APR 13 1966

GEAP-5084
JANUARY 1966

EURAEC
JOINT U.S.-EURATOM RESEARCH
AND DEVELOPMENT PROGRAM

1598

MASTER

NOT APPROVED FOR PUBLIC RELEASE
THE AEC AND ITS CONTRACTORS ONLY

RADIAL VANE STEAM SEPARATOR DEVELOPMENT

SIXTH QUARTERLY REPORT OCTOBER - DECEMBER 1965

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

R.H. MOEN

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
PROJECT AGREEMENT 42

NOTICE

This report was received under the provisions
of the NSAEC/Euratom arrangement and is subject to the terms thereof.

Rx D

ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

To expedite dissemination of technical information to those persons requiring it, this report has been issued without the administrative review necessary to protect the interest of the U.S. Government, the European Atomic Energy Community (Euratom) and the contractor. The contractor's report agrees that it is passed up to him in confidence and that he will maintain that confidence and make no disclosures or publication of the contents that would be detrimental to the interests of the U.S. Government, the European Atomic Energy Community (Euratom) and the contractor.

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

EURAEC
GEAP-5084
JOINT US-EURATOM
Research and
Development Program
January 1966

NOT APPROVED FOR PUBLIC RELEASE. AVAILABLE
TO THE AEC AND ITS CONTRACTORS ONLY.

CFSTI PRICES

H.C. \$ 4.00; MN .75

RADIAL VANE STEAM SEPARATOR DEVELOPMENT

Sixth Quarterly Report

October-December 1965

R. H. Moen

Prepared for the

U. S. ATOMIC ENERGY COMMISSION

Contract AT(04-3)-189

Project Agreement 42

Printed in U.S.A. Available from the
Clearing House for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Gaithersburg, Maryland
NBS Monograph No. 100

ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

LEGAL NOTICE

THIS DOCUMENT WAS PREPARED UNDER THE SPONSORSHIP OF THE ATOMIC ENERGY COMMISSION PURSUANT TO THE JOINT RESEARCH AND DEVELOPMENT PROGRAM ESTABLISHED BY THE AGREEMENT FOR COOPERATION SIGNED NOVEMBER 8, 1958, BETWEEN THE GOVERNMENT OF THE UNITED STATES OF AMERICA AND THE EUROPEAN ATOMIC ENERGY COMMUNITY (EURATOM). NEITHER THE UNITED STATES, THE U.S. ATOMIC ENERGY COMMISSION, THE EUROPEAN ATOMIC ENERGY COMMUNITY, THE EURATOM COMMISSION, NOR ANY PERSON ACTING ON BEHALF OF EITHER COMMISSION:

- A. MAKES ANY WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED, WITH RESPECT TO THE ACCURACY, COMPLETENESS, OR USEFULNESS OF THE INFORMATION CONTAINED IN THIS DOCUMENT, OR THAT THE USE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THIS DOCUMENT MAY NOT INFRINGE PRIVATELY OWNED RIGHTS; OR
- B. ASSUMES ANY LIABILITIES WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THIS DOCUMENT.

AS USED IN THE ABOVE, "PERSON ACTING ON BEHALF OF EITHER COMMISSION" INCLUDES ANY EMPLOYEE OR CONTRACTOR OF EITHER COMMISSION OR EMPLOYEE OF SUCH CONTRACTOR TO THE EXTENT THAT SUCH EMPLOYEE OR CONTRACTOR OR EMPLOYEE OF SUCH CONTRACTOR PREPARES, HANDLES, DISSEMINATES, OR PROVIDES ACCESS TO, ANY INFORMATION PURSUANT TO HIS EMPLOYMENT OR CONTRACT WITH EITHER COMMISSION OR HIS EMPLOYMENT WITH SUCH CONTRACTOR.

TABLE OF CONTENTS

	<u>Page No.</u>
1.0 SUMMARY	1-1
2.0 PRINCIPAL INVESTIGATORS AND REPORTS ISSUED	2-1
2.1 Principal Investigators	2-1
2.2 Reports Issued	2-1
2.3 Background Report	2-1
3.0 STATEMENT OF PROBLEM	3-1
3.1 Task A, Wall Flow	3-1
3.1.1 Task A-1, Upper Vortex Thickness	3-1
3.1.2 Task A-II, Wall Flow Model	3-1
3.1.3 Task A-III, Lower Vortex Characteristics	3-3
3.1.4 Task A-IV, Water-Steam Interface	3-3
3.2 Task B, Plenum	3-3
3.3 Task C, Vanes	3-3
3.4 Task D, Carryover	3-3
3.5 Task K, Carryunder	3-3
3.6 Task F, Model Separators	3-4
3.7 Task G, Test Facility Modification	3-4
4.0 ACCOMPLISHMENTS DURING THE REPORT PERIOD	4-1
4.1 Task A, Wall Flow	4-1
4.1.1 Task A-1, Upper Vortex Flow	4-1
4.1.2 Task A-II, Wall Flow Model	4-7
4.1.3 Task A-III, Lower Vortex Characteristics	4-7
4.1.4 Task A-IV, Steam-Water Interface	4-7
4.2 Task D, Plenum	4-7
4.3 Task C, Vanes	4-7
4.4 Task D, Carryover	4-11
4.5 Task E, Carryunder	4-11
4.6 Task F, Model Separators	4-11
4.7 Task G, Large Air-Water Facility Modification	4-13
5.0 FUTURE WORK	5-1
APPENDIX A - UPPER VORTEX THICKNESS CALCULATIONS	A-1
APPENDIX B - WALL FLOW VELOCITY AND PRESSURE MEASUREMENTS FOR FCRV-3 AND FCRV-4	B-1

TABLE OF CONTENTS (Cont)

	<u>Page No.</u>
APPENDIX C - RAW AND CALCULATED TEST DATA FOR FCRV-3 AND FCRV-4	C-1
APPENDIX D - ORIFICE CALIBRATIONS FOR THE LARGE AIR-WATER TEST FACILITY	D-1
REFERENCES	-1-
APPROVALS	-2-
DISTRIBUTION LIST	-3-

LEGAL NOTICE

This document was prepared under the sponsorship of the United States Atomic Energy Commission pursuant to the Joint Research and Development Program established by the Agreement for Cooperation signed November 8, 1958 between the Government of the United States of America and the European Atomic Energy Community (Euratom). Neither the United States, the U. S. Atomic Energy Commission, the European Atomic Energy Community, the Euratom Commission, nor any person acting on behalf of either Commission:

- A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

As used in the above, "person acting on behalf of either Commission" includes any employee or contractor of either Commission or employee of such contractor to the extent that such employee or contractor or employee of such contractor prepares, handles, disseminates, or provides access to, any information pursuant to his employment or contract with either Commission or his employment with such contractor.

LIST OF ILLUSTRATIONS

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	Sketch of the Full Circle Radial Vane Separator; FCRV-2 with Annular Outlet	3-2
2	Effect of V_1 on the Velocity at the Nozzle Bottom	4-6
3	FCRV-3 Pressure Drop	4-8
4	FCRV-4 Pressure Drop	4-9
5	FCRV-2 Pressure Drop	4-10
6	FCRV-4 Carryunder	4-12
B-1a	Wall Flow Measurements in FCRV-4 - Axial Velocity: Seventy-two 6-inch Nozzles	B-2
B-1b	Wall Flow Measurements in FCRV-4 - Tangential Velocity: Seventy-Two 6-inch Nozzles	B-3
B-2a	Wall Flow Measurements in FCRV-4 - Axial Velocity: Eighteen 30-inch Nozzles	B-4
B-2b	Wall Flow Measurements in FCRV-4 - Tangential Velocity: Eighteen 30-inch Nozzles	B-5
D-I	Air Flow - Orifice Diameter = 3.549 inches	D-2
D-II	Air Flow - Orifice Diameter = 5.070 inches	D-3
D-III	Water Flow	D-4
D-IV	Equivalent Carryunder versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 0.805 inch	D-5
D-V	Equivalent Carryunder versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 1.288 inches	D-6
D-VI	Equivalent Carryunder versus Carryunder Air Flow Rate	D-7
D-VII	Carryunder Air Flow - Orifice Diameter = 0.805 inch	D-8
D-VIII	Carryunder Air Flow - Orifice Diameter = 1.288 inches	D-9

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
I	Ranges of Test Conditions for Upper Vortex Thickness Measurements	4-1
II	Comparison of Predicted and Observed Upper Vortex Thickness for FCRV-3	4-2
III	Comparison of Predicted and Observed Upper Vortex Thickness for FCRV-4	4-3
IV	Experimental Vane Discharge Angles and Calculated Vertical Velocity Components	4-4
V	Vertical Vane Jet Velocity Components	4-5
A-I to A-VIII	Values of the Function, T , and the Vertical Velocity at the Nozzle Bottoms, $V_{z,n}$, as a Function of Nozzle Length, z , for Various Values of the Vane Jet Vertical Velocity Component on Entering the Upper Vortex, V_1	
A-I	$V_1 = 0.0$ ft/sec	A-8
A-II	$V_1 = 0.5$ ft/sec	A-10
A-III	$V_1 = 1.0$ ft/sec	A-12
A-IV	$V_1 = 1.3$ ft/sec	A-14
A-V	$V_1 = 1.5$ ft/sec	A-16
A-VI	$V_1 = 2.0$ ft/sec	A-18
A-VII	$V_1 = 2.5$ ft/sec	A-20
A-VIII	$V_1 = 3.0$ ft/sec	A-22
A-IX	Variation of the Calculated Upper Vortex Thickness at the Bottom of Six-inch Nozzles as a Function of V_1	A-24
A-X	Variation of the Calculated Upper Vortex Thickness at the Bottom of Thirty-inch Nozzles as a Function of V_1	A-25
B-I	Wall Flow Data for Run No. 100801	B-6

LIST OF TABLES (Cont)

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
B-II	Wall Flow Data for Run No. 100802	B-7
B-III	Wall Flow Data for Run No. 100803	B-7
B-IV	Wall Flow Data for Run No. 101901	B-8
B-V	Wall Flow Data for Run No. 102301	B-8
B-VI	Wall Flow Data for Run No. 102302	B-9
B-VII	Wall Flow Data for Run No. 102501	B-10
B-VIII	Wall Flow Data for Run No. 102701	B-11
B-IX	Wall Flow Data for Run No. 102801	B-12
B-X	Wall Flow Data for Run No. 102802	B-12
B-XI	Wall Flow Data for Run No. 110203	B-13
B-XII	Wall Flow Data for Run No. 110308	B-14
B-XIII	Wall Flow Data for Run No. 110901	B-15
B-XIV	Wall Flow Data for Run No. 110902	B-15
B-XV	Wall Flow Data for Run No. 110903	B-16
B-XVI	Wall Flow Data for Run No. 112401	B-17
B-XVII	Wall Flow Data for Run No. 112402	B-18
B-XVIII	Wall Flow Data for Run No. 112901	D-19
B-XIX	Wall Flow Data for Run No. 120304	B-20
B-XX	Wall Flow Data for Run No. 120901	B-21
B-XXI	Wall Flow Data for Run No. 121001	B-22
B-XXII	Wall Flow Data for Run No. 121301	B-23

LIST OF TABLES (Cont)

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
B-XXIII	Wall Flow Data for Run No. 121401	B-24
B-XXIV	Wall Flow Data for Run No. 121402	B-25
C-I	Raw Data for FCRV-3 Tests	C-2
C-II	Calculated Data for FCRV-3 Tests	C-4
C-III	Raw Data for FCRV-4 Tests	C-6
C-IV	Calculated Data for FCRV-4 Tests	C-7

FOREWORD

The United States and the European Atomic Energy Community (EURATOM), on May 29, and June 18, 1958, signed an agreement which provides a basis for cooperation in programs for the advancement of the peaceful applications of atomic energy. This agreement, in part, provides for the establishment of a Joint U.S. -EURATOM research and development program which is aimed at reactors to be constructed in Europe under the Joint Program.

The work described in this report represents the Joint U.S. - EURATOM effort which is in keeping with the spirit of cooperation in contributing to the common good by the sharing of scientific and technical information and minimizing the duplication of effort by the limited pool of technical talent available in Western Europe and the United States.

1.0 SUMMARY

The major share of the FCRV-3 and FCRV-4 testing was completed during this past quarter. These tests showed satisfactory carryover, carryunder, and pressure drop performance of the model radial vane separator in air-water service. Nozzle lengths up to the maximum available (30 inches) were tested, and tests were carried out with all vanes active (maximum nozzle length = 12 inches). The tests also show that the upper vortex thickness can be predicted satisfactorily, that turning vanes (plenum deflectors) are not required (but could be used to decrease the upper vortex thickness if desired), and that the upper vortex surface is relatively smooth and not unstable. Equipment has been designed and built to study the distribution of carryunder in the wall flow. Equipment has been designed to determine the effect of vertical steam velocity on separation on the vanes.

2.0 PRINCIPAL INVESTIGATORS AND REPORTS ISSUED

2.1 PRINCIPAL INVESTIGATORS

R. H. Moen	Project Engineer
J. E. Gifford	Test Engineer
A. A. Kudirka	Analysis of Carryover and Carryunder Phenomena

The simplified method of solution of the equations for the upper vortex thickness (Section 4.1) was suggested by C. L. Peterson of Computation and Data Processing.

2.2 REPORTS ISSUED

<u>EURAE</u> <u>C Number</u>	<u>Report</u> <u>Number</u>	<u>Title</u>
1253	GEAP-4728	Radial Vane Steam Separator Development, First Quarterly Report, June-September 1964
1301	GEAP-4783	Radial Vane Steam Separator Development, Second Quarterly Report, October-December 1964
1365	GEAP-4847	Radial Vane Steam Separator Development, Third Quarterly Report, January-March 1965
1450	GEAP-4914	Radial Vane Steam Separator Development, Fourth Quarterly Report, April-June 1965
	GEAP-4935*	Radial Vane Steam Separator Development - Experimental Study of Carryunder Sources in a Radial Vane Separator, A. A. Kudirka and J. E. Gifford
1533	GEAP-4967	Radial Vane Steam Separator Development, Fifth Quarterly Report, July-September 1965

2.3 BACKGROUND REPORT

GEAP-4272, "Nuclear Superheat Project, Internal Steam Separation, Development of Radial Vane Steam Separators," R. H. Moen, May 31, 1963.

*Report prepared and sent to the USAEC, but not formally issued as of this writing.

3.0 STATEMENT OF PROBLEM

The purpose of this program is to complete the development [begun under Project Agreement 13 of this contract and reported in GEAP-4272⁽¹⁾] of the radial vane steam separator for use as an improved internal steam separator for boiling water reactors. This development will be accomplished by means of analysis and tests of the various components of the radial vane steam separator, in addition to tests of model, full circle, radial vane separators. Assuming a successful development program, a Phase II of this program will be requested which will involve the design, installation, and test of a radial vane steam separator in an operating boiling water reactor such as the reactor being built for Kernkraftwerk RWE - Bayernwerk, GmbH (KRB reactor) at Gundremmingen, Germany. The program has been classified into tasks corresponding to the various regions of flow, the performance characteristics, and the type of work. The various regions of flow are discussed in the following paragraph, and then a discussion of the purpose of each task is presented.

The radial vane separator utilizes the centrifugal force imposed on a stream flowing on a concave surface to bring about separation of the steam and water. This centrifugal force is many times larger than the gravitational force; e.g., the centrifugal force on the fluid on a vane of the model separator (FCRV-2) used in the tests reported here is about 55 times the gravitational force at the surface of the earth. The steam-water mixture from the core of a reactor flows from the plenum chamber over the core into nozzles from which the mixture flows onto the concave surface of vanes attached to the periphery of the plenum. The steam which is separated on the vanes flows upward between the vanes. The water flows off the ends of the vanes onto the circular reactor wall where it forms a vortex of water accelerating downward called the upper vortex. This vortex flows into a lower vortex below the vanes, and from there to the recirculating pumps. A sketch of the model separator is shown on Figure 1.

3.1 TASK A, WALL FLOW

A knowledge of the characteristics of flow on the circular wall of the model is needed to know how to design for flow on the wall of a reactor. This task has been broken into four related sub-tasks to aid understanding: 1.) the upper vortex thickness, 2.) the wall flow model, 3.) the lower vortex characteristics, and 4.) the water-steam interface.

3.1.1 Task A-1, Upper Vortex Thickness

The thickness of the upper vortex formed by the water from the vanes (the vane jets) flowing onto and down the wall of the reactor is important to know in order to aid in predicting the maximum allowable vane circle radius, to predict the time necessary to remove entrained steam caused by the vane jets flowing into the upper vortex, and to determine the optimum or desirable vane length. This upper vortex thickness was predicted in GEAP-4272, and the purpose of this task is to verify the prediction experimentally as a function of the system variables (volumetric flow rate, nozzle length, and wall radius), or develop an improved prediction.

3.1.2 Task A-II, Wall Flow Model

To understand better the flow on the wall, the interaction between the upper and lower vortexes should be known. The purpose of this task is to determine experimentally whether the predicted (in GEAP-4272)

Figure 1. Sketch of the Full Circle, Radial Vane Separator, FCRV-2 with Annular Outlet

jetting action of the upper vortex flowing into the lower vortex and the resultant eddy between the upper vortex jet and the plenum wall do, in fact, exist, and what the characteristics are. If the flow does not behave as predicted, then a new model must be developed, if possible.

3.1.3 Task A-III, Lower Vortex Characteristics

The behavior of the lower vortex should be known in order to predict how much of the entrained steam carried under from the upper vortex flowing into the lower can be removed in the available space, how deep the lower vortex should be, and what effects obstructions might have. The purpose of this task is to determine analytically and experimentally what the relation is between the surface area and shape of the lower vortex, and its capability for removing steam carried under.

3.1.4 Task A-IV, Water-Steam Interface

The maximum vane circle radius and the amount of entrainment of steam into the upper vortex by the vane jets is a function of the surface characteristics of the upper vortex. The purpose of this task is to determine analytically and experimentally the shape of this interface - the height and frequency of waves, the amount of spray droplets, and the disturbing action of the vane jets.

