CORE RESTRAINT DEVELOPMENT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING NOVEMBER 30, 1976

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Westinghouse Advanced Reactors Division

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CORE RESTRAINT DEVELOPMENT
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November 30, 1976

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1.0 INTRODUCTION AND SUMMARY

1.1 GENERAL

This quarterly progress report covers work performed between September 1, 1976 and November 30, 1976.

1.2 SUMMARY OF OBJECTIVES

The liquid metal fast breeder reactor (LMFBR) requires a core restraint system to provide both axial and radial support for the reactor assemblies. The primary requirements of the core restraint system are: (1) fuel, control, blanket, and removable shield assemblies must be located in predictable and reproducible positions; (2) refueling should be accomplished without damage to the assemblies; and (3) operating loads must not be excessive. Variables affecting the core restraint system are primarily the radiation-induced materials effects of swelling, creep, and load pad friction characteristics. These cause bowing deformations of the core assemblies during life. The objective of this development program is to evaluate potential restraint concepts both analytically and empirically, and develop, verify, and qualify analytical tools to be used to characterize core restraint systems. A test facility will be prepared with the capability of modeling axial and radial core support and restraint systems of various LMFBR designs. Simulated core assemblies will be designed and fabricated. Attendant analyses will indicate important structural parameters to be considered in fabrication and subsequent testing. Development of three-dimensional analytical models will be continued for detailed performance studies of particular core restraint systems.

1.3 SUMMARY OF PRIOR WORK

Near-term activities of the national program are directed toward the specific needs of the Clinch River Breeder Reactor Plant (CRBRP) core restraint design and development effort. Beginning in Fiscal Year 1972, considerable effort has been directed toward these activities. A comparative performance study was issued in 1972. This effort was based on concepts with which design and/or analysis was available. Following this study, the core restraint concept was selected for the CRBRP. Construction of the full-scale three-dimensional core restraint facility was initiated in 1972. At that time, compaction tests on the 199-assembly mockup of the FTR core were nearing completion at HEDL. Planar Core Mockup (PCM) tests were initiated under the direction of GE. Both of these efforts marked the beginning of an established data base for detailed analysis of LMFBR core restraint systems. PCM tests initiated the evaluation of specific bridging properties under planar loading conditions. A significant product of the PCM tests and subsequent development work at GE was the technology necessary to accurately measure interfacial loads between test core assembly load pads. In early Fiscal Year 1974, the National Core Restraint Program Plan was issued by Westinghouse. This document identified key elements of the national plan necessary to develop a satisfactory core restraint system for the LMFBR program. This program plan, issued in preliminary form one year earlier, had been updated to reflect the requirements of the CRBRP project. One of the main objectives of the national program was the development of analytical tools for core restraint structural analysis. In 1973, ANL and

Westinghouse reviewed existing structural analysis codes in an effort to select one to be used to develop a special core restraint code. As prescribed by the program plan, both three-dimensional inelastic (NUBOW-3D) and semi-empirical (PARABOW) computer code development efforts were initiated in Fiscal Year 1973.

In Fiscal Year 1974, a specification for a Core Restraint Thermal Hydraulic Transient Code (CORTAC) was prepared by GE. ANL has developed a two-dimensional version of this code. The construction of the three-dimensional test facility was completed. A technique to accurately measure duct assembly position and elastic bow under test was developed by Westinghouse. This capability, combined with the "adjustable above core load pad" feature, used on three-dimensional simulated fuel assemblies, resulted in a highly flexible test bed for detailed core restraint development testing. Instrumented assemblies provided by GE to measure interfacial loads are in use to provide discrete load data for bridging studies.

Initial 121-assembly tests (Phase I-V) at ARD were completed. Data were transmitted to LMFBF contractors on a regular basis for use in specifying CRBRP design criteria and calibration of structural codes under development. PARABOW, NUBOW 3-D (inelastic) and CORTAC development and calibration effort at ANL is complete. PARABOW was run at Westinghouse. The modeling techniques used by ANL in PARABOW have been incorporated in codes used by ARD. Withdrawal force tests on single assemblies at HEDL were completed.

Assembly of a fixture for withdrawal and insertion of the Simulated Fuel Assemblies (SFAs) began in June 1975. A study was initiated to investigate the best method to simulate an insertion/withdrawal assembly. The use of a hex duct assembly array was the primary object of this study. These insertion/withdrawal assemblies will be used in full core testing.

In February 1975, ARD provided a recommendation for the National Core Restraint Development Program that included work scopes, projected schedules, and necessary budgets. A working meeting was held September 3, 1975 with ERDA and PMC to review the status of the National Core Restraint Program. It was agreed that friction tests scheduled to be performed at HEDL were to be included in the ARD FY-76 work scope. It was also suggested that the Recommendation for the National Core Restraint Program be revised to reflect changes in funding levels.

Upon completion of Phase V tests, extensive checks of the facility alignment were performed. The SFAs were realigned in preparation for the 121 Assembly straight core tests. A special test to evaluate the facility loading characteristics was developed and completed. Phase VI (straight core) and Phase VII (Load Transmissibility) tests were completed and test data was reduced, transferred to punch cards, and transmitted to program participants.

Another work place meeting was held on November 3-4, 1975 to review the Advanced Core Restraint Concepts and to discuss the details of the revised Recommendation. The revision was based on the inputs provided by ARD, GE/FBRD, and ANL.

