JOINT US/EURATOM R & D PROGRAM
AT (11-1)-1272

Investigation of Vapor Volume Fraction and Slip Velocity
Under the Euratom Program

EUR/AEC Report.

742 ✓

QUARTERLY PROGRESS REPORT
APRIL 15, 1963 – JUNE 30, 1963

Prepared for the
U. S. ATOMIC ENERGY COMMISSION
Under the US/EURATOM Agreement

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Facsimile Price \$ 2.60
Microfilm Price \$ 1.95

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

July 10, 1963

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PROJECT STATEMENT

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 US-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 US-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 ABSTRACT

Vapor volume fraction (void fraction) experiments using a gamma attenuation technique have been planned. The experiments will be conducted using steam-water flow in a vertical 3 in. pipe over a wide range of liquid velocities at 600, 1000, and 1500 PSIA. Conditions of low liquid flow (down to zero liquid velocity) will be investigated which will make the results applicable to a "riser" in a natural circulation system.

The experimental program required designing a test section (the 3 in. pipe) and a steam generator. While the design of the test section was straightforward, the steam generator required considerably more attention because of the large flow and power requirements. Both designs have been completed.

All components of the gamma attenuation detection system were assembled and checked to be sure they were in proper operating condition.

An IBM-1620 computer program was written to reduce the count rate data, taken during the experiments, to void fractions.

A calibration of the void detection system was accomplished by scanning a Lucite-air mock-up of a water-steam flow pattern. The measured void fraction distribution was in good agreement with the known void distribution of the Lucite-air geometry.

2.0 PRINCIPAL INVESTIGATORS

The following investigators were active on the program this quarter:

Winfred A. Bezella

Glenn J. Kangas

Kenneth F. Neusen

3.0 STATEMENT OF THE PROBLEM

This calendar quarter there have been activities in the following areas:

3.1 Description of Testing Program

Planning of the testing program was necessary with respect to selection of range of variables and specific test equipment.

3.2 Design of Test Section and Steam Generator

Since the major pieces of test equipment were not stock items, they had to be designed to meet the needs of the program.

3.3 Design of Gamma Attenuation Detection System

It was necessary to select and assemble the components of the gamma detection system to insure that they were all functioning properly and accurately.

3.4 Data Reduction Program

A computer program was written to fill a need for a fast and efficient means of reducing the count rate data to void fractions.

3.5 System Calibration

A check of the accuracy of the void measuring system was obtained by scanning a Lucite-air test piece.

4.0 DESCRIPTION OF WORK

4.1 Description of Testing Program

The major objective of the Investigation of Vapor Volume Fraction and Slip Velocity program is to obtain void fraction (vapor volume fraction) data for a steam-water mixture in a large round duct. These data are to be taken for an extensive range of flow conditions which will include flows near (and including) zero liquid velocity. The test section chosen for the study is a 2.9 in ID pipe, 4 ft long and instrumented with pressure taps along its length. This selection of geometry and flow conditions will make the results of this program immediately applicable to a "riser" in a natural circulation system.

The range of two-phase flow conditions to be studied are as follows:

Pressure - 600, 1000, and 1500 psi

Superficial Liquid Velocity - 0, 1, 2.5, 10, and 20 fps

Superficial Vapor Velocity - up to 30 fps

Since the range of liquid flows will include zero liquid velocity, the concepts of superficial liquid and vapor velocities are used and are defined as follows:

$$\bar{U}_{go} = \frac{W_g}{A\rho_g} \qquad \bar{U}_{Lo} = \frac{W_L}{A\rho_L}$$

In each definition A represents the cross sectional area of the entire pipe. Consequently, these velocities are the velocities that would occur if one phase occupied the whole pipe. Using superficial velocity instead

of slip ratio will circumvent the failure of the slip ratio concept at zero liquid velocity.

