pressure rod seal.	
05/31/84	Oil leak from piston rod housing.	Replaced rings and packing.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
08/20/85	Water leak in low pressure head. High pressure shaft seal leaking. High pressure valve leaking.	Cleaned trap. Cleaned valves. Replaced rings, seals, and wipers. Set piston clearance.
08/21/85	High pressure seal leak.	Replaced high pressure seal.
08/26/85	Scraper rings need replacing.	Installed new packing and scraper rings.
09/21/85	Packing leaks.	Installed new packing.
05/29/87	Oil loss. Suspect rod packing not correctly broken in.	Replaced oil scrapers. Replaced gaskets.
09/28/87	Excessive air leakage from high pressure packing.	Replaced high pressure packing.
12/19/87	Air blowing from piston rod packing on high pressure end.	Replaced high pressure packing.
04/01/88	Excessive air leakage from high pressure rod packing.	Replaced packing.
PROBLEM TYPE: Valves		
06/02/83	Repair loose valve on high pressure end.	
05/09/84	High pressure valves leaking, causing intercooler to relieve.	
09/14/84	High pressure reed valve has blown gasket.	Installed new valves and cover gaskets.
11/15/84	Bad high pressure valves.	Installed new valve.
12/10/85	Air and water leak at intercooler tube bundle inspection plate.	Cleaned trap. Installed new low pressure discharge valves and new pilot valve.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
12/01/86	Air leaking by unloader on high pressure end of compressor causes intercooler relief valve to open.	Removed and rebuilt 3-way valve to unloader.
07/14/87	Water dripping from suction header after compressor idle for 8 hours.	Installed new head gasket and intercooler gaskets. Cleaned and tested trap. Replaced rusty high pressure discharge valves.
10/31/87	Wrong type of gasket material on inner port plate. Gasket blew out.	Rebuilt valves and cleaned all parts. Replaced high pressure piston and head, discharge valves, and cover plates. Replaced gaskets.
AUXILIARY COMPRESSOR AA		
PROBLEM TYPE: Belts		
01/10/85	Adjust or replace belts.	
PROBLEM TYPE: Controls		
06/24/83	No dead band for loading and unloading.	
PROBLEM TYPE: Heat Exchangers and Traps		
02/22/85	Clean aftercooler tubes.	Removed heads and cleaned.
PROBLEM TYPE: Leaks		
07/03/81	Instrument line has hole in it and is leaking water.	
05/07/82	Water leak at head.	

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
02/05/83	Air leak at upper section of cylinder cover.	
02/19/83	Leaking gasket.	
04/27/83	Aftercooler inlet union leaks air.	
05/18/83	Air leak at head gasket.	
07/04/83	Water in oil.	
09/07/83	Various fittings are leaking air.	
10/18/83	Air leak at flange plate on side of compressor.	
04/01/84	Head gasket is leaking.	Replaced side cover gasket.
05/31/84	Leaking head gasket.	Tightened head gasket bolts.
09/06/84	Various air leaks.	Tightened plate bolts.
02/12/85	Gasket on side near top of head is still leaking.	Installed hold down bars and new gaskets.
02/21/85	Replace gaskets under top and side plates.	Replaced gaskets.
05/24/85	Excessive leak at head gasket.	
10/21/85	Leak at gasket.	Installed new gaskets on cover.
12/12/85	Leakage at top right plate.	Installed new cover plate gasket.
01/05/86	All 4 inner bolts on side plate are leaking air.	Torqued bolts.
07/24/86	Tighten or replace fittings in sense line.	Tightened fittings.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
07/26/86	Cooling water leak from head gasket.	
08/14/86	Air leaks around top of compressor.	Tightened top cover bolts.
01/07/87	Leak at discharge cover plate.	
06/17/87	Head gasket is leaking water.	
09/20/87	Evaluate/repair/replace cracked housing.	Replaced intake and discharge valve, head gasket, cylinder gasket,framehead oil cover gasket and discharge cover plate.
10/08/87	Oil has milky appearance.	Replaced rings, valves, gaskets, packing, bearings, crankshaft and belts.
12/23/87	Air leaks from top plate.	Replaced gaskets and torqued bolts.

