UNCLASSIFIED

CLASSIFICATION LEVEL
(S, C OR U)

ATOMICS INTERNATIONAL
A Division of North American Rockwell Corporation

AI-AEC-MEMO COVER SHEET

REPORT TITLE

PNPF CONTROL ROD MODIFICATION TERMINATION REPORT

AUTHOR

D. J. Sobo

AI-AEC-MEMO 12648

(This Document Contains _____ Pages.)
(This is Copy _____ of _____ Series _____)

CLASSIFICATION TYPE
(RD OR DI)

*AI-AEC-MEMOs are working papers and may be expanded,
modified, or withdrawn at any time, and are intended for
internal use only.*

THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE PATENT BRANCH, AEC.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of information, apparatus, method, or process disclosed in this report.

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

UNCLASSIFIED

CLASSIFICATION LEVEL
(S, C OR U)

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DO NOT REMOVE THIS SHEET

DISCLAIMER

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

DISCLAIMER

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

CONTENTS

	Page
I. Introduction	I-1
II. Control Rod Drive Modifications	II-1
A. Description of the Original Control Rod	II-1
1. General Description	II-1
2. Control Rod Operation	II-3
3. External Circuitry	II-5
B. Failure Analysis of the Original Control Rod	II-7
1. Power Coil Failures	II-7
2. Position-Indication System Failures	II-8
3. External Failures	II-8
C. Design Modifications	II-9
1. In-Core vs Ex-Core Drives	II-9
2. Control Rod Drive Modifications	II-11
3. Modification Details	II-12
4. External Wiring Modifications	II-21
5. Backup Designs	II-23
References, Section II	II-24
III. Fabrication	III-1
A. Manufacturing and Quality Assurance Controls	III-1
B. Fabrication Development	III-5
1. Coil-Winding Description	III-5
2. Drying and Curing	III-7
3. Starting and Crossover Leads	III-7
4. Testing	III-8
5. Training	III-9
References, Section III	III-10
IV. Weld Development	IV-1
A. Weld Classifications	IV-1
B. CRD Welds	IV-1
C. Weld Specifications	IV-14

CONTENTS

	Page
D. Summary of Pore Size Criteria.	IV-15
E. Weld Development and Qualification.	IV-23
1. Indicator Coil to End Plate Weld	IV-23
2. Indicator Coil End-Plate to Tube.	IV-23
3. Indicator Coil Pinch-Off Tube and Adaptor Tubes to End Plate	IV-25
4. Indicator Coil MI Cable to Adaptor Tube.	IV-25
5. Indicator Coil Plug	IV-25
6. Multicoil Inlay	IV-25
7. Coil End Ring Welds	IV-27
8. Cover Plate Weld	IV-27
9. Screw Weld	IV-29
10. MI Cable to Shell Weld	IV-29
11. Single Coil Form Weld	IV-36
12. Single Coil Surfacing and Single Coil Bobbin to Shell.	IV-37
13. MI Cable Welds	IV-39
F. Welding Status at Program Termination.	IV-39
References, Section IV	IV-42
V. Test Program	V-1
A. Electrical Feedthrough Evaluation	V-1
B. CRD Bearing Evaluation	V-7
C. CRD Magnetic Jack Mockup	V-9
D. Mark II (Original Design) Static Dry Test	V-9
E. Defective Coil Test.	V-11
F. Continuation, Defective Coil Test	V-17
G. Defective Cable Test	V-19
H. MI Cable Qualification Test	V-22
I. Effect of Organic Environment on Terminations.	V-23
J. Coil Thermal Overstress	V-24
K. Prototype Magnetic Jack Test.	V-27
L. Control Rod Drive Acceptance Test	V-29

CONTENTS

	Page
M. Lead Production Drive Test in Reactor	V-29
N. Production Drive Tests in Reactor	V-30
O. Readout Instrumentation Acceptance Test	V-31
References, Section V.	V-32
VI. Status at Termination	VI-1
VII. Conclusions.	VII-1

TABLES

II-1. Control Rod Drive Design Modification Alternates	II-10
II-2. Required Coil Forces	II-16
II-3. Coil Design Conditions	II-18
III-1. Data on Piqua Power Coils Before Hot Organic Testing.	III-9
IV-1. CRD Weld Classification	IV-2
IV-2. CRD Weld Inspection Requirements	IV-2
IV-3. Control Rod Drive Welds	IV-3
IV-4. CRD Weld Quality Requirements	IV-17
IV-5. CRD Weld Inspection Criteria	IV-19
IV-6. Piqua Control Rod MI Cable to Shell Weld	IV-31
IV-7. Weld Status at CRD Program Termination	IV-40
V-1. Control Rod Drive Test Program	V-3
V-2. CRD Bearing Test Results	V-8

FIGURES

II-1. Piqua Magnetic Jack Control Rod Drive	II-2
II-2. Original Power Coil Circuit	II-4
II-3. Original Position and Indicator Circuits	II-6
II-4. Piqua Control Rod Drive Power Coil Modifications.	II-12
II-5. Modified Control Rod Drive	II-13

FIGURES

	Page
II-6. Modified Rod Drive Core Arrangement, Electrical Cabling	II-14
III-1. Typical Completed Manufacturing Production Order (MPO)	III-2
III-2. Example of Quality Control Acceptance Procedure (PNPF Copper-Stud to Coil-Bobbin Weld Sampling Plan)	III-4
III-3. Wet-Winding Operation	III-6
IV-1. Typical MI Cable Sleeve-Bracket Welds	IV-9
IV-2. Position Coil Welds	IV-9
IV-3. Indicator Coil Welds	IV-10
IV-4. Thermistor Cable Bracket Welds	IV-10
IV-5. Cable Support Bracket and Plug Support Assembly Welds	IV-11
IV-6. Plug Guide Assembly and Upper Housing Assembly Welds	IV-11
IV-7. Multicoil Welds	IV-12
IV-8. Single Coil Welds	IV-12
IV-9. Coil Case Tack, Screen, and Wire Termination Welds	IV-13
IV-10. MI Cable Welds	IV-13
IV-11. Indicator Coil Collar-to-End-Plate Weld	IV-22
IV-12. Indicator Coil End-Plate-to-Tube Weld	IV-24
IV-13. Cover Plate Weld	IV-28
IV-14. Screw Weld	IV-28
IV-15. MI Cable-to-Shell Weld, Sample No. A-14	IV-34
IV-16. Single-Coil Surfacing and Bobbin-to-Shell Weld	IV-38
V-1. Control Rod Drive Grip Coil Performance	V-10
V-2. Defective Coil Insulation Resistance	V-13
V-3. Defective Coil Winding Resistance	V-14
V-4. Sample of Power-Coil Electrical Tough Pitch Copper Wire After 1500 Hours Exposure to 650° F Organic Coolant	V-16
V-5. Sample of Power-Coil Electrical Tough Pitch Copper Wire Not Exposed to Organic Coolant	V-16
V-6. Coil Circuit Resistance in 650° F Organic	V-18
V-7. Coil Insulation Resistance in 650° F Organic	V-20
V-8. Defective Mineral-Insulated Cable Assembly	V-21

FIGURES

	Page
V-9. Defective Mineral-Insulated Cable Insulation Resistance	V-22
V-10. Defective Mineral-Insulated Cable-to-Shell Weld From Thermal Overstress Test (Taken at 40X)	V-28
VI-1. Total Control Rod Development Program Status at the Time of Program Termination	VI-3
VI-2. Modified Control Rod Development Production Parts Status at the Time of Program Termination	VI-5

I. INTRODUCTION

The Piqua Nuclear Power Facility (PNPF) is an 11.5 Mwe organic-cooled and -moderated reactor central station power plant located at Piqua, Ohio. Criticality was first achieved on June 10, 1963, with full-power operation accomplished on January 27, 1964. The reactor plant operated with about a 66% availability until January 13, 1966. At that time, the reactor was shut down due to a scram caused by the degasifier system; the plant has been shut down since.

Following the plant shutdown, investigation revealed massive coke formation in the reactor moderator region. The coking problem coupled with a generally unreliable operation of the control rods led to a decision to modify the plant to remove the cause of coke formation and also to improve the control rod system to make a significant increase in operating reliability. This report describes the control rod drive (CRD) modification program.

The original PNPF control rod was a modification of an earlier magnetic jack design developed by Oak Ridge National Laboratory. Further development work at Atomics International resulted in the design of a control rod drive suitable for in-core operation. The decision to utilize an in-core control rod drive for the PNPF was based upon the following considerations:

- 1) An in-core drive would eliminate the penetrations and associated sealing problems of an ex-core drive.
- 2) An in-core drive significantly simplifies fuel-handling problems.
- 3) With an in-core drive the shielding effect of the heat-transfer fluid can be used.

Although excellent performance was obtained with two developmental magnetic jack control rod drives, the performance of the production control rod drives under actual reactor service conditions was characterized by repeated failures requiring excessive maintenance and rework. Following the final plant shutdown in January 1966, a task force was organized to review in detail all aspects of control rod design and performance.

Following an intensive review of performance and design requirements, it was recommended that new control rod drives of a modified design be fabricated, tested, and used in the PNPf restart core.

The control rod drive modification program was well underway when the entire PNPf program was terminated on December 13, 1967.

This report summarizes the results of all activities related to the PNPf Control Rod Modification Program up to the time of program termination.

Starting with a description of the original PNPf control rod design, a discussion of the causes of unreliable operation is made. The basis and rationale for the modification are presented, and the design details are shown.

The manufacturing and quality assurance programs are discussed, as are the winding and welding. Particular emphasis is placed on the details associated with the qualification of critical welds.

The test program is presented and results discussed. The report concludes with a summary of the program status at the time of termination.

II. CONTROL ROD DRIVE MODIFICATIONS

This section of the report covers the design modifications made to the control rod drive. Starting with a brief description of the original control rod design, this section continues with a discussion of the causes of the unreliable operation of the CRD's. The basis for their modification is presented, and the design modifications are discussed.

A. DESCRIPTION OF THE ORIGINAL CONTROL ROD

A brief description of the original design of the Piqua magnetic jack control rod drive is included in this section for background information (see Figure II-1, a pictorial representation of the control rod and its means of operation).

1. General Description

The original Piqua control rod drive is a unitized assembly consisting of drive coil case, position-indication coil assembly, snubber assembly, poison section, and connecting housings. The drive coil case consists of twenty coils arranged in eight coil circuits, representing four functions, hermetically sealed in the coil case. The coils are mounted on the coil case central tube and spaced by pole pieces which carry and direct the magnetic flux. The central tube and outer sleeve are welded to the coil case end flanges, sealing the coils from the reactor coolant. The electrical leads are brought out through two five-pin feed-throughs utilizing glass compression seals. Fixed and movable armatures are located within the central channel of the coil case. Belleville spring cushion washers are located at each end of the movable armature to snub travel and reduce armature breakaway time.

The position-indication transducer assembly is bolted to the upper flange of the coil case. The transducers consist of coils mounted on a tube through which the drive rod passes. The long-position coil is located to see full travel of the end of the drive rod. The signal transmitted is a function of the change in reactance which results as the drive rod passes through the center of the coils. A thermistor is provided to obtain compensation caused by changes in permeability of the drive rod as a function of temperature. Indicator coils

Figure II-1. Piqua Magnetic Jack Control Rod Drive

serving a marker function are located to pick up full-in and full-out positions. The signal from the indicator coils is a peak voltage as a solid slug at the end of the drive rod passes through the indicator coil and increases the inductive coupling between the long-position coil and the indicator coil. The position-indication transducer assembly is enclosed in the drive upper housing. The upper end of the upper housing is terminated in a grapple ledge, which accommodates the fuel-handling machine grapple.

A lower control rod housing is bolted to the lower side of the drive coil case. The lower housing contains the stacked Belleville spring control rod snubber section and terminates at the lower end in a diameter which indexes to the head of the fuel element in which the control rod poison section is to operate. The control rod position section consists of B_4C -filled stainless steel tubes brazed in a circular array. The poison section extends down through the center of the snubber assembly and the drive rod extends up through the channel formed by the ID's of the fixed and movable armatures and the long-position coil.

The electrical leads from the power coils and the position-indicating coils to the upper drive plug are 18-gage Ni-clad Cu conductors with a nominal 9 mils of fiberglass insulation held in place with stainless steel overbraid. This section of the electrical wiring operated in the reactor coolant.

The electrical connection to the top of the drive was accomplished with a receptacle which mated with the upper drive plug. The receptacle was connected to long flexible jumper leads which spanned the upper guide grid and penetrated the vessel at special nozzles. Vessel penetrations were made through four conductor Conax packing glands.

2. Control Rod Operation

As shown in Figure II-1, power coils are positioned in the coil case in the following sequence from top to bottom; lift coils, grip coils, pull-down coils, and hold coils. The movable armature is located in the elevation between the lift and pull-down coils. The fixed armature is positioned at the elevation of the hold coils. Energizing hold or grip coils expand and frictionally hold the split drive rod to the fixed and movable armatures respectively. Energizing the lift or pull-down coils moves the movable armature to the up or down limits of travel.

3-8-68 UNCL

7736-5215

Figure II-2. Original Power Coil Circuit

When the rod is stationary the hold coils are energized, holding the split drive rod to the fixed armature. To lift the rod the coils are energized in the following sequence:

- 1) The pull-down coil is energized to pull the movable armature against its lower stop.
- 2) The grip coils are energized to hold the drive rod to the movable armature.
- 3) The lift coils are energized and the hold and pull-down coils are de-energized, which moves the movable armature to the upper limit of its travel, thus moving the drive rod one step.
- 4) The hold coils are energized and the grip coils are de-energized, transferring the holding of the drive rod from the movable armature to the fixed armature.

The sequence is repeated for each succeeding step. The procedure for insertion is identical except that energizing of lift and pull-down coils is reversed in the sequence.

3. External Circuitry

The control rods are operated on direct current. Twenty-two rectifier-type power supplies are provided. One power supply is used for the hold coil circuits in each of the 13 control rods. Three power supplies are used for the grip, lift, and pull-down currents required by each of the three drivers.

As shown in Figure II-2, each power supply consists of a Variac variable voltage transformer and a full-wave bridge rectifier. Switching for rod selection is accomplished by relays on the dc side of the bridge. Diode voltage spike protection is provided on both ac and dc sides of the bridge. Dc ammeters are incorporated in all driver coil circuits. Variac adjustment is used to obtain the desired operating currents. Breaker over-current protection is provided on the ac side of each power supply.

The drivers consist of electric-motor-driven cams which actuate micro-switches. The mode of operation is selected at the drive console control panel.

3-4-68 UNCL

7736-5216

Figure II-3. Original Position and Indicator Circuits

The modes available are (1) one rod on manual control, and (2) one rod on manual and one or two rods on automatic control. All rods not being driven are held stationary with only hold coil circuits energized. Scramming is accomplished by de-energizing all hold coil circuits.

As shown in Figure II-3, the position indication provided at the console consists of a percentage withdrawal indicator and up and down limit indicators for each of the thirteen rods. The up and down limit indicators are small unmarked dial ac voltmeters directly reading the output from the control rod drive indicator coils. The percentage withdrawal indicator is a dc voltmeter reading the rectified output from the inductance sensing bridge which has the long-position coil in the leg being measured.

In addition to the position indication provided for each rod, any rod connected to a driver has three step counters which register up, down, and subtractive steps. They provide resolution of small rod movements in 0.050-in. steps.

B. FAILURE ANALYSIS OF THE ORIGINAL CONTROL ROD

A failure analysis of the original PNP control rod was made and completely reported in Reference 1. The results of this analysis are summarized in the following paragraphs.

1. Power Coil Failures

The unitized coil case did not perform its intended function of keeping the power coils dry. Organic leakage resulted from either, or a combination of, weld failure, electrical feedthrough leakage, or the presence of stringers.

Pin-to-pin and pin-to-ground short circuits were found at the coil case electrical feedthroughs. These failures were caused by pyrolytic decomposition of the organic material which leaked into the coil case. Open circuits were also found at the electrical feedthrough wire terminations. The open circuits were caused by mechanical failures resulting from the very high temperature rise (400°F) which occurred due to underdesign of the feedthrough pins.

Layer-to-layer, wire-to-wire, and wire-to-ground short circuits were found in the power coil windings. These failures resulted from defects in the

anodized insulation on the aluminum coil wires, and on defects in the coil bobbin insulation.

Short circuits were found in the wiring from the coil case electrical feedthroughs to the control rod jumper connector. These failures were due to mechanical failures at the wiring terminations.

Short and open circuits were found in the electrical jumper cable between the control rod and the reactor vessel penetrations. These failures occurred because of mechanical damage resulting from the moving of the jumpers during fuel-handling operations.

2. Position-Indication System Failures

Examination of the indicator coils indicated that, although they were still functional, there was organic leakage at the electrical feedthroughs. Conductive material, probably pyrolytically decomposed organic, was causing insulation resistance degradation at the feedthroughs. Coil wiring wire-to-wire and layer-to-layer short circuits were produced as thermal cycling disrupted the wire insulation.

The position coils and thermistor coils were satisfactory from the electrical point of view. However, some position coils were severely bent at their upper extension. This condition was caused by thermal stress resulting from rapid cooling of the outer cylinder of the position coil, as compared to the inner tube upon which the coil is wound.

