Docket No. 50-346
License No. NPF-3
Serial No. 1-525
May 15, 1985

TOLEDO EDISON

RICHARD P. CROUSE
Vice President
Nuclear
(419) 249-5221

Mr. James G. Keppler, Regional Administrator
United States Nuclear Regulatory Commission
Region III
799 Roosevelt Road
Glen Ellyn, IL 60137

Dear Mr. Keppler:

On April 4, 1985, your office issued a Confirmatory Action Letter (CAL) (Log No. 1-1144) to Toledo Edison regarding the failed Control Rod Drive Mechanism (CRDM) Lead Screw Nut Leaf Spring on Davis-Besse Nuclear Power Station Unit No. 1. Toledo Edison provided its formal response on April 11, 1985, (Serial No. 1-512) which you found acceptable and in conformance with the CAL. Your letter of April 12, 1985 (Log No. 1-1151) documented this finding. In accordance with our commitment to provide a summary of the status of our activities which were planned or in progress at that time, we are pleased to provide the enclosed information.

Pursuant to your request (Log No. 1-1151) and a conference call on April 12, 1985 between our Staffs, Table 5-1 in Response 5 of Enclosure 1, Responses to NRC Metallurgical Questions, (Serial No. 1-512) has been revised to reflect the repeated emission spectroscopy utilized to determine the tramp element composition for several leaf spring specimens. These bulk chemistry results for the spring material indicate that the samples are within normal 17-7 PH compositional specifications. Revised Response 5 is provided in Enclosure 1.

Response 6 in Enclosure 1 has been revised to reflect completion of the microprobe examination of the fracture surface deposit chemistry of the leaf spring rivet hole surface. Your Staff had concurred, during a conference call with Toledo Edison on April 16, 1985, with performing a microprobe examination of the rivet hole surface rather than the lead screw nut surface. The examination results show the presence of only elements associated with the chemical composition of the leaf spring or elements normally seen in the primary water of the reactor coolant system. Elements (such as sulfur or chloride) from compounds which could contribute to a corrosive environment in the crevice area were not present. These results were discussed with your Staff in a conference call on April 30, 1985.

B&W report "Evaluation of Control Rod Drive Leaf Spring Failures at Davis-Besse" (Enclosure 2, Attachment A of Serial No. 1-512) has been finalized following the completion of Babcock and Wilcox's engineering review. This report is attached as Enclosure 2, Attachment A. It concludes that the most probable cause of the leaf spring failure was mechanical interference between the spring and the inside of the CRDM when the locking pin (attached to the broken spring) was not properly latched.

B&W report "Preliminary Examination of CRDM Leaf Spring and Foreign Debris Samples" Enclosure 2, Attachment B of Serial No. 1-512, has been finalized. This report is attached as Enclosure 2, Attachment B and contains details of the Babcock and Wilcox Lynchburg Research Center's examination techniques, results and discussion. The report concludes that the most probable cause of the leaf spring failures was mechanically induced overstress. Furthermore, it concludes that it is unlikely that either a stress corrosion cracking (SCC) or a hydrogen embrittlement mechanism affected the properties of the leaf springs examined. The recommendations for additional examinations as identified in this B&W report will be dispositioned in the Leaf Spring Failure Mechanism Validation Program described in Enclosure 4.

Enclosure 3, Results of RCS Chemical Analysis, provides the analysis results of a recent Davis-Besse reactor coolant system sample. These results indicate that the level of sulfur is within the expected ranges for reactor coolant water.

Enclosure 4, Leaf Spring Failure Mechanism Validation Program, describes the plan and schedule for further validating the Davis-Besse leaf spring failure mechanism. This additional program is tentatively scheduled to commence in June, 1985 and be completed in December, 1985. Toledo Edison will notify the NRC if the results of this effort indicate that mechanical overstress is not the most probable failure cause.

To assist your review, the Appendix to this submittal cross-references the above previously open items with the location of closure information.

A review of the enclosed information shows that the conclusions of Toledo Edison's Safety Evaluation, Enclosure 3 to Serial 1-512, remain valid. Accordingly, the Safety Evaluation is not resubmitted.

Based on the results of the extensive testing completed on the leaf springs by Babcock and Wilcox and the results of the RCS chemical analysis, Toledo Edison is confident that impact due to mechanical interference was the failure mechanism for all Davis-Besse failed leaf springs. All leaf springs on trippable control rod drives have been verified as properly in place and intact and are capable of performing their design function. All trippable control rods have been satisfactorily drop time tested in accordance with Technical Specification requirements. With the submittal of this information, Toledo Edison has achieved compliance with the provisions of both your CAL (Log No. 1-1144) and additional request of April 12, 1985 (Log No. 1-1151). Accordingly, Toledo Edison requests that the CAL for the leaf spring issue be closed by NRC-Region III.

Very truly yours,

RPC:DRW:lah
cc: DB-1 NRC Resident Inspector
P. Courtland, NRC-Washington

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Appendix

CROSS-REFERENCE OF TOLEDO EDISON
OPEN ITEMS AND CLOSURE LOCATION

Open Item	Closure Location in Serial No. 1-525
Perform a microprobe examination of the leaf spring rivet crevice and revise Response 6 of Enclosure 1 in Serial 1-512.	Enclosure 1, Response 6
Submit to NRC plans and schedule for a testing program to further validate the evaluated leaf spring failure mechanism.	Enclcsure 4
Re-do emission spectroscopy for one of the springs to determine tramp element composition. Submit to NRC the revised Table 5.1 of Enclosure 1 to Serial 1-512.	Enclosure 1, Response 5
Provide the results of an RCS sample chemical analysis to the NRC.	Enclosure 3
Provide finalized B&W engineering report to the NRC.	Enclosure 2, Attachment A
Provide finalized LRC report to the NRC.	Enclosure 2, Attachment B
Clarify statement in Enclosure 2, Attachment B, Section 3 of Serial 1-512 regarding something unique in the service environment of Davis-Besse.	Enclosure 2, Attachment B, Section 3, Pages 22-23.
Clarify discussion of lab fracture surfaces as referenced in Serial 1-512, Enclosure 2, Attachment A, Subsection 4.C.b; page 8 of 38.	Enclosure 2, Attachment B, Section 2.4.

Docket No. 50-346
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May 15, 1985
Enclosure 1

TOLEDO EDISON RESPONSES TO NRC METALLURGICAL QUESTIONS

QUESTION 5:

"Chemical and physical test results of the failed material (proper heat treatment)."

RESPONSE 5:

Table 4 in Section 2.6 of Enclosure 2, Attachment B to Serial No. 1-525 includes the bulk chemistries for five (5) leaf springs of heat 300130. All of these five leaf springs are of the same TH-1050 heat treat condition.

Table 5-2 shows hardness measurement results for the March 1985 failed leaf spring at Davis-Besse, Location E-3.

Table 5-2

Hardness Measurement	Hardness
Rockwell C	40.6
Standard Deviation	2.3
Vickers Micro-hardness	381
Standard Deviation	14.8
Vickers Conversation to Rockwell C	38.8

These chemistry and hardness results along with observed microstructures are as expected for 17-7 PH in the TH-1050 condition.

QUESTION 6:

"Fracture surface deposit chemistry (micro-probe)."

RESPONSE 6:

Microprobe examination was performed at the Massachusetts Institute of Technology on the fracture surface of DB-10 as described in Section 2.7 of LRC's "Examination of CRDM Leaf Spring and Foreign Debris Samples Removed from Davis-Besse 1" (see Enclosure 2, Attachment B of this submittal).

Docket No. 50-346
License No. NPF-3
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May 15, 1985
Enclosure 2

CRDM LEAF SPRING B&W REPORTS

Enclosure 2 contains the following B&W finalized reports:

Attachment A - Evaluation of Control Rod Drive Leaf Spring Failures at Davis-Besse.

Attachment B - Examination of CRDM Leaf Spring and Foreign Debris Samples Removed From Davis-Besse 1.

In addition, Attachment C, CRDM Leaf Spring Data for Heat 230232, has been included for leaf springs B&W identification numbers DB-14, DB-15 and DB-16 (see Table 1 of Enclosure 2, Attachment A).

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Enclosure 2
Attachment A

EVALUATION OF

CONTROL ROD DRIVE

LEAF SPRING FAILURES

AT DAVIS-BESSE

TABLE OF CONTENTS

1. ABSTRACT

This report presents the results and conclusions of a study performed by Babcock & Wilcox performed for the Toledo Edison Co. The objective of this study was to identify the cause for slow rod drop times of a Control Rod Drive Mechanism (CRDM) which had been located on the Davis Besse Unit #1 reactor. The study was conducted by disassembling the CRDM and performing detailed laboratory inspections on pertinent subassemblies. It was determined that the drive failed to insert properly due to a piece of a screw which had entered the CRDM housing, from a maintenance tool used to handle the CRDM leadscrew during refuelings.

It was also determined that the leadscrew locking spring in this drive had broken off, but had not contributed to the slow rod drop times. Studies showed that the most probable cause of the failure was the interference of this spring and another component within the CRDM when the locking pin attached to the broken spring was not properly latched. From the results of the study, it was recommended that the DB-1 reactor could resume power generation without concern of recurrence once the CRDM leafsprings were inspected to verify that they were properly positioned.

2. SUMMARY

CRDM E-3 was removed from the Davis-Besse Unit #1 reactor in late March 1985 to investigate the reason for slow rod drop times. It was determined that the slow rod drop times were as a result of a piece of a screw which had entered the CRDM housing and become lodged in the rotor assembly. It was determined that one of the CRDM maintenance tools was missing a screw of the same type, size, and material as was found within the drive. From this, it was concluded that recurrence of this type of failure could be prevented by inspection, tightening and locking all fasteners and small features on the CRDM maintenance tooling prior to their usage.

