UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OCT 2 8 1980

General Electric Company
ATTN: Dr. G. G. Sherwood, Manager
Safety and Licensing
175 Curtner Avenue
San Jose, California 95114

Dear Dr. Sherwood:

SUBJECT: ACCEPTANCE FOR REFERENCING TOPICAL REPORT NEDE-24057 P ASSESSMENT OF REACTOR INTERNALS VIBRATION IN BWR/4 AND BWR/5 PLANTS

The Nuclear Regulatory Commission has completed its review of the General Electric Company Licensing Topical Report NEDE-24057 "Assessment of Reactor Internals Vibration in BWR/4 and BWR/5 Plants," including the Amendments Nos. 1 and 2. The topical report provides an introduction as to the need for the test program; a summary of the report; a description of the reactor internals involved in the program; a description of the test including its scope, sensor types and locations, test conditions for preoperational, precritical, and startup tests as well as flow modes; inspection program; and data acquisition system; the results of the vibration measurements; the analysis and discussion of the tests; and the program conclusions. The summary of our evaluation is attached.

As a result of our review, we generally concluded: that the overall vibration assessment programs are adequate and the inspection results are satisfactory; that the inspection of internals immediately following the completion of preoperational tests is acceptable; that the steam dryer assemblies are adequate to sustain flow induced vibration expected in service; that the accessibility for inspection is acceptable; that for plants which are closely similar to the valid prototypes, confirmatory tests consisting only of non-instrumented preoperational testing and subsequent inspection of internals are acceptable; that the confirmatory test program using instrumented vibration monitoring during hot startup test without inspection in lieu of confirmatory preoperational flow test with inspection is acceptable. Specific conclusions as to prototype and non-prototype plant classifications and the specific limitations are as stipulated in the Regulatory Position section of the attached Topical Report Evaluation.

We find the topical report NEDE-24057(P) (proprietary version) and NEDO-24057(NP) (non-proprietary version) and their two supplements -1 and -2, are acceptable for referencing in the operating license application of the BWR/4 and BWR/5 plants listed in table 1 to 5 of the

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attached Topical Report Evaluation, provided conditions established for the specific plant as delineated therein are met in its implementation of Regulatory Guide 1.20, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing." In order to satisfy the conditions specified in the Topical Report Evaluation, additional plant specific information shall be submitted for NRC review on a case by case basis.

Pending the availability of test results, we are unable to conclude that the internals of the Chinshan 1 can be referenced as the valid prototype for licensing applications.

As for the internals in Bailly, a similarly constructed program as for Tokai 2 is acceptable only if the program and test results of the Chinshan internals, BWR/4-201 "size prototype becomes available and is accepted by NRC. In lieu of this, additional measurements comparable to the BWR/4 prototype programs may be implemented for qualifying Bailly internals as the prototype of the BWR/4-201" size internals.

We do not intend to repeat the review of the safety features described in the topical report and found acceptable in the attachment. Our acceptance applies only to the features described in the topical report and under the conditions discussed in the attachment.

In accordance with established procedure, it is requested that General Electric Company publish an approved version of these reports, proprietary and non-proprietary, within three months of receipt of this letter. The revisions are to incorporate this letter and the attached topical report evaluation following the title page and thus just in front of the abstract. The report identifications of the approved reports are to have a -A suffix.

Should Nuclear Regulatory Commission criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, General Electric Company and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Robert L. Tedesco, Assistant Director
for Licensing
Division of Licensing

TOPICAL REPORT EVALUATION

REPORT TITLE Assessment of Reactor Internals Vibration in BWR/4 and BWR/5 Plants

ORIGINATING The General Electric Company

REPORT NO.: NEDE-24057, November, 1977
NEDE-24057-1 (Amendment No. 1), December, 1978
NEDE-24057-2 (Amendment No. 2), June, 1979

REVIEWED BY: Mechanical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission

August, 1980

## INTRODUCTION

The structural components inside a reactor are called reactor internals. Reactor internals are important to safety and should be designed to cope with loads resulting from potential seismic events, postulated pipe break events, in addition to loads resulting from normal plant operations and anticipated operational occurrences. In addition to certain optional surveillance programs such as loose parts monitoring and core barrel motion monitoring, reactor internals are subjected to a comprehensive vibration assessment program which includes preoperational and initial startup flow testing.

Based on the recommendations of Regulatory Guide 1.20, for the first-of-a-kind prototype reactor, the vibration assessment program includes pre-test analysis for vibration predictions, vibration monitoring during the flow testing, and the post-test inspection of reactor internals. The purpose is to verify structural integrity prior to commercial operation for steady state and transient flow induced vibratory loads. The non-prototype reactor which is similar to the prototype, may have part of the program requirements reduced, dependent upon the degree of design similarity. Additional requirements may be needed if design modifications in the non-prototype are intended to resolve some identified operating problems. Furthermore, BWR test program requirements differ from PWRs due to the difficulty of conducting a hot flow test prior to fuel loading and in performing an inspection after the completion of the startup hot testing following fuel loading. An option which has evolved for BWR's is to conduct an inspection after the equivalent cold flow testing and to perform additional vibration monitoring during the subsequent precritical and startup phases of the hot flow testing.

## SUMMARY OF TOPICAL REPORT

NEDE-24057 provides an overview of current and future vibration assessment programs for BWR/4 and BWR/5 internals. Descriptions in the report include the vibration prediction methodology used; the sensor types and locations in the several plants having vibration tests conducted; the scope and objectives of the internals inspection program; typical test results from vibration measurement sensors and the internals inspection; the general vibration characteristics of various components and assemblies; analytical basis for the test acceptance criteria, and comparisons of some predicted and measured vibration amplitudes.

Conclusions of NEDE-24057 may be summarized briefly as the following:

A. Based on satisfactory test results and operating records of 11 BWR/4 plants, valid prototypes were established for reactor internals of vessel sizes 183, 218, and 251 inches. The plants are Duane Arnold, Fitzpatrick, and Browns Ferry 1 respectively.

B. Vibration measurements are planned in the lead BWR/5 plants to evaluate the jet pumps, which differ from the BWR/4 jet pumps. Measurements are also planned for the BWR/4 - 201" size prototype, the Chinshan 1 plant in Taiwan, China.

C. The Tokai 2 plant in Japan has been established as the BWR/5 - 251" size prototype based on satisfactory test results.

D. BWR/4 or BWR/5 plants having internals similar to the above mentioned prototype plants have been designated to conduct non-prototype test programs as characterized by Regulatory Guide 1.20.

E. Vibration problems encountered in BWR/4 plants with feedwater spargers and incore instrument tubes have been resolved by design modifications which were developed in flow test facilities and subsequently confirmed through in plant testing.

In conclusion, the General Electric Company has proposed that the vibration assessment programs presented in NEDE-24057 meet the requirements of Regulatory Guide 1.20. They claim that the satisfactory test results, the record of 11 operating plants, and the planned vibration assessment programs provide the needed assurance that the design of BWR/4 and BWR/5 internals is adequate to withstand flow induced vibration resulting from normal plant operations and anticipated operational occurrences.

## SUMMARY OF STAFF EVALUATION

A. Objectives of Staff Review:

NEDE-24057 was evaluated emphasizing:

(1) Whether the completed or planned vibration assessment programs presented in NEDE-24057 meet the intent of Regulatory Guide 1.20.

(2) Whether any experienced operating problems have been resolved, or acceptable measures for resolution have been proposed in NEDE-24057.

B. Staff Evaluation and Conclusions:

(1) The adequacy of the vibration assessment programs and test results were evaluated for the various size BWR/4 prototype internals. The prototypes include the 251" size Browns Ferry 1, the 218" size Fitzpatrick, and the 183" size Duane Arnold. Vibration was measured during the preoperational, precritical and startup flow tests. The internals were visually inspected after the preoperational tests. The staff evaluation has concluded that the overall vibration assessment programs are adequate and the test and inspection results are satisfactory.

(2) The acceptability of inspection of internals conducted immediately following the preoperational testing was investigated. The concern is that such a test is conducted during cold flow conditions without fuel. NEDE-24057 indicated that vibration amplitudes are consistently and substantially higher during cold flow preoperational test conditions as compared to start up and normal operating conditions conducted hot, following fuel loading. Based on additional detailed test data from the Fitzpatrick test (topical report NEDE-23673) regarding vibration at the shroud head assemblies, we have concluded that inspection of internals immediately following the completion of preoperational test is acceptable, provided the recirculation system was operated at flow rates up to and exceeding the rated mass flow for normal operation, which was the case in all of the three above prototype tests.

(3) Inspection of the steam dryer assemblies conducted after the preoperational cold flow testing was questioned, since the effects of an actual vibration environment with hot steam were not simulated during the test. The steam dryer assemblies were not instrumented, hence any vibration which occurred during start up hot testing was not measured. However, the steam dryer vane assemblies were qualified via a combination of laboratory vibration testing and analysis. Based on the foregoing investigation and the satisfactory history of operation in operating BWR's, we have concluded that the steam dryer assemblies are adequate to sustain flow induced vibration expected in service.

(4) We have investigated the accessibility of BWR internals for inspection after the preoperational test, especially the clearance between jet pumps and the size of opening at the shroud base plate and supports. We have concluded that the accessibility for inspection is acceptable.

(5) We have evaluated the acceptability of the vibration assessment programs for non-prototype BWR/4 internals. For those plants which are closely similar to the prototypes identified in item (1) above. Comfirmatory tests consisting only of non-instrumented preoperational testing and subsequent inspection of the internals are acceptable. This acceptance is based on the discussion in item (2) above, and the acceptable option

permitted by Regulatory Guide 1.20 for BWR plants. BWR/4 plants in this category include the 218" size in Hatch 2 and Shorehem, and the 251" size in Susquehanna 1 and 2, Hope Creek 1 and 2, and Fermi 2 plants.

(6) In lieu of conducting confirmatory tests consisting of a non-instrumented preoperational test with subsequent inspection, another option provided in Regulatory Guide 1.20 for BWR non-prototype internals is to conduct a confirmatory test without inspection but with instrumented vibration monitoring during the hot start-up test to ensure that the measured internals vibration is similar in nature and comparable in amplitude to those in the designated prototype internals. We have evaluated the program using this option presented for the internals of the 218" size in Cooper, Hatch 1, Brunswick 1 and 2 plants, and the 251" size in Browns Ferry 2 and 3, and Peach Bottom 2 and 3 plants. We have concluded that the presented programs are acceptable.

(7) NEDE-24057 indicated that the Chinshan 1 plant in Taiwan, China was designated as the plant for the BWR/4-201" size prototype internals. Since the test results are not yet available for staff review, we are unable to conclude that the internals of the Chinshan 1 may be referenced at this time as the valid prototype for other plant licensing applications.

(8) For BWR/5 internals, NEDE-24057 indicated that the vibration assessment program was completed in the Tokai-2 plant in Japan for the BWR/5-218" size prototype. We have evaluated the vibration assessment program and test and inspection results of Tokai 2. Since the Tokai 2 internals are generally similar to the Browns Ferry 1, a BWR/4-251" prototype except for the design of the jet pumps, vibrations measurements at Tokai-2 were concentrated at the jet pumps and at the shroud head upper bolt guide ring. These locations were selected since they would indicate the effect of jet pump motion and overall shroud motion. We have concluded that the program, the test results and the inspection results of the Tokai 2 internals are acceptable. Programs are also presented for the Zimmer plant for the BWR/5-218" size internals, and for the Bailly plant for the BWR/5-201" size internals. Since the internals in Zimmer are generally similar to the BWR/4-218" size prototype in Fitzpatrick, similar to the case of Tokai 2 and its BWR/4-251" counterpart, a vibration assessment program having all the major elements as the Tokai 2 program is acceptable for qualifying the Zimmer internals as the 218" size prototype. As for the internals in Bailly, a similarly constructed program as for Tokai 2 is acceptable only if the program and test results of the Chinshan internals, BWR/4-201" size prototype, becomes available and is accepted by the NRC. In lieu of this, additional measurements comparable to the BWR/4 prototype programs may be implemented for qualifying Bailly internals as the prototype of the BWR/5-201" size internals.

(9) NEDE-24057 indicated that LaSalle 1 (a BWR/5-251") will have an internal vibration assessment program with vibration measurements of the jet pumps during preoperational, precritical and startup tests, and inspection following the preoperational testing. Since the LaSalle 1 internals are

similar to the internals of Tokai 2, the BWR/5-251" prototype, except for differences in the jet pump adaptor design, we have concluded that the proposed program is acceptable and will consider LaSalle 1 as an non-prototype category II plant.

(10) NEDE-24057 indicated that the vibration assessment program for WPPSS-2 internals (a BWR/5-251") will have an instrumented confirmatory test during startup and will not have preoperational flow test and inspection. Areas of the jet pumps and the shroud head upper guide ring will be instrumented. The report also indicated that the programs for non-prototype LaSalle 2 and Nine Mile Point 2 internals will have non-instrumented preoperational test and subsequent inspections. These proposed programs are consistent with the treatment of non-prototype BWR/4 internals and meet the intent and acceptable options available in Regulatory Guide 1.20 as discussed in item (5) and (6) above. We conclude that the proposed confirmatory test program are acceptable.

(11) We have evaluated the effects of problems experienced in the BWR internals of operating plants, some of which include in-core channel box wear, feedwater sparger failure and the failur of jet pump holddown beam bar (HDBB). Generic review of the channel box and sparger problems have been completed by the staff. The design modifications which have been implemented in operating BWR plants and in plants under licensing application have been acceptably covered in NEDE-24057. The jet pump HDBB failure occurred in BWR/3 plants and was caused by progressive intergranular stress corrosion. This is a long duration process similar to the sparger and channel box problems which is beyond the scope of the assessment programs of Regulatory Guide 1.20. The on-going short term staff action for the jet pump HDBB includes degradation surveillance and replacement of the failed HDBB during a planned plant fuel outage. Permanent resolution of this problem is expected prior to the issuance of an operating license for any plant included in NEDE-24057.

REGULATORY POSITIONS

The staff, based on evaluation of GE topical report NEDE-24057, has concluded the following relative to the preoperational and startup vibration assessment and testing program for GE BWR/4 and BWR/5 internals:

A. Valid prototype internals are established for the plants listed in Table 1. These plants have satisfactorily completed the vibration assessment program in compliance with the Regulatory Guide 1.20:

Table 1

Valid Prototypes - Operating

| Plant Name | Valid Prototype Internals Type and Size |
|---|---|
| Browns Ferry 1 | BWR/4-251" |
| Fitzpatrick | BWR/4-218" |
| Duane Arnold | BWR/4-183" |
| Tokai 2 | BWR/5-251" |

The Prototype internals in Table 1 are acceptable to be referenced in the plant licensing applications.

B. The plants listed in Tables 2 and 3 below having reactor internals substantially similar to their individually referenced valid prototype are acceptable to be designated as Non-prototype Category I in accordance with Regulatory Guide 1.20:

Table 2

Non-Prototype, Category I - Operating

| Plant Name | Reactor Type & Size | Plant with designated prototype internals |
|---|---|---|
| Browns Ferry 2 & 3 | BWR/4-251" | Browns Ferry 1 |
| Peach Bottom 2 & 3 | BWR/4-251" | Browns Ferry 1 |
| Cooper | BWR/4-218" | Fitzpatrick |
| Hatch 1 & 2 | BWR/4-218" | Fitzpatrick |
| Brunswick 1 & 2 | BWR/4-218" | Fitzpatrick |

Table 3

Non-Prototype, Category I - Under Construction

| Plant Name | Reactor Type & Size | Plant with designated Valid Prototype internals |
|---|---|---|
| Susquehann 1 & 2 | BWR/4-251" | Browns Ferry 1 |
| Hope Creek 1 & 2 | BWR/4-251" | Browns Ferry 1 |
| Limerick 1 & 2 | BWR/4-251" | Browns Ferry 1 |
| Fermi 2 | BWR/4-251" | Browns Ferry 1 |
| Shoreham | BWR/4-218" | Fitzpatrick |
| LaSalle 2 | BWR/5-251" | Tokai 2/LaSalle 1 |
| WPPSS 2 | BWR/5-251" | Tokai 2 |
| Nine Mile Point 2 | BWR/5-251" | Tokai 2 |

The vibration assessment Programs presented in NEDE-24057 for plants in Tables 2 and 3 are acceptable. Acceptability of the non-prototype program implementation is contingent upon NRC review on a case by case basis of the test and inspection results.

