U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.20

COMPREHENSIVE VIBRATION ASSESSMENT PROGRAM FOR REACTOR INTERNALS DURING PREOPERATIONAL AND INITIAL STARTUP TESTING

A. INTRODUCTION

Criterion 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that structures, systems, and components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Section 50.34, "Contents of Applications; Technical Information," of 10 CFR Part 50 requires the applicant to determine and to specify the margin of safety associated with normal operation and anticipated operating transients.

This guide presents a method acceptable to the NRC staff for implementing the above requirements with respect to the internals of light-water-cooled reactors[1] during preoperational and initial startup testing.[2] Inservice inspections and inservice monitoring programs to verify that the reactor internal components have not been subjected to structural degradation as a result of vibration during normal reactor operation are not covered by this guide.

[1]Reactor internals, as used in this regulatory guide, comprise core support structures and adjoining internal structures. Core support and internal structures are defined in Article NG-1120 of Section III (Nuclear Power Plant Components) of the ASME Boiler and Pressure Vessel Code.

[2]Consistent with Regulatory Guide 1.68, "Preoperational and Initial Startup Test Programs for Water-Cooled Power Reactors," preoperational testing as used in this guide consists of those tests conducted prior to fuel loading, and intial startup testing refers to those tests performed after fuel loading.

B. DISCUSSION

Reactor internals important to safety are designed to accommodate steady-state and transient vibratory loads for the service life of the reactor. This guide presents a comprehensive vibration assessment program for use in verifying the structural integrity of the reactor internals for flow-induced vibrations prior to commercial operation. The overall program includes individual analytical, measurement, and inspection programs. The term "comprehensive" appears in the title of the overall program to emphasize that the individual programs should be used cooperatively to verify structural integrity and to establish the margin of safety. For example, the analytical program not only should be used to provide theoretical verification of structural integrity but also should be the basis for the choice of components and areas to be monitored in the measurement and inspection programs; the measurement program should be used to confirm the analysis, but the program (i.e., data acquisition, reduction, interpretation processes) should be sufficiently flexible to permit definition of any significant vibratory modes that are present but were not included in the analysis; the inspection program should be considered and used as a powerful tool for quantitative (e.g., as an indicator of maximum total relative motion) as well as qualitative (e.g., establishment of boundary conditions by inspection evidence at component interfaces) verification of both the analytical and measurement program results.

The original guidelines of Regulatory Guide 1.20 have been refined in this revision to incorporate items that will expedite review of the applicant's vibration assessment program by the NRC staff. Generally, this has been accomplished by increased specificity in the guidelines

for the vibration analysis, measurement, and inspection programs and by inclusion of guidelines for scheduling significant phases of the comprehensive vibration assessment program.

The original guidelines served as the basis for testing many prototype and similar-to-prototype (referred to in this guide as non-prototype) reactor internals. Operating experience and the tendency for the design of subsequent reactor internals to differ somewhat from that of the initially designated prototypes have, in some instances, made the basic prototype and non-prototype classifications difficult to apply, resulting in the need for time-consuming case-by-case resolution of reactor internal classifications and corresponding vibration assessment programs.

This revision expands on the previous classifications and outlines an appropriate comprehensive vibration assessment program for each class. The new classifications are defined in regulatory position C.1 below. In general, the expanded classifications and corresponding programs allow for the use, under certain conditions, of prototype reactor internals that have experienced some adverse inservice vibration phenomena as limited prototypes and for the use, under certain conditions, of reactor internals that are in some respects structurally dissimilar from the designated prototype as limited non-prototypes. The expanded classifications will make the use of this guide compatible with design and operating experience.

C. REGULATORY POSITION

The classifications provided in regulatory position C.1 should be used by the applicant to first categorize the reactor internals according to design, operating parameters, and the operating experience of potential prototypes. The appropriate comprehensive vibration assessment program should then be established from the guidelines specified for that classification in the succeeding sections of this guide. The comprehensive vibration assessment programs outlined in this guide are summarized in Figure 1.

1. Classification of Reactor Internals Relative to the Comprehensive Vibration Assessment Program

1.1 Prototype. A reactor internals configuration, that, because of its arrangement, design, size, or operating conditions, represents a first-of-a-kind or unique design for which no Valid Prototype exists.

1.2 Valid Prototype. A reactor internals configuration that has successfully completed a comprehensive vibration assessment program for Prototype reactor internals and has experienced no adverse inservice vibration phenomena. A Valid Prototype that is subsequently modified in design (e.g., as in item 1.3 below) remains a Valid Prototype relative to its original design.

