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Basis for Snubber Aging Research: Nuclear Plant Aging Research Program

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ABSTRACT

This report describes a research plan to address the safety concerns of aging in snubbers used on piping and equipment in commercial nuclear power plants. The work is to be performed under Phase II of the Snubber Aging Study of the Nuclear Plant Aging Research Program of the U.S. Nuclear Regulatory Commission with the Pacific Northwest Laboratory (PNL) as the prime contractor. Research conducted by PNL under Phase I provided an initial assessment of snubber operating experience and was primarily based on a review of licensee event reports. The work proposed is an extension of Phase I and includes research at nuclear power plants and in test laboratories. Included is technical background on the design and use of snubbers in commercial nuclear power applications; the primary failure modes of both hydraulic and mechanical snubbers are discussed. The anticipated safety, technical, and regulatory benefits of the work, along with concerns of the NRC and the utilities, are also discussed.

SUMMARY

This report proposes a research plan to address and investigate aging and degradation of the safety-related hydraulic and mechanical snubbers used on piping and large equipment in commercial nuclear power plants. The proposed research will provide the structure for the Phase II Snubber Aging Study for U.S. Nuclear Regulatory Commission (NRC) Nuclear Plant Aging Research (NPAR) Program. Data developed during the research will be incorporated into a technical database on managing the aging and service life of snubbers. The scope and intent of this work does not include an evaluation of the potential impact of snubber failures on specific systems in power plants or on the overall reliability of the plants.

This research would be an extension of the work performed by Pacific Northwest Laboratory (PNL) in the NPAR Program, Phase I Snubber Aging Study, and would be performed at nuclear power plants and in test laboratories. In Phase I, the primary objectives were to conduct an initial aging assessment of snubbers and to evaluate the concept of snubber reduction in commercial nuclear power plants. Although snubber reduction programs may reduce the total population by 50 to 80%, management of the remaining snubber population will continue to be a concern with some of the earlier design conservatism and redundancy removed. The Phase II research work proposed is based, in part, on a study of snubbers in U.S. nuclear power plants by Lake Engineering Company, conducted for PNL under the NPAR program. A survey of U.S. commercial nuclear plant utilities on their use of snubbers, conducted for PNL by Wyle Laboratories, was also used to identify research needs.

The following are key elements of the proposed snubber research:

- review of existing service data
- development of service-life monitoring guidelines
- evaluation of the effects of compression set in hydraulic seals
- evaluation of accelerated methods for predicting seal life
- evaluation of radiation effects on elastomeric seals
- identification of seals most affected by aging
- development of a better understanding of aging in mechanical snubbers.

The benefits to be derived are principally safety related, including enhanced performance prediction of safety-related piping and equipment, mitigation of snubber aging effects, reduction of staff radiation exposures, and reduction of rad waste. Numerous technical benefits are also expected, including the identification of aging trends, information useful in developing service life monitoring guidelines, establishment of the technical

bases for determining service life, evaluation of the effects of compression set in seals, and enhancement of snubber design, materials and maintenance. The research plan will also provide a data base that can be used to address regulatory and snubber technology issues. Regulatory benefits anticipated include contributions to Standard Review Plans, Regulatory Guides, Plant Technical Specifications, and ASME/ANSI OM-4 Standards, based on the broader, more comprehensive data base that would be developed.

The research proposed is designed to address the following questions about the aging of mechanical and hydraulic snubbers:

- How do snubbers age and degrade?
- What are the failure characteristics of snubbers?
- What are the safety implications of snubber aging?
- What technical information is needed to improve performance and life prediction for snubbers?

The results will contribute toward a more reliable and predictable snubber population in the nuclear power industry. Such snubbers and snubber management will improve safety and assist in meeting the objectives of the NRC NPAR program. The data base to be developed will be made available to nuclear utilities, snubber manufacturers, snubber service companies and to the NRC. Planned interfaces will ensure technology transfer to utilities and manufacturers.

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1.0 INTRODUCTION

This report proposes a research plan to address and investigate aging and degradation of the safety-related hydraulic and mechanical snubbers used on piping and large equipment in commercial nuclear power plants. Data developed during the research will be incorporated into a technical database on managing the aging and service life of snubbers. The scope and intent of this work does not include an evaluation of the potential impact of snubber failures on specific systems in power plants or on the overall reliability of the plants.

Details on the research recommendations are included in Section 5.0. The safety benefits to be derived from the research include enhanced performance prediction of piping and equipment snubbers, mitigation of snubber aging effects, reduction of staff radiation exposures, and reduction of rad waste. Numerous technical benefits are also expected, including the identification of aging trends, development of service life monitoring guidelines, establishment of technical bases for determining service life, evaluation of the effects of compression set in seals, and enhancements of snubber design, materials and maintenance. Regulatory benefits anticipated include contributions to Standard Review Plans, Regulatory Guides, plant Technical Specifications, and ASME/ANSI OM-4 Standards based on the broader, more comprehensive data base that would be developed.

The research proposed will be performed under Phase II of the Snubber Aging Studies for the Nuclear Plant Aging Research(1) (NPAR) Program of the U.S. Nuclear Regulatory Commission (NRC), with the Pacific Northwest Laboratory (PNL)(a) as the prime contractor. The NPAR Snubber Aging Study conducted in Phase I(2) laid the foundation for the research currently being conducted under Phase II. Interim work completed under Phase II by PNL and subcontractors Lake Engineering and Wyle Laboratories in 1987 and 1988 has provided the background data and planning for the research described in this report. A summary of research completed under Phase II is included.

In addressing the need for further research into safety-related concerns for the use of snubbers in commercial nuclear power plants, the report identifies questions that need to be addressed to establish snubber aging guidelines:

- How do snubbers age and degrade?
- What are the failure characteristics of snubbers?
- What are the safety implications of snubber aging?

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute.

- What technical information is needed to improve performance and life prediction for snubbers?

Integral to this report are an evaluation of the feasibility of conducting additional research on snubber aging (or service life) and a survey of utilities on the use of snubbers in operating nuclear plants. The full text of the feasibility evaluation, "The Feasibility of Conducting an In-depth Snubber Aging Evaluation," was completed by Lake Engineering Company and is presented in Appendix A. The full text of the utility survey, "Utility Snubber Survey," was prepared by Wyle Laboratories and is presented in Appendix B. Both documents provide background and support for recommendations proposed in this report and are summarized in the main body of the report.

This report includes technical background on snubbers, the primary problems associated with snubber failure, and preliminary findings on the degradation of both mechanical and hydraulic snubbers. Special attention is given to results of preliminary research on sealing devices and fluids in hydraulic snubbers. The report also addresses snubber concerns of the NRC and the nuclear power plant industry and how these concerns integrate with the anticipated benefits of the approach proposed in this report.

2.0 BACKGROUND

Snubbers are restraining devices used to control the movement of pipe and equipment during abnormal dynamic conditions such as earthquakes, turbine trips, safety/relief valve discharge, and rapid valve closure. The design of a snubber allows free thermal movement of a component during normal operating conditions but restrains the component in off-normal conditions.

Environmentally induced degradation of snubbers is a principal concern of designers and users of these devices. Background on the failure modes and potential causes of degradation are discussed in this section.

2.1 GENERAL

Snubber designs are either hydraulic (Figure 2.1) or mechanical (Figure 2.2). General Design Criteria (10 CFR.50) dictate that restraining devices be installed in appropriate locations on pipes and equipment in commercial nuclear power plants. Snubbers may be grouped into two basic categories by usage:

- Piping snubbers are manufactured in approximately seven sizes, up to a normal rated load of 130,000 lbs. Sizing of snubber load is primarily due to seismic considerations. The majority of piping snubbers are mechanical.

- Equipment snubbers are almost exclusively hydraulic and are used to restrain large equipment, such as reactor coolant pumps and steam generators. They are manufactured in load ratings up to 2,000,000 lbs. Sizing of the snubber load is based primarily on rupture of connecting piping. Some seismic loading is included.

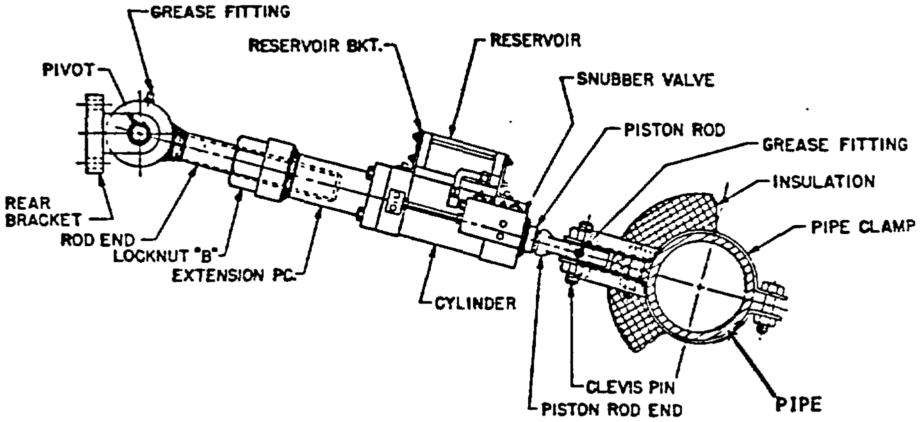

FIGURE 2.1. Typical Hydraulic Snubber

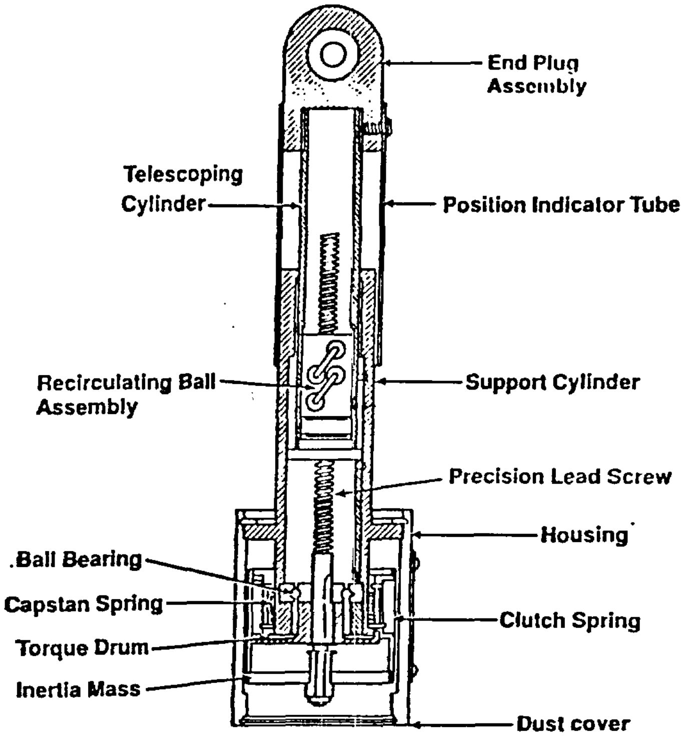

FIGURE 2.2. Typical Mechanical Snubber

There are approximately 66,000 snubbers installed in U.S. nuclear power plants. Of this total, 15,000 are hydraulic piping snubbers, 50,000 are mechanical piping snubbers, and 1,200 are hydraulic equipment snubbers. Snubber reduction programs, underway or planned, will impact the total snubber population.

2.2 SNUBBER DEGRADATION

Snubbers are subject to degradation from a number of influences. Such influences can result in long-term or short-term snubber failures.

2.2.1 Long-Term Failures

The majority of snubbers installed in commercial nuclear plants are subjected to environmental influences that are within the design capacity parameters of the snubber and, for most applications, the degradation influences are long term and gradual. Such influences include normal operating temperatures (generally less than 160°F), operating radiation levels, and relative humidity. Degradation associated with such influences might involve, for example, a gradual loss of low-pressure sealing force and permanent deformation of seals in hydraulic snubbers or a gradual increase in drag force in mechanical snubbers. Failures resulting from such influences, if they occur, are most likely to occur after substantial service time (i.e., five years or more depending on environment).

Failures resulting from long-term degradation may be minimized by scheduled maintenance, e.g., seal replacement, or replacement of snubbers. However, because the probability of failure might actually increase due to handling or assembly errors, unnecessary maintenance or snubber replacement should be minimized. Practical methods are needed, therefore, for monitoring long-term degradation in both hydraulic and mechanical snubbers.

Technical research proposed for the Phase II Snubber Aging Study (see Section 5.0) will emphasize evaluation of degradation effects on snubbers from typical nuclear plant operating environments.

2.2.2 Short-Term Failures

A limited number of snubbers are subject to failure resulting from applications that are beyond their design capacity. These include high amplitude vibration,[a] abnormally high temperatures, and transient loads. Short-term failures generally occur within one or two operating cycles. They may be reduced by modification of the environment, augmented surveillance, frequent maintenance, frequent replacement of snubbers, or retrofitting with more durable snubbers for a specific application.

Failures can also result from influences that are not related to time in service or to the plant operating environment. Such failures include construction or installation damage, and design, manufacturing, and maintenance deficiencies.

2.3 AGING OF HYDRAULIC SNUBBERS

The major concern in the aging of hydraulic snubbers is seal degradation. There are also some concerns regarding the effects of long-term service on the hydraulic fluids used in snubbers.

2.3.1 Primary Failure Modes of Hydraulic Snubbers

Hydraulic snubber failures are generally active, i.e., they fail to provide adequate restraint of dynamic loads because they fail to lock up. Failure to lockup may be a result of hydraulic fluid loss. Fluid losses could result from seal degradation or tube joint leakage.

2.3.2 Seal Shelf Aging

During storage, the physical characteristics of rubber seal products can be degraded by various environmental stresses including heat, moisture, sunlight, air, ozone, and stress. However, in this study, no attempt will be made to correlate such degradation directly with seal performance. The aging of seals in shelf storage may be reduced to a negligible level by adhering to

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(a) Vibration amplitude greater than the mechanical clearances within the snubber and attachments.

recommended storage procedures such as those provided in Military Handbook 695.(3) The Phase II study discussed in this report, therefore, will be limited to an evaluation of service aging.

2.3.3 Seal Service Aging

Elastomeric seals age principally because of chemical changes that degrade their physical properties. The rate at which such changes occur depends, primarily, on the level of operational environmental stresses to which they are subjected, such as temperature and radiation.

Under low-pressure conditions, when the seal is not energized by fluid pressure, sealing force is provided by the elasticity of the seal material only. In some cases, additional low-pressure sealing force is provided by the inclusion of spring elements in the seal design.

The anticipated snubber failure mechanism associated with elastomeric seal aging is gradual loss of fluid under low-pressure conditions resulting from a reduction in sealing force against the gland surface. Seal failure when the snubber is activated is of less concern, because sealing force is generally increased significantly due to fluid pressure. In fact, it is not uncommon that a seal leaking under low-pressure conditions will seal adequately when the snubber is pressurized.

The amount of sealing force required under low-pressure conditions depends on a number of factors, including the following:

- seal configuration
- seal hardness
- mating surface condition
- fluid viscosity
- fluid pressure.

Relaxation of low-pressure sealing force may be measured directly in laboratory tests using a relaxometer (see Appendix A). However, seal degradation is most practically monitored in service by measurement of compression set (that portion of initial seal compression that results in permanent deformation). A seal with 0% compression set, for example, will exert maximum sealing force. Zero sealing force, on the other hand, will be exerted by a seal with 100% compression set.

2.3.4 Fluid Aging

Most hydraulic snubbers use some form of silicone-based hydraulic fluid. The basic hydraulic properties of methyl phenyl polysiloxane fluids, such as

GE SF-1154[a] Fluid which is used in most hydraulic snubbers, experience negligible permanent changes due to nuclear plant operating environments.

The viscosity of any fluid will vary with temperature. Some hydraulic fluids are, however, subject to permanent increases in viscosity from gamma radiation. Changes in viscosity can cause moderate changes in snubber activation parameters, e.g., locking velocity and release rate. Potential viscosity changes should, therefore, be recognized when using hydraulic snubbers in nuclear power plants.

One hydraulic fluid begins to generate hydrochloric acid after exposure to one megarad of gamma radiation.(4) However, this fluid is used in only a limited number of equipment snubber applications.

2.3.5 Fluid Contamination

Fluid contamination can be in the form of solid particles or moisture. Solid particle contamination is most often the result of improper cleaning of parts before assembly or inadequate filtration of fluid during purging and filling. For the most part, particles may be prevented from entering a snubber in service through the use of sealed reservoirs or vented reservoirs with a filtered breather cap. In isolated applications with high-amplitude vibration, however, particle contamination can result from abrasion of seals or metal parts.

Water in hydraulic fluid can cause internal corrosion, potentially affecting sealing surfaces or generating solid contaminants. But the incidence of snubber failures in this regard has been limited. Before filling a snubber, water in hydraulic fluids may be minimized by proper fluid storage, sampling, and/or demoisturization processes. Water absorption while in service is not a problem for snubbers with sealed (pressurized) reservoirs. However, it is impossible to prevent some moisture absorption in snubbers with vented reservoirs. The potential for internal corrosion may be minimized through the use of internal plating or corrosion resistant materials.

2.4 AGING OF MECHANICAL SNUBBERS

The effects of long-term service on mechanical snubbers have not been fully evaluated. Long-term evaluation of inservice performance will be necessary to determine and evaluate degradation mechanisms. A better understanding of aging in mechanical snubbers is needed.

2.4.1 Primary Failure Mode of Mechanical Snubbers

Mechanical snubber failures generally involve failure of the snubber to perform its passive function, i.e., to allow free thermal motion, due to

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(a) Manufactured by General Electric Co., Waterford, New York.

either jamming or excessive drag or breakaway force. Such failures are influenced by a number of factors including corrosion caused by moisture, boric acid, vibration, temperature, orientation, or inadvertant mishandling.

A definitive correlation between drag force and service time under various environmental conditions has not been established. A complication exists in that the same snubbers are not tested during each refueling outage. More research is needed to evaluate the increasing drag-load trends in mechanical snubbers.

2.4.2 Environmental Effects

The effects of vibration on the performance of mechanical snubbers may be evaluated to some degree by laboratory testing; some research has been completed in this regard.(5) The effects of other environmental stresses, such as elevated temperature and humidity, cannot be easily determined by laboratory testing and are probably best evaluated by root cause and failure analysis of snubbers removed from service. Parameters and methods that may be used to monitor inservice degradation of mechanical snubbers need to be identified.

3.0 UTILITY SURVEY

A nuclear plant utility survey of members of the Snubber Utility Group (SNUG) was initiated by the PNL NPAR staff. Information requested in the survey was directed toward the kinds of snubbers in use and the operational data/status of those snubbers in service. The questionnaire distributed to SNUG members requested snubber information in the following areas:

- quantity and type of snubbers
- operating experience
- environmental data
- service-life information
- utility needs for additional technical information.

A sufficient number of utilities responded to allow the drawing of conclusions relative to snubber type, population size, industry concerns, standard practice, and performance trends. Details of the survey are provided in a Wyle Laboratories Report, included as Appendix B of this report. A summary of the results from those SNUG members who responded is provided below:

1) The snubber population for the 24 utilities that returned completed surveys comprises 17,649 mechanical snubbers and 10,089 hydraulic snubbers for a total of 27,738 snubbers. This data is from 38 power plants and comprise an estimated 43% of the total snubber population of the utilities surveyed.

2) Seven of the 12 utilities responding identified mechanical snubber sizes 1/4 and 1/2 kip as requiring more frequent repair or replacement.

3) All of the utilities stated that they had spare parts programs, and the inventory at 16 utilities was valued in excess of $100,000.

4) Of the 19 utilities with hydraulic snubbers, 50% indicated failures involving fluid or seals.

5) A wide variety of responses was received to the requests for descriptions of seal-related failures.

6) Most of the responding utilities reported their failure analysis program was informal.

7) Most utilities reported a decreased snubber failure rate with increased operating experience.

8) Over 75% of the utilities surveyed identified seals in hydraulic snubbers as an aging-related concern. The next most frequently identified concern was fluid degradation.

9) Many plants replace seals at conservative intervals recommended by the snubber manufacturer. (A question regarding the definition of service life revealed inconsistent responses.)

10) Ethylene propylene seals continue to be the most widely used throughout the industry.

3.1 UTILITY CONCERNS COMMON TO MAINTENANCE/REPAIR

The principal concerns expressed in the survey are frequency of maintenance/repair for the smaller size snubbers, either mechanical or hydraulic, and the seal life of the hydraulic snubbers. These two concerns are discussed below.

3.1.1 Hydraulic Snubbers

The predominant areas of interest for hydraulic snubbers are seals and seal life and associated effects on performance. The approaches of utilities to determine seal life vary widely, suggesting a need to develop a basis for standardization in this area. The following are other areas of common concern on which additional technical information would be helpful:

- long-term performance of Tefzel® seals
- the effects of aging on hydraulic fluids.

Information in these areas will be collected during the Phase II study.

3.1.2 Mechanical Snubbers

Mechanical snubbers of 1/4 and 1/2 kip sizes were identified in the survey as the most often used snubbers, mechanical or hydraulic. These two sizes were also mentioned most often as requiring replacement or repair.