3. External Failures

After resolution of initial startup problems and replacement of components with inadequate electrical capability no major failures were known to have occurred in the external circuits and components. Two conditions were observed, however, that may have contributed to the power system failures. The first condition is that unfiltered full-wave bridge rectifiers are utilized to supply dc power to the power coils. The high ripple factor of this design subjects the marginal aluminum-oxide film insulation system of the power coils to an additional 57% voltage-to-ground over the dc voltage required for operation. The second condition is the existence of the 120-cps ripple frequency in the

impressed coil voltage which can result in additional heating in those portions of the rod drive working at high magnetic flux density. This hysteresis and eddy current heating is estimated to total about 15% of the dc coil power input.

The position-indication system external to the core, although generally functional, left much to be desired. A 2% meter readout was used, resulting in poor accuracy. The indicated position was affected directly by variations in line voltage, resulting in loss of accuracy and drift. A multiple ground system was used, resulting in drift and noise. Finally, the step counters were not entirely satisfactory, due to rod slippage rather than circuit faults.

C. DESIGN MODIFICATIONS

With the failure analysis completed and the decision made to modify the control rods for increased operational reliability, it was necessary to evaluate the alternatives for the best modification within reasonable budget and schedule constraints. In the following paragraphs, the choice between in-core and ex-core drives is examined, and the selected detail-design modifications are discussed. Wiring modifications to the external controls are presented, and a brief description of the backup design is given.

1. In-Core vs Ex-Core Drives

The major alternate consideration in the control rod modification program was whether to use in-core or ex-core drive units. Any ex-core drive would have to be top-mounted since it was obviously impractical to reconstruct the reactor for bottom drive units. Furthermore, an additional constraint was that of a wet-poison column since the organic flow was required for adequate cooling of the B_4C poison column.

The significant advantage of an ex-core drive is the accessibility for maintenance. However, the disadvantages, in view of the PNP reactor, as it exists, are:

- 1) The reactor vessel top would have to be modified to allow ex-core drive units. Recoding of the vessel would be required. The modification would have to be performed in place, or the containment access modified to allow top-head removal.

TABLE II-1
CONTROL ROD DRIVE DESIGN MODIFICATION ALTERNATES

Function	Alternates	Discussion	Selection
Power coils	Original design with anodized aluminum wire	Generally unsatisfactory due to low quality anodized aluminum wire, effort would have to be concentrated on inspection technique and quality control.	Reject
	Original design with copper wire	Because of form factors involved in insulation, would run hotter than original design, does allow maximum utilization of existing parts. No leakage redundancy between coils.	Utilize as backup modification
	Separate sealed coils with copper wire	Better heat transfer, coils will operate with acceptable temperature rise. Allows for true leakage-redundancy.	Selected as reference modification
Wiring and seals	Wet wiring from power coils to jumper connector (original design)	Generally satisfactory operation, but susceptible to mechanical damage, difficult to repair.	Utilize as backup modification
	Mineral-insulated (MI) sheathed cable from power coils to jumper connector	Very resistant to mechanical damage, allows best seal to power coils.	Select
	Wet jumper cable (original design)	Susceptible to mechanical damage.	Reject
	Wet jumper cable, but protected with flexible conduit.	Protected from mechanical damage, easily movable during fuel-handling operations.	Select
	Dry jumper cable	No advantage over wet design based upon performance. Difficult to maintain seals.	Reject
	Wet connectors at control rod jumper and reactor penetration (original design)	Satisfactory operation in original design.	Select
	All dry wiring and connectors	Would make fuel-handling operations excessively difficult.	Reject
Position coil	Wet wiring (original design) but stronger upper section	Satisfactory operation in original design. Upper section needs new design to prevent bowing due to thermal stress.	Select
Indicator coil	Dry wiring (original design)	Satisfactory operation in original design.	Select
Thermistor coil	Wet wiring (original design)	Satisfactory operation in original design.	Select
Fixed and movable armatures, drive rod, etc.	Original design	Satisfactory operation in original design	Select

AI-AEC-TDR-12648
II-10

- 2) The penetrations for the control rods would require additional seals to the reactor vessel.
- 3) Since the poison column must run wet, an extension rod would have to extend up through the penetration and would be driven by magnetic coils located outside the penetration. Since organic material could rise up into this area, it could possibly freeze and interfere with dropping the poison column under scram conditions. To eliminate this drawback, organic would have to be circulated, thus complicating the design of an ex-core drive.

Item 3 leads to the most significant drawback to an ex-core drive. Whereas the in-core has had its safety feature conclusively demonstrated in operation, the ex-core has never had its safety feature conclusively demonstrated in an organic reactor. If ex-core drives were utilized, an extensive development test program would have to be performed to verify safety capability.

The trade-off then was between the advantage of maintainability for an ex-core drive vs the difficulty of developing a safe ex-core drive unit. On the other hand the safety of the in-core unit had been demonstrated, and it was felt that by utilizing the in-core concept a modification program could improve the reliability of the in-core drive to where access for maintenance would not be a significant requirement.

Based upon the above reasoning the in-core control rod drive was retained as the reference design.

2. Control Rod Drive Modifications

a. Alternates Considered and Basis for Selection

With the in-core CRD established as a reference design, the possible modifications to the CRD were examined. Alternates considered and their basis for selection are given in Table II-1. The selected modification had the following features:

- 1) The power coils were changed from the original unitized design using anodized Al wire to a design utilizing individually sealed, truly redundant coils with Cu wire. A comparison is shown in Figure II-4.

66-7710-156-8A

Figure II-4. Piqua Control Rod Drive
Power Coil Modifications

- 2) The cabling from the control rod jumper plug to the power coils was changed from unprotected wet wiring to MI sheathed wiring.
- 3) The upper mechanical section of the position coil was changed to eliminate bowing as a result of earlier design deficiencies.
- 4) The jumper cable from the reactor vessel penetration was changed from unprotected to mechanically protected wet wiring cable.
- 5) Other design features which had demonstrated their capability during power operation were retained with no change, thus allowing maximum utilization of existing hardware.

3. Modification Details

The modified CRD is shown in Figure II-5 and the modified jumper cable in II-6. Details are discussed in the following paragraphs.

7710-2547A

Figure II-5. Modified Control Rod Drive

AI-AEC-TDR-12648

II-13

7-7710-043-7A

Figure II-6. Modified Rod Drive Core Arrangement, Electrical Cabling

a. Upper Section

The upper section of the CRD was modified so that the plug connecting to the jumper was free to slide in the upper drive housing. In the original design the plug was rigidly attached to the upper portion of the position coil; this led to the bowing problem discussed in B-2 of this section. Other minor mechanical modifications were made to account for the use of MI cable in lieu of the original wet wiring.

b. Position Coil

No major modifications, other than deleting the rigid attachment to the CRD plug mentioned above, were made.

c. Indicator Coils

The original CRD utilized a mid-position indicator coil in addition to the "up" and "down" coils. Although the coil was provided with a midtravel calibration check, operating experience indicated it was not necessary; hence the coil was deleted.

The electrical feedthrough connectors in the original design were unsatisfactory from the leakage viewpoint. The modified indicator coil uses MI cable as the feedthrough.

The original design used 2500 turns of 30-gage Cerametemp magnet wire encapsulated in a proprietary ceramic insulation. The modified indicator coil uses 1000 turns of 27-gage wire wet wound in AI-1 encapsulant. Data from Reference 2 indicated that the 1000-turn coil would develop sufficient output voltage when coupled with exterior circuit modifications, discussed in C-4 of this section, to perform the required function. The use of AI-1 encapsulant was based on making the coil winding identical to that used in the power coils; the use of this particular encapsulant is discussed below under the discussion of the modification to the power coils.

d. Thermistor Coil

No modifications were made to the thermistor coil other than adding brack-etry to support its MI cable.

e. Power Coils

The modification of the power coils from the original single sealed outer case to individually sealed coils presented the major design problem in the CRD modification program. This involved the distribution of magnetic flux from the coil windings into the pull-rod and armatures to develop the required magnetomotive force to hold or actuate the drive system. Design considerations are (1) the required forces, (2) available space, (3) magnetic saturation, and (4) temperature rise. The complete magnetic analysis is given in Reference 3 and highlighted below.

The forces involved for system actuation are shown in Table II-2.

TABLE II-2
REQUIRED COIL FORCES

Function	Grip	Hold	Pull	Lift
	Holds Rod During Motion	Holds Rod When Stationary	Cocks Armature Into Down-Position, Moves Rod During Down-Stroke	Cocks Armature Into Up-Position, Moves Rod in Up-Direction
Rod weight (lb)	67	67	†	67
Armature weight (lb)	0	0	-26	26
Acceleration force (lb)*	2	0	2	2
Spring force (lb)	0	0	300	300
Friction (lb)	0	0	†	49
Hydraulic force (lb)	10.7	10.7	†	10.7
Total force required (lb)	79.7	77.7	27.6	454.7
Magnetic force required (lb)	797§	777**	27.6	454.7

*Based on 100 steps/min., 0.050 in./step.

†In the down sequence, the weight of the rod and the hydraulic force assist the sequence and are greater than the developed friction.

§Coefficient of friction between drive rod and movable armature assumed equal to 0.1.

**Coefficient of friction between drive rod and stationary armature assumed equal to 0.1.

With the required magnetic forces established, the flux density in the air gap between the magnetic poles can be calculated from

$$B = \frac{72 \times 10^6 F}{A} ,$$

where

B = flux density (lines/in.²),

F = force required (lb), and

A = pole area (in.²).

With the flux density between the poles established, the remainder of the magnetic circuit can be analyzed to establish the total ampere turns (NI) required to establish that flux density.

For air gaps and leakage paths,

$$NI = 0.313B^2 \ell ,$$

where

NI = ampere turns, and

ℓ = gap or path length (in.).

For paths in iron, NI can be evaluated by first finding H, the magnetic field intensity, from a B-H saturation curve. NI can then be calculated from

$$NI = H\ell ,$$

where

H = magnetic field intensity (ampere turns/in.), and

ℓ = path length, (in.).

Finally, summing all the ampere turns required for the various paths establishes the coil ampere turn requirement.

Once the ampere turn requirement is established, coil design can be implemented by trade-offs between wire size, space available, power consumption,

and temperature rise. The coil temperature rise can be established from the power dissipated in the coil. The power is given by the expression

$$P = \frac{\pi}{2} \left[\frac{D_o + D_r}{ht} (NI)^2 \right] \frac{\rho}{f},$$

where

P = power dissipated in the coil (watts),

D_o = coil OD (in.),

D_r = coil ID (in.),

h = coil winding-width (in.),

t = coil radial-thickness (in.),

N = number of turns,

I = coil current (amp),

ρ = conductor resistivity (ohm-in.), and

f = coil space-factor.

The various trade-offs were made and are summarized in Table II-3. Electrical and magnetic data are from Reference 3, thermal data from Reference 4.

TABLE II-3
COIL DESIGN CONDITIONS

	Grip	Hold	Pull	Lift
Voltage (volts)	53.3	28.3	55.9	60.6
Current (amp)	4.29	2.26	9.78	10.6
Power loss/pole (watts)	148.5	63.8	222.5	255
Number of turns/pole	224	224	415	415
Factor of safety	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{2}$
Maximum steady-state coil temperature in 650°F organic (°F)	<780	<780	<780	<780
Maximum ΔT between adjacent coils in 650°F organic (°F)	18	24	24	18

Additional thermal analysis noted in Reference 4 established a maximum ΔT of 67°F at the pull coil when the control rod assembly, at 70°F, was placed into the reactor at 400°F. This same worst case transient condition resulted in a ΔT of 42°F between the stainless-steel sheath and the conductor of the MI cable.

Based upon the transient and steady-state thermal analysis, and the materials selection, discussed below, a detailed stress analysis was performed and reported in Reference 5. The stress analysis was based upon the criteria of Section III (Nuclear Vessels) of the ASME Boiler and Pressure Vessel Code. In all cases stress levels were maintained below the allowables.

Materials selection for the coil forms were based upon structural and magnetic considerations. Low-carbon steel was selected for high permeability magnetic paths, and Inconel 600 for low permeability paths. These materials resulted in a combination having the required magnetic properties and almost identical coefficients of thermal expansion. The probable weld problem was recognized, but stress, magnetic, and schedule considerations were overriding factors.

At the time the Piqua control rod drives were designed, anodized aluminum insulation systems showed considerable promise for high-temperature applications. Quality control difficulties, however, and damage to the insulation in installation and resulting from thermal cycling in practice have shown that anodized aluminum insulation for the Piqua control rod drives were unreliable. Quality control problems were so difficult that the original supplier of wire for the prototype control rod drive units was forced to abandon production of this product, and the subsequent supplier of the wire for the original production control rods had considerable difficulty in delivering satisfactory wire.

A satisfactory high-temperature insulation system which produced a well-insulated solid coil was developed by Atomics International as part of the AEC-SNAP development program. This system utilizes double glass served wire which is wet wound into coils with a ceramic encapsulant, air dried, vacuum dried, and finally fired at 1200°F. The latest of these high-temperature insulating systems uses an encapsulant designated AI-1. Several years of experience

with this and similar high-temperature insulation systems resulted in the availability of a suitable replacement for the anodized aluminum insulation system. The improved high-temperature insulation has demonstrated the capability to operate above 1000°F for extended periods with no degradation in insulation characteristics. This wiring system was selected for use in the modified CRD.

f. Jumper Cable

The original jumper was one piece from the CRD top plug to the vessel penetration. The modification replaced the existing jumper assembly with a removable flexible jumper which runs from the CRD plug to the vessel wall and a fixed leadout assembly which runs from the vessel wall to the vessel penetrations.

The flexible jumper assembly is removed during fuel-handling operations to minimize flexing and handling damage. The proven lavite-insulated plug and receptacle configuration is used for the additional plug and receptacle necessary to make this jumper section removable. The leadwires are 14 gage in place of the original 16 and the fiberglass insulation thickness was increased from 9 to 21 mils. The leadwires are run in flexible metal conduit between plugs to prevent concentrated flexure points and to provide additional protection against mechanical damage.

The fixed leadout assembly consists of a preassembly of leads in a flexible metal conduit to eliminate the loads imposed on the leads while being pulled through the existing fixed conduit. The leadwire is the same type as originally used but increased in size from 16 to 14 gage. The fiberglass insulation thickness between conductor and overbraid is increased from 9 to 21 mils.

The Conax vessel penetrations were removed in installing the fixed leadout assemblies. The Conax fittings were replaced with a Conax fitting providing increased space between conductors and between conductors and ground. This improves insulation resistances at the vessel penetrations.

g. Poison Section and Drive Rod

No modifications were made to the poison section, drive rod, and fixed and movable armatures, as they were satisfactory as-built.

4. External Wiring Modifications

a. Power-Coil Circuit Modifications

A number of changes to the original power-coil control circuits were found necessary to realize the maximum reliability gain from the establishment of true magnetic jack coil redundancy. The modifications were:

- 1) Fuses were added for each redundant power-coil circuit to isolate a defective coil circuit from the power supply in the event of a single-coil failure.
- 2) Diode protection was added to each redundant coil power-coil circuit on the coil side of the fuse to protect the coil from excessive voltage in the event of a sudden current interruption.
- 3) Transient voltage suppression was extended to include the grip, raise, and lower power supplies. Suppression was originally applied to the hold power supplies only.
- 4) The common return circuit was isolated from ground at the power supply. The common groundpoint is now the coil case for all coils. This change reduces the coil enclosure penetration requirements by 50%.
- 5) Diodes between rectifiers and common return circuit of all power supplies were eliminated. They are no longer required.
- 6) Balance resistors were deleted from the magnetic jack power coil circuits. Precision coil winding and improved insulation system design should eliminate excessive circuit unbalance between coils in a coil group.

b. Position-Indication Instrumentation Circuit Modifications

The original bridge excitation voltage of 70 volts ac 60 cps was obtained from the output of an adjustable voltage transformer. The output voltage of this transformer was dependent on its input voltage, load, and ambient temperature. With such a supply the accuracy of the position-indication circuits was limited, since their output is directly proportional to the input voltage.

To reduce errors in instrumentation from this source, a regulated power supply is required. Three Behlman-Invar "Invertron" power supply units were included in the modified position-indication instrumentation system to supply bridge excitation power. The units have a voltage regulation of 0.5% for input voltage variations of $\pm 10\%$. Frequency regulation is $\pm 0.1\%$.

Distribution of bridge excitation power and individual circuit fault protection by fuses is provided by a power distribution panel. The 13 position-indication circuits are divided into three groups. One power supply normally feeds a single group; however, in the event of failure of a single supply or a power supply outage for maintenance, the load may be switched to an alternate supply. Each supply is capable of operating continuously when connected to two groups. These circuit modifications insure that loss of a single position-indication circuit will not result in loss of the remaining circuits and that loss of a single power supply will not result in more than temporary loss in position indication for approximately one-third of the control rods.

The basic bridge/rectifier design was retained for each position-indication circuit to provide (1) a 0 to 100% indication on individual dc panelmeters and (2) full range dc signals to an accurate digital voltmeter for precise indication of rod position.

The original-design up/down indication circuitry had ac voltmeters connected directly across the indication coil terminals to monitor full-up and full-down control rod position. The small size of the panelmeters (1 in.) and analog output of the circuit introduced considerable operator difficulty in rapidly determining the status of a control rod. The up/down indication readout using ac voltmeters has been eliminated. The modified circuits have indication lights to provide positive readout of the up/down status of control rods.

In the modified position-indication system an up/down logic panel has been added. This panel contains two dc power supplies, 13 "up" and 13 "down" voltage comparators. Input signals from the up and down indicator coils are rectified and filtered to provide a dc input signal to the appropriate voltage comparator. An adjustable reference voltage is developed by a potentiometer excited from a regulated dc power supply. The input signal is compared with

the reference signal in the voltage comparator, and the comparator develops an output whenever the setpoint corresponding to either the up or down limits of travel of the control rod is reached. The output signal from the comparator drives the individual up/down indicator lights.

