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Effects of Postulated Event Devices on Normal Operation of Piping Systems in Nuclear Power Plants

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ABSTRACT

This report considers the effect of pipe-whip restraints and snubbers on the normal operation of piping systems in nuclear power plants. Also considered are the effect of these postulated event devices on reliability, economics, and the exposure of plant personnel to radiation.

Field data were gathered from three nuclear power plants that had applied for Operating Licenses. Criteria, design philosophies, and data were obtained from the respective nuclear steam system suppliers, architects-engineers and utilities.

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EXECUTIVE SUMMARY

This report considers the effect of pipe-whip restraints and snubbers on the normal operation of piping systems in nuclear power plants, as well as their effects on reliability, economics, and the exposure of personnel to radiation.

The results of this study indicate that an ever increasing number of snubbers is being used to deal with the protection of piping systems which are subjected to the myriad of dynamic loads and load combinations defined for commercial nuclear power plants. Sufficient effort to keep the use of snubbers to a minimum has not been applied. As an example of what could be done, as a result of the simple analytical techniques used in this study the number of snubbers on five systems selected at random was reduced from 45 to 29. The most needed improvement is design. The required periodic testing of snubbers results in increased radiation exposure to personnel, potential for damage to the snubber through handling, and a decrease in reliability for the piping system.

For pipe-whip restraints, this study identified two problem areas. The first is that too many break locations are designated, and the second is that 50 percent of the restraints reviewed hinder inservice inspection (ISI). The most significant problem is the restriction on ISI and general plant access. In many cases, pipe-whip restraints will have to be dismantled so that maintenance and inspection activities can be performed. This will increase the radiation exposure for personnel and create a potential for damage to equipment and the restraint as a result of handling. With respect to the design and installation of the restraints, the industry is generally doing a good job. The data for restraints that could be reviewed in both the plant hot and cold conditions indicate no piping interference for normal plant operating conditions; however, in some cases, the gapping is not sufficient to allow free piping deflection during upset plant conditions, including seismic events. This lack of sufficient gapping could invalidate the seismic analysis because the pipe would be restrained to a degree in one direction, but free in the other.

The following recommendations are made to minimize the problems associated with the use of snubbers and pipe-whip restraints:

The design agents piping analysis personnel must develop an increased awareness of the problems associated with using snubbers and the steps that shall be taken to minimize the use of snubbers. Where snubbers are required, they should be accessible to maintenance and inspection personnel.

Care must be taken to limit the interference between pipe-whip restraints and welds that will be subjected to ISI. The size of pipe-whip restraints must be kept to a minimum. This will require the use of restraints that will absorb more energy. The conservatism in piping system analyses -- such as lumping operating conditions and using maximum load values, which lead to the designation of break locations -- must be eliminated.

The excessive use of snubbers and pipe-whip restraints may result somewhat from the limited space available for routing pipe and isolating it from critical equipment. If sufficient space were available, large deflections of piping systems subjected to dynamic loading may not be objectionable and the number of snubbers needed to provide restraint could be reduced. Additional space would allow for better separation of piping systems and equipment, thus eliminating the need for a number of pipe-whip restraints. Based on these considerations, building size versus piping and equipment design should be reviewed to determine the effects on safety, reliability, and economics for the life of the plant.

In the process of developing regulations, guides, technical positions, and so forth, the NRC must look at the relationship of proposed new requirements to past requirements to eliminate the continual adding of conservatisms. The process of pipe rupture postulation must be reviewed beginning with the potential for the event. The existing NRC pipe rupture requirements should be updated to recognize the impact of succeeding requirements on each other. The criteria of Regulatory Guide 1.46 include factors of safety to account for the possibility of flaws not found in construction and to account for vibratory loading not readily determined in the design process. These are followed by ISI requirements for the life of the plant to detect flaws before they become critical. Other NRC positions require vibration monitoring of critical piping systems during preoperational testing. The requirements for ISI and vibration monitoring are attempts to reduce the potential of the problem occurring and should be adhered to. However, in the light of these requirements, it seems reasonable to expect the NRC to review existing pipe-break criteria and eliminate conservatisms such as U (cumulative usage factor) $\leq$ 0.1 that exist. A review must be performed to determine the impact on the actual design on systems of mandated plant events and subsequent load combinations and mathematical combination techniques. This is most necessary when addressing the functional capability of essential piping systems and operability of active components. In this case postulated plant events such as LOCA and SSE must be combined with normal and upset plant operating conditions using a stress criteria that is related to upset operating conditions. In most cases, the only response available to industry to these load combinations may be the use of snubbers. This study indicates, qualitatively, that the reliability or safety that was anticipated in specifying the load events may not be present when an excessive number of snubbers are used.

Existing piping design criteria for protection against catastrophic failure are based on static load data on single components. A complex piping system of a nuclear power plant is made up of a number of components which are subjected to a wide range of loading, (the majority of which are dynamic). The little dynamic testing that has been performed indicates the existing criteria for piping is very conservative. Actual dynamic events in operating nuclear plants generally verified this fact. A concerted effort should be undertaken to determine the adequacy of piping systems when they are subjected to dynamic loading. This effort should involve the testing of complex piping systems subject to the load events associated with nuclear plant piping. Based on the test results, new criteria for dynamic stress limits should be developed. In the interim, the existing damping values used in the seismic analysis of piping should be reviewed to reduce conservatisms.

1.0 BACKGROUND

Postulated Event Devices in use today in nuclear power plants are generally in two forms, dynamic-motion snubbers and pipe-whip restraints. Dynamic-motion snubbers are being used in great numbers to assist in maintaining stresses in piping at allowable levels for low-probability events such as earthquake loading. Limited space in containment and reactor buildings results in piping system designs that are less flexible than could be expected for other industries, such as fossil power and petrochemical. In these industries, the use of very flexible piping designs is possible because of the space that is available. Piping can deflect large amounts without striking other equipment or structure, and fundamental frequencies are very low (for example 0.5 Hz) as compared to those in nuclear power systems. As a result, the piping does not respond to the seismic event. The reduced flexibility in nuclear plants means that piping generally has fundamental frequencies which fall slightly below or in the beginning portion of the applied response spectra (for example 3 Hz) and has much higher thermal expansion stress levels. To reduce seismic stresses, the fundamental frequencies of piping should be increased to levels beyond those associated with peak accelerations of the spectra (for example 7 Hz).

1.1 Snubbers

In the past five years, a considerable amount of work has gone into the design of snubbers. This work has been related to the determination of the snubber characteristic (spring rate, load capacity, and so forth) as well as the development of a more dependable device. In the piping-analysis area, significant improvements have been made in the modeling of snubber devices to predict more accurately their effect on the dynamic response. It must be recognized that the snubber characteristic is only one item that has an effect on the dynamic response of piping; it may not be the most important. When one considers all of the variables that make up the analytical representation of the real system, this becomes increasingly apparent. Some of the other variables which affect piping response are nozzle flexibility, anchor flexibility, support flexibility, and gapping and building response variation.

1.2 Pipe-Whip Restraints

The concept of a spectrum of postulated pipe breaks which defines the loss-of-coolant accident (LOCA) evolved primarily to establish a basis for containment design, and secondarily to investigate the reactor thermal-hydraulic characteristics. At that time, the selection of breaks was made independently of the likelihood of such failures. In the development of the assessment of availability safety systems to shut down the reactor, postulated pipe-break criteria were extended as an event that required consideration of loadings which result from specific breaks. The loadings include (1) those associated with the fluid-dynamic phenomena internal to the system, (2) jet forces from the break which impinge on other equipment, and (3) the pipe itself whipping about with the potential for impacting other equipment. One technique to resolve this is to separate systems physically so that the loadings associated with the postulated rupture have no effect on other equipment.

For systems not employing separation, pipe-whip restraints are required to mitigate the consequences of postulated pipe rupture. These restraints capture the ruptured system and prevent it from whipping about and impacting other safety-related equipment and structures. They are also used to limit the loads within the ruptured system to a given segment of the pipe, so that operating valves are protected. Two approaches are used to develop systems of pipe-whip restraints. They are

(1) elastic or brute-strength design

(2) elastic-plastic or energy absorption design

The major concern regarding pipe-whip restraints is whether they inadvertently prevent the pipe from expanding properly during normal and upset plant operating conditions. This concern arises from the fact that a significant number of interfaces must come together properly for the pipe-whip restraint to perform its intended function. The analyst must provide appropriate load and deflection data to the restraint designer; the designer must design a device which does not interfere with normal pipe motion yet limits the dynamic loads associated with impact; the fabricator must build a structure which mirrors the design; the piping and pipe-whip installation must be as exact as possible. In any situation where so many variables exist, controls must be established. There must be assurance that the initial conditions presented by the analyst are representative of what will be experienced by the piping. In the final case, the gap between pipe and restraint (if any is called for), the load on the restraint, and the pipe motion during operation are dependent on the initial input.

2.0 INTRODUCTION

The Nuclear Regulatory Commission (NRC) is evaluating existing criteria which establish postulated events for the design of commercial nuclear power plants. An integral part of this program is to determine the effect of postulated event devices (PED) on the normal operation of piping systems. Under contract number NRC-03-77-167, Teledyne Engineering Services (TES) was directed to provide technical assistance to the NRC in this area.

The PEDs considered in this study were

(1) Pipe-whip restraint

(2) Snubbers, mechanical and hydraulic

The primary concern was to determine the effect of a PED on the stress level and normal operation of a piping system. To accomplish this, three nuclear power plants were selected for study. The basic philosophy of the selection process was to pick a reasonable industry cross-representation of nuclear steam system suppliers (NSSS) and architect-engineers (AEs) for plants that were not yet operating. It was agreed by all concerned that the names of the specific plants, NSSS, and AEs involved in this study would not be identified in this report. All data were gathered at the three chosen plants and are presented without relationship to plant or design agent.

Detailed information with respect to design and installation practices used by the design agents was obtained. This information was used as a basis for onsite audits of the "as-built" condition, as well as a comparison of approaches used by the "industry." A review of the interaction between piping systems and the PEDs during cold and hot (plant operating) conditions was planned. This was accomplished for one unit only, because the other units in the program did not have an operating license at the time the study was performed and hot condition data could not be obtained.

3.0 PLANT DATA

3.1 General

The data-gathering task was broken into two sub-tasks as discussed below.

3.1.1 Design Discussion

Initial discussions with the responsible designers was planned to ensure that the philosophy used in the piping system and support design would be completely understood. Design and operating conditions, load combinations, and acceptance criteria were discussed. All piping system analyses and/or results were reviewed in detail. Detailed support designs were obtained and discussed. (The responsible designers were the NSSS and AE for each plant.)

3.1.2 Plant Site Visits

Plant site visits were made both in cold (shutdown) and hot (operating) conditions. During these site visits, data were gathered on all accessible PEDs. The PEDs consisted of pipe whip restraints and snubbers (both hydraulic and mechanically operated). In addition, data were also gathered on rigid restraints. The data gathered consisted of

(1) Clearances in all directions on pipe-whip restraints. These were checked to ensure that sufficient clearance was available for normal and upset modes of plant operation.

(2) Comparison of the "as-built" condition with the intended design.

(3) The amount of travel space available for snubbers.

(4) The amount of slop in the snubber assembly.

(5) Preoperational test records (for example, snubber lock-up rate and bleed rate tests). Where available these records were reviewed.

(6) Comparisons of snubber supplementary steel-stiffness data with the "as-analyzed" condition.

(7) Comparisons of rigid restraint-stiffness data with the "as-analyzed" condition.

3.2 Design Philosophies Encountered

During discussion with the responsible designers, it became apparent that design agents use significantly different design philosophies in considering similar loadings.

3.2.1 Pipe-Whip Restraints

The location of pipe-whip restraints is a function of the location and type of pipe breaks postulated.

At Plants 1 and 3, pipe-break locations were chosen on the basis of stress levels as described in Sections 3.6.1 and 3.6.2 of the Standard Review Plan for piping inside and outside containment. At Plant 2 breaks were postulated at all fittings, with the exception of the nuclear steam supplier piping; for this piping, break locations were chosen as a function of stress levels.

Depending on which method is used the resulting number of postulated pipe breaks and required pipe-whip restraints is dramatically different. For example, the break-at-every-fitting approach increases the number of pipe-whip restraints required significantly.

The choice of which method to use for pipe break locations is based on scheduling problems. In the case of the NSSS, where only one or two familiar systems are involved, the stress-rule approach is generally used. However, because of scheduling, the AE is sometimes forced to use the fittings rule because complete analyses and stress reports are not available when base pads and reinforcing steel are to be put in place.

The physical design of the pipe-whip restraints varied significantly from plant to plant. The types encountered were

(1) Box type (see Figures A.1 and A.2)

(2) Ring type (see Figures A.3, A.8, A.10, A.17 and A.18)

(3) Box with crushable bumpers (see Figure A.9)

(4) U-bolt type (see Figures A.4, A.5, and A.7)

(5) Tie rods (see Figures A.4, A.5 and A.6)

(6) Variations of 1 through 5 above.

As can be seen in the photos, with the exception of those with crushable inserts, most were designed in the elastic range. This design required massive amounts of steel and caused congestion throughout the plant. (See, for example, Figures A.12 through A.16.)

All the design agents chose the gap settings for those pipe-whip restraints in a similar manner. That is, the gap is set to accommodate the thermal expansion during normal operation of the piping system, with an additional small margin. In most cases, the design agent would verify the analytically predicted piping movements during hot functional testing and, if needed, the gap would be modified.

In some cases, it was found that the gap determination was only a function of Normal operating condition and did not consider any other modes of operation such as upset or seismic events. However, the possibility exists for interference with piping deflections during these other events, and in the case of the seismic event, the pipe-whip restraint could provide partial restraint in one direction only.

3.2.2 Snubbers

During the discussion with the design agents for the different plants, a significant difference in design philosphies was found regarding the use of snubbers and rigid restraints to sustain dynamic loadings.

In Plant 1, a maximum number of rigid restraints was used in designing the support system for weight and thermal-expansion loadings. In this way, the thermal-expansion stress is increased to near its maximum allowable value, and the number of snubbers that had to be added later to sustain dynamic loadings was minimal.

In Plant 2, a more flexible support system was used. That is, the use of rigid restraints at this point was minimal, and the thermal-expansion stresses were kept at a nominal level with respect to allowable values. To sustain the dynamic loadings, snubbers were used exclusively so that

(1) Thermal-expansion stresses were not increased.

(2) Iteration was not required for the thermal-expansion stress analyses.

In Plant 3, the same approach was used as in Plant 1, except that the snubbers were represented analytically as rigid members.

The use of these different philosphies resulted in a significantly different number of snubbers being required for similar loading conditions. Table 1 summarizes the number of snubbers installed in each plant in this study.

Table 1. Comparison of the Number of Snubbers Installed in each Plant Studied

Plant	Type	Analytical Treatment	No. of Snubbers in Plant
1	PWR (3-loop)	Springs	520
2	BWR	Rigid	946 (375 in containment)
3	PWR (4-loop)	Rigid	800

Field data were gathered on a large number of snubbers. For each snubber installation inspected, the following were noted:

(1) The type (mechanical or hydraulic) and size of each snubber

(2) Location (Is the snubber installed within one pipe diameter of its location as shown on the piping drawings?)

(3) Supplementary steel stiffness (Is the stiffness of the supplementary steel generally consistent with the value used in the analysis? This was a judgment on the part of the inspectors, all of whom were experienced piping analysts and designers.)

(4) Oil Level (For hydraulic snubbers, the level of oil in the cold condition and in the operation mode was noted. If at any time the outlet port was not covered with oil or was installed at the wrong end of the snubber, this was noted. See, for example, Figure A.32.)

(5) Piston condition (Was it clean, dirty, or painted in such a way that motion of the piston would be impeded?)

(6) Interference: To determine if the expected thermal expansion of the piping would be impeded by the snubber, the following were noted:

    (a) Piston setting in both the cold and hot condition (How much travel is available in closing or opening?)

    (b) Total piston length

    (c) Expected thermal expansion at the point of attachment (see, for example, Figures A.19, A.28, A.30, and A.31)

(7) Accessibility (of each snubber, considering the physical congestion, ease of movement in the area, radiation levels, and required maintenance. See, for example, Figures A.22, A.24, A.26, and A.27.)

Pictures of actual installations are presented in Appendix A.

The mathematical representation of the snubbers for the piping system analyses also varied from one design agent to another. For Plant 1, the snubber was represented by a spring. The value of the spring rate was a function of both the snubber and the supplementary steel stiffness. For Plants 2 and 3, the snubber (and its frame support) was modelled as an infinitely rigid member in the direction of application.

For all plants in this study

(1) No gap in the snubber assembly was considered.

(2) The snubbers were assumed to be massless.

(3) The snubbers were assumed to allow free thermal expansion.

3.2.3 Rigid Restraints

In addition to pipe-whip restraints and snubbers, rigid restraints were inspected during the plant-site visits.

The following data were noted for the rigid restraints inspected:

(1) Installation (Is the installation in accordance with the restraint detail considering direction of restraint provided and location on the piping systems?)

(2) Restraint Stiffness (Is the stiffness generally consistent with the value used in the analysis, or is the value such that excessive deformation will occur under the design loadings? This was a judgment on the part of the inspectors, all of whom were experienced piping analysts and designers.)

(3) Interference (Does the restraint design restrain the piping system in a direction not intended? This decision is made considering the analytically predicted thermal-expansion movements at the restraint.)

3.2.4 Data Summary

A summary of the data gathered is presented in Table 2. The consequences of this summary are discussed in Section 5.0, and the detailed data are presented in Appendix B.

Table 2. Field Data Summary

Component	Number
<u>Pipe-Whip Restraints</u>	
Observed	142
Data documented for(1)	25
Interference marginal(2)	2
ISI hindered	14
<u>Snubbers</u>	
Observed	241
Inaccessible	53
Oil level observed 1/2 or less	14
Oil level empty (i.e., below outlet)	1
Leaking	3
Piston dirty or painted	38
Fully extended (acting as restraint)	3
Concerned with above(3)	14
<u>Rigid Restraints</u>	
Total observed	157
Interferences	4
Improper analytical stiffness representation	5
Not installed	1

(1) Because incomplete construction of all pipe-whip restraints in Plants 2 and 3 was not complete, conclusive data could be gathered for only 25 pipe-whip restraints. The accessibility of welds at the restraints (in Plants 2 and 3) was observed, and, as in Plant 1, approximately 50% of the pipe-whip restraints will hinder the ISI.

(2) A lot of attention is paid to pipe-whip restraints. Therefore, interference with piping movements is not expected. ISI, however, is significantly affected.

(3) Includes those that are fully extended, leaking and have an empty oil level, as well as 7 of the 14 with low oil level.

3.3 Effect of Changing Loads and Criteria

Two of the three plants included in this study experienced dramatic changes in loading conditions and criteria long after initial designs were finalized. These two plants also were subjected to changes in dynamic-loading events. It is the opinion of the design agents and TES that this had a significant impact on the number of snubbers specified for these plants. To determine the actual numbers would require a review of all drawings made before these changes, and, in many cases, the older revisions are not available.