1.3 Conditional Prototype. A Valid Prototype that later experiences adverse inservice vibration phenomena and subsequently has been modified in arrangement, design, size, or operating conditions is designated a Conditional Prototype. Upon satisfying conditions described elsewhere in this guide, the Conditional Prototype serves as the reference design for Non-Prototype, Category III and IV, reactor internals configurations.

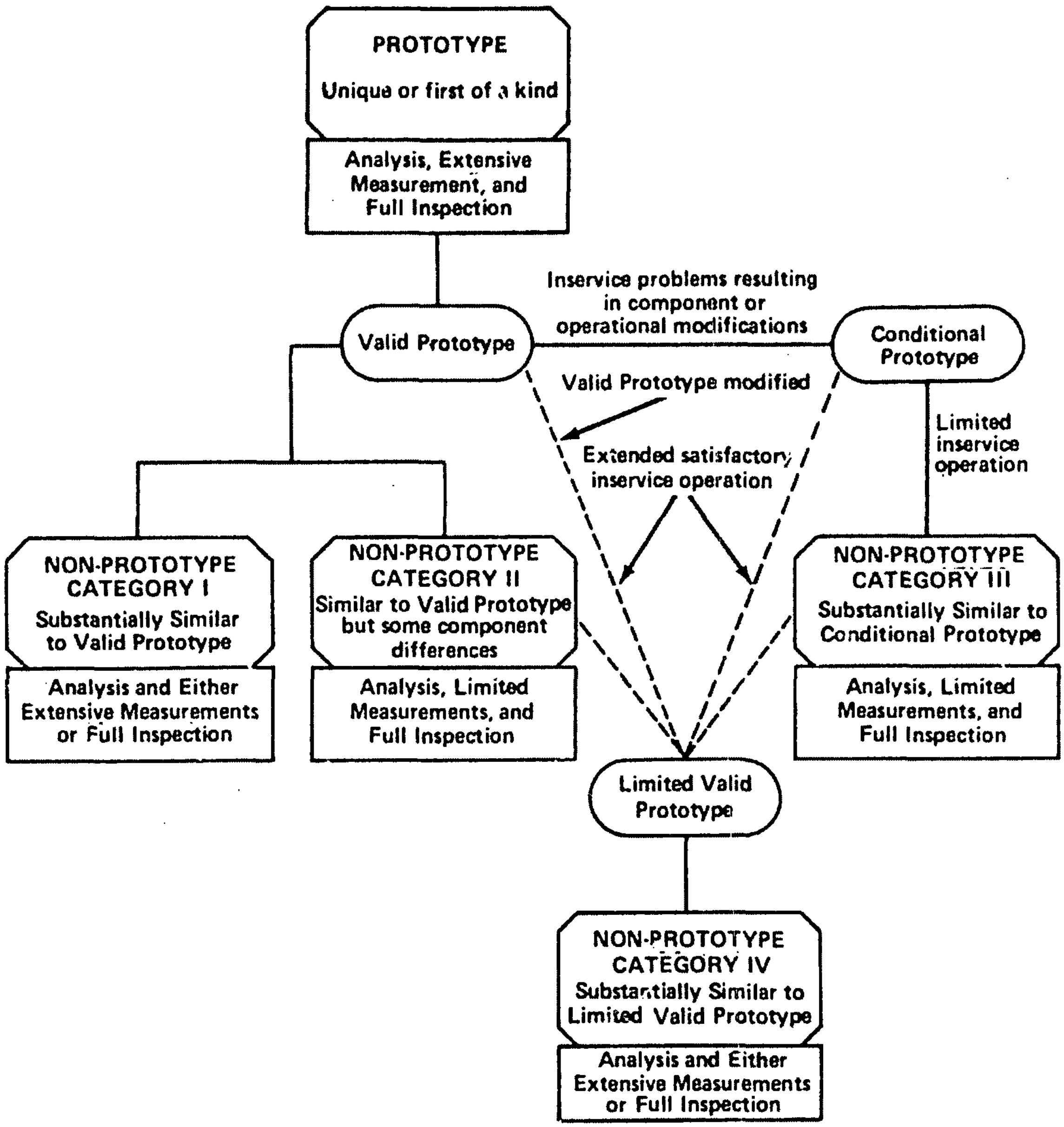
1.4 Non-Prototype, Category I. A reactor internals configuration with substantially the same arrangement, design, size, and operating conditions as a specified Valid Prototype and for which nominal differences in arrangement, design, size, and operating conditions have been shown by test or analysis to have no significant effect on the vibratory response and excitation of those reactor internals important to safety.