The addition of two more voltage comparators, a flip/flop and a driver module to the up/down logic panel, provides the means for the digital voltmeter counter to determine rod drop time. In the measurement of rod drop time the indicator coil output signals are rectified and filtered, then delivered to voltage comparators. Both the up and the down comparators receive an adjustable-potentiometer reference signal from a dc power supply. With this circuit a signal to set the flip/flop is developed when the signal from the up indicator coil reaches a preset start-voltage level corresponding to a definite up position of the rod. The flip/flop is reset when the signal from the down indicator coil reaches a preset stop-voltage level corresponding to a definite down position of the rod. The flip/flop output, conditioned by the driver, is used to start and stop the digital voltmeter counter. Since the counter operates at a known and constant countrate, this circuitry permits the direct readout of rod drop time.

With the substitution of the system scram switch contacts for the up voltage comparator, the same circuitry can be used to permit direct readout of rod scram time.

5. Backup Designs

Feasibility studies of two backup design modifications were made. The prime backup modification was a Cu-wire-wound version of the original design. This backup modification would have had the advantage of requiring less mechanical development than the reference modification, but would have had somewhat higher operating temperatures, and would have been more susceptible to organic leakage.

An ex-core drive was also considered as a backup modification. The ex-core drive would have been either an organic-cooled Cu-wound version of the original design, or a modification of the "latch-jack" drive used on PWR reactors. Magnetic, thermal, and stress calculations are given in References 6, 7, and 8, respectively. Although feasible, these backup designs had the major disadvantage of requiring an extensive test program to demonstrate safety capability.

REFERENCES, SECTION II

1. "Piqua Control Rod Drives Evaluation," NAA-SR-MEMO-12142
2. "PNPF Control Rod Position Indicating System," NAA-SR-TDR-12202
3. Rev. II, "Piqua Magnetic Jack Electromagnetic Calculations," NAA-SR-MEMO-12171
4. "Thermal Analysis-Piqua Control Rod Drive Modification," NAA-SR-MEMO-12238
5. "Structural Analysis of the Magnetic Jacks for Piqua Control Rods," NAA-SR-TDR-12330 Rev
6. "Electromagnetic Analysis for the Grip Coils of Proposed Backup Designs of the Piqua Magnetic Jack," NAA-SR-MEMO-12412
7. "Thermal Analysis - Piqua Control Rod Drive Backup Design," NAA-SR-MEMO-12413
8. "Stress Analysis - Piqua Reactor Mark V Control Rod Drive," NAA-SR-MEMO-12417

III. FABRICATION

This section of the report covers two aspects of the modified CRD fabrication effort. The first is the manufacturing and Quality Assurance controls put into effect to assure product control. The second is the development work required during the fabrication process.

A. MANUFACTURING AND QUALITY ASSURANCE CONTROLS

The modified CRD's were fabricated at AI. Fabrication was controlled through Manufacturing Production Orders (MPO) coupled with a comprehensive Quality Assurance program plan.

The MPO is used to issue fabrication and inspection instructions based upon requirements in engineering drawings and specifications. The objective of the MPO is to organize supply and movement of materials and other supporting activities to meet manufacturing quality, quantity, and schedule requirements. The engineering drawing establishes manufacturing and quality requirements; the MPO authorizes fabrication, and serves as a record of material verification, a permanent inspection record, and configuration report. When completed, the MPO is an "as-built" history of all actions taken during development, fabrication, or process operations.

Figure III-1 is an MPO for the fabrication of 150 wire termination ferrules for CRD wiring. The wire ferrules were a rather simple part, being a 0.125-in. OD tube, 0.066-in. long, with a 0.020-in. wall, made from 304 stainless-steel tubing.

Eight separate steps were required for the desired control. These were:

- 1) Draw material from warehouse.
- 2) Verify that material specification is to drawing requirements.
- 3) Fabricate parts.
- 4) Inspect fabricated parts.
- 5) Vapor-degrease parts per AI process specification.
- 6) Inspect cleaning operation.

ATOMICS INTERNATIONAL A Division of North American Aviation Inc.										ENGR.		Q.C.		MFG.	
DOC ID. P.A.		GENERAL ORDER OR CONTRACT		SUB-ACCT. AND TASK		WORK RELEASE ACTIVITY/ SUB-CONTRACT SERIAL NO.		RESPONSIBLE DEPT. GROUP AND UNIT		M.P.O.		PLANNING LEVEL			
7731		22320		584-305		784-420		584305		2					
PAGE 1 OF 1		MODEL FIQUA		LOT 150		BATCH		HEAT		SCHED. START DATE 07177		SCHED. COMPL. DATE 07147		PERT. NTKW. ID	
PART NO. N69122096 "NR"															
PART NAME WIRE TERMINATION FERRULE															
NEXT ASSEMBLY N69122052.33.34.35															
PLANNER T. SHIGELUNI															
OPER. NO.		DEPT.		UNIT		SERIAL		OPERATIONS		QTY. DATE		QTY. REJECT		OPER. OR INSP.	
								BILL OF MATERIAL							
1		789		16		1 EA. TUBE - ST. STL. 304, MIL-T-8504, 135 O.D. X .030 W X 50" 714-466950									
2		754		531		VERIFY PREVIOUS INSPECTION ACCEPTANCE				7/1/67		7/1/67			
3		789		000		FABRICATE 150 EA. N69122096 FERRULE PER DRAWING				158		7/1/67			
						IDENTIFY PER SPEC. N69122096 (BAG & TAG)				7/1/67		7/1/67			
4		754		531		INSPECT OPERATION #3				7/1/67		7/1/67			
5		789		41		DEGREASE PER SPEC. ST01106A0002 & NOTE #4 OF DRAWING, & BAG IN PLASTIC.				7/21/67		7/21/67			
6		754		531		VERIFY CLEANING OPERATION #5				7/21/67		7/21/67			
7		754		531		VERIFY THAT ALL PREVIOUS INSP. OPER'S HAVE BEEN ACCEPT STAMPED				7/1/67		7/1/67			
8		789		16		HOLD FOR N/A		NOT CLASSIFIED							
						PROCESS COMPLETED MPO TO PLAN. & CONTROL.									
NO PCS. REC. 150		CONTROL CENTER 16-789		BY STOCKROOM NO. QP-2		CLERK CLOCK NO. 352430		DATE 7/24/67							

FORM N71-K-2 REV. 3-65

7736-5211

Figure III-1. Typical Completed Manufacturing Production Order (MPO)

7) Verify inspection.

8) Hold parts in Control Center for next assembly.

The MPO in Figure IV-1 gives these steps and indicates the degree of documentation and control used for CRD part fabrication.

In addition to the normal fabrication inspection, additional controls were imposed to assure product quality. These controls were formalized in a Quality Assurance Program Plan and are highlighted below:

- 1) Quality Assurance engineers attended all design reviews to insure that all significant factors affecting performance, reliability, and inspectability had been considered.
- 2) Fabrication and inspection activities were continually audited to assure adherence to inspection procedures and engineering requirements.
- 3) Quality Assurance maintained complete configuration control over all procured material, including source inspection and verification of raw material certification.
- 4) Quality Assurance did the training, examination, and certification of all personnel engaged in destructive and nondestructive inspection and testing.
- 5) The Quality Assurance Laboratory, in conjunction with Quality Assurance Engineering personnel, qualified weld procedures and certified that the procedures, personnel, and associated equipment were capable of producing welds of the desired quality level.
- 6) Product Control was responsible to assure that any instrument used to measure conformance to engineering requirements had evidence of current calibration status before inspection acceptance.
- 7) A Material Review Board (MRB) was formed to determine disposition of parts not conforming to engineering requirements. The MRB consisted of members of the Engineering Program Office and Quality Assurance staffs.

All nonconforming parts were classified by the MRB as either "major" or "minor." Those classified major but which allowed the nonconforming part to

ATOMICS INTERNATIONAL
A Division of North American Aviation Inc

QUALITY CONTROL
ACCEPTANCE PROCEDURE

NO 1110 0030 11
DATE: August 3, 1967
SUPERSEDES QCAP DATED Jan. 9, 1967

PART NO N69122043	REV	DESCRIPTION PIQUA MAGNETIC JACK POWER BOBBINS	PROGRAM PNPF RECOVERY	ORIGINATOR <i>[Signature]</i>	DATE 8-3-67
GO 7710	MATERIAL	WPO/PO	Noted below	SUPERVISOR <i>[Signature]</i>	DATE 8-3-67
EQUIPMENT				APPROVAL <i>[Signature]</i>	DATE 8-7-67
				APPROVAL <i>[Signature]</i>	DATE 8-7-67
				APPROVAL <i>[Signature]</i>	DATE 8-7-67
				APPROVAL <i>[Signature]</i>	DATE 8-7-67
RESP DEPT NO	SEQ NO	OPERATION DESCRIPTION			
		<u>SCOPE OF WORK</u>			
		This Quality Control Acceptance Procedure specifies the procedure to be followed in processing the resistance welded ground stud samples which represent the quality of production stud welds on Piqua Magnetic Jack Power Coil Bobbins made during a work shift.			
		<u>GENERAL</u>			
		Welding of the resistance welded ground stud preproduction samples and of studs on the bobbins shall be as required in ST0107NAC034, Para. 3.4 and delivered to the manufacturing control station, Eq-001, sequence 1 through 9 followed as necessary.			
(PART DELETED FOR PURPOSES OF THIS ILLUSTRATION)					
<u>TEST METHODS AND DRAWINGS</u>					
Prove S. S. Steel to ST0107NAC034, Welding Percussion Stud, Copper to Steel Weld Procedure #1191					
<u>Drawings:</u>					
N69122027, Hold Coil Bobbin Assembly					
N69122029 Grip Coil #1 Bobbin Assembly					
(PART DELETED)					
<u>EQUIPMENT</u>					
Baldwin LimaHamilton (BLH) Tensile Tester					
Omarc (Percussive Welder).					
<u>QUALIFICATION</u>					
As required by Weld Procedure #1191 and Para. 3.5.1.2 of Specification ST0107NAC034, (10 samples).					
<u>Acceptance</u>					
The three preproduction samples shall be visually inspected to the requirements of ST0107NAC034, Para. 3.4 and delivered to the manufacturing control station, Eq-001, sequence 1 through 9 followed as necessary.					
(PART DELETED)					

4-18-68 UNCL

7736-5212

Figure III-2. Example of Quality Control Acceptance Procedure
(PNPF Copper-Stud to Coil-Bobbin Weld Sampling Plan)

be used were forwarded to the AEC for their concurrence with the MRB decision; those designated minor but which allowed the nonconforming part to be used were forwarded to the AEC for their information. All operations associated with a major discrepancy were discontinued until AEC concurrence was obtained. (At the time of Program termination no major discrepant parts had been dispositioned for ultimate usage on the modified CRD's.)

Finally, acceptance procedures were set up by Quality Assurance personnel to define specific tests and/or inspections required by specifications or drawing requirements, and which were over and beyond inspection requirements listed on MPO's. In particular, these plans established sampling rates and schedules for the inspection of critical welds. Such welds were those which were either containment welds (seal welds) or ones that could not be inspected by conventional nondestructive methods to assure their integrity.

An example of such a Quality Control Acceptance Procedure is shown in Figure III-2. This procedure covers the tensile test sampling plan for the welding of the ground studs to the coil bobbins. This particular weld cannot be inspected by conventional radiography due to its geometry; consequently, the tensile test sample plan was utilized.

B. FABRICATION DEVELOPMENT

A review of the fabrication effort indicated two areas where development activity would be required. The first was in welding, particularly the dissimilar-material welds. Weld development is discussed in Section IV of this report.

The second area of fabrication development was in coil winding. Although the choice of wire, encapsulant, and process was based upon SNAP (Systems for Nuclear Auxiliary Power) experience, the modified CRD coil design imposed new conditions such as larger wire diameter, thicker coil cross-section, and the interaction of new material combinations which had not been previously encountered. Consequently, a coil-winding development program was undertaken, as discussed in the following paragraphs.

1. Coil-Winding Description

The high-temperature wire insulation system developed for use on SNAP components was selected for the power and indicator coils. This system

Figure III-3. Wet-Winding Operation

7568-18413

AI-AEC-TDR-12648

III-6

consisted of Fiberglas-insulated copper wire wet-wound with AI-1 cement encapsulant. Mica sheet served as ground insulation between the encapsulated wire and the coil bobbin. The wet-winding equipment is shown in Figure III-3.

2. Drying and Curing

Since the coil bobbins are fabricated from mild-steel stock, the element of corrosion was of prime consideration. The drying and curing of the wet-wound coils necessarily required subjecting the coils to an elevated temperature schedule for 16 hr. The moisture and steam generated from the encapsulant caused considerable corrosion of the mild-steel bobbins. A modified drying schedule was then worked out, with emphasis on reducing the time the bobbin and wires were exposed to the wet encapsulant. Several coils were wound and dried and the final drying schedule was evolved, as described in References 1 and 2. This drying schedule provides an essentially dried coil three hours after it is removed from the machine.

Since the drying schedule involves approximately 90 min at temperatures to 225°F, some consideration was given to corrosion of the conductor in this environment. Several samples of wire were taken from coils which had gone through the drying cycle and in which no noticeable corrosion had taken place.

Following the drying cycle the coils were cured to 800°F in vacuum. This temperature was sufficient to prevent future hygroscopic activity.

3. Starting and Crossover Leads

Originally the start leads for each coil were located along one pole face and protected with a mica sheet from the body of the coil. However, the thickness of the wire (0.050 in.) caused a poor wire lay in the coil. It became impossible to lay the wire in the coil cavity in a regular manner. For this reason slots were cut in the pole faces, diagonally from the crossover slot to the core of the bobbin. This slot was insulated with Fiberglas cemented in place with encapsulant. All subsequent coils were made with this technique. The lay of the wire was improved and the number of turns of wire for a given cavity was increased.

The multiple coils for the magnetic jack, made from one continuous length of conductor, required three crossovers during winding. These were made at

slots cut into the pole periphery. At each crossover the winding direction was reversed so that two coils were wound clockwise and two counterclockwise on each multiple coil. First attempts to make these crossovers and reverse the winding direction resulted in damage to the Fiberglas wire insulation. The relatively heavy (17-AWG) copper wire was difficult to work with and generally resisted attempts to provide a smooth lay of wire at the crossovers. Kinks and bends placed in the wires in this operation were difficult to remove. It thus appeared that an auxiliary device would be required to make the operation smoother. A tool (described in Reference 3) designed for this purpose was fastened to the bobbin at the crossover, and the wire was looped over the tool. The winding machine would then provide the leverage for reversal, with manual operation of the winding head making the crossover. This technique has proven quite successful.

4. Testing

After the drying and curing cycles had been firmly established, all subsequent coils were checked for insulation resistance at 50 volts dc and possible dielectric breakdown at 1000 volts dc at room temperature. Typical readings for these coils were 10^9 ohms at 50 volts and 5×10^8 ohms after 1 min at 1000 volts.

Six single-type power coils made especially for evaluation in hot organic were thermal cycled between room temperature and 800°F; coil resistances were monitored on a bridge, and insulation resistances on a megger at room temperature, and at 300, 600, and 800°F. The values are given in Table III-1.

Other tests conducted on this program included thermal cycle tests and mechanical shock tests. One multiple coil was subjected to 60 thermal cycles between 400 and 800°F in vacuum, with no apparent change in coil quality. Readings of coil and insulation resistances were taken at intervals during the 60 thermal cycles, but no significant change was noted in the readings.

The mechanical shock test consisted of dropping a multiple coil on the floor to determine the extent of damage. After a multiple coil had been dropped four times from about three feet, the coil was examined. Very little change was noted in the physical appearance of the coil proper, although the mild-steel

TABLE III-1
DATA ON PIQUA POWER COILS BEFORE
HOT ORGANIC TESTING

Temperature (°F)	Readings	Resistances	
		Coil (ohms)	Insulation (megohms)
Room	1	2.542	30,000 ↓
	2	2.551	
	3	2.544	
	4	2.603	
	5	2.570	
	6	2.559	
300	1	3.438	↓
	2	3.338	
	3	3.393	
	4	3.562	
	5	3.430	
	6	3.470	
600	1	4.950	190
	2	4.800	390
	3	4.854	280
	4	5.207	150
	5	5.027	150
	6	5.060	120
800	1	5.953	50
	2	5.817	30
	3	5.815	35
	4	6.271	25
	5	6.087	30
	6	6.093	46

bobbin showed areas of damage where the bobbin had contacted the floor. Subsequent measurements at 1000 volts indicated no change in the dielectric properties of the coil.

5. Training

Following successful development of coil winding, drying, and curing techniques a comprehensive operator training program was started to transfer acquired skills to fabrication personnel. As of Program termination, 54 coils had been completely wound with a yield in excess of 98%.

REFERENCES, SECTION III

1. "Wet Coil Winding - Piqua Magnetic Jack Coils," ST0613NA0036
2. "Coil Winding, Wet - Piqua Indicator Coils," ST0613NA0038
3. "Winding Development on Piqua Coils," NAA-SR-TDR-12343

IV. WELD DEVELOPMENT

This section of the report covers weld development associated with the CRD, a discussion of weld classification as related to service application, a tabulation of all welds, a summary of weld specifications and quality requirements, individual welds discussed in detail (with emphasis on the critical welds), and a summary of the welding status as of Program termination.