The spring that retains the leadscrew nut locking pin was found to be broken in two places and the main part was found and inspected. The failure of this spring, and a similar spring that failed in 1981, had fracture surfaces that exhibited predominantly intergrannular fracture patterns. Although this could lead to the conclusion that a stress corrosion cracking mechanism was operating, there was significant evidence to indicate a mechanical failure mechanism.

It is believed that these springs failed because they had been left in an unlatched state at some time in the past. While in the unlatched state, these springs could interfere with a surface of the torque tube cap as the rods are fully withdrawn. There is more than sufficient force available from the drive stator to cause this spring to fail. Since all the CRDMs on the DB-1 head have been inspected to verify all the springs are intact, and fully latched, it is very reasonable to expect that there will be no further failure of these parts. All those springs which were found to be unlatched were removed from service to ensure that no potentially damaged parts would be placed back into service.

3. INTRODUCTION

On March 22, 1985 a rod drop test was performed on CRDM (Core Location E-3) resulting in a drop time of 9.7 seconds. The CRDM was exercised in accordance with existing procedures for freeing a jammed CRDM and produced a drop time of 7.4 seconds on a subsequent trip. One additional effort was made to free the CRDM by exercising it and checking the drop time. Following the third rod drop test the CRDM would not withdraw on command from its dropped position (fully inserted into the core). It was decided to remove and replace the CRDM. This report presents the details of the inspections that followed, and defines a probable cause for the failure.

Following removal of the drive, a preliminary inspection was performed at Davis Besse where a leaf spring was observed to be missing. The spring is used to retain the locking pin between the leadscrew extension and the leadscrew nut (See Figures 1 through 4 and Appendix A for details of CRDM operation). The drive was subsequently shipped to a Babcock & Wilcox facility at Parks Township, Pennsylvania where the drive was disassembled and some foreign material as well as the missing spring were found inside the drive. The foreign material and spring were then sent to the Babcock & Wilcox Research Center (LRC) in Lynchburg, Virginia for evaluation.

4. CRDM INSPECTIONS AND OBSERVATIONS

A. Removal of the CRDM from the Reactor

A plan was established for determining the source of the apparent mechanical drag in the control rod drive line at location E-3 in the Davis Besse I reactor. This plan provided for the uncoupling of the control rods and parking of the leadscrew on the top of the torque tube key in order to determine if the drag was being generated in the CRDM. The uncoupling was easily accomplished. However, the force required to raise the leadscrew to the parking position was reported to vary widely, with a maximum of 220 pounds being applied to accomplish this task. Since the procedures normally restricted the force to be applied to 170 pounds, it was determined that there was an excessive mechanical drag in the CRDM.

Following CRDM removal, a visual examination was made of the leadscrew nut area in order to determine the condition of the leaf spring which retains a pin that locks the nut to the leadscrew upper extension. A failure of this spring was experienced on another CRDM at DB-1 in 1981, and was related to sluggish rod insertion times. There was suspicion that this failure might be similar. Although the examination indicated that the spring was not visible, this area is obstructed from direct viewing by the motor tube configuration. A boroscope was used to provide a more detailed examination, and the absence of the locking spring from the leadscrew nut was confirmed.

B. Disassembly and Examination of the CRDM at the B&W Parks Township Facility

The CRDM was packaged and shipped to the B&W refurbishment facility at Parks Township, Pennsylvania. Upon receipt, it was immediately disassembled in an attempt to identify the source of the mechanical drag experienced during the parking activities at the site and to confirm the condition of the leadscrew nut locking spring.

During the disassembly, the following non-standard conditions were experienced:

a. The Rotor Assembly was jammed onto the leadscrew. As a result, both components were removed together through the bottom of the CRDM pressure housing. The rotor was finally removed from the leadscrew by dragging it over the lower end of the leadscrew while generating a series of deep scratches on the Leadscrew lower extension.

b. The Leadscrew had a series of latch marks on the load bearing edge of the threads which formed a helical pattern along its entire length. The pattern had a pitch of approximately 8 threads on the portion of the leadscrew which passes through the rotor in the top 3/4 of its travel, and the pitch spacing of the spiral marks was stretched out to approximately 15 threads for about 3 revolutions at the lowermost portion of its travel.

c. The segment arms in the rotor assembly were observed to not be fully collapsed to the normal leadscrew release position. After partial disassembly of the rotor, a small foreign particle was removed from the space between one of the segment arms and the rotor tube. There were two inward impressions in the outside surface of the rotor tube and corresponding impressions in the one segment arm where this piece had become lodged. Examination of the piece of foreign material indicated that it might be a part of a small threaded fastener. The maximum size of the piece was estimated to be about 1/8 inch. The curved outside surface of one of the segment arms also had a few irregular impressions about 1/8 inch in size.

d. Upon removal of the leadscrew from the torque taker and torque tube, a piece of the leadscrew nut locking spring was discovered to be broken. The base of the spring remained firmly secured to the leadscrew nut and most of the leaf section, including the locking pin, was found to be magnetically attached to the position indicator magnet housing. The small flared section

at the end of the spring was also broken off and was not recovered from the CRDM.

e. Two small pieces of unidentified foreign material were recovered from the interior of the CRDM. One was found in the upper end of the motor tube, and the other was recovered from the roller nut cavity section of the motor tube. Initial impressions were that they were remanents of some threaded fastener.

f. A visual examination of the Motor tube bore, the interior of the torque tube and snubber cylinder assembly, and the entire torque taker indicated that there was no detectable source of mechanical interference in these components. All of the small components used in the assembly of the CRDM were examined and found to be in place on the CRDM and accounted for.

g. A visual examination of the torque tube cap has shown a depression and material deformation on the inside edge on the bottom surface. The angular position of this impression was approximately 45 degrees CCW from the slot for the key which locks the torque tube cap to the torque tube.

C. <u>Examination of Components at the Lynchburg Research Center</u>

Once received at the Lynchburg Research Center, the parts were photographed, analyzed for chemical content, and the fracture surfaces examined. The following describe the results of the inspections:

a. All three of the foreign objects were identified to be portions of a 1/4 - 20 Allen head setscrew which was made of a martensitic type of carbon steel. All three pieces exhibited some vestiges of the threaded surface and were all the same pitch.

b. The most recently broken leaf spring (core location E-3) was found to have fracture surfaces at both ends which exhibited a predominantly intergrannular fracture pattern. It was determined that another portion of the spring material exhibited a similar fracture surface when fractured in the lab by an impact loading. The fracture surface at the narrower end

(by the tip) was found to be the most recent of the two fracture surfaces due to the amount of deposits on the surface. Details of the leaf spring evaluation follow in the next section.

c. In addition to the parts described in a and b above, LRC also examined the following leafsprings:

SOURCE	CORE LOCATION	SPRING CONDITION	COMMENTS
DAVIS-BESSE	E-5, L-6	UNBROKEN	FOUR OUT
" "	O-5, H-6	"	OF POSITION
" "	H-12	"	INSPECTED (IN-POSITION)
" "	M-5	PARTIAL BREAK	OUT OF POS.
" "	C-7	BROKEN	FAILED 1981
ALLIANCE RESEARCH CENT.		BROKEN	FAILED OUTSIDE CRDM
PARTS CENTER	(4 SPRINGS)	NEW	-------

D. <u>Follow-on Inspections at the Davis-Besse Site</u>

Once it was determined that the foreign objects appeared to be portions of a 1/4 - 20 Allen head set screw, the personnel at the site proceeded to inspect the tooling and equipment in the vicinity of the CRDMs. It was found that the light-weight leadscrew handling tool had a 1/4 - 20 set screw missing from the assembly. There was no indication as to how long that part might have been missing.

Twelve (12) CRDM leadscrews were selected at random, and raised to the parked position to allow a detailed inspection of their locking springs. It was found that all of them had the spring in place, but that two of them were not properly seated into their appropriate locking hole. It was determined that the leadscrew nut would require some unquantified rotation before the locking pin could engage in the locking slot in the upper leadscrew extension.

One of these two leadscrew nuts with the unlocked springs was removed from its drive and shipped to the LRC for investigation of its condition. It was believed that this spring had probably been sitting in its extended position for an prolonged period of time (probably years) and would be a good example of how this material behaves in a stressed state over time in the reactor operating environment. Any indications of a long-term stress cracking failure mechanism would most likely be observable on this piece.

To assure that the springs were currently in an unbroken state, all of the CRDM leadscrews except the APSRs were raised and inspected to verify that the spring was present, was correctly seated within its locking slot, and that the spring retained its "springiness." This inspection revealed that all but three of the remaining locking pins were found to be in-place. Of the five springs which were found unlocked at the DB-1 site, four were inserted into their locked position, and one was removed from the CRDM with a through crack found at the rivet hole nearest the tip of the spring. This crack ran from one outside edge to the rivet hole.

Since that time, all of the leadscrew nut locking springs which were found in the extended position were removed from their drive to assure that no potentially damaged springs were placed back into service. Dye penetrant inspection of a number of these have not shown any cracks. Additionally, six other good leadscrew nuts were removed to allow visual inspection of the springs. No cracks were detected.

E. Leaf Spring Material Evaluation

a. Material Specification

The material specified for the leaf spring in the leadscrew nut locking assembly is 17-7 PH stainless steel in accordance with AMS 5528, heat treated to Condition H-1050 (now TH-1050).