Some concern was expressed pertaining to increasing mechanical snubber drag force with service time. This may be more of an application/design problem caused by high amplitude vibration that needs to be studied within the overall context of snubber degradation. What effect increased drag has on mechanical snubber performance was raised as an issue for which more data is desired. In general, more performance data is needed for mechanical snubbers exhibiting increased drag loads or that are subject to vibration applications.

® Tefzel is a registered trade name of duPont Company

3.2 COMMON PRACTICES

All utilities anticipate a certain number of snubber failures and maintain fairly substantial inventories of spare units and parts. One approach, though, is to anticipate potential failures which may involve identifying piping systems known to have transients and to correct the problem before actual failures occur. When failures occur, engineering analyses are generally performed to determine the failure mode. The feasibility and practicality of these practices will be examined in the research proposed in developing service-life monitoring guidelines.

3.2.1 Hydraulic Snubber Practices

Seal-life programs are becoming more widespread with increased reliance on service data and seal-life evaluation studies. Actual experience, in many instances, indicates a seal life beyond snubber manufacturers' original recommendations. Acceptance criteria for hydraulic snubbers have also been relaxed where allowed by engineering evaluation, thus reducing the number of reported failures.

3.2.2 Mechanical Snubber Practices

Acceptance limits for drag tests and, in some cases, acceleration have been increased where justified by engineering analyses. If such analyses had been applied originally, the total number of failures due to excessive drag force would have been significantly less. Other acceptance criteria could also be expanded where an engineering evaluation is allowed. Some mechanical snubbers, particularly those prone to handling, installation or construction damage are being replaced with larger capacity snubbers or snubbers that are more resistant to such degradation and damage.

3.3 PERFORMANCE TRENDS

Average failure rates for snubber examinations and testing were calculated using the questionnaires received from SNUG members. These rates are listed in Table 3.1. Coincidentally, reported failure rates for both mechanical and hydraulic snubbers turned out to be similar.

Some plants have indicated a recent decrease in failure rate for snubbers. This is attributable to the overcoming of construction and handling-induced problems in nuclear plants as well as increased understanding of the operability of snubbers. Therefore, snubbers in a significant number of plants, according to the utility survey, are performing far better than the rates in Table 3.1 would indicate. However, other plants that are early in their plant-life cycle are experiencing higher failure rates due to construction-induced problems.

With this general understanding, utilities seem to be interested in learning more about specific characteristics of snubbers that will further improve performance.

TABLE 3.1. Average Reported Snubber Failure Rates in SNUG Questionnaire

Category	Mechanical Snubber Failure Rate, %	Hydraulic Snubber Failure Rate, %
Examination Failures	1.1	1.2
Testing Failures	7.3	5.9

Note: Snubber failure rates are expressed as a percentage of the total number of snubbers examined or tested which did not meet acceptance criteria during the most recent inservice inspection.

4.0 EVALUATION OF SNUBBER AGING

The feasibility of conducting an in-depth aging study of snubbers in the nuclear plant environment was evaluated in 1987 by Lake Engineering Company. A copy of the Company's report is contained in Appendix A. Highlights of the report are discussed in the following sections. Included are utility needs, NRC and industry concerns, contributions to regulations and standards, and safety, technical and regulatory benefits. The section also provides the background and overall need for the proposed work.

4.1 BACKGROUND

Historically, manufacturers' recommendations for hydraulic snubber seal and fluid replacement intervals are generally conservative and often result in unnecessary snubber overhauls or replacements. In contrast to this, the recommended 40-year maintenance-free service life of mechanical snubbers, originally recommended by snubber manufacturers, appears not to be conservative enough. Therefore, these recommendations do not meet the safety and operational needs of the NRC or the utilities.

Inservice testing and examination of mechanical snubbers has more recently been included in plant Technical Specifications. In addition, the majority of plants with mechanical snubbers have only recently started commercial operation. Long-term service data is therefore limited.

The service data for both hydraulic and mechanical snubbers are often incomplete in terms of documentation of environmental parameters and failure causes. In addition, inconsistencies exist in parameter measurement, inspection, testing, and documentation methods such that data from some plants cannot be readily combined or compared with data from others.

Some utilities have implemented seal life studies which have extended the originally predicted seal life for the majority of plant snubbers. Such studies are often based on extrapolation of compression set data for seals removed from service. Accelerated aging studies have also been conducted. The use of either approach often involves comparison of compression-set data with a maximum, often conservative allowable value. The specific value of the accelerated-aging approach as well as the establishment of realistic compression-set limits have not yet been determined.

4.2 NRC REGULATORY AND INDUSTRY CONCERNS

NRC Regulatory Guides, Code of Federal Regulations (10 CFR 50, Appendix A) and Technical Specifications (including applicable ASME B&PV Codes) are intended to insure that nuclear power plants be designed for safety and be operated to protect the public health and safety. Snubbers are identified as specific safety-related devices used to mitigate the effects of normal and off-normal equipment and piping loads.

A current trend is to reduce the number of snubbers installed in nuclear power plants. Both the NRC and the utilities have an interest in ensuring the reliability of the remaining snubbers. This includes mitigation of the effects of aging, which can best be accomplished by acquiring reliable service-life data.

Current approaches to establishing snubber service life are diverse and include the following:

- service life based on the snubber manufacturers' recommendations (generally conservative for hydraulic snubbers)
- review of available technical data (i.e., laboratory test reports, etc.)
- accelerated aging tests or analyses
- service history
- extrapolation of measured degradation parameters (e.g., compression set).

The ultimate substantiation of snubber service life, however, is acceptable performance for a given time period under known environmental conditions. However, such data for hydraulic snubbers is not abundant because many utilities continue to replace seals and fluid at conservative intervals. This practice can be disadvantageous in that additional snubber failures can be introduced because of maintenance errors or damage during installation. This practice also results in unnecessary personnel radiation exposure.

Effective management of snubbers may best be accomplished through adequate knowledge of their long-term performance capabilities and effective methods for in-service inspection. The Phase II study will provide increased knowledge in the above regard. Adequate performance data will enable manufacturers to improve designs and manufacturing practices. Maintenance and/or snubber replacement frequency may more appropriately be based on the known influences of various operating environments. Troublesome snubbers may be more effectively replaced by snubbers known to be suitable for the environment or application. In some cases, elimination of certain snubbers may be justified.

4.3 CONTRIBUTION TO STANDARD TECHNICAL SPECIFICATIONS, CODES AND QUALIFICATION STANDARDS

The phase II snubber aging study will result in improved knowledge pertaining to snubber aging characteristics. This knowledge will contribute significantly to the operational standards, qualification standards and codes for snubbers. This includes the NRC Standard Technical Specifications,(6) ASME Section XI,(7) and ASME/ANSI OM-4.(8)

4.3.1 Standard Technical Specifications

Standard Technical Specification requirements for snubbers are currently undergoing extensive review within the NRC in order to ensure a comprehensive technical basis for inservice inspection and service life for snubbers in all plants. In part, NRC Standard Technical Specifications for Snubbers require the following:

- establishment of a program in which snubber service life is continuously monitored[a] and either extended or shortened based on service history
- failure evaluation for any snubber that fails to meet functional test acceptance criteria during inservice testing.

The Phase II Study will complement and contribute to the NRC review by providing technical input and recommendations for snubber service life monitoring and failure evaluation guidelines. Parameters (or attributes) will be identified for effective monitoring of both hydraulic and mechanical snubbers in order to minimize snubber failure rate as well as establish a uniform population of snubbers in terms of failure potential.

4.3.2 Snubber Qualification Standards

Although there are no industry qualification standards per se for snubbers, many procurement specifications include requirements pertaining to qualification testing. Probably the most notable of these is GE Specification 21A3502[9] which, in many respects, became an industry standard for snubber qualification testing in the 1970s. A number of mechanical and hydraulic snubber models have been qualified in accordance with this specification.

Typical qualification test requirements include measurement of static performance parameters (i.e., activation level, release rate, and drag force) and measurement of dynamic performance parameters (i.e., spring rate, peak to peak displacement, and dead band) at both 70°F and 200°F. Performance adequacy following a loss of coolant accident (LOCA) is typically evaluated by measuring the above parameters after subjecting the snubbers to the various anticipated LOCA environments.

Snubbers, however, are subject to a number of environmental stressors and potential aging mechanisms, the long-term effects of which cannot always be evaluated by qualification testing. The Phase II study will provide information useful for evaluating the longevity of various designs and

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(a) Mandatory monitoring is required to ensure that the service life is not exceeded between surveillance inspections. The original as-installed expected service life is typically based on manufacturer's recommendations and is extended or shortened based on technical evaluation and/or service history, i.e., test results and failure history.

materials in nuclear power plant applications. Improved snubber qualification methods for evaluating the effects of long-term aging will also be identified.

4.3.3 Contribution to Codes

Inservice examination and testing requirements for snubbers are currently defined in Plant Technical Specifications and in the ASME Boiler and Pressure Vessel Code, Section XI. More specific requirements for snubbers in this regard are delineated in ASME/ANSI OM-4 which is included, by reference, in Section XI. Phase II study results should provide input for operating and maintenance guidelines to improve ASME/ANSI OM-4 from a safety and operations perspective.

4.4 BENEFITS OF THE PHASE II SNUBBER AGING STUDY

The Phase II Snubber Aging Study will provide an expanded data base with distinct safety, technical and regulatory benefits. Such benefits are discussed below.

4.4.1 Safety Benefits

The primary safety benefits of the Phase II Study are listed below:

- improved component reliability due to 1) mitigation of the effects of snubber aging, and 2) establishment of a more uniform population of snubbers in terms of failure prediction.
- reduction of personnel radiation exposure
- reduction of rad waste.

4.4.2 Technical Benefits

The Phase II study presents a number of technical benefits which will also contribute to improved plant safety. Some are listed below:

- identification of aging trends
- establishment of technical data to be used in developing service-life monitoring guidelines
- enhanced usefulness of service data in monitoring snubber service life
- consistent service data format for more suitable consolidation into an industry data base
- definitive technical basis for evaluating snubber service life

- identification of useful failure evaluation methods
- identification and categorization of realistic operating environments
- identification of key aging stressors
- technical input for evaluating the effects of compression-set in snubber seals
- identification of aging-resistant designs and materials
- improved operations and maintenance practices.

4.4.3 Regulatory Benefits

Regulatory benefits will result from the broader data-information base provided by the Phase II NPAR study. Specific aging and service-related issues will be identified to provide a basis for revising regulations where applicable. Regulatory benefits include the following:

- contribution to regulatory standards (Section 4.3)
- information that may be used in establishing service life monitoring guidelines
- centralized and unified approach to regulation
- identification of generic issues related to service life.

5.0 RESEARCH PLAN/RECOMMENDATIONS

This section presents a description of the seven main tasks to be included in the plan. The recommended tasks are as follows:

- Review of existing service data.
- Development of service-life monitoring guidelines.
- Evaluation of the effects of compression set.
- Evaluation of accelerated aging methods for predicting seal life.
- Evaluation of the effect of radiation on elastomeric seals.
- Identification of seals most affected by aging
- Development of a better understanding of aging in mechanical snubbers.

The need for research proposed in each task is supported by the information provided in the foregoing sections and in Appendixes A and B.

5.1 REVIEW OF EXISTING SERVICE DATA

The purpose of this task will be to review service data from a selected number of plants. Plants will be selected based on willingness to participate and the usefulness of their data in evaluating trends and identifying performance indicators relative to snubber aging. Representation of the various snubber types and operating environments will also be emphasized along with comprehensive failure evaluation data.

5.1.1 Background

For the most part, comprehensive trend analyses have not been completed. For example, the effect of time alone on mechanical snubber drag force has not been conclusively evaluated. This task will include a review of existing data for possible verification of such trends.

Since service data alone are often misleading or inconclusive, this task will include extensive interface with plant maintenance and engineering personnel, to clarify the data, and to provide practical insight. This task will also include a review of existing service-life monitoring programs, including a review of plant seal-life studies.

5.1.2 Failure Evaluation

A comprehensive review of failure evaluation data will be conducted. This will involve extensive discussions with plant personnel. Failed or degraded snubbers will be disassembled for identification of aging failure mechanisms and snubber parts that are particularly susceptible to aging degradation. Previous test data for failed mechanical snubbers will be reviewed in search of "signatures" related to the actual failure mechanisms.

5.1.3 Summary of Reviews

In summary, the service-data review will provide information in the following areas:

- aging trends for hydraulic and mechanical snubbers
- the proportion of snubber failures that have been aging related
- aging-related failure mechanisms
- trendable performance indicators
- performance indicators that might indicate impending snubber failure
- snubber components that are particularly susceptible to aging degradation
- aging-resistant designs or materials
- the range of operating environmental stresses
- information useful in developing practical service-life monitoring guidelines.

5.2 DEVELOP RECOMMENDATIONS FOR SERVICE-LIFE MONITORING GUIDELINES

Guidelines are needed for obtaining data that is more usable in trending degradation and/or forecasting snubber malfunctions. The purpose of the task described here is to provide technical information useful to the NRC for developing such guidelines. The limitations of current service data in monitoring snubber service-life are also discussed in this section.

5.2.1 Background

Most Plant Technical Specifications require service-life monitoring for snubbers. The following paragraph is typical of many Technical Specifications:

> The service-life of hydraulic and mechanical snubbers shall be monitored to ensure that the service-life is not exceeded between surveillance inspections. The maximum expected service-life for various seals, springs, and other critical parts shall be determined and established based on engineering information and shall be extended or shortened based on monitored test results and failure history. Critical parts shall be replaced so that the maximum service-life will not be exceeded

> during a period when the snubber is required to be OPERABLE. The parts replacements shall be documented and the documentation shall be retained in accordance with Specification 6.10.3.

Most plants replace seals in hydraulic snubbers at regular, often conservative intervals. However, because specific aging mechanisms have not as yet been identified for mechanical snubbers, they are not generally maintained or replaced regularly, unless a problem is known to exist.

Some service data for snubbers have been accumulated by the various operating plants. This includes data pertaining to preservice examination and testing, inservice examination and testing, maintenance, and service time. Such data are not, however, totally useful in evaluating the effects of aging.

5.2.2 Inservice Testing and Examination

Snubber operability in the active (dynamic) mode is normally verified by measurement of activation level and/or release rate. The operability of a snubber in the passive mode (i.e., the ability of the snubber to allow free thermal motion) is usually determined during inservice tests by direct measurement of either breakaway force (the force required to initiate motion of the snubber) or drag force (the force exerted by the snubber when stroked at a given velocity).

A snubber is usually categorized as "failed" when its ability to meet dynamic or passive requirements cannot be verified. In some cases, a snubber may be failed as a result of a test parameter that is not within specified limits. An example of this type of failure would be a breakaway force measurement equal to 2.5% of the snubber's rated load versus a specified limit of 2%. Another example might be a locking velocity of 30 in./min as compared to a specified maximum of 25 in./min.

A snubber may also fail as a result of a complete malfunction. Examples of this type of failure are snubbers that are frozen (i.e., jammed) or that fail to activate at any velocity or acceleration. As opposed to an "out-of-specification" failure which might be the result of gradual degradation, the complete malfunction type of failure is often the result of a specific event such as severe overloading. Such failures are more difficult to predict.

5.2.3 Limitations of Existing Service Data

The type of service data on snubbers that currently exists is not totally adequate for predicting trends. For example, visual examination data pertaining to snubber sealing integrity have often been recorded subjectively, e.g., "drops of fluid observed" or "reservoir fluid low." In many cases, specific environmental stresses, such as vibration or temperature related to snubber use, have not been documented, so it is impossible to arrive at any correlative conclusions. In addition, degradation trends such as increasing drag force in mechanical snubbers are difficult to detect because inservice tests are not conducted on the same snubbers during each refueling outage.

As a consequence of the above limitations, owners and regulators of nuclear plants have been unable to conclusively evaluate the effects of aging on snubber performance based on existing service data. This is especially true for mechanical snubbers for which the only meaningful data is that obtained during functional testing or by stroking the snubber by hand.

5.2.4 Research

A need exists to identify meaningful inservice evaluation methods for identifying aging trends and for tracking degradation in both hydraulic and mechanical snubbers. Such information will be useful to the NRC and utilities in developing service-life monitoring guidelines that could be used to augment or modify existing visual examination and testing requirements.

The Phase II Study will identify and/or develop improved service-life monitoring methods, specifically in the following areas.

5.2.4.1 Monitoring Parameters

Parameters will be identified in the following areas that are meaningful in monitoring the service-life of both mechanical and hydraulic snubbers:

- application or environmental parameters that may be correlated with the level of aging degradation or that are useful in identifying failure causes
- parameters that are meaningful in tracking the level of service degradation
- parameters that are useful in predicting imminent snubber malfunctions.

5.2.4.2 Failure Evaluation Guidelines

Recommendations for guidelines will also be provided under Phase II for failure evaluation of snubbers. Such recommendations will include information in the following areas:

- common failure mechanisms
- common failure causes
- critical or vulnerable parts
- diagnostic testing methods
- leakage location techniques

- post-disassembly examination and testing
- microscopic examination
- measurement of fluid contamination level.

5.2.4.3 Data Collection Format

A recommended data format will be developed. Pertinent aging-related data requirements will be identified in the following areas:

- inservice test data
- maintenance data
- documentation of transients and operating environments
- preassembly and post disassembly inspection and dimensional data.

Consistency in data recording methods will be emphasized so that the resulting data will be usable in an industry data base.

5.3 EVALUATION OF THE EFFECTS OF COMPRESSION SET

The purpose of the Phase II task described here is to evaluate the effects of various compression-set levels on the low-pressure performance of various seal configurations used in snubbers.

5.3.1 Background

Several plant specific programs to evaluate seal life for hydraulic snubbers measure compression set of seals exposed to actual service or to laboratory-aging simulation. These measured or extrapolated compression-sets must be compared with a maximum allowable value in ensuring low-pressure sealing integrity. In many cases, compression-set limits have been conservatively established because of the lack of specific technical data.

5.3.2 Configurations

The four most common snubber-seal configurations are described below. It is estimated that these configurations represent 90% of all snubber seals for which compression set is a meaningful degradation parameter. Each configuration has unique characteristics that warrants a separate evaluation.

5.3.2.1 O-Ring

The O-Ring (Figure 5.1) is the most universal elastomeric seal. It is used in all hydraulic snubbers using rubber seals. O-rings are used primarily as static seals for both low and high pressure applications.

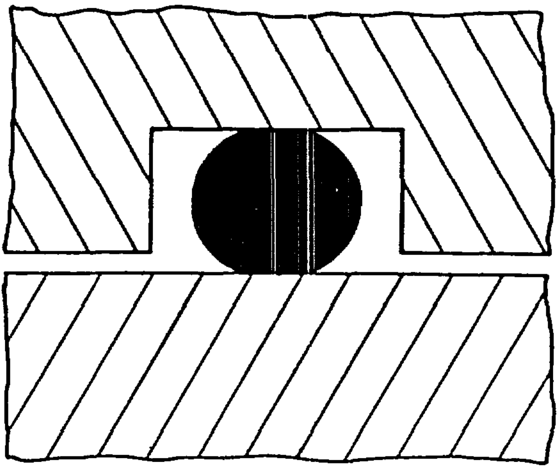

FIGURE 5.1. O-Ring

5.3.2.2 Tee Seal

The Tee seal (Figure 5.2) is used in dynamic sealing applications, i.e., where there is relative motion between the seal and its mating surface. It is essentially an anti-roll version of the O-ring seal. It is used for high- and low-pressure applications as both a piston seal and piston rod seal.

The low-pressure sealing mechanism of the Tee seal is essentially the same as that of the O-Ring. Anti-extrusion rings are provided on either side of the seal which, in combination with the seal's lateral legs, resist spiraling of the seal when the snubber is stroked. As with the O-ring, compression set for the tee seal is measured along the axis of compression (i.e., between the two sealing surfaces).

5.3.2.3 Miller Rod Seal

The Miller Rod Seal (Figure 5.3) is an energized lip seal which uses a pressure ring with a wave spring to provide additional sealing force in low-pressure applications. This seal is used exclusively in Grinnell snubbers.

The Miller rod seal has two distinct low-pressure sealing mechanisms. The dynamic sealing function along the piston rod is provided by the lip portion of the seal. In contrast to the O-ring and Tee seal, low-pressure sealing force is provided primarily by the wave spring included in the seal assembly.