The specific values of superficial vapor velocity have not yet been chosen but there will be four values investigated at each liquid velocity. These values will be chosen later in the test program to give as good a spread in the range of average void fractions as is compatible with the power supply.

While the primary means of measuring void fraction will be the gamma attenuation method, the voids in the duct will also be determined by using the static pressure head method at low flow rates. When the flow velocities become large the static head method will become inaccurate because the frictional components of the pressure drop will dominate. The static head data will be compared to the integrated gamma attenuation data to determine at what flow conditions the static head method is no longer accurate.

The test program will be performed in the High Pressure Heat Transfer Loop located at Allis-Chalmers Greendale Laboratory.

The loop is an all stainless steel facility rated at 1500 psi and 700 F. with a flow capacity of 600 gpm, with multiple valving arrangements making possible either forced or natural circulation flow. The loop is designed to accommodate boiling, superheating or simultaneous boiling, superheating experiments. Direct current electrical resistance heating is used to simulate nuclear heating. Up to 2.2 MWe is available at a maximum of 60,000 amps. Figure 1 is a schematic showing major loop components and the flow path.

Figure 1 - Heat Transfer Loop Schematic

4.2 Design of Test Section and Steam Generator

The test section for the program consists of a 6 ft section of 3" sch 80 pipe, four feet of which will be investigated for vapor volume fraction distribution. The steam generator is mounted in a four foot section of 6" sch 80 pipe immediately below the test section. An assembly drawing of the test assembly is shown in Figure 2.

The test section is instrumented with pressure taps placed axially 6 in. apart. Exit bulk temperatures will be measured using thermocouples.

The steam generator for the test program was designed by revising an existing test section. The steam generator consists of a 69 pin bundle assembly, 44 in. long. It is designed to produce 1500 KWe heat output at a heat flux of 200,000 Btu/hr-ft². Figure 3 shows the pin bundle assembly.

The test assembly is designed in a manner to allow both horizontal and vertical scanning with the gamma beam positioning rack.

Maximum design pressure for both the test section and steam generator is 1500 psia.

4.3 Design of Gamma Attenuation Detection System

The gamma attenuation system for detecting voids is composed of the following items:

1. Cesium 137 source
2. .017 x .625 x 3.5 in. lead collimation slot
3. Scintillation detector

SECTION 'A-A'

NOTES
 1. GASKET CUT-OUT TO BE DONE IN FIELD
 UNDER ENGINEERING SUPERVISION.
 2. ALIGN ASSEMBLY PER SECTION 'A-A'
 THEN WELD IT. TO INSURE FIT ON LOOP.

QTY. SOI REQ.	IT.	DESCRIPTION	MATERIAL	PART NUMBER DRAWING	WT.
1	1	MODIFIED BOILER ELEMENT MOCK-UP		93-501-205	501
1	2	LOWER CONNECTION		93-501-820	501
1	3	STEAM GENERATOR HOUSING		93-501-821	501
1	4	WELD IN RISEP TEST SECTION		93-501-822	501
1	5	MODIFIED BUNDLE ASSEMBLY		93-501-479	501
1	6	BOTTOM ELECTRODE		93-501-156	001
1	7	4" 1500" BLIND FLANGE (SEE NOTE 2)	ASTM A108 60 L252	90-719-045	018
28	8	7/8" UNC-34 X .38 LG. MET. SOC. HD. CAP. SCREW	SST. 18-8	90-415-120	122
28	9	1/25" UNC-24 X 11.5 LG. CONTINUOUS THD. STUD	STEEL	TN15	009
28	10	1/25" UNC-28 NPK S.F. MET. NUT	STEEL	90-431-041	120
28	11	INSULATION-M/S .03 THK X 6 X 16 LG. SHEET	DURABLE	TN15	011
6"	12	WELD ROD (ASTM A230-SST CL. 8 308 IS-16)	ACN 119	TN15	012
4	13	GASKET M/S 0.5 O.D. X .06 THK. SHEET (ASTM A230)	DURABLE	TN15	013

