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Results of LWR Snubber Aging Research

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Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report describes the aging research results and recommendations for snubbers used in commercial nuclear power plants. Snubbers are safety-related devices used to restrain undesirable dynamic loads at various piping and equipment locations in nuclear power plants (NPPs). Each snubber must accommodate a plant's normal thermal movements and must be capable of restraining the maximum off-normal dynamic loads, such as a seismic event or a transient, postulated for its specific location. The effects of snubber aging and the factors that contribute to the degradation of their safety performance need to be better understood. Thus, Phase II of Nuclear Plant Aging Research was conducted to enhance the understanding of snubber aging and its consequences. Pacific Northwest Laboratory staff and their subcontractors, Lake Engineering and Wyle Laboratories, visited eight sites (encompassing thirteen plants) to conduct interviews with NPP staff and to collect data on snubber aging, testing, and maintenance. The Phase II research methodology, evaluation, results, conclusions, and recommendations are described in the report. Effective methods for service-life monitoring of snubbers are included in the recommendations.

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Summary

Snubbers are safety-related devices used to restrain undesirable dynamic loads at various piping and equipment locations in nuclear power plants (NPPs). Snubber operability is mandated by the Code of Federal Regulations (CFRs). The CFRs stipulate that systems, structures, and components (SSCs), e.g., snubbers, shall be designed to withstand the effects of normal and off-normal dynamic phenomena.[1] In the mid 1980s, the U.S. Nuclear Regulatory Commission (NRC) recognized the need to enhance snubber performance through aging studies and improved service-life monitoring techniques. The NRC's Nuclear Plant Aging Research (NPAR) Program Plan provided the vehicle and the logical sponsorship to undertake preliminary investigations into snubber performance and aging. Pacific Northwest Laboratory (PNL) and its subcontractors, Lake Engineering (Greenville, Rhode Island) and Wyle Laboratories (Huntsville, Alabama), performed the snubber research.

This report describes the Phase II NPAR in-plant aging research conducted to enhance the understanding of snubber aging and its consequences. The in-plant aging research was based on a research plan by Brown et al.[2], which clarified the relationship between snubber aging and snubber degradation and identified additional information on aging hydraulic and mechanical snubbers that require further investigation and analysis.

This report presents snubber aging research, testing and failure data, and service-life monitoring recommendations that distinguish between aging- and nonaging-related snubber failures. The graphics, tables, and supporting text illustrate this distinction. The report supports the perspective that snubber failures are closely related to age-related degradation caused by inservice operational environmental influences, e.g., vibration and elevated temperature. Due to the lack of service-related information pertaining to mechanical snubbers, special emphasis was placed on gathering such information for these devices.

The following objectives were developed for the aging investigation of mechanical and hydraulic snubbers:

- enhance the understanding of how snubbers degrade due to aging
- enhance the understanding of snubber failure characteristics
- determine the technical information needed to improve the level of snubber performance.

To meet these objectives, in-plant research was undertaken with cooperating nuclear utilities. Two information-gathering methods were used during the research. The first method included interviews with plant maintenance and engineering staff. The second involved analysis of plant operating data, including maintenance records and inservice testing and examination records. Plant selection was based on several factors, including availability of staff, plant procedures, snubber types and length of service, and plant types (BWR and PWR). It should be noted that the in-plant research was conducted on generic types of snubbers, i.e. acceleration-limiting mechanicals and lockup/bleed hydraulics. These generic types constitute a majority of snubbers installed in U.S. NPPs.

Thirteen plants at eight different sites were visited during a three-month interval. Snubbers used at five of the sites were primarily mechanical; snubbers at the remaining three sites were primarily hydraulic. In addition to the site visits, over 70 telephone interviews were conducted with knowledgeable staff at NPPs throughout the U.S. Snubber "hands-on" research was also conducted at Lake Engineering's facilities; this work involved the disassembly, examination, and measurement of mating parts associated with hydraulic snubber seals.

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[1] Normal dynamic reactions are those associated with thermal expansion and contraction of plant systems during normal startups or shutdowns. Off- normal dynamic reactions involve loads not associated with normal operations such as postulated seismic events.

[2] Brown, D. P., G. R. Palmer, E. V. Werry, and D. E. Blahnik. 1990. *Basis for Snubber Aging Research: Nuclear Plant Aging Research Program.* NUREG/CR-5386 (PNL-6911), prepared for the U.S. Nuclear Regulatory Commission by Pacific Northwest Laboratory, Richland, Washington.

A primary goal of the site visits was to gather information that would fulfill the objectives. The first two objectives were met through an assessment and evaluation of recent snubber performance history at the sites visited. By distinguishing between snubber failures related to service (aging) and failures related to nonservice (nonaging) causes, it was concluded that approximately half of all snubber failures may be attributed to service-related influences. Service-related failures are defined as those due to environmental influences, transients, and vibration; nonservice-related failures are defined as those due to other influences such as installation damage, maintenance deficiencies, manufacturing defects, not related to service time.

All of the environmental influences, including elevated temperature, vibration, and moisture, can degrade the performance of mechanical snubbers by increasing drag and breakaway forces and by changing the activation acceleration thresholds. Data in one plant indicated an increasing trend in mechanical snubber drag force with service time. For hydraulic snubbers, high temperatures in isolated operating areas can rapidly degrade seal performance. Radiation probably contributes less significantly to aging than was originally hypothesized. The research indicates that fluid leakage in hydraulic snubbers is commonly associated with leaking hydraulic fittings; however, it was not determined precisely what percentage of the fitting leakage is caused by this service environment. Furthermore, the research indicates that a significant number of seal leaks are attributed to short-term degradation in high temperature applications. At one BWR plant, the incidence of seal leakage was higher at elevated temperatures in the drywell than in other areas of the plant. This finding supports the premise that seal degradation can be accelerated by exposure to higher temperatures.

The following recommendations for service-life monitoring guidelines were developed as a result of the in-plant research:

- It is important to distinguish between service-related and nonservice-related failures. For this reason, the root cause of snubber failure or degradation should be determined. Diagnostic testing is useful for this purpose as well as visual evaluation, particularly during snubber disassembly. Personnel training in these activities is also recommended.
- Because plant operating environments may differ from design specifications, general area and environmental conditions should be monitored. Depending on the range of environmental stressors in the plant, it may be practical to establish more than one service-life population.
- Snubber applications (locations) involving specific severe environmental influences (e.g., high temperatures, high amplitude vibration) should be isolated and assessed on a case-by-case basis. Such applications may require in situ monitoring, frequent surveillance, maintenance or snubber replacement.
- Service life for the general snubber population (i.e., snubbers in a moderate environment that are not subject to short-term degradation) should be established by trending relevant degradation parameters. Because the primary failure mechanism of concern for seals is low pressure leakage, snubber seal life should be primarily based on predicted low pressure seal performance. Baseline data is essential for trending.
- "Hands-on" evaluation methods, such as hand stroking, are useful in identifying potential snubber degradation, particularly degradation caused by dynamic load transients.
- Evaluation of test parameter time traces obtained during routine functional tests is useful in identifying performance anomalies that may be indicators of snubber degradation.
- Test machines used for trending and for diagnostic tests should be capable of providing a time trace of load and velocity. Important criteria for test

machines used for trending are accuracy and repeatability. Another important feature, especially for diagnostic testing, is the ability of a test machine to vary the magnitude of test parameters such as velocity and load.

Service-life projections based on data from snubbers exposed to the actual plant operating environment are generally preferable to analytical service-life projections.

Overall, the nuclear industry is making progress in snubber inspection, testing, maintenance, and reduction programs. These activities provide a basis for an improved understanding of snubber performance. Plant staff have identified severe environments and have modified the environment or replaced snubbers with more durable models. Additionally, more effective and realistic functional test acceptance limits have been developed to significantly reduce failure rates. Although many plants routinely evaluate snubbers for failure causes, the research indicates that many plants have yet to implement formal service-life monitoring programs.

Acknowledgments

The authors of this report acknowledge the support and technical guidance of J. P. Vora and J. J. Burns, Jr., of the Nuclear Regulatory Commission during the course of this research under the Nuclear Plant Aging Research (NPAR) Program. We extend our appreciation the Snubber Utility Group (SNUG) and the ASME Operation and Maintenance (ISTD) Working Group on Mechanical Equipment Restraints for their cooperation and support throughout the work and for their technical comments on the research results. We also wish to thank the nuclear power plant industry, especially those utilities that provided information and/or participated in the in-plant research visitations. A special thanks goes to Glen Palmer, Siemens Nuclear Power Service, Inc., for his technical comments and input to this work and his long-term contributions to snubber research through his Phase II research efforts and association with the ASME ISTD Working Group. We also thank M. H. Kimel, of Wyle Laboratories, who provided strong program management support for the in-plant research and Mr. John Mucci, of Wyle Laboratories, for his productive site interviews and data collection efforts. We are grateful for the contributions from the following staff members of Pacific Northwest Laboratory: A. B. Johnson, Jr., for Project Management support and technical guidance; S. H. Bush, for his timely peer review and assistance throughout the research effort; and R. C. Pedersen for his propitious technical editing of the report.

Definitions

Activation:	The change of conditions from passive to active, in which the snubber resists the rapid displacement of the attached pipe or component.
Aging:	Showing the effects of time or use in the physical characteristics of a snubber.
Aging management:	Engineering, operations, and maintenance activities to control aging degradation and failures due to aging of snubbers to within acceptable limits.
Aging mechanism:	Process that gradually changes the physical characteristics of a snubber with time or use.
As-found testing:	Testing before conducting any activity that could affect test results (usually applies to snubber testing after removal of a snubber from service, but before any maintenance activities are conducted).
Bleed rate:	(See "Release rate.")
Breakaway force:	The minimum applied force required to initiate extension or retraction of the snubber.
Compression set:	The amount of permanent deformation of a seal expressed as a percentage of the initial seal deflection.
Degradation:	Immediate or gradual deterioration in the physical characteristics of a snubber, which could impair performance of any of its design functions.
Degradation cause:	The circumstances during design, manufacture, or use that have led to degradation.
Degradation mechanism:	Physical process that results in degradation.
Degradation mode:	The manner or state in which a snubber degrades.
Diagnostic testing:	Testing to determine the cause or mechanism associated with degradation or failure.
Drag force:	The force required to maintain snubber movement at a low velocity before activation.
Dynamic seal:	A seal used where there is relative motion between the seal and its mating surface.
Examination:	Visual observation for detecting of improper installation and impaired functional ability caused by physical damage, leakage, corrosion, or degradation from environmental or operating conditions.
External seal:	A seal used to isolate the hydraulic system from the surrounding environment.

Definitions

Failure:	Inability or interruption of ability of a snubber to perform its design function within acceptance criteria.
Failure analysis:	Systematic process of determining and documenting the mode, mechanism, causes, and root cause of the failure of a snubber.
Failure mechanism:	Physical process that results in a failure.
Failure mode:	The manner or state in which a snubber fails.
Failure mode group (FMG).	A group of snubbers that have failed and those other snubbers that have potential for similar failure.
High-amplitude vibration:	Vibration having an amplitude greater than the mechanical clearances in the snubber's end attachments.
High-pressure seal:	A seal that provides a sealing function under high-pressure conditions (i.e., greater than 100 psi).
Hydraulic snubber:	A restraining device in which load is transmitted through a hydraulic fluid.
Inspection:	Observation or measurement to verify that the physical characteristics of a snubber conform to acceptance criteria.
Internal seal:	A seal used to isolate high-pressure and low-pressure chambers in the snubber.
Locking velocity:	The extension or retraction velocity of the snubber piston rod at which the control valve locks, no longer allowing free motion.
Low-amplitude vibration:	Vibration having an amplitude less than the mechanical clearances in the snubber's end attachments.
Low-pressure leakage:	Seal leakage when the snubber is not activated (i.e., when the snubber is unlocked and not pressurized).
Low-pressure seal:	A seal that functions under low-pressure conditions (i.e., less than 100 psi).
Mechanical snubber:	A mechanical device designed to restrain piping or equipment during abnormal accelerations and to allow free thermal movement under normal operating conditions.
Normal operating conditions:	Operating conditions during reactor startup, operating at power, hot standby, reactor cooldown, and cold shutdown.

Position setting:	Measurement that indicates stroke location as measured from the snubber's fully retracted position.
Post-maintenance testing:	Testing after maintenance for component functionality and for verifying correct maintenance.
Predictive maintenance:	A form of preventive maintenance performed periodically or continuously to monitor, inspect, test, diagnose, or trend a snubber's performance or condition indicators; results indicate or forecast functional ability or the nature and schedule of planned maintenance prior to failure.
Preventive maintenance:	Periodic, predictive, or planned maintenance performed before failure of a snubber in order to extend its service life.
Release rate:	The rate of the axial snubber movement under a specified load after the snubber is activated.
Root cause:	The fundamental reason(s) for an observed condition, which when corrected prevents its recurrence.
Seal life:	The amount of time that a seal is allowed to remain in service without replacement. Seal life begins at the time that the seal is installed and continues for a pre-established period based upon expected performance.
Service life:	Period from initial operation of a snubber to retirement or overhaul.
Service life population:	A population of snubbers having the same service life.
Static seal:	A seal application where there is no relative motion between the seal and its mating surface.
Stressors:	Factors that promote degradation.
Surveillance:	Observation or measurement of the performance or physical characteristics of a snubber to verify that it conforms to acceptance criteria.
Synergistic effects:	Changes in the physical properties of a snubber or a subcomponent caused by two or more stressors interacting so that the total change is different from the changes caused by each stressor acting independently.
Trending:	Recording and analyzing in service data with respect to some independent parameter (usually time or cycles).

1 Introduction

Mechanical and hydraulic snubbers are safety-related devices designed to restrain undesirable dynamic loads at various piping and equipment locations in nuclear power plants (NPPs). Snubber operability in Nuclear Power Plants (NPPs) is mandated by Title 10, Part 50 of the Code of Federal Regulations (CFRs), Appendix A and Appendix B. These regulations stipulate that systems, structures, and components (SSCs), which includes snubbers, shall be designed to withstand the effects of normal and off-normal dynamic phenomena.[1] Each snubber must accommodate normal thermal movements of plant piping or equipment and be capable of restraining the maximum off-normal dynamic loads postulated for its specific location. However, snubbers are subject to the effects of aging, and the factors that degrade their safety performance need to be better understood. This report describes the Phase II NPAR in-plant aging research conducted to enhance the understanding of snubber aging and to mitigate aging effects.

In the mid 1980s, the U.S. Nuclear Regulatory Commission (NRC) recognized the need to enhance snubber performance through aging studies and improved service-life monitoring techniques. The NRC's Nuclear Plant Aging Research (NPAR) Program Plan, Rev. 1, (USNRC 1987)[2] provided the vehicle and the logical sponsorship to undertake preliminary investigations into snubber performance and aging.

The NPAR Program Strategy has traditionally specified a two-phase approach. Phase I of the NPAR snubber research was undertaken by the Pacific Northwest Laboratory[3] in 1985 and resulted in an initial aging assessment of snubbers and a snubber reduction evaluation study by Bush et al. (1986). The Phase II snubber research was conducted by PNL with support from Lake Engineering (Greenville, Rhode Island) and Wyle Laboratories (Huntsville, Alabama). The interim Phase II study by Brown et al. (1990) resulted in preliminary investigations that further clarified the aging questions and identified additional information on aging that should be assembled and analyzed for both hydraulic and mechanical snubbers. Twenty-four nuclear power utilities were also surveyed for information on snubber operating experiences.

The preliminary Phase II investigations defined the snubber in-plant research scope and determined that a special research emphasis should be placed on mechanical snubbers. The following objectives provide the scope of the Phase II research described in this report:

- determine how snubbers age and degrade
- define snubber failure characteristics
- determine the technical information needed to improve snubber service-life performance.

To meet these objectives the in-plant research involved:

- reviewing existing service data
- evaluating the effects of compression set of hydraulic snubber seals
- developing service-life monitoring guidelines
- improving the understanding of aging in mechanical snubbers.

The research staff planned and conducted in-plant research that involved selecting the sites for research, visiting the sites, and gathering and analyzing data on snubber performance.

The methodology of the snubber in-plant research is described in Section 2.0. Sections 3.0, 4.0, and 5.0 discuss the results, conclusions, and recommendations from the in-plant research, respectively. Section 6.0 includes recommendations for additional snubber research. In addition to supplementing investigations by

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[1] Normal dynamic reactions are those associated with thermal expansion and contraction of plant systems during normal startups or shutdowns. Off normal dynamic reactions involve loads not associated with normal operations such as postulated seismic events.

[2] The NRC's initial version of the NPAR program plan was issued in July of 1985.

[3] Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

Brown et al. (1990), the research findings presented in this report support key elements of the NPAR program strategy, including dissemination of technical information, recommendations to improve applicable codes and standards, guidelines for service-life predictions, and liaison with industry and NRC staff. Additionally, the report supports the assumption that snubber failures are closely related to aging degradation caused by operational environmental influences, e.g., vibration and elevated temperature.

2 Methodology of Snubber Aging Research

This section describes the site selection process and the in-plant research methodology used to determine the effects of aging on snubber performance.

2.1 Methodology

Plant selection and the method of on-site visits are discussed in the following sections.

2.1.1 Key Site Selection

Selecting the cooperative key sites was an important preliminary step of the in-plant research. Key sites are defined as those plants that participated directly in the research by providing their facilities and making available appropriate engineering and maintenance staff for on-site interviews by NPAR staff and subcontractors. Plants with effective inspection and testing programs and staff with experience in root cause analysis were primary candidates.

The following criteria were applied in the site selection process:

- willingness to participate
- snubber type, i.e., mechanical or hydraulic
- plant type, i.e., BWR or PWR
- snubber service time
- knowledge and/or available information in the following areas:
  - failure evaluation
  - root cause evaluation
  - identification of operating environment and measurement of the level of environmental stressors
  - effects of environments on snubber performance
  - testing
  - snubber tracking
  - snubber trending
- experience in utilizing in situ environmental monitoring instrumentation.

2.1.2 In-Plant Research Methodology

After the key sites were selected, site visits were planned and scheduled. Technical staff at each plant devoted two to three days to assist in gathering relevant information during the site visits, and extensive snubber documentation was made available for review by the in-plant investigators. A total of thirteen plants at eight sites (A through G) were visited during a three-month interval (see Figure 2.1). Five sites were designated as key sites in evaluating mechanical snubbers. Of these, three (six plants) are of PWR design and two (four plants) are of BWR design. Two sites were designated as key sites in evaluating hydraulic snubber aging. Both of these sites (4 plants) are BWR design. One site was visited for information pertaining to in situ monitoring of environmental stressors; the plant is a BWR design.

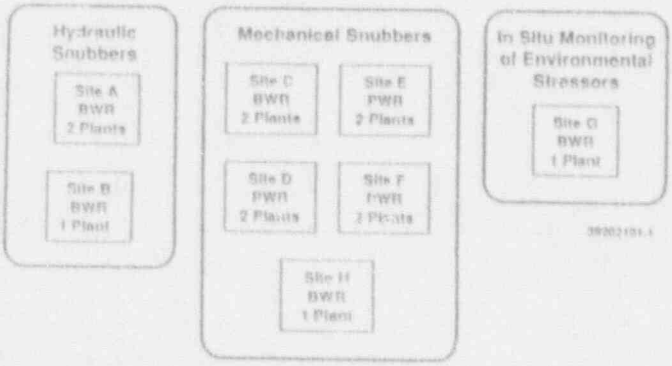

Figure 2.1 Scope of Snubber In-plant Research at Eight Sites (A through G)

The research methodology used during the site visits consisted principally of the following:

- on-site interviews with knowledgeable plant personnel
- review of plant operating history
    - snubber tracking databases
    - failure evaluation reports
    - functional test data
    - maintenance practices.

Other methods used during the in-plant research consisted of the following:

- approximately 70 telephone contacts made with various operating plant personnel
- specific research involving snubber disassembly, examination, and measurement of parts. The activity occurred both on-site and off-site. (This activity was conducted at Lake Engineering Company's, Rhode Island, facility for the evaluation of compression [illegible] of hydraulic snubber seals. This work is discussed further in Section 3.2.3 of this report.)
- use of "in-house" information available to Wyle Laboratories, Lake Engineering Company and PNL. (Personnel from Wyle Laboratories and Lake Engineering Company have many years of experience working with NPP snubbers and supporting equipment.)

3 Evaluation of the In-Plant Snubber Research

In this section, the research data on snubber performance and failure causes and mechanisms is evaluated.

3.1 Review of Available Industry Service Data

A key goal of the plant visits was to evaluate the recent performance history for both mechanical and hydraulic snubbers in NPP service. Data on the number of recorded failures and data on the types of failures and degradation was also reviewed. An important distinction was made between data on aging-related and nonaging-related failures; this is addressed in Section 3.1.2. Summary reports for all site visits are included in Appendix A.

During the site visits, information was obtained from plant operating records. The Snubber Utility Group (SNUG) database[1] and "in-house" databases were also reviewed. It should be noted that the majority of failures for both mechanical and hydraulic snubbers have been identified by functional testing. The number of failures found by visual examination, on the other hand, has been minimal.

From the number of failures evaluated during the site visits, some correlations can be made between failure mechanisms and failure causes under comparable service conditions. However, significant differences in plant design, the lack of precise time-based environmental data and the effects of more than one environmental stressor often prevent the use of snubber aging data on a generic basis. This supports the need for some degree of plant-specific service-life monitoring.

It should be noted here that approximately 95% of all mechanical snubbers in NPP service are the acceleration limiting type; most of the remaining 5% incorporate a velocity limiting feature. Approximately 99% of all hydraulic snubbers in NPP service utilize a dual mode, lock-up/bleed type control valve; the remaining 1% utilize a single mode, velocity limiting design. The aging research primarily focused on the aging characteristics of acceleration limiting mechanical snubbers and lock-up/bleed type hydraulic snubbers. Much of the information, however, obtained in the research would also be expected to be characteristic of the remaining snubber types due to similarities of design features, e.g., ball nut and screw for mechanicals, seals for hydraulics, and common environmental stressors.

3.1.1 Snubber Performance Versus Failure Mechanisms and Causes

Snubber failure causes may be generally categorized into five groups:

- Deficiencies in installation, handling, and maintenance
- Environmental influences (e.g., elevated temperature, moisture, etc.)
- Transients (overloading)
- Vibration
- Design or manufacturing deficiencies.

3.1.1.1 Mechanical Snubbers

Table 3.1 lists by category the number and causes of 357 mechanical snubber failures reported by Sites C, D, E and F. Data supporting these failure causes were obtained during plant site visits. Table 3.1 is graphically illustrated in Figure 3.1. A more detailed discussion of the effects of aging on mechanical snubbers is provided in Section 3.3.

3.1.1.2 Hydraulic Snubbers

Of a total of 86 reported hydraulic snubber failures from plant Sites A and B, the number of failures is listed by

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[1] The first compilation of data on snubber inspections and tests covering the period 1976 to 1988, issued by SNUG, was made available by the Nuclear Management and Resources Council (NUMARC) to the NRC and PNL in January 1989. An internal, unpublished, review of the data was provided by PNL staff in September of 1989.

Table 3.1 Mechanical snubber failures by category

Category	Number of Failures
Installation/mishandling/maintenance	143
Environment	59
Transients and vibration	94
Manufacturing Defects	52
Unknown	9
Total Number of Failures	**357**

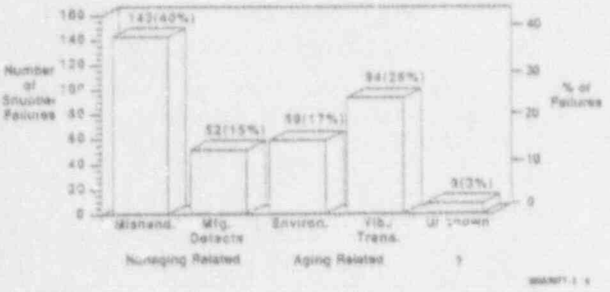

Figure 3.1 Mechanical snubber failures by category

failure cause category in Table 3.2. This is graphically illustrated in Figure 3.2.

3.1.2 Aging-Related Versus Nonaging-Related Failures

As shown in Figure 3.1, for mechanical snubbers, 59 failures were attributed to the *environment* category and 94 were attributed to the *transients* and *vibration* category. Thus, approximately 43% (153 out of 357) of the failures were associated with actual plant service and are classified as aging-related failures (see Figure 3.3).

Table 3.2 Hydraulic snubber failures by category

Category	Number of Failures
Installation/mishandling/maintenance	16
Environment	26
Transients and vibration	18
Manufacturing Defects	4
Unknown	22
Total Number of Failures	**86**

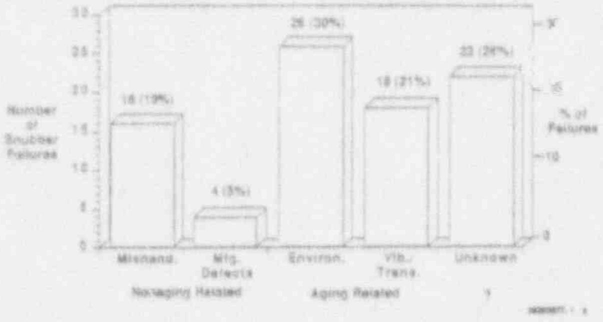

Figure 3.2 Hydraulic snubber failures by category

As shown in Figure 3.2, for hydraulic snubbers, 26 failures were attributed to the *environment* category and 18 were attributed to the *transients* and *vibration* category. Plant service influences, therefore, accounted for approximately 51% of the total number of aging-related failures (see Figure 3.4).

Note: *Data for both hydraulic and mechanical snubbers reflects failures identified between 1984 and 1990. The majority of mechanical snubber data reflect failures identified during the first three or four refueling outages. The hydraulic snubber data reflect failures identified between the tenth and fifteenth years of plant operation.*

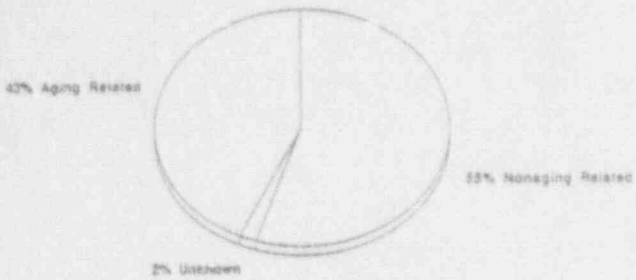

Figure 3.3 Aging-related versus nonaging-related failures in mechanical snubbers

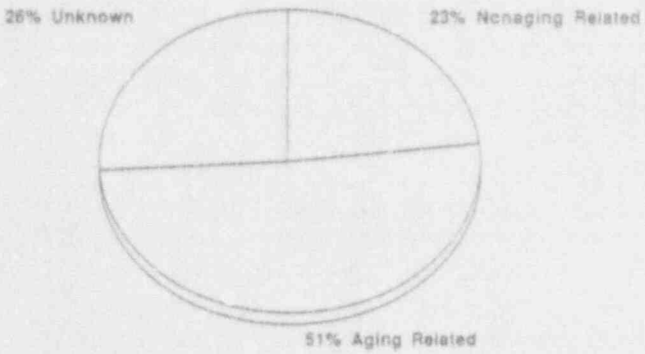

Figure 3.4 Aging-related versus nonaging-related failures in hydraulic snubbers

3.1.3 Environmental Effects on Elastomeric Seal Degradation Rate

The number of leaking snubbers noted in the drywell during a recent visual examination for one plant at Site A was compared with those found in the remainder of the plant. The results are tabulated in Table 3.3. As indicated in the data, the incidence of leakage was significantly greater for those snubbers installed in the drywell (see Figure 3.5). This indicates that, at least for this plant, monitoring a separate population (by plant area) for purposes of establishing seal life may be practical.

3.1.4 Seals and Leakage

The following subsections discuss maintenance practices and aging phenomena that are associated with hydraulic fluid leakage.

Table 3.3 Hydraulic snubber leaks versus plant location in a BWR plant

Area	Total Snubbers Inspected	No. of Indicated Leaks	% of Indicated Leaks
Drywell	263	39	14.8
Remainder of the Plant	287	27	9.4

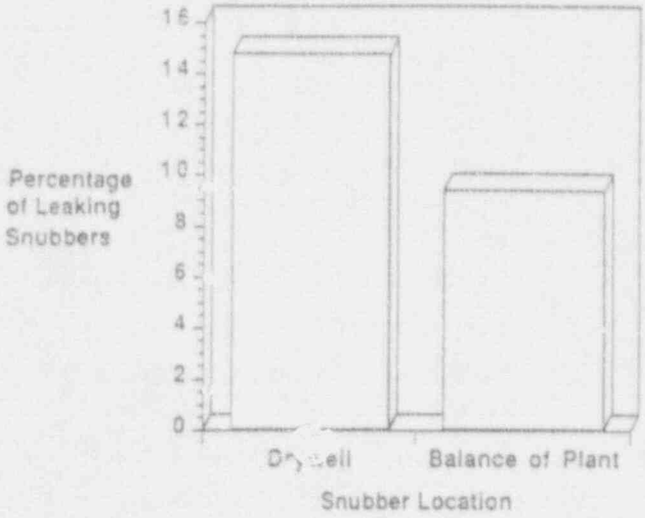

Figure 3.5 Leaking hydraulic snubbers by location in a BWR plant

3.1.4.1 Aging Versus Non-Aging Related Seal Degradation

Most cases of hydraulic snubber seal leakage are not directly attributable to long-term environmental effects. This conclusion is based, in part, upon data collected in the research as well as discussions with plant personnel and the field experience of the authors. This is illustrated by the maintenance observation data presented in Table 3.4. Table 3.4 indicates that from a total of 15 hydraulic snubbers at Site A removed from service because of significant leakage, there was very little evidence of seal degradation due to aging (see Figure 3.6). However, most operating plants have identified a limited number of snubbers in isolated areas (generally involving high temperature) where seal

Table 3.4 Maintenance observations for 15 leaking snubbers at Site A

Snubber	Observations
1	Finger-tight fill plug. No thread sealant.
2	Elevated temperature affected paint. No thread sealant. 1/2-diameter tear in the accumulator piston seal. Particles in the fluid.
3	No thread sealant. Loose fill plug. Thread damage. Pinched O-Ring in the main cylinder head (gland area). Residue from pinched O-Ring on the main cylinder. Also, residue on cylinder head.
4	No thread sealant. Main cylinder O-Ring pinched on gland end. Seal was cut during assembly. Thread damage at fill plug. Fill plug tight.
5	No thread sealant. Discoloration of fluid.
6	Loose fill plug. No thread sealant.
7	No evidence of reason for fluid loss. (Bergen original).
8	Loose fill plug. No thread sealant. Main piston backing ring slight wear.
9	No thread sealant. Loose fill plug. Thread damage accumulator head. Pinched main cylinder seal.
10	Loose fill plug.
11	Poor O-Ring installation in accumulator cap/accumulator cylinder. Loose fill plug.
12	Loose fill plug. Damaged fill plug threads.
13	Torn accumulator piston seal.
14	Loose fill plug. Wear on fill plug hold threads.
15	No thread sealant. Fill plug tight.

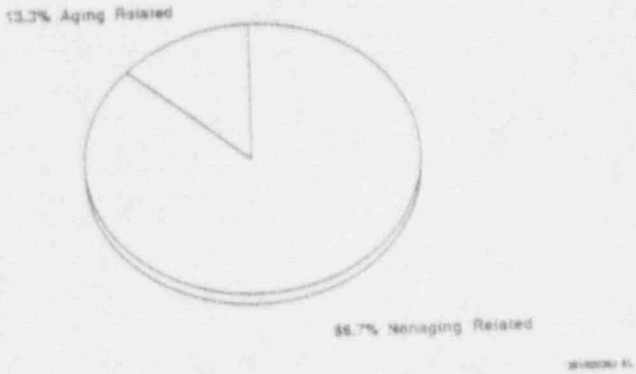

Figure 3.6 Aging versus nonaging-related seal leakage

degradation has resulted in leakage in a relatively short period (1 to 2 operating intervals). Management of these snubbers generally involves augmented inspections and/or frequent seal replacements.

As noted in Section 3.1.3, a comparison of the percentage of leaking snubbers observed in the drywell for Site A with the percentage of leaking snubbers for the balance of plant indicates a higher incidence of leakage in the drywell (see Table 3.3). Operating temperatures in the upper levels of the drywell for this plant are known to have exceeded 220°F; short-term degradation of ethylene propylene (less than two years) can be expected under such conditions. Operating temperatures for most plants, on the other hand, are significantly less than this, i.e., 150°F or less. The higher incidence of leakage for the Site A drywell snubbers is probably the result of a combination of seal degradation and a lower fluid viscosity at elevated temperatures.

A number of plants have implemented programs for monitoring elastomeric seal degradation in the general snubber population. Such programs can extend or reduce seal life based on operating experience. They are described in more detail in Section 3.2.3 of this report.

3.1.4.2 Thread Seals

Thread seals used with the control valve screws for some hydraulic snubbers have commonly exhibited low-level fluid leakage that is generally not sufficient to render the snubber inoperable between refueling outages.

It should be noted, however, that, despite the susceptibility of these seals to aging degradation, thread seal leakage is often the result of seal damage due to improper installation of the seals or other nonservice-related degradation. For example, installing snubbers without using washers between the seal and lock nut invariably results in damage to the seal.

3.1.4.3 Hydraulic Fitting Leakage

A significant portion of the total number of hydraulic snubber leakage problems, for the nuclear industry in general, has been associated with leaking hydraulic fittings. These fittings are used to connect the control valve to the hydraulic cylinder and to connect the reservoir to the control valve.

It is not possible to determine precisely what percentage of the leaking fittings is directly the result of the service environment. However, it should be noted that such fittings are highly susceptible to leakage due to misalignment, damage, and abuse. The SNUG database[1] indicates that from a total of 247 hydraulic snubbers that were found to be leaking due to either seal or fitting leakage, 157 of these (64%) were the result of fitting leakage.

3.1.5 Evaluation of Plant Service-Life Monitoring Methods

The NRC Standard Technical Specifications (STS) (USNRC 1984) require that plants maintain a service-life monitoring program. The Working Group on Mechanical Equipment Restraints is developing service-life monitoring requirements that will likely be included in Su[illegible]n ISTD of the Operations and Maintenance (OM[illegible]e. A non-mandatory appendix that will provide some guide lines for service-life monitoring is also being developed by the Working Group.

Formal service-life monitoring programs have not been established at all NPPs. For some plants, service-life monitoring involves ensuring that only seals and fluid are replaced in hydraulic snubbers at prescribed intervals. However, it should be noted that most plants have implemented maintenance practices that have helped to identify practical methods for a service-life monitoring program.

3.1.5.1 Realistic Determination of Snubber Failure or Degradation Causes

In many cases, determining the cause of snubber failure has been a relatively simple task. In other cases, it has been impossible to determine the actual cause of failure or degradation. From interviews with plant personnel and review of failure evaluation data, it is apparent that the experience and judgement of personnel involved in failure evaluations have been critical in identifying realistic failure causes. In some cases, inspectors have erroneously identified the failure cause as a result of either the lack of an in-depth evaluation or inadequate training.

3.1.5.2 Determination and Documentation of Snubber Operating Environment

Plants have used a variety of methods to determine the operating environment. For some plants the defined snubber operating environment is based on the maximum value of various environmental parameters described in the plant design specification. However, the research has determined that, in isolated applications, environmental parameter values can exceed specified design levels. Such applications are generally plant specific and are often identified by monitoring snubber degradation.

In many cases, severe operating environments that were previously unidentified were brought to light by characteristics noted during visual examination, snubber overhaul, or during failure evaluation. Examples of such characteristics and the environments to which they relate are discussed in Table 5.1.

In some cases, various types of measuring instruments (see Appendix B) have been used to define the environment precisely. However, such equipment is generally limited to applications where moderate to severe

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[1] The first compilation of data, covering the period 1976 to 1988, on snubber inspections and tests issued by SNUG, was made available by the Nuclear Management and Resources Council (NUMARC) to the NRC and PNL in January 1989. An internal, unpublished, review of the data was provided by PNL staff in September 1989.

environments are anticipated or where the equipment is used as a diagnostic aid to identify the cause of service degradation.

Some plants have obtained localized area temperature data, for example, at various levels in the drywell, using portable temperature monitoring devices. In cases of rapid snubber degradation resulting from high temperatures, precise temperature information has been limited. In general, more precise information is needed in this regard to establish practical temperature-time limits.

Area radiation information is typically available from a plant's radiation protection department. Since there is little documented evidence of degradation due to radiation (see Section 3.2.1.1), radiation monitoring of specific snubber locations is not common.

Most plants have identified the existence of high amplitude vibration (see Appendix B) from information obtained during visual examination, testing, or failure evaluation. Metal filings, darkened hydraulic fluid, deformed connecting pins, elongated attachment holes, and fretting of mating parts are all signs of vibration effects. Some plants have instrumented snubbers in order to obtain more specific information in this regard (see Appendix B). In addition to loosening of threaded fasteners, significant wear of connecting pins and attachment hardware can result from low amplitude vibration in conjunction with snubber weight forces. A photo of a worn clevis pin damaged from low amplitude vibration is illustrated in Appendix J, Figure J-9.

3.1.5.3 Transients

As with vibration, transients, such as those caused by water or steam hammer, turbine trip, etc., can induce loads that are beyond the snubber's design capacity, often rendering the snubber immediately inoperable. Some snubbers are exposed to periodic load transients that are within the rated capacity of the snubber; however, if such transients are not mitigated, snubbers might undergo progressive degradation that can also result in failure.

3.1.5.4 Management of Snubbers Subject to Rapid Degradation

Many plants have augmented inspection procedures for evaluating snubbers that are susceptible to rapid degradation due to a severe operating environment or dynamic transients. For example, freedom of movement for snubbers suspected of having experienced a dynamic transient is often verified by hand stroking or rotation of the snubber about its spherical end bearings.

3.1.5.5 Other Useful Monitoring Considerations

A number of additional considerations and maintenance practices identified in the plant research are discussed in Section 5.4. These are used to form a basis for the service-life monitoring recommendations in Section 5.1.

3.2 Evaluation of Hydraulic Snubber Aging

The following subsections discuss the primary aging factors associated with degradation in hydraulic snubber performance, such as, elevated temperature, vibration and moisture. Typical failure modes for the majority of hydraulic snubbers, and associated failure mechanisms and causes, are shown in Table 3.5. Separate subsections are also included pertaining to the effects of load transients, service-life evaluation techniques, and the effects of compression set on low pressure seal performance. Elastomeric seals most affected by aging are also discussed in a separate subsection.

3.2.1 Aging Factors for Hydraulic Snubbers

3.2.1.1 Radiation

During the course of the snubber aging research, no cases of snubber degradation were identified that were specifically attributed to radiation. However, this may be partially due to the lack of in-depth failure analysis data. Although the effects of radiation on snubber degradation are probably less than was originally anticipated, radiation cannot be totally dismissed as a contributor to seal and fluid degradation.

Table 3.5 Typical hydraulic snubber failure causes

Failure Mode	Failure Mechanism	Failure Cause
Low-Locking Velocity	High fluid viscosity	Inadequate material control; low test temperature
	Gelated fluid	Component vibration
	Incorrect valve parts	Inadequate material control; improper assembly
	Incorrect setting	Field tampering; inadequate calibration
Low Bleed Rate	High fluid viscosity	Inadequate material control; low test temperature
	Gelated fluid	Component vibration
	Incorrect setting	Field tampering; inadequate calibration
	Particulate contamination	Inadequate parts cleaning
High-Locking Velocity	Low fluid viscosity	Inadequate material control; high test temperature
	Air in fluid	Inadequate purge; seal degradation resulting in loss of fluid
	Incorrect setting	Inadequate calibration procedure
	Incorrect valve part	Improper assembly
	Piston seal by-pass	Seal degradation
High Bleed Rate	Air in fluid	Inadequate purge; seal degradation resulting in loss of fluid
	Low fluid viscosity	Inadequate material control; high test temperature
	Water in fluid	High humidity environment

Laboratory evaluations pertaining to the effects of gamma radiation on elastomeric seals have been conducted (Barbarin 1977 and Mosca 1977). However, the results of such evaluations are difficult to apply in service because of the absence of precise radiation level information for each snubber location, variations in seal materials and compounds, and shielding provided by the snubbers' metallic components. The potentially synergistic effects of radiation in combination with other environmental stressors have also not been fully substantiated.

3.2.1.2 Elevated Temperature

Elevated temperature is generally considered to be the most prevalent degradation stressor for hydraulic snubbers. This is based on the relatively high incidence of degradation or failure in high temperature applications. In applications where hydraulic snubbers are subjected to abnormally high temperatures (above 250°F) significant degradation may result in a relatively short period, e.g., within one or two operating intervals. In applications involving low temperatures, (less than 120°F) degradation may progress gradually over a period of ten or more years.

Specifically, the effects of elevated temperature include

- acceleration of compression set inducement in elastomeric seals
- accelerated oxidation effects on elastomeric seals, i.e., cross-linking, resulting in embrittlement and/or surface fissures.
- deformation of plastic hydraulic reservoirs
- adhesion of dynamic seals to mating surfaces

3.2.1.3 Moisture

Hydraulic snubber degradation due to moisture is generally in the form of corrosion. In some cases, severe corrosion has resulted in structural failure of springs used in pressurized reservoirs; however, this problem was limited to a specific snubber design in a particularly humid environment and has since been corrected. Some snubbers have experienced pitting of piston rod plating in a very humid environment, e.g., in coastal areas.

Regarding hydraulic snubbers subjected to moisture, internal corrosion resulting in the generation of corrosion products can cause a malfunction of the snubber control valve. Such degradation has been documented for a limited number of hydraulic snubbers in high humidity environments, with reservoirs that are vented to the atmosphere.

3.2.1.4 Vibration

High-amplitude vibration, i.e., vibration with an amplitude greater than the clearances in the end attachments, can result in wear and localized overheating of mating parts. Such wear can result in particle generation, potentially effecting control valve performance. The incidence of seal wear due to vibration is surprisingly low. Applications involving continuous high- or low-amplitude vibration can result in loosening of threaded fasteners and/or wear or deformation of clevis pins and attachment holes (see Appendix J, Figure J.9).

High amplitude vibration has also resulted in deformation of poppets and poppet seats in hydraulic snubber control valves. However, the incidence of such degradation has been mitigated by the incorporation of improved materials.

In many cases, extreme high-amplitude vibration can result in gelation of the hydraulic fluid (see Appendix J, Figure J.2). The exact cause of this gelation is not known; however, it is speculated that the gelation is caused by localized mechanical working of the hydraulic fluid due to continuous motion of the piston, resulting in changes in the fluid's physical properties.

3.2.2 Transient Loads

Snubbers are subject to transient dynamic loads due to abnormal operating conditions such as water hammer, turbine trip, etc. Such transients occasionally exceed the rated load capacity of the snubber, in which case significant damage can result, rendering the snubber immediately inoperable. Such damage is typically in the form of a bent piston rod for compressive loads and sheared piston/piston rod threads for tensile loads.

Hydraulic snubbers are also subject to transient dynamic loads that are less than the design capacity of the snubber. Such transients can cause excessive wear of mating parts, fatigue of structural members, and gelation of hydraulic fluid.

3.2.3 Elastomeric Seal Life Evaluation Techniques

Seal replacement intervals recommended by snubber manufacturers have generally been conservative due to the lack of service data at the time of the recommendations. Recent experience with seals manufactured from environmentally suitable elastomers such as ethylene propylene and fluorocarbon rubber (Viton)[1] has indicated minimal degradation.

Methods used to predict seal life fundamentally involve either accelerated aging studies or actual inservice data, these are discussed below.

3.2.3.1 Accelerated-Aging Studies

Seal life for some plants is based on a mathematical model (Arrhenius) (Gillen 1980) that correlates a given degradation parameter, e.g., stress relaxation, with a given environmental stressor, e.g., temperature and time. Seal life is then monitored based on recorded time at various operating temperatures. An example of this approach, used at Site A, is included in Appendix C.

The accelerated-aging model and associated analytical seal life projections are useful design tools for selecting optimum materials and designs. However, to predict seal life from this approach alone--without substantiation by service data--is impractical because of the number of variables involved. Such variables include:

- seal material or compound
- seal configuration, e.g., O-ring, lip seal, tee seal, boss seal, thread seal, and spring-energized seal
- seal thickness
- fluid medium

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[1] Viton is a registered tradename of duPont Company.

- mating surface finish
- initial squeeze.

Furthermore, the accelerated-aging model becomes overly complicated and unreliable when more than one environmental stressor is involved, e.g.,

- temperature
- radiation
- moisture
- air exposure
- fluid effects.

3.2.3.2 Evaluation of Seals Removed from Service

Many plants monitor seal life based on data from seals removed from actual service in the plant. With this approach, a practical seal life may be projected and periodically updated for the general snubber population. Snubbers needing more frequent attention in particularly severe environments may also be identified and managed on a case-by-case basis.

The most commonly used seal life projection method is extrapolation of compression set (which is directly related to seal relaxation). The basis for this approach is illustrated in Figure 3.7.