A. WELD CLASSIFICATIONS

Weld quality requirements are based on Atomics International Specification NA0107-023, "Welding, Fusion."⁽¹⁾ This general welding specification, discussed in more detail below, calls out 3 grades of welds; grades, classification, application, and examples are indicated in Table IV-1. Based on the specification, each weld in the CRD was reviewed during the design stage, and classified.

Assignment of a particular classification to a weld does not imply that a unique technique is used to make the weld; the same technique is used to make a weld regardless of its classification. The difference between welds Grade A, B, or C, is the type of inspection; inspection requirements are shown in Table IV-2.

Welds classified as Grade A have the more stringent inspection requirements. Specific details of weld quality requirements are discussed below.

The inspection requirements are not all-inclusive, and can be modified by a note on the fabrication drawings; for example, an additional inspection requirement on all Grade A welds used in the CRD is helium leak checking. In some cases, radiographic inspection is not practicable, and a sampling plan is used in lieu of x-ray. Specific inspection requirements for the CRD welds are discussed below.

B. CRD WELDS

The various CRD welds are given in Table IV-3 and are shown in Figures IV-1 through IV-10.

TABLE IV-1
CRD WELD CLASSIFICATION

Grade	Classification	Application	Example
A	Primary Structural	<ol style="list-style-type: none"> 1. Weld joints stressed to >75% of material capability. 2. A weld, the failure of which would endanger the safety of personnel. 3. A weld, the failure of which would result in a significant system failure. 4. A containment weld. 	MI cable-to-shell weld
B	Secondary Structural	<ol style="list-style-type: none"> 1. Weld joints stressed to 50 to 75% of material capability. 2. A dissimilar material weld which is not considered a Grade A weld. 	Upper housing assembly, attachment of grapple end to upper outer housing tube
C	Nonstructural	Weld joints stressed to <50% of material capability.	Thermistor cable support bracket

TABLE IV-2
CRD WELD INSPECTION REQUIREMENTS

Method of Inspection	Weld Classification		
	Grade A	Grade B	Grade C
Visual	X	X	X
Dimensional	X	X	X
Dye Penetrant	X	X	-
Radiographic	X	X	-

No.	Weld Name	Purpose of Weld	Seal Weld	Weld Grade	Materials Being Welded	Filler Material	Type Weld	Weld Thickness or Depth (in.)	Weld Procedure	No. of Welds Per CRD	AI Drawing No.	See Figure No.
1	MI Cable Guide Sleeve to Bracket	Hold MI cable guide sleeves in various brackets in upper section of control rod.	No	C	304-304	308 or 308L	Fillet	0.03	-	14	N69122010 & N69122011	1
2	MI Cable Termination Assy to Plug Support	Hold MI cable terminations in lower penetration to plug	No	C	304-304	308 or 308L	Fillet	0.03	-	13	N69122010	1
3	Ground Wire Adaptor	Hold ground wire adaptor in lower plug assembly housing	No	C	304-304	308 or 308L	Fillet	0.06	-	3	N69122010	1
4	Thermistor MI Cable to Cable Guide	Hold MI cable in cable entry guide at thermistor	No	C	304-316	316 or 316L	Fillet	0.03	-	2	N69122011	1
5	Thermistor and Lower Indicator Coil MI Cable to Cable Guide	Hold MI cable in cable guide at upper section of indicator coil assembly	No	C	304-316	316 or 316L	Fillet	0.03	-	2	N69122011	1
6	Position Coil Flange to Tube	Attach position coil lower flange to coil tube	No	B omit x-ray	304-304	308 or 308L	Groove	0.09	-	1	N69122012	2
7	Position Coil Sheath to Flange	Attach position coil outer sheath to lower flange	No	C	321-304	347	Butt	0.25-0.50	-	1	N69122012	2
8	Position Coil Adaptor to Tube	Attach position coil upper adaptor to coil tube	No	B omit x-ray	304-304	308 or 308L	Fillet	0.12	-	1	N69122012	2
9	Position Coil Index Pin	Attach index pin to adaptor	No	C	304-304	308 or 308L	Fillet	0.06	-	1	N69122012	2
10	Position Coil Spacer	Attach position coil spacer to coil tube	No	C	304-304	308 or 308L	Fillet	0.06	-	1	N69122012	2
11	Indicator Coil Collar to End Plate	Attaches end plates and outer ring (collar)	Yes	A limited x-ray	MT 1015-1020	Oxweld 65	Fillet	0.09	1183	4	N69122013	3
12	Indicator Coil End Plate to Tube	Attaches end plates to coil tube	Yes	A limited x-ray	1020-321	ER 312	Fillet	0.06	1182	4	N69122013	3
13	Indicator Coil Pinch-Off Tube to End Plate	Attaches pinch-off tube to coil end plate	Yes	A limited x-ray	1020-304	ER 312	Fillet	0.06	1182	2	N69122013	3
14	Indicator Coil Adaptor Tube to End Plate	Attaches MI cable adaptor tube to coil end plate	Yes	A limited x-ray	1020-304	ER 312	Fillet	0.09	1182	4	N69122013	3
15	Indicator Coil MI Cable to Adaptor Tube	Attaches MI cable to adaptor tube	Yes	A limited x-ray	316-304	ER 308	Fillet	0.03	1184	4	N69122013	3
16	Indicator Coil Plug	Seals pinch-off tube plug	Yes	A	304-304	None	Butt	0.02	1204	2	N69122013	3

Table IV-3. Control Rod Drive Welds (Sheet 1 of 3)

No	Weld Name	Purpose of Weld	Seal Weld	Weld Grade	Materials Being Welded	Filler Material	Type Weld	Weld Thickness or Depth (in)	Weld Procedure	No. of Welds Per CRD	AI Drawing No	See Figure No
17	Thermistor Cable Support Bracket	Attach cable support bracket to thermistor assembly	No	C	304-304	308 or 308L	Fillet	0.12-0.39	-	1	N69122014	4
18	Thermistor Cable Support Bracket Details	Weld for assembling detail parts to form bracket	No	C	304-304	308 or 308L	Fillet	0.06	-	5	N69122046	4
19	Cable Support Bracket Details	Attach cable support tube to plate	No	C	304-321	347	Fillet	0.06	-	2	N69122016	5
20	Plug Support Assy Details	Attach plug support sleeve to flange and plate	No	C	304-321	347	Fillet	0.06	-	4	N69122017	5
21	Plug Support Assy Index Pin	Attach index pin to plate	No	C	304-304	308 or 308L	Fillet	0.06	-	1	N69122017	5
22	Jumper Guide Assy	Attach flange to guide	No	C	304-321	347	Fillet	0.06	-	1	N69122020	6
23	Jumper Guide Pin	Attach pin to guide	No	C	304-321	347	Fillet	0.06	-	1	N69122020	6
24	Upper Housing Assy	Attach grapple end to upper outer housing tube	No	B omit x-ray	304-304	ER 308	Groove	0.25	1201	1	N69122021	6
25	Multi-Coil Inlay	Apply non-magnetic filler between pole pieces of multi-coil bobbin	Yes	A	MT 1015-Inconel 92	Inconel 92	Groove	0.20	1025	16	N69122027 N69122029 N69122037	7
26	Coil End Ring	Attach end rings to bobbin and shell	Yes	A omit x-ray, sample	MT 1015-A365	None	Electron Beam Butt	0.10	1216	24	N69122032 N69122033 N69122034 N69122035	7,8
27	Cover Plate	Attach wire termination cover plate to coil shell	Yes	A omit x-ray	MT 1015-A365	Oxweld 65	Fillet	0.03	1033	8	N69122032 N69122033 N69122034 N69122035	7,8
28	Screw	Seal coil screw to shell	Yes	A omit x-ray	MT 1015-1018	Oxweld 65	Fillet	0.03	1035	8	N69122032 N69122033 N69122034 N69122035	7,8
29	MI Cable Clip	Attach protective clip to coil assembly	No	C	MT 1015-304	312	Fillet	0.06	-	8	N69122032 N69122033 N69122034 N69122035	7,8
30	MI Cable to Shell	Attach MI cable to coil assy	Yes	A partial x-ray, sample	MT 1015-316	ER 312	Groove	0.045	1211	8	N69122032 N69122033 N69122034 N69122035	7,8

Table IV-3. Control Rod Drive Welds
(Sheet 2 of 3)

No.	Weld Name	Purpose of Weld	Seal Weld	Weld Grade	Materials Being Welded	Filler Material	Type Weld	Weld Thickness or Depth (in.)	Weld Procedure	No. of Welds Per CRD	AI Drawing No.	See Figure No.
31	Single Coil Form	Attach bobbin end pieces to make coil form	Yes	A	MT 1015-Inconel 600	Inconel 92	Groove	0.15	1178	4	N69122055 N69122056 N69122091 N69122092	8
32	Single Coil Surfacing	Provide surfacing on single coil shells for later weld	Yes	A	MT 1015-Hastelloy W	Hastelloy W	Groove	0.10	1215, Sheet 1	4	N69122061	8
33	Single Coil Bobbin to Shell	Provide seal between Inconel bobbin and shell	Yes	A	Inconel 600 Hastelloy W	None	EB Butt	0.10	1215, Sheet 2	4	N69122032 N69122034	8
34	Coil Stud	Attach ground stud to coil case	No	C	OFHC Copper-MT 1015	None	Percussive Stud	-	107NA0034	8	N69122027 N69122029 N69122037 N69122055 N69122056 N69122091 N69122092	7,8
35	Coil Case Tack Welds	Attach the various coil cases to each other	No	C	MT 1015-MT 1015	Oxweld 65	Groove	0.12	-	72	N69122043	9
36	Screen Weld	Attach screen to ring	No	C	304-304	308 or 308L	Fillet	0.06	-	8	N69122049	9
37	Wire Termination Weld	Weld Advac connectors back to back by means of guide which can then pass through cable support bracket and avoid short-circuiting wires	No	C	304-316	Hastelloy W	Fillet	0.03	-	4	N69122050	9
38	MI Cable -- Nickel Leadwire to Advac Connector	Provide seal at point where leadwire comes out of connector	Yes	A	Nickel-Nickel	308L	Fillet	0.05	CSI* 9920-14	28	ST686-N76001	10
39	MI Cable -- Nickel Leadwire to MI Cable Conductor	Provide electrical connection between nickel leadwire and cable conductor	No	C	Nickel-28% Nickel Clad Copper Wire	None	Butt	-	CSI* 9920-14	28	ST686-N76001	10
40	MI Cable -- Sealing Sleeve or Sealing Flange to Advac Connector	Provide seal and attach Advac connector to MI cable	Yes	A	316-316	308L	Fillet	0.015	CSI* 9920-14	28	ST686-N76001	10
41	MI Cable -- Sealing Sleeve or Sealing Flange to MI Cable Sheath	Provide seal and attach sleeve on flange to sheath	Yes	A	316-304	308L	Fillet	0.03	CSI* 9920-14	28	ST686-N76001	10
42	MI Cable -- Weld Clip	Attach weld clip to MI cable sheath	No	C	304-304	308L	3 place Tack	0.04	CSI* 9920-14	16	ST686-N76001	10
43	MI Cable -- Weld Sleeve to Sheath	Attach weld sleeve to cable sheath	No	C	316-304	308L	Fillet	0.04	CSI* 9920-14	4	ST686-N76001	10

*Continental Sensing, Inc., Melrose Park, Illinois

Table IV-3. Control Rod Drive Welds
(Sheet 3 of 3)

AI-AEC-TDR-12648
IV-7

Figure IV-1. Typical MI Cable Sleeve-Bracket Welds

7736-5217

Figure IV-2. Position Coil Welds

7736-5218

Figure IV-3. Indicator Coil Welds

7736-5219

Figure IV-4. Thermistor Cable Bracket Welds

7736-5220

Figure IV-5. Cable Support Bracket and Plug Support
Assembly Welds

7736-5221

Figure IV-6. Plug Guide Assembly and Upper Housing
Assembly Welds

7736-5222

Figure IV-7. Multicoil Welds

7736-5223

Figure IV-8. Single Coil Welds

7736-5224

Figure IV-9. Coil Case Tack, Screen, and Wire Termination Welds

7736-5225

Figure IV-10. MI Cable Welds

7736-5226

Table IV-3 identifies each weld, indicates its purpose, whether or not the weld is an organic seal weld, the weld grade, materials being welded, the required filler material, if any, type and size of weld, and the number of welds per control rod. Since Grade A welds require a welding procedure, documents covering same are identified. Cross-references to figures and fabrication drawings are also indicated.

Table IV-3 shows that there are 43 types of welds on each CRD: 17 types of Grade A, 3 types of Grade B, and 23 types of Grade C. On each CRD, there are 383 welds: 180 Grade A, 3 Grade B, and 200 Grade C. There are 19 different material combinations welded: 9 combinations use similar materials and 10 use dissimilar materials

Although the quantity of welds may appear large, it should be noted that many of the welds are lightly stressed material attachment welds. For example, 72 Grade C welds are required merely to attach the various coils to each other to provide the required joining and mechanical alignment.

C. WELD SPECIFICATIONS

AI Specification NA0107-023, "Welding, Fusion," was selected as the basis for CRD weld requirements. This specification had been used extensively and successfully at AI for weldments used in liquid metal service; it classifies 3 grades of weldment which adequately cover the various service requirements of the Piqua CRD welds, and personnel at AI are familiar with its usage.

No development work was required for Grade B and C welds since the quality requirements are lower than those for Grade A welds, and no difficulty was anticipated. Qualification of Grade B and C welds were not required; however, prior to making any weld, the weldor is certified for proficiency. NA0107-023 contains a weldor certification procedure which is similar to that required by Section IX of the ASME Boiler and Pressure Vessel Code.

Work was initiated in development and qualification of the various Grade A welds. It soon became apparent that difficulty in meeting porosity requirements was being experienced. This led to a complete review of porosity requirements and culminated in a relaxation of acceptance criteria from those

in NA0107-023 to those in AI Specification ST0607NA0021⁽²⁾ which are identical to the porosity requirements in Section III of the ASME Boiler and Pressure Vessel Code. The reasons for the difficulty and for relaxing the porosity requirements are indicated below.

It was also found that electron beam welds require a separate specification; AI Specification ST0607NA0019⁽³⁾ was written to fulfill this need. Similarly, the specialized percussion welding of the coil ground stud required a separate specification; ST0107NA0034.⁽⁴⁾ Finally, the weld requirements for the vendor-supplied MI cable were put directly into the procurement specification, ST686N76001.⁽⁵⁾

The acceptance criteria for all welds are shown in Table IV-4. Inspection criteria for all welds are shown in Table IV-5.

D. SUMMARY OF PORE SIZE CRITERIA

The previous ease of meeting the NA0107-023 pore requirements, when using austenitic stainless steels, was not being experienced in either the CRD weld procedure qualification or production part fabrication. This difficulty was associated principally with several of the joint geometries involving dissimilar metal welds of Inconel 600 to 1015 carbon steel and the filling of 1015 carbon steel multicoil bobbin assembly grooves with Inconel 92 filler metal. Difficulty was also noted in the mild-steel to austenitic-stainless-steel welds. It also became apparent that either excessive rework of parts or extensive weld development would be required if the NA0107-023 pore limit requirements were to remain in force.

As a result, a reevaluation of the stress analysis calculations was made on each of the control-rod, critical, seal-weld joints.⁽⁶⁾ Extensive effort was also placed on determining the maximum pore size allowable based on: (1) the calculated stress levels in these joints, (2) the experience of industry as related to pore size allowance in seal weldments, and (3) the judgment of two consultants on stress analysis and weld quality requirements, Dr. J. Lubahn from Colorado School of Mines, and Professor R. McCauley, Head of Ohio State University Welding Engineering Department and President of the American Welding Society.

-

•

•

•

Weld Classification											
Defect	Grade A-TIG		Grade A-EB			Grade A-MI Cable		Grade B		Grade C	
Joint Penetration	100%		100%			100%		100%		Not applicable	
Undercuts, Notches, and Overlap	None		None			None		Depth - 10% of t or 0.030 in. whichever is less Length - 10% of weld length (cumulative)		Depth - 25% of t* Length - 25% of weld length (cumulative)	
Build-up or Reinforcement	20% of t or 3/32 in. whichever is less		20% of t or 3/32 in. whichever is less			20% of t or 3/32 in. whichever is less		20% of t or 1/8 in. whichever is less		40% of t or 1/4 in. whichever is less	
Drop-thru or Melt-thru	t of 0.010 in. and less 50% of t t of 0.010 to 0.030 in. 25% of t t of over 0.030 in. 10% of t or 1/16 in. whichever is less		t of 0.010 in. and less 50% of t t of 0.010 to 0.030 in. 25% of t t of over 0.030 in. 10% of t or 1/16 in. whichever is less			t of 0.010 in. and less 50% of t t of 0.010 to 0.030 in. 25% of t t of 0.030 in. - 10% of t or 1/16 in. whichever is less		Same as Grade A except t of over 0.030 in. - 10% of t or 1/8 in. whichever is less		Not applicable	
Concavity (suck-back)	None		None			None		5% of t or 0.040 in. whichever is less		Not applicable	
Slag Inclusions or Lack of Fusion			Inclusions shall be evaluated as porosity. Incomplete fusion not allowed.			Inclusions shall be evaluated as porosity. Incomplete fusion not allowed.		Maximum length - 100% of t or 0.125 in. whichever is less Width 25% t		Not applicable	
t of											
Less than 1/4 in.	12% t or 0.015 in. whichever is less										
1/4 to 1/2 in.	0.025-in. maximum										
1/2 to 1 in.	0.050-in. maximum										
1 to 2 in.	0.100-in. maximum										
2 in. and greater	0.125-in. maximum										
Fillet Weld Leg Sizes	<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>		<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>
t of											
Less than 0.020 in.	t	3t	t	3t		t	3t	t	5t	t	5t
0.020 to 0.065 in.	t	2t	t	2t		t	2t	t	3t	t	3t
0.066 in. and greater	t	1.5t	t	1.5t		t	1.5t	t	2t	t	2t
Cracks	None detectable		None detectable			None detectable		None detectable		None detectable by visual examination	
Surface or Subsurface Porosity	†		§			0.005-in. maximum (corresponds to about 0.25T %)		Not applicable		Not applicable	
			Nominal Joint Thickness (in.)	Maximum Allowable Pore Size (in.)	Allowable Total Pore Index						
			0.059	0.020	160						
			0.094	0.036	240						
Metallic Inclusions	Evaluate as porosity		Evaluate as porosity			Evaluate as porosity		Not applicable		Not applicable	
Helium Leak Rate	1 x 10 ⁻⁷ cc/sec		1 x 10 ⁻⁷ cc/sec			1 x 10 ⁻⁸ cc/sec		Not applicable		Not applicable	

t designates base metal thickness of the thinnest member joined.