A simple example, followed through to completion, will illustrate the problem. A system has been designed and analyzed to accommodate the set of loading conditions described in the Design Specification. Sufficient flexibility has been provided to accommodate the thermal expansion associated with the heat-up of the piping system and attached equipment. At the same time, a set of restraints -- including snubbers -- has been developed to provide sufficient restraint against specified dynamic loadings. Based on the completed analysis, including any Class 1 fatigue evaluation, a set of pipe-whip restraints has been provided to protect the plant against postulated pipe rupture. The system including all supports and restraints, has been fabricated and installed. Then, a new set of dynamic loading events must be considered. This new dynamic condition is more severe than that used in the original design. The analyst must accommodate this event for the existing system in a short period of time. The easiest and quickest resolution is to add more snubbers. This approach eliminates the need to modify the existing support system and to reconsider the effect of any added rigid restraints on the thermal-expansion stresses. The impact on construction activities is minimal because the analysts only have to add snubbers and not remove and replace an entire support system or modify piping.

This example is, of course, a generalization, but, it fits the pattern not only of the two plants that were part of this study but of a number of others that were in the construction phase as well. In the few cases where piping systems and supports were not completely installed, the same design process occurred because it was still the quickest and most efficient design solution. This has a far reaching effect on economics and reliability over the life of the plants (as discussed in Section 4, "Analytical Approach").

The major revision of loads which created this situation are

(1) Reevaluation of BWR suppression pool loads

(2) Earthquake redefinition

In some cases, in conjunction with the change in loading definition, NRC also imposed a change in criteria. The change in criteria tended to produce more conservative results than the original criteria and affected load and event combinations, mathematical combination techniques (for example, absolute sum versus square root sum of the squares), and allowable stress criteria. This change further complicated the problem for the analyst and contributed to the situation of adding snubbers to piping systems.

4.0 ANALYTICAL APPROACH

4.1 Limiting the Use of Snubbers

It is important that the industry recognize the impact of the use of snubbers. This must begin with the analyst who is the individual responsible for designating them. First, the analyst must recognize that the snubber is a device which relys on mechanical and hydraulic mechanisms and therefore can be variable. Secondly, the analyst is designating the use of a device which is expensive to purchase, critical to install, and requires inspection and testing for the life of the plant. Because these points are significant with respect to plant safety, personnel safety, radiation protection, and economics, they require more than a cursory review when the analyst is designating use of these devices.

There is certainly a need to use snubbers to accommodate the dynamic loads imposed on the piping system while still allowing for free thermal motion during normal plant operations. Without such devices, the industry would be unable to respond to the myriad of both real and postulated loading events. The intent of the following discussion is to point out that there are situations in which a little more effort on the part of the analyst can eliminate some of these devices.

4.1.1 Design Philosophies

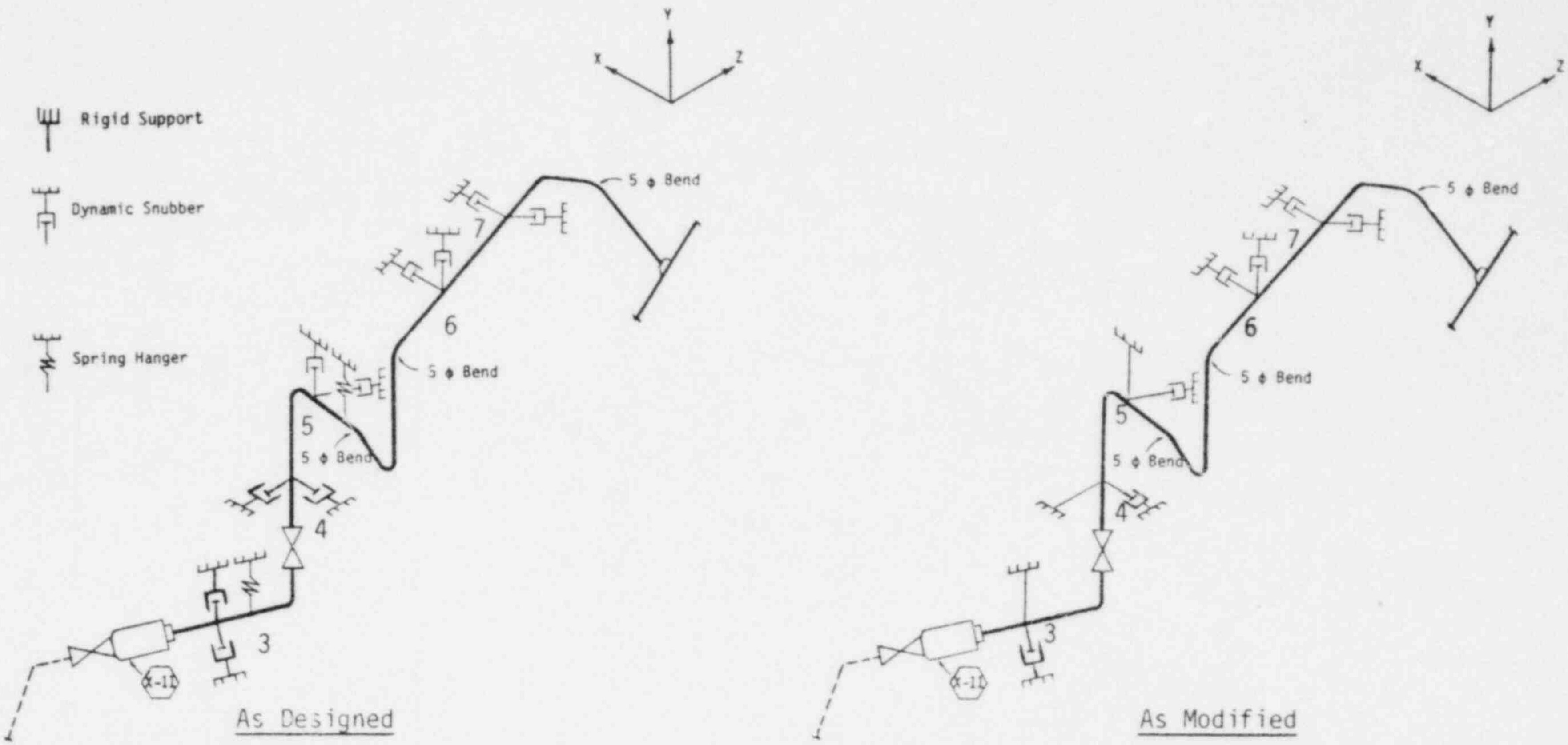
The designer is faced with developing a system design that meets all of the criteria imposed by codes and regulatory authorities while being limited by the relatively small areas found in containment, reactor buildings, and auxiliary buildings. Because of space limitations, the designer begins with a system that is not very flexible; the number of rigid restraints that can be applied is limited because the systems would be overstressed. At the same time, the designer must accommodate dynamic events which impose very high loads and deflections on the system. The initial reaction is to develop a system geometry that provides flexibility and then to use snubbers to accommodate the dynamic events. A little more effort could provide the same system protection while limiting the use of snubbers.

For example, using the results of available expansion analysis, the designer can determine which locations on the system are not deflecting in a given direction or are subjected to minimum deflections. At these locations, fixed restraints can be applied because they will have little, if any, effect on the thermal expansion of the system (defined as Method 1 in Table 3). Additionally, the analyst can select locations on the system where it would be advantageous to provide support for the dynamic event. At these locations, assuming system deflections are not zero or minimum, the analyst can determine the resultant thermal motion of the pipe and apply a fixed restraint at a 90^{0} angle to that motion (defined as Method 2 in Table 3). This approach may not result in the most advantageous direction to restrain the pipe, but it may be sufficient. (Some examples of this approach are shown in Figures 2 through 5.) The resultant motion approach does require more time for analysis, but the effort is well spent if it results in decreasing the number of snubbers. The use of snubbers where thermal expansion deflections are zero or minimum is poor engineering. It must be recognized that the discussion in Section 3.3 ("Effect of Changing Loads and Criteria") had a significant impact on many of the systems reviewed in this study, and the pressures of timely response to NRC criteria and load changes may have overridden good engineering judgment.

The techniques outlined above are relatively simple. There are certainly other approaches which could serve the same purpose. The industry must educate the piping designer about the impact of the use of snubbers on reliability, economics, and plant maintenance. The designer must have the time to eliminate snubbers wherever possible.

4.1.2 Comparison of Approaches

Table 3 is a brief summary of the number of snubbers that were eliminated by using the two approaches outlined above. Because of the constraints of time and economics, it was impossible to perform the work necessary to develop comparisons for each system in every plant; however, a sample system in each plant was reviewed.



Node Point	Deflections (in.)		
	X	Y	Z
3	-.36	-.09	.20
4	-.53	.00	-.02
5	-.35	-.02	-
6	.83	-.34	-
7	-	.00	-

Note

Three snubbers at node points 3, 4, and 5 can be replaced with rigid restraints because the deflections in the direction of the restraint ≈ 0.00. This eliminates two spring hangers at node points 3 and 5.

Figure 1. Comparison of As Designed to As Modified - System 1

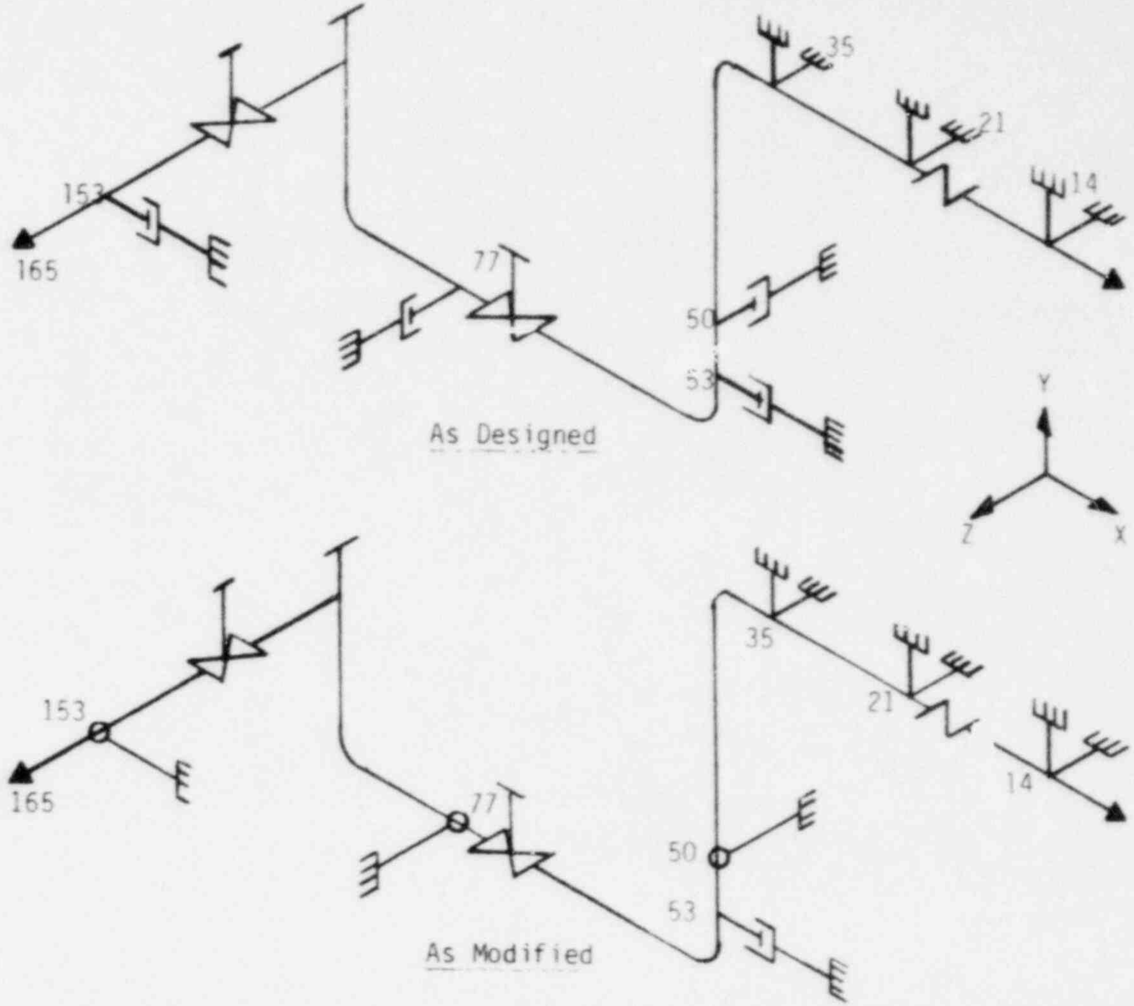
Legend

Dynamic Snubber

Rigid Support w/Pins

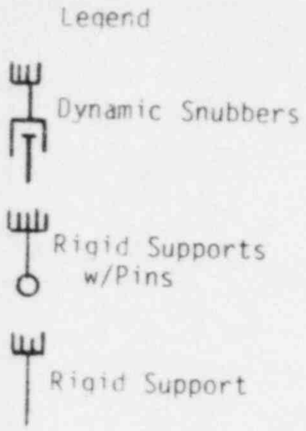
Rigid Support

Frequencies (cps)		
Mode	As Built	As Modified
1	10.8	10.54
2	13.08	13.08
3	14.27	14.26
4	16.15	16.14
5	17.46	17.46
6	17.80	17.69
7	20.24	19.41
8	20.84	20.24
9	22.23	22.19
10	22.44	22.44
Max Seismic Stress (psi)		
Node	As Built	As Modified
153	4900	5064
Max Thermal Stress (psi)		
Node	As Built	As Modified
165	13134	13134

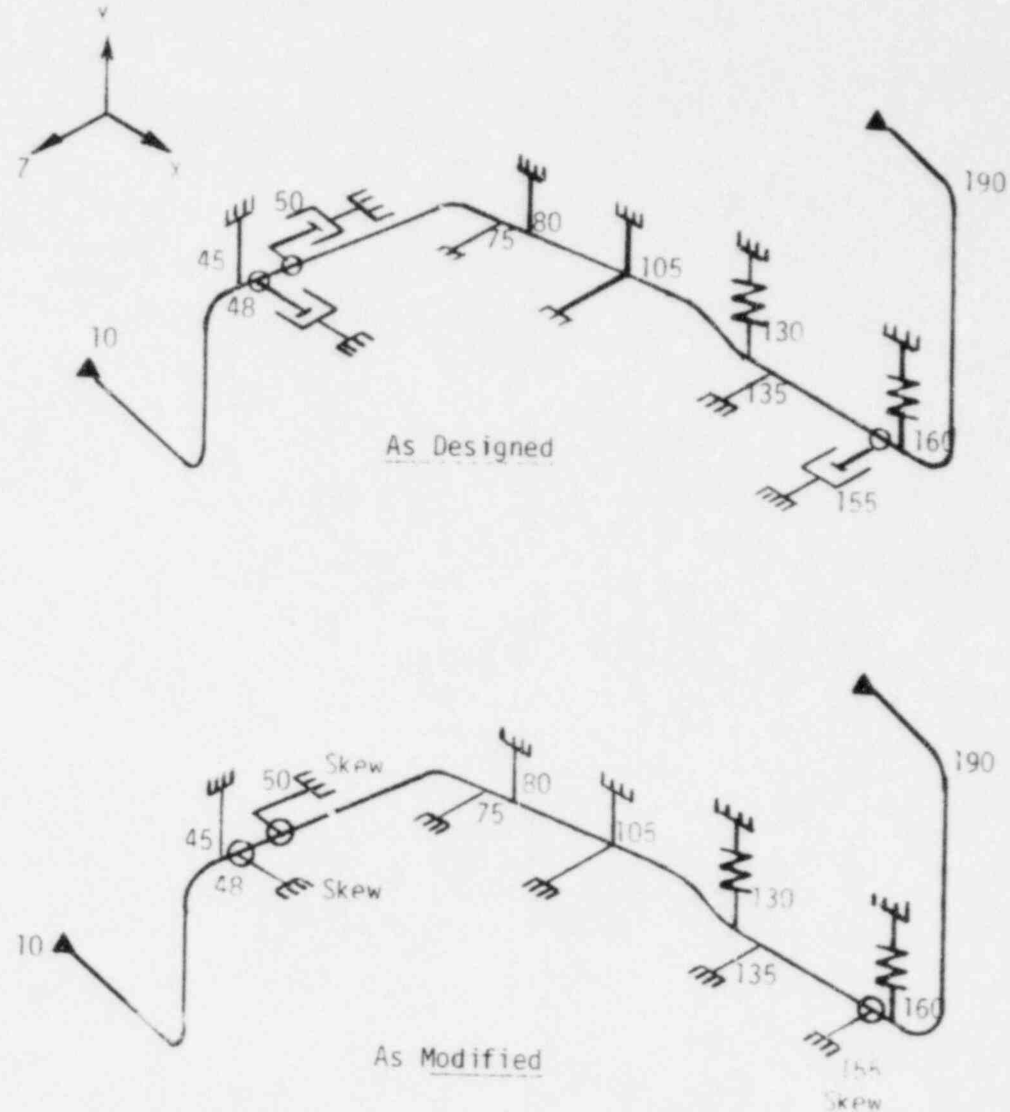


Note Three snubbers at 50, 77 and 153 can be replaced with rigid restraints that act 90° to the resultant thermal movement.