The chemical composition of the material as specified is:

Carbon	0.9% max	Manganese	1.00% max
Phosphorous	0.040% max	Nickel	6.50-7.75%
Sulfur	0.030% max	Chromium	16.00-18.00%
Silicon	1.00% max	Aluminum	0.75-1.50%

The mechanical properties required after the final heat treatment in the H-1050 Condition are:

Ultimate Tensile Strength	180,000 psi minimum
Yield Strength (0.2% offset)	150,000 psi minimum
Elongation, two inches	6% minimum
Hardness	38 R_c minimum

All of the material used in the fabrication of the leaf springs were certified as meeting all the requirements specified in the Royal Industries Heat Treat Specification #RPS-250 x 418, Rev. D for chemical composition and physical properties.

b. Evaluation of the Service Leaf Springs

The broken leaf springs were examined and evaluated at the Lynchburg Research Center. The results of this evaluation are reported in a letter report from G.O. Hayner and T.J. Zeh to E.J. Domaleski, dated May, 1985, and titled: "Examination of CRDM Leafspring and Foreign Debris Samples Removed from Davis-Besse 1", number RDD:85:5104-02:03. This examination states several findings which are significant. The fracture mode indicated failure occurred intergranularly, probably resulting from an impact loading. The material is notch sensitive and exhibited low impact resistance during lab evaluations.

c. Conclusions of the Spring Material Evaluation

Based on the evaluation of the failed leaf springs, the likely cause of failure wasinitially narrowed to two possible mechanisms: mechanical impact or stress corrosion cracking, with the mechanical impact finally being determined to be the most probable.

The role of mechanical impact is supported by the fact that few springs have failed during service and that if the spring is not properly positioned there is an interference with the torque tube cap at the top of the CRDM. This interference would occur during withdrawal and would impose an impact load to the end of the spring. The mechanical impact is further supported by the location of fracture initiation at the inside surface resulting from the bending outward of the spring during loading. The self-restraint of the leafspring design prevents it from bending inward. Mechanical fracture tests performed in the lab at various loading application rates have shown intergrannular fracture surfaces which are similar to those observed in the field failures.

During the initial investigastions, it was felt that a SCC mechanism might be supported by the appearance of the service fracture, the location of the fracture initiation, and the probability of a crevice environment. However, this mechanism was not supported by the detailed inspections performed by LRC. In the most revealing of the inspections, microprobe examination of the fracture surfaces failed to detect any of the chemicals which would have been required to produce a SCC failure. These microprobe examinations were performed on the surfaces of the partially cracked spring at the point where the possibility of SCC was felt to be most likely.

Even if the above does not eliminate SCC, data indicates that a stress level of half the minimum specification yield strength can be designated a "safe stress" for growth of surface cracks up to .010 inches deep due to stress corrosion. Spring stresses were determined to be 62 ksi for the worst cases of prolonged operational loadings. The yield strength of the material

is 150 ksi minimum. A comparison of the maximum spring stresses to the material yield strength is low enough that it should remove stress corrosion as a major concern.

The stresses present from the interaction of the three materials present at the rivet location (17-7 PH, 304 SS, and Inconel rivets), may have contributed to the failure at these joints in the 1981 Davis Besse and ARC springs, rather than at some other location. Calculations of the thermal stresses at this point show light loading in the spring material in relationship to the spring's yield strength. However, the stresses due to the initial fastening of the rivet are not known and could be significant, depending on the amount of cold work in the rivet. Should a crack occur in this area it is expected that the residual stresses would be relieved and that the spring would continue to function since a crack would be expected to occur on one side only.

No evidence for failure by fatigue, wear or normal stress overload was obtained during the course of the evaluation.

A review of the fabrication history, the service records, and operating procedures, and the results of the failed leaf spring evaluation indicates that the failure is not a materials deficiency. The characteristics of the material is such that it will not resist impact loadings or bending by deformation. The low ductility characteristics of the material (i.e., 6-8%) will, for all practical purposes, not deform prior to failure. From a material viewpoint, if the installed leaf springs are properly located in accordance with the original design, and still exhibit flexibility, there is no technical reason to believe that they are not servicable.

5. DESIGN RELATED INVESTIGATIONS

The design of the CRDM, the related tooling, and operations were investigated to determine by what means the leadscrew locking pin and spring might become stressed to a point where the spring might fracture. These investigations first centered around developing various concepts for potential ways in which loads could be applied to the spring. These concepts were evaluated for feasibility or likelihood based on tolerances and/or historical observations. From that point, the spring was analytically modeled as a cantilevered beam with various loadings applied for the various loading situations. In this way, the more likely loading concepts could be evaluated for their capability to cause the observed damage to the leafspring.

The investigation revealed that the most likely way in which the failure occurred was with the tip of an unlocked spring interfering with the torque tube cap when the leadscrew was raised to the full out position.

A. Potential Load Application Concepts & Discussions

When investigating the operation and servicing of the CRDM, a number of concepts for potentially producing the magnitude of loads described above were hypothesized. These concepts and related discussions are presented below:

- Extended Leafspring Hitting the Torque Tube Cap on Leadscrew Parking - A worstcase tolerance stackup has shown that an extended spring could hit or interfere with either the necked-down region or the bottom surface of the torque tube cap on withdrawal. If sufficient force were applied, the spring could be broken. Although several of the leadscrew nuts were found with the locking pins not disengaged from the leadscrew, the probability of their failure in this way is not likely due to the use of a spring scale and great care in limiting the lifting loads to 20 pounds over the hanging assembly weight. Again, if the spring were loaded in this fashion, the spring would have broken and the loose segment would have dropped off immediately. The spring tip would not have shown in the inspection which was performed in Nov. 1984.

- Extended Leafspring Jamming in the Torque Tube Cap During Operation - Although there are strict limits on the lifting loads while parking the leadscrews, no such carefully controlled limit is in place during operation. If the leafspring was extended out during power operation, the tip may interfere with the torque tube cap (See Fig. 5). The likelihood of an end loading of the spring is enhanced if the leadscrew nut is rotated 45 degrees from the normal locking position. At these locations, there are a series of holes which are used for engaging the alternate uncoupling tool. The possibility exists that a corner of the spring can catch on one of these holes while the rod is being raised to the full out position (See Fig. 6). The CRDM stator has more than ample capability to exert sufficient force to break the spring if it is caught as described. When the rod is in the fully withdrawn position, an unlatched leafspring will be bent inwards by interference between the tip and the torque tube cap bore. The stresses induced in this fashion will be about 94,000 psi at the rivet holes and 30,000 psi at the root of the spring.

When properly engaged, the leafspring will not interfere with the torque tube cap. A worst case tolerance stackup, considering the locking pin in the proper position, shows a minimum clearance of 0.024 inch between the tip of the spring and the bore of the torque tube cap. To further support the integrity of the properly latched spring, in all the reactor-years of operation at other sites, there have been no other incidents where this spring has failed.

It was found that, at some time in the past at the DB-1 site, some of the drive leadscrew locking pins were not properly installed. Since there is evidence that at least one of these springs failed as a result of being similarly misplaced, it does seem to be a reasonable assumption that both of these springs failed from unusual loadings due to improper placement. Additionally, this hypothesis is further reinforced by the fact that the recent inspections of DB-1 CRDM from Location

E-3 exhibited marks on the bottom of the torque tube cap similar to what that spring might have made, had it hung up there.

- Leafspring End Loading From Splined Socket - The Leadscrew Installation/Removal tool (PN 703096-1051) was designed to lift the locking pin and rotate the nut for uncoupling the leadscrew from the top of the torque taker. Studies into this tool's design and operation have shown it is not likely to have caused an end load which damaged the spring. First, a worstcase tolerance stackup has revealed that there is at least .020 inch of lifting chamfer available to lift the spring. Second, if the tool did break the spring when it was last used, the tip of the spring could have been broken off. Under those conditions, the spring inspection performed in November, 1984 would not have confirmed presence of the end of the spring.

Observations of a leafspring assembly showed a tendency for the locking pin to resist lifting from the locking slot if the pin was at the top of the locking slot. As a result of this observation, the LRC report suggests minimizing the use of tools lifting the spring for leadscrew uncoupling. The observed situation is not likely to have contributed to the two observed spring failures since, again, the spring inspection in November, 1984 would not have confirmed the presence of the end of the spring.

The LRC report indicated that the most likely failure mechanism for the partially broken spring and the ARC spring was due to this locking pin hangup. Although this mechanism is feasible, it may not be the most probable mode of failure for these springs considering the timing and sequence of events associated with these failures:

The ARC spring failed during handling of the leadscrew outside of the CRDM housing, immediately after being lifted from storage in a horizontal position. At the ARC facility, the handling of the leadscrew assembly has historically been awkward as a result of a limited amount of headroom. The top end of the leadscrew is

exposed to atypical handling methods and loadings which would not be representative of operational conditions. These atypical conditions are very likely to have contributed to the observed failure at ARC.

The Davis-Besse spring with the partial failure at the rivit hole was observed to have a deep scratch mark on the backside of the "ski-jump" tip. Although this scratch was found to be recent because of the brightness of the exposed material, the partial crack was felt to be older. The most revealing aspect of the scratch was that it was at an angle to the longitudinal axis of the leafspring. The most likely opportunity for this scratch to have occurred recently would have been after this locking pin was found disengaged, then reinserted and found to not be locking solidly. When the nut runner was slid under the ski-jump to lift the locking pin out of engagement, it would be reasonable to expect that the partially broken spring end would rotate and the contact point shift laterally. The abnormal loadings between the partially broken spring and the nut runner could then have contributed to the observed scratches.