†The total area of porosity as determined from radiographic film shall not exceed 0.060T square inches in any 6-in. length of weld. If the weld is less than 6-in. long, the total area of porosity will be reduced in proportion.

The maximum pore dimension shall be 20% of T, or 1/8 in., whichever is smaller, except that an isolated pore separated from an adjacent pore by 1 in. or more may be 30% of T, or 1/4 in., whichever is less.

In any 1-in. length of weld or 2T, whichever is smaller, porosity may be clustered to a concentration four times that permitted by 0.06T. Such clustered porosity shall be included in the porosity in any 6-in length of weld which includes the cluster.

Aligned porosity shall be acceptable providing the summation of the diameter of the pores is no more than T in a length 12T or 6 in., whichever is less, providing each pore is separated by a distance at least 6 times the diameter of the largest adjacent pore. Aligned porosity indications shall be counted in the total area of permissible indications in any 6-in. length of weld.

§The maximum porosity size and total amount of porosity allowed in a single lineal inch of welded joint shall be in accordance with the total allowable index amounts listed below. The maximum allowable porosity size and total allowable porosity index amounts will vary according to the thickness of the thinnest joint member. The total porosity index shall be determined by adding the individual pore index numbers assigned to each pore according to its size. The assigned number shall be equal to the pore size in thousandths of an inch. The pore size shall be determined as the length of its greatest diametral dimension. Thus, a pore with 0.021-in. greatest dimension will be assigned an index number of 21. The smallest assigned pore index shall be one. In acceptable welds the total porosity index of existing porosity shall not exceed the amount listed below for any individual inch of joint length. The minimum distance between pores shall be two times the size of the largest adjacent pore. Conformance to this minimum distance requirement shall be established by assuming all porosity to be in one plane.

T designates weld thickness or size (See Table 3),

Table IV-4. CRD Weld Quality Requirements

Grade	Weld No. (from Table V-3)	Weld Name	Visual	Dimensional	Penetrant	Radiograph	Helium Leak	Other
A	-	Qualification Samples - all Grade A Welds	X	X	X	X	X	Metallographic examination at 40X required for TIG, 100X for EB
A	11	Indicator Coil Collar to End Plate	X	X	X	X	X	Radiographs evaluated for inclusions, porosity, and transverse cracks only. Due to fillet weld geometry, it is not possible to verify that full joint penetration to the theoretical and actual weld throat has been achieved. Metallographic examination of representative parts required to verify joint penetration.
A	12	Indicator Coil End Plate to Tube	X	X	X	X	X	
A	13	Indicator Coil Pinch-off Tube to End Plate	X	X	X	X	X	
A	14	Indicator Coil Adaptor Tube to End Plate	X	X	X	X	X	
A	15	Indicator Coil MI Cable to Adaptor Tube	X	X	X	X	X	
A	16	Indicator Coil Plug	X	X	X	X	X	
A	25	Multicoil Inlay	X	X	X	X	X	
A	26	Coil End Ring	X	X	X		X	Production welds not inspectable by radiography. Pre-production and post-production samples are fully inspected, including radiography and metallographic examination at 100X. (A production run is defined as 4 single or 4 multicoils) Failure of any sample is cause or rejection of the production lot.
A	27	Cover Plate	X	X	X		X	Production welds not inspectable by radiography. (These are lightly stressed final closure welds)
A	28	Screw	X	X	X		X	
A	30	MI Cable to Shell	X	X	X	X	X	Weld can only be radiographed for 60% coverage of porosity and nonmetallic inclusions, and 100% for tungsten inclusions. In addition, 3 consecutive samples are to be welded and accepted, to requirements of qualification samples, prior to production welding. If there is no production welding in a 7-day period, 3 new samples are required.
A	31	Single Coil Form	X	X	X	X	X	
A	32	Single Coil Surfacing	X	X	X	X		Helium leak testing performed at final assembly
A	33	Single Coil Bobbin to Shell	X	X	X		X	Production weld not inspectable by radiography. Pre- and post-production samples are fully inspected, including radiography and metallographic examination at 100X. (A production run is 4 single coils.) Failure of any sample is cause for rejection of the production lot.
A	38	MI Cable - Nickel Leadwire to Advac	X	X	X	X	X	
A	40	MI Cable - Sealing Sleeve on Sealing Flange to Advac	X	X	X	X	X	
A	41	MI Cable - Sealing Sleeve on Sealing Flange to MI Cable Sheath	X	X	X	X	X	
B	6,8,24	Grade B Welds	X	X	X			
C	34	Coil Stud	X	X				Three samples shall be prepared and shall be tested before and after each production run to verify a tensile strength of 10,000 psi minimum and a perpendicularity of $\pm 5\%$. Failure of any sample is cause for rejection of the production lot.
C	1-5 7,9 10,17-23, 29,34-37, 39,42,43	All Other Grade C Welds	X	X				

Table IV-5. CRD Weld
Inspection Criteria

Dr. Lubahn's appraisal was essentially that there was indeed a sound basis upon which to establish relaxed pore requirements in all the CRD welds. This was based upon information contained in a Westinghouse report.⁽⁷⁾ This report leads to the conclusion that the joint geometry has a far greater influence on performance than has porosity. Furthermore, porosity should have negligible influence on weld performance up to 10% pore fraction in the weld when pores are essentially spherical and isolated so that no two pores are closer than the diameter of the larger pore. All joint geometries, including critical seal welds appeared adequate when viewed with respect to the low number of expected duty fatigue cycles (20 cycles) for the Piqua CRD.

An analysis was then performed at AI using the basis suggested by Dr. Lubahn. This analysis included:

- 1) Determination of the gross stress field in the weld, (this work is reported in NAA-SR-TDR-12330),⁽⁶⁾
- 2) Estimation of the increase in general stress field due to presence of pores,
- 3) Estimation of the local stress concentration factors due to pores, and
- 4) From the above estimation, determination of cyclic strain range and resultant fatigue life as a function of pore size and distribution.

The analysis relating to 2, 3, and 4 above are contained in NAA-SR-TDR-12439.⁽⁸⁾ This analysis shows that:

- a) Pores up to $1/2 t$ (of thinner member) and separated by $<1 \times$ diameter of the largest pore occupying less than 10% of the weld volume are acceptable, (this condition presents a maximum localized stress concentration factor of 2.05),
- b) A condition such as in a) above would result in an overall stress factor of <1.25 in the total weld, and
- c) The condition of a) would enable a minimum fatigue life of 110 duty cycles in the highest stressed welds in the Piqua jacks. This is a factor of five greater than that expected in service. Consultation with Prof. McCauley assisted confirmation of the above discussed analysis.

1975M-1

7736-5227

10X

Figure IV-11. Indicator Coil Collar-to-End-Plate Weld

In modifying the original weld specifications, a degree of conservatism was adopted by using the pore size and distribution allowances used by the Rocketdyne Division of North American Rockwell, and as called out in Rocketdyne Specification RA0107-042,⁽⁹⁾ for electron beam welds. For TIG welds, Section III of the ASME Boiler and Pressure Vessel Code was used. For purposes of comparison, the original requirement for an isolated pore was a maximum size of 10% of the thinnest member joined, whereas the ASME code allows 30% and the Rocketdyne EB weld specification allows about 35%.

E. WELD DEVELOPMENT AND QUALIFICATION

Throughout the design stages of the CRD modification, all welds, regardless of classification, were continually reviewed with regard to the development and qualification which would be required. All Grade A welds required qualification, and all welds required some development (if only a practice run) to assure practicability. This section of the report discusses the development and qualification of the Grade A welds.

1. Indicator Coil Collar to End Plate Weld (Weld No. 11, Table IV-3; AI Weld Procedure 1183)

This is a mild-steel to mild-steel open corner joint. No difficulty was encountered in qualifying this weld. Figure IV-11 is a typical macrosection of this weld.

2. Indicator Coil End-Plate to Tube (Weld No. 12, Table IV-3; AI Weld Procedure 1182)

Each indicator coil has two mild steel end plates welded to the center tube, as shown in Figure IV-3. Originally, one end plate utilized a fillet weld; the other plate utilized a V-groove weld. Although both welds were qualified easily, it was subsequently found that the initial run of production parts were being rejected due to cracks, excessive porosity, and lack of fusion in the groove weld. The groove weld was changed to a fillet weld, requalified, and no further problems were encountered. Figure IV-12 is a typical macrosection of the qualified fillet weld.

2007M-2

7736-5228

9X

Figure IV-12. Indicator Coil End-Plate-to-Tube Weld

3. Indicator Coil Pinch-Off Tube and Adaptor Tubes to End Plate
(Weld No. 13 and 14; Table IV-3; AI Weld Procedure 1182)

These are 304 stainless steel to mild steel fillet welds. No difficulties were encountered in qualifying these welds.

4. Indicator Coil MI Cable to Adaptor Tube (Weld No. 15, Table IV-3;
AI Weld Procedure 1184)

This is a 316-304 stainless steel fillet weld; no difficulty was encountered in qualifying this weld.

5. Indicator Coil Plug (Weld No. 16, Table IV-3; AI Weld Procedure 1204)

The original design of the pinch-off tube required that the tube be crimped and the crimped end welded. However, experience at AI has shown that crimping tubes of this size sometimes cracks the tube. Consequently, the design was changed to provide for insertion and welding of a tapered seal plug into the open tube end. No difficulty was experienced in qualifying the weld.

6. Multicoil Inlay (Weld No. 25, Table IV-3; AI Weld Procedure 1025)

This is a procedure for depositing Inconel 92 filler metal in a groove machined in 1015 carbon steel. The final machining of the hold-and-grip coil bobbins leaves the Inconel 92 as a nonmagnetic insert between mild steel magnetic pole pieces.

During initial development work, 32 grooves were filled with Inconel 82 filler material by using the machine TIG process with a stringer bead technique. Radiographs of these joints revealed cracks in the weld metal. Subsequent metallographic examination showed there were hot short cracks. Four grooves were then filled by the metal arc process using Inconel 192 electrodes, which are the equivalent of Inconel 92 filler wire used with the TIG process. These joints exhibited cracks and porosity when radiographed; consequently the metal arc process was eliminated from the list of possible processes.

Inconel 92 filler material was then used with the machine TIG process. One crack was experienced; this was a transverse, low temperature stress crack. Lack of fusion difficulties were eliminated by meticulous grinding to fair in the deposited bead between each pass. Four grooves were filled to qualify the Weld Procedure.

A production run of approximately ten bobbins (40 grooves) resulted in a heavy incidence of lack of fusion and porosity. More development welds were made by use of an oscillating torch for the first two passes of each groove. Higher welding current was used with more wire. The thinking thus far was to keep the heat input as low as possible to allow the weld bead to cool rapidly to avoid hot cracks in the weld. This technique was successful; consequently, four grooves were filled in accordance with the revised variables to qualify the revised procedures.

Production was resumed. The percentage of acceptable parts, including those bobbins that were repaired, was approximately 85%. The rate of production, however, was very slow. In the meantime, work on another weld procedure revealed that hot cracks were not obtained when a large weld bead was deposited. As a result of this discovery, more development work was performed with the bobbins to increase the rate of production.

Development work was directed to fill the groove with the least number of passes. Some grooves were filled with one pass. However, because of the lack of up and down slope control on the wire feeder, it was not possible to obtain a satisfactory overlap (the area in which the start and stop portions of the weld bead come together). The procedure that gives the best results is a two-pass weld with the first pass being machined to provide a uniform configuration for the second pass. The sequence of welding is important to prevent circumferential cracks in the weld due to longitudinal shrinkage of the bobbin.

Final qualification of the weld procedure was met by filling the grooves according to the weld procedure, and having the part machined to the rough machining dimensions. The welds were then dye penetrant inspected on the ID and OD and radiographically inspected. The specification allows repairs to be made at this point as long as the discrepancy does not exceed 5% of the length of the weld. After the part was acceptable, it was stress relieved and machined to the final dimensions. It was again dye penetrant and radiographically inspected and helium leak tested. No weld repairs are acceptable at this point. The bobbins used in qualification of the weld procedure were sectioned and microscopically examined for microfissuring and other discontinuities. None were found.

7. Coil End Ring Welds (Weld No. 26, Table IV-3; AI Weld Procedure 1216)

At each end of the multicoil and at one end of the single-coil bobbins, a closure weld is made between the bobbin and the shell by means of a seal ring. Originally, a TIG weld was to be used between these mild steel parts. However, early development work indicated that the Mica used inside the coil for insulation was being severely damaged due to heat input from the welding process. Consequently, the weld process was changed from TIG to Electron Beam (EB).

Development effort on the EB weld process was concentrated on establishing machine variables required to achieve a satisfactory weld. Joint fitup and cleanliness were found to be critical. Once all variables had been properly determined, qualification was achieved.

8. Cover Plate Weld (Weld No. 27, Table IV-3; AI Weld Procedure 1033)

This weld was originally a mild-steel to mild-steel fillet weld. The original qualification was easily accomplished after one preliminary practice weld.

The first two production welds were made on the prototype control rod. Both of these welds failed the helium leak check. Two new samples were then made, and although these samples passed the leak test, they were rejected on the basis of visual inspection of the back side of the weld. Inspection disclosed that the requirement for backup inert gas had been overlooked.

Since it was necessary to requalify the weld, one additional change was made; the fillet geometry was modified so that the "built-in crack" was not aligned in the direction of principal stress.

With the addition of backup gas and the joint geometry modification, requalification testing was initiated. Two successive attempts to requalify failed due to excessive isolated porosity. Program termination precluded further effort on this weld. No significant difficulty in requalifying would be anticipated; only a slight change in welder technique to account for the additional cooling effect of the backup gas should be required.

Figure IV-13 is a macrosection of a typical weld.

Figure IV-13. Cover Plate Weld

Figure IV-14. Screw Weld

9. Screw Weld (Weld No. 28, Table IV-3; AI Weld Procedure 1035)

This was originally a mild-steel to stainless-steel fillet weld. Although initial qualification was accomplished without any problems, subsequent practice welds exhibited cracking. The screw material was changed to mild steel, and the weld requalified. Figure IV-14 is a macrosection of the qualification weld.

10. MI Cable to Shell Weld (Weld No. 30, Table IV-3; AI Weld Procedure 1211)

The MI cable to shell weld is considered to be the most critical seal weld in the CRD assembly due to thermal stresses. The weld consists of joining a 316 stainless steel MI cable sleeve to the 1015 steel coil outer shell.

Original weld qualification for this joint was based on achieving a minimum 0.050-in. weld thickness.

Qualification comprised welding five simulated joints. The completed welds were subjected to visual and penetrant inspection and macro-examination.

In conjunction with the qualification, work was performed to determine the effect of the "stack up" of materials on the joint as a whole. One task was concerned with the effect of accumulated weld shrinkage on the admixture of materials; the other with the actual production welding conditions.

The first task was to determine the effect of the addition of various materials and the accumulated shrinkage stresses on the whole joint. A specimen was made and weld beads of the following materials were deposited in sequence, one on top of another: Hastelloy W, Inconel 600, and type 312 stainless steel. Not only were the materials mixed but the shrinkage of the two weld beads put residual stresses into the specimen, particularly in the corners. Sections were taken through the weld beads for microscopic examination. No microfissures or detrimental defects were found in the specimens.

The task of determining the effect of welding across a mixture of mild steel, Inconel 600, and Hastelloy W, including an electron beam weld between the Hastelloy W and the Inconel 600, was accomplished by making a specimen which was part of an electron beam weld qualification. Five simulated MI cables were welded into the specimen. Each weld was visually and dye penetrant inspected and then sectioned for microscopic examination. These tests failed to reveal any defects.

At this point, it was discovered that the requirement for radiographic inspection of the qualification samples had been inadvertently omitted. Consequently, on 7-20-67, two additional sample welds were made. These two samples were to be radiographically inspected, and then metallographically examined for the 0.050-in. penetration requirement.

The results (and subsequent test results), are shown in Table IV-6. Not only did the radiograph indicate unacceptable amounts of tungsten, but the metallographic examination indicated that the required penetration of 0.050 in. had not been achieved.

While these results were being evaluated, it was noted that the backup supplier of MI cable had submitted a design of the weld sleeve which differed slightly from that being furnished by the prime supplier. Stress analysis⁽⁶⁾ indicated that the minimum penetration required for the alternate sleeve would be 0.054 in. Since simulated parts of the alternate design were available, four development welds were made on 8-3-67. The electrode size was changed from 0.04 to 0.06-in. diameter for these welds. The results shown in Table IV-6 indicate that acceptable radiographs were obtained, but the required penetration was not obtained.