Figure 2. Comparison of As Designed to As Modified - System 2



Frequencies (cps)		
Mode	As Built	As Modified
1	6.289	6.29
2	8.838	8.776
3	9.457	9.619
4	10.49	11.02
5	12.61	12.83
6	17.07	17.07
7	17.49	18.85
8	26.51	26.69
9	27.85	27.75
10	28.53	30.13
Max Seismic Stress (psi)		
Node	As Built	As Modified
190	11642	11318
Max Expansion Stress (psi)		
Node	As Built	As Modified
190	8988	8988

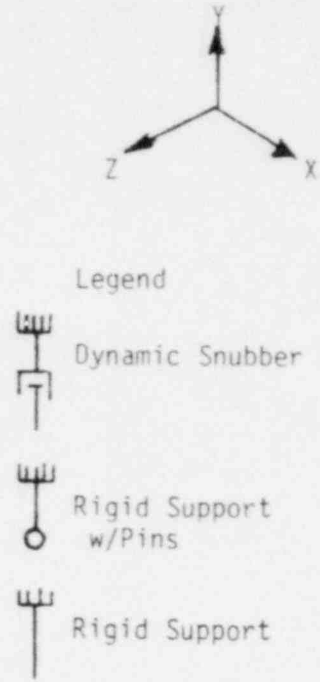


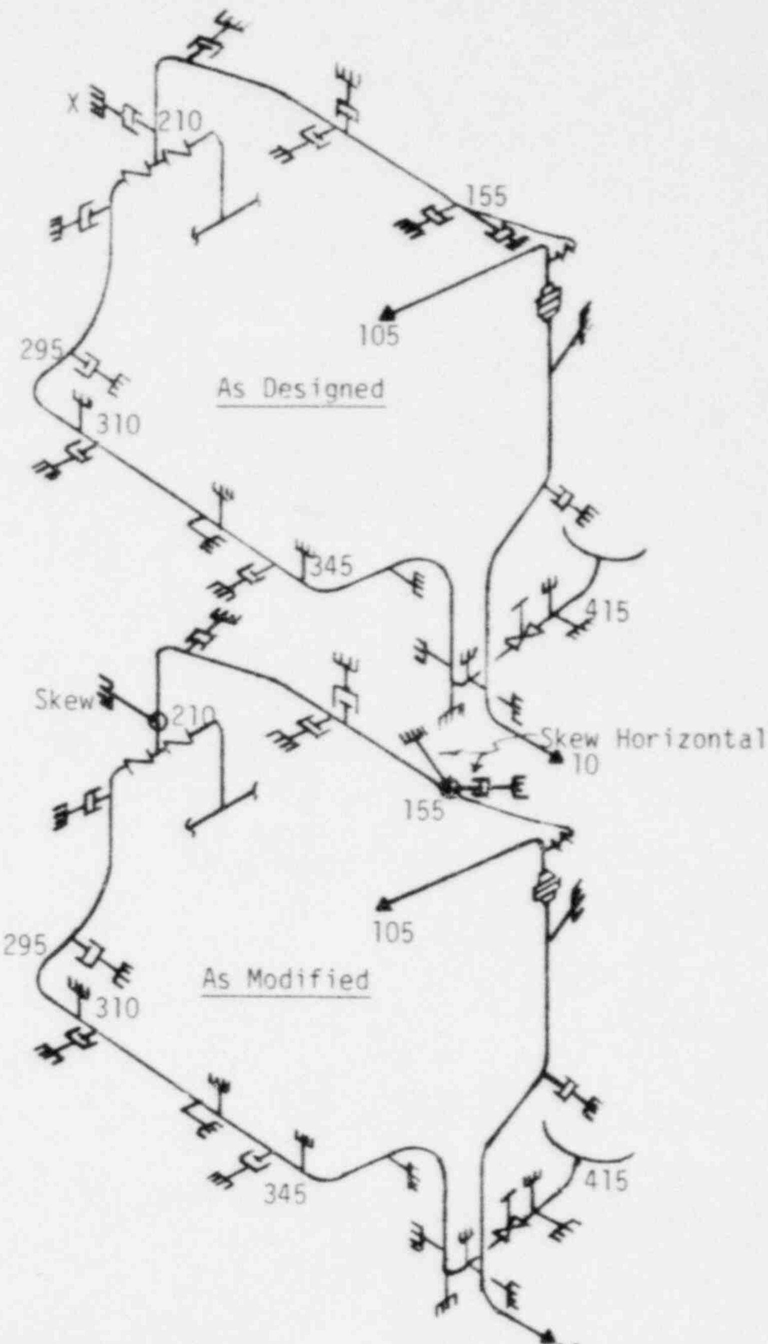
Note Three snubbers at 48, 50 and 155 can be replaced with rigid restraints that act 90° to the resultant movement.

Figure 3. Comparison of As Designed to As Modified - System 3

Natural Frequencies (cps)		
Mode	As Built	As Modified
1	5.3	5.3
2	6.3	6.3
3	7.1	7.1
4	7.8	7.8
5	9.7	9.6
6	13.1	13.1
7	17.8	17.8
8	19.4	19.4
9	21.3	21.2
10	22.5	22.5
11	23.6	23.5
12	25.8	25.8
13	27.7	27.7
14	28.7	28.8
15	29.9	30.4
Max Seismic Stress* (psi)		
Node	As Built	As Modified
10	20539	20536
Thermal Stress (psi)		
Node	As Built	As Modified
105	17051	17051

*fictitious response spectra





Note

Two snubbers have been eliminated. The X snubber at node 210 can be replaced with a skewed horizontal restraint. The two horizontal snubbers at node 155 can be replaced by a rigid and a snubber skewed in the horizontal plane.

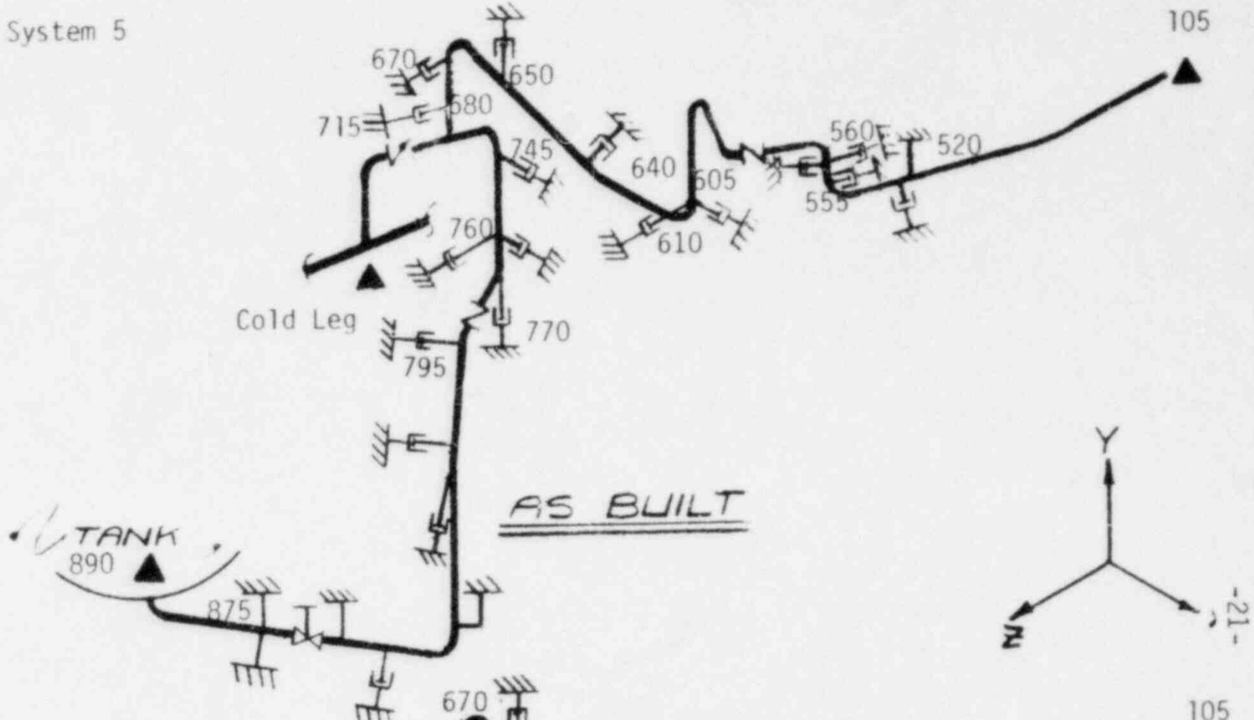
Figure 4. Comparison of As Designed to As Modified - System 4

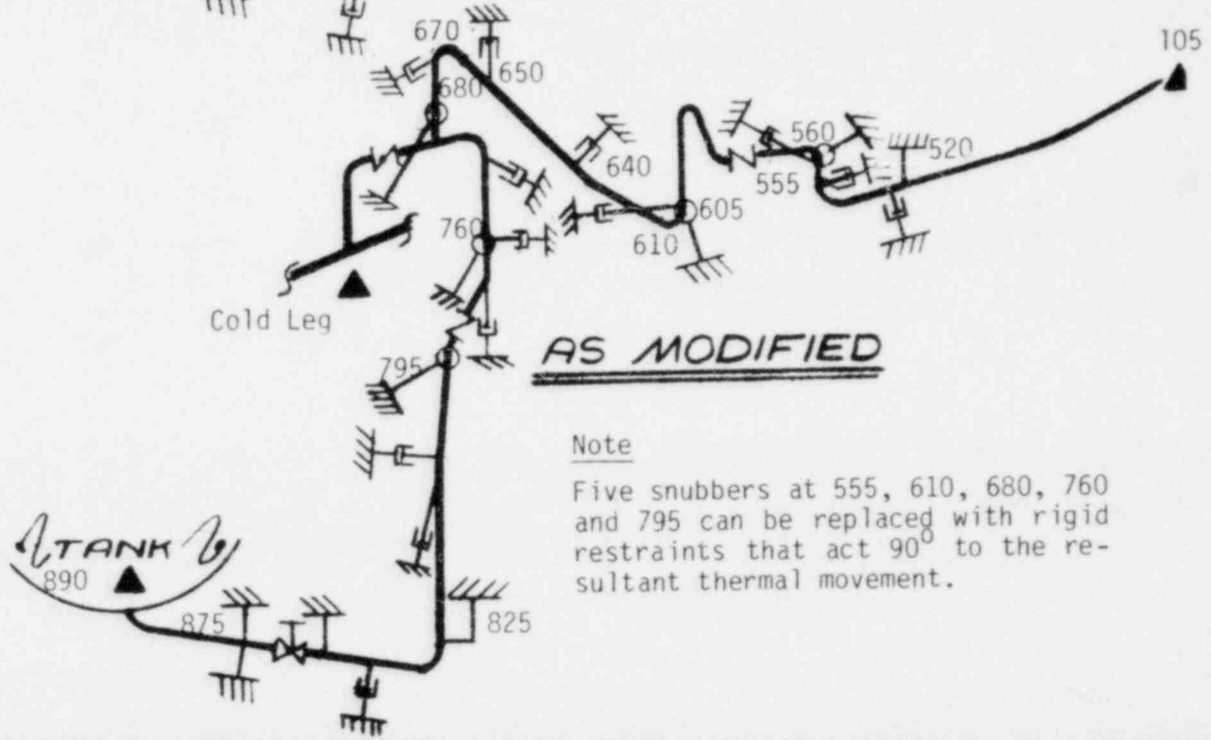
Frequencies (cps)		
Mode	As Built	As Modified
1	7.279	7.255
2	13.01	12.99
3	14.75	14.00
4	16.31	15.98
5	20.88	20.88
6	21.79	21.82
7	26.46	25.01
8	28.20	28.16
9	32.71	31.76

Max Seismic Stress (psi)		
Node	As Built	As Modified
555	15980	15724

Max Thermal Stress (psi)		
Node	As Built	As Modified
715	5790	5790

System 5





Legend

Dynamic Snubber

Rigid Support w/Pins

Rigid Support

Note

Five snubbers at 555, 610, 680, 760 and 795 can be replaced with rigid restraints that act 90° to the resultant thermal movement.

Figure 5. Comparison of As Designed to As Modified - System 5

Table 3. Snubber Elimination

System	Original No. of Snubbers	Final No. of Snubbers	Snubbers Eliminated	
			Method 1(1)	Method 2(2)
1	10	7	3	(3)
2	4	1	0	3
3	3	0	0	3
4	11	9	0	2
5	17	12	(3)	5

Notes:

(1) Method 1 is the zero, or minimum deflection method.

(2) Method 2 is the resultant motion method.

(3) No attempt made using the specified method.

In summary, the very simple techniques used here have reduced the number of snubbers used on five sample systems from 45 to 29. The following discussions on economic impact and reliability will indicate the importance of this effort.

4.1.3 Economic Impact

There are economic advantages to limiting the use of snubbers. The most obvious is the initial cost of the snubber. The second is concerned with the installation. Because the snubber is a device, installation must consider the impact on operability. That is, the installation must allow for travel in the piston, making end-to-end dimensions critical; hydraulic devices must be installed with the reservoir in the proper position, and pistons must be free of paint, nicks, or weld spatter. Manipulation or handling of the device by the fitter is more difficult than it is for a standard, rigid-type support. The third reason for limiting snubbers is the requirement for periodic inspection and testing of them. The present requirement for testing of hydraulic snubbers requires removal of the devices from their installed locations, transporting them to a test fixture somewhere else in the plant, testing them, and (if they are acceptable) reinstallation in their intended locations. The biggest problem encountered in this process is that damage may occur as a result of handling. It must be recognized that these are operating devices that can be affected by handling. Although the actual test itself is the smallest part of the cost involved, the greater economic impact is associated with the removal and subsequent reinstallation of the snubbers.

Therefore, it is critical that the analyst recognize the economic impact each time the use of a snubber is designated. This decision has far reaching effects, resulting in long-term costs for the plant operator.

4.1.4 Reliability Impact

Qualitatively, the reliability question as related to snubbers is a simple one: a system without any of these devices on it is more reliable than a system with them. Any time a mechanical or hydraulic device must be counted on to function, reliability is reduced. Nontheless, snubbers are needed so that piping systems in confined spaces can be designed to be flexible enough to stand the thermal-expansion loads and, at the same time, be rigid enough to withstand the dynamic loads imposed on them. It is important that the analyst reduce the number of snubbers on a given system to increase reliability.

When considering a system which has been designed with 12 snubbers versus the same system using 6, one would expect the 6-snubber system to be more reliable. In reality, this determination is not that easy to make. Based on the approaches being used to designate snubber locations in the industry, many snubbers are at locations which could accommodate a rigid support. Therefore, the snubber locking up during normal operation in such locations does not result in excessive stresses. The same snubber, however, may be critical with respect to providing protection against dynamic loading, and failure of the device to lock up could result in an overstressed situation. In such an instance, failure to lock up has a significant impact on reliability. A case could also be made for the situation in which lock up during normal operation results in overstressing the pipe, while failure to lock up during dynamic events would not be that critical.

Both of these situations highlight the case for not using a snubber. In the first case, the designer could have provided a rigid support without greatly affecting expansion stresses. In the second case, the snubber probably could have been eliminated entirely because its absence did not have a severe effect on dynamic event stresses. Snubbers should only be used where absolutely necessary. If this is done, the impact on reliablity of each snubber will be important, and the industry can respond by spending time and dollars monitoring devices that are, in fact, critical.

4.2 Limiting the Use of Pipe-Whip Restraints

The industry supports limiting the use of pipe-whip restraints. The results of this study indicate that in spite of support, the use of these restraints has been overspecified. Again, this has occurred because designers are not aware of the effect of these pipe-whip restraints on the long-term economics and overall reliability of the plant. Much of the problem is created by the scheduling of construction and design activities. The major problem is with the postulation of events.

4.2.1 Design Philosophies - Break Locations

The approaches of the nuclear steam supplier and the AE differ significantly, particularly in regard to the main coolant/reactor recirculation system. These system geometries are fixed, and the rupture location is essentially established for any plant. The only variables are seismic excitations, and their effect on Class 1 pipe stresses and, subsequently, on postulated rupture locations is minimal. The NSSS, therefore, can establish postulated rupture locations using stress criteria for the main coolant/reactor recirculation piping very early in the design stage. This allows the NSSS to give firm pipe-whip restraint locations and loadings to the civil/structural designer.

On the other hand, the AE does not have the same situation. Many of the piping systems have not had geometries finalized at the time the civil/structural departments need information on restraint locations and loadings to establish embedments. The piping stress analysis will not be available for a number of months; therefore, the analyst/designer tends to use the most conservative approach and selects postulated rupture locations at every fitting. As the piping analyses are completed, the option to reduce the number of locations originally chosen exists; however, in some cases this is not done. Experience indicates that for Class 1 piping systems, this approach need not be taken. The important loads which determine rupture locations are essentially independent of pipe routing. The dominant conditions are the operating transient on the system (which result in Ta-Tb, ΔT_1 and ΔT_2 loadings (see NB-3650 of Reference 1) and the local geometries (socket welds, type of branch connection, and so forth). The thermal expansion and seismic loads which are a function of pipe routing have only a minor effect on the cumulative usage factor. Based on this, the stress results associated with postulation of rupture location for a Class 1 system in a given type of reactor should be essentially consistent from plant to plant, assuming the same type plant. Therefore, having a preliminary piping layout and past experience with the type of plant and the NSSS, the AE should be able to review past stress reports to develop postulated rupture locations based on stress criteria. This procedure should then reduce the excessive number of locations obtained when the every-fitting approach is used.

An additional variation in approach is the conservatism used in the Class 1 analysis. The analyst has the option of making assumptions which can be extremely conservative. This approach can appear to be economically advantageous because it limits the number of engineering hours spent on analysis, and the Code criteria can be met using this approach.

The major assumptions that are made that can be conservative are

(1) Lumping transients in an overly conservative manner

(2) Using maximum values of Ta-Tb, ΔT_1 and ΔT_2, ignoring the fact that they may occur at different times for a given transient

This approach could result in stresses and cummulative usage factors which meet the Code criteria but fail to meet the NRC-recommended criteria for selection of rupture locations. For Class 1 piping, a substantial difference exists between the cummulative usage factor allowed by the Code (1.0) and that used by the NRC to select rupture location (0.1).

A review of the number of techniques available to prevent pipe rupture indicates that conservatisms are added to conservatisms, with the end result being a decrease in reliability. First, there is the NRC requirement that a Usage Factor of 0.1 is sufficiently high to postulate a rupture. This is a factor of safety of 10 on Code Usage Factor.

Next, Section XI of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (Reference 2) requires that welds are monitored during the life of the plant so that flaws can be detected before they reach "critical size" (that is, a size at which fracture would occur). Thus, there is a conservative requirement to postulate a break, as well as a requirement to monitor welds so that breaks will not occur. These requirements are followed by an NRC requirement to monitor vibrations of piping systems during pre-operational testing and plant start to ensure that vibration-induced stresses are properly accounted for and to ensure that the dynamic analyses performed are acceptable. One of the reasons for the factor of safety of 10 on the Usage Factor was to account for vibratory loadings that could not be accounted for in the design. The industry is, therefore, faced with a break postulation criterion that is conservative to account for "unknown" loadings, an inspection criterion to prevent fracture (or breaks), and a preoperational vibration monitoring program to cover "unknown" loadings. ISI and preoperational vibration monitoring may be sufficient to eliminate the need to postulate breaks in certain piping systems because the use of pipe-whip restraints (which goes hand in hand with break postulation) provides a ready, although temporary solution to the problem. Such systems might include those which are ferritic and amenable to U.T.* examination, and in addition are subject to possible failure via fatigue crack growth rather than via a corrosion sensitive mechanism.

Each time the NRC imposes new requirements, the NRC staff should review the impact on existing requirements. As discussed above, it appears that as more precise techniques were implemented, there was no effort to go back and eliminate the original conservatisms that were applied to cover the unknowns.

To reduce the impact of the conservatism of the NRC requirement on cumulative usage factor and stress, the piping design rules of NB-3650 of Section III of the ASME Code were revised to remove conservatism. Essentially, the piping rules were modified to recognize that the radial gradient is not a secondary stress and is objectionable only in fatigue and in thermal ratcheting. Placing it in the secondary stress category in the Code rules was conservative and was a simple technique for accounting for any thermal ratcheting effects. This conservatism was acceptable to the industry and did not create any hardships or affect reliability. However, when the NRC

*U.T.: Ultrasonic Testing

began to use the rules and criteria of the Code for pipe-rupture postulation (and applied a reduction factor of 10 to a usage factor that was already conservative), the rules needed to be reviewed to eliminate overly conservative criteria. This was done by removing the linear portion of the radial gradient, ΔT_1, from the secondary category and considering its effect in fatigue and thermal ratcheting only. This change should reduce the number of postulated break locations and, therefore, reduce the number of pipe-whip restraints. The important point to be made here is that the NRC uses criteria which were generated for a very specific purpose to form a basis for considerations which the criteria were never intended to cover. If a criterion were being developed by the industry for postulation of rupture locations, it is not likely that it would resemble the present rules of Section III because those rules are intended to assume integrity of the pressure boundary if properly applied.