- o Leafspring Impacted by the Lightweight Leadscrew Handling Tool - The light weight leadscrew Handling tool (PN 707869-1040) is too big in diameter to fit in the annulus between the top of the leadscrew nut and the ID wall of the torque tube. The maximum available clearance at worstcase tolerances is 0.6588 inch and the clearance required for the lifting tool is 1.022 inch. This conclusion applies to both the lightweight and the heavy (normal) leadscrew lifting tool. The normal tool with the nut runner removed is the same dimension.

B. Analyses of Various Loadings and Stresses

Figure 4-1 shows sketches of the various leaf spring beam analysis model loading configurations which are discussed below.

- o Bending Out From the Center of the Nut (FIG 4-1A) - Since the spring is manufactured with an initial deformation, when it is mounted on the leadscrew nut, there is a preload and steady-state stress imposed. This stress is increased by the normal effort of lifting the pin out of the locking slot. Using a simple beam model, it is calculated that the steady state tensile stress is about 23,000 psi at the root of the spring (at the mounting flange). Additionally, the stress at the rivet hole closest to the base was calculated to be about 12,000 psi.

  When this spring is lifted about an additional 1/8 inch to release the locking pin, the root stress increases to about 66,000 psi. These stresses are significantly lower than the yield strength of the material in question and are not likely to be a source of the spring failure.

- o Lateral Loads Imposed on the Locking Pin (FIG 4-1B) - It was recognized that the lateral clearances between the slots and the locking pins could result in a lateral and torsional stressing of the spring material, if the tolerances were stacked up wrong. Assuming these worst case tolerances, it was calculated that the lateral loads could produce stresses on the order of 77,000 psi when combined with the outward preload stresses of 29,000 psi. This situation would occur when the leadscrew uncoupling method was used and the relocking of this pin was being verified. This technique is no longer in use because of previous experiences with galling of the threaded interfaces.

- o End Loads Imposed on the Tip of the Spring (FIG 4-1C) - If an axial force was imposed on the end of the spring, the situation would be similar to column buckling with a significant amount of loading eccentricity imposed. Two models were considered, one looking at the bend at the spring-end only and the other with the spring held outward away from the re-inforcement of the leadscrew nut.

  The strength of the spring tip was analyzed assuming that the piece was fixed at the bend. It was determined that a

nominal end load of about 500 pounds would introduce 200,000 psi in bending stress into the bend.

If the spring were assumed to be lifted off the nut seating surface, then the moments associated with an end load of 168 pounds, combined with the outward bending stress, could result in a stress of 200,000 psi at the root of the spring.

- Inward Tip Loadings on an Extended Spring (FIG 4-1D) - If the unlocked leaf spring were raised into the reduced diameter portion of the torque tube cap, and the top of the leadscrew then leaned in the direction of the spring, then the end would receive a horizontal loading. This loading, considering the available deflection of the leadscrew will result in a stress of 147,000 psi at the locking pin rivet holes. To accomplish this, the force required to tilt the leadscrew in that direction would be about 10-20 pounds.

- Interaction of the Rivet in the Hole - An estimate of the combined stress in the spring material adjacent to the rivet hole is 53,000 psi. This includes the effects of the stresses due to the installation of the rivet, the effect of thermal expansion of the rivet in the hole, and the differential thermal expansion between the rivet holes. This may be considered as a primary membrane stress in the spring material. This estimate includes an allowance for the strain hardening of the Inconel 600 rivet material.

- Differential Thermal Expansion Between the Locking Pin and Spring - An estimate of the stresses in the spring material due to the differential thermal expansion of the 304 SS locking pin and the 17-7 PH spring was calculated to be about 49,000 psi tension at the edge of the hole, at the narrowest cross section. This stress applies only at the elevated operating temperatures and assumes that there is no slippage between the two parts at the rivet joint. However, the rivets are not strong enough to sustain this type of load and are likely to deform in shear before the spring deforms or breaks. As a result, it is reasonable to assume that the joint loading is limited to about a half of that calculated above. If the locking pin is in its latched position, there are no other loading stresses superimposed onto these thermal stresses since the spring is supported on a flat surface in this area.

- Combined Stresses in the Spring - During normal operation, the primary membrane stress in the spring adjacent to a rivet hole is 53,000 psi and the bending stress is 12000 psi. At the root of the spring, the bending stress is 23,000 psi.

6. CAUSE OF FAILURE TO MEET ROD DROP TIME

The Control Rod Drive Mechanism located at core location E-3 failed to meet the specified rod drop time as a result of a foreign object entering the drive mechanism housing and lodging itself in the rotor assembly. This foreign object was found located in a position that prevented the rotor segment arms from disengaging the leadscrew assembly when the stator magnetic field was removed. Because of the steep helix angle of the doublethreaded leadscrew, the rotor assembly was able to spin under the axial load of the leadscrew as it dropped the control rod into the core. The foreign object was identified to be part of a 1/4 - 20 Allen head set screw similar to one found missing from the light-weight leadscrew handling tool. This tool is used in every refueling outage to raise and lower the leadscrews when removing the RV head.

7. PROBABLE CAUSE OF THE BROKEN SPRING

The most probable cause of the spring material failure is as a result of the leadscrew locking pin on that drive having been left in the unlatched position. With the locking pins unlatched from their locking slots, the tip of the spring can easily interfere with the reduced diameter portion of the torque tube cap located near the top of the drive (See Figure 5). Inspection of the torque tube cap in the drive recently removed for this investigation shows an indication of something having struck it in a manner which would be expected from this failure mechanism.

Although these springs should not be in the extended position if they are properly locked and checked, it was found that five of the drives on the DB-1 head had these springs sitting in the extended position. It is conceivable then, that the two other failed springs might also have been in the extended position. At least one of the five extended springs which were removed from service also exhibited signs of distress, probably due to having struck the torque tube cap. All of the extended springs were removed from service.

Tolerance studies have shown that these springs will not interfere with the torque tube cap if the locking pin is properly engaged in its locking slot. Thus, there is no further concern over the potential of recurrence since the springs in all the DB-1 CRDMs were inspected and proper seating confirmed. This confidence in the acceptable ongoing performance with the springs in their proper position is supported by the extensive service experience with this CRDM design at the remaining B&W reactors across the country.

It is believed that the unlatched locking pins were left in the improper position when they were last lifted during the initial installation of the drives. No further examinations were made since that time to verify proper spring seating.

8. FACTS SUPPORTING RETURN TO POWER

- o The CRDM exhibiting slow drop time has been replaced and the capability of the replacement component, along with the other trippable drives, to meet required drop times has been confirmed by test.

- o The cause of the slow drop time is understood and does not apply to either the replacement drive or the other drives.

- o The integrity of the leaf springs has been established by exercising the springs.

- o CRDMs where pins were discovered to be out of position have had the extended springs removed and new replacements installed. The locking pin positions have been verified, thus eliminating possible interference, and subsequent spring damage.

- o On one leafspring, a partial crack was observed in the rivet area. It is expected that upon cracking the residual stresses, in the spring were relieved and that the spring would have continued to function properly.

9. RECOMMENDED CORRECTIVE ACTIONS

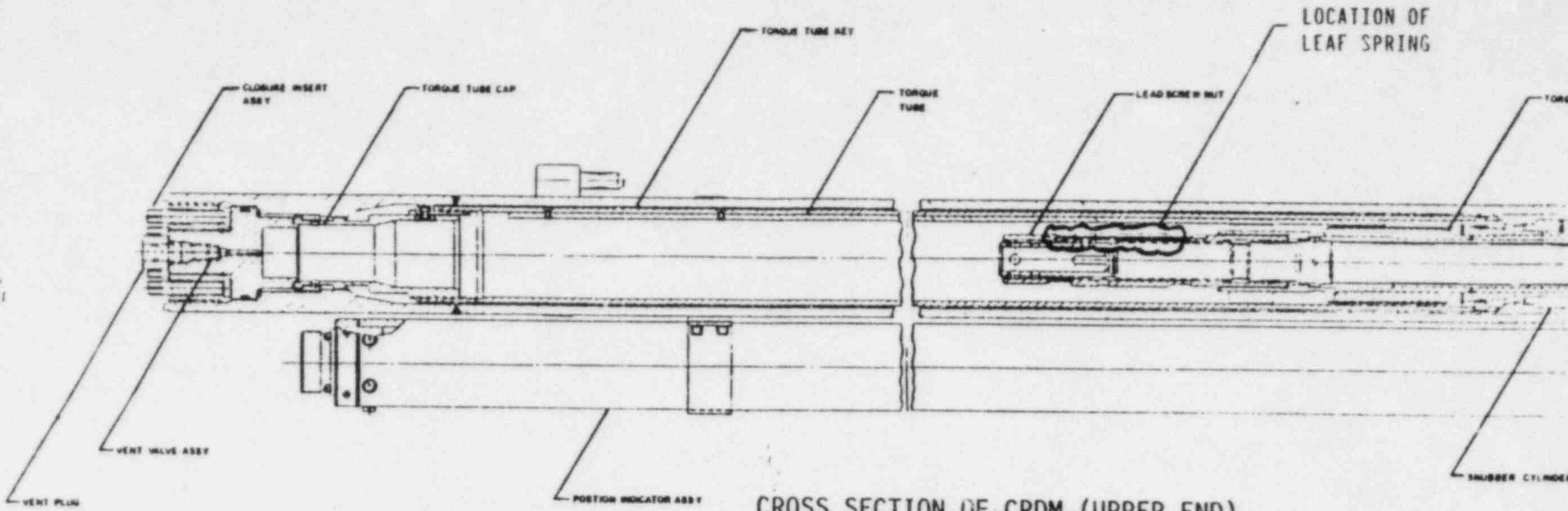
- Regarding the Foreign Objects:

  This incident clearly demonstrates the operating problems which can result from the presence of foreign objects in the system. In order to minimize the probability of foreign objects entering the system, it is recommended that procedures be reviewed to verify that an inspection of the tooling is required prior to use to assure that small appurtenances are tightly attached. Where possible, these appurtenances should be locked to the tool.