For example, for a static seal that had been in service for seven years with a measured compression set of 50%, using a compression set limit of 90%, seal life, t_2, may be calculated using the following equation:

$$t_2 = t_1 \times \frac{C_L}{C_{max}} = \frac{(7)(90)}{50} = 12.6 \text{ years}$$

where t_2 = seal life (in years)
t_1 = accumulated service time (7 years)
C_L = compression set limit (90%)
C_{max} = measured compression set value (50%).

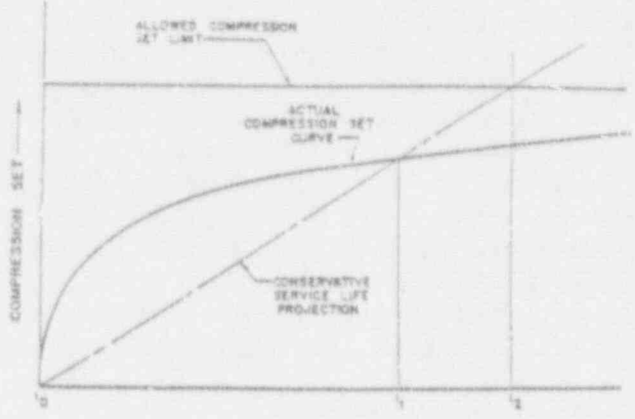

Figure 3.7 Compression set extrapolation

3.2.3.3 Other Elastomeric Seal Life Evaluation Methods

A number of other approaches have been used to substantiate seal life for snubbers. These include seal life projections based upon available laboratory data and evaluation of trends in snubber functional test data.

Accurate determination of seal life based on laboratory test data is difficult. Conclusive laboratory data supporting the long-term effects of temperature aging on seals is limited. This is primarily due to the difficulties encountered in simulating the effects of time. Although some information is available pertaining to the effects of radiation on elastomeric sealing materials, it is extremely difficult to apply this information to establish a practical seal life for snubbers in service (see Section 3.2.1.1).

Since the incorporation of environmentally suitable elastomers, there has been little evidence of seal failure when a snubber is activated, i.e., pressurized. Moreover, the primary aging concern is gradual relaxation of sealing force when the snubber is not activated. Therefore, a substantiation of seal life based solely on functional test results is not appropriate.

3.2.3.4 Plant-Specific Seal Life Considerations

Seal life evaluations, for the most part, have been plant- or site-specific. Due to the lack of precise environmental data, the potential for combined environmental influences and variations in seal compounds and configurations, it is difficult to generically categorize seal life for hydraulic snubbers (e.g, eight years for an application temperature of 140°F). Another difficulty in applying generic data is that the levels of environmental stressors at various snubber locations often differ from the levels specified in the plant design specifications. (It should be noted that environmental parameters included in design specifications are generally specified as maximum values; actual operating levels may be lower, or occasionally higher, than the specified value.) Various plant-specific seal life studies have indicated variations in seal degradation from one plant to another with similar design specifications.

Plant-specific seal life evaluations are appropriate for most hydraulic snubbers. However, it may be generally stated that seals manufactured from most ethylene propylene compounds, in mild operating environments (low temperature, low humidity, low radiation level) will likely exhibit little or no degradation over extended periods of time. More precise plant data is needed, however, in order to quantify seal life in this regard.

Ultimately, seal life should be based on successful of operating experience in the actual plant environment. Seal life extension evaluations should be considered as interim site-specific methods for progressively extending seal life from current conservative limits.

3.2.4 Effects of Compression Set on Low-Pressure Elastomeric Seal Performance

The purpose of this portion of the in-plant research was to verify practical compression set limits for the various seal configurations that are commonly used in hydraulic snubbers.

The chief concern regarding aging of hydraulic snubber seals is relaxation of sealing force under low-pressure conditions. Compression set is most often used as a direct indicator of the level of seal relaxation. Seal life projections are often based on comparison of a predicted compression set level with an established compression set limit.

Compression set, C, may be defined by the following equation:

$$C = \frac{W_o - W_1}{W_o - W_s}$$

where W_o = original seal thickness

W_s = compressed seal thickness as it is installed in the seal gland

W_1 = recovered seal thickness after the seal is removed from the gland.

Most static seals (seals where there is no relative motion between mating parts) will still perform adequately under low pressure conditions at 100% compression set. For a degree of conservatism, a compression set limit of 90% is typically used for projecting seal life in static seals used in hydraulic snubbers. For an additional degree of conservatism, a compression set limit of 80% is typically used for dynamic seals, i.e., seals where there is relative motion between mating parts.

Note: As a design tool, when selecting an optimum seal material based on laboratory-aging simulation, more conservative limits may be specified, due to the absence of actual service data.

3.2.4.1 Methodology to Collect Compression Set Data

The basic approach was to obtain nonleaking snubbers with seals that are expected to have a high level of compression set. Snubbers with extended service in a high-temperature environment were priority candidates. It was anticipated that such snubber samples could be found in either nonsafety-related applications in nuclear plants or in fossil fuel plants. Although snubbers in high-temperature environments were sought for their higher propensity for compression set, correlating operating temperatures with compression set is not a part of this study.

The selected snubbers were then subjected to a preliminary evaluation. The purpose of the preliminary evaluation was to determine, by measuring compression set in one or two representative seals, whether or not the remaining seals could be expected to have a high level of compression set.

Snubbers meeting the criteria established in the preliminary evaluation were then subjected to a secondary evaluation in which compression set was measured for all seals expected to have high levels of compression set.

A total of 24 NPP personnel were contacted either for candidate snubbers that might be available from the plant or for the names of fossil fuel plant contacts in the same utility. Eight major utilities with fossil fuel plants were also contacted. In addition, two hydraulic snubber vendors were contacted for snubber candidates available from their services groups.

3.2.4.2 Results of the Compression Set Examinations

A total of only six snubber samples were made available. Two major factors that limited the availability of snubber samples were 1) the limited amount of lead time allowed to obtain the required snubber samples in NPPs (snubber availability generally coincides with scheduled overhauls), and 2) the lack of replacement snubbers in fossil fuel plants.

Of the six available samples only two snubbers showed sufficient seal degradation in the preliminary evaluation to warrant a secondary evaluation. A summary of the preliminary and secondary evaluations is included in Appendix D.

3.2.4.3 Additional Data Evaluation

In order to augment the limited amount of data obtained in the evaluations described above, additional in-house data were reviewed for maximum recorded compression set levels for various nonleaking seal configurations.

3.2.4.4 Summary of Compression Set Evaluation

Table 3.6 lists maximum measured values for compression set for various nonleaking seal configurations. These configurations are illustrated in Figures 3.8 through 3.12. It should be noted that tabulated compression set values by no means reflect a limit for compression set for the respective seal configurations. They reflect only the maximum compression set value recorded, providing some degree of support for the typical compression set limits discussed in this section.

Table 3.6 Maximum measured compression set for various nonleaking seal configurations

Seal Configuration	Seal Type	Maximum Measured Nominal (3) Compression Set	Source of Data (5)
O-Ring	Static	57%	(2)
O-Spring Lip Seal	Dynamic	69%	(1)
Quadra Spring Lip Seal	Dynamic	69%	(2)
U Cup Piston Seal(4)	Dynamic	100%	(2)
Miller Piston Rod Seal (Static Portion)	Static	93%	(1)

Note: (1) NPAR study.
(2) In-house data.
(3) Nominal compression set is calculated using nominal cross-section dimensions for original seal thickness.
(4) Internal seal integrity verified by functional testing.
(5) These data were obtained from 5 different snubbers.

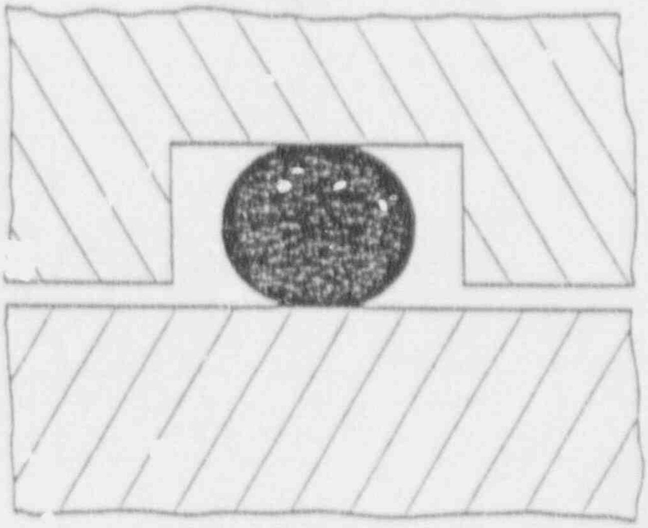

Figure 3.8 O-Ring

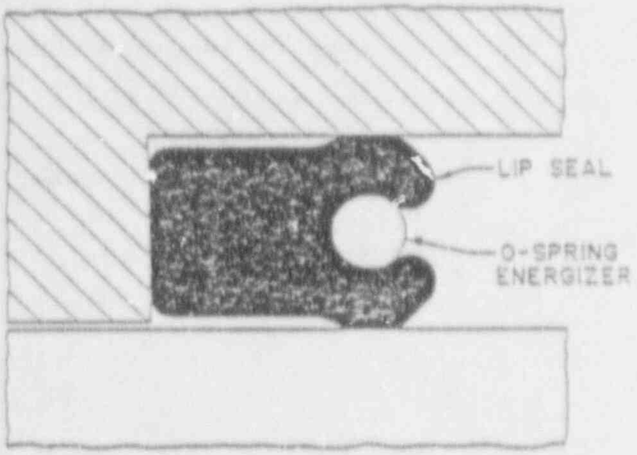

Figure 3.9 O-Spring lip seal

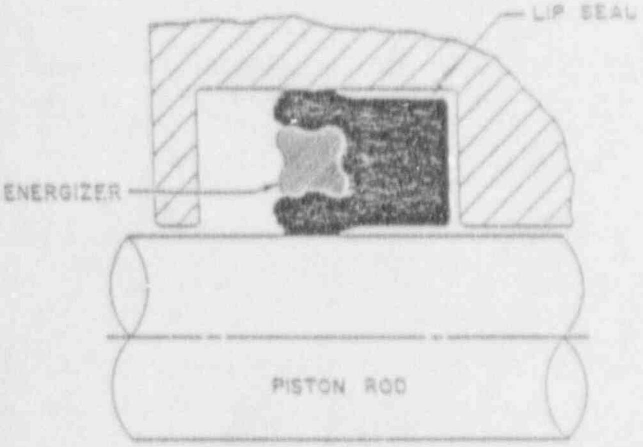

Figure 3.10 Quadra spring lip seal

Optimum compression set limits cannot be established based on the research because of the limited amount of data presently available. Additional research is required to accomplish this goal. In view of the limitations discussed in Section 3.2.4.2, such research should allow sufficient lead time and provide for replacement snubbers to increase the number of available snubber samples. Future seal data from plants with extended service will also be useful in further substantiating compression set limits.

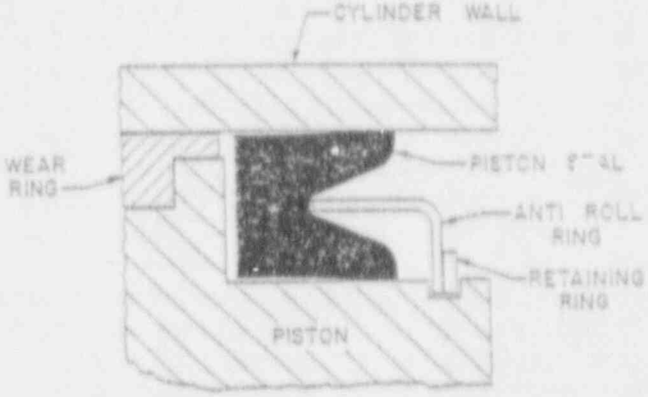

Figure 3.11 U-Cup piston seal

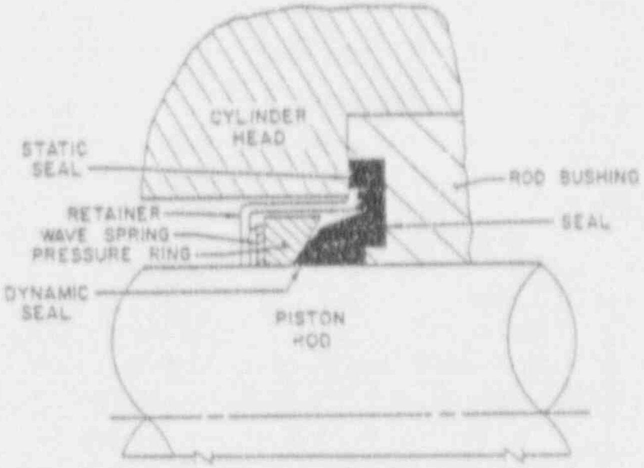

Figure 3.12 Miller piston rod seal

3.2.4.5 Internal Seals

The primary consideration regarding degradation of internal seals, e.g., piston seals, is progressive relaxation of sealing force such that locking velocity or bleed rate might be affected. However, snubbers with U-Cup piston seals with a measured compression set of 100% have been tested with no observed effect on these parameters.

3.2.5 Elastomeric Seals Most Affected by Aging

As discussed in Section 3.2.4, low pressure sealing capability is of primary concern for the effects of aging on hydraulic snubber seals. External seals, i.e., seals that, if leaking, would result in loss of fluid from the snubber, are considered to be the most critical in this regard.

The propensity of seals to age-related degradation may be characterized as follows:

- In general, the higher the surface area to volume ratio, the greater the propensity for a seal to take a set. Seals with a small cross-section thickness, therefore, are more susceptible to compression set inducement.
- Seals installed near or on the snubber surface appear to be more affected by the service environment (in terms of embrittlement and high compression set) than seals that are installed deeper within the snubber.
- Seals that are exposed to air are prone to degradation due to oxidation, particularly at elevated temperatures. Although seals also degrade due to radiation, signigicant effects in this regard have not been substantiated by the service data.
- Dynamic seals are generally more susceptible to leakage due to the relatively low initial squeeze that is characteristic of such seals, continuous changes in the seal-gland interface, and the potential for wear.
- Thread seals used to seal straight threads on some snubber models are particularly prone to service degradation, generally in the form of increased hardness and high set. It should be noted that thread seals are installed at the surface of the snubber and are exposed to air.

3.3 Evaluation of Mechanical Snubber Aging

The purpose of this evaluation is to develop an improved understanding of aging of mechanical snubbers based on recent operating experience.

Systems typically identified as problem safety-related systems for mechanical snubbers are listed in Table 3.7. Snubbers used on non-safety-related systems are also subject to degradation. However, plant data in this regard are not as comprehensive.

Table 3.7 Typical problem systems for mechanical snubbers

PWR Plant	BWR Plant
• Component Cooling	• High-Pressure Core Spray
• Reactor Coolant	• Low-Pressure Core Spray
• Safety Injection	• Residual Heat Removal
• Steam Generator Blow Down	• Main Steam (particularly between isolation valves and stop valves)

Snubbers on small piping branching from relatively large piping (e.g., drain lines and instrumentation lines) are particularly susceptible to overloading caused by dynamic transients. Snubbers installed at pipe locations near connections to rotating equipment are susceptible to degradation due to vibration.

Until recently, service data on mechanical snubbers was limited because mechanical snubbers were not used on a large scale in nuclear plants until the late 1970s. A significant portion of the data that have been available pertained to some of the earlier problems encountered during pre-operational tests and initial ISI. Many of the reported failures were associated with construction damage, manufacturing defects, and isolated severe environments that have since been corrected.

Failure modes of mechanical snubbers may be grouped in three basic categories:

- high-drag or high-breakaway force (this includes frozen snubbers)
- high-acceleration threshold
- low-acceleration threshold.[1]

Table 3.8 represents a consolidation of typical mechanical snubber failure causes associated with the three failure modes described above. A more detailed classification of failure causes, as determined by failure analysis for Site C, is included in Appendix G.

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[1] Some plants have a lower limit for acceleration. Although a low acceleration by itself is not a major concern, it may indicate a problem within the snubber that could lead to inoperability.

Table 3.8 Typical mechanical snubber failure causes

Failure Mode	Failure Mechanism	Failure Cause
High Drag Force	Bent screw shaft	Overload
	Inertia mass rubbing against dust cover	Overload
	Foreign materials on screw shaft	Dusty Envir.
	Foreign materials on indicator tube	Dusty Envir.
	Cracked thrust bearing	Overload
	Dry lubricant	Elev. Temp.
	Corrosion of torque drum	Moisture
	Corrosion of capstan spring	Moisture
	Rough spots on planetary gears	Handling Damage
	Thrust bearing fretting	Vibration
	Capstan spring wound too tight	Mfg. Def.
	Binding of telescoping members	High Side Load
	Loose bearing retainer nut	Mfg./Hand. Def.
	Telescoping members not concentric	Mfg. Def.
	Weld spatter on indicator tube	Const. Damage
	Bent guide rods	Overload
	Flaked plating on ball screw	Mfg. Def.
Exceeded Maximum Acceleration Limit	Capstan spring not wound tight enough	Mfg. Def.
	Capstan spring not installed correctly	Mfg. Def.
	Worn capstan spring	Vibration
	Keeper ring not installed correctly	Mfg. Def.
	Excessive lubricant on torque drum	Mfg. Def.
	Lubricant on inertia mass	Mfg. Def.
	Bent clutch tang	Mfg. Def.
	Fractured ball screw shaft	Overload
	Capstan spring wear	Vibration
Below Minimum Acceleration Limit	Corrosion of capstan spring	Moisture
	Corrosion of clutch spring	Moisture
	Damaged capstan spring	Mfg. Def./Vibr.
	Damaged thrust bearing	Overload/Vibr.
	Torque drum retainer bent	Overload

leaking, would result in loss of fluid from the snubber, are considered to be the most critical in this regard.

The propensity of seals to age-related degradation may be characterized as follows:

- In general, the higher the surface area to volume ratio, the greater the propensity for a seal to take a set. Seals with a small cross-section thickness, therefore, are more susceptible to compression set inducement.
- Seals installed near or on the snubber surface appear to be more affected by the service environment (in terms of embrittlement and high compression set) than seals that are installed deeper within the snubber.
- Seals that are exposed to air are prone to degradation due to oxidation, particularly at elevated temperatures. Although seals also degrade due to radiation, signigicant effects in this regard have not been substantiated by the service data.
- Dynamic seals are generally more susceptible to leakage due to the relatively low initial squeeze that is characteristic of such seals, continuous changes in the seal-gland interface, and the potential for wear.
- Thread seals used to seal straight threads on some snubber models are particularly prone to service degradation, generally in the form of increased hardness and high set. It should be noted that thread seals are installed at the surface of the snubber and are exposed to air.

3.3 Evaluation of Mechanical Snubber Aging

The purpose of this evaluation is to develop an improved understanding of aging of mechanical snubbers based on recent operating experience.

Systems typically identified as problem safety-related systems for mechanical snubbers are listed in Table 3.7. Snubbers used on non-safety-related systems are also subject to degradation. However, plant data in this regard are not as comprehensive.

Table 3.7 Typical problem systems for mechanical snubbers

PWR Plant	BWR Plant
• Component Cooling	• High-Pressure Core Spray
• Reactor Coolant	• Low-Pressure Core Spray
• Safety Injection	• Residual Heat Removal
• Steam Generator Blow Down	• Main Steam (particularly between isolation valves and stop valves)

Snubbers on small piping branching from relatively large piping (e.g., drain lines and instrumentation lines) are particularly susceptible to overloading caused by dynamic transients. Snubbers installed at pipe locations near connections to rotating equipment are susceptible to degradation due to vibration.

Until recently, service data on mechanical snubbers was limited because mechanical snubbers were not used on a large scale in nuclear plants until the late 1970s. A significant portion of the data that have been available pertained to some of the earlier problems encountered during pre-operational tests and initial ISI. Many of the reported failures were associated with construction damage, manufacturing defects, and isolated severe environments that have since been corrected.

Failure modes of mechanical snubbers may be grouped in three basic categories:

- high-drag or high-breakaway force (this includes frozen snubbers)
- high-acceleration threshold
- low-acceleration threshold.[1]

Table 3.8 represents a consolidation of typical mechanical snubber failure causes associated with the three failure modes described above. A more detailed classification of failure causes, as determined by failure analysis for Site C, is included in Appendix G.

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[1] Some plants have a lower limit for acceleration. Although a low acceleration by itself is not a major concern, it may indicate a problem within the snubber that could lead to inoperability.

Table 3.8 Typical mechanical snubber failure causes

Failure Mode	Failure Mechanism	Failure Cause
High Drag Force	Bent screw shaft	Overload
	Inertia mass rubbing against dust cover	Overload
	Foreign materials on screw shaft	Dusty Envir.
	Foreign materials on indicator tube	Dusty Envir.
	Cracked thrust bearing	Overload
	Dry lubricant	Elev. Temp.
	Corrosion of torque drum	Moisture
	Corrosion of capstan spring	Moisture
	Rough spots on planetary gears	Handling Damage
	Thrust bearing fretting	Vibration
	Capstan spring wound too tight	Mfg. Def.
	Binding of telescoping members	High Side Load
	Loose bearing retainer nut	Mfg./Hand. Def.
	Telescoping members not concentric	Mfg. Def.
	Weld spatter on indicator tube	Const. Damage
	Bent guide rods	Overload
	Flaked plating on ball screw	Mfg. Def.
Exceeded Maximum Acceleration Limit	Capstan spring not wound tight enough	Mfg. Def.
	Capstan spring not installed correctly	Mfg. Def.
	Worn capstan spring	Vibration
	Keeper ring not installed correctly	Mfg. Def.
	Excessive lubricant on torque drum	Mfg. Def.
	Lubricant on inertia mass	Mfg. Def.
	Bent clutch tang	Mfg. Def.
	Fractured ball screw shaft	Overload
	Capstan spring wear	Vibration
Below Minimum Acceleration Limit	Corrosion of capstan spring	Moisture
	Corrosion of clutch spring	Moisture
	Damaged capstan spring	Mfg. Def./Vibr.
	Damaged thrust bearing	Overload/Vibr.
	Torque drum retainer bent	Overload

Failure causes listed in Table 3.8 may be grouped into three basic categories:

- service-related, single occurrence
- service-related, progressive degradation
- nonservice-related.

3.3.1 Aging Factors for Mechanical Snubbers

The primary influences associated with progressive degradation in mechanical snubber performance are vibration, moderate load transients,[1] elevated temperature, and moisture.

3.3.1.1 Effects of Vibration on Mechanical Snubbers

Mechanical snubbers, particularly the smaller sizes, are subject to degradation from high- and low-amplitude vibration. High-amplitude vibration is vibration having an amplitude that exceeds the mechanical clearances in the snubber's end attachments. This type of vibration can result in localized fretting and wear of mating parts, such as the lead screw, thrust bearing, capstan spring, pins, and attachment lugs. It can also result in an increase in drag force, an increase in mechanical clearances, jamming, and/or an increase in the acceleration threshold.

Low-amplitude vibration is defined as vibration with an amplitude less than the mechanical clearances in the snubber. This type of vibration can lead to loosening of fasteners and, in combination with the weight of the snubber, can cause wear of clevis pins and attachments, resulting in elongated attachment holes. Continuous high-frequency, low-amplitude vibration can cause internal wear, which may increase drag force.

3.3.1.2 Elevated Temperature

Elevated temperature has often caused solidification of lubricants used in mechanical snubbers. This effect increases friction and results in an increase in drag force.

3.3.1.3 Moisture

Moisture can cause internal corrosion that in turn can lead to increasing drag force, jamming, and/or a decrease in the snubber's acceleration threshold as a result of a build up of rust between the capstan and capstan spring. Moisture-related corrosion has been a concern for snubbers installed in a vertical orientation, where water may be trapped in the snubber.

Degradation due to moisture can occur over an extended period. Degradation can also occur in a relatively short time due to a one-time exposure to large amounts of moisture, e.g., steam leak. Identification of the specific cause requires a comprehensive root cause evaluation.

3.3.2 Evaluation of Changes in Drag Loads Versus Service Time

As was discussed in Section 3.3.1.1, progressively increasing drag force is another consideration. There is some justification for periodic drag force testing of representative snubber samples from the general snubber population. An evaluation of the effects of service time on mechanical snubber drag force is discussed in the following subsections.

3.3.2.1 Average Drag Force Versus Time - Different Snubber Samples

For Site D (two plants), data were available for snubbers of the same size that were tested on the same test machine. Unfortunately, no snubber had been tested more than once to date (i.e., there were no repeat tests for any one snubber). However, it was anticipated that, if service time significantly affects drag force, then an average of the measured drag force values for the same size snubber for successive refueling outages might indicate such a trend.

Data from both units for five successive refueling outages were reviewed for two sizes of mechanical snubbers. The data were evaluated for both peak and average drag

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[1] Moderate load transients are defined as frequently occurring load transients that are less than the rated capacity of the snubber, such as those occurring during pump start-up.

force in tension and compression. The number of samples for each size at each Reactor Fuel Outage (RFO) ranged from 4 to 26.

Associated data and plots of drag force versus time are included in Appendix E. As may be observed in the time plots, the results of the evaluation are inconclusive.

3.3.2.2 Average Drag Force Versus Time - Same Snubber Samples

For Site F, data were available for a total of 47 mechanical snubbers of the same size that had been tested on at least two and sometimes three occasions using the same test machine. Peak and average drag force values for each RFO were plotted versus time (see Figure 3.13). Associated data and trending plots for individual snubbers are included in Appendix F. As with Plant D, both average drag force and peak drag force for both the tension and compression directions were evaluated. It should be noted that all snubbers had been in service for approximately five years before the initial test data point was obtained.

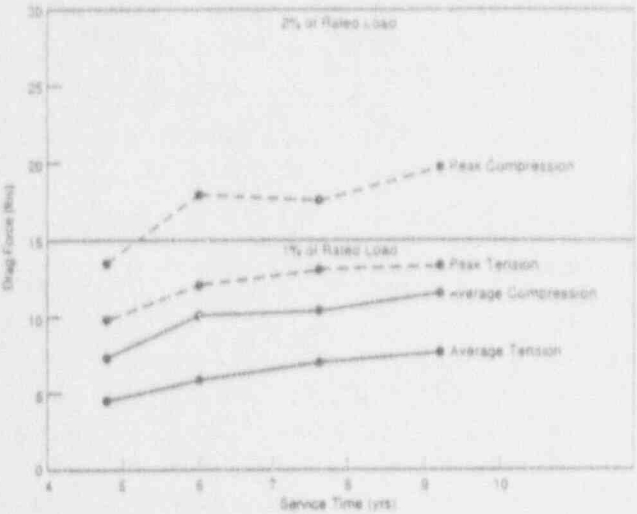

Figure 3.13 Average drag force versus service time for 47 mechanical snubbers

As can be observed from Figure 3.13, there appears to be a slight trend toward increasing drag force with service time, at least for one mechanical snubber model and size at this particular plant. The data support the need to monitor snubbers in moderate environments, possibly using a selected number of representative snubbers. However, the magnitude of the drag force value is generally small, i.e., less than 2% of rated load for all but four snubber samples, and less than 3% of rated load for all but one snubber sample.

3.3.3 Dynamic Transients

A significant number of cases of documented degradation or failures in mechanical snubbers have been associated with dynamic transients. Some transients, such as those caused by water or steam hammer, can significantly overload a snubber and result in instantaneous failure. Other, lower load transients such as those due to sudden valve opening may result in progressive degradation depending on the number of load cycles.

Typical failure mechanisms associated with overload involve fracture of the thrust bearing and/or buckling of the ball screw or slender attachment hardware. Inability of the snubber to provide free motion in the passive mode is often the result of such damage (i.e., jamming or high drag).

Failure mechanisms associated with lower load transients generally involve wear or local fretting similar to that resulting from high-amplitude vibration. Such degradation can result in an increase in snubber drag force. Many plants have implemented procedures whereby snubbers that are potentially subject to transients are identified and evaluated using augmented inspection methods (Section 3.1.5.4).

4 Conclusions

4.1 Snubber Performance History

For most plants, the greatest number of snubber failures has been associated with nonservice-related influences, such as mishandling damage and manufacturing defects that were detected during initial plant operation. After identifying isolated severe environments during initial plant operation, plant personnel have modified the snubbers' environment, replaced snubbers with more durable models, or eliminated the snubbers as part of a snubber reduction program. Snubber functional test acceptance limits have also been generally broadened.[1] These methods of snubber management have significantly reduced snubber failure rates.

Aging management for snubbers involves 1) identifying snubbers susceptible to rapid degradation and minimizing their potential for failure by conducting augmented inspections or by requiring frequent maintenance or replacement, and 2) monitoring for progressive degradation in the remaining plant snubbers and scheduling preventive maintenance accordingly. Many plants have implemented elastomeric seal life monitoring programs for hydraulic snubbers. Beyond seal life studies, however, most plants have yet to implement a formal service-life monitoring program for snubbers.

In general, approximately one-half of all recent snubber failures for the key plants evaluated have been caused by aging-related service influences. By contrast, review of failure evaluation data for one plant indicated that only 25% of the evaluated seal failures were aging related.

The most significant influences resulting in snubber degradation are elevated temperature, vibration, dynamic transients, and moisture. The effects of radiation, on the other hand, appear to be significantly less than originally anticipated. This is probably because of the relatively low actual radiation levels, the shielding effects provided by the snubber body, and the frequency of seal replacements.

4.2 Service-Life Monitoring

The following conclusions are drawn from the in-plant snubber research and provide the basis for service-life monitoring guidelines:

- Many plants utilize an automated database that simplifies tracking and retrieval of pertinent information that may be used for monitoring snubber service life. An example of a snubber data sheet associated with such a system is included in Appendix H.

- Plant data indicate that a significantly large portion of the total number of snubber failures have resulted from nonservice-related influences. This supports the need to distinguish between service-related and nonservice-related degradation or failures to ensure that nonservice-related failures are excluded from the database that is used to monitor snubber service life.

- Variations in snubber degradation rate due to significant variations in environment from one area in the plant to another may warrant establishing separate service life categories for different snubber populations.

- The primary degradation influences for both hydraulic and mechanical snubbers are elevated temperature, vibration, and load transients.

- Moisture can cause corrosion of both internal and external snubber parts. Such degradation is more prevalent for mechanical snubbers. External corrosion is easily detected during visual examination and may be an indicator of internal corrosion. Methods used to identify internal corrosion include boroscopic examination, hydraulic fluid analysis, and snubber disassembly.

- Snubbers are particularly susceptible to service degradation when installed

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[1] Some plants initially applied manufacturer's production acceptance limits, which are generally much more narrow than limits required for snubber operability.

  - on small piping branching from large piping
  - near high temperature components
  - in congested areas with significant personnel traffic
  - near connections to rotating equipment.

- Plant-specific seal life evaluation studies have been conducted at several plants. Some plants are trending drag force data in a selected number of mechanical snubbers. Realistic service-life projections have involved the use of trendable degradation parameters that relate to the anticipated degradation mechanisms.
- Plant systems for which snubber degradation appears to be prevalent include
  - component cooling
  - reactor coolant
  - safety injection
  - steam generator blowdown
  - high-pressure core spray
  - low-pressure core spray
  - residual heat removal
  - main steam.
- Typical failure mechanisms and causes are listed in Tables 3.3 and 3.7.
- Mechanisms and root causes for failure and degradation should be determined (where practical). This requires experienced personnel.
- Plant operating environments may differ from the original design specification. General area operating parameters, therefore, should be measured over time and documented.
- Plants should make a concerted effort to identify applications involving severe operating environments. Snubber failures in such applications may be mitigated by augmented surveillance, frequent maintenance or replacement, retrofit with more durable snubbers, or by eliminating the snubber in an approved design review.
- Augmented surveillance may be appropriate for snubbers in severe operating environments and may involve attributes that are not normally included during inservice inspection (ISI) visual examination.
- "Hands-on" surveillance methods may be used in addition to visual inspections. Such methods can be used to detect vibration and elevated temperature and to identify frozen snubbers. They can also be used to identify anomalies that may indicate the need for preventive maintenance.
- Evaluation of functional test traces is very useful in identifying the cause of snubber failure, or in identifying anomalies indicative of impending snubber failure.
- Diagnostic tests may be used to augment inservice test data in identifying the cause of snubber failure or degradation. Snubber test equipment that provides a time trace of test parameters is useful for evaluating snubber degradation or failure. Variation of test parameters is often necessary for diagnostic testing. Test machine accuracy and repeatability is required for trending.
- Elastomeric seal life evaluations include analytical methods, e.g. Arrhenius projections, and methods based on service data. Any seal life evaluation method for snubbers should be based primarily on predicting low-pressure seal performance and should be updated based on service data.
- Monitoring of snubber reservoir fluid level is the most practical method for verifying fluid leakage.
- Snubber damage due to mishandling or personnel traffic may be minimized by inspection of such snubbers just before start-up following an outage.

- One plant has reported that acceleration thresholds have decreased for some mechanical snubbers as a result of internal corrosion that effectively decreases the clearance between the capstan spring and the braking surface (See Appendix A). As a result, this plant has established minimum and maximum acceptance limits for acceleration threshold. In the absence of baseline data, however, it is difficult to determine whether or not the acceleration threshold has actually decreased or whether it was low to begin with. In areas where baseline data are available, acceleration threshold may be an effective parameter for identifying such degradation.

- Critical snubber parts should be identified and may vary depending on the environmental stressor involved. Snubber service life should be based on the part anticipated to have the shortest life for the primary environmental stressor.

- Snubber test parameters generally include activation level, release rate, and breakaway or drag force. These parameters are useful for both ISI and for service-life monitoring. A clear definition of any parameter should be established by each plant. This definition should be consistently applied thereafter. Parameter definitions for ISI purposes may differ from the corresponding definitions used for service-life monitoring.

4.3 Effects of Compression Set on Low-Pressure Elastomeric Seal Performance

Static seals in hydraulic snubbers can seal adequately, even at a compression set of 100%. However, general limits used for most seal life evaluations are 90% for static seals and 80% for dynamic seals. These limits were substantiated to some degree using compression set data obtained in this study. However, further research involving more substantial data is needed in this area.

4.4 Service Aging of Mechanical Snubbers

Mechanical snubber performance can be progressively affected by aging, particularly when snubbers are exposed to one or more environmental stressors. Performance is related to drag force, breakaway force, and acceleration threshold. Primary influences affecting degradation are elevated temperature, vibration, moisture, and dynamic transients.

Snubbers subject to severe environments should be identified and managed with appropriate preventive maintenance. Long-term service in moderate operating environments may also affect snubber performance. Mechanical snubbers in moderate operating environments should be monitored by testing representative samples; baseline data are extremely important in this regard.

5 Recommendations

5.1 Service-Life Monitoring Recommendations

The following recommendations for service-life monitoring are based on the results and conclusions of the in-plant research activities.

5.1.1 Determination of Snubber Failure or Degradation Causes

A principal goal of a service-life monitoring program should be to develop means for separating service-related and nonservice-related failures. It is important that the root cause of snubber failure or degradation (e.g., snubber overload due to dynamic transient, high-amplitude vibration beyond the design capacity of the snubber, and application temperature exceeding that specified for continuous use) be identified along with the failure mode (e.g., high drag force or low activation) and the failure mechanism (e.g., deformation of the ball screw shaft or solidification of grease).

Failure evaluation data sheets should include key categories such as failure mode, failure mechanism, failure cause, environment, service time, abnormal conditions, visual observations, test data, and test observations. It is important that personnel involved in failure evaluation be adequately trained in correctly tracing a failure to its cause. Failure evaluation data sheets should be designed and formatted in a manner that encourages systematic and thorough analysis.

Figure 5.1 illustrates a systematic analysis approach to root cause failure identification. Table 5.1 lists typical irregularities that may be observed during visual examination or during snubber disassembly. The table characterizes features of snubber degradation and may be useful in pinpointing the potential cause.

5.1.2 Determination and Documentation of Operating Environment

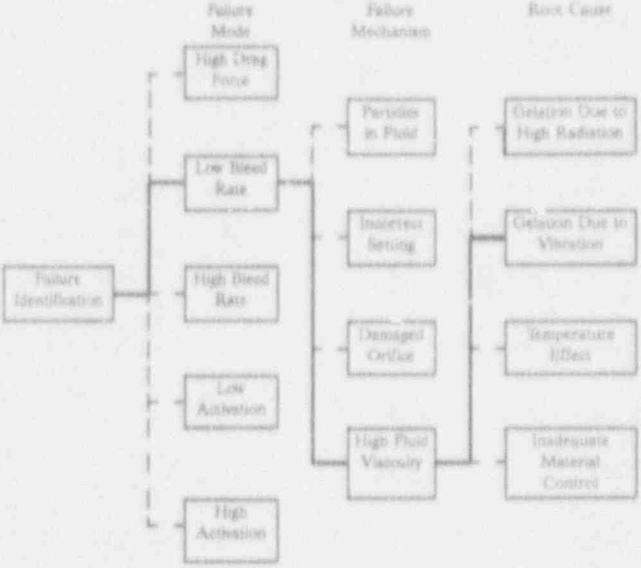

Figure 5.1 Flow chart - typical root cause determination

Service-life monitoring takes into consideration the capability of the various snubber models to endure the full range of plant environments (benign to severe). Indicators of severe operating conditions can often be identified during snubber overhauls and other maintenance-related activities.

Determining specific environmental information often involves specialized instrumentation and equipment that would be impractical for use at every snubber location. Such equipment, therefore, should be used in applications where moderate to severe environments are anticipated or as a diagnostic aid in determining the cause of snubber degradation or failure. Various methods and equipment used to identify or measure specific environmental parameters are described in Sections 5.1.2.1 through 5.1.2.4. Additional information in this regard is included in Appendix B.

5.1.2.1 Temperature

Continuous temperature recording devices are available to indicate the general area temperatures within the plant (which often vary by elevation) or to measure local snubber or component temperatures. Temperature-sensitive tape may be placed directly on the snubber to

Table 5.1 Typical indicators of snubber degradation

Observation	Potential Indicator of:
Dark hydraulic fluid	High-amplitude vibration
Black material on piston rod	High-amplitude vibration
Excessive piston and cylinder wear	High-amplitude vibration
Worn capstan spring tangs	High-amplitude vibration
Fretting	High-amplitude vibration
Unsymmetrical wear of clevis pins	High-amplitude vibration
Elongation of attachment holes	High- or low-amplitude vibration
Loose fasteners	High- or low-amplitude vibration
Symmetrical wear of clevis pins	Low-amplitude vibration
Discoloration of metallic parts	High temperature
Embrittled piston rod wiper	High temperature
Rod wiper adhered to piston rod	High temperature
High seal compression set	High temperature
Seal surface cracks	High temperature in air
Lack of fluid pigmentation	High radiation level
Corrosion of metallic parts	High humidity/leaking components
Bent piston rod or attachments	Overloading
Changes in cold/hot position setting	Increased drag or jamming

determine maximum temperature. One shortcoming of this approach, however, is that a time/temperature profile is not provided. Contact and noncontact temperature measuring devices (e.g., infrared type) are also available.

5.1.2.2 Radiation

Normal radiation levels of an operating plant do not usually contribute significantly to snubber degradation. This is probably due to the following considerations:

- actual in-plant radiation levels are, in most cases less than was originally anticipated

- the snubber body provides a significant amount of shielding

- originally anticipated radiation effects were based upon a 40-year dose; in actuality, snubber parts that are sensitive to radiation degradation are replaced at intervals that are significantly less than 40 years.

Data pertaining to plant radiation levels can generally be obtained from health physics area surveys. Measurement of radiation levels specifically for service-life monitoring is not recommended except in evaluating the cause of snubber degradation in cases where other causes have been ruled out.

5.1.2.3 Vibration

Vibration may be continuous, in which case snubbers may degrade in as little time as one operating interval. Vibration may also be intermittent (e.g., during pump startup), in which case it may be undetected for long periods and result in long-term degradation of the snubber.

The available methods for detecting and measuring vibration vary from simple visual observation, detection by feel, portable vibration measuring instrumentation, and remote vibration measuring equipment. Examples of some alternatives to detect vibration, along with actual inservice applications, are described in Appendix A (Site G) and Appendix B.

Snubbers subject to vibration can often be detected by visual examination. Metal filings, darkened hydraulic fluid, deformed connecting pins, elongated attachment holes, and fretting of mating parts are all signs of vibration effects.

5.1.2.4 Transients

As with vibration, the existence of dynamic load transients may often be identified during routine snubber inspections, augmented inspections, and failure evaluation. Deformed structural members, jammed snubbers, and deformed internal parts are all potential indicators of dynamic overloading. In situ devices such as load-measuring clevis pins are available for monitoring snubber loads in applications where such transients are suspected (Appendix B).

5.1.3 Managing Snubbers in Severe Operating Environments

Significant environmental stressors that can affect snubber performance include overloading, vibration, elevated temperature, moisture, chemicals, and radiation. Despite the best design and post-startup inspections, isolated cases of snubbers operating in severe environments may be identified as plant operation continues. Unfortunately, such applications are often not identified until the snubbers are functionally tested. This supports the need for some random functional testing; however, the extent of functional testing currently required by technical specifications may not be necessary as plants gain empirical knowledge pertaining to the plant operating environments and the associated snubber capabilities.

Snubber failures in applications involving severe operating environments may be mitigated by conducting augmented inspections, periodic maintenance, periodic replacement with like kind, retrofitting with snubbers more suitable for the environment, or eliminating the snubber by approved engineering analysis methods.

5.1.4 Augmented Surveillance

A number of practices may be used for evaluating snubbers for degradation and for identifying operating environments. Since evaluation methods often do not employ quantifiable parameters, judgment is required on the part of the inspector. Experience of inspection personnel is therefore important.

5.1.4.1 Hand-Stroking

Probably the most common "hands-on" evaluation method is hand-stroking of mechanical snubbers. This method is often used to identify snubbers that are damaged or jammed due to transients. In this method, the inspector removes the connecting pin at one end of the snubber and slowly strokes the snubber while feeling and listening for abnormalities such as intermittent or continuous excess noise or resistance.

Using this method, an experienced inspector can often identify impending failure. For example, when a mechanical snubber is hand-stroked, periodic resistance, accompanied by a chaffing sound for each revolution of the inertia mass, indicates binding caused by lack of concentricity of rotating parts. Irregular, intermittent noise and resistance, on the other hand, indicate surface discontinuities on the lead screw.

5.1.4.2 Rotation of Snubbers in Place

Jammed snubbers (i.e., snubbers unable to allow free thermal motion) may often be identified by attempting to rotate the snubber about its spherical end attachment bearings. If the snubber is not free to rotate, it is possible that axial loading exists that is the result of jamming or premature lock-up. It should be noted, however, that this method is most effective for snubbers with a load capacity of 3,000 lb, or less. Normal friction in the bearings often prevents rotation of larger sizes.

5.1.4.3 Hand Detection of Vibration

Detection of vibration by placing a hand on the snubber during operation is a useful technique for evaluating accessible snubbers.

5.1.4.4 End of Outage Inspection

Just before startup, reinspection of snubbers that are susceptible to damage due to outage-related activities will reduce the probability of plant operation with inoperable snubbers. Future verification that consequent failures were not the result of service-related influences would otherwise be more difficult.

5.1.5 Trending

Note: Trending of test data is discussed further in Section 5.1.6.4.

Progressive degradation in the general snubber population (i.e., those snubbers not subject to rapid degradation) should be monitored by trending applicable degradation parameters for a selected number of snubbers that are representative of the plant operating environment. Such degradation parameters might include compression set for elastomeric seals (Section 3.2.2) or drag force for mechanical snubbers (Section 3.3.2). Some important considerations in this regard are listed below:

- The establishment of baseline data is essential for identifying trends. Data to be used for identifying trends should be sufficiently accurate to demonstrate trends.

- Trending parameters that relate directly to the anticipated aging failure mode should be used. Such parameters might include drag force for mechanical snubbers or elastomeric seal compression set for hydraulic snubbers.

  Note: An important example of inappropriate monitoring parameters is the use of functional test data, i.e., locking velocity and release rate for monitoring or trending seal degradation. Although functional test results can be affected to some extent by seal degradation, the primary aging failure mode for snubber seals (i.e., loss of low-pressure seal integrity) would not be reflected in functional test data.

- Acceleration threshold (activation level) in acceleration-limiting mechanical snubbers is a potentially trendable parameter that may indicate internal snubber degradation. A decreasing acceleration threshold may indicate internal corrosion (Section 4.2) or increased friction between the inertia mass and its spindle. An increasing acceleration threshold may indicate weakening of the capstan spring tangs as a result of wear or a decrease in friction between the capstan spring and its braking surface.

- Although changes in active hydraulic snubber parameters [i.e., locking velocity and bleed (release) rate] can indicate snubber degradation, these parameters are not considered practical trending parameters for monitoring progressive degradation.

- Reservoir fluid level is the most appropriate parameter for monitoring snubber fluid leakage.

5.1.6 Testing

The following functional test parameters are normally measured during inservice testing (IST):

- Activation Level: Locking velocity for poppet-valve hydraulic snubbers. Acceleration threshold for acceleration-limiting mechanical snubbers.

- Release Rate: Snubber velocity at a given load.

- Drag Force: Snubber resistance load at a given stroke velocity.