C. The BWR/5 internals in the Bailly and Zimmer plants should be designated as the prototypes for sizes 201" and 218" respectively. The vibration assessment program presented in the report for Zimmer is acceptable. The program for Bailly should be revised to include additional measurements pending the availability of test results of Chinshan internals in Taiwan, China, as previously discussed. Acceptability of establishing the Bailly and Zimmer internals as valid prototypes is contingent upon review by the staff of the results of the programs for each plant.

Table 4

Prototype - Under Construction

| Plant Name | Internals Type & Size |
|---|---|
| Bailly | BWR/5-201" |
| Zimmer | BWR/5-218" |
| Chinshan | BWR/4-201" |

E. The BWR/5 internals in LaSalle 1 plant are acceptable to be designated as Non-prototype Category II in accordance with Regulatory Guide 1.20. The vibration assessment program presented in Amendment No. 2 of NEDE-24057 for LaSalle 1 is acceptable. Acceptability of LaSalle 1 as a Non-Prototype Category II plant is contingent upon NRC review of the test and inspection results after the completion of the program.

Table 5

Non-Prototype, Category II
Under Construction

| Plant Name | Reactor Type & Size | Plant with designated valid prototype internals |
|---|---|---|
| LaSalle 1 | BWR/5-251" | Tokai 2 |

F. The resolution of IE Bulletin 80-07 concerning the observed cracking of jet pump holddown beams should be considered an open issue in the operating license review of all BWR plants. Each plant should document its proposed action to resolve the problem prior to the issuance of an operating license

NEDO-24057A
Class I
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LICENSING TOPICAL REPORT

# ASSESSMENT OF REACTOR INTERNALS VIBRATION IN BWR/4 AND BWR/5 PLANTS

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## ABSTRACT

*This report presents results of reactor internals vibration tests and measurements conducted in prototype BWR/4 plants of 251 inch, 218 inch, and 183 inch vessel sizes. Results are also presented for supplemental tests of certain internal design features of later BWR/4 plants. All results are shown to be within acceptable limits. Visual inspections of internals following flow testing showed no evidence of vibration. Plans are outlined for additional vibration measurements in BWR/4 and BWR/5 plants containing new design features. Confirmatory test plans for subsequent similar BWR/4 and BWR/5 plants are discussed.*

# 1. INTRODUCTION

Vibration of reactor internals is monitored during preoperational and startup testing of BWRs which contain new internal design configurations or features. Vibration measurements and inspections of internals following flow testing are made in response to requirements of NRC Regulatory Guide 1.20. Vibration measurements for core support structures and major internal components were made in three BWR/4 plants: the 251 size prototype, Browns Ferry 1; the 218 size prototype, Fitzpatrick; and the 183 size prototype, Duane Arnold. Feedwater sparger vibration measurements were made at the Cooper and Browns Ferry 2 plants for the interference-fit installation and at Brunswick 1 for the welded-in installation. Vibration of in-core instrument tubes was monitored in the Browns Ferry 3 plant.

Satisfactory completion of these tests establishes valid prototype BWR/4 design configurations for reference by subsequent similar plants. The prototype test results also support some component designs in BWR/5 plants. The prototype is a composite, in that various design features were tested in several different plants rather than in a single plant.

Plants similar to the prototype are required to conduct a confirmatory test to verify satisfactory vibration performance of internals through measurements or through inspection. General Electric is committed to confirm satisfactory vibration performance of internals through preoperational flow testing followed by inspection for evidence of excessive vibration.

## 2. SUMMARY

This report contains in Section 3 a brief general description of BWR reactor internals, followed in Section 4 by a description of the vibration test programs which are conducted in several BWR/4 plants. Sensor types and locations are identified and test conditions (Preoperational, Precritical, and Startup) are defined. The scope and objectives of the internals inspection program are discussed. In Section 5, results of the vibration measurement and inspection programs are presented. General vibration characteristics of the various components and assemblies are discussed, and measured vibration amplitudes are compared with test acceptance criteria.

Section 6 presents the analytical basis for the test acceptance criteria and describes the data analysis method used in the evaluation of test results. Section 6 also contains a discussion of the vibration predictions which were made for BWR/4 prototype plants and presents a comparison of predicted and measured vibration amplitudes. Application of the test results to subsequent BWR/4 and BWR/5 plants is discussed in Section 7.

Key conclusions presented in Section 8 are summarized as follows:

a. These test results demonstrate the adequacy of BWR/4 internals with respect to vibration and establish valid prototype internals design configurations for reference in the qualification of subsequent similar plants of 218 and 251 inch vessel sizes. All quantitative measurements are found to be within acceptable limits. Visual inspections for wear, cracking, or loose parts have shown no evidence of vibration problems.

b. Design modifications to feedwater spargers and in-core bypass flow paths were developed in out-of-reactor test facilities and have been confirmed by in-plant tests and subsequent satisfactory in-service operation as valid reference designs. Current and future plans for vibration testing of these and other internal components place increased emphasis on the use of out-of-reactor flow test facilities.

c. Vibration measurements are planned in lead BWR/5 plants to evaluate the jet pumps, which differ from the BWR/4 jet pumps. Measurements are also to be made in the 201 size BWR/4 prototype plant, Chinshan 1, completing requirements for in-plant vibration measurements in BWR/4 and BWR/5 plants.

d. The preoperational flow test and inspection is a practical and adequate confirmatory vibration test for non-prototype plants. The BWR/4 plants will be qualified by this test are Hatch 2, Shoreham, Fermi 2, Limerick 1 and 2, Hope Creek 1 and 2, and Susquehanna 1 and 2. BWR/5 plants to receive the preoperational test and inspection are LaSalle 1 and 2, Hanford 2, and Nine Mile Point 2.

Thus, extensive vibration measurements in prototype plants together with satisfactory operating experience in 11 BWR/4 plants have established the adequacy of reactor internals designs.

# 3. DESCRIPTION OF INTERNALS

Figure 3-1 shows the BWR internals assembly. For purposes of vibration test description, the internal components are grouped as follows:

a. The shroud and shroud head assembly. This includes the steam separator and standpipe assemblies, which are attached to each other and to the shroud head. Steam separators are of the same design in all BWR/4 and BWR/5 plants. The shroud is fixed at the shroud support plate, which is reinforced by gussets or by shroud support legs.

b. The fuel assemblies, which are supported vertically by the fuel support castings and control rod guide tubes and laterally by the shroud through the core plate and the top guide.

c. The jet pump assemblies, each consisting of a riser pipe and two jet pumps. Support points are at the inlet nozzle, the riser brace, and the shroud support plate.

d. The control rod guide tubes, which provide vertical support to the fuel assemblies and are in turn supported by the control rod housings, the stub tubes, and the bottom head. These are of the same design in all BWR/4 and BWR/5 plants.

e. The in-core housing, guide tube, and stabilizer assembly. The housings extend up through the bottom head and are welded to the guide tubes which extend up to the core plate. The incore guide tubes are attached to each other at approximately midspan by stabilizer bars. This design is also common to BWR/4 and BWR/5 plants.

f. The in-core instrument tubes, which extend up through the incore housings and guide tubes and between the fuel channels in the core region.

g. The feedwater spargers, which are supported at the inlet thermal sleeve and at each end of the header. The thermal sleeve may be welded to the nozzle or installed with an interference fit.

Other internal components, such as the steam dryer assembly, have not been vibration tested because they are not considered to be important to safety or susceptible to significant vibration.

# 4. TEST DESCRIPTION

## 4.1 TEST SCOPE

**4.1 Test Scope.** The vibration test program for BWR 4 and 5 reactor internals provides for extensive vibration measurements and post-test inspection of major new internal design configurations or features, and for confirmatory tests of subsequent similar internals through either vibration measurements or post-test inspection. A vibration test program has been designed for each plant to meet these general requirements, taking into consideration similarities and differences of designs among the various plants and the timing of initial plant startup schedules. These test plans have been modified over a period of time in response to plant operating experience, testing experience and results, and changes in Regulatory requirements.

Table 4-1 summarizes the vibration test programs and its basis. BWR/4 and BWR/5 plants are listed together by plant size. Under Internals Designs Characteristics are listed the key dimensions, flow parameters, and design features which were considered in specifying the test program. The core and shroud structures are substantially similar inBWR/4 and BWR/5 plants, while the jet pumps are substantially different. Other design features common to BWR/4 and BWR/5 are noted in Section 3 above.

The vibration test program is described for each plant inTable 4.1 in terms of the components which are instrumented and the tests and measurements which are performed.

Results of vibration measurements in seven plants are presented in Section 5 of this report. Three of these were prototype plants, for which the test scope was as follows:

- 251-BWR/4 Prototype (Browns Ferry-1)
  Shroud and shroud head assembly.
  Jet Pump assemblies.
  Control rod housing and guide tube assembly.
  Incore housing, guide tube and stabilizer assembly.

- 218-BWR/4 Prototype (Fitzpatrick)
  Shroud and shroud head assembly.
  Jet pump assemblies.
  Fuel channels.

- 183-BWR/4 Prototype (Duane Arnold)
  Shroud and shroud head assembly.
  Jet pump assemblies.
  Control rod housing and guide tube assembly.
  Incore housing, guide tube, and stabilizer assembly.

The feedwater spargers with the interference fit installation were instrumented at Cooper (a 218 size BWR/4) and at Browns Ferry 2 (a 251 size BWR/4). The welded-in sparger was instrumented at Brunswick 1 (a 218 size BWR/4). In these plants, instrumentation was also provided on the shroud head and on the jet pumps to confirm prototype test results for these components.

The vibration test program at Browns Ferry 3 covered the in-core instrument tube vibration fix, in addition to confirmatory shroud head, jet pump and feedwater sparger vibration measurements.

Other aspects of the vibration test program of Table 4-1, including future test plans, are discussed in Section 7.

## 4.2 SENSOR TYPES AND LOCATIONS

Vibration measurement sensors used in BWR/4 tests are strain gages, displacement transducers, and accelerometers. Other sensors installed to aid in determining causes of vibration include differential pressure transducers and photocells which were used as recirculation pump speed indicators.

**Table 4-1**

**REACTOR INTERNALS VIBRATION PROGRAM FOR BWR 4 AND 5 PLANTS**

| | INTERNALS DESIGN CHARACTERISTICS — Core and Shroud Structure | | | | | | | | INTERNALS DESIGN CHARACTERISTICS — Jet Pumps | | | | | | | VIBRATION TEST PROGRAM — Instrumented Components | | | | | | | VIBRATION TEST PROGRAM — Tests and Measurements | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vessel Diameter (I.D., inches) | Product Line | Power, MWt | Recirculation Flow lb/hr, x 10⁶ | Number of Fuel Assemblies | Shroud Diameter O.D., inches) | [illegible] Steam | Shroud Support Legs | Nozzle Type (holes per Nozzle) | Nozzle Velocity ft/sec | Length of Mixer, inches (approx.) | Length of Diffuser, inches (approx) | Diameter at Discharge, inches | Discharge Velocity, ft/sec | Ratio of Driven Flow to Drive Flow (M) | Jet Pumps | Shroud | Shroud Head | Control Rod and In-Core Guide Tubes | Feedwater Spargers | Fuel Channels | In-Core Instrument Tuves | Preoperational Flow Test and Inspection | Preoperational Vibration Measurements | Precritical Vibration Measurements | Startup Vibration Measurements | Note |
| Duane Arnold | 183 | 4 | 1593 | 49.0 | 368 | 145 | 10[illegible] | yes | 1 | 159 | 89 | 119 | 14.1 | 16.9 | 1.39 | X | X | X | X | | | | X | X | X | X | (1) |
| Chinshan 1 | 201 | 4 | 1775 | 53.0 | 408 | 165 | 1[illegible] | yes | 1 | 162 | 89 | 107 | 14.1 | 14.6 | 1.30 | X | X | X | | X | | | X | X | X | X | (2) |
| Bailly | 201 | 5 | 1931 | 61.5 | 444 | 165 | 13[illegible] | no | 5 | 191 | 54 | 145 | 14.1 | 16.9 | 1.92 | X | | X | | | | | X | X | X | X | |
| Fitzpatrick | 218 | 4 | 2436 | 77.0 | 560 | 178 | 16[illegible] | no | 1 | 160 | 100 | 100 | 17.1 | 14.4 | 1.25 | X | X | X | | | X | | X | X | X | X | (1) |
| Cooper | 218 | 4 | 2381 | 73.5 | 548 | 178 | 15[illegible] | no | 1 | 160 | 100 | 100 | 17.1 | 13.7 | 1.15 | X | | X | | | | | | | X | X | (1) |
| Hatch 1 | 218 | 4 | 2436 | 78.5 | 560 | 178 | 1[illegible] | no | 1 | 160 | 100 | 100 | 17.1 | 14.7 | 1.30 | X | | X | | | | | | | | X | (1) |
| Hatch 2 | 218 | 4 | 2436 | 77.0 | 560 | 178 | 16[illegible] | [illegible]o | 1 | 160 | 100 | 100 | 17.1 | 14.4 | 1.25 | | | | | | | | X | | | | (1) |
| Brunswick 1 | 218 | 4 | 2436 | 77.0 | 560 | 178 | 16[illegible] | [illegible]es | 1 | 160 | 100 | 100 | 17.1 | 14.4 | 1.25 | X | | X | | X | | | | | | X | (1) |
| Brunswick 2 | 218 | 4 | 2436 | 77.0 | 560 | 178 | 163 | [illegible]es | 1 | 160 | 100 | 100 | 17.1 | 14.4 | 1.25 | X | | X | | X | | | | | X | X | (1) |
| Shoreham | 218 | 4 | 2436 | 77.0 | 560 | 178 | 163 | n[illegible] | 1 | 160 | 100 | 100 | 17.1 | 14.4 | 1.25 | | | | | | | | X | | | | |
| Zimmer | 218 | 5 | 2436 | 78.5 | 560 | 178 | 163 | yes | 5 | 208 | 57 | 142 | 17.1 | 14.7 | 2.19 | X | | X | | | | | X | X | X | X | |
| Browns Ferry 1 | 251 | 4 | 3293 | 102.5 | 764 | 207 | 211 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.3 | 2.00 | X | X | X | X | | | | X | X | X | X | (1) |
| Browns Ferry 2 | 251 | 4 | 3293 | 102.5 | 764 | 207 | 211 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.3 | 2.00 | X | | X | | X | | | | | | X | (1) |
| Browns Ferry 3 | 251 | 4 | 3293 | 102.5 | 764 | 207 | 211 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.3 | 2.00 | X | | X | | X | | X | | | X | X | (1) |
| Peach Bottom 2 and 3 | 251 | 4 | 3293 | 102.5 | 764 | 207 | 211 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.3 | 2.00 | X | X | | | | | | | | | X | (1) |
| Susquehanna 1 and 2 | 251 | 4 | 3293 | 100.0 | 764 | 207 | 225 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.0 | 1.92 | | | | | | | | X | | | | |
| Hope Creek 1 and 2 | 251 | 4 | 3293 | 100.0 | 764 | 207 | 225 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.0 | 1.92 | | | | | | | | X | | | | |
| Limerick 1 and 2 | 251 | 4 | 3293 | 100.0 | 764 | 207 | 225 | yes | 1 | 187 | 110 | 87 | 19.1 | 15.0 | 1.92 | | | | | | | | X | | | | |
| E Fermi 2 | 251 | 4 | 3293 | 100.0 | 764 | 207 | 225 | no | 1 | 187 | 110 | 87 | 19.1 | 15.0 | 1.92 | | | | | | | | X | | | | |
| Tokai 2 | 251 | 5 | 3293 | 106.5 | 764 | 207 | 225 | yes | 5 | 228 | 61 | 132 | 19.0 | 15.9 | 1.98 | X | | X | | X | | | X | X | X | X | (2) |
| Lasalle 1 | 251 | 5 | 3293 | 108.5 | 764 | 207 | 225 | no | 5 | 228 | 61 | 132 | 19.0 | 16.2 | 2.04 | | | | | | | | X | | | | |
| Lasalle 2 | 251 | 5 | 3293 | 108.5 | 764 | 207 | 225 | yes | 5 | 228 | 61 | 132 | 19.0 | 16.2 | 2.04 | | | | | | | | X | | | | |
| Hanford 2 | 251 | 5 | 3323 | 108.5 | 764 | 207 | 225 | yes | 5 | 228 | 61 | 132 | 19.0 | 16.2 | 2.04 | | | | | | | | X | | | | |
| Nine Mile Point 2 | 251 | 5 | 3323 | 108.5 | 764 | 207 | 225 | yes | 5 | 228 | 61 | 132 | 19.0 | 16.2 | 2.04 | | | | | | | | X | | | | |

Notes: (1) Test Complete
(2) Test in Progress

The strain gages are manufactured by Ailtech (Model SG 125). They consist of a nickel-chrome alloy filament in a Type 321 stainless steel tube of 0.040-inch diameter, with an integral flange for spot welding. The effective gage length is one inch. They were used to measure the dynamic strain in several components:

a. Jet pump riser braces: a typical installation is shown in Figure 4.1.

b. Feedwater spargers: Figure 4.2 shows the as-installed locations for the Brunswick 1 spargers. Other installations are similar in that one sparger is provided with eight strain gages, and the remainder with two.

c. Incore instrument tubes. Figure 4-3 shows the strain gage installation at Browns Ferry 3.

d. Fuel channels. Figure 4-4 shows the Fitzpatrick installation.

e. Shroud support legs. Figure 4-5 shows the installation at Duane Arnold. Similar locations were used at Browns Ferry 1.

f. Control rod housing stub tube. Strain gages were located just above the stub tube to vessel weld as in Figure 4-6, in the Browns Ferry 1 and Duane Arnold plants.

g. Incore housing. Gages were located as in Figure 4-7 in the Browns Ferry 1 and Duane Arnold plants.