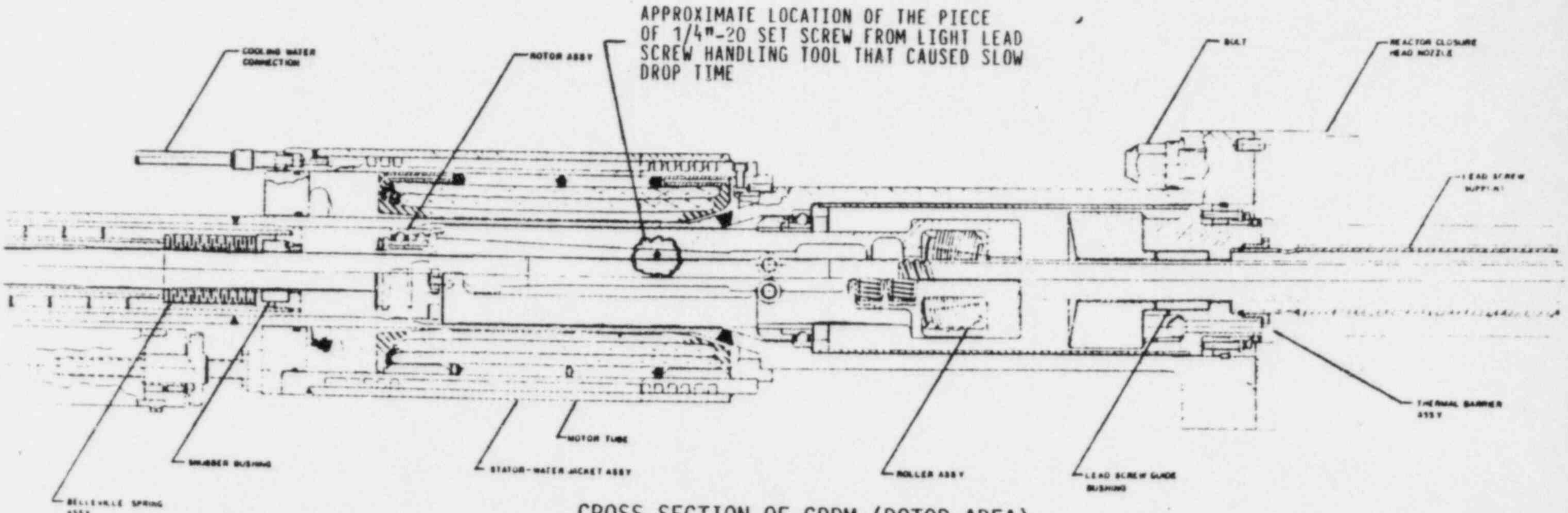
- Regarding the Leadscrew Locking Pin and Spring:

  Since a total of five pins were found not to be in their correct locations it is recommended that the procedures for maintenance of the CRDM be reviewed, and modified if needed, to assure that they include instructions to verify that the locking pins are properly positioned.

  It is also recommended that CRDM maintenance procedures include a requirement to exercise the leaf spring at each refueling outage until the acceptability of the 17-7 ph material has been established for this application in the control rod drive mechanism.



CROSS SECTION OF CRDM (UPPER END)



CROSS SECTION OF CRDM (ROTOR AREA)

