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LOCATION OF TEST BUNDLE INSTRUMENTATION
AND ANTICIPATED EXPERIMENTAL VALUES
FOR THE CFTL AG-1 BUNDLE

J. P. Sanders

Paper No. 3

Session 5

OECD-NEA Coordinating Group on
Gas-Cooled Fast Reactor Development

6th GCFR Heat Transfer Specialists Meeting

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION
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ABSTRACT

The placement of instrumentation within the CFTL AG-1 test section to meet the following objective is described. The objectives are threefold: (1) to provide values for the evaluation of the performance of the test section, (2) to compare the experimental data with values determined by pretest calculations to indicate the approach to conditions that can lead to a bundle failure, and (3) to acquire data during testing that will form a data base for subsequent use in the verification of computational procedures used in the licensing of the Gas Cooled Fast Reactor. Anticipated values for the various instruments have been determined using the computational procedure, SAGAPO, modified for the AG-1 geometry. These results are used as the basis for the specification of differential pressure cells and the range of readings anticipated from the thermocouples. Part of the results for the full flow, full power case are presented.

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LOCATION OF TEST BUNDLE INSTRUMENTATION AND ANTICIPATED EXPERIMENTAL VALUES FOR THE CFTL AG-1 BUNDLE

J. P. Sanders

INTRODUCTION

The Core Flow Test Loop (CFTL) is being constructed at the Oak Ridge National Laboratory (ORNL) by the U.S. Department of Energy (DOE) to confirm the thermal-flow and structural performance of core elements designed by General Atomic (GA) for the Gas Cooled Fast Reactor (GCFR). The test bundles will be prototypical subsections of the core elements with electrically heated fuel rod simulators (FRS) used to represent the thermal performance of the fuel rods. Helium will be circulated upward through the test section at system pressures up to 10.5 MPa and with inlet temperatures up to 350°C. The temperature, flow, and pressure of the helium will be regulated to represent a range of GCFR conditions from normal operation to severe accident transients.

The AG-1 bundle is a 37-rod simulation of a symmetrical segment of a fuel element for the GCFR. The 37 rods are arranged in a hexagonal array as shown in Fig. 1. The array contains three support rods, which are positioned as shown in Fig. 1, to maintain the spacing of the grid spacers. The actual length of the fuel rods is represented by the FRS with an inlet (lower) blanket length of 940 mm, a heated length of 1200 mm, and a total length of 2860 mm. The surface of the FRS is roughened in a manner that is prototypical of the fuel rods over the simulated core length. A drawing of a single FRS is shown in Fig. 2.

To simulate the structural response of the fuel rods, the electrical connections for the fuel rod simulators have been made at only one end. This allows the FRS to expand or deflect under thermal gradients in much the same manner as the fuel rod. These electrical leads enter from the lower tube sheet of the AG-1 bundle and extend upward through the inlet axial blanket. Due to resistance in these electrical connectors, there is heat generated in this inlet axial blanket, which is about 4% of the total heat generated in the core segment and is constant with axial position. The heat generated in the core is simulated with a wound Nichrome-V or Kanthal tape of varying width so that a chopped cosine axial power distribution can be generated. There is no heat generated in the simulated outlet (upper) axial blanket.

During the preliminary design and construction phase for the loop and the test bundles, it became obvious that each test bundle would represent a significant financial investment (more than one million dollars). In addition, the on-line data acquisition system (DAS) has the ability to record, reduce, and display experimental data during the test operation. An effort was then initiated to perform pretest calculations to determine the values anticipated from the instrumentation during the various tests. On-line comparison of these calculated values with the experimental measurements will indicate the approach to failure conditions so that unanticipated bundle failures can be avoided.

It was also obvious that the same computational procedures that were used for design of the GCFR core assemblies should be used for pretest calculation of anticipated experimental values. These same procedures can subsequently be used to establish the basis for calculations used in the application for a license to construct and operate the GCFR plant. The process of performing pretest calculations, on-line comparisons, and post-test evaluations using this computational procedure constitutes a basis for the validation of the procedure for licensing purposes.

The objectives of the placement of instrumentation in the test bundle are threefold. First, the instrumentation shall determine the operating conditions and permit the evaluation of the performance of the test bundle. Second, the instrumentation shall indicate conditions that might lead to bundle failure. Third, the instrumentation shall supply a body of data that can be used to verify the capability of the computational procedure to determine operational conditions over the range of anticipated flows, powers, and pressures for the geometries that will be encountered in the GCFR.