1.5 Non-Prototype, Category II. A reactor internals configuration with substantially the same size and operating conditions as a specified Valid Prototype, but with some component arrangement or design differences that are shown by test or analysis to have no significant effect on the vibratory response and excitation of those unmodified reactor internals important to safety.

1.6 Limited Valid Prototype. A Non-Prototype, Category II or III, reactor internals configuration that has successfully completed the appropriate comprehensive vibration assessment program and has itself experienced no adverse inservice vibration phenomena. An operating Valid Prototype that has demonstrated extended satisfactory inservice operation subsequent to a design modification may be considered a Limited Valid Prototype relative to the modified reactor internals configuration. A Conditional Prototype that has demonstrated extended satisfactory inservice operation may be considered a Limited Valid Prototype.

1.7 Non-Prototype, Category III. A reactor internals configuration with substantially the same arrangement, design, size, and operating conditions as a specified Conditional Prototype with insufficient operating history to justify it as a Limited Valid Prototype. Differences in arrangement, design, size, and operating conditions should be shown by test or analysis to have no significant effect on the vibratory response and excitation of those reactor internals important to safety.

1.8 Non-Prototype, Category IV. A reactor internals configuration with substantially the same arrangement, design, size, and operating conditions as a specified Limited Valid Prototype, where nominal differ-



Reactor internals configuration for which comprehensive vibration assessment program is defined.

Summary of comprehensive vibration assessment programs.

Reactor internals reference design which, together with its test and operating experience, provides the basis for a specific comprehensive vibration assessment program.

------- Indicates alternative paths

FIGURE 1 – SUMMARY OF COMPREHENSIVE VIBRATION ASSESSMENT PROGRAMS

ences in arrangement, design, size, and operating conditions have been shown by test or analysis to have no significant effect on the vibratory response and excitation of those reactor internals important to safety.

Associated with the Prototype and the Category I, II, III, and IV Non-Prototype classifications are the comprehensive vibration assessment programs delineated in regulatory positions C.2 and C.3 and summarized in Figure 1. The foregoing classifications are defined relative to the three prototype reference design classifications (i.e., Valid Prototype, Conditional Prototype, Limited Valid Prototype) upon whose design, test, and operating experience the individual comprehensive vibration assessment programs are based.

2. Comprehensive Vibration Assessment Program for Prototype Reactor Internals

The comprehensive vibration assessment program should be implemented in conjunction with preoperational and initial startup testing. It should consist of a vibration analysis, a vibration measurement program, an inspection program, and a correlation of their results.

2.1 Vibration Analysis Program

The vibration analysis should be performed for those steady-state and anticipated transient conditions that correspond to preoperational and initial startup test and normal operating conditions. The vibration analysis submittal should include a summary of:

1. The theoretical structural and hydraulic models and analytical formulations or scaling laws and scale models used in the analysis.

2. The structural and hydraulic system natural frequencies and associated mode shapes which may be excited during steady-state and anticipated transient operation.

3. The estimated random and deterministic forcing functions, including any very-low-frequency components, for steady-state and anticipated transient operation.

4. The calculated structural and hydraulic responses for steady-state and anticipated transient operation. (The random, deterministic, overall integrated maximum response, any very-low-frequency components of response, and the level of cumulative fatigue damage should be identified.)

5. A comparison of the calculated structural and hydraulic responses for preoperational and initial startup testing with those for normal operation. (Normal operating conditions that are not accurately or sufficiently simulated by the test conditions should be identified.)

6. The anticipated structural or hydraulic vibratory response (defined in terms of frequency, amplitude, and modal contributions) that is appropriate to each of the sensor locations for steady-state and anticipated transient preoperational and startup test conditions.

7. The test acceptance criteria with permissible deviations and the basis for the criteria. (The criteria should be established in terms of maximum allowable response levels in the structure and presented in terms of maximum allowable response levels at sensor locations.)