PROBLEM TYPE: Mechanical

DATE	PROBLEM	ACTION TAKEN
08/05/82	Compressor is locked up; will not run.	
09/07/82	Low oil level.	
09/22/82	Compressor tripped twice on low oil level signal.	
12/13/82	Low oil level.	
12/18/82	Compressor started smoking and appears to have burned up.	
07/11/84	Compressor not pumping air.	Reassembled crankshaft assembly, set head clearance. Packing seals and cover plates.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
09/21/85	Crankcase appears to be full of water, which is leaking from head down push rod and into crankcase at push rod seals.	Rebuilt compressor.
07/14/86	Add oil to compressor.	
10/08/87	Oil has milky appearance.	Replaced rings, valves, gaskets, packing, bearings, crankshaft and belts.
10/27/87	Worn oil stop plate.	Fabricated oil stop plate.
PROBLEM TYPE: Piston Rings		
10/08/87	Oil has milky appearance.	Replaced rings, valves, gaskets, packing, bearings, crankshaft and belts.
PROBLEM TYPE: Seals		
09/20/87	Oil level 1/4" below normal.	Replaced faulty scraper rings and added oil.
PROBLEM TYPE: Valves		
05/09/82	Unloader valve stuck open.	
06/20/83	Compressor continues to overload BLR; not unloading.	
09/20/87	Evaluate/repair/replace cracked housing.	Replaced intake and discharge valve, head gasket, cylinder gasket,framehead oil cover gasket and discharge cover plate.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
10/08/87	Oil has milky appearance.	Replaced rings, valves, gaskets, packing, bearings, crankshaft and belts.
AUXILIARY COMPRESSOR "BB"		
PROBLEM TYPE: Belts		
01/12/83	Inspect, tighten, or replace drive belts as needed.	
09/14/83	Replace belts thrown off; one remained on.	
10/30/84	Adjust or replace belts as needed.	
01/09/85	Adjust or replace belts as needed.	
PROBLEM TYPE: Controls		
02/28/82	Safe stop switch not working.	
12/22/82	Irregular compressor operation; loads and unloads constantly.	
01/31/83	Compressor is coming on and going off.	
04/27/83	Replace cooling water solenoid; check crankcase for water.	
03/05/87	Compressor won't start in "AUTO" on low pressure.	Cleaned relay, replaced a screw in delay diaphragm, and replaced Agastat relay.
01/24/88	Compressor trips on low oil level during sustained run - level low or switch problem?	Added oil and corrected loosely connected lead.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
PROBLEM TYPE: Heat Exchangers and Traps		
02/22/85	Clean aftercooler tubes to remove scale and any debris that may be limiting water flow.	Removed heads, cleaned, and reinstalled.
PROBLEM TYPE: Leaks		
01/03/81	Unloader is leaking air.	
06/01/81	Air leak around head - blown seal.	
01/12/82	Unloader is leaking air.	
03/10/83	Water leak at cooling water inlet union.	
03/11/83	Repair copper tubing leaks on loading system.	
03/23/83	Water in oil.	
03/22/84	Possible blown head gasket.	
07/12/84	Air leak at cover gasket.	Replaced cover gasket.
03/07/85	Leaks around top and side plates.	Replaced gaskets. Installed hold-down bars on lower discharge valve cover plate.
10/31/85	Air leak in seal between head and main body.	Tightened bolts to stop leak.
10/31/85	3 of 4 bolts on inspection cover plate are leaking air.	Tightened bolts.
03/19/86	Repair to reduce leaks.	Torqued plate bolts to stop leak.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
PROBLEM TYPE: Mechanical		
03/31/81	Compressor has broken shaft.	
02/16/84	Oil level below normal.	
05/25/84	Noisy crankshaft and discolored oil.	Disassembled compressor and rebuilt.
05/31/84	Repeated trips on low oil level; add oil or fix limit switch.	
07/13/84	Add oil to crankcase.	Added oil.
07/25/84	Compressor makes loud knocking noise when started and running.	Removed head and adjusted piston clearance.
10/04/84	Compressor does not build pressure. Air blows out intake when running and when first stopped. Keeps tripping on overload.	Rebuilt compressor. Replaced gasket studs and nuts.
01/17/85	Shaft appears to be uncoupled or broken - pulley turns but no shaft movement.	Installed new crankshaft, new valves, new piston, rings, piston rod, connector rod, and gaskets.
07/03/85	Compressor is making a bad knocking sound when unloaded.	Replaced crankshaft and connecting rod.
07/24/85	Compressor is making a bad knocking sound.	Replaced crankshaft and rod assembly. Installed new bearings.
06/15/86	Air leak around shaft.	Worn internals. Rebuilt compressor.
09/22/87	Evaluate/repair/replace cracked housing headframe near inlet valve cover.	Replaced lower frame and rebuilt compressor.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
11/03/87	Water coming from intake filter when compressor is unloaded. Compressor is also knocking loudly.	Disassembled, inspected, and reassembled compressor.
05/02/88	Suspected leak at piston rod seal.	Rod locking washer came loose and jam nut backed off. Readjusted piston rod - ran again and same thing happened. Installed lock washer.
PROBLEM TYPE: Piston Rings		
01/17/85	Shaft appears to be uncoupled or broken - pulley turns but no shaft movement.	Installed new crankshaft, new valves, new piston, rings, piston rod, connector rod, and gaskets.
PROBLEM TYPE: Seals		
02/01/85	Oil leak around piston shaft.	Repacked piston shaft.
03/07/85	Leaking piston shaft seal.	Replaced shaft seals.
PROBLEM TYPE: Valves		
08/26/84	Intake blows air every other stroke; repair damaged intake valve.	Replaced intake valve.
01/17/85	Shaft appears to be uncoupled or broken - pulley turns but no shaft movement.	Installed new crankshaft, new valves, new piston, rings, piston rod, connector rod, and gaskets.
10/23/85	Compressor cycles; loads and unloads continuously on 3-5 second cycle.	Rebuilt intake unloader.