On 8-11-67, a breakdown in communications occurred, and parts for two of the prototype coils, Lift- and Hold-Coil No. 2, were welded using parts from the prime supplier of MI cable having a 0.050-in. penetration requirement. An unauthorized 2-pass weld was used. (It should be noted that, since this is a manual weld, the number of passes is not considered an "essential" variable by specification. The weldor was not making an unauthorized deviation. However, since the weld was originally qualified as a single pass weld, controls were established so that all subsequent welds would be made with a single pass.)

One of the preproduction, and one of the postproduction samples failed to meet the minimum requirements of helium leak and weld undercut. The prototype parts were therefore rejectable. However, it was decided not to scrap these parts, but to allow them to be used for the prototype control rod test, noting that they were not representative.

Date	Sample No.	Purpose	Type Joint	Filler	X-Ray	Dye Penetrant	He Leak	Visual	Minimum Penetration	Comments
~7-20	17	Sample	I	312	W* W	- -	- -	- -	- 0,047	0,050 Penetrant required, 0,04-in. electrode used
~8-3	- - -	Develop	II	312	OK OK OK OK	- - - -	- - - -	- - - -	OK OK 0,047 0,049	0,06-in. electrode used, 0,054-in. penetration required
8-11	- - -	Pre-sample	I	312	OK OK OK	OK OK OK	Leak OK OK	Undercut OK OK	0,050 0,054 OK	2-Pass weld used
	-	Post-sample	I	312	-	Failed OK	Leak OK	Undercut OK	OK	
8-11	Lift 2 Hold 2	Proto-type	I	312	- -	OK OK	OK OK	OK OK	- -	2-Pass weld used
8-16	- - - -	Qual	II	312	W W OK OK OK	OK OK OK OK OK	OK OK OK OK OK	OK OK Undercut Undercut OK	0,054 min ↓ 0,067 max	2-Pass weld, 0,054 min required
10-3-67	4-A 4-B 4-C	Day 1	III	312	OK OK OK	OK OK OK	OK OK OK	OK OK OK	0,063 0,063 0,063	Crack — oxide fold Welder did not use qualified variables. Backup gas not used.
10-13-67	- - -	Practice	III	312	OK W OK	- - -	- - -	- - -	0,043 - -	
10-18-67	6-A 6-B 6-C	Day 1	III	312	0,012 W Crack OK	OK OK OK	OK OK OK	OK OK OK	0,069 0,071 0,067	Crack located in base metal
10-20-67	6-D 6-E 6-F	Day 1	III	312	OK 0,010 W Crack OK	OK OK OK	OK OK OK	Undercut Undercut OK	0,054 0,036 0,054	Crack in base metal
10-26-67	- - -	Develop	IV	312	Porosity OK OK OK	OK OK OK	OK OK OK	OK Undercut OK	- - -	
10-31-67	- - -	Develop	IV	312	Porosity Porosity Porosity	OK OK OK	OK OK OK	Undercut Undercut Undercut	- - -	
~11-3	A-10 C-10 H-10 D-10	Develop	V	304 Insert	OK 0,015 W OK OK	OK OK OK OK	- - - -	OK OK OK OK	0,068 - - 0,050	35% Thinning at sleeve
11-6-67	E-9 E-10 G-7 C-9 H-7	Develop	V	310 Insert	Crack 0,010 pore 0,010 pore OK Crack	OK OK OK OK Failed	OK OK OK OK Leak	- - - - -	- - - - -	
11-7-67	A-9 E-7 F-7 D-9 A-4 B-4 C-4 D-4	Develop	V	310 Insert	OK OK OK OK Crack 0,008 W OK Crack	OK OK OK OK OK OK OK	OK OK OK OK OK OK OK	OK OK OK OK OK OK OK	0,049 0,051 0,048 0,058 - - - -	Crack not found after 7 cuts and polishes
~11-8	G-4 D-8 E-8 H-8	Develop	V	Nioro Braze	0,015 W 0,027 pore OK OK	OK OK OK OK	OK OK OK OK	OK OK OK OK	- 0,050 0,054 0,048	Scattered porosity through all samples Crack
11-13-67	Z-1 Z-2	Practice	V	309 Insert	- -	OK OK	- -	OK OK	OK OK	
11-13	12-A 12-B 12-C 12-D 12-E	Qual	V	309 Insert	OK OK Crack OK OK	OK OK OK OK OK	OK OK OK OK OK	OK OK OK OK OK	0,054 0,054 0,054 0,054 0,050	Crack not found after 9 cuts and polishes 2 Cracks, 0,015 and 0,003-in. long, possibly due to burr on sleeve
11-15	H-12 F-12 K-12 G-13 H-13 A-14 B-14 C-14	Develop	V	309 Insert	0,010 P, 0,010 W Crack OK 0,015 pore OK OK 0,010 W Crack	OK OK OK OK OK OK OK	- - - - - - -	OK OK OK OK OK OK OK	0,052 0,035 0,038 0,048 0,046 0,060 0,052 0,067	Crack not found after 8 cuts and polishes 0,002-in. Crack 0,017-in. Crack
11-16-67	D-14 E-14 EE-14 F-14 G-14 H-14 A-15 B-15 C-15 D-15 E-15 F-15	Develop	VI	309 Insert	OK 0,015 pore 0,010 pore 2 - 0,010 pore OK OK 0,015 W OK 0,010 pore 0,018 pore 0,015 pore 2 - 0,010 pore OK	OK OK OK OK OK OK OK OK OK OK OK OK	- - - - - - - - - - - -	OK OK OK Undercut OK OK OK OK OK OK OK	0,052 0,048 0,040 0,039 0,042 0,048 0,046 0,033 0,061 0,046 0,040 0,073	Cu start block used Cu start block used
11-17	2-G 2-H	Develop	VI	312	0,015 pore OK	OK OK	- -	OK OK	0,046 0,065	
11-21	16-A 16-B 16-C 16-D 16-E 16-F 16-G	Develop	VI	309 Insert	2 - 0,010 pore OK 4 - 0,010 pore 0,010 pore 0,005 W 0,005 W, 0,010 P OK	OK OK OK OK OK OK OK	- - - - - -	OK OK OK OK OK OK OK	0,054 0,081 0,065 0,050 0,062 0,054 0,066	
12-1	20-D 20-A 20-B 20-C 20-P	Develop	V	309 Insert	0,010 P, 0,008 W OK 0,010 pore 0,005 pore OK	OK OK OK OK OK OK OK	- - - - -	OK OK OK OK OK	0,062 0,058 0,058 0,062 0,066	
12-1	19-A 19-B 19-C 19-D 19-F	Develop	VI	309 Insert	0,010 pore 0,010 pore 2 - 0,010 1 - Disp 2 - 0,010 pore 0,020 pore	OK OK OK OK OK OK OK	- - - - -	OK OK OK OK OK	0,073 0,088 0,065 0,077 0,046	0,015 in. crack
12-4	20-E 19-E 19-G 19-H	Develop	VI	312	0,010 pore 0,010 pore 0,010 pore 0,010 P, 0,010 W	OK OK OK OK OK	- - - -	OK OK OK OK	0,063 0,060 0,061 0,056	
≈12-7	17-H 18-F 18-G 18-H	Develop	VI	90% Ag 10% PD Braze	0,015 pore OK Crack OK	OK OK OK OK	OK OK OK OK	OK OK OK OK	0,052 0,062 0,065 0,040	Crack not found by met. — Due to geometry of fitup. Showed as crack on X-ray.

*W indicates tungsten

TYPE I AND III JOINT (V GROOVE)
TYPE II SAME BUT 0.060 IN IS 0.095 IN.

TYPE IV JOINT (J GROOVE)

TYPE V JOINT (1/2 V GROOVE)
SAME DIM. AS TYPE I

TYPE VI JOINT
(1/2 V GROOVE AND THICK
SHOULDER SLEEVE)

TYPE I REQUIRES 0.050-IN. PENETRATION
TYPE II REQUIRES 0.054-IN. PENETRATION
TYPE III, IV, V, AND VI REQUIRE 0.045-IN.
PENETRATION

Table IV-6. Piqua Control Rod
MI Cable to Shell Weld
(Data from 7-20-67 to present)

On 8-16-67, an attempt was made to qualify the 2-pass weld by using parts having a minimum penetration requirement of 0.054-in. Of the five samples made, two failed due to excessive tungsten inclusions, two failed due to weld undercut, and one was satisfactory.

At this point, agreement was reached with the backup vendors of MI cable to use the same sleeve design as that of the prime supplier. Also, a review of the stress analysis calculations⁽⁶⁾ revealed that the minimum weld thickness could be dropped to the calculational minimum of 0.045 in. with no loss in integrity.

On 10-3-67, an attempt was made to both qualify the weld and produce satisfactory preproduction samples. This work was done simultaneously due to schedule considerations. All samples were satisfactory except for one which exhibited an oxide fold type crack. Investigation revealed that the welder had deviated from previously established variables (e.g., electrode, size, current), and inadvertently had not used backup purge gas.

Following a practice run on 10-13-67, qualification and preproduction samples were attempted again on 10-18-67 and 10-20-67. The results are shown in Table IV-6. As can be seen, parts were rejectable due to tungsten inclusions, undercut, and inadequate penetration.

The weld joint configuration was then changed from a V-groove to a J-groove, and development samples were welded on 10-26-67 and 10-31-67. As can be seen from Table IV-6, the results were unsatisfactory due to excessive porosity and weld undercut.

It was now becoming obvious that the qualification of this weld was going to be extremely difficult, particularly if a procedure with a high yield was to be developed. Therefore, weld development proceeded along several concurrent paths. These were:

- 1) Use the manual weld process, but including use of a consumable filler material insert,
- 2) Attempt to qualify as above (manual weld with manual feed of filler wire),

2022M-1

8X

2022M-1

15X

2022M-1

160X

7736-5231

Figure IV-15. MI Cable-to-Shell Weld, Sample No. A-14

AI-AEC-TDR-12648

IV-34

- 3) Change to a brazing process,
- 4) Change to an automatic welding process, and
- 5) Improved inspection techniques.

Further discussion is contained in the following paragraphs.

a. Use of Consumable Filler

Welds were made by using: a 304-stainless steel insert on 11-3-67; a 310 insert on 11-6-67 and 11-7-67; and a 309 insert on 11-13-67, 11-15-67; 11-16-67, 11-21-67, and 12-1-67. The results are shown in Table IV-6.

The 304 insert weld was used primarily to test feasibility, since 304 would not normally be the choice of a filler material, but was quickly available.

The 310 insert welds were in general unsatisfactory due to cracking, excessive porosity, and excessive tungsten inclusions.

Changing to 309 (which is more of a ferrite former than 310) did not seem to alleviate the problem, nor did slight changes in weld geometry.

At program termination, plans were underway to obtain 312 insert material. The use of 312 inserts would have necessitated a special mill run, since this material is not available in the size required to make an insert. Since 312 is the best ferrite former for this weld, some degree of optimism can be expressed, but making satisfactory welds using 312 inserts has yet to be demonstrated.

Figure IV-15 shows macro- and microsections of Sample A-14. The MI cable does not appear in the section since it was removed. Also, the 8X magnification photo is a mirror image of the 15X and 160X photos due to the lens system used. Note the smooth weld, showing no undercut or thinning, and the penetration which was achieved. Also note that the crack does not quite come to the surface of the weld.

b. Use of Filler Wire

One final group of sample welds was made on 12-4-67 by using the previously utilized manual process but a thick shoulder sleeve; the Type VI joint is shown on Table IV-6. Although welder proficiency had improved, the welds were still unacceptable due to excessive porosity and tungsten inclusions.

c. Brazing

Two sets of samples were made by brazing. One set, made 11-8-67 used an 80%-gold, 10%-nickel braze. The other set, made 12-7-67 used a 90%- silver, 10% palladium braze material. All samples were made by the TIG torch method. In the TIG torch method, the braze material is put in place, and the electrode from a TIG process weld machine is used to melt the braze material.

As shown in Table IV-6, neither braze material produced satisfactory results; however, only a limited number of samples are available, and no conclusion regarding the adequacy of this process should be made.

d. Automatic Welding

An effort was made to locate or build a fixture for automatic welding. At the time of program termination, no suitable fixture had been found.

e. Improved Inspection Techniques

One of the major problems with this critical seal weld was the fact that the production parts could not be fully inspected. Depth of penetration could be assumed to be met consistently once the weld procedure is qualified, based upon metallographic examination of preproduction samples. Therefore, a program was initiated to determine to what level production parts could be radiographed. A complete coil with MI cable-to-shell weld was made, and defects (pores) were put into the weld by drilling holes. The resultant parts were radiographed. The results are reported in Reference 10 and show that the entire production weld can be radiographed for tungsten inclusions and that half the weld can be radiographed for porosity.

In conclusion it can be stated that as of program termination the development work leading to qualification of the MI cable-to-shell weld was not complete. Brazing, automatic welding, and 312 insert welding should be continued concurrently to achieve the required qualification status.

11. Single Coil Form Weld (Weld No. 31, Table IV-3; AI Weld Procedure 1178)

This weld was designed for use in joining the Inconel 600 sleeve to the 1015 carbon steel sleeve so as to complete a single coil bimetallic bobbin. A V-groove weld preparation was used. The procedure was qualified by using the machine TIG process with Inconel 92 filler.

12. Single Coil Surfacing and Single Coil Bobbin to Shell (Weld No. 32 and 33, Table IV-3; AI Weld Procedure 1215)

As was the case with the coil end ring welds, the original weld between the Inconel 600 portion of the single coil and the single coil case was to be made by the TIG process. However, it was found that the heat input from the TIG process was damaging the coil mica insulation, and the process was changed to electron beam (EB) welding.

The EB welding was originally subcontracted to the Rocketdyne Division of North American Rockwell. During the development phase, Rocketdyne experienced considerable difficulty with this weld, attributing the major problem to the basic incompatibility between Inconel 600 and mild steel. This condition would result in a weld joint of unpredictable quality, a situation which existed because of the inability to accurately control the relative degree of dilution by the dissimilar metal alloys in the weld zone. In areas where dilution of the weld zone by the mild steel was not within maximum limits, the propensity toward cracking was apparent. At the time of subcontract termination, efforts were being made at Rocketdyne to achieve dilution control by displacing the weld beam from the weld centerline.

When the development work was reinitiated at AI, it was decided that a surfacing approach, to eliminate the metallurgical incompatibilities, would have the best chance of success. Development work with surfacing materials was begun by selecting and metallurgically evaluating candidate surface materials with respect to compatibility with the 1015 mild steel. The materials selected were known to be compatible with the Inconel 600 alloy. Stringer bead overlays employing a manual TIG process were deposited on a thick section of mild steel which was representative of the 1015 steel material used for production components. The surfacing materials deposited were Inconel Types 62, 82, 92, and Hastelloy W.

During deposition of the overlays, it was the operators' observation that Hastelloy W and Inconel 62, in that order, were the most easily controlled. The puddles were clean and sufficiently fluid to exhibit good melting and fusion to the carbon steel. A maximum interpass temperature of 350°F was maintained during overlay welding. Following welding, longitudinal and transverse sections for

metallurgical analysis were removed. The results indicated that the Hastelloy W is the most compatible with respect to the structure of the as-deposited metal above the dilution zone and can be used to achieve a gradual metallurgical transition into the parent metal. The remaining candidates indicated, to varying degrees, a relatively sharp, well-defined boundary between the parent mild steel and the deposit which formed the overlay. With the exception of one transverse section of the Inconel 82 overlay, no microfissures were observed. Microhardness surveys were made across the fusion zones to confirm the metallographic observations. These results indicate that microhardness transverses of both the Hastelloy W and Inconel 82 are relatively uniform. Because of the microfissuring tendency, however, the Inconel 82 was eliminated from contention. As a result, Hastelloy W was selected for the surfacing material.

Developmental effort for the EB weld was concentrated on fitup, cleaning, machine settings, and beam focus. After many development welds were made, adequate variable control was established, and qualification was accomplished. Figure IV-16 is a macrosection of this weld.

8111-7-1

14X
7736-5232

Figure IV-16. Single-Coil Surfacing and
Bobbin-to-Shell Weld

13. MI Cable Welds (Weld No. 38, 40, and 41, Table IV-3; CSI Weld Procedure 9920-14)

All development and qualification work upon the MI cable welds was performed by the vendor, Continental Sensing, Inc., Melrose Park, Illinois.

The vendor experienced problems with cracking, porosity, and tungsten inclusions during his early efforts. These problems were solved by imposing cleanliness requirements, and by the use of proprietary chill blocks and welding fixtures.

Prior to starting the production run of MI cables, the vendor had been instructed to deliver to AI, 8 sample cables made to qualified procedures. These cables were delivered and subjected to an engineering evaluation which established that the various welds were qualified. Prior to notifying the vendor to proceed with the production run of MI cables, the CRD program was terminated.

Two backup vendors were also attempting to manufacture MI cable. These vendors, Rama Industrial Heater Co., San Jacinto, California, and Scientific Engineering and Manufacturing Co., Inc., North Hollywood, California, were not able to submit sample cables for evaluation prior to CRD program termination.

F. WELDING STATUS AT PROGRAM TERMINATION

At the time of program termination, all welding problems with the exception of the MI cable to shell weld, had been adequately resolved. Additional development work would have led to qualification of the MI-cable-to-shell weld.

Table IV-7 shows the status of welding at the time of program termination. The prototype control rod, which consists of only the Magnetic Jack Portion of the CRD had 80% of the welding completed. The 17 complete CRD's had 10% of the welding completed.