2.2 Vibration Measurement Program

A vibration measurement program should be developed and implemented to verify the structural integrity of the reactor internals, to determine the margin of safety associated with steady-state and anticipated transient conditions for normal operation and to confirm the results of the vibration analysis. The vibration measurement program should include a description of:

1. The data acquisition and reduction system, including:

a. Transducer types and their specifications, including useful frequency and amplitude ranges.

b. Transducer positions, which should be sufficient to monitor significant lateral, vertical, and torsional structural motions of major reactor internal components in shell, beam, and rigid body modes of vibration, as well as significant hydraulic responses and those parameters that define the input forcing function.

c. Precautions being taken to ensure acquisition of quality data (e.g., optimization of signal-to-noise ratio, relationship of recording times to data reduction requirements, choice of instrumentation system).

d. On-line data evaulation system to provide immediate verification of general quality and level of data.

e. Procedures for determining frequency, modal content, and maximum values of response.

2. Test operating conditions, including:

a. All steady-state and transient modes of operation.

b. The planned duration of all testing in normal operating modes to ensure that each critical component will have been subjected to at least 10^7 cycles of vibration (i.e., computed at the component's minimum significant response frequency) prior to the final inspection of the reactor internals. (If it is not feasible to perform an inspection following the accumulation of 10^7 cycles, the structural integrity of the reactor internals should be verified by measurements which demonstrate that no significant change in structural response resulting from component damage has occurred between the time vibration testing was initiated and after 10^7 cycles were accrued.)

c. Disposition of fuel assemblies. (Testing should be performed with the reactor internals important to safety and the fuel assemblies (or dummy assemblies which provide equivalent dynamic mass and flow characteristics) in position. The test may be conducted without real or dummy fuel assemblies if it can be shown by analytical or experimental means that such conditions will yield conservative results.)

2.3 Inspection Program

The inspection program should provide for inspections of the reactor internals prior to and following operation at those steady-state and transient modes consistent with the test conditions for regulatory position C.2.2.2. The reactor internals should be removed from the reactor vessel for these inspections. If removal is not feasible, the inspections should be performed by means of examination equipment appropriate for in situ inspection. The inspection program should include:

1. A tabulation of all reactor internal components and local areas to be inspected, including:

a. All major load-bearing elements of the reactor internals relied upon to retain the core support structure in position.

b. The lateral, vertical, and torsional restraints provided within the vessel.

c. Those locking and bolting components whose failure could adversely affect the structural integrity of the reactor internals.

d. Those surfaces that are known to be or may become contact surfaces during operation.

e. Those critical locations on the reactor internal components as identified by the vibration analysis.

f. The interior of the reactor vessel for evidence of loose parts or foreign material.

2. A tabulation of specific inspection areas that can be used to verify segments of the vibration analysis and measurement program.

3. A description of the inspection procedure, including the method of examination (e.g., visual and nondestructive surface examinations), method of documentation, access provisions on the reactor internals, and specialized equipment to be employed during the inspections to detect and quantify evidence of the effects of vibration.

2.4 Documentation of Results

The results of the vibration analysis, measurement, and inspection programs should be reviewed and correlated to determine the extent to which the test acceptance criteria are satisfied. A summary of the results should be submitted to the Commission as follows:

1. If the results of the comprehensive vibration assessment program are acceptable, the final report should include:

a. A description of any deviations from the specified measurement and inspection programs, including instrumentation reading and inspection anomalies, instrumentation malfunctions, and deviations from the specified operating conditions,

b. A comparison between the measured and analytically determined modes of structural and hydraulic response (including those parameters from which the input forcing function is determined) for the purpose of establishing the validity of the analytical technique,

c. A determination of the margin of safety associated with normal steady-state and anticipated transient operation,

d. An evaluation of measurements that exceeded acceptable limits not specified as test acceptance criteria or of observations that were unanticipated and the disposition of such deviations.

2. If (1) inspection of the reactor internals reveals defects, evidence of unacceptable motion, excessive or undue wear, (2) the results from the measurement program fail to satisfy the specified test acceptance criteria, or (3) the results from the analysis, measurement, and inspection programs are inconsistent, the final report should also include an evaluation and description of the modifications or actions planned in order to justify the structural adequacy of the reactor internals.

The collection, storage, and maintenance of all records relevant to the analysis, measurement, and inspection phases of the comprehensive vibration assessment program should be consistent with Regulatory Guide 1.88, "Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records," which describes a method acceptable to the NRC staff for complying with Criterion XVII, "Quality Assurance Records," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50.

2.5 Schedule

A schedule should be established and submitted to the Commission during the construction permit review. The schedule should provide that:

1. The reactor internals design will be classified in the Preliminary Safety Analysis Report (PSAR) as a prototype or a specific category of non-prototype. (If the internals are classified as non-prototype, the applicant should identify the applicable prototype reactor internals in the PSAR. Experimental or analytical justification for the non-prototype classification should be presented during the construction permit review.)