- Breakaway Force: Force required to initiate snubber motion.

These parameters are also useful in identifying potential degradation or in determining the cause of snubber failure.

5.1.6.1 Evaluation of Inservice Test Results

Since existing IST plans are statistically based on the number of failures, test results are often evaluated on only a pass/fail basis. Most test machines, however, provide a continuous trace of load and velocity for both activation tests and drag force tests. Such traces often contain information useful in identifying snubber degradation. For example, during mechanical snubber drag force testing, such characteristics as the number of load spikes, consistency of load spikes, duration of load spikes, noise, variations in drag force with stroke position, and directional sensitivity are all useful in identifying potential snubber degradation or impending snubber failure (see Figures 5.2 through 5.6). For hydraulic snubbers, traces can be used to identify air in the snubber or a clogged bleed orifice.

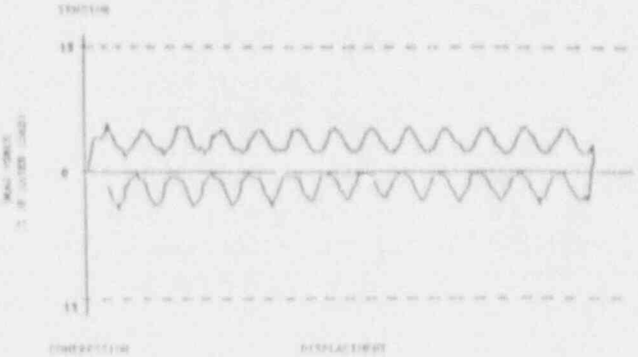

Figure 5.2 Mechanical snubber with normal drag force trace

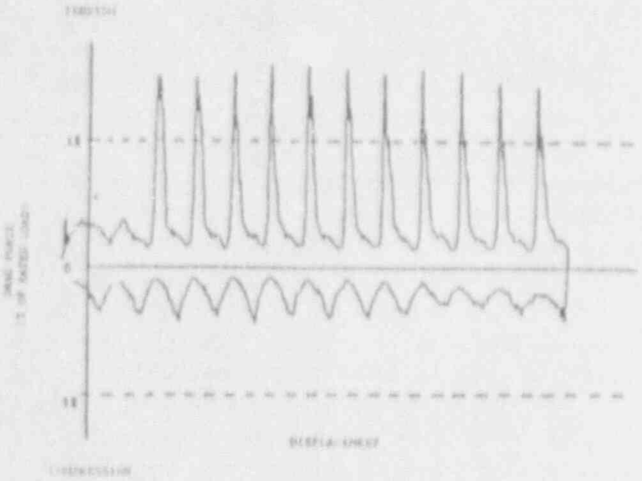

Figure 5.3 Mechanical snubber drag force with consistent spikes

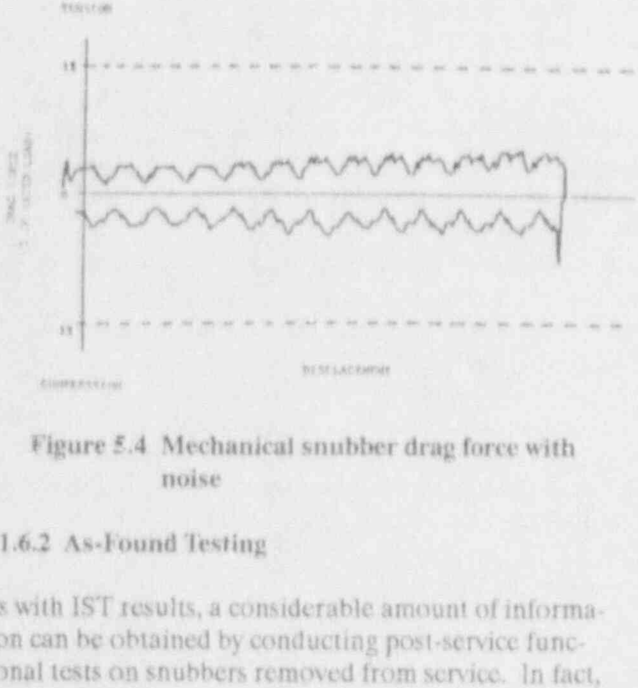

Figure 5.4 Mechanical snubber drag force with noise

5.1.6.2 As-Found Testing

As with IST results, a considerable amount of information can be obtained by conducting post-service functional tests on snubbers removed from service. In fact, as a general rule, such tests are recommended any time a snubber is removed from service, regardless of whether or not the snubber is to be reinstalled.

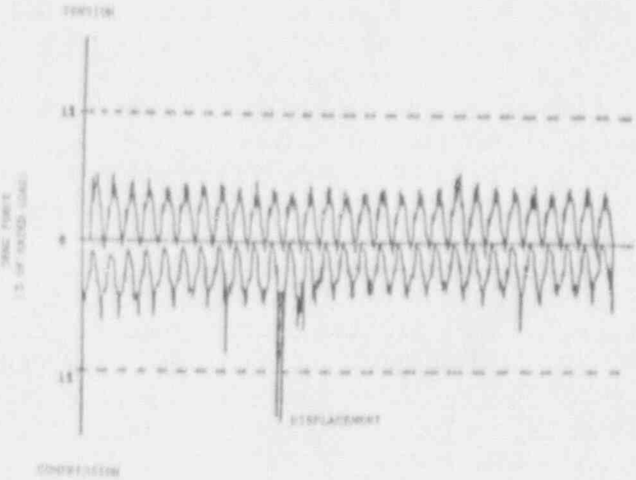

Figure 5.5 Mechanical snubber drag force with occasional spikes

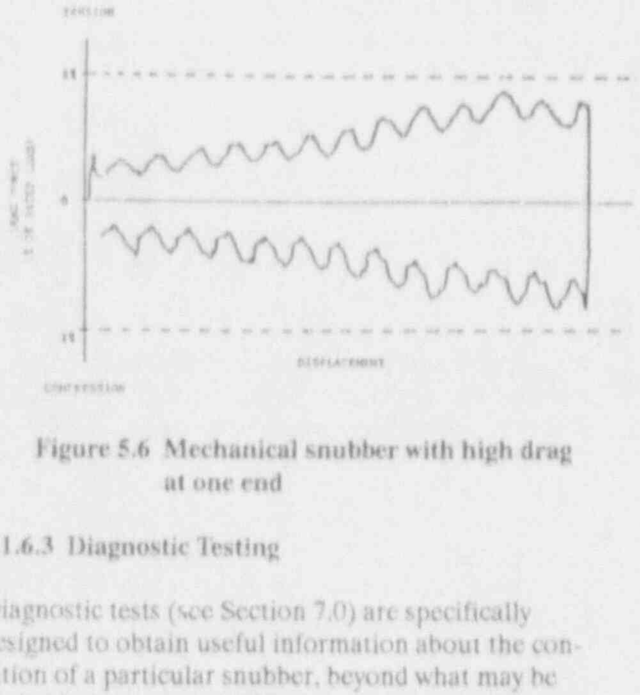

Figure 5.6 Mechanical snubber with high drag at one end

5.1.6.3 Diagnostic Testing

Diagnostic tests (see Section 7.0) are specifically designed to obtain useful information about the condition of a particular snubber, beyond what may be available from routine IST or as-found tests. For failures, diagnostic tests are often helpful in identifying the failure mechanism before disassembling the snubber.

Repeat tests are helpful in determining the repeatability of a given anomaly. For example, a load spike observed during a mechanical snubber drag force test that repeats in the same location for several tests would indicate the existence of a surface imperfection at one point on the lead screw. However, a spike that does not repeat in the same location or does not repeat at all indicates particulate contamination, e.g., dirt or sand.

It may sometimes be desirable to vary test parameters such as applied load, drag-force velocity, or test time duration in order to observe the effect on snubber performance. For example, extending the time duration for a hydraulic snubber bleed rate test is a good method for identifying bleed orifice blockage as the cause of an observed low bleed rate.

5.1.6.4 Trending Test Results

Trending is a useful tool for monitoring progressive snubber degradation. If test data are to be used for trending, the following should be considered in addition to those considerations listed in Section 5.15:

- Because the prevalent failure mode is failure to allow free thermal motion, a potential trending parameter for mechanical snubbers is drag force. This is supported by test data obtained that suggest an increase in drag force with service time for mechanical snubbers.[1]

- It is important that test data to be used for trending are consistently obtained using the same type of test machine, under the same test conditions. Ideally, the data from the same snubber should be used for comparison purposes.

- Administrative limits for functional test results are intended to ensure replacement or repair of a given snubber before failure. However, it is important to have a reasonable indication that the selected test parameter is progressing toward the failure limit. Overly restrictive administrative limits can have the negative effect of limiting the amount of data available for trending. They can also encourage replacement of reliable snubbers.

If test data are obtained for a different set of snubbers at each refueling outage, then IST results are not appropriate for trending. Similarly, if snubbers are tested on different types of test machines, then test data are generally not adequate for identifying trends.

Another important consideration involves defining the test parameter. For example, for ISI purposes, drag force may be defined as the highest (peak) resistance force when stroking the snubber from end to end. On the other hand, for trending, drag force may best be measured as an root mean square (RMS) average of the measured resistance force throughout the stroke range. A test parameter, therefore, must be defined both from the standpoint of snubber operability (i.e., for ISI) and from the standpoint of service-life monitoring (i.e., for trending).

5.1.6.5 Test Equipment

Note: Test machines are discussed here in terms of their application for service-life monitoring.

The types of snubber test equipment currently used in the industry vary considerably. Some provide only a single value for a given test parameter such as load or velocity, while others provide a continuous trace of the parameter versus time. The operation of some test equipment is totally manual, while others are fully automated. In general, it is recommended that functional test equipment be provided with a data acquisition system (either analog or digital) that is capable of providing a continuous trace of load and velocity versus time for the duration of the test. As discussed in Section 5.1.6.1, information from such traces is useful in detecting degradation and identifying failure mechanisms.

Some test equipment is of a "go/no-go" nature, in which the snubber is determined to be either operable or inoperable; however, this method neither accounts for variations in test results nor measures exact values for the given test parameter. Such equipment is not useful for test interpretation, diagnostic testing, or trending. Snubbers that fail functional tests using this equipment are often retested using a more accurate test machine.

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[1] Such a trend is yet to be fully substantiated

Many test machines are totally automatic. Automatic test machines may be advantageous for ISI because operator bias is minimized. Thus, data from automatic testers are generally acceptable for trending purposes. However, for diagnostic testing, the test operator should be able to vary the level of various test parameters for exploratory purposes.

It should be noted that whenever a snubber is tested in a different type of test machine than the one previously used, a number of new variables are introduced that may complicate the identification of trends. Such variables include test control methods and parameters, data acquisition systems, etc. For this reason, trending tests are most effectively conducted using the same test machine as well as the same test methods.

5.1.7 External Seal Leakage Detection and Leakage Rate Determination

Minor seal leakage is common for many snubber types and applications. A number of influences can cause seal leakage. A leaking snubber, however, does not necessarily imply inoperability nor does it necessarily require immediate snubber overhaul.

Measurement and trending of reservoir fluid level is probably the most practical approach to monitoring for external seal leakage. For this reason, reservoir fluid level should be recorded whenever fluid is added. An example of this method is discussed in Appendix A for Site A.

The location of seal leakage in many cases may be obvious by visual observation. However, in some cases the precise location of the seal leakage may require a time consuming follow-up evaluation.

It should be noted that in many cases, seal leakage can be the result of improper snubber assembly, defective parts, etc. A practical method for checking for seal leakage following snubber overhaul is to place the snubber on an absorbent (paper) pad where it can be observed for a period of time before installation.

5.1.8 Visual Examination

Snubbers are normally visually examined during each refueling outage in compliance with technical specification ISI requirements. However, the intent of these examinations is to identify characteristics that might indicate snubber inoperability. Several visual examination attributes included in ISI visual examinations are not related to service degradation. Service-life monitoring examinations may be conducted at the same time as those required for ISI or separately. However, qualification of personnel for such examinations is critical (see Appendix L).

Visual characteristics that would provide information in regard to service degradation are listed below. These snubber attributes may be used to define a visual examination checklist for service-life monitoring.

- deformed structural member or piston rod
- loose or missing threaded fasteners
- cold or hot position varies from specified value
- evidence of corrosion
- evidence of solid deposits (e.g., boric acid) from leaking components
- loss of hydraulic fluid since previous visual examination
- metal filings on or in the vicinity of the snubber
- observed fluid leakage
- evidence of significant dark (i.e., black or dark brown) material deposit on piston rod
- rod wiper adhered to piston rod
- abnormal color of hydraulic fluid
- wear or deformation of clevis pins

- elongation of attachment holes
- evidence of wear on support cylinder
- cracked or deformed fluid reservoir
- evidence of foreign material (e.g., water, solid particles, etc.) in hydraulic fluid
- discoloration of metallic parts due to elevated temperature.

5.2 Recommendations for the Working Group on Mechanical Equipment Restraints

Based upon the results of the NPAR research, a number of suggestions are made in regard to the OM Code, Section IST, Subsection ISTD, Part 4 (ASME 1990). These suggestions are to be recommended to the Working Group on Mechanical Equipment Restraints for consideration in the next revision of Subsection ISTD.

In general, recommendations pertain to service-life monitoring, visual examination attributes, and failure grouping. A detailed discussion of these recommendations is included in Appendix K. The recommendations are summarized in the following sections.

5.2.1 Service-Life Monitoring Recommendations

Service-life monitoring recommendations proposed for consideration in Subsection ISTD are generally based upon the recommendations discussed in Section 5.1. Specifically, they include:

- determination of snubber failure causes
- determination and documentation of the snubber operating environment
- evaluation of inservice test results
- diagnostic testing
- as-found testing
- trending
- augmented surveillance methods
- establishment of service-life categories.

5.2.2 Visual Examination Attributes

Typical visual examination attributes that may be used to update the Subsection ISTD, Appendix B, "Dynamic Restraint Examination Checklist Items," are suggested for consideration by the Working Group on Mechanical Equipment Restraints. Recommended attributes are listed separately in the following categories:

- preservice examination attributes only
- preservice and inservice examination attributes
- service-life monitoring examination attributes.

5.2.3 Failure Grouping and Corrective Action

Subsection ISTD currently requires that any snubber that fails to meet functional test acceptance criteria be classified into one of the following failure mode groups (FMGs):

- design/manufacturing
- application induced
- maintenance/repair/installation
- transient dynamic event
- isolated
- unexplained.

Depending upon the failure mode group, various corrective actions may apply. Recommendations are made in the following areas pertaining to failure grouping and associated corrective action.

5.2.3.1 Terminology

It is recommended that the following terms (as defined in Section 7.0) pertaining to aging be incorporated into the proposed ISTD 8.0, Service-Life Monitoring:

- failure mode
- failure mechanism
- failure cause
- root cause.

5.2.3.2 Isolated Failure Mode Group

It is recommended that the isolated FMG be eliminated.

5.2.3.3 Failure Categories

Based upon the results of root cause evaluations, it is recommended that snubbers with a similar propensity for failure be grouped together to facilitate corrective action. How such root failure-cause groups are defined involves judgment on the part of the owner; a failure group should be defined after a failure has been identified. However, for purposes of determining follow-up action in Subsection ISTD, it is suggested that failures need only be identified as service related, nonservice related, or unexplained.

5.2.3.4 Replacement or Modified Snubbers

It is suggested that some flexibility be provided in ISTD 1.11.1 to allow for continued use of existing snubber models in cases where more compatible models are not available.

5.3 Uniform Snubber Population Classifications by Environment

Many utilities have elected to pre-group snubbers based on design differences for purposes of ISI. This approach presupposes that failure causes will be associated only with snubbers in the predefined group.

Another method of pre-grouping that is commonly used for ISI purposes is to categorize snubbers as either accessible or inaccessible and to examine them as separate populations. This approach is generally the result of practical considerations in order to minimize inspection activities during refueling outages, rather than having anything to do with susceptibility to degradation.

From the standpoint of service-life monitoring, a primary consideration for pre-grouping should be based on anticipated variations in service life. Snubbers in isolated severe environments, e.g., those with high temperatures and vibration operating conditions, should be separated from general population and managed on a case-by-case basis. For plants with general environmental extremes, such as temperature, it may be desirable to group the general snubber population into two or more subpopulations with separate service lives.

5.4 Snubber Maintenance Recommendations

A number of maintenance recommendations were identified during the NPAR in-plant research. Recommendations generally are associated with the service-life monitoring guidelines discussed in Section 5.1. A detailed discussion of maintenance recommendations is presented in Appendix L. Specific topics in this regard are listed below:

- General Maintenance Practices
- Identification of the Operating Environment
- Snubbers Prone to Rapid Degradation in Severe Environments
- Failure Evaluation
- Failure Grouping
- Modification of Operating Environment
- Snubber Elimination
- Augmented Inspections
- Snubber Maintenance Frequency
- Trending

- Baseline Data
- Snubber Data Base
- Functional Test Equipment
- Spare Snubber Rotation
- Personnel Qualification
- As-Found Evaluation
- Coordination and Communication
- Replacement Parts and Materials

6 Recommendations for Additional Snubber Research

Although compression set limits currently in use are supported by limited data available from this in-plant research, additional compression set studies should be undertaken to strengthen the credibility of the compression set limits and to establish optimal compression set limits. As plants accumulate service time, such data will probably become available.

This research has identified environmental conditions that are the most significant aging factors for snubbers. Development of service-life monitoring programs that ascertain realistic humidity, vibration, and temperature conditions are therefore encouraged within the industry. As plants implement service-life monitoring programs, a significant amount of additional service data will become available regarding these critical environmental influences and the associated age-related degradation of snubbers. Additional research would be required to evaluate this information.

Results of the work reported here should be transferred to industry in an active and assertive manner. A workshop/presentation developed from the in-plant research is suggested. The workshop would be presented to engineering, quality assurance (QA), and maintenance staff at the plant sites. The workshop should consist of two separate presentations, one for engineering and maintenance management staff and the other for the staff who perform the work; e.g., craft supervisors and craft workers.

7 References

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Appendix A

Plant Visit Summary Reports

Appendix A

Plant Visit Summary Reports

This Appendix includes trip reports for eight key sites (one each from site A through G) visited as part of the NPAR snubber aging study. Plants are assigned letter codes from A through H. Information pertaining to hydraulic snubbers was obtained from Plants A and B. Information pertaining to mechanical snubbers was obtained from Plants C, D, E, F, and H. Information pertaining to in situ monitoring of environmental stressors was obtained from Plant G.

INTEROFFICE MEMO

Plant A

TO: D. P. Brown DATE: August 17, 1990

FROM: S. Cole RE:

The following are notes from my visit to the plant.

1. Notified resident NRC Inspector of upcoming plant visit and meetings. Notification date: 7/31/90.

2. Arrived on site 8/8/90 and was escorted by the snubber engineer. In depth discussion took place with the snubber engineer, and the snubber maintenance foreman.

3. General Plant Information

   A. The plant consists of two mid-sized boiling water reactors. The plant began commercial operation in the mid-1970's.

   B. Each unit has over 600 Bergen-Paterson snubbers of which about 550 are safety related (most of the snubbers are the M77 model). In addition to these, the plant has approximately 350 hydraulic snubbers available as spares for both units.

   D. The plant utilizes a seal life with several separate populations based upon accelerated aging tests and modified on a regular basis by temperature for those snubbers in the drywell.

4. Plant has instituted (starting in 1986) a comprehensive maintenance program which includes the following items:

   - Filtering of snubber fluid immediately prior to use with a 5 micron filter. (Plant found it hard to keep pre-filtered fluid clean over long periods of time.)
   - Sand blasting (glass beads) to bare metal of all metalic parts.
   - Complete deconning of all metalic parts using a freon blaster.
   - Replacement (rather than repair) of most questionable parts.
   - Automatic replacement of poppet springs and piston rings.
   - Use of the same trained personnel to rebuild snubber each cycle.
   - All rebuilds take place in a "clean" room used only for snubbers.

5. Plant is retro-fitting snubber poppets to a higher bleed rate poppet. This newer poppet still allows the snubber to meet bleed rate limits as defined in the plant technical specifications while moving the actual bleed rate more toward the middle of the allowable range (the plant suffered significant number of functional failures due to low bleed rates in the past.)

6. Due to a combination of the changing of the poppets, improved maintenance and changing of the functional test procedure to allow 1/2" bleed testing as opposed to full stroke bleed testing the number of functional failures has fallen dramatically.

7. Fluid Leakage

A. Fluid leakage (as indicated by low reservoir level) during visual examinations for the last three Unit 2 outages can be summarized as follows:

Refuel Outage	Number Inspected	Total Leaking	Significant Leaks
7	581	50 (8.9%)	12 (2.1%)
8	553	49 (8.9%)	5 (0.9%)
9	553	59 (10.7%)	6 (1.1%)
OVERALL AVERAGE:		9.4%	1.4%

Note: The number of leaking snubbers is not the actual total number but rather those snubbers whose total indicated fluid has fallen below a given amount (5 3/4) since the last outage. Significant leaks are those who's total indicated fluid has fallen below 3 1/4.

B. Those snubbers with significant leakage were disassembled and inspected giving the following results.

Refuel Outage	Number Significant Leaks	Aging Related	Non-Aging Related
7	12	2 (16.6%)	10 (83.3%)
8	5	2 (40.0%)	3 (60.0%)
TOTAL	17	4 (23.5%)	13 (76.1%)

Note: Failure data was unavailable for those snubbers with significant leakage from refuel outage number 9.

C. A third category of leaking snubbers are those snubbers which show visual signs of leakage but still have an acceptable reservoir fluid level. These snubbers can be considered to either have a very slow leakage rate or only started to leak just prior to their inspection.

Refuel Outage	Total Leaks	Visual Leaks	Indicated Leaks
8	66	17 (25.7%)	49 (74.2%)
9	87	22 (25.3%)	65 (74.7%)
OVERALL AVERAGE:		25.4%	74.5%

Note: This data is not available from refuel outage no. 7.

8. Critical Snubber Parts

Snubber parts must frequently be replaced during rebuild (excluding those parts automatically replaced) include: piston, cylinder tubes and piston rods.

A. Pistons and Cylinder Tubes

These parts are most frequently replaced due to scoring of the piston and inner cylinder tube surface. This condition appears to be caused by vibration, with side loading being a significant degradation accelerator. This condition is considered to be aging related.

B. Piston Rods

Piston rod degradation most often consists of dings and scratches. These dings and scratches are most often caused by human error. (Metal to metal contact with the piston rod). This condition is not aging related.

9. Snubber Fluid Degradation

A. The plant has a significant number of snubbers, which when disassembled, yield darkened fluid with globules of a black grease-like substance. This effect is typical of snubbers that have been subjected to extensive high amplitude vibration.

It should be noted that darkened fluid and particulate contamination was found in a significant percentage of the low bleed snubbers that were disassembled and inspected during RFO 7.

It should also be noted that due to changes in bleed rate testing criteria, many of these snubbers would no longer be considered functional failures.

B. Chemical Analysis

Fluid was chemically analyzed from 10 snubbers found to have darkened fluid following the most recent outage. Chemical analysis revealed that the black globules were composed of silicon rather than grease. Prior to being analyzed each sample was graded for visual clarity. Analysis revealed that those samples which were visually darker/had more black globules, and had a higher content of iron in the fluid. The iron is attributed to wear products resulting from wear of the cylinder tube and piston due to vibration.

Note: No particle counts where made from the fluid samples during analysis.

10. Snubber Trending

The plant recently set up a computer based trending system that allows sorting searching and seeking of any snubber attribute by any other. The snubber engineer used this system to search snubbers with indicated leakage vs. snubber location (i.e. drywell and balance of plant).

Area	Total Snubbers	# of Indicated Leaks	% of Indicated Leaks
Drywell	263	39	14.8%
Balance of Plant	287	27	9.4%

Thus snubbers located in the drywell showed a leakage rate 57.4% greater than those in the balance of the plant. It should be noted that temperatures in the drywell are significantly higher than anywhere else in the plant. Some correlation between plant operating temperature and seal degradation rate is, therefore, supported by this data.

11. Review of plant failure evaluations shows piston and cylinder tube scoring (possibly accelerated by side loading) to be the single largest failure cause. Scoring also leads to metalic particles in the fluid which can shorten seal life and foul the bleed poppets.

One unexpected failure cause that cropped up a significant number of times was fouling of the poppet by pieces of lint. The frequency of this failure cause has fallen off dramatically since the plant's adoption of improved maintenance procedures.

CONCLUSIONS

It is my opinion that the plant has a very effective hydraulic snubber program. The utility appears to not only strive to meet the intent of the Codes, Standards and Technical Specifications applicable to hydraulic snubbers but often to surpass them.

Areas where I believe the plant to be particularly effective in the handling of their snubber program include:

- The rebuilding of snubbers in a "clean room" atmosphere to prevent the inclusion of foreign material in the snubber.
- The use of a 5 micron filter to filter snubber fluid prior to use.
- The plant having a flexible snubber trending system up and running.
- The adjusting of snubber seal life up or down on a regular basis depending on ambient temperature.
- The use of the same personnel to perform snubber testing and rebuilding each cycle. This is facilitated by the smooth transition of personnel into and out of the snubber group coupled with a relatively low turnover rate.

Areas where I consider there may be room for improvement in the plant's snubber program include:

- The plant's reliance on area temperature monitors to track snubber environments rather than performing specific environmental surveys.

  The need to go more in depth on root caue evaluations. This is particularly important since there exists a significant number of the same types of failures whose root causes have been listed in the past as unknown.

SMC:aca:1125A

Plant B

LAKE ENGINEERING COMPANY

OFFICE MEMERANDUM

TO: D. P. Brown DATE: July 16, 1990

FROM: S. M. Cole RE:

The following are notes from my visit to the plant:

1. Notified resident NRC Inspector of upcoming plant visit and meetings. Notification date: 7/3/90.
2. Arrived on site 7/9/90 and was escorted by the snubber engineer. In depth discussions took place with the current snubber engineer and the previous snubber engineer.
3. General Plant Information
   - A. The Plant is a mid-sized boiling water reactor which began commercial operations in the mid-1970's.
   - B. Plant was originally supplied with approximately 350 hydraulic snubbers, all of which were Grinnell Figure 200's.
   - C. Due to agressive and on-going snubber reduction programs, the plant now has 120 hydraulic snubbers (all Grinnell Figure 200). Of these, 64 are safety related. All hydraulic snubbers are accessible.
   - D. In 1990, the plant began 18-month refuel cycles; prior to 1990, the plant was on 12-month cycles.
   - E. Seal life is based upon an accelerated aging study that correlates service time with operating temperature.
4. Snubber failures and rebuilds by outage:

Year	Failures	Rebuilds
1986	7(1)	84
1987	0	12
1988	2	27
1989	0	10
1990	0	app. 40(2)

Note: (1) Current plant theory is that these failures were caused by incorrect test procedures (i.e. too high ramp rate, etc.) rather than actual snubber failures.

(2) The reason for the high number of rebuilds in 1990 was to prevent expiration of shelf life on seal kits in the warehouse.

5. The plant has conducted specific area temperature surveys for all hydraulic snubbers with the exception of those located near the ceiling of the Heater Bay. This area may be the harshest environment in the plant consisting of temperatures exceeding 150°F and a possibly significant amount of vibration.

   A. The highest specific temperature surveyed was 125°F.

   B. Looking into resurveying snubber environments in more detail (possibly including vibration measurements) because of changing environments due to construction (outages).

6. A group of 15 snubbers in the Heater Bay regularly are found to have darkened fluid. The darkened fluid often has globules of a black grease-like substance dispersed throughout.

   A. These snubbers are visually inspected on a more frequent basis than required by preventative maintenance procedures.

   B. Upon evidence of fluid darkening, snubbers are rebuilt as a matter of course.

   C. No failure or root cause exams or fluid testing performed because these are all non-safety related snubbers. (Plans to fluid test these snubbers in future).

   D. Per former snubber engineer, if these snubbers are left in place after the fluid turns dark, the fluid will thicken and congeal.

7. Plant has an extremely large percentage of spare snubbers to installed snubbers. Total number of spares is about 80.

   A. Spare snubbers are rotated to ensure those spares that have the oldest rebuild dates are installed first.

   B. Usually rebuilds number of snubbers required for replacement plus about 50% for emergencies.

   C. Extra snubbers may be rebuilt when the warehouse has seal kits nearing the end of their shelf life to avoid having to dispose of the kits.

8. Root cause evaluations indicate the plant has several snubbers that regularly fail due to being stepped on (broken reservoirs and connecting tubing). These are safety related snubbers, which per tech spec, require failure and root cause evaluation. Even though being stepped on is a non-service related root cause, due to the frequency of this problem the plant is considering treating these snubbers as if they were in a severe environment.

9. Failure evaluations are only performed if they have an operability related failure of a tech spec (safety related) snubber.

   A. Root cause evaluations are done automatically as part of failure evaluations.

   B. Recent revisions to plant procedures require the taking of photos during failure evaluations to aid in the documentation of failure causes and modes.

10. In the opinions of both snubber engineers, the plant experiences few to no age related snubber failures unless the snubbers are located in harsh environments.

11. For the past three years (3 cycles), the plant has performed all hydraulic snubber testing in-house (both ISI and functional).

    A. The plant also rebuilds hydraulic snubbers in-house.

    B. In process of buying Bergen-Paterson MK IV test machine (have been leasing this model) with upgraded computer and printer.

    C. It is their belief that doing rebuilds and testing in-house allows them tighter control of the snubber life cycle.

12. The plant currently uses two mainframe computer programs (utility owned and specific) to track snubbers.

    A. The programs are reasonably comprehensive and include tracking of the following fields: serial number, model, make, CIC (mark number), last test date, installed date, maintenance history, class and comments.

    B. The single biggest problem with this system is that it takes approximately six months to update following an outage.

    C. Currently setting up a new system to allow better trending of snubber characteristics than current systems allow.

       - New system will allow search, sort and seek of any field by any other fields.

       - New system should be operational in about six months.

13. The plant has found the most critical (prone to failure) parts of Grinnell snubbers to be thread seals and tubing connections. A significant percentage of leaking snubbers has been traced to thread seals. In the past, tubing connections were a significant source of leakage in the snubbers. The plant replaced these connections with Swagelock fittings to minimize this source of leakage.

14. Specific concerns of plant personnel:

    A. Hot and cold setting of snubbers need to be reverified on a semi-regular basis due to changing plant conditions.

    B. Drawings must always be kept updated.

    C. Some plants were built to one spec and then changed to another farther into their life (i.e. Section III vs. B 31.7). This makes it difficult to rotate snubbers.

    D. Side-loading resulting from the use of long extension pieces may accelerate snubber degradation caused by vibration.

CONCLUSIONS

It is my opinion that the plant has an effective snubber program. There is evidence that the utility is dedicated to not only meeting the intent of the Codes, Standards and Technical Specifications applicable to hydraulic snubbers, but to surpassing them when possible.

Areas where I believe the plant to be particularly effective in the handling of their snubber program include:

- The use of the same personnel to perform rebuilds and visual inspections each outage. This is facilitated by the smooth transition of in-going and out-going snubber personnel coupled with a relatively low turnover rate.
- The performing of an environmental survey to define snubber environments.
- Augmented inspection of snubbers in harsh environments.
- Photographic documentation during failure evaluations.
- Utility leasing/buying their own state of the art snubber test machine.
- Good snubber tracking system up and running.
- Currently setting up a system to allow the trending of snubbers.

Areas where I consider there may be room for improvement in the plant's snubber program include:

- Performing more frequent and more in depth failure evaluations.
- Finding and correcting the root cause of failing non-safety related snubbers.
- Performing specific environmental surveys for all snubbers.
- Minimizing the time needed to update the computerized snubber database following outages.

SMC:aca:1110A

Notes from investigation and information reviewed during the visit and subsequent discussion with Plant Personnel which includes; (Tech Staff), (Tech Staff) and (Tech Staff) and myself.

1. (NRC Sr. Resident Inspector) was notified of the impending visit to the plant and subsequent meetings. - Ext. 2490, called in on 7/3/90 at 10:30 AM.

2. Arrived at the plant on July 5, 1990, AM and was escorted by with whom I met with for the rest of the day.

General Plant Information:

a. There are 2 BWR Units of M.W. sizes - Unit 1 went into operation in and Unit 2 went into operation in . Both units have been through refueling outages with #2 unit just completed this past spring.

b. The units were constructed with P.S.A snubbers ranging from PSA 1/4 through PSA-100. The total population for the two units at start was 2384 which was divided as 1244 each for Unit 2 and 1140 each for Unit 1. Of this population a total of 2265 snubbers were tested by the end of the first refueling outage for both units, with the remaining snubbers being deleted and 3 being exempted from ISI.

c. The testing of all snubbers was precipitated by the high percentage failure rate encountered during 1st R.O. for Unit #1 which began and continued through . During this first outage 104 snubbers had failed in Unit 1 and 53 snubbers would fail in the first Unit 2 refueling course which started on Jan. and continued through April . During the second R.O. for both units, a massive snubber reduction program had brought down the total population from 2384 to a total of 487 snubbers. This process was completed with full calculation review and necessary design changes.

d. During units 2 refueling outage all snubbers in service were again tested and a total of 8 snubbers for unit 1 and 18 for Unit 2 failed the functional test.

e. Failures are categorized by 1) Installation and Handling Deficiencies, - 2) Environmental Failure, - 3) Failure due to transient or vibration load, - 4) Manufacturing defects - Snubbers failed in categories 2 & 4 were relatively few in number, representing less than 1% of the total population by group sizing (1/4 & 1/2) small and (1 through 100) large. Failure attributed to Category # 3, which indicated transient or vibration or both, were given greatest attention as these were the ones most likely to fail again. Aside from the system operating low level vibration (amplitude and frequency), some systems had special problems requiring engineering review, such systems were:

1) High Pressure Core Spray (   ) venting relocation (Failure #5)

2) Low Pressure Core Spray (   ) High Point Venting (11, 12, 50, 59)

3) Residual Heat Removal (   ) suction lines from vessel to RHR Pump (71.79).

4) Residual Heat Removal (RHR) discharge lines outside primary containment. (Failure 58,60,61, 66, 74, 82 for A Loop), (Failure 62, 63, 64, 72 for B Loop).

All the above systems required engineering evaluation and or plant modification in order to eliminate transient load and low level vibration causing snubber failure.

f. Other snubbers failed in various system where small drain and vent lines were connected to large lines and forces induced from the large piping, although not having detrimental effect on the larger snubbers directly connected to the main system, they were effecting the smaller supports by induced vibration and transients. The system was modified to avoid future failure.

3) A 100% testing of the 238 snubbers left in service in Unit 1 second R.O. and a total of 8 snubbers failed to meet functional test limits. A tear-down and inspection was conducted to determine the cause of failure which were categorized as follows:

a. 6 each due to installation and handling deficiencies, 2 each manufacturing defects.

It is evident that the snubber reduction program through elimination and modification was proved very effective considering the failure of the 8 units during the second R.O. were attributed to causes other than fatigue related.

4) During the third R.O. the eight snubbers which had failed in the previous outage were retested, in addition a 10% test sample was implemented with the snubbers divided into two groups:

1) Small, consisting of PSA 1/4 and PSA 1/2 (3 tested),
2) Larger, consisting of PSA-1 through PSA-100 (22 tested) - There were two failures in this surveillance, one was from the retest group and one PSA 1/4 from the sample plan.

Therefore, 3 additional snubbers were tested without failure. There was no failure in the large group.

It is evident that failure rates have decreased drastically by addressing system loads, transients, environment, location and other factors contributing to past failures as experienced during 1 R.O. -

The classification of primary causes of failure and consequent evaluation is an effective method of separating snubber units which would have a repeatable failure as it is caused by environment and/or load, - Other failures attributed to handling or installation deficiencies, manufacturing defects, are considered random failure and are addressed separately. Safety analysis and necessary corrective actions were performed for each individual failure and at a system level.

5) The same events were noted and addressed for Unit 2 with comparable results. The number of failures are somewhat different, however the investigation and corrective actions were conducted with the same diligence and thoroughness.

The failures occurred as follows:

1 R.O. - 53 total failures with 19 each in Category 1 6 each in Category 2, 23 each in category 3 and 5 each in category 4.

2 R.O. - 18 total failures with 16 each in category 1 and 2 each in category 4.

3 R.O. - No failure recorded

6) An overall view of failures for the
Unit 1 & 2 listed by failure cause and sizes (small & large):

1 R.O. - 157 total failures of which 74 each were small 1/4 & 1/2, 83 each were large 1 through 100.

2 R.O. - 26 total failures of which 6 a were small, 20 ea were large.

3 R.O.- 2 total failures, of which both were small snubbers (PSA-1/4)

Further grouping by failure cause as defined by plant engineering:

Category 1: Installation and Handling Deficiencies
Total failures 100 units (46 large bore, 54 small bore). These failures ranged from poor handling, storage or installation practices.

Category 2: Environmental Failures
Total failures 17 units (1 large bore, 16 small bore)
These failures appeared divided into two groups, a) small snubbers failed due to grease drying out and causing excessive drag, b) units corroded internally due to being sprayed or dripped upon by water while in service.

Category 3: System Transient and/or vibration loads
Total failures 49 units (40 large bores, 9 small bores) These failures are attributed primary to system transient loads during service, such as pump start-stop, valve opening - closing, causing snubber internals to degrade. The failed parts are listed as a) Thrust bearing races damaged or broken, b) Capstan spring damaged, c) ball screw bent or stripped.

Category 4: Manufacturing Defects
Total Failures 19 units (14 large bore, 5 small bore) These failures are attributed to assembling or manufacturing problems existing as unit was reviewed from PSA - The most common being improper installation of capstan spring (to loose or to tight) and excessive grease. - Since most of these snubbers failed activation limits, these defects are not noted with hand stroke.
stated that since PSA performed a functional test on representative number for each size of snubber, it is very possible to install a defective unit as new snubbers are not functionally tested before installation.

There was also a very informative meeting between myself and and of the plant technical staff who have been involved with the snubber program for an extended period. - The following is a summary of their personal views and concerns based on passed experience.

It is commonly agreed that continuous and/or periodic low level (amplitude and frequency) vibration has the most damaging effect on mechanical snubbers. This vibration may be induced by components change of state, like valves opening and closing, pumps starting and stopping, or it may be inherent to system design, as process flow. personnel have aggressively attacked the problems concerning support system in eliminating or minimizing failures by evaluating and resolving root cause. For example replacing snubbers with rigid support by verifying calculation, modifying systems in order to eliminate transients, revising systems ISI procedures, moving snubber supports to more effective and less damaging location. Also considering the replacement of some mechanical snubbers with lisega hydraulic as no other options were available. Heat shields are used in localized high temperature and additional chiller installed to lower ambient temperature in the upper part of the containment dome, changing procedure for venting system during test and the training of personnel in the handling of snubbers.

8) Standard Procedure is employed in snubber inspection which include visual, hand stroking, performance testing and failure evaluation. If a snubber fails, it is disassembled, inspected, identify failed part or parts and determine root cause. A report is written with the above findings which also includes system, location and conditions that may effect snubber performance. Where performance test results are marginal, good work practice is employed. Spikes of high amplitude, however of short duration may be considered acceptable. Grease has been the cause of high drag where the temperature is above 140°F. It has been noted that where the temperature for a component reached 400°F and sustained for 36 hours, the adjacent snubber failed because of grease failure. A snubber also had a marginal performance test after being subjected to 300°F for 48 hours.

Where temperature and vibration are suspected for the failures thermocouples and accelerometers are utilized in evaluating working conditions and environment.

Conclusion:

It is of my opinion that the personnel at have a very effective ongoing surveillance and testing snubber program. This is evident in the tremendous reduction in snubber failure since the first R.O.. This was accomplished through investigation of component, system, environment and failure analysis. Resolution utilizing analysis by the architect engineer support calculation by the A&E and special testing by the system engineer were used to determine if system modification, snubber relocation or support redesign was warranted, which also led to a very extensive snubber reduction program. Personnel training and effective work practices were also implemented in order to eliminate or reduce failures due to handling.

Due to grease failure, I would think a qualification test may be warranted to determine lubricant requirements, classification of snubbers by system, size and environment may facilitate the possibility of necessary augmented inspection for specific application.

John Mucci
Wyle Laboratories
Huntsville, Alabama 35807
(205) 837-4411 ext. 583

Plant D

BATTELLE NPAR RESEARCH

MEETING NOTES - 5/1/90
Attachment 1

Page 1

John Mucci and David Brown met with for evaluation of existing plant data on mechanical snubbers (Objective 1B).

Unit 1 went on line in 19 . Unit 2 went on line in 19 . Breakdown of snubbers is as follows:

Unit 1:	Hydraulic	-	889 (Grinnell)
	Mechanical	-	684 (Pacific Scientific)
	TOTAL		1573
Unit 2:	Hydraulic	-	115 (Grinnell)
	Mechanical	-	1571 (Pacific Scientific)
	TOTAL:		1686

Plant has limited failure evaluation data. Just initiated failure evaluation (root cause analysis) 2 years ago.

Plant has some snubbers located on the top of the steam generators (highest temperature area) that are buried in insulation and that have consistently jammed (discovered by hand stroking).

So far, for both units, there are approximately 11 mechanical snubbers that have failed functional tests. They have had numerous others that have failed hand stroking (conducted for all snubbers on high energy lines). Plant has had no failed hydraulics.

Current drag acceptance limits are 2% (administrative) and 3% (failure limit). For acceleration the limit is 0.025g.

Plant has no PSA 1/4's (those that they did have, have been replaced with PSA 1/2's).

to provide a breakdown of the snubber population by size.

is the snubber guy at (E) He should be contacted in regard to a previous high failure rate that they encountered on PSA 1/2's.

Reviewed some of their failure analysis sheets. Plant has a tendency to attribute failures to snubber overload. This may be reasonably valid since failures were discovered by hand stroking on high energy lines (i.e. lines known to have transients).

They have recently implemented a plan whereby any snubbers that are removed as a part of their snubber reduction program are functionally tested to obtain a test bench mark. They also hand stroke any remaining snubbers on that system. Any snubbers that are used to replace snubbers that failed the hand stroke, are also functionally tested to obtain a bench mark. Replacement snubbers would also get tested again during the next outage. This data is used for trending.

BATTELLE NPAR RESEARCH

MEETING NOTES - 5/1/90
Attachment 1

Currently, their service life monitoring program just involves hand stroking, but will eventually involve bench testing. Service life monitoring is currently limited only to those systems to which they previously had problems. They will phase in systems that they anticipate they may have problems on.

During their last outage, they hand stroked all snubbers on high energy lines (i.e. those lines known to have transients).

Their Technical Specifications allow them to exclude hand stroked failures from having to be considered as ISI failures. However, they haven't had any that have coincided with their functional test sample. Had they, they would have considered them to be ISI failures even though they are not obligated to do this.

The following action items for the Battelle evaluation were established:

- For evaluation of drag force trends:
    - Evaluate data for sizes 1/2 and 1
    - Measure drag force for various amounts of service time (exclude data from test plots indicating abnormal results such as uneven load patters).
    - Record serial no., size, unit no., tens, drag, comp. drag, service time (RFO no.), and location (to provide environmental information).
- Get functional test printouts for all functional test failures for which a failure evaluation was conducted (both units).
- Try to obtain functional test printouts (from previous tests) for snubbers that failed the hand stroke evaluation.
- Get a copy of failure evaluation format.

Plant E

TRIP REPORT

John Mucci 8/23/90

Notes from Investigation and Information reviewed during the visit and subsequent discussion with of the Engineering Staff assigned to support systems.

·General Plant Information:

a. There are two units of 1150 M.W. sizes - Unit #1 went into operation in and has been through refueling outages. Unit #2 went into operation in , and is now going through its third refueling outage.

b. The units were constructed with mostly PSA ranging from 1/4 KIP to 100 KIP. The total population for the two units are 1720 all mechanical with hydraulic (8 each) LESEGA used on the steam generator for Unit #1, and a total of 1100 mechanical with (8 each) hydraulic LESEGA for Unit #2. There has been a removal or replacement of 120 snubbers in Unit #1 through a snubber reduction program. During the first 3 RO a total of over 1000 snubbers had been tested through ISI for Unit #1 with a total of 85 failures during performance test. There were also over 500 tested in Unit #2 with a total of 69 failures during the first two refueling outages.

c. Failures are categorized by:

1) Environment
2) Overloading
3) Handling or mishandling
4) Manufacturing Defects
5) Vibration
6) Unknown

As for percentage of the total failures, Cat#1 with 20%, Cat #2 with 17%, Cat #3 with 28%, Cat #4 with 22%, Cat #5 with 8% and Cat #6 with 5%. This would account for 28% as aging related, 67% as non-aging related and 5% unknown.

d. As for systems having the most failures we can identify and classify them as follows:

1) Component Cooling System ( )
2) Reactor Cooling System ( )
3) Safety Injection System ( )
4) Steam Generator Blowdown Recycle ( )

The above systems exhibited the highest snubber failures with approximately 55% of the total with the remaining 45% being distributed among more than 20 other systems which experienced snubber failures.

1) The snubber reduction program is not in full swing as result of timing and priority. They have also purchased some Teledyne Load Pins with which to monitor continuous or transient loads in separate systems with overload failures. They have also replaced some PSA with corrosion problems, with A/D because of unit construction.