FIGURE 1
CRDM GENERAL ARRANGEMENT

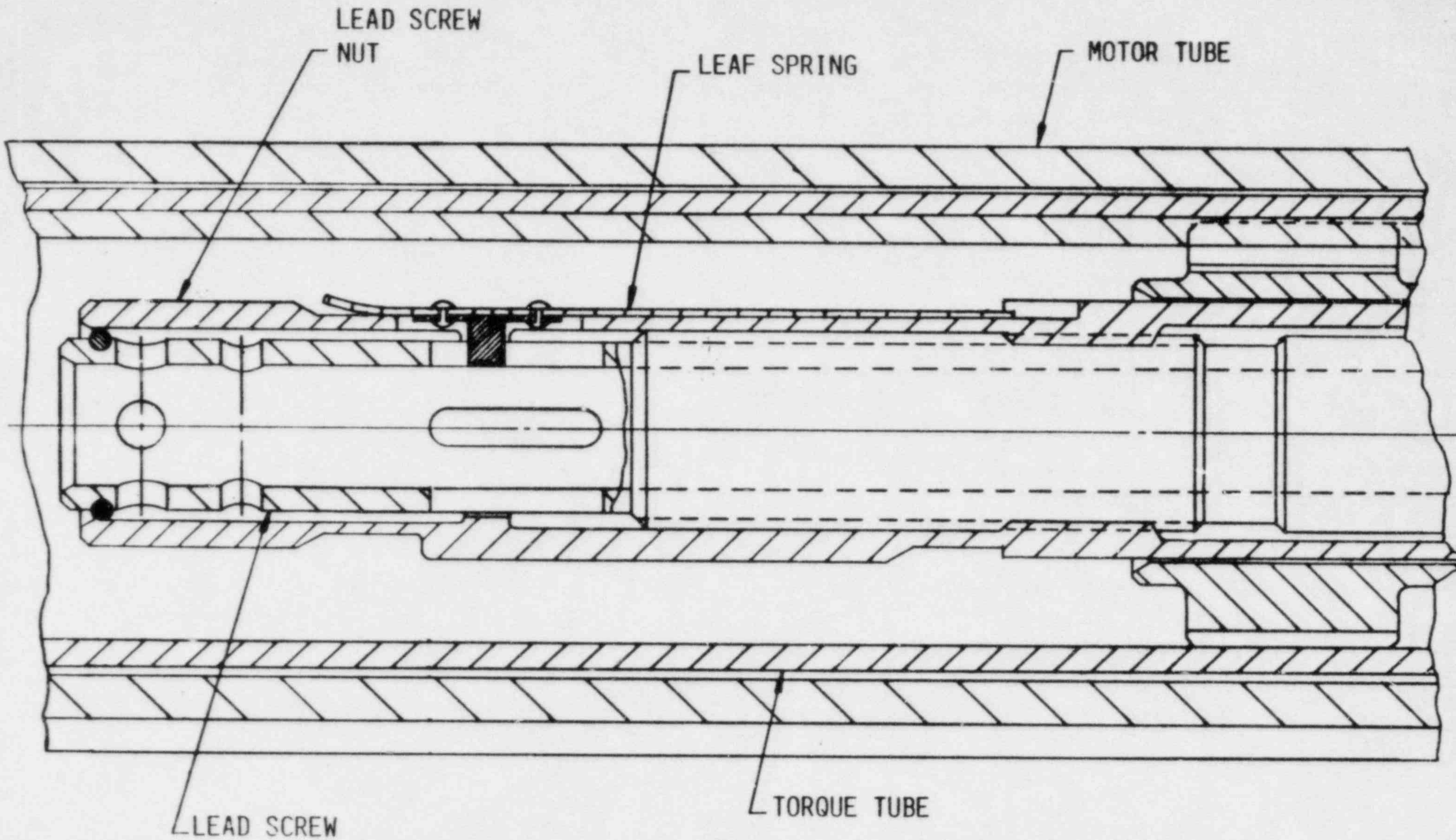


FIGURE 2
CROSS SECTION OF LEAD SCREW AND LEAD SCREW NUT
WITH LEAF SPRING IN LATCHED POSITION

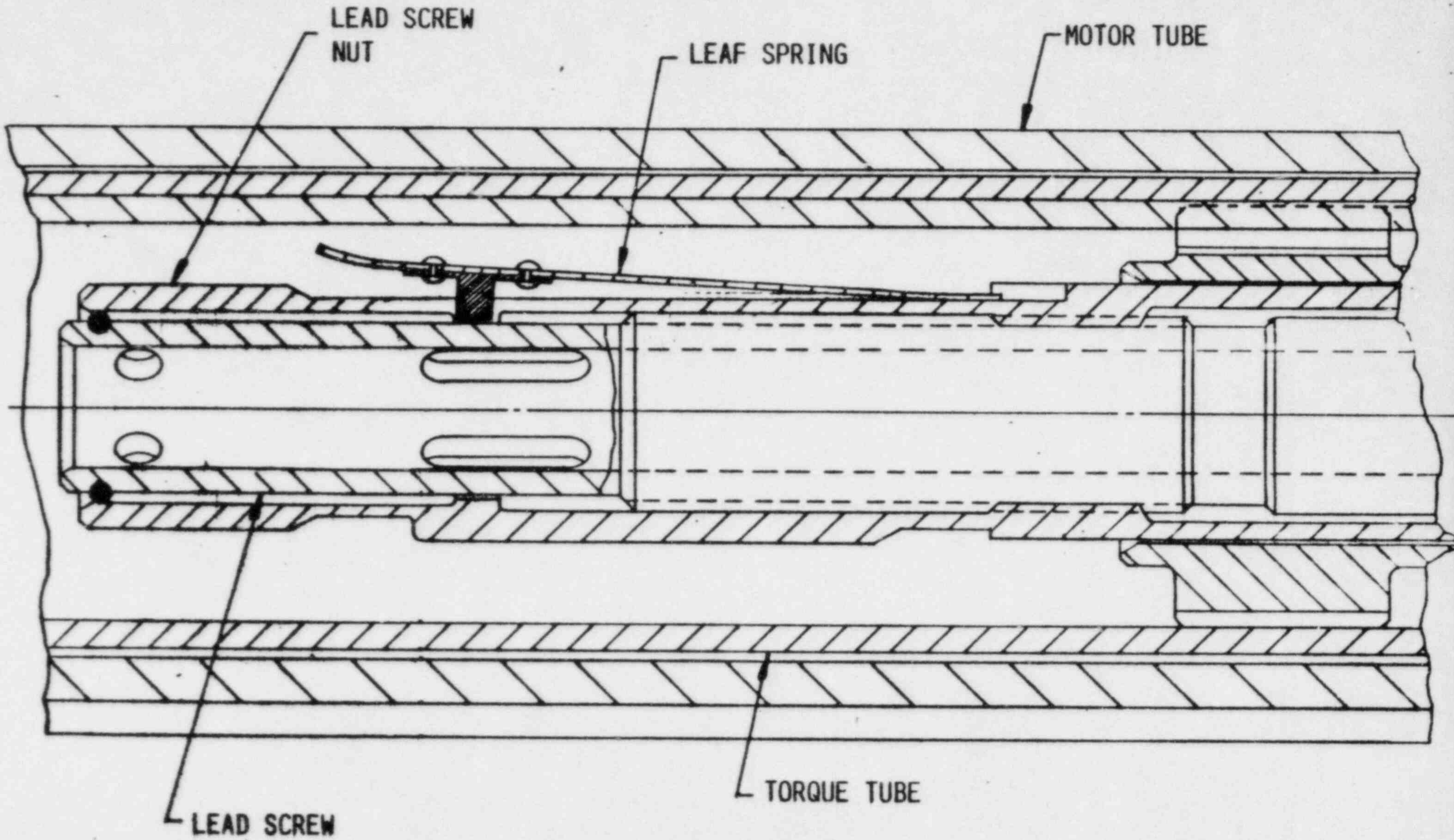
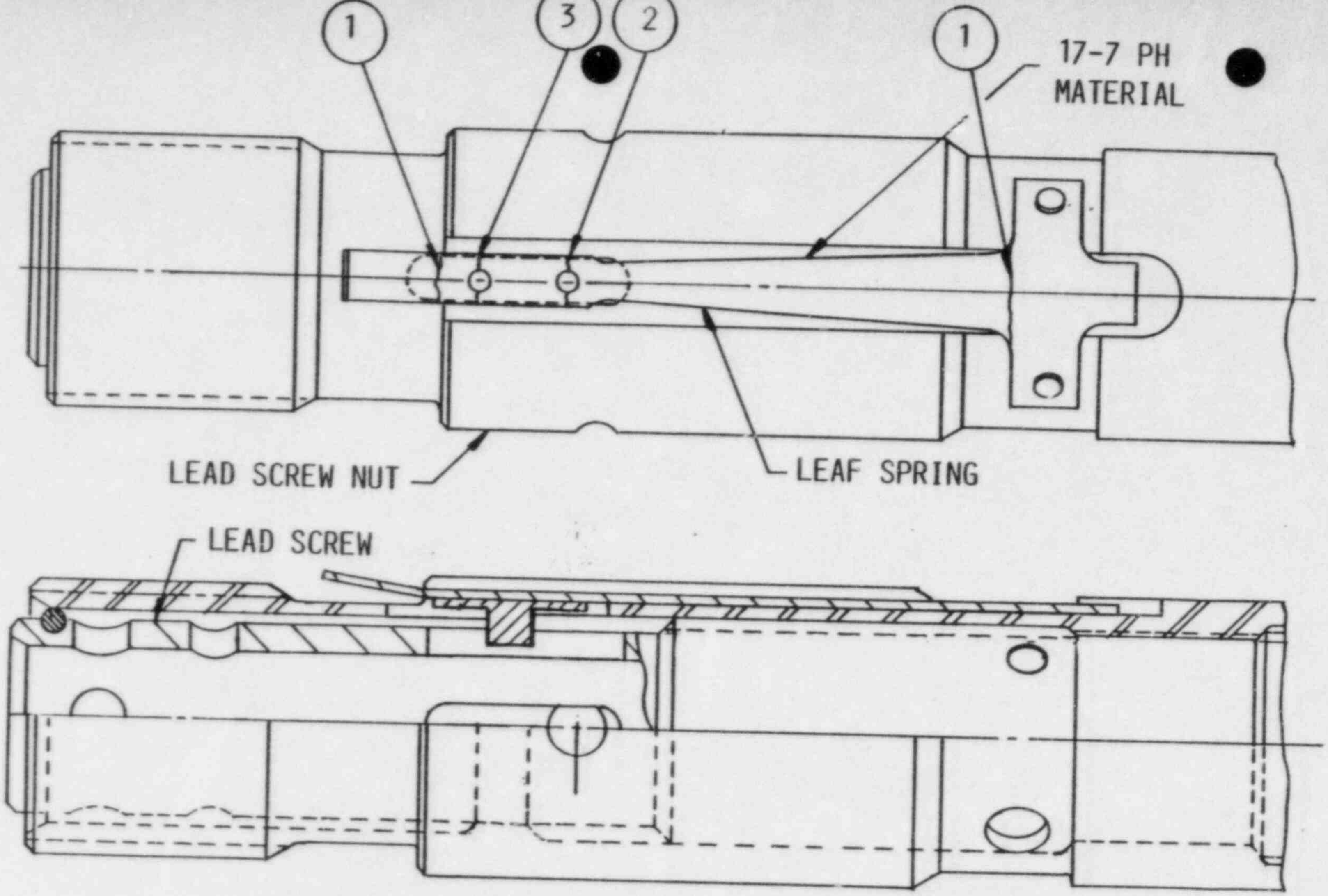