The effects of the changes in Code rules on postulated break locations can be seen in Table 4. For nine piping models, the number of break locations determined by using Regulatory Guide 1.46 was reduced from 79 under old Code rules, to 42 under the new Code rules. Assuming a break at every fitting, the number of break locations would be 265.

4.2.2 Design Philosophies - Whip Restraints

In the design of pipe-whip restraints two general philosophies exist. The first is the use of elastic design. In this case the pipe- whip restraint is designed to carry all loads imposed on it while it remains essentially elastic. This results in rather large structures in some cases because of the severe loading imposed by a whipping pipe. These large structures create severe access problems for operating and maintenance personnel over the life of the plant; they can result in increased radiation exposure for the workers by forcing them to take longer routes to get from point to point. These structures also make repair of equipment more difficult and time consuming because of local interference with restraints, and removal of the restraints is often required so that maintenance or ISI can be performed. The second design approach is energy absorption. That is, the pipe-whip restraint is designed to go plastic when subjected to pipe-rupture loads. This plastic action absorbs a considerable amount of the energy present in the whipping pipe without transmitting it to the building structure. Energy-absorbing devices are usually smaller than the elastically designed devices. They allow the pipe to deflect substantially at the restraint location because the concept of energy absorbtion results in large restraint deformation. Because of this, the pipe must be in a location in which large deflections would not damage other safety-related piping and equipment. To develop a restraint which absorbs large amounts of energy without transmitting it to the building structure, a considerable amount of material data must be available, in addition to a reasonable amount of qualification testing, and a good understanding of the imposed loads must be developed.

4.2.3 Comparison of Approaches

A number of piping models were reviewed to determine the number of rupture locations postulated using different criteria. Because time and funds made it impossible to review and use Stress Reports from the plants studied to develop this data, TES used Stress Reports prepared for other clients. The criteria used for this comparison were those of Regulatory Guide 1.46, using both the new and old Code rules, as well as the approach of postulating a break at every fitting. The comparison is presented in Table 4.

Table 4. Comparison of Number of Break Locations

Piping Model	Postulated Rupture Locations: Break at Every Fitting	Postulated Rupture Locations: Regulatory Guide 1.46	Regulatory Guide 1.46 with new Code Rules
1	21	7	4
2	22	6	5
3	26	7	5
4	23	7	4
5	44	11	6
6	48	9	6
7	29	13	4
8	20	8	4
9	32	11	4
Totals	265	79	42

As in the case of snubbers, time and economics made it impossible to develop this comparison for each system and to extend the more detailed analytical approach to any of the three plants studied.

It is important to recognize that the elimination of a postulated pipe-rupture location usually results in the elimination of at least one unnecessary pipe-whip restraint. This should be an important goal of the analyst.

4.2.4 Economic Impact

A review of Section 3.0 ("Plant Data") and the associated photographs indicates the size of some of the whip restraints that are being designed and installed in nuclear plants today. The cost of fabrication and installation of some of these devices is comparable to that associated with the supports for major plant equipment. When the number of these restraints is considered, the overall costs -- including design and analysis -- are dramatic. For the energy absorbing devices, costs are associated more with the intricacy of the fabrication and installation than with their size. While the costs associated with these PEDs are obvious and certainly recognized by the industry, the costs associated with trying to operate, maintain and examine a plant that has an excessive number of these devices are not so obvious. When the access of plant personnel is limited, their productivity and efficiency are also limited, and, in this case, their exposure to radiation is increased. This has significant economic impact over the plant life. For example, where a pipe-whip restraint has been placed over a weld that must be examined under the ISI requirements of Section XI, the cost of a very simple task has been increased a number of times. The restraint must first be designed to be removable; this, of course, increases the initial design, fabrication, and installation costs. Before the weld is examined, a crew must dismantle the restraint to provide access for the examination. After the examination is performed, the crew must reassemble the restraint, ensuring that original installation tolerances, bolt torques, and so forth are reestablished. The primary activity becomes removal and reassembly of a restraint rather than the examination, and the associated costs are substantial. The same situation exists for equipment maintenance when a pipe-whip restraint interferes with access or with removal. Each time a pipe-whip restraint must be removed and reassembled, the potential for damage to existing equipment and to the restraint is increased.

4.2.5 Reliability Impact

The first and most obvious impact of a pipe-whip restraint on reliability is when the restraint interferes with the normal deflection of the piping system. This situation can result in overstressing and eventual failure. A review of Section 3 of this report indicates that for the one plant for which complete data were obtained, interferences did not exist. This can be attributed to the checking of gaps by the design agent during system operating conditions. This checking must be done to ensure that any gaps that were designed to exist actually do exist during system-operating-temperature conditions. If they do not, then adjustments to the restraints must be made at that time. One of the logistical problems associated with performing this check accurately is that the gaps are obscured by the insulation normally placed on the system before it is brought up to temperature for preoperational tests. Procedures must require that insulation not be installed around any gapped support before it is checked in the hot condition and sign-off. Checking gaps in the cold condition only is not acceptable because the actual system deflection may not be that predicted by the analysis. In fact, experience indicates that prediction of exact operating deflections of piping systems is quite unlikely.

Another item with respect to gapped pipe-whip restraints is their effect on the dynamic analysis for seismic or water/steam hammer loadings. The designer must ensure that any gap in the operating condition is sufficient to allow free motion of the pipe at the restraint location during these events. If this is not the case, then the analyst must account for the nonlinear effect of the restraint on the dynamic response of the piping system. For example, if a gap of 1/16 in. is provided between the pipe and restraint in the direction of the whipping pipe motion and 3/4 in. is provided in the opposite direction during normal operating conditions, a potential problem exists if the seismic motion is 1/2 in. First, the pipe travels 1/16 in. and then impacts the whip restraint, thus generating dynamic loads not accounted for in the analysis. Because the pipe is being restrained and loadings are being generated, energy is being stored; this energy is released when the pipe deflects in the opposite direction. This additional energy can result in deflections larger than the predicted 1/2 in. and could result in impact in the other direction. This impact load would be much higher than the first because the pipe has accelerated through a space of 13/16 in. and the existing dynamic analysis could be invalidated. For the case where the pipe-whip restraint is designed to have zero gap during normal operation then a gap must exist in the other direction to accommodate the deflection that will occur during plant or system cooldown. In this case, a nonlinear condition has been designed into the system. During a dynamic event, the pipe is restrained in one direction and free in the other.

Perhaps the biggest impact on reliability is that associated with limiting access for maintenance and examination. Just as in the case with snubbers, the more the restraint must be handled, the more the possibility of damage or misalignment on reassembly exists. Removal and reassembly become the major tasks, which can tend to decrease the importance of the examination or maintenance effort. Also, forcing personnel to spend excessive time in areas of potentially high radiation wearing the required protective clothing and breathing apparatus tends to decrease their efficiency and their accuracy.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Response of Industry

The cooperation of the utilities, the AEs, and NSSS who participated in this study was outstanding. Their sharing of information, design approaches, and opinions was responsive to the needs of the study. The general conclusions are presented below.

5.1.1 Snubbers

In general, the industry is able to deal quite well with the protection of piping systems subjected to many different defined dynamic loads and load combinations through the use of snubbers. Devices of this type are needed because of the lack of space in containment and in the reactor and auxiliary buildings. Because of this lack of space, sufficient room is not provided for piping to deflect large amounts of energy when subjected to these loadings without impacting other piping, critical equipment, or structures.

The most needed improvement is design. It is apparent that sufficient effort to keep the use of snubbers to a minimum has not been applied. The industry must recognize the deleterious effect on plant reliability and economics when the designer designates the use of a snubber. The industry must allow the designer sufficient engineering time and analysis dollars to ensure that the majority of snubbers designated as "needed" truly are needed. The NRC must recognize that changing requirements imposed on the industry which result in excessive use of snubbers may not increase plant reliability. In these cases, time must be allowed to respond to new requirements with design approaches and long-term plant modifications that provide the additional protection or reliability that was anticipated. For example, it may be better to allow a plant to modify a piping system and supports over a long period of time if this results in the elimination of unnecessary snubbers. The industry must examine the long-term economic impact of using a number of snubbers versus modifying an entire system and reducing their use.

Another area of design that needs improvement is snubber location. Of the 241 snubbers looked at in the field, 53 were determined to be inaccessible. The designer cannot always avoid this situation, but placing design emphasis on minimizing snubbers would decrease this problem. In some cases the snubber is hidden behind mechanical equipment such as pumps, and in others a 30-ft ladder would be required to reach the device. These situations will only increase the problems associated with removal and testing and could result in further degradation of reliability. Again, good design practice could have alleviated many of these problems. It is interesting to note that some of the accessibility problems are created by the proximity of pipe-whip restraints (see for example Figures A.20, A.21, and A.33).

One further caution would be to ensure that protection is provided for the hydraulic tubing from remote reservoirs to the snubber. The use of remote reservoirs to increase snubber reliability by providing an essentially continual source of hydraulic fluid was an excellent industry response to leaking hydraulic snubbers. However, when the tubing is located so that it may be damaged by workmen during normal plant operation or maintenance, then we have done little to alleviate this problem (see Figures A.26, A.35, A.36, and A.37).

The problems associated with poor installation can, and, in some cases, are being resolved by good field inspection prior to plant operation.

5.1.2 Pipe-Whip Restraints

The general designs utilized for pipe-whip restraints are of the elastic and energy absorbing types. In both cases, the presence of a gap between the pipe and the restraint is required to allow free movement of the pipe during normal operation. This gap is kept as small as possible to reduce the dynamic loading associated with impact. When one considers all of the interfaces that must come together for the pipe-whip restraint to perform its intended function properly, then one can recognize how well the industry is doing in this area. Many feet of large diameter piping is routed through a building filled with critical components and large steel and concrete structures, and must also penetrate walls and floors. The pipe is normally prefabricated at a shop away from the site just as the restraint is. The designer has analyzed the system using an isometric representation of the actual product and predicts operating deflections of the piping system. When the pipe is in place and the restraint installed, the required gap is present.

Two problem areas related to the use of pipe-whip restraints were found. The first is the over-designation of pipe-rupture locations by the designer. This results because conservatism was used in doing Class 1 fatigue analyses and because required analyses are often not available during the stage of construction when the structural personnel need information on pipe-whip restraints. In these cases, the designer usually postulates a break at every fitting, which is one of the techniques allowed by the regulatory authorities. After completion of the stress analysis, the designer may respecify break locations and recommend reducing restraints. This may or may not be accepted by the utility. In one plant in our study, this situation occurred, and the utility elected to install all of the original postulated restraints. Fortunately, these were essentially all energy-absorption types and did not result in massive structures. The second problem exists when a pipe-whip restraint covers a weld that must be examined as part of the plant ISI program. This is very disconcerting because ISI is a technique adopted by the industry to continuously monitor weld joints for critical-size flaws. However, in this instance, a device which is designed to accommodate loading from a postulated event restricts or inhibits the examination which is intended to prevent the same postulated event. It is the opinion of TES that performing the examination is far more critical to safety than the pipe-whip restraint. The industry must be more critical of this situation and ensure that these interferences do not exist.

5.2 Impact on Safety and Reliability

Section 4.0 of this report discusses these issues in detail and only the conclusions reached by this study will be presented here.

5.2.1 Radiation Exposure

As seen from previous discussions, the use of snubbers results in increased radiation exposure for maintenance personnel who are associated with the periodic testing of these devices. The only alternative is to keep the use of snubbers to a minimum. The industry may, in time, develop a device which provides the same service without requiring periodic examination or testing to demonstrate adequacy.

For the pipe-whip restraint, increased radiation exposure results from the restriction to general accessibility imposed by these large structures as well as from the interference with ISI activities. In the case of general accessibility, many of the large pipe-whip restraints limit the access of plant and maintenance personnel to equipment and to areas of compartments. This does not mean that the equipment and compartments cannot be reached; however, the time involved in getting to and from a specific location with tools and equipment is increased. For cases in which whip restraints must be disassembled to provide access and then reassembled after the maintenance or inspection task is completed, the increase in radiation exposure is obvious. The only apparent alternatives are to limit the use of these devices in the design stage, to develop a pipe-whip restraint that does not require the use of such massive structures, to create a system of examinations or automatic monitoring devices for measuring flaw sizes to eliminate the need for these restraints, or to review the present requirements for postulating sudden pipe ruptures which result in the need for these devices.

5.2.2 Inservice Inspection

Previous sections of this report have discussed the long-term impact on reliability and costs associated with the use of snubbers. The following data taken from two consecutive refueling outages at an operating plant provide detailed example. Two 4-man crews working 12-hour shifts removed or replaced an average of 8 shock suppressors per shift from containment and the reactor building. A 2-man crew tested and rebuilt as required an average of 12 suppressors per shift. This results in an average of 13 man hours per suppressor for removal, testing (and rebuilding as required) and replacement. A further concern is the fact that each member of the removal and replacement crew was subjected to 1.5 hours of radiation of varying levels per suppressor. In this particular case, the average radiation level was 250 millirem per hour.

In the case of pipe-whip restraints, previous discussion in this report points up the problems related to hinderance of ISI. The data summary in Section 3.2.4 indicates that more than one-half of the pipe-whip restraints for which total data were obtained interfere or restrict ISI work on welds. Some of these problems can be seen in the photographs in Appendix A.

5.2.3 Gap-Effect

Concern has been voiced in recent years over the effects on dynamic loading of gaps that are inherent in supports, such as snubbers and pipe-whip restraints. This study indicates that the gaps required to allow free thermal expansion are present in pipe-whip restraints. The application of rigid field inspection of the installed device and the monitoring of system expansion has done much to alleviate this concern. Still, the presence of a gap has a potential for modifying the dynamic response of a piping system during a seismic event. This can result from full restraint of the system in only one direction and/or from impact of the pipe with the restraint as the existing gap is closed. It is important to recognize that one cannot take a system problem and examine only a portion of it (that is, gap effects) and arrive at meaningful conclusions. For example, a simple, single degree of freedom system would indicate that a gap has a significant effect on the loading generated in the support and pipe as a result of impact. However, if one includes the yielding that occurs locally at the pipe support interface as well as the yielding allowed in the pipe for a pipe rupture case, then the results can indicate that the simple linear-elastic analysis is conservative. TES has performed analyses of this type, and a summary of that work appears in Reference 3. The conclusion reached in that report is that nonlinear material and structural analysis results in loads that are less than those for a linear-elastic analysis.

In the case of snubbers, the industry practice ranges from assuming the restraint is rigid, to assuming some flexibility for the restraint, using experimental data, which generally include the gap effect. The flexibility approach is certainly more mathematically correct for representation of the snubber. However, it is only one part of the overall dynamic analysis that has an effect on results. Other effects which also must be considered are

Damping values
Spectra enveloping
Enveloping ground input time histories
Equipment nozzle restraint
Anchor flexibility

The first three items provide conservatism to the analysis, and the effect of the last two is dependent upon the assumptions made by the analyst. The point to be made is that the treatment of the snubber is only one item that affects the analysis and it may not be the most important. The industry must begin to look at overall conservatisms, or the lack thereof, instead of taking each item or assumption separately and looking at its effect. This item by item approach results in conservatism piled on conservatism, with the result being an overly conservative design which may not increase plant reliability. In fact, if it results in the excessive use of snubbers, it would reduce reliability.

5.2.4 Snubber Mass Effect

This is an item which had not been an area of concern when this study began. However, in the process of review it was discovered that there are systems for which the effect of the snubber mass may be important. Perhaps the best example is the pressurizer relief system. For this case, a number of snubbers are used to carry the fluid loads associated with valve operation. The fluid loads are high, which requires the use of large snubbers.

Further, there is little in the way of structure to which to attach snubbers so there are long snubber assemblies. Also, the pipe clamps required for loads of this magnitude are special designs and range from 1 to 2 in. in thickness and are 6 to 12 in. long, while the nominal pipe diameter varies from 4 in. to 14 in. The concern is not with the fluid-load problem but with the seismic event. During an earthquake, the snubber is excited just as the pipe is. In fact, the snubber is one of the paths through which building motion is transmitted to the pipe. TES concern is with seismic motion that excites the snubber assembly mass which is locked up. This effect results in loads on the piping system which were not considered in the design.

5.3 Recommendations for Improvement

5.3.1 Design and Analysis

Design agents must make their piping analysis personnel aware of the problems associated with using snubbers. Time to minimize their use must be allowed. Where snubbers are required, they should be accessible to maintenance and inspection personnel.

Care must be taken to limit the interference between pipe-whip restraints and welds that will be subjected to ISI. The size of pipe-whip restraints must be kept to a minimum. This will require the use of more energy-absorbing types of restraints. Conservatism in analysis which lead to the specification of break locations must be eliminated.

5.3.2 Building-Size Effects

The excessive use of snubbers and pipe-whip restraints may result primarily from the limited space available for routing pipe and isolating it from critical equipment. If sufficient space were available, large deflections of piping systems subjected to dynamic loading may not be objectionable, and the number of snubbers needed to provide restraint could be limited. This is the kind of situation that exists in other energy facilities where piping deflections of 2 to 4 ft are not objectionable because the pipe is extremely flexible and can withstand this type of event. Added space would allow for better separation of piping systems and equipment, thereby eliminating the need for a number of whip restraints. Based on this, it seems appropriate that a study of building size versus piping and equipment design should be performed to review the effects on safety, reliability and economics for the life of the plant. Perhaps, if the industry recognized the long-term impact of snubbers and pipe-whip restraints, the original containment sizes would have been much larger.

5.3.3 Nuclear Regulatory Commission

In the process of developing regulations, guides, technical position, and so forth, the NRC must look at the impact of its decisions on plant reliability and safety and at the relationship of proposed new requirements to past requirements. A specific issue may be determined to have an impact on safety, thereby requiring an action by the regulators. However, in the process of addressing specific issues, the regulator must anticipate a possible industry response, as well as reviewing and revising existing requirements. That is, the regulator must consider what can be done to provide additional plant protection for the event of concern, as well as considering if response will create a safety issue itself? The regulator must also consider if existing requirements include conservatisms to cover what is covered in the new requirement, and, if so, should the existing requirements be revised to eliminate the multiplicity of conservatisms? In the case of postulated pipe rupture, the response of industry has been to provide pipe-whip restraints and to perform periodic examination of welds. Unfortunately, these two responses are at odds with each other when the restraint interferes with the examination. Further, if the restraint interferes with normal pipe motion, then it can cause the event (pipe failure) to occur.

The existing NRC pipe-rupture requirements must be updated to recognize the impact of succeeding requirements on each other. The criteria of Regulatory Guide 1.46 include margins to account for the possibility of flaws not found in construction and to account for vibratory loading not readily determined in the design process. These are followed [illegible]I requirements for the life of the plant to detect flaws before they become critical. Additional NRC positions require vibration monitoring of critical piping systems during preoperational testing. Obviously, the requirements for ISI and vibration monitoring are good attempts to reduce the potential of the problem occurring and should be followed. However, it seems reasonable now to expect the NRC to review existing pipe-break criteria and eliminate conservatisms that exist.