3.2 TASK B, PLENUM

Knowledge of the flow in the inlet steam-water plenum of the radial vane separator and in the nozzles from which flow moves on to the vanes is important for rational design of the separator. The purpose of this task is to consider analytically and experimentally what the optimum or most desirable flow conditions are within the plenum, at the entrance to the nozzles, and in the nozzles. The design in this region can affect the pressure drop, the steam-water separation, the carryover between the vanes, and the surface characteristics of the vane jet. For these reasons a study of these regions is important.

3.3 TASK C, VANES

The primary purpose of this task is to study the effect of nozzle length on performance of the radial vane separator. Current indications, as reported in GEAP-4272, are that the nozzle length may be extended to a greater value than is now used (18 inches). To find the point where the separated steam velocity causes carryover from the vane jet and, thus, limits performance, is the major purpose of this task. A review of the reasons and experimental data on the basis of which the present design was chosen will be carried out, and, possibly, changes in the nozzle and vane design will be carried out.

3.4 TASK D, CARRYOVER

The purpose of this task is to determine the source of carryover droplets and the distribution of carryover with height within and above the vanes.

3.5 TASK E, CARRYUNDER

The purpose of this task is to determine the source, size, and distribution of carryunder within the lower vortex. Related studies will involve the flow on the vane and on the wall in the upper vortex.

3.6 TASK F, MODEL SEPARATORS

Under this task are included all of the tests of new, full-circle, radial vane separators. These model separators will be of larger diameter, have a greater number of active vanes and nozzles, or be of some improved design. The tests will be carried out in the Air-Water Test Facility and the Steam-Water Test Facility.

3.7 TASK G, TEST FACILITY MODIFICATION

The purpose of this task is to modify the Large Air-Water Test Facility at San Jose for the purpose of testing the separators of Task F which will require more flow than can be obtained in the Small Air-Water Test Facility. This latter facility is identical in size and configuration to the Steam-Water Test Facility.

4.0 ACCOMPLISHMENTS DURING THE REPORT PERIOD

4.1 TASK A, WALL FLOW

4.1.1 Task A-1, Upper Vortex Flow

The thickness of the upper vortex was measured in the FCRV-3 and FCRV-4 at various elevations below the nozzles with varying qualities and flow rates. The ranges of conditions covered in these experiments are shown in Table I. Shown in Tables II and III is the comparison of the observed and the predicted upper vortex thickness just below the nozzles for these tests. The complete wall flow test data are shown in Tables B-I through B-XXIV in Appendix B. Figures B-1 and B-2 are representative plots of the measured axial and tangential velocity profiles observed in FCRV-4. Sketched on these figures also is the water surface profile. Corresponding plots of other FCRV-4 runs are not published because they are similar to these. Representative plots for FCRV-3 were shown in Reference (2).

TABLE I

RANGES OF TEST CONDITIONS FOR UPPER VORTEX THICKNESS MEASUREMENTS

October - December 1965

<u>Unit</u>	<u>Nozzle Length (inches)</u>	<u>Wall Cylinder Diameter (inches)</u>	<u>Total Volumetric Flow* (ft³/h)</u>	<u>Equivalent Inlet Quality (Weight Percent)</u>
FCRV-3	6 to 30	36 to 42	62 to 184	2.5 to 25.5
FCRV-4	6 to 30	72	158 to 229	5.5 to 15

*Calculated at vane conditions.

Shown in Appendix A are the derivations of the equations for predicting the upper vortex thickness which was originally presented in Reference (1), a simplified method of calculation of the upper vortex thickness at the nozzle bottoms, and the calculations to determine the thickness below the nozzle bottoms. Tables A-I through A-VIII include the functions required for use of the simplified method of calculation.

Examination of Tables II and III shows that the observed upper vortex thickness varies about ± 30 percent from that calculated assuming $V_1 = 1.3$ feet per second. This velocity, V_1 , is the vertical velocity component of the vane jets where they intersect the upper vortex. A positive value for V_1 (or $V_{z,n}$ - the upper vortex velocity at the nozzle bottoms) indicates downward flow. Some of the data show larger variations than the ± 30 percent, and it is expected that the larger variations obtained are due to an error in the instrument setup. Some of these runs will be rechecked. The ± 30 percent variation is most likely due to experimental error in determining the distance from the wall to the air-water interface, to experimental error in determining the actual flow conditions at the time each data point was taken, and, in the case of the nozzles greater than 6 inches in length, there is also an effect of the relative location of the

TABLE II

COMPARISON OF PREDICTED* AND OBSERVED UPPER VORTEX THICKNESS FOR FCRV-3

Run Number	r_w	Number of Nozzles	z_n	z	Q_w	A	Calculated Thickness At Nozzle Bottoms (inches)	Calculated Thickness at First Sensing Position (inches)	Observed Thickness at First Sensing Position (inches)	Percent Deviation of Observed from Calculated Value (%)
	Wall Cylinder Radius (feet)		Nozzle Length (feet)	Distance from Nozzle Bottoms to First Sensing Position** (feet)	Volumetric Water Flow Rate (ft ³ /sec)	$\left(= \frac{\pi z_n}{Q_w} \right)$ (sec/ft ²)				
100801	1.5	16	1.5	0.54	6.72	0.701	1.43	1.03	1.06	+3
100802	1.5	16	1.5	1.04	5.73	0.824	1.21	0.72	1.05	+45
100803	1.5	16	1.5	1.04	8.06	0.585	1.73	1.03	1.0	-3
101901	1.5	12	2.5	0.54	7.50	1.047	1.26	1.00	0.79	-21
102301	1.75	12	2.5	0.54	7.59	1.035	1.08	0.86	0.60	-30
102302	1.75	12	2.5	0.54	8.08	0.970	1.16	0.92	0.65	-29
102501	1.75	48	0.5	0.54	4.82	0.326	1.40	0.76	0.65	-14
102701	1.75	48	0.5	0.54	7.83	0.201	2.34	1.24	1.34	+8
102801	1.75	48	0.5	1.54	7.14	0.220	2.13	0.74	0.80	+8
102802	1.75	48	0.5	1.54	9.33	0.168	2.83	0.98	0.90	-8
110203	1.75	48	1.0	0.54	7.9	0.398	1.73	1.13	0.83	-27
110308	1.75	48	1.0	0.54	7.86	0.400	1.72	1.12	1.45	+30
110901	1.75	12	2.5	0.54	6.5	1.208	0.92	0.73	0.85	+16
110902	1.75	12	2.5	0.54	11.7	0.671	1.69	1.34	1.57	+17
110903	1.75	12	2.5	0.54	8.03	0.978	1.14	0.91	1.20	+32

*The water layer thickness and velocity at the nozzle bottoms are calculated by the equations and methods presented in Appendix A assuming $V_1 = 1.3$ ft/sec.

**The sensing positions are located below the nozzle bottoms so the vane jet velocity will not interfere with observations.

TABLE III

COMPARISON OF PREDICTED* AND OBSERVED UPPER VORTEX THICKNESS FOR FCRV-4

Run Number	r_w Wall Cylinder Radius (feet)	Number of Nozzles	z_n Nozzle Length (feet)	z Distance from Nozzle Bottoms to First Sensing Position** (feet)	Q_w Volumetric Water Flow Rate (ft ³ /sec)	A $\left(= \frac{\pi z_n}{Q_w} \right)$ (sec/ft ²)	Calculated Thickness At Nozzle Bottoms (inches)	Calculated Thickness at First Sensing Position (inches)	Observed Thickness at First Sensing Position (inches)	Percent Deviation of Observed from Calculated Value (inches)
112401	3.0	72	0.5	0.45	12.9	0.122	2.19	1.26	1.18	-6
112402	3.0	72	0.5	0.45	15.3	0.103	2.62	1.50	1.05	-30
112901	3.0	72	0.5	0.45	9.9	0.159	1.67	0.96	1.20	+25
120304	3.0	72	1.0	0.45	14.1	0.223	1.77	1.22	1.80	+48
120901	3.0	72	1.0	0.45	12.8	0.245	1.60	1.11	1.25	+13
121001	3.0	72	1.0	0.45	16.7	0.188	2.11	1.45	1.80	+24
121301	3.0	18	2.5	0.95	14.3	0.549	1.18	0.83	1.30	+57
121401	3.0	18	2.5	0.95	11.2	0.701	0.92	0.65	1.50	+131
121402	3.0	18	2.5	0.95	16.8	0.468	1.39	0.98	1.65	+68

*The water layer thickness and velocity at the nozzle bottoms are calculated by the equations and methods presented in Appendix A, assuming $V_1 = 1.3$ ft/sec.

**The sensing positions are located below the nozzle bottoms so the vane jet velocity will not interfere with observations.

sensing probe and the vane jets. A test at constant flow conditions using different observers and different sensing positions at each level will be carried out to check these conjectures. Another source of error is in setting the value of V_1 .

Variation in V_1 will affect the thickness predictions. The use of $V_1 = 1.3$ feet per second in Tables II and III was based on calculations for the FCRV-2 geometry assuming horizontal flow from the nozzles. The actual observed flow is not horizontal from the nozzle, especially in the FCRV-3, and the geometry of the FCRV-3 and FCRV-4 is different from the FCRV-2. At the present time, only a few tests have been made to determine the angle of discharge from the vanes. A test of the FCRV-4 with 30-inch nozzles at three different inlet qualities was carried out to determine the angle of discharge from the vanes this quarter. The results of this test are shown on Table IV. Examination of this table indicates that flow from the vane ends is horizontal or slightly upward. The flow from the nozzles then must have an upward component greater than this since gravity has had a chance to decrease the vertical component from that at the nozzle exit. The calculated vertical velocity component at the nozzles and at the upper vortex surface is shown on Table V. The vertical velocity change varies directly with the time of travel of the jet. This time of travel is the horizontal distance travelled divided by the horizontal water velocity. The distance the vane jet travels from the nozzle to the vane end is about 7.5 inches, and the distance from the vane end to the upper vortex surface is estimated to be 14 inches for the FCRV-4. This latter estimate was obtained by sketching the wall cylinder on the FCRV-4 drawing [Drawing No. 706E244, Figure B-4, Reference (3)] and measuring the distance approximately. Examination of Table V indicates that for the conditions studied, V_1 varies from 1.2 to 3.6 feet per second. This value is a strong function of the angle of discharge, and more information on this should be and will be obtained.

TABLE IV
EXPERIMENTAL VANE DISCHARGE ANGLES AND CALCULATED
VERTICAL VELOCITY COMPONENTS

Eighteen 30-Inch Nozzles							
Angle Measured at Midvane Position							
Run Number	Volumetric Flow Rates at Plenum Conditions (10^3 ft ³ /h)		Equivalent Inlet Quality at Plenum Conditions (Weight Percent)	Homogeneous Plenum Vertical Velocity at Midvane* (ft/sec)	Measured Angle of Discharge from Vane* (degrees)	Discharge Velocity Vector (ft/sec)	Vertical Velocity Component* (ft/sec)
	Total	Water					
1	167	61	7.6	-2.4	-3	25	-1.3
2	171	40	13.3	-2.5	0	21	0
3	101	62	4.9	-1.5	-4	25	-1.8

*Negative indicates upward component.

TABLE V
VERTICAL VANE JET VELOCITY COMPONENTS*

Run Number	Measured Velocity Component at Vane End (ft/sec)	Calculated Velocity at Nozzle** (ft/sec)	V_1
			Calculated Velocity at Upper Vortex Surface† (ft/sec)
1	-1.3	-2.9	+1.7
2	0	-1.9	+3.6
3	-1.8	-3.4	+1.2

*Negative indicates upward velocity.

**Velocity = Vane Discharge Velocity - $2g$ [Vane Arc Length (= 7.5 inches)/Water Velocity].

†Velocity = Vane Discharge Velocity + $2g$ (14/12/Water Velocity).

The effect of V_1 on the upper vortex thickness is illustrated on Figure 2. For V_1 varying from 1.2 to 3.6 feet per second, $V_{z,n}$ varies from 7.82 to 8.98 feet per second or approximately $V_{z,n} = 8.4 \pm 7$ percent. The upper vortex thickness varies approximately inversely so the upper vortex thickness could be expected to vary ± 7 percent with V_1 . * This is small compared to the observed variation, and indicates that the experimental error is in excess of 20 percent which is reasonable for the experimental setup used.

Comparison of Tables IV and V shows that the vertical velocity at the nozzle calculated from the measured vane discharge angle is about equal to the calculated homogeneous vertical velocity at the midnozzle position in the plenum for the FCRV-4 for the runs recorded. This observation is a little surprising since a flow map would indicate nearly horizontal flow at this point. This observation will be checked as more data on angle of discharge is obtained.

Some information on the clearance required between the upper vortex surface and the outside diameter of the vane circle of the radial vane separator has been obtained by means of the FCRV-3 tests. The 36-inch wall cylinder was found to be inadequate to handle the wall flow. A thick layer of water rotating above the vanes along the wall and falling back between the vanes limited the flows in the FCRV-3. The use of a 42-inch-diameter-wall cylinder permitted normal operation. The vane-to-wall clearance in the 36-inch case (~6 inches) is about three to five times the maximum upper vortex thickness. This clearance in the 42-inch case (~9 inches) is three to ten times the maximum upper vortex thickness. The minimum ratio in each case exceeds the factor of 2 used for design. For the FCRV-4 this clearance (~8 inches) amounted to three to nine times the maximum upper vortex thickness, again greater than the design ratio of 2. Further tests of the FCRV-3 and FCRV-4 with varying wall cylinder diameters will be necessary to evaluate the significance of this. Another controlling variable, such as the vertical velocity of the vane jets, may be controlling.

*Tables A-IX and A-X show the upper vortex thickness as a function of V_1 for two specific runs.

Figure 2. Effect of V_1 on the Velocity at the Nozzle Bottom

The conclusion to be drawn from these experiments and calculations is that the upper vortex thickness may be predicted within about 20 percent. The prediction will probably be better for larger water flows. An experimental study of the angle of discharge will aid in these calculations. Further tests are necessary to establish the vane-to-wall cylinder clearance.

4.1.2 Task A-II, Wall Flow Model

The data of the tables and graphs of Appendix B, reporting the results of tests of the FCRV-3 and FCRV-4 during this quarter, confirm the picture of the flow on the wall as predicted in Reference (1). The same flow is anticipated to occur in a reactor.

4.1.3 Task A-III, Lower Vortex Characteristics

The data obtained on FCRV-3 and FCRV-4 during this quarter, which is presented in the tables and graphs of Appendix B, indicate that the flow in the lower vortex is the same as that observed in the FCRV-2; i.e., the tangential velocity in the lower vortex is independent of radius. This will permit calculation of the lower vortex shape and aid in calculation of the bubble separation times required in the lower vortex.

4.1.4 Task A-IV, Steam-Water Interface

Visual and instrumental observations indicate that the waves on the upper vortex surface are of small amplitude. Further information on this will be obtained during the next quarter.

4.2 TASK B, PLENUM

Nozzle pressure drop data for FCRV-3 are shown on Figure 3 and for FCRV-4 on Figure 4 compared to the pressure drop for the FCRV-2. The latter curve was determined from Figure 5, which is a plot of FCRV-2 data from Reference (1) plotted as pressure drop in feet of mixture versus nozzle velocity, both calculated at plenum conditions assuming homogeneous flow conditions. The best curve having a slope of 2.0 was drawn through the data. The variation of FCRV-3 pressure drop is probably due to improper measurement due to the high plenum velocities. The FCRV-4 data line up on the FCRV-2 curve as is expected since the nozzle designs of the two model separators are the same (as also is FCRV-3).

4.3 TASK C, VANES

During the course of testing the FCRV-3 and FCRV-4, nozzle and vane flows in excess of the maximum observed in the FCRV-2 have been found. The maximum flow observed in the FCRV-4 is equivalent to a flow of 9400 cubic feet per hour for an 18-inch by 1/4-inch nozzle. This flow rate was observed on Run No. 112902, and is calculated at vane conditions as were the tests of the FCRV-2. The quality calculated at plenum conditions for this run was 10 percent. The maximum flow rate observed in the FCRV-3 amounted to 9360 cubic feet per hour with an inlet plenum quality of 13 percent. This was Run No. 102801. These vane flows exceed the maximum reported vane flow in steam-water for the FCRV-2 by over 60 percent. They exceed the maximum values obtained in air-water tests of the FCRV-2 by over 30 percent.

During tests of the FCRV-4 using 30-inch nozzles and the 72-inch-diameter-wall cylinder, it was observed that when the flow on the surface of the vane touched the back of the adjacent vane near the end,

Figure 3. FCRV-3 Pressure Drop

Figure 4. FCRV-4 Pressure Drop

Figure 5. FCRV-2 Pressure Drop

part of the flow reversed. This water which flowed in the reverse direction accelerated downward off the vane and apparently was not broken up by the rising air flow. This is the first time that this phenomenon has been observed, and it is encouraging to note that the reverse flow does not seem to be affected by the air flow. This is of significance to reactor design because it means that tolerances allowed for vane spacing at the ends of the vanes may be relatively large.

4.4 TASK D, CARRYOVER

The carryover observed during the FCRV-3 and FCRV-4 tests has been judged qualitatively. There is no quantitative measurement for this at present. The results are presented in the tables in Appendix C. The main conclusion is that carryover seemed to be acceptable on all the FCRV-3 and FCRV-4 tests for all water levels below the nozzle bottoms. A really positive evaluation of steam-water performance is not possible from these air-water tests, but it was qualitatively noted in the FCRV-2 tests that where the air-water carryover became noticeable, the steam-water carryover became high.

The judgment of the acceptability of carryover in these tests was obscured because of splashing caused by some water from the nozzles flowing upwards and hitting the outer vane support ring. This splash was not counted as carryover because a better nozzle top design and outer vane support design will remove this problem. The judgment on carryover was made after the large drops caused by this splashing had been removed from consideration.

4.5 TASK E, CARRYUNDER

Carryunder measurement during testing of the FCRV-4 this quarter showed that all carryunder is less than 0.2 weight percent (equivalent) for all water levels above the outlet. These results are shown on Figure 6. Corresponding results for the FCRV-3 were shown on Figure 8 of Reference (2). Carryunder only exceeded 0.2 weight percent when the water level fell below the top of the annular outlet. This is outside the design conditions. The water level was varied from the nozzle bottoms down to the level below the outlet.