2) They have a formal failure analysis program addressing each failure with respect to failure mode, failure cause and corrective action. They had a photo of a snubber destroyed by overload, and also a metallurgical analysis of identifying material stress which is included in the data collected.

3) Failures have occurred on all systems, however, the steam generator blowdown system has had a higher number of failures than any other system. Supports on primary system have less failures due to contamination or leaky components as in general leaks are less likely to develop and when they develop they are addressed with higher priority.

4) The plant has a tracking program in their computer system called ASIS, which addresses snubbers and support systems. They have divided the snubbers in three groups, Small, Medium, and Large and includes all relevant data associated with each unit. The system is not complete, as much of the necessary data has not been entered addressing past test data, failure causes, failure mechanism, ambient environment, which would be used eventually to establish service trend. It is the opinion of snubber personnel that because of basic design and lay out differences which exist between plants, a standard approach to service life monitoring would not be entirely practical as each plant would have their own peculiarity associated with system design and operation, however, some basic surveillance and monitoring standards may be decided.

5) They identified the most critical snubber parts as the screw shaft, thrust bearing as the items which exhibit load related failures.

6) It is of the opinion of the snubber personnel that the test machine should have the automatic capability to test snubbers, however, it should allow the operator to vary input parameters without complicated procedure. This would allow the evaluation of snubber performance at levels different than the preset Tech. Spec. requirements.

Plant F

TRIP REPORT -
John Mucci
Job 17131

A discussion was conducted between J. Mucci of Wyle and Snubber Engineering Central Support.

- The plant has been in operation since the early 80's however, the testing program for snubbers was initiated during the forth refueling outage (2R4) which took place in April
- Since then all the snubbers have been tested twice and many have been tested more than twice.
- This effort was concentrated on Unit #2 Mechanical Snubbers and in particular, PSA-1, which had an original population of 60 ea., however, several have been since replaced with AD-501 in cases where the inherent design was more suitable.
- has also replaced all of their PSA-1/4 and PSA-1/2 with AD-41, AD-43 and AD-71R because of a high failure rate of the original PSA caused in most part by miss-handling during inspection and testing.
- A total of 47 exam data was collected all from Unit #2 as Unit #1 only had a total population of 3 in PSA-1 Model.
- All data was reviewed and 16 exams were selected for trending based on in-service-time. Data from these exams were grouped together, separated by tension run, compression run, which included average and peak values - graphs have been created in order to identify any possible trend or trends.
- The exams used in the evaluation are from snubbers installed at different locations in the plant, inside and outside containment, at elevations from 370' to 420' with temperature ranging from 140°F to 90°F. These temperatures are not considered accurate as we were unsuccessful locating operating temperature ranges for Unit #2. A temperature study was conducted of Unit #1 in 1987 for justification for continued operation, and it is generally assumed that temperatures for Unit #2 are approximately 20°F lower at respective locations. It is noted however, that varying temperatures do not reflect major changes in service performance.

OFFICE MEMORANDUM

Plant G

TO: File
RE: Visit at for discussion of in-situ monitoring equipment

FROM: D. Brown
DATE: August 24, 1990

On 8/17/90, I visited and met with the following personnel:

- ISI
- Nuclear Engineering

We discussed vibration problems they had experienced on the mainsteam bypass piping. Vibration frequency was approximately 400 Hz. and was actually the result of radial pulsations of the pipe wall. The vibration was causing localized cracking in the vicinity of interval attachment lugs used for the snubber pipe clamp. Vibration was monitored using strain gauges; data was retrived remotely. The vibration problem was, for the most part, resolved by increasing the pipe wall thickness and by installation of two multiple orifice plates within the pipe. Vibration amplitude was reduced by a factor of 10.

One remaining strut that was located upstream of the orifice plates remained subject to high amplitude vibration. The strut was instrumented with strain gauges for monitoring load; substantial loads were documented.

LVDT's (linear variable differential transformers) generally are not acceptable for monitoring vibration. They are, however, useful for measuring thermal displacement and have been used in this respect at this plant.

Vibration can also be monitored using portable vibration monitoring instrumentation. Two devices that were discussed in this regard are:

- o Ackania hand-held vibration monitoring equipment.

  This instrument has a circular chart that provides direct readings of vibration amplitude. Frequency can be determined based on chart speed.

- o B & K hand-held accelerometer

  This instrument has the capability of providing velocity and displacement data vs. time integrating by acceleration .

Both of the above described instruments are acceptable for monitoring accessible systems, but must be hard-wired for use with remote data retrieval systems for inaccessible systems.

The plant had also experienced transients in the HPSI system where they were experiencing back flow through the check valves. Other types of transients they have experienced are caused by turbine trip, SRV venting, pump start, etc.

Force measuring pins are probably the most practical way to measure axial loads on snubbers and struts due to system transients. Such equipment was particularly useful for axial supports on the mainsteam piping system for straight runs of pipe.

In general, due to environmental considerations such as heat, wear, etc., monitoring instrumentation is not readily practical for continuous use on various systems. Load pins had to be considered as temporary modifications of supports.

They had also experienced problems with high frequency vibration (approximately 800 Hz.) on mainsteam piping with a secondary vibration at 10 Hz. The high frequency vibration appeared to be due to pulsating radial pipe expansion and contraction similar to that experienced on the mainsteam bypass system. The 10 Hz. vibration appeared to involve gross movement of the piping system as opposed to the pulsating wall; in this case, they were able to use a spring loaded LVDT to measure vibration. In their opinion, the low frequency vibration was the result of small pressure pulses within the reactor which were also monitored at 10 Hz.

In their opinion, accelerometers are not really a good choice of instrumentation for measuring piping or support response to dynamic transients. However, their experience has been positive in using these devices for measuring steady state vibration.

Snubbers installed on severely vibrating piping systems have, for the most part, been removed as part of a snubber reduction program. However, two 50 KIP snubbers remain and are continuously degraded. These snubbers are monitored and replaced frequently.

Plant personnel provided an extensive amount of back-up data including isometrics, instrumentation specifications, etc., that apply to the subject of this memo.

Plant H

Battelle
Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509) 375-3915

August 2, 1990

Dave Brown
Lake Engineering Company
P.O. Box 296
10 Austin Avenue
Greenville, RI 02828

Subject: Snubber Test Data from

Dear Dave,

Attached is the test data that we received from . Also included is a portion of the plant's Technical Specifications, snubber acceptance criteria and the validator acceptance criteria.

The test data does show a number of repeat tests for various sizes. The results shown are for a validator, not a test machine.

I have reviewed most of the data; however I haven't completed a summary for all sizes. For the repeat tests of 1, 2, and 3 year intervals, the sizes ...1/2, 3, and 10 (all PSAs), according to my analysis, show the following results:

- for the PSA size 1/2...out of a total of 18 repeat tests,

  5 indicate an increase in drag
  8 indicate an improvement or less drag
  2 indicate the same status
  3 snubbers failed

- for the PSA size 3...out of a total of 6 repeat tests,

  4 indicate an increase in drag
  2 indicate an improvement or less drag
  0 failures

- for the PSA size 10...out of a total of 25 repeat tests,

  12 indicate an increase in drag
  13 indicate an improvement or less drag
  0 failures

Twenty-five years of science 25 for DOE and the Northwest

August 2, 1990
Dave Brown
Page 2

Also included in the data are 1/4, 1, and 35 size snubbers, I haven't summarized all of these at this time. For the 1/2s, 3s, and 10s the test data is not conclusive in showing increasing drag over time, i.e., the 10s and 1/2s show improvement over time. If you have any questions give me a call.

Sincerely,

Ellwood

Ellwood V. Werry
Senior Development Engineer
Energy Sciences Department

EVW/cdr

Enclosures

cc: Mike Kimel
Scott Cole w/o enclosures
John Mucci w/o enclosures
Don Blahnik w/o enclosures

Appendix B

In Situ Monitoring Methods and Equipment for Snubbers

Appendix B

In Situ Monitoring Methods and Equipment for Snubbers

This section includes a discussion and examples of in situ monitoring methods and equipment for snubbers.

Methods and equipment are available to monitor snubbers periodically or continuously for service stressors and degradation. Snubbers can be monitored either individually or collectively on a system basis. In situ monitoring is commonly used to confirm design loads and to help analyze problem snubbers located in severe environments. Stressors commonly monitored are load, vibration, and temperature. Snubber stroke position can also be monitored to verify thermal movements; displacement transducers are often used for this purpose.

Load Monitoring

Snubber loads can be monitored when the calculated design loads are to be verified or when piping and equipment adjustments need to be made. Loads can also be monitored on specific snubbers where overloading or excessive drag force is suspected. Snubbers placed in locations subject to water and steam hammer or flow stratification can be monitored for excessive loading.

Loads are commonly measured using shear pin transducers that replace the snubber clevis pins (Figure B.1) during the monitoring procedure. The shear pin transducer uses a strain gage element that is sensitive to shear loads (Figure B.2). Bi-axial shear pin transducers are available where two components of the load need to be measured. The measurements can be read on a real time or recorded basis.

Temperature Monitoring

Snubbers subject to a potentially high temperature environment can be evaluated by monitoring the snubber's local temperature. The monitoring data can identify applications that require augmented surveillance or environmental modifications. The data can also help improve service-life predictions in such applications.

Temperatures can be accurately monitored, even in difficult access areas, using portable, non-contact infrared temperature measurement tools on a spot or continuous basis. Where practical, thermocouples and RTDs can be used to provide continuous data on the snubber at the heat source. Thermometers are used for measuring temperatures where access is possible. Temperature-sensing tape can be used to register peak temperatures on the snubber during operations. A shortcoming of the latter two alternatives, however, is that a continuous record is not provided.

Vibration Monitoring

Where vibration is suspected, snubbers can be monitored using state-of-the-art vibration monitoring equipment. Characterization of these conditions can help mitigate vibration effects through corrective action, such as system modification.

Various remote and local vibration monitoring equipment is available. Hand-held instruments are easier to use, but are limited to use only in those locations that are accessible during plant operation. Remote monitoring of vibration is another alternative; this approach generally involves instrumenting the pipe or snubber with accelerometers. Typical acceleration monitoring instrumentation is shown in Figure B.3. Acceleration location isometrics are shown in Figure B.4. Frequency and amplitude are the most important parameters for characterizing vibration.

Note: Displacement transducers are generally not practical for use in monitoring snubber vibration due to their lack of adequate response.

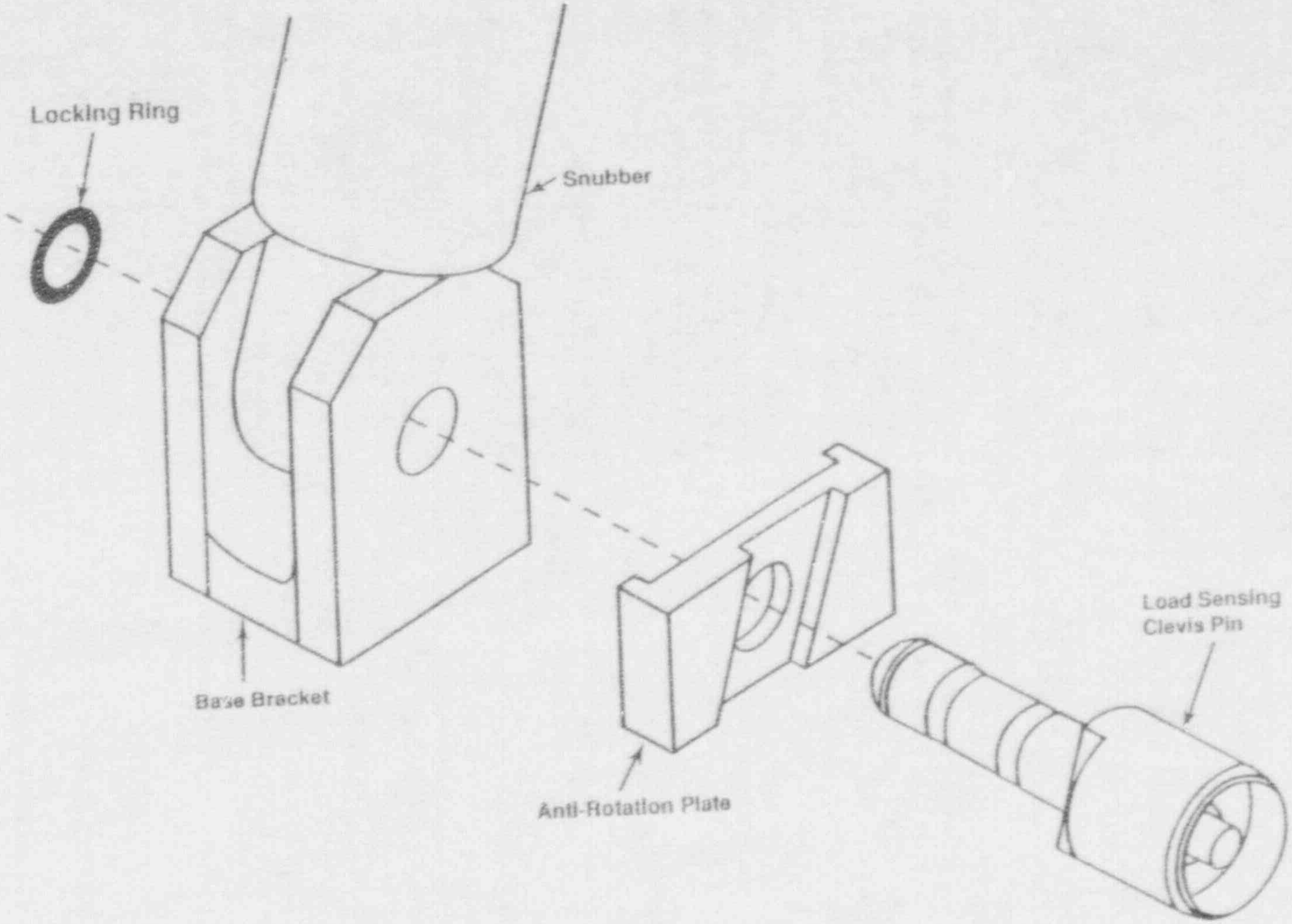
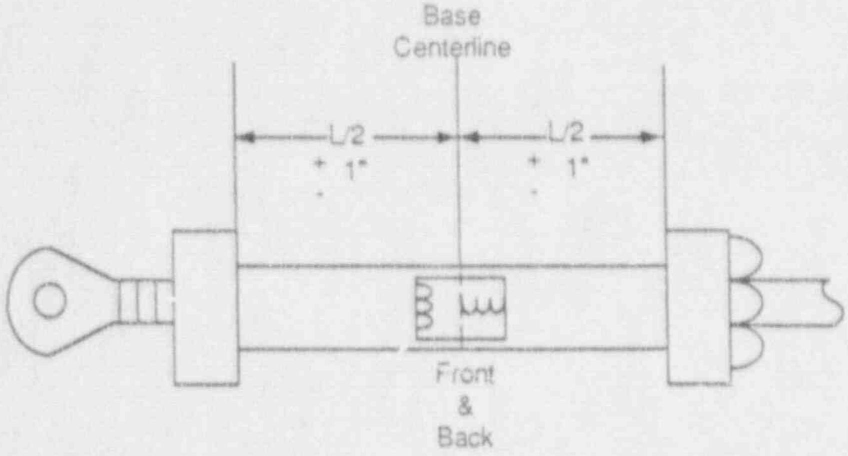
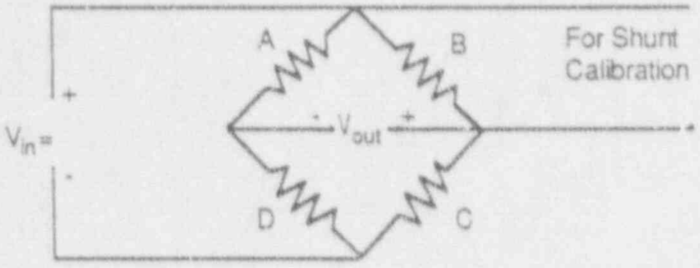


Figure B.1 Load sensing clevis pin



Place Two (2) - 2 Element 90° Tee Rosettes at
Mid Span of Strut 180° Apart.



A - Front Axial
B - Front Poisson
C - Back Axial
D - Back Poisson

Strain Gage Bridge Connection

R9106142.1

Figure B.2 Stain gage element for load monitoring of snubbers

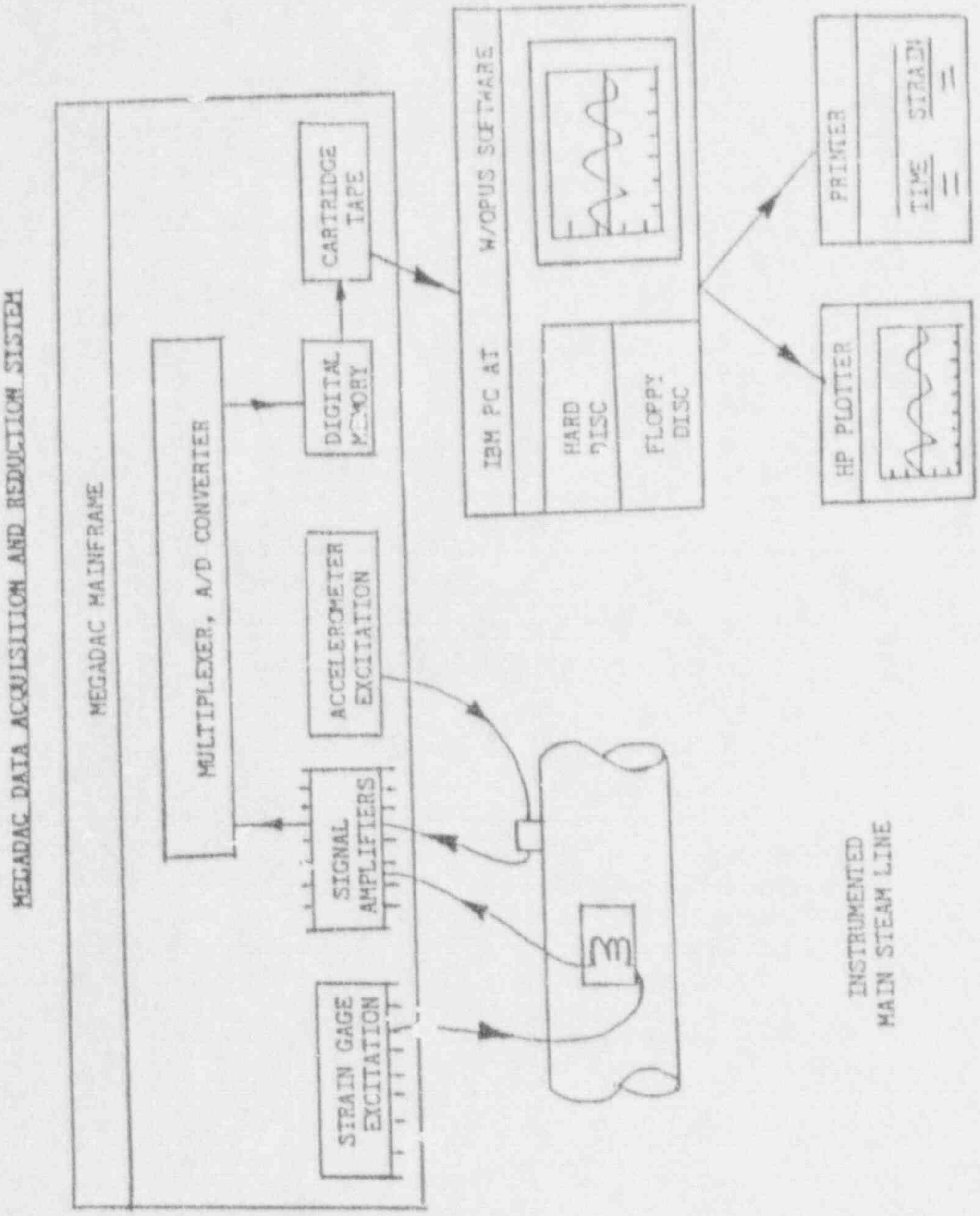
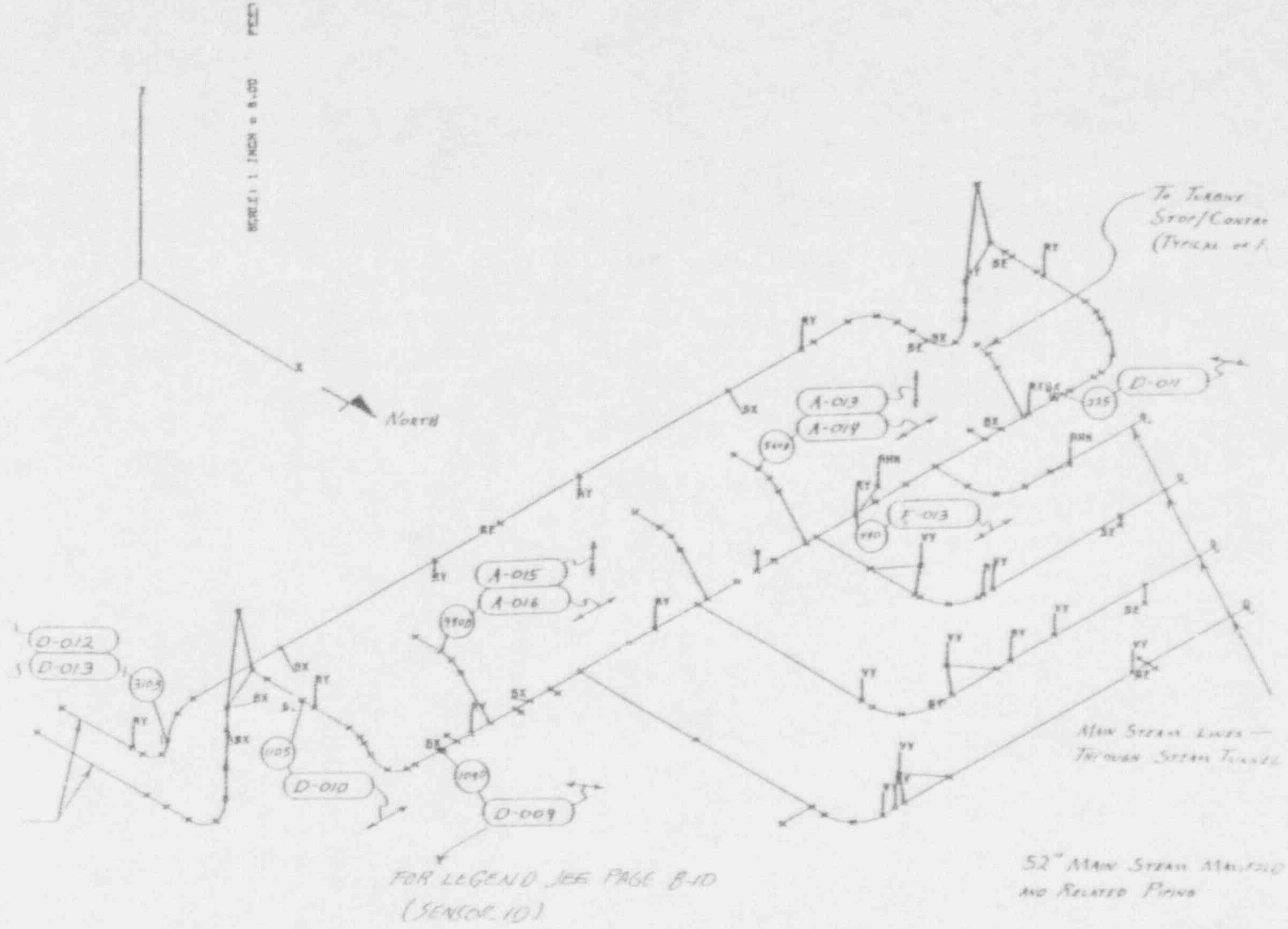


Figure B.3 Acceleration monitoring instrumentation scheme



FOR LEGEND SEE PAGE B-10 (SENSOR ID)

Figure B.4 Typical acceleration location isometric

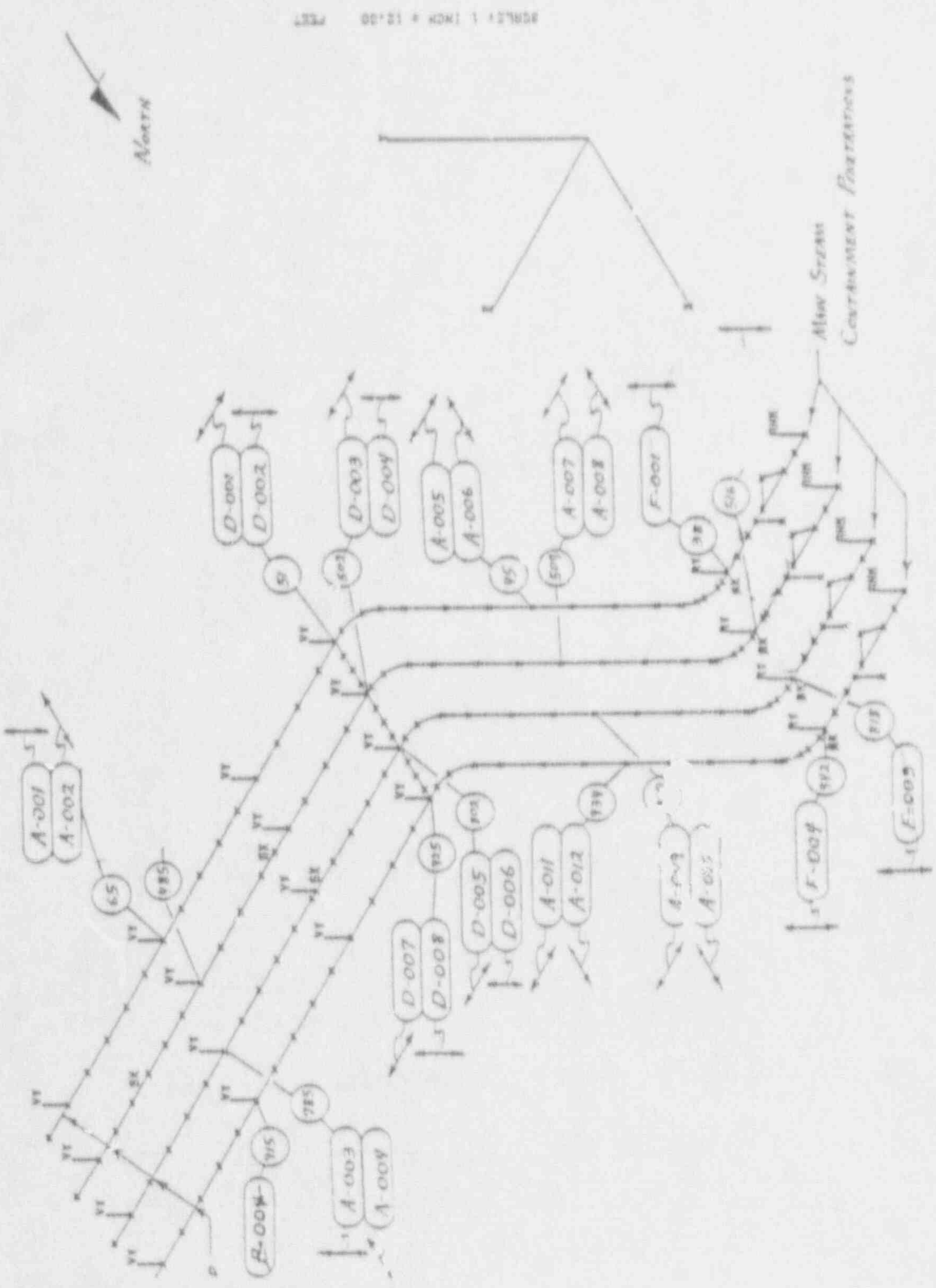


Figure B.4 (Continued)

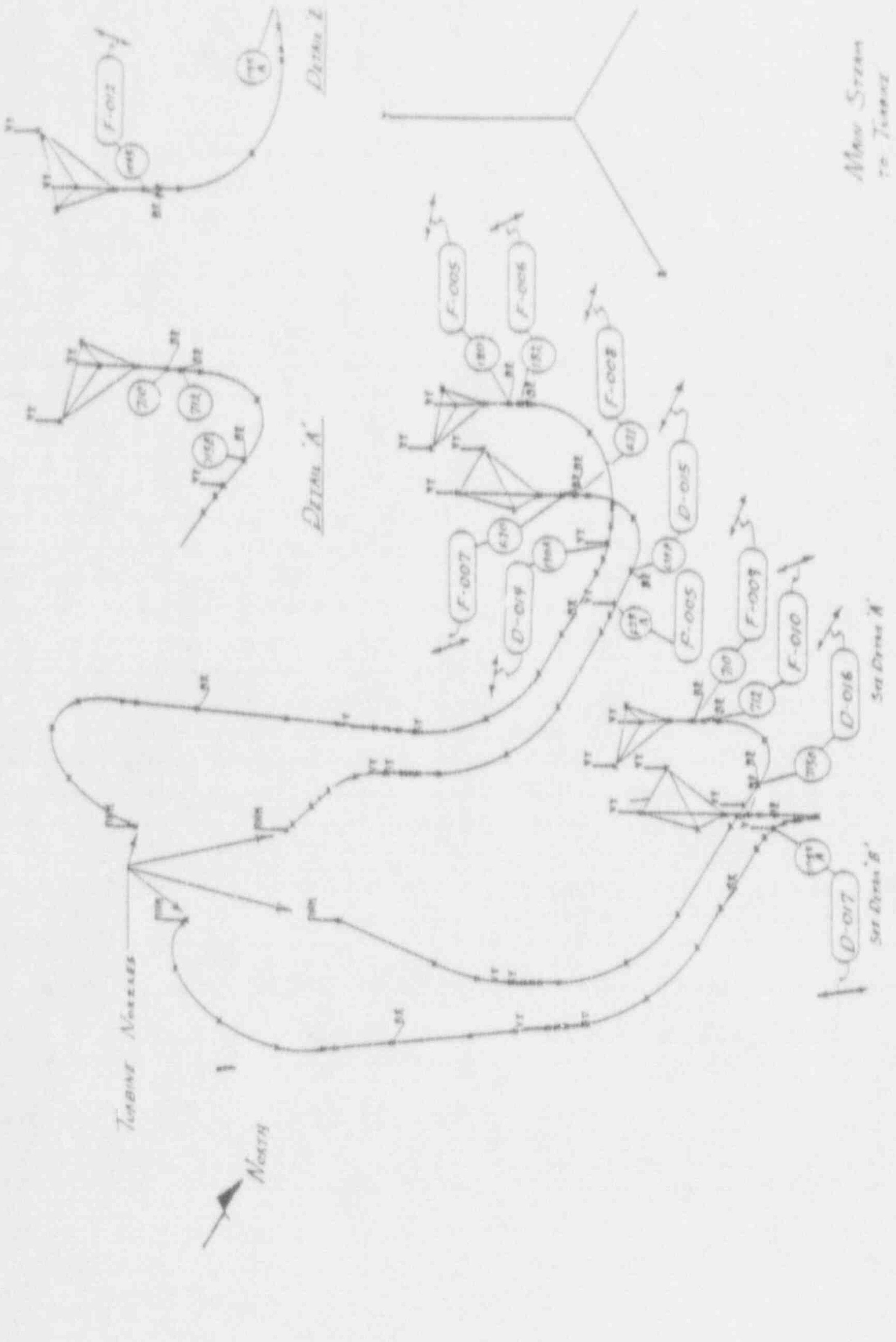


Figure B.4 (Continued)

TRANSIENT VIBRATION DATA

Test Mode: Turbine Stop Valve Trip
System Main Steam

SENSOR ID*	LEVEL 1 ALLOWABLE (Mils, lbs, or psi)	LEVEL 2 EXPECTED (Mils, lbs, psi)	MAXIMUM ZERO - PEAK READING** (Mils, lbs, psi)	WITHIN LEVEL 1 ALLOWABLE (Yes/No)	WITHIN LEVEL 2 EXPECTED (Yes/No)
A-009	NA	NA	47.2	NA	NA
A-010	NA	NA	41.6	NA	NA
A-011	NA	NA	47.7	NA	NA
A-012	NA	NA	33.7	NA	NA
A-013	NA	NA	218	NA	NA
A-014	NA	NA	267	NA	NA
A-015	NA	NA	261	NA	NA
A-016	NA	NA	210	NA	NA
F-001A	15300	13900	6462	YES	YES
F-002	33200	30100	16946		
F-003	36400	33100	17424		
F-004A	38900	35300	14228		
F-007	17400	15800	7011		
F-008	38000	34500	7418		
F-009	19800	18000	6607		
F-010	37100	33700	7512		
F-012	81400	74000	2777		
F-013	57300	52100	24055		
P-005	NA	NA	686	NA	NA

NOTES: *A - Accelerometer, Vibration in mils zero-peak
F - Force, Static Force in lbs
P - Pressure, Static Pressure in psi

**Maximum positive or negative deviation from initial, baseline value.

NA - Not Applicable - Measurements for information only.

TRANSIENT VIBRATION DATA

Test Mode: Turbine Stop Valve Trip
System Main Steam

SENSOR ID*	LEVEL 1 ALLOWABLE (Mils)	LEVEL 2 EXPECTED (Mils)	MAXIMUM ZERO - PEAK READING** (Mils)	WITHIN LEVEL 1 ALLOWABLE (Yes/No)	WITHIN LEVEL 2 EXPECTED (Yes/No)
D-001	NA	NA	31	NA	NA
D-002	NA	NA	24	NA	NA
D-003	NA	NA	66	NA	NA
D-004	NA	NA	FAILED	NA	NA
D-005	NA	NA	121	NA	NA
D-006	NA	NA	24	NA	NA
D-007	NA	NA	43	NA	NA
D-008	NA	NA	30	NA	NA
D-009	NA	NA	32	NA	NA
D-010	NA	NA	56	NA	NA
D-011	NA	NA	79	NA	NA
D-012	NA	NA	155	NA	NA
D-013	NA	NA	164	NA	NA
D-014	402	366	163	YES	YES
D-015	NA	NA	113	NA	NA
D-016	NA	NA	79	NA	NA
D-017	404	367	81	YES	YES
A-001	NA	NA	6.4	NA	NA
A-002	NA	NA	6.8	NA	NA
A-003	NA	NA	12.8	NA	NA
A-004	NA	NA	8.5	NA	NA
A-005	NA	NA	35.3	NA	NA
A-006	NA	NA	12.1	NA	NA
A-007	NA	NA	25.7	NA	NA
A-008	NA	NA	46.3	NA	NA

NOTES: *A - Accelerometer, Vibration in mils zero-peak
D - Displacement, Vibration in mils zero-peak
**Maximum positive or negative deviation from initial, baseline value.
NA - Not Applicable - Measurements for information only.

Other Monitoring Methods and Equipment

Other methods and equipment are available for evaluating specific snubber characteristics that may relate to service degradation.

- Fluid particle analysis equipment can be used to identify and to establish the density and size of solid particles in the hydraulic fluid. Such equipment is particularly useful for evaluating potential degradation in snubbers that are left in place for extended periods, e.g., snubbers that are not removed for refurbishment or functional testing. Particle contamination can result from internal corrosion products or from wear due to vibration.
- A boroscope is a useful device for internal visual examination of snubbers. This apparatus can be used to detect evidence of wear or other internal damage resulting from service.
- Spectrographic analysis equipment is often used to identify the source of contaminants in snubbers.
- Aerometers are used to determine the level of entrained and dissolved air in the hydraulic fluid.
- Various types of equipment are also available for determining the moisture content of hydraulic fluid.
- Acoustic emissions technology offers some potential for in situ monitoring (e.g., vibration) of snubbers. This method should be evaluated further.

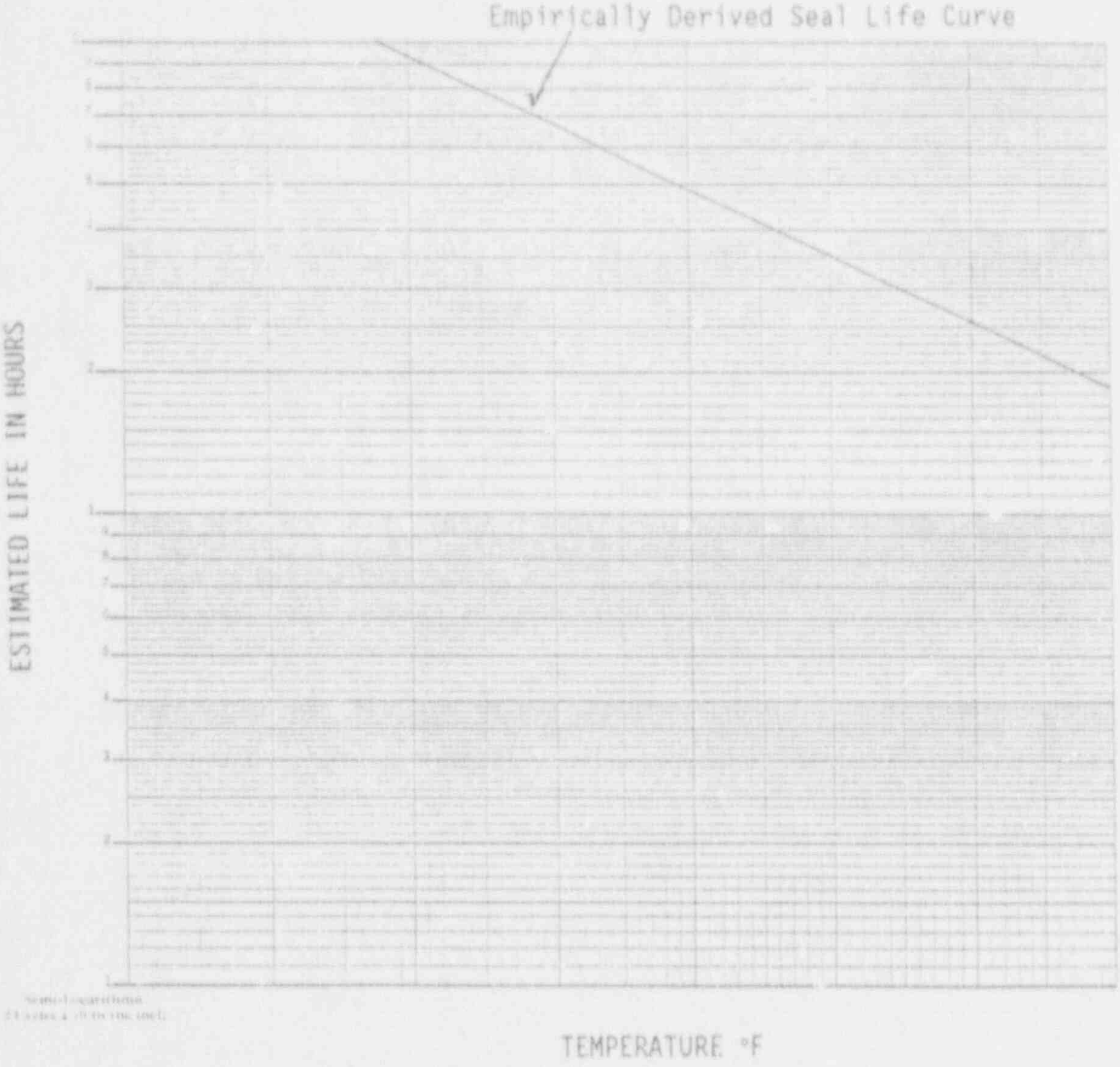
Appendix C

Typical Arrhenius Seal Life Extrapolation (Plant A)

Appendix C

Typical Arrhenius Seal Life Extrapolation (Plant A)

This Appendix generically illustrates an empirically derived seal life curve reflecting an Arrhenius type relationship between seal life and temperature. A mathematical representation in this regard is also included.



$$\ln(L) = mT^n + b$$

L = life
m = constant
T = Temperature
n = constant
b = constant

Appendix D

Effects of Compression Set on Low Pressure Seal Performance

Appendix D

Effects of Compression Set on Low Pressure Seal Performance

This Appendix contains procedures and results for evaluation of seals removed from nonleaking snubbers that were anticipated to have high compression set. The goal of this evaluation was to obtain data that could be used to substantiate compression set limits, based upon low pressure performance, for various configurations of elastomeric seals. Inspection data sheets are included to show snubber conditions and as-found seal dimensions. Due to the limited amount of data in this regard, optimum compression set limits could not be totally confirmed.

PRELIMINARY SEAL EVALUATION SUMMARY

COMPRESSION SET LIMITS STUDY

Preliminary evaluations were performed on six snubbers with no visible signs of leakage. For the preliminary evaluation, easily accessible face seals were chosen. These are located between the valve body and reservoir on Bergen-Paterson snubbers and between valve body and cylinder cap on Grinnell model PH-74 snubbers.

To justify a secondary evaluation, a minimum compression set level of 45% was established. Only two of the six preliminary evaluations yielded a high enough level of compression set to justify secondary evaluations. The results of the preliminary evaluations were as follows:

Sample Number	Snubber Type	Plant Type	Comments
1	Bergen-Paterson	Fossil	This snubber had been in service for a relatively short time period, reportedly in a severe environment. Evaluation did not, however, result in compression set levels high enough to justify continued evaluation.
2	Grinnell PH-74	Fossil	This snubber had been in service for approximately 15 years. This snubber had been shipped with no fluid and was removed from further consideration.
3	Grinnell PH-74	Fossil	This snubber had been in service for approximately 15 years under high temperature (a) conditions. Visual inspection revealed no signs of leakage. Compression set evaluation resulted in levels that were high enough to justify a secondary evaluation.
4	Bergen-Paterson	Fossil	This snubber had a long service life in a relatively moderate environment. Visual inspection revealed no signs of leakage. Preliminary evaluation did not justify a secondary evaluation.
5	Bergen-Paterson	Nuclear	This snubber had a short service life in a high temperature (a) environment. Visual inspection revealed no signs of leakage. Preliminary evaluation did not justify a secondary evaluation.
6	Bergen-Paterson	Nuclear	Moderate service life (6 years) in a high temperature (a). No leakage. Secondary evaluation conducted.

(a) Greater than 150°F.

SECONDARY COMPRESSION SET EVALUATION

1.0 BACKGROUND

This procedure delineates the methods used to measure compression set in seals removed from snubbers selected for compression set evaluation for the NPAR Snubber Aging Study.

2.0 EVALUATION PARAMETERS

Note: Values for the below described parameters are included in Table 3 for Grinnell snubbers and Table 4 for Bergen-Paterson snubbers. Where more than one measurement was obtained for given seal or gland, average values are listed.

2.1 Original Seal Thickness

Since original seal thicknesses (W_o) were not measured, thickness values are based upon manufacturer's information (nominal values).

2.2 Recovered Seal Thickness

Recovered seal thickness (W_1) is defined as the post-service thickness of the seal after removal from the gland.

2.3 Compressed Thickness (Simply Compressed Seals)

Compressed thickness (W_s) is the thickness of the seal when it is installed in the gland. The compressed thickness for each simply compressed seal was determined from snubber dimensional data obtained during the evaluation. Specific equations used in this regard are listed below for each seal.

Note: Dimensional variables are identified in Figures 1 through 4 and Table 1 for Grinnell snubbers and in Figures 5 through 7 and Table 2 for Bergen-Paterson snubbers.

2.0 EVALUATION PARAMETERS

2.3 Compressed Thickness (Simply Compressed Seals) (Cont'd)

2.3.1 Compressed Thickness (Bergen-Paterson Snubbers)

2.3.1.1 Item 3 - Reservoir Piston Seal

$$W_s = \frac{I - H}{2}$$

2.3.1.2 Item 4 - Valve/Reservoir Mounting Seal

$$W_s = J$$

2.3.1.3 Item 13 - Piston Rod Seal

$$W_s = \frac{S - R}{2}$$

2.3.2 Compressed Thickness (Grinnell Snubbers)

2.3.2.1 Item 1 - Piston Rod Seal

$$W_s = H$$

2.3.2.2 Item 2 - Piston Seal

$$W_s = \frac{P - Q}{2}$$

2.3.2.3 Item 11 - Valve Mounting Seal

$$W_s = F$$

2 .0 EVALUATION PARAMETERS

2.4 Compression Set

Compression set is defined as the amount of permanent deformation expressed as a percentage of the initial seal compression. Compression set (C) was calculated using the following formula:

$$C = \frac{W_o - W_1}{W_o - W_s} \times 100$$

where W_o = initial seal thickness

W_1 = recovered seal thickness after removal from the gland

W_s = gland width (or compressed thickness of the seal when installed)

2.5 Instrumentation and Test Equipment

Dimensional data was obtained using calibrated measuring devices* such as micrometers, depth gages, calipers, feeler gages, etc.