With respect to dynamic-load events, the regulatory authorities and industry must be careful to look at the overall impact on safety. For example, to rule that snubbers must be handled analytically in a specific fashion (which in itself is conservative) is unacceptable without looking at the overall conservatism of the dynamic analysis. Imposing conservatism on each part of the process can result in excessive conservatism on the whole, and this excess can result in a design that is not as safe or reliable as anticipated. A review must be performed to determine the impact of mandated plant events and subsequent load combinations and mathematical combination techniques on the actual design of systems. This is most necessary when addressing the functional capability of essential piping systems and operability of active components. In this case, postulated plant events such as LOCA and SSE must be combined with normal and upset plant operating conditions using a stress criterion that is related to upset operating conditions. In most cases, the only response available to industry to these combinations is the use of snubbers. This study indicates qualitatively that the reliability or safety that was anticipated in specifying the events may not be present when snubbers are used. The regulators must be more aware than the designer is to the potential response to a specific requirement. Only then can they have an understanding of the overall effect on reliability, safety, and maintenance of a proposed regulation.

5.3.4 Dynamic-Stress Limits

To properly address dynamic loading, the response of piping systems, and the failure mechanism, some detailed investigation needs to be performed. The industry has the computational tools to predict the response of a piping system fairly accurately if all of the variables are properly considered. The imposed dynamic loading is generally considered to be conservatively developed. The real problem appears to be in the area of criteria or failure mechanism. It is important to recognize that the criteria are based on providing a margin of safety on the limit load. The real problem is that the concept of limit load is associated with static loading on a given component. In reality, there is a complex piping system made up of a number of components to which a wide range of loading is applied -- from the static load associated with deadweight to the dynamic load associated with a waterhammer or a seismic event. To use static limits based on static testing of a single component does not seem appropriate. The effect of dynamic loading on the collapse mechanism of a piping system is a more complex problem primarily because little data are available. However, it is possible to draw some generalizations from those incidents of dynamic loadings associated with fluid transients such as turbine trip, waterhammer, and relief valve blow loads that have occurred in operating nuclear power plant piping systems. A number of main steam lines were subjected to dramatic dynamic loading associated with a turbine trip transient. These piping systems had not been designed with this event as a consideration and subsequently experienced large deflections (1 to 2 ft). The calculated stress resulting from the measured deflections were 5 to 10 times the existing static allowables. A number of components had calculated loads applied that were well beyond the theoretical static limit load, yet no evidence of large plastic deformations was evident, no collapse mechanism existed, and no flaws were developed in the system. Similar situations have occurred in other main steam systems, steam dump lines, main steam relief systems, and a number of water-filled systems.

Very little is being done to study dynamic collapse of piping systems. In Reference 3 a list of six studies is given on page 22. Of this list, only four studies are directly related to the problem of dynamic capacity. Any change in the existing criteria that would increase the capacity of a piping system to carry dynamic loading without reducing the present factors of safety on actual collapse would also reduce the need for snubbers and increase reliability. Efforts in dynamics should be focused in the direction of developing dynamic-stress-limit criteria rather than dealing with bits and pieces of the dynamic problem (such as gapping effects, load combinations, support stiffness, and so forth) using the existing static criteria as a base.

6.0 REFERENCES

(1) ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Power Plant Components."

(2) ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

(3) TES Technical Report TR-3742-2, "Technical Program to Identify Significant Problems Related to Piping Systems in LWR Power Plants," dated August 1, 1980; prepared for Sandia Laboratories, Albuquerque, N.M. (available from TES).

APPENDIX A

PHOTOS OF PIPE WHIP RESTRAINTS AND SHOCK SUPPRESSORS

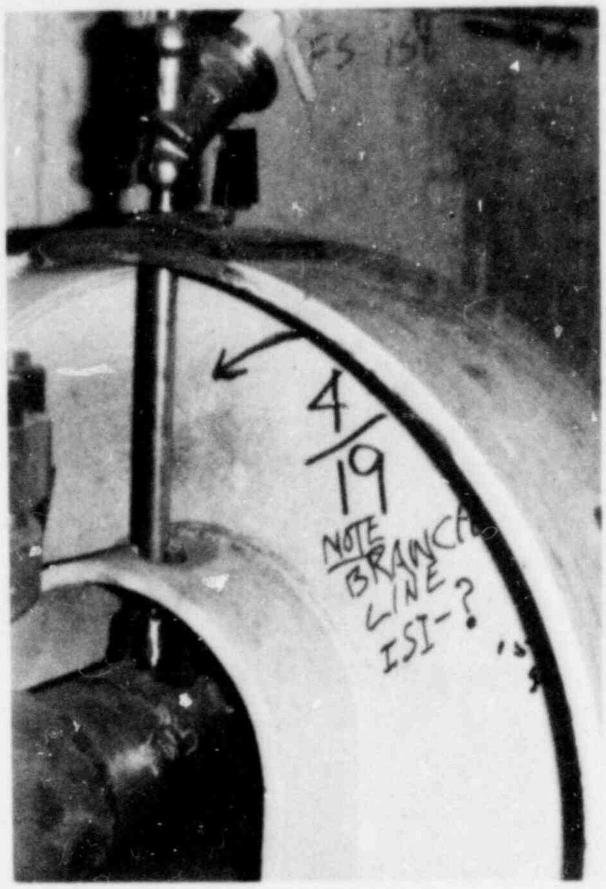


Figure A.1 Pipe whip restraint, box type

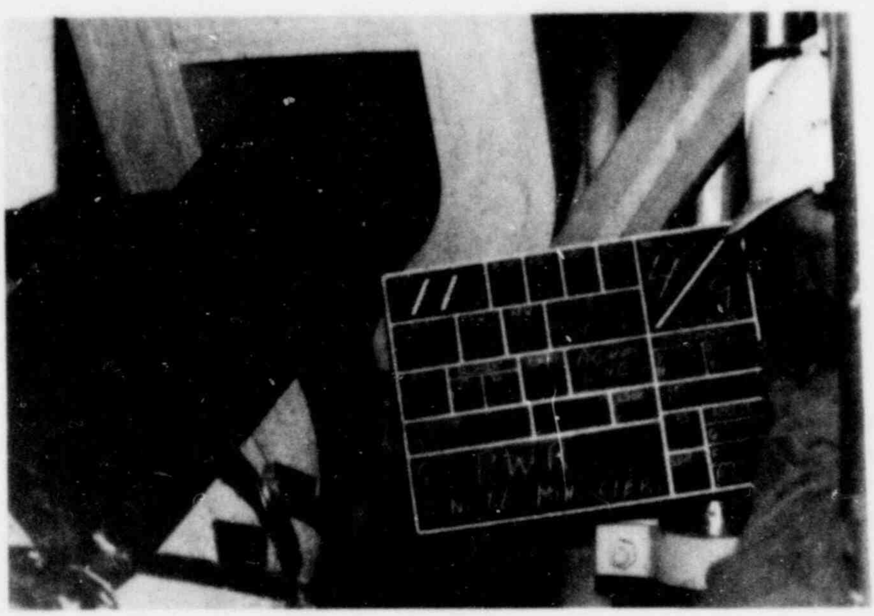


Figure A.2 Pipe whip restraint, box type

Figure A.3 Pipe whip restraint, ring type

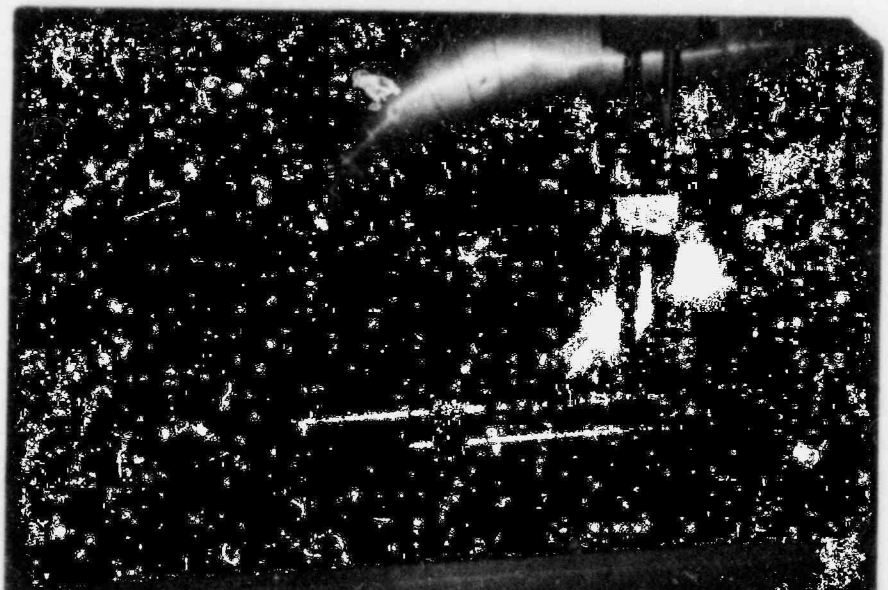


Figure A.4 Pipe whip restraint, U-bolt type with tie rod (note the number)

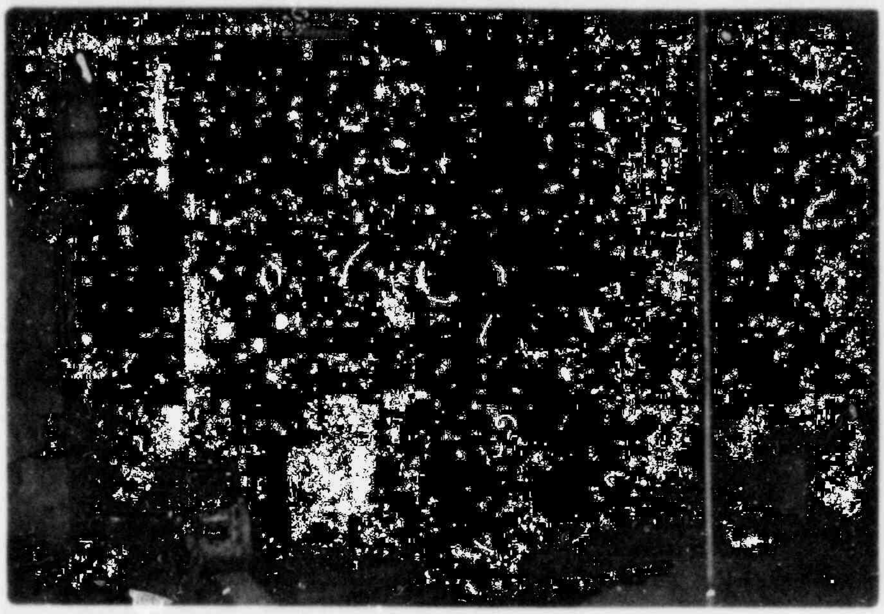


Figure A.5 Pipe whip restraint no. 454, U-bolt type with tie rods

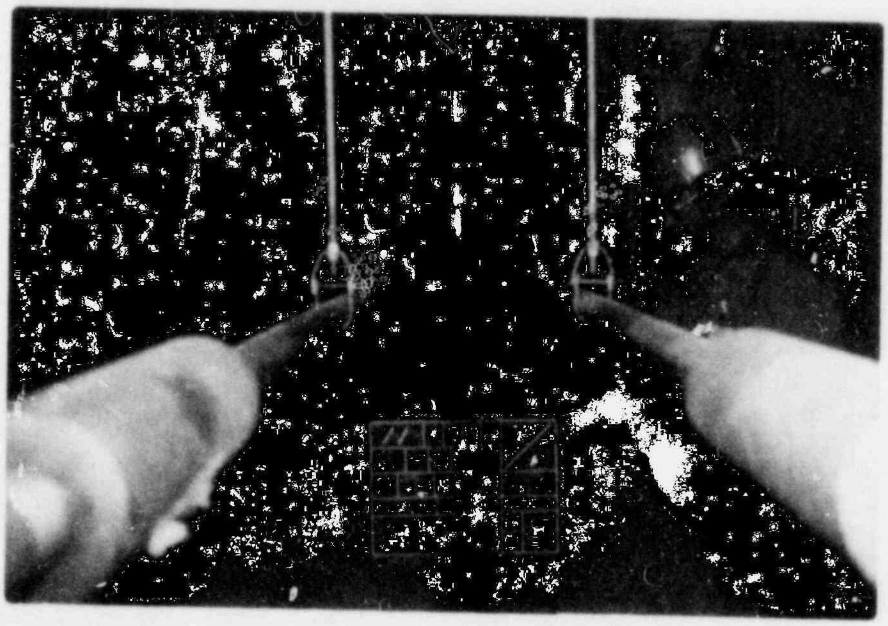


Figure A.6 Pipe whip restraint, with tie rods extending more than 80 ft (note the weight support required for the tie rods)

Figure A.7 Pipe whip restraint no. 463, U-bolt type

Figure A.8 Pipe whip restraint, ring type

Figure A.9 Pipe whip restraint no. 514, box type with crushable insert

Figure A.10 Pipe whip restraint, weld inaccessible for inservice inspection

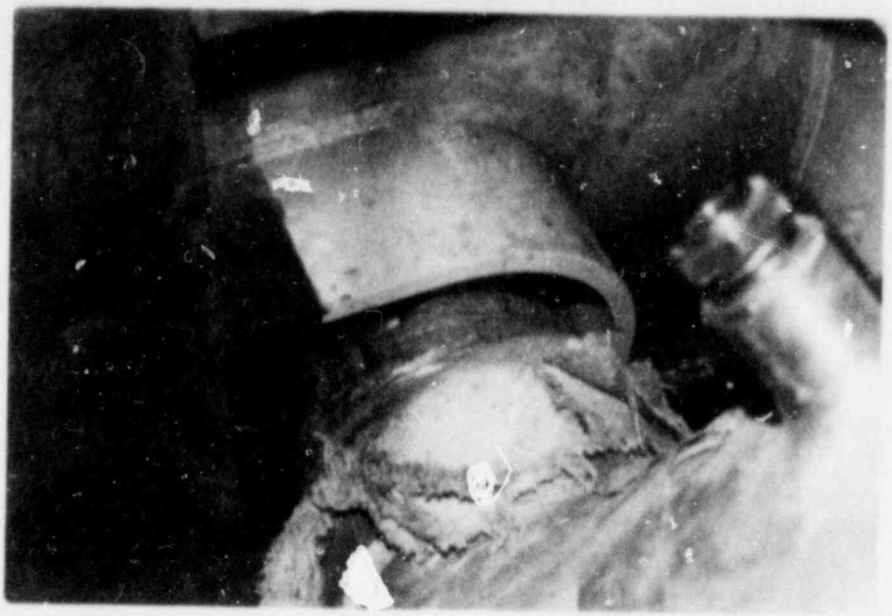


Figure A.11 Pipe whip restraint, weld inaccessible for inservice inspection

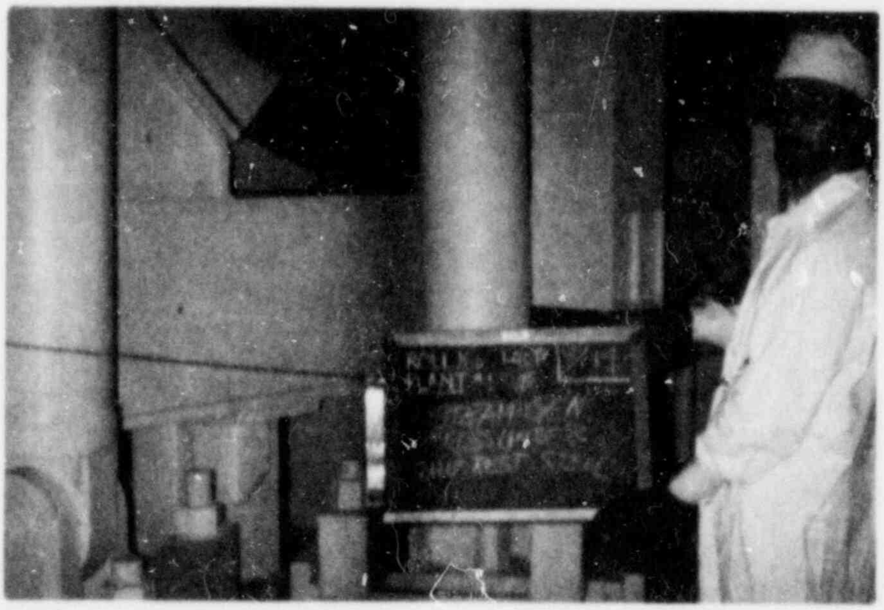


Figure A.12 Pipe whip restraint (note size of steel)