The test facility alignment was checked and adjusted after Phase VII testing. The I/W fixture was then installed on the top of the core. The Phase VIII (Withdrawal Test - Procedure ARD 9014) was issued and testing was completed. The data has been reduced and transferred to punch cards.

An evaluation of SFA twist, based on data obtained from SFAs used on test phases VI and VII, was completed. An addendum to the Phase VI test procedure, incorporating a tool developed to measure inter-assembly gaps, was implemented and completed.

The design drawings for the full-core jaw actuator system were completed. Purchase orders have been placed for all jaw actuator system components.

All of the Simulated Assemblies for full core testing were designed and approved. Additional Simulated Fuel Assemblies (SFAs) and Simulated Blanket Assemblies (SBAs) needed for full core testing were assembled and prepared for final alignment. Components for the Simulated Removable Radial Shield Assemblies (SRRSAs) were ordered. The spare 121 Assembly SFAs not being used in testing were modified to the full core configuration. All of the eight new Instrumented Load Measurement Assemblies (ILMAs) to be used in full core testing were delivered.

Components for the friction tests were received at ARD, assembled, and initially checked for proper alignment with the I/W fixture. A test procedure for testing was prepared.

A National Core Restraint Development Program meeting was held at ARD on June 8-9, 1976. Comparisons of 3-dimensional test facility data and analytical predictions were reviewed. Significant differences between the analytical model and test facility were identified. Short term and long term agreements and commitments were established.

As a result of the June meeting, a fixture was designed and procured to verify that the hexagonal load pads are regular (have equal sides). A sample of test hardware will be checked to determine the magnitude and extent of any deviation.

An engineering study was initiated to analytically determine an operating envelope of assembly lock-up due to initial position. This envelope is dependent on normal load, initial rotation magnitude, and frictional effects.

A statistical study examining the effects of twist on the 121-Assembly compaction characteristics at the boundary of "zero" load was completed and issued. Documentation of the computer method used in this analysis is in progress.

A test to examine the effects of assembly orientation of the 121-Assembly core compaction characteristics was developed. The test procedure was written, approved and issued. Procurement and fabrication of test hardware was completed.

The survey section of the friction test was initiated. A test to obtain statistical data on stacks of load pads and an engineering study reporting the results was completed.

A preliminary analysis of Phase VI Duct Bow Measurement Assembly (DBMA) data was completed and issued. An engineering study of the Phase VI Instrumented Simulated Fuel Assembly (ISFA) data is being prepared.

Development of the TRITON Code at ARD is continuing. The basic analytical model capabilities of the code will be extended to include effects of gamma heating and a bypass flow channel for control assembly analysis.

1.4 CURRENT PROGRESS

The test procedure for the Orientation Test (Operation Instruction ARD 9009 - Addendum B) was developed and issued. The test was initiated and completed in this reporting period. Data analysis is in progress. An engineering study reporting the results of the test will be issued.

During the June 8 and 9 meeting a task force was identified to revise the National Core Restraint Development Program Plan. Members of the task force met on September 20 and a draft of the revised program plan was issued.

The survey portion of the friction test of ARD test hardware was completed in this reporting period. An engineering study reporting the results is being prepared. Based on the results of this test, an alternate low friction material was selected for the 121 Assembly Low Friction test which will be performed in the next reporting period.

A preliminary study has been initiated to determine the design possibilities of an internal actuation device. This device will be used to simulate the expansion of a group of assemblies thereby loading the core from an internal location instead of externally with the jaw mechanisms.

The Instrumented Load Measurement Assembly (ILMA) instrumentation was put in place and is operational. Initial calibration testing is in progress. All ILMA hardware and instrumentation will be inspected and calibrated prior to the start of full core testing.

Phase X (Facility Characterization for Non-Uniform Loading) testing was completed. A temporary structure for position indicators which was independent of the loading mechanism was designed and fabricated for this test.

The design of an independent transducer supporting structure for full core testing similar to the one used for Phase X testing has been completed. Purchase orders for the structure will be issued in the next reporting period.

All components for the SFAs and SBAs are on site. Approximately 45 percent of the components for the SRRSAs have been received. The remaining components will be delivered in the next reporting period.

2.0 PROJECT ADMINISTRATION

2.1 OBJECTIVES

The objectives of this task are to assure that the project is successfully completed, on schedule, within budget, and to the satisfaction of the Energy Research and Development Administration; to assure compliance with contractual obligations; and to coordinate this project with other ERDA - sponsored and Westinghouse - sponsored LMFBR development projects. *

Overall project direction and day-to-day administrations will be provided under this task. Plans and control will be established and maintained; periodic reviews will be held with ERDA; correspondence and reports will be coordinated; and day-to-day technical and administrative liaison with ERDA will be provided.