Force applied by the wave spring, in a direction parallel to the axis of the piston rod, is translated into a radial force by means of a beveled pressure ring which forces the seal lip against the rod. In lieu of a compression-set limit for this portion of the seal, a limit will be established for permanent deformation of the seal in the direction of the wave

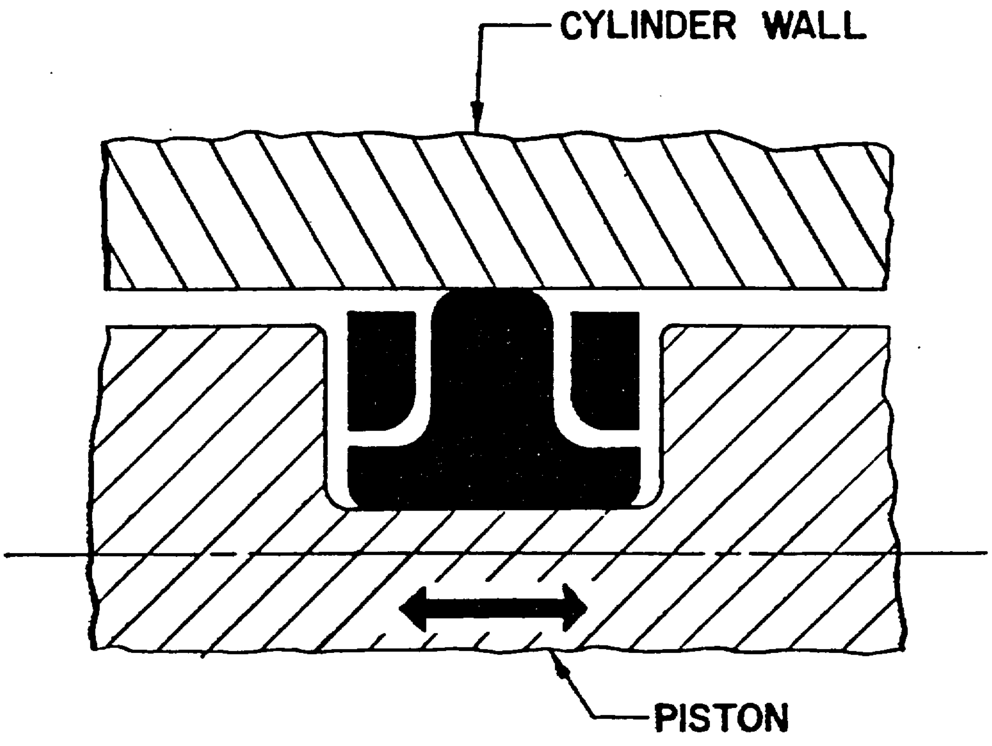

FIGURE 5.2. Tee Seal

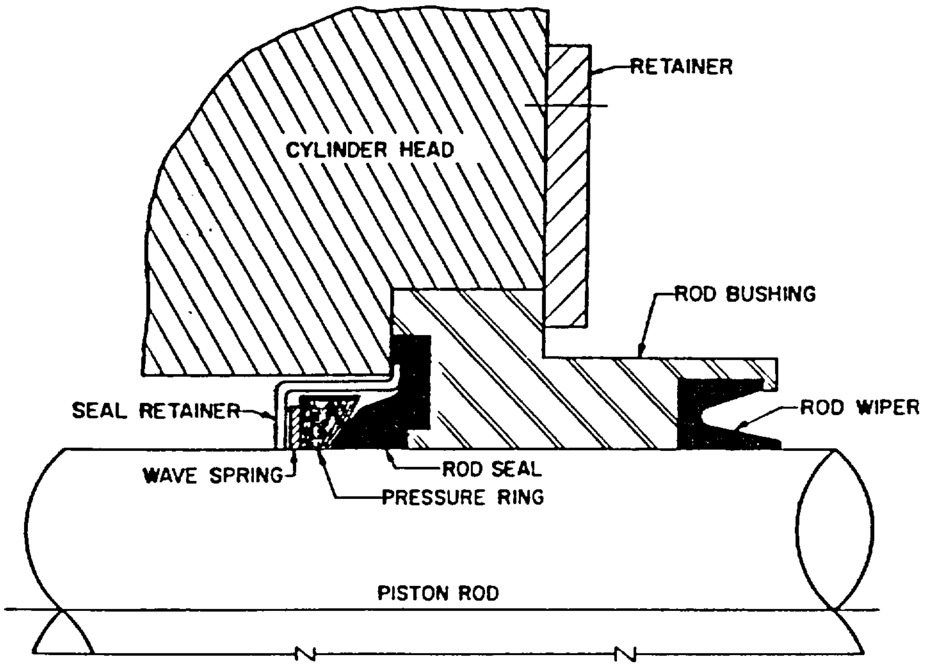

FIGURE 5.3. Miller Rod Seal

spring force. The deformation limit will depend, in part, on the range of travel of the spring and associated dimensional tolerances.

The static sealing function of the Miller rod seal takes place between the rod bushing and the cylinder head (see Figure 5.3). As with the O-ring and Tee seal, compression set for this portion of the seal is measured along the axis of compression (i.e., between the two sealing surfaces).

5.3.2.4 O-Spring Lip Seal

The O-spring lip seal (Figure 5.4) is more commonly known by the trade names of Polypak® and Polyseal®. This seal uses an elastomer energizer for higher sealing force in low-pressure applications. As with the O-ring and Tee seal, compression set for the O-spring lip seal is measured along the axis of compression.

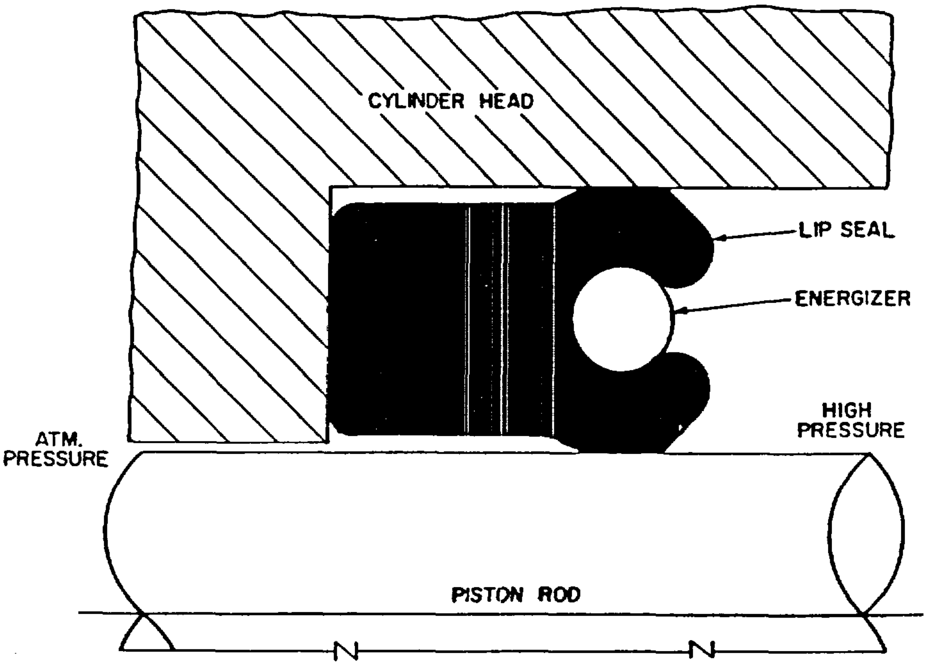

FIGURE 5.4. O-Spring Lip Seal

® Polypak is a tradename of Parker Hannifin Corp.
® Polyseal is a tradename of Microdot Company.

5.3.3 Methodology

The effects of compression set may be determined by 1) evaluation of seals from snubbers removed from service or 2) evaluation of seals with laboratory-induced compression set. Either approach involves verification of the low-pressure sealing integrity of seals having various levels of compression set. The following sealing variables must be considered:

- static versus dynamic applications
- viscosity of the hydraulic fluid
- fluid pressure
- mating surface finish
- initial seal compression
- gland dimensions and tolerances
- seal dimensions and tolerances
- seal hardness
- seal thickness.

In order to ensure that all manufacturing differences are considered, a thorough review of manufacturer's drawings will be included. This will also involve inspection and measurement of actual snubber parts.

5.3.3.1 Evaluation of Seals Removed from Service

This approach to determining the effects of compression set involves evaluating snubbers with extended service in relatively high-temperature environments, whereby seals would be expected to have a high compression set. Sealing integrity will be verified by visual inspection and/or low-pressure leakage tests. Snubbers will then be disassembled for measurement of seal and gland dimensions to be used in determining compression set.

It must be kept in mind that the purpose of this task is to correlate compression set with sealing integrity. In this respect, seals with relatively high levels of compression set must be evaluated. Such seals are not readily available from snubbers in safety-related nuclear applications due to the frequency of seal replacement. Therefore, the study will evaluate seals from snubbers that are more likely to have relatively high levels of compression set. This includes snubbers used in non-safety-related or non-nuclear applications, e.g., in fossil fueled power plants.

5.3.3.2 Laboratory-Induced Compression Set (Alternative Approach)

In this approach to determining the effects of compression set, various levels of compression set will be induced in seals in fixtures that are representative of the actual seal glands. Sealing integrity will be determined by conducting leakage tests on the seals before their removal from the fixtures. Seals will then be removed from the fixtures and subsequently measured to determine compression set.

Compression set will be induced on an accelerated basis by subjecting the seals to a high-temperature environment in a laboratory. The relationship between time, temperature, and compression set for the material(s) to be used will be determined by testing, in advance of the actual seal tests, in order that desired levels of compression set may be practically induced.

5.4 EVALUATION OF ACCELERATED AGING METHODS FOR PREDICTING SEAL LIFE

This task will provide technical input to be used in evaluating accelerated aging methods for predicting snubber seal life.

5.4.1 Background

Accelerated aging has been used to predict the life of elastomeric snubber seals. In this method, the aging effects of a degradation stress such as elevated temperature are accelerated. Results are then used to predict long-term seal performance.

Accelerated aging methods are usually based on an assumed fundamental relationship between the degradation stress and the degree of degradation. The most commonly used accelerated aging method is known as the constant overstress technique(10) in which a degradation stress variable (e.g., temperature) is raised to a level above that experienced in service, and the time required to attain various degrees of degradation is monitored. Based on data obtained in overstress experiments, the time required to attain various degrees of degradation at the ambient stress level (e.g., operating temperature) is predicted by extrapolation. An Arrhenius model (see Section 5.4.3) is often used to extrapolate temperature aging data.

The actual aging process in polymers subjected to a given degradation stress is the result of one or more chemical reactions. The level of the environmental stress will generally affect the rate of such reactions. A basic requirement of the constant overstress accelerated aging approach is that all aging reactions must be accelerated to the same degree. If all reactions are not accelerated equally, the validity of predicting long-term degradation by this method cannot be substantiated.

5.4.2 Methodology

In evaluating the constant overstress accelerated aging method for rubber seals, the following approach will be used. Figure 5.5 provides a

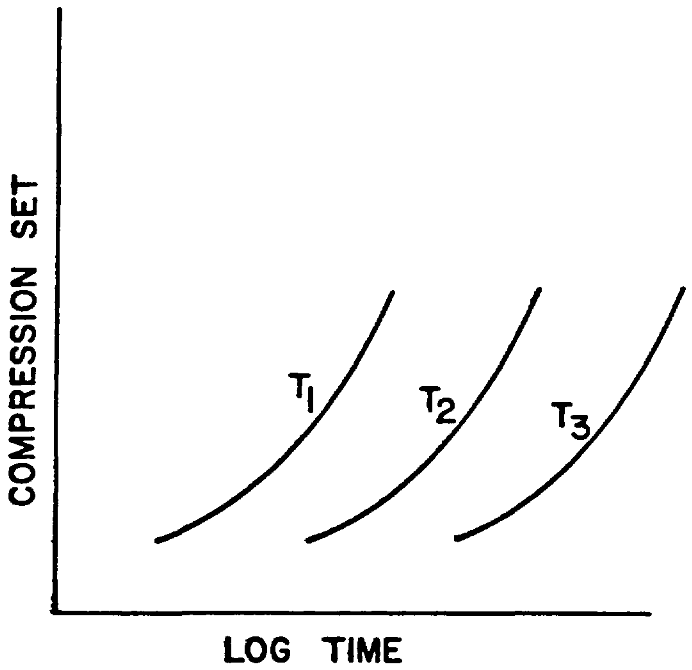

FIGURE 5.5. Compression Set Versus Log Time at Various Temperatures

hypothetical representation of the relationship between compression set and log time for a given seal material at three different temperature levels (T_1, T_2, and T_3). If constant acceleration of all underlying aging reactions exists, the curves would be superposable by horizontal shifts in the log time axis. In other words, the time value associated with each level of compression set for temperature T_1 could be multiplied by a constant shift factor (aT) to obtain the corresponding time value for temperature T_2. The relationship between this shift factor and temperature is often represented by an Arrhenius relationship

$$a_T :: \exp \left[\frac{K}{T} \right]$$

where T is the temperature and K is a constant.

Samples of common ethylene propylene and fluorocarbon rubber seal compounds used in the O-rings in hydraulic snubbers will be compressed in test fixtures. The seals, in fixtures, will be subjected to various temperatures to simulate aging. Compression set (or seal force) will be measured at prescribed time intervals. For each temperature variation, compression set (or seal force) will be plotted versus log time (Figure 5.5). The plotted data will then be evaluated by superimposition to determine whether constant acceleration of the underlying aging process exists.

If constant acceleration is verified, one of the aging temperatures will be selected as a reference temperature and the thermal shift factor (a_T) for the remaining temperatures will be calculated. Arrhenius behavior will be substantiated if a linear relationship exists between log a_T and T^{-1}.

5.5 EVALUATE THE EFFECT OF RADIATION ON ELASTOMERIC SEALS

The purpose of this task will be to determine the general effect of realistic operating radiation levels on elastomeric snubber seals.

5.5.1 Background

The effects of radiation aging in most applications may be negligible in comparison to the effects of temperature aging. Thus the role of radiation as an aging stress for elastomeric snubber seals may be less than was originally anticipated. Radiation effects were often evaluated by subjecting seals to laboratory radiation doses equivalent to 40 years of exposure in high radiation areas. Realistically, however, radiation levels for most snubber applications are relatively low. Furthermore, elastomeric seals will continue to be replaced at intervals less than 40 years. Another consideration is that snubber seals are partially shielded from radiation and associated oxidation by the snubber body and fluid.

5.5.2 Methodology

Representative snubbers will be acquired for use as test samples and refurbished with new seals and fluid. Gland and replacement seal dimensions will be measured as well as replacement seal hardness.

A predetermined number of the snubbers will be subjected to laboratory radiation doses that could be expected for a realistic service interval during normal plant operation. Control sample snubbers will be subjected to the same temperature/time environment as that experienced during laboratory irradiation. Snubbers will then be disassembled for measurement and comparison of seal compression set. Seal hardness will also be compared. Degradation, if any, in addition to that in the control sample seals, will be attributed to the effects of radiation.

A number of plants have implemented seal-life evaluation programs in which degradation parameters are measured for seals removed from snubbers during scheduled snubber rebuilding. To augment the above described radiation evaluation, such data will be reviewed for comparison of degradation data from high- and low-radiation areas.

5.6 IDENTIFICATION OF WEAK SEALS

This task will be to identify the seals in snubbers most affected by aging. The purpose for this task is to identify the weak seal i.e., the seal most prone to failure as the result of aging in the more common snubber models.

5.6.1 Background

For any given snubber model, seal replacement intervals should be based on the life of the weakest seal. If, for example, it is determined that the piston rod seal will fail before other seals in one kind of snubber, then seal replacement intervals should be based on the service-life of that seal. Because all seals are normally replaced when rebuilding a snubber, the service-life of other seals is less significant.

5.6.2 Weak Seal Identification

Existing data from cooperating plants will be reviewed, including data from visual inspection and service-life monitoring programs in an attempt to identify the seals most prone to aging degradation.

This task could also involve some laboratory testing, to be conducted in a manner similar to that to be used for establishing compression-set limits. Seals will be installed in fixtures and subjected to elevated temperatures in a controlled environment for rapid aging. Weak seals will be identified by comparison of the times-to-failure for the various kinds of seals tested. Results will be based on a statistically representative number of test samples.

5.7 UNDERSTANDING AGING IN MECHANICAL SNUBBERS

The purpose of this task will be to develop a better understanding of aging in mechanical snubbers. In-service and post-service examinations and the most recent information on mechanical snubbers will be reviewed.

5.7.1 Background

The mechanical snubber population has increased substantially since 1977. They are the predominant snubber type used in the plants coming on line in the 1980s. Compared to hydraulic snubbers, mechanical snubbers are relatively new, and therefore, a large in-service database, either of long- or short-term information, has not been generally available. This has resulted in a relatively small amount of knowledge pertaining to identifiable mechanical snubber aging mechanisms.

It is the intent of this task to broaden this information base. It is expected that the research described in this report will enhance the availability of service data by the planned pro-active interface with utility staffs and examination of utility records. The Phase II research will provide a means to gather the information, to evaluate the information, and to suggest appropriate recommendations for the management of snubber aging.

Although the mechanical snubbers share some of the same failure mechanism as hydraulic snubbers, e.g., design and installation errors, worn or broken parts, wear and excess loads, their primary failure modes (see Section 2.3.1 vs. Section 2.4.1) may produce radically different consequences. When a hydraulic snubber loses enough hydraulic fluid to cause it to fail, it cannot perform its lock-up function during a seismic event. It will, however, allow expansion and contraction of piping during thermal cycles. On the other hand, lock-up failure of a mechanical snubber, during expansion and contraction of thermal cycles could cause damage to piping systems by providing a rigid constraint. Because thermal motion in pipes and equipment is an operational reality, the consequences of a mechanical snubber failure may be significantly more important to NPPs than a failure of a hydraulic snubber.

Even though Phase I studies(2) by PNL indicated less failure data was available on mechanical snubbers than on hydraulic snubbers, the available data on mechanical snubbers appeared to show that several mechanisms can lead to failure. Corrosion, vibration, lateral loads, severe loads, e.g., water hammer damage, and maintenance errors are prime factors in mechanical snubber failures. The principal failure mode for mechanical snubbers appears to be high drag.

It is the intent of the Phase II research to provide a broader and clearer understanding of mechanical snubber failures through evaluation of existing data and data gathered through the cooperative utility studies of the Phase II research. The Phase II research will provide the overall basis for understanding aging trends and for recommending monitoring guidelines. A specific goal will be to identify the relationship between mechanical snubber drag force and operating environment or service time.

5.7.2 Methodology

To assemble and evaluate performance data, mechanical snubbers with various service times and from various operating environments will be examined and tested. Then the causes of degradation will be assessed. Available databases for more recent performance data will be reviewed. Also information on trends of increasing drag force obtained from the review of existing service data in Section 5.1 will be evaluated.

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APPENDIX A

THE FEASIBILITY OF CONDUCTING AN IN-DEPTH SNUBBER AGING EVALUATION

CONTENTS

FIGURES

TABLES

APPENDIX A

A.1.0 INTRODUCTION

This report discusses the feasibility of conducting an in-depth aging evaluation of snubbers and places emphasis on the technical, safety and regulatory benefits to be derived from the study. The report includes a comprehensive discussion of the following four main topics:

- Snubber Descriptive Information - Included is a description of mechanical and hydraulic types, common failure modes, common hydraulic fluids, and current installation practices/trends.
- Hydraulic Snubber Seals - The various seal configurations are discussed in detail with emphasis on functional categories, seal materials and common seal failure modes. Seal Aging is discussed in detail with special emphasis on aging processes of elastomers and seal degradation. Current bases for shelf life, storage life, and service life are reviewed.
- Snubber Aging Evaluation Benefits - The benefits of an evaluation are reviewed with respect to technical, safety and cost considerations.
- Key Elements of a Snubber Service-life Evaluation - This section indicates more emphasis should be placed on recent service data and long-term degradation than outdated data and short-term degradation. It is noted that the success of the evaluation will be directed by contact with the utilities and that effective coordination with the U.S. Nuclear Regulatory Commission (NRC) staff, Snubber Utility Group (SNUG) and Pacific Northwest Laboratory (PNL) is important to the evaluation process.

A.2.0 SNUBBER DESCRIPTIVE INFORMATION

A.2.1 DEFINITION OF SNUBBERS

Hydraulic snubbers (Figure A.2.1) and mechanical snubbers are devices used in plants to restrain pipes or equipment when subjected to abnormal dynamic conditions such as those due to earthquakes, pipe ruptures, transient loads, and turbine trips. The design of a snubber is such that it will allow free thermal movement during normal operating conditions. Snubbers may be grouped into two basic size categories:

- Piping Snubbers - These snubbers are generally used to restrain pipes, and are manufactured in approximately seven sizes up to a normal rated load of 120,000 lbs.

- Equipment Snubbers - These snubbers are almost exclusively hydraulic and are used to restrain large equipment such as reactor coolant pumps and steam generators. They are manufactured in load ratings up to 2,000,000 lbs.

A.2.2 EARLY PROBLEMS WITH SNUBBERS

Between 1973 and 1975 a number of failed hydraulic snubbers were discovered during routine power plant inspections.(1)(2)(3) Problems involved, for example, extensive leakage of Bergen-Paterson snubbers and failure of certain Grinnell snubbers to lock-up at the required velocity. There were also some reported instances of permanently locked Grinnell snubbers.