This report describes the placement of instrumentation within the AG-1 bundles to fulfill these objectives. It is recognized that there are many possible arrangements for the sensors that might meet these objectives. This particular distribution, however, reflects consideration given to the many possible deviations that may be encountered in the anticipated operations, and an effort has been made to provide an indicator of the more probable events. Where possible, instrumentation has been located to give redundant information that can be used to decrease the uncertainty associated with the various measurements of bundle operating conditions. This report also presents anticipated values at the sensor locations for operating conditions at 100% design flow and 100% design power. These values plus the results calculated for four additional combinations of flows and

powers were used as the basis for the selection of transducers in the specification of the instrumentation for the AG-1 bundle.

DESCRIPTION OF THE AG-1 BUNDLE

The cross section of the 37-rod bundle is shown in Fig. 1. The FRS are each 8 mm in outside diameter and the center-to-center pitch is 12 mm. The three support rods are 7.6 mm O.D. with a wall that is 1.35 mm thick. These support rods have annular spacer tubes that have an outside diameter of 9.6 mm and an inside diameter of 7.7 mm. The spacer tubes have a smooth surface over those axial segments of the bundle in which the FRS are smooth, and the surface of the spacer tubes are roughened over those segments where the FRS surface is roughened. The bundle is enclosed in a hexagonal duct that has a wall thickness of 4.0 mm. The minimum gap width between the edge rods and the hexagonal duct wall is 80% of the gap width between the interior FRS.

Figure 3 identifies the distance from the outer surface of the tube sheet to the important axial features of the bundle such as the start of roughening and heating, the end of roughening and heating (in a downstream or upward direction), and the location of the leading edge of the spacer grids. The axial dimension of the spacer grids is 15.0 mm. Letters on the reference scale of Fig. 3 signify axial locations of all thermocouples in the AG-1 bundle.

In the GCFR assembly, the inlet coolant flow is parallel to the axial dimension of the bundle. In the CFTL bundle, it is not possible to represent this inlet flow path in a typical manner. Because of the requirement to attach the electrical connectors and the instrumentation leads at the tube sheet, which is also the pressure boundary, the flow must enter the bundle in a direction that is perpendicular to the axis at this upstream (lower) extremity of the bundle. The flow enters the test vessel, which encloses the test bundle, through a single pipe that is perpendicular to the bundle axis. The flow is then passed through a series of concentric baffles, as shown in Fig. 22 (a foldout drawing at the back of this report), so that a symmetric profile is developed relative to the axis of the bundle. The hexagonal duct forms the last wall of this baffle, so that the coolant essentially "overflows" the baffle through a circumferential gap at the inner (upper) surface of the tube sheet. This radial velocity is then converted into a prototypical axial velocity profile as the flow develops within the bundle.

A calculation to determine the axial distance required for the development of this profile at full flow conditions was performed using the FLAC computational method provided by GA. The results of this computation, which were presented in a recent ORNL GCFR annual report¹, indicate that the flow becomes essentially fully developed at a point 180 mm from the outer (lower) surface of the tube sheet.

Since the FRS are supported at the tube sheet in much the same manner as the fuel rods in the GCFR assembly, the structural simulation of the assembly begins at this point. Restraints (load pads) have been placed on the outer surface of the hexagonal duct at two axial locations. One location is at the end of the heated segment, which represents the GCFR core, and the other is at the outlet (upper) end of the hexagonal duct. In the GCFR fuel element, the lower end of the hexagonal duct is supported by the inlet nozzle at a point that does not correspond with the support for the fuel rods. In the AG-1 bundle, the hexagonal duct is rigidly supported at the tube sheet. There is some loss in prototypicality due to the requirement that the FRS are fixed at the same point as the hexagonal duct; however, compensating effects in the type of support maintain an adequate representation of the structural performance for the remainder of the bundle.

BASIS FOR SPECIFICATION OF THERMOCOUPLE POSITION

As shown in Fig. 2, there are six internal thermocouples located at 60° intervals around the inner circumference of the cladding of the FRS. These thermocouples may be located at any axial position along the length of the FRS. Two thermocouples in the same FRS may be located at the same axial position; however, all six may be at different axial locations. This freedom allows the maximum flexibility in positioning the thermocouples, and it does not impart any additional problems in the fabrication of the FRS.