FIGURE 3
CROSS SECTION OF LEAD SCREW AND LEAD SCREW NUT
WITH LEAF SPRING IN UNLATCHED POSITION



(1) TED 1985 CRACKS

(2) TED 1981 CRACK

(3) ARC 1984 CRACK

FIGURE 4

HISTORY OF LEAF SPRING CRACKS

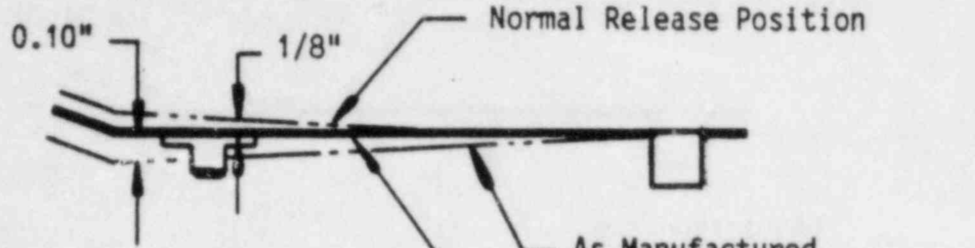


FIGURE 4-1A

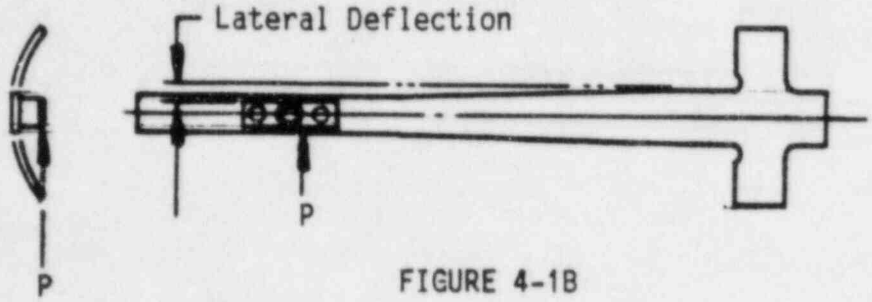


FIGURE 4-1B

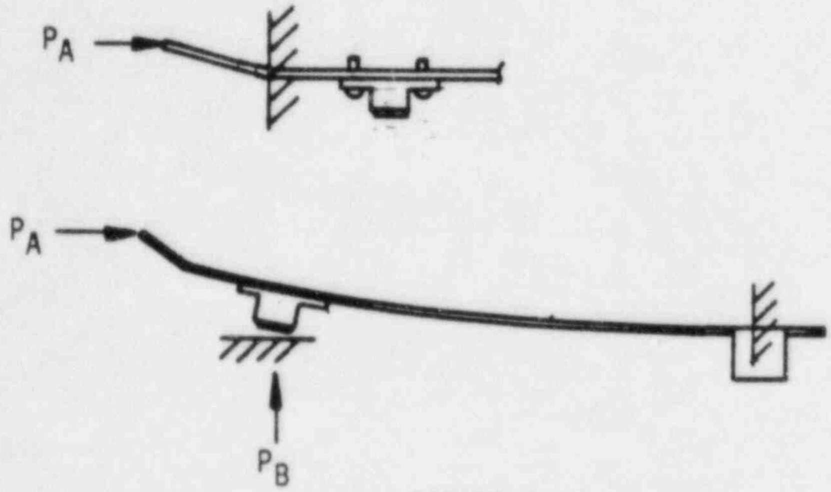


FIGURE 4-1C

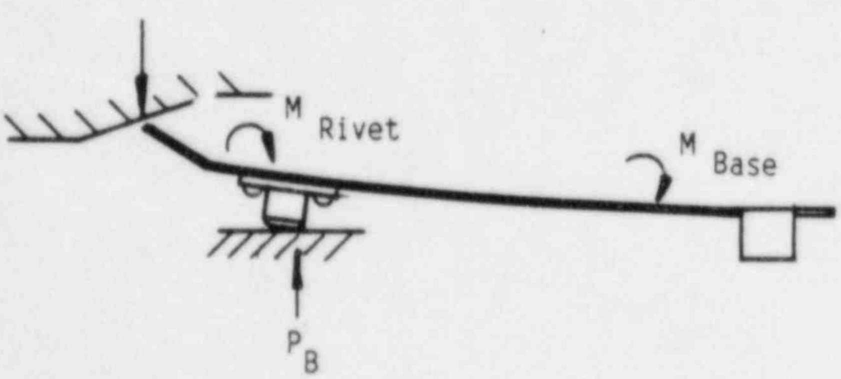


FIGURE 4-1D

BEAM LOADING MODELS

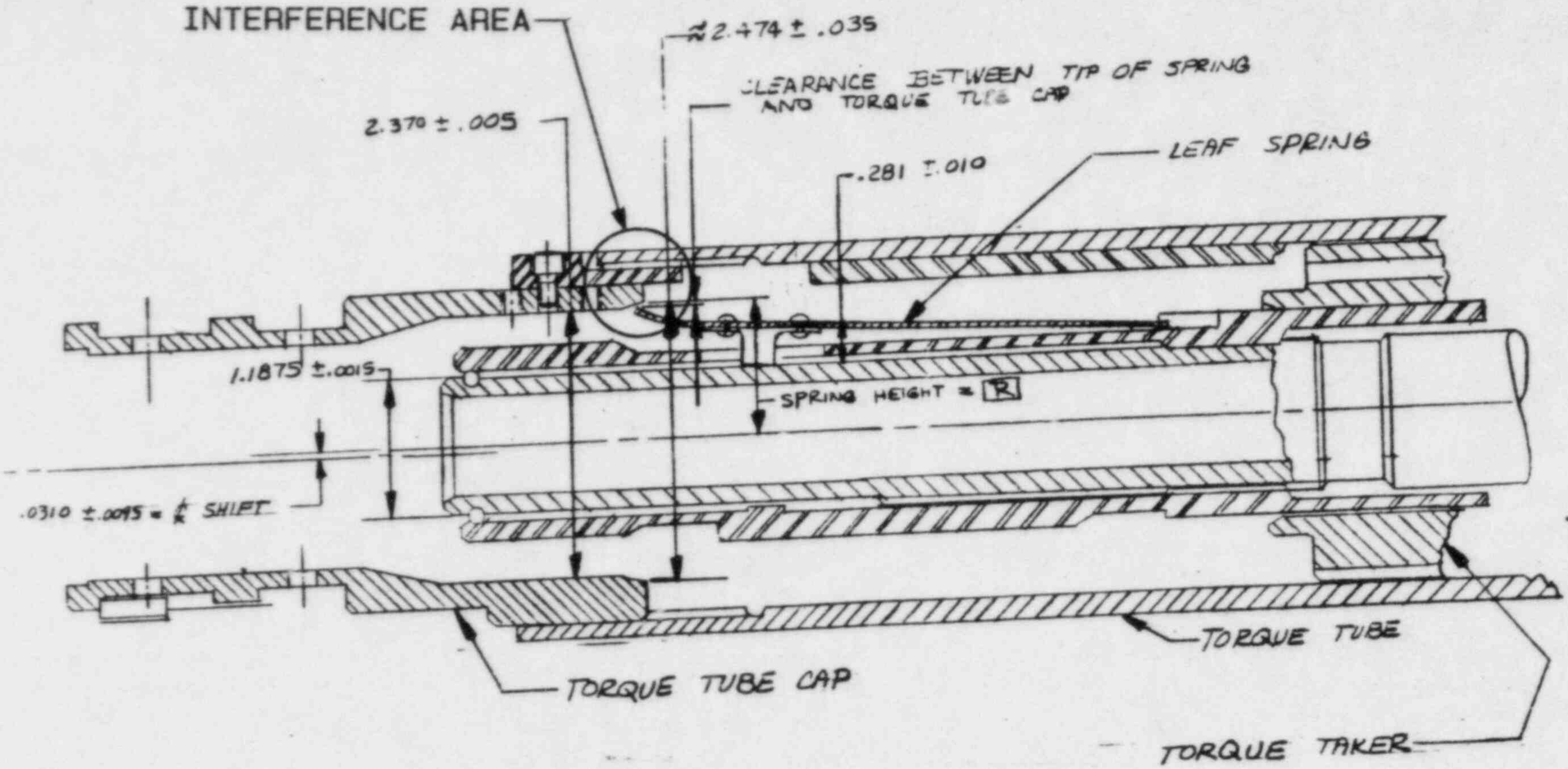


FIGURE 5
INTERFERENCE BETWEEN
EXTENDED SPRING &
BASE OF TORQUE TUBE CAP

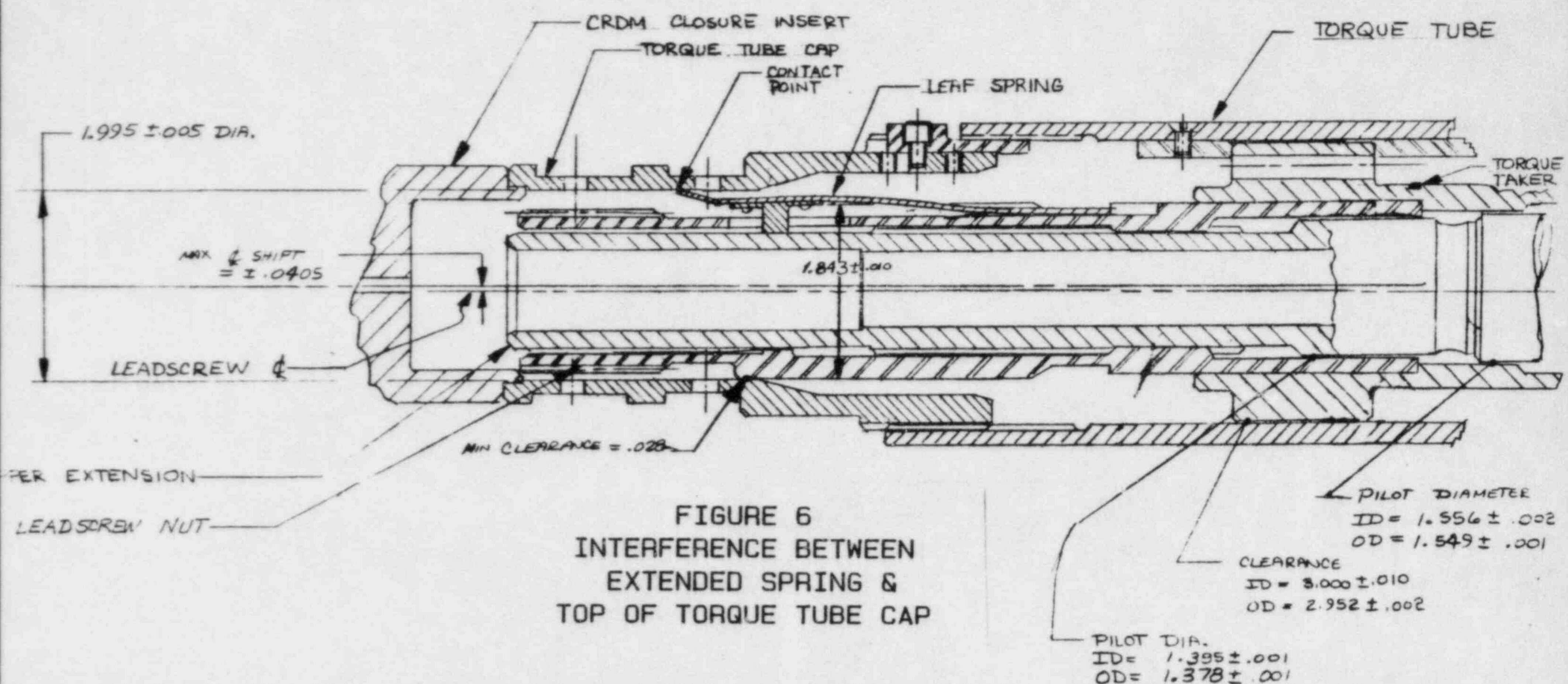


FIGURE 6
INTERFERENCE BETWEEN
EXTENDED SPRING &
TOP OF TORQUE TUBE CAP

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APPENDIX A

BRIEF DESCRIPTION OF CRDM DESIGN

When current to the stator is interrupted, the segment arms collapse, allowing disengagement of the roller nuts with the leadscrew. This rapid outward movement of the segment arms and roller nuts is accomplished by four springs in the lower rotor assembly. Once the disengagement of the leadscrew has occurred, the drive line, including the control rod, falls by means of gravity for rapid shutdown of the reactor.

Functional Description

The major subassemblies and components and the functions they perform in the various operational modes are described in more detail as follows.

Motor Tube

The motor tube forms the primary coolant pressure boundary when bolted to nozzles on the reactor head. It is a four-section weldment housing the rotor assembly, the thermal barrier, the leadscrew, and the torque tube assemblies. It is designed, fabricated, tested, and stamped in accordance with the rules set forth in the ASME code, Section III for a Class I appurtenance as well as being designed to comply with ASME, Section XI, Inservice Inspection. The wall of the motor tube between the rotor assembly and the stator is constructed of magnetic martensitic Type 403 stainless steel. The upper extension of the motor tube functions as a pressurized enclosure for the withdrawn leadscrew; the extension is made of austenitic Type 304 stainless steel, transition-welded to the upper end of the magnetic motor tube section. The lower end of the motor tube section is transition-welded to an austenitic stainless steel machined forging, which is flanged to connect with the reactor vessel's control rod nozzle. Double gaskets seal the flanged connection between the motor tube assembly and the reactor vessel.