Vibration of the shroud head and steam separator assembly was measured in all plants using Validyne variable reluctance accelerometers located on the upper bolt guide ring. Figure 4-8 is a typical installation, except that in some earlier plants the accelerometers were 120° apart instead of the 60° shown. The 60° spacing is more convenient to install and equivalent in terms of mode identification. The sensitive axis of the accelerometers is in the tangential direction. The specified frequency response of these sensors is 0 to 50 Hz. They are used in conjunction with a double integrator (see Subsection 3.3) to provide the dynamic displacement response from 2 to 50 Hz.

Accelerometers were also used at Duane Arnold to measure radial vibration of the shroud wall at the midplane elevation. Three accelerometers were located at the 20, 46, and 98° azimuths to resolve possible shell modes of the shroud cylinder. Displacement transducers of the linear variable differential transformer (LVDT) type were used to measure jet pump vibration relative to the reactor vessel. Figure 4-9 shows a typical installation on the jet pump in which the LVDT housing is mounted on the vibrating structure and the probe senses motion relative to the stationary pressure vessel. The LVDT's which were mounted on the shroud flange in prototype plants sensed radial and tangential motion relative to the reactor vessel at the zero and 180 degree azimuths.

In the Browns Ferry 3 plant, eight piezoelectric accelerometers were mounted on the lower ends of in-core instrumentation tubes, external to the reactor vessel, to serve as impact detectors. Figure 4-10 shows the sensor locations. Accelerometers thus mounted can detect intermittent contact between incore tubes and fuel channels. The accelerometers are Endevco Model 2272 (2 to 5500 Hz response), which are used in conjunction with Endevco Model 2731A charge converter systems.

Recirculation pump speeds, which have been found to correlate with vibration frequency in some cases, were measured with two photocell and lamp assemblies which sense changes in light caused by black marks on the pump-motor coupling. Spikes are produced and recorded once per revolution. The frequency of the spikes is the pump speed.

Differential pressure transducers of the variable reluctance type were installed in the prototype plants to aid in the identification of sources or causes of vibration. These were located on the core plate, the shroud wall, and the shroud head. In addition, absolute pressure transducers were installed in the Fitzpatrick recirculation lines, downstream of the recirculation pump discharge, to measure pump-induced pressure oscillations which could influence the vibration of reactor internals.

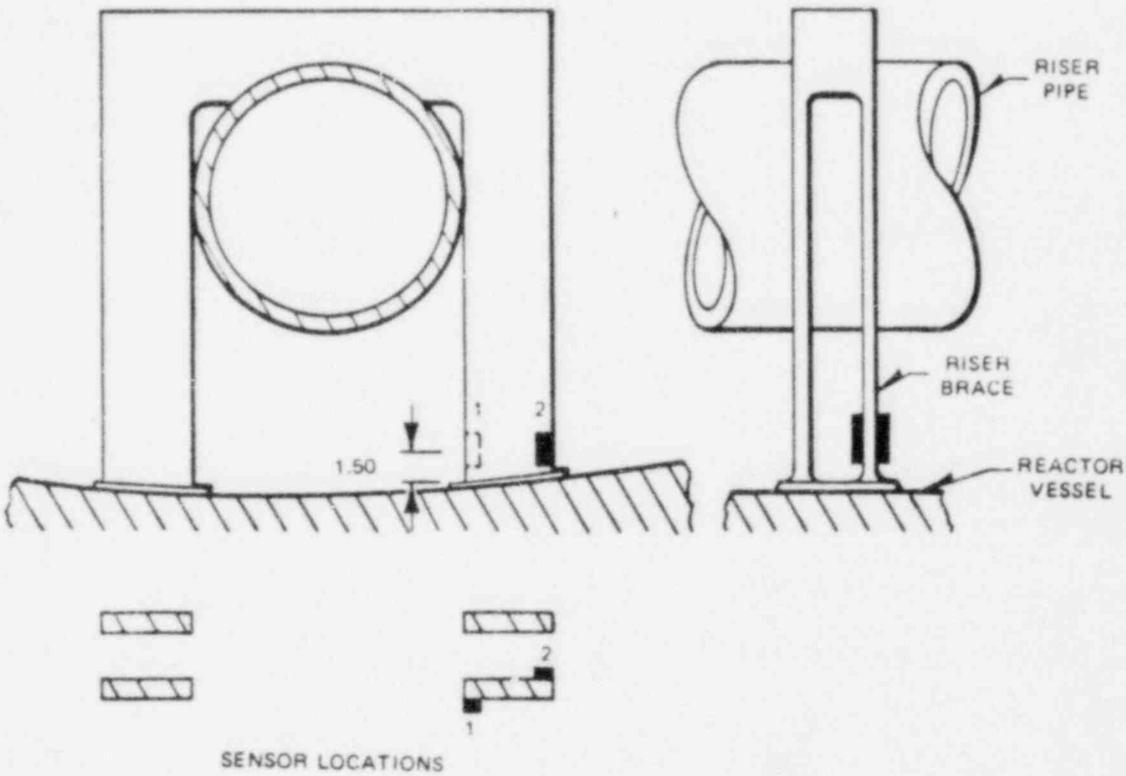



*Figure 4-1. Typical Strain Gage Locations on Jet Pump Riser Braces.*

| | | SPARGER AT VESSEL AZIMUTH | | | |
|---|---|---|---|---|---|
| | | 45° | 135° | 225° | 315° |
| LOCATION ON SPARGER ARM | A | S9/11* | S12/14* | S22, S23 | |
| | B | | | S19, S20 | |
| | C | | | S17, S18 | |
| | D | | | S15, S16 | S24/26* |

* PAIR OF GAGES CONNECTED IN A SWITCHABLE HALF-BRIDGE

ALL SENSORS (DESIGNATED S9 THROUGH S26) ARE ORIENTED PARALLEL TO THE SPARGER ARMS.

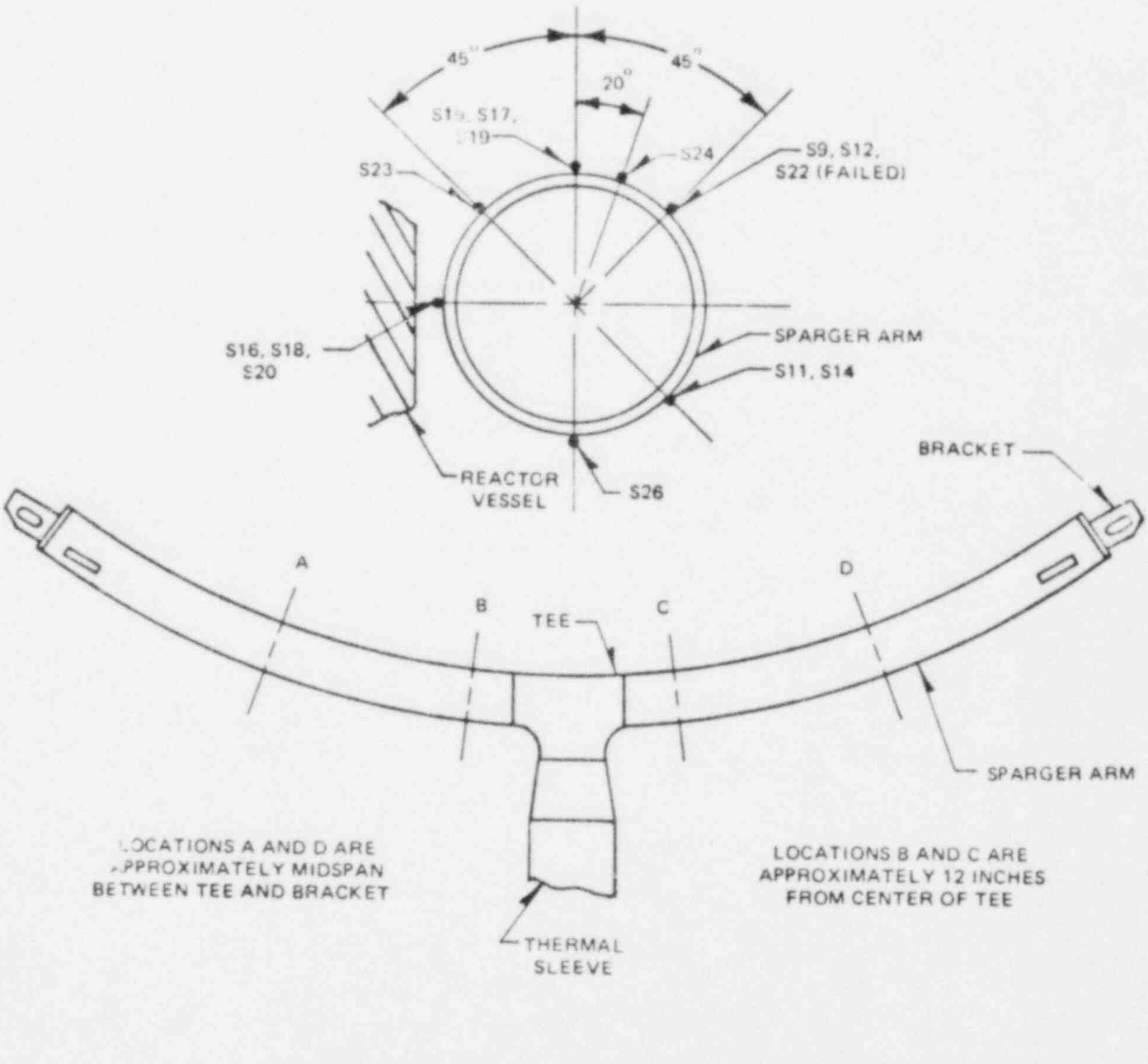



*Figure 4-2. Strain Gage Location on Feedwater Spargers at Brunswick 1.*

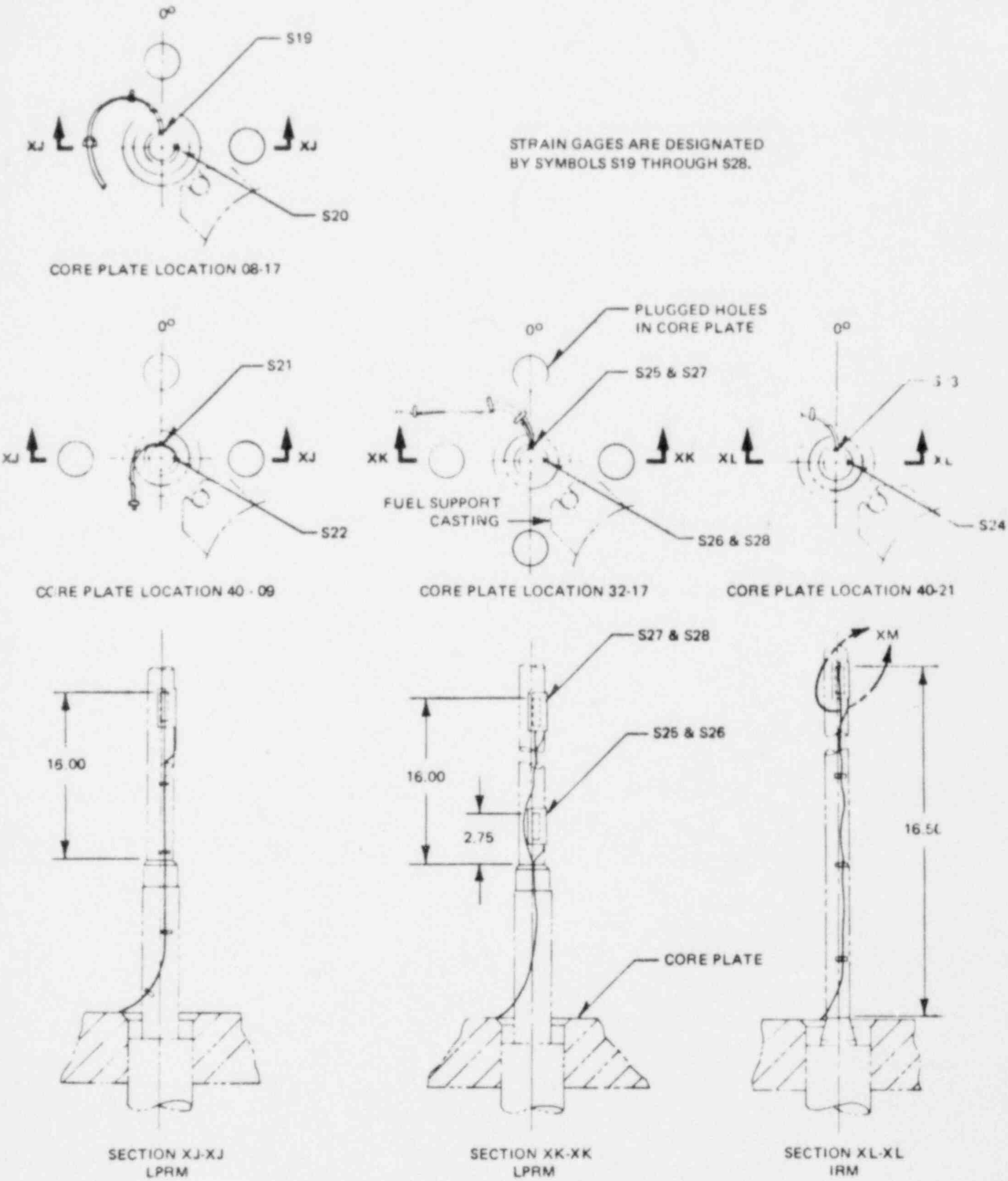



*Figure 4-3. Strain Gage Locations on Incore Instrument Tubes at Browns Ferry 3.*