The Bergen-Paterson snubber problem was later determined to have been caused by incompatibility between the polyurethane seals and the hydraulic fluid. Failure of the Grinnell snubbers to lock was determined to have been

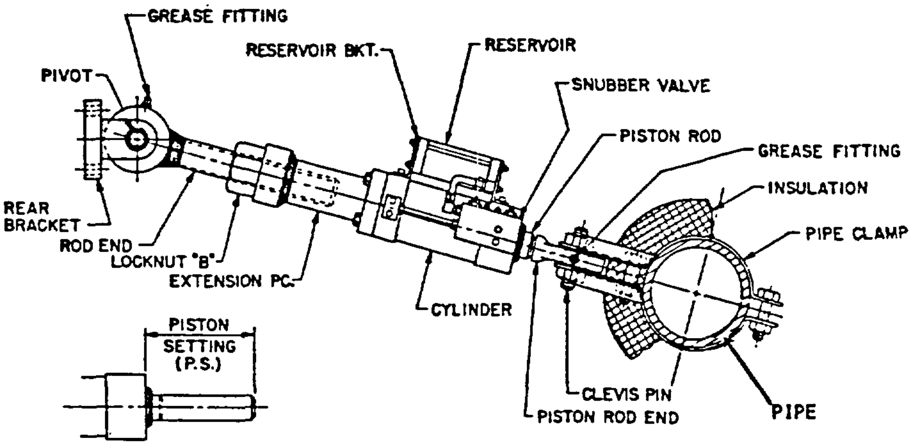

FIGURE A.2.1. Typical Hydraulic Snubber

caused by the use of hydraulic fluid with a viscosity less than that specified by Grinnell. Failure of the Grinnell snubbers to unlock was found to be the result of total blockage of the bleed orifice.

As a result of leakage problems with early hydraulic snubbers, a significant trend developed in the industry toward the use of mechanical snubbers. This occurred in the mid-1970s.

A.2.3 EXAMINATIONS FOR RELIABILITY/TECHNICAL SPECIFICATION REQUIREMENTS

Many early hydraulic snubber problems were identified and corrected by changes in design and maintenance practices. However, the general performance reliability of hydraulic snubbers remained questionable. This led to NRC requirements, in the form of Plant Technical Specifications(4), for periodic examination and testing of snubbers. Original Technical Specifications required the following:

1. Within six months, visually examine all safety-related hydraulic snubbers with a load rating of 50,000 lbs. or less. Examinations, thereafter, shall be in accordance with Table A.2.1 below.

2. If seals are not proven to be compatible with the environment, reexamine all safety-related snubbers every 30 days.

3. During the next refueling outage, test 10 or 10% (whichever is less) of all safety-related snubbers. Retest an additional 10 or 10% for each inoperable snubber. Continue testing in this manner.

Since the implementation of the above requirements, improved seal materials, designs, and maintenance have resulted in a significant improvement in snubber operability level and a more uniform population of hydraulic snubbers in terms of failure potential. The probability of a forced outage for snubber reexamination has, consequently, been reduced.

TABLE A.2.1. Examination Schedule

Number of Snubbers Found Inoperable During Examination	Next Required Inspection Interval
0	18 months ± 25%
1	12 months ± 25%
2	6 months ± 25%
3 or 4	124 days ± 25%
5, 6, or 7	62 days ± 25%
≥8	31 days ± 25%

Mechanical snubbers and snubbers with a load rating greater than 50,000 pounds were excluded from the early Technical Specifications. Most Plant Technical Specifications have since been revised(4) as follows:

- All safety-related snubbers, hydraulic and mechanical, regardless of size are included.
- The requirement for snubber reexamination every 30 days if seal compatibility has not been proven has been eliminated.
- Alternative sampling plans for testing (in addition to the 10% plan) are now available.

A.2.4 FAILURE MODES OF SNUBBERS

Hydraulic and mechanical snubber primary failure modes are significantly different and have different results. Hydraulic snubber failures are usually associated with an inability to respond to or restrain dynamic loads, i.e., active failure modes.

A.2.4.1 Failure Modes of Hydraulic Snubbers

Such failures may be caused by a number of mechanisms including loss of fluid and improper control valve settings. A detailed list of hydraulic snubber failure mechanisms is provided in NUREG/CR-4279(5).

Hydraulic snubber failures are often the result of transients (e.g., water hammer) and misapplications such as continuous pipe or equipment vibration and/or abnormally high temperatures. Failures also often result from nonservice-related influences such as manufacturing defects, assembly errors, improper installation, or damage during handling.

In terms of aging, seals are of primary concern for hydraulic snubbers. Seal degradation due to aging is most significantly affected by elevated temperature and to a lesser degree by radiation.

A.2.4.2 Failure Modes of Mechanical Snubbers

Mechanical snubber failures are usually associated with an inability of the snubber to allow free thermal motion, i.e., passive failure modes. This failure mode is particularly prevalent in the less rugged, smaller models which are more vulnerable to damage during installation or construction.

As with hydraulic snubbers, mechanical snubber failures are often the result of transients, misapplications, or non-time-related influences. Specific aging mechanisms, per se, have not been positively identified for mechanical snubbers. To some extent, this is probably due to the lack of readily monitored attributes. The only meaningful information in this regard is test data. To date, such data has not been totally useful for trending, since the same snubbers are not tested during each outage. More research is needed in this regard.

A.2.4.3 Reversal of Trend to Hydraulic Snubbers

On initiation of in-service testing for mechanical snubbers in the early 1980s, a higher than expected failure rate was experienced (see Section A.5.0). This failure rate has led to a renewed trend in the use of hydraulic snubbers. In fact, a number of manufacturers are now offering direct hydraulic snubber replacements for smaller sizes of mechanical snubbers.

Hydraulic seal service life remains an issue of major importance to the utilities and the NRC. Snubber seals are replaced periodically as a preventative maintenance measure in anticipation of aging degradation. Seal replacement intervals are generally conservative because of the unknown extent of degradation. However, the advantages of such a precautionary approach are often offset by the increased risk of errors or damage during snubber overhaul.

A.2.5 HYDRAULIC FLUIDS

Silicone hydraulic fluids are almost universally used in hydraulic snubbers because of their relatively inert and heat resistant characteristics. These fluids are unaffected by aging under all environmental influences except radiation. Because of cross-linking, a permanent increase in viscosity can result on exposure to gamma radiation. However, for fluids used in the majority of hydraulic snubbers this effect is negligible.

Although not aging related, the viscosity of all silicone fluids varies with temperature. Such variations can affect control valve performance. Parameters such as locking velocity and bleed rate, therefore, should be correlated with temperature.

Hydraulic fluids may become contaminated with air, moisture and/or particulates, all of which can affect snubber performance. This is particularly true of snubbers with vented reservoirs. The use of adequate fluid processing equipment and procedures can minimize such contamination during production and rebuilding. Pressurized reservoirs minimize the potential for reintroduction of such contaminants.

The basic type of silicone fluid used depends on the snubber model. Some of the more common fluids are described below.

- General Electric SF-1154 - SF-1154 fluid is a methyl phenyl polysiloxane fluid. It is by far the most commonly used snubber fluid in the U.S. Notable physical characteristics are listed below:

- low lubricity
- excellent heat resistance
- nominal viscosity: 190 centistokes
- significant change in viscosity with temperature (i.e. a 50% reduction in viscosity from 70°F to 100°F)
- high radiation resistance (i.e. 15% increase in viscosity at 35 megarads; gellation at 500 megarads)
- propensity to absorb moisture (can cause internal corrosion).

- General Electric SF-96/1000 Fluid - SF-96/1000 is a dimethyl polysiloxane fluid. It is used in a limited number of Grinnell snubbers that utilize a shuttle type control valve. Notable physical characteristics are listed below:

  - high lubricity
  - nominal viscosity: 1000 centistokes
  - moderate change in viscosity with temperature (i.e. a 30% reduction in viscosity from 70°F to 100°F)
  - moderate radiation resistance (gellation at 7 megarads).

- General Electric Versilube F 50 - Versilube F 50 fluid is a methyl chlorophenyl fluid. Most Anker-Holth snubbers originally used F 50 fluid. This fluid has since been replaced with SF-1154 fluid in a number of these snubbers. Notable physical characteristics are listed below:

  - high lubricity
  - nominal viscosity: 70 centistokes
  - excellent temperature/viscosity characteristics
  - low to moderate radiation resistance
  - gellation at 20 megarads
  - starts to generate acid at one megarad.

- General Electric SF-1147 Fluid - SF-1147 fluid is a methyl alkyl polysiloxane silicone fluid. It is used in a limited number of Anker-Holth and in some Paul Monroe snubbers. Notable physical characteristics are listed below:

  - high lubricity
  - nominal viscosity: 50 centistokes
  - moderate temperature/viscosity characteristics
  - high radiation resistance (gellation at 500 megarads).

A.2.6 CURRENT PRACTICES TRENDS

A.2.6.1 Snubber Minimization

Some plants have fewer than 100 piping snubbers. For others, however, as many as 2,000 have been specified in order to ensure rigidity of the piping system. The number of equipment snubbers varies from as few as 4 to as many as 36 per plant.

Snubber minimization programs have enabled a number of utilities to significantly reduce the number of piping snubbers used in their plants. Similar efforts to reduce the number of equipment snubbers are under way for some plants.

The advantages to the utility of snubber minimization are associated with decreased maintenance costs as well as decreased examination and testing costs. Another advantage is a reduction in the probability of encountering a snubber failure during in-service examination, thus reducing the risk of increased examination frequency, as required by Technical Specifications.

There is also a safety benefit associated with minimization of snubbers prone to passive failures. This results from the reduced potential for overstressing the component due to high drag force or snubber jamming during normal plant operations.

A.2.6.2 "Life-of-Plant" Seals

Some snubbers are manufactured with seals that are designed for a 40-year life. These snubbers incorporate the use of thermoplastic seals (i.e., Tefzel® and Hytrel®) and metallic seals. Such snubbers are manufactured by Paul-Munroe Enertech Inc. and Taylor Devices. Bergen-Paterson Corp. has also manufactured a limited number of such snubbers.

Some plants have elected to retrofit equipment snubbers, originally fitted with elastomeric seals, with thermoplastic and metallic seals. This often involves extensive rework due to more stringent surface finish and tolerance requirements.

A.2.6.3 Increased Service Life of Elastomeric Seals

A number of utilities have extended the life of elastomeric seals by conducting seal life evaluation studies. Such studies generally involve either service related data or laboratory test data.

A.2.6.4 Revised Technical Specifications

The potential of a forced outage for reexamination of snubbers still exists, particularly for plants with a large number of safety-related

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snubbers. In addition, the current examination frequency table (Table A.2.1) does not coincide with scheduled outages for plants with other than an 18-month refueling cycle. A number of utilities have, therefore, requested relief from, or have proposed alternatives to, existing examination frequency requirements. The NRC is evaluating alternatives to current requirements that will minimize the potential for operating with failed snubbers while reducing the need for forced reexamination outages. Accommodation of plants with unique snubber populations and shorter or longer refueling cycles is also a major consideration in this evaluation.

A.3.0 SEALS USED IN HYDRAULIC SNUBBERS

The seals used in hydraulic snubbers have varied functions, configurations and materials; these are discussed in the following sections.

A.3.1 FUNCTIONAL CATEGORIES FOR SEALS

Snubber seals may be grouped into the following functional categories: "static/dynamic," "low pressure/high pressure," and external/internal." These categories are not mutually exclusive.

A.3.1.1 Static/Dynamic Seals

Static seals are used where there is no relative motion, except possibly the flexing of the seal under pressure. Examples of static seals in snubbers are valve mounting seals, cylinder-end seals, reservoir seals, port seals, fitting seals, and thread seals.

Dynamic seals are used where there is relative motion between the seal and its mating surface. Examples of dynamic seals in snubbers are piston rod seals, piston seals, and reservoir plunger seals.

A.3.1.2 Low Pressure/High Pressure

Low-pressure seals are used to seal that portion of the hydraulic system that is not pressurized during snubber activation. Normally, the pressure applied to such seals (i.e., reservoir pressure) is less than 30 psig. Examples of such seals are reservoir and associated fitting seals.

High-pressure seals are used to seal that portion of the hydraulic system that is pressurized during activation. Depending on the snubber design, pressures applied to such seals range from 2000 to 15,000 psi. Examples of high-pressure seals are piston rod seals, piston seals, and cylinder end seals. Most high-pressure seals are also required to seal under low-pressure conditions.

A.3.1.3 External/Internal Seals

External seals isolate the hydraulic system from the surrounding environment. Failure of an external seal would lead to loss of fluid from the hydraulic system. Examples of external seals are piston rod seals, cylinder-end seals, and reservoir seals.

Internal seals are designed to isolate the high-pressure portion of a snubber from the low-pressure portion. Failure of an internal seal would not lead to loss of hydraulic fluid. Examples of internal seals are piston seals and internal valve seals.

A.3.2 ELASTOMERIC SEALS

An elastomer is defined in the Parker O-Ring Handbook(6) as a "high polymer that can be or has been modified to a state exhibiting little plastic flow and quick or nearly complete recovery from an extending force." In the following, types of elastomeric seals are described. Included are the basic "common snubber seal elastomers" and "common elastomeric seal configurations."

A.3.2.1 Common Snubber Seal Elastomers

Ethylene Propylene (EPR, EPDM) rubber, consisting of ethylene and propylene monomers, and sometimes a third monomer, is the most widely used elastomer in hydraulic snubbers. It won broad acceptance for snubber applications after initial problems with polyurethane seals that were found to be incompatible with the hydraulic fluid (Section A.2.2). It was basically selected over other fluid compatible elastomers due to its superior radiation resistance. Parker Seal Company recommends a maximum service temperature of 300°F for EPR. However, most hydraulic snubber manufacturers recommend a maximum continuous use temperature of 200°F.

Fluorocarbon rubber (FKM) is more commonly known by the DuPont trade name Viton®. This material is also available under the 3M trade name Fluorel®. Fluorocarbon rubber seals are used in a number of Anker-Holth equipment snubbers as well as in Milwaukee equipment snubbers. They were also used in earlier models of Grinnell snubbers.

Fluorocarbon rubber (FKM) has a maximum recommended service temperature of 400°F, although continued service beyond one year at this temperature is questionable. FKM is acceptable for use with silicone fluids and exhibits good resistance to aging. Some snubbers using this material have been in service for almost 15 years with no obvious degradation of sealing integrity. This material has also been used extensively for snubber seals in foreign nuclear facilities. FKM is somewhat less resistant to radiation than EPR. (This may have less significance than was originally anticipated because of the relatively low-radiation exposure of seals during normal operation.)

A.3.2.2 Common Elastomeric Seal Configurations

There are basically six different configurations of elastomeric seals used in snubbers. These are O-rings, packing seals, gaskets, lip seals, tee seals, and thread seals. Each configuration is discussed below:

- O-Rings - O-Rings (Figure A.3.1) are the most universal elastomeric seals. They are used in virtually all hydraulic snubbers utilizing rubber seals. O-ring applications are used in both low- and high-pressure static sealing applications.

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® Fluorel is a registered trade name of the 3M Company.

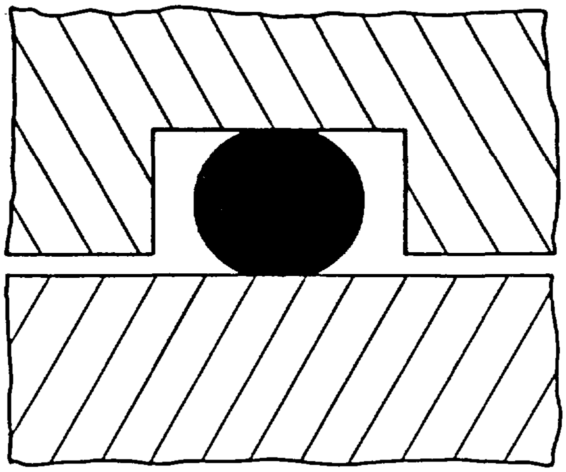

FIGURE A.3.1. O-Ring

- Packing Seals - Packing seals (Figure A.3.2) are used in some snubber models (e.g., Milwaukee, modified Boeing, and early Grinnell snubbers) primarily as piston rod seals. They have both a low-pressure and high-pressure function. The Polypak® seal is sometimes referred to as a packing seal but for purposes of discussion here it will be considered an energized lip seal (see paragraph below).

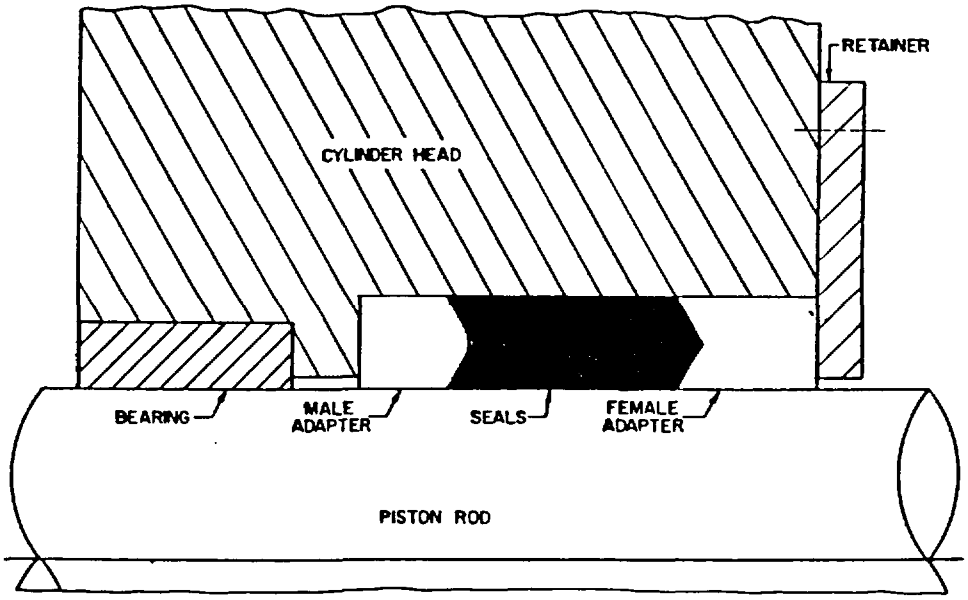

FIGURE A.3.2. Packing Seal

® Polypak is a trade name of Parker Hannifin Corp.

- Gaskets - Gaskets (Figure A.3.3) are used to a limited extent in hydraulic snubbers, primarily as low-pressure static seals.

- Energized Lip Seals - energized lip seals use a metallic or elastomeric energizer (spring) to provide a high sealing force under low-pressure conditions. When fluid pressure increases, sealing force is increased by the pressure itself. The O-spring lip seal (Figure A.3.4) utilizes an elastomeric energizer; this seal is used in Bergen-Paterson and Basic Engineers snubbers and in some models of Grinnell snubbers. Another type of energized lip seal is the Miller rod seal (Figure A.3.5), which uses a pressure ring and metallic wave spring design; this seal is used exclusively in Grinnell snubbers.

- Non-energized Lip Seals - non-energized lip seals do not utilize an energizer. They are used in internal high-pressure applications, (e.g., as piston seals).

- Tee Seals - The Tee seal (Figure A.3.6) is essentially an anti-roll version of the O-ring seal. It is used for high- and low-pressure applications as both a piston seal and piston rod seal in E-Systems snubbers, Anker-Holth snubbers, and some earlier models of Grinnell snubbers.