In the assembly of the bundle, it will be possible to rotate and index the FRS in the assembly so that the six thermocouples will be at any desired angular position. Discussions with persons experienced in the assembly of similar bundles indicate that the required angular positioning will introduce no unusual problems during assembly.

There is a practical limit, however, to the number of arrangements that are selected for the thermocouples in the rod. For each arrangement or type of FRS, there should be at least one spare FRS that, at the time of bundle assembly,

can be used as a replacement in the event that a rod is found to fail during the process. If it is further stipulated that a substitution of types can be made at the time of assembly, which would be required if there were two failed FRS of one type, then assembly can begin with the number of spares equal to the number of types.

Internal FRS Thermocouple Locations

To limit the expense associated with the manufacture of spare rods, the number of FRS types for this first bundle has been limited to four. The circumferential and axial locations of each of the thermocouples for each of the types, designated A, B, C, and D, are shown in Fig. 4. Note that four pairs of thermocouples in three of the types (A, C, and D) are located in diametrically opposed locations at the same axial position. These pairs will be used to measure diametrical gradients that are anticipated or that may be generated by FRS deformation during operation.

The letters (B, D, F, J, L, N, S, and U) in Fig. 4, designating the axial locations, correspond to those in Fig. 3. It is possible to see the significance of the chosen axial positions. Note that the dimensions given are the assembled length at ambient temperature. Under operating conditions, these relative positions will change slightly depending upon the temperature of the components. At relatively high powers or low flows at low power, the FRS will expand from the tube sheet more than the support rods, which positions the grid spacers.

The first two thermocouple positions at 900 mm (B) and 1015 mm (D) bracket the first grid spacer, the beginning of roughening and the beginning of heating. Even though the heat generation in the inlet blanket is low, the measurement at 900 mm (B) should indicate any significant flow maldistribution that might occur among the subchannels in this section. The measurement at this position should also indicate the effect of axial conduction from the "heated length," which begins at 940 mm. The measurement at 1015 mm (D) will indicate the effect of the initiation of roughening and heating on the flow distribution. It would be helpful in the evaluation of "separate effects" if these two features were not so close to each other and to the grid spacer. A partial evaluation of these separate effects may be obtained from experiments with one or more unheated rods.

The thermocouple at 1500 mm (F) is at the midspan between two grid spacers and is near the point of maximum heating. It is in this section of the bundle that the maximum gradients across the bundle (and therefore across the FRS) are anticipated - particularly during testing with

a skewed power. Since the FRS have the least support at the midspan, it is the point at which the maximum displacement of the rods is expected. These displacements will decrease the flow area on the hotter side of the rod, thus decreasing the flow, which in turn will make that side of the rod even hotter. This self-aggravating sequence can lead most easily to excessive temperature and to FRS and bundle failure. Two pairs of diametrically opposed thermocouples have been placed at this axial position to give the maximum probability of detecting the approach to this failure mechanism.

The thermocouple locations at 1590 mm (J) and 1620 mm (L) occur on the upstream and downstream sides of a grid spacer that is positioned in a region of high thermal flux and high coolant temperature. These two thermocouples, which are at adjacent positions on the circumference of the FRS for types B and C, will indicate the effect of the spacer grid on heat transfer in the roughened section. Calculations indicate that significant circumferential gradients will exist at this position. These thermocouples will confirm the existence of those gradients.

The location of the thermocouple at 1700 mm (N) determines the thermal gradient at the midspan between two spacer grids. Again diametrically opposed pairs have been placed in the type B and D rods.

The location at 2050 mm (S) is just downstream from a spacer grid at a point of significant thermal flux and near the point of highest gas temperatures. One pair of diametrically opposed thermocouples has been placed at this location in the type D rod.

The thermocouples at 2160 mm (U) are downstream of the end of the heated section (at 2140 mm) and the end of the roughened section. The thermocouple reading at this location should indicate the bulk temperature of the gas. For steady-state operation, the only difference between the gas temperature and this reading will be due to axial conduction of heat in the FRS.

Gas-Stream Thermocouple Locations

Gas-stream thermocouples attached to the spacer grids, shown at locations H, V, and X in Fig. 3, will be used to evaluate the significance of the internal FRS thermocouple readings. For example, a high reading on the internal thermocouple could result from either a restriction of flow (due to deformation of an FRS) in the adjacent subchannel or an increased thermal resistance between the internal thermocouple and the FRS cladding. The gas thermocouple

readings can be used to evaluate the cause of the higher internal thermocouple reading.

