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**FLOW-INDUCED VIBRATION
FOR LIGHT-WATER REACTORS**

**PROGRESS REPORT
(APRIL 1981 — JUNE 1981)**

OCTOBER 1981

M. R. TORRES

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**GENERAL ELECTRIC COMPANY
NUCLEAR ENGINEERING DIVISION
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U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR NUCLEAR ENERGY
OFFICE OF LIGHT WATER REACTORS
UNDER CONTRACT DE-AC02-77ET34209**

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CONTENTS

	<u>Page</u>
ABSTRACT	ix
INTRODUCTION	xi
TASK 1-FUNDAMENTAL STUDIES	1-1
Task 1.1 External Flow Over Tube Banks - Cross Flow (CR&D)	1.1-1
Task 1.1a Preliminary Buffeting Experiments	1.1-2
Task 1.1b Water-Based Tests at High Reynolds Number	1.1-2
Task 1.1c Buffeting of Cylinder Arrays in a Turbulent Cross Flow	1.1-2
Task 1.1d Fluidelastic Instability Boundaries	1.1-4
Task 1.2 External Flow Over Tube Banks - Parallel Flow (ANL)	1.2-1
Task 1.2a State-of-the-Art Assessment	1.2-2
Task 1.2b Single Cylinders in Nominally Parallel Flow	1.2-2
Task 1.2c Fluidelastic Interaction in Parallel Flow	1.2-5
Task 1.2d Experimental Study of Tube Arrays in Parallel Flow	1.2-6
Task 1.2e Development of Mathematical Models and Design Guides	1.2-7
Task 1.3 Leakage Flow Mechanisms (CR&D and NED)	1.3-1
Task 1.4 Random Vibration Effects (ANL and NED)	1.4-1
TASK 2-MODEL AND FULL-SIZE COMPONENT TESTS	2-1
Task 2.1 Lower Plenum (NED)	2.1-1
Task 2.1a Lower Plenum One-Tenth Scale FIV Test	2.1-1
Task 2.1b Lower Plenum Quarter-Scale FIV Test	2.1-2
Task 2.1c Lower Plenum Full-Scale FIV Test	2.1-2
Task 2.2 Fuel Assembly (NED)	2.2-1
Task 2.2a Fuel Assembly Cold FIV Test	2.2-2
Task 2.2b Fuel Spacer Preload FIV Test	2.2-2
Task 2.2c Hot FIV Test	2.2-4
Task 2.3 Jet Pumps	2.3-1
Task 2.3a Jet Pump Cold FIV Test	2.3-2
Task 2.3b Jet Pump Hot FIV Test	2.3-2
Task 2.4 Lower Pressure Coolant Injection Coupling	2.4-1
TASK 3-LWR FIV DESIGN METHODS, GUIDES AND CRITERIA	3-1
TASK 4-PROGRAM ADMINISTRATION	4-1
DISTRIBUTION	D-1

TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1.1-1	Ratio of Fluctuating Force in the Strouhal Frequency Band to Full Spectrum	1.1-5
2.2-1	Test Matrix	2.2-7
2.2-2	Test Flow Conditions	2.2-8
2.2-3	Summary of Two-Phase Flow Induced Vibration Parameters	2.2-9

ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1.1-1	Strouhal Lift Power Spectrum	1.1-6
1.1-2	Strouhal Lift Power Spectrum	1.1-7
1.1-3	Strouhal Lift Power Spectrum	1.1-8
1.1-4	Strouhal Lift Coefficients	1.1-9
1.1-5	Effect of Grid Turbulence on a Staggered Array of 1.71 Pitch and Three Rows	1.1-10
1.1-6	Strouhal Frequencies Measured on a Three Row Staggered Array	1.1-11
1.2-1	RMS Values of Resultant of Tube Displacement	1.2-11
1.2-2	Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0$	1.2-12
1.2-3	Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0.32$ cm	1.2-13
1.2-4	Spatial Configurations of the Displacement; $U = 6$ m/s, $e = 0.48$ cm	1.2-14
1.2-5	Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0.56$ cm	1.2-15
1.2-6	Normalized Spectra Data Band (////) for $x/l = 0.625$ and no Upstream Flow Spoilers. The Curve (----) is drawn for $K = 5$ and $\phi = 2\pi \times 10^{-6}$	1.2-16
1.2-7	Pressure Coefficients for $d_h = 1.17$ cm, ____; and $d_h = 3.71$ cm, ---. Locations Denoted by $\diamond$, $x/l = 0.125$; $\circ$, $x/l = 0.375$; Δ , $x/l = 0.625$	1.2-17
2.2-1	Test Setup (Single-Rod Test)	2.2-10
2.2-2	Spacer Location Detail	2.2-11
2.2-3	Instrumented Fuel Rods	2.2-12
2.2-4	3x3 Rod Bundle Overview	2.2-13
2.2-5	Test Configurations, Instrumented Rod Only	2.2-14
2.2-6	Single Rod Results with Rod Suspension - Rod 1	2.2-15
2.2-7	3x3 Results with Rod Suspension - Rod 1	2.2-16
2.3-1	Jet Pump Pairs	2.3-4

ABSTRACT

Flow-Induced Vibration for Light Water Reactors (FIV for LWRs) is a program designed to improve the FIV performance of light water reactors through the development of design criteria, analytical models for predicting behavior of components, and general scaling laws to improve the accuracy of reduced-scale tests, and through the identification of high FIV risk areas. The program is managed by the General Electric Nuclear Power Systems Engineering Department and has three major contributors: General Electric Nuclear Power Systems Engineering Department (NPSED), General Electric Corporate Research and Development (CR&D) and Argonne National Laboratory (ANL). The program commenced December 1, 1976. This progress report summarizes the accomplishments achieved during the period from April 1981 to June 1981.

INTRODUCTION

The Flow-Induced Vibration for Light Water Reactors Program (FIV for LWRs) is being conducted for the Office of Nuclear Power Systems, U.S. Department of Energy (DOE). The goal of the program is to increase nuclear plant availability and to reduce radiation exposure by substantially reducing the downtime caused by FIV failure of components. It is a balanced effort of fundamental studies, analyses, tests of idealized conditions, and realistic tests of reactor components, all leading to the preparation of design guides and criteria for LWRs. The program is broken into four major tasks:

- Task 1 - Fundamental Studies - General Electric Corporate Research and Development (CR&D) and Argonne National Laboratory (ANL)
- Task 2 - Model and Full-Size Tests - General Electric Nuclear Technology Department (NTD)
- Task 3 - Design Methods, Guides and Criteria (NTD)
- Task 4 - Program Administration (NTD)

A brief summary of the objectives of these tasks and a description of the technical progress achieved over the period from January 1, 1981, through March 31, 1981, are provided in the following sections. Additional background information can be obtained from other "Flow-Induced Vibration for Light Water Reactors Progress Reports" listed as follows:

1. December 1976 - May 1977, GEAP-24055, COO/4175-1.
2. June - September 1977, GEAP-24124, COO/4174-2.
3. October - December 1977, GEAP-24151, COO/4175-5.
4. January - March 1978, GEAP-24163, COO/4175-9.
5. April 1978 - December 1979, GEAP-24248, DOE/N/4175-14.