2.2 PRIOR WORK

The project schedule was updated monthly to reflect the progress attained during each month. Work related to the present investigation and performed prior to this period has been reported in the following reports:

WARD-3045T2B-1	Core Restraint Development First Quarterly Progress Report for the Period Ending February 29, 1972.
WARD-304572B-3	Core Restraint Development Second Quarterly Progress Report for Period Ending May 31, 1972.
WARD-3045T2B-4	Comparative Performance of Three Candidates LMFBR Core Restraint Systems Considering Uncertainties in Irradiated Materials Effects, October 1972.
WARD-3045T2B-5	Core Restraint Development Quarterly Progress Report for Period Ending August 31, 1972.
WARD-3045T2B-7	Core Restraint Development Quarterly Progress Report for Period Ending November 30, 1972.
WARD-CR-3045-1	Core Restraint Development Quarterly Progress Report for Period Ending May 31, 1973.
WARD-295	National Core Restraint Development Program, July, 1973.
WARD-CR-3045-3	Core Restraint Development Quarterly Progress Report for Period Ending August 31, 1973.
WARD-CR-3045-4	Core Restraint Development Quarterly Progress Report for Period Ending November 30, 1973.
WARD-CR-3045-5	Core Restraint Development Quarterly Progress Report for Period Ending February 28, 1974.

WARD-CR-3045-6	Core Restraint Development Quarterly Progress Report for Period Ending May 31, 1974.
WARD-CR-3045-7	Core Restraint Development Quarterly Progress Report for the Period Ending November 30, 1974.
WARD-CA-75-074	Recommendation for Core Restraint Development Activity Work Scope for the Period Fiscal Year 1975 Through Fiscal Year 1979.
WARD-CR-3045-8	Core Restraint Development Quarterly Progress Report for the Period Ending February 28, 1975.
WARD-CR-3045-9	Core Restraint Development Quarterly Progress Report for Period Ending May 31, 1975.
WARD-CR-3045-10	Core Restraint Development Quarterly Progress Report for Period Ending August 31, 1975.
WARD-CR-3045-11	Core Restraint Development Quarterly Progress Report for Period Ending November 30, 1975.
WARD-CR-3045-12	Core Restraint Development Quarterly Progress Report for Period Ending February 29, 1976.
WARD-CR-3045-13	Core Restraint Development Quarterly Progress Report for Period Ending May 31, 1976.
WARD-CR-3045-14	Core Restraint Development Quarterly Progress Report for Period Ending August 31, 1976.

2.3 CURRENT PROGRESS

The schedule for this task has been updated monthly to reflect work accomplished during the month, and the effect of current progress upon task milestones has been evaluated.

3.0 TECHNICAL PROGRESS

3.1 SUMMARY OF OBJECTIVES

The objective of the National Core Restraint Program is to develop, verify, and qualify the analytical tools necessary for core restraint analysis of large core arrays. Three-dimensional effects of ducts loaded under simulated operating conditions are to be experimentally evaluated. This evaluation will provide the data necessary for development of modeling techniques and specialized core restraint analytical codes. Loading conditions to be evaluated experimentally include studies of both operating and refueling conditions. Special load transmissibility studies will also be carried out to identify effective modes of duct loading under lateral seismic accelerations. Specific tasks necessary to satisfy this objective are as follows:

- Systematically evaluate the core restraint concepts against reactor system requirements.
- Develop the analytical methods required to evaluate the concept and components.
- Perform the necessary tests to aid in the selection and verification of analytical techniques.
- Verify that the selected concept meets the requirements of the LMFBR core restraint system.
- Monitor and transmit requirements to LMFBR technology programs to obtain design data to be used in analysis.

Core restraint system design is dominated by the need to accommodate the effects of fast flux irradiation on core structural materials. Irradiation-induced swelling and creep can produce permanent bowing, transverse swelling, and dilation of the core assembly flow ducts. This problem of predicting the mechanical and structural response of the core to both thermal and mechanical loading is of particular concern to the core restraint system designer. The core restraint system must be selected so as to minimize the adverse effects of swelling and creep on core performance. Specifically, it must be shown that core former and interassembly gaps are sufficient to provide for satisfactory insertion/withdrawal loads and are suitable for reactivity insertion margins without compromising core assembly duct integrity. Due to the complexity of the structural core restraint model and the effects of three-dimensional loading, analyses of systems of this type are complex. Nonuniform gap distribution within the system is such that individual ducts may act either as individual mechanisms or as elements of an elastically coupled system.

3.2 PRIOR WORK

The test facility structural steel, core plates, and lateral loading system drives were assembled and aligned during the second quarter of 1973. The floor surrounding the test area was paved and sealed. Control panel modules were assembled, and first generation instrumentation and controls were installed. Lateral jaw actuator assemblies were installed and aligned. Mechanisms for jaw movement were functionally checked. Core plate friction bushings to simulate inlet nozzle friction characteristics were installed. The method for alignment of the facility was documented and issued.

The design for the simulated fuel assembly to perform core restraint development tests for the Demonstration Plant was established and necessary hardware was procured. A detailed analysis of the load pad to be used on the simulated fuel assembly was performed. Friction testing of coupled materials led to material selection for load pads. Load pads were designed and fabricated. A fixture for alignment of the simulated fuel assemblies was designed and fabricated.

An alternate approach to provide three-dimensional core restraint analysis was developed and incorporated into the program plan. This system utilized a semi-empirical analytical technique for overall system studies and specialized three-dimensional codes for localized studies. An effort to develop this capability was initiated at ANL. Design of a system for measuring simulated fuel assembly bow during compaction tests was completed. Equipment was procured, calibrated, and installed.

All electrical measuring instruments were calibrated, functionally tested, and prepared for characterization testing. The signal conditioning electronics for the instrumented simulated fuel assembly (ISFA) units and the cabling for this system were installed. Installation and checkout of the simulated fuel assembly alignment fixture was completed.