Most of the internal FRS thermocouples will be positioned so that they are centered on a physical subchannel in the bundle. A physical subchannel is defined as the symmetric flow area enclosed by three FRS in the center of the bundle or by two FRS and the bundle wall at the edge of the bundle. A layout of the thermocouple positions chosen for the AG-1 bundle is shown in Fig. 5. This arrangement is oriented with respect to the planned gradient for a power skew in the bundle during testing.

Note in Fig. 5 that all positions are defined by indicating the type of FRS (A, B, C, or D) and the rotation of the indexing point, which is the position of the upstream thermocouple in the rod. As a matter of final convenience, the thermocouple positions can be individually defined by giving the rod number and the designation for the azimuth that connects the center of the rod and the thermocouple. The centerline of the inlet pipe to the test section is used as a reference point both for identifying the numbers assigned to the FRS positions and for referencing the thermocouple positions as shown in Figs. 6 and 7.

The gas-stream thermocouples will be installed on the spacer grids through the use of metal clips. As shown in Fig. 8, the thermocouple lead will penetrate the spacer tube and the support rod at the spacer grid. The thermocouple lead will continue through the support rod to the bundle tube sheet. Positions for the gas-stream thermocouples are shown as leads extending from the support rods in Fig. 5.

THERMOCOUPLE LOCATIONS ON HEXAGONAL AND ANNULAR DUCTS

In the CFTL test vessel configuration, there is an annular shroud around the hexagonal duct of the bundle as shown in Fig. 22. This annular shroud provides a flow channel, adjacent to the test vessel wall, for the flow of an attemperation stream. The annular shroud also forms the structural members that interact with the support plates on the hexagonal duct. Essentially stagnant helium at the system pressure fills the space between the annular shroud and the hexagonal duct.

The helium flow coming to the test vessel is divided, through the use of flow control valves, into the bundle flow and the attemperation flow. These two streams are recombined at the bundle exit. This arrangement allows significant transients to be produced within the test

section with a minimum impact on the piping of the loop. The attemperation flow provides cooling for the test vessel wall, which is the pressure boundary for the containment of the high-pressure helium. This attemperation flow also mixes with flow from the test bundle to reduce the thermal stress in the outlet piping during the test sequences.

The maximum temperatures will be encountered in the test section when the flow through that section is low. Because of the design feature just described, the attemperation flow during this part of the test will be high. This gives the potential, especially for testing with low test section flows, for significant heat loss from the hexagonal duct to the annular shroud.

This situation is particularly atypical of the GCFR operation, which is being modeled in the CFTL. In the GCFR, low flows with significant heating are encountered in the upset conditions following a reactor trip. Each fuel element is surrounded by other fuel elements, so there is no potential for heat loss from the hexagonal duct. In addition, there is gamma heating in the hexagonal duct, so that the hex duct actually becomes a significant heat source in comparison with the afterheat generated in the fuel rods.

For the AG-1 bundle, no effort has been made to further insulate the hexagonal duct from heat losses to the annular shroud or to represent the heat generated in the hexagonal duct during "shut-down" cooling. The presence of the stagnant helium provides a sufficient resistance to the loss of heat during full-flow, full-power operation so that the experimental results will be meaningful. It is important, however, to include an estimate of the heat loss from the hexagonal duct in all computations for the bundle. Thermocouples have been placed on the outer surface of the hexagonal duct and the inner surface of the annular shroud at three axial locations. At each of these three axial locations, thermocouples have been placed at either 4 or 6 circumferential positions on the hexagonal duct and at 2 circumferential positions on the annular shroud as indicated in Fig. 9, again the letters correspond to the axial locations designated in Fig. 3. These positions have been selected so that the thermocouples on the hexagonal duct can "see" the thermocouples on the annular shroud. This will permit a calculation of the heat transported between the two surfaces by radiation as well as conduction and natural convection transport through the helium.

PRESSURE TAP LOCATIONS IN THE AG-1 BUNDLE

In the selection of locations for pressure taps, it is desirable to isolate the contributions to the overall pressure loss associated with a number of individual effects in the bundle. These effects include the entrance and form loss associated with the spacer grids, the entrance effect at the start of roughening and the start of heating, the acceleration losses associated with the decrease in gas density due to heating, and the change in frictional loss associated with an increase in gas temperature.