Figure 2 - Test Assembly

NOTES
1. THIS ASSEMBLY TO BE MADE FROM
DWG. 43-500-886

REF. NO.	IT.	DESCRIPTION	MATERIAL	PART NUMBER	QTY.	W.T.
1	1	MODIFIED BUNDLE ASSEMBLY (SEE NOTE 1)		43-901-479	501	
2	2	CONNECTOR		43-202-050	001	
3	3	END PLUG		43-101-357	001	
4	4	SILVER SOLDER	AC #6	THIS	000	
5	5	FLUX	AC #1	THIS	005	
6	6	STUD - M/F 1/8" DIA DWG. 43-500-886 (SEE NOTE 1)		THIS	006	
7	7	STUD - M/F 1/8" DIA DWG. 43-500-886 (SEE NOTE 1)		THIS	007

Figure 3 - Pin Bundle Assembly

4. Preamplifier
5. Radiation analyzing amplifier
6. High voltage supply
7. Scaler
8. Gamma beam positioning rack

A block diagram of the system is shown in Figure 4, and a detail of the detector and source is shown in Figure 5.

The 2.0 Curie Cesium 137 source has a half life of 30 years. Hence, there is no concern over source decay. The characteristic 0.66 Mev gamma emission of Cesium 137 makes it suitable for this application where the beam must penetrate approximately 0.6 in of steel.

A 1.25 in diam sodium iodide crystal is used with a photomultiplier tube in the scintillation detector. The crystal is located up against the collimator slot and there is lead shielding around the entire crystal and photomultiplier tube.

The preamplifier, amplifier, and scaler arrangement will be used to do integral counting with base level discrimination. By setting the discriminator on the plateau of the integral spectrum just below the 0.66 Mev peak, the problem of counting multiple scattered photons should be practically eliminated. The collimation geometry should reduce single scattered photons that are counted to a negligible fraction.

The gamma traverse rack is designed to assure accurate positioning of the source and detector. Horizontal position can be determined and reproduced to within 0.005 in.

Figure 4 - Gamma Attenuation Detection System

NOTE

SOURCE AND DETECTOR
ARE LEAD SHIELDED

Figure 5 - Source Holder and Detector

4.4 Data Reduction Program

An IBM-1620 computer program has been written in FORTRAN language to reduce the large amount of experimental data, which will be obtained, to local and volume averaged void fractions. This computer program will analyze an individual set of chordal gamma beam intensity measurements through the test section. A maximum of 60 individual radial positions for each horizontal test section traverse constitute a computer problem or run. Any number of runs or problems consisting of horizontal gamma beam intensity traverse measurements, may be processed at one time with only one read-in of the object deck required. If desired, the individual void fraction output values may be punched on cards in a form suitable for input to another computer program.

1. Input Data

A minimum amount of data preparation is required to fulfill the program's input requirements. The majority of the input data has been arranged in a tabular format to minimize key punch time. Supplied as input are tables containing the radial gamma-ray count rate profile data for the test section filled first with water then with steam and finally with the two-phase mixture. A table containing the volume weighting fraction of each radial position must also be supplied for each calculation. Standard reference count rates, obtained with a steel absorber, for each of the three fluid conditions must also be inputted. A six digit run identification number and the number of radial points to be

processed complete the input specification.

The input consists of the following information:

1. Identification card
2. Two-phase Count Rate Table
3. Volume Fraction Table
4. Water and Steam Standard Absorber Data
5. Water Count Rate Table
6. Steam Count Rate Table

This information is fed into the machine consecutively in the above order. If more than one set of runs are to be analyzed, succeeding runs are merely fed into the machine consecutively.