TABLE IV-7
WELD STATUS AT CRD PROGRAM TERMINATION
(Sheet 1 of 2)

Weld Number	Weld Name	Weld Grade	Qualification Status	Welding Status			
				Prototype		Production	
				Required	Made	Required	Made
1(a)	MI Cable Guide Sleeve to Bracket	C	Not applicable	Not applicable		238	0
2(a)	MI Cable Termination Assembly to Plug Support	C	Not applicable	Not applicable		221	0
3(a)	Ground Wire Adaptor	C	Not applicable	Not applicable		51	0
4(a)	Thermistor MI Cable to Cable Guide	C	Not applicable	Not applicable		34	0
5(a)	Thermistor and Lower Indicator Coil MI Cable to Cable Guide	C	Not applicable	Not applicable		34	0
6	Position Coil Flange to Tube	B	Not applicable	Not applicable		17	17
7	Position Coil Sheath to Flange	C	Not applicable	Not applicable		17	15
8	Position Coil Adaptor to Tube	B	Not applicable	Not applicable		17	17
9	Position Coil Index Pin	C	Not applicable	Not applicable		17	17
10	Position Coil Spacer	C	Not applicable	Not applicable		17	17
11(b)	Indicator Coil Collar to End Plate	A	Qualified	Not applicable		68	0
12(b)	Indicator Coil End Plate to Tube	A	Qualified	Not applicable		68	0
13(b)	Indicator Coil Pinch-off Tube to End Plate	A	Qualified	Not applicable		34	0
14(b)	Indicator Coil Adaptor Tube to End Plate	A	Qualified	Not applicable		68	0
15(b)	Indicator Coil MI Cable to Adaptor Tube	A	Qualified	Not applicable		68	0
16(b)	Indicator Coil Plug	A	Qualified	Not applicable		34	0
17(c)	Thermistor Cable Support Bracket	C	Not applicable	Not applicable		17	0
18	Thermistor Cable Support Bracket Details	C	Not applicable	Not applicable		85	85
19	Cable Support Bracket Details	C	Not applicable	Not applicable		34	34
20	Plug Support Assembly Details	C	Not applicable	Not applicable		68	60
21	Plug Support Assembly Index Pin	C	Not applicable	Not applicable		17	15

(a) Simple similar metal bracket type welds No problems anticipated.

(b) Two indicator coil assemblies were made, except for weld Nos. 11, 15, and 16 for Developmental Tests Parts were made using qualified weld procedures No problems encountered, and none anticipated for production run.

(c) Same type of weld as No. 18, below. No problems anticipated.

AI-AEC-TDR-12648
IV-40

TABLE IV-7
WELD STATUS AT CRD PROGRAM TERMINATION
(Sheet 2 of 2)

Weld Number	Weld Name	Weld Grade	Qualification Status	Welding Status			
				Prototype		Production	
				Required	Made	Required	Made
22(d)	Jumper Guide Assembly	C	Not applicable	Not applicable		17	0
23(d)	Jumper Guide Pin	C	Not applicable	Not applicable		17	0
24(e)	Upper Housing Assembly	B	Not applicable	Not applicable		17	0
25	Multi-Coil Inlay	A	Qualified	16	16	272	124
26	Coil End Ring	A	Qualified	24	24	408	0
27(f)	Cover Plate	A	Not qualified	8	2	136	0
28	Screw	A	Qualified	8	0	136	0
29	MI Cable Clip	C	Not applicable	8	2	136	0
30(g)	MI Cable to Shell	A	Not qualified	8	2	136	0
31	Single Coil Form	A	Qualified	4	4	68	24
32	Single Coil Surfacing	A	Qualified	4	4	68	6
33	Single Coil Bobbin to Shell	A	Qualified	4	4	68	0
34	Coil Stud	C	Not applicable	8	8	136	55
35	Coil Case Tack Weld	C	Not applicable	72	0	1224	0
36	Screen Weld	C	Not applicable	Not applicable		136	136
37(h)	Wire Termination	C	Not applicable	Not applicable		68	0
38	MI Cable-Nickel Leadwire to Advac Connector	A	Qualified	56	56	476	0
39	MI Cable-Nickel Leadwire to MI Cable Conductor	C	Not applicable	56	56	476	0
40	MI Cable-Sealing Sleeve or Sealing Flange to Advac Connector	A	Qualified	56	56	476	0
41	MI Cable-Sealing Sleeve or Sealing Flange to MI Cable Sheath	A	Qualified	56	56	476	0
42	MI Cable-Weld Clip	C	Not applicable	32	32	272	0
43	MI Cable-Weld Sleeve to Sheath	C	Not applicable	8	8	68	0

(d) Same type of welds as No. 20. No problems anticipated.

(e) Conventional similar material pipe type butt weld using V-groove joint preparation. No problems anticipated.

(f) Qualification in progress at time of program termination.

(g) Further development work on weld required.

(h) Simple attachment weld. No problems anticipated.

REFERENCES, SECTION IV

1. AI Specification NA0107-023, "Welding, Fusion"
2. AI Specification ST0607NA0021, "Weld Porosity Requirements, Control Rod, PNPf"
3. AI Specification ST0607NA0019, "Welding, Electron Beam, Control Rod Drive Mechanisms, PNPf"
4. AI Specification ST0107NA0034, "Welding, Percussion Stud, Copper to Mild Steel"
5. AI Specification ST686N76001, "Cable Assembly, Hermetically Sealed"
6. NAA-SR-TDR-12330, "Structural Analysis of the Magnetic Jacks for Piqua Control Rods"
7. WAPD-XCE-151, "Fatigue Notch Factors for Small Defects in Welds"
8. NAA-SR-TDR-12439, "Effects of Weld Porosity on the Fatigue Life of Welds in the Piqua Control Rods"
9. Rocketdyne Specification RA0107-042, "Process and Quality Requirements for Electron Beam Welding"
10. NAA-SR-TDR-12637, "Piqua Control Rod MI Cable Weld Radiographic Inspection Feasibility Study"

V. TEST PROGRAM

Early in the CRD modification program a comprehensive test plan was set up to provide the required engineering data and to verify performance requirements. A summary chart of the test program and its results up to the time of program termination is shown in Table V-1.

In Table V-1 each test is shown, along with a summary of test conditions. For comparative purposes a description of reactor design conditions is also shown. The test procedure documentation reference is included, as is a summary of the test results.

Each test is discussed in detail in the following paragraphs.

A. ELECTRICAL FEEDTHROUGH EVALUATION

The purpose of this test was to evaluate the performance of electrical feedthroughs considered for use in the power-coil case modification.

Three types of electrical feedthrough insulators were tested:

- 1) U.S. Stoneware Co. Alite Catalog No. C-250, MI cable, 12-gauge single lead.
- 2) Advac Products, Inc. Catalog No. 246-1, MI cable, 12-gauge single lead.
- 3) Advac Products, Inc. Catalog No. 465-4, MI cable, 12-gauge four leads.

The test was designed to simulate the operating environment and the cyclical variations of temperature, pressure, and current in which the feedthroughs were expected to perform. The temperature was varied from 300 to 800°F, the pressure across the feedthrough seal from 50 to 300 psig, and the current held constant at 10 amp.

Two test capsules were used, one for single-lead feedthroughs and the other for the four-lead feedthroughs. A helium atmosphere was maintained at 3 psig inside the capsule, and a molten Santowax OMP environment at 300-psig pressure was established and maintained on the outer surface of the capsule by nitrogen gas.

-

-

-

-

Test	Test Objective	Poison Section Travel Requirements	Operating Temperature and Cycles	Operating Pressure and Cycles	Transients Above Operating Conditions	Transients Below Operating Conditions	Coolant Analysis	Test Documentation	Test Results
Reactor Design Conditions	-	2140 full-travel cycles, up and down, in 20 yr based on 100 full-travel cycles, four scheduled test scrams, and 10 unscheduled scrams per year.	350°F refueling to 650°F maximum operating. 100 cycles in 20 yr, two scheduled plus three unscheduled per yr. Rate 50°F/hr.	0 to 135 psig 100 cycles in 20 yr, two scheduled plus three unscheduled per yr. Rate 100 psig/min.	Operating to 750°F and 300 psig Five cycles in 20 yr. Arbitrary design value. Rates 50°F/hr, 300 psig/min.	400 to 100°F at atmospheric pressure, 10 cycles in 20 yr. Design insertion rate 5 ft/sec. Arbitrary design value.	Ash 10 ppm maximum. MS ²² value 500 maximum. Carbonyl 600 ppm maximum. Water content 2000 ppm maximum. High boiler 0 to 30%	-	-
Electrical Feedthrough Evaluation	Evaluate electrical feedthroughs being considered for CRD modification.	-	300 to 800°F at 83.3°F/hr. 24 cycles.	300 psig.	50 to 300 psig at 300°F. 24 cycles.	-	Santowax OMP.	AI-66-TDR-7.	Single feedthrough satisfactory, multiple feedthrough unsatisfactory.
CRD Bearing Evaluation	Determine coefficient of friction between armature and bushing for candidate CRD materials.	15,000 cycles.	500°F. No cycling.	-	-	-	Santowax OMP.	NAA-SR-TDR-12320.	300 series stainless steel, with "Tufftride" coating against chrome plate gives best wear surface. Coefficient of friction = 0.69 maximum.
CRD Magnetic Jack Mockup	Verify ability to maintain dimensional alignment during assembly welding and verify ability to withstand handling loads.	-	-	-	-	-	-	TR-691-51-003.	Dimensional stability and ability to withstand handling loads verified.
Mark II (Original Design) Static Dry Test	Establish the static load capability of the Original Piqua CRD and thus provide a basis of comparison for the modified CRD.	-	-	-	-	-	-	DTP-691-51-009.	Modified CRD design shows about 200% better static load capability than original CRD design, as calculated.
Defective Coil Test	Establish compatibility of the wire insulation system with reactor coolant.	-	1000 hr in 650°F organic. Coil temperature determined by power density.	Saturation pressure corresponding to organic temperature.	-	-	1) Distilled Piqua coolant. 400-ppm H ₂ O initial content. 2) 1800-ppm H ₂ O initial content.	TP-691-51-001. DTP-691-51-001. TR-691-51-001.	Compatibility established, but ETP copper wire embrittled. Change to OFHC copper wire recommended.
Continuation, Defective Coil Test	Establish compatibility of the wire insulation system with reactor coolant.	-	1000 hr in 650°F organic.	Saturation pressure corresponding to organic temperature.	-	-	Distilled Piqua coolant 400-ppm H ₂ O initial moisture content.	DTP-691-51-010. TI-691-22-007.	Compatibility established, OFHC copper wire did not exhibit embrittlement.

Test Program
(Sheet 1 of 2)

Test	Test Objective	Poison Section Travel Requirements	Operating Temperature and Cycles	Operating Pressure and Cycles	Transients Above Operating Conditions	Transients Below Operating Conditions	Coolant Analysis	Test Documentation	Test Results
Defective Cable Test	Determine the performance of a defective MI cable in reactor coolant.	-	1000 hr in organic at 650°F.	Coolant saturation pressure.	-	-	Distilled Piqua coolant, 400-ppm H ₂ O initial moisture content.	DTP-691-51-002, TR-691-22-007.	Satisfactory operation demonstrated for 1500 hr
MI Cable Qualification	Quality MI cable for PNPf service.	-	100 cycles 350 to 650°F at 100°F/hr-1000 hr at 650°F.	100 cycles 0 to 200 psig at 350°F. 1000 hr at 200 psig. Rate of change 300 psig/min.	10 cycles 650 to 750°F at 300 psig. Rates 100°F/hr, 300 psig/min.	20 cycles 400 to 100°F at atmospheric pressure.	Distilled Piqua coolant and HB-40 as applicable.	ST0403NA0039.	Test not performed due to Program termination.
Effect of Organic Environment on Terminations	Determine effect of reactor coolant on wire terminations.	-	1000 hr in organic at 650°F.	Saturation pressure corresponding to organic temperature.	-	-	Distilled Piqua coolant, 400-ppm H ₂ O initial moisture content.	DTP-691-51-011.	Test not performed due to Program termination.
Coil Thermal Overstress	Determine effect of thermal overstress on power-coil welds.	-	-	Ambient.	60 cycles 400 to 70°F, 30°F/min.	-	Salt bath.	TI-691-51-001.	All welds performed satisfactorily. (No leakage.)
Prototype Magnetic Jack Test	Establish the magnetic, electrical, and thermal performance characteristics of the modified CRD magnetic jack.	-	100 cycles 350 to 650°F at 100°F/hr-1000 hr at 650°F.	100 cycles 0 to 200 psig at 350°F. 1000 hr at 200 psig. Rate of change 300 psig/min.	10 cycles 650 to 750°F at 300 psig. Rates 100°F/hr 300 psig/min.	20 cycles between 400 to 100°F at atmospheric pressure. Rate equivalent to design insertion rate of 5 ft/sec.	Distilled Piqua coolant and HB-40 as applicable.	TP-691-51-004.	Test not performed due to Program termination.
CRD Acceptance Test	Verify mechanical, electrical, and magnetic acceptability.	-	-	-	-	-	-	ST0620NA0052	Test not performed due to Program termination.
Lead Production Drive Test in Reactor	Establish operating levels, determine wear characteristics, provide complete system checkout.	1000 full-travel cycles, up and down, plus 60 scrams.	350 to 550°F, 4 to 10 cycles.	0 to 135 psig, 20 cycles.	-	10 cycles, reactor at 350 to 400°F to control rod thimble in fuel storage pool at 100°F.	Piqua values during test period.	TP-691-51-006 DTP-691-51-006	Test not performed due to Program termination.
Production Drive Tests in Reactor	Verify that production units attain performance levels established by lead production unit.	12 full-travel cycles plus 10 scrams at 350°F, 12 full-travel cycles plus 10 scrams at 550°F.	350 to 550°F, 2 to 9 cycles.	0 to 135 psig, 8 to 18 cycles.	-	-	Piqua values during test.	TP-691-51-006. DTP-691-51-006.	Test not performed due to Program termination.
Readout Instrumentation Acceptance Test	Verify acceptability of position system readout equipment.	-	-	-	-	-	-	ST0203NA0068	Test not performed due to Program termination.

Table V-1. Control Rod Drive Test Program
(Sheet 2 of 2)

The single-lead feedthroughs performed satisfactorily throughout the test sequence; the four-lead feedthroughs failed due to organic leakage. Indications are that the material which provided the mounting support on the feedthrough could not withstand the 300-psig pressure without deforming. The deformation caused a breakdown of the lead insulation and a leak at the seal, allowing organic material to flow into the test capsule.

As a result of the test, Advac single-lead feedthroughs were used in the CRD modification. This test is documented in Reference 1.

B. CRD BEARING EVALUATION

The purpose of this test was to determine the coefficient of friction between the magnetic jack armature and bushing for candidate materials. This test was required because magnetic calculations were based (conservatively) upon a coefficient of friction of 0.1 existing.

Various test specimens of simple geometries representing two flat surfaces in contact were prepared. The specimens were machined to fit holders that secured them within a test chamber filled with Santowax OMP and heated to 500°F. Input motion was provided by an electric motor driving a bell crank mechanism forcing the moving specimen to oscillate on the fixed specimen. The sliding velocity was set at 5 in./min and each oscillation represented 1 in. of linear travel.

Test results are shown in Table V-2.

As can be seen, either Type 304 or 321 stainless steel, when hard faced by Tufftriding, has excellent wear-resistant properties when sliding against chrome-plated mild steel immersed in Santowax OMP at 500°F. Sliding friction coefficients may be as high as 0.69 upon initial contact between these surfaces, but this value can be expected to decrease as wear-in occurs.

Tufftrided Inconel 600 does not have as hard nor as good a wear-resistant surface as the 300 series stainless steel, but initial friction coefficients are similar under similar environmental conditions.

Bare surfaces of either 304 stainless steel or Inconel 600 can be expected to gall and have friction coefficients greater than 1.0 when in sliding contact with chrome-plated mild steel immersed in Santowax OMP at 500°F.

TABLE V-2
CRD BEARING TEST RESULTS

Sample Materials	Temperature (°F)	Travel (in.)	μ = Coefficient of Friction		Comments
			Start of Test	End of Test	
Inconel 600 (Tufftrided) vs Mild Steel (Chrome Plated)	500	30,262	0.6	0.45	High spots of Tufftrided surface were polished but not worn through. μ was as low as 0.40 at 15,000 in. of travel.
321 SS (Tufftrided) vs Mild Steel (Chrome Plated)	500	30,070	0.64	0.4	Friction reduced to 0.41 after 50 in. of travel. μ varied between 0.46 and 0.41 for the next 15,000 in. travel.
Inconel 600 (Bare Surface) vs Mild Steel (Chrome Plated)	500	30,391	1.1	0.55	Fluctuation in friction coefficient occurred throughout the test. μ reduced to 0.45 after only 2700 in. Remained fairly constant for the rest of testing. Surface wear and galling occurred on the Inconel. Negligible change to the chrome.
304 SS (Tufftrided) vs Mild Steel (Chrome Plated)	500	30,076	0.69	0.46	After 15 in. of travel friction coefficient reduced to 0.63 and steadily reduced to 0.4 after 120 in. Friction coefficient never exceeded 0.48 throughout the rest of the testing.
Inconel 600 (Tufftrided) vs Mild Steel (Chrome Plated)	500	15,270	0.85	0.65	Little or no wear of chrome-plated rider. Tufftriding broke through on one spot of Inconel. Other area is highly polished and worn thin. μ reduced to 0.45 after 120 in. Steady increase to 0.65 after 4020 in.
304 SS (Bare Surface) vs Mild Steel (Chrome Plated)	500	15,288	1.35	0.76	Severe galling over two-thirds surface of stainless. Slight wear of mating chrome-plated rider. No seizure occurred.