Unfortunately, in the AG-1 bundle design, the start of heating and the start of roughening are separated by only 10 mm in the axial direction. Therefore, it is not possible to isolate these entrance effects. Entrance and form loss effects for the spacer grids will differ in the smooth and in the rough axial segments, so measurements for representative spacer grids in both segments are desired.

The axial locations selected for the pressure taps are shown in Fig. 10. In this drawing, another set of letters correspond to the axial positions of the taps. The pressure taps are to be located at the center of the flats of the hexagonal duct surrounding the bundle. For those taps that are paired to measure pressure differentials, both taps are located on similar (with respect to the arrangement of the support rods) faces. These pairings of locations are shown in Fig. 11. In this drawing, the two letters associated with each location indicate the azimuthal direction from the center of the bundle (Fig. 6) followed by the axial location (Fig. 10). The pressure gradient shown is based on the SAGAPO² calculation for 100% design flow.

CALCULATION OF ANTICIPATED VALUES

Calculations of temperature and pressure within the test section were made for five sets of operating conditions. These calculations were made with two objectives in mind. First, the calculated values should indicate the range of anticipated readings from the instruments. This information was useful in specifying the type and connections for differential pressure cells among the various pressure taps, and it was helpful in evaluating the error that could be tolerated in the thermocouple readings. Second, the values were used to generate sets of pseudo-data that were written on a magnetic tape for use in

the development of code verification procedures by GA.

This calculation was performed using a modification of the SAGAPO² computational procedure which had been made operational at ORNL and which had been modified for the CFTL AG-1 bundle. (Representation of the larger diameter hanger rods was included in the calculations.) Since the SAGAPO computational procedure is written only for steady-state calculations, only that type of calculation could be performed. A range of conditions was represented by selecting five combinations of flow and power from 100% of design conditions to very low flows and powers.

This version of SAGAPO does not have computational procedures to represent either circumferential or axial conduction in the FRS, and radiation transport of heat across the bundle is not represented. At full flow and power, however, these phenomena make relatively small contributions. The results for this case for 100% flow and 100% power are shown in Fig. 11 for the bundle pressure drop, and in Figs. 12, 13, 14, 15, 16, 17, and 18 for some of the temperature distributions.

In Fig. 11, the pressure in the bundle is plotted as a function of axial position. The location of Differential Pressure (DP) cells across the taps is indicated. A consideration of the accuracy of the DP cell and the range of readings from full flow to very low flows was used to specify intermediate connections for DP cells. At low flows, the readings from some of the DP cells will not be meaningful.

Many of the internal thermocouples in the FRS were located with the purpose of detecting abnormal cooling conditions due to rod deformation. If the rods move closer together, then coolant flow will be reduced on that surface and the temperature will increase. Just the reverse of that condition will exist on the diametrically opposite side of the rod. Diametrically opposed thermocouple pairs have been placed in some of the rods at the position of minimum support, which is at the midplane between two spacer grids.

As another cause and effect relationship, diametrical thermal gradients will result in differential expansion on opposite sides of the rod and these, in turn, will cause the rod to bow or deform. If deformation of the rod causes it to move closer to an adjacent heated rod, then the process will be self-aggravating. Fortunately, according to the axial profiles shown in Figs. 14 and 15, the maximum diametrical thermal gradients occur near the spacer grids, which are at the point of maximum structural support. Thermal gradients in the rod at this point, however, can

result in forces that will act on the rod and cause bowing at a point away from the spacer grid.

STRUCTURAL INSTRUMENTATION FOR THE AG-1 BUNDLE

In an attempt to further evaluate the structural response of the bundle to the varying test conditions, X-ray markers have been placed in some of the FRS as shown in Fig. 2. The markers are segments of platinum wire that is the same diameter as the outer sheath of the thermocouple (0.51 mm). To facilitate the manufacture of the FRS, the thermocouple inserts are continuous over the length of the FRS. From the inlet end of the FRS to the thermocouple, a groove in the boron nitride preform insulator positions the thermocouple and thermocouple lead against the FRS sheath. Downstream from the thermocouple position, this groove is filled first with the platinum marker (if one is used at that position) and then by additional thermocouple lead wire. During the manufacturing process, the continuation of the thermocouple lead wire is used to position the thermocouple both axially and circumferentially in the FRS.

The platinum markers have been placed at those positions where the maximum amount of structural deformation would be anticipated, if it occurs. These positions are at the midplane between the spacer grids and at the points where either the thermal flux or the surface temperature is at a maximum.