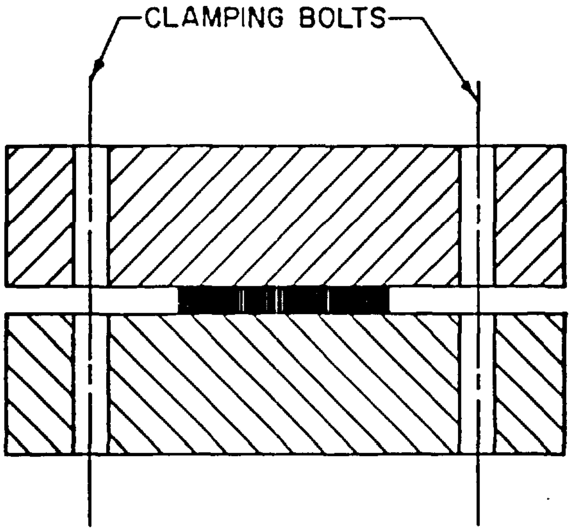

FIGURE A.3.3. Gasket

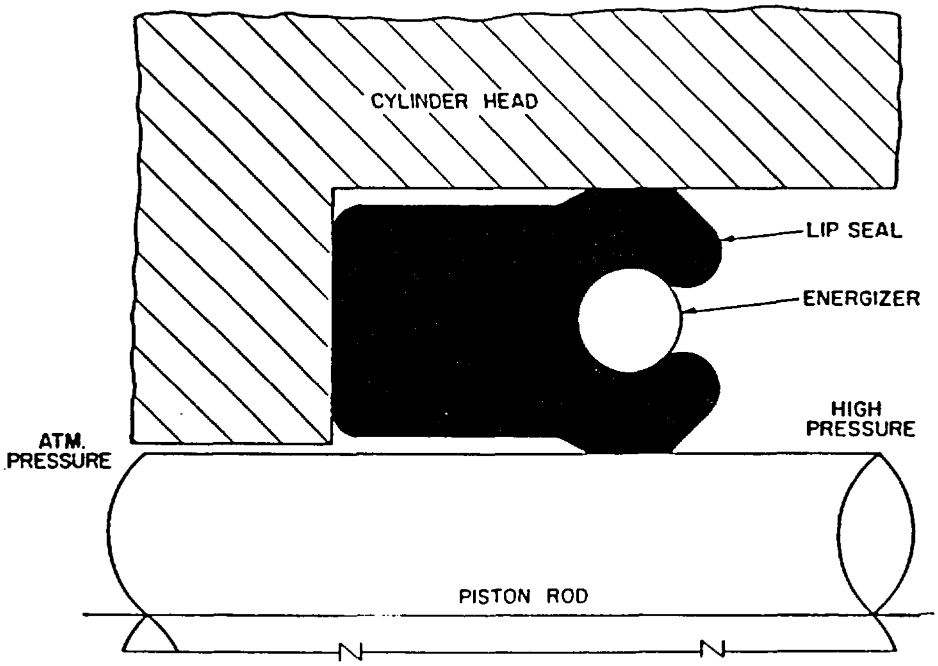

FIGURE A.3.4. O-Spring Lip Seal

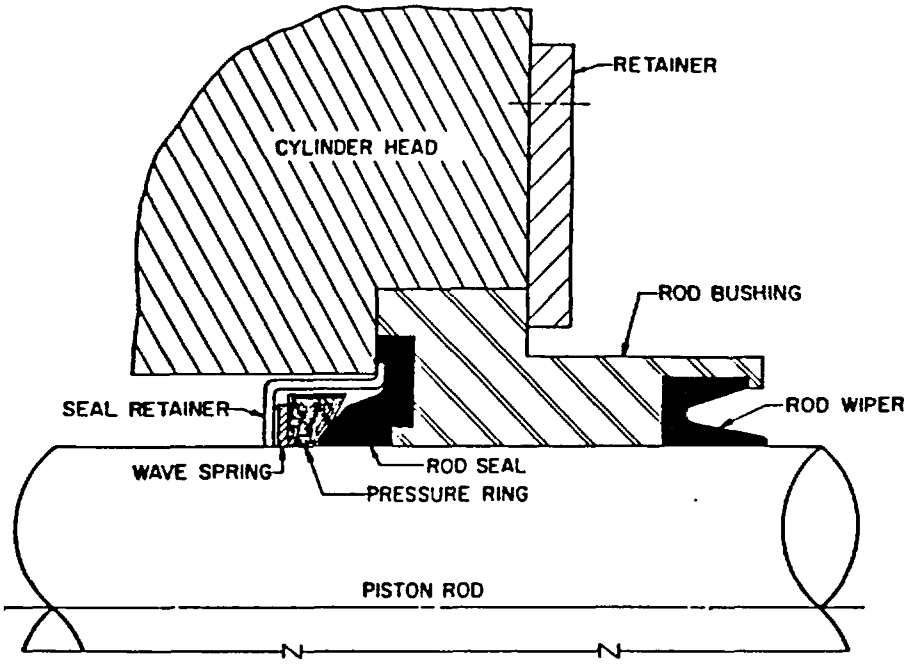

FIGURE A.3.5. Miller Rod Seal

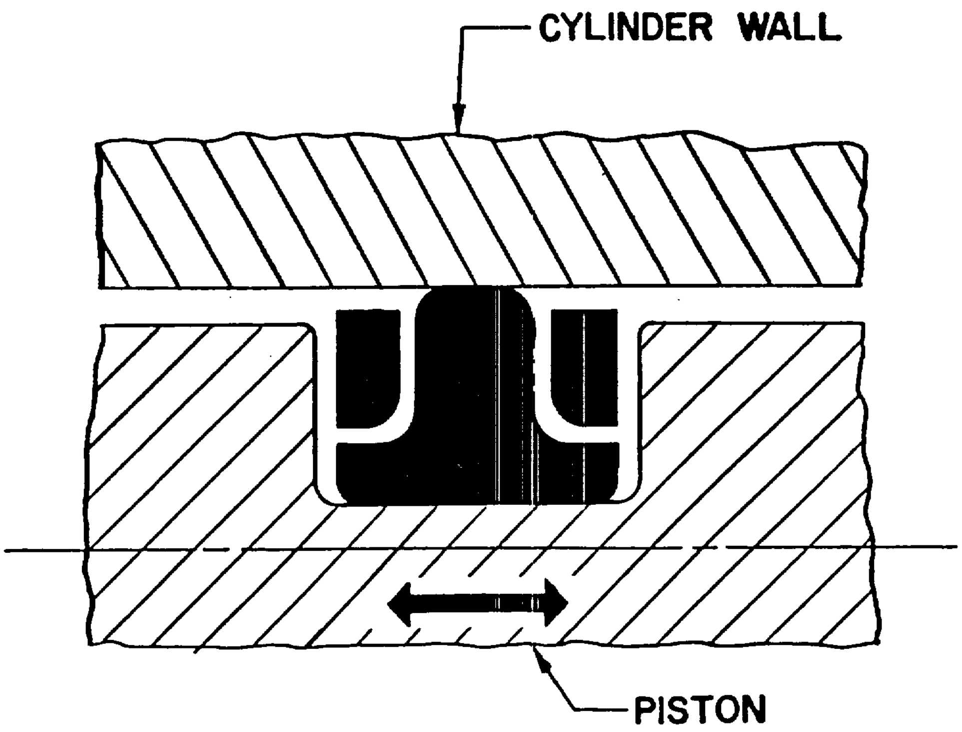

FIGURE A.3.6. Tee Seal

- Thread Seals - Thread seals (Figure A.3.7) are used to seal straight screw threads such as those used on control valve adjustment screws and on certain hydraulic tube fittings. Thread seals are both high- and low-pressure seals.

Snubbers are generally provided with a piston rod wiper which is molded from a hard elastomer or thermoplastic. Wipers are not seals but are designed to prevent contaminants from being drawn into the snubber by motion of the piston rod.

A.3.3 METALLIC SEALS

Metallic seals are commonly used in hydraulic snubbers incorporating "life-of-plant" seals. It is virtually impossible to use metallic seals in a dynamic application without encountering some leakage, however minimal. For this reason, metallic seals are not practical for use as piston rod seals without the use of a secondary, non-metallic sealing element.

Compared to elastomers, metallic seals have a very low elastic deflection range or "memory." Manufacturing tolerances and surface finish requirements for them are, therefore, much more critical than for elastomeric seals. However, metal seals exhibit little relaxation due to aging. In fact, it may generally be stated that, if a metallic seal performs adequately when installed, there is little chance of failure due to aging.

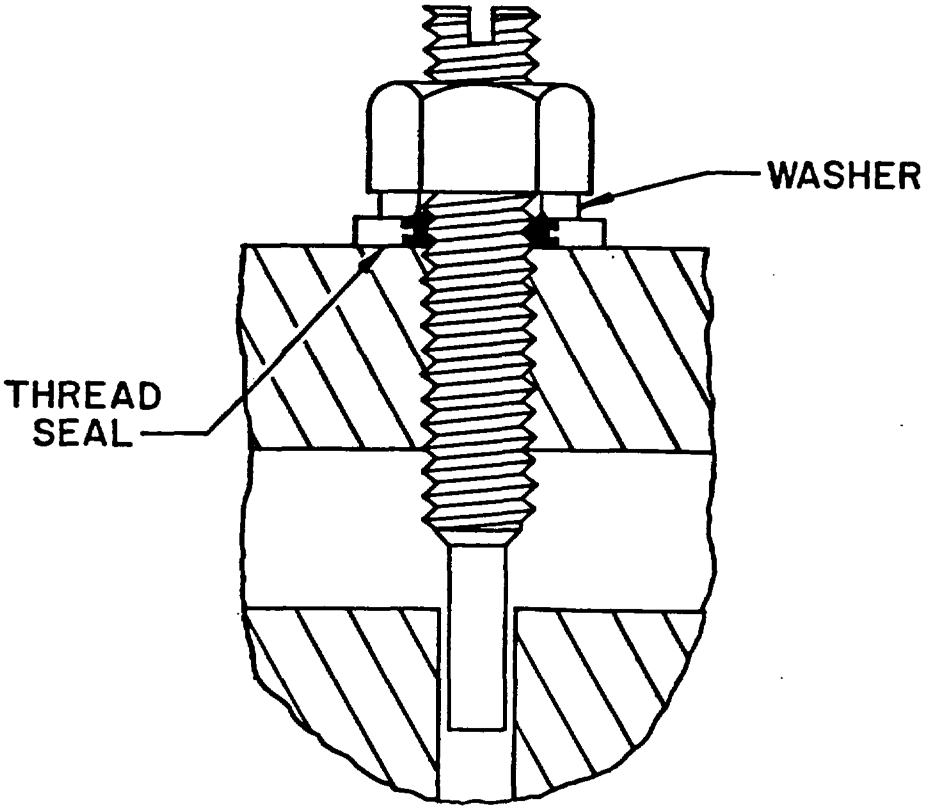

FIGURE A.3.7. Thread Seal

A.3.3.1 Metal O-Rings

Metal O-rings are used only in static sealing applications and are available in most sizes normally provided for elastomeric O-rings. Aside from geometrical similarities, however, metal and elastomeric O-rings have little in common.

When compressed, the cross section of a metal O-ring deforms to the shape of an hour glass (Figure A.3.8), resulting in a double line of contact along the mating surface. A discontinuity in seal contact often occurs in the area where the seal was welded during manufacturing and can result in leakage.

A.3.3.2 Metal C-Rings

A metal C-ring is essentially a metal O-ring that has been cut open along its circumference, providing a larger range of elastic deflection. However, under low pressure conditions, the sealing force against the mating surface is significantly less than that for metal O-rings.

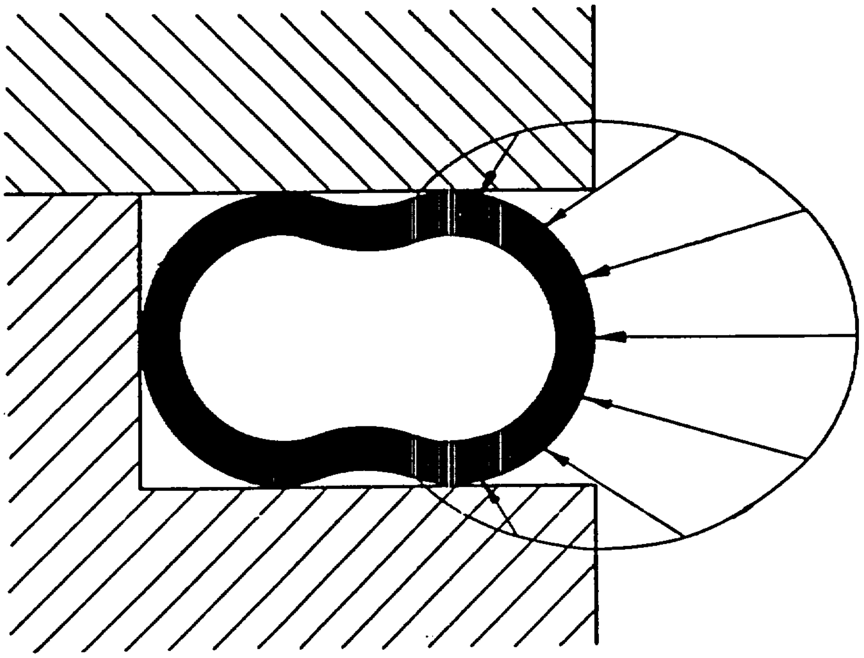

FIGURE A.3.8. Metal O-Ring

Metal C-rings are recommended for static sealing applications at low and moderate pressure only. The open edge design also provides for a self-energizing function when the seal is pressurized.

A.3.3.3 Metal Piston Rings

Metal piston rings (Figure A.3.9) are used as internal dynamic seals only. They are generally manufactured from grey cast iron and require some break-in for effective sealing. When pressurized, the rings are forced against the surfaces of the seal gland and cylinder wall, increasing sealing effectiveness. Some fluid by-pass is always encountered.

A.3.3.4 Miscellaneous Fitting and Port Seals

A number of metallic seal types are used as static seals for hydraulic plugs and fittings. Examples are boss seals and ferrule type seals.

A.3.4 THERMOPLASTIC SEALS

Thermoplastic seals (Figure A.3.10) are used in static and dynamic applications as both high- and low-pressure seals in some hydraulic snubbers. Because of the cold flow characteristics of thermoplastics, such seals must be either totally contained when compressed or spring or pressure energized in order to maintain a sealing force. As with metallic seals, thermoplastic seals are much less forgiving than their elastomeric counterparts, requiring

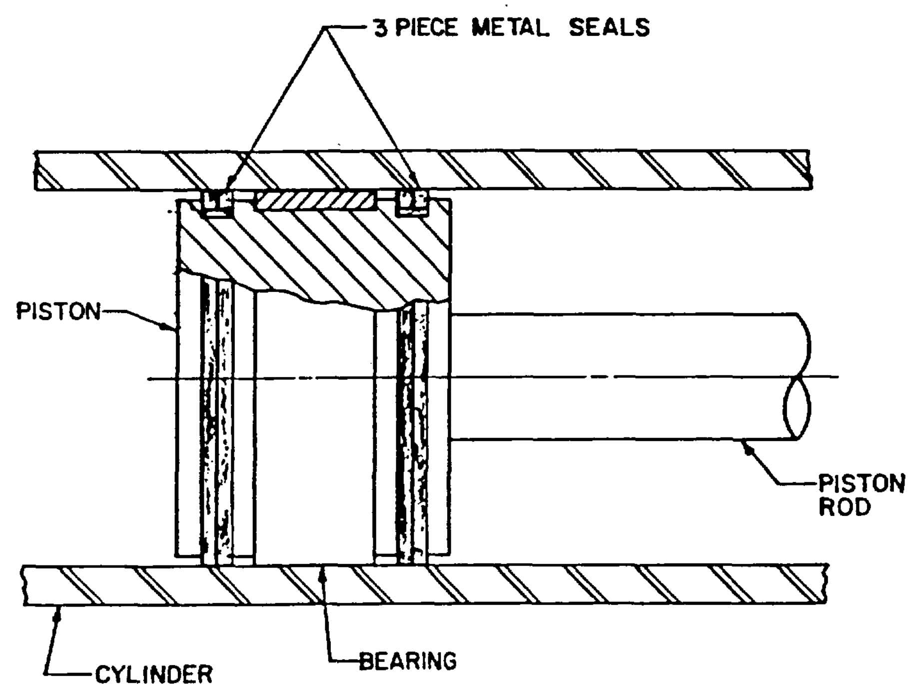

FIGURE A.3.9. Metal Piston Rings

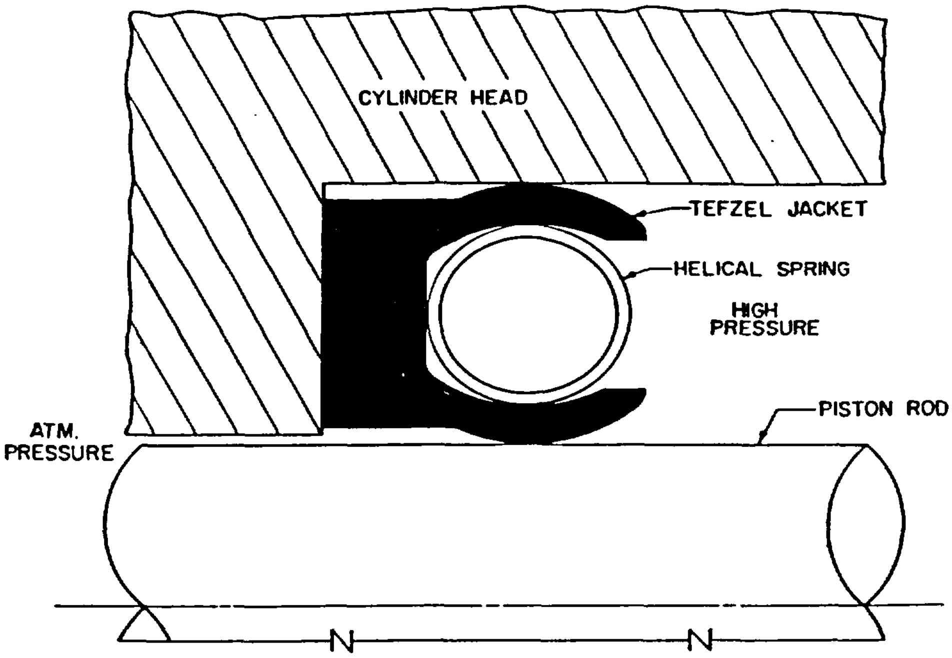

FIGURE A.3.10. Thermoplastic Seal

more stringent machining finishes and tolerances. Considerable rework is often required when snubbers that were originally designed to incorporate elastomeric seals are retrofitted with thermoplastic and metallic seals.

The following describes the two thermoplastic materials used in snubber seals.

- Tefzel® - Tefzel is an ethylene tetrafluoroethylene fluoropolymer. It has a maximum recommended continuous use temperature of 300°F and is inert to silicone fluids used in hydraulic snubbers. Tefzel is generally resistant to property changes due to aging.

  Tefzel is similar in appearance to Teflon®; however, Teflon consists of carbon and fluorine atoms only, the Tefzel fluoropolymer also contains hydrogen atoms. Tefzel is significantly more resistant to radiation than Teflon. Specifically, Tefzel will only undergo a 20% reduction in elongation after exposure to 10 megarads whereas Teflon will start to embrittle at 40,000 rads.

  Tefzel is used in piston rod seals, piston seals, and static face seals in hydraulic snubbers manufactured by Paul-Munroe Enertech, Inc.

  Tefzel seals have been used in some equipment snubbers manufactured by Bergen-Paterson Corp. Some snubbers that originally used elastomeric seals have been retrofitted with Tefzel seals.

  The strength and hardness of Tefzel may be increased significantly by the addition of fillers such as fiberglass. Low-pressure sealing effectiveness, however, is generally diminished.

- Hytrel® - Hytrel is a polyester elastomer consisting of a polyester glycol soft segment and a polyether hard segment. This material has been used for a number of non-nuclear applications since 1973. Hytrel, for example, is often used as the material that provides the "spring" in a telephone receiver cord.

  Hytrel will endure substantial radiation exposure without significant degradation of properties. Specifically, Hytrel will experience negligible property changes even after exposure to 15 megarads.

  Hytrel is used as the primary material for piston rod seals in equipment snubbers manufactured by Taylor Devices, Inc. These snubbers are continuously pressurized ensuring a continuous sealing force even when the snubber is not activated. An advantage of Hytrel over Tefzel in this application is its lower coefficient of friction.

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® Hytrel is a registered trade name of the DuPont Company.

A.3.5 SEAL FAILURE MECHANISMS

Some seal failure mechanisms include extrusion, adhesion, roll, wear, seal damage, gland damage, cracks or ruptures, and inadequate sealing force. These are discussed below.

A.3.5.1 Extrusion

When pressurized, pressure energized seals such as O-rings are forced against the mating surface and into the various gland gaps to form a tighter seal. Depending on design clearances and the degree of pressurization, the seal may flow (extrude) into gaps between mating parts (Figure A.3.11). When this occurs to the point that the seal will not recover, sealing effectiveness is usually lost.

Harder seal materials are more resistant to extrusion. Potential for extrusion is also minimized by the use of a back-up ring (Figure A.3.12). Seal extrusion in snubbers is rare and is most often the result of design or manufacturing inadequacies.

A.3.5.2 Adhesion

Elastomeric and thermoplastic seals occasionally adhere to the mating surface (e.g., piston rod surface) when there is no relative motion for an extended period of time. This is generally thought to be the result of molecular interaction between the two materials. The propensity for such adhesion is increased with elevated temperature. Seal adhesion can lead to an increase in snubber breakaway force and decreased sealing effectiveness.