One of the purposes in building the FCRV-4 was to observe the effect of wall radius on carryunder. However, no effect has been found in the FCRV-3 and FCRV-4 tests. To study this carryunder problem experimentally further, equipment has been designed and built to sample wall flow in order to establish the distribution of carryunder in the wall flow. This information can then be used to aid in the design of a reactor separator.

4.6 TASK F, MODEL SEPARATORS

The tests of the FCRV-3 and FCRV-4 during this quarter have established the following in air-water tests.

1. Nozzle lengths up to the maximum of the model separators (30 inches) performed satisfactorily.
2. The FCRV-3 operates satisfactorily with all the vanes and nozzles active, i. e., in use. The maximum lengths tested with all nozzles and vanes active was 12 inches. This length is the maximum attainable with the capacity of the Large Air-Water Test Facility.

Figure 6. FCRV-4 Carryunder

3. The carryover performance is satisfactory in all tests.
4. Turning vanes or plenum deflectors were found to not be necessary in the FCRV-4 while they were found to be necessary in the FCRV-3. The need for these in the FCRV-3 is brought about by the high vertical plenum velocities and small turning radius. It is noted that it might be beneficial to use plenum deflectors in a large-diameter plenum for the purpose of reducing the upper vortex thickness by imparting a downward velocity to the vane jets. This would increase the term V_1 discussed in subsection 4.1.
5. The upper vortex thickness is reasonably well predicted by the equation presented in Appendix A.
6. The air-water interface, i.e., the upper vortex surface, shows no signs of large amplitude waves or instability.
7. The carryunder performance is good at all water levels and operating conditions within the design of the model separator.

The major unresolved problems concern items 1 and 2 above. Further tests to determine the limiting nozzle lengths must be carried out. The tests of the two-vane unit during the third quarter were not conclusive in setting a maximum nozzle length. They showed that the long nozzle lengths operate satisfactorily as nozzles; however, the effect of vertical steam velocity between the vanes was not obtained. It is

thought that most of the steam escaped out the end of the vane rather than flowing vertically upward between the vanes, so no conclusions can be drawn concerning the effect of vertical steam velocity. It is this vertical flow of steam between the vanes that is expected to be limiting. A new two-vane unit has been designed to assure that all or nearly all of the steam must flow upward between the vanes. Procurement of this unit will be begun in January 1966.

The tests with all the vanes and nozzles active was carried out using only 6- and 12-inch nozzles because of the capacity limitations of the FCRV-3. Equipment for another test using eighteen 30-inch nozzles operating side-by-side has been designed and procured. This test will utilize 18 of the 48 vanes on one section of the FCRV-3. It is expected that in spite of the unsymmetrical flow a good test of 30-inch nozzles operating side-by-side will be obtained.

Further tests will also be carried out to determine the distribution of carryunder in the wall flow. This information will be required for the design of a reactor separator.

The above tests of the effect of nozzle length on performance of individual vane pairs and on performance of groups of vanes are of great significance to the radial vane steam separator development since calculations indicate that 24-inch nozzles will be required for the KRB reactor and that 45-inch nozzles will be required for a 1000-MW boiling water reactor described in Reference (4). The 24-inch length required for the KRB reactor results from the need to use a wall cylinder having a diameter of about 124 inches, which is about the diameter of the core shroud. This wall cylinder is required because of the presence of vertical components along the vessel wall in the KRB reactor precluding use of the reactor vessel wall as the wall cylinder.

4.7 TASK G, LARGE AIR-WATER FACILITY MODIFICATION

The Large Air-Water Test Facility has now been used for the tests of the FCRV-3 and FCRV-4 during this quarter and part of the preceding quarter. The performance of this facility matches the design conditions. In the FCRV-4 tests, the maximum capacity of the pump and compressor were attained.

5.0 FUTURE WORK

The following items are scheduled for completion during the seventh quarter.

1. Continue and complete the FCRV-3 and FCRV-4 tests to determine the effect of wall cylinder diameter on performance. These tests will determine the effect of wall cylinder diameter on carryover, carryunder, and upper vortex thickness. In addition, tests to determine reproducibility of wall flow data will be carried out.
2. Carry out the studies to determine carryunder distribution in the wall flow. This will be done using the 72-inch wall cylinder for the FCRV-4 and the 42-inch wall cylinder for the FCRV-3.
3. Test eighteen 30-inch nozzles and vanes operating side-by-side in the FCRV-3 to determine the effect of long nozzles and vanes operating together.
4. Determine the effect of vertical steam velocity between the vanes on separation of the steam and water. The purpose of this test is to find the maximum allowable nozzle length. To do this will require procurement of the equipment by competitive bid. The drawings for the equipment will be completed in mid-January 1966.
5. Review the data and results of the test program for the purpose of determining how many of the original objectives of the program have been attained.
6. Prepare a proposal for a Phase II, assuming that all indications are that the radial vane separator will perform adequately in a reactor.

APPENDIX A

UPPER VORTEX THICKNESS CALCULATION

In this Appendix the derivation of the equations for the upper vortex thickness in and below the nozzle region is presented, a simplified method of calculation is shown along with tables of required values, and calculations to convert measured thicknesses below the nozzle region to thicknesses at the nozzle bottoms are made. A tabulation of upper vortex thicknesses as a function of nozzle length wall cylinder radius, and flow parameter, A , were presented in Appendix A of the Reference (5) for $V_1 = 1.3$ ft/sec. Tabulations for $V_1 = 0, 0.5, 1.0, 1.5, 2.0, 2.5$, and 3.0 are available, but have not been published since the results can be calculated using the simplified method.

Equation for Upper Vortex Thickness

This derivation was presented originally in Reference (1), but is presented again here for convenience. The equation for upper vortex thickness may be obtained by making a material balance and a momentum balance in the axial direction on a ring of water in the wall flow. The ring of interest is formed by considering the water on the wall between the planes perpendicular to the axis of the separator at z and $z + \Delta z$.

Assumptions:

1. Steady state; i. e., no time dependence.
2. Incompressible flow.
3. Symmetrical flow; i. e., no dependence on circumferential position.
4. Axial velocity independent of radial position.
5. The volumetric flow rate per unit length (Q_w/z_n) is a constant.
6. The water is in free fall; consequently there is no axial pressure gradient.

The material balance is made as follows:

$$\text{Input from water above } z = \left[\rho V_z \pi (r_w^2 - r_i^2) \right]_z,$$

$$\text{Input from vanes} = \rho Q_w \frac{\Delta z}{z_n},$$

$$\begin{aligned} \text{where } Q_w &= \text{nozzle flow in ft}^3/\text{sec} \\ &\text{and } z_n \text{ is the nozzle length in feet} \end{aligned}$$

$$\text{Output} = \left[\rho V_z \pi (r_w^2 - r_i^2) \right]_{z + \Delta z}.$$

For steady state, the output equals the input. Setting these equal and letting Δz approach zero yields the following:

$$\frac{d}{dz} \left[V_z (r_w^2 - r_i^2) \right] = \frac{Q_w}{\pi z_n} = \frac{1}{A}, \quad (1)$$

where

$$A = \frac{\pi z_n}{Q_w}.$$

This is integrated to

$$V_z (r_w^2 - r_i^2) = \frac{z}{A} + C.$$

If $r_i = r_w$ when $z = 0$, then $C = 0$ and the following equation is obtained.

$$V_z = \frac{1}{A} \frac{z}{r_w^2 - r_i^2} = \frac{Q_w}{\pi (r_w^2 - r_i^2)} \quad (2)$$

Equation (1) may be expanded to

$$\frac{1}{V_z} \frac{dV_z}{dz} = \frac{2r_i}{r_w^2 - r_i^2} \frac{dr_i}{dz} + \frac{1}{A V_z (r_w^2 - r_i^2)} \quad (3)$$

Combining this with Equation (2) yields

$$\frac{1}{V_z} \frac{dV_z}{dz} = \frac{2r_i}{r_w^2 - r_i^2} \frac{dr_i}{dz} + \frac{1}{z} \quad (4)$$

The momentum balance is made in a similar manner. No pressure terms are included since the water is in free fall.

$$\text{Input from above } z = \left[\rho V_z^2 \pi (r_w^2 - r_i^2) \right]_z \text{ and}$$

$$\text{Input from the vanes} = \rho Q_w \frac{\Delta z}{z_n} V_1 ,$$

where V_1 is the axial velocity attained by the input liquid due to the acceleration of gravity during the time between leaving the nozzle and arriving at r_i . (Thus $V_z = V_1$ when $z = 0$.)

$$\begin{aligned} \text{Increase in momentum due to} \\ \text{acceleration of gravity} &= \rho g \pi (r_w^2 - r_i^2) \Delta z \text{ and} \end{aligned}$$

$$\text{Output} = \left[\rho V_z^2 \pi (r_w^2 - r_i^2) \right]_{z + \Delta z} .$$

As before, set the input equal to the output and allow Δz to shrink to zero. This yields

$$\begin{aligned} \frac{d}{dz} \left[V_z^2 (r_w^2 - r_i^2) \right] &= \frac{Q_w V_1}{\pi z_n} + g (r_w^2 - r_i^2) = \\ &= \frac{V_1}{A} + g (r_w^2 - r_i^2) . \end{aligned} \quad (5)$$

This may be expanded to

$$\frac{1}{V_z} \frac{dV_z}{dz} = \frac{r_i}{r_w^2 - r_i^2} \frac{dr_i}{dz} + \frac{V_1}{2A V_z^2 (r_w^2 - r_i^2)} + \frac{g}{2 V_z^2} \quad (6)$$

Combining Equations (4) and (6) to eliminate $\frac{1}{V_z} \frac{dV_z}{dz}$ yields

$$\frac{r_i}{r_w^2 - r_i^2} \frac{dr_i}{dz} = \frac{V_1}{2A V_z^2 (r_w^2 - r_i^2)} + \frac{g}{2V_z^2} \frac{1}{z} \quad (7)$$

Substituting in for V_z from Equation (2) yields

$$\frac{r_i}{(r_w^2 - r_i^2)} \frac{dr_i}{dz} = \left[\frac{V_1}{2A (r_w^2 - r_i^2)} + \frac{g}{2} \right] \frac{A^2 (r_w^2 - r_i^2)^2}{z^2} - \frac{1}{z} \quad (8)$$

This nonlinear, ordinary differential equation may be solved for r_i as a function of z by approximation. Having r_i as a function of z permits determination of V_z using Equation (2). For the current vane design, it is estimated that $V_1 \cong 1.3$ ft/sec in all cases.

For the upper vortex in the region below the vanes there is no input from the vanes. The material balance becomes

$$V_z (r_w^2 - r_i^2) = C \quad (9)$$

The constant may be evaluated at $z = z_n$ since all the water from the vanes passes through this point.

$$\rho V_{z,n} \left[\pi (r_w^2 - r_{i,n}^2) \right] = \rho Q_w = \rho \pi C.$$

Therefore,

$$C = \frac{Q_w}{\pi},$$

and Equation (9) becomes

$$V_z (r_w^2 - r_i^2) = \frac{Q_w}{\pi} \quad (10)$$

The momentum balance becomes

$$\frac{d}{dz} \left[V_z^2 (r_w^2 - r_i^2) \right] = g (r_w^2 - r_i^2) \quad (11)$$

Now, substitute Equation (10) in Equation (11) to get

$$\frac{d}{dz} \left[\frac{Q_w V_z}{\pi} \right] = g (r_w^2 - r_i^2)$$

$$\frac{Q_w}{\pi} \frac{dV_z}{dz} = g (r_w^2 - r_i^2) \quad (12)$$

Substitution of Equation (10) in Equation (12) yields

$$\frac{dV_z}{dz} = \frac{g}{V_z}$$

or

$$V_z dV_z = g dz$$

Integrating this from $z = z_n$ ($V_z = V_{z,n}$) to $z = z$ ($V_z = V_z$) yields

$$V_z^2 - V_{z,n}^2 = 2g(z - z_n),$$

which can be rearranged to

$$V_z = \sqrt{2g(z - z_n) + V_{z,n}^2} \quad (13)$$

Combining this with Equation (10) yields

$$r_w^2 - r_i^2 = \frac{Q_w}{\pi \sqrt{2g(z - z_n) + V_{z,n}^2}} \quad (14)$$

which shows that r_i increases and the water thickness ($r_w - r_i$) decreases as z increases.

Simplified Solution

If the following transformation is substituted into Equation (8), a simplified equation is obtained.

$$T = \frac{z^2}{\Lambda (r_w^2 - r_i^2)} \quad (15a)$$

This equation may be rearranged to:

$$r_i = \sqrt{r_w^2 - \frac{z^2}{AT}} \quad (15b)$$

Equation (8) becomes:

$$T \frac{dT}{dz} = V_1 T + g z^2 \quad (16)$$

Equation (2) becomes:

$$V_z = \frac{T}{z} \quad (17)$$

Now a tabulation of T and V_z as functions of z may be made for various values of V_1 . Shown in Tables A-I through A-VIII are T and V_z for $V_1 = 0.0, 0.5, 1.0, 1.3, 1.5, 2.0, 2.5$, and 3.0 . This provides a simpler presentation of the results than the tabulation of upper vortex thickness as a function of z_n , r_w , and A presented in Reference (5).

To determine an upper vortex thickness, values of V_1 , z_n , r_w , and Q_w are specified. The value of A is calculated using Equation (1). A value of T is taken from the tabulation of T versus z for $z = z_n$. The radius of the water surface, r_i , is then calculated using Equation (15b). The vertical velocity at the nozzle bottoms, $V_{z,n}$, may be obtained from the tabulation of V_z or by use of Equation (17) with $z = z_n$. The use of the table is demonstrated below.

Calculation of Upper Vortex Thickness at Nozzle Bottoms

Consider Run No. 112401 (See Tables C-III and C-IV):

$$r_w = 36 \text{ inches} = 3 \text{ feet,}$$

Seventy-two 6-inch nozzles,

$$Q_w = \frac{46,600 \text{ ft}^3/\text{h}}{3600 \text{ sec/h}} = 12.9 \text{ ft}^3/\text{sec,}$$

$$A = \frac{(\pi) (0.5)}{12.9} = 0.122 \text{ sec/ft}^2,$$

$$T \text{ (from Table A-IV)} = 1.931 \text{ ft}^2/\text{sec,}$$

$$r_i = \sqrt{(3)^2 - \frac{(0.5)^2}{(0.122)(1.931)}} = 2.818 \text{ feet} = 33.8 \text{ inches},$$

$$r_w - r_i = 36.0 - 33.8 = 2.2 \text{ inches},$$

$$V_{z,n} \text{ (from Table A-IV)} = 3.86 \text{ ft/sec.}$$

Thus, the thickness of the upper vortex at the nozzle bottoms with $V_1 = 1.3$ ft/sec for this case is 2.2 inches. It is shown in Table A-IX how the upper vortex thickness varies with V_1 at the conditions of the above example, i. e., with 6-inch nozzles. Experimental results with the FCRV-4 using 30-inch nozzles indicate that a V_1 of about 1.2 to 3.6 ft/sec occurs. This should be representative of the V_1 for reactors where the plenum velocity will be relatively low (about 5 ft/sec) as it is in the FCRV-4 (4.5 ft/sec for the above test. The variation of upper vortex thickness at the bottom of 30-inch nozzles as a function of V_1 is shown in Table A-X.

Calculation of Upper Vortex Thickness Below Nozzle Bottoms

The water in this region is in free fall with no input. Equation (14) may be used to calculate r_i^2 at the point of interest using the velocity at the nozzle bottom for $V_{z,n}$. The new water layer thickness may then be calculated.

Consider the thickness of the water layer at a point 5.4 inches below the nozzle bottoms for the example used above. Equation (14) may be rearranged to:

$$r_w - r_i = r_w - \sqrt{r_w^2 - \frac{Q_w}{\pi \sqrt{2g(z - z_n) + V_{z,n}^2}}},$$

where $r_w - r_i$ is in feet.

$$r_w - r_i = 3.0 - \sqrt{(3.0)^2 - \frac{12.9}{\pi \sqrt{(2)(32.2)\left(\frac{5.4}{12}\right) + (3.86)^2}}}$$

$$r_w - r_i = 3.0 - 2.896 = 0.104 \text{ feet} = 1.26 \text{ inches.}$$

This compares with an experimental value for this case of 1.18 inches. A tabulation of the experimental and predicted upper vortex thicknesses obtained in the tests this quarter is shown in Tables II and III.