It is necessary to select the position of the marker so that the position can easily be determined by making X-ray images of the bundle from two directions. Consideration was given to the choice of locations so that clear images can be obtained without interference from other markers or structural components. Relative distances from both the X-ray source and the photographic plate must be evaluated, since these distances determine the sharpness of the images.

Two types of FRS platinum markers are used. The 0.51-mm diameter marker, which is placed in the downstream lead of the thermocouple, is 12.5 mm in length. The second type of marker has a 4.76-mm diameter and a length of 12.5 mm; it will be placed in the center of the FRS at axial positions above (downstream) the termination of the central heater tape and conductor. This larger marker will allow superior imaging during future stages of testing when real-time information is gathered during transient tests. A third type of marker is used on the duct; it will consist of two segments that are 2.0 mm or larger in diameter and 12.5 mm in length. These segments in the form of an "X" will be

placed on the detector side of the duct at the mean axial location for each set of FRS markers.

Figure 19 indicates the mean axial locations for the platinum markers; the locations are designated as A, B, C, D, E, and F, which are at 1535, 1665, 1935, 2065, 2535, and 2665 mm. For a given location, there are two FRS marker sublevels, L1 and L2, that are 12.5 mm above and 12.5 mm below the mean axial location, respectively. This separation is necessary to prevent overlap and superposition of markers in the detector imaging plane. The axial centers of the FRS markers are positioned at these sublevels. The duct markers are located between these sublevels at the mean axial location.

The FRS markers at locations A, B, C, and D (Fig. 19) are located in axial alignment with internal thermocouples in the FRS. All have been placed above (downstream) a thermocouple that is located at 1500 mm (location F in Fig. 3). Two different patterns are specified for these markers. One pattern is repeated at FRS marker locations A and C as shown in Fig. 20a, and the other pattern is repeated at FRS marker locations B and D as shown in Fig. 20b.

Two different patterns are required for the FRS markers at locations D and F (Fig. 19). These markers are located at the center of the FRS and are separated into the two sublevels indicated previously. The patterns at D and F are shown in Figs. 21a and 21b.

Duct markers are placed at all axial locations. The relative positions of the duct markers, the X-ray source, and the corresponding detector are shown in the figures.

For the "Stage I" loop design, the plans call for the use of a portable X-ray source together with photographic plates as the detector. The time delay in developing and evaluating the photographic plates will exclude the use of the X-ray markers to determine the positions during even a slow transient or the use of the X-ray images as a protection of the bundle from unanticipated failures. This type of data must be inferred from the thermocouple readings obtained within the bundle.

A program, designated as FASAP and written at ORNL, will be used to relate thermal gradients and anticipated structural response.

Additional instrumentation is provided within the test bundle to evaluate structural response. These include both accelerometers and acoustic microphones at the bundle inlet

and outlet. At present there exists no correlation between measurements from these instruments and bundle performance. These instruments will be important in determining either that there is no response or that there is a distinct change in the level of response under operating conditions encountered in the sequence of testing.

SUMMARY

The AG-1 bundle for the Core Flow Test Loop contains 37 rods in a hexagonal array with a center-to-center spacing of 12 mm. Three of the rods are spacer tubes having outer sleeves that are 7.6 mm in outside diameter. These spacer tubes axially position spacer grids, which maintain the radial positions of the remaining 34 electrically heated fuel rod simulators. These FRS are 8.0 mm in outside diameter. The FRS are attached to the bundle lower tube sheet, which is the pressure boundary for the test vessel. All electrical connections for the FRS heaters and internal thermocouples exit through the end of the FRS that penetrates the tube sheet. Additional thermocouples have been placed in the gas stream within the test section. A hexagonal duct surrounds the bundle, and pressure taps and thermocouples have been specified for locations along its outer surface. Finally, an annular shroud surrounds the hexagonal duct. This shroud separates the hexagonal duct from an attemperation flow of helium at the inlet bundle temperature, and it also provides structural restraints at the free end of the bundle.

The placement of thermocouples in the FRS, in the helium gas stream, on the hexagonal duct, and on the annular shroud have been specified so that the experimental data required for bundle protection and code verification can be obtained for the bundle operating conditions. Locations for pressure taps have been specified for the hexagonal duct wall, and the placement of differential pressure cells and the anticipated readings for these transducers has been given. Locations for X-ray markers within the FRS have been specified in a manner that will allow evaluation of the bundle structural response using radiographs made from several directions.