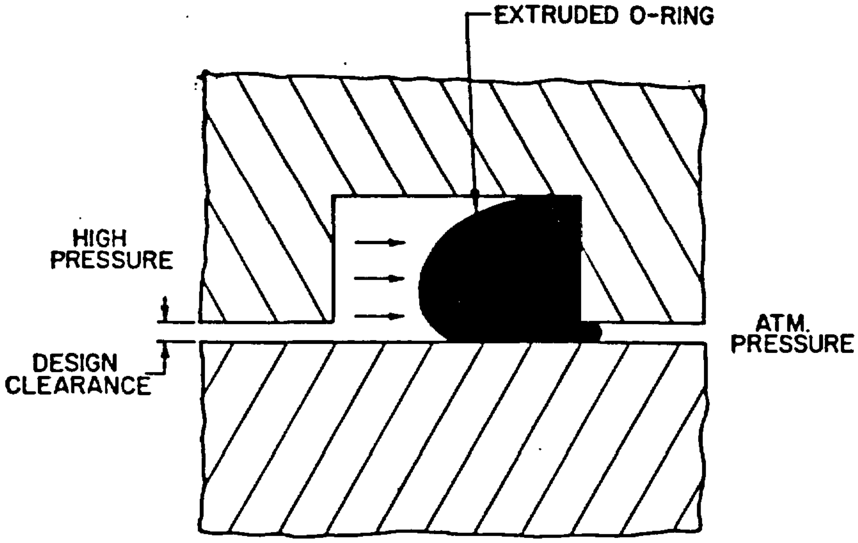

FIGURE A.3.11. Extruded O-Ring

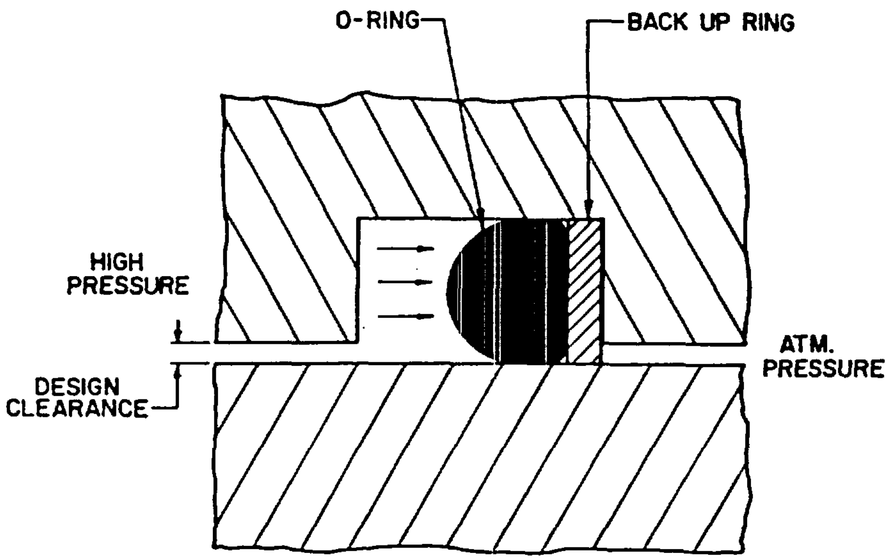

FIGURE A.3.12. O-Ring with Back-Up Ring

A.3.5.3 Roll

This failure mechanism periodically occurs for seals used in dynamic applications, e.g., piston or piston rod seals. Seal roll is caused by friction between the seal and a moving mating surface, such as a piston rod. The seal tends to roll or spiral rather than to slide along the moving surface.

O-rings used in dynamic applications have the highest propensity for rolling. Fortunately, O-rings are not commonly used as dynamic seals in snubbers. Those seals that are used as dynamic seals generally have a built-in resistance to rolling due to their design configuration.

A.3.5.4 Wear

Normally, seal wear is a problem for snubbers only under conditions of high amplitude vibration.(a) Most snubbers are not designed for continuous use in such environments. Thermally induced motion of the piping or equipment rarely causes significant seal wear.

Piston or piston rod seal wear can adversely affect sealing effectiveness and can result in contamination of the hydraulic fluid due to the generation of abraded particles.

(a) High amplitude vibration is defined as vibration in which the amplitude is greater than the snubber pin and bearing clearances such that it results in relative motion between the snubber piston rod and the rod seal.

A.3.5.5 Seal Gland Damage

Seal or gland damage (i.e., cuts, nicks, abrasions, etc.) can occur from a number of causes including the following:

- improper handling
- improper seal installation
- service damage, i.e., scored piston rod surface
- improper seal storage
- hard debris that are forced over the rod seal by motion of the piston rod.

A.3.5.6 Cracks or Ruptures

Cracks or ruptures can occur in Tefzel seals, particularly when they are pressurized at elevated temperatures. The exact cause of such failures has not been identified: a possible contributor is the stress induced by restrained thermal growth (see Section A.5.7, Shrinkage); another is material laminations which are detectable by L/P exams. Such failures are not likely to occur with elastomers.

A.3.5.7 Inadequate Sealing Force

Inadequate sealing force can result from a number of causes including the following four.

A.3.5.7.1 Design/Manufacturing Inadequacies

This includes insufficient initial squeeze as a result of an incorrectly specified seal size and/or incorrect gland dimensions.

A.3.5.7.2 Shrinkage

Elastomer shrinkage can occur as a result of incompatibility with the hydraulic fluid whereby plasticizers are leached from the seal material. This type of shrinkage, however, is less common than earlier experiences(2) due to the use of compatible seal materials.

Thermoplastic seal shrinkage can occur as the result of differential thermal expansion between the seal material and the seal gland. In this case, the seal essentially becomes remolded when exposed to elevated temperatures, resulting in a reduction in the outside diameter of the seal when the temperature is reduced (Figure A.3.13). Because thermoplastic seals have

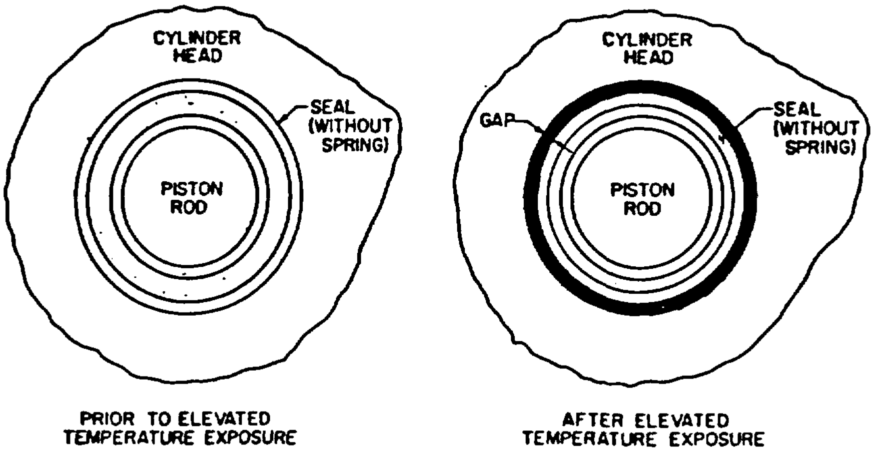

FIGURE A.3.13. Heat Shrinkage of Thermoplastic Seals

little memory, they must compensate for such dimensional changes through the use of internal springs or high internal pressures that force the seal lips against the gland.

A.3.5.7.3 Insufficient Tightening of Mating Parts

Insufficient tightening of mating parts, e.g., plugs, fittings, and thread seal nuts, can result in inadequate sealing force.

A.3.5.7.4 Stress Relaxation/Aging

The low-pressure sealing force of elastomeric and plastic seals will reduce with service time due to stress relaxation. Relaxation may be accelerated by certain environmental stresses such as radiation and temperature.

A.3.5.8 Short-Term and Nonservice-Related Failures

Snubber seal failures are often the result of environmental influences that are beyond the design capacity of the snubber. Such influences include transient loads, high-amplitude vibration, and environmental temperatures above the design specified maximum. Failures resulting from such influences can occur in less time than the service life specified by the manufacturer (five to seven years for most hydraulic snubbers). Also, failures commonly result from nonservice-related influences such as design or manufacturing defects, assembly errors, and handling or construction damage.

Thorough preservice testing and examination will minimize nonservice-related failures. The incidence of short-term failures due to severe environments may be minimized by augmented in-service examination and/or more frequent seal replacement. Short-term and nonservice-related failures should be identified by root cause evaluation and subsequently culled from the data base used to establish service life for the general snubber population.

A.4.0 SEAL AGING

A.4.1 SEALING MECHANISMS

A.4.1.1 General

Sealing occurs when the clearances or leakage paths between the seal and its mating surface are so small that fluid will not pass through because of surface tension. Obviously, as pressure increases or fluid viscosity decreases, smaller passages are required in order to hold the fluid back.

An additional requirement for sealing is that the pressure exerted by the seal against the gland be greater than the system pressure in order to prevent the seal from lifting away from the sealing surface.

It should be noted that for piston rod seals, a certain amount of wetting of the piston rod will be observed when the rod is moved in and out a number of times. This is a normal occurrence and results from fluid that is drawn out of the snubber by extension of the piston rod.

For convenience in distinguishing between various seal types, a number of sealing mechanisms are defined below.

A.4.1.2 Tortuous Path Seal

In the tortuous path sealing mechanism, enough sealing contact area is provided such that the fluid must wind its way through a complexity of passages that effectively "dead end" before the fluid reaches the other side of the seal. There is generally enough surface area to compensate for any sealing contact discontinuities. Gaskets and packings are representative of this sealing mechanism.

A.4.1.3 Line Contact Seal

In this sealing mechanism, a continuous high-force contact line exists against the sealing surface such that the largest gap along this line is small enough to prevent fluid passage. As opposed to the tortuous path type seal, there is little redundancy provided with the line contact seal. If the line of contact is broken, leakage will occur. O-rings, lip seals, and tee seals are representative of this type of sealing mechanism.

A.4.1.4 Mechanical Seal

For mechanical seals, the sealing mechanism results from a close fit between the seal surface and mating surface, thus minimizing the size of potential leakage paths. Metal piston rings are representative of mechanical seals used in snubbers.

A.4.1.5 Displaced Material Seal

Sealing occurs for a number of static seals by permanently deforming material (either the seal or the gland). In so doing, the material is forced into the various minute passages along the sealing surface.

Almost all static metallic seals require some permanent material deformation in order to seal effectively. Such seals often incorporate soft coatings such as silver or copper in order to improve sealing effectiveness.

Other examples of displaced material seals in snubbers are high-pressure metal fitting seals (crimped ferrule), soft metal rings, and pipe threads.

A.4.1.6 Pressure Energized Seals

Pressure energized seals actually seal more effectively at higher pressures by applying a higher sealing force, decreasing the size of potential leakage passages. Examples of pressure energized seals are lip seals, O-rings, vee (or chevron) packings, tee seals, and piston rings.

A.4.2 PHYSICAL PROPERTIES OF ELASTOMERS

Elastomeric seal aging is often measured in terms of changes in physical properties. This includes hardness (durometer), tensile strength, elongation, modulus, and compression set.

A.4.2.1 Hardness (Durometer)

Elastomer hardness is generally measured using a durometer scale ranging from 0 (soft) to 100 (hard). Hardnesses for elastomeric seals generally range from 70 to 90 durometer (Shore A Scale).

A softer sealing material, i.e., 70 to 75 durometer, is likely to be used in low-pressure sealing applications where the seal must conform to the various surface discontinuities of the gland. Harder seals, i.e., 80 to 85 durometer, are more often used in high-pressure applications because of their higher resistance to extrusion. Elastomers of 90 durometer are often used for back-up rings and piston rod wipers.

For a given initial squeeze, a harder seal will experience more compression set (permanent deformation) than a softer seal.

A.4.2.2 Tensile Strength

Tensile strength is the tensile stress at break for a given elastomer. It is difficult to relate tensile strength directly to sealing performance. Although an indicator of seal degradation, it is used more often as a measure of production uniformity.

Tensile strength for a typical elastomer is 2,000 psi at 300% elongation.

A.4.2.3 Elongation

Elongation is defined as the increase in length over the original length at break. As with tensile strength, it is difficult to relate this parameter directly to sealing effectiveness. It is often used as a measure of a seal's ability to be stretched during installation or as a measure of a seal's ability to recover after overloading. It is also a measure of seal embrittlement.

A.4.2.4 Modulus

In contrast to metals, for which the modulus may be defined as the slope of a stress/strain curve, elastomers do not have linear elastic characteristics much beyond a strain of 15%.

Modulus for elastomers is, therefore, defined as tensile stress at a given strain. As with tensile strength and elongation, modulus is used as a measure of production uniformity and is not directly relatable to sealing effectiveness.

A.4.2.5 Compression Set

In the rubber industry, two basic methods are used to measure compression set.

- Constant Stress Method - The constant stress method is often used to compare the general compression set resistance of various materials. In this method, a constant compressive stress, typically 400 psi, is applied to the material at a predetermined temperature for a predetermined period of time. In this method, compression set, C.S., is calculated using the following equation:

$$\text{C.S.} = \frac{\text{(original thickness - thickness after test)}}{\text{(original thickness)}}$$

- Constant Strain Method - The constant strain method is used to measure the amount of permanent set of a material after exposure to a given environment. In this method, the material is initially compressed a fixed amount and then exposed to a prescribed environment. Material thickness is measured after exposure to the environment for a given time period. In this method, compression set (C.S.) is calculated using the following equation:

$$\text{C.S.} = \frac{\text{(original thickness - thickness after test)}}{\text{(initial compression)}}$$

The constant strain method is the most commonly used measure of compression set for seals. Further reference to compression set in this report will assume this method is used.

Compression set is probably the most important, readily measured parameter associated with seal aging. It is not truly a physical property but more a measure of seal degradation. Compression set can be correlated with low-pressure sealing force and, in this sense, can be used as a measure of a seal's ability to seal under low-pressure conditions. For very low initial squeeze values, i.e., less than 0.010 in., a seal will experience significant compression set in a short period of time. However, for seals compressed within the range recommended by most seal manufacturers, compression set is generally independent of the initial squeeze.

Compression set, of itself, is not a total indicator of a seal's ability to continue to perform adequately. An acceptable compression set depends on a number of factors (see Section 3.6). Indeed, in many cases, a seal will continue to seal effectively at 100% compression set.

A.4.3 SEAL AGING MECHANISMS AND STRESSORS

The effects of aging on seals, in general, result from chemical processes in the seal material. Some of these chemical processes may be accelerated by environmental stressors such as temperature, radiation, humidity, hydraulic fluid incompatibility, and ultraviolet light. The resulting changes may adversely affect a seal's ability to function. For example, a seal exposed to long periods of sunlight during storage may develop surface cracks. A seal used with an incompatible fluid, on the other hand, may soften to such an extent that its resistance to extrusion under pressure is significantly affected.

A snubber differs from most hydraulic cylinder applications because it is in the passive mode for most of its useful life, with little or no motion of the piston rod and with no applied load (except during functional testing). Of primary concern, therefore, is long-term leakage under low-pressure conditions in the normal plant operating environment. Although the ability of the seals to maintain a pressure boundary under load is also important, the incidence of this type of seal failure in snubbers has been extremely low and has generally been related to design deficiencies or assembly errors rather than aging.

Low-pressure sealing integrity can be affected by a reduction in sealing force due to stress relaxation. The performance of a seal (particularly a dynamic seal) under low-pressure conditions can also be affected by an increase in hardness, resulting in an inability of the seal to conform to discontinuities in the mating surface.

In the laboratory, the force (or back stress) exerted by a seal can be measured using a relaxometer. In this device, (Figure A.3.14) the seal is compressed a predetermined amount using the center screw. A measured external force is then applied. The force exerted by the seal is the external force required to separate the compression plate from the screw (as indicated by a break in electrical continuity).

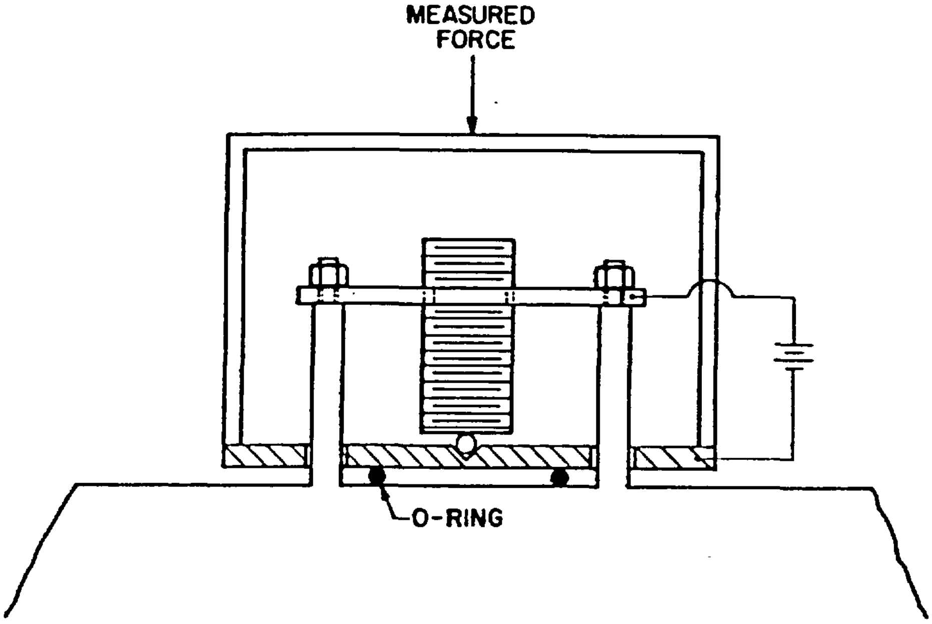

FIGURE A.3.14. Relaxometer

Direct measurement of sealing force for seals used in snubbers in service is impractical. However, compression set is a useful parameter in this regard, because it is easily measured and may be related to low-pressure sealing force.

Sealing effectiveness, however, cannot be determined by measurement of compression set alone. The acceptability of a given compression-set value depends on a number of variables such as seal configuration, surface roughness, hardness, fluid viscosity, and pressure.

A.4.3.1 Long-Term Degradation Stressors

Long-term seal degradation is defined here as degradation, within the specified environmental limits of the snubbers, that will generally not result in failure in less time than the maintenance interval recommended by the manufacturer. Most environmental stressors resulting from normal plant operation would be considered long-term degradation stressors. However, there may be isolated applications in which snubbers are exposed to environmental stresses that are beyond the recommended "continuous use" limits of the snubber; such applications could result in short-term seal failure.

A.4.3.1.1 Operating Temperature

Environmental temperatures in most plants under normal operating conditions do not exceed 160°F. However, some BWR plants have reported environmental temperatures above 200°F.

Property changes in polymers due to long-term exposure to elevated temperature are primarily the result of molecular cross-linking (see Section A.6.4). The extent to which temperature accelerates aging has not been established. The results of a study by Parker Seals(7) appear to indicate that, for at least one ethylene propylene compound, stress relaxation is independent of temperature between the limits of 130°F and 170°F.

A.4.3.1.2 Operating Radiation

Property changes resulting from changes in molecular cross-link density generally occur when a polymer is exposed to radiation. In evaluating the effects of radiation on seals, however, a number of factors must be considered. These include the effect of radiation dose rate, the effect of shielding provided by the seal gland, and the potentially synergistic effects of radiation in combination with other stressors such as elevated temperature.

A previous study(8) has indicated that compression set values ranging from 29% to 67% were experienced for various fluorocarbon and ethylene propylene elastomers after exposure to 10 megarads in air. The same study indicates that compression sets in excess of 90% were experienced for these materials after exposure to 100 megarads (accident radiation exposure). Another study(9) indicates that compression sets ranging from 31% to 72% were experienced for various ethylene propylene compounds after exposure to 30 megarads in GE SF-1154 silicone fluid.

In most nuclear power applications, snubbers are exposed to a total radiation dose that is substantially less than the above dose levels. Furthermore, the radiation exposure of many seals is reduced even more due to shielding provided by the snubber body and components. The role of radiation, therefore, as a snubber aging stressor, may be considerably less than was originally anticipated.

A.4.3.1.3 Hydraulic Fluid as an Aging Stressor

Depending on seal/fluid compatibility, shrinkage or swelling in seals can occur. Fluids can also affect seal hardness, tensile strength, and elongation.

Seal materials currently used in hydraulic snubbers, however, are generally compatible with the various fluids used. Nevertheless, the effects of other degradation stressors such as elevated temperature and radiation should be evaluated in combination with fluid stressors.

A.4.3.1.4 Low Amplitude Vibration

Low amplitude vibration is defined as vibration having amplitude less than the mechanical clearances within the snubber and its attachments. The combined effects of snubber weight forces on pins and attachments along with low amplitude vibration can occasionally result in gradual wearing of pins and attachment holes. This can lead to an increase in mechanical clearances and loss of structural integrity.

A.4.3.2 Short-Term Degradation Stressors

Degradation resulting from environmental stresses that exceed the design capacity of the snubber will generally result in failure in a period less than the maintenance interval recommended by the manufacturer. Such degradation involves a limited number of snubbers and should not be included in the data base used to establish seal life for the general snubber population. Failures may be minimized by augmented surveillance and/or more frequent seal replacement for such snubbers.

Typical short-term degradation stressors are listed below.

A.4.3.2.1 High Amplitude Vibration

High amplitude vibration is defined as vibration having an amplitude that exceeds the mechanical clearances within the snubber and its end attachments. Snubbers are not designed for long-term, continuous use in such applications. High amplitude vibration will degrade seals, bearings, and other snubber parts in a very short time because of wear and heat generated by friction.

A.4.3.2.2 Transient Loads

Seal failure can result from transient loads. As with vibration, systems prone to such failures should be closely monitored.

A.4.3.2.3 High Temperature

Snubbers are occasionally exposed to environmental temperatures that are higher than the maximum specified for continuous operation. Such applications often involve snubbers that are installed in close proximity to hot pipes or equipment or in areas with poor ventilation. Such applications can result in premature seal failure due to hardness changes, high compression set, or adhesion of the piston rod seal to the piston rod.

A.4.3.3 Accident Degradation Stressors

Accident degradation stressors are normally associated with a loss of coolant accident (LOCA) environment. Post-accident snubber performance is normally substantiated by qualification testing. Typical accident environmental stressors are listed below and are generally postulated to occur over a period from 24 to 72 hours:

- high temperature (i.e., 350°F decreasing to 250°F)
- high radiation (i.e., 100 megarads - gamma)
- steam.