TABLE 1

LIST OF SEALS AND SEAL RELATED PARTS

FOR GRINNELL MODEL PH-74 SNUBBER WITH MILLER CYLINDER

Part Number	Part	Quantity Per Snubber
1	Miller Piston Rod Seal	1
2	Miller Piston Seal	2
3	Miller Cylinder Tube End Seal	2
4	Reservoir Tube End Seal	2
5	Valve Barrel Seal (External)	2
6	Valve Barrel Seal (Internal)	2
7	Fitting Seal	4
8	Reservoir Connecting Tube Boss Seal (PH-74 only)	2
9	Valve Body Plug Seal (PH-74 only)	1
10	Miller Fill Plug Seal (PH-74 only)	2
11	Valve Mounting Seal (PH-74 only)	2
12	Thread Seal - Valve Connecting Tube (PH-74 only)	2
13	Thread Seal - Locking Velocity Screw	2
14	Thread Seal - Bleed Rate Screw (PH-74 only)	2
18	Miller Rod Bushing	1
19	Miller Cylinder Tube	1
20	Reservoir Tube	1
21	Reservoir End Cap	2
22	Valve Barrel	2
23	Valve/Reservoir Conn. Tube (PH-74 only)	1
26	Miller Piston/Piston Rod Assembly	1
27	Valve Body	1
28	Valve Block (PH-74 only)	1
29	Miller Cylinder Head	1
30	Miller Cylinder Cap	1
31	PH-74 Tube Fitting	2

TABLE 2

LIST OF SEAL RELATED PARTS

Part Number	Part	Quantity Per Snubber
1	Reservoir Bleed-off Screw Seal	1
2	Reservoir Tube End Seal	1
3	Reservoir Piston Seal	1
4	Valve/Reservoir Mounting Seal	2
5	Connector Tube/Stop Plug Boss Seal	2
6	Port Plug Seal	(2)
7	Relief Valve Plug Internal Seal	1
8	Relief Valve Plug Boss Seal	1 (1)
9	Back-up Ring	1
10	Connector Tube Sliding Seal	1
11	Cylinder Tube End Seal	1
12	Allemite Fitting Seal	1
13	Piston Rod Seal	1
14	Reservoir Bleed-off Screw	1
15	Reservoir Tube	1
16	Reservoir Cap	1
17	Reservoir Piston	1
18	Control Valve Body	1
19	Poppet Stop Plug	1
20	Port Plug	1
21	Relief Valve Plug	4
22	Connector Tube	1
23	Cylinder Head	1
24	Piston	1
25	Piston Rod	1
26	Rod Bearing	1
27	Cylinder Cap	1
28	Cylinder Tube	1
29	Reservoir Head	1

NOTE: (1) Manifold configuration only

(2) Quantity varies depending upon snubber size and configuration

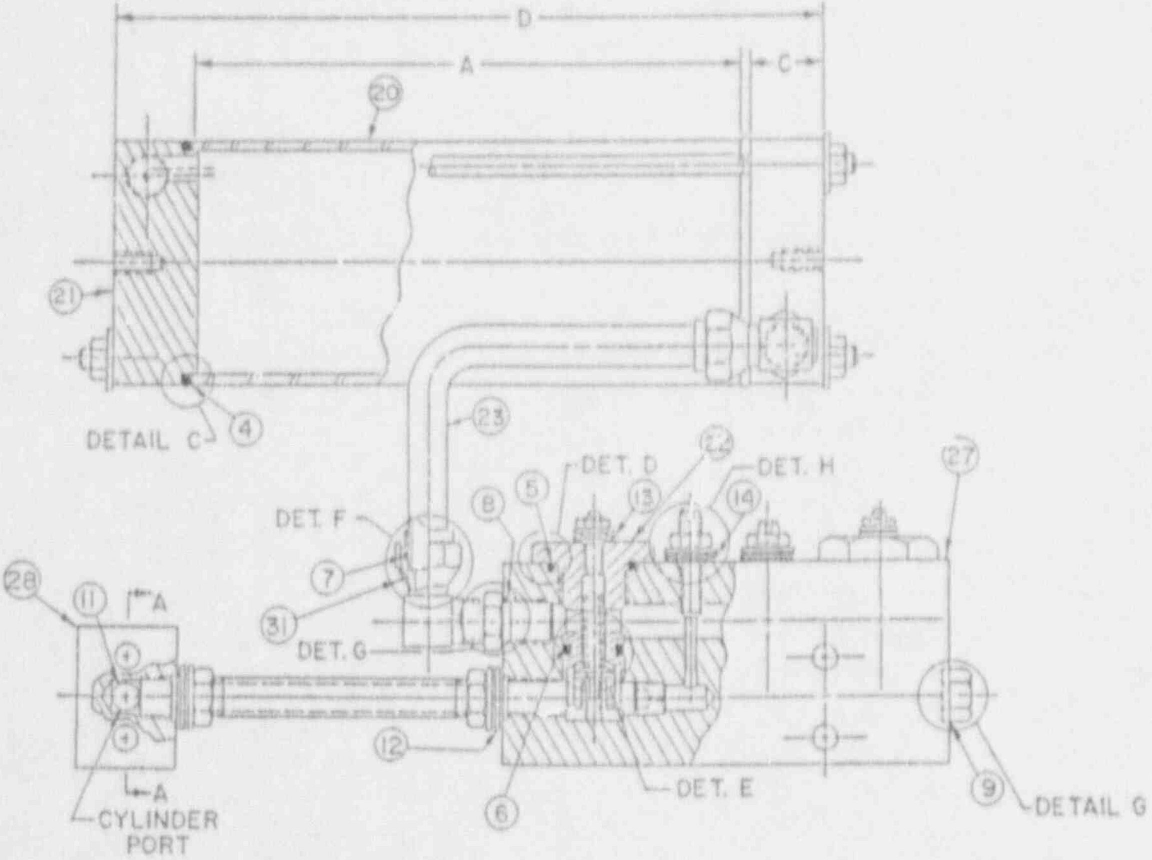


FIGURE 1
GRINNELL FH-74 VALVE AND RESERVOIR ASSEMBLY

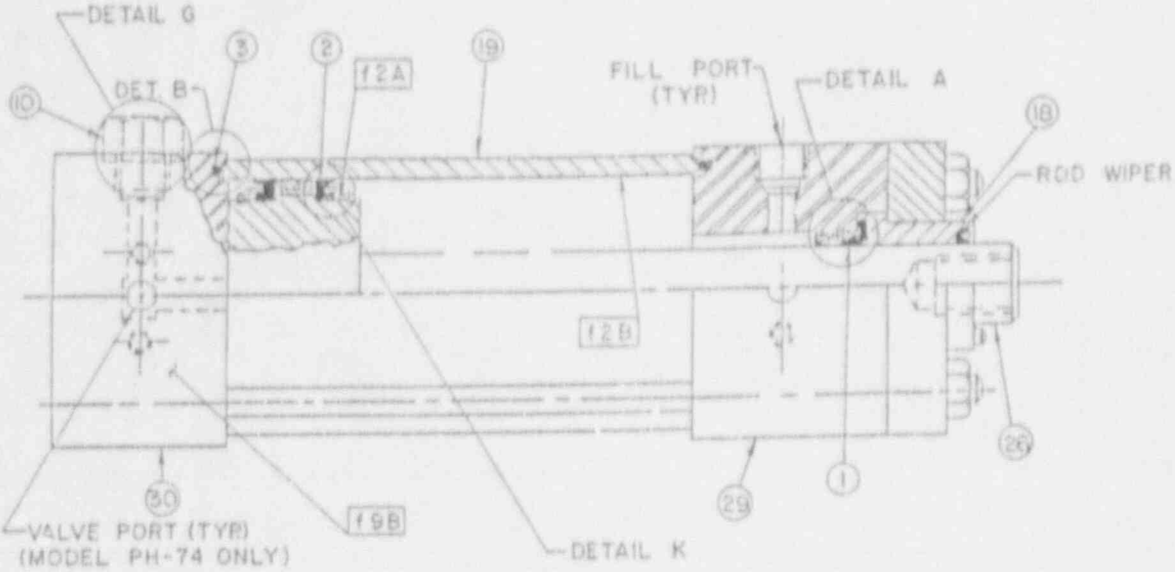
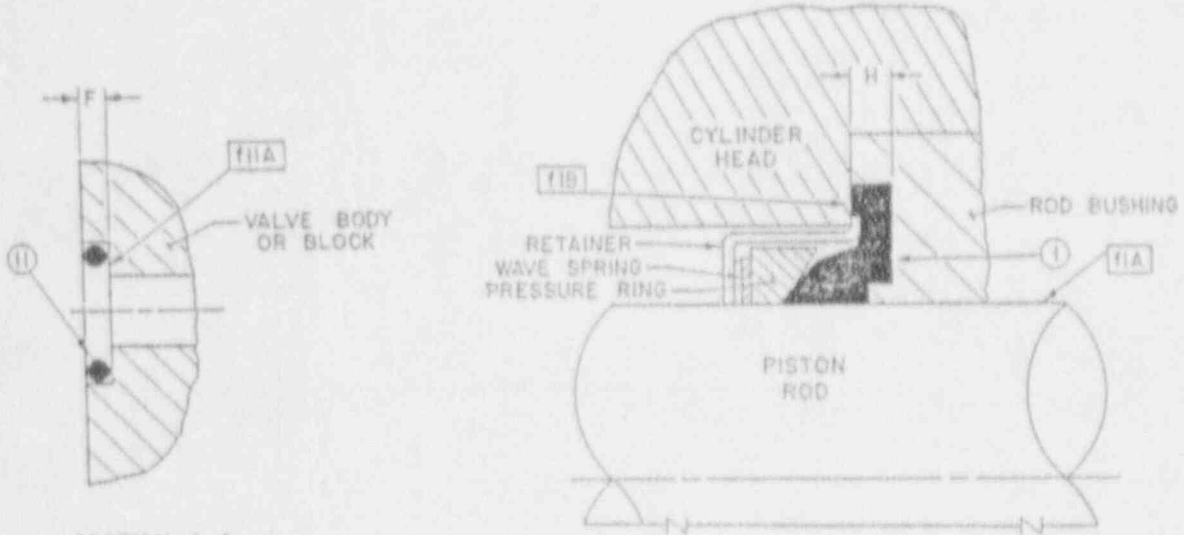


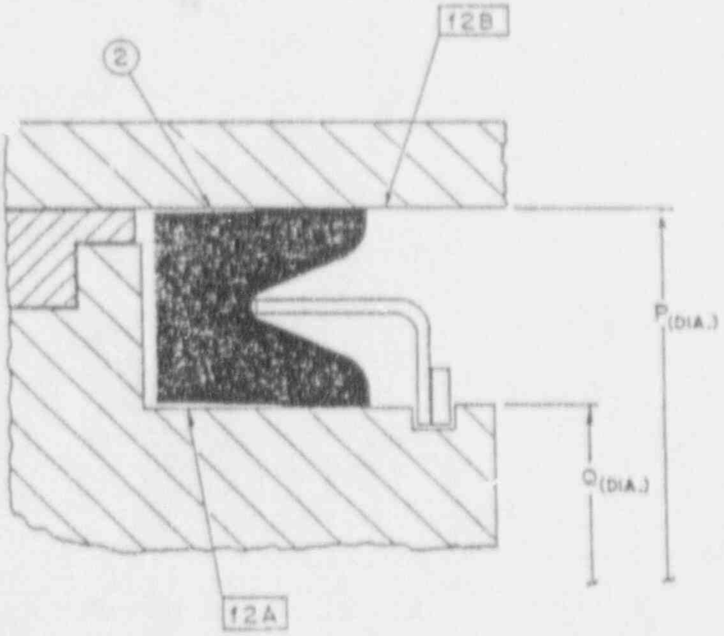
FIGURE 2
GRINNELL MILLER CYLINDER ASSEMBLY



SECTION A-A

DETAIL A

FIGURE 3
GRINNELL DETAILS - SHEET 1



DETAIL K

FIGURE 4
GRINNELL DETAILS - SHEET 2

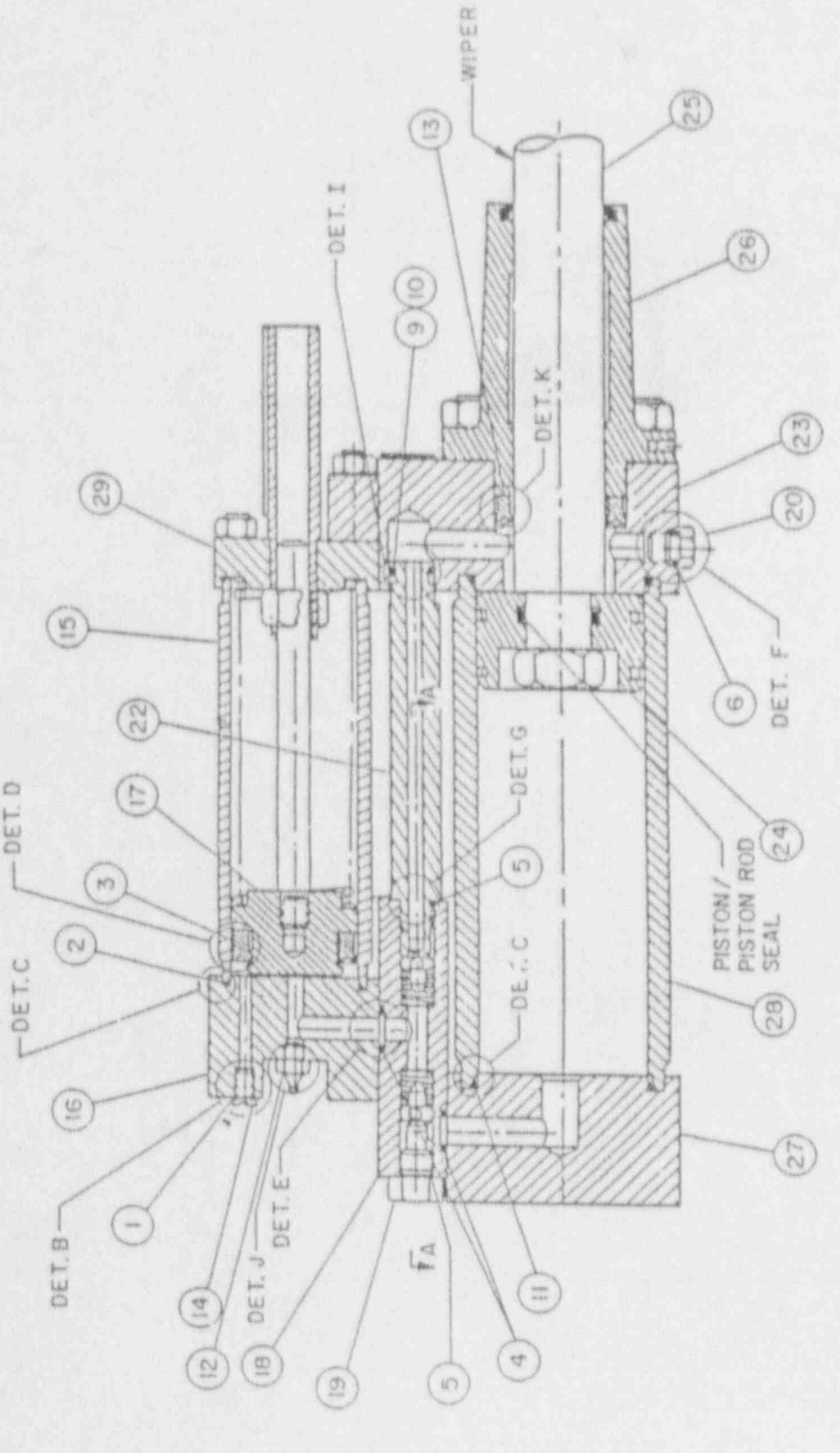
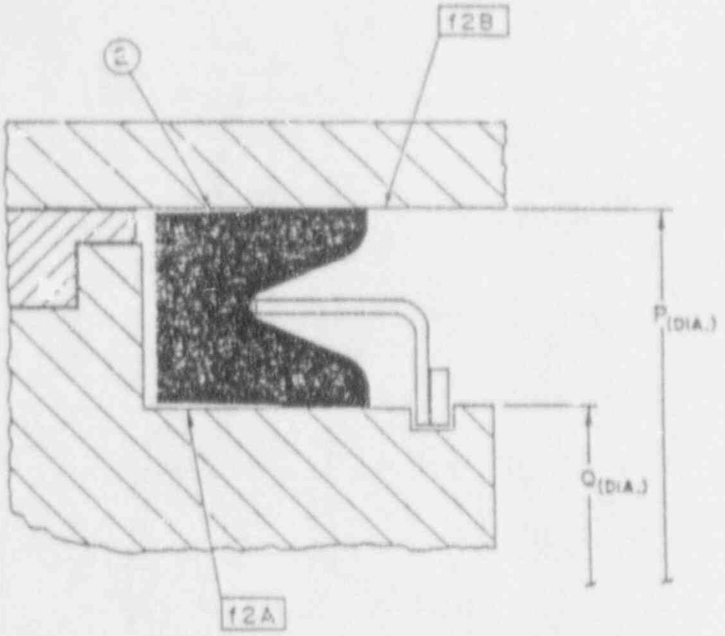


FIGURE 5
BERGEN-PATERSON GENERAL ASSEMBLY



DETAIL K

FIGURE 4
GRINNELL DETAILS - SHEET 2

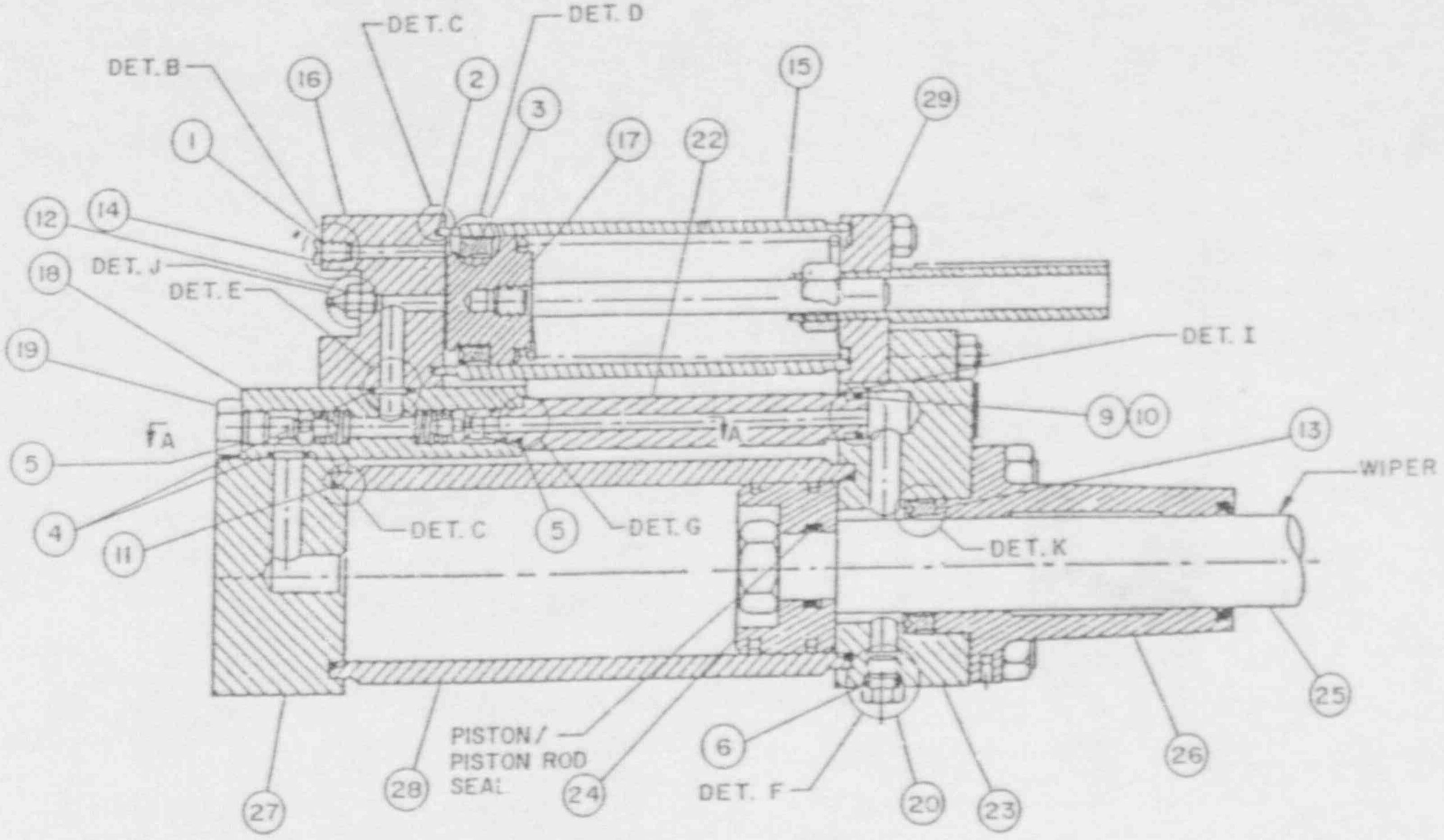


FIGURE 5
BERGEN-PATERSON GENERAL ASSEMBLY

TABLE 3

GRINNELL EVALUATION PARAMETERS

Seal No.	Wo (inches)	W1 (inches)	Ws (inches)	Compression Set (%)
1	.128	.103	.101	93%
2	.330	.276	.250	69%
11	.070	.061	.030	52%

TABLE 4

BERGEN-PATERSON EVALUATION PARAMETERS

Seal No.	Wo (inches)	W1 (inches)	Ws (inches)	Compression Set (%)
3	.312	.276	.250	50%
4	.103	.098	.078	20%
13	.312	.273	.250	63%

DATA SHEET 1

Page 1 of 1

GRINNELL

Snubber Sample Number: 3
Size (Bore X Stroke): PH-74
Configuration: Miller

GENERAL COMMENTS:

- Snubber in good physical condition.
- Reservoir level ≥ 1/2 full.
- No visible signs of leakage.
- Wiper crumbled when removed
  - Wiper hard and brittle (high temperature exposure.)
- No signs of high amplitude vibration degradation.

Insp. by: Date: 7/3/90

DATA SHEET 2

Page 1 of 1

GRINNELL

Snubber Sample Number: 3
Model: PH-74
Cylinder Type: Miller

POST-SERVICE SEAL DIMENSIONAL DATA

Ref. Part No.	Radial/ Face	Loc. Code	Sequence Number	Meas. (W1) (inches)	Comments
2	R	B	1	.275	
			2	.270	
			3	.280	
			4	.278	
1	N/A	--	1	.061	
			2	.060	
			3	.061	
			4	.061	
11	F	A	1	.102	
			2	.102	
			3	.103	
			4	.104	

COMMENTS:

Insp. by: Scott McCle Date: 7/3/90

DATA SHEET 3

Page 1 of 1

GRINNELL

Snubber Sample Number: 3
Model: PH-74
Cylinder Type: Miller

POST-DISASSEMBLY PART DIMENSIONAL DATA

Part No.	Loc. Code	Dim.	Sequence Number	Meas. (W1) (inches)	Comments
18	-	H	1	.101	
			2	.100	
			3	.101	
			4	.101	
19	-	P	-	4.001	
	A	T	1	.119	
			2	.122	
			3	.120	
			4	.122	
	B	T	1	NA	
			2		
			3		
			4		
26	B	Q	-	3.502	
27	-	F	1	.050	
			2	.051	
			3	.049	
			4	.050	

COMMENTS:

Insp. by: Scott McCl   Date: 7/3/90

DATA SHEET 6

Page 1 of 1

BERGEN-PATERSON

Snubber Sample Number: 6
Size (Bore X Stroke): 30
Configuration: Manifold

GENERAL COMMENTS:

° Snubber in good physical condition.

• Reservoir level - 7/8 marks, Piston rod extension 7/8"

• No visible signs of leakage.

° Fluid very dark with black globules. *

° Heavy scoring on cylinder tube and piston.

° Reservoir piston seal (item 3) has severe surface cracking along outside diameter and top of seal.
- piston seal energizer also shows signs of cracking.
- outside diameter of seal has shiny/glazed appearance.

* It should be noted that only fluid in cylinder tube was darkened. Fluid in reservoir was relitively clean.

Insp. by:

Date: 7/18/90

DATA SHEET 5 Page 1 of 1

BERGEN-PATERSON

Snubber Sample Number: 6
Size (Bore X Stroke): 30
Configuration: Manifold

POST-SERVICE SEAL DIMENSIONAL DATA

Ref. Part No.	Radial/ Face	Loc. Code	Sequence Number	Meas. (W1) (inches)	Comments
3	R	-	1	.275	
			2	.277	
			3	.276	
			4	.277	
4	F	A	1	.097	
			2	.098	
			3	.098	
			4	.097	
13	R	-	1	.271	
			2	.273	
			3	.274	
			4	.272	

COMMENTS:

Insp. by: Scott M Cole Date: 7/18/90

DATA SHEET 4

Page 1 of 1

BERGEN-PATERSON

Snubber Sample Number: 6
Size (Bore X Stroke): 30
Configuration: Manifold

GENERAL COMMENTS:

- Snubber in good physical condition.
- Reservoir level - 7/8 marks, Piston rod extension 7/8".
- No visible signs of leakage.
- Fluid very dark with black globules. *
- Heavy scoring on cylinder tube and piston.
- Reservoir piston seal (item 3) has severe surface cracking along outside diameter and top of seal.
  - piston seal energizer also shows signs of cracking.
  - outside diameter of seal has shiny/glazed appearance.

* It should be noted that only fluid in cylinder tube was darkened. Fluid in reservoir was relitively clean.

Insp. by: Scott McCabe Date: 7/18/90

DATA SHEET 5

Page 1 of 1

BERGEN-PATERSON

Snubber Sample Number: 6
Size (Bore X Stroke): 30
Configuration: Manifold

POST-SERVICE SEAL DIMENSIONAL DATA

Ref. Part No.	Radial/ Face	Loc. Code	Sequence Number	Meas. (W1) (inches)	Comments
3	R	-	1	.272	
			2	.277	
			3	.276	
			4	.277	
4	F	A	1	.097	
			2	.098	
			3	.098	
			4	.097	
13	R	-	1	.271	
			2	.273	
			3	.274	
			4	.272	

COMMENTS:

Insp. by: Scott M Cole Date: 7/18/90

DATA SHEET 6 Page 1 of 1

BERGEN-PATERSON

Snubber Sample Number: 6
Size (KIPS): 30
Configuration: Manifold

POST-DISASSEMBLY PART DIMENSIONAL DATA

Part No.	Loc. Code	Dim.	Sequence Number	Meas. (W1) (inches)	Comments
15	-	I	1	3.999	
			2	3.999	
17	-	H	-	3.500	
18	A	J	1	.078	
			2	.077	
			3	.078	
			4	.078	
23	-	S	-	2.500	
25	-	R	-	2.000	

COMMENTS:

Insp. by: Scott M Cole Date: 7/18/90

Appendix E

Evaluation of Drag Force Versus Time (Plant D)

Appendix E

Evaluation of Drag Force Versus Time (Plant D)

This Appendix includes drag force data obtained from Plant D for two sizes of mechanical snubbers. The data were used in an attempt to correlate drag force with time. All snubbers were tested on the same test machine. No snubbers were tested on more than one occasion. Average drag force (i.e., average of the drag force values for several snubbers) is plotted versus service time. No trends are evident.

Table E.1 Historical drag force data for snubbers at Plant D, Unit 1 (PWR)

	Average T	Average C	Peak T	Peak C
1984 PSA-1/2	4.33	4.33	8.0	7.0
	3.24	2.48	5.0	3.2
	2.16	2.7	3.24	3.6
	1.62	1.62	2.37	2.4
	2.2	2.2	3.3	3.3
	1.7	1.1	2.5	2.0
	1.1	2.0	2.2	3.0
	1.9	1.65	2.7	2.7
	2.0	2.2	3.2	3.8
	2.2	2.7	3.25	4.3
	2.24	**2.30**	**3.57**	**3.53**
1984 PSA-1	3.75	6.3	7.5	12.5
	5.0	5.0	10.0	11.5
	5.0	3.75	10.0	8.0
	3.1	5.0	7.5	10.0
	4.21	**5.01**	**8.75**	**10.5**
1985 PSA-1/2	2.0	1.7	2.66	2.2
	2.2	2.2	3.3	3.3
	4.5	6.5	9.0	13.0
	1.3	1.4	2.8	2.65
	3.75	4.65	4.7	6.0
	4.85	2.65	10.8	4.8
	3.0	2.55	4.9	6.5
	3.08	**3.09**	**5.45**	**5.50**
PSA-1	2.75	5.0	9.2	10.0
	2.70	2.5	6.25	6.0
	2.72	**3.75**	**7.72**	**8.0**

Note: numbers in **bold** indicate averages.

T = tension drag force (lb).
C = compression drag force (lb).

Table E.1 (Continued)

	Average T	Average C	Peak T	Peak C
‾	2.0	2.5	4.4	4.5
↑	1.65	1.75	3.25	3.20
	2.0	2.2	3.50	3.75
	7.7	10.25	12.0	15.5
	3.1	3.0	4.8	4.3
	1.60	2.05	3.85	3.90
1986	3.10	2.10	5.50	3.50
PSA-1/2	1.60	1.90	3.20	3.3
	2.10	3.3	3.3	5.1
	1.70	1.8	3.0	3.0
	1.60	2.0	2.2	3.0
	1.75	1.0	3.25	2.0
	0.9	0.9	1.80	1.5
⊥	**2.37**	**2.67**	**4.20**	**4.35**
↑	3.75	2.2	6.5	6.2
	3.3	2.5	6.25	7.0
	2.0	5.0	6.25	7.0
PSA-1	5.0	4.0	11.5	8.0
	2.5	3.0	5.0	8.75
	3.75	3.75	8.75	8.75
⊥	**3.38**	**3.40**	**7.37**	**8.53**
‾	1.3	1.6	2.0	2.75
↑	1.25	1.6	2.25	2.2
	1.2	1.7	1.95	2.7
	1.1	1.1	2.0	2.15
1987	1.7	1.85	3.0	1.0
PSA-1/2	1.25	.9	2.16	1.0
	2.3	1.6	3.85	3.40
	6.5	7.8	8.2	9.75
	1.5	1.1	2.1	1.6
	1.6	2.6	2.6	3.2
⊥	**1.97**	**2.18**	**3.01**	**3.26**
PSA-1	3.3	3.0	6.3	7.0

Table E.1 (Continued)

	Average T	Average C	Peak T	Peak C
	2.89	2.11	5.55	4.12
	4.60	2.35	6.95	4.80
	3.37	3.10	6.5	6.15
	2.45	2.75	6.0	5.62
1988	2.95	2.75	6.10	4.45
PSA-1/2	2.37	2.75	4.40	4.35
	1.78	2.45	4.20	4.65
	3.30	1.92	6.25	3.92
	2.76	5.20	5.10	7.05
	2.95	**2.82**	**5.67**	**5.01**
	5.56	4.55	10.95	11.67
	5.79	5.71	13.27	12.96
	6.75	4.15	11.02	8.66
PSA-1	5.17	6.53	11.17	15.99
	6.24	9.42	13.52	22.98
	7.63	5.64	13.30	13.30
	5.63	5.36	12.12	11.55
	7.25	5.91	13.42	12.75
	6.25	**5.90**	**12.35**	**13.73**
	7.40	5.20	13.0	11.0
	5.20	4.50	8.30	7.80
1989	3.75	2.75	6.0	3.75
PSA-1/2	5.25	3.25	7.0	5.40
	1.60	1.10	3.10	1.90
	0.85	1.25	1.75	2.10
	2.0	2.25	3.50	4.25
	3.72	**2.90**	**6.09**	**5.17**
	2.5	2.75	5.0	7.50
PSA-1	9.0	2.50	17.5	6.25
	5.0	6.25	10.0	12.0
	5.5	**3.83**	**10.8**	**8.58**

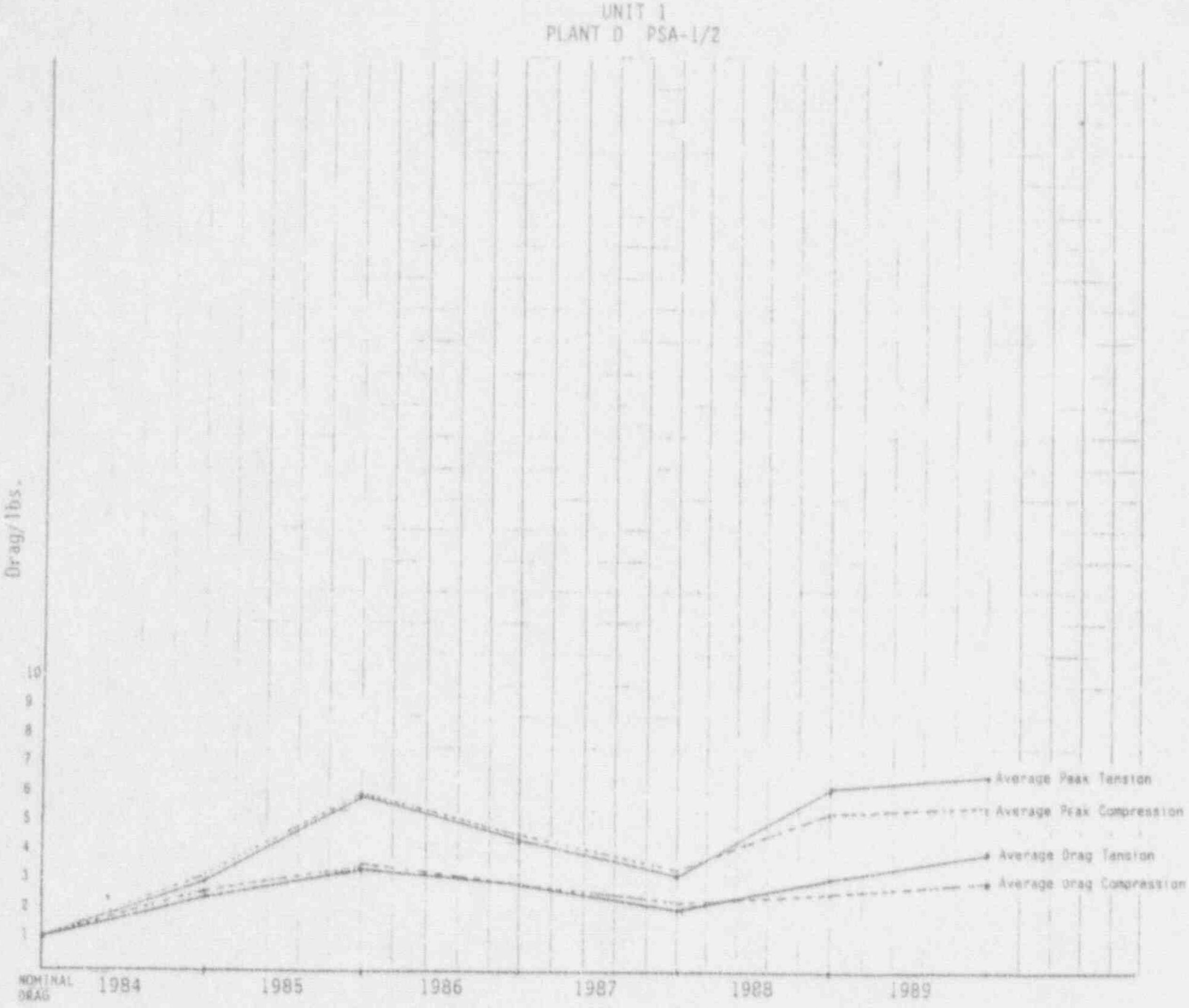


Figure E.1 PSA-1/2 drag force versus service time Unit 1, Plant D

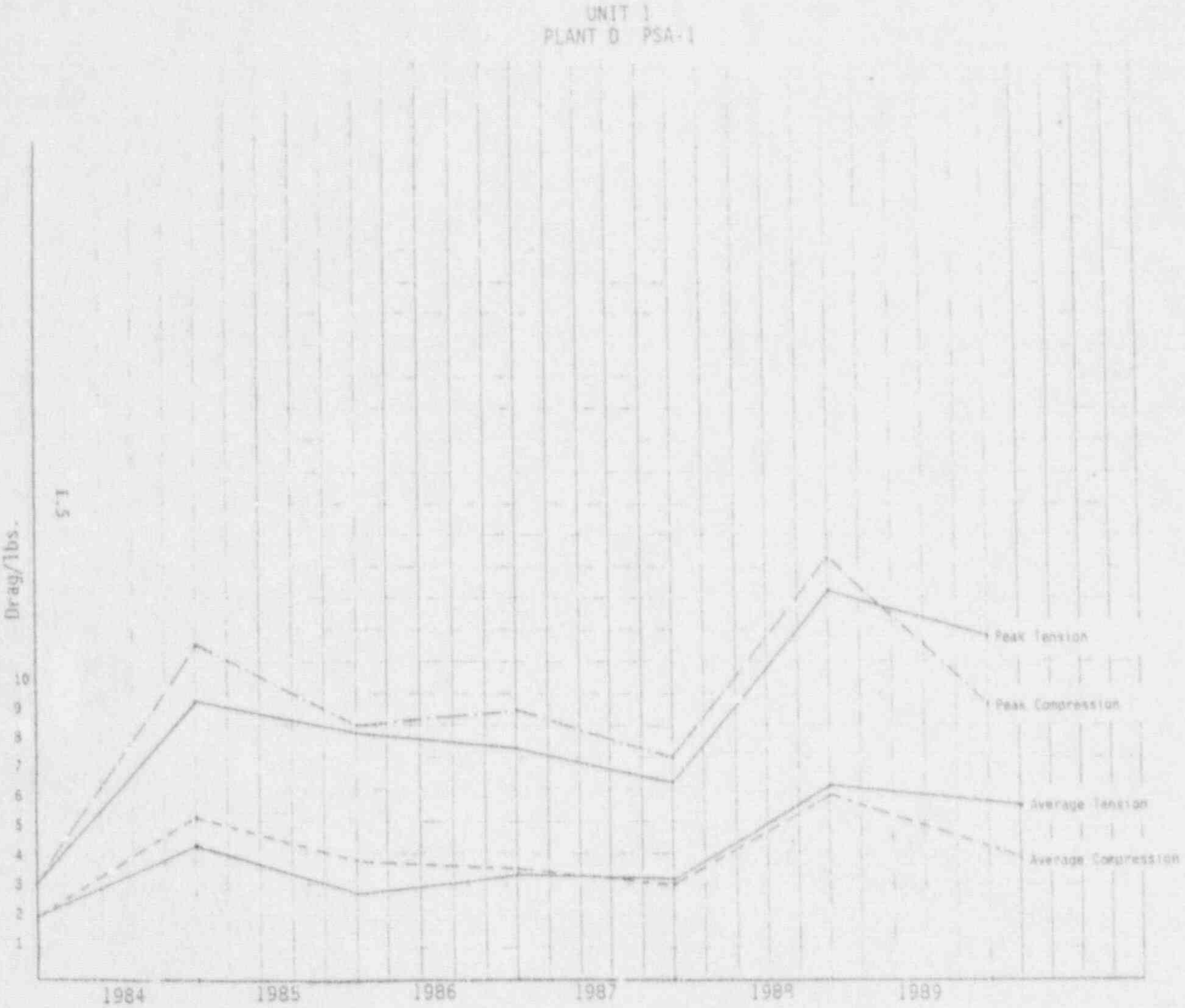


Figure E.2 PSA-1 drag force versus service time

Table E.2 Historical drag force data for snubbers at Plant D, Unit 2 (PWR)

	Average T	Average C	Peak T	Peak C
1985	2.00	1.60	3.20	3.25
	1.56	1.00	2.20	2.10
	1.25	1.75	3.20	3.75
	1.60	1.40	3.25	2.35
	3.20	2.70	5.40	5.30
	1.50	3.00	3.25	6.50
	2.25	2.45	3.25	3.25
	1.90	1.80	3.10	3.00
	1.80	1.45	3.25	2.50
PSA-1/2	2.70	1.60	3.75	2.60
(26)	2.20	1.75	3.75	3.25
	4.85	1.60	9.30	2.90
	1.68	1.75	3.20	3.25
	1.95	2.85	3.00	4.20
	2.20	1.45	3.50	2.65
	2.60	2.75	5.90	4.60
	1.70	1.45	2.70	2.25
	3.40	3.24	5.40	5.20
	2.00	2.10	2.70	3.10
	2.00	3.70	4.30	7.58
1985	3.10	3.00	3.85	4.35
	2.10	1.70	3.25	2.40
	3.40	3.60	5.65	7.10
	1.00	1.10	2.15	2.16
	1.80	1.70	2.90	2.70
	1.15	1.40	2.25	2.20
–	**2.05**	**2.07**	**3.75**	**3.6**
	8.20	9.50	15.00	26.00
	7.50	3.00	17.50	12.50
	6.00	4.00	12.50	10.00
	3.50	3.75	10.00	8.75
	5.00	5.20	11.00	11.50
	5.50	4.50	11.50	11.25
PSA-1	3.00	3.75	7.50	11.00
(15)	3.75	3.95	10.00	12.00
	6.00	2.50	13.00	11.00
	4.00	4.50	17.50	12.50
	11.00	8.50	18.50	17.50
	4.85	11.00	10.50	24.00
	6.00	3.50	12.00	15.00
	3.50	4.50	8.50	11.50
	5.43	**6.01**	**12.50**	**13.90**

T = tension drag force (lb).
C = compression drag force (lb).