II. Calculation and Output

To obtain the local void fraction at each point an iterative calculational procedure is employed. First the all-water, $W(1)$; and all-steam, $S(1)$, count rates are adjusted to the count rate conditions present during the two-phase determination. This is accomplished using the standard steel absorber count rates; TPAB, WAAB, and STAB which are obtained just prior to the two-phase, all-water and all-steam traverses respectively. The adjusted or normalized all-water and all-steam count rates then become:

$$WCR(1) = (TPAB/WAAB) \cdot W(1)$$

$$SCR(1) = (TPAB/STAB) \cdot S(1)$$

The local void fraction can then be calculated using the two-phase count rate, $V(I)$, measured at that point:

$$X(I) = \frac{\ln V(I)/WCR(I)}{\ln SCR(I)/WCR(I)}$$

This local void fraction calculation is performed for each of the radial points. The test section average void fraction is obtained using the inputted volume fraction $C(I)$ for each point:

$$\text{AVE VOID FRAC} = \sum_{I=1}^K X(I)C(I)$$

The calculated local void fractions and volume averaged void fraction are printed out. Inputted quantities such as the reference absorber data, number of radial points, and run identification number also appear as output. A test section data list is also printed which allows insertion of the water flow rate, steam flow rate and system pressure for easy identification of each problem.

The program listing can be found in Figure 6 detailing the mathematical operations and input and output formats.

4.5 System Calibration

In order to check the accuracy of the void measuring system when used on a geometry similar to that of the planned experimental program, a simple experiment was executed on a known void distribution. This was accomplished by making traverses across a three inch pipe which had a Lucite cylinder inserted in it. Since Lucite has an attenuation coefficient similar to

```

08300      1 READ 2,RUN,K,TPAB
08348      PRINT 3
08372      PRINT 5,RUN,K
08408      DIMENSION V(60),W(60),S(60),X(60),L(60),C(60)
08408      DO 40 I=1,60
08420          L(I)=0.
08480          V(I)=0.
08528          X(I)=0.
08576          W(I)=0.
08624          S(I)=0.
08672          C(I)=0.
08720      40 CONTINUE
08756          DO 30 I=1,K,9
08768          READ7,V(I),V(I+1),V(I+2),V(I+3),V(I+4),V(I+5),V(I+6),V(I+7),V(I+8)
09104      30 CONTINUE
09140          DO 50 I=1,K,9
09152          READ8,C(I),C(I+1),C(I+2),C(I+3),C(I+4),C(I+5),C(I+6),C(I+7),C(I+8)
09488      50 CONTINUE
09524          READ 9,WAAB,STAB
09560          PRINT 10
09584          PRINT 11,TPAB
09608          PRINT 12,WAAB
09632          PRINT 13,STAB
09656          PRINT 18
09680          PRINT 19
09704          PRINT 20
09728          DO 31 I=1,K,9
09740          READ7,W(I),W(I+1),W(I+2),W(I+3),W(I+4),W(I+5),W(I+6),W(I+7),W(I+8)
T0076      31 CONTINUE
T0112          DO 32 I=1,K,9
T0124          READ7,S(I),S(I+1),S(I+2),S(I+3),S(I+4),S(I+5),S(I+6),S(I+7),S(I+8)
T0460      32 CONTINUE
T0496          WAB=TPAB/WAAB
T0532          SAB=TPAB/STAB
T0568          D=0
T0604          DO 33 I=1,K
T0616          SCR=SAB*S(I)
T0676          WCR=WAB*W(I)
T0736          T=V(I)/WCR
T0796          R=SCR/WCR
T0832          A=LOG(T)
T0856          B=LOG(R)
T0880          L(I)=1
T0928          X(I)=A/B
T0988          D=D+X(I)*C(I)
T1084      33 CONTINUE
T1120          DO 34 I=1,K,3
T1132          PRINT 25,L(I),X(I),L(I+1),X(I+1),L(I+2),X(I+2)
T1360      34 CONTINUE
T1396          PRINT 36,D
T1420          PAUSE
T1432          IF (SENSE SWITCH 3)26,29
T1452      26 DO 27 I=1,K,8
T1464      27 PUNCH 28,X(I),X(I+1),X(I+2),X(I+3),X(I+4),X(I+5),X(I+6),X(I+7)
T1800      29 PAUSE
T1812          GO TO 1
T1820      2 FORMAT (F7.0,I3,F7.0)
T1852      3 FORMAT (30X27HVOID DATA REDUCTION PROGRAM /)
T2002      5 FORMAT (11X11HRUN NUMBER=,F8.0,16X21HNUMBER RADIAL POINTS=,I3,/)
T2180      7 FORMAT (F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0)
T2242      8 FORMAT (F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5)
T2304      9 FORMAT (F7.0,F7.0)
T2332     10 FORMAT (14X17HTEST SECTION DATA,14X17HREF ABSORBER DATA,)
T2502     11 FORMAT (16X16HWATER FLOW RATE=,15X10HTWO PHASE=,F8.0,3HCMP)
T2680     12 FORMAT (16X16HSTEAM FLOW RATE=,15X5HWATER,4X1H=,F8.0,3HCMP)
T2872     13 FORMAT (16X16HSYSTEM PRESSURE=,15X5HSTEAM,4X1H=,F8.0,3HCMP/)
T3068     18 FORMAT (26X28HRADIAL VOID FRACTION PROFILE /)
T3212     19 FORMAT (16X3HRAD,3X4HVOID,9X3HRAD,3X4HVOID,9X3HRAD,3X4HVOID)
T3442     20 FORMAT (16X3HLOC,3X4HFRAC,9X3HLOC,3X4HFRAC,9X3HLOC,3X4HFRAC)
T3672     25 FORMAT (15X,I3,3X,F7.5,6X,I3,3X,F7.5,6X,I3,3X,F7.5)
T3834     28 FORMAT (F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5,F7.5)
T3892     36 FORMAT (/14X18HVOL AVE VOID FRAC=,F7.5,/)
T4008      END