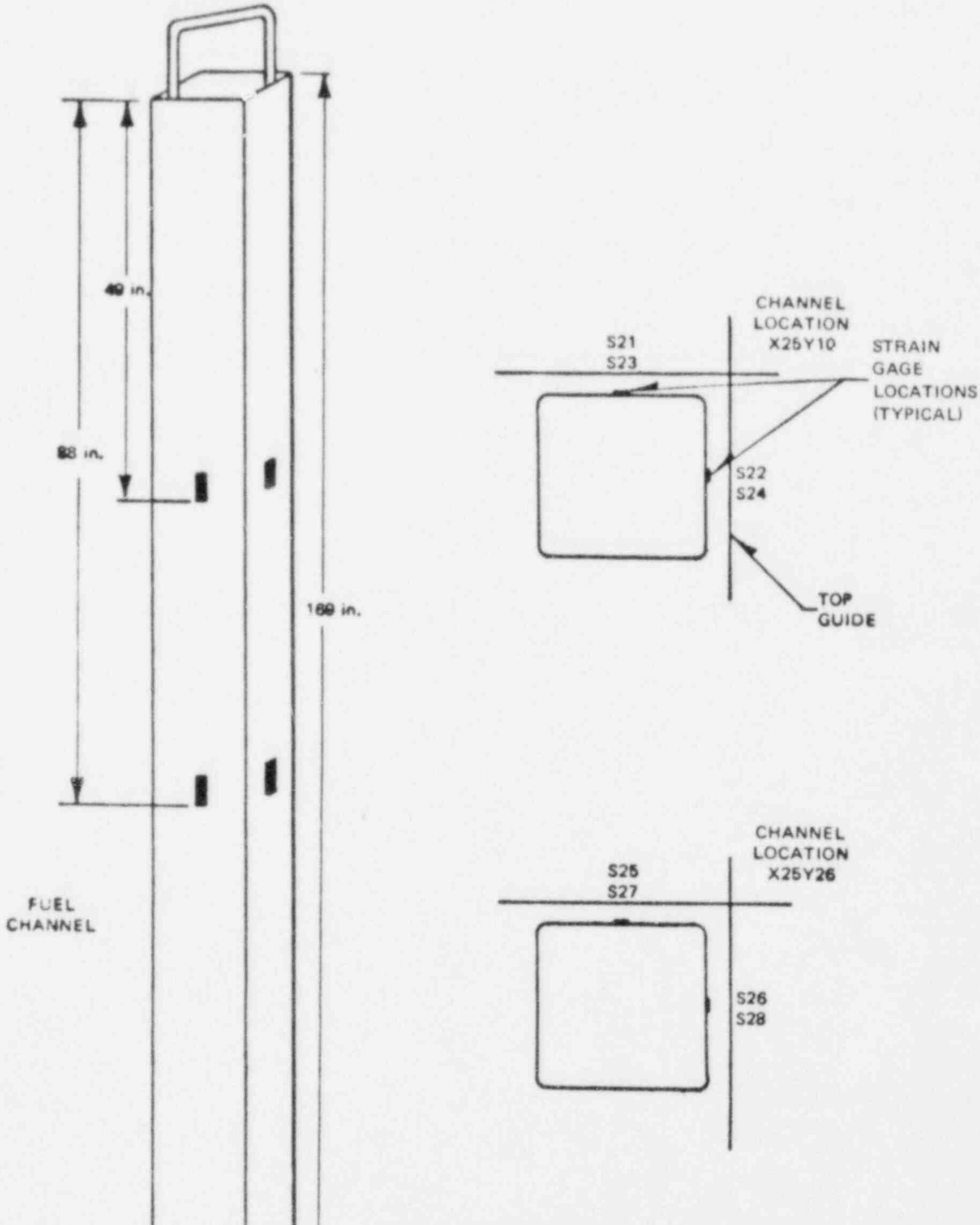



*Figure 4-4. Strain Gage Locations on Fuel Channels at Fitzpatrick.*

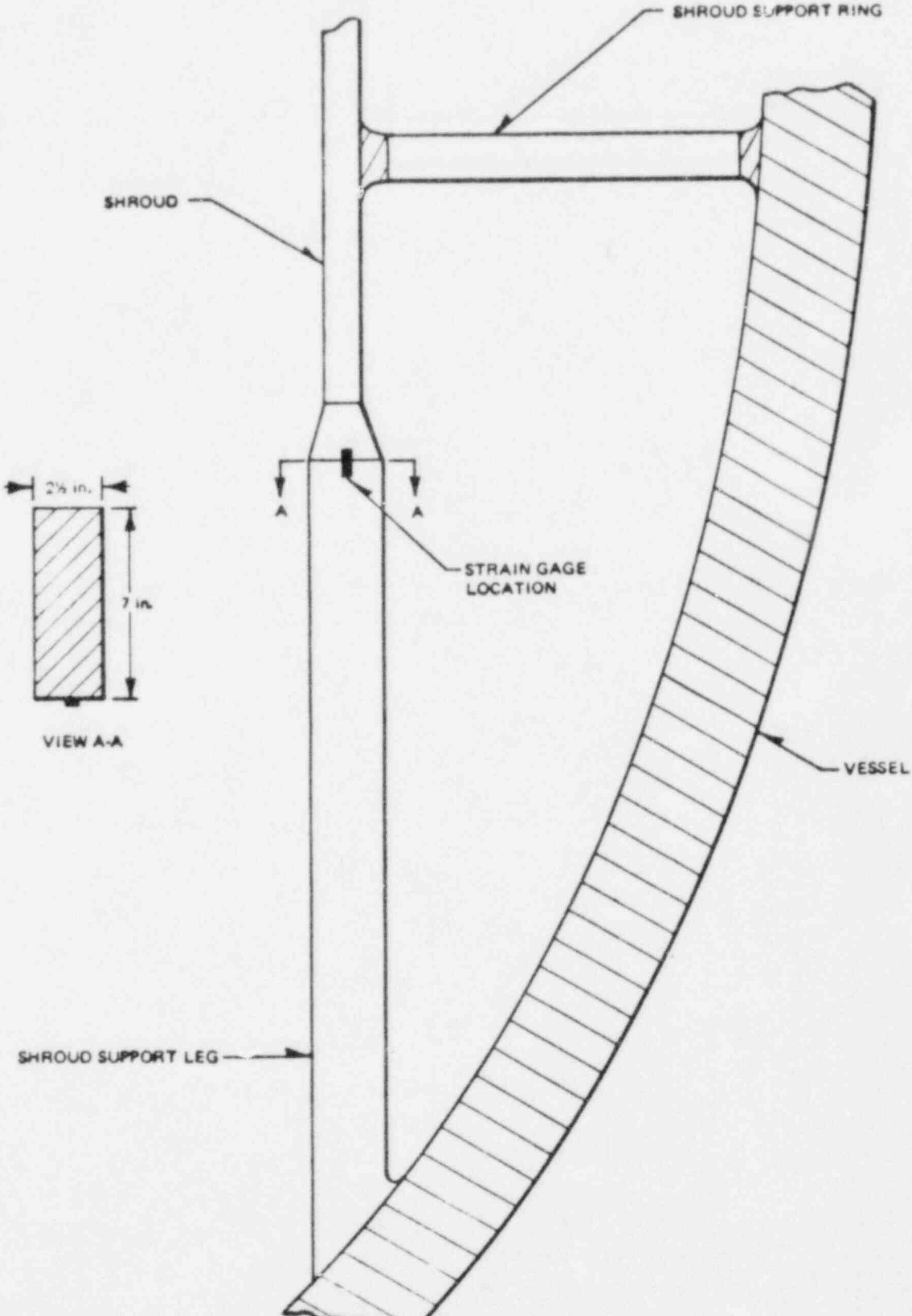



*Figure 4-5. Strain Gage Locations on Shroud Support Legs at Duane Arnold.*

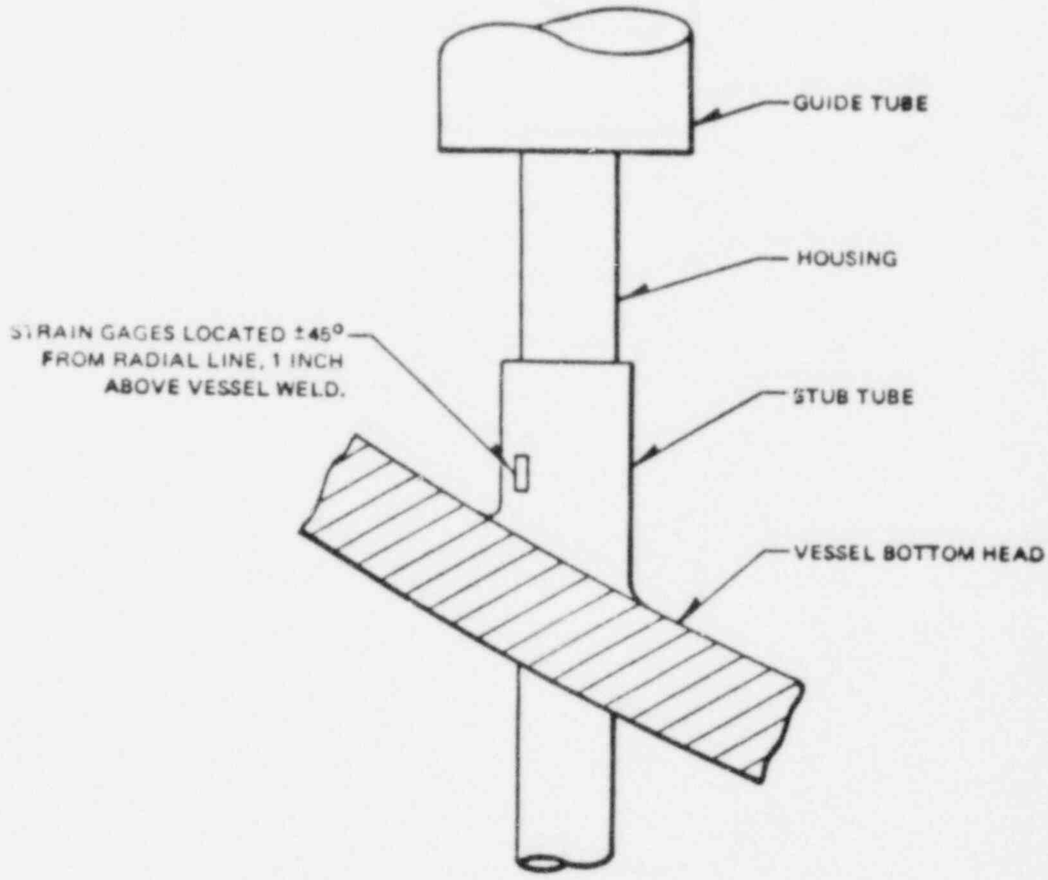



*Figure 4-6. Strain Gage Locations on Control Rod Housing Stub Tube.*

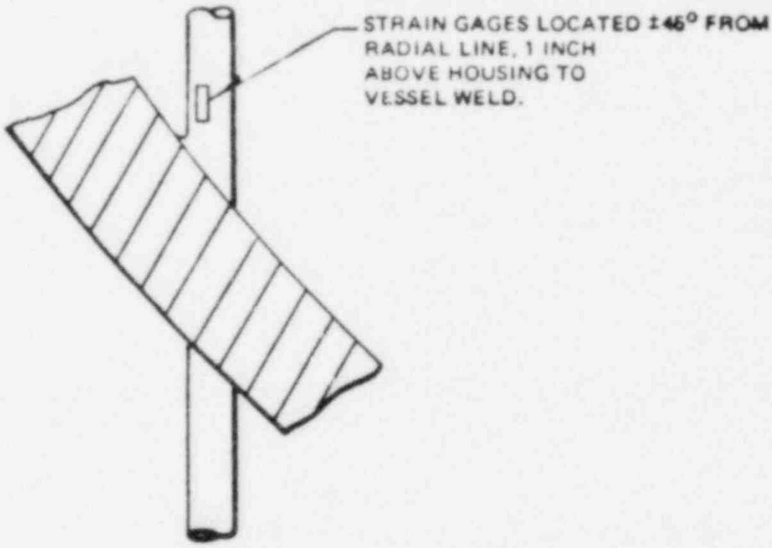



*Figure 4-7. Strain Gage Locations on In-Core Housing.*

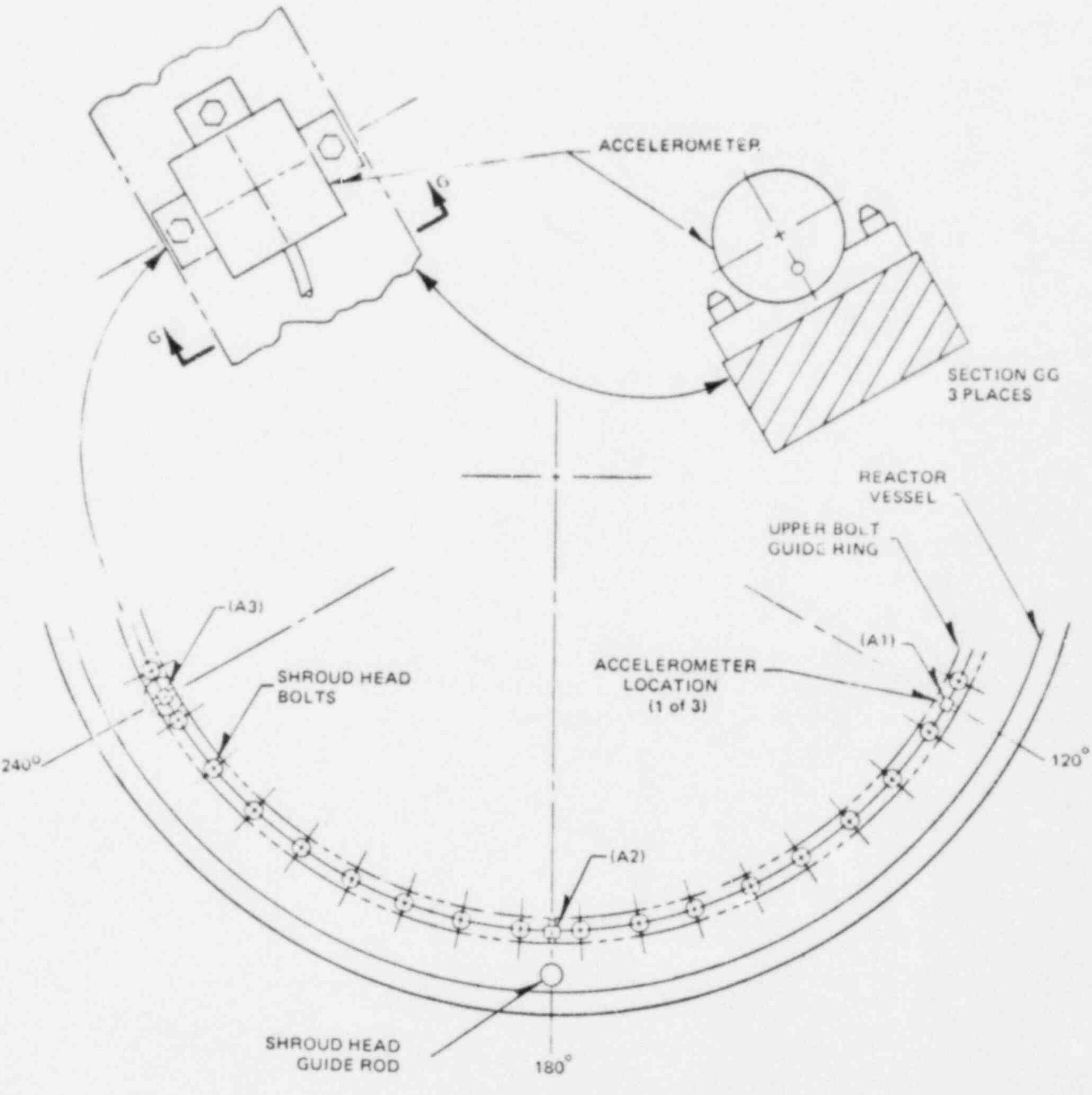



*Figure 4-8. Accelerometer Locations on Upper Bolt Guide Ring.*

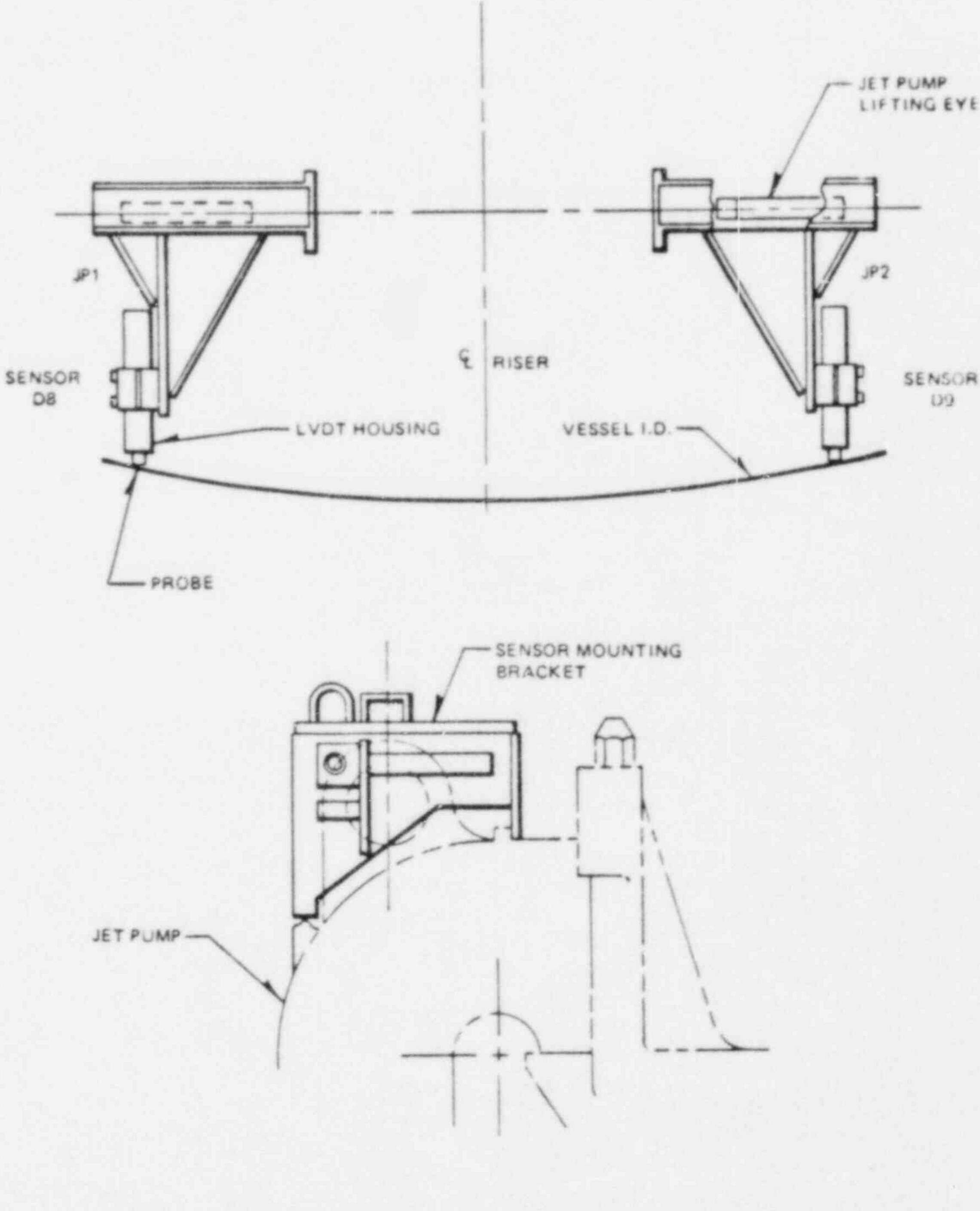
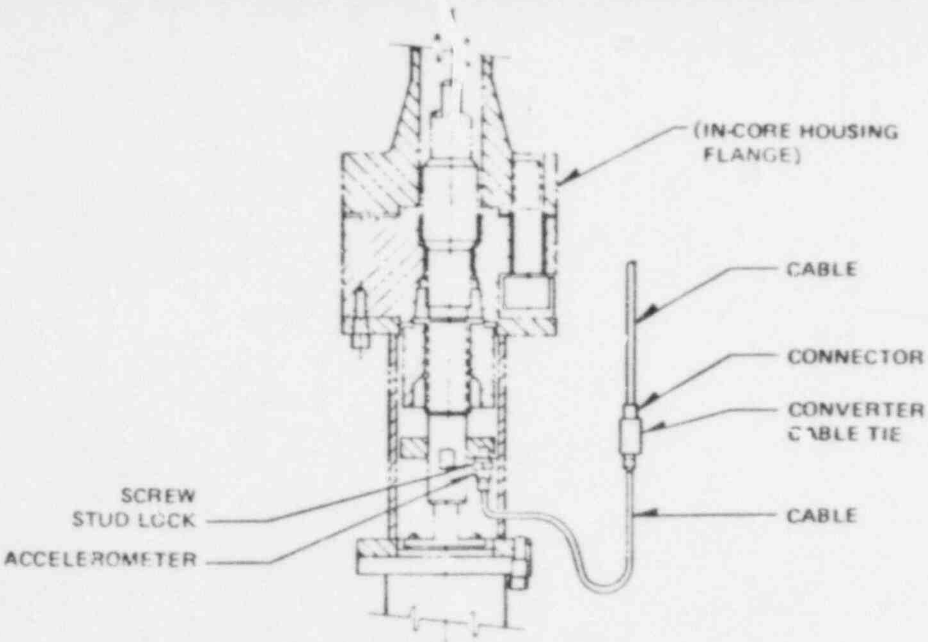
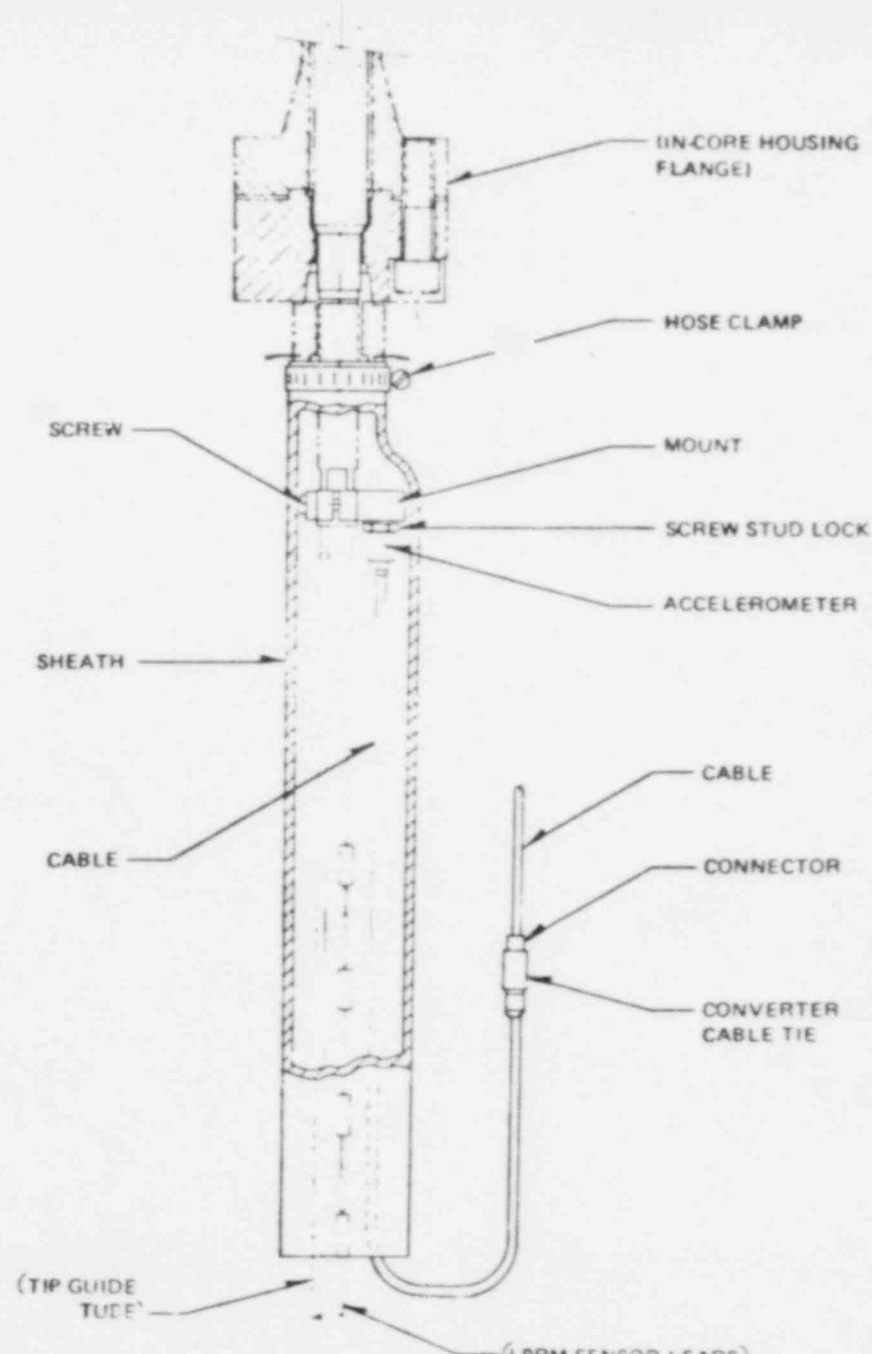



*Figure 4-9. Displacement Sensor (LVDT) Installation on Top of Jet Pump (Brown's Ferry-1)*




ACCELEROMETER INSTALLATION ON IRM

| INSTRUMENTED TYPE | TUBES LOCATION |
|---|---|
| LPRM | 08-17 |
| LPRM | 32-17 |
| LPRM | 40-09 |
| IRM | 40-21 |
| LPRM | 32-33 |
| LPRM | 40-33 |
| LPRM | 32-49 |
| LPRM | 32-57 |




ACCELERUMETER INSTALLATION ON LPRM

*Figure 4-10. Accelerometer Locations on In-Core Instrument Tubes at Browns Ferry 3. Parentheses denote reactor hardware.*

A summary of the internal vibration instrumentation in prototype plants is given in Tables 4-2 through 4-6. In these tables, sensor numbers are prefixed by A for accelerometer, D for displacement sensor (LVDT) and S for strain gage.

## 4.3 TEST CONDITIONS

In prototype plants, vibration measurements were made during preoperational, precritical, and plant startup testing. Vibration of in-core instrument tubes was monitored during precritical and startup testing at Browns Ferry 3. Feedwater sparger vibration data in Cooper, Browns Ferry 2, and Brunswick 1 were recorded only during startup testing.

### 4.3.1 Preoperational Tests

Preoperational testing of prototype plants was performed prior to fuel loading, with all internal components installed except the fuel assemblies and the incore instrumentation. The recirculation system was operated at flow rates up to and exceeding rated mass flow, with water temperature in the range of 100 to 200°F. The reactor vessel was flooded with water to a level above the top flange. Balanced, unbalanced, and transient flow conditions were obtained. The recirculation system was operated a minimum of 48 hours at the maximum flow condition, followed by inspection of internals (see Subsection 4.4).

### 4.3.2 Precritical Tests

Precritical testing was performed after fuel loading, with the reactor assembly complete. Flow and temperature conditions were similar to those for preoperational testing, but the test was of shorter duration.

### 4.3.3 Startup Tests

Vibration measurements were made during startup testing on intermediate and full power load lines* to cover the entire range of possible flow and power conditions of reactor operation. Figure 4-11 shows the specific flow and power conditions for the Fitzpatrick startup vibration measurements. Similar test conditions were obtained at the other plants, except that at Brunswick 1 the two intermediate load lines were combined into one at approximately 60% power. In addition to these balanced flow conditions, unbalanced flow and transient tests were also performed.

### 4.3.4 Flow Modes

Balanced flow conditions (two-loop operation of the recirculation system) produce the highest core and steam separator flow velocities. Single-loop operation produces the highest flow velocities in the jet pumps and in the reactor lower plenum. Unbalanced flow conditions (dissimilar loop flows) can produce high jet pump vibration excitation under certain conditions. Transient tests consisting of single-pump and two-pump trips are performed to provide flow sweeps from which possible critical flow conditions of pump speeds can be identified.