The hardware for simulated fuel assemblies was delivered and assembly was initiated. An alternate optical alignment target to be used in the duct bow measurement assemblies (DBMA) was designed as a cost reduction effort.

Design of a special fixture for insertion/withdrawal tests was completed and materials were ordered.

A revised test plan which expanded testing in critical areas was issued. The test facility was characterized before testing was started to determine facility deflections in order to identify uncertainties in recording actual jaw position. Phases I through V of the test plan were completed. Data were reduced and distributed to participating contractors.

A recommendation for the work scope (Fiscal Year 1975 through Fiscal Year 1979) for the National Core Restraint Development Program, was issued to ERDA/RRD and to all program participants for review and comment. In May 1976 a meeting with ARD, GE/FBRD and HEDL was held to review items required by proposed DADs. Work scopes for ARD and GE were prepared.

Procurement procedures to obtain load pad friction test hardware for testing at HEDL were initiated at ARD. The simulated blanket assembly (SBA) was designed and purchase orders were issued. Design of the simulated removable radial shield assembly (SRRSA) was initiated.

Design of the instrumented load measurement assemblies (ILMA) was completed and approved. The design of the jaw actuator system to be used for full-core testing was completed.

Following completion of Phase V testing, sources of probable causes for facility misalignment were identified and corrected. The facility alignment procedure was revised to include the use of a new alignment tool which improved the initial radial positioning of the jaw assemblies. The SFAs and ISFAs were aligned to a "straight" condition. A special test to evaluate symmetrical loading characteristics was completed and an engineering study reviewing the results was issued. The study conclusions indicate that the initial positioning of the assemblies and friction have significant effects on core load distribution. Another significant parameter is the load pad across-flats tolerance which can introduce load variations of up to 1500 pounds (7.5% of maximum load) from one sector to the next.

An evaluation of facility instrumentation was completed. Values used in the evaluation were taken from facility instrumentation calibration data. An automatic calibration verification system for the facility instrumentation was made operational.

The Phase VI (straight core) test procedure was issued and testing was completed. Phase VI testing includes the collection of duct bow data as well as compaction data. The data from Phase VI has been reduced and transmitted to program participants.

Friction testing of load pads was scheduled to be performed at ARD. A test apparatus was designed and procurement procedures were initiated. All of the test components were received and assembled in 1976.

An Engineering Study was completed on a comparison of the CRBRP fuel assembly and the SFAs. Components for the SBAs have been received and the assembly of the SBAs has been initiated. The design of the Simulated Removable Radial Shield Assembly (SRRSA) was reviewed. The Engineering Study on the design of the Simulated Removable Radial Shield Assemblies (SRRSA) was completed, approved, and issued.

Prior to initiation of the Phase VII (Load Transmissibility Test) the facility was realigned. The Load Transmissibility Test was to aid in the analysis of core former reaction load distribution during a seismic event. The data has been reduced and transferred to punch cards.

Upon completion of Phase VII (Load Transmissibility) testing, the facility was completely realigned and all instrumentation were recalibrated. Locations of pin target datums were verified and adjusted as needed.

A feasibility study was completed on a special insertion/withdrawal assembly proposed for use in the full-core insertion/withdrawal tests. The objectives of these tests are: (1) establish maximum withdrawal and insertion load requirements and (2) establish the relationship between withdrawal loads and jaw loading. The test data will also be used to determine pad loads for the ACLP and TLP. The special assembly will accurately depict the outer profile of the CRBRP fuel assembly over its entire length, its flexural rigidity, and maximum tilt condition at the inlet nozzle.

The following engineering studies were completed.

- Results of Phase VI Duct Bow Measurement Assemblies (DBMA).
- Statistical study examining the analytical effects of twist on the 121-Assembly core compaction characteristics at the boundary of "zero" load.

The instrumentation for the 8 Instrumented Load Measurement Assemblies (ILMAs) has been installed. Calibration of this hardware is scheduled for April 1977. All of the full core modification hardware has been received. This modification is scheduled for January 1977.

3.3 Current Progress

During the June 8 and 9 National Core Restraint Development Program meetings, several items were identified which could contribute to differences between analytical predictions and 121 Assembly test data. One parameter identified was the initial orientation of the SFAs. To establish the influence of this parameter, a test procedure was developed and issued in August 1976. The test was initiated on September 10 and was completed on November 2, 1976. The data has been reduced and is being evaluated. An engineering study reporting the results is being prepared. The data will be prepared for transmittal to program participants in the next reporting period.

A test procedure (ARD-9019) to be used with the hex form verification fixture was developed, approved, and issued. The test will be completed in the next reporting period. The analytical 2-D model to determine the influence of radial variations was completed. Empirical data from the hex form test will be used in the model to determine the influence on 121 Assembly test data.

The survey section of the friction test of 121 Assembly test hardware was completed in this reporting period. The data from this test is being evaluated and an engineering study will report the results. Additionally, tests were performed to select an alternate friction material. A Teflon spray was selected for use in additional 121 Assembly Straight Core Testing. The spray has been procured and is currently being applied to the load pads on the SFAs.

The task force to revise the program plan met at ERDA/RRD on September 20. A draft of the revised plan was issued in October. Representatives from EPDA, HEDL, ANL, GE, AND W-ARD reviewed input and established a charter for the National Program.