```

Figure 6 - Program Listing of Void Data Reduction

water it was used to simulate an annular flow of water on the wall of the pipe.

The Lucite cylinder had an OD of 2.900 inches and was bored out over half of its length to 2.048 inches ID giving an average void fraction ($\bar{R}_g$) of 49.8 per cent. The portion of the cylinder which was solid served to simulate the all-water case.

Three gamma traverses were made (empty, all-Lucite, Lucite-void mixture). The resulting count rates were reduced to void fractions using the data reduction program. The comparison of the measured void distribution to the known actual distribution served as a calibration check on the whole system. This comparison is shown in Figure 7. The agreement between measured and actual is very good but a slight amount of improvement may be gained when another positioning aid which has been designed is ready for use. The average void fraction computed for the calibration run was 48.9 per cent compared to the actual 49.8 per cent which also gives an indication of good system accuracy.

Figure 7 - Calibration of Void Detection Equipment

5.0 PLANS FOR FUTURE WORK

5.1 Experiment

Work will continue on fabrication and installation of the test section and steam generator for the experimental portion of the program. Additional calibration tests will be run with the Lucite section to further refine the technique of locating the gamma beam position relative to the pipe wall.

5.2 Analysis

A review of the literature for two-phase flow models will be conducted so that when the experimental data becomes available, comparisons of measured and predicted vapor volume fractions can be made. Further use will probably be made of the IBM-1620 to calculate void fraction profiles from analytical models which will in turn be compared to the experimental profiles.

6.0 CONCLUSIONS

Since the primary test equipment is not yet fabricated, there was no two-phase testing done this quarter. However, a preliminary calibration test of the system indicated that reliable void fraction profiles can be obtained with the gamma attenuation system.

A data reduction program which was written for the IBM-1620 should prove a fast and efficient tool for converting count rate data to vapor volume fractions.

6.1 Proposal

Figure 8 shows progress to date as compared to proposed schedule.

Figure 8 - Schedule of Progress Chart