## 4.4 INSPECTION PROGRAM

A direct close-up visual inspection of internals were conducted in each of the prototype plants following the preoperational tests (Subsection 4.3.1). These tests included 48 hours at high flow, which produced in excess of $10^6$ cycles of vibration of major internals at their lowest dominant response frequencies. Following this test, the vessel head, the dryer, and the shroud head were removed and the vessel was drained. Access to the lower plenum was provided by opening a manhole in the shroud support.

Figures 4-12 and 4-13 show the key dimensions affecting lower plenum access to the 218 and 251 size BWR/4's. There is sufficient clearance to permit direct observation of all the peripheral control rod and in-core guide tubes

*A load line is obtained at a fixed control rod pattern which produces a designated power level at rated recirculation flow. See Figure 4-11.

**Table 4-2**
**SHROUD, SHROUD SUPPORT, AND SHROUD HEAD VIBRATION INSTRUMENTATION**

| | Browns Ferry 1 (251-BWR/4) | Fitzpatrick (218-BWR/4) | Duane Arnold (183-BWR/4) |
|---|---|---|---|
| Shroud Head — Tangential Motion at upper bolt Guide ring | A1, A2, A3 | A1, A2, A3 | A1, A2, A3 |
| Shroud Head Flange | | | |
| Radial | D2, D4 | D2, D4 | D1, D3 |
| Tangential | D1, D3 | D1, D3 | D2, D4 |
| Shroud Wall, Radial | | | A4, A5, A6 |
| Shroud Support Legs (axial strain) | S29, S38, S45 | (gusset shroud support) | S35, S36, S37 |

**Table 4-3**
**JET PUMP VIBRATION INSTRUMENTATION**
**BROWNS FERRY 1 (251-BWR/4)**

| Jet Pump Pair: | 1-2 | 3-4 | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 | 17-18 | 19-20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Riser Brace, Top Outside | | | S5 | S3 | S1 | | | S17 | S15 | S13 |
| Riser Brace, Bottom Inside | | | S6 | S4 | S2 | | | S18 | S16 | S14 |
| Riser Brace, Outside Edge | S10 | S7 | | | | S22 | S19 | | | |
| Riser Brace, Inside Edge | S12 | S9 | | | | S24 | S20 | | | |
| Riser Brace, Bottom Center | S11 | S8 | | | | S23 | S21 | | | |
| Top of Riser, Tangential | D7 | | D5 | | | | | | | |
| Top of Riser, Vertical | D6 | | | | | | | | | |
| 180° Elbow, Radial | D8,D9 | | | | | | | | | |
| Top of Diffuser, Tangential | D10,D12 | | | | | | | | | |
| Top of Diffuser, Radial | D11,D13 | | | | | | | | | |

**Table 4-4**
**JET PUMP VIBRATION INSTRUMENTATION**
**FITZPATRICK (218-BWR/4)**

| Jet Pump Pair: | 1-2 | 3-4 | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 | 17-18 | 19-20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Riser Brace, Top Outside | S10 | S8 | S6 | S3 | S1 | S20 | S18 | S15 | S13 | S11 |
| Riser Brace, Bottom Inside | S9 | S7 | S5 | S4 | S2 | S19 | S17 | S16 | S14 | S12 |
| Top of Riser, Tangential | D8 | | D11 | | | | | | | |
| 180° Elbow, Radial | D6,D12 | | D7,D9 | | | | | | | |
| Top of Diffuser, Tangential | D15 | | | | | | | | | D14 |
| Top of Diffuser, Radial | D16 | | | | | | | | | D13 |
| Top of Riser, Vertical | D5 | D10 | | | | | | | | |

**Table 4-5**
**JET PUMP VIBRATION INSTRUMENTATION**
**DUANE ARNOLD (183-BWR/4)**

| Jet Pump Pair: | 1-2 | 3-4 | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 |
|---|---|---|---|---|---|---|---|---|
| Riser Brace, Top Outside | S1 | S3 | S5 | S7 | S9 | S11 | S13 | S15 |
| Riser Brace, Bottom Inside | S2 | S4 | S6 | S8 | S10 | S12 | S14 | S16 |
| 180° Elbow, Radial | | | D5,D6 | D7,D8 | | | | |
| Top of Riser, Vertical | | | D9 | D11 | | | | |
| Top of Riser, Tangential | | | D10 | D12 | | | | |
| Top of Diffuser, Tangential | | | | D15 | D13 | | | |
| Top of Diffuser, Radial | | | | D16 | D14 | | | |

Table 4-6
CONTROL ROD GUIDE TUBE AND
INCORE GUIDE TUBE VIBRATION INSTRUMENTATION

| | Browns Ferry 1 (251-BWR/4) | | Duane Arnold (183-BWR/4) | |
|---|---|---|---|---|
| | Location | Sensors | Location | Sensors |
| Control Rod Guide Tube (Sensor on CRD Stub Tube at Vessel Weld) | 50-51 | S27,S28 | 38-23 | S17,S18 |
| | 54-31 | S32,S33 | 42-23 | S19,S20 |
| | 58-31 | S34,S35 | 42-19 | S21,S22 |
| | 54-15 | S39,S40 | 38-11 | S23,S24 |
| | 42-03 | S43,S44 | 19-03 | S25,S26 |
| Incore Guide Tube (Sensors on housing at vessel weld) | 48-53 | S25,S26 | 32-25 | S27,S28 |
| | 56-33 | S30,S31 | 40-25 | S29,S30 |
| | 56-17 | S36,S37 | 08-13 | S31,S32 |
| | 40-17 | S41,S42 | 08-09 | S33,S34 |