Instrumentation for the ILMAs was made operational. Initial calibration tests have been started and will continue through the next reporting period. All hardware and instrumentation will be inspected and calibrated prior to the initiation of full core testing.

The Core Restraint Test Facility characterization for Non-Uniform Loading Conditions test procedure (Operation Instruction ARD -9020) was developed and issued. The test was initiated on November 8 and completed on November 16. A temporary supporting frame independent of the facility loading mechanisms was fabricated and position indicators were installed on this frame. Differences between the facility indicators and the new indicators will be used to determine the facility load/deflection characteristics for conditions where the facility is not uniformly loaded.

The design of an independent supporting structure for the position transducers for the full core tests has been completed. Detailed drawings are complete. Purchase requisitions for the components will be issued in the next reporting period. This structure will eliminate the need to correct for facility deflections in full core tests since the position indicators will not be attached to the loading mechanisms.

All facility components and hardware to be used in full core testing have been inspected and accepted. The transition from 121 Assembly testing to Full Core testing will begin in January 1977.

All of the components for the SFAs and SBAs are on site. The SFAs currently being used for 121 Assembly testing will be modified to the full core configuration upon completion of the 121 Assembly tests. Approximately 20 spare SFAs have already been modified. Approximately 45 percent of the components for the SRRSAs are on site. Another 22 percent are almost ready for shipping. The remainder are expected in the next reporting period.

3.3.1 Program Status

A working meeting was held at ERDA/RRD on September 20 to review proposed input for the National Program Plan. The Task Force with representatives from ERDA, HEDL, ANL, GE, and W-ARD was established to draft a revised plan for the National Program. During this meeting a charter was prepared to provide a basis for subsequent planning and identification of activity scope. The text of the Charter is as follows:

The object of this program is to develop the technology required to design LMFBR core restraint systems and to support applicable licensing processes. Included within the scope of the program are the following activities:

- 1) Perform tests and analyses necessary to provide data to support the elements of the program.
- 2) Develop, verify, and qualify analytical methods and techniques for evaluation of concepts and components.
- 3) Develop and maintain design guidelines for core restraint systems.
- 4) Evaluate core restraint concepts and identify the technology needed for their design.
- 5) Monitor and transmit requirements to LMFBR technology program to obtain design data to be used in analysis.
- 6) Develop guidelines for collecting, processing and correlating in-service core restraint data.

The terms "development," "verification," and "qualification" refer to those activities directly supporting the National Program objective of providing the technology to design an LMFBR core restraint system:

Development - basic "build from the ground up" processes necessary to produce a desired aspect of the technology.

Verification - comparison with sample problems and benchmark solutions to establish that the basic functions of the code (computer program) are correct.

Qualification - determine that a particular model (using a verified code) is correctly predicting the characteristics of the National Core Restraint Program system or structure under evaluation.

Code - computer program, the product of a development effort that has been verified and documented for use by a potential user of the analysis tool.

Model - a particular representation of a physical component or system which may consist or make use of one or more analytical codes, or physical representation; in completed form the model must be qualified.

The first draft of the program plan was issued on October 8, 1976. This document was prepared from input from each of the Task Force members, comments were then submitted to Westinghouse ARD (as chairman) and Draft #2 issued on November 22.

The second draft was issued to a wider distribution for review and comment prior to preparation of the final plan.

Efforts to reduce the differences between analytical code predictions of the test facility and the empirical test data are still continuing. Analytical and empirical studies conducted during the last reporting period have improved the analytical model significantly. However, additional improvements are still necessary. Development efforts identified during the last reporting period to satisfy this end are nearing completion. Friction tests of individual test hardware load pads necessary to identify the effective coefficient of friction are now complete. An alternate friction coefficient material has been selected for the final 121-Assembly Tests scheduled for December, 1976. Dimensional measurements to determine the degree of eccentricity in the hex load pads have been completed; evaluation of this data will be completed during the next reporting period. Compaction tests to evaluate initial position effects (orientation and x-y) were completed in November. All tests for the 121-Assembly Core are scheduled to be completed by January 1, 1977 in accordance DRS 31.4.01. At that time modification of the facility for full core tests (DRS 31.4.02) will be initiated on schedule.

3.3.2 Three-Dimensional Development Tests

Evaluation and proof testing of candidate or prototypical LMFBR core restraint systems requires a full-scale mechanical test facility. Facility testing complements two- and three-dimensional analytical efforts in the core restraint field and provides the capability of modeling a reactor core with a particular core restraint system. The test facility is able to model a variety of core restraint systems.

A primary objective of the core restraint testing programs is to verify the results of analytical models which are being developed to simulate the CRBRP Core Restraint System. These models will be used to determine the effects that a variety of operating conditions and configurations have on such parameters as fuel assembly insertion/withdrawal loads and restraint system loads. The core restraint test results will be used to qualify the three-dimensional analytical models.

All phases of the initial test program (Phases I-V) are complete as defined in "Core Restraint Development 121 Assembly Compaction Test Plan, TP No. 31.4.01 - Revision No. 1". Additionally, Phases VI and VII were defined and completed in accordance with program requirements. Data from all phases have been reduced, stored on punch cards, and transmitted to ANL.

The test facility was completely realigned following completion of Phase VII testing. The jaw alignment was checked and adjusted per Operation Procedure ARD-9003. All facility instrumentation, including LVDT's, BLH load cells, and ISFA faces, were inspected and repaired where needed. All instrumentation was then recalibrated.