TABLE A-I

VALUES OF THE FUNCTION, T, AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 0 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	0.
0.050	0.05177	1.03537
0.100	0.14642	1.46424
0.150	0.26900	1.79332
0.200	0.41415	2.07075
0.250	0.57879	2.31517
0.300	0.76084	2.53614
0.350	0.95877	2.73934
0.400	1.17139	2.92838
0.450	1.39776	3.10612
0.50	.	3.27
0.550	1.88867	3.43395
0.600	2.15199	3.58664
0.650	2.42651	3.73310
0.700	2.71181	3.87402
0.750	3.00749	4.00909
0.800	3.31320	4.14150
0.850	3.62861	4.26896
0.900	3.95345	4.39272
0.950	4.28744	4.51309
1.000	4.63033	4.63033
1.050	4.98192	4.74468
1.100	5.34197	4.85634
1.150	5.71030	4.96548
1.200	6.08673	5.07228
1.250	6.47109	5.17607
1.300	6.86321	5.27939
1.350	7.26295	5.37996
1.400	7.67016	5.47869
1.450	8.08471	5.57566
1.500	8.50647	5.67098
1.550	8.93532	5.76472
1.600	9.37114	5.85666
1.650	9.81382	5.94777
1.700	10.26327	6.03722
1.750	10.71937	6.12536
1.800	11.18204	6.21225
1.850	11.65118	6.29704
1.900	12.12670	6.38248
1.950	12.60853	6.46591
2.000	13.09656	6.54828
2.050	13.59074	6.62963
2.100	14.09098	6.70999
2.150	14.59722	6.78940
2.200	15.10937	6.86780
2.250	15.62736	6.94550
2.300	16.15118	7.02225
2.350	16.68070	7.09817
2.400	17.21588	7.17328
2.450	17.75667	7.24762
2.500	18.30300	7.32120

TABLE A-1 (Continued)

$$V_1 = 0 \text{ ft/sec}$$

Z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
2.550	18.85483	7.39405
2.600	19.41289	7.46619
2.650	19.97474	7.53764
2.700	20.54272	7.60842
2.750	21.11599	7.67854
2.800	21.69449	7.74803
2.850	22.27818	7.81690
2.900	22.86701	7.88518
2.950	23.46094	7.95286
3.000	24.05992	8.01997
3.050	24.66392	8.08653
3.100	25.27289	8.15255
3.150	25.88679	8.21803
3.200	26.50558	8.28299
3.250	27.12923	8.34745
3.300	27.75769	8.41142
3.350	28.39093	8.47490
3.400	29.02891	8.53792
3.450	29.67160	8.60046
3.500	30.31897	8.66255
3.550	30.97098	8.72422
3.600	31.62759	8.78544
3.650	32.28878	8.84624
3.700	32.95452	8.90663
3.750	33.62477	8.96660
3.800	34.29950	9.02618
3.850	34.97868	9.08537
3.900	35.66230	9.14418
3.950	36.35030	9.20261
4.000	37.04268	9.26067
4.050	37.73939	9.31837
4.100	38.44042	9.37571
4.150	39.14574	9.43271
4.200	39.85532	9.48936
4.250	40.56914	9.54568
4.300	41.28717	9.60167
4.350	42.00938	9.65733
4.400	42.73576	9.71267
4.450	43.46627	9.76770
4.500	44.20090	9.82242
4.550	44.93963	9.87684

TABLE A-II

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 0.5 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	0.50000
0.050	0.06320	1.26397
0.100	0.16859	1.68588
0.150	0.30165	2.01102
0.200	0.45721	2.28605
0.250	0.63220	2.52881
0.300	0.82487	2.74855
0.350	1.03278	2.95081
0.400	1.25567	3.13918
0.450	1.49229	3.31619
0.500	1.74184	3.48367
0.550	2.00366	3.64302
0.600	2.27719	3.79532
0.650	2.56192	3.94142
0.700	2.85742	4.08213
0.750	3.16329	4.21772
0.800	3.47918	4.34898
0.850	3.80478	4.47621
0.900	4.13978	4.59976
0.950	4.48394	4.71994
1.000	4.83700	4.83700
1.050	5.19874	4.95118
1.100	5.56895	5.06269
1.150	5.94744	5.17169
1.200	6.33402	5.27835
1.250	6.72852	5.38282
1.300	7.13079	5.48522
1.350	7.54067	5.58568
1.400	7.95802	5.68430
1.450	8.38270	5.78117
1.500	8.81459	5.87640
1.550	9.25357	5.97005
1.600	9.69952	6.06220
1.650	10.15234	6.15293
1.700	10.61191	6.24230
1.750	11.07814	6.33036
1.800	11.55093	6.41718
1.850	12.03018	6.50280
1.900	12.51583	6.58728
1.950	13.00776	6.67065
2.000	13.50592	6.75296
2.050	14.01021	6.83425
2.100	14.52056	6.91455
2.150	15.03691	6.99391
2.200	15.55917	7.07235
2.250	16.08729	7.14991
2.300	16.62119	7.22661
2.350	17.16082	7.30248
2.400	17.70611	7.37755
2.450	18.25700	7.45184
2.500	18.81344	7.52538
2.550	19.37537	7.59818

TABLE A-II (Continued)

$$V_1 = 0.5 \text{ ft/sec}$$

Z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
2.600	19,94273	7.67028
2.650	20,51548	7.74169
2.700	21,09356	7.81243
2.750	21,67692	7.88252
2.800	22,26552	7.95197
2.850	22,85931	8.02081
2.900	23,45823	8.08905
2.950	24,06226	8.15670
3.000	24,67134	8.22378
3.050	25,28543	8.29030
3.100	25,90449	8.35629
3.150	26,52848	8.42174
3.200	27,15736	8.48668
3.250	27,79110	8.55111
3.300	28,42969	8.61514
3.350	29,07298	8.67880
3.400	29,72105	8.74198
3.450	30,37383	8.80461
3.500	31,03128	8.86668
3.550	31,69337	8.92771
3.600	32,36008	8.98891
3.650	33,03135	9.04969
3.700	33,70717	9.11005
3.750	34,38750	9.17000
3.800	35,07232	9.22956
3.850	35,76159	9.28872
3.900	36,45528	9.34751
3.950	37,15337	9.40592
4.000	37,85583	9.46396
4.050	38,56262	9.52164
4.100	39,27373	9.57896
4.150	39,98913	9.63594
4.200	40,70879	9.69257
4.250	41,43268	9.74887
4.300	42,16079	9.80483
4.350	42,89308	9.86048
4.400	43,62954	9.91580
4.450	44,37013	9.97082
4.500	45,11484	10.02552
4.550	45,86364	10.07992

TABLE A-III

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 1.0 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	1.00000
0.050	0.07722	1.54448
0.100	0.19524	1.95244
0.150	0.33999	2.26661
0.200	0.50688	2.53441
0.250	0.69300	2.77201
0.300	0.89636	2.98787
0.350	1.11548	3.18708
0.400	1.34919	3.37299
0.450	1.59658	3.54795
0.500	1.85666	3.71371
0.550	2.12937	3.87158
0.600	2.41355	4.02258
0.650	2.70890	4.16755
0.700	3.01500	4.30714
0.750	3.33145	4.44193
0.800	3.65790	4.57237
0.850	3.99403	4.69886
0.900	4.33956	4.82174
0.950	4.69423	4.94129
1.000	5.05779	5.05779
1.050	5.43001	5.17144
1.100	5.81069	5.28245
1.150	6.19964	5.39099
1.200	6.59667	5.49722
1.250	7.00161	5.60129
1.300	7.41431	5.70331
1.350	7.83461	5.80341
1.400	8.26237	5.90169
1.450	8.69746	5.99825
1.500	9.13976	6.09317
1.550	9.58913	6.18654
1.600	10.04547	6.27842
1.650	10.50866	6.36889
1.700	10.97861	6.45801
1.750	11.45521	6.54583
1.800	11.93836	6.63242
1.850	12.42798	6.71783
1.900	12.92398	6.80209
1.950	13.42627	6.88526
2.000	13.93477	6.96738
2.050	14.44940	7.04849
2.100	14.97009	7.12861
2.150	15.49677	7.20780
2.200	16.02936	7.28607
2.250	16.56780	7.36347
2.300	17.11203	7.44001
2.350	17.66198	7.51573
2.400	18.21758	7.59066
2.450	18.77878	7.66481
2.500	19.34553	7.73821

TABLE A-III (Continued)

$$V_1 = 1.0 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	V z_n Velocity at Nozzle Bottom (ft/sec)
2.550	19.91777	7.81089
2.600	20.49543	7.86286
2.650	21.07848	7.95414
2.700	21.66686	8.02476
2.750	22.26052	8.09493
2.800	22.85940	8.16487
2.850	23.46348	8.23280
2.900	24.07269	8.30093
2.950	24.68700	8.36847
3.000	25.30636	8.43545
3.050	25.93073	8.50188
3.100	26.56007	8.56776
3.150	27.19433	8.63312
3.200	27.83349	8.69797
3.250	28.47750	8.76231
3.300	29.12631	8.82616
3.350	29.77991	8.88953
3.400	30.43825	8.95243
3.450	31.10129	9.01487
3.500	31.76900	9.07686
3.550	32.44135	9.13841
3.600	33.11831	9.19953
3.650	33.79984	9.26023
3.700	34.48591	9.32052
3.750	35.17650	9.38040
3.800	35.87156	9.43989
3.850	36.57108	9.49898
3.900	37.27502	9.55770
3.950	37.98335	9.61604
4.000	38.69605	9.67401
4.050	39.41309	9.73163
4.100	40.13444	9.78889
4.150	40.86008	9.84580
4.200	41.58998	9.90238
4.250	42.32411	9.95861
4.300	43.06245	10.01452
4.350	43.80498	10.07011
4.400	44.55166	10.12538
4.450	45.30249	10.18033
4.500	46.05742	10.23498
4.550	46.81645	10.28933

TABLE A-IV

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
 AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
 LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
 VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$V_1 = 1.3 \text{ ft/sec}$		
z_n	T	$V_{z,n}$
Nozzle Length (ft)	(ft ² /sec)	Velocity at Nozzle Bottom (ft/sec)
0	0	1.3
0.05	0.08882	1.77635
0.10	0.21459	2.14593
0.15	0.36674	2.44495
0.20	0.54077	2.70383
0.25	0.73387	2.93548
0.30	0.94411	3.14702
0.35	1.17002	3.34292
0.40	1.41048	3.52620
0.45	1.66456	3.69901
0.50	1.93148	3.86297
0.55	2.21062	4.01930
0.60	2.50139	4.16898
0.65	2.80331	4.31278
0.70	3.11595	4.45136
0.75	3.37352	4.58523
0.80	3.77188	4.71485
0.85	4.11450	4.84059
0.90	4.46651	4.96279
0.95	4.82764	5.08172
1.00	5.19765	5.19765
1.05	5.57631	5.31077
1.10	5.96342	5.42129
1.15	6.35878	5.52938
1.20	6.76222	5.63519
1.25	7.17357	5.73886
1.30	7.59266	5.84051
1.35	8.01935	5.94026
1.40	8.45349	6.03821
1.45	8.89496	6.13445
1.50	9.34362	6.22908
1.55	9.79935	6.32216
1.60	10.26204	6.41378
1.65	10.73159	6.50399
1.70	11.20788	6.59287
1.75	11.69081	6.68047
1.80	12.18030	6.76684
1.85	12.67625	6.85203
1.90	13.17857	6.93609
1.95	13.68718	7.01907
2.00	14.20200	7.10100
2.05	14.72294	7.18192
2.10	15.24994	7.26188
2.15	15.78293	7.34090
2.20	16.32182	7.41901
2.25	16.86656	7.49625
2.30	17.41708	7.57265
2.35	17.97332	7.64822
2.40	18.53522	7.72301
2.45	19.10271	7.79702
2.50	19.67574	7.87029
2.55	20.25425	7.94284

TABLE A-IV (Continued)

$$V_1 = 1.3 \text{ ft/sec}$$

z_n	T	$V_{z, n}$
Nozzle Length (ft)	(ft ² /sec)	Velocity at Nozzle Bottom (ft/sec)
2.60	20.83819	8.01469
2.65	21.42752	8.08586
2.70	22.02217	8.15636
2.75	22.62209	8.22622
2.80	23.22725	8.29545
2.85	23.83759	8.36407
2.90	24.45307	8.43209
2.95	25.07363	8.49954
3.00	25.69925	8.56642
3.05	26.32988	8.63275
3.10	26.96547	8.69854
3.15	27.60599	8.76381
3.20	28.25139	8.82856
3.25	28.90165	8.89281
3.30	29.55671	8.95658
3.35	30.21655	9.01987
3.40	30.88113	9.08269
3.45	31.55041	9.14505
3.50	32.22437	9.20696

TABLE A-V

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 1.5 \text{ ft/sec}$$

z_n	T	$V_{z,n}$
Nozzle Length (ft)	(ft ² /sec)	Velocity at Nozzle Bottom (ft/sec)
0.	0.	1.50000
0.050	0.09319	1.86374
0.100	0.22606	2.26063
0.150	0.38402	2.56015
0.200	0.56342	2.81712
0.250	0.76163	3.04653
0.300	0.97680	3.25601
0.350	1.20754	3.45010
0.400	1.45272	3.63181
0.450	1.71147	3.80326
0.500	1.98301	3.96602
0.550	2.26671	4.12130
0.600	2.56202	4.27004
0.650	2.86845	4.41301
0.700	3.18558	4.55083
0.750	3.51301	4.68402
0.800	3.85041	4.81301
0.850	4.19746	4.93819
0.900	4.55388	5.05987
0.950	4.91941	5.17833
1.000	5.29380	5.29380
1.050	5.67684	5.40652
1.100	6.06832	5.51665
1.150	6.46804	5.62438
1.200	6.87583	5.72985
1.250	7.29151	5.83321
1.300	7.71493	5.93456
1.350	8.14594	6.03403
1.400	8.58448	6.13172
1.450	9.03018	6.22771
1.500	9.48315	6.32210
1.550	9.94318	6.41495
1.600	10.41017	6.50636
1.650	10.88400	6.59636
1.700	11.36458	6.68505
1.750	11.85179	6.77245
1.800	12.34556	6.85844
1.850	12.84578	6.94367
1.900	13.35237	7.02786
1.950	13.86524	7.11038
2.000	14.38432	7.19216
2.050	14.90953	7.27294
2.100	15.44078	7.35275
2.150	15.97801	7.43163
2.200	16.52116	7.50942
2.250	17.07014	7.58673
2.300	17.62491	7.66360
2.350	18.18538	7.73846
2.400	18.75152	7.81313
2.450	19.32324	7.88704
2.500	19.90050	7.96020

TABLE A-V (Continued)

$$V_1 = 1.5 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
2.550	20.48325	8.03265
2.600	21.07142	8.10439
2.650	21.66497	8.17546
2.700	22.26384	8.24587
2.750	22.86799	8.31563
2.800	23.47736	8.38477
2.850	24.09192	8.45330
2.900	24.71161	8.52124
2.950	25.33639	8.58861
3.000	25.96622	8.65541
3.050	26.60106	8.72166
3.100	27.24086	8.78737
3.150	27.88558	8.85257
3.200	28.53519	8.91725
3.250	29.18965	8.98143
3.300	29.84891	9.04512
3.350	30.51295	9.10834
3.400	31.18173	9.17110
3.450	31.85521	9.23339
3.500	32.53336	9.29524
3.550	33.21614	9.35666
3.600	33.90352	9.41765
3.650	34.59548	9.47821
3.700	35.29197	9.53837
3.750	35.99298	9.59813
3.800	36.69846	9.65749
3.850	37.40839	9.71646
3.900	38.12274	9.77504
3.950	38.84148	9.83329
4.000	39.56459	9.89115
4.050	40.29203	9.94865
4.100	41.02378	10.00580
4.150	41.75982	10.06261
4.200	42.50011	10.11907
4.250	43.24463	10.17521
4.300	43.99337	10.23102
4.350	44.74628	10.28650
4.400	45.50335	10.34167
4.450	46.26456	10.39643
4.500	47.02988	10.45109
4.550	47.79929	10.50534

TABLE A-VI

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 2.0 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	2.00000
0.050	0.11044	2.20889
0.100	0.26026	2.60289
0.150	0.43312	2.88750
0.200	0.62642	3.13208
0.250	0.83786	3.35146
0.300	1.06583	3.55278
0.350	1.30905	3.74014
0.400	1.56648	3.91619
0.450	1.83727	4.08283
0.500	2.12072	4.24143
0.550	2.41620	4.39309
0.600	2.72318	4.53864
0.650	3.04120	4.67877
0.700	3.36984	4.81405
0.750	3.70871	4.94495
0.800	4.05790	5.07187
0.850	4.41589	5.19516
0.900	4.78359	5.31510
0.950	5.16036	5.43196
1.000	5.54597	5.54597
1.050	5.94018	5.65731
1.100	6.34279	5.76617
1.150	6.75362	5.87272
1.200	7.17249	5.97708
1.250	7.59924	6.07939
1.300	8.03369	6.17976
1.350	8.47572	6.27831
1.400	8.92517	6.37512
1.450	9.38192	6.47029
1.500	9.84594	6.56389
1.550	10.31681	6.65601
1.600	10.79472	6.74670
1.650	11.27946	6.83604
1.700	11.77093	6.92407
1.750	12.26902	7.01087
1.800	12.77365	7.09647
1.850	13.28472	7.18093
1.900	13.80215	7.26429
1.950	14.32585	7.34659
2.000	14.85574	7.42787
2.050	15.39175	7.50817
2.100	15.93380	7.58752
2.150	16.48182	7.66596
2.200	17.03574	7.74352
2.250	17.59549	7.82022
2.300	18.16101	7.89609
2.350	18.73224	7.97117
2.400	19.30911	8.04546
2.450	19.89157	8.11901
2.500	20.47955	8.19182

TABLE A-VI (Continued)

$V_1 = 2.0 \text{ ft/sec}$		
z_n	T	$V_{z,n}$
Nozzle Length (ft)	(ft ² /sec)	Velocity at Nozzle Bottom (ft/sec)
2.550	21.07302	8.26393
2.600	21.67190	8.33535
2.650	22.27615	8.40699
2.700	22.88572	8.47619
2.750	23.50056	8.54566
2.800	24.12061	8.61450
2.850	24.74585	8.68275
2.900	25.37621	8.75042
2.950	26.01166	8.81751
3.000	26.65214	8.88405
3.050	27.29763	8.95004
3.100	27.94808	9.01551
3.150	28.60345	9.08046
3.200	29.26369	9.14490
3.250	29.92878	9.20886
3.300	30.59868	9.27233
3.350	31.27334	9.33532
3.400	31.95273	9.39786
3.450	32.63682	9.45995
3.500	33.32558	9.52159
3.550	34.01897	9.58281
3.600	34.71695	9.64360
3.650	35.41951	9.70397
3.700	36.12659	9.76394
3.750	36.83818	9.82352
3.800	37.55425	9.88270
3.850	38.27476	9.94150
3.900	38.99969	9.99992
3.950	39.72900	10.05797
4.000	40.46267	10.11567
4.050	41.20068	10.17301
4.100	41.94299	10.23000
4.150	42.68959	10.28665
4.200	43.44044	10.34296
4.250	44.19551	10.39894
4.300	44.95479	10.45460
4.350	45.71825	10.50994
4.400	46.48587	10.56497
4.450	47.25761	10.61969
4.500	48.03347	10.67410
4.550	48.81341	10.72822