A.4.3.4 The Aging Process in Elastomeric Seals

Elastomers are heterogeneous materials. Long-term behavior (e.g., stress relaxation) is governed by a number of chemical reactions. In addition, the relative influence of each reaction may vary depending on the level of the degradation stress. This presents considerable difficulty in developing a mathematical model for elastomer seal aging. These aging reactions are described by Parker Hannifin Corp.(6) as follows.

A.4.3.4.1 Scission

This process involves a cutting of the molecular bonds, i.e., dividing the chain into smaller segments. Ozone, ultra-violet light, and radiation can cause degradation of this type.

A.4.3.4.2 Cross Linking

This is a molecular process whereby additional intermolecular bond are formed. Heat and oxygen are principal causes of this type of attack.

A.4.3.4.3 Modification of Side Groups

This is a process resulting in a change in the complex, weaker fringe areas of the molecular construction due to a chemical reaction. Moisture, for example, can promote this activity.

A.4.3.5 Aging of Thermoplastic Seals

The following considerations pertaining to thermoplastic seals should be highlighted:

- Cold Flow - Thermoplastics exhibit "cold flow" or creep characteristics such that, over a period of time, the material tends to flow toward the area of least restraint. A thermoplastic O-ring, for instance, when compressed in its gland would tend to flow toward the side clearance areas in the O-ring groove, resulting in a reduction in sealing force and associated spring-back. Cold flow is accelerated by elevated temperature. Thermoplastic seals must be either totally confined or must use springs or pressure in order to insure a continuous sealing force.

- Effects of Radiation on Thermoplastics - Hytrel is generally resistant to radiation in air, having good retention of properties after being subjected to 100 megarads. Little information is available, however, as to the combined effects of silicone fluid immersion, elevated temperature, and radiation.

  Tefzel generally retains most physical properties important for sealing after exposure to normal operating levels of radiation. A moderate reduction in elongation (i.e., 20 to 30%) will be experienced after exposure to 10 megarads with an 80% reduction at 100 megarads.

A.4.4 SEALING VARIABLES

Generalizations regarding seal life are difficult because of the number of variables involved. An acceptable condition for one application or seal configuration may be unacceptable for another. Some specific variables in this regard are discussed below:

- Seal Configuration - A number of seal configurations are used in snubbers. Each one has its own sealing mechanism, which in some cases, may be unrelated to the sealing mechanisms of other configurations.

- Snubber Manufacturer - Even when similar materials and configurations are employed, design and manufacturing differences between snubber manufacturers can affect sealing performance and associated seal life. Such differences may include manufacturing tolerances, machining methods, clearances, surface finish, squeeze, etc.

- Seal Materials and Compounds(a) - For each basic elastomer a number of compounds are available. It is estimated that there are at least 20 elastomer compounds used for snubber seals in U.S. nuclear plants. Compounding is a state of the art; compound formulas are generally proprietary. A slight change in chemical composition can affect physical properties.

- Seal Manufacturer - Seal processing differences can affect seal performance and life. Even with similar elastomer compounds, differences in curing agents, mold design, allowance for shrinkage, etc., can affect seal properties and dimensions.

- Fluid Medium - The hydraulic fluid used in the snubber is an important variable. An acceptable O-ring compression set, for example, in sealing a fluid with a viscosity of 1000 centistokes might be unacceptable in sealing a 50 centistoke fluid.

- Temperature - Temperature not only affects aging, it can also directly affect sealing performance. A seal with marginal compression set, for example, might seal adequately at its service temperature but begin to leak during shut-down because of thermal contraction of the seal. On the other hand, a higher fluid viscosity at the lower temperature might actually improve sealing.

- Surface Roughness - Gland surface finish is of considerable importance particularly for metallic and plastic seals. A lighter sealing force is normally specified for dynamic seals in order to minimize wear. Therefore, effective dynamic sealing requires a smoother surface than static sealing.

(a) Compound refers the specific mixture of ingredients.

The type of surface finish is also important. For example, machining grooves in an O-ring gland that are parallel to the circumference of the O-ring will provide a more effective seal than grooves that are parallel to the sealing direction. Mating surface finish can be adversely affected by corrosion and abuse.

- Seal Storage - It is difficult to relate seal storage time and conditions directly to subsequent service life. Yet these parameters could influence sealing effectiveness and should therefore be considered in an overall evaluation of seal life. This is probably best accomplished by establishing adequate controls on seal storage time and/or conditions.

- Other Sealing Variables - Other sealing variables include the following:

  - seal thickness
  - initial compression
  - system pressures (low and high).

A.5.0 CURRENT BASIS FOR SEAL LIFE

Three categories of seal life are discussed below. These are shelf life, storage life, and service life.

A.5.1 SHELF LIFE

There is no hard and fast rule as to how long seals may be stored without significant degradation of properties. Shelf aging depends not only on storage time but also on storage conditions such as heat, moisture, sunlight, air, ozone, and stress. Storage guidelines have been provided by snubber and seal manufacturers which generally follow the recommendations of Military Handbook 695(10) for elastomeric seals. Recommended shelf life ranges from 5 to 10 years for EP compounds and up to 20 years for fluorocarbon rubber compounds. Shelf life is indefinite for thermoplastic seals.

A.5.2 STORAGE LIFE

Some utilities and snubber manufacturers have elected to establish an intermediate category for seal life. This category is referred to here as "storage life" and refers to the life of the seals after they have been installed in the snubber but before the snubber is exposed to service conditions. This might apply to snubbers that are stored in a warehouse for an extended period of time. One manufacturer, for instance, recommends a maximum snubber storage life of five years, with an additional service life of five years.

It should be remembered that the crucial event, in terms of seal life, is the initial compression of the seal. When the seal is installed, the clock starts and the seal begins to relax. The rate of relaxation, however, under storage conditions might differ from that under actual service conditions.

A.5.3 SERVICE LIFE

Most operating nuclear plants have established a standard seal service life for the general snubber population. Many plants continue to replace seals at intervals initially recommended by the snubber manufacturer (i.e., every five to seven years).

A basic disadvantage to frequent seal replacement is that it is impossible to obtain extended performance data that could be used to substantiate a longer service life. Another important disadvantage is the increased probability of seal or snubber failures resulting from damage or errors during overhaul. Even with stringent maintenance controls, such influences as incorrect seal size, defective seals, damaged surfaces, improper assembly, inadequate tightening of parts, missing parts, and contamination are realistic concerns.

Several plants have implemented seal life evaluation studies in order to establish more realistic seal replacement intervals. Several approaches in this regard are described below.

A.5.3.1 Review of Available Laboratory Data

One approach has been to establish service life based on a review of laboratory reports pertaining to the effects of environmental stressors on the properties of elastomers. Although some information is available on the effects of gamma radiation as well as short-term accident environments, little information is available regarding the long-term effects of temperature aging.

A.5.3.2 Review of Industry Service Data

Efforts to consolidate industry service data are under way by the Snubber Utility Group (SNUG). However, service data is not always complete or in the most usable form for evaluating service life. Service data often does not include information in some or all of the following areas:

- failure causes (i.e., aging or non-aging related)
- operating environment (i.e., temperature and radiation dose rate)
- seal installation date
- seal manufacturer and compound
- fluid replenishment history (i.e., date and quantity)

There is, therefore, a need to establish a standardized format for snubber service data that would make it more useful in a consolidated industry data base.

A.5.3.3 Accelerated Aging

In this method, the aging effects of a degradation stress such as temperature are accelerated. Results are then used to predict long-term seal performance.

Generally, for accelerated aging methods, the effects of each degradation stress must be evaluated separately. Multiple parameter (e.g., temperature and radiation) evaluations are extremely complicated.

Accelerated aging methods are usually based on an assumed fundamental relationship between the degradation stress and the degree of degradation. The most commonly used accelerated aging technique is known as the constant overstress technique.(11) In this technique, the degradation stress variable is raised to a level above that experienced in service, and the time required to attain various degrees of degradation is monitored.

The actual aging process in polymers in terms of any given degradation stress is the result of one or more chemical reactions. A basic precept in the constant overstress accelerated aging technique is that all aging reactions are accelerated to the same degree. Figure A.5.1, for instance, might be representative of the relationship between compression set and log time for a given seal configuration and material at three different temperature levels (T_1, T_2, and T_3). If all the aging reactions were accelerated to the same degree, the curves would be superposable by horizontal shifts in the log time axis. In other words, the time value associated with each level of compression set for Temperature 1 could be multiplied by a constant shift factor (a_T) to obtain the corresponding time value for Temperature 2. The relationship between the shift factor and temperature is often represented by an Arrhenius term, i.e.,

$$a_T :: \exp\left[\frac{K}{T}\right]$$

where K is a constant.

If superposition is not possible, the various reactions were not accelerated equally. In that case, the validity of predicting long-term degradation by accelerated aging would be dubious.

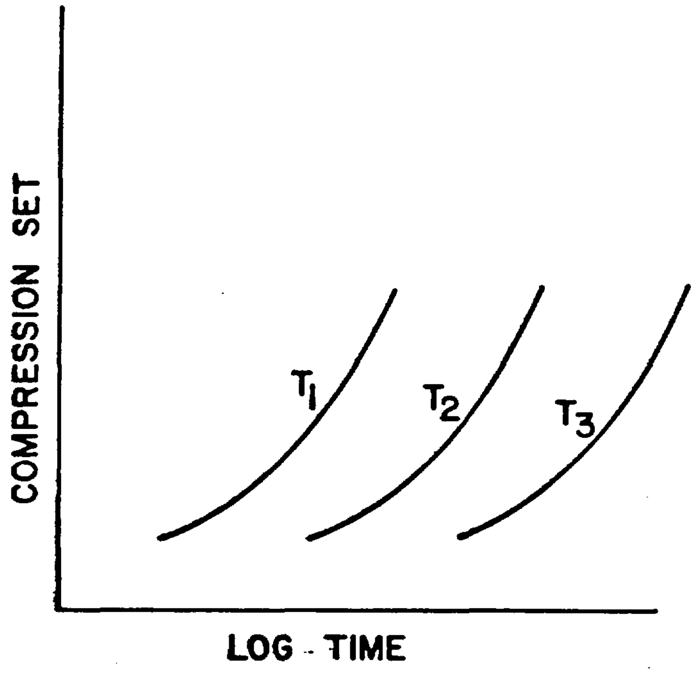

FIGURE A.5.1. Compression Set Versus Log Time at Various Temperatures

Associated with any accelerated aging method, there must be an established maximum level of acceptable degradation (e.g., compression set). Methods for establishing this threshold level are discussed in Section A.5.3.7.

A.5.3.4 Service History

The true indicator of seal life is proven service history. The advantage of this approach over laboratory or analytical methods is that data from the actual service environment is used, such that the combined effects of all degradation stresses are accounted for.

A number of utilities have reported successful operation with seals having extended service (e.g., up to 15 years). Of particular interest is the number of snubbers with extended service using fluorocarbon rubber (Viton®) seals.

Typical Plant Technical Specifications state the following:

> The maximum, expected service life for various seals, springs, and other critical parts shall be determined and established based on engineering information and shall be extended or shortened based on monitored test results and failure history.

A key element in establishing seal life based on service history is the exclusion of non-aging related failures from the service-life data base. In this regard, comprehensive failure evaluation is a valuable tool. This often involves training of personnel in root cause determination techniques.

Various approaches have been used in establishing seal life based on actual service data. Some of these approaches are described below.

A.5.3.4.1 Extrapolated Failure Rate

In this approach, augmented examinations of accessible snubbers were conducted over an 8-1/2-year period. Seals were replaced just before the start of the study. The performance rate of accessible snubbers was assumed to be representative of that for inaccessible snubbers. This was substantiated by regular examinations of inaccessible snubbers as required by Technical Specifications.

Failures associated with seals were plotted versus time. A higher failure rate was observed in the initial years and was attributed to non-aging related factors. Failure rates were observed to diminish in the later years, indicating that extensive seal failures were not imminent.

Based on extrapolation, along with continuous verification during scheduled ISI, the seal service life for inaccessible snubbers has been extended to 13 years, whereas originally it was limited to 10 years.

A.5.3.4.2 Statistical Evaluation of Compression Set

This approach involves measurement of the compression set of ethylene propylene O-rings from snubbers that had been in service for various time periods. Compression set data was grouped by seal-service period (i.e., 2 to 3 years, 3 to 4 years, etc.). The mean and mean plus 2 standard deviation compression set values for each service period group were then calculated and plotted versus service time. No apparent trend in compression set versus service time was observed.

A.5.3.5 Parallel Seal Evaluation

In this method, various properties were measured for seals removed from snubbers during scheduled overhauls. These seals had been in service for approximately seven years. The seals were then installed in test fixtures that were representative of the actual seal gland. For control purposes, new seals were also installed in similar fixtures. The fixtures were then placed in containers filled with hydraulic fluid. The seals, in containers, were placed in the vicinity of their respective snubbers for continued exposure to the operating environment.

This is a continuing program. During each outage, seals are removed from the test fixtures and various physical properties are measured. Backstress is compared against established threshold values.

A.5.3.6 Extrapolation of Degradation Parameters

This method involves measurement of seal-degradation parameters such as compression set and hardness for seals removed from snubbers with established amounts of service time. Seal life is determined by assuming a conservative, e.g., linear, relationship between time and compression set and by extrapolating the time required to attain a predetermined compression set limit (see Figure A.5.2).

By necessity, long-term projections of seal life based on short-term data are often conservative. An alternative approach is to progressively reevaluate seal life during each refueling outage. As data is added, a more accurate representation of the relationship between compression set and time is established. By using this approach, seal life may be progressively extended, while, at the same time, building an extended service data base reflecting acceptable seal performance.

A.5.3.7 Establishing the Degradation Parameter Limits

Back stress is inversely related to compression set. Compression set is also more easily measured. It is, therefore, practical to establish a compression set threshold below which zero leakage can be expected. This threshold may be determined using a number of techniques.

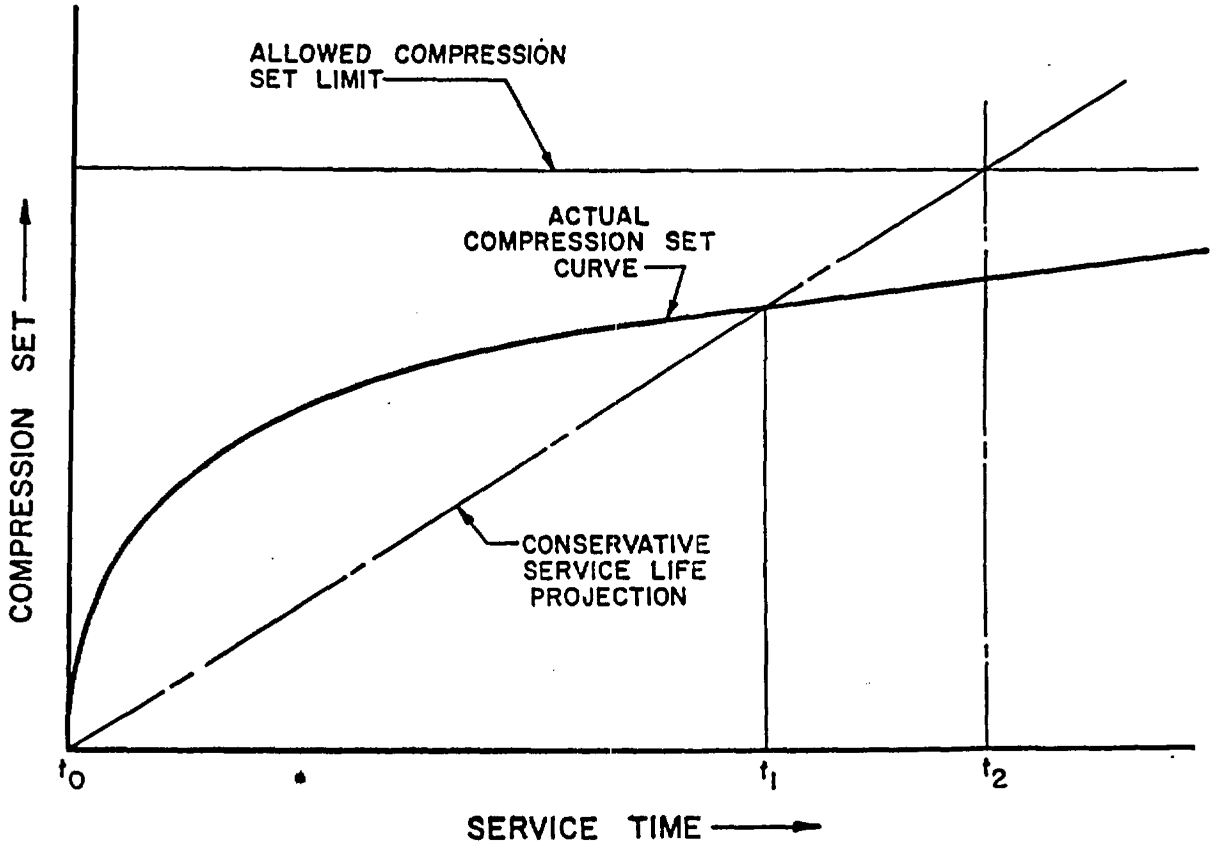

FIGURE A.5.2. Extrapolation of Compression Set

In some cases, limits have been based on conservative technical judgment rather than on a direct correlation with sealing performance. An alternative approach is to establish limits equal to or less than the measured compression set of similar seals removed from non-leaking snubbers. Another alternative is to induce compression set in seals in snubbers or fixtures replicating the actual seal gland and then evaluate sealing effectiveness.

A.6.0 BENEFITS OF A SNUBBER AGING STUDY

An industry snubber service life evaluation presents technical, safety, and regulatory benefits described below.

A.6.1 TECHNICAL BENEFITS

Technical benefits of a snubber aging study include the following:

- identification of aging trends
- technical input for development of service-life monitoring guidelines
- enhanced usefulness of service data in monitoring snubber service life
- consistent service data format more suitable for consolidation in an industry data base
- definitive technical bases for evaluating snubber service life
- identification of useful failure evaluation methods
- identification and categorization of realistic operating environments
- identification of key aging stressors
- technical input for determining compression set limits
- identification of aging-resistant designs and materials
- improved operations and/or maintenance practices.

A.6.2 SAFETY BENEFITS

The primary snubber safety benefits include the following:

- mitigation of the effects of snubber aging on overall plant safety
- more uniform population of snubbers in terms of failure prediction
- reduction of personnel radiation exposure
- reduction of rad waste.

A.6.3 REGULATORY BENEFITS

Regulatory benefits will be enhanced by the broader data-information base provided by the Phase II study. Specific operational problems and issues will be identified to revise the regulations where applicable. Specific regulatory benefits include the following:

- contribution to regulatory standards
- input for establishing service life monitoring guidelines
- centralized and unified approach to regulation
- identification of generic issues related to service life
- augmentation of the NRC NPAR Program.

A.7.0 KEY ELEMENTS OF A SNUBBER AGING EVALUATION

A.7.1 EMPHASIS ON RECENTLY ACQUIRED SERVICE DATA

Since the incorporation of improved designs, materials, and maintenance practices, the incidence of snubber failure has markedly decreased. Furthermore, improved failure evaluation practices have led to more precise identification of the cause of failures. It is, therefore, important that an evaluation of snubber aging place heavy emphasis on more recent service data.

A.7.2 EMPHASIS ON LONG-TERM DEGRADATION

Some snubbers are subject to environments that are beyond their design limits, resulting in short-term failures (i.e., in less than five years). Such environments include continuous high amplitude vibration, transient loads, and isolated temperature extremes. Because short-term failures are difficult to predict, snubber reliability for such applications is best maintained by some of the following methods:

- modification of the environment
- augmented inspections and tests
- frequent snubber maintenance or replacement

A snubber aging study should place heavy emphasis on evaluating the long-term aging effects of operating environments that are within the design specified limits of the snubber. This will lead to optimum snubber reliability by helping to establish realistic maintenance or replacement intervals for the majority of plant snubbers.

A.7.3 MINIMIZATION OF VARIABLES

As was discussed in Section A.3.0, numerous variables must be considered in a snubber aging study. In order to minimize complexity, the study should attempt to identify and eliminate those variables with negligible significance. Parameters of minimal significance might be best included by combining them with other parameters in a worst-case analysis.

For example, it may be determined that degradation due to radiation is not as significant as that due to temperature. In this case, it might be practical to assume that all snubbers will be exposed to the same radiation dose and to evaluate the effects of variations in temperature only.

It may also be practical to identify which seal in a given snubber model is most vulnerable to aging degradation. In an evaluation of the effects of aging on seals, it would be best to concentrate on the seal with the shortest life, because all seals are replaced during rebuilding.

A.7.4 EMPHASIS ON MORE COMMON CONFIGURATIONS

A snubber aging evaluation should place primary emphasis on more common snubber models and seal configurations.

A.7.5 DIRECT CONTACT WITH UTILITY PERSONNEL

Review of LERs and service data are useful tools in evaluating snubber service life. However, such data by itself is often misleading. A snubber aging study should, therefore, include direct contact and discussions with utility personnel.