A method was developed which automatically performs daily calibration verifications on test facility instrumentation. This verification reduces the number of potential retests necessary as a result of undetected broken lead wires, poor connections, or excessive amplifier drift.

The Insertion/Withdrawal (I/W) Fixture was installed on top of the 121-Assembly core in March 1976. The Phase VIII Operation Instruction (ARD 9014: Withdrawal Test on 121 Assembly Straight Core) was written and implemented. A sector of 11 DBMA's were withdrawn for this test. Upon completion of the test the data was reduced and transferred to punch cards.

Following the Phase VIII test, a sample group of SFAs were inspected in the Q.A. lab to determine the amount of relative twist between the TLP and ACLP. The results of the study showed that on a statistical basis, the ACLPs and TLPs were aligned within the tolerances specified by the Core Restraint designers (and well within the expected manufacturing tolerances of CRBRP fuel assemblies).

A sample of 11 ACLPs was selected at random to determine an overall dimension of a stack up of ACLPs. A comparison of the data obtained from this sample and a previous manufacturing tolerance study indicated excellent correlation between the data from these two studies. It was, therefore, concluded that the statistically determined across flats dimensions for the ACLPs and TLPs should be used for analytical predictions. Compaction percentages for the straight core data are now based on the actual gaps rather than the nominal .015 inch gap dimension.

The Phase VIII test procedure (~~Withdrawal Tests~~ on 121 Assembly Straight Core) was issued in April 1976. The Insertion/Withdrawal machine was assembled and installed above the core. Testing was completed in April 1976.

The 121-Assembly Compaction/Twist Test was performed in accordance with the Phase VI, Addendum A test procedure. During this test data was obtained on the effects of twist on compaction characteristics at high jaw loads.

Facility components for the transition from 121-Assembly testing to full core testing arrived at ARD. All small hardware and 90% of the facility components were received.

Two statistical studies were performed. A manufacturing tolerance study indicated that the ACLP and TLP are 0.002 and 0.001 inches, respectively, larger than the nominal across flats dimension. This tolerance effect precludes 100% compaction based on 0.015 inch nominal gap dimension. The second engineering study describes the relative twist between the TLP and ACLP. The mean relative twist was determined to be -8.0 minutes with a standard deviation of +10.0 minutes. The net effect of twist must be determined for a core array.

The Simulated Blanket Assemblies were assembled and stored in the new storage racks. The 8 Instrumented Level Measurement Assemblies (ILMA) were received from GE/FBRD. The new ILMAs will be inspected and calibration acceptance tests will be performed.

A National Core Restraint Development Program meeting was held at ARD on June 8-9, 1976. Each contractor's progress was reviewed. A task force to prepare a revised program plan was formed and additional 121 assembly special tests were suggested. These special tests included:

- Evaluation of Load Pad Hex Form
- Assembly Orientation Testing
- Additional TLP and ACLP Stack-Up Verification Testing
- Evaluation of Frictional Effects on Core Compaction

A fixture for evaluating the hex form has been designed and manufactured. An analytical 2-D model is also being developed to determine the influence of radial variations in load pad hex form for the 121 assembly load pad array.

A test method and procedure was developed to examine the assembly orientation impact on compaction studies.

A test to further examine the dimensional stack-up of eleven test components (ACLP's and TLP's) was completed and an engineering study describing the results was issued.

The friction tests on 3-D test components were initiated. The initial section of testing will evaluate the "as-built" coefficient of friction. Selection of an alternate friction material for use in a 3-D 121-Assembly Low Friction Core Compaction Test is the objective of these tests.

A tool to measure inter-assembly gaps was designed, fabricated, inspected, and calibrated. A series of test runs to determine inter-assembly gaps was added to the Phase VI test procedure as Addendum A. Gap measurements were obtained to the extremes of the load pad faces to determine the twist of the TLP relative to the ACLP. The test was completed and the data reduced. The data has been partially transferred to punch cards. The transferral will be completed in the next reporting period.

During the National Core Restraint Development meeting of June 8 and 9 it was established that an effort would be made to identify and quantify the causes of the differences between analytical predictions and test data. One parameter identified is the initial orientation of the SFAs during a test. During a compaction cycle the assemblies may slide and rotate in the bushing in the core plate. The occurrence of translational motion can be determined from existing Duct Bow Measurement Assembly (DBMA) data. However, rotational motion cannot be determined with this data. Therefore, tests were scheduled to obtain rotational data. A test procedure (ARD-9009, Addendum B) has been developed and issued for the performance of this test. The test hardware was procured and the additional instrumentation has been calibrated. The test began and was completed in this reporting period. Test performance was similar to previous 121-Assembly straight core tests except that no ISFA or DBMA data was accumulated. SFA Rotational data was collected. "Rotational data" are the values read from dial indicators (DI) attached to certain selected assemblies below the core plate and indicating rotation and translator of the inlet nozzles. Each of the ten SFAs had three DIs associated with it. (See Figure 1). Each DI was read at every data point for a total of 194 points. This data is in the process of being reduced and analyzed. The analysis will determine what contribution SFA initial orientation and subsequent rotation make to the core compaction rate.