6. January - June 1980, GEAP-24926, DOE/ET/34209/16.
7. July - September 1980, GEAP-24368, DOE/ET/34209/17.
8. October - December 1980, GEAP-24369, DOE/ET/34209/18.
9. January - March 1981, GEAP-24370, DOE/ET/34209/19.

TASK 1 - FUNDAMENTAL STUDIES

The purpose of Task 1 is to develop a better fundamental understanding of FIV phenomena as related to light water reactors (LWRs). A combination of tests and analyses considers geometries and FIV mechanisms common to the LWR. Particular emphasis is given to characterizing the FIV forcing functions for use in establishing predictive models. The task is divided into four major areas:

Task 1.1 - External Flow over Tube Banks - Cross Flow (CR&D)

Task 1.2 - External Flow over Tube Banks - Parallel Flow (ANL)

Task 1.3 - Leakage Flow Mechanisms (CR&D)

Task 1.4 - Random Vibration Effects (ANL)

Progress has been achieved on Tasks 1.1 and 1.2 over the report period and is described on the following pages. Task 1.4 has been completed and the final results are documented in DOE report COO/4175-10, "Random High-Cycle Fatigue Analysis."

TASK 1.1 - EXTERNAL FLOW OVER TUBE BANKS - CROSS FLOW (CR&D)

Task 1.1, performed by General Electric Corporate Research and Development, is designed to develop a better understanding of the response of tube arrays to fluid cross flow. It consists of six activities:

Task 1.1a - Preliminary Array Definition Experiments

Task 1.1b - Water-Based Tests at High Reynolds Numbers

Task 1.1c - Buffeting of Cylinder Arrays in Turbulent Cross Flow

Task 1.1d - Fluidelastic Instability Boundaries

Task 1.1e - Proof Test

Task 1.1f - Design Guides

Progress achieved over the report period on these activities is described as follows:

Task 1.1a - Preliminary Buffeting Experiments (S. D. Savkar, R.M.C. So)

Task Description

The objective of this task was to develop an experimental scheme capable of directly measuring the unsteady forces induced on cylinders immersed in a turbulent cross flow. The measurement scheme will be used in several of the Task 1.1 test programs.

Work Completed This Report Period

Task 1.1a, as previously reported, was successfully completed in an earlier report period. Work on this activity has been terminated.

Task 1.1b - Water-Based Tests at High Reynolds Number (S. Savkar/T. Litzinger/
R. So)

Task Description

Task 1.1b consists of a series of experiments performed in water, using the Garfield Thomas Water Tunnel at Pennsylvania State University, to study the buffeting of a cylinder in turbulent cross flow. The primary objective is to measure and correlate the unsteady forces induced by the cross flow on the cylinder as a function of Reynolds number and turbulence. The program is designed to complement the cross flow in air activities studied in Task 1.1c.

Work Completed This Report Period

All the work related to this activity is now complete.

Task 1.1c - Buffeting of Cylinder Arrays in a Turbulent Cross Flow (S. Savkar/
T. Litzinger)

Task Description

Task 1.1c consists of a series of experiments performed in air to study the buffeting of single cylinders and cylinder arrays in a turbulent cross flow. The experiments are directed toward characterizing the forces exerted on the cylinder as a function of such parameters as Reynolds number, upstream turbulence, Strouhal number, and cylinder array geometry. The program utilizes the force measurement scheme developed in Task 1.1a to characterize the cylinder forces.

Work Completed This Report Period

During this reporting period, multi-row array testing on staggered tube arrays was begun. Initial runs were made with arrays three rows deep with the load cell cylinder in the second row. The resulting data were much more organized than the single row results discussed in the last report. All three pitch patterns (pitch-to-diameter ratios), that is, 1.2, 1.5 and 1.71 were tested. The data were reduced in two modes. In the first, the full spectra were

integrated to obtain fluctuating lift and drag coefficients. Then only the energy contained in the Strouhal peak was integrated. A sample spectrum for each of the three cases, with no grid, is illustrated in Figures 1.1-1, 1.1-2, and 1.1-3. The average ratio of the energy in the Strouhal peak to the full spectrum is given in Table 1.1-1. The deviation of the ratio from the average was generally less than 20%, hence the average numbers indicate a meaningful trend over the range of flows tested. These data would suggest that the flow through an array of rigid tubes, all of the same diameter and arranged in an equilateral, staggered pitch pattern, appears to be very coherent. This coherence is in spite of the fact that the downstream tubes are located in the turbulent wakes of the upstream tubes, and that the organizing influence of the array is further enhanced as the array spacing is tightened. The effect of turbulence is to destroy this organizing influence by inducing an early transition. For the range of flows tested, this results in a reduction in the amplitude of the fluctuating forces.

Figure 1.1-4 presents a plot of the lift coefficients for the three arrays over the range of Reynolds numbers tested in a uniform flow condition. The lift coefficients are based on the upstream velocity and include only the contribution around the Strouhal peak. The Reynolds number is based on the upstream velocity and the tube diameter. Surprisingly, there was very little difference between the pitch-to-diameter ratios of 1.5 and 1.71. These levels are in fact of the same order as the isolated cylinder (taking the full spectrum into account). The lift coefficients for p/d of 1.2 are significantly higher. All three sets of lift coefficients show a presence of transition. This is better illustrated in Figure 1.1-5 where 1.71 pitch-to-diameter data with and without grid turbulence (clean flow) are plotted. The data in Figure 1.1-5 were obtained by integrating the full spectra since the grid turbulence cases often lacked a clear cut Strouhal peak. The differences between Figures 1.1-4 and 1.1-5 have been discussed in the context of Table 1.1-1. While the evidence for transition is strong, it is not conclusive at this stage since the range of Reynolds numbers covered is limited.

The Strouhal number data for the three runs discussed above are plotted in Figure 1.1-6. In terms of their trends, these data agree best with Chen¹. The Strouhal numbers at $p/d = 1.2$ agree almost precisely with Chen, while those at spacing ratios of 1.5 and 1.7 are somewhat higher. However two things should

be remembered when making these comparisons. The current data are a decade or higher in terms of Reynolds numbers than those tested by Chen. In the range of Reynolds numbers tested herein, the data show a strong evidence of transition. So a part of the difference between Chen's data and current data could be traced to these differences in the test conditions.

Task 1.1d - Fluidelastic Instability Boundaries (T. F. Balsa)

Task Description

A combined test and analysis program is directed toward establishing the nature and boundary of fluidelastic instability of arrays as a function of array geometry. A near-term objective is the numerical prediction of the forces on an oscillating single cylinder at high Reynolds numbers (10^4 to 10^7). These predictions should be useful in establishing whether the forces can produce a hydroelastic instability, or whether they simply excite cylinder motion through their fluctuating or unsteady component.

Work Completed This Report Period

Preliminary theoretical models were formulated and critical experiments were outlined in previous reporting periods. Activity on this task was terminated after the first contract suspension. No further work is planned.

References

1. Y. N. Chen, "Flow Induced Vibration and Noise in Tube Bank Heat Exchangers Due to von Karman Streets," 1968 Trans. ASME, Series B, J. Eng. for Industry, Vol. 90, pp. 134-146.