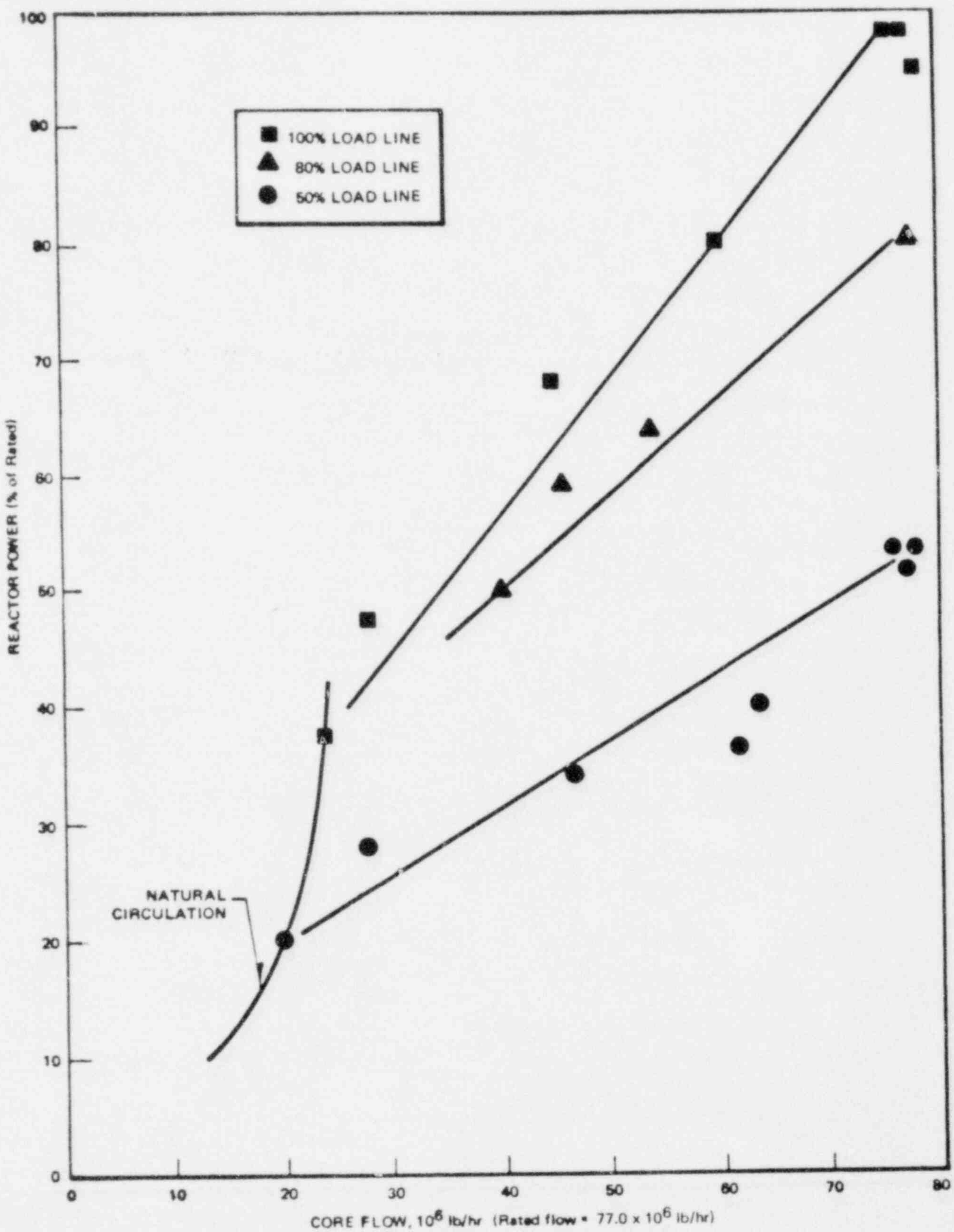



*Figure 4-11. Startup Test Conditions for Vibration Measurements (Fitzpatrick). (balance loop flows only)*

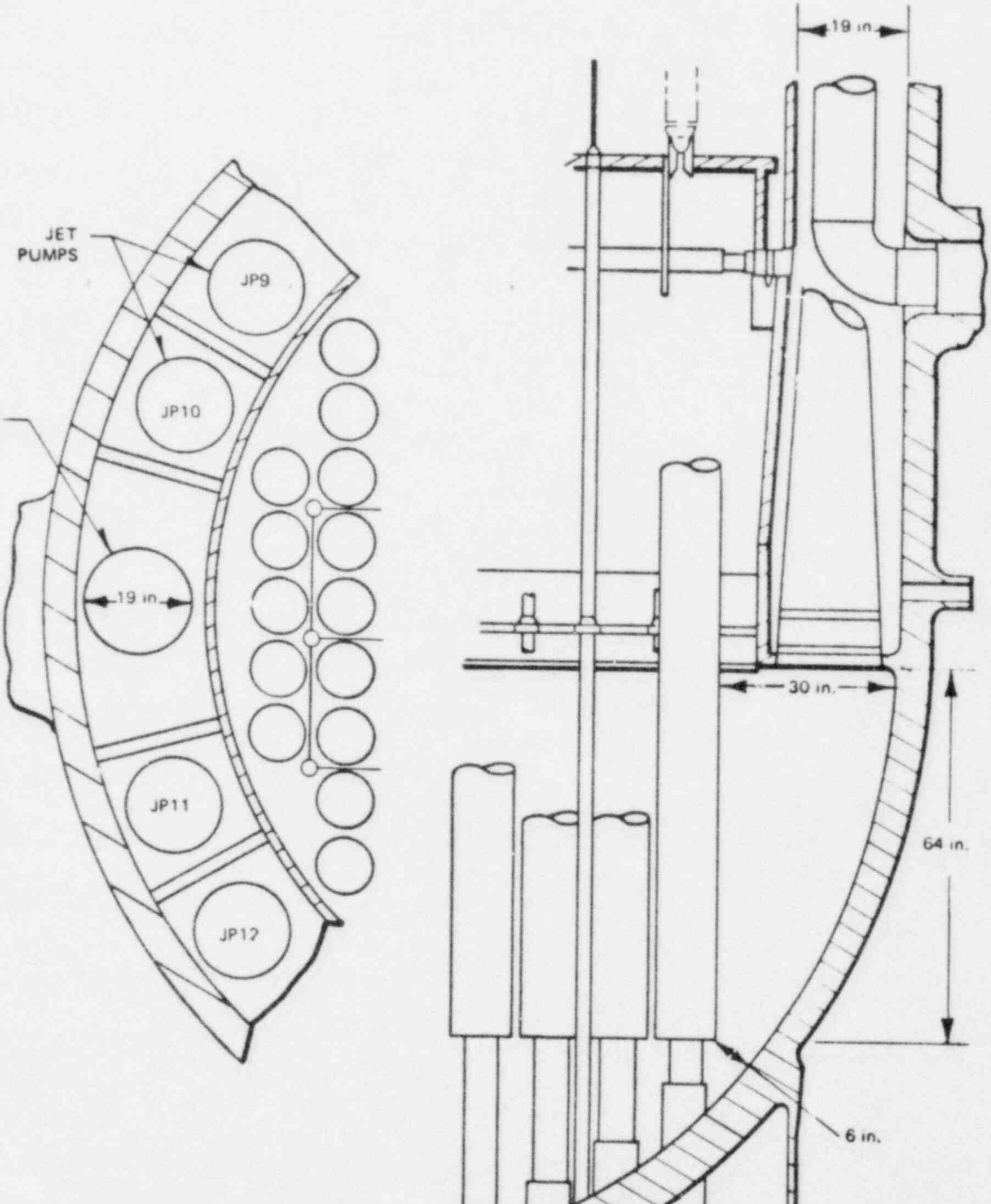



*Figure 4-12. Lower Plenum Access 218-BWR/4 (Fitzpatrick).*

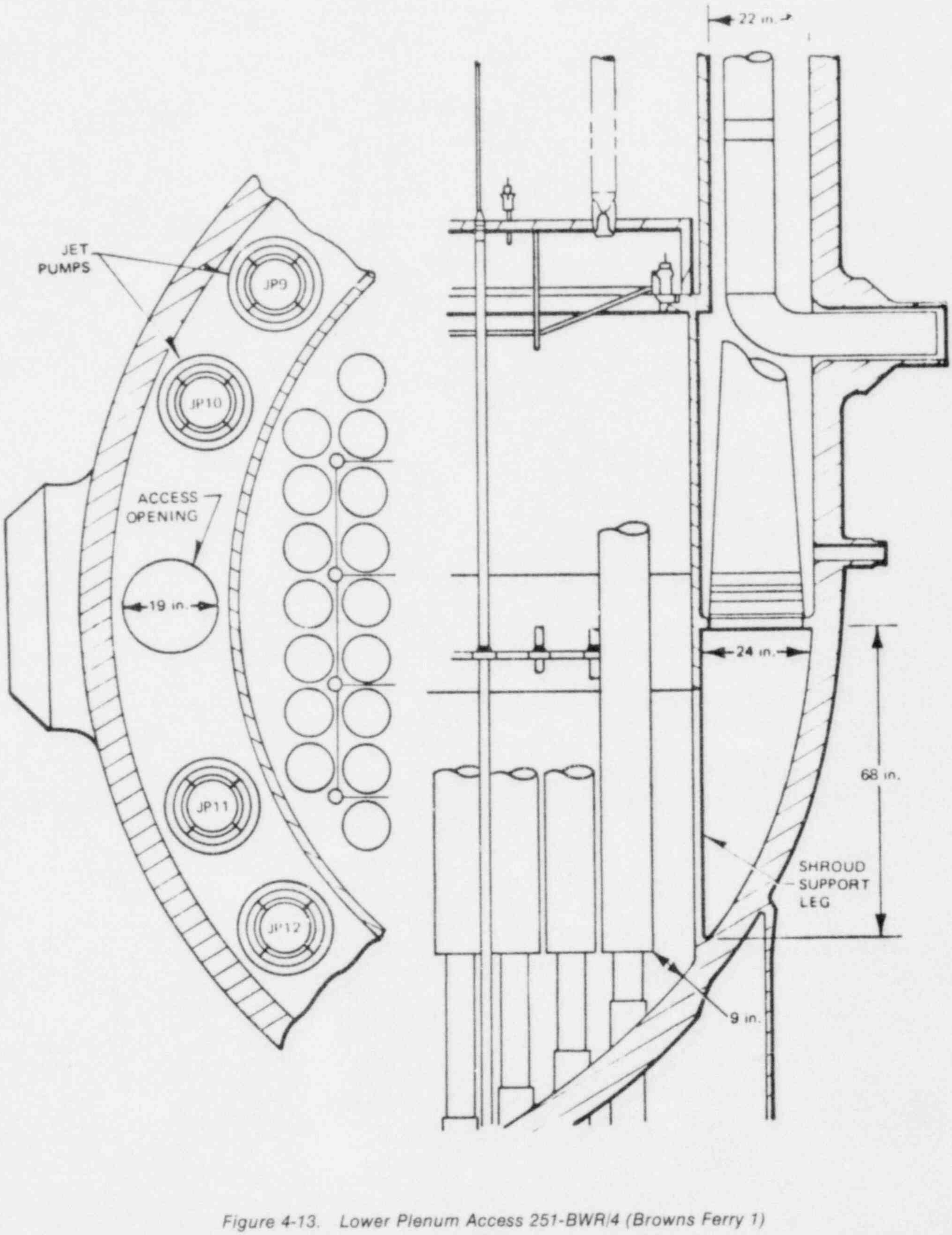



*Figure 4-13. Lower Plenum Access 251-BWR/4 (Browns Ferry 1)*

and of the welds joining the jet pumps and the shroud to the shroud support plate. In the shroud-to-vessel annulus, there is sufficient clearance between the outermost jet pumps (JP 10 and 11 in the examples shown) to permit direct observation of the full length of these jet pumps.

Inspection of internals by direct visual observation was conducted. No wear, cracking, loosening of bolts, debris or loose parts or other evidence indicative of a vibration problem were observed. The scope of the inspection was as follows:

a. Peripheral control rod drive and in-core guide tubes, housings, and their lower joints.

b. In-core guide tube stabilizer connections and stabilizer bars. Plenum region for evidence of loose and/or failed parts.

c. Inside surfaces of the jet pump adapter to shroud support welds and jet pump diffuser to jet pump adapter welds.

d. Liquid control and delta pressure line and bracket welds.

e. The shroud-to-shroud support weld.

f. Jet pump instrument lines and brackets.

g. The jet pump annulus for evidence of loose parts.

h. Jet pump beams, beam bolts, wedges, and locator screws.

i. Jet pump riser braces and welds.

j. Shroud head and shroud bolt lug welds.

k. Shroud and shroud head flange locating pins for evidence of deleterious motion marks other than those caused from normal installations.

l. Core support plate bolt keepers.

m. Steam separators and standpipes, shroud head bolt support ring brackets and supports.

n. Feedwater sparger and attachments.

o. Core spray lines, brackets, and core spray spargers.

## 4.5 DATA ACQUISITION SYSTEM

The vibration measurement system is composed of the transducers, the signal conditioning units, magnetic tape recorders, and chart recorders. Figure 4-14 is a block diagram of the measurement systems. Appendix A contains specifications of system components.

Strain gages are used either singly or in pairs to form a quarter or half of a Wheatstone bridge circuit. Excitation is provided at 5V and 3kHz. The modulated 3kHz signal is converted to ± 1V dc for ± 100 microstrain ($\mu\epsilon$) by the demodulator. The oscillator and demodulator are Validyne models MC1-20 and CD-19, respectively.

A 3kHz excitation voltage is provided to the accelerometer by the special balance unit. A linear amplifier and integrator is used to convert the accelerometer output to displacement units. These Validyne Model AM49 units have a frequency response of 2 Hz to 5 kHz.

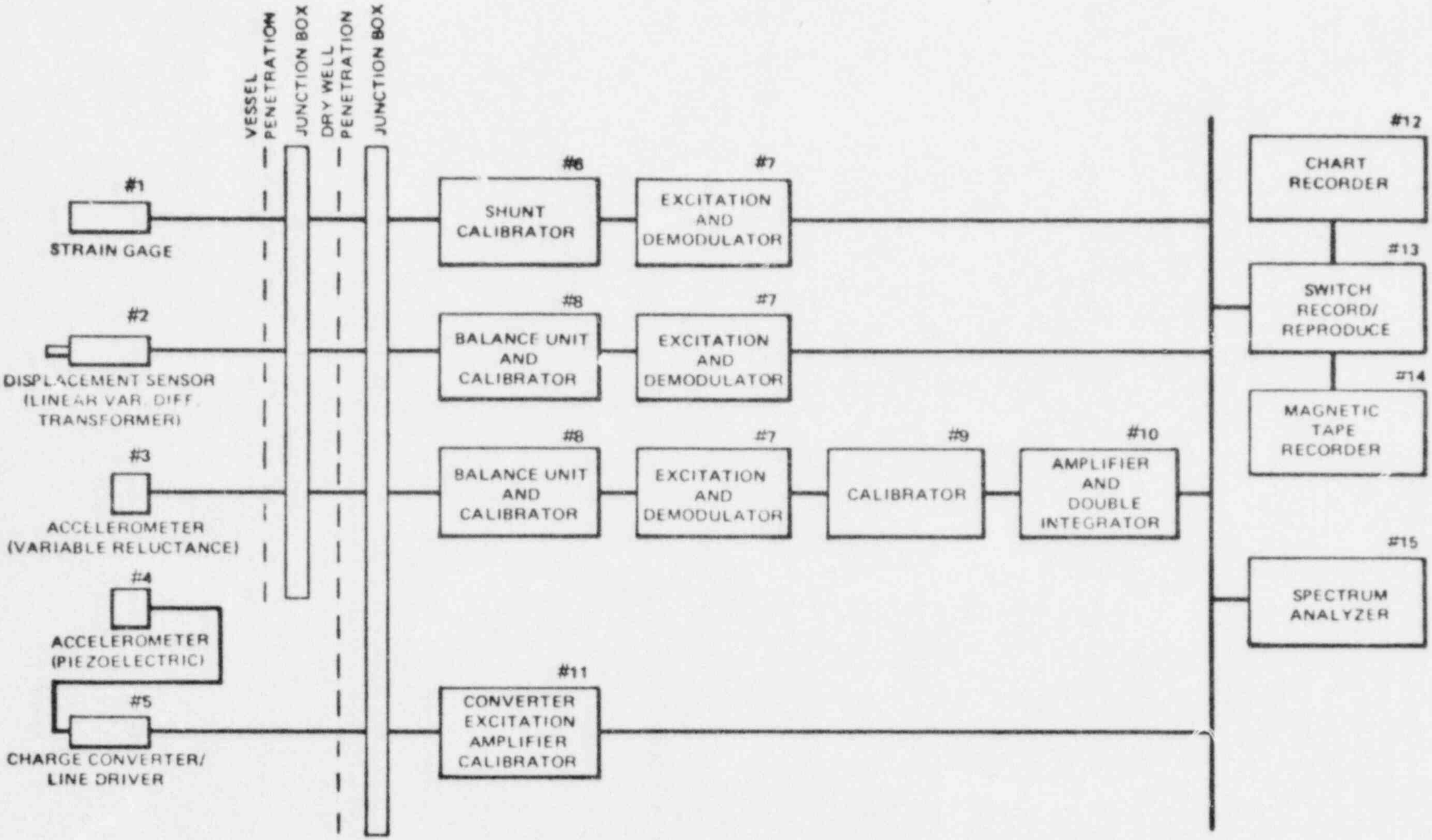



*Figure 4-14. Block Diagram of Vibration Measurement Systems. For component specifications, see Appendix A).*

The block diagram of the LVDT system is similar to that for the strain gage, except that the shunt/calibrate unit is replaced by a specially built balance box which provides input to the demodulator. The balance box can be switched to apply a calibration signal to the demodulator.