TABLE A-VII

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 2.5 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	2.50000
0.050	0.12854	2.57083
0.100	0.29701	2.97011
0.150	0.48641	3.24271
0.200	0.69502	3.47510
0.250	0.92097	3.68388
0.300	1.16289	3.87618
0.350	1.41954	4.05582
0.400	1.69010	4.22525
0.450	1.97375	4.38612
0.500	2.26984	4.53968
0.550	2.57779	4.68688
0.600	2.89708	4.82846
0.650	3.22727	4.96504
0.700	3.56798	5.09711
0.750	3.91882	5.22510
0.800	4.27940	5.34936
0.850	4.64968	5.47022
0.900	5.02913	5.58792
0.950	5.41758	5.70271
1.000	5.81480	5.81480
1.050	6.22058	5.92436
1.100	6.63472	6.03156
1.150	7.05704	6.13655
1.200	7.48735	6.23946
1.250	7.92550	6.34040
1.300	8.37133	6.43948
1.350	8.82470	6.53681
1.400	9.28546	6.63247
1.450	9.75349	6.72655
1.500	10.22867	6.81912
1.550	10.71088	6.91024
1.600	11.20000	7.00000
1.650	11.69593	7.08844
1.700	12.19867	7.17563
1.750	12.70781	7.26161
1.800	13.22357	7.34643
1.850	13.74576	7.43014
1.900	14.27428	7.51278
1.950	14.80906	7.59439
2.000	15.35002	7.67501
2.050	15.89708	7.75467
2.100	16.45017	7.83341
2.150	17.00921	7.91126
2.200	17.57414	7.98825
2.250	18.14489	8.06440
2.300	18.72140	8.13974
2.350	19.30360	8.21430
2.400	19.89143	8.28810
2.450	20.48484	8.36116
2.500	21.08377	8.43351

TABLE A-VII (Continued)

$$V_1 = 2.5 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
2.550	21.68816	8.50516
2.600	22.29797	8.57614
2.650	22.91313	8.64646
2.700	23.53360	8.71615
2.750	24.15933	8.78521
2.800	24.79028	8.85367
2.850	25.42639	8.92154
2.900	26.06762	8.98883
2.950	26.71393	9.05557
3.000	27.36527	9.12176
3.050	28.02161	9.18741
3.100	28.68289	9.25255
3.150	29.34909	9.31717
3.200	30.02016	9.38130
3.250	30.69607	9.44494
3.300	31.37677	9.50811
3.350	32.06224	9.57082
3.400	32.75243	9.63307
3.450	33.44732	9.69487
3.500	34.14685	9.75625
3.550	34.85103	9.81719
3.600	35.55979	9.87772
3.650	36.27311	9.93784
3.700	36.99096	9.99756
3.750	37.71331	10.05688
3.800	38.44013	10.11582
3.850	39.17139	10.17439
3.900	39.90706	10.23259
3.950	40.64711	10.29041
4.000	41.39152	10.34788
4.050	42.14026	10.40500
4.100	42.89329	10.46178
4.150	43.65061	10.51822
4.200	44.41217	10.57433
4.250	45.17796	10.63011
4.300	45.94794	10.68557
4.350	46.72211	10.74071
4.400	47.50042	10.79555
4.450	48.28286	10.85008
4.500	49.06941	10.90431
4.550	49.86003	10.95825

TABLE A-VIII

VALUES OF THE FUNCTION, T , AND THE VERTICAL VELOCITY
AT THE NOZZLE BOTTOM, $V_{z,n}$, AS A FUNCTION OF NOZZLE
LENGTH, z_n , FOR VARIOUS VALUES OF THE VANE JET VERTICAL
VELOCITY COMPONENT ON ENTERING THE UPPER VORTEX, V_1

$$V_1 = 3.0 \text{ ft/sec}$$

z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
0.	0.	3.00000
0.050	0.14719	2.94373
0.100	0.33564	3.35642
0.150	0.54299	3.61993
0.200	0.76828	3.84140
0.250	1.00999	4.03997
0.300	1.25694	4.22313
0.350	1.53815	4.39472
0.400	1.82281	4.55704
0.450	2.12023	4.71161
0.500	2.42978	4.85957
0.550	2.75095	5.00174
0.600	3.08327	5.13879
0.650	3.42632	5.27126
0.700	3.77972	5.39960
0.750	4.14313	5.52418
0.800	4.51625	5.64531
0.850	4.89878	5.76327
0.900	5.29048	5.87831
0.950	5.69109	5.99062
1.000	6.10040	6.10040
1.050	6.51820	6.20781
1.100	6.94430	6.31300
1.150	7.37851	6.41610
1.200	7.82067	6.51723
1.250	8.27061	6.61649
1.300	8.72819	6.71400
1.350	9.19327	6.80983
1.400	9.66570	6.90407
1.450	10.14536	6.99680
1.500	10.63214	7.08809
1.550	11.12590	7.17800
1.600	11.62656	7.26650
1.650	12.13399	7.35393
1.700	12.64810	7.44006
1.750	13.16879	7.52502
1.800	13.69597	7.60887
1.850	14.22956	7.69165
1.900	14.76946	7.77340
1.950	15.31559	7.85415
2.000	15.86789	7.93394
2.050	16.42626	8.01281
2.100	16.99065	8.09078
2.150	17.56097	8.16789
2.200	18.13716	8.24416
2.250	18.71915	8.31962
2.300	19.30689	8.39430
2.350	19.90030	8.46821
2.400	20.49934	8.54139
2.450	21.10393	8.61385
2.500	21.71403	8.68561

TABLE A-VIII (Continued)

$V_1 = 3.0 \text{ ft/sec}$		
z_n Nozzle Length (ft)	T (ft ² /sec)	$V_{z,n}$ Velocity at Nozzle Bottom (ft/sec)
2.550	22.32958	8.75570
2.600	22.95853	8.82713
2.650	23.57683	8.89692
2.700	24.20842	8.96608
2.750	24.84526	9.03464
2.800	25.48730	9.10261
2.850	26.13450	9.17000
2.900	26.78681	9.23683
2.950	27.44418	9.30311
3.000	28.10658	9.36886
3.050	28.77396	9.43409
3.100	29.44629	9.49880
3.150	30.12351	9.56302
3.200	30.80560	9.62675
3.250	31.49252	9.69001
3.300	32.18423	9.75280
3.350	32.88069	9.81513
3.400	33.58187	9.87702
3.450	34.28773	9.93847
3.500	34.99825	9.99950
3.550	35.71338	10.06011
3.600	36.43310	10.12030
3.650	37.15737	10.18010
3.700	37.88616	10.23950
3.750	38.61944	10.29852
3.800	39.35719	10.35716
3.850	40.09937	10.41542
3.900	40.84596	10.47332
3.950	41.59692	10.53087
4.000	42.35223	10.58806
4.050	43.11186	10.64490
4.100	43.87579	10.70141
4.150	44.64399	10.75759
4.200	45.41643	10.81344
4.250	46.19310	10.86896
4.300	46.97395	10.92417
4.350	47.75898	10.97908
4.400	48.54815	11.03367
4.450	49.34144	11.08796
4.500	50.13884	11.14196
4.550	50.94031	11.19567

TABLE A-IX

VARIATION OF THE CALCULATED UPPER VORTEX
THICKNESS AT THE BOTTOM OF 6-INCH
NOZZLES AS A FUNCTION OF V_1

Run Number 112401

 $r_w = 3$ feet $Q_w = 12.9 \text{ ft}^3/\text{sec}$

V_1	$V_{z,n}$	$12 (r_w - r_i)$
VERTICAL VELOCITY COMPONENT OF THE VANE JET ENTERING UPPER VORTEX	VERTICAL VELOCITY OF THE UPPER VORTEX AT THE NOZZLE BOTTOMS	UPPER VORTEX THICKNESS AT THE NOZZLE BOTTOMS
(ft/sec)	(ft/sec)	(inches)
0	3.27	2.61
0.5	3.48	2.44
1	3.71	2.29
1.3	3.86	2.19
1.5	3.97	2.13
2	4.24	1.99
2.5	4.54	1.86
3	4.86	1.73

TABLE A-X

VARIATION OF THE CALCULATED UPPER VORTEX
THICKNESS AT THE BOTTOM OF 30-INCH
NOZZLES AS A FUNCTION OF V_1

Run Number 121301

$r_w = 3$ feet

$Q_w = 14.3 \text{ ft}^3/\text{sec}$

V_1	$V_{z,n}$	$12 (r_w - r_i)$
VERTICAL VELOCITY COMPONENT OF THE VANE JET ENTERING UPPER VORTEX	VERTICAL VELOCITY OF THE UPPER VORTEX AT THE NOZZLE BOTTOMS	UPPER VORTEX THICKNESS AT THE NOZZLE BOTTOMS
(ft/sec)	(ft/sec)	(inches)
0	7.32	1.27
0.5	7.53	1.23
1	7.74	1.20
1.3	7.87	1.18
1.5	7.96	1.16
2	8.19	1.13
2.5	8.43	1.10
3	8.69	1.06

APPENDIX B

WALL FLOW DATA

The velocity, direction of flow, and static pressure measured in the wall flow of the FCRV-3 and FCRV-4 are presented in the tables of this appendix. The complete data for each run tabulated here may be found in Appendix C. Representative graphs of the axial and tangential velocities observed in the FCRV-4 are presented for two runs (Figures B-1 and B-2). The other runs showed similar curves. Curves for the FCRV-3 were presented in Figures 2 through 5 of Reference (2).

Figure B-1a. Wall Flow Measurements in FCRV-4 - Axial Velocity: Seventy-two 6-inch Nozzles

Figure B-1b. Wall Flow Measurements in FCRV-4 - Tangential Velocity: Seventy-two 6-inch Nozzles

Figure B-2a. Wall Flow Measurements in FCRV-4
Axial Velocity: Eighteen 30-inch Nozzles

Figure B-2b. Wall Flow Measurements in FCRV-4
Tangential Velocity: Eighteen 30-inch Nozzles

TABLE B-I

WALL FLOW DATA FOR RUN NO. 100801 *

FCVR-3

Sixteen 18-inch nozzles

36-inch-diameter-wall cylinder

Volumetric water flow rate = 24,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-29.5	0.10	4.5	-16	2.63	-3.7	13.0
-29.5	0.50	6.2	-15		-4.2	15.5
-29.5	1.00	6.2	-11		-3.1	15.9
-23.5	0.10	21.2	-15	3.50	-4.7	17.4
-23.5	1.10	15.9	-14		-4.02	16.1
-23.5	2.00	7.9	0		0.0	15.2
-23.5	2.60	7.3	0		0.0	14.0
6.5	0.10	36.8	33	1.06	10.4	15.8
12.5	0.10	14.2	38	1.07	12.8	16.4
12.5	0.30	30.8	39		12.7	15.7
12.5	0.50	29.8	40		13.3	15.8
12.5	0.70	30.8	38		12.2	15.6
12.5	0.90	23.2	40		9.7	11.5
24.5	0.10	30.8	43	0.68	12.9	13.9
24.5	0.40	31.3	43		13.3	14.3
36.5	0.12	33.1	46	0.67	13.3	12.9
36.5	0.32	33.1	46		14.1	13.7
36.5	0.54	27.1	46		13.6	13.2
48.5	0.22	28.0	51	0.47	14.2	11.5
48.5	0.43	26.2	51		14.4	11.7
60.5	0.12	26.2	54	0.72	13.6	9.9
60.5	0.30	26.2	54		13.9	10.1
60.5	0.50	18.5	55		12.2	8.6
60.5	0.70	10.9	57		13.9	9.0
72.5	0.20	26.8	31	5.80	5.5	9.2
72.5	0.50	28.0	24		4.5	10.2
72.5	1.50	30.2	13		2.5	10.9
72.5	2.50	28.9	8		1.6	11.3
72.5	3.50	25.9	2		0.4	10.3
72.5	3.70	23.7	0		0.0	9.9
72.5	3.90	22.0	-2		-0.3	9.2
72.5	4.50	17.5	-10		-1.4	8.1
72.5	5.00	14.9	-11		-1.4	7.2

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-II

WALL FLOW DATA FOR RUN NO. 100802*

FCRV-3

Sixteen 18-inch nozzles

36-inch-diameter-wall cylinder

Volumetric water flow rate = 20,600 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
12.5	0.20	11.3	36	1.05	11.5	16.1
12.5	0.50	28.3	36		11.2	15.7

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-III

WALL FLOW DATA FOR RUN NO. 100803*

FCRV-3

Sixteen 18-inch nozzles

36-inch-diameter-wall cylinder

Volumetric water flow rate = 29,000 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
12.5	0.20	35.2	36	1.00	11.6	16.4
12.5	0.60	35.2	35		12.0	17.1

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-IV

WALL FLOW DATA FOR RUN NO. 101901*

FCRV-3

Twelve 30-inch nozzles

36-inch-diameter-wall cylinder

Volumetric water flow rate = 27,000 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
6.5	0.19	24.2	40	0.79	11.8	14.1
6.5	0.39	26.0	39		11.7	14.5
6.5	0.59	23.2	42		12.1	13.5
18.5	0.40	26.0	43	0.70	12.4	13.3
18.5	0.20	25.0	44		12.1	12.8
30.5	0.15	21.0	46	0.60	11.8	11.3
30.5	0.35	21.0	47		12.4	11.6

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-V

WALL FLOW DATA FOR RUN NO. 102301*

FCRV-3

Twelve 30-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 27,300 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
0.5	0.10	19.8	31	0.60	7.9	13.2
0.5	0.40	18.6	31		7.7	12.8
0.5	0.20	19.5	31		8.1	13.5
6.5	0.10	20.9	34	0.60	9.1	13.5
6.5	0.20	21.5	35		9.5	13.6
6.5	0.30	21.3	35		9.4	13.4
6.5	0.40	19.5	35	0.60	9.1	13.0
12.5	0.10	22.8	39		10.7	13.2
12.5	0.20	23.2	39		10.8	13.3
12.5	0.30	23.9	39		10.6	13.1
12.5	0.40	22.7	39		10.5	13.0

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-VI

WALL FLOW DATA FOR RUN NO. 102302

FCRV-3

Twelve 30-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 29,100 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
0.5	0.15	25.9	27	0.65	8.2	16.0
0.5	0.35	26.8	26		7.6	15.6
6.5	0.15	26.8	30	0.65	8.7	15.0
6.5	0.40	27.2	30		8.7	15.0
12.5	0.10	22.8	35	0.85	9.9	14.1
12.5	0.20	25.9	35		10.0	14.2
12.5	0.30	26.8	35		10.1	14.5
12.5	0.50	27.8	35		10.3	14.7
12.5	0.70	23.0	35		9.6	13.7

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-VII

WALL FLOW DATA FOR RUN NO. 102501*

FCRV-3

Forty-eight 6-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 17,400 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-11.5	0.35	9.8	5	3.95	1.1	12.2
-11.5	1.35	8.8	8		1.7	11.8
-11.5	2.35	7.4	8		1.6	11.1
-11.5	3.35	5.9	-7		-1.3	10.3
6.5	0.15	13.0	48	0.65	8.7	7.9
6.5	0.35	12.9	47		8.5	7.9
6.5	0.55	11.6	49		8.1	7.1
18.5	0.05	13.6	55	0.25	10.1	7.2
18.5	0.15	11.4	56		8.9	6.1
30.5	0.05	16.3	59	0.42	11.7	7.0
30.5	0.15	16.4	59		11.9	7.1
30.5	0.25	15.8	59		11.7	7.1
48.5	0.30	12.5	54	1.30	9.0	6.6
48.5	0.60	14.2	54		10.2	7.4
48.5	0.90	11.5	55		9.2	6.4
48.5	1.20	8.3	56		5.8	3.9
60.5	0.30	17.2	59	1.14	11.1	6.6
60.5	0.60	12.0	58		8.4	5.3
60.5	0.90	8.2	63		6.5	3.3
72.5	0.25	19.0	53	0.83	7.6	5.7
72.5	0.55	17.2	52		6.7	5.2
84.5	0.40	25.9	37	2.90	4.0	5.4
84.5	0.90	25.8	30		3.4	5.8
84.5	1.40	25.0	22		2.3	5.7
84.5	2.0	24.5	12		1.1	5.4
84.5	2.5	24.0	8		0.7	5.2
84.5	2.8	23.2	3		0.3	5.2

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-VIII

WALL FLOW DATA FOR RUN NO. 102701*

FCRV-3

Forty-eight 6-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 28,200 ft³/h

<u>Sensing Position</u>		Wall Static Pressure (inches of water)	Angle of Flow** (degrees from horizontal)	Water Layer Thickness (inches)	Axial Velocity (ft/sec)	Tangential Velocity (ft/sec)
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-11.5	1.0	26.8	2	5.70	0.4	12.3
-11.5	2.0	23.2	4		0.8	10.9
-11.5	3.0	19.4	4		0.7	9.9
-11.5	4.0	17.2	-6		-1.1	10.3
-11.5	5.0	10.0	-7		-1.0	7.8
-11.5	5.5	1.5	1		0.9	5.1
6.5	0.29	28.9	32	1.34	9.7	15.5
6.5	0.59	27.8	35		10.0	14.3
6.5	0.89	19.8	36		8.7	11.8
6.5	1.19	12.0	36		5.8	8.2
18.5	0.22	29.2	40	0.82	11.9	14.4
18.5	0.42	28.0	40		11.9	14.1
18.5	0.62	19.8	42		10.0	11.1
30.5	0.19	26.8	44	0.89	12.1	12.8
30.5	0.39	28.3	43		12.7	13.6
30.5	0.59	25.8	44		12.3	12.7
48.5	0.27	30.5	40	1.07	11.7	14.2
48.5	0.57	29.2	40		11.8	14.1
48.5	0.87	15.4	39		8.2	10.1
60.5	0.08	25.8	46	0.69	12.7	12.3
60.5	0.28	20.8	40		12.4	12.3
60.5	0.48	25.0	37		11.3	15.1
72.5	1.0	28.0	13		3.3	14.3
72.5	2.0	24.3	7		1.8	14.6
72.5	4.0	20.8	-5		1.0	11.6
72.5	5.0	17.0	-6		1.0	9.2
72.5	6.0	12.2	-3		0.3	6.0
72.5	6.7	7.8	3		0.5	9.4

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-IX

WALL FLOW DATA FOR RUN NO. 102801*

FCRV-3

Forty-eight 6-inch nozzles
 42-inch-diameter-wall cylinder
 Volumetric water flow rate = 25,700 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
18.5	0.20	28.2	38	0.80	10.9	14.0
18.5	0.50	27.5	39		11.6	14.4

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

Table B-X

WALL FLOW DATA FOR RUN NO. 102802*

FCRV-3

Forty-eight 6-inch nozzles
 42-inch-diameter-wall cylinder
 Volumetric water flow rate = 33,600 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
18.5	0.20	25.0	39	0.90	12.2	15.0
18.5	0.50	25.0	39		12.6	15.5