The purpose for this instrumentation is to allow on-line data reduction using the data acquisition system (DAS), which can be compared with pretest calculations, to prevent operation at conditions that can lead to FRS or bundle failure before it is planned in the testing sequence. The information recorded during the test sequence will verify the operational characteristics of the bundle and

permit extrapolation of these operating characteristics to the full sized GCFR bundle. A data base will be created that can be used to verify the computational procedures, which will be used to qualify the design for licensing purposes.

Preliminary calculations for steady-state operation have been made using a version of the SAGAPO code that has been modified to represent the larger diameter support rods. These calculations, made at five different operating levels, have been used as the basis for the specification of anticipated readings from the instrumentation during testing.

REFERENCES

1. Uri Gat, P. R. Kasten, Gas-Cooled Reactor Programs, Gas-Cooled Fast Reactor Program Annual Progress Report for Period ending December 31, 1978, ORNL-5560, Oak Ridge National Laboratory (August 1979).
2. A. Martelli, SAGAPO - A Computer Code for the Thermo-fluiddynamic Analysis of Gas-Cooled Fuel Element Bundles, KFK-2483, Kernforschungszentrum, Karlsruhe, FRG (August 1977).

CFTL AG-1 BUNDLE (Actual Size)

Fig. 1. Cross section of CFTL AG-1 bundle.

Fig. 2. Details of CFTL fuel rod simulator.

Fig. 3. Axial location of CFTL AG-1 bundle thermocouples.

Fig. 4. Arrangement of thermocouples in FRS.

Fig. 5. Arrangement of types of FRS in the AG-1 bundle.

Fig. 6. Thermocouple designation and definition of angular position of all bundle instrumentation.

TEST BUNDLE CROSS SECTION

(RODS 11, 15, AND 19 ARE SUPPORT RODS, ALL OTHERS ARE FRS.)

NOTE: A LINE FROM CENTER OF ANY FRS OR SUPPORT ROD THROUGH A THERMOCOUPLE IN THAT FRS OR SUPPORT ROD WOULD BE PARALLEL TO AND IN THE SAME DIRECTION AS A LINE FROM CENTER OF THE THERMAL SHROUD (SEE FIGURE 6) TO THE ANGULAR POSITION LETTER

Fig. 7. Diagram showing significance of "ANGULAR POSITION" in bundle instrumentation.

Fig. 8. Sketch of installation of gas-stream thermocouple.
(Exploded isometric drawing. Direction of flow is downward.)

Fig. 9. Thermocouple positions on outer surface of hexagonal duct and inner surface of annular shroud.

Fig. 10. Axial location of pressure taps.

Fig. 11. Location of pressure taps, connection of DP cells, and axial pressure gradient for full flow in the AG-1 bundle.

Fig. 12. Surface and gas temperatures calculated for a symmetrical segment of the AG-1 bundle for full flow and full power.

Fig. 13. Temperature difference across a corner rod as a function of axial position (rectangles at lower edge of graph indicate spacer positions).

Fig. 14. Temperature difference across an edge rod as a function of axial position (rectangles at lower edge of graph indicate spacer locations).

Fig. 15. Temperature difference between the surface of an edge rod and the bulk gas in the adjacent interior channel (rectangles indicate spacers).

Fig. 16. Temperature difference between the surface of a corner rod and the bulk gas in the adjacent interior channel (rectangles indicate spacers).

Fig. 17. Temperature difference between the surface of an edge rod and the bulk gas in the adjacent wall channel (rectangles indicate spacers).

Fig. 18. Temperature difference between the surface of a corner rod and the bulk gas in the corner channel (rectangles indicate spacer positions).

Fig. 19. Axial location of X-ray markers in the AG-1 bundle.

Fig. 20a. Patterns of X-ray markers in the AG-1 bundle in the heated section of the FRS at axial locations A and C.

Fig. 20b. Patterns of X-ray markers in the AG-1 bundle in the heated section of the FRS at axial locations B and D.

Fig. 21a. Pattern of X-ray markers in the AG-1 bundle in the upper axial blanket section of the FRS at location E.

Fig. 21b. Pattern of X-ray markers in the AG-1 bundle in the unheated upper axial blanket section of the FRS at location F.

Fig. 22. Layout drawing of the CFTL pressure vessel with the AG-1 bundle in place.