During initial 121-Assembly testing, it was observed that if the jaws were set at a uniform position, uniform loads did not result. Since the correction factors which were applied to the raw position data were determined for the case of uniform loading and did not necessarily apply to non-uniform conditions, a special test was developed to determine the facility load/deflection characteristics for non-uniform load conditions. The test was designated as Phase X. The test procedure was implemented immediately and was completed within the month. Data will be transferred to punch cards in the next reporting period.

Upon completion of the Phase X test, the SFAs were removed from the facility and the load pads (both ACLPs and TLPs) were coated with a teflon film in preparation for the low friction test. A procedure was developed which specifies the method to be used to spray the load pads. The Phase VI test procedure was modified (Addendum C) to include a series of compaction cycles with the assemblies coated with the low friction material. This test will be performed in the next reporting period.

FIGURE 1 Dial Indicator Arrangement for Phase VI, Addendum B Testing

3.3.3 Test Component Friction Test

Friction testing of 3-D test components is necessary to certify the load pad friction coefficient presently used in the 121 Assembly Test. These tests will be performed using the 3-D Above Core Load Pads (ACLP) and Top Load Pads (TLP).

The survey test section of the friction tests was completed on November 1, 1976. The objectives of this test are listed below:

- Check out test fixture.
- Determine present "as built" coefficient of friction for Metco-vs-Metco interface.
- Determine low friction coating that can be applied to the load pads for a 121-Assembly Compaction Test.

The results of this section of testing are being evaluated and will be reported in an engineering study. The engineering study will be released in mid-December 1976. The static and dynamic coefficients of friction were determined for all cases. The effects of initial load and wear-in were also examined. The results of the coefficient of friction are based on normal load and not contact pressure. The relationship between normal load/coefficient of friction is more applicable to the core restraint testing rather than contact pressure.

The coefficient of friction was determined for a random sample of TLPs and ACLPs over a load range of 250 to 1000 pounds. Preliminary results of the Metco-vs-Metco interface indicate a mean static coefficient of friction of 0.24 for initially clean surfaces. This was essentially constant over the range of loads tested. Test data indicated that this value increases with cycling of the contact surfaces under load and approaches the value of 0.5 reported earlier.* An evaluation of the results of these friction tests will be completed during the next reporting period.

Several friction tests were performed on various interface materials such as:

- Stainless Steel-vs-Metco
- Metco-vs-Molybdenum Disulfide
- Teflon Tape-vs-Metco
- Molybdenum Disulfide-vs-Molybdenum Disulfide
- Teflon Spray Coating-vs-Teflon Spray Coating

The Teflon spray was selected as the low friction dry coating to be used in the 121-Assembly Low Friction Compaction Test. A static coefficient of friction of 0.05 was obtained by using the Teflon spray coating. This provides the following necessary conditions:

- Low static coefficient of friction
- Ease of application
- Thin coating thickness
- Long lasting

* "Core Restraint Development Quarterly Progress Report for Period Ending August 31, 1973," WARD-CR-3045-3 (Availability: USERDA Technical Information Center).

- Stable during testing

All of the above conditions are necessary to perform the 121 Assembly Low Friction Compaction Test. Additional large sample friction tests are scheduled prior to loading of the full core SFAs.

3.3.4 Simulated Fuel Assemblies

Calibration of simulated fuel assemblies (SFA) used in core restraint loading requires a high degree of precision. Prior to assembly of each unit, individual components are manufactured and prepared for assembly. Targets for bow and position measurements are installed. Outlet and inlet nozzle components are then secured to the spine weldment and the alignment fixture and locating the bow measurement targets on the centerline of the spine, the above core load pad (ACLP) is set into position. The serial number is then attached.

Following 121-assembly tests, the existing simulated fuel assemblies (SFA) will be modified to simulate the CRBRP fuel assemblies for full-core testing. A design has been prepared which will minimize the amount of machining necessary to perform the modification. Deflection and stress analysis was utilized to aid in the final design analysis. Purchase requisitions for the modifications were prepared, approved, and issued. Modification of twenty spare assemblies is complete.

An Engineering Study was completed on a comparison of the CRBRP Fuel Assembly Reference Design and the simulated fuel assemblies. A review of the present design of the SFA assembly showed that it is an accurate simulation of the CRBRP fuel assembly.

Drawings of the full-core simulated fuel assemblies are complete. Contracts were placed for the fabrication of all components. A study has been made of the comparison of the CRBRP blanket assembly and a simulated blanket assembly (SBA). A study of the simulated removable radial shield has also been issued.

All of the components for the SBAs have been received. Approximately 94 percent of the SBAs have been assembled and placed in the storage racks. The remainder will be assembled when ACLPs being used for the friction tests (Section 3.3.3) become available.

Simulated Removable Radial Shield Assembly (SRRSA) proposals were evaluated and a design completed based on the design of actual RRS assembly. Purchase orders for the spine assemblies, ACLPs, and shield blocks have been placed. The simulated assembly consists of a mechanical tube with the same flexural rigidity as the actual assembly and two noncompliant load pads. The TLP will be a fixed position while the ACLP may be offset up to 0.625 inches. The outlet nozzle is identified to the SFA outlet nozzle.

Approximately 93 percent of the TLPs for the SRRSAs have been received and accepted. Approximately 35 percent of the ACLPs for the SRRSAs have been received and approximately 11 percent have been accepted. The remainder will be received and/or inspected in the next reporting period. Approximately 60 percent of the spines have been completed to the original order, however, shipment of these components has been delayed as the result of a minor design change. Delivery of the complete order is expected in the next reporting period.