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XI

WALL FLOW DATA FOR RUN NO. 110203*

FCRV-3

Forty-eight 12-inch nozzles
 42-inch-diameter-wall cylinder
 Volumetric water flow rate = 28,400 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft./sec)</u>	<u>Tangential Velocity (ft./sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
6.5	0.18	17.2	40	0.83	9.2	11.0
6.5	0.48	16.2	40		9.1	10.8
18.5	0.10	17.2	46	0.75	10.2	9.8
18.5	0.45	17.1	46		10.7	10.4
12.5	0.22	21.5	45	0.62	10.5	10.5

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XII

WALL FLOW DATA FOR RUN NO. 110308*

FCRV-3

Forty-eight 12-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 28,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-18.5	0.10	16.2	9	6.05	1.6	10.2
-18.5	1.10	18.5	9		1.6	10.2
-18.5	2.10	16.2	8		1.3	9.3
-18.5	3.10	12.8	10		1.5	8.6
-18.5	4.10	12.2	2		0.0	7.3
-18.5	5.10	8.7	1		0.0	5.2
-18.5	6.10	6.2	1		0.0	3.1
-18.5	7.10	6.0	-38		-1.9	2.5
6.5	0.15	16.2	40	1.45	8.6	10.2
6.5	0.65	13.2	42		7.7	8.6
6.5	1.15	7.0	49		4.0	3.4
18.5	0.10	17.4	51	0.90	10.3	8.4
18.5	0.35	17.2	52		11.6	9.1
18.5	0.65	11.1	52		9.1	7.1
24.5	0.10	12.0	55	0.84	11.4	8.0
24.5	0.25	18.1	55		12.4	8.7
24.5	0.55	13.9	54		10.5	7.7
42.5	0.15	4.8	52	1.85	4.5	3.2
42.5	0.65	11.5	48		8.5	7.6
42.5	1.15	10.0	48		8.0	7.2
42.5	1.55	6.0	50		4.0	3.4
54.5	0.05	19.0	50	0.90	10.8	9.1
54.5	0.55	15.5	51		10.4	8.4
66.5	0.20	20.7	46	2.00	-	-
66.5	0.70	19.8	41		8.6	9.8
66.5	1.20	14.5	33		5.4	8.3
78.5	1.00	30.5	28		5.5	10.4
78.5	2.00	27.5	19		3.3	9.5
78.5	3.00	25.9	6		0.9	8.4
78.5	4.00	24.0	-2		-0.2	6.8
78.5	5.00	23.0	-5		-0.6	6.4
78.5	6.00	20.8	-5		-0.5	5.2
78.5	7.00	19.8	-5		-0.6	6.4
78.5	8.00	17.2	2		0.2	5.2

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XIII

WALL FLOW DATA FOR RUN NO. 110901*

FCRV-3

Twelve 30-inch nozzles
 42-inch-diameter-wall cylinder
 Volumetric water flow rate = 23,400 ft³/h

<u>Sensing Position</u>		Wall Static Pressure (inches of water)	Angle of Flow** (degrees from horizontal)	Water Layer Thickness (inches)	Axial Velocity (ft/sec)	Tangential Velocity (ft/sec)
Inches Below Nozzle Bottoms	Inches From Wall					
0.5	0.10	15.4	37	0.90	7.9	10.5
0.5	0.40	15.4	35		7.7	11.0
0.5	0.70	8.7	41		5.6	6.4
6.5	0.10	19.0	41	0.85	9.9	11.4
6.5	0.40	17.2	41		9.8	11.3
6.5	0.70	10.2	43		6.1	6.6
12.5	0.20	19.8	46	0.90	11.1	10.7
12.5	0.50	18.6	46		11.1	10.7
12.5	0.80	10.2	49		6.8	5.9

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XIV

WALL FLOW DATA FOR RUN NO. 110902*

FCRV-3

Twelve 30-inch nozzles
 42-inch-diameter-wall cylinder
 Volumetric water flow rate = 42,100 ft³/h

<u>Sensing Position</u>		Wall Static Pressure (inches of water)	Angle of Flow (degrees from horizontal)	Water Layer Thickness (inches)	Axial Velocity (ft/sec)	Tangential Velocity (ft/sec)
Inches Below Nozzle Bottoms	Inches From Wall					
0.5	0.15	25.9	35	1.40	9.9	14.2
0.5	0.55	21.2	36		8.9	12.3
0.5	1.05	9.5	40		5.8	6.9
6.5	0.12	31.0	39	1.57	11.7	14.4
6.5	0.62	31.0	38		11.3	14.5
6.5	1.12	15.5	39		8.4	10.4
12.5	0.15	19.8	43	2.00	14.5	15.6
12.5	0.55	33.8	45		14.0	14.0
12.5	1.15	10.2	47		7.7	7.2
12.5	1.75	33.8	43		14.6	15.6

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XV

WALL FLOW DATA FOR RUN NO. 110903**

FCRV-3

Twelve 30-inch nozzles

42-inch-diameter-wall cylinder

Volumetric water flow rate = 28,900 ft³/h

Sensing Position		Wall Static Pressure (inches of water)	Angle of Flow** (degrees from horizontal)	Water Layer Thickness (inches)	Axial Velocity (ft/sec)	Tangential Velocity (ft/sec)
Inches Below Nozzle Bottoms	Inches From Wall					
0.5	0.10	21.5	38	1.15	9.7	12.4
0.5	0.40	21.5	36		9.4	12.9
0.5	0.80	12.9	38		6.8	8.7
6.5	0.15	23.2	43	1.20	11.5	12.3
6.5	0.45	24.0	41		11.4	13.1
6.5	0.85	12.2	43		9.1	9.8
12.5	0.30	25.8	45	1.35	12.6	12.6
12.5	0.70	27.5	45		12.3	12.3
12.5	1.10	12.9	47		8.2	7.5
30.5	0.10	14.5	24	2.60	6.6	14.9
30.5	1.10	20.8	30		8.3	14.4
30.5	2.10	17.2	0		0.0	0.3
42.5	0.10	28.5	50	1.40	12.1	10.2
42.5	0.80	23.2	47		12.1	11.3
42.5	1.10	15.4	45		8.8	8.8
54.5	0.05	22.5	44	5.55	9.6	10.0
54.5	1.05	19.5	32		5.9	9.5
54.5	2.05	15.5	5		0.7	8.4
54.5	3.05	14.1	-11		-1.6	8.2
54.5	4.05	11.5	-16		-0.9	3.1
54.5	5.05	9.5	-15		-1.4	5.3
66.5	0.20	36.2	3		0.6	11.4
66.5	1.20	32.0	6		1.2	11.8
66.5	2.20	28.0	7		1.5	12.0
66.5	3.20	25.8	3		0.6	11.6
66.5	4.20	23.0	1		0.2	10.3
66.5	5.20	19.0	-2		-0.3	8.5
66.5	6.20	17.2	-2		-0.2	6.6
66.5	7.20	15.5	1		0.0	3.4

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XVI

WALL FLOW DATA FOR RUN NO. 112401**

FCRV-4

Seventy-two 6-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 46,600 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-6.6	0.15	17.2	-2	1.60	-0.5	14.8
-6.6	0.55	19.0	-2		-0.5	14.9
-6.6	0.95	16.2	-1		-0.3	14.9
-6.6	1.35	14.5	-2		-0.5	14.6
5.4	0.10	29.9	18	1.18	6.0	18.6
5.4	0.50	32.9	16		5.5	19.2
5.4	0.90	26.5	17		5.6	18.2
17.4	0.10	29.0	24	0.80	8.2	18.4
17.4	0.40	31.5	24		8.3	18.6
17.4	0.70	17.2	27		7.0	14.2
29.4	0.10	21.0	31	0.80	8.7	14.5
29.4	0.40	25.2	29		9.3	16.7
29.4	0.70	22.0	28		8.5	15.9
41.4	0.15	26.0	33	0.55	10.4	16.0
41.4	0.35	28.3	32		10.2	16.6
53.4	0.20	30	46	0.40	12.5	12.1
65.4	0.10	25.4	48	0.50	13.8	12.4
65.4	0.30	25.9	50		14.6	12.3
77.4	0.05	16.2	50	1.30	12.3	10.3
77.4	0.55	16.2	42		10.2	11.3
77.4	1.05	11.2	27		5.0	9.9
89.4	0.08	22.5	32		5.9	9.5
89.4	1.08	23.8	25		5.1	10.9
89.4	2.08	22.5	16		3.4	11.7
89.4	3.08	20.1	10		2.0	11.4
89.4	4.08	19.0	-2		-0.4	10.8
89.4	5.08	17.2	-1		-0.3	9.9
89.4	6.08	15.5	-1		-0.3	9.7

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XVII

WALL FLOW DATA FOR RUN NO. 112402*

FCRV-4

Seventy-two 6-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 55,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-6.6	0.05	-2.3	3	2.95	0.4	6.7
-6.6	1.05	10.3	3		0.8	15.5
-6.6	2.05	23.2	-1		-0.2	10.8
-6.6	2.55	4.5	4		0.5	7.3
5.4	0.10	34.5	23	1.05	8.1	19.2
5.4	0.60	30.0	21		6.8	17.8
17.4	0.05	29.0	29	1.15	6.9	12.5
17.4	0.35	34.5	29		10.1	18.3
17.4	0.65	32.9	27		9.2	18.2
29.4	0.10	28.2	36	0.75	11.0	15.1
29.4	0.30	30.0	34		10.7	15.9
29.4	0.50	31.0	34		11.0	16.4
41.4	0.10	29.2	38	0.80	11.6	14.8
41.4	0.40	33.0	38		12.9	16.6
41.4	0.70	18.5	38		7.9	10.1
53.4	0.10	30.0	54	0.60	13.9	10.1
53.4	0.30	28.0	47		14.4	13.4
53.4	0.50	23.8	44		12.6	13.0
65.4	0.15	29.2	47	0.85	5.6	5.2
65.4	0.35	31.2	48		5.6	5.2
65.4	0.75	22.8	48		11.2	10.1
77.4	0.10	24.9	50	0.90	14.4	12.1
77.4	0.40	29.2	49		16.8	14.6
77.4	0.70	16.2	43		9.2	9.9
89.4	1.00	21.8	43		11.2	12.0
89.4	2.00	22.5	31		9.1	15.1
89.4	3.00	17.5	15		4.0	15.1
89.4	4.00	14.5	2		5.2	14.9
89.4	4.32	12.8	0		-	15.0
89.4	5.00	12.5	-3		7.7	14.7
89.4	6.00	11.1	-4		-9.8	13.9
89.4	7.00	11.5	-5		-11.8	13.4

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XVIII

WALL FLOW DATA FOR RUN NO. 112901**

FCRV-4

Seventy-two 6-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 35,600 ft³/h

<u>Sensing Position</u>		Wall Static Pressure (inches of water)	Angle of Flow** (degrees from horizontal)	Water Layer Thickness (inches)	Axial Velocity (ft/sec)	Tangential Velocity (ft/sec)
Inches Below Nozzle Bottoms	Inches From Wall					
-6.6	0.05	7.2	8	1.35	1.4	9.7
-6.6	0.55	7.9	6		1.1	10.3
-6.6	1.05	6.5	5		0.8	8.9
5.4	0.10	19.2	27	1.20	7.2	14.1
5.4	0.60	17.9	27		7.0	13.8
5.4	1.10	17.4	27		4.3	8.6
17.4	0.10	17.9	37	1.00	8.6	11.4
17.4	0.40	18.2	37		10.1	13.4
17.4	0.70	13.9	37		7.8	10.4
29.4	0.10	17.3	43	1.00	10.4	11.2
29.4	0.50	19.9	42		11.1	12.4
29.4	0.90	9.5	42		6.8	7.5
41.4	0.10	16.0	49	0.80	10.7	9.5
41.4	0.40	17.0	48		11.9	10.7
41.4	0.70	8.5	49		7.3	6.4
53.4	0.15	18.0	52	0.55	12.6	9.9
53.4	0.45	15.5	52		11.1	9.2
65.4	0.05	16.2	59	0.60	12.5	7.5
65.4	0.25	17.2	59		13.8	8.3
65.4	0.45	14.5	58		11.4	7.2
77.4	0.05	16.0	62	0.90	13.6	7.4
77.4	0.35	17.5	60		14.2	8.2
77.4	0.65	10.2	53		8.6	6.6
89.4	0.05	15.5	46		6.7	6.4
89.4	1.05	16.0	35		5.3	7.6
89.4	2.05	13.8	20		2.8	7.6
89.4	3.05	12.0	8		1.0	7.6
89.4	4.05	11.2	0		-	7.0
89.4	4.15	11.2	-3		-0.4	7.0
89.4	5.05	10.6	-4		-0.5	6.8
89.4	6.05	10.2	-7		-0.8	6.7

*See Appendix C for complete operating conditions.

**Negative value indicates upward flow.

TABLE B-XIX

WALL FLOW DATA FOR RUN NO. 120304*

FCRV-4

Seventy-two 12-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 50,700 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
5.4	0.10	16.1	33	1.80	8.0	12.2
5.4	0.60	16.6	32		8.6	13.7
5.4	1.10	14.8	32		7.5	12.0
5.4	1.60	7.8	35		5.4	7.8
11.4	0.15	16.5	40	1.80	10.6	12.6
11.4	0.65	17.8	41		11.5	13.2
11.4	1.15	11.3	39		7.9	9.7
11.4	1.65	4.4	43		4.8	5.2
23.4	0.10	20.0	45	1.30	12.4	12.4
23.4	0.60	20.0	44		11.3	11.7
23.4	1.10	6.1	45		6.5	6.5
35.4	0.10	20.0	51	1.00	13.8	11.2
35.4	0.40	22.6	49		14.0	12.2
35.4	0.70	16.5	51		13.0	10.5
47.4	0.10	15.7	54	1.30	13.9	10.1
47.4	0.50	20.9	53		14.0	10.5
47.4	0.90	11.3	48		7.4	6.6
53.4	0.15	20.0	46	3.25	9.7	9.4
53.4	0.55	20.0	47		10.3	9.6
53.4	0.95	17.4	45		8.8	8.8
53.4	1.35	21.8	32		6.1	9.8
53.4	1.75	13.0	29		4.2	6.5
53.4	2.15	9.6	14		1.9	7.7
53.4	2.55	14.8	14		2.0	8.0
53.4	2.95	8.7	0		0.0	7.0
53.4	3.15	9.6	-1		-0.1	7.4
59.4	0.05	20.9	46		8.6	8.3
59.4	1.05	24.4	34		6.5	9.6
59.4	2.05	19.1	27		4.5	8.8
59.4	3.05	15.7	11		1.7	8.6
59.4	4.08	14.8	1		0.1	8.2
59.4	4.10	17.4	0		0.0	8.2
59.4	5.05	14.8	-5		0.7	7.6
59.4	6.05	13.9	-8		-1.0	7.0
59.4	6.65	13.0	-3		-0.4	6.7

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XX

WALL FLOW DATA FOR RUN NO. 120901*

FCRV-4

Seventy-two 12-inch nozzles
 72-inch-diameter-wall cylinder
 Volumetric water flow rate = 46,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
5.4	0.10	9.2	35	1.25	6.5	9.3
5.4	0.50	9.0	35		6.3	9.0
5.4	0.90	6.9	35		5.4	7.7
17.4	0.05	9.9	50	1.20	9.7	8.2
17.4	0.45	11.2	46		9.1	8.8
17.4	0.85	6.9	48		7.4	6.6
29.4	0.05	13.5	56	1.0	11.2	7.5
29.4	0.45	13.0	54		11.6	8.4
29.4	0.85	4.0	57		5.6	3.7
41.4	0.05	13.5	56	0.75	11.2	7.5
41.4	0.35	15.5	57		13.0	8.4
41.4	0.65	12.0	57		11.5	7.4
53.4	0.10	15.0	55	1.50	9.0	6.3
53.4	0.40	15.0	54		4.9	3.5
53.4	0.70	14.1	53		8.1	6.1
53.4	1.10	13.0	46		5.9	5.7
53.4	1.40	11.2	39		4.6	5.7
65.4	0.10	24.0	42		4.9	5.5
65.4	1.10	24.0	30		3.6	6.3
65.4	2.10	20.5	24		2.6	5.8
65.4	3.10	21.0	9		0.9	6.0
65.4	3.88	20.5	0		0.0	5.1
65.4	4.10	20.0	-4		-0.4	5.2
65.4	5.10	20.0	-13		-1.1	4.7
65.4	6.10	19.5	-11		-0.9	4.7
65.4	7.10	19.2	-16		-1.4	5.0
65.4	8.10	19.0	-15		-1.3	5.0

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XXI

WALL FLOW DATA FOR RUN NO. 121001*

FCRV-4

Seventy-two 12-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 60,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
5.4	0.10	14.4	26	1.80	6.0	12.4
5.4	0.50	14.4	24		5.6	12.5
5.4	0.80	13.6	24		5.4	12.2
5.4	1.10	12.4	23		4.9	11.5
5.4	1.40	7.9	24		3.8	8.6
5.4	1.70	5.6	24		3.4	7.6
17.4	0.10	15.3	37	1.40	8.6	11.4
17.4	0.50	5.9	37		7.3	9.7
17.4	0.90	5.4	38		6.4	8.2
17.4	1.30	6.4	36		5.3	7.3
29.4	0.10	16.6	42	1.20	10.1	11.2
29.4	0.40	18.8	41		10.6	12.4
29.4	0.70	17.4	40		10.0	11.8
29.4	1.00	8.9	41		6.8	7.8
41.4	0.05	9.2	47	1.07	11.8	11.0
41.4	0.35	11.4	46		12.2	11.8
41.4	0.65	18.9	46		11.8	11.4
41.4	0.95	6.9	45		5.4	5.4
53.4	0.05	17.4	42	4.25	8.6	9.6
53.4	1.05	15.9	36		6.6	9.1
53.4	2.05	13.4	16		2.0	7.1
53.4	2.70	11.4	0		0.0	6.4
53.4	3.05	10.9	-9		-0.9	5.9
53.4	4.05	10.6	-15		-0.1	5.2
65.4	0.10	26.6	31		4.8	8.0
65.4	1.10	27.4	24		3.8	8.6
65.4	2.10	25.4	20		3.1	8.5
65.4	3.10	25.2	9		1.3	8.4
65.4	4.10	23.6	0		0.0	7.9
65.4	5.10	22.9	-8		-1.0	7.3
65.4	6.10	22.4	-13		-1.6	7.0
65.4	7.10	21.2	-15		-1.8	6.6
65.4	8.10	20.2	-15		-1.6	6.0