The demodulated signals are recorded on tape and chart recorders. The 14-channel FM tape recorders, operated at 15 inches per second, have a center frequency of 27 kHz and an information frequency range of zero to 5kHz. The 6-channel Brush chart recorders have channel widths of 40 mm with 50 divisions per channel. The frequency response of the pen is 40 Hz at full scale and 100 Hz at 10 divisions.

System calibration procedures provide an overall sensitivity of 0.0005 inch (1/2 mil) per chart division for the LVDT output and the double-integrated accelerometer output, and 5 $\mu\epsilon$ per chart division for the strain gages. The tape recorder input sensitivity is 0.010 inch per volt for the accelerometers and LVDTs, and 100 $\mu\epsilon$ per volt for strain gages. The spectrum analyzer used in conjunction with this data acquisition system is a Barry Research 2002A Number 6 model, used with a Hewlett-Packard 7035B x-y recorder.

The output of the externally mounted Endevo accelerometer and charge converter system is fed to a signal conditioning amplifier with variable attenuator settings. Output is recorded on a high speed, 6-channel chart recorder (Honeywell Model 1858 0 to 5000 Hz) and also on an FM tape recorder operated at 30 inches per second, with a center frequency of 54 kHz and an information frequency range of zero to 10 kHz.

# 5. RESULTS OF VIBRATION MEASUREMENTS

## 5.1 SUMMARY

In this section, results of the vibration measurements are presented on a component basis. Results from all plant tests of a particular component type are presented concurrently. First, startup test results are presented and compared to acceptance criteria, establishing the adequacy of design margins in actual reactor operating conditions. Then, vibration amplitudes in preoperational testing are compared to those in normal power operating modes to establish the preoperational test as an adequate simulation of reactor operating conditions.

The complete data record for a prototype plant test is voluminous, involving typically 50 to 60 vibration sensors and a like number of test points. The results presented in this report reflect maximum measured vibration amplitudes, or are selected for purposes of example and illustration of the methods which were used in evaluation of the results.

## 5.2 SHROUD AND SHROUD HEAD ASSEMBLY

### 5.2.1 Startup Test Results

(GE Company Proprietary)

(GE Company Proprietary)

### 5.2.2 Shroud Support Design Variations

Some BWR/4's utilize shroud support legs to reinforce the shroud plate, while others utilize gusset plates for this purpose. A comparison of analysis and test results for Fitzpatrick, which utilizes the gussets, and Brunswick 1 and 2, which utilize shroud support legs, shows that there is no significant difference between these designs from the standpoint of vibration characteristics. The Fitzpatrick and Brunswick plants are 218 size BWR/4's.

These comparisons are shown on the table below.

| | **Calculated Natural Frequencies** | |
|---|---|---|
| | **Mode 1** | **Mode 2** |
| Fitzpatrick (gusset) | 4.74 Hz | 6.20 Hz |
| Brunswick (support legs) | 4.76 Hz | 6.13 Hz |

| | **Measured Vibration Responses** | |
|---|---|---|
| | **Amplitude (mils)** | **Frequency (Hz)** |
| Fitzpatrick (gusset) | | |
| normal operation | 11 | 4.8 |
| natural circulation | 11 | 5.2 |
| Brunswick 1 (support legs) | | |
| normal operation | 10 | 5.4 |
| natural circulation | 11 | 5.5 |
| Brunswick 2 (support legs) | | |
| normal operation | 11.5 | 5.2 |

### 5.2.3 Preoperational Test Results

(GE Company Proprietary)

(GE Company Proprietary)

In summary, shroud and shroud head vibration amplitudes are within acceptable limits in all test conditions and are significantly higher in preoperational test conditions than in startup and normal operating conditions.

## 5.3 JET PUMPS

### 5.3.1 Startup Test Results

(GE Company Proprietary)

Table 5-1
VIBRATION TEST RESULTS

FITZPATRICK JET PUMPS 1 AND 2
MAXIMUM PEAK-TO-PEAK AMPLITUDES AND ASSOCIATED FREQUENCIES
(GE Company Proprietary)

(GE Company Proprietary)

(GE Company Proprietary)

Table 5-2
VIBRATION TEST ACCEPTANCE CRITERIA

FITZPATRICK JET PUMPS 1-2

| Mode | Mode Shape* | Frequency Hz | S10 ($\mu\epsilon$) | S9 ($\mu\epsilon$) | D5 (mils) | D8 (mils) | D6 D12 (mils) | D16 (mils) | D15 (mils) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Allowable Amplitudes | | | | | | |
| 1 | T,A | 23.4 | +97 | −97 | — | 42 | — | — | 21 |
| 2 | R-V,S | 23.9 | +186 | −7 | 32 | — | 78 | 64 | — |
| 3 | R-V,S | 29.2 | +129 | −132 | 25 | — | 38 | — | — |
| 4 | R,A | 32.5 | −95 | −29 | — | 11 | 20 | 36 | — |
| 5 | T,A | 33.1 | 221 | −204 | — | 8 | — | — | 18 |
| 6 | R-V,S | 38.6 | −104 | +250 | 44 | — | 32 | — | — |
| 7 | R,A | 40.9 | +98 | −239 | — | 7 | 14 | 152 | 12 |
| 8 | R,S | 42.2 | +33 | — | 17 | — | 80 | 104 | — |
| 9 | T,S | 47.6 | +26 | −33 | — | — | — | — | 66 |
| 10 | T,A | 48.7 | — | — | — | 30 | — | — | 97 |

*R = Radial
T = Tangential
V = Vertical
S = Symmetric Deformed Shape
A = Antisymmetric Deformed Shape

(GE Company Proprietary)

Table 5-3
EVALUATION OF TEST RESULTS

F[illegible]PATRICK JET PUMPS 1 AND 2
(GE Company Proprietary)

(GE Company Proprietary)

Table 5-4
MAXIMUM AMPLITUDES OF JET PUMP VIBRATION
AT DUANE ARNOLD DURING STARTUP TESTING
(GE Company Proprietary)

(GE Company Proprietary)

Table 5-5
**MAXIMUM AMPLITUDES OF JET PUMP VIBRATION AT BROWNS FERRY 1 DURING STARTUP TESTING**
**(GE Company Proprietary)**

**(GE Company Proprietary)**

### 5.3.2 Preoperational Test Results

Table 5-6 is a comparison of preoperational to startup test results for all of the strain gages on the Fitzpatrick jet pumps. Vibration amplitudes in preoperational testing are comparable to those in power operating conditions, although they are not uniformly higher. However, maximum amplitudes in one-loop preoperational testing are substantially higher than those at rated power.

A similar comparison of the Browns Ferry 1 jet pump test results for preoperational and startup conditions showed that preoperational testing yielded generally higher responses. **(GE Company Proprietary)**

From these results it is concluded that preoperational testing adequately simulates the jet pump vibration responses in power operation. In current and future preoperational flow tests, extended operation in the one-loop mode is specified, so as to produce a minimum of $10^6$ cycles of jet pump vibration at amplitudes higher than those in normal operation. The specified test duration in one-loop operation is 14 hours on each recirculation loop, which produces $10^6$ cycles at the lowest dominant response frequency of 20 Hz (See Subsection 7.2.2).

## 5.4 CONTROL ROD AND INCORE GUIDE TUBES

### 5.4.1 General

Sensor locations for these components were shown in Figures 4-6 and 4-7 and in Table 4-6. Vibration measurements were made in both Browns Ferry 1 and Duane Arnold. Results from both plants were similar, although more data was obtained from Duane Arnold because of sensor failures in Browns Ferry 1.

The Duane Arnold 183 size BWR/4 results are considered applicable to the entire BWR/4 and BWR/5 product line, because designs of these components are all similar and flow velocities are highest in Duane Arnold. Model tests have been conducted which show that the peripheral guide tubes are subject to the highest crossflow velocities, and that this velocity is essentially equivalent to the jet pump discharge velocity. These velocities are shown in Table 4-1.

Table 5-6
FITZPATRICK JET PUMP VIBRATION
RISER BRACE STRAIN (MICROSTRAIN) AT FREQUENCY (Hz)
MAXIMUM FLOW CONDITIONS
(GE Company Proprietary)

(GE Company Proprietary)

### 5.4.2 Test Results

Vibration of the control rod guide tube and housing assembly, as measured by strain gages near the housing stub tube to vessel weld (Figure 4-6), is very low and well within acceptable limits. Maximum amplitudes at Duane

(GE Company Proprietary)

Vibration amplitudes for in-core housing and guide tube assemblies in Duane Arnold, as measured by strain gages near the vessel penetration (Figure 4-7), are summarized in Table 5-7. Amplitudes are substantially higher in one-loop operations as compared to balanced flow conditions, because jet pump discharge velocities are approximately 50% higher in one-loop operation. However, amplitudes are well within acceptable limits in all test conditions.

(GE Company Proprietary)

Results in Table 5-7 show no significant difference in vibration response characteristics in preoperational as compared to startup test conditions, supporting the conclusion that preoperational test conditions adequately simulate reactor operating conditions.

**Table 5-7**
**VIBRATION TEST RESULTS FOR INCORE GUIDE TUBES AT DUANE ARNOLD**
**(GE Company Proprietary)**

(GE Company Proprietary)

## 5.5 FUEL CHANNELS

(GE Company Proprietary)

## 5.6 FEEDWATER SPARGERS

(GE Company Proprietary)

(GE Company Proprietary)

### 5.7 IN-CORE INSTRUMENT TUBE

Browns Ferry 3 is the first domestic BWR/4 to adopt the in-core vibration fix, which consists of a plugged core plate and holes in the fuel lower tie plate to augment leakage flow. Results of in-core vibration and impact monitoring showed acceptable levels of vibration.The thimble-mounted accelerometers (Figure 4-10) showed activity at some locations, which may be indicative of intermittent low-level impacting; however, amplitudes were no higher than those previously detected in a reactor with no leakage augmentation holes. The internal straingages showed evidence of low-amplitude motion of the in core tubes at their natural frequencies.

(GE Company Proprietary)

(GE Company Proprietary)

## 5.8 DYNAMIC PRESSURE MEASUREMENTS

(GE Company Proprietary)

# 6. ANALYSIS

## 6.1 TEST ACCEPTANCE CRITERIA

The maximum allowable peak stress amplitude (Sa) for sustained vibration stress has been specified as 10,000 psi for BWR internals of Type-304 stainless steel. This is more conservative than the current ASME Section III allowable alternating stress of 26,000 psi for cycles in excess of $10^6$, and is considered applicable for projected in-service vibration cycles of $10^9$ or more.

To apply this criterion, a dynamic structural analysis is performed to relate peak stresses to the measured strains or displacements at sensor locations. The steps in this analysis are as follows:

1. Mathematical models are developed using finite element computer codes. The model for the composite structure, including the fuel, shroud, steam separators, reactor pressure vessel, and control rod guide tubes, is the seismic analysis model for these components. Separate models of the jet pump and feedwater spargers are required.

2. Natural vibration modal displacements, stresses, and frequencies are calculated for each of the lower modes.

3. The location of highest peak stress is identified, and the modal strains and displacements at sensor locations are determined relative to the peak stress on a normalized basis, such that the highest peak stress in each mode is 20,000 psi. This is the allowable stress range, twice the allowable amplitude.

4. The resulting table of strains and displacements for each natural vibration mode and frequency is the criteria used for evaluation of test results. Table 5-2 is an example of such a table.

In applying the criteria, the natural mode shape which best approximates the observed mode is determined by considering relative amplitudes at different sensor locations on the structure and also by comparison of observed to calculate frequencies. The stress comparison is then made on the basis of the sensors which are most sensitive to vibration in this mode.

## 6.2 DATA ANALYSIS METHODS

Vibration amplitudes and frequencies are determined by direct measurement from the chart records. The magnetic tape data is available as a backup if other data analysis methods are required. Taped data is evaluated when the vibration response frequency exceeds the linear range of the chart recorders.

Frequencies are measured from chart records by means of a variable scale. Amplitudes are characterized by maximum peak-to-peak values occurring over a period of time, generally 1 minute or more. This is conservative in that the criteria are based on the assumption of vibration at a constant sustained amplitude, whereas actual vibration amplitudes are generally random and seldom reach the reported values.

Response spectrum plots were made for each sensor at several test conditions. These serve as an aid in identifying predominant response frequencies. Spectra are obtained off-line or from the magnetic tape records.

## 6.3 VIBRATION PREDICTION

Expected vibration responses of major components in prototype plants were predicted to the in-plant tests. This prediction was based on a special analysis of the response signals measured from reactor internals or similar design. This vibration prediction method is particularly appropriate where standard hydrodynamic theory cannot be applied due to complexity of the structure and flow conditions. Elements of the vibration prediction method are outlined as follows:

1. Dynamic analysis of major components and subassemblies is performed to identify natural vibration modes and frequencies. (See Section 6.1 above).

2. Data from previous plant vibration measurements is assembled and examined to identify predominant vibration response modes of major components. In general, response modes are similar but response amplitudes vary among BWRs of differing size and design.

3. Parameters are identified which are expected to influence vibration response amplitudes among the several reference plants. These include hydraulic parameters such as velocity and steam flow rates and structural parameters such as natural frequency and significant dimensions.

4. Correlation functions of the variable parameters are developed which, multiplied by response amplitudes, tend to minimize the statistical variability between plants. A correlation function is obtained for each major component and response mode.

5. Predicted vibration amplitudes for components of the prototype plant are obtained from these correlation functions, based on applicable values of the parameters for the prototype plant. The predicted amplitude for each dominant response mode is stated in terms of a range, taking into account the degree of statistical variability in each of the correlations. The predicted mode and frequency are obtained from the dynamic analyses of Paragraph 1 above.

Details of the vibration prediction methodology are given in Appendix B, which is the 251 size BWR/4 prototype vibration prediction previously documented in the Browns Ferry 1 FSAR.

Table 6-1 presents the correlation functions which were determined by step 4 above. The parameters from which these correlation functions were derived are:

a) For the Shroud and shroud head structure:
   Steam flow per separator, $Q_0$
   Shroud diameter, $D_S$
   Reactor power, P
   Calculated fundamental frequency, $f_1$

b) For the jet pumps:
   The ratio of driven flow to drive flow, M
   Jet pump nozzle velocity, $V_n$

c) For the control rod guide tubes
   Jet pump diffuser exit velocity, $V_D$
   Shroud diameter, $D_S$
   Reactor power, P

Table 6.2 presents the predicted and measured vibration amplitudes for the 251 size BWR/4 prototype, Browns Ferry 1. The predicted amplitudes are expressed in terms of a range which includes the measured amplitude with 75% confidence, based on the Tchebycheff inequality in statistical analysis which states that 75% of the measurements should fall within two standard deviations of the expected value. Four of five measured amplitudes fall within the predicted range, consistent with the full confidence level for the prediction. The fifth is slightly above the predicted range. These predictions apply at full power, balanced flow conditions; hence, the tabulated amplitudes are not necessarily the highest measured amplitudes.

Table 6.3 presents the predicted and measured vibration amplitudes for the 218 size BWR/4 prototype. Three of five measured amplitudes fall within the predicted range and a fourth is slightly above the predicted range. The fuel channel strain is substantially higher than predicted, but this data was obtained during preoperational cold flow testing rather than in the hot condition for which the prediction applies. As was noted in Section 5.5, the measured fuel channel strains are not significant from a structural viewpoint.

It is concluded from these comparisons that results of vibration measurements in BWR/4 plants are in reasonably good agreement with vibration predictions.

Table 6-1
CORRELATION FUNCTIONS OF VIBRATION PREDICTION

(GE Company Proprietary)

Table 6-2
COMPARISON OF VIBRATION MEASUREMENTS AND PREDICTIONS FOR BROWNS FERRY-1
(GE Company Proprietary)

(GE Company Proprietary)

Table 6-3
COMPARISON OF VIBRATION MEASUREMENTS AND PREDICTIONS FOR FITZPATRICK (218-BWR/4 PROTOTYPE)
(GE Company Proprietary)

(GE Company Proprietary)

# 7. DISCUSSION

## 7.1 BWR/4 VIBRATION MEASUREMENTS

The in-plant test results presented in this report demonstrate the design adequacy of major BWR/4 core support and internal structures with respect to vibration. This has been confirmed by satisfactory operating experience for these components in several BWR/4 plants. Additional confirmation is provided by the results of instrumented confirmatory tests which have been successfully completed in a number of operating plants.