Table 1.1-1

RATIO OF FLUCTUATING FORCE IN THE STROUHAL FREQUENCY BAND TO FULL SPECTRUM

<u>P/d</u>	<u>C' LST/C' L FULL</u>	<u>C' D. ST/C' D FULL</u>
1.2	0.92 (+ 5%)*	0.83 (+ 8%)*
1.5	0.48 (+ 20%)	0.73 (+ 30%)
1.71	0.44 (+ 20%)	0.74 (+ 20%)

*The numbers in the brackets are the maximum percent spread of the data about the mean over the range of flows tested. The Reynolds number range spanned $3 \times 10^4 < Re < 2 \times 10^5$.

Figure 1.1-1. Strouhal Lift Power Spectrum

Figure 1.1-2. Strouhal Lift Power Spectrum

Figure 1.1-3. Strouhal Lift Power Spectrum

Figure 1.1-4. Strouhal Lift Coefficients

GEAP-24385

Figure 1.1-5. Effect of Grid Turbulence on a Staggered Array of 1.71 Pitch and Three Rows

Figure 1.1-6. Strouhal Frequencies Measured on a Three Row Staggered Array

TASK 1.2 - EXTERNAL FLOW OVER TUBE BANKS - PARALLEL FLOW (ANL)

Task 1.2, performed by Argonne National Laboratory, is designed to develop a better understanding of the response of tube arrays subjected to parallel flow. The specific objectives include the following:

- (1) Determine, by a systematic series of experiments, the dependence of amplitude of motion and forces on Reynolds number, upstream flow conditions, array geometry, and weak cross flow for tube arrays in essentially parallel flows;
- (2) Establish weak cross-flow-induced fluidelastic stability boundaries; and
- (3) Evolve design methodology to estimate the fluid forces and resulting vibration response.

The program is divided into five subtasks:

Task 1.2a - Review of Available Data from Flow-Induced Vibration Tests and Assessment of the State of the Art in Understanding/Modeling Parallel Flow-Induced Vibration Phenomena and/or Response

Task 1.2b - Experimental Study of Single Cylinders in Nominally Parallel Flows Typically Encountered in Channels and Reactor Plenums

Task 1.2c - Experimental Study of Fluidelastic Interaction that Can Result in Coupled Response and/or Instabilities in Rod/Shell Systems, Tube Bundles, Tubes in Asymmetric Flow Channels, and Systems with Nonuniform Cross Sections

Task 1.2d - Experimental Study of Tube Arrays in Parallel Flow

Task 1.2e - Development of Mathematical Models and Participation in Design Guides Evaluation (Task 3)

The primary test fluid will be water. Incoming flow conditions, together with a weak cross flow, will be used to establish the effects of the parameters of interest. The flow will be varied over a sufficient range to clearly establish the role of Reynolds number. Besides acquiring data of significance to the parallel flow FIV of tube arrays, analytical tools that can be evolved into design guides will be devised.

A description of the progress achieved on these subtasks over the periods from April 1981 to June 1981 follows.

Task 1.2a - State-of-the-Art Assessment

Task Description

Task 1.2a consists of a day-to-day review of available parallel FIV literature applicable to light water reactors in order to maintain a current knowledge of the state of the art.

Work Completed This Report Period

Other than a continued general review of the FIV literature, no work was performed on this activity during the report period.

Task 1.2b - Single Cylinders in Nominally Parallel Flow (W. H. Lin, T. M. Mulcahy, W. P. Lawrence, B. G. Jones)

Task 1.2b consists of two complementary parallel FIV programs on isolated cylinders. Experiments are performed in water using the ANL Flow Induced Vibration Test Facility, and in air using the University of Illinois at Urbana open cycle air loop at the Thermal Hydraulics Laboratory. Work performed on these programs is described as follows.

Activity 1 - Annular Region (Water)**Task Description**

Parallel FIV experiments are performed on isolated cylinders in water to determine the cylinder response, wall pressure statistics, cylinder resonances, and fluid damping as a function of the independent parameters. The ultimate goal is to develop an analytical response prediction model characterized by the test data. The independent test parameters include a wide range of Reynolds numbers, hydraulic diameters, cylinder structural boundary conditions, and, most important, upstream flow disturbances. The creation and characterization of upstream flow disturbances as a test parameter will be the unique contribution of this work.

The specific objectives are to:

- (1) Provide test data to develop an integrated analytical-experimental model for predicting response of a rod located symmetrically in a cylindrical region subjected to fully developed flow with and without upstream flow disturbances; and
- (2) Establish sensitivity (scaling) of wall pressures with respect to rod vibration, Reynolds number, hydraulic diameters, and upstream disturbances (turbulence).

Work Completed This Report Period

The experimental results from measurements of wall-pressure fluctuations on a circular rod concentrically located in three different circular channel flows with various upstream disturbances caused by flow spoilers are being reported in two parts. Part 1, completed and published¹, presents the results from tests with no flow spoilers. Part 2 was published during the current reporting period to include tests with flow spoilers². This completes Activity 1 of Task 1.2b.

Activity 2 - Annular region (Air)

Task Description

Two fundamental parallel FIV studies are being conducted: in one the wall and fluid field fluctuating pressures will be measured simultaneously, and in the other the wall fluctuating pressures and the turbulent velocity field will be measured simultaneously. The first will allow determination of the stochastic structure of the pressure field and a look for correlation relationships between the fluid stochastic pressure field and that at the wall. The second study will allow determination of the turbulent velocity field and examination of its relationship to the stochastic wall pressures. These studies will be conducted in air flows in which a simply supported central rod is mounted in a circular tube to provide a concentric annular flow field.

The research program is centered around four interrelated experimental objectives to be carried out in a concentric single pin annular geometry turbulent air flow as follows:

- (1) Measure turbulent velocity intensity levels and mean velocity profiles in the flow region;
- (2) Measure pressure correlation in the flow region and compare with existing analytical data;
- (3) Measure the correlation between the fluctuating flow field pressure and wall pressure fluctuations on the rod; and
- (4) Measure the correlation between the fluctuating flow field velocity and wall pressure fluctuations on the rod.

The end result of this fundamental study should be better quantitative and qualitative understanding of the flow phenomena which generate the wall pressure field.

Work Completed This Report Period

This activity has been completed and reported.

**Task 1.2c - Fluidelastic Interaction in Parallel Flow (W. H. Lin and
J. A. Jendrzeczyk)**

Task Description

To develop a better understanding of the fluidelastic interaction that can result in coupled response and/or instabilities in parallel flow systems, a single rod asymmetrically positioned in a circular flow channel is being investigated. Wall pressure fluctuations and rod response will be measured for a range of Reynolds numbers, hydraulic diameters, and reduced velocities, in order to provide the basis for developing a mathematical model to predict response and scaling relations.

Work Completed This Report Period

Root-mean-square values of the tube displacements in the x and y directions were obtained by integrating the PSDs of displacement over the frequency domain. The resultant vector magnitude is calculated as $z = \sqrt{x^2 + y^2}$. Due to contamination of the acceleration signals by high levels of flow noise, particularly at the higher flow rates, data were bandpass-filtered to eliminate contributions at frequencies below 15 Hz and above 45 Hz, thereby retaining only the response centered about the fundamental frequency of the tube.