Table D.1 (cont'd)
UTILITY NUCLEAR PLANT AIR COMPRESSOR MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
11/20/85	Replace intake and discharge valves.	

Table D.2
UTILITY NUCLEAR PLANT AIR DRYER MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
SERVICE/CONTROL DRYER "A"		
PROBLEM TYPE: Controls		
08/30/87	Dryer will not purge at all.	Replaced burned out timer motor.
PROBLEM TYPE: Desiccant and Filters		
05/18/84	Desiccant needs to be replaced.	Replaced desiccant.
09/21/87	Remove dirty filters and inspect prefilter and afterfilter for clogging or wear.	Disassembled and cleaned moisture trap. Replaced afterfilter elements.
PROBLEM TYPE: Valves		
04/22/88	Dirty valve - air dryer continuously blows down.	Replaced purge air valve and 2" galvanized union. Cleaned muffler.
09/16/88	Change out desiccant. Repair/replace 0-FCV-32-45B.	Desiccant was good. Replaced 0-VLV-32-45B and cleaned lines.
SERVICE/CONTROL DRYER "B"		
PROBLEM TYPE: Desiccant and Filters		
10/14/83	Replace desiccant.	
09/21/87	Remove dirty filters and inspect prefilter and afterfilter for clogging or wear.	Disassembled and cleaned moisture trap. Replaced afterfilter elements.

Table D.2 (cont'd)
UTILITY NUCLEAR PLANT AIR DRYER MAINTENANCE CALLS
(BY PROBLEM TYPE)

DATE	PROBLEM	ACTION TAKEN
10/18/88	Change out desiccant; air header delta P @ 25 psi.	Desiccant OK. Changed out desiccant in sight glass.
PROBLEM TYPE: Valves		
08/30/87	Dryer will not purge at all.	Replaced Tower 1 purge valve.
04/14/88	Dryer is not operating correctly.	Disassembled 2" and 1" check valves. Found clay-like pebbles in 1" valve, not allowing valve to seat. Cleaned and reassembled.
SERVICE/CONTROL DRYER "C"		
PROBLEM TYPE: Desiccant and Filters		
09/21/87	Remove dirty filters and inspect prefilter and afterfilter for clogging or wear.	Disassembled and cleaned moisture trap. Replaced afterfilter elements.
AUXILIARY DRYER "BB"		
PROBLEM TYPE: Desiccant and Filters		
02/16/88	Desiccant needs replacement due to high delta P - 6 psid, limit is 5 psid.	Changed out desiccant.

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11. ABSTRACT (200 words or less)
This report was produced under the Detection of Defects and Degradation Monitoring of Nuclear Plant Safety Equipment element of the Nuclear Plant Aging Research Program. This element includes the identification of practical and cost-effective methods for detecting, monitoring, and assessing the severity of time-dependent degradation (aging) of control and service air compressors and dryers in nuclear power plants. These methods are to provide capabilities for establishing degradation trends prior to failure and developing guidance for effective maintenance.

The topics of this Phase I assessment report are failure modes and causes resulting from aging, manufacturer-recommended maintenance and surveillance practices, and measurable parameters (including functional indicators) for use in assessing operational readiness, establishing degradation trends, and detecting incipient failure. The results presented are based on information derived from operating experience records, manufacturer-supplied information, and input from plant operators.

For each failure mode, failure causes are listed by sub-component, and parameters potentially useful for detecting degradation that could lead to failure are identified.

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