In-service vibration problems with feedwater spargers and in-core instrument tubes resulted in modifications to the original BWR/4 design. These components were not tested in the prototype plants. In both cases, solutions to these problems were developed in flow test facilities (1, 2, 3) and confirmed through in-plant vibration measurements.

The feedwater sparger vibration problem was resolved by using either an interference fit or a welded attachment of the thermal sleeve to the nozzle. Both solutions have been tested in a feedwater sparger test facility and in several operating plants. Additional testing of the welded-in design is planned during 1978 at two foreign plants (Tokai 2 and Chinshan 1) which utilize top-mounted discharge nozzles.

In view of the satisfactory test results in hand and the availability of flow test facilities of proven capability, no additional feedwater sparger or in-core tube vibration measurements are planned in domestic BWR/4 or BWR/5 plants. Future design changes in these components which are not significant departures from previous designs will be tested in the flow test facilities. Specifically, an improved interference fit feedwater sparger, which has features to improve end-of-life performance characteristics, will be tested in the flow facility only. This approach has significant technical advantages, in that conditions of partial deterioration can be tested in the flow facility to establish design margins whereas, the in-plant test can evaluate only the as-installed condition.

Vibration measurements will be conducted in a foreign BWR/4, Chinshan 1, which is the prototype 201-size plant. The shroud head and shroud head flange will be instrumented in a manner similar to Fitzpatrick (see Table 4-1). These test results may be referenced by a domestic 201-size BWR/5, Bailly, which has a shroud structure of similar design.

## 7.2 BWR/4 CONFIRMATORY TESTS

### 7.2.1 Instrumented Confirmatory Tests

Operating BWR/4 plants other than the prototype plants were provided with instrumentation to confirm that vibration of internals is similar to that in the prototype plants. The minimum-scope confirmatory tests consisted of four strain gages on each of two jet pumps, and three accelerometers on the shroud head. Vibration measurements made during startup testing have produced results similar to those for like components in prototype plants. In some cases, special tests of other components such as the feedwater sparger were conducted concurrently.

### 7.2.2 Preoperational Flow Test and Inspection

The extended preoperational flow test followed by inspection of internals will be performed in future BWR/4 and BWR/5 plants in accordance with Regulatory Guide 1.20 for Non-prototype, Category I plants. The flow test and inspection confirms the proper installation and assembly of internals. Extensive vibration measurements in prototype plants, together with satisfactory operating experience, have established the adequacy of these internal design configurations.

The flow test and inspection is similar to that previously conducted in the BWR/4 prototype plants (Section 4.4) except that (1) the inspection is to be conducted before as well as after the test to provide better assurance that any changes due to flow testing are noted, and (2) the test duration is extended from 48 to a total of 63 hours, which is sufficient to produce $10^6$ cycles of vibration of major components at the flow conditions producing the highest vibration amplitudes in the respective components. Thirty-five hours of testing at maximum flow produces $10^6$ cycles of vibration of the shroud and shroud head assembly (see Subsection 5.7.3). Fourteen hours of single loop operation of each recirculation loop produces $10^8$ cycles of vibration of the jet pumps and in excess of $10^8$ cycles of vibration of the incore housings and guide tubes, at conditions of highest vibration response.

The sequence of operations for the BWR/4 confirmatory flow test and inspection is as follows:

1. Conduct inspection of internals (Section 4.4). Record condition of each component.

2. Install temporary cover on lower plenum access hole. Install shroud head and vessel head.

3. Flood vessel and pressurize to approximately 100 psi. The water level will be above the vessel closure flange elevation.

4. Operate recirculation system at rated flow, 100–200°F, in the following flow modes:

| | |
|---|---|
| A-loop only, 14 hours<br>B-loop only, 14 hours<br>2-loop operation, 35 hours | Total test duration, 63 hours |

5. Drain vessel and remove vessel head, shroud head, and lower plenum access cover.

6. Conduct inspection of internals as in Paragraph 1, above.

7. Weld access cover to shroud support plate (prior to fuel loading).

Provisions for inspection access for these tests are as previously discussed in Section 4.4 for the prototype plants. All component types, including those in the reactor lower plenum, are accessible for direct visual observation. Visual aids, such as binoculars and periscopes, may also be used.

### 7.3 BWR/5 VIBRATION MEASUREMENTS

The BWR/5 reactor internals differ from previously tested BWR/4 internals in the use of the five-hole nozzle jet pumps. Instrumentation will be installed in lead BWR/5 plants of each size to measure the jet pump vibration responses. These vibration measurements are planned in Tokai 2 (a 251 size BWR/5), Zimmer (a 218 size BWR/5) and Bailly (a 201 size BWR/5). Four of the ten jet pump assemblies will be instrumented in each of the three plants. Instrumentation on each assembly will consist of four strain gages on the jet pump riser brace and four strain gages on the jet pumps. The gages on the riser braces are near the vessel attachment weld, which is a relatively high stress point in most jet pump vibration modes. The other four gages are primarily to provide additional information for modal identification.

Accelerometers will also be provided on the shroud head upper belt guide ring in these plants to confirm that vibration of the shroud structure is within acceptable limits and similar to that of the respective BWR/4 prototype plants.

Vibration measurements will be made during preoperational, precritical, and startup testing as was done for the BWR/4 prototype plants. A visual inspection of internals will be made before and after the preoperational tests.

This measurement and inspection program is designed to meet requirements of NRC Regulatory Guide 1.20 for Non-prototype, Category II plants.

### 7.4 BWR/5 CONFIRMATORY TESTS

A preoperational flow test and inspection will be performed in La Salle 1 and 2, Hanford 2, and Nine Mile Point 2 in accordance with provisions of Regulatory Guide 1.20 for Non-prototype, Category I plants. Test conditions and inspection procedures are as described in Subsection 7.2.2 for BWR/4 confirmatory tests, except that the flow testing is conducted at a higher temperature. This is necessary to reduce water density and avoid overloading the constant-speed recirculation pumps at high flow rates. Pump heat provides the necessary temperature increase. Currently, it is planned to conduct these preoperational tests at close to normal operating temperature and pressure.

# 8. CONCLUSIONS

## 8.1 VIBRATION MEASUREMENT RESULTS

Extensive vibration measurements of major internal components in prototype BWR/4 plants have shown satisfactory results during all conditions of preoperatonal and initial startup testing. These results together with extensive satisfactory in-service operating experience in 11 BWR/4 plants established valid prototype internals design configurations for reference in the qualification of subsequent similar BWR/4 and BWR/5 plants.

The major components and assemblies which have been tested include: (a) the shroud, shroud support, and shroud head assemblies for the 183, 218 and 251 size BWR/4 and BWR/5 plants; (b) the jet pumps for the 183, 218 and 251 size BWR/4s; and (c) the control rod and in-core guide tube and housing assemblies for all BWR/4 and BWR/5 plants.

The major components remaining to be qualified by in-plant vibration measurements include the BWR/5 jet pumps (to be evaluated in Tokai 2, Zimmer, and Bailly) and the 201 size BWR/4 and BWR/5 shroud and shroud head assembly (to be evaluated in Chinshan 1).

## 8.2 PLANS

Current and future plans for BWR internals vibration testing place increased emphasis on the use of out-of-reactor flow test facilities. Vibration problems which were encountered in BWR/4 plants with feedwater spargers and incore instrument tubes have been resolved by design modifications which were developed in flow test facilities and subsequently confirmed through in-plant tests.

The availability of flow test facilities of proven capability permits vibration testing of internal component designs on a more timely basis and in greater depth than does in-reactor testing. Assembly and flow parameters can be varied over a greater range in test facilities than is possible in the reactor, leading to a more comprehensive evaluation of design margins

Recognizing this, General Electric has under construction a large high-flow hydraulic facility ($HF^2$) capable of full-scale vibration testing of jet pumps, lower plenum components, and in-core components as well as smaller internal components. The $HF^2$ facility together with other smaller flow facilities will be used in the future to assess the vibration performance of BWR internals designs. In-plant vibration measurements will be made as necessary to confirm and supplement results from test facilities.

## 8.3 PROTOTYPE PLANT TEST RESULTS

Results of prototype plant tests establish the preoperational flow test and inspection as a practical and adequate confirmatory test for plants similar to the prototypes. Vibration response levels of major components are shown to be as high or higher in preoperational test conditions as compared to plant operating conditions, which is conservative for purposes of the test. Provisions have been made for access to all areas of the reactor permitting direct visual inspection of all component types. Successful implementation of the required inspection in the three prototype plants has demonstrated that these provisions are adequate.

Satisfatory vibration performance of internals will be confirmed by preoperational flow testing and inspection in Non-prototype, Category I plants, in accordance with provisions of NRC Regulatory Guide 1.20. Plants in this category include Hatch 2, Shoreham, Fermi 2, Limerick 1 and 2, Hope Creek 1 and 2, Susquehanna 1 and 2, La Salle 1 and 2, Hanford 2, and Nine Mile Point 2.

## 9. REFERENCES


1. "Brunswick Steam Electric Plant Unit 1 Safety Analysis Report for Plant Modifications to Eliminate Significant In-Core Vibrations," General Electric Co. NEDO-21215, April 1976, and NEDC-21215 (Company Proprietary), June 1975.

2. Torres, M. R., "Feedwater Sparger Cold Flow Vibration Tests," General Electric Co. NEDO-20554, June 1974.

3. "Feedwater Sparger Failure—Post Operation Evaluation of Design 3 and Correlation of Finding with Design 4," Millstone Power Station Unit 1 Interim Report, Addendum 4, October 2, 1974.

## APPENDIX A

## SPECIFICATIONS OF COMPONENTS OF THE DATA ACQUISITION SYSTEMS

#1 STRAIN GAGE

Manufacturer: Ailtech
Model: SC 125
Specifications:

Resistance: 120 ± 3.5 ohms
Gage Factor, Nominal: 1.80
Rated Strain Level: ±6000 microinches per inch
Fatigue Life: Exceeds $10^6$ cycles at ±1000 microinches per inch
Transverse Sensitivity: Negligible
Operable Temperature Range—Static: −452 to +650°F
—Dynamic: −452 to +1500°F
Gage Factor Change with Temperature: Varies inversely with temperature approximately 1% per 100°F.
Nuclear Radiation: Negligible
Material: Type-321 Stainless Steel

#2 Linear Variable Transformer

Manufacturer: Columbia Research Lab., Inc.
Model: Modified Catalog No. SL-200-S3R
Specifications:

Range: ±0.200 inch
Frequency (Optimum): 60 Hz
Null Voltage: 2.00 mV
Output Voltage: 1.08V
Sensitivity: 0.86 mV/0.001 inch per Volt input
Linearity: ±0.25%

LVDT Case

Manufacturer: General Electric
Model: Drawing 761E392
Specifications:

Operates underwater at ~1200 psi and from 70-550°F in a radiation field of $10^{10}$ n/cm²-sec fast neutrons (above 1.0 MeV) and $10^{13}$ MeV/cm²-sec gamma.
Excitation: 5V 3 kHz from Validyne module case
Linearity: within ±2% over range of ±0.20 inch about null position

#3 Accelerometer (Variable Reluctance)

Manufacturer: Validyne
Model: A14-532
Specifications:

Nom. Sensitivity: 3.5 Mv/v/g
Freq. Response: 0–350 Hz
Resonant Frequency: 335 Hz
Max. Acceleration: ±500 g
Linearity: ± 1/2%

#4 Accelerometer (Piezoelectric)

Manufacturer: Endevco
Model: No. 2272 (w/isolation stud Endevco Model No. 2986B)
Specifications:

Acceleration: 0–1000 pk g
Frequency: 2–7000 Hz
Charge sensitivity: 13 PC/g ± 20%

#5 Charge Converter/Line Driver

Manufacturer: Endevco

Model No.: 2731A

Capacitance: 5000 PF max.

#6 Strain Gage Shunt Calibrator

Manufacturer: Comp. Design Laboratory

Model: Drawing 117C460

(specially built for General Electric)

Specifications:

To provide electrical equivalent of mechanical strain by shunting a 1 megohm resistor across the dummy resistor.

This change in bridge balance resistance provides a 1-to-1 microstrain equivalent signal for calibrating the chart recorder.

#7 Excitation and Demodulator

Manufacturer: Validyne

Model: CD-19 plug-in carrier demodulator

Specifications:

Power Requirements: 5V rms, 3 kHz, ±15 Vdc from MC1

Input Sensor Sensitivity: 1 mV/V, 2.5 mV/V, 10 mV/V, 25 mV/V

Selector switch with 0–100% vernier potentiometer.

Output: ±10Vdc at 10 mA

Non-linearity: ±0.05% full-scale maximum

Frequency Response: 0–10, 0–50, 0–200, and 0–1000 Hz, flat ± 10%

Module Case

Manufacturer: Validyne

Model: MC1-20

Oscillator: Output voltage - 5V RMS, center tapped adjustable

Frequency: 3 kHz ±1%

Power Supply: Output - 7.5 or 15 volts, 25 watts

#8 Balance Unit and Calibrator

Manufacturer: Validyne

Model: CD - 19 - 529 (specially built for GE)

#9 Amplifier Calibration Unit

Manufacturer: Validyne

Model: CB - 51

Specifications: Potentiometer adjustable calibration signal injected into amplifier unit.

#10 Linear Amplifier and Integrator

Manufacturer: Validyne Engineering Corp.

Model: AM 49

Specifications:

Power requirements: ±15 VDC from MC-1

Output Voltage ±10 VDC at 25 MA

Gain: 2.5 to 100 times in 6 steps

Attenuation: 0 to 100% adjustable

10 turn calibrated dial

Frequency Response: 0 to 5kHz DC

2 to 5kHz AC

Filter Switch: selectable low pass; 0 to 50, 0 to 200, 0 to 1000; 0 to 5000 Hz

#11 Amplifier, Converter Excitation (#5) and Calibrator
- Manufacturer: Endevco
- Rack Adapter: Model No. 4948
- Amplifier: Model No. 2735 PQG
  - Overall gain: 500X
  - Input impedance: 100K ohms
  - Output impedance: 25 ohms
- Band Pass Filter: Part No. 3579-501-502
  - Range: 500 to 5000 Hz (−5% atten. freq.) Pass band.
  - Unity gain, flat within ± 1dB in pass band.
  - Attenuation: 12dB per octave outside pass band.

#12 Chart Recorder
- Manufacturer: Clevite Corporation, Brush Instruments Division
- Model: Mark 260 recorder
- Specifications:
  - Number of Channels: 6 analog, 4 event
  - Channel Width: 40 mm, 50 div./channel
  - Writing Method: Pressurized fluid
  - Chart Speeds: Eight: 1, 5, 25, 125 mm/sec<br>1, 5, 25, 125 mm/min
  - Chart Speed Accuracy: ±0.25%
  - Electrical Measurement Range: 1 millivolt per chart division to 500 volts dc full scale
  - Maximum Signal Input: 500 volts dc or peak to peak
  - Frequency Response: 50 div. ±1 div. to 40 Hz<br>10 div. ±1 div. to 100 Hz<br>3 dB down at 125 Hz
  - Sensitivity: 1 mV/div. to 10 volts/div.

#13 Switching Circuit
- Manufacturer: General Electric
- Model: Special
- Specifications:
  - Passive elements (toggle switches and multiposition switches and relays)

#14 Tape Recorder
- Manufacturer: Consolidated Electrodynamics Corp.
- Model: VR3360
- Specifications:
  - Tape Speed: 15 in/sec
  - Center Frequency: 27.0 kHz
  - Information Frequency: 0–5 kHz ±0.5 dB
  - Full-Scale Signal-to-Noise Ratio (rms Signal/rms Noise): 43 dB
  - Harmonic Distortion: 1.5%
  - Input Level: 0.5 to 10 volts rms adjustable

#15 Spectrum Analyzer
- Manufacturer: Barry Research
- Frequency Ranges: 0–20 Hz, 0–50 Hz, 0–200 Hz and 0–1000 Hz
- Input: 0.1 V to 10V rms (−20 dB, −10 dB, 0 dB)
- Dynamic Range: 45 dB below single tone overload
- Number of Synthesized Filters: greater than 400
- 3 dB Bandwidth of Synthesized Filter: 0.4% of analysis range cosine time weighting

# APPENDIX B

## BROWN'S FERRY I REACTOR INTERNALS VIBRATION PREDICTION

(General Electric Company Proprietary)

# APPENDIX C

## PRE TVA VIBRATION HOT TEST DATA

(General Electric Company Proprietary)