The rms magnitude of the resultant displacement vector is plotted versus mean flow velocity in Figure 1.2-1. As seen from Figure 1.2-1, the rms displacement increases with increasing eccentricity (proximity to the channel wall) and with increasing flow speed, with one exception - rms displacements associated with the case of an eccentricity of 0.556 cm (7/32 in.) are slightly less than those with an eccentricity of 0.476 cm (3/16 in.) when the flow velocity is above 15 m/s. Also, if a power function relationship is assumed to represent the dependence of vibration response on mean flow speed it can be noted from Figure 1.2-1 that the variation in the exponent is greater than 2, is approximately a constant for the eccentric cases, and is less than 2 for the concentric case.

Typical spatial patterns of tube response are plotted in Figures 1.2-2 to 1.2-5. Each figure is for a different value of eccentricity; however, the flow speed is the same at 6 m/s. Eight samples from eight evenly distributed time intervals are plotted for each case, with the interval between two neighboring plots at approximately 12 seconds. The plots present the instantaneous positions of the center of the tube and are plotted to the same scale on all four figures to facilitate comparisons. As seen from the plots, the response is random and, for a fixed flow speed, increases as the eccentricity (proximity to the wall) increases.

A purpose of the study is to determine, through a series of systematic measurements of the tube response in eccentric annular flows, whether or not the fluidelastic interaction is sufficiently strong to cause large-amplitude motion or instability when the gap between the tube and the flow channel wall becomes small. It can be concluded that while fluidelastic interaction acts to increase tube response amplitude as the gap between the test element and the flow channel wall becomes smaller, large amplitude motions, as might cause the tube to impact with the wall, do not occur for the range of eccentricities tested.

A topical report presenting the results of this study has been prepared during the reporting period and is being reviewed internally.

Task 1.2d - Experimental Study of Tube Arrays in Parallel Flow (W. H. Lin,
T. M. Mulcahy, J. A. Jendrzejczyk)

Task Description

Task 1.2d consists of an experimental study of the wall pressures and response of rods in a seven-tube array. As in Task 1.2b, the ultimate goal is to generate data for use in developing a vibration response prediction model. The independent test parameters include a wide range of Reynolds numbers and upstream flow disturbances,

Work Completed This Report Period

Efforts during the reporting period focused on the preparation of a topical report presenting results of the seven-rod array tests. The report was com-

pleted along with an internal review.. It will be published during the next quarterly reporting period.

Task 1.2e - Development of Mathematical Models and Design Guides (W. H. Lin, T. M. Mulcahy)

Task Description

Experimental results from subtask activities 1.2b and 1.2d will be used to evaluate and improve prediction methods for parallel flow induced vibration. The methods will be further evaluated via comparisons of predicted response with results from model and full-sized tests (Task 2). Critical flow velocities associated with the onset of fluidelastic instabilities will be expressed in terms of system parameters. Validated design guides will be developed for inclusion in an FIV Handbook.

Work Completed This Report Period

Work continued on the deveopment of an improved prediction method that takes into account the spatial nonhomogeneity of the wall-pressure filed for the case of free stream turbulence and/or flow discontinuity at the entrance to the flow channel. An exponential decay of the intensity of the wall-pressure power spectral density is assumed, and Corcos' model for the cross-spectral density of the fluctuating wall-pressure field is modified accordingly. The coefficients describing the axial decay are obtained from a least-squares fit to the experimental data. The model and its correlation with experimental response measurements will be presented in detail in the quarterly report for the next reporting period.

A second approach to the development of an improved prediction method was attempted. This approach involves the establishment of a functional relationship to bound the turbulent boundary layer wall-pressure PSD in an effort to derive a minimum upper bound on the rms vibration response of the cylinder. The bounding method approach is motivated by the scatter resulting from attempts to normalize wall-pressure data and the spatial nonhomogeneity of flows in real situations which involve free stream turbulence and developing flows.

A simplified characterization of the cross-spectral density of the wall-pressure field S_p which will bound vibration response due purely to a turbulent boundary layer is

$$S_p(\bar{x}, \omega) = d_e^2 S_{po} \exp(-\bar{x}/\ell_c) \cos\left(\frac{\bar{x}\omega}{V_c}\right) \quad (1)$$

where

$$\bar{x} = x_2 - x_1, \quad x_2 > x_1$$

$d_e \equiv 1.25 d$ is an effective pipe diameter bounding the circumferential correlation of the pressure field around the diameter d .

$V_c \equiv 0.8 V$ is an average convection velocity of turbulence eddies in flow with mean velocity V .

$\ell_c \equiv$ one-half channel width is the distance over which pressures remain significantly correlated.

$S_{po}(\omega) = (q^2 d_h / V) S(\omega)$ is the single point ($x_1 = x_2$) wall-pressure PSD, where q is the dynamic pressure, and d_h is the hydraulic diameter. The recommended frequency distribution $S(\omega)$ is recoverable from Figure 1.1-6, with $K = 1$; noting $\phi \sim 6 \times 10^{-6}$, $\Phi_{po} = 2\pi S_{po}$, and $(0.01 K, K\phi)$ and $(4, \phi)$ are coordinates on the approximation curve.

Application of Equation (1) is limited to the parameter range:

$$0.63 < \frac{\omega d_h}{V} < 15.7; \quad 0.03 < \frac{\omega d}{V}; \quad 7.0 < \frac{\omega \ell}{V}. \quad (2)$$

Since damping increases with flow velocity, upper bounds on response can be obtained by using damping estimates for still fluids. For structures with widely separated natural frequencies, only the response in the lowest mode need be calculated, since it is dominant³. Otherwise the response in all modes must be calculated.

It is proposed that the response of a rod in an annular region with flow channel discontinuities (abrupt changes in cross section, etc.) be determined by piecewise application of Equation (1) over axial segments of the rod length with appropriate values of K and ℓ_c . Each axial segment should be small enough to justify the use of averaged flow parameters, but must be larger than ℓ_c .

(factor of 10) for piecewise application of Equation (1) to be valid. The correlation length ℓ_c is estimated as the channel width, based on measurements of this difficult parameter for somewhat similar geometries⁴.

When normalized, all the single point PSDs, $\Phi_{po} = 2\pi S_{po}$, from the annular flow tests at $x/\ell = 0.625$ fit into the data band shown in Figure 1.2-6. The high frequency plateau at ordinate value 6×10^{-6} was determined¹ to be the spectrum level of fully developed flow. The higher plateau at lower frequencies is the remnants of upstream disturbances. Utilizing the curve shown in Figure 1.2-6, $K = 1$ approximates fully developed flow while $K = 5$ approximates the data; corresponding pressure coefficients are $C_p = 0.005$ and 0.006 , respectively. The transducers at $x/\ell = 0.875$ failed, and disappearance of the high plateau could not be confirmed. All the data at $x/\ell = 0.375$ fit in the band of Figure 1.2-6, except for the largest hydraulic diameter with an upstream grid.

At $x/\ell = 0.125$, the effects of upstream disturbances were significant. No high frequency plateau region existed, as shown in the data of Figure 1.2-6. The shape of the spectra were closer to the approximate curve, with relatively more energy being concentrated at lower frequencies. Blockage effects, pipe-to-annulus or grids, created these relatively larger pressure fluctuation levels at $x/\ell = 0.125$, but were attenuated when convected down the rod. Because larger attenuation occurs at higher frequencies, the smallest eddies are most immersed in the boundary layer, the plateau region associated with a fully developed boundary layer is revealed at $x/\ell = 0.375$ and 0.675 . As would be suspected, the attenuation rate depends on hydraulic diameter, which made the normalized data band at $x/\ell = 0.125$ wider than for the other locations.