2. A commitment will be established during the construction permit review regarding the scope of the comprehensive vibration assessment program.

3. A description of the vibration measurement and inspection phases of the comprehensive vibration assessment program will be submitted to the Commission in sufficient time to permit utilization of Commission recommendations. (A 90-day comment and review period by the staff should be assumed by the applicant for scheduling purposes.)

4. A summary of the vibration analysis program will be submitted to the Commission a minimum of 60 days prior to submittal of the description of the vibration measurement and inspection programs.

5. The final report, which summarizes the results of the vibration analysis, measurement, and inspection programs, will be presented to the Commission within 120 days of the completion of vibration testing.

3. Comprehensive Vibration Assessment Programs for Non-Prototype Reactor Internals

Non-prototype reactor internals important to safety should be subjected during the preoperational and initial startup test program to all significant flow modes associated with normal steady-state and anticipated transient operation under the same test conditions imposed on the applicable prototype. Evaluation of the effects of such operation on the structural integrity of the non-prototype reactor internals should be based on the results of a comprehensive vibration assessment program developed for the specific non-prototype classification (i.e., Category I, II, III, or IV). The comprehensive vibration assessment programs for non-prototype reactor internals are outlined below. These programs should be scheduled and documented in accordance with the guidelines for the program delineated in regulatory positions C.2.4 and C.2.5 for Prototype reactor internals.

3.1 Non-Prototype, Category I

3.1.1 Vibration Analysis Program

The Valid Prototype should be specified and sufficient evidence should be provided to support the classification Non-Prototype, Category I.

The vibration analysis for the Valid Prototype, which includes a summary of the anticipated structural and hydraulic response and test acceptance criteria, should be modified to account for the nominal differences that may exist between the Non-Prototype, Category I, and Valid Prototype reactor internals.

3.1.2 Vibration Measurement Program

The vibration measurement program may be omitted if the inspection program is implemented.

If a measurement program is implemented in lieu of an inspection program, sufficient and appropriate instrumentation should be incorporated to verify that the vibratory response of the Non-Prototype, Category I, reactor internals is consistent with the results of the vibration analysis, test acceptance criteria, and the vibratory response observed in the Valid Prototype. The vibration measurement program should include a description of the data acquisition and reduction systems and test operating conditions consistent with the general guidelines for the vibration measurement program delineated in regulatory position C.2.2 for Prototype reactor internals.

3.1.3 Inspection Program

If an inspection program is implemented in lieu of a vibration measurement program, the guidelines for the inspection program delineated in regulatory position C.2.3 for Prototype reactor internals should be followed.

The inspection program may be omitted if the vibration measurement program is implemented. However, if significant discrepancies exist between anticipated and measured responses for specific components, those components should be removed from the

reactor vessel and a visual examination performed. Components for which removal is not feasible should be examined in situ by means of appropriate inspection equipment. In any case, the interior of the reactor vessel should be visually checked for loose parts and foreign material.

3.2 Non-Prototype, Category II

3.2.1 Vibration Analysis Program

The Valid Prototype should be specified, and sufficient evidence should be provided to support the classification Non-Prototype, Category II, which requires demonstrating that the structural differences that exist between the Non-Prototype, Category II, and Valid Prototype reactor internals have no significant effect on the vibratory response and excitation of those unmodified Non-Prototype, Category II, components.

The vibration analysis for the Valid Prototype, which includes a summary of the anticipated structural and hydraulic response and test acceptance criteria, should be modified to account for the structural differences that exist between the Valid Prototype and Non-Prototype, Category II, reactor internals.

Test acceptance criteria should specifically be established for those Non-Prototype, Category II, reactor internal components with structural differences relative to the Valid Prototype.

3.2.2 Vibration Measurement Program

A vibration measurement program should be implemented on the Non-Prototype, Category II, reactor internals during preoperational and initial startup testing.

The vibration measurement program should include a description of the data acquisition and reduction systems and test operating conditions consistent with the general guidelines for the vibration measurement program delineated in regulatory position C.2.2 for Prototype reactor internals.

Sufficient and appropriate instrumentation should be used to define the vibratory response (i.e., frequency, amplitude, modal content) of those reactor internal components important to safety that have been modified relative to the Valid Prototype for the purpose of demonstrating that the test acceptance criteria are satisfied and establishing the margin of safety.