3.3.5 Instrumented Load Measurement Assemblies

Early in the conception of the Core Restraint Development Program, it was recognized that some method of measuring interfacial loads would be necessary to fully evaluate load distributions in the core. It was established that GE would provide two such systems for the 121-Assembly test program at ARD. The system used is dimensionally and mechanically prototypical of the CRBRP fuel assembly. The dimensional and mechanical characteristics are documented in an Engineering Study. The data output is linked to the data acquisition system used for three-dimensional testing. During the course of testing, these systems are moved to different locations in the test core. This provides the information necessary to evaluate system repeatability, symmetry and bridging networks.

GE/FBRD has designed and fabricated eight more systems based on Development Requirements Specification (DRS) 31.4.04. These assemblies will satisfy full core testing needs. All of the assemblies and all of the signal conditioners have arrived.

To accommodate full core SFA dimensions and mechanical characteristics, the two 121 core ISFA; will be dismantled and machined during the next quarter. A contract for the machining work has been let. Along with the eight full core instrumented assemblies there will be ten ISFAs available for full core testing.

All 120 channels of additional low level signal conditioning units have been installed. Although scheduled for this reporting period, the acceptance testing for the eight new systems has not been completed due to a rigorous test schedule which has occupied the necessary equipment and manpower. The acceptance testing will be completed as soon as possible during the coming quarter.

3.3.6 Hexagon Form Verification

During the June 8 & 9 National meeting, it was indicated that the hardware presently in use in 121-Assembly testing could meet drawing requirements but not completely satisfy the intent of designers. In particular, it was determined that the hexagon load pads (both ACLP and TLP) might have a form eccentricity (See Figure 2) which could have been passed by the inspectors. To determine the magnitude and extent of any possible eccentricity, a fixture (Figure 3) was designed and procured which will provide data from which eccentricity can be calculated. A procedure for specifying the fixture's use has been prepared and issued.

The particular condition being investigated is the one shown in Figure 2. All across flats dimensions and angle dimensions may meet drawing requirements. However, the hexagon may not be regular and the "center" may not be equidistant from all faces. The eccentricity is shown in the figure as the distance "e".

The fixture shown in Figure 3 centers a load pad in its V-block section. Dial indicators will be installed in the sides and will be positioned so that they are equidistant from the center of the fixture. Then, when the indicators contact the load pad surfaces, they should have identical readings. Differences in the readings will be used to determine the eccentricity. Both ACLPs and TLPs used in 121-Assembly testing will be characterized in this test.

FIGURE 2 - NON-REGULAR HEXAGON

FIGURE 3 - HEX FORM VERIFICATION FIXTURE

3.3.7 Facility Modification for Full-Core Tests

Prior to initiation of full-core testing, some structural modification will be made to the facility. These will include: larger jaws and improved jaw alignment system; an adjustment in the height of jaws; and the installation of new bushings into the lower core plates. Detail drawings of the required modifications have been completed and approved. Incorporated in the modifications are changes to provide a more efficient and more accurate method of aligning the jaw assemblies. Reconfigured alignment targets are also included.

All of the hardware and components have been received. The bushings for the SFAs, SBAs and SRRSAs have been received and accepted.

The data acquisition system has been expanded for the full-core tests. The computer programs will be modified as necessary for full-core testing when 121-Assembly testing has been completed.

The SFA alignment fixture will be modified upon completion of 121-Assembly testing to accommodate the shorter full core SFAs. The fixture will also be relocated which will allow the alignment procedure to be simplified and shortened. Additionally, the alignment support is being strengthened to provide a more stable base.

Improved alignment targets for the core plates have been designed and procured. These targets will be installed during the transition from 121-Assembly testing to the full core configuration.

A method to support the position transducers independently of the loading mechanism has been designed. The facility currently supports the transducers from the loading frame. A result of this present configuration is that frame deflections cause position transducer movements. The current system is calibrated for this condition. The independent transducer support structure will eliminate the need to compensate for facility deflection.

3.3.8 TRITON Code Development

Development and documentation of the TRITON code continued at WARD. Work continued on the documentation final draft of the basic 7-assembly cluster TRITON model. The earlier (stagnant sodium in the interstitial gaps) version of TRITON was updated to include the latest duct temperature and I/O modifications for possible transmittal to HEDL. The first draft of the basic 7-assembly model documentation was prepared. Modifications to the code's data storage methods resulted in 30% reduction in job cost. Work was initiated on incorporating capability to analyze radial shield assemblies.

Testing was carried out comparing TRITON and MOHICAN duct temperatures for the CRBRP Parfait Core. The maximum deviation between cross-duct temperature difference calculated by the two codes was 4°F.

Use of the TRITON Code in conjunction with AFMs (alternate fuel management scheme) core restraint analyses has shown that a calculational instability still exists when very low (near zero) interstitial gap flow rates are used. An extensive review of the inter-assembly heat transfer model and solution techniques to correct the calculational instabilities is continuing. In the interim, the TRITON Code use will be restricted to use with cases where the interstitial gap flow rates are negligible, while an earlier version of TRITON is available for stagnant sodium in the gap.

Development of the TRITON code will continue. The basic analytical capabilities of the TRITON code will be extended to include a model of radial shield assemblies. A model for control assemblies will be added when the calculational instabilities associated with low interstitial gap flow rates are resolved.