No penetrations are provided through the CRDM pressure boundary.

Closure and Vent Assembly

The upper end of the motor tube is closed by a closure insert assembly containing a vent valve. The vent valve, when used in conjunction with a special venting tool, functions to bleed off non-condensable accumulated gases in the top of the reactor vessel. These valves are in the open position during filling and draining of the reactor coolant system to allow air passage. The valve and the closure insert have double seals,

1 metallic and 1 rubber O-ring. The insert is retained by a closure nut threaded to the inside of the motor tube. The sealing load for the closure is applied by jackscrews threaded through the closure nut.

Rotor Assembly

The rotor assembly, when actuated through a magnetic coupling by the stator, engages, holds, and positions the leadscrew. The major components of the rotor assembly are the rotor tube, the segment arms, the roller nuts, and the bearings.

The rotor tube is the central structure of the rotor assembly and is equipped with bearings at each end.

The segment arms (magnetic stainless steel) are mounted on the rotor tube by four pivot pins (two per segment arm), allowing them to rotate with and pivot on the rotor tube. The upper portion of the segment arms forms a four-pole, collapsible rotor. The lower portion includes a collapsible split nut designed to latch, drive, and unlatch the leadscrew. Four compression springs, located below the segment arm pivot pins, hold the roller nuts disengaged from the leadscrew. To engage the leadscrew, a force greater than the spring force must be applied to the segment arms above the pivot by the magnetic field of the stator. These same springs, in the absence of stator current, force the segment arms and roller nuts to disengage the leadscrew, allowing the control rod to fall into the core by means of gravity.

The four roller nuts are located in the lower portion of the segment arms. Each segment arm contains two roller nuts mounted on spindles to mate with the leadscrew thread when the rotor assembly is latched. The roller nuts are spaced 90 radial degrees apart. Each one is also inclined at the helix angle of the leadscrew. The magnetic field established by the stator will pull the upper portion of the rotor segment arms outward. Due to the pivoting action, the lower portion of the segment arms moves inward, causing the roller nuts to engage the leadscrew.

The thrust bearing carries all axial loads applied to the rotor and is located in the lower portion of the rotor tube. A synchronizing pin and bearing in the upper portion of the rotor tube ensures that both segment arms move together.
The CRDM bearings are lubricated by water.

Leadscrew Assembly

This assembly is comprised of the following major components: an upper extension, a lower extension, several locking sleeves, a male coupling, and a leadscrew. The leadscrew assembly is the connecting link between the rotor assembly the control rod through a breach lock-type coupling. When the rotor assembly rotates, the leadscrew assembly is prevented from rotating by the torque taker keyslot engagement to the key of the torque tube assembly. The leadscrew assembly travels along the vertical centerline of the drive. In its travel, the leadscrew passes through the torque tube, the rotor assembly, and the thermal barrier assembly.

Torque Tube and Torque Taker

The torque tube is a separate tubular assembly containing a key that extends the full length of leadscrew travel. The torque tube, in conjunction with the torque taker, prevents the leadscrew from rotating. The torque taker is attached directly to the leadscrew. This assembly is secured in elevation and against rotation at the lower end of the closure assembly by a retaining ring, keys, and closure insert. The lower end of the torque tube houses a hydraulic snubber assembly and is the down-stop. The leadscrew contacts the closure insert assembly for the upper mechanical stop. The torque taker assembly contains the canned position indicator magnet and the snubber piston. Also on the torque taker assembly is a keyway which mates with the key in the torque tube. This arrangement serves to prevent leadscrew rotation as well as to radially center the upper leadscrew.

Snubber Assembly

The total snubber assembly is comprised of a piston that is the lower end of the torque taker assembly and a hydraulic snubber cylinder and a Belleville spring assembly which is attached to the lower end of the torque tube. The cylinder is the area in which the free-fall tripped leadscrew control rod assembly is decelerated hydraulically. The damping characteristics of the snubber are determined by the size and position of a number of holes in the snubber cylinder wall and the water leakage at the snubber piston and bushing. At the end of the hydraulic snubbing stroke, any remaining energy is absorbed by the Belleville spring

assembly by a slight instantaneous overtravel past the normal down-stop.

Thermal Barrier Assembly

The thermal barrier restricts the circulations of hot primary fluid and acts as an insulator between the reactor vessel head and the drive. In this way the rotor assembly temperature is held well below primary coolant temperature during normal operation. Clearance in the bushing located in the center of the housing allows unrestricted leadscrew travel. Four ball-check valves are installed at the base of the thermal barrier to permit inflow to the mechanism during a reactor trip, but restrict convection coolant flow during hold or normal run modes.

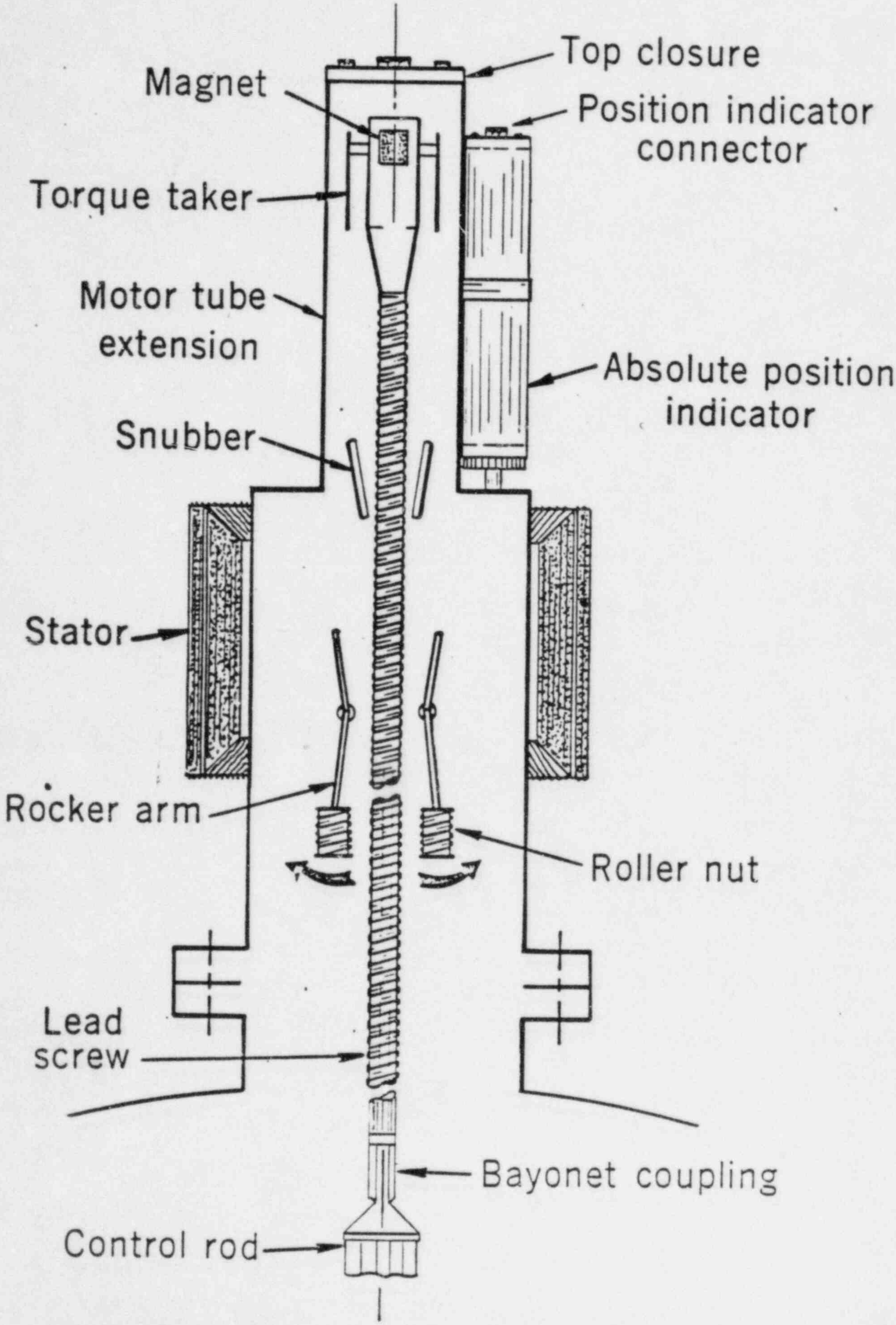
Stator and Water Jacket Assembly

The stator utilized on the CRDM and APSR is a four-pole, six-phase, reluctance-type stepping motor. It is cylindrical in shape and is installed by slipping it over the motor tube pressure housing. The stator is surrounded by a cooling water jacket through which cooling water circulates to provide cooling for the stator windings. All power, instrumentation, and cooling connections to the drive mechanism are located on the stator-water jacket assembly.

Position Indicator Assembly

The position indicator assembly is located outside but connected directly to the upper part of the motor tube. It consists of a square fiberglass housing which contains a network of magnetically operated reed switches. This assembly is used to determine to absolute position of the leadscrew within the drive. From this information the position of the control rod in the reactor is determined. As the leadscrew moves up and down within the drive, the torque taker and magnet travel with it. As the magnet travels vertically, the equally spaced reed switches in the position indicator close whenever the magnet is in their immediate vicinity. A 2 on, 3 on, 2 on sequence of switch activation is used to change circuit resistance that, in turn, measures rod position.

Control rod drive schematic



Docket No. 50-346
License No. NPF-3
Serial No. 1-525
May 15, 1985
Enclosure 2
Attachment B

EXAMINATION OF CRDM LEAF SPRING AND FOREIGN DEBRIS SAMPLES REMOVED FROM DAVIS-BESSE 1