Table E.2 (Continued)

	Average T	Average C	Peak T	Peak C
	1.30	1.30	2.40	3.00
1986	1.10	1.50	2.00	3.20
	1.05	2.00	2.20	3.25
	1.20	1.85	2.00	2.65
	1.70	2.40	3.25	3.75
	1.85	1.10	3.85	2.40
	1.10	1.60	1.60	2.50
	1.55	4.80	4.00	13.00
PSA-1/2	2.20	2.70	3.50	5.40
(19)	1.00	1.60	1.75	3.00
	1.20	1.65	2.45	2.75
	1.10	.90	2.05	1.55
	1.35	1.95	2.55	2.35
	3.40	2.75	4.75	3.85
	1.20	1.20	2.20	1.95
	0.95	1.45	1.65	2.20
	2.35	1.65	3.70	2.60
	2.25	1.00	3.20	3.25
–	**1.62**	**1.95**	**2.87**	**3.60**
	3.45	3.25	6.90	7.00
	4.25	6.30	11.00	14.00
PSA-1	3.75	2.50	6.25	6.75
(6)	3.40	4.45	8.25	9.00
	3.50	3.60	7.50	11.25
	5.10	3.75	16.0	15.0
–	**3.90**	**3.97**	**9.31**	**10.5**
	1.70	1.60	3.00	4.80
	2.00	2.85	3.50	4.30
	2.40	3.50	6.50	4.50
	3.30	1.40	2.40	8.50
	1.60	5.40	7.00	4.32
1987	2.50	3.15	7.40	3.00
PSA-1/2	1.00	2.25	4.80	2.65
(14)	1.90	3.25	2.70	2.4
	2.40	3.00	3.00	4.3
	3.25	2.20	4.30	6.4
	1.60	4.80	5.40	2.2
	4.40	2.15	3.20	10.0
	3.00	2.00	3.60	4.7
	3.20	1.55	2.20	4.2
–	**2.44**	**2.80**	**4.21**	**4.5**
	5.00	4.00	10.00	8.75
	3.75	2.75	7.00	6.50

Table E.2 (Continued)

	Average T	Average C	Peak T	Peak C
PSA-1	5.00	3.00	11.00	7.50
(6)	2.50	3.00	6.00	7.50
	2.50	3.75	5.10	8.75
	3.00	3.70	8.20	20.0
	3.62	**3.36**	**7.88**	**9.8**
	2.62	6.07	6.10	8.69
	3.07	4.08	5.58	7.44
	1.65	1.66	2.85	5.70
	2.92	2.63	5.44	6.73
	5.03	4.26	7.33	6.94
	1.73	3.33	3.08	6.40
	3.55	2.05	5.38	3.63
1988	1.43	3.05	2.96	5.11
(21)	3.65	2.48	6.06	5.50
	4.26	2.64	5.64	6.37
	8.62	4.74	16.30	8.63
PSA-1/2	2.53	1.85	3.75	3.08
	4.39	4.72	11.20	12.70
	3.69	2.47	6.25	4.95
	1.38	2.90	2.92	4.41
	4.49	3.85	7.55	9.43
	3.72	1.91	6.01	4.54
	3.74	1.81	6.20	3.76
	3.99	2.30	6.14	5.52
	1.66	3.14	3.95	6.74
	2.54	2.27	5.29	4.30
–	**3.36**	**3.05**	**6.0**	**6.21**
	6.19	5.67	11.00	11.96
	4.69	5.99	10.24	10.34
	5.61	5.01	11.92	10.15
	6.42	5.63	13.93	12.64
	6.43	4.51	14.63	11.99
PSA-1	3.68	6.08	6.95	12.87
(11)	16.68	9.12	37.13	21.52
	11.64	7.90	22.74	15.68
	9.76	10.18	18.59	13.30
	6.85	6.18	15.71	12.00
	6.49	8.45	21.29	23.97
–	**7.67**	**6.79**	**16.74**	**14.66**
	4.20	2.70	8.66	4.32
	1.90	1.20	3.70	3.25
	4.32	3.25	6.80	7.00
	0.85	3.25	2.00	4.85
	3.25	3.25	5.10	5.40
	4.60	5.40	7.60	7.60

Table E.2 (Continued)

	Average T	Average C	Peak T	Peak C
PSA-1/2	1.10	1.10	2.00	1.60
1989	1.70	1.20	2.20	1.80
(16)	2.30	2.00	4.32	3.30
	1.20	1.60	2.25	3.00
	2.00	1.00	3.25	2.00
	2.25	3.10	4.05	6.10
	1.35	1.40	2.70	2.50
	3.10	3.20	5.40	4.30
	1.70	1.95	3.25	3.25
	1.15	1.65	2.20	2.30
	2.31	**2.32**	**4.21**	**3.**
	2.00	2.25	7.00	5.10
	2.00	2.00	5.00	4.90
	5.00	4.50	11.00	12.00
PSA-1	3.75	3.10	8.50	7.00
(11)	5.30	3.90	18.00	11.00
	3.00	5.00	7.50	10.50
	4.45	3.20	7.00	7.00
	3.75	3.00	8.50	7.00
	3.75	2.50	8.55	6.20
	2.50	3.20	7.50	7.00
	3.75	5.00	10.50	9.25
	3.56	**3.42**	**8.91**	**7.96**

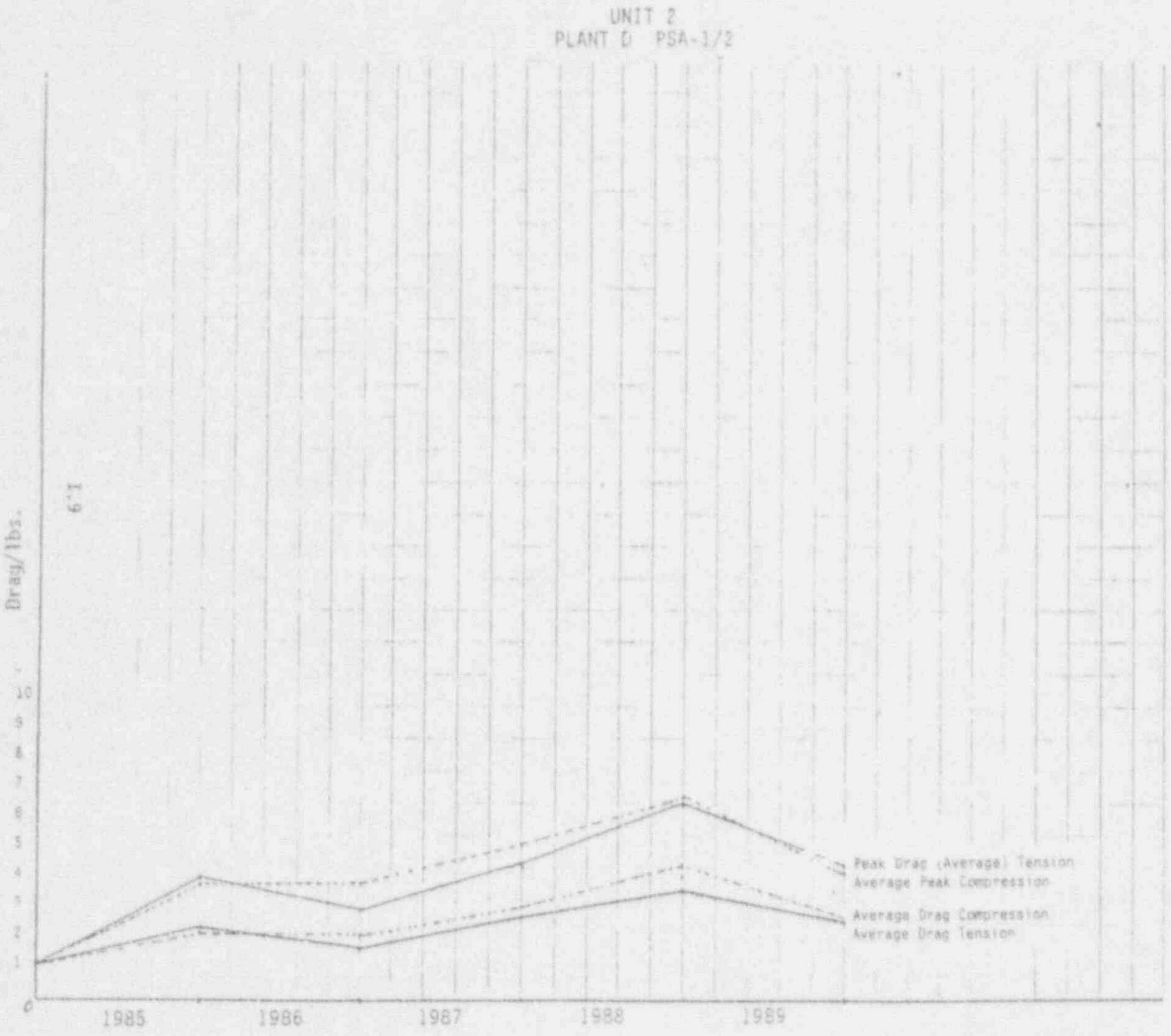


Figure E.3 PSA-1/2 drag force versus service time Unit 2, Plant D

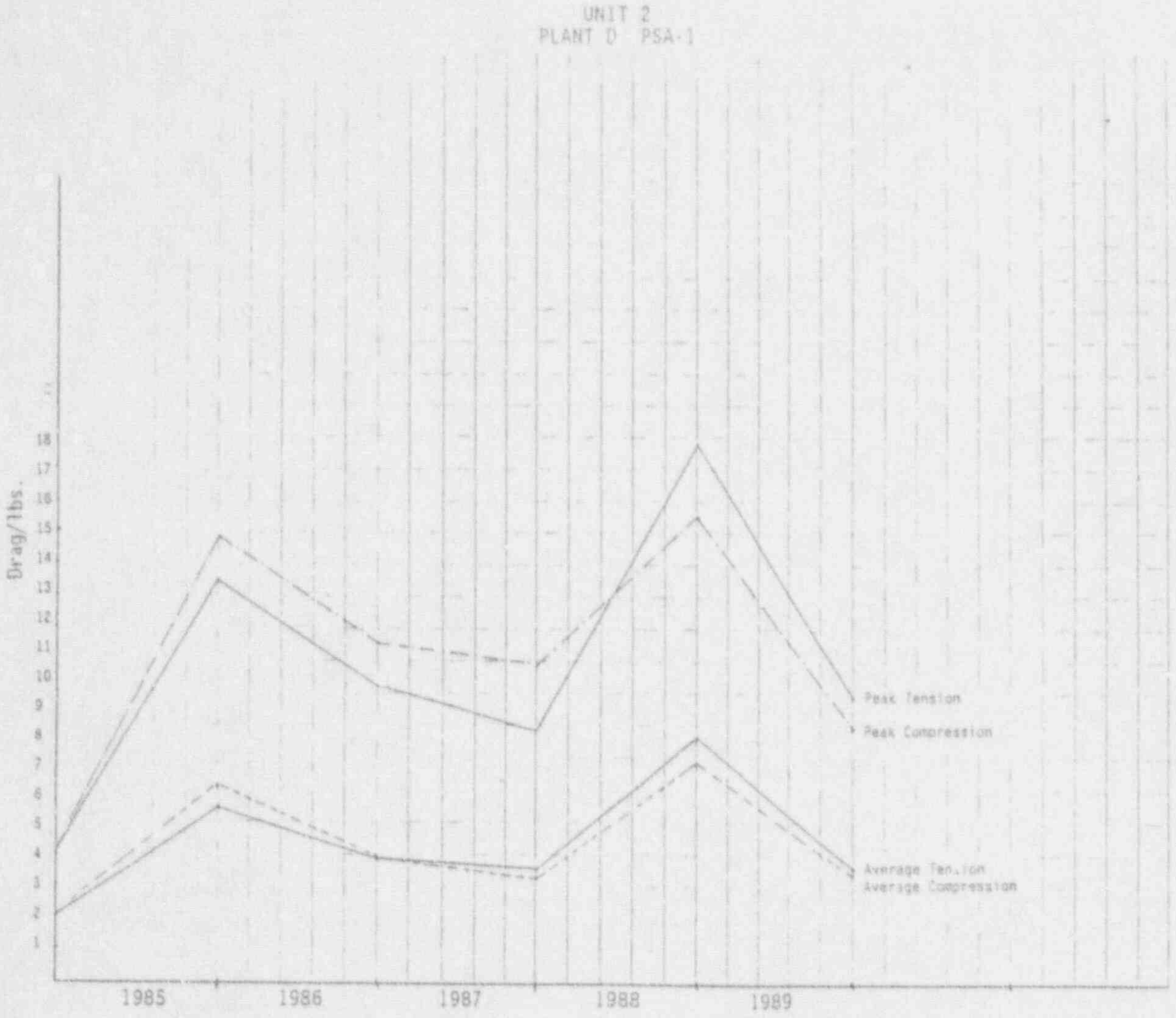


Figure E.4 PSA-1 drag force versus service time Unit 2, Plant D

Appendix F

Evaluation of Drag Force Versus Time (Plant F)

Appendix F

Evaluation of Drag Force Versus Time (Plant F)

This Appendix contains drag force data from site F for one size of mechanical snubber. The data were used in an attempt to correlate drag force with service time. All snubbers were tested using the same type of test machine. All snubbers were tested on a minimum of two separate occasions (refueling outages). Average drag force (average for all snubbers at each refueling outage) is plotted versus service time. Individual snubber drag force is also plotted versus service time for five typical snubbers, samples A through E. Some trend toward increasing drag force with service time is observed.

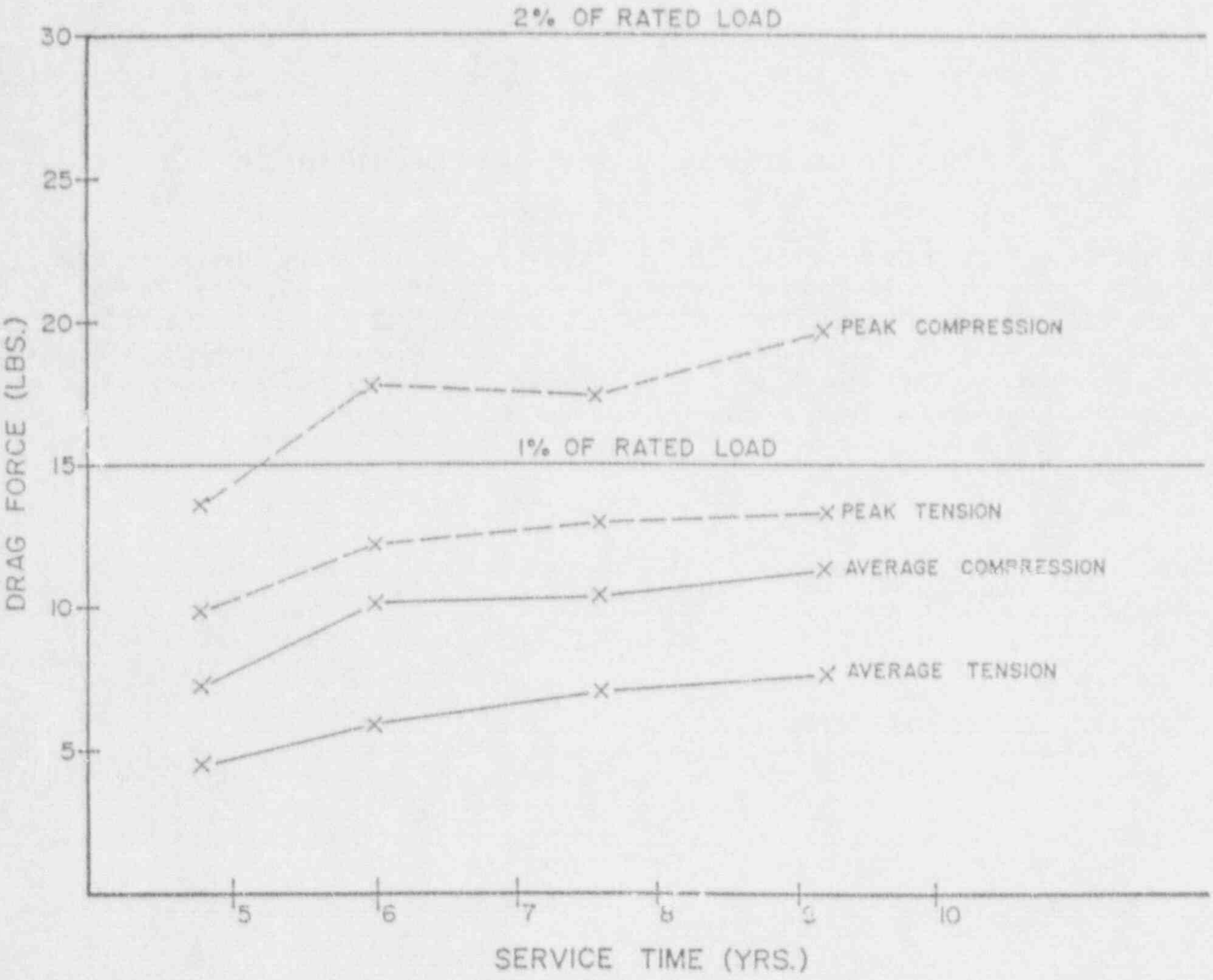


Figure F.1 Drag force vs. service time, Plant F average of all samples

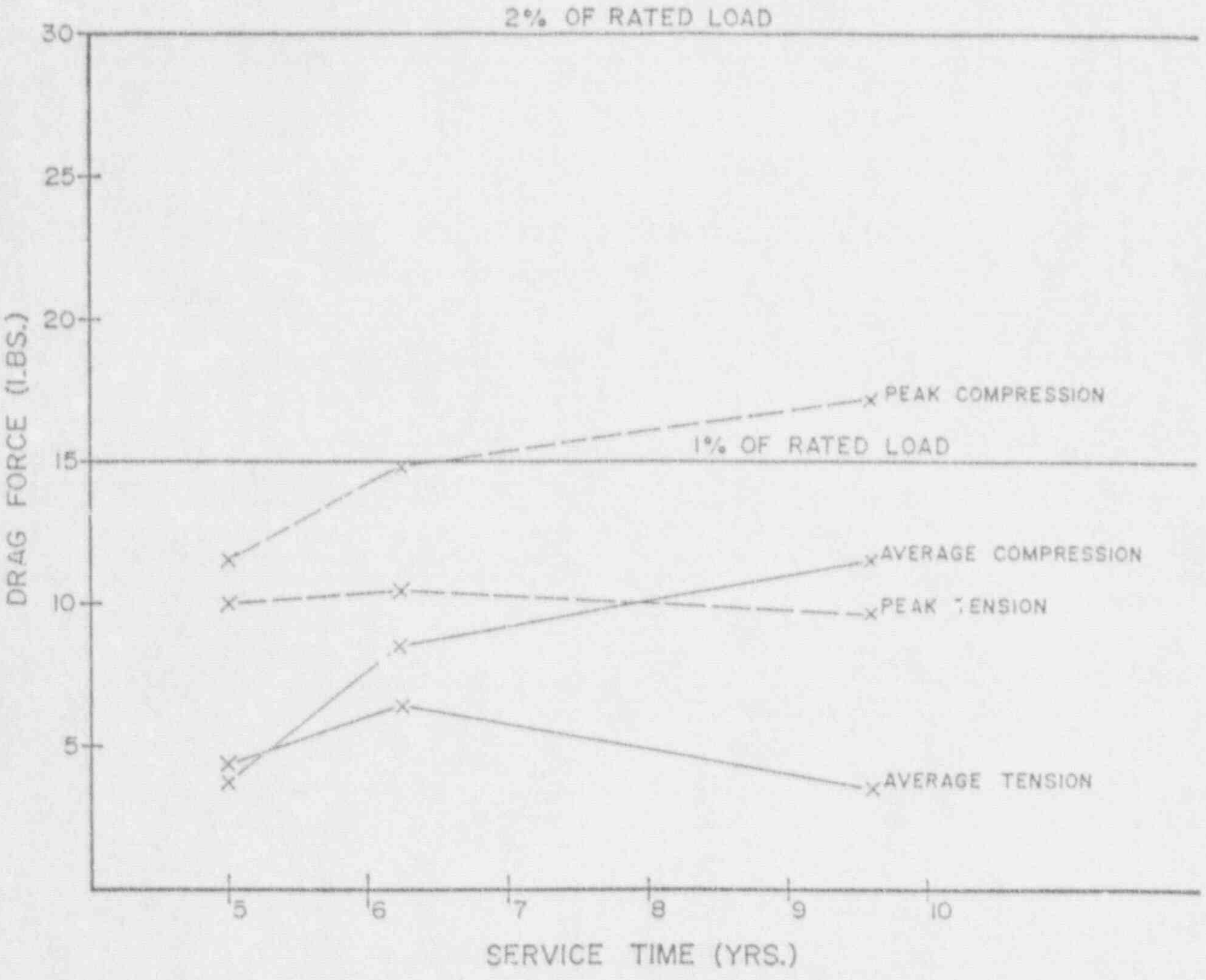


Figure F.2 Drag force vs. service time, Plant F sample A (# 188)

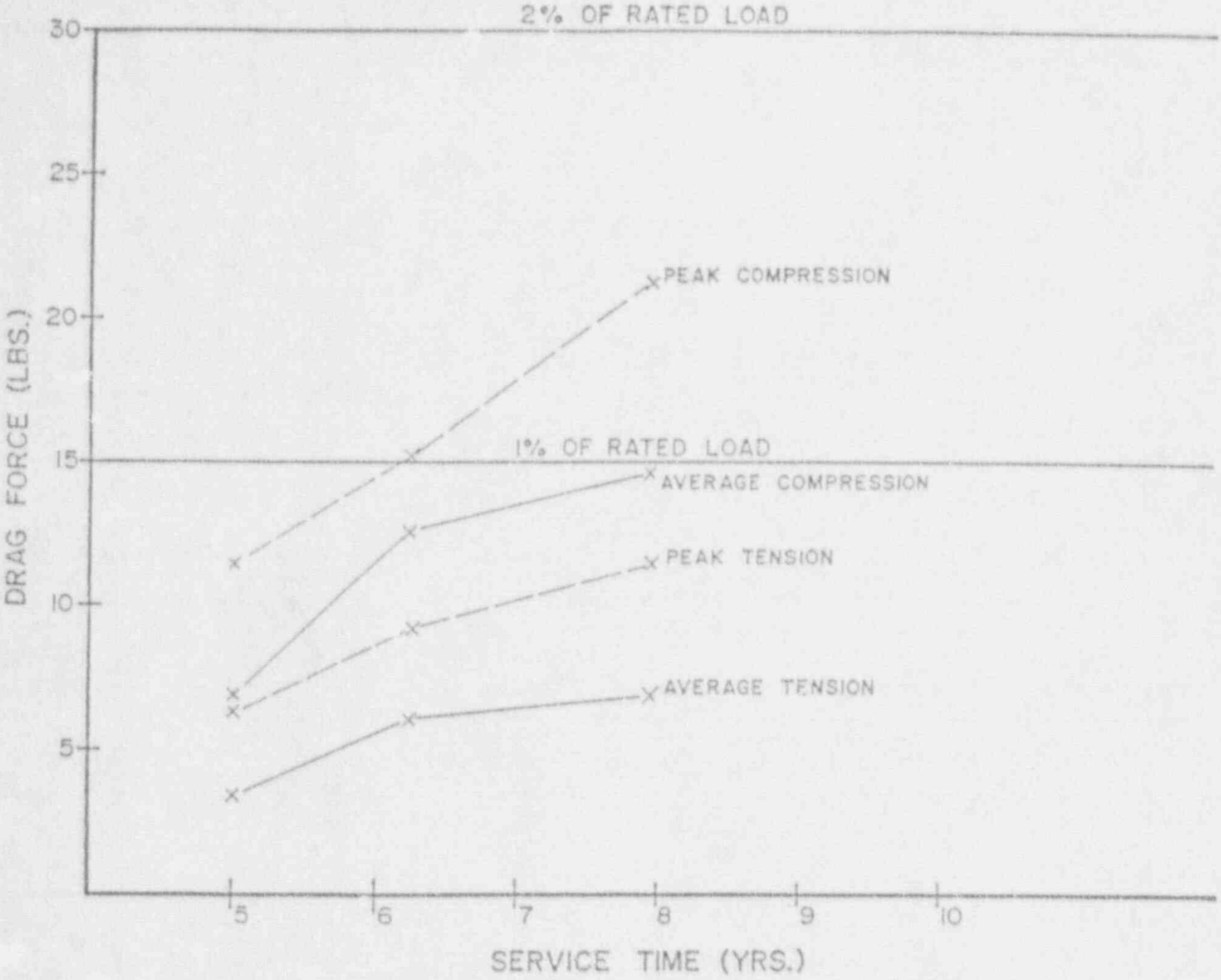


Figure F.3 Drag force vs. service time, Plant F sample B (# 96)

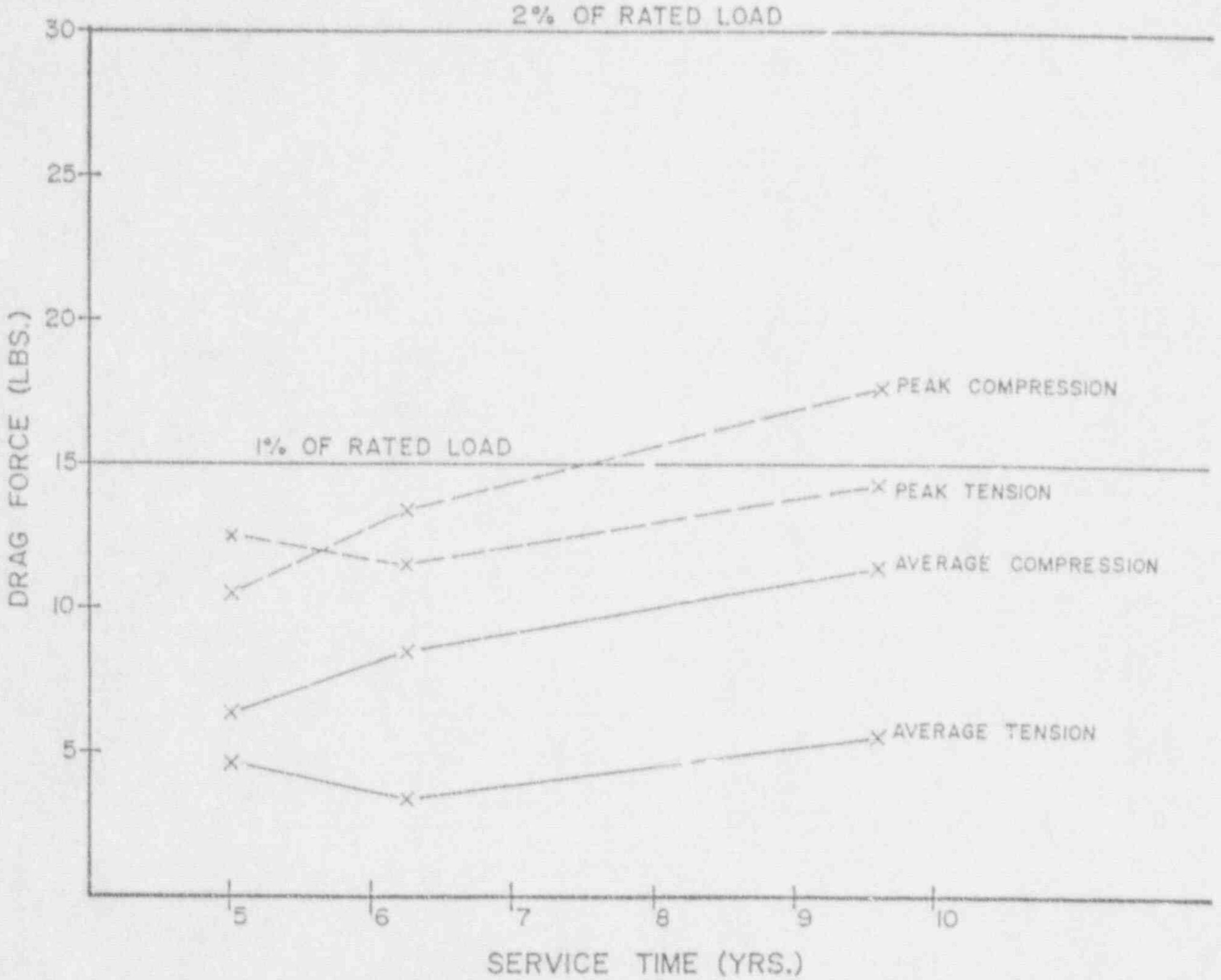


Figure F.4 Drag force vs. service time, Plant F sample C (# 62)

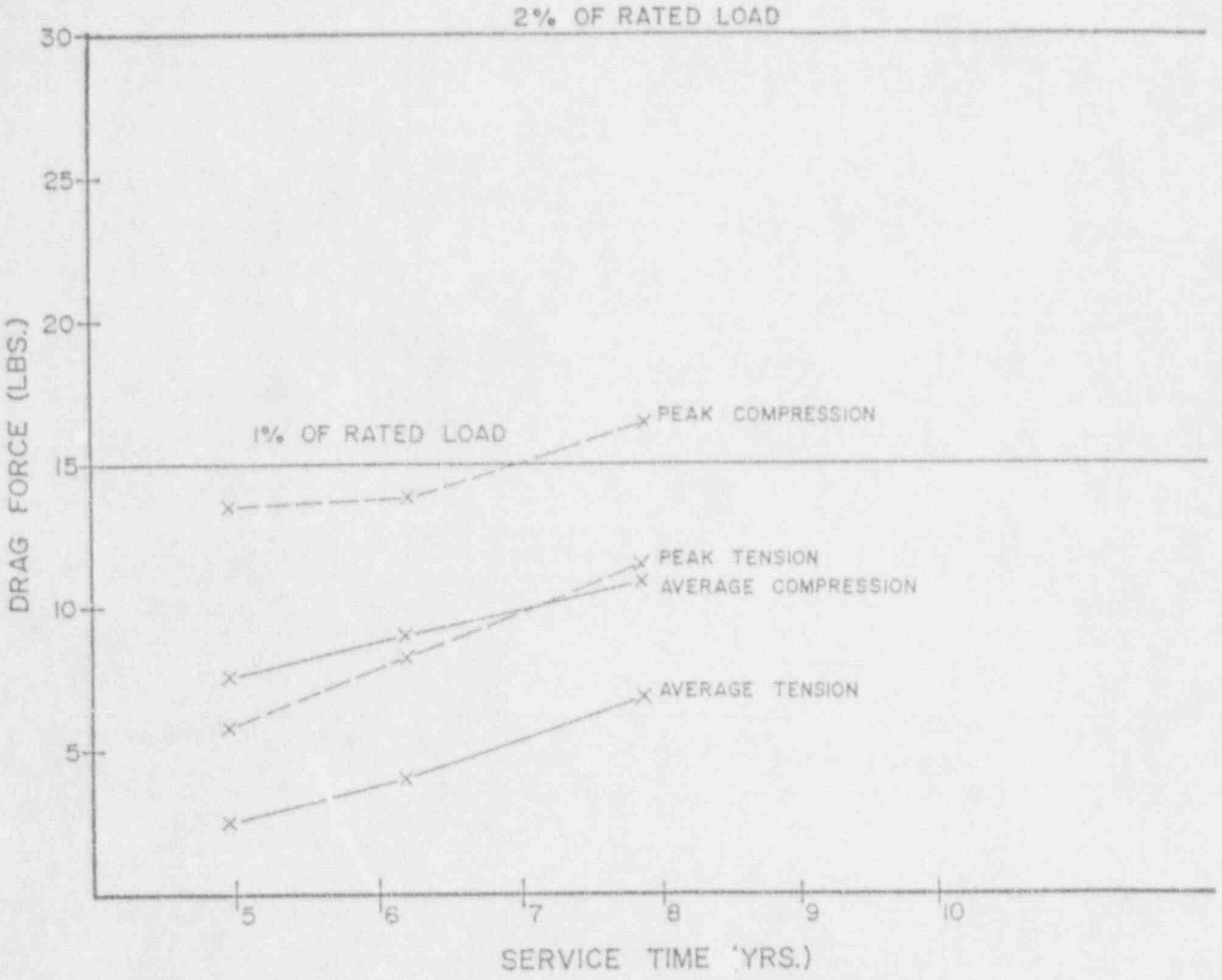


Figure F.5 Drag force vs. service time, Plant F sample D (# 13)

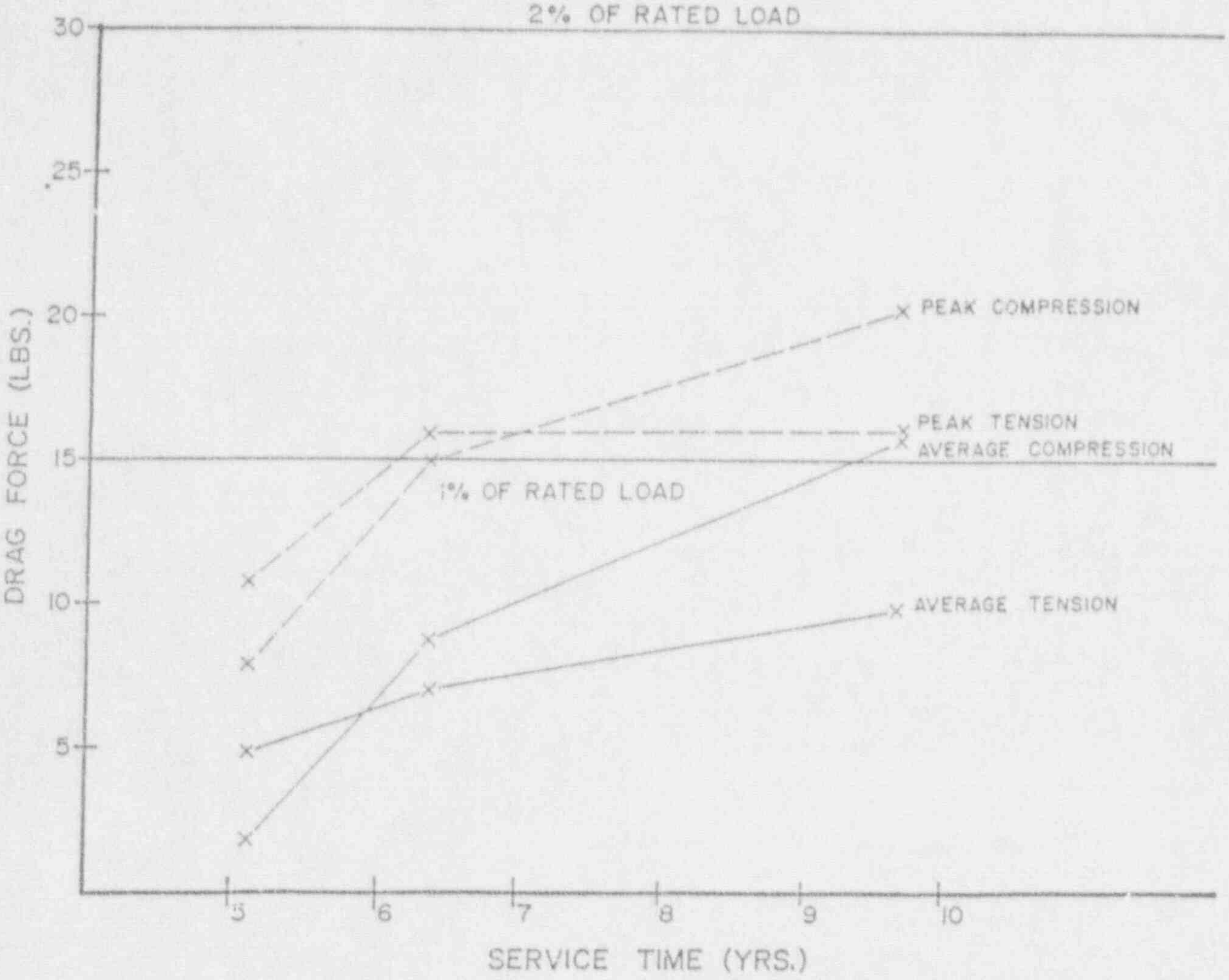


Figure F.6 Drag force vs. service time, Plant F sample E (# 15)

Table 1 Historical drag force data, Plant F

Exam Number		2R4[a]	2R5	2R6	2R7
7	Av. T	1.6 + 7.0 - 4.3	3.7 + 7.8 - 6.8		
	Av. C	12.9 + 15.2 - 14.1	15.1 + 12.4 - 13.8		
	Pk. T	6.0 + 12.5 - 9.3	8.4 + 11.3 - 9.8		
	Pk. C	18.0 + 20.0 - 19.0	23.3 + 19.3 - 21.3		
8	Av. T	5.5 + 3.9 - 4.7	4.0 + 5.3 - 4.7	4.8 + 9.8 - 7.3	
	Av. C	10.1 + 10.9 - 10.5	8.9 + 8.1 - 8.5	11.1 + 8.1 - 9.6	
	Pk. T	10.0 + 6.1 - 8.0	11.6 + 10.0 - 10.8	12.7 + 21.6 - 17.2	
	Pk. C	14.0 + 14.0 - 14.0	15.1 + 13.9 - 14.5	20.5 + 17.2 - 18.8	
13	Av. T	3.1 + .8 - 2.0	1.9 + 5.2 - 3.6	8.3 + 4.1 - 6.2	
	Av. C	6.6 + 7.4 - 7.0	9.4 + 7.6 - 8.5	8.8 + 11.8 - 10.3	
	Pk. T	6.0 + 4.2 - 5.1	5.3 + 8.5 - 7.9	11.8 + 10.2 - 11.0	
	Pk. C	13.0 + 13.0 - 13.0	14.2 + 12.0 - 13.1	14.2 + 17.8 - 16.0	
14	Av. T	1.6 + 3.5 - 2.6	7.5 + 5.7 - 6.6		
	Av. C	.4 + 4.7 - 2.6	7.3 + 6.2 - 6.8		
	Pk. T	6.2 + 7.0 - 6.6	12.6 + 10.4 - 11.5		
	Pk. C	6.0 + 10.0 - 8.0	12.8 + 14.6 - 13.7		
15	Av. T	4.7 + 5.9 - 5.3	8.1 + 7.[illegible] - 7.6		9.71 + 10.74 - 10.2
	Av. C	2.7 + 2.0 - 2.4	9.6 + 8.[illegible] - 9.1		15.52 + 16.76 - 16.1
	Pk. T	9.5 + 13.0 - 11.3	16.9 + 16.[illegible] - 16.5		15.66 + 17.01 - 16.3
	Pk. C	9.0 + 8.0 - 8.5	16.6 + 14.6 - 15.5		20.28 + 21.30 - 20.8
16	Av. T	4.3 + 3.9 - 4.1	4.0 +		
	Av. C	.8 + .4 - .6	10.4 +		
	Pk. T	10.0 + 9.0 - 9.5	8.5 +		
	Pk. C	5.0 + 6.0 - 5.5	16.0 +		
17	Av. T	5.1 + 3.1 - 4.1	6.3 + 7.3 - 6.8		
	Av. C	3.1 + 5.5 - 4.3	10.1 + 9.6 - 9.8		
	Pk. T	10.0 + 6.6 - 8.3	9.9 + 10.9 - 10.4		
	Pk. C	8.0 + 10.0 - 9.0	15.3 + 17.2 - 17.1		
18	Av. T	2.0 + 1.2 - 1.6	6.2 + 6.4 - 6.3		
	Av. C	12.5 + 12.9 - 12.7	10.8 + 8.5 - 9.7		
	Pk. T	6.0 + 7.0 - 6.5	10.8 + 10.3 - 10.6		
	Pk. C	19.0 + 17.5 - 18.3	17.8 + 14.3 - 16.1		
24	Av. T	9.0 + 9.0 SCRAP	9.3 + 7.5 - 8.4	14.8 + 9.2 - 12.0	
	Av. C	9.4 + 11.7	.6 + 10.2 - 5.4	14.2 + 4.7 - 9.6	
	Pk. T	32.0 + 35.0	14.7 + 10.9 - 12.8	23.0 + 16.3 - 19.8	
	Pk. C	30.0 + 35.0	9.4 + 21.1 - 15.3	29.3 + 22.5 - 25.9	
26	Av. T	7.0 + 11.3 SCRAP	8.4 + 21.5 - 14.9	4.2 + 3.4 - 3.8	
	Av. C	7.0 + 15.2	15.5 + 15.1 - 15.3	10.1 + 9.5 - 9.8	
	Pk. T	19.0 + 24.0	13.3 + 26.3 - 19.8	10.8 + 11.6 - 11.2	
	Pk. C	22.0 + 28.0	23.7 + 22.7 - 23.2	17.1 + 17.1 - 17.1	

(a) 2 = unit 2 (PWR), R = refueling outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Table 1 (Continued)

Exam Number		2R4[a]	2R5	2R6	2R7
42	Av. T	6.2 + 5.1 - 5.6	3.5 + 7.3 - 5.5		
	Av. C	4.7 + 5.9 - 5.3	7.3 + 6.6 - 6.9		
	Pk. T	11.0 + 12.0 - 11.5	8.8 + 12.8 - 10.8		
	Pk. C	10.0 + 12.0 - 11.0	12.4 + 11.8 - 12.1		
43	Av. T	3.9 + 5.1 - 4.5	4.8 + 5.1 - 4.9		
	Av. C	7.4 - 7.4	8.0 + 9.4 - 8.7		
	Pk. T	7.0 + 9.0 - 8.0	9.1 + 8.3 - 8.7		
	Pk. C	13.0 + 13.0	13.8 + 14.6 - 14.1		
44	Av. T	4.7 + .4 - 2.6	8.5 + 4.7 - 6.6		
	Av. C	10.1 + 10.9 - 10.5	10.4 + 12.0 - 11.2		
	Pk. T	7.5 + 5.0 - 6.3	11.7 + 8.2 - 9.9		
	Pk. C	15.0 + 16.0 - 15.5	17.0 + 17.8 - 17.4		
45	Av. T	2.8 + 4.3 - 3.6	3.3 + 3.1 - 3.2		
	Av. C	9.8 + 10.1 - 9.9	6.6 + 9.9 - 7.8		
	Pk. T	6.0 + 8.0 - 7.0	7.5 + 9.6 - 8.6		
	Pk. C	14.0 + 15.0 - 14.5	12.9 + 15.9 - 14.4		
46	Av. T	5.1 + 4.3 - 4.7	10.4 + 5.3 - 7.9		
	Av. C	4.7 + 3.9 - 4.3	14.1 + 8.9 - 11.5		
	Pk. T	10.0 + 9.0 - 9.5	14.2 + 9.1 - 11.6		
	Pk. C	24.0 + 18.0 - 21.0	27.1 + 17.0 - 22.0		
47	Av. T	4.3 + 3.5 - 3.9	2.0 + 5.1 - 3.5		
	Av. C	12.9 + 12.9 - 12.9	9.4 + 9.9 - 9.7		
	Pk. T	10.0 + 10.0 - 10.0	7.6 + 10.1 - 8.3		
	Pk. C	18.0 + 18.0 - 18.0	16.8 + 17.7 - 17.2		
62	Av. T	5.9 + 3.5 - 4.7	2.8 + 3.7 - 3.3		5.22 + 5.90 - 5.5
	Av. C	7.8 + 4.3 - 6.1	10.5 + 6.3 - 8.4		10.44 + 12.20 - 11.3
	Pk. T	14.0 + 11.0 - 12.5	10.8 + 12.3 - 11.6		13.22 + 14.91 - 14.1
	Pk. C	12.2 + 8.5 - 10.4	17.3 + 11.2 - 14.3		17.86 + 17.86 - 17.86
88	Av. T	6.2 + 5.5 - 5.8	3.5 + 2.7 - 3.1		
	Av. C	2.7 + 7.4 - 5.1	5.5 + 5.0 - 5.3		
	Pk. T	12.0 + 12.0 - 12.0	10.3 + 11.1 - 10.7		
	Pk. C	15.0 + 24.0 - 14.5	17.5 + 30.7 - 24.1		
89	Av. T	5.1 + 3.9 - 4.5	15.6 + 16.1 - 15.8		
	Av. C	14.0 + 7.4 - 10.7	6.5 + 17.7 - 12.1		
	Pk. T	28.0 + 24.0 - 26.0	55.0 + 49.9 - 52.5		
	Pk. C	22.0 + 16.0 - 19.0	25.2 + 37.3 - 31.3		
90	Av. T	17.9 + 8.6 SCRAP	15.1 + 10.6 - 12.8		
	Av. C	20.3 + 21.1	21.3 + 28.7 - 24.8		
	Pk. T	>30.0 + >30.0	27.9 + 25.9 - 26.9		
	Pk. C	>30.0 + >30.0	32.5 + 45.6 - 39.0		

(a) 2 = unit 2 (PWR), R = refueling outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Table 1 (Continued)

Exam Number		2R4[a]	2R5	2R6	2R7
95	Av. T	2.3 + 3.9 - 3.1	4.5 + 5.5 - 5.0	4.7 + 5.3 - 5.0	
	Av. C	8.6 + 11.3 - 9.9	8.2 + 4.2 - 6.2	6.8 + 9.1 - 8.0	
	Pk. T	10.0 + 11.5 - 10.8	11.4 + 14.2 - 12.8	15.1 + 15.8 - 15.4	
	Pk. C	13.0 + 16.0 - 14.5	17.3 + 8.8 - 13.1	14.5 + 18.1 - 16.3	
96	Av. T	3.1 + .39 - 3.5	3.4 + 8.8 - 6.1	8.5 + 5.4 - 7.0	
	Av. C	9.0 + 5.1 - 7.0	12.2 + 13.4 - 12.8	15.8 + 14.0 - 14.9	
	Pk. T	7.0 + 6.0 - 6.5	7.1 + 11.4 - 9.3	12.9 + 10.4 - 1..7	
	Pk. C	13.0 › 10.0 - 11.5	13.3 + 17.0 - 15.2	22.1 + 20.7 - 21.	
99	Av. T	7.8 + 7.6 - 7.7	15.5 + 25.4 SCRAP	8.3 + 7.1 SCRAP	Changed to AD-153
	Av. C	7.0 + 7.6 - 7.3	31.1 + 43.7	7.1 + 9.8	
	Pk. T	20.0 + 23.0 - 21.5	39.7 + 49.8	15.3 + 13.7	
	Pk. C	17.0 + 26.0 - 21.5	50.0 + 30.0	21.0 + 20.4	
108	Av. T	.4 + 2.0 - 1.2	4.8 + 3.4 SCRAP	9.3 + 11.6 - 10.4	
	Av. C	8.2 + 9.0 - 8.6	5.9 + 7.9	15.3 + 11.1 - 13.2	
	Pk. T	4.0 + 7.0 - 5.5	8.1 + 6.5	20.2 + 22.1 - 21.2	
	Pk. C	14.0 + 14.0 - 14.0	11.3 + 13.1	29.3 + 22.8 - 26.0	
109	Av. T	2.3 + 3.5 - 2.9	10.1 + 10.9 - 10.5	Changed to AD-151	
	Av. C	13.7 + 14.0 - 13.9	14.9 + 15.1 - 15.0		
	Pk. T	7.0 + 8.0 - 7.5	15.1 + 18.0 - 16.5		
	Pk. C	20.0 + 20.0 - 20.0	^1.2 + 24.0 - 22.6		
110	Av. T	5.5 + 5.1 - 5.3	10.3 + 6.3 - 8.3		7.98 + 8.52 - 8.2
	Av. C	9.4 + 7.0 - 8.2	11.9 + 9.8 - 10.9		10.35 + 5.27 - 7.8
	Pk. T	9.0 + 10.0 - 9.5	15.7 + 11.9 - 13.8		12.52 + 13.13 - 12.8
	Pk. C	14.0 + 12.0 - 13.0	18.8 + 15.5 - 17.2		17.40 + 10.05 - 13.7
111	Av. T	4.3 + 2.7 - 3.5	8.8 + 8.6 - 8.7		6.20 + 4.73 - 5.5
	Av. C	7.8 + 9.4 - 8.6	10.1 + 9.0 - 9.5		6.56 + 5.61 - 6.1
	Pk. T	8.0 + 8.0 - 8.0	14.8 + 16.0 - 15.4		12.66 + 8.69 - 10.7
	Pk. C	14.0 + 14.0 - 14.0	16.0 + 17.2 - 16.6		11.39 + 9.37 - 10.3
112	Av. T	4.7 + 6.6 SCRAP	2.5 +	13.3 + 13.2	
	Av. C	.4 + 12.1	7.9 +	12.2 + 11.8 Changed	
	Pk. T	8.0 + >30.0	5.7 +	20.1 + 19.2 to	
	Pk. C	6.0 + 19.0	12.2 +	18.3 + 16.9 AD-71R	
113	Av. T	3.5 + 2.0 - 2.8	11.5 + 4.8 SCRAP	Changed to AD-71R	
	Av. C	3.9 + 2.0 - 3.0	10.9 + 13.6		
	Pk. T	10.0 + 8.0 - 9.0	16.7 + 9.3		
	Pk. C	14.0 + 9.0 - 11.5	19.5 + 21.3		
116	Av. T	3.5 + 3.5 - 3.E	3.1 + 3.4 - 3.3		
	Av. C	1.6 + 2.0 - 1.8	7.3 + 5.4 - 6.4		
	Pk. T	6.0 + 6.0 - 6.0	6.5 + 7.6 - 7.0		
	Pk. C	6.0 + 7.0 - 6.5	11.7 + 11.6 - 11.6		