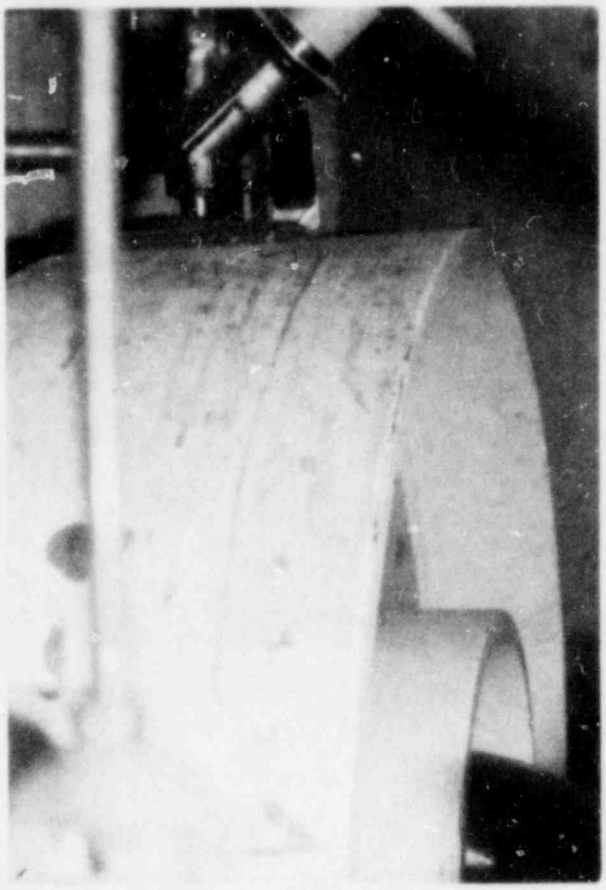


Figure A.13 Pipe whip restraint, weld inaccessible for inservice inspection

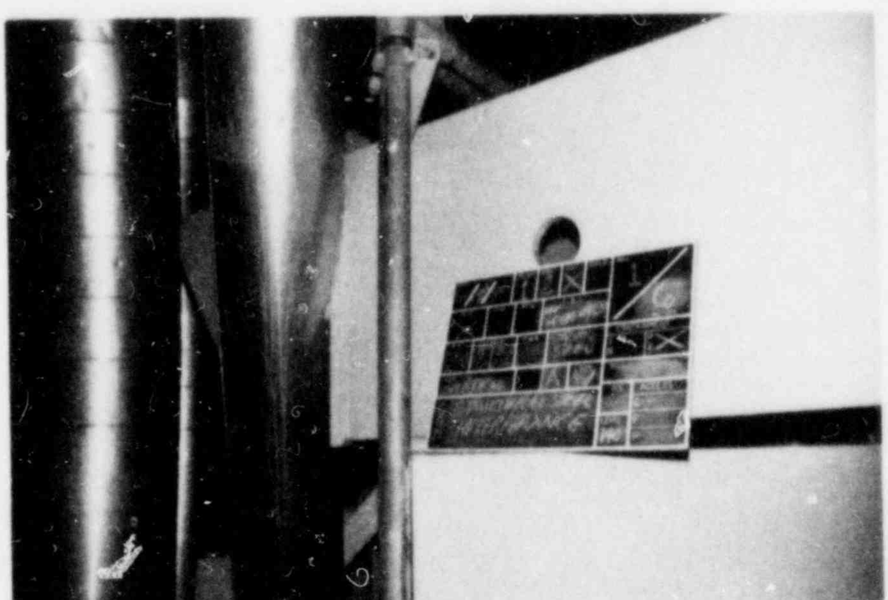


Figure A.14 Pipe whip restraint steel

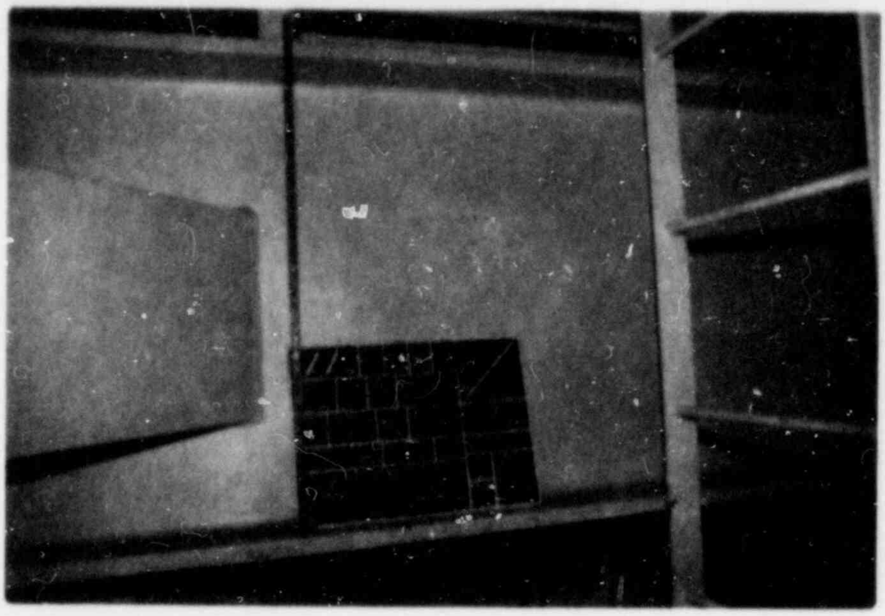


Figure A.15 Pipe whip restraint steel
(note size of steel)

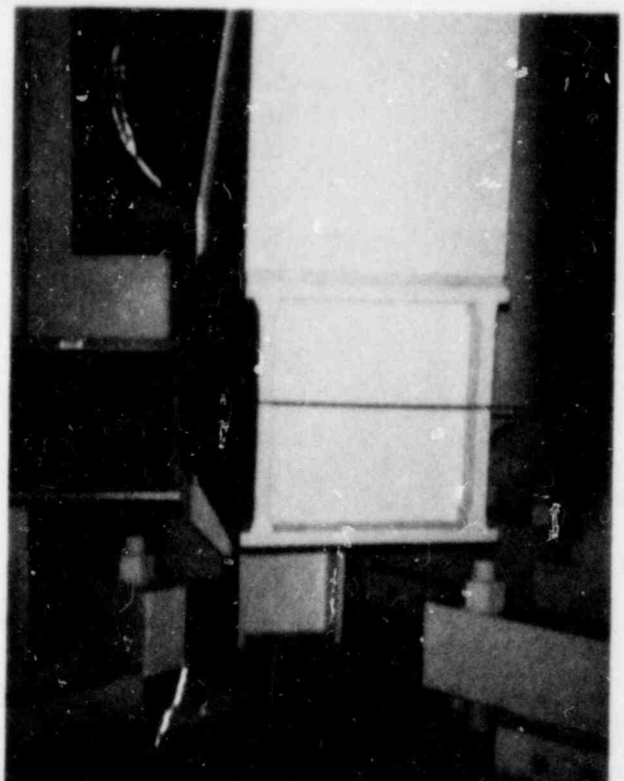


Figure A.16 Pipe whip restraint steel
(note size of steel)

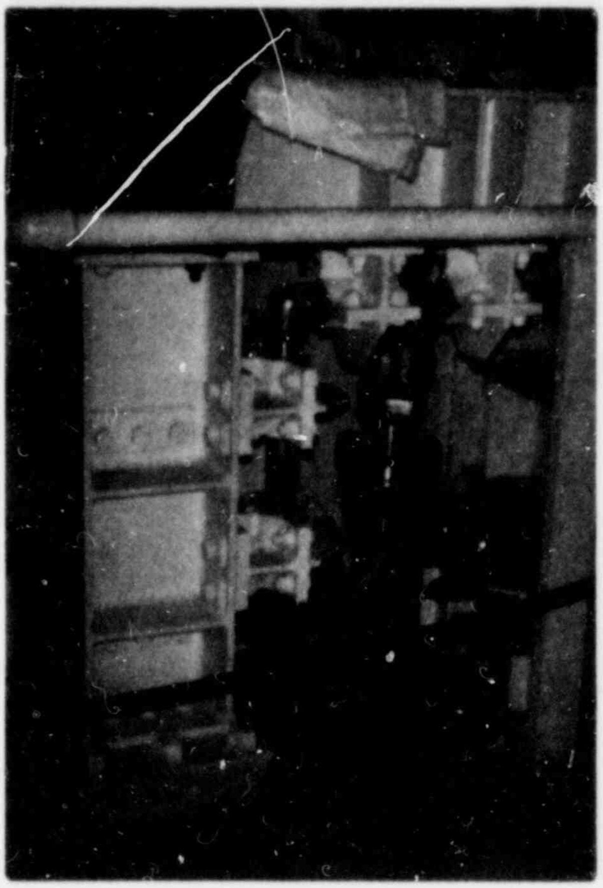


Figure A.17 Pipe whip restraint steel (note size of steel)

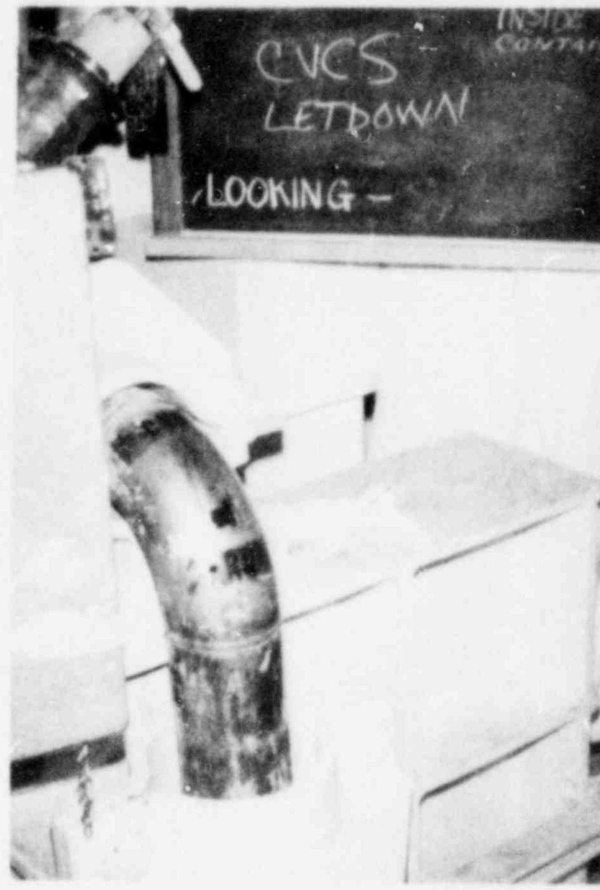


Figure A.18 Pipe whip restraints

Figure A.19 Hydraulic snubber, piston fully extended

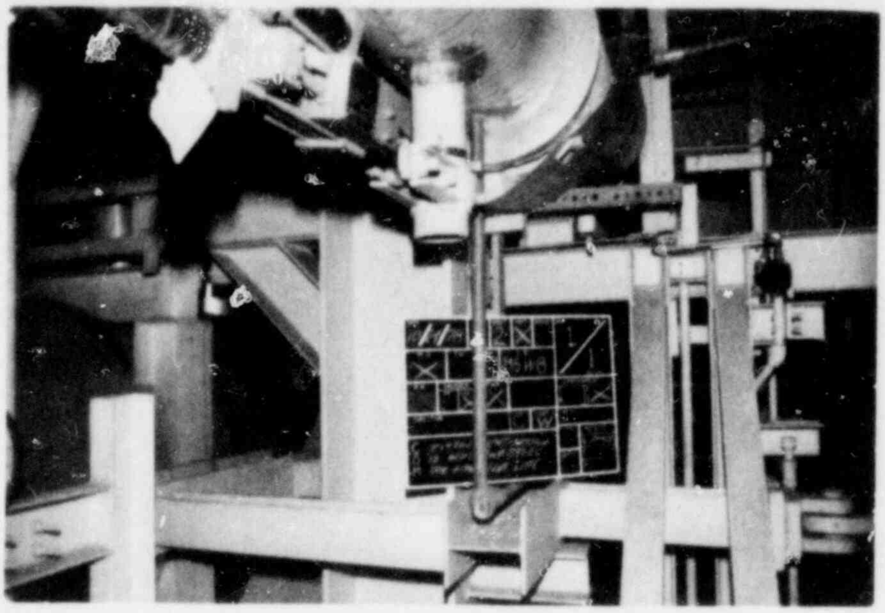


Figure A.20 Snubber installation (note extravagant design required to avoid pipe whip restraint steel)

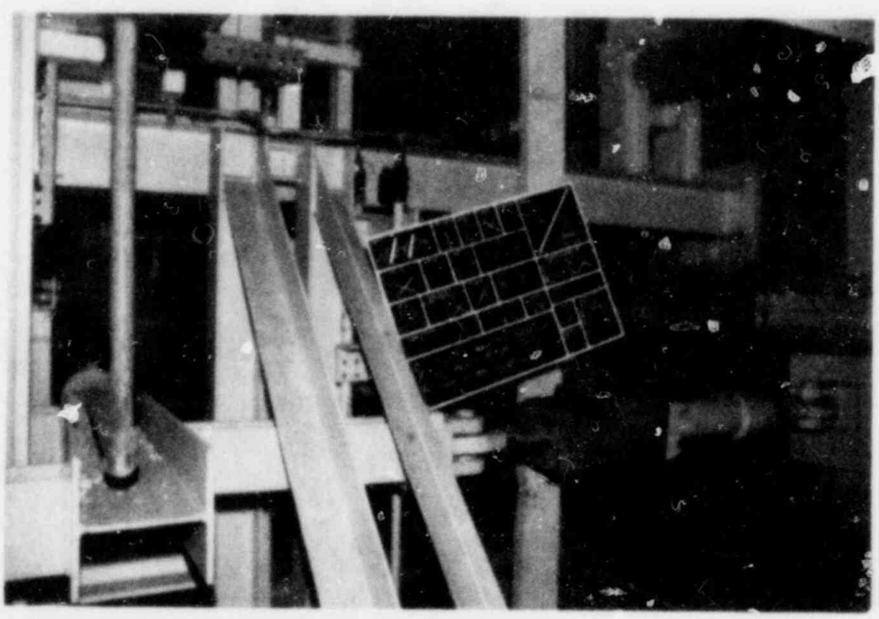


Figure A.21 Snubber installation (note extravagant design required to avoid pipe whip restraint steel)

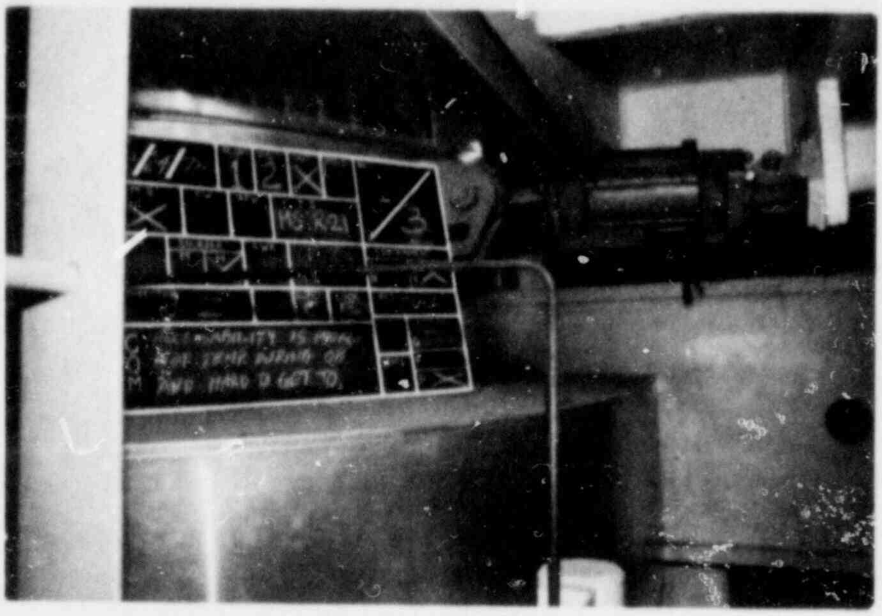


Figure A.22 Snubber installation (note inaccessibility)

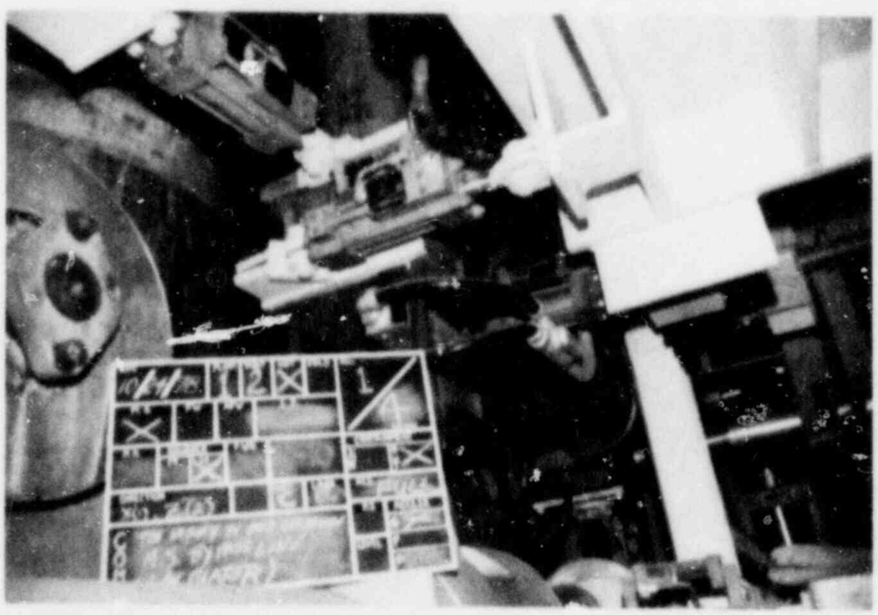


Figure A.23 Snubbers (note excessive number required)

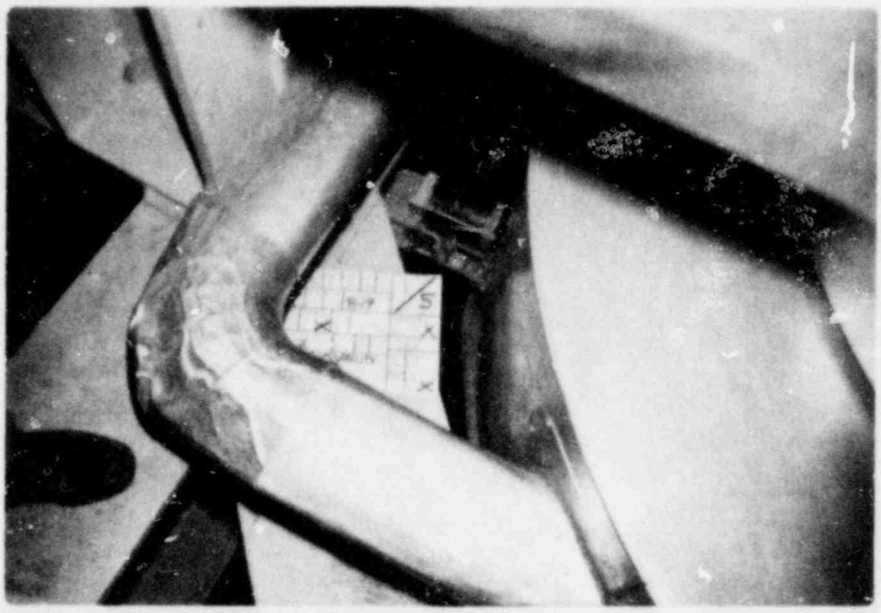


Figure A.24 Snubber installation (note inaccessibility)

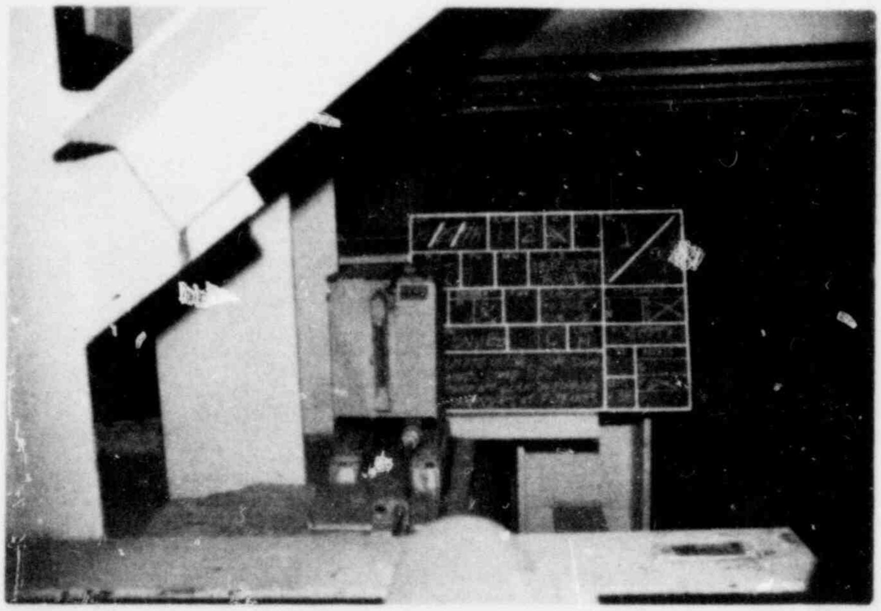


Figure A.25 Remote oil reservoir for two hydraulic snubbers (note reservoir is empty)