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XXII

WALL FLOW DATA FOR RUN NO. 121301*

FCRV-4

Eighteen 30-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 51,600 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-0.6	0.10	28.3	23	2.50	4.3	10.2
-0.6	0.80	28.8	21		6.5	6.8
-0.6	1.50	19.8	16		4.3	15.0
-0.6	2.20	6.8	12	1.30	1.8	8.3
11.4	0.05	22.8	29		8.4	15.1
11.4	0.55	27.3	28		8.9	16.8
11.4	1.05	13.8	29	1.07	6.7	12.1
23.4	0.15	24.8	35		10.7	15.3
23.4	0.55	27.8	34		11.1	16.5
23.4	0.95	8.8	38	1.0	5.8	7.5
35.4	0.05	22.3	40		11.2	13.4
35.4	0.45	26.8	39		12.1	14.9
35.4	0.85	13.8	39	0.85	8.7	10.7
47.4	0.10	24.8	43		12.7	13.6
47.4	0.40	29.8	43		13.6	14.6
47.4	0.70	12.8	45		9.5	9.5
59.4	0.10	18.8	39		9.7	11.9
59.4	1.10	16.8	26		5.9	12.0
59.4	2.10	12.8	5		0.9	10.5
59.4	2.55	10.8	0		0.0	10.2
59.4	3.10	10.8	-6		-1.1	10.3
59.4	4.10	9.8	-12		-2.1	9.7
59.4	5.10	9.3	-5		-0.8	8.9
59.4	6.10	6.8	-4		-0.6	8.2
59.4	7.10	5.3	2		-0.3	7.6

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XXIII

WALL FLOW DATA FOR RUN NO. 121401 *

FCRV-4

Eighteen 30-inch nozzles

72-inch-diameter-wall cylinder

Volumetric water flow rate = 40,200 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-0.6	0.15	15.7	27	2.65	5.3	10.3
-0.6	0.65	15.7	25		5.9	12.7
-0.6	1.05	10.2	27		5.1	10.0
-0.6	1.55	7.7	20		3.4	9.4
-0.6	2.05	7.2	17		2.8	9.1
-0.6	2.55	2.7	22	1.50	2.4	6.0
11.4	0.15	16.2	34		8.2	12.2
11.4	0.55	16.2	33		8.2	12.6
11.4	0.95	9.2	30		6.8	11.7
23.4	0.10	17.2	39		9.8	12.1
23.4	0.40	19.2	38	0.85	9.7	12.5
23.4	0.70	15.2	45		5.7	5.7
35.4	0.10	15.7	45		9.6	9.6
35.4	0.30	17.2	46		10.4	10.0
35.4	0.50	16.7	46		10.0	9.7
47.4	0.10	14.2	49	1.00	11.2	9.7
47.4	0.50	18.2	45		11.4	11.4
47.4	0.90	8.2	35		6.0	8.5
59.4	0.10	19.2	37		7.2	9.6
59.4	1.10	17.2	28		5.0	9.4
59.4	2.10	15.4	14		2.1	8.5
59.4	3.10	15.2	3		0.5	8.8
59.4	3.60	13.4	0		0	8.5
59.4	4.10	12.7	-3		-0.4	7.9
59.4	5.10	12.2	-5		-0.6	7.4
59.4	6.10	12.2	-8		-1.0	7.3
59.4	7.10	10.7	-8		-0.9	6.7
59.4	8.10	10.7	-8		-0.8	5.5

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

TABLE B-XXIV

WALL FLOW DATA FOR RUN NO. 121402*

FCRV-4

Eighteen 30-inch nozzles,
 72-inch-diameter-wall cylinder
 Volumetric water flow rate = 60,300 ft³/h

<u>Sensing Position</u>		<u>Wall Static Pressure (inches of water)</u>	<u>Angle of Flow** (degrees from horizontal)</u>	<u>Water Layer Thickness (inches)</u>	<u>Axial Velocity (ft/sec)</u>	<u>Tangential Velocity (ft/sec)</u>
<u>Inches Below Nozzle Bottoms</u>	<u>Inches From Wall</u>					
-0.6	0.10	27.0	27	2.60	7.2	14.2
-0.6	0.70	30.0	22		7.0	17.3
-0.6	1.30	25.0	17		5.1	16.6
-0.6	1.90	19.0	13		3.6	16.0
-0.6	2.50	4.0	11		1.3	7.0
11.4	0.15	17.5	29	1.65	8.7	15.6
11.4	0.55	32.0	30		10.1	17.5
11.4	0.95	29.0	27		8.8	17.2
11.4	1.35	15.0	28		6.1	11.5
23.4	0.15	12.0	34	1.25	12.1	18.0
23.4	0.65	30.0	34		11.3	16.8
23.4	1.15	7.0	34		5.4	8.0
35.4	0.10	8.0	40	3.80	13.4	16.0
35.4	0.70	28.0	35		11.2	16.1
35.4	1.30	8.0	9		1.5	9.6
35.4	1.70	5.5	0		0.0	3.8
35.4	2.50	6.0	-11		-1.8	9.4
35.4	3.10	5.0	-10		-1.4	7.8
35.4	3.70	3.5	-4		-0.5	6.8
47.4	0.10	23.5	23		6.4	15.0
47.4	1.10	30.0	17		4.8	15.7
47.4	2.10	28.5	10		2.8	15.8
47.4	3.20	25.0	0		0.0	14.9
47.4	4.10	24.0	-4		-1.0	13.8
47.4	5.10	20.5	-7		-1.8	14.3
47.4	6.10	14.5	-7		-1.4	11.2
47.4	7.10	13.0	-10		-1.9	10.6
47.4	8.10	8.9	-4		-0.6	8.2

* See Appendix C for complete operating conditions.

** Negative value indicates upward flow.

APPENDIX C

The raw and calculated data for the FCRV-3 and FCRV-4 runs during the sixth quarter are presented in this appendix.

<u>Table No.</u>	<u>Subject</u>
C-I	FCRV-3 Raw Data
C-II	FCRV-3 Calculated Data
C-III	FCRV-4 Raw Data
C-IV	FCRV-4 Calculated Data

TABLE C-I

RAW DATA FOR FCRV-3 TESTS⁽¹⁾

Run Number ⁽²⁾	Air Flow Rate Data			Water Flow Rate Data		Lower Vortex Water Levels		Plenum Pressure Data			Carryunder Data		Carryover Observation ⁽⁸⁾
	Orifice Upstream Pressure (inches Hg)	Orifice Pressure Drop ⁽³⁾ (inches Hg)	Air Temperature (°F)	Orifice Pressure Drop ⁽⁴⁾ (inches Hg under water)	Water Temperature ⁽⁵⁾ (°F)	at radius of 12.5 inches (inches below vane bottoms) ⁽⁶⁾	at radius of 14.5 inches (inches below vane bottoms) ⁽⁶⁾	Lower Plenum (inches of Hg)	Below Nozzles (inches of Hg)	Top	Orifice Upstream Pressure (inches of water)	Orifice Pressure Drop ⁽⁷⁾ (inches of 0.827 oil)	
Wall cylinder diameter = 36 inches.													
Sixteen 18-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 0.50 ft ² .													
Three curved plenum deflectors located at 0, 4, and 8 inches below nozzle tops.													
100701	33.7	1.65	157	4.8	104	48	43.3	28.7	19.8	17.6	2.0	2.5	Acceptable
100702	31.2	0.45	157	5.8	102	50	45.8	27.3	18.4	16.6	4.0	6.7	Acceptable
100703	36.4	1.65	165	5.35	102	54	-	31.3	22.1	20.7	3.1	4.2	Acceptable
100704	40.0	3.9	180	3.8	102	75	74.3	32.2	23.3	22.0	2.0	2.7	Acceptable
100705	36.3	5.85	182	2.5	102	-	-	26.1	19.0	17.6	0.3	0.5	Low
100801	40.2	3.9	175	3.7	85	48.5	44	32.1	23.4	20.9	1.5	2.0	Acceptable
100802	37.7	5.35	170	2.68	77	75	-	27.8	20.3	17.9	0.4	0.5	Acceptable
100803	39.0	1.7	170	5.38	80	51	-	33.6	23.6	22.2	1.5	2.0	Acceptable
Wall cylinder diameter = 36 inches.													
Twelve 30-inch nozzles; tops of active nozzles located at 3 inches below vane tops; nozzle flow area = 0.625 ft ² .													
Three curved plenum deflectors located at 6, 10, and 14 inches below nozzle tops.													
101901	33.8	3.7	175	4.7	70			25.4	15.5	15.5	3.0	4.5	Low
Wall cylinder diameter = 42 inches.													
Twelve 30-inch nozzles; tops of active nozzles located at 3 inches below vane tops; nozzle flow area = 0.625 ft ² .													
Three curved plenum deflectors located at 0, 10, and 20 inches below nozzle tops.													
102101	37.6	2.45	180	6.3	100	46.5	-	31.0	19.5	26.8	2.5	3.5	Acceptable - low
102301	33.6	3.7	175	4.6	85	46	41.5	25.8	16.3	25.1	1.0	1.5	Acceptable - low
102302	42.8	5.5	197	5.6	90	51	45.5	32.8	21.1	32.9	2.7	4.5	Acceptable
Wall cylinder diameter = 42 inches.													
Forty-eight 6-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 0.50 ft ² .													
Three curved plenum deflectors located at 0, 2, and 4 inches below nozzle tops.													
102501	20.0	2.5	150	1.9	87	45.5	43.0	20.4	20.2	-	0.1	0.2	Acceptable
102701	39.7	4.2	173	5.0	90	46.0	40.0	31.6	-	16.8	0.2	0.1	None
102801	40.9	6.2	167	4.2	57	43.5	37.5	30.0	-	17.7	0.3	0.2	Low
102802	40.8	2.8	165	7.0	60	43.5	-	34.6	-	23.5	1.0	1.0	Low

(1) Wall flow data not included in this tabulation (see Appendix B).

(2) The six digits of the Run Number give the month (first two digits) and date (second two digits) of the test. The last two digits give the order in which the runs were made.

(3) Orifice diameter = 3.549 inches (see Figure D-1).

(4) Orifice diameter = 10.675 inches (see Figure D-3).

(5) Water temperature equals air-water mixture temperature.

(6) Vane bottoms are 3 inches below nozzle bottoms.

(7) Orifice diameter = 0.805 inch (see Figure D-4)

(8) Qualitative measure only.

TABLE C-I (Continued)

Run Number ⁽²⁾	Air Flow Rate Data			Water Flow Rate Data		Lower Vortex Water Levels		Plenum Pressure Data			Carryunder Data		Carryover Observation ⁽⁸⁾
	Orifice Upstream Pressure (inches Hg)	Orifice Pressure Drop ⁽³⁾ (inches Hg)	Air Temperature (°F)	Orifice Pressure Drop ⁽⁴⁾ (inches Hg under water)	Water Temperature ⁽⁵⁾ (°F)	at radius of 12.5 inches (inches below vane bottoms) ⁽⁶⁾	at radius of 14.5 inches	Lower Plenum	Below Nozzles	Top	Orifice Upstream Pressure (inches of water)	Orifice Pressure Drop ⁽⁷⁾ (inches of 0.827 oil)	
Wall cylinder diameter = 42 inches.													
Forty-eight 12-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 1.0 ft ² .													
Three curved plenum deflectors located at 0, 4, and 8 inches below nozzle tops.													
110201	39.5	8.9	100	3.5	50	26	-	25.0	15.2	12.6	0	0	High Acceptable - High Acceptable
110202	32.9	4.6	130	4.5	50	33	-	24.1	13.9	12.8	1.0	1.0	
110203	34.9	4.7	145	5.2	57	35	31	26.0	15.2	13.7	1.4	1.8	
110301	29.2	4.0	155	4.1	75	58	55	22.0	12.4	12.8	1.0	2.0	
110302	24.2	3.1	150	3.6	75	61	58.5	18.4	10.0	10.9	0	1.0	
110303	20.6	4.0	145	2.0	70	62	62	13.8	7.6	7.2	0	0	
110304	-	-	-	2.4	70	41	-	9.0	3.1	1.1	0	1	
110305	-	-	-	0.5	70	62	-	7.2	2.0	0.1	0	0	
110306	-	-	-	3.7	70	38	-	10.4	3.9	3.5	5	8	
110307	-	-	-	6.6	70	32	-	15.5	8.0	8.2	13	20	
110308	35.1	4.8	165	5.0	80	43.5	40.0	26.4	15.4	15.1	3.0	4.0	
110401	35.2	10.3	102	2.0	57	47.5	-	18.9	11.7	9.0	low	low	
110402	41.1	7.2	150	4.7	57	43.5	-	28.8	17.6	13.5	2.0	3.0	
Wall cylinder = 42 inches.													
Twelve 30-inch nozzles; tops of active nozzle located 3 inches below vane tops; nozzle flow area = 0.625 ft ² .													
Three curved plenum deflectors located at 0, 10, and 20 inches below nozzle tops.													
110801	39.3	6.2	155	4.1	75		21	28.5	19.3	30.4	0	0	Low Acceptable Acceptable Acceptable Acceptable Acceptable (Increasing) Acceptable Acceptable
110802	40.8	10.1	160	2.6	75		21	24.7	16.8	31.3	0	0	
110803	43.0	5.4	165	5.6	75		21	33.4	21.9	34.4	0	0	
110804	42.6	9.3	165	3.6	75		21	27.7	18.1	33.7	0	0	
110805	42.2	5.9	165	5.0	75		21	31.8	20.4	32.7	0	0	
110806	42.1	3.6	165	7.0	75		21	34.8	21.9	31.7	0	0	
110807	41.2	2.8	155	8.3	75		21	34.9	21.7	30.7	0	0	
110808	43.8	1.3	155	12.0	75		21	39.5	23.9	33.2	0	0	
110809	-	-	-	6.2	75			16.0	8.8	6.7	5	5	
110810	-	-	-	4.0	75			13.8	6.2	4.0	1.7	1.7	
110811	-	-	-	7.7	75			19.1	11.4	9.3	6.7	6.7	
110812	-	-	-	10.7	75			23.9	15.0	14.2	5.0	5.0	
110813	-	-	-	14.9	75			30.4	20.2	19.7	2.5	2.5	
110901	41.8	9.8	175	3.4	60	41.0	37.5	26.3	16.9	31.2	0.5	0.5	Acceptable Acceptable Acceptable
110902	44.0	1.6	150	11.1	70	38.0	32.0	39.3	24.3	33.2	0.5	0.5	
110903	42.2	6.1	165	5.3	70	40.0	36.0	31.5	19.9	33.2	1.5	1.5	

TABLE C-II

CALCULATED DATA FOR FCRV-3 TESTS⁽¹⁾

Run Number ⁽²⁾	Weight Flow Rates			Volumetric Flow Rates						Inlet Equivalent Quality ^(3,5) (weight percent)	Homogeneous Mixture Density in Plenum (lb/ft ³)	Homogeneous Nozzle ⁽³⁾ Velocity (ft/sec)	Pressure Drop ⁽³⁾		
	Air	Water	Total	Air		Water	Total		(psi)				(feet of homogeneous mixture)	Carryunder ⁽⁵⁾ (weight percent)	
				at plenum conditions ⁽³⁾	at vane conditions ⁽⁴⁾		at plenum conditions ⁽³⁾	at vane conditions ⁽⁴⁾							
	(10 ³ lb/h)					(10 ³ ft ³ /h)									
Wall cylinder diameter = 36 inches.															
Sixteen 18-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 0.5 ft ² .															
Three curved plenum deflectors located at 0, 4, and 8 inches below nozzle tops.															
100701	4.7	1710	1715	41.2	66.3	27.6	68.8	93.9	6.9	24.9	38.2	9.2	52.9	0.15	
100702	2.4	1890	1892	21.3	34.1	28.6	49.9	62.7	3.4	37.9	27.6	8.6	32.6	0.23	
100703	4.7	1820	1825	39.0	67.4	29.4	68.4	96.8	6.2	26.7	38.0	10.5	56.6	0.19	
100704	7.4	1520	1527	59.6	106.0	24.5	84.1	130.5	10.9	18.2	46.7	11.1	88.1	0.18	
100705	8.1	1210	1218	71.6	116.0	19.5	91.1	135.5	15.6	13.4	50.7	9.0	96.5	0.10	
100801	7.5	1505	1512	58.9	101.1	24.2	83.2	125.3	10.9	18.2	46.2	10.9	86.3	0.16	
100802	8.5	1280	1289	74.0	115.4	20.6	94.7	136.0	15.3	13.7	52.6	9.4	98.6	0.10	
100803	4.9	1810	1815	37.8	66.2	29.0	66.8	95.2	6.1	27.2	37.1	11.3	59.6	0.12	
Wall cylinder diameter = 36 inches.															
Twelve 30-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.625 ft ² .															
Three curved plenum deflectors located at 6, 10, and 14 inches below nozzle tops.															
101901	7.6	1680	1688	67.3	102.0	27.0	94.3	129.0	11.1	17.90	41.9	7.58	60.7	0.21	
Wall cylinder diameter = 42 inches.															
Twelve 30-inch nozzles; tops of active nozzles located at 3 inches below vane tops; nozzle flow area = 0.625 ft ² .															
Three curved plenum deflectors located at 0, 10, and 20 inches below nozzle tops.															
102101	5.8	2020	2026	46.2	82.7	32.4	78.6	115.1	6.7	25.8	34.9	11.4	63.4	0.14	
102301	6.9	1700	1707	56.1	94.5	27.3	83.4	121.8	9.3	20.5	37.1	10.2	71.8	0.18	
102302	9.0	1810	1819	62.2	125.0	29.1	91.3	154.1	9.7	19.9	40.6	13.2	95.4	0.19	
Wall cylinder diameter = 42 inches.															
Forty-eight 6-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 0.50 ft ² .															
Three curved plenum deflectors located at 0, 2, and 4 inches below nozzle tops.															
102501	5.2	1075	1080	54.5	70.6	17.4	71.85	87.9	13.5	15.03	39.9	4.6	43.5	0.07	
102701	7.8	1760	1768	64.6	107.6	28.2	92.8	135.8	10.2	19.05	51.6	9.8	73.7	0.03	
102801	9.5	1600	1610	77.2	123.2	25.7	102.9	148.9	10.6	15.6	57.2	8.7	79.8	0.05	
102802	6.4	2090	2096	47.2	84.5	33.6	80.8	117.1	5.5	25.9	44.9	11.5	63.8	0.08	

(1) Wall flow data not included in this tabulation.
 (2) The six digits of the Run Number give the month (first two digits) and date (second two digits) of the test. The last two digits give the order in which the runs were made.
 (3) Calculated at a pressure equal to the average of the pressures below the nozzles and the top of the plenum (see Raw Data).
 (4) Volumetric flow calculated at atmospheric pressure.
 (5) Calculated assuming a homogeneous steam-water mixture at 1000 psig with the same phase volumes as the air-water flow.