A.7.6 COORDINATION WITH OTHER AGENCIES

A snubber aging study should involve continuous coordination and collaboration with the NRC and SNUG and with the ASME/ANSI OM-4 and Section XI Working Groups.

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APPENDIX B

UTILITY SNUBBER SURVEY

APPENDIX B

UTILITY SNUBBER SURVEY

Included in this appendix is the survey of the SNUG utility members for information on all aspects of snubber experience for the Pacific Northwest Laboratory (operated for the U.S. Department of Energy by Battelle Memorial Institute).

APPENDIX B

UTILITY SNUBBER SURVEY

Battelle Contract B-N1358-A-U

Work Order No. 1, Task 3

Wyle Laboratories

Job No. 17928/17017

Revision No. 1

Prepared by: Glen R. Palmer 9-22-88

Glen R. Palmer

CONTENTS

INTRODUCTION

As part of Battelle Pacific Northwest Laboratories' Contract No. B-N1358-A-U, Wyle Laboratories was to support Battelle in performing a survey of SNUG utilities for information on all aspects of snubber operation experience.

The data has been received, summarized and reported here in such a way as to keep the identity of the utilities confidential.

It is estimated that with twenty-four utilities participating in the survey, we have accounted for approximately 43% of the snubber population being evaluated. These numbers and ratios have been verified with SNUG who maintains a data base which presently is proprietary to SNUG members only and not available to the general industry.

SNUBBER OPERATING EXPERIENCE

SURVEY

1. <u>GENERAL</u>

A. What is your snubber population <u>per</u> <u>unit</u> (if multiple units, list each separately).

Unit ____ Mechanical Qty. Total _____ Hydraulic Qty. Total ____

Unit ____ Mechanical Qty. Total _____ Hydraulic Qty. Total ____

<u>SIZE</u>	<u>QTY</u>	<u>MANUFACTURER</u>

B. Do you have a spare parts program? ( ) Yes ( ) No

C. If so, what do you inventory?

( ) Parts ( ) Entire Units ( ) Both ( ) Seals ( ) Fluid

D. Approximately how much inventory do you carry?

( ) $25,000 ( ) $25,000-$100,000 ( ) $100,000

Comments ____

____

____

E. Are there any specific sizes/items that have required replacement or repair more frequently than any other? ( ) Yes ( ) No

F. If so, what are they?

____

____

____

G. Snubbers that do not meet specified criteria generally are catagorized as "failures". In your experience relative to your plant what have the primary causes of those visual and test failures been?

____

____

____

__________________________(Use Back if Necessary)

H. Describe what you would consider to be a seal related failure.

____

____

____

____

I. Do you have a written or informal failure mode analysis program?

( ) Written ( ) Informal

If yes, please describe ____________________________

____

____

____

J. If possible, estimate how much, on an average, it costs your utility to refurbish/replace each snubber. This would include the overall cost per snubber per life of plant. Please separate large bore (120,000 lb.) vs small bore snubbers. (Removal, rebuild, testing, reinstallation.) If not, guess.

( ) Estimate, ( ) Guess, $______ Per Large Bore Snubber
$______ Per Small Bore Snubber
$______ Per Mechanical Snubber

K. In your experience, does it cost more to maintain hydraulic or to maintain/replace mechanical snubbers.?

( ) Hydraulic ( ) Mechanical

L. What factors do you base your answer on?

____

____

____

2. **MECHANICAL SNUBBERS** (As Applicable to Your Plant)

A. Have you become aware of any aging related concerns with your mechanical snubbers?

( ) Yes ( ) No

If so, explain ______________________________

____

____

B. What is your testing criteria for mechanical snubbers?

( ) Breakaway Drag ( ) Running Drag ( ) Activation ( ) Final Drag

What is your acceptance criteria? ______________________________

____

____

C. Upon completion of your latest outage inspection and test program what would the percentage be of snubbers examined or tested, that didn't meet your criteria?

Examined __________ % Tested __________ %

D. Is that an improvement from previous statistics?

( ) Yes ( ) No ( ) Same

E. Are there any performance related characteristics of mechanical snubbers that you would like to see more data on? ( ) Yes( ) No

If yes, what are they? ______________________________

____

____

____

3. **HYDRAULIC SNUBBERS** (As Applicable to Your Plant)

A. What aging related concerns do you have with your hyraulic snubbers?

( ) Seals ( ) Fluid ( ) Other __________

B. Do you have a written seal life program or report? ( ) Yes ( ) No

C. Do you have a written fluid life program? ( ) Yes ( ) No

D. What seal material and compound is in your snubbers?

____

____

E. Specify the following for each type of seal material in your snubbers.

1. What do you consider shelf life?

_____ years for ____________________ material

_____ years for ____________________ material

2. What do you consider service life?

_____ years for ____________________ material

_____ years for ____________________ material

3. When do you consider service life to begin?

( ) When the snubber is installed in the plant
( ) When the snubber is rebuilt or manufactured
( ) Other __________________________

Explain ______________________________________

____

____

F. Upon which of the following do you base your answer?

( ) OEM Recommendation
( ) Vendor Interum Assessment Recommendation
( ) In-House Aging Assessment
( ) Consultant or Industry Laboratory Aging Assessment
( ) Service History
( ) Other ________________________________

G. What is your testing criteria for hydraulic snubbers?

( ) Running Drag ( ) Lock-Up ( ) Release (Bleed)

What is your acceptance criteria? ________________________

____

____

H. Upon completion of your latest outage inspection and test program what would the percentage be of snubbers examined & tested that didn't meet your criteria?

Examined __________ % Tested __________ %

I. Is that an improvement from previous statistics?

( ) Yes ( ) No

J. Explan any further detail of primary failure mode cause. (Ref. 1.G)

____

____

____

K. What percentage of examinations or functional test failures are attributable to seal failure?

Examination _________%. Test _________%

L. What percentage are attributable to fluid problems?

Examination _________%. Test _________%

M. What is the longest satisfactory service life you have experienced and for what size of snubber/manufacturer/seal material?

____ yrs. ___________ Snubber Descr. ___________ Seal Material

N. Describe the operating environment and location.

____

____

____

O. Are there any performance related characteristics of hydraulic snubbers that you would like to see more data on? ( ) Yes ( ) No

If yes, what are they? ____________________________

____

____

4. **COMMENTS:**

____

____

____

Mail Completed Survey To:

Glen R. Palmer/Survey Results
Post Office Box 1008
Huntsville, Alabama 35807

SUMMARY OF TOTAL DATA REPORTED
FROM (24) UTILITIES
FOR (38) PLANTS

I. GENERAL

A. Snubber population totals

Mechanical	Hydraulic	Total
17,649	10,089	27,738

B. Do utilities have spare parts program?

All Yes

C. If so, what is in inventory?

Parts	7	utilities
Entire Units	13	"
Both	13	"
Seals	16	"
Fluid	18	"

D. Value of inventory:

One has less than $25,000.

Seven have between $25,000 and $100,000.

Sixteen have greater than $100,000.

E/F. Are there sizes/items that require replacement or repair more than others?

12 - Yes, 12 - No Of the twelve yes, eight used both mechanical and hydraulic. Of the twelve no, seven used both mechanical and hydraulic. PSA 1/4's and 1/2's were mentioned most often as having problems. They also were the most often used. Grinnell was mentioned twice along with PMH/Remco, once.

G. **Primary causes of failures for both visual & test:**

1. Visual
    - a. Seal Leakage
    - b. Corrosion on ball and bushing
    - c. Cracking of plastic (lexan) reservoirs
    - d. Loss of fluid through connecting tubes of remote reservoirs
    - e. Low or no fluid in reservoir
    - f. Snubbers installed in areas that have substantial thermal movement combined with high loading are difficult to keep aligned and the tie rods take the load and overstress the rod and piston seals.
    - g. Foreign material on piston rod damaging seals
    - h. Reservoir orientation
    - i. Cracked bushings
    - j. Fluid contamination
    - k. Fluid leaks from valve blocks and lost screws
    - l. Snubber damaged in installation-improper care by using them as lift points, ladders, etc.
2. Testing
    - a. High drag-design and environmental conditions
    - b. Frozen-plant conditions
    - c. High lock-up velocities-seal problems
    - d. High activiations-valve problems
    - e. Overload - mechanical
    - f. Valve and spring failure
    - g. Contaminated fluid
    - h. Air in snubber
    - i. Vibration
    - j. Heat
    - k. Capstan spring too small binding on the capstan.
    - l. Rebuild problems

H. Describe what you would consider to be a seal related failure.

1. Degradation of seal surfaces causing high lockup velocities.
2. Failure of rod or cylinder seal.
3. Leaking hydraulic fluid.
4. Not able to obtain rated or test load while snubber is locked up due to large amounts of leakage.
5. Snubber that fails it's functional test as a result of a seal failure.
6. a.) Total loss of fluid, b.) cracked, hardened seal, c.) deformed seal-tears, cuts, etc.
7. Fluid leakage past front seal around piston rod, leakage past piston seals, and fluid leakage at sightglass or snubber body.
8. Any failure mechanism that causes seal leakage to the extent that the snubber fails functional testing.
9. Gradual disintegration of the seals due to age, radiation, heat, etc., resulting in leak-by or particles of the seals lodging in orifices or valves causing control mechanisms to fail.
10. Loss of fluid or failure to lock-up could both be sealed related failures.
11. Damage of seals at high temperature, leakage of seals.
12. Evidence of fluid leakage.
13. Aged seal.
14. A leak is always a potential, but a deteriorated or damaged seal would most likely be considered a seal related failure.
15. Fluid leaking, wiper seal out of place.
16. Internal, external leakage
17. Seal degradation due to fluid loss
18. Excessive bleed after lock-up
19. Low fluid level due to deformed seal.

I. **Do you have a written or informal failure mode analysis program?**

Of the twenty-four utilities reporting, nine have written or formal programs while the rest are informal. Not all responses described the evaluation process. However, those who did seemed to pursue some sort of engineering analysis to determine cause of failure.

J. **If possible, estimate how much, on the average, it costs your utility to refurbish/replace <u>each</u> snubber. This would include the overall cost per snubber per life of plant. Please separate large bore (greater than 120,000 pounds) vs. small bore snubbers (removal, rebuild, testing, reinstallation).**

An average of the responses reported resulted in the following:

Large Bore Hydraulic:	25.9K
Small Bore Hydraulic:	16.8K
Mechanical Snubber:	20.5K

K. **In your experience, does it cost more to maintain hydraulic or maintain/replace mechanical snubbers?**

Although the average cost estimates furnished show small bore hydraulics to be the most economical, the overall industry "perception" is that hydraulics are more expensive. Combining large bore with small bore would support that perception.

II. MECHANICAL SNUBBERS

A. **Have you become aware of any aging related concerns with your mechanical snubbers?**

Two utilities out of twenty-four responding to this question voiced a concern over increased drag forces over time. Due to vibration, grease, or capstan spring problems.

B. **What is your testing criteria for mechanical snubbers, and your acceptance criteria?**

Breakaway drag, running drag varied from 1% rated load up to 5% in some cases. Activation varied from .02 g's to .04 g's.

C/D. **Upon completion of your latest outage inspection and test program, what would the percentage be of snubbers examined or tested that didn't meet your criteria? Is that an improvement from previous statistics?**

Average number of visual examination failures.	1.1%
Average number of testing failures.	7.3%

These were generally stated as improvements from previous statistics.

E. **Are there any performance related characteristics of mechanical snubbers that you would like to see more data on? If yes, what are they?**

1. Extent of degradation on PSA mechanical snubbers when drag values are between 5 and 10%. Uniformity of test results when a particular snubber is tested using different vendor test equipment.
2. Data on long range effects from high radiation/high temperature or high vibration environments.
3. Thrust on PSA snubbers subject to vibration.
4. Failure load.

III. HYDRAULIC SNUBBERS

A. **What aging related concerns do you have with your hydraulic snubbers?**

Seventeen utilities voiced concerns over seals, seven over fluid, one over spring rates.

B. **Do you have a written seal life program or report?**

Ten utilities reported they have written seal life programs. One is in preparation.

C. **Do you have a written fluid life program?**

Five utilities reported having written fluid life programs. One is in preparation.

D. **What seal material and compound is in your snubber?**

EPR	17
TEFZEL	8
Viton	3

E. **Specify the following for each type of seal material in your snubbers.**

1. **What do you consider shelf life?**

   EPR shelf life ranged from 5 years to 10 years with nine reporting five and five reporting ten.

   Tefzel shelf life was 40 years.

   Viton shelf life was 10 years.

2. **What do you consider service life?**

   EPR service life ranged from five to twenty-five years, with most reporting five to seven years.

   Tefzel service life ranged from five to forty years with most reporting forty years.

   Viton service life was ten to twenty years.

3. **When does service life begin**

When installed in plant	(9)
When rebuilt or manufactured	(12)
From first functional test of unit	(1)

F. **Upon which of the following do you base your answer?**
Some utilities use multiple factors to base their response on:

OEM Recommendations	(5)
Vendor Interim Assessment	(7)
In-House Aging Assessment	(8)
Consultant or Laboratory Assessment	(2)
Service History	(4)
SNUG Information	(2)

G. **What is your testing criteria for hydraulic snubbers?**
Running drag, lock-up and release (bleed) are basic parameters. However, some plants (10), depending on the snubber type, did not indicate a requirement for drag test. Acceptance criteria varied widely due to plant design, as well as, snubber type. Lock-up from .1 - 40 IPM and bleed from .01 - 64 IPM.

DRAG	LOCK-UP IPM	BLEED IPM
-	-	5 - 30
-	8 ± 2	.2 ± .05
-	8 ± 2	4 ± 1
1%	5	.35
1%	8 ± 2	.5
100#	2 - 20	2 - 15
5%	1 - 40	.1 - 25
-	1 - 23	.1 - 10
-	.5 - 30	.01 - 20
2%	Varies	4 - 25
-	1 - 30	.1 - 10
-	1 - 40	.1 - 25
-	-	.15 - 20
5000#	8.5 ± 2.5	.2 ± .05
5000#	8 ± 2	.2 ± .05
5%	2 - 64	.5 - 64
-	6 - 10	1.5 - 5
10,000#	.1 - 20	.07 or Less

H. **Upon completion of your latest outage inspection and test program, what would the percentage be of snubbers examined and tested that didn't meet your criteria?**

Examined	1.2%
Tested	5.9%

I. **Is that an improvement from previous statistics?**

Yes	(6)	utilities
No	(11)	"
Same	(1)	"

Of those indicating NO, (6) were well below the average statistics already. This would indicate that overall performance is improving from previous years.

J. **Explain any further detail of primary failure mode <u>cause</u> (Ref. I.G)**

1. The primary failure mode cause is the degradation of EPR piston seals which result in too high lock-up velocities.
2. Seal deterioration.
3. Test failure: bleed adjustment <u>screw</u> incorrectly set. Examination failure: Rod eye became disengaged from piston rod due to pipe vibration. Set screws/loctite/ revised torque requirements implemented.
4. Low or zero bleed rate
5. Degraded seals and springs contributed to failures of snubbers which had been in service 10 years.
6. Failed to lock-up at required velocity. The recent refuel outage was the first outage that hydraulic snubbers were tested for specific lock-up velocity.
7. Failure was attributed to the test equipment and method.
8. No hydraulic snubbers failed to date.
9. Introduction of grease into the snubber caused bleed rate failure.
10. Particles introduced into the fluid caused snubber failure.

K. **What percentage of examinations or functional test failures are attributable to seal failure?**

Examinations:	6.0% of examination failures were attributed to seal failure.
Test:	11.6% of test failures were attributed to seal failure.

L. **What percentage are attributable to fluid problems?**

Examination:	1.4% of examination failures were attributable to fluid problems.
Test:	7.7% of test failures were attributable to fluid problems.

M. **What is the largest satisfactory service life you have experienced and for what size of snubber/manufacturer/seal material?**

YEARS	TYPE	SEALS
5	Rexnord	EPR
7	Grinnell	EPR
8	BPPC	EPR
10	Grinnell	EPR
10	Grinnell	EPR
10	Grinnell	EPR
15	Grinnell	EPR
4	Power Piping	EPR
12	Grinnell	EPR
10	Grinnell	EPR
9	Grinnell	EPR
10	Milwaukee	Viton A
3	Paul-Munroe	Tefzel
3	Paul-Munroe	Tefzel
5	BPPC	EPR
7.5	BPPC	EPR
5	BPPC	EPR
16	ANKER-HOLTH	Viton A

As the data suggests there have been several instances where EPR seals have attained a 10 year service life. Tefzel does not have a long enough history to produce long service statistics yet.

N. **Describe the operating environment and location.**

1. Steam generator in containment high heat and radiation
2. BWR Reactor building dry and heated, rod levels vary.
3. Temperature - 130° F, Radiation 30MR
4. Steam generator base, medium Rod area, ambient - 90° F
5. Secondary plant, significant vibration
6. Turbine building, main steam lines
7. Moderate temperature, low radiation, small thermal movements, no system transients, no vibration various Aux. building locations
8. All locations in the plant
9. In containment, high radiation, humidity, 120° F
10. Steam generator snubbers
11. Steam generator, 110° F, 70% humidity, low radiation
12. Upper elevation dry well 200 - 220° F

A wide variety of environments exists from which data has been accumulated.

O. **Are there any performance related characteristics of hydraulic snubbers that you would like to see more data on? If so, what are they?**

1. Performance and test results of snubber having Tefzel piston seals.
2. Fluid and seal performance as a function of temperature, radiation, and age.
3. Drag testing
4. Spring rate data
5. Seal life and fluid life
6. Temperature correlation to lock-up and bleed rate
7. Tefzel seal material over extended usage (6-10 years)

8. Shelf life seals and fluid. EPR shelf and service life expectancy.

IV. COMMENTS

No significant comments other than a desire for meaningful results to come from the survey.

SNUBBER OPERATING EXPERIENCE

SURVEY SUMMARY

1. The snubber population for the twenty-four utilities having returned completed surveys is made up of 17,649 mechanical snubbers and 10,089 hydraulic snubbers for a total of 27,738 snubbers. This data comes from thirty-eight power plants.

2. Of the twelve utilities responding positively to a question on specific items requiring replacement or repair more frequently than any other, seven identified PSA 1/4, 1/2.

3. All of the utilities stated they had spare parts programs and inventory was valued in excess of $100,000 at sixteen utilities.

4. Of the nineteen utilities identified as having hydraulic snubbers, fifty percent indicated failures involving fluid or seals.

5. There was a wide variety of responses to the question which asked the utilities to describe a seal related failure.

6. Most of the responding utilities reported their failure mode analysis program was informal.

7. Only two utilities surveyed thought there may be some aging related concerns for mechanical snubbers.

8. Most utilities reported improvement in their inspection and testing program statistics.

9. Over seventy-five percent of the utilities surveyed, identified seals as an age related concern with their hydraulic snubbers. The next most identified item was fluid.

10. Ethylene propylene seals continue to be the most widely used throughout the industry with manufacturers recommended service life prevailing. A question regarding the definition of service life revealed inconsistent responses throughout the industry with several sources listed as providing the basis for this response.

SNUBBER POPULATION SPECIFICS*

MANUFACTURER	SIZE								
MECHANICAL									
	¼	½	1	3	10	35	100		
o Pacific Scientific	3005	2563	2509	2178	1822	1832	306		
	40	70	150	500	1600	5500	12,500		
o Anchor Darling	118	272	202	131	109	27	21		
HYDRAULIC									
	1½	2½	3½	4	5	6	10		
o Grinnell	4174	2158	366	182	182	117	36		
	14K	50K	75K	150K	200K	400K	1000K		
o Paul Munroe	18	46	11	20	16	4	93		
	1½	2	2½	4	5				
o Power Piping	89	67	60	14	30				
	3K	10K	20K	30K	50K	70K	130K	200K	1747K
o Bergen-Paterson	463	296	72	39	15	3	8	2	72
	1000K	1900K							
o Milwaukee	30	42							
	800K								
o Anker-Holth	16								
	1000K								
o Rexnord	32								
	30.XX								
o Lisega	54								

* All utilities did not furnish size and quantity detail. Therefore, totals differ from overall mechanical and hydraulic total.

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11. ABSTRACT *(200 words or less)*

This report describes a research plan to address the safety concerns of aging in snubbers used on piping and equipment in commercial nuclear power plants. The work is to be performed under Phase II of the Snubber Aging Study of the Nuclear Plant Aging Research Program of the U.S. Nuclear Regulatory Commission with the Pacific Northwest Laboratory (PNL) as the prime contractor. Research conducted by PNL under Phase I provided an initial assessment of snubber operating experience and was primarily based on a review of licensee event reports. The work proposed is an extension of Phase I and includes research at nuclear power plants and in test laboratories. Included is technical background on the design and use of snubbers in commercial nuclear power applications; the primary failure modes of both hydraulic and mechanical snubbers are discussed. The anticipated safety, technical, and regulatory benefits of the work, along with concerns of the NRC and the utilities, are also described.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

mechanical snubbers, hydraulic snubbers, aging, failure mode, service-life monitoring, data collection, seal life, compression set, utility cooperative program, inservice testing and examination

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