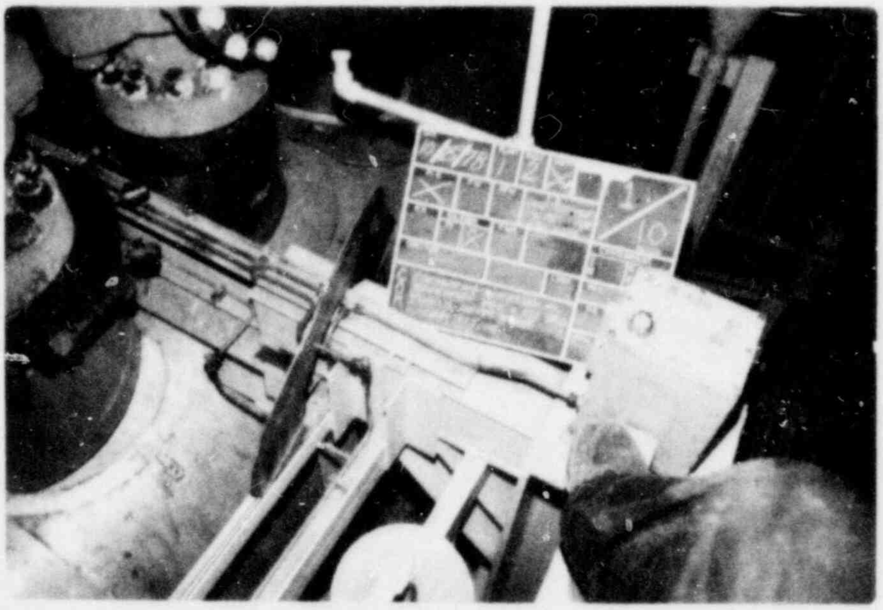


Figure A.26 Remote oil reservoir (note inaccessibility and dangerous (unprotected) routing of reservoir tubing)

Figure A.27 Hydraulic snubber (note inaccessibility)

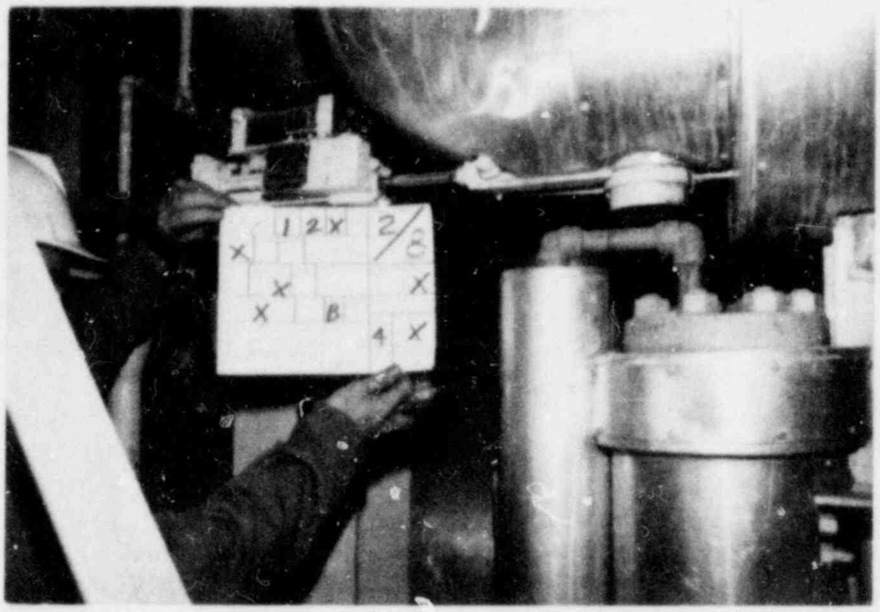


Figure A.28 Hydraulic snubber; interface with insulation could cause binding of snubber during system warmup

Figure A.29 Hydraulic snubber (note low oil level and dangerous location)

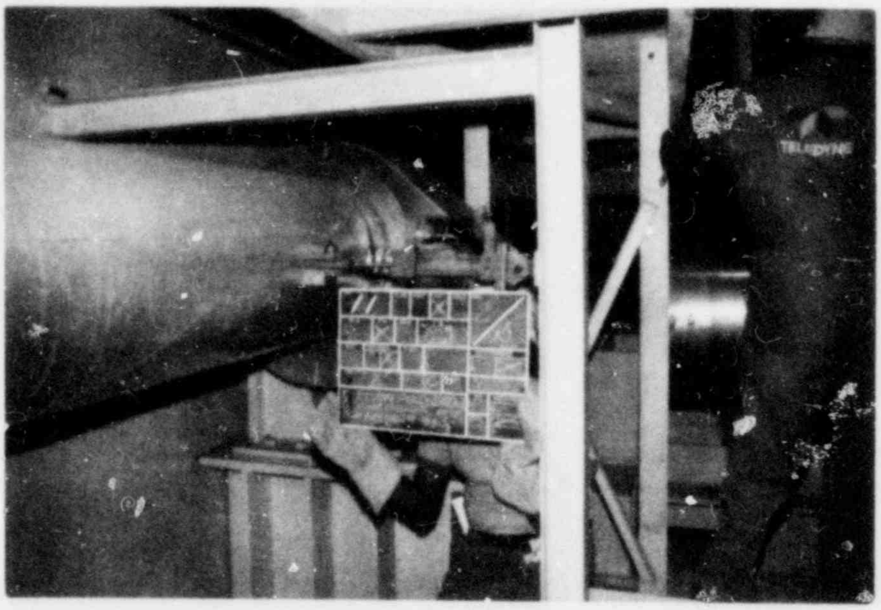


Figure A.30 Hydraulic snubber, piston fully extended

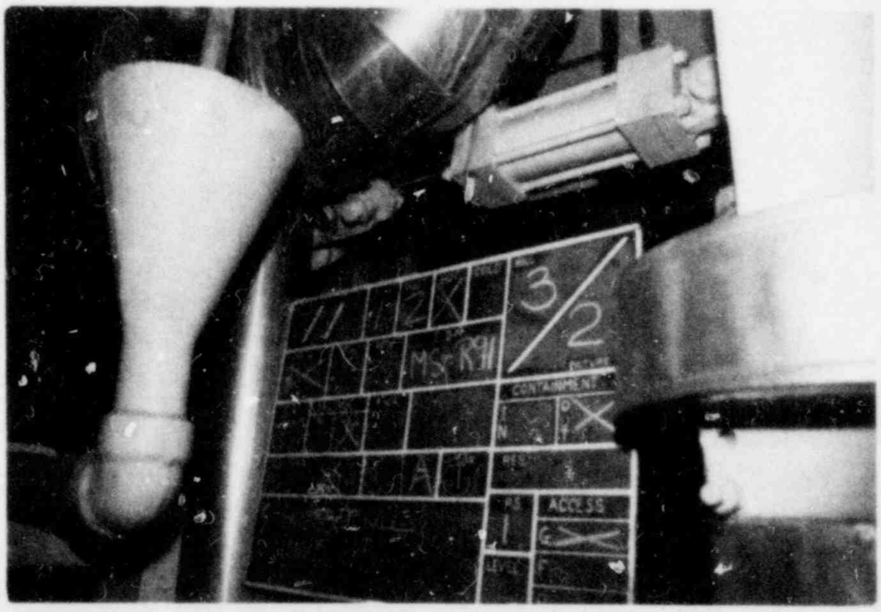


Figure A.31 Hydraulic snubber (note that snubber potentially will bind during system warmup)

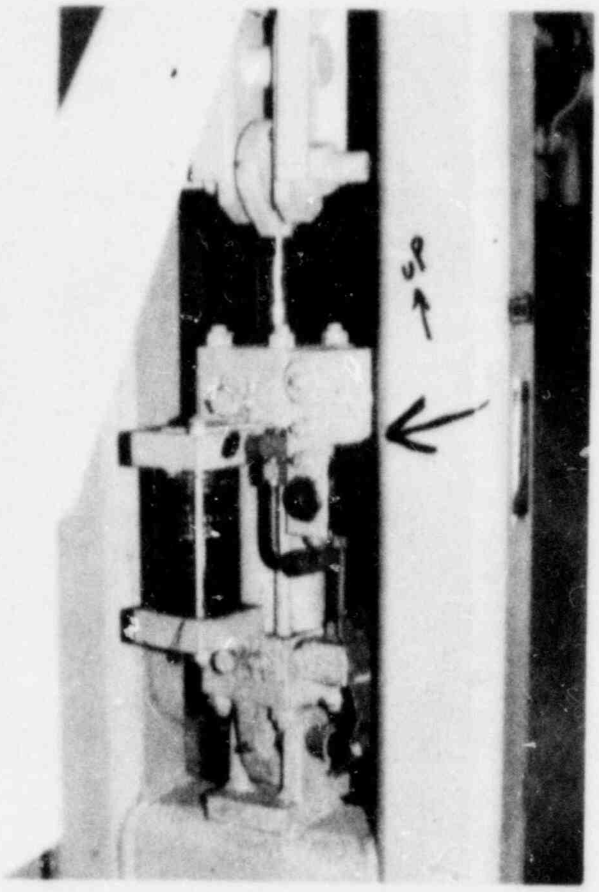


Figure A.32 Hydraulic snubber, reservoir installed with port on wrong side

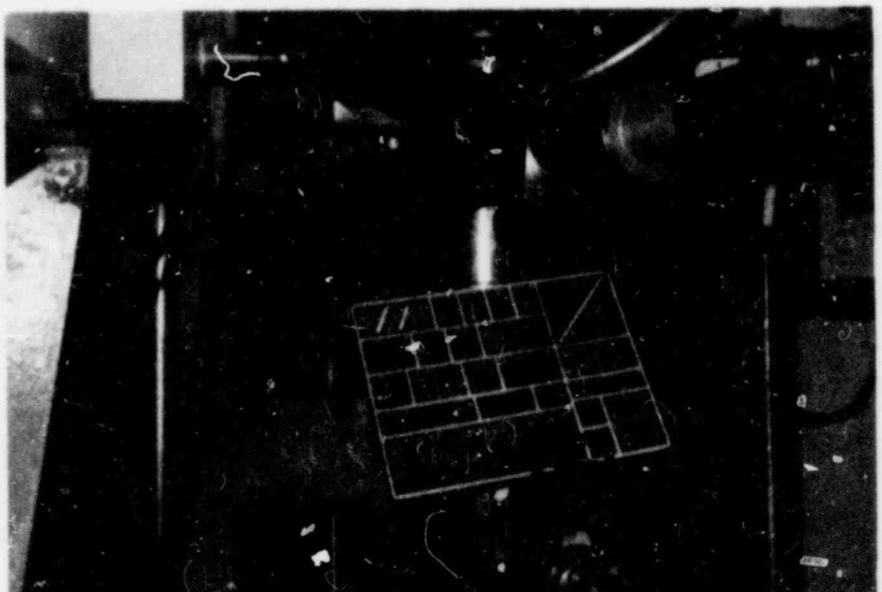


Figure A.33 Mechanical snubber no. 261 (note complex design required to avoid excessive steel for pipe whip restraint)

Figure A.34 Hydraulic snubber oil

Figure A.35 Hydraulic snubber with remote oil reservoir (note large size and dangerous routing of reservoir tubing)

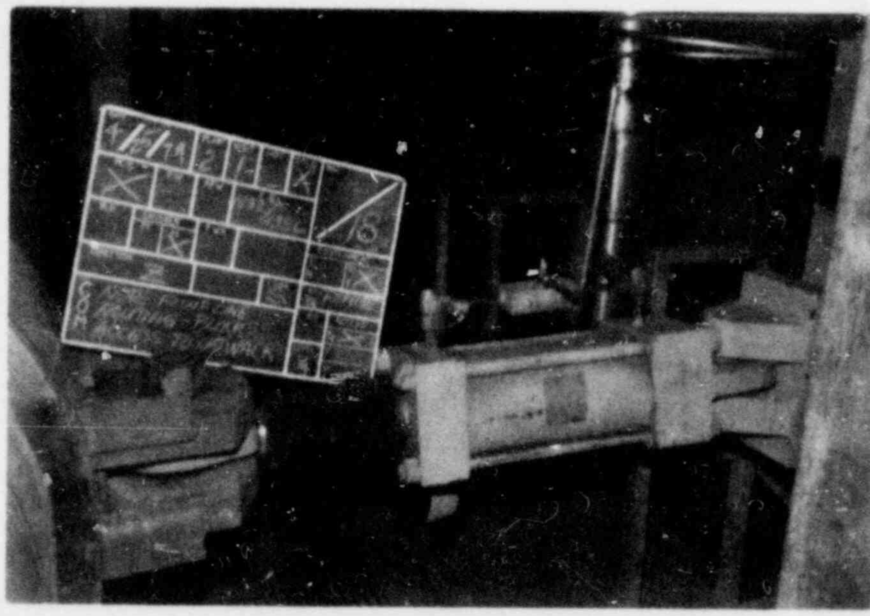


Figure A.36 Hydraulic snubber with remote oil reservoir (note large size and dangerour routing of reservoir tubing)

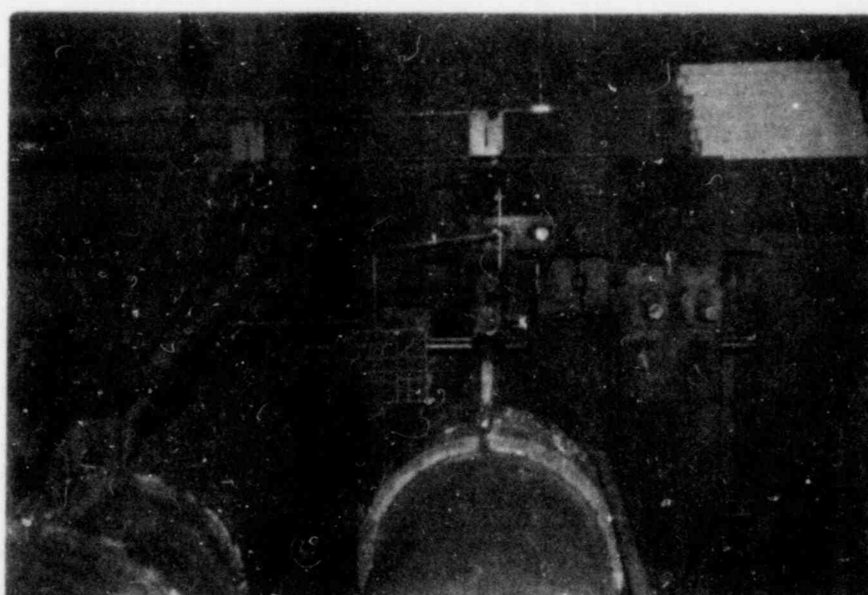


Figure A.37 Hydraulic snubber with remote oil reservoir (note large size and dangerour routing of reservoir tubing)

APPENDIX B

PLANT DATA

PIPE WHIP RESTRAINTS

Restraint No.	Interference	ISI Hindered	Comment
216	No	Yes, Partial	
217	No	Yes, 2 Welds Total for U.T.	
218	No		
219	No	Yes, Partial	
227	No		
228	Marginal		
229	No		
230	No	Yes, Partial	
231	Marginal		
156	?	Congestion & VLV Maint. Impeded.	
@ Unit II 15 Observed		Yes, 9 of them	Most of 9 allow only partial ISI (i.e., 30-50%). One covers weld in total.
379-483	(See Note 2)	50%	
807-878	(See Note 3)	50%	

Notes:

1. Only a minimum number of pipe whip restraints were inspected at Plant #1 due to the fact that most were encased in insulation.

2. At Plant #2, Pipe Whip Restraints (Restraints 379 through 483) were inspected but all data except for ISI interference was inconclusive since gap settings were not completed.

3. At Plant #3, Pipe Whip Restraints (Restraints 867 through 878) were inspected but all data except for ISI interference was inconclusive due to incomplete gap settings and installations.

TABLE B.1

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
15	H	OK	1/2 2/3	D	No	G	
16	H	OK	3/4	D	No	G	
17	H	OK	3/4 3/4	C	No	G	
18	H	OK		D	No	G	
19	H	OK	3/4 3/4	C	No	G	
20	H	OK	2/3	D	No	G	
21	H	OK	7/8 7/8	C	No	G	
22	H	OK	7/8	C	No	G	
23	H	OK	1/2 7/8	C	No	G	
24	H	OK	2/3	C	No	G	Extravagant design due to P.W.R
25	H	OK	3/4	C	No	G	
26	H	OK	3/4 3/4	C	No	G	
27	H	OK	3/4	C	No	G	
28	H	OK	3/4	D	No	G	
29	H	OK	3/4 3/4	C	No	G	
30	H	OK	3/4 3/4	C	No	G	
31	H	OK	3/4	C	No	G	
32	H	OK	Full 2/3	D	No	G	wrong dir. Check new analysis
33	H	OK	OK OK	C	No	P	
34	H	OK	3/4 3/4	D	No	G	

TABLE B.2

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
35	H	OK	full full	C	No	P	
38	H	OK	1/2 1/2	D	Yes	G	Restricts Motion
39	H	OK	7/8 7/8	C	Potential	G	See Fig. A.31
41	H	OK	full full	C	No	G	
48	H	OK	3/4 3/4		Potential	G	Potential bind up during cooldown of body with pipe.
56	H	OK	3/4 3/4	C	No	G	
62	H	OK	Full NI	C	No	G	
63	H	OK	Full NI	C	NO	G	
64	H	OK	Full NI	C	No		
65	H	OK	Full NI	C	No	G	
66	H	OK	OK NI	C	No	P	Observations made from distance; high radiaiton
67	H	OK	OK NI	C	No	P	Observations made from distance, high radiation
68	H	OK	OK NI	C	No	P	Observations made from distance; high radiation
71	H	OK	1/2 NI	C	Yes	G	Motion restricted
72	H	OK	NI	NI	No	P	High radiation
73	H	OK	NI NI	NI	No	P	Observed from distance, high radiation
74	H	OK	Full NI	C	No	G	
75	H	OK	NI NI	NI	Inconclusive	P	Need 30 foot ladder

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
76	H	OK	NI NI	NI	Inconclusive	P	Need 30 foot ladder
77	H	OK	NI NI	NI	Inconclusive	P	High radiation
78	H	OK	NI NI	NI	Inconclusive	P	High radiation
79	H	OK	NI NI	NI	Inconclusive	P	High radiation
80	H	OK	NI NI		Inconclusive	P	High radiation
82	H	OK	3/4 NI	D	No	G	
83	H	OK	3/4 NI	C	No	G	
84	H	OK	7/8 NI	C	No	G	
85	H	OK	2/3 NI	C	No	G	
86	H	OK			Inconclusive	P	Inaccessible
88	H	OK	3/4 NI	C	Inconclusive	G	
91	H	OK	NI NI	NI	Inconclusive	P	High Radiation
92	H	OK			Inconclusive	P	High Radiation
94	H	OK	2/3 NI	C	No	G	
95	H	OK	2/3 NI	D	No	G	
96	H	OK			Inconclusive	P	High radiation
97	H	OK		C	Inconclusive	P	High Radiation
98	H	OK		C	Inconclusive	P	High Radiation
99	H	OK	Full NI	C	No	G	
100	H	OK			?	G	Solid Y-restraint installed
101	H	OK	2/3 NI	C	No	G	
102	H	OK	2/3 NI	C	No	G	
103	H	OK	Full NI	D	No	G	