For the axial location closest to the entrance and grids, the effects of upstream disturbances were significant and depend upon the flow channel hydraulic diameter. This is illustrated in Figure 1.2-1 by the magnitudes of the pressure coefficients. As another comparison, the curve of Figure 1.2-6 was best fit to the spectral data with the result: for $d_h = 3.71$ cm with a grid spoiler, $K = 250$ and $C_p = 0.0625$, while without a spoiler $K = 10$ and $C_p = 0.0075$; for $d_h = 2.44$ cm or 1.17 cm with or without a grid spoiler, $K = 15$ and $C_p = 0.009$ or $K = 50$ and $C_p = 0.018$, respectively. Essentially, the grids had no effect on the surface pressures, except in the largest hydraulic diameter channel where the sharp contraction in channel size at the upstream end of the rod

dominated any grid effects. Even for the largest channel size only grids approaching solid blockages of 50% produced significantly different results. All these same qualitative dependencies on channel contractions and grids were observed in a companion study⁵ of the rod response. Currently under study is the correlation of K and C_p with the solid blockages of the upstream disturbances.

References

1. Mulcahy, T. M., Wambsganss, M. W., Lin, W. H., Yeh, T. T., Lawrence, W. P., "Measurements of Wall Pressure Fluctuations on a Cylinder in Annular Water Flow with Upstream Disturbances; Part I: No Flow Spoilers," GEAP-24310, DOE/N/4175-15, ANL-CT-81-11, January 1981.
2. Mulcahy, T. M., Wambsganss, M. W., Lin, W. H., Yeh, T. T., Lawrence, W. P., "Measurements of Wall Pressure Fluctuations on a Cylinder in Annular Water Flow with Upstream Disturbances; Part II: Flow Spoilers," GEAP-24340, DOE/ET/34209-17, ANL-CT-81-11, January 1981.
3. Chen, S. S., Wambsganss, M. W., "Parallel-Flow-Induced Vibration of Fuel Rods," Nucl. Eng. Des. 18, pp. 253-278 (1972).
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5. Mulcahy, T. M., Yeh, T. T., Miskévics, A. J., "Turbulence and Rod Vibrations in an Annular Region with Upstream Disturbances," GEAP-24173/ANL-CT-79-12/COO-4175-8 (January 1979) (Also, J. Sound Vib. 69(1), pp. 59-69 (1980)).

Figure 1.2-1. RMS Values of Resultant of Tube Displacement

TOP VIEW

t_0 sec

$(t_0 + 12)$ sec

$(t_0 + 24)$ sec

$(t_0 + 36)$ sec

$(t_0 + 48)$ sec

$(t_0 + 60)$ sec

$(t_0 + 72)$ sec

$(t_0 + 84)$ sec

Figure 1.2-2. Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0$

TOP VIEW

t_1 sec

$(t_1 + 12)$ sec

$(t_1 + 24)$ sec

$(t_1 + 36)$ sec

$(t_1 + 48)$ sec

$(t_1 + 60)$ sec

$(t_1 + 72)$ sec

$(t_1 + 84)$ sec

Figure 1.2-3. Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0.32$ cm

Figure 1.2-4. Spatial Configurations of Tube Displacement; $U = 6$ m/s, $e = 0.48$ cm

Figure 1.2-5. Spatial Configurations of Tube Displacement;
 $U = 6$ m/s, $e = 0.56$ cm

Figure 1.2-6. Normalized Spectra Data Band (////) for $x/l = 0.625$ and no Upstream Flow Spoilers. The Curve (—) is drawn for $K = 5$ and $\phi = 2\pi \times 10^{-6}$

Figure 1.2-7. Pressure Coefficients for $d_h = 1.17$ cm, _____; and $d_h = 3.71$ cm, ----. Locations Denoted by $\diamond$, $x/l = 0.125$; $\circ$, $x/l = 0.375$; $\triangle$, $x/l = 0.625$

TASK 1.3 - LEAKAGE FLOW MECHANISMS (CR&D AND NED)

Task 1.3, performed by General Electric Corporate Research and Development and Nuclear Engineering Division, is designed to establish a better understanding of leakage-type flow-induced vibrations for geometries common to light water reactors. The technical objectives include the following:

- (1) Mathematically model and classify components involving leakage flows. Identify flow/geometric and structural features leading to an instability.
- (2) Experimentally illustrate the general classification with critically selected experiments.
- (3) Contribute input to design guides for critical reduced velocity $U/f_n L$ as a function of flow/geometric and structural features to eliminate or reduce possibility of self-induced vibrations. Proof test the design guide by application to a selected LWR component.

Task Description

Task 1.3 is divided into four subtasks:

Task 1.3a - Modeling and Classification of Classes of Components with Leakage Flow-Induced Vibration Susceptibility

Task 1.3b - Simple Experiments to Illustrate Concepts and Governing Parameters Identified by Mathematical Models

Task 1.3c - Proof Test of Evolving Design Guides on a Selected LWR Component

Task 1.3d - Leakage Flow-Induced Vibration Design Guide

Work Performed This Report Period

Activity on this task has not been initiated as yet since it is not yet funded.

TASK 1.4 - RANDOM VIBRATION EFFECTS (ANL AND NED)

Task 1.4 consists primarily of a literature survey to review existing random vibration fatigue damage rules and experimental data related to interpretation of FIV data. Based on this review, suitable random fatigue damage criteria will be developed and recommended for application to LWR components subjected to flow-induced vibration.

Task Description

Task 1.4 is broken into three subtasks:

Task 1.4a - Survey of Literature

Task 1.4b - Derivation of Procedure/Criteria

Task 1.4c - Design Guides

Work Performed This Report Period

This task has been completed.

TASK 2 - MODEL AND FULL-SIZE COMPONENT TESTS

Task 2 is devoted to the FIV testing of realistic model and prototypical geometries, rather than the idealized geometries studied in Task 1. Model and full-scale testing of several LWR components will be performed to extend the Task 1 results and provide input for the development and verification of empirical relations, scaling laws, and predictive models generated as part of Task 3. The components tested will, in general, be from General Electric's most recent boiling water reactor product line, the BWR/6. Task 2 is divided into five component test programs:

Task 2.1 - Lower Plenum

Task 2.2 - Fuel Assembly

Task 2.3 - Jet Pump

Task 2.4 - Low Pressure Coolant Injection Line

Task 2.5 - LWR Component (undefined)

Progress achieved for each of these component tests for the report period is described on the following pages.

TASK 2.1 - LOWER PLENUM (NED)

Task 2.1 is an experimental FIV study of tubes in an array. The array is a mix of tubes with different diameters. The flow environment combines regions of cross flow and parallel flows. The results from this task will be evaluated using results from the fundamental studies (Tasks 1.1 and 1.2) in order to highlight the important FIV mechanisms in real LWR components. The first steps in this study were to perform FIV tests on tenth-scale and quarter-scale models of a BWR lower plenum. This provided preliminary data and the experience necessary to run a productive full-scale model test. The final step in this process is to measure vibration in an LWR before power generation startup. This will verify the more extensive full-scale model results.

Task 2.1 consists of four subtasks:

Task 2.1a - Lower Plenum One-Tenth Scale FIV Test

Task 2.1b - Lower Plenum Quarter-Scale FIV Test

Task 2.1c - Lower Plenum Full-Scale FIV Test

Task 2.1d - Lower Plenum Operational LWR Field FIV Test

Progress achieved on Task 2.1 is described on the following pages.