Sufficient and appropriate instrumentation should be used to monitor those reactor internal components important to safety that have not been modified relative to the Valid Prototype to confirm that the vibratory response of such components complies with the guidelines for Non-Prototype, Category II, reactor internals and is consistent with the results obtained for similar components during the measurement program on the Valid Prototype.

3.2.3 Inspection Program

An inspection program that follows the guidelines for the inspection program delineated in regulatory position C.2.3 for Prototype reactor internals should be implemented.

3.3 Non-Prototype, Category III

3.3.1 Vibration Analysis Program

The Conditional Prototype should be specified, and sufficient analytical or experimental evidence should be provided to support the classification Non-Prototype, Category III, as well as to demonstrate the applicability of data from the vibration measurement program on the Prototype to the Conditional Prototype. It should be demonstrated that:

1. The Conditional Prototype is substantially similar in arrangement, design, size, and operating conditions to the Non-Prototype, Category III, reactor internals.

2. Response modes attributable to the inservice vibration problems and ensuing component or operational modifications do not significantly affect the applicability of the results of the vibration measurement program on the Prototype to the Conditional Prototype, or response modes attributable to the inservice vibration problems and ensuing component or operational modifications do affect the applicability of the results of the vibration measurement program on the Prototype to the Conditional Prototype, but the effects are limited to structural components and response modes that permit clear separation of these effects from other results of the vibration measurement program.

Details concerning the adverse vibration experience of the Conditional Prototype should be provided, as should experimental or analytical information which demonstrates that the vibration problems associated with the Conditional Prototype have been corrected for both it and the applicable Non-Prototype, Category III, reactor internals.

The vibration analysis on the Prototype to the Conditional Prototype, which includes a summary of the anticipated structural and hydraulic response and test acceptance criteria for the measurement program on the Prototype, should be modified to account for the component or operational modifications applicable to the Conditional Prototype and Non-Prototype, Category III, reactor internals.

Test acceptance criteria, with permissible deviations, should be specified for reactor internal components important to safety. Each component should be categorized according to whether the results from the vibration measurement program on the Prototype to the Conditional Prototype are applicable.

3.3.2 Vibration Measurement Program

A vibration measurement program should be implemented on the Non-Prototype, Category III, reactor internals during preoperational and initial startup testing.

Sufficient and appropriate instrumentation should be used to define the vibratory response of those reactor components important to safety which, because of structural or operational modifications relative to the original design of the Conditional Prototype, are expected to have response characteristics substantially different from those measured for that component during the vibration measurement program on the Prototype to the Conditional Prototype.

All other components should be monitored with sufficient and appropriate instrumentation to confirm that the measured response for each component is substantially similar to that obtained during the vibration measurement program on the Prototype to the Conditional Prototype.

The vibration measurement program should satisfy the general guidelines for a Prototype measurement program as delineated in regulatory position C.2.2.

3.3.3 Inspection Program

An inspection program that satisfies the guidelines for the inspection program delineated in regulatory position C.2.3 for Prototype reactor internals should be implemented.

3.4 Non-Prototype, Category IV

3.4.1 Vibration Analysis Program

The Limited Valid Prototype should be specified, and sufficient evidence should be provided to support the classification Non-Prototype, Category IV.

3.4.2 Vibration Measurement Program

A vibration measurement program may be omitted if the inspection program is implemented.

If a measurement program is implemented in lieu of an inspection program, sufficient and appropriate instrumentation should be incorporated to verify that the vibratory response of the Non-Prototype, Category IV, reactor internals is consistent with the results of the vibration analysis, test acceptance criteria, and the vibratory response for the referenced Limited Valid Prototype.

The vibration measurement program should be consistent with the guidelines delineated in regulatory position C.3.1.2 for the measurement program for Non-Prototype, Category I, reactor internals.

3.4.3 Inspection Program

If an inspection program is implemented in lieu of a vibration measurement program, the guidelines for the inspection program delineated in regulatory position C.3.1.3 for Non-Prototype, Category I, reactor internals should be followed.

D. IMPLEMENTATION

The purpose of this section is to provide guidance to applicants and licensees regarding the NRC staff's plans for utilizing this regulatory guide.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used in the evaluation of submittals for operating license or construction permit applications docketed after August 21, 1975.

If an applicant wishes to use this regulatory guide in developing submittals for applications docketed on or before August 21, 1975, the pertinent portions of the application will be evaluated on the basis of this guide.