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
105	H	OK	1/2 NI	C	No	G	
106	H	OK	NI		?	G	Rigid in 2 directions
107	H	OK	2/3 NI	C	No	G	OK
108	H	OK	Full NI	C	No	G	
109	H	OK	3/4 NI	C	No	G	
110	H	OK	1/2 NI	C	No	G	
111	H	OK	3/4 NI	C	No	G	
112	H	OK	3/4 NI	C	No	G	
113	H	OK	5/8 NI	C	No	G	
116	H	OK	Full NI	D	No	G	
118	H	OK			Inconclusive	P	High radiation
122	H	OK	OK NI		No	P	Innac. - observations made from distance
123	H	OK	OK NI		No	P	Innac. - observations made from distance
127	H	OK	3/4 NI		No	G	Piston buried in insulation
128	H	OK	3/4 NI	C	Yes	G	Questionable, may bind up
129	H	OK	3/4 NI	C	No	G	
130	H	OK			No	P	Very inaccessible; high rad. and high

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
132	H	OK	3/4 NI	C	Potential	G	
133	H	OK	3/4 NI		Inconclusive	P	Inaccessible - high radiation
134	H	OK	OK NI		No	P	Observations made from distance
135	H	OK	OK NI		No	P	Observations made from distance
144	H	OK	1/4 LOW	C	No	G	Fluid leaking ; fluid level below outlet (See Figure A.29)
145	H	OK	1/3 LOW	D	No	G	Fluid below outlet level; outlet at wrong end (see Figure A.32)
147	H	OK	7/8 7/8	D	No	G	
150	H	OK	3/4 3/4	D	No	G	
153	H	OK	3/4	P	No	G	
166	H	OK	1/2 2/3	D	No	G	Leaking
167	H	OK	1/2 1/2	C	No	G	Leaking
168	H	OK	3/4 3/4	D, P	No	G	
169	H	OK	3/4	D	No	G	
173	H	OK	1/2 1/2	C	No	G	
176	H	OK				G	Not Installed
184	H	OK	1/2 0	C	No	G	Oil res. filled but appears to be leaking

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
185	H	OK	2/3 3/4	C	No	G	Outlet is almost uncovered
187	H	OK	2/3 2/3	D	Yes	G	Fully Extended (See Figure A.30)
189	H	OK	3/4	D	No	G	
191	H	OK	3/4 3/4	D	No	G	
196	H	OK			No	P	High Radiation
200	H	OK	3/4 NI	C	No	G	
212	H	OK			No	P	High Radiation
213	H	OK			No	P	High Radiation
224	H	OK	2/3 NI	C	No	G	
226	H	OK	2/3 NI	C	No	G	
233	H	OK	NI Full	D	Inconclusive	F	Extravagant design (See Figure A.21)
235	H	OK	NI 2/3	D	Inconclusive	G	
238	M	OK	X X	C	Inconclusive	G	
239	M	OK	X X	C	Inconclusive	G	
240	M	OK	X X	C	No	G	
241	M	OK	X X	C	No	P	
243	H	OK	7/8	C	No	G	(See Figure A.22)
245	H	OK	3/4		No	P	Inaccessible unless insulation removed and cold (See Figure A.27)
248	M	OK	X X	C	No	G	
250	H	OK	0 0	D	No	F	Oil found empty - was filled and appears to leak (See Figure A.25)
251	H	OK	NI 1/2	C	No	G	

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
252	M		X X	C	No	G	
253	M		X X	C	No	P	
255	H	OK	2/3 Full	C	No	G	OK
256	M	OK	NA		No	G	
257	M	OK	NA	C	No	G	
258	M	OK	NA	C	No	G	OK
259	M	Marginal Stiffness	NA	C	No	G	
260	H	Marginal Stiffness	3/4 full	C	No	G	
261	M		NA	C	Inacc.	P	Area very congested. (See Figure A.33)
262	H	OK		C	Inacc.	P	
263	H	OK		C	Inacc.	P	
264	M	Marginal Stiffness	NA	C	No	G	
265	M	OK	NA	C	No	G	
266	M	OK	NA	C	No	G	
267	M	OK	NA	C	No	G	
268	M	OK	NA	C	No	G	
269	M	OK	NA	C	No	P	Poor Access
270	M	OK	NA	C	No	G	
271	H	OK	3/4"?		No	G	Installation incomplete.

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
272	H	OK		C	No	G	
273	H	OK	3/4 full	C		G	
274	H	OK	7/8 full	C	No	G	
275	M	OK	NA	C	No	G	
276	M	OK	NA	C	No	G	
277	M	Marginal Stiffness	NA	C	No	G	
278	H	Marginal Stiffness	90%	C	No	G	
279	H	OK	75%	C	No	G	
280	M	OK	NA	C	No	G	
281	M		NA	C	No	G	
282	M		NA	C		G	
283	M	OK	NA	C	No	G	
284	M	Marginal Stiffness	NA	C	No	G	Doesn't appear to be axial in design
285	M	OK	NA	C	No	P	Couldn't get to installation
286	M	OK	NA	C	No	G	Installation in wrong location
287	M	OK	NA	D	Inacc.	P	5" stroke 3000 lb. load
288	H	OK	75%	C	No	G	
289	M	OK	NA	C	No	G	
290	M	OK	NA	C	No	G	
291	H	Excessive	75%	C	No	G	

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
292	H	OK	80%	C	No	G	
293	M	OK			N/A	G	Snubber not installed
294	H	OK	2/3 full	C	No	F	
295	H	OK	1/2	D	?	P	Poor Access
296	H	OK	2/3 full	C	No	G	
297	H	OK	2/3 full	C	No	G	
298	M	OK			Potential See Note 7	G	Interference
299	H	OK	70%		Inconclusive	G	
300	H	OK	80%	C	Inconclusive	G	
301	-	OK			Inconclusive	P	Covered completely
302	-	OK			Inconclusive	G	Not installed
303	H	OK	90%		Inconclusive	G	Covered completely
304	-	OK			Inconclusive	G	Not installed
305	H	OK	70%	(Covered)	Potential, See Note 7	G	Completely closed
306	-	OK			Inconclusive	G	Not installed
307	H	OK			Yes	G	Interference
308	H	OK	1/2	C		G	
309	M		NA	(Covered)	Inconclusive	G	
310	H		80%	(Covered)	Inconclusive	G	
311	H		80%		Potential See Note 7	G	5" stroke, fully compressed

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
312	H	OK	55%	(Covered)	Inconclusive	G	
313	H	OK	85%	(Covered)	Inconclusive	G	
314	M	OK	NA	(Covered)	Inconclusive	G	OK, 6" Stroke Snubber rating = 50 kip
315	-	OK			Inconclusive	P	Inaccessible
316	M	OK			Inconclusive	G	
317	H	OK			Inconclusive	P	Can't get to.
318	M	OK	N/A	C	Inaccessible	G	
319	M	OK		C	Inconclusive	G	
320	H	OK	80%	C	Inconclusive	G	
321	M	OK	N/A	C	Inconclusive	G	
322	H	OK	80%	C	Inconclusive	G	
323	H	OK	75%	D	Inconclusive	G	
324	H	OK	80%	D	Inconclusive	G	
325	M	OK		D	Inconclusive	G	
326	M	OK			Inconclusive	G	
327	M	OK	NA	C	Inconclusive	G	
328	H	OK	60%	D	Inconclusive	G	
329	H	OK	80%	C	Inconclusive	G	
330	H	OK	90%	D	Inconclusive	G	
331	H	OK	60%	D	Inconclusive	G	
332		OK			Inconclusive	G	Not Installed

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
333	M	OK	NA	C	No	G	
334	M	OK	NA	C	No	G	
335	M		NA		Inconclusive	P	Visual obser. only; inaccessible
336	M	OK	NA	C	No	P	2.5" available. Very hard to get to but not impossible.
337	H	OK	100%	C	inconclusive	G	* motion available; 2" = west; 3" = east
338	M	OK	NA	C	No	G	
339	H	OK	7/8 full	C	No	G	5" stroke
340	M	Marginal Stiffness	NA	C	No	G	
341	H	Marginal Stiffness	Full		No	G	
342	H	OK			No	G	
343	H	OK	Full		No	G	Looks good except for remote reservoir lines.
344	H				Inconclusive	G	Not installed during this visit - it appears to have been removed for repairs.
345	H	OK			No	G	
346	H	OK			No	G	

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
347	H	OK			No	G	
348	H	OK	1/3		Inconclusive	G	Plastic Line from Remote Oil Tank
349	H		3/4		Inconclusive	G	Can move up a great deal.
350	H		80% full		Inconclusive	G	Large -no marking; remote res. Note fragile feed lines (See Figure A.36)
351	H		85% full	D	Inconclusive	G	10" stroke
352	H				Inconclusive	G	
353					Inconclusive	P	Can't get at
354	H		Full	C	Inconclusive	G	Looks good except for res. line, could be easily bumped (See Figure A.35)
355	H	OK	3/4 full	C	No	G	5" stroke, ok
356	H		Full	C	Inconclusive	G	5" stroke, looks ok
357	H	OK			No	G	
358	H	Marginal Stiffness			Inconclusive	P	
359	H	Excessive - 1 dir. only			Inconclusive	F	
360	H	OK			Inconclusive	P	
361	H	OK	90% full	D	No	G	Double remote res.; 10" stroke
362	H	OK	3/4 full	D	No	G	10" stroke; double remote res.

TABLE B.2 (CONTINUED)

SNUBBERS

Restraint No.	Type	Supplementary Steel Stiffness	Oil Level Hot/Cold	Piston	Interference	Accessibility	Comment
363				D	Inconclusive	G	
364					Inconclusive	G	
365	M			C	Inconclusive	G	
366	H		90%	C	Inconclusive	G	
367	H		90%	D	No	G	
368	H		70%	C	Inconclusive	G	
369	H			C	Inconclusive	P	Can't get to
370				D	Inconclusive	G	
371					Inconclusive	P	Inaccessable
372	M		N/A	C	Inconclusive	G	
373					Inconclusive	G	Not installed
374					Inconclusive	G	Not Installed
375	M		NA	C	Inconclusive	P	Can't get to
376	M			C	Inconclusive	G	6" stroke; 10K load
377	H			C	Inconclusive	P	Can't get at
378					Inconclusive	P	Inaccessible

TABLE B.2 (CONTINUED)

NOTES (To Be Used with Table B.2:

1. M = Mechanical; H = Hydraulic
2. Location - Is it within one pipe diameter of intended location?
3. In compliance with design.
4. Is it in compliance with snubber stiffness/analytical assumption?
5. Piston Setting = The distance snubber can move in positive direction.
6. Information not available to inspection team.
7. Installation at time of inspection looked suspect; that is, the snubber was free to move only in one direction.
8. Piston: C = Clean, D = Dirty, P = Paint.
9. Accessibility: G = Good, F = Fair, P = Poor.
10. Oil levels are given with reference to 100% full.
11. NI = Not inspected.

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
1	Y	OK	OK	No	
2	Y	OK	OK	No	
3	Y	OK	OK	No	
4	Y	OK	OK	No	
5	Y	OK	OK	Yes	X_{th} = -1/2", X_{avail} = -1/2", In hot cond. pipe touching in -X direction.
6	Y	OK	OK	No	
7	Y	OK	OK	No	
8	Y	OK	OK	No	
9	Y	OK	OK	No	
10	Y	OK	OK	No	
11	Y	OK	OK	No	
12	Y	OK	OK	No	
13	Y	OK	OK	No	
14	Y	OK	OK	No	
36	Y	OK	OK	No	
37	Y	OK	OK	No	
40	Z	OK	OK	No	
42	X, Z	OK	OK	No	
43	X, Z	OK	OK	No	

TABLE B.3

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
44	X, Z	OK	OK	No	
45	Y	OK	OK	No	
46	Y	OK	OK	No	
49	Z	OK	OK	No	
50	Z	OK	OK	No	
51	X, Z	OK	OK	No	
52	X, Z	OK	OK	No	
54	Y	OK	OK	No	
55	Y	OK	OK	No	
57	Z	OK	OK	No	
58	X, Z	OK	OK	No	
59	X, Z	OK	OK	No	
60	X, Z	OK	OK	No	
69	Y	OK	OK	No	Inspected Cold Condition Only
70	Y	OK	OK	No	Inspected Cold Condition Only
87	Y	OK	OK	No	Inspected Cold Condition Only
89	Y	OK	OK	No	Inspected Cold Condition Only
90	X	OK	OK	No	Inspected Cold Condition Only
93	Y	OK	OK	No	Inspected Cold Condition Only
104	X, Y	OK	OK	No	Inspected Cold Condition Only
114	X	OK	OK	No	Inspected Cold Condition Only

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
115	Y	OK	OK	No	Inspected Cold Condition Only
119	Y	OK	OK	No	Inspected Cold Condition Only
120	Y	OK	OK	No	Inspected Cold Condition Only
121	Y	OK	OK	No	Inspected Cold Condition Only
124	Lat	OK	OK	No	Inspected Cold Condition Only
125	Lat	OK	OK	No	Inspected Cold Condition Only
126	Z	OK	OK	No	Inspected Cold Condition Only
131	Y	OK	OK	No	Inspected Cold Condition Only
136	Y	OK	OK	No	
137	Y	OK	OK	No	
138	Y	OK	OK	No	
139	Y	OK	OK	No	
140	Y	OK	OK	No	
141	Y	OK	OK	No	
142	Y	OK	OK	No	
143	Z		OK	No	Buried in insul.
146	Z	OK	OK	No	
148	X	OK	OK	No	
149	Z	Not in Comp. w/Design	OK	No	
151	Z	OK	OK	No	

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
152	Z	OK	OK	No	
154	Z	OK	OK	No	
155	Y	OK	OK	No	
156	Y	OK	OK	No	
157	Y	OK	OK	No	
158	Y	OK	OK	No	
159	Y	OK	OK	No	
160	Y	OK	Marginal Stiffness	No	Restraint detail not available
161	Y	OK	OK	No	
162	Y	OK	OK	No	
163	Z				Not installed; put in between 1st and 2nd visit
164	Z	OK	OK	No	
165	Z	OK	OK		
170	Z		OK		
171	Z	OK	OK	No	
172	Z	OK	Marginal Stiffness	No	Restraint detail not available
174	Z	OK	OK	No	
175	Z	OK	OK	No	
177	Z	OK	OK	No	

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
178	Y	OK	OK	Yes in lat. dir. by railing(K small)	
179	Y	OK	OK	No	
180	Y	OK	OK	No	
181	Y	OK	OK	No	
182	Y	OK	OK	No	
183	Y	OK	OK	No	
186	X	OK	OK	Yes	
188	Z	OK	OK	No	
190	Z	OK	OK	No	
192	Z	OK	OK	No	
193	Z	OK	OK	No	
194	Y	OK	OK	No	Inspected Cold Condition Only
195	Z	OK	OK	No	Inspected Cold Condition Only
199	Z	OK	OK	No	Inspected Cold Condition Only
203	X, Y, Z	OK	OK	No	Inspected Cold Condition Only
204	Y, Z	OK	OK	No	Inspected Cold Condition Only
205	Y, Z	OK	OK	No	Inspected Cold Condition Only
206	Y, Z	OK	OK	No	Inspected Cold Condition Only
207	Y, Z	OK	OK	No	Inspected Cold Condition Only

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
208	Y, Z	OK	OK	No	Inspected Cold Condition Only
209	X, Y	OK	OK	No	Inspected Cold Condition Only
210	X, Y	OK	OK	No	Inspected Cold Condition Only
211	X, Y	OK	OK	No	Inspected Cold Condition Only
214	X	OK	OK	No	Inspected Cold Condition Only
220	Y	OK	OK	No	Inspected Cold Condition Only
221	Y	OK	OK	No	Inspected Cold Condition Only
222	X, Y, Z	OK	OK	No	Inspected Cold Conditions Only
223	X, Y	OK	OK	No	Inspected Cold Condition Only
225	X	OK	OK	No	Inspected Cold Condition Only
232	Y	OK	OK	No	Inspected Hot Condition Only
234	Y	OK	OK	No	Inspected Hot Condition Only
237	Y		One Way Only	No	Inspected Hot Condition Only
236	Y	OK	OK	No	Inspected Hot Condition Only
242	Y	OK	OK	No	Inspected Hot Condition Only
244	Y	OK	OK	No	Inspected Hot Condition Only
246	Z	OK	OK	No	Inspected Hot Condition Only
247	Y	OK	OK	No	Inspected Hot Condition Only
249	Y	OK	OK	No	Inspected Hot Condition Only
254	Y	OK	OK	No	Inspected Hot Condition Only

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
484		OK	OK	Yes	Interference - Pipe can only move down .5" @ snubber Y = .73"
485		OK	OK	No	OK
486		OK	OK	No	Pipe can move down only 9/16" but wants to go - 1.06"
487		OK	OK	No	OK
488	Y	OK	OK	No	OK
489	Y	OK	OK	No	OK
490	Y	OK	OK	No	OK
491		OK	OK	No	OK, in crane wall
492		OK	OK	No	OK
493	Y	OK	OK	No	OK
494	Y	OK	OK	No	OK
495	Y	OK	OK	No	OK
496	Y	OK	OK	No	OK
497	Y	OK	OK	No	Question lateral movement on top of restraint
498		OK	OK	No	Looks good, no welds on pipe - used clamps
499	Y	OK	OK	No	OK
500	Y	OK	OK	No	OK
501	Y	OK	OK	No	OK
502	Z	OK	OK		

TABLE B.3 (CONTINUED)

RIGID RESTRAINTS

Restraint No.	Direction	Installation	Restraint Stiffness	Interference	Comments
503	X, Y	OK	OK	No	Visual Scan only, access poor, in tunnel
504	x, y	OK	OK	No	Visual scan ony, access poor, in tunnel
505	Y	OK	OK	No	OK
506	Y	OK	OK	No	OK
507		OK	OK	No	OK, But may not slide well
508	Y	OK	OK	No	OK but may not slide well
509	X	OK	OK	No	OK
510	X	OK	OK	No	OK
511	Y	OK	OK	No	OK
512	Y	OK	OK	No	OK
513	X	OK	OK	No	OK
514	Y	OK	OK	No	OK (See Figure A.9)
515		OK	OK	No	OK
516		OK	OK	No	OK
517		OK	OK	No	
518		OK	OK	No	
519		OK	OK	No	
520	Y	OK	OK	No	
521		OK	OK	No	
522		OK	OK	No	

(505–508:) All of these are within 10' of each other - apparently due to high seismic loadings and heavy valves. This may be good lines to work with on seismic analysis to show how ridiculous loads are.

TABLE B.3 (CONTINUED)

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This report considers the effect of pipe-whip restraints and snubbers on the normal operation of piping systems in nuclear power plants. Also considered are the effect of these postulated event devices on reliability, economics, and the exposure of plant personnel to radiation.

Field data were gathered from three nuclear power plants that had applied for Operating Licenses. Criteria, design philosophies, and data were obtained from the respective nuclear steam system suppliers, architects-engineers and utilities.

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