Task 2.1a - Lower Plenum One-Tenth Scale FIV Test (M. A. DeCoster, S. L. Kushman)

Task Description

A one-tenth scale model of a BWR lower plenum was constructed of clear cast epoxy to study the flow patterns in the lower plenum via flow visualization in 1974. Later, velocity probes were inserted into the flow stream to obtain quantitative measurements of the flow distribution. In 1976, flow-induced vibration tests were initiated to determine the vibrational characteristics of control rod guide tubes in the lower plenum. The tests were completed in late 1976.

Work Performed This Report Period

The one-tenth-scale lower plenum model test and analysis program was completed during a previous report period. Results were documented in GE report GEAP-24124, "Flow-Induced Vibration for Light Water Reactors Progress Report (June - September 1977)."

Task 2.1b - Lower Plenum Quarter-Scale FIV Test (M.A. DeCoster)**Task Description**

A quarter-scale model of a BWR lower plenum was constructed by GE in 1974 to study flow distribution and vibration levels of lower plenum components. The model was situated at the Colorado State University Hydro-machinery Laboratory. Flow and shake tests performed in 1974, 1975, and 1976 yielded extensive flow distribution vibration data for various designs. The final tests were completed in the last quarter of 1976.

Work Performed This Report Period

The quarter-scale lower plenum model test and analysis program was completed prior to the commencement of the Flow-Induced Vibration for Light Water Reactors program. Results were documented in GEAP-24124.

Task 2.1c - Lower Plenum Full-Scale FIV Test (M.A. DeCoster)**Task Description**

Task 2.1c consists of the FIV testing of prototype LWR components in the lower plenum of the 60° sector model at the High Flow Hydraulic Test Facility (HF)². The test components were made at the same facility and to the same standards as actual reactor components. The components are full scale but the sector model contains one-sixth the number of components in a reactor. The components in the lower plenum are cylinders of various diameters in an array pattern. Water flows around the outside of these components.

The test program consists of a series of shake tests followed by flow tests. In the shake tests, a single component is forced to vibrate by an electromagnetic shaker or impact hammer. The input force and resulting motion are measured, and the information is processed to define the structural characteristics of the component. In the subsequent flow tests, the vibration response of the components, as well as certain aspects of the FIV forces, are measured for a variety of operational and nonoperational flow conditions.

Work Performed This Report Period

All work has been completed with the exception of a topical report which is currently underway.

TASK 2.2 - FUEL ASSEMBLY (NED)

Task 2.2 is designed to fully investigate the FIV characteristics of a prototype fuel assembly. The primary objectives are to:

- (1) Establish the FIV character of a typical fuel assembly including mode shapes, frequencies, character of response, and assessment of the stability margin as a function of system damping and flow;
- (2) Determine the relationship between the FIV characteristics and coolant properties; i.e., coolant temperature (ambient versus LWR operational conditions) and quality (single-phase water versus two-phase water-stream); and
- (3) Proof-test the concepts and forcing function estimates devised in Task 1.

Task 2.2 will be useful in verifying and extending the fundamental studies on parallel flow over tube banks of Task 1.1. It will provide input to the analytical model development of Task 3.1 and the scaling development (importance of temperature) of Task 3.2.

Task 2.2 is divided into three test programs:

Task 2.2a - Fuel Assembly Cold FIV Test

Task 2.2b - Fuel Spacer Preload FIV Test

Task 2.2c - Hot FIV Test

A description of progress achieved during this report period is given in the following pages.

Task 2.2a - Fuel Assembly Cold FIV Test**Task Description**

Task 2.2a consists of the FIV testing of a prototype 8 x 8 fuel assembly over a wide range of hydraulic conditions using the General Electric Large Tank Hydraulic Loop. The fuel assembly was instrumented with accelerometers, pressure transducers, and strain gages to measure the dynamic characteristics of the fuel assembly components.

Work Performed This Report Period

The cold flow-induced vibration testing of a prototypical 8 x 8 fuel assembly was completed early in the program and was reported in previous progress reports.

Task 2.2b - Fuel Spacer Preload FIV Test (C. G. Hayes)**Task Description**

These tests will investigate the effect of fuel spacer spring preload on the FIV characteristics of fuel rod. Specifically, the test results should indicate:

- (1) At what flow-preload conditions the fuel rod loses contact with the spacer springs and begins vibrating within the spacer.
- (2) The vibration levels (rod-spacer impact acceleration levels) that result when the conditions in (1) above are met.
- (3) The effect of spacer spring preload and stiffness on fuel rod FIV characteristics (frequency and amplitude).

The test program will consist of the following elements:

- (1) Single-rod flow test,
- (2) 3 x 3 rod bundle flow test.

The tests will be performed at the General Electric High Flow Hydraulic Facility.

Single Rod Flow Test

A single full-scale fuel rod is supported by segments of actual lower and upper tie plates as shown in Figure 2.2-1. The inside diameter of the test cylinder has been sized to approximate the hydrodynamic mass and hydraulic diameter of a single rod in an actual fuel assembly. The simulated fuel spacer location and preload adjustment fixture are shown in Figure 2.2-2. The adjustment fixture will allow for easy adjustment of spring preloads. The locations of both the preload fixture and hard supports will match the spacer locations of actual fuel assemblies.

Several different instrumented rods are used to determine fuel FIV characteristics. The fuel rods to be used with their respective instrumentation are shown in Figure 2.2-3.

3 x 3 Rod Bundle Flow Test

These tests utilized the same instrumented fuel rods described for the single rod test, surrounded by eight dummy (non-instrumented) rods (Figure 2.2-4). Actual fuel spacers were used, with the preload being adjusted by controlling the amount of spring deflection caused by rod insertion into the fuel bundle. Only the preload on the central, instrumented rod is controlled. The range of preloads tested is 0-3 pounds, which is inclusive of the preloads nominally encountered in present fuel designs.

Work Performed This Report Period

All single rod and 3x3 rod array flow induced vibration tests were completed during this report period. Extensive investigation and analysis of the test data have been performed. In Table 2.2-1, a tabulation of the test matrix is provided. The terms "Rod Suspension" and "Without Rod Suspension" indicate whether the instrumented fuel rod is suspended slightly above the lower tie plate - lower end plug seating surface or is merely resting on the lower tie plate (Figure 2.2-5).

The tests shown in Table 2.2-1 were performed at the flow rates shown in Table 2.2-2. Because of the greater flow area in the 3x3 test, flow rates were limited to a maximum of 175% of the 100% condition shown. The flow velocities were matched between the single rod and 3x3 test.

All tests were performed in the temperature range 70° - 90°F.

Typical test results for both the single fuel rod and 3x3 fuel rod are provided in Figures 2.2-6 and 2.2-7, respectively. Key conclusions from this test are as follows:

- (1) The fuel rod vibration in all cases tested was extremely low level.
- (2) Fuel rod vibration increases with increases in coolant flow rate.

In general, fuel rod vibration is not sensitive to fuel spacer lantern spring preload. However, in one test condition a twofold increase in fuel rod vibration was experienced at low preloads.

A topical report documenting these fuel flow induced vibration tests is currently being prepared. It will be issued in the third or fourth quarter of 1981.