TABLE C-II (Continued)

Run Number ⁽²⁾	Weight Flow Rates			Volumetric Flow Rates						Pressure Drop ⁽³⁾				
	Air	Water	Total	Air		Water	Total		Inlet Equivalent Quality ^(3, 5) (weight percent)	Homogeneous Mixture Density in Plenum (lb/ft ³)	Homogeneous Nozzle Velocity (ft/sec)	psi	(feet of homogeneous mixture)	Carryunder ⁽⁵⁾ (weight percent)
				at plenum conditions ⁽³⁾	at vane conditions ⁽⁴⁾		at plenum conditions ⁽³⁾	at vane conditions ⁽⁴⁾						
	(10 ³ lb/h)			(10 ³ ft ³ /h)										
Wall cylinder diameter = 42 inches.														
Forty-eight 12-inch nozzles; tops of active nozzles located 9 inches below vane tops; nozzle flow area = 1.0 ft ² .														
Three curved plenum deflectors located at 0, 4, and 8 inches below nozzle tops.														
110201	11.9	1485	1497	104.6	152.8	23.8	128.4	176.6	18.0	11.7	35.7	6.8	84.0	0
110202	8.0	1680	1688	70.4	102.1	27.0	97.4	129.1	11.5	17.3	27.1	6.6	54.4	0.11
110203	8.1	1770	1778	72.1	104.9	28.4	100.5	133.3	11.3	17.7	27.9	6.8	55.4	0.13
110301	7.0	1580	1587	66.1	94.7	25.4	91.5	120.1	11.5	17.3	25.4	6.2	51.5	0.14
110302	6.0	1490	1496	59.1	80.4	23.9	83.0	104.3	11.0	18.0	23.1	5.1	40.8	0.12
110303	6.6	1120	1127	70.8	87.7	18.0	88.7	105.7	16.4	12.7	24.6	3.6	40.8	< 0.1
110304	-	1220	1220	-	-	19.6	19.6	-	-	-	-	-	-	0.13
110305	-	500	500	-	-	8.0	8.0	-	-	-	-	-	-	< 0.13
110306	-	1550	1550	-	-	24.9	24.9	-	-	-	-	-	-	0.3
110307	-	2000	2000	-	-	32.1	32.1	-	-	-	-	-	-	0.35
110308	8.0	1760	1768	72.3	109.1	28.2	100.6	137.4	11.4	17.6	27.9	7.4	61.1	-
110401	12.4	1100	1112	120.8	162.0	17.7	138.4	179.6	25.5	8.0	38.5	5.1	90.9	< 0.15
110402	10.0	1700	1710	85.2	129.8	27.3	112.5	157.1	13.5	15.2	31.3	7.1	72.2	0.17
Wall cylinder diameter = 42 inches.														
Twelve 30-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.625 ft ² .														
Three curved plenum deflectors located at 0, 10, and 20 inches below nozzle tops.														
110801	9.6	1600	1610	70.5	129.0	25.7	96.2	154.7	12.1	16.8	42.7	12.2	104.9	0
110802	12.1	1270	1282	90.7	163.1	20.4	111.1	183.5	18.2	11.5	49.4	11.8	146.6	0
110803	9.0	1830	1839	62.7	121.4	29.4	92.1	150.8	9.6	20.0	40.9	13.8	99.4	0
110804	11.6	1460	1472	83.9	156.3	23.4	107.3	179.7	15.2	13.7	47.7	12.7	133.3	0
110805	9.4	1720	1729	67.2	126.7	27.6	94.8	154.3	10.8	18.2	42.1	13.0	102.6	0
110806	7.4	2100	2107	52.4	98.9	33.7	86.1	132.6	7.2	24.5	38.3	13.1	77.1	0
110807	6.5	2280	2287	46.9	87.8	36.6	83.5	124.4	6.0	27.4	37.1	12.8	67.3	0
110808	4.5	2720	2725	31.3	61.1	43.7	75.0	104.8	2.6	36.3	33.3	14.0	55.5	0
110809	-	1970	1970	-	-	-	31.6	-	-	-	-	3.8	-	-
110810	-	1630	1630	-	-	-	26.2	-	-	-	-	2.5	-	-
110811	-	2100	2100	-	-	-	33.7	-	-	-	-	5.1	-	-
110812	-	2580	2580	-	-	-	41.4	-	-	-	-	7.2	-	-
110813	-	3020	3020	-	-	-	48.5	-	-	-	-	9.8	-	-
110901	11.8	1460	1472	85.6	155.4	23.4	109.0	178.8	15.4	13.5	48.4	11.8	125.9	< 0.1
110902	5.2	2620	2625	35.1	68.8	42.1	77.2	110.9	4.0	34.0	34.3	14.1	59.7	0.04
110903	9.6	1800	1810	67.6	128.0	28.9	96.5	156.9	13.1	18.76	42.9	13.1	100.6	0.12

TABLE C-III
RAW DATA FOR FCRV-4 TESTS⁽¹⁾

Run Number ⁽²⁾	Air Flow Rate Data			Water Flow Rate Data		Lower Vortex Water Levels		Plenum Pressure Data			Carryunder Data		Carryover ⁽⁸⁾
	Orifice Upstream: Pressure (inches Hg)	Orifice Pressure Drop ⁽³⁾ (inches Hg)	Air Temperature (°F)	Orifice Pressure Drop ⁽⁴⁾ (inches Hg under water)	Water Temperature ⁽⁵⁾ (°F)	at radius of 30.0 inches (inches below vane bottoms) ⁽⁶⁾	at radius of 32.5 inches	Lower Plenum (inches Hg under water)	Below Nozzles (inches Hg under water)	Top	Orifice Upstream Pressure (inches of water)	Orifice Pressure Drop ⁽⁷⁾ (inches of 0.827 oil)	
Wall cylinder diameter = 72 inches.													
Seventy-two 6-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.75 ft ² .													
112301	-	-	-	4.0	60	51	-	9.1	4.1	2.4	0	0	
112302	-	-	-	6.0	60	47	46.5	10.0	5.0	3.7	0.5	0.5	
112303	-	-	-	8.0	65	43	42.5	11.0	6.0	4.6	3.0	3.0	
112304	-	-	-	10.0	65	40	39.0	12.0	7.0	5.7	7.0	7.0	
112305	-	-	-	12.0	65	31	29.5	12.8	8.0	6.7	15.0	15.0	
112306	-	-	-	14.0	65	27	25.5	14.0	9.1	7.8	16.0	16.0	
112307	29	2.7	150	13.5	60	54	-	18.8	16.8	18.3	8.0	8.0	Acceptable
112401	29.7	2.7	135	13.5	70	51	47.0	19.5	16.8	18.3	3.5	3.5	Acceptable
112402	26.0	1.5	120	19.0	80	55.5	50.0	20.8	18.2	19.3	1.5	1.5	Acceptable
112901	24.7	3.1	130	8.0	60	54.5	52.0	13.0	10.7	11.8	2.7	2.7	Acceptable
112902	29.9	2.8	150	15.0	65	0	-	19.5	15.6	18.1	0.2	0.2	Acceptable
-	-	-	-	30.0	60			10.8	6.0	4.6	5.5	6.5	Acceptable
Wall cylinder diameter = 72 inches.													
Seventy-two 12-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 1.5 ft ² .													
120201	-	-	-	30.0	60	-8	-	10.8	6.0	4.6	5.5	6.5	
120301	22.0	3.4	105	25.7	50	17.5	14.5	8.5	7.4	9.0	1.1	1.3	Acceptable
120302	21.1	3.2	110	19.2	50	20.5	18.5	7.8	5.5	7.7	2.5	3.0	Acceptable
120303	20.6	3.2	110	14.0	50	23.5	22.5	6.6	4.8	6.2	3.5	4.0	Acceptable
120304	22.1	3.5	120	21.8	60	27.0	25.0	8.0	6.6	8.0	4.5	5.0	Acceptable
120901	14.7	1.9	100	13.3	50	27.0	26.0	6.8	4.3	5.7	12.0	16.5	Acceptable
120902	21.6	3.2	120	25.2	55	23.5	21.5	8.0	7.3	9.0	3.0	3.5	Acceptable
121001	15.8	1.6	105	22.5	60	24.0	22.0	8.7	6.6	7.7	4.0	5.5	Acceptable
Wall cylinder diameter = 72 inches.													
Eighteen 30-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.94 ft ² .													
121301	28.3	3.1	140	16.6	62	55	50.5	17.2	15.1	16.7	1.4	1.9	Acceptable
121401	24.9	3.5	118	10.2	55	50	47.5	11.8	9.9	9.7	0.8	1.0	Acceptable
121402	23.6	1.2	115	22.8	55	37.5	32.0	18.9	16.2	15.6	0.3	0.4	Acceptable

- (1) Wall flow data not included in this tabulation (see Appendix B).
- (2) The six digits of the run number give the month (first two digits) and date (second two digits) of the test. The last two digits give the order in which the runs were made.
- (3) Orifice diameter = 5.070 inches (see Figure D-2).
- (4) Orifice diameter = 10.675 inches (see Figure D-3).
- (5) Water temperature equals air-water mixture temperature.
- (6) Vane bottoms are 3 inches below nozzle bottoms.
- (7) Orifice diameter = 0.805 inch (see Figure D-4).
- (8) Qualitative measure only.

TABLE C-IV

CALCULATED DATA FOR FCRV-4 TESTS⁽¹⁾

Run Number ⁽²⁾	Weight Flow Rates			Volumetric Flow Rates					Inlet Equivalent Quality (3, 5) (weight percent)	Homogeneous Mixture Density in Plenum (lb/ft ³)	Homogeneous Nozzle ⁽³⁾ Velocity (ft/sec)	Pressure Drop ⁽³⁾		
	Air	Water	Total	Air at plenum ⁽³⁾ conditions	at vane conditions ⁽⁴⁾	Water	Total at plenum ⁽³⁾ conditions	at vane conditions ⁽⁴⁾				psi	feet of homogenous mixture	Carryunder ⁽⁵⁾ (weight percent)
Wall cylinder diameter = 72-inches. Seventy-two 6-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.75 ft ² .														
112301	-	1580	1580	-	-	25.4	-	-	-	-	1.0	-	-	0
112302	-	1930	1930	-	-	31.0	-	-	-	-	2.1	-	-	0.06
112303	-	2220	2220	-	-	35.6	-	-	-	-	2.6	-	-	0.12
112304	-	2500	2500	-	-	40.2	-	-	-	-	3.1	-	-	0.16
112305	-	2720	2720	-	-	43.7	-	-	-	-	3.6	-	-	0.22
112306	-	2950	2950	-	-	47.4	-	-	-	-	4.2	-	-	0.22
112307	12.7	2890	2903	105.0	167.1	46.4	151.4	203.5	10.2	19.2	56.0	8.6	64.5	
112401	12.91	2900	2912	108.7	172.3	46.6	155.3	218.9	10.4	18.8	57.6	8.6	66.0	0.10
112402	9.23	3440	3449	77.2	124.8	55.2	132.4	180.0	6.5	26.0	49.1	9.2	50.5	0.06
112901	13.25	2220	2233	126.3	174.4	35.6	161.9	209.6	15.1	13.8	60.4	5.5	57.4	0.12
112902	13.0	3050	3063	110.3	171.0	49.0	159.3	220.0	10.2	19.3	59.0	8.3	61.6	?
Wall cylinder diameter = 72 inches. Seventy-two 12-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 1.5 ft ² .														
120201	-	4300	4300	-	-	69.0	-	-	-	-	2.6	-	-	0.09
120301	13.8	4000	4014	140	176.9	64.2	203.7	241.1	9.8	19.7	37.6	4.0	29.1	0.05
120302	13.4	3450	3463	141.2	171.8	55.3	196.5	227.1	11.3	17.6	36.3	3.2	26.3	0.08
120303	13.3	2950	2963	143.9	170.5	47.3	195.1	217.8	13.2	15.2	36.1	2.7	25.4	0.10
120304	13.9	3160	3174	146.5	178.2	50.7	197.2	228.9	12.6	16.1	36.5	3.5	21.7	0.10
120901	8.7	2880	2889	95.8	111.7	46.2	142.0	157.9	9.0	20.2	27.9	2.5	17.5	0.22
120902	13.0	3960	3973	132.8	168.9	63.5	201.2	232.4	9.2	19.8	40.9	4.0	29.0	0.07
121001	8.75	3750	3759	92.7	115.0	60.2	152.9	175.4	7.2	24.6	28.3	3.5	20.6	0.10
Wall cylinder diameter = 72 inches. Eighteen 30-inch nozzles; tops of active nozzles located 3 inches below vane tops; nozzle flow area = 0.94 ft ² .														
121301	13.4	3210	3223	117.1	176.2	51.6	168.7	227.8	10.2	19.2	50.0	7.4	55.8	0.08
121401	14.2	2500	2514	138.5	184.4	40.2	178.7	224.6	14.7	14.5	52.9	4.8	49.3	0.06
121402	8.25	3750	3758	70.8	110.0	60.3	131.1	170.3	5.6	28.6	38.8	7.8	38.6	0.03

(1) Wall flow data not included in this tabulation (see Appendix B).
(2) The six digits of the run number give the month (first two digits) and the date (second two digits) of the test. The last two digits give the order in which the runs were made.
(3) Calculated at a pressure equal to the pressures.
(4) Volumetric flow calculated at atmospheric pressure.
(5) Calculated assuming a homogeneous steam-water mixture at 1000 psig with the same phase volumes as the air-water flow.

APPENDIX D

CALIBRATION CURVES FOR THE LARGE AIR-WATER TEST FACILITY

The calibration curves for air flow, water flow, and carryunder are presented in this appendix.

Figure No.

D-1	Air Flow - Orifice Diameter = 3.549 inches
D-2	Air Flow - Orifice Diameter = 5.070 inches
D-3	Water Flow
D-4	Equivalent Carryunder versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 0.805 inch
D-5	Equivalent Carryunder versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 1.288 inches
D-6	Equivalent Carryunder versus Carryunder Air Flow Rate
D-7	Carryunder Air Flow - Orifice Diameter = 0.805 inch
D-8	Carryunder Air Flow - Orifice Diameter = 1.288 inches

Figure D-1. Air Flow - Orifice Diameter = 3.549 inches

Figure D-II. Air Flow - Orifice Diameter = 5.070 inches

Figure D-III. Water Flow

Figure D-IV. Equivalent Carryunder Versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 0.805 inch

Figure D-V. Equivalent Carryunder versus Carryunder Air Orifice Pressure Drop - Orifice Diameter = 1.288 inches

Figure D-VI. Equivalent Carryunder versus Carryunder Air Flow Rate

Figure D-VII. Carryunder Air Flow - Orifice Diameter = 0.805 inch

Figure D-VIII. Carryunder Air Flow · Orifice Diameter = 1.288 inches

REFERENCES

1. Moen, R. H., "Nuclear Superheat Project, Internal Steam Separation, Development of Radial Vane Steam Separators," GEAP-4272, May 31, 1963.
2. Moen, R. H., "Radial Vane Steam Separator Development, Fifth Quarterly Report, July-September 1965, GEAP-4967, EURAEC 1533, October 1965.
3. Moen, R. H., "Radial Vane Steam Separator Development, Third Quarterly Report, January-March 1965," GEAP-4847, EURAEC 1365, April 1965.
4. "1000 MW_e Boiling Water Reactor Plant Feasibility," GEAP-4476.
5. Moen, R. H., "Radial Vane Steam Separator Development, Fourth Quarterly Report, April-June 1965," GEAP-4914, EURAEC 1450, July 1965.

Approved:

D. H. Imhoff, Manager
Engineering Development

C. H. Robbins, Manager
Mechanical and Process Development

R. H. Moen, Project Engineer
Radial Vane Steam Separator Development Project

DISTRIBUTION LIST

	<u>No. Copies</u>
United States Atomic Energy Commission San Francisco Operations Office Berkeley, California Attention: Director, Reactor Division	24
United States Atomic Energy Commission Division Reactor Development Washington 25, D. C. Attention: Chief, Water Reactors Branch	2
Attention: Assistant Director, Office of Foreign Activities	1
United States Atomic Energy Commission Oak Ridge Operations Office Oak Ridge, Tennessee Attention: Director, Reactor Division	1
DTIE Oak Ridge, Tennessee Attention: R. L. Metter	3
Allis-Chalmers Manufacturing Company Nuclear Power Department-Greendale Post Office Box 512 Milwaukee, Wisconsin Attention: G. Johnson	1
Babcock and Wilcox Company Atomic Energy Division Post Office Box 1260 Lynchburg, Virginia Attention: Librarian	1
Combustion Engineering, Inc. Nuclear Division Prospect Hill Road Windsor, Connecticut Attention: Business Manager	1
Northern States Power Company Minneapolis, Minnesota Attention: E. C. Ward	1
Argonne National Laboratory Post Office Box 299 Lamont, Illinois Attention: A. V. Crewe	1
General Nuclear Engineering Corporation Post Office Box 245 Dunedin, Florida Attention: J. M. West	1
Westinghouse Electric Corporation Atomic Power Department Post Office Box 355 Pittsburg, Pennsylvania Attention: J. M. Wright	1