---

[a] 2 = unit 2 (PWR), R = refuc'ing outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Table 1 (Continued)

Exam Number		2R4[a]	[illegible]	2R6	2R7
117	Av. T	5.1 + 4.3 - 4.7	1.8 + 3.2 - 2.5		
	Av. C	1.2 + 5.9 - 3.5	4.3 + 9.6 - 7.0		
	Pk. T	8.0 + 8.0 - 8.0	5.6 + 7.1 - 6.4		
	Pk. C	9.0 + 11.0 - 10.0	9.1 + 15.0 - 12.0		
141	Av. T	3.1 + 3.5 SCRAP	2.3 + 5.7 - 4.0		
	Av. C	.8 + 2.0	5.8 + 6.4 - 6.1		
	Pk. T	7.0 + 7.0	8.7 + 9.1 - 8.9		
	Pk. C	>30.0 + >30.0	10.0 + 10.7 - 10.4		
142	Av. T	7.0 + 4.7 - 5.8	13.2 + 4.5 - 8.8		
	Av. C	8.6 + 3.1 - 5.8	14.8 + 16.2 - 15.5		
	Pk. T	12.0 + 10.0 - 11.0	19.6 + 13.6 - 16.6		
	Pk. C	17.0 + 10.0 - 13.5	21.4 + 23.7 - 22.6		
144	Av. T	3.9 + 2.3 - 3.1	5.9 + 12.8 - 9.4	8.1 + 6.6 SCRAP	4.56 + 4.81 - 4.7
	Av. C	[illegible] + 3.1 - 1.8	20.6 + 16.3 - 18.4	12.5 + 9.6	7.93 + 2.51 - 5.2
	Pk. T	7.0 + 6.0 - 6.5	17.2 + 23.7 - 20.4	15.7 + 18.0	8.59 + 11.05 - 9.8
	Pk. C	4.0 + 8.0 - 6.0	29.3 + 23.5 - 26.4	17.9 + 18.5	10.93 + 9.69 - 10.3
146	Av. T	2.3 + 1.2 - 1.8	4.4 + 9.3 - 6.9		
	Av. C	2.3 + 4.7 - 3.5	10.1 + 7.7 - 8.9		
	Pk. T	8.0 + 5.5 - 6.8	7.9 + 13.0 - 10.5		
	Pk. C	7.0 + 10.0 - 8.5	15.7 + 13.4 - 14.5		
147	Av. T	5.5 + 3.5 - 4.5	5.1 + 5.6 - 5.4		
	Av. C	7.4 + 9.4 - 8.4	4.0 + 13.3 - 8.6		
	Pk. T	9.0 + 8.0 - 8.5	11.1 + 9.9 - 10.5		
	Pk. C	12.0 + 13.0 - 12.5	11.5 + 19.5 - 15.5		
153	Av. T	2.0 + 2.7 - 2.4	3.3 + 1.8 - 2.5		
	Av. C	10.9 + 8.6 - 9.8	9.5 + 9.1 - 9.3		
	Pk. T	8.0 + 8.0 - 8.0	7.0 + 6.3 - 6.6		
	Pk. C	18.0 + 18.0 - 18.0	16.4 + 16.0 - 16.2		
182	Av. T	9.0 + 6.2 - 7.6	13.9	11.0 + 11.9 SCRAP	Replaced with AD-153
	Av. C	10.1 + 8.6 - 9.3	18.9	10.0 + 13.8	
	Pk. T	16.0 + 15.0 - 15.5	41.8	45.9 + 49.9	
	Pk. C	16.0 + 16.0 - 16.0	32.5	27.9 + 30.0	
184	Av. T	7.8 + 1.2 - 4.5	10.1 + 6.2 - 8.1	[illegible] + 7.8 - 5.4	
	Av. C	10.5 + 15.6 - 13.0	16.0 + 12.8 - 14.4	9.9 + 14.3 - 12.1	
	Pk. T	13.0 + 7.0 - 10.0	17.2 + 14.3 - 15.6	11.8 + 9.3 - 10.5	
	Pk. C	14.0 + 21.0 - 17.5	23.0 + 22.0 - 22.6	15.3 + 15.1 - 15.2	
188	Av. T	6.2 + 2.7 - 4.5	8.6 + 4.6 - 6.5		3.44 + 3.44 - 3.4
	Av. C	2.3 + 5.5 - 3.9	7.2 + 10.0 - 8.6		10.30 + 12.54 - 11.4
	Pk. T	10.0 + 10.0 - 10.0	12.8 + 8.1 - 10.4		9.71 + 9.71 - 9.7
	Pk. C	8.0 + 15.0 - 11.5	13.2 + 16.6 - 14.9		16.54 + 17.45 - 17.0

(a) 2 = unit 2 (PWR), R = refueling outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Table 1 (Continued)

Exam Number		2R4[a]	2R5	2R6	2R7
192	Av. T	7.0 + 7.8 - 7.4	.8 + 1.8 - 1.3		13.74 + 10.86 - 12.3
	Av. C	18.' + 18.7 - 18.7	11.8 + 14.6 - 13.2		20.52 + 10.52 - 15.5
	Pk. T	14.0 + 28.0 - 21.0	14.2 + 7.3 - 10.7		24.20 + 17.62 - 20.9
	Pk. C	26.0 + 29.0 - 27.5	19.2 + 25.3 - 22.3		27.91 + 45.80 - 36.8
19'	Av. T	4.7 + 10.1 - 7.4	4.4 + 7.1 - 5.8		9.52 + 10.35 - 9.9
	Av. C	3.5 + 3.5 - 3.5	14.1 + 9.6 - 11.8		9.98 + 10.0 - 10.0
	Pk. T	11.0 + 17.0 - 14.0	10.6 + 14.0 - 12.3		18.74 + 17.54 - 18.1
	Pk. C	12.0 + 16.0 - 14.0	37.7 + 30.9 - 34.4		17.52 + 17.30 - 17.4
195	Av. T	2.7 .39 - 1.5	6.2 + 5.8 - 6.0		7.58 + 5.83 - 6.7
	Av. C	6.2 5.9 - 6.0	12.2 + 9.6 - 10.9		12.88 + 10.37 - 11.6
	Pk. T	6.0 + 3.0 - 4.5	11.7 + 10.4 - 11.1		12.03 + 10.69 - 11.3
	Pk. C	17.0 + 13.0 - 15.0	25.7 + 16.2 - 21.0		17.98 + 16.62 - 17.3
202	Av. T	3.1 + 16.6 SCRAP	6.7 + 4.8 - 5.7	3.2 + 3.0 - 3.1	
	Av. C	12.1 + 10.5	4.2 + 6.3 - 5.3	7.7 + 5.5 - 6.6	
	Pk. T	18.0 + >30.0	11.9 + 9.3 - 10.6	11.6 + 7.4 - 9.5	
	Pk. C	22.0 + 18.0	10.8 + 11.7 - 11.2	13.2 + 10.7 - '1.9	
205	Av. T	5.9 + 4.3 - 10.1	6.4 + 11.3 - 8.9	7.7 + 9.5 - 8.6	
	Av. c	6.2 + 5.9 - 6.0	14.5 + 14.8 - 14.6	6.9 + 10.5 - 8.7	
	Pk. T	10.0 + 10.0 - 10.0	13.7 + 16.9 - 15.3	12.2 + 14.5 - 13.3	
	Pk. C	12.0 + 10.0 - 11.0	,9.9 + 20.7 - 20.3	13.3 + 16.3 - 14.8	
244	Av. T	3.9 + 9.0 - 6.5	8.7 + 10.7 - 9.7	4.1 + 6.6 SCRAP	Replaced with AD-501
	Av. C	7.8 + 12.5 - 10.1	14.7 + 11.9 - 13.3	7.9 + 5.1	
	Pk. T	8.0 + 14.0 - 11.0	12.7 + 14.8 - 13.7	9.3 + 10.0	
	Pk. C	18.0 + 18.0 - 18.0	22.5 + 21.6 - 22.0	16.2 + 10.4	
245	Av. T	3.5 + 6.6 - 10.0	7.8 + 5.2 - 6.5	2.3 + 3.5 SCRAP	Replaced with AD-501
	Av. C	12.9 + 14.0 - 13.5	12.4 + 3.1 - 7.7	4.5 + 4.4	
	Pk. T	7.5 + 12.0 - 9.8	11.9 + 8.9 - 10.4	5.5 + 6.9	
	Pk. C	18.0 + 22.0 - 20.0	18.8 + 9.7 - 14.4	10.5 + 11.3	
247	Av. T	3.1 + 1.6 - 2.3	8.3 + 6.1 - 7.2	13.7 + 6.2 - 10.0	
	Av. C	4.7 + 3.9 - 4.3	5.8 + 9.5 - 7.6	7.5 + 7.5 - 7.5	
	Pk. T	12.0 + 8.0 - 10.0	12.1 + 10.5 - 11.3	19.5 + 13.4 - 11.4	
	Pk. C	10.0 + 10.0 - 10.0	15.3 + 14.9 - 15.1	15.5 + 16.0 - 15.8	
248	Av. T	1.6 + 3.1 - 2.4	6.0 + 3.2 - 4.6		
	Av. C	3.1 + 1.2 - 2.2	8.7 + 5.1 - 6.9		
	Pk. T	8.0 + 10.0 - 9.0	15.2 + 9.6 - 12.4		
	Pk. C	10.0 + 8.0 - 9.0	15.3 + 13.8 - 14.5		
254	Av. T	4.3 - 4.3	6.4 + 8.4 - 7.4		
	Av. C	5.5 + 9.8 - 7.7	8.7 + 9.0 - 8.8		
	Pk. T	8.0 - 8.0	22.5 30.2 - 26.3		
	Pk. C	16.0 + 14.0 - 15.0	33.3 + 25.4 - 29.3		

(a) 2 = unit 2 (PWR), R = refueling outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Table 1 (Continued)

Exam Number		2R4[(a)]	2R5	2R6	2R7
255	Av. T	3.5 + 3.1 = 3.3	4.4 + 9.0 = 6.7		
	Av. C	9.4 + 8.2 = 8.8	11.8 + 15.2 = 13.5		
	Pk. T	10.0 + 10.0 = 10.0	10.3 + 16.4 = 13.4		
	Pk. C	17.0 + 16.0 = 16.5	18.3 + 23.2 = 20.7		
269	Av. T	9.8 + 6.6 = 8.2	8.7 + 3.3 = 6.0		
	Av. C	1.2 + 6.6 = 3.9	16.8 + 10.5 = 13.6		
	Pk. T	20.0 + 15.0 = 17.5	27.6 + 13.5 = 20.5		
	Pk. C	7.0 + 15.0 = 11.0	24.2 + 18.3 = 21.2		
273	Av. T	3.9 + 5.5 = 4.7	2.1 + 4.4 = 3.3	4.1 + 2.7 SCRAP	Replaced with AD-501
	Av. C	2.0 + 3.9 = 3.0	11.6 + 9.1 = 10.3	5.8 + 6.0	
	Pk. T	8.0 + 11.0 = 9.5	5.9 + 8.5 = 7.2	7.0 + 7.1	
	Pk. C	13.0 + 12.0 = 12.5	18.1 + 15.6 = 16.8	10.7 + 12.2	
293	Av. T	5.5 + 7.8 = 6.6	4.2 + 6.2 = 5.2		
	Av. C	14.8 + 14.0 = 14.4	16.5 + 12.6 = 14.6		
	Pk. T	10.0 + 13.0 = 11.5	9.3 + 12.7 = 11.0		
	Pk. C	20.0 + 21.0 = 20.5	27.2 + 43.9 = 35.6		
295	Av. T	2.3 + 3.1 = 2.7	7.3 + 4.4 = 5.9		
	Av. C	7.4 + 10.1 = 8.7	17.1 + 10.0 = 13.5		
	Pk. T	9.0 + 8.0 = 8.5	.2 + 4.9 = 2.5		
	Pk. C	14.0 + 16.0 = 15.0	6.6 + 12.7 = 9.7		
393	Av. T		4.1 + 5.1 = 4.6		12.27 + 6.78 = 9.5
	Av. C		14.1 + 6.7 = 10.4		16.25 + 8.32 = 12.3
	Pk. T		9.4 + 10.1 = 9.7		17.59 + 11.91 = 14.7
	Pk. C		19.8 + 12.8 = 16.3		21.20 + 12.47 = 16.8

(a) 2 = unit 2 (PWR), R = refueling outage number, T = tension drag force (lbs.), C = compression drag force (lbs.)

Appendix G

Typical Mechanical Snubber Failure Causes (Plant C)

Appendix G

Typical Mechanical Snubber Failure Causes (Plant C)

This Appendix contains a list of mechanical snubber failure causes documented by plant personnel at Plant C. Failure causes are categorized in accordance with the following functional test failure categories:

- high drag force
- exceeded maximum acceleration limit
- below minimum acceleration limit.

TYPICAL MECHANICAL SNUBBE FAILURE CAUSES

PLANT C

HIGH DRAG FORCE

- o Lubricant dried out internally. Unit exposed to radiant heat from reactor recirculating pump.
- o Significant corrosion of torque drum and Capstan Spring. Torque carrier screw shaft bend caused when Unit tried to stroke under thermal expansion.
- o Weld slag spattered on indicating tube caused binding during stroke.
- o Guide rods and bearing assembly bent. Unit improperly twisted with wrench to align pad eye during installation.
- o Capstan Spring ear damaged [illegible] window. Unit improperly pulled apart while dust cover rings were loosened to align Unit pad eye during installation.
- o Internally corroded. Installed in normally dry area of primary containment. May have been improperly stored during initial plant construction.
- o Repetitive vibratory loads on Unit caused balls in thrust bearing to cut groove in its races.
- o Capstan Spring wound too tight by manufacturer. Rubbed on Unit cylinder during normal stroke instead of spinning freely caused breaking action of Unit.
- o Unit mounted vertically and housing became filled with water. Internals severely corroded. Poor protection during maintenance activities in the area.
- o Telescoping members binding due to high side load of unit.
- o Rough spots on planetary gears and shaft of unit due to poor handling of large snubber.
- o Bearing retainer nut became loose which occured due to handling or was loose at fabrication.
- o Fouling of snubber internals with dirt and metal filing causing binding.
- o Screw shaft sheared in two places. Unit overloaded due to system transient.
- o Poor machining of inner and outer telescoping members at factory. Pieces not concentric, causing a rub on one side.

TYPICAL MECHANICAL SNUBBER FAILURE CAUSES Page 2

PLANT C

HIGH DRAG FORCE (Cont'd)

- Slight bend in screw shaft near inertia areas. Inertia mass rubbing inside of dust cover.
- Dirt and dust on screw shaft thereby restricting movement.
- Adhesive on indicating tube causing binding of telescoping member. (Adhesive was left from tape used to cover unit with plastic during plant construction).
- Damaged inner race of thrust bearing (cracked in several places) due to transient overload forces.

EXCEEDED MAXIMUM ACCELERATION LIMIT

- Spring not wound tightly enough at factory. Would not tighten against cylinder at required acceleration.
- Capstan Spring not properly installed. Spring ears outside clutch window, unit could not activate.
- Small retaining parts of snubber internals were loose, Capstan Spring worn when unit was rattled during service checks.
- Improper assembly of internals did not allow Capstan Spring to tighten fully to activate Unit.
- Manufacturer's defect. Keeper ring not installed properly.
- Snubber ws damaged during handling. Stroked too hard causing it to lock.
- Dirt between inertia mass and lead screw caused mass to slip during activation.
- Capstan Spring not properly placed in unit at factory. Spring ears outside clutch window so unit could not activate.
- Dried dirt and grease in torque drum and inertia mass area, causing high acceleration.

TYPICAL MECHANICAL SNUBBER FAILURE CAUSES

PLANT C

BELOW MINIMUM ACCELERATION LIMIT

- Capstan Spring installed crooked at factory. Bound up on dust cover during cycling.
- Dirt and grit was caked on seat area of Capstan Spring, causing it to activate too low.
- Snubber inner thrust bearing race chipped, torque drum retainer bent. Subjected to frequent transients within design limits.
- Excessive grease placed in inertia mass area at factory causing slippage of internal parts during activation test.
- Severe corrosion of Capstan and clutch spring area. Unit was leaked upon by damaged pump seal.

Appendix H

Typical Mechanical Snubber Examination Record

Appendix H

Typical Mechanical Snubber Examination Record

This Appendix Contains a typical mechanical snubber examination record. This record was not obtained from one of the key study plants.

```
                                          Snubber Examination Record
************************************************************************************************************
Exam Number . . . . . :  89         Orientation to Pipe :  90          ISO Number . . . . . : 1-P-AB-177
Hanger Number . . . . :             High Vibration? . . : N            System . . . . . . . : AB
Component Number. . . :             Service Temperature : 135          Loop . . . . . . . . :
Serial Number . . . . : 36291       Humidity. . . . . . : DRY          Line Number. . . . . : 1-AB-1CCA-038
Size. . . . . . . . . : PSA 1/4     Radiation Condition : 5            N-5 Number . . . . . : 888111
Rated Load. . . . . . :   350       Accessibility Code. : 9            Scaffold Required? . : N
Design Type . . . . . : MSML        Building/Room . . . : 4220         Safety Class . . . . : A-Q
Functional Type . . . : M1          Elevation . . . . . : 113          Nuclear Class. . . . :
Date Seals Replaced :  /  /         Drywell Zone. . . . : 10           Hot Piston Set . . . : 2 9/16
Date New Seals Due. :  /  /         Grid Row. . . . . . : 1'N 18       Cold Piston Set. . . : 1 7/16
Date Installed. . . : 02/26/88      Grid Column . . . . : 1' E R       Movement . . . . . . : +1 1/8
Vertical Orientation:  90           Drawing Number. . . :              Last FT Date . . . . : 09/22/89
Location Description:                                                  Last FT Result . . . : P
************************************************************************************************************
 Perform Visual Exam? Y  Date Performed: 09/20/89  Result: S  Examiner:

          Work Order/NOA #:              Date Initiated:  /  /    Date Resolved:  /  /    Failure Code:
      Description:
       Resolution:
                  Acceptance Code:    Date Re-Examined: 10/11/89  Result: S  Examiner:
************************************************************************************************************
Functional Test Code: F  Date Performed: 09/22/89  Result: P  Examiner:
         Date As-Left Test Performed:  /  /    Result:    Examiner:

                                                         As Found                               As Left
                   Mechanical Snubber         Acceptance Tension  Compression  Acceptance Tension  Compression
           Breakaway Drag - Extended. (LBF)              1.81       6.44
           Breakaway Drag - Midstroke (LBF)              0.00       0.00
           Breakaway Drag - Retracted (LBF)              0.00       0.00
           Initial Running Drag . . . (LBF)              1.39       5.12
           Acceleration Limit . . . . (G's)              0.0073     0.0074
           Final Running Drag . . . . (LBF)              4.67       4.78
           Load Achieved. . . . . . . (LBF)              215        217

           Work Order/NOA #:             Date Initiated:  /  /    Date Resolved:  /  /    Failure Code:
      Description:
       Resolution:
                                   Acceptance Code:    Failure Analysis Code:
************************************************************************************************************
Snubber Replacement Code:    Incoming Snubber From Spares? N
Replacement Exam Number:    0  Component Number:        Serial Number:               Size:
Date Installed:  /  /    Disposition of Removed Snubber:

Work Package Reviewed and Accepted: Y  Reviewer:
```

Appendix I

Sample Mechanical Snubber Failure Evaluation Report

Appendix I

Sample Mechanical Snubber Failure Evaluation Report

This Appendix contains a failure evaluation report that reflects comprehensive evaluation of a mechanical snubber that was found to be frozen in service. The report reflects the methods used to identify and verify the problem and to determine the cause of failure.

This Appendix also includes a failure evaluation report associated with failure of two mechanical snubbers due to overload in the compression direction.

SYNOPSIS OF EVENTS

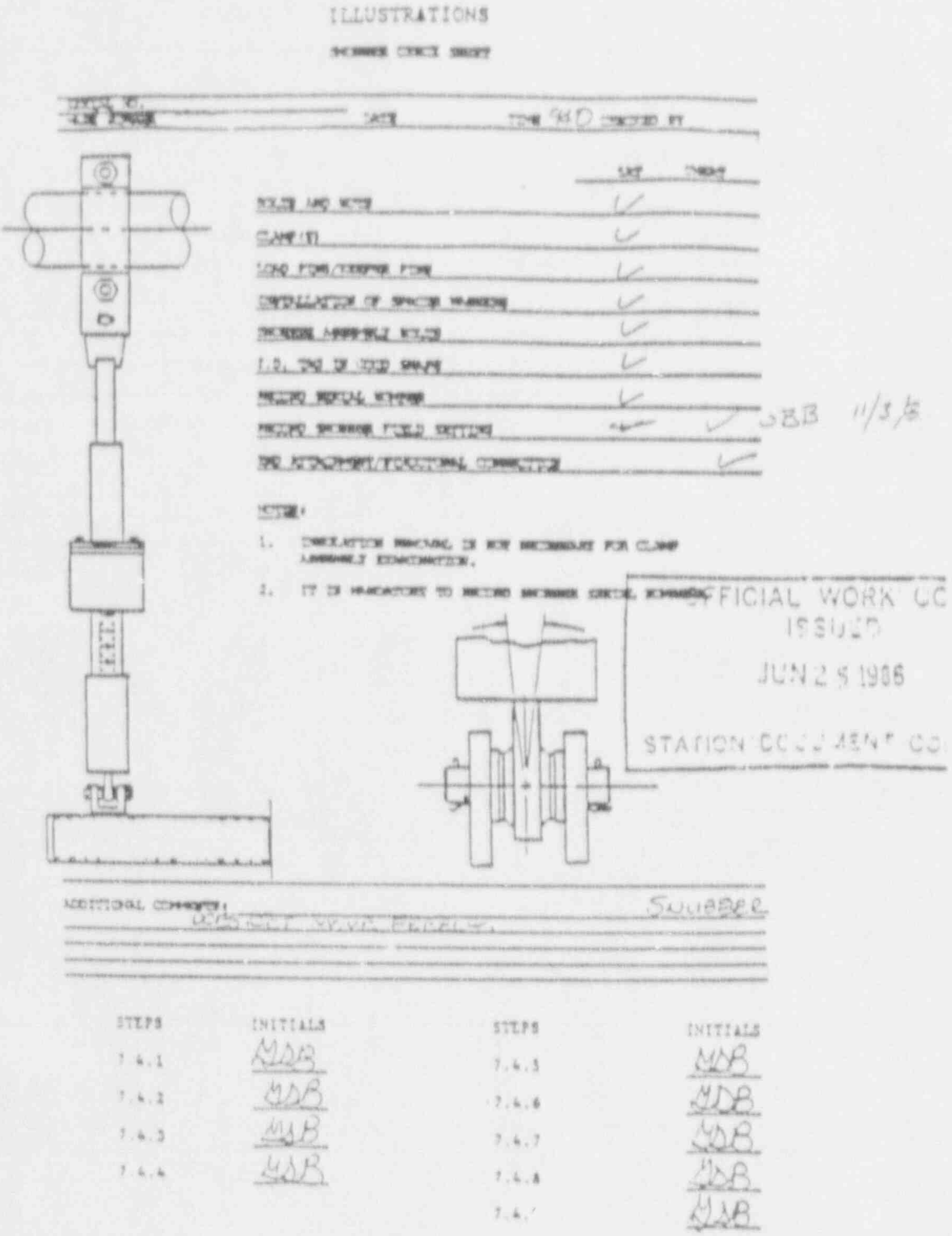
The following is a brief recount of the events surrounding the failure of high temperature snubber Serial No.

Per the requirements of Technical Specification a VT-3 examination was performed on support no. on 10/18/86. The exam, sited two conditions: the insulation for the reactor vessel head appeared to be binding the snubber extension tube, and paint on the lower bail bushing was hindering free rotation in the cone of action. Condition Report (CR) was written to evaluate these findings.

While reviewing the CR, Design Engineering found the field setting to be over 1 1/2 " off the design setting. MR was generated to address this additional concern. At this time the operability of the snubber was not believed to have been compromised, and on 10/28/86 Maintenance Work Order (MWO) was written to correct the conditions noted in the field.

On 11/04/86, MR was work released to change the snubber setting in the field. CR was written on 11/05/86 as a means of documenting the events prior to the discovery of the incorrect field setting.
On 11/06/86, Design Engineering was informed that the line to which the suject snubber was attached shifted over 1 1/2 " when the clamp was removed. This was the first indication that the snubber was damaged. FCN 1 to MR was then generated to document the snubber failure analysis (but was later cancelled as not required), and FCN 2 was generated to replace the failed snubber with one already installed just a few feet away.

was brought to the site on 11/09/86 to perform the snubber failure analysis. The cause of failure was determined to be from foreign matter lodged in the screw shaft assembly.



ILLUSTRATIONS

SNUBBER CHECK SHEET

[illegible] NO.
[illegible]   DATE   TIME 910 CHECKED BY

	SAT	UNSAT
BOLTS AND NUTS	✓	
CLAMP(S)	✓	
LOAD PINS/COTTER PINS	✓	
INSTALLATION OF SPACER WASHERS	✓	
SNUBBER ASSEMBLY BOLTS	✓	
I.D. TAG IN GOOD SHAPE	✓	
RECORD SERIAL NUMBER	✓	
RECORD SNUBBER FIELD SETTING	✓	✓ SBB 11/3/86
END ATTACHMENT/STRUCTURAL CONNECTION		✓

NOTES:

1. INSULATION REMOVAL IS NOT NECESSARY FOR CLAMP ASSEMBLY EXAMINATION.
2. IT IS MANDATORY TO RECORD SNUBBER SERIAL NUMBER.

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STATION DOCUMENT CO

ADDITIONAL COMMENTS: SNUBBER
[illegible]

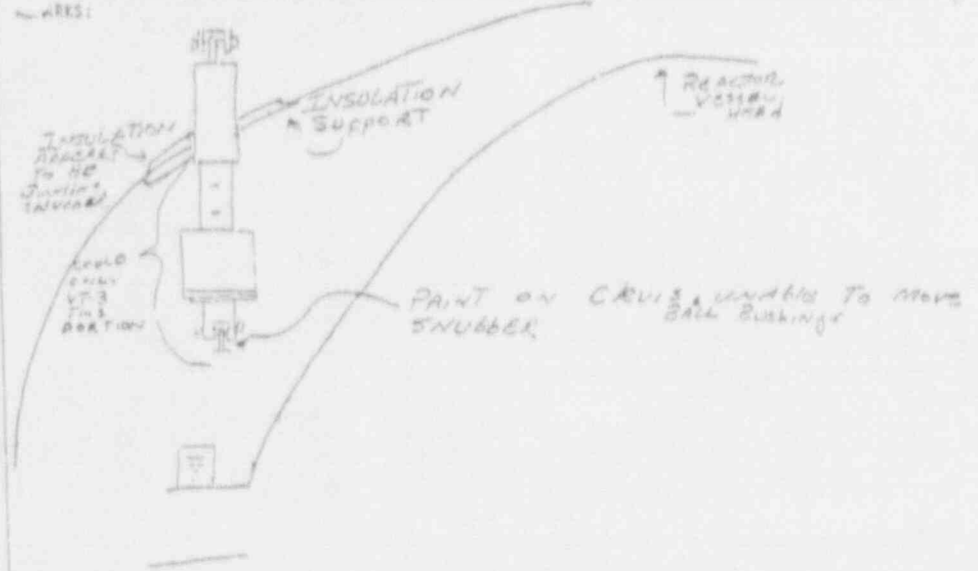
STEPS	INITIALS	STEPS	INITIALS
7.4.1	MDB	7.4.5	MDB
7.4.2	MDB	7.4.6	MDB
7.4.3	MDB	7.4.7	MDB
7.4.4	MDB	7.4.8	MDB
		7.4.[illegible]	MDB

VISUAL INSPECTION VT-3 INSPECTION REPORT

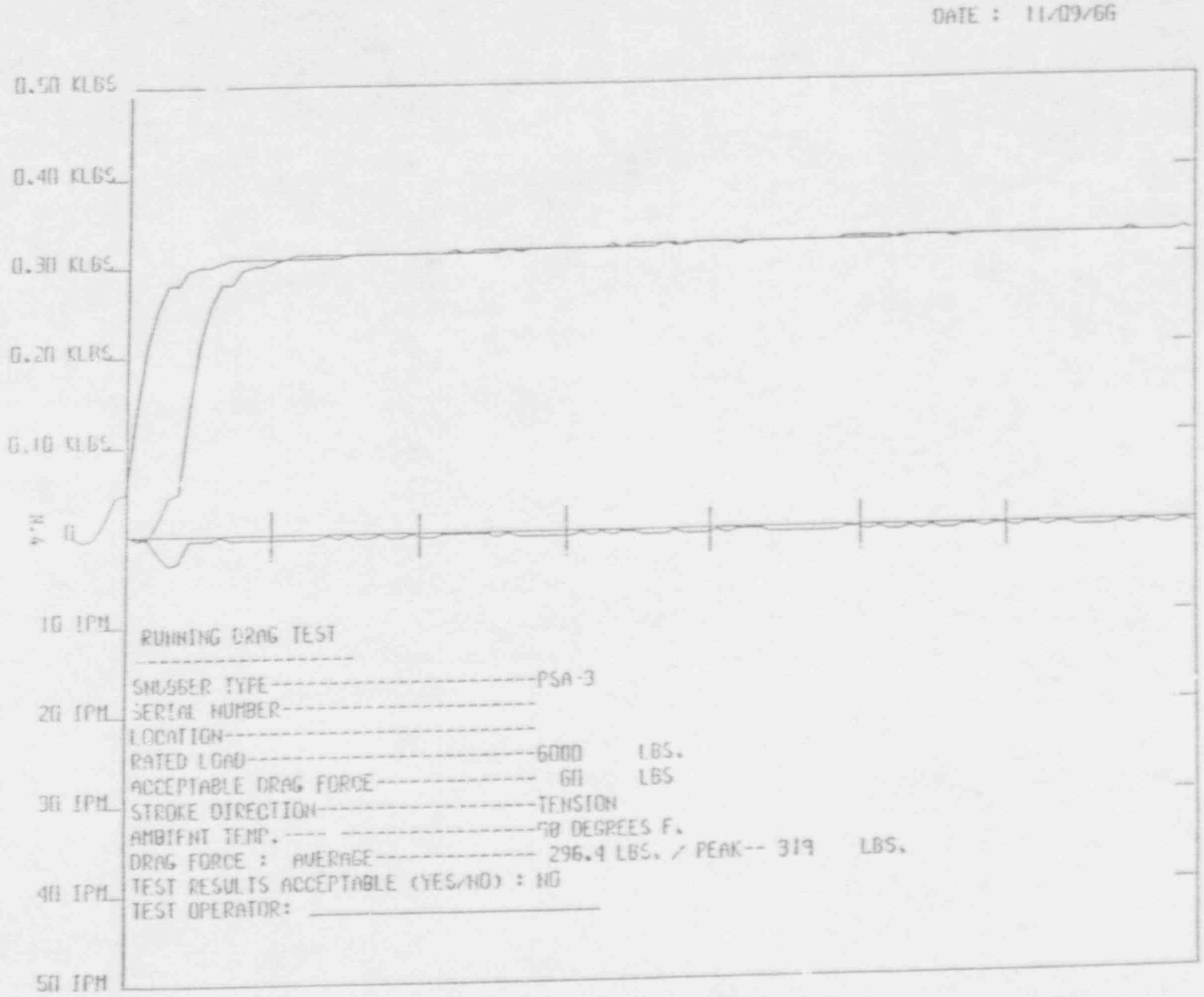
NO.	DATE: 10/18/86	COMPONENT ID	COMPONENT S/N	VT EXAMINER: SIGNATURE:	INSP. INI B/R/
TIME: 16min	PROCEDURE NO.	DRAWING NO.	SYS. CODE	LOCATION: DRYWELL EL. under insulation support	
ILLUMINATION VERIFIED: ☒ SAT ☐ UNSAT	EXAMINATION METHOD: ☒ DIRECT ☐ REMOTE		MATE USED N/A		

ID ITEM NO.	ATT. CODE	ATTRIBUTE INSPECTED N-NA, S-SAT, R-Recordable	RESULTS S,R,N	ATT. CODE	RECORDABLE CONDITIONS/COMMENTS
1.	T13	PREREQUISITES	S		
2.	T13	IDENTIFICATION	S		
3.	T13	ALIGNMENT	S		
4.	T13	PHYSICAL DAMAGE	S		
5.	T13	END ATTACHMENT	R		SEE REMARKS
6.	T13	CLAMPS	S		
7.	T13	WELDING	S		
8.	T13	INTERNALS	N		
9.	T13	SLIDING SURFACES	N		
10.	T13	FIELD SET DIMENSIONS	S		RECORD: 1½"

REMARKS:



N.3



```
DATE :  11/09/66

RUNNING DRAG TEST
------------------
SNUBBER TYPE-----------------------PSA-3
SERIAL NUMBER----------------------
LOCATION---------------------------
RATED LOAD-------------------------6000     LBS.
ACCEPTABLE DRAG FORCE--------------  60     LBS
STROKE DIRECTION-------------------TENSION
AMBIENT TEMP.---- -----------------70 DEGREES F.
DRAG FORCE :  AVERAGE-------------- 296.4 LBS. / PEAK-- 319    LBS.
TEST RESULTS ACCEPTABLE (YES/NO) : NO
TEST OPERATOR: ____________________
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Subject: Preliminary Report of Test and Failure Analysis Performed on PSA High Temperature Snubber S/N , November 9 and 10, 1986, at the Nuclear Station

1. On November 9 and 10, 1986, Mr. and Mr. , both of , assisted Station personnel in a test and disassembly for failure analysis of the subject PSA High Temperature Snubber. The snubber had been found in a locked-up, fully compressed position; and, when removed, could not be hand stroked. A determination was made to perform an as found breakaway test at the locked-up position, modified such that a load over 600 lbs-force (10% of full rated load) would not be exceeded. This limit, 10 times the minimum drag, was imposed to avoid potential further damage. The test was conducted and no movement was noted at a load of less than 400 lbs-force. A decision was made that no additional load would be applied and that the snubber would be disassembled for failure analysis.

2. Disassembly was performed by station personnel using both the station procedure and the Pacific Scientific Document No. PS-193, Rev. 4, March 1986. As each step was performed, components were inspected by Mr. . All steps through step AB of paragraph 4-3 of PS-193 were performed, except that the anti-rotation key was not removed, per step Z. The ball screw assembly was not removed from the ball screw shaft. Photographs were taken throughout the disassembly.

3. The following unusual conditions were noted during disassembly:

   a. All parts were noted to be in good condition with very little signs of wear at bearing or other moving contact areas. Except for the locked-up ball screw shaft, all moving parts appeared to function normally. There were no bright metal contact points on the capstan spring and spring tangs.

   b. The fine white powder and residual grease usually found in PSA snubbers was not evident. Instead, a black powder was found which was believed to be carbonized grease resulting from the high temperature application. This black powder could be wiped from surfaces and was not built up except on the bearing surfaces for the inertia mass. The inertia mass did not bind on these bearing surfaces.

   c. The telescoping cylinder was observed to have three bands of discoloration on its circumference. These bands did not exhibit signs of heavy wear or pitting and were only visible over an arc of about 120 degrees. The longitudinal spacing of these bands was measured. It was found that relative to the location of the lip on the support cylinder tube, the three bands corresponded to the snubber at cold, hot, and as found settings. The bands appeared to be the result of a steady side-load on the snubber.

d. The snubber did not show evidence of unlocking until the ball screw assembly was removed from the telescoping tube. When the end plug was removed, care was taken to empty the tube on a clean cloth. This was also accomplished while unstaking the telescoping cylinder from the ball screw assembly. Several particles of grit were noted on the cloth. Two bright metal particles appeared to come from the unstaking process. The other particles and were not easily identified as to source. Upon inspection a similar particle was noted inside the telescoping tube. That particle did not jar loose and was left in place. In service the snubber was mounted in a vertical position with the end plug up. In this position the snubber would be susceptible to lock-up in tension if a particle in the tube had fallen into the ball screw.

e. When free of all other assemblies, the ball screw would move hesitatingly up and down the ball screw shaft under its own weight. A slight touch would re-initiate motion. The shaft appeared satisfactory, but lacked signs of movement and wear. The ball screw appeared satisfactory, but would not sustain motion for more than two or three revolutions up or down the shaft under its own weight. As the ball screw was worked from end to end, this condition improved, but not to the extent of free motion from end to end.

f. Prior to testing and disassembly, plant personnel had indicated that the hanging position of the snubber was in an axially displaced position to one side, such that spherical bearing movement would be required. They further indicated that the spherical bearing on the housing end was frozen by paint, and that this bearing motion had been freed only after deconning had removed the paint. Evidence of this paint in and around the bearing was noted.

Conclusions reached from the above and other conditions found are as follows:

a. The snubber had been subjected to very little motion and apparently no vibration. All parts appeared in good condition.

b. Lack of lubricant did not appear to restrict motion of the inertia mass, thrust bearing, or other moving parts, except for the ball screw and shaft assembly.

c. The bands on the telescoping tube are clear evidence of side loading at the three positions of extension noted by measurement. This evidence of side loading is supported by the frozen spherical bearing.

d. Evidence of some grit in the telescoping tube was found after some shock to the assemblies during removal of the end cap, and unstaking the ball screw assembly. Other evidence of grit was found on the tubes inside wall. The ball screw was locked until these disassembly steps were performed. As the snubber was hung vertically, any grit in the tube could have fallen into the ball screw.

e. The screws securing the indicating tube to the end plug were found finger tight. Likewise, the set screws below were found finger tight. The end plug was misaligned approximately 10 degrees from the rear housing, indicating possible readjustment or removal during installation for alignment purposes.

f. The ball screw assembly appeared reasonably free in full length action only after removal from the telescoping tube. The noted hesitation in the travel of the ball screw on the screw shaft may have caused lock-up; however, only a light touch was required to initiate continued motion.

OVERALL CONCLUSION

Most probable cause of lock-up was from grit wedged in the ball screw assembly. This cause is not considered generic to the high temperature type snubber.

RECOMMENDATIONS

1. Hand stroking other similarly installed snubbers would indicate no lock-up condition exists and probably less than minimum running drag of 60 lbs-f. Based upon the excellent condition noted in the disassembled snubber, a high probability exists these snubbers are fully functional.

2. Although evidence of side loading was found, this did not appear to be the cause of lock-up. However, spherical bearings should be kept free from paint, etc., to allow complete freedom of motion.

3. The loose screws in the end plug showed no evidence of "lock tite," and were in fact barely finger tight. This, plus the visible realignment of the end plug indicates a possible removal at one time, and a source of particle contamination. PSA installation instructions should be followed.

4. The ball screw and shaft assembly should be replaced and the snubber rebuilt per PS-193 (with special instructions regarding parts and grease required for the high temperature snubber obtained from Pacific Scientific Co.). The removed ball screw and shaft should be returned to Pacific Scientific Co. for further analysis.

January 19, 1987

The cause of failure of ball-screw shafts from two system snubbers is attributed to sudden loading of the snubber resulting in buckling of the shafts. The fracture mode of the precipitation hardened stainless steel shafts is combined ductile and brittle fracture. Seams and cracking at the crowns of the threads are attributed to thread rolling during the manufacturing process and are not related to the snubber failures. Confirming chemical analysis shows the ball-screw shaft material to be 17-4 PH stainless steel.

INTRODUCTION

The failed snubbers are Pacific Scientific size 1 snubbers with a load rating of 1500 pounds. The service location of the snubbers was the auxiliary steam line for the Unit 1 auxiliary feedwater turbine. Failure of the snubbers was detected during routine surveillance required by technical specifications.

MACRO-EXAMINATION

The damaged ball screw shafts and capstan springs are shown in Figures 1 and 2. The shaft from sample 405-I fractured at two locations while 405-II fractured at a single location. The ball screw shafts plastically deformed adjacent to the fracture locations by bending prior to fracture. A tensile shear lip and compressive shear lip on both shafts indicated the shafts buckled under compressive loading. The specific location and size of the shear lips varied from fracture to fracture. The major portion of the fracture face possessed a shiny, brittle appearance (Figure 3). The key between the ball screw shaft and capstan spring housing was twisted out of the key slot in both snubbers indicating the shaft experienced a sudden torsional load. Seams formed during the thread rolling process are visible at the crowns of the threads.

FIGURE 1 As received view of snubber ball-screw shaft and torque transfer drum. Shaft failed in buckling as the result of a sudden compressive load. Fracture occurred at two locations. Ma-661.

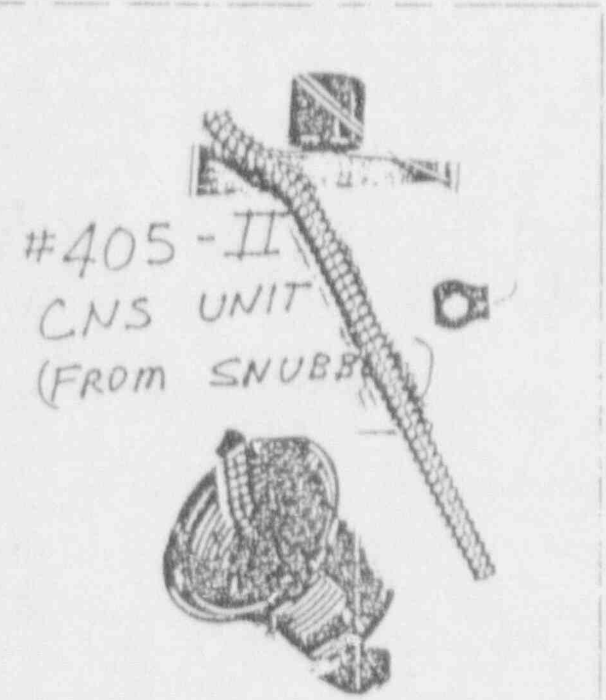


FIGURE 2 Second snubber ball-screw shaft which failed by buckling. Close inspection of capstan spring housing shows the key to the ball-screw shaft twisted out of the key slot. Ma-662.

The chemical analysis of the shaft material is consistent with that of 17-4 precipitation hardened stainless steel.

CONCLUSIONS

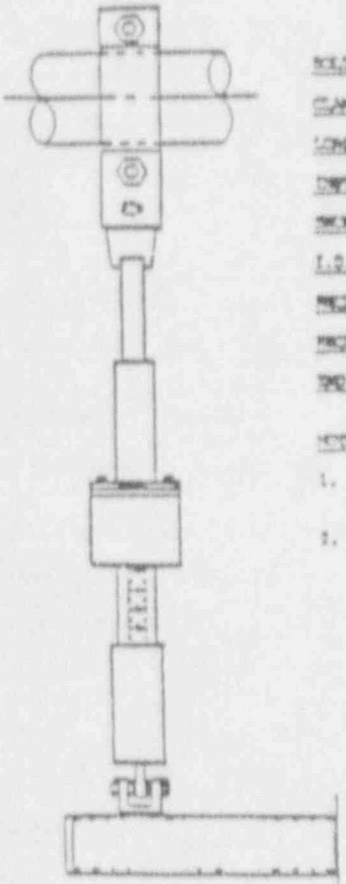
The ball-screw shafts of the Pacific Scientific size 1 snubber failed in buckling as a result of a sudden compressive overload force applied externally to the snubber. The keys between the ball-screw shaft and capstan spring housing were twisted out of the key slot by a sudden application of torque. The fracture faces are characterized by a combination of tensile and compressive fracture indicative of buckling. The material is in the hardened condition and the chemistry appears to be correct. The load required to buckle the ball-screw shaft has not been determined.

If the Metallurgy Lab can be of further assistance, please call.

ILLUSTRATIONS

SNUBBER CHECK SHEET

SNUBBER NO.
HGR NUMBER ______ DATE ______ TIME 940 CHECKED BY ______

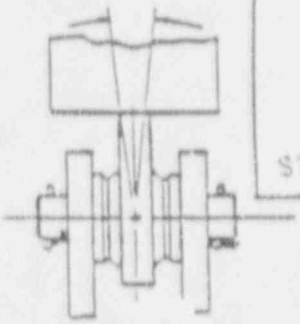


	SAT	UNSAT
BOLTS AND NUTS	✓	
CLAMP(S)	✓	
LOAD PINS/KEEPER PINS	✓	
INSTALLATION OF SPACER WASHERS	✓	
SNUBBER ASSEMBLY BOLTS	✓	
I.D. TAG IN GOOD SHAPE	✓	
RECORD SERIAL NUMBER	✓	
RECORD SNUBBER FIELD SETTING	~~✓~~	✓ JBB 11/3/8
END ATTACHMENT/STRUCTURAL CONNECTION		✓

NOTES:

1. INSULATION REMOVAL IS NOT NECESSARY FOR CLAMP ASSEMBLY EXAMINATION.
2. IT IS MANDATORY TO RECORD SNUBBER SERIAL NUMBERS.

OFFICIAL WORK CO
ISSUED
JUN 25 1986
STATION DOCUMENT CO



ADDITIONAL COMMENTS: SNUBBER
[illegible]

STEPS	INITIALS	STEPS	INITIALS
7.4.1	MDB	7.4.5	MDB
7.4.2	MDB	7.4.6	MDB
7.4.3	MDB	7.4.7	MDB
7.4.4	MDB	7.4.8	MDB
		7.4.9	MDB

Appendix J

Typical Visual Indicators of Snubber Degradation

Appendix J

Typical Visual Indicators of Snubber Degradation

This Appendix contains photographs of snubbers and snubber parts associated with various types of degradation.

Figure J.1 Mechanical snubber telescoping cylinder (with side loading marks from support cylinder in hot, cold, and as-found position)

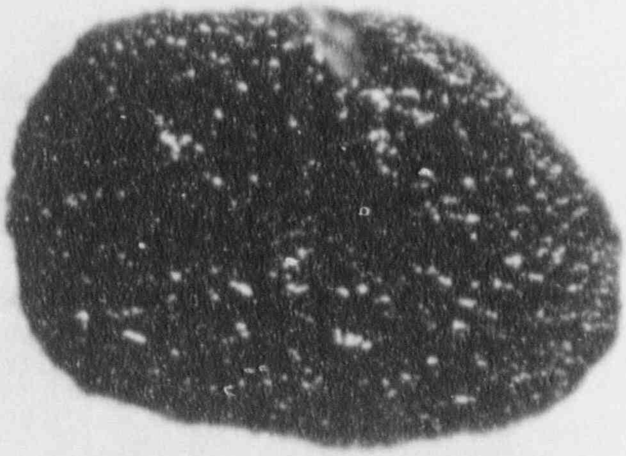


Figure J.2 Gelated, blackened hydraulic fluid (snubber subjected to high amplitude vibration)

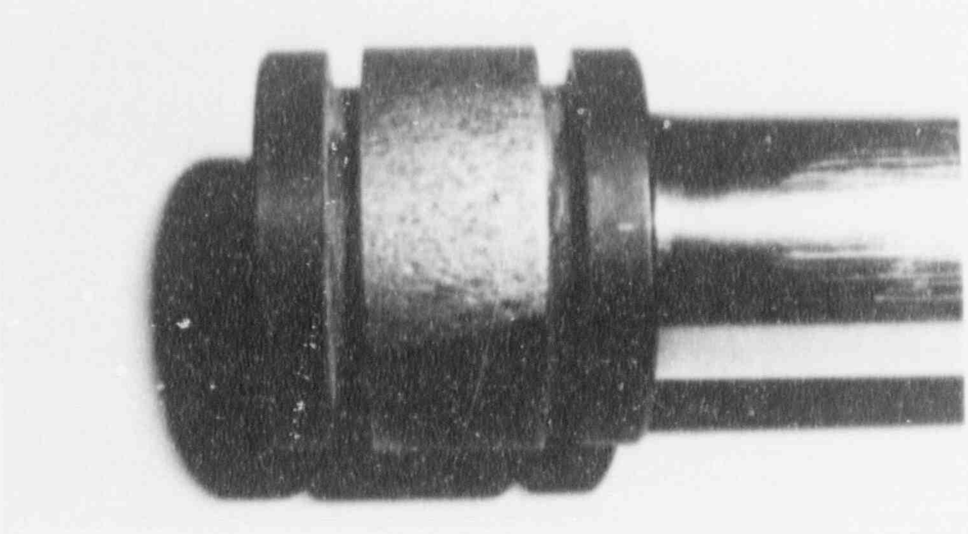


Figure J.3 Extensive piston wear (snubber subjected to high amplitude vibration)

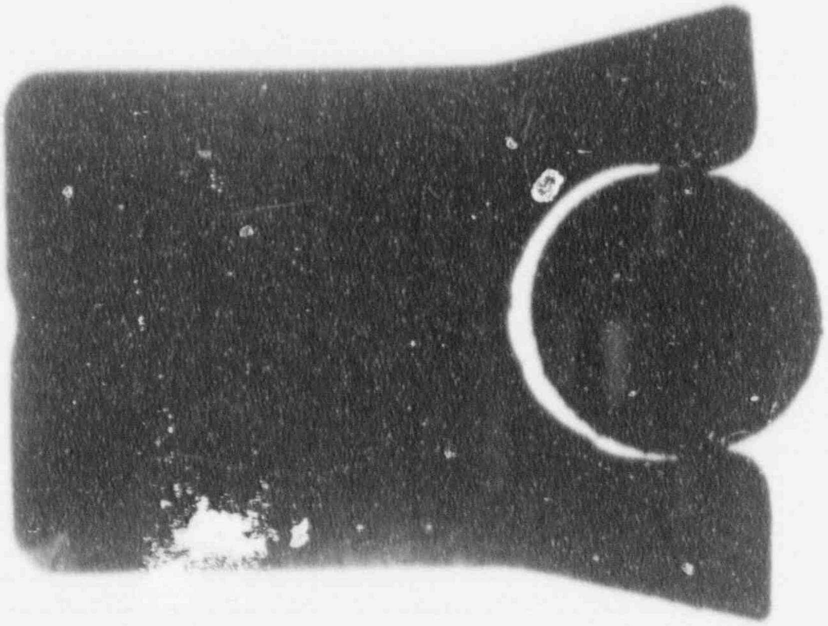


Figure J.4 Typical used o-ring lip seal (removed from snubber with 7 years service in moderate operating environment)

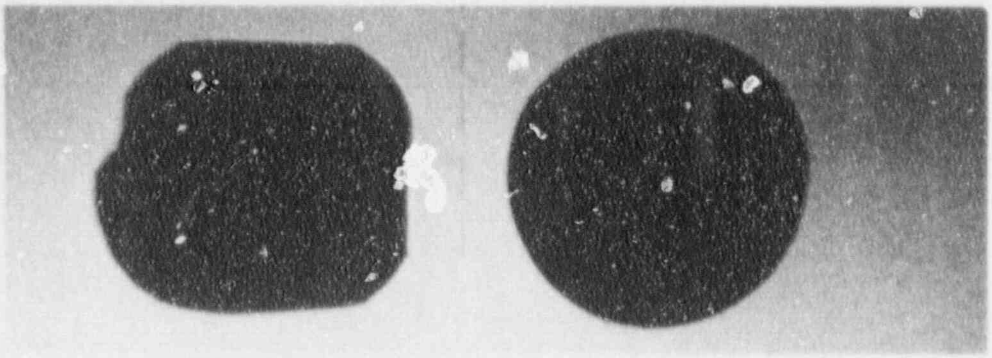


Figure J.5 Section photograph - o-ring with extensive set (left side) (removed from snubber with 1-1/2 years service in high temperature environment > 250° F)

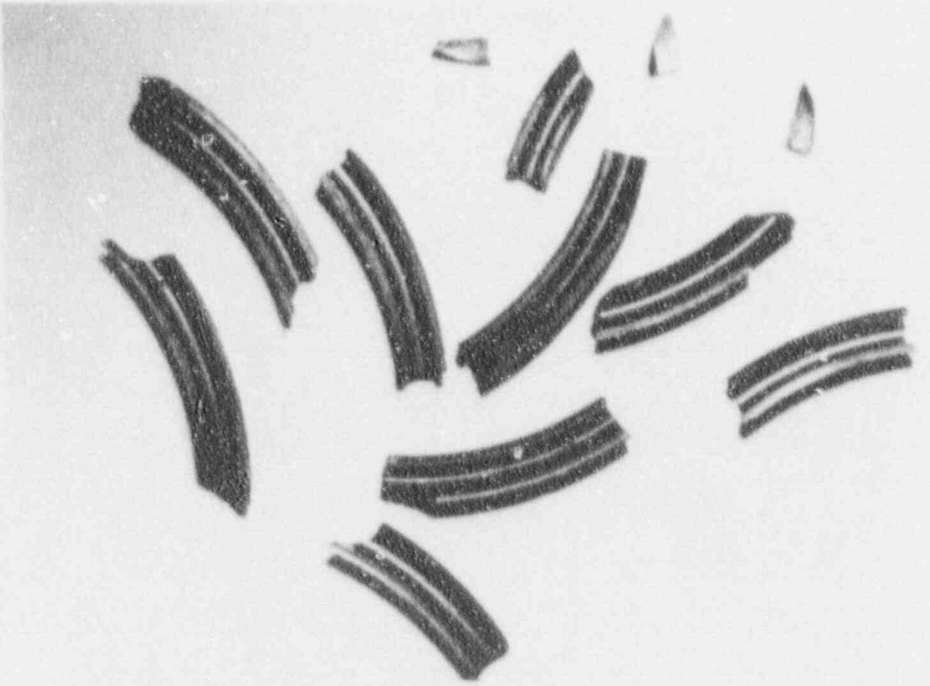


Figure J.6 Embrittled rod wiper (removed from snubber with 1-1/2 years service in high temperature environment, > 250° F)

Figure J.7 Embrittled o-ring with surface cracks (removed from snubber with 1-1/2 years of service in high temperature environment > 250° F)

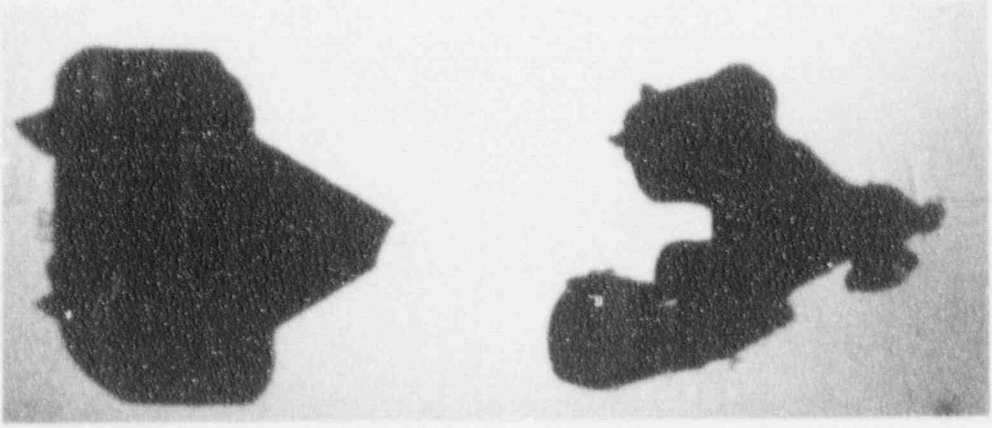


Figure J.8 Section photograph - damaged thread seal (right side) (seal damaged due to failure to utilize flat washer with nut)

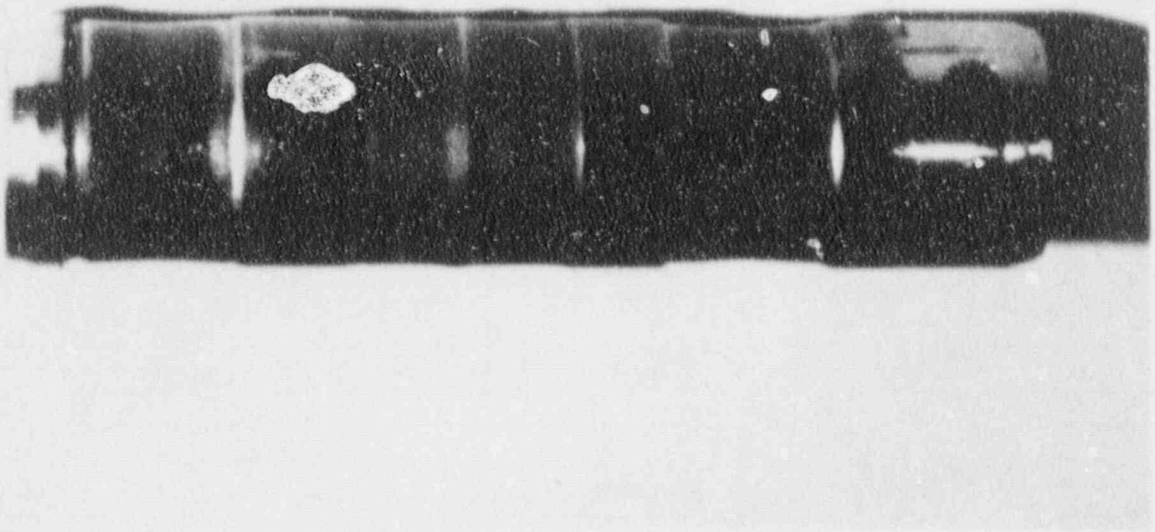


Figure J.9 Uniformly worn clevis pin (snubber subjected to continuous, low amplitude vibration)

Appendix K

Recommendations for Subsection ISTD

Appendix K

Recommendations for Subsection ISTD

This appendix includes recommendations identified from the NPAR In-plant Research for the Operations and Maintenance (OM) Part 4 Code, Section IST, Subsection ISTD, Examination and Performance Testing of Nuclear Power Plant Dynamic Restraints (Snubbers).

Contents

1 NPAR Snubber Aging Research Recommendations for ISTD

As a result of information obtained during the NPAR Snubber Task research, recommendations are made in the three following areas for the next revision of the ASME OM Code, Subsection ISTD:

- Service-Life Monitoring
- Visual Examination Attributes
- Failure Grouping and Corrective Action.

2 Service-Life Monitoring Recommendations

Service-life monitoring recommendations were developed from the results of the NPAR research. Major recommendations are highlighted below for consideration in the next revision of ISTD (Section 8.0 and Appendix F).

It should be noted that suggestions pertaining to service-life monitoring include a number of recommendations for testing in addition to that specified in ISTD, Section 7.0. Such testing includes trending tests, diagnostic tests, and post-service as-found tests. If such tests are included in ISTD, a statement should be included to specify that the results of such tests will not require testing of additional snubber samples in accordance with ISTD Section 7.9 or 7.12.

2.1 Determination of Snubber Failure or Degradation Causes

A service-life monitoring program will be most effective if it distinguishes between service-related and nonservice-related failures. It is important that the root cause of snubber failure or degradation (e.g. dynamic transient, vibration, excessive temperature, etc.) be identified along with the failure mode (e.g., high drag force, low activation, etc.) and the failure mechanism (e.g., deformation of screen shaft, solidification of grease, etc.).

It is suggested that failure evaluation data sheets provide key information, including failure mode, failure mechanism, failure cause, environment, service time, abnormal conditions, visual observations, test data, test observations, etc.

For effective determination of failure cause and root cause, it is important that personnel involved in failure evaluation have adequate experience. Failure evaluation data sheets should not be formatted in a manner that might lead the examiner to a potentially incorrect failure cause.

Table 1 lists typical irregularities that may be observed during visual examination or during snubber disassembly. These items characterize features of snubber degradation and may be useful to pinpoint the potential cause.

2.2 Determination and Documentation of the Operating Environment

Service-life monitoring techniques take into consideration the capability of the various snubber models to endure the full range of plant environments (benign to severe). Previously unidentified severe environments may often be identified by root cause evaluation of failed or degraded snubbers. Information regarding the snubber endurance capability is often obtained from operating experience (i.e., from failure data or by monitoring degradation).

Determination of specific environmental information often involves specialized instrumentation and equipment that would be impractical for use at every snubber location. The use of such equipment, therefore, would be most practical for those applications where moderate to severe environments are anticipated or as a diagnostic aid in determining the cause of snubber degradation.

Table K.1 Typical indicators of snubber degradation

Indicator	Possible Cause
Dark hydraulic fluid	High amplitude vibration
Black material deposit on rod	High amplitude vibration
Excessive piston and cylinder wear	High amplitude vibration
Worn capstan spring tangs	High amplitude vibration
Localized ball screw fretting	High amplitude vibration
Unsymmetrical wear of clevis pins	High amplitude vibration
Elongation of attachment holes	High and/or low amplitude vibration
Loose fasteners	High and/or low amplitude vibration
Symmetrical wear on clevis pins	Low amplitude vibration
Discoloration of metallic parts	Excessive temperature
Hardened piston rod wiper	Excessive temperature
Rod wiper adhered to piston rod	Excessive temperature
High compression set	Excessive temperature
Cracked seal	Excessive temperature
Lack of fluid pigmentation	High radiation level
Corrosion of metallic parts	High humidity/leaking components
Bent piston rod or attachments	Overloading
Changes in cold/hot position setting	Increased drag or jamming

Various methods and equipment used for measurement of specific environmental parameters are described below.

2.2.1 Temperature

Temperature-sensitive tape is useful for identifying hot spots. Ideally, however, to monitor environmental temperatures, a time/temperature profile is most useful. Chart recorders or digital data acquisition systems (e.g., bit loggers, computers, etc.) may be used for this purpose.

2.2.2 Radiation

Normal radiation levels in operating plants do not usually contribute significantly to snubber degradation. Pertinent data pertaining to plant radiation levels can generally be obtained from health physics area surveys. Measurement of radiation levels specifically for service-life monitoring does not seem justified, except in cases of snubber degradation where other potential causes have been ruled out.

2.2.3 Vibration

A number of methods and equipment for detecting and measuring vibration are available. They vary from simple visual observation, detection by "hands on" inspection, portable vibration measuring instrumentation, and remote vibration measuring equipment. Vibration can often be identified during routine snubber visual examination or during failure evaluation. Characteristics such as metal filings, darkened hydraulic fluid, deformed connecting pins, elongated attachment holes, and fretting of mating parts are indicators of vibration.

2.2.4 Transients

As with vibration, dynamic load transients that exceed the snubber load capacity may often be identified during routine inspections (e.g., observation of deformed structural members), augmented inspections (e.g., during hand-stroking of the snubber), and failure evaluation (e.g., deformed internal parts). In situ devices, such as load measuring clevis pins, are also available to monitor snubber load in applications where such transients are suspected.

2.3 Inservice Testing Results

Evaluation of time traces (e.g., load and velocity) obtained during routine functional testing is useful in identifying degradation that could lead to functional failure if not corrected. For example, an unusual number of load spikes may indicate the presence of dirt or other solid particles in the snubber; a single load spike may indicate local fretting of the ball screw. Follow-up diagnostic tests (see below) are useful for further evaluating such anomalies.

2.4 Diagnostic Testing

Diagnostic tests may be used to obtain information beyond that available from routine functional test data. Results from diagnostic testing can be helpful in identifying the failure or degradation mechanism. For example, a progressive decrease in the "bleed" velocity of a hydraulic snubber during a sustained load can be indicative of particulate contamination of the hydraulic fluid. Test equipment used for diagnostic tests should be configured to allow the application of various levels of controlled test parameters such as load and velocity.

2.5 As-Found Testing

Considerable information can be obtained by conducting post-service tests on snubbers removed from service.

2.6 Trending

Trending is a useful tool to monitor progressive snubber degradation. Trending has a number of important considerations:

- The establishment of baseline data is essential for trending.

- Trending data should be sufficiently accurate so that trends may be identified.

- Trending parameters should relate directly to the anticipated aging failure mode. Such parameters include, but are not limited to, drag force for mechanical snubbers and seal compression set for hydraulic snubbers.

  Note: An important example of inappropriate monitoring parameters is the use of functional test data for monitoring or trending seal degradation. Although seal degradation can affect functional test results to some extent, loss of low pressure sealing integrity--the primary aging failure mode for snubber seals--would not be reflected in functional test data.

- If test data are to be used for trending, it is recommended that the data be obtained consistently by the same type of test machine, under the same test conditions. Ideally, the same snubber should be used. Snubbers selected for trending should be representative of the service environment related to the snubber population to be monitored.

- Reservoir fluid level is the most appropriate trending parameter for monitoring snubber leakage.

  Trends in average drag force are generally more detectable than for peak drag force.

- A number of plants have established administrative limits for functional test parameters in order to prompt the replacement or repair of a given snubber before failure. This approach assumes that the parameter in question (e.g., drag force) is progressing toward the failure limit, which may or may not be the case. It is therefore recommended that administrative limits be established at a level that is outside the range of normal variations for the given parameter. Premature replacement or maintenance can increase the probability of snubber failure by introducing potential maintenance or manufacturing defects and reduce the potential benefits of the trending analysis.

2.7 Augmented Surveillance Methods

Various "hands-on" methods may be used to identify snubber degradation and to detect severe environmental conditions. These include hand stroking for verification of free movement, rotation of the snubber about its spherical bearings as a check for jamming, hand detection of vibration, and hand detection of high temperature.

2.8 Service-Life Categories

Depending on the significance of environmental extremes from one area in the plant to another, separate and distinct service-life populations may be practical. For example, it may be practical to establish a separate service-life population for snubbers in the upper level of the drywell for some BWR plants, due to relatively high temperatures in that area that may result in more rapid seal degradation. On the other hand, isolated applications involving very severe environments (e.g., steam tunnel, pressurizer cubical, etc.), should be managed separately on a case-by-case basis.

3 Visual Examination Attributes

Many attributes that should be included in snubber pre-service examinations need not be checked again during inservice examination. Snubber characteristics that are potential indicators for inoperability, e.g., empty reservoir, missing clevis pin, etc., are normally evaluated during inservice inspection (ISI). For service-life monitoring, characteristics that relate more to degradation prior to failure are emphasized. It is, therefore, recommended that Appendix B (Recommended Examination Checklist Items) be divided into three basic checklists: one for pre-service examination only, another for inservice and pre-service examination, and another for service-life monitoring.

3.1 Recommended Examination Checklist Attributes (Pre-Service Examination Only)

It is recommended that snubbers be visually examined for the following unacceptable attributes during pre-service examination only:

- snubber installed with preset locking screws (used for shipment only)
- snubber installed in wrong location
- protective coverings or shipping plugs not removed
- snubber freedom of movement impaired by interference with adjacent equipment
- other one-time pre-service checks recommended by the manufacturer.

3.2 Recommended Examination Checklist Attributes (Pre-Service and Inservice Examination)

Visual examination attributes that may indicate snubber inoperability during pre-service inservice examinations are listed below:

- non-pressurized reservoir oriented such that hydraulic fluid cannot gravitate to snubber
- severe corrosion or solid deposits that could impair snubber performance

- inadequate swing clearance
- paint on piston rod (could cause a frozen condition)
- permanent deformation (e.g. bending) of the snubber or its structural attachments
- inadequate reservoir fluid level
- clevis pin not installed
- weld arc strikes, weld slag, adhesive, or other deposits on piston rod or support cylinder (could cause a frozen condition)
- loose or missing fasteners
- cold or hot position setting varies from specified value
- spherical bearing not fully engaged in attachment lug

3.3 Recommended Examination Checklist Attributes (Service-Life Monitoring)

Typical attributes that should be noted for service-life monitoring purposes are as follows:

- evidence of corrosion
- evidence of solid deposits (e.g., boric acid) from leaking components
- loss of hydraulic fluid since previous visual examination
- metal filings on or in the vicinity of the snubber
- observed fluid leakage
- evidence of significant dark (i.e., black or dark brown) material deposit on piston rod
- rod wiper adhered to piston rod
- abnormal color of hydraulic fluid
- wear or deformation of clevis pins
- elongation of attachment holes
- evidence of wear on support cylinder
- cracked or deformed fluid reservoir
- evidence of foreign material (e.g., water, solid particles, etc.) in hydraulic fluid
- discoloration of metallic parts due to heat.

4 Failure Grouping and Corrective Action

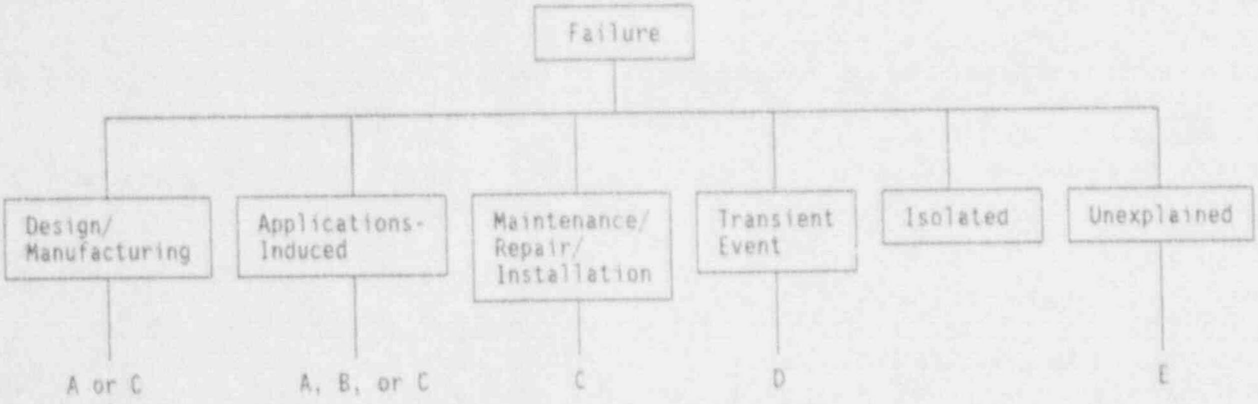
Subsection ISTD currently requires that any snubber that fails to meet functional test acceptance criteria be classified into one of six Failure Mode Groups (FMGs) (see Figure K.1). Depending on the FMG, various corrective action alternatives may apply.

The following recommendations pertain to the classification of failures and follow-up corrective action.

4.1 Definitions

It is recommended that the following definitions be included in Subsection ISTD. These definitions are consistent with those proposed by the Technical Committee on Common Aging Terminology (CAT):

- Failure Mode: The manner in which the snubber failed (e.g., high drag force, high acceleration, high bleed rate, low locking velocity, etc.).



A: Replace all FMG snubbers with compatible snubbers; no additional testing.
B: Change the environment; no additional testing.
C: Additional testing in FMG.
D: Test or stroke all FMG snubbers; no additional testing.
E: Continue testing in sampling plan.

Figure K.1 Current failure categorization and additional testing requirements

- Failure Mechanism: The physical process that resulted in failure (e.g., deformation of screw shaft, thermally induced compression set, etc.).

- Failure Cause: The circumstances during design, manufacture, or use which led to failure (e.g., excessive temperature, defective plating process, vibration, side loading, etc.).

- Root Cause: The fundamental reason(s) for failure which, when corrected, prevents its recurrence.

4.2 Elimination of the Isolated Failure Mode Group

Isolated failures should be identified by root cause evaluation. However, due to their singular nature, such failures cannot represent a group. It is therefore recommended that the isolated failure mode group be eliminated.

4.3 Distinction Between Service-Related and Nonservice-Related Failures

A snubber failure that is associated with a manufacturing or design deficiency could nonetheless be service related. For example, the root cause for a seal failure resulting from the inadvertent use of a seal material that is less resistant to heat than the material specified by the manufacturer may be identified as inadequate material control (a manufacturing-related failure cause). Although the seal may not have endured for as long as one manufactured from the specified material, it is likely that it did provide some amount of service prior to failure. The option should be allowed, therefore, for continued use of additional snubbers that may utilize this material, provided that the environment is adjusted to be compatible with the seal material.

Snubbers with a potential for failure from the same *root cause* should be assigned to the same root cause group (RCG) in order to take steps that would reduce potential failure during future operation. However, in order to establish additional testing requirements (ISTD), it need only be determined whether or not the failure is service-related, nonservice-related, or unexplained (see Figure K.2). Therefore, it is probably not necessary to pre-establish failure cause groups in Subsection ISTD.

Categorization using the snubber-grouping plan in Figure 2 would distinguish between service-related and nonservice-related failures. This is important for two reasons:

1. To monitor the rate of occurrence of service-related failures.

2. To provide the option to modify the environment for *all snubbers* subject to service-related failures without having to test additional snubbers. (This option is currently allowed for "applications-induced" failures only.)

Resulting data would facilitate the compilation of useful failure statistics, both plant-specific and for the industry in general, and would allow flexibility in establishing various RCGs in an industry data base without concern over conflict with ISTD.[1]

By comparing Figures K.1 and K.2, it can be seen that additional testing requirements associated with the proposed classification system are consistent with those currently in the ISTD standard. One change, however, is that the option to replace, modify, or repair all snubbers in the RCG (failed and unfailed) without requiring additional testing would be allowed for all failures. This option was previously allowed only for design, manufacturing, and application-induced failures.

4.4 Replacement or Modified Snubbers

Snubbers are occasionally subject to operating environments for which they have not been qualified. Such environments include dynamic load transients, high amplitude vibration, high temperature, etc. Paragraph ISTD 1.11.1 of the standard requires that replacement or modified snubbers have a proven suitability for the

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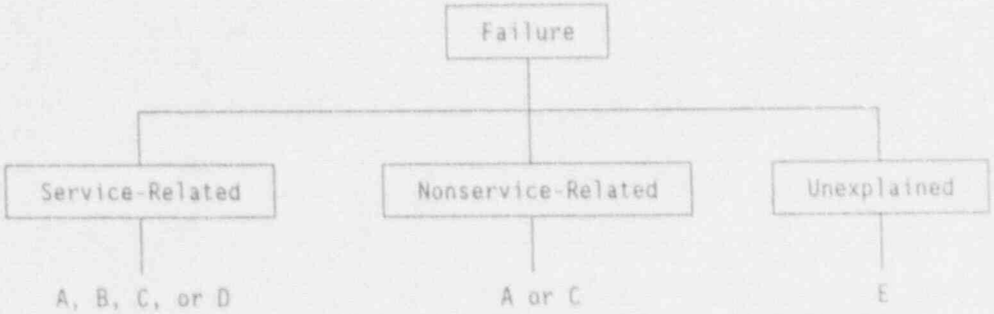
[1] The Snubber Utility Group (SNUG) has encountered difficulties in establishing failure categories for the SNUG data base due to potential inconsistencies with FMGs currently included in ISTD.



A: Replace all RCG snubbers with compatible snubbers; no additional testing.
B: Change the environment; no additional testing.
C: Additional testing in RCG.
D: Test or stroke all transient event snubbers; no additional testing.
E: Continue testing in sampling plan.

Figure K.2 Proposed failure categorization and corrective action application or environment. Because environmentally compatible snubbers are not available for all such applications, utilities often have no alternative but to continue to use the same snubber model or another unqualified model.

It is suggested, therefore, that some flexibility be provided in ISTD 1.11.1 that would allow for continued use of existing snubber models in such cases. For example, requirements for augmented inspections for these applications would ensure that snubbers would be replaced or maintained before failure.

Appendix L

Snubber Maintenance Recommendations

Appendix L

Snubber Maintenance Recommendations

This appendix includes a number of recommendations pertaining to snubber maintenance that were developed during the NPAR research.

Contents

1 General Maintenance Practices

In general, the effects of aging on snubber performance may be mitigated through the implementation of sound maintenance practices, including an effective service-life monitoring program. The goal of snubber aging management should be to ensure that snubbers are removed from service or maintained prior to failure. In this regard, if a snubber is suspected of being in a failed condition, it should not be repaired, modified, or altered before determining its operability, in compliance with current inservice inspection (ISI) requirements. However, this does not include snubbers not suspected of being in a failed condition that are subjected to preventive maintenance (e.g., the addition of hydraulic fluid to a low fluid reservoir).

2 Identification of the Operating Environment

Stressors of primary concern for snubbers are heat, vibration, transient loads, and moisture. Measurement of temperature and humidity levels in various plant areas is recommended; such information is useful in predicting snubber service life and for identifying possible [illegible] service-life populations. However, some judgement must be used in deciding the number and location of areas to be monitored.

Measurement of environmental parameters for specific snubber locations should be limited to applications for which severe operating conditions are suspected or used as a diagnostic aid to verify the cause of degradation or failure. Characteristics noted during visual examination or testing of degraded snubbers are often helpful in identifying the existence of severe operating environments. A number of instruments and techniques are available to measure environmental parameters, including temperature-sensitive tape, thermocouples, portable area temperature and humidity monitors, hand-held and remote vibration measuring equipment, load measuring clevis pins, strain gauges, etc. Various data acquisition systems are available for use in obtaining a time profile for environmental parameters.

3 Snubbers Prone to Rapid Degradation in Severe Environments

Snubbers in isolated applications that are prone to rapid degradation, i.e, within two to three operating cycles, should be identified and managed on a case-by-case basis. Such applications frequently involve small capacity snubbers installed on piping that is attached to large capacity, high energy systems. Snubbers with particularly long extension pieces appear to be vulnerable to such degradation. Environmental stressors that can cause rapid degradation include high amplitude vibration, dynamic transients, and high temperature, e.g., above 250°F. Such applications may require augmented inspections (Section 8.0) or maintenance or frequent replacement with new or refurbished snubbers. Other alternatives include replacement with snubber models or materials that are more compatible with the environment, e.g., Viton seals for high temperature applications, modification of the environment (Section 6.0), or elimination of the requirement for a snubber at that location (Section 7.0).

4 Failure Evaluation

Determination of the cause of snubber failures or degradation is essential for adequate management of snubber aging. Separation of service-related and nonservice-related degradation and failures is necessary to ensure that nonservice-related degradation is not included in the data base used to monitor snubber aging. Also important is identification of the root cause in order that conditions resulting in the degradation or failure may be rectified.

Various techniques and considerations are recommended for evaluating and documenting failure or degradation causes. These include:

- pre-identification of logical steps to be used in the evaluation
- visual examination
- personnel training
- diagnostic testing (Section 13.1)
- photographic documentation of observations
- metallographic analysis
- hydraulic fluid analysis (Section 8.6)
- chemical analysis
- physical property analysis.

5 Failure Grouping

Failure grouping is a useful method for ensuring that all snubbers subject to a particular root cause of failure are identified and managed accordingly. Implementation of this method involves using insight and judgement to optimize its effectiveness.

Failure groups should be based upon the *root cause* of failure, not necessarily the simple cause. It may be determined, for example, that the failure cause for a given snubber was high temperature, and that the root cause was a local steam leak associated with a valve having a particular manufacturing defect. The failure group should include only those snubbers that are subject to degradation from that root cause, i.e., degradation due to leakage from that valve or other valves having potential for the same manufacturing defect. Elimination of the root cause, e.g., repair of defective valves, and evaluation of all snubbers in the group would justify elimination of the failure group as well as any augmented inspection requirements. However, this would not justify the elimination of special requirements for other snubbers that may be subject to high temperature degradation resulting from another root cause.

For the above reasons, failure groups should not be established prior to the identification of a failure and its subsequent root cause analysis.

6 Modification of the Operating Environment

One method for minimizing snubber degradation in a severe operating environment is to modify that environment. Examples of this approach involve the following:

- use of heat shields for high temperature applications
- repair of leaking components in order to reduce the humidity or corrosives
- improved plant ventilation or cooling
- system modification to reduce vibration or dynamic transients
- use of protective boots to minimize corrosion.

7 Snubber Elimination

Snubber applications involving severe operating environments and snubber models that are particularly susceptible to service degradation should be priority targets in a snubber elimination program. This supports the need for close coordination between maintenance and engineering personnel (Section 17.0).

8 Augmented Inspections

Augmented inspections, i.e., inspections in addition to that required during routine ISI, are recommended for snubbers in severe operating environments (Section 3.0) and for snubbers susceptible to rapid degradation. A number of techniques and hardware that are useful for conducting such inspections are described in the following subsections.

8.1 Hand Stroking

Removal of one clevis pin and hand stroking a mechanical snubber while listening and feeling for abnormalities is a useful method for identifying degradation that could lead to eventual snubber failure. This method requires some judgement on the part of the inspector, supporting the need for experienced personnel and adequate training (Section 15.0). This method is also particularly useful for identifying degradation due to dynamic transients.

8.2 Rotation in Place

A useful method for evaluating snubbers that are suspected of being locked-up (or jammed) is to attempt to rotate the snubber about its longitudinal axis within the physical limits allowed by the clevis attachments. If the snubber can be rotated freely, the probability is low that the snubber is locked, since lockup during thermal motion of the piping or equipment would have resulted in a significant axial load, prohibiting free rotation of spherical end bearings. This method is most effective for snubbers with a load capacity of 3,000 lb or less.

8.3 Augmented Testing

Snubber degradation may often be detected by evaluating functional test traces. Diagnostic testing (Section 13.1) in which controlled test parameters are varied is also useful in this regard.

8.4 Measurement of Degradation Stressors

Various degradation stressors such as operating environment, dynamic transients, etc., may be monitored using various types of instrumentation or devices (Section 2.0). Such methods are particularly useful for monitoring snubbers subject to severe operating conditions.

8.5 Boroscopic Evaluation

A boroscope is sometimes useful for internal inspection of hydraulic snubbers. Such inspections may reveal, for example, significant wear of internal parts or the existence of solid particles caused by wear or internal corrosion.

8.6 Fluid Analysis

Microscopic evaluation of hydraulic fluid samples can identify the existence of solid contaminants and can often be used to identify the source of such particles, e.g., particles generated during machining, corrosion products, wear products, etc. Moisture evaluation of the fluid is also useful for evaluating fluid from snubbers with vented reservoirs in high humidity environments.

9 Snubber Maintenance Frequency

Scheduled maintenance should be based on realistic considerations in regard to progressive degradation. It should be noted that frequent, unnecessary maintenance, e.g., seal replacements, can actually increase the probability of snubber failure due to damage or errors.

Maintenance frequency should be based on an assessment of the degradation rate for the general snubber population in the plant, i.e., those snubbers in the normal plant operating environment, excluding isolated snubbers in severe environments (Section 2.0). If degradation data from snubbers in service are to be used to establish the scheduled maintenance frequency, then such data should be obtained from snubbers exposed to operating environments that represent the environmental extremes for the general population of snubbers, e.g., snubbers from the upper level of the drywell etc. In some cases, depending upon environmental variations in the plant, it may be practical to establish more than one service-life population.

10 Trending

10.1 Evaluating Trends in Test Results

In general, evaluations to identify trends in snubber degradation should not rely on functional test data obtained during ISI. Such data is often not useful for identifying trends because more than one data point for the same snubber is often not available (i.e. the same snubbers are not tested during each outage. For this reason, if test data, e.g., snubber drag force, are to be used for trending, representative snubbers should be selected and tested periodically, using the same test machine. For any trending evaluation, the establishment of baseline data (Section 11.0) is extremely important. Such tests should be conducted separately from routine ISI tests.

10.2 Parameters for Trending

Parameters to be used for trending should relate to the anticipated degradation mechanism, e.g. compression set in seals or drag force for mechanical snubbers.

10.3 Reservoir Fluid Level

Reservoir fluid level for snubbers with a pressurized reservoir can be easily determined by observing the fluid level indicator. However, for vented reservoirs used on many hydraulic snubbers the fluid level may not be easily quantified. Verification of progressive fluid loss is therefore difficult. A method to verify fluid loss from one inspection to the next is to mark the fluid level on the reservoir and to compare the level with this mark during subsequent inspections.

10.4 Administrative Acceptance Limits

If administrative functional test acceptance limits are used to identify snubbers to be replaced or overhauled, they should not be too restrictive such that snubbers that are not progressively degrading are unnecessarily replaced or refurbished.

10.5 Baseline Data

If degradation parameters, e.g. snubber drag force, are to be monitored for trends, the establishment of baseline data is essential (Section 11.0).

11 Baseline Data

For trends to be identified, more than one data point for a given parameter is required with respect to time (or number of cycles). Therefore, attempts to identify trends based on a single inservice data point, e.g. drag force, without the existence of baseline (initial) values, require unnecessarily conservative assumptions. Two examples in this regard are the assumption that a measured drag force value of 2% indicates that drag forces is increasing, and 2) the assumption, in calculating compression set, that the initial seal thickness was the maximum value allowed by the manufacturer.

11.1 Baseline Test Data

It is recommended that baseline test data for snubber activation parameters (locking velocity, release rate, acceleration threshold, etc.) and drag force (for mechanical snubbers) be obtained for plant snubbers, whenever possible. Ideally, this data should be consistently obtained under the same test conditions, using the same test machine (Section 13.2). Baseline data would be available for comparison with inservice data for identifying degradation trends.

11.2 Baseline Seal Data

Premeasurement of the section thickness of replacement seals before their installation in the snubber will provide baseline data that may be used for a more accurate (i.e., less conservative) evaluation of seal life at a future date. Similarly, baseline data for seal hardness would also be useful.

Data from plant seal life evaluations have indicated variations in seal degradation for various plants and for different seals in the same snubber in the same plant. Unless the seal compound is documented, it is impossible to determine whether or not such variations are the result of differences in seal materials.

Documentation of seal compounds for replacement seals will provide a basis for evaluating the performance characteristics of various seal compounds.

12 Snubber Data Base

An automated snubber data base is strongly recommended for managing snubber service data, documenting snubber installation locations, and documenting maintenance activities. It is important that such data bases be updated regularly.

13 Functional Test Equipment

It is recommended that a snubber test machine be maintained at the plant, in addition to any test equipment that might be temporarily located at the plant during ISI. The plant test machine should be available for diagnostic testing, trending, and verification of degradation.

13.1 Diagnostic Testing

Diagnostic tests are extremely useful for verifying test results obtained during ISI and for determining the mechanisms associated with any failures or degradation. For diagnostic testing, the test machine should be capable of producing a time-related trace of test parameters, e.g., velocity and load. Manual operation of the tester is also important as well as the ability to vary the level of controlled test parameters.

13.2 Trending

ISI data is generally not usable for identifying degradation trends, such as increasing drag force in mechanical snubbers. Separate trending tests should be conducted using the same test machine that was used to establish baseline data (Section 11.0) for the selected snubbers. The test machine should have some automated capability to minimize operator influence during trending tests. Since average drag force is generally more meaningful in identifying trends, a data management system capable of calculating average drag force would be useful.

13.3 Verification of Degradation

The operability of snubbers for which degradation or failure is suspected, e.g., unacceptable snubbers identified during visual examinations, may be evaluated by functional testing. The availability of an in-house test machine will allow for expeditious evaluation, in lieu of shipping the snubbers off-site or postponement of testing until ISI tests are conducted.

14 Spare Snubber Rotation

Replacement (rotation) of snubbers removed from service with spare snubbers is useful in reducing the need for snubber refurbishment during refueling outages. The following suggestions pertain to spare snubber rotation:

- Judgement should be used for snubbers with a significant amount of remaining service life that are removed for reasons other than maintenance, e.g., for functional testing. Arbitrary replacement of such snubbers will reduce the amount of service data that will be available for use in the service life data base, and possibly increase the probability of snubber failure due to the introduction of maintenance or manufacturing deficiencies that may exist in the replacement snubbers.

- Seal life begins when the seals are installed. Therefore, in order to optimize service life, seal replacements for spare hydraulic snubbers should be scheduled so that the period of time between seal replacement and anticipated snubber installation is

- A data base for tracking the various installed locations for each snubber should be maintained (Section 12.0).
- If snubbers with remaining service life are removed and then reinstalled without refurbishment, every effort should be made to install the snubbers in the same locations from which they were removed. The cause of failure or degradation of snubbers that were installed in various plant locations would otherwise be extremely difficult to determine.

15 Personnel Qualification

A key maintenance consideration in managing snubber aging is the qualification of maintenance personnel. Adequate training is obviously important, but since good maintenance practice involves considerable judgement, experience is of equal importance. Steps should therefore be taken to minimize turnover of experienced maintenance personnel.

As a minimum, training in the following areas is recommended:

- snubber testing, diagnostic testing, testing for trends, and recognition of test anomalies
- snubber visual examination and recognition of meaningful visual anomalies
- snubber rebuilding and recognition of meaningful anomalies during overhaul
- determination of failure or degradation causes (Section 4.0)
- snubber handling, installation and storage procedures.

16 As-Found Evaluation

As-found evaluations may provide information that is useful in identifying and managing degradation that might otherwise have gone undetected. It is recommended that snubbers removed from service be visually examined and functionally tested before reinstallation in the plant and before performing any maintenance. Hand stroking of mechanical snubbers is also recommended.

17 Coordination and Communication

Continuous coordination between ISI, maintenance, engineering, quality assurance, and engineering staff is important. For example:

- Coordination with ISI staff can optimize service data for both ISI and service-life monitoring use.

- Coordination with engineering staff can ensure elimination of problem applications in a snubber reduction program.

- Communication with operations staff will aid in the identification of dynamic transients.

18 Replacement Parts and Materials

The use of replacement parts that are most resistant to degradation due to the service environment are recommended. Examples here include:

- use of temperature-resistant lubricants
- use of temperature-resistant seal materials, e.g., Viton
- use of corrosion-resistant materials for snubbers in high humidity environments.

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11. ABSTRACT *(200 words or less)*

This report describes the aging research results and recommendations for snubbers used in commercial nuclear power plants. Snubbers are safety-related devices used to restrain undesirable dynamic loads at various piping and equipment locations in nuclear power plants (NPPs). Each snubber must accommodate a plant's normal thermal movements and be capable of restraining the maximum off-normal dynamic loads, such as a seismic event or transient, postulated for its specific location. The effects of snubber aging and the factors that contribute to the degradation of their safety performance need to be better understood. Thus Phase II of Nuclear Plant Aging Research was conducted to enhance the understanding of snubber aging and its consequences. Pacific Northwest Laboratory staff and their subcontractors, Lake Engineering and Wyle Laboratories, visited eight sites (encompassing thirteen plants) to conduct interviews with NPP staff and to collect data on snubber aging, testing, and maintenance. The Phase II research methodology, evaluation, results, conclusions, and recommendations are described in the report. Effective methods for service-life monitoring of snubbers are included in the recommendations.

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