Task 2.2c Hot FIV Test (C. G. Hayes, W. J. McDonough, M. R. Torres)

Task Description

Flow tests will be performed on a 3 x 3 array of fuel rods under reactor temperature and pressure (550°F, 1050 psia) at the General Electric heat transfer test facility ATLAS. This is the final test in the fuel area. The primary purpose is to determine the effect of two-phase boiling conditions on fuel rod vibrations. The test will be run in four steps:

- (1) Single-phase water flow at 180°F to compare to results from Task 2.2b.
- (2) Single-phase hot flow at 550°F to determine any effect from temperature.
- (3) Two-phase hot flow with no heat input to the fuel rod (constant quality).

(4) Two-phase hot flow with nucleate boiling from rod heating.

Work Completed This Report Period

A team of engineers and technicians from different organizations are contributing to this test. The responsible engineer is holding bi-weekly progress meetings. All test preparation work is proceeding on schedule. This includes fabrication of special test hardware, writing test procedures, assembling the instrumentation package, and preparation of computer programs specifically needed for this test. Simulated fuel pellets were loaded into the zircalloy fuel rods. Accelerometers and other transducers have also been installed into the fuel rods. Spacers (3x3) have been cut from standard 8x8 spacers. The ceramic channel sections have been received and will be machined soon to accommodate transducers. All modifications to the ATLAS test facility computer software have been completed and reviewed. This hot fuel two-phase fuel vibration test is right on schedule. Testing will start the first week of August 1981.

A short analytical study to understand the effect various flow regimes (single-phase, two-phase, boiling) will have on fuel vibration response was undertaken and completed during this report period (Reference 3). A single fuel rod was modeled as a one degree of freedom system and the hydrodynamics of bubbly and annular flow regimes were developed. The large pressure drop in two-phase flow was identified as possibly the key parameter responsible for higher vibration levels observed in past two-phase parallel flow experiments. This short analytical study will be useful in understanding and correlating test results from the upcoming fuel two-phase flow induced vibration experiments. Key conclusions arrived at from this analytical study were:

- (1) The inertia of the fuel rod, which consists of the rod's weight and added mass, decreases with increasing voids, hence the fuel rod's natural frequency should increase slightly with increasing quality (χ).
- (2) In the bubbly flow analysis, the damping was shown to decrease with increasing void fraction (α), while in the annular analysis, the damping was found to increase with increasing voids. For the range of values investigated in the analysis, the rod response was found insensitive to damping, except when vibrating near the resonance frequency.

- (3) When the (fluid) forcing function on the fuel rod is assumed proportional to the pressure drop of the flow, this excitation term was found to increase as the square of $1/(1-\alpha)$. This increase in the forcing function is believed to be the main cause of the higher amplitude of vibration observed in two-phase experiments reported in the literature.
- (4) To obtain the same levels of vibration as a two-phase fluid using a single phase fluid, simulation tests should be performed at the following mass flux, G ,

$$\frac{G_1\phi}{G_2\phi} = \left(\frac{1 - \chi}{1 - \alpha} \right)^{0.875}$$

$G_1\phi$ represents the mass flux of a simulated single-phase experiment, and $G_2\phi$ refers to the actual two-phase system to be simulated. The equation is believed to be conservative since it takes into account the phase separation as developed in the annular flow analysis, rather than the homogeneous, no-slip condition of the bubbly flow analysis.

- (5) The two-phase flow parameter of added mass, damping (ξ) and the pressure drop multiplier ($\phi_{\chi 0}^2$) developed in this paper are summarized in Table 2.2-3.

References

1. Test Plan and Procedure 241.0708, "Fuel Spacer Preload Flow Induced Vibration Test," Rev. 0, Supp. A.
2. "Preliminary Design Handbook for Flow Induced Vibration of Light Water Reactors," K. S. Ananthanarayamn, GEAP-24258, pp 5-14.
3. McDonough, W. J. "An Analytical Investigation of the Vibration of Simply Supported Cylindrical Rod in Two-Phase Parallel Flow," University of California, Berkeley, June 1981.

Table 2.2-1
TEST MATRIX

	Configuration		Single Rod		3x3	3x3
	Rod Suspension		Yes		No	Yes
<u>Preload, lbs.</u>	<u>Rod Number</u>		<u>1</u>	<u>3</u>	<u>1</u>	<u>3</u>
0.07					x	x
0.1			x	x		
0.25			x	x		
0.5			x	x	x	x
0.75			x	x		
1.0			x	x	x	x
2.5*			x	x	x	x

*Nominal beginning of life

Table 2.2-2
TEST FLOW CONDITIONS

Flow Rate <u>%</u>	Flow Velocity <u>ft/sec</u>	Mass Flux <u>lbs/hr ft²</u>	Test Configuration	
			<u>Single Rod</u>	<u>3x3</u>
50	3.3	7.4×10^5		x
75	5.0	1.1×10^6		x
100	6.6	1.5×10^6	x	x
150	9.9	2.2×10^6	x	x
175	11.6	2.6×10^6	x	x
200	13.2	3.0×10^6	x	
250	16.6	3.7×10^6	x	

Table 2.2-3
SUMMARY OF TWO-PHASE FLOW INDUCED VIBRATION PARAMETERS

Flow Regime

Bubbly

Annular

Added Mass

$$\rho_H \pi r_i^2 \ell \frac{1 + \left(\frac{r_i}{r_o}\right)^2}{1 - \left(\frac{r_i}{r_o}\right)^2}$$

$$\rho_\ell \pi \left[(r_i + \delta)^2 - r_i^2 \right] \ell$$

$$\rho_H = \alpha \rho_g + (1 - \chi) \rho_\ell$$

Damping,

$$\zeta_o + \frac{\pi}{16} c_n \frac{C_I \rho_H D^2}{m} \left(\frac{u}{\omega_n D} \right)$$

$$\zeta_\ell + \frac{\pi}{16} \frac{1 + \left(\frac{r_i}{r_i + \delta}\right)^2}{1 - \left(\frac{r_i}{r_i + \delta}\right)^2} \frac{\rho_\ell D^2}{m} \left(\frac{u}{\omega_n D} \right)$$

$$\zeta_o = \zeta_\ell \left[1 + \chi \left(\frac{\zeta_\rho}{\zeta_g} - 1 \right) \right]^{-1}$$

or

$$4 \zeta_\ell$$

Two Phase
Multiplier

$$1 - \chi \left(\frac{\rho_f}{\rho_g} - 1 \right)$$

$$\left(\frac{1 - \chi}{1 - \alpha} \right)^{1.75}$$

Figure 2.2-1. Test Setup (Single-Rod Test)

Figure 2.2-2: Spacer Location Detail

Figure 2.2-3. Instrumented Fuel Rods

Figure 2.2-4. 3x3 Rod Bundle Overview

CONFIGURATION 1

ROD RESTING ON LTP

CONFIGURATION 2

ROD SUPPORTED AT UTP
NOT SEATED AT LTP

Figure 2.2-5. Test Configurations, Instrumented Rod Only

SINGLE ROD RESULTS W/ROD SUSPENSION ROD 1

MIDDLE SPACER ELEVATION

Figure 2.2-6. Single Rod Results with Rod Suspension - Rod 1

3X3 RESULTS W/ROD SUSPENSION ROD 1

MIDDLE SPACER ELEVATION

Figure 2.2-7. 3x3 Results with Rod Suspension - Rod 1

TASK 2.3 - JET PUMPS

Task 2.3 is designed to investigate and quantify the FIV characteristics of a jet pump assembly. A typical jet pump assembly is shown in Figure 2.3-1. There are 20 jet pumps in the current BWR design. Jet pump primary components are a mixer and diffuser which are joined together at a thermal expansion slip joint. Approximately one-third of the reactor core flow is taken from the vessel, pumped through a piping manifold system, and returned to the vessel, where it is discharged from the jet pump nozzle at high velocity (~ 200 ft/sec) into the initial stage of the jet pump mixer. The nozzle flow entrains the surrounding water into the jet pump throat where the two flows mix and then diffuse, to be finally discharged into the lower core plenum at velocities up to 40 ft/sec. The jet pump has many characteristics that can contribute to flow-induced vibrations (e.g., high-velocity flow in small pipes, high-velocity flow in a pipe turning 180° within a small radius, and high-velocity jets exiting into a confined region). However, the two characteristics which are judged to be the most significant contributors are, in order of magnitude:

- Leakage flow through the mixer-diffuser slip joint interface.
- Mixing of the high-velocity drive flow with the entrained suction flow in the mixer.

Jet pump tests have been performed hot (550°F) and cold ($60 - 180^\circ\text{F}$), under operational and nonoperational conditions, at rated and above-rated flows.

Task 2.3 is divided into three subtasks:

Task 2.3a - Jet Pump Cold FIV Test

Task 2.3b - Jet Pump Hot FIV Test

Task 2.3c - Jet Pump Mechanistic Test

Task 2.3a - Jet Pump Cold FIV Test**Task Description**

Four prototype BWR/6-238 jet pumps (two jet pump pairs) are flow-tested over a wide range of hydraulic conditions, using the High Flow Hydraulic Facility 60° Sector Test Stand. The jet pumps are heavily instrumented with accelerometers, pressure transducers, strain gages, and displacement sensors so as to determine the dynamic characteristics and vibration response, as well as to characterize the forcing function. Tests are performed at temperatures ranging from 60°F to 180°F.

Work Performed This Report Period

All testing and analysis of jet pumps have been completed. Topical reports are in progress.

Task 2.3b - Jet Pump Hot FIV Test**Task Description**

Flow tests are performed on single prototypical jet pumps under reactor temperature and pressure (550°F, 1050 psia) at the Pacific Gas and Electric Moss Landing Power Station, where the GE Steam Water Test Facility is located. The test program is designed to establish a better understanding of the relationship between the vibration response of the component and the key fluid and geometric parameters, particularly in the slip joint region. The program is separated into two activities, each described below.

- (1) The first activity consists of the thorough FIV testing of a BWR/5 201-in. jet pump. This jet pump is of interest to the FIV for LWR Program because its geometric and fluid characteristics (lower fundamental frequency and higher slip joint pressure drop than other designs) make it more susceptible to slip joint-type vibration stabilities. Sufficient vibration instrumentation will be utilized to characterize the natural frequencies, mode shapes, primary forcing functions, and system response for various flow conditions.

- (2) The second activity consists of the very limited FIV testing of BWR 218-in. and 251-in. jet pumps. The data, consisting primarily of vibration response as a function of flow condition, are acquired through the addition of several vibration sensors to jet pumps scheduled for hydraulic performance testing at the Moss Landing facility. The additional data will provide significant information concerning the effect of geometry (diffuser length, slip joint geometry, etc.) on the dynamic response of this LWR component.

Work Performed This Report Period

All flow-induced vibration testing of single prototypical jet pumps under reactor temperature and pressure in the Pacific Gas and Electric Moss Landing Steam Water Test Facility has been completed. Much of the vibration data has been reduced and analyzed. Topical reports documenting this work will be issued.

Figure 2.3-1. Jet Pump Pairs

TASK 2.4 - LOW PRESSURE COOLANT INJECTION COUPLING

The low pressure coolant injection (LPCI) system is part of the boiling water reactor emergency core cooling system. Not used during normal operation, its sole purpose is to restore and maintain the desired water level in the reactor vessel after a loss-of-coolant accident (LOCA). The coupling hardware consists primarily of two 10-in.-ID elbows, joined together by a 26-in.-long sleeve. Collars which thread on the two elbows capture the sleeve during installation and hold it in place (to accommodate differential thermal expansion, the sleeve is not welded to the elbows).

The LPCI is subject to FIV under both normal plant operation and emergency (LOCA) modes. Under normal operating conditions, when there is no flow through the LPCI, downcomer annulus flow buffets the LPCI coupling. In addition, a steady-state pressure drop across the collar-sleeve slip joints induces leakage flow which can result in fluid-elastic coupling. In the LOCA mode, the high flow velocities through the coupling produce turbulent buffeting of the inner walls. Also, as in the normal operating mode, slip joint differential pressures exist which can induce some leakage flow.

Task Description

Task 2.4 consists of flow-testing a prototypical BWR/6 238-in. LPCI coupling in the High Flow Hydraulic Facility's General Purpose Test Tank.

This test program should provide some fundamental understanding of the flow-induced vibration characteristics of large piping configurations with slip joints.

Work Performed This Report Period

All test activities have been completed, and efforts are now directed toward data reduction and analysis, as well as final test documentation. Preliminary results from data analysis were reported in GEAP-24248. Data analysis is continuing and a final report is being prepared.

TASK 3 - LWR FIV DESIGN METHODS, GUIDES AND CRITERIA

The primary purpose of Task 3 is the development of FIV guides and criteria which can be utilized by engineers for the design of LWR components. This is accomplished through the generation of analytical models and empirical relations, using the results of the fundamental studies, full-scale component tests, and actual plant vibration data generated in Tasks 1 and 2. Additionally, Task 3 is designed to establish scaling laws for FIV testing of reactor components, as well as to provide analytical support for the model testing of Task 2. The technical objectives are to:

- (1) Develop analytical methods and computer codes for predicting the FIV response of reactor components;
- (2) Develop empirical relations, scaling laws, and practical design guides for reactor design utilizing the information generated in Tasks 1 and 2; and
- (3) Verify analytical methods by comparison with full-scale development tests and actual plant vibration data as available.

Task 3 is divided into three separate activities:

Task 3.1 - Predictive Model Development

Task 3.2 - Scaling

Task 3.3 - Correlation with Full-Scale Tests and Plant Data

Work Performed This Report Period

No significant time or funds were used during this reporting period on Task 3, so there is no progress to report.

TASK 4 - PROGRAM ADMINISTRATION

Task Description

The purpose of Task 4 is to provide the overall management of the program, including coordination, reports, and reviews. In addition, it is to ensure that the program's fundamental studies, model and full-size component tests, and analytical method development are responsive to the PWR as well as the BWR needs in the area of flow-induced vibrations.

Work Performed This Report Period

Quarterly progress reports up to April 1981 were completed and submitted to reprographics for publication.

Extensive program management effort was applied to determine total expected program costs relative to authorized program budget. Corrective action was undertaken to stay within allocated resources.

Dan Geising will be handling DOE Project Manager responsibilities as Jeff Hangst has left DOE.

Martin Torres will be handling GE Program Manager responsibilities as Dr. Mark DeCoster has left the General Electric Company.

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