From the results of these tests it was shown that any of the surfaces tested, except those with Tufftriding removed, could be used as bearing surfaces in the Piqua control rod design. The most desirable choice was 300 series stainless steel, with Tufftriding applied, against the hard chrome-plate. These surfaces showed negligible wear under 20-psi loading after over 30,000 in. of travel while immersed in Santowax OMP at 500°F.

This test is documented in Reference 2.

C. CRD MAGNETIC JACK MOCKUP

The purpose of this test was to verify the ability to maintain dimensional alignment of the power-coil cases during assembly welding, and to verify the ability of the assembled power coils to withstand handling loads.

The coil assemblies were fabricated following the complete production sequence. Intensive step-by-step inspection was made to provide a basis for evaluating the adequacy of processes and techniques planned for production usage.

Production tooling consisting of an expandable mandrel arbor was utilized to hold the power coils during final assembly welding. After assembly a bending movement test was conducted on an Instron testing machine.

Test results showed that the individual coils maintained dimensional stability during all welding, coil winding, coil curing, and final closure welding operations. Final assembly alignment met the 0.002-TIR concentricity requirement. The bending moment test indicated that the power-coil assembly would withstand at least 370% of the expected load with no permanent deflection or weld cracking occurring.

This test is documented in Reference 3.

D. MARK II (ORIGINAL DESIGN) STATIC DRY TEST

The purpose of this test was to establish the static load capability of the original Piqua CRD to provide a basis for comparison with the modified CRD.

It was originally intended (Reference 4) that a dry dynamic test be performed to establish load capability. In this, an original (Mark II) control rod

4-18-68 UNCL

7736-5201

Figure V-1. Control Rod Drive Grip Coil Performance

removed from the PNPf reactor was to be operated in air, and the load capability of the CRD established by adding weights to the poison section. The test was attempted but proved infeasible because of damage to the drive components. It was found that unlubricated wear was occurring between the pole pieces and movable armature, resulting in lodging of magnetic particles in the air gap.

Consequently the static test was devised. In this the magnetic jack of Mark II design, Serial No. 11, was assembled using a test pull rod. The movable armature was positioned in contact with the upper pole piece and actuated using incremental values of coil current. The test pull rod was then actuated and a force-displacement curve obtained.

The axial load developed is equal to the radial force times the coefficient of friction. Test results are shown in Figure V-1 for the grip coil. Also shown on Figure V-1 are the calculated values for the grip coil of the modified CRD, and it can be seen that the modified CRD has a greatly increased force capability (200%) over the original design.

This test is documented in References 5 and 6.

E. DEFECTIVE COIL TEST

The purpose of this test was to determine the performance of representative CRD power-coil assemblies operating with defective coil enclosures in organic coolant.

Six power coils representative of Lift Coil No. 2 were wound on test bobbins machined from solid C-1015 tube stock. These coils were identical to production coils in winding design, winding material, insulating material, and electrical creepage and clearance distances. ETP coil wire was used. The start lead was brought out rather than being grounded to the coil case to facilitate electrical measurements. Holes of approximately 1/8-in. diam were provided in the termination access cover and in the outer case adjacent to the cable entry to ensure venting and filling of the coil enclosure with organic.

Single-conductor MI metallic-sheathed cables were seal-welded into the coil and provided with an adapter sleeve for penetrating the test chamber enclosure through Swagelock seals. The MI cable conductors were connected to

the finish leads of the coils in accordance with the design termination process, and the termination had representative insulation. The coils were divided into two groups of three coils each.

Both groups were tested in Piqua coolant (Santowax OMP), with approximate initial water contents of 400 ppm for Group I and 1800 for Group II. The coolant temperature was maintained at 650°F. One coil in each group was operated at 6.25-amp dc current, another at 8.85, and the third at 10. Leakage current vs time was monitored on the coils to determine the effect of loss of coil seal integrity on the power-coil winding.

Provisions were made in the test rig to circulate coolant through a sample chamber to obtain periodic samples of coolant for moisture determinations, and to add controlled amounts of water to produce and maintain the specified environments. After short-term operation in high-moisture-content organic, the moisture content was reduced to a level of approximately 100 ± 50 ppm for the remainder of the test. Moisture was reduced by venting. The coils were energized from full-wave rectified ac power supplies.

In addition to the measurements for determining coil-insulation resistance, measurements of coil resistance as a function of time at 650°F were also obtained.

Curves of coil-insulation resistance and coil-winding resistance are shown in Figures V-2 and -3, respectively. The following conclusions were established:

- 1) The insulation resistance-to-ground in all coils before submerging in organic coolant was 40,000 megohms or greater at 300°F; 150 megohms or greater at 600°F; and 25 megohms or greater at 800°F. Within a few hundred hours after applying power to the submerged coils, the insulation resistance-to-ground dropped to between about 0.5 and 0.01 megohms.
- 2) The coils exhibited a complex behavior pattern for leakage current. The only conclusion that can be drawn is that the six coils would have operated satisfactorily for 1000 hr submerged in organic.
- 3) The two coils which were operated at 100% of design power (6.25 amp) increased their resistance at a rate of about 5% per 1000 hr of operation

Figure V-2. Defective Coil Insulation Resistance

4-18-68 UNCL

7736-5203

Figure V-3. Defective Coil Winding Resistance

at full power. This increase in resistance was the result of H_2 embrittlement of the wire as determined by post-test examination of the wire from a test coil. It is assumed that H_2 embrittlement occurred in all six coils; however, the increased resistivity of the wire in the coils operated above design power was not observed because of the relatively low shunt resistance which developed in them.

Normal ETP Cu wire contains an O_2 impurity on the order of 200 ppm. When submerged in organic coolant at elevated temperatures H_2 diffuses into the Cu at elevated temperatures, and combines with the O_2 to form H_2O . Since the diffusion rate of the H_2 molecule is much greater than that of the H_2O molecule, the resulting internal high water-pressure produces fissures in the Cu. These fissures are the direct cause of increased resistivity and greater brittleness of the wire. This effect has been extensively reported in the literature (see Reference 7). Photomicrographs of sample wire, both exposed and not exposed to the organic environment, are shown in Figures V-4 and -5, respectively.

- 4) The four coils operated at above the design power level all showed a complex behavior pattern. The apparent coil resistance of these four coils increased during the first days of operation. During this time the moisture concentration of the test chamber gradually decreased to about 130-ppm water. The apparent increase in coil resistance was caused by an increase in winding-to-winding leakage resistance as moisture was driven out of the system. As the test progressed beyond the first few days the apparent winding resistance of the four coils which operated above normal power decreased again. The decreases in apparent winding resistance, varying from about 25 to 50%, were caused by a decrease in the winding-to-winding resistance. During the last few hundred hours of testing, the apparent winding resistance remained nearly constant.

As a result of this test, the ETP wire was changed to OFHC. The test is documented in References 8, 9, and 10.

7736-5204

Figure V-4. Sample of Power-Coil
Electrical Tough Pitch Copper Wire
After 1500 Hours Exposure to
650°F Organic Coolant

7736-5205

Figure V-5. Sample of Power-Coil
Electrical Tough Pitch Copper Wire
Not Exposed to Organic Coolant

F. CONTINUATION, DEFECTIVE COIL TEST

The purpose of this test was to further explore the compatibility of the power-coil wire insulation system with the reactor coolant.

Three coils were tested. No. 1 was obtained from the previous defective coil test; 7 and 8 (the 2nd and 3rd coils) were identical to the production coils (including the use of OFHC wire) in winding design, winding material, insulating material, and electrical creepage and clearance distances. The start lead was brought out rather than being grounded to the coil case to facilitate electrical measurements. The start and finish leads were routed out of the termination access hole in the outer case. Single-conductor MI metallic sheathed cables were provided with an adapter sleeve for penetrating the test chamber enclosure through Swagelock seals. The MI cable conductors were connected to the start and finish leads of the coils.

The three coils were tested in Piqua coolant (Santowax OMP) with approximately 400-ppm initial water content. The coolant temperature was maintained at 650°F. Coils 1 and 2 were operated at 6.25-amp dc current, and Coil 3 at 4.1. Coil insulation resistance-to-ground and winding resistance were monitored to determine the effect of loss of coil-seal integrity on the power-coil winding. Provisions were made in the test rig to circulate coolant through a sample chamber to obtain periodic samples of coolant for moisture determination, and to add controlled amounts of water to produce and maintain the specified environments. After short-term operation in 400-ppm moisture content organic, the moisture content was reduced to a level of approximately 100 ppm for the remainder of the test. Moisture was reduced by venting. The coils were energized from full-wave rectified ac power supplies.

The new coil operating at 6.25 amp (No. 7) developed a short circuit to ground at the starting end of the winding very early in the test. This normally grounded starting was insulated and brought out for test purposes. The test was continued on this coil to provide circuit resistance data.

The coil circuit resistances, measured periodically throughout the test, are plotted on Figure V-6. Two characteristics, the large variation in the resistance readings and the gradual resistance increase, represented by the median

AI-AEC-TDR-12648
V-18

4-17-68 UNCL

7736-5206

Figure V-6. Coil Circuit Resistance in 650° F Organic

straight lines, are evident. The variation of the measured resistance may be due to intermittent changes in the turn-to-turn insulation resistance. The trend toward increasing resistance is probably due to change in the conductor material. With the ETP Cu the resistance increase was attributed to creation of void in the conductor due to H_2 embrittlement. The OFHC Cu conductor eliminated the H_2 embrittlement problem, as expected and as evidenced by post-test metallographic examination.

The noted slower rate of resistance increase of the OFHC coils may have signified that the embrittlement phenomenon was still occurring but at a reduced rate. The insulation resistance measured during the test is shown on Figure V-7, with median straight line indicating gradual decrease. The higher resistance level and the lower rate of degradation of the new coil are probably attributable to various design improvements over those in Coil No. 1.

As a result of these tests, it was established that the power-coil wiring system, OFHC Cu wire insulated with AI-1 cement, was compatible with the reactor coolant. Due to degradation of wire and insulation resistances, the only conclusion that can be reached is that the coils should be designed to be leaktight over their design life.

This test is documented in References 11, 12, and 13.

G. DEFECTIVE CABLE TEST

The objective of this test was to determine the performance of defective (leaking) MI cable in reactor coolant.

Two test specimens representative of Piqua control rod drive MI-cable assembly construction were fabricated as shown in Figure V-8. The assemblies consist of 16 AWG Ni-clad Cu MI cable, upper and lower end seals (Advac No. 215-1), a lower weld sleeve, and an upper sleeve. The Advac end seals and sleeves were TIG-welded to the MI cables. The conductor was brazed to the "A"-Ni Advac tube. Defects representative of cable assembly failure modes were built into the specimens as follows:

Cable No. 1: Defective Advac insulator-to-sleeve braze.

Cable No. 2: Defective MI cable sheath (burn through weld).

AI-AEC-TDR-12648
V-20

4-17-68 UNCL

7736-5207

Figure V-7. Coil Insulation Resistance in 650°F Organic

TEST SPECIMEN NO.	DEFECT
1	FRACTURED LOWER ADVAC INSULATOR-TO-SLEEVE BRAZE
2	DEFECTIVE MINERAL-INSULATED CABLE SHEATH BURNTHROUGH AT WELD CLIP

4-18-68 UNCL

7736-5208

Figure V-8. Defective Mineral-Insulated Cable Assembly

These cables were otherwise representative of the production cables in all electrical characteristics. No. 1 was installed in the Group I test chamber, No. 2 in the Group II chamber of the test in Section V-D. The chambers contained Piqua reactor coolant Santowax OMP at 650°F. The Group I chamber initial moisture content was adjusted to a nominal 400 ppm, the Group II to 1800. The conductors were energized with full-wave rectified alternating current from an adjustable isolated 60-cps supply. Cable leakage current was monitored with a constant voltage of 50 volts dc maintained on the conductor. The cable assemblies had one end in organic, the other in air. The cables penetrated the test chamber through Swagelock fittings clamped to the upper sleeve and welded into the chamber head.

The water concentration was gradually reduced to about 130 ppm in both chambers during the first few days of operation. The initial readings of insulation resistance on Cables 1 and 2 after a few hours in wet organic were 100 and 58 megohms, respectively. The insulation resistance gradually increased with time at temperature so that at the end of the test period the insulation resistance

values were nearly an order of magnitude higher than those at the beginning. Figure V-9 is a graph of insulation resistance as a function of testing time.

Figure V-9. Defective Mineral-Insulated Cable Insulation Resistance

Post-test examination showed evidence of organic penetration into the MgO insulator material of only about 1 in.

Test results indicate that unsealed MI cable probably could operate for an extended period of time in organic without any significant adverse effect.

This test is documented in References 14 and 15.

H. MI CABLE QUALIFICATION TEST

The purpose of this test was to qualify the MI cable for its intended usage in the PNPf reactor.

One each of the two types of MI cables required were to be tested. These items were to be randomly selected from a lot of production MI cable. The following tests were to be performed in the sequence indicated:

- 1) Visual examination
- 2) Insulation resistance test
- 3) Dye penetrant examination
- 4) Helium leaktest
- 5) Bend test
- 6) Electrical continuity test
- 7) Helium leaktest
- 8) Thermal cycle and pressure tests in organic strength test
- 9) Dielectric strength test
- 10) Endurance test in organic
- 11) End seal mechanical strength test
- 12) Post-test visual examination, helium leaktest, and dye penetrant examination.

This test had not been performed at the time of Program termination. Test procedure is documented in Reference 14.

I. EFFECT OF ORGANIC ENVIRONMENT ON TERMINATIONS

The purpose of this test was to verify the compatibility of the various CRD wire terminations with the reactor coolant.

Twenty-five each of samples of the various wire terminations used in the CRD were to be fabricated in accordance with production drawings and specifications. The samples to be tested were:

- 1) Solid 17-AWG Cu lead wire brazed to the MI-cable solid-Ni extension wire.
- 2) Solid 17-AWG Cu coil finish lead wire welded to the solid 17-AWG Cu lead wire from the MI cable.
- 3) Solid 22-AWG Cu indicator coil extension wire brazed to the MI-cable solid-Ni extension wire.

4) Solid 0.005-in.-diam W lead wire (from thermistor coil) brazed to solid 18-AWG Cu lead wire.

5) The Cu coil ground stud welded to the coil bobbin.

Twenty of the samples were to be tested in organic at 650°F for 1000 hr. The remaining five samples were to be utilized as controls.

This test had not been performed at the time of Program termination. The test plan is documented in Reference 15.

J. COIL THERMAL OVERSTRESS

The purpose of this test was to determine the effect of thermal overstress on the CRD power-coil welds.

The basic criterion for test design was that every thermal shock should overstress the weld joints for a significantly greater number of cycles than the coil would be expected to experience in service.

An analysis was made to estimate the thermal stresses the coil would be subjected to in the test (see Reference 16). The standard condition of submerging the coil from 70°F into 400°F organic was compared to 600°F organic and 400°F salt bath; the analysis showed that the 400°F salt bath was as severe a thermal shock as the 600°F organic. Because the former is easier to handle than the latter it was chosen as the hot medium. Hence every cycle subjected the coil to a thermal shock 200°F greater than actual service conditions, and all welded joints would be overstressed. Ambient air was chosen as the cooling medium.

The number of times that the magnetic drive would be subjected to thermal shock would be dependent upon reactor life, number of shutdowns, etc.; 20 was estimated as a reasonable number of operating thermal cycles. The test was then set for 60 cycles, or three times the number of cycles that was anticipated in service.

An engineering requirement of the test was that if a weld joint should fail, it must be detected before the coil is subjected to further thermal cycles. Detecting the failed joint at the cycle in which it failed would make it easier to determine the cause of failure and the stresses which caused the failure.

The failure-detection requirement was met by a helium leakcheck. Rather than undergoing a continuous monitoring, the coil was checked at the conclusion of each thermal cycle. The usual technique for helium leakchecking is to evacuate the coil and apply helium to its exterior. Where the exterior is hotter than the interior, a crack would probably start from the exterior and its largest dimension would be at the exterior. During leak detection the salt would solidify in the crack and the external pressure would effectively plug the crack, if not too large, thus making detection doubtful. The method chosen for leak detection was internal pressurization of the coil with helium and detection of helium leakage from the coil exterior by "sniffing" techniques. To accommodate the leak detection method the MI cable was replaced with a hollow stainless-steel tube which served as the entry into the coil interior.

To obtain the required thermal gradient across the coil it was necessary to exclude the salt bath from the inside diameter of the coil. This was accomplished by clamping two steel plates on the top and bottom faces of the coil. Heat transfer from the plates to the coil was prevented by placing 1/8-in.-thick asbestos sheeting between them.

Temperature measurements of the OD and ID walls were obtained by thermocouples. The ID thermocouple was threaded through the asbestos sheet. Calibrated thermocouples, checked in the temperature range of interest, were attached by spot welding to the coil walls.

Twelve cycles were run in a mockup test to determine if the thermocouples and seal plates would function as required. Then the mockup assembly was disassembled. Only the edges of the asbestos sheeting showed evidence of exposure to the salt bath. The thermocouples performed as expected.

The test coil was then helium leakchecked by the standard technique of evacuating the coil and applying helium to the coil exterior. When the test proved no leakage was occurring the calibrated and checked thermocouples were attached to the walls and the asbestos sheeting and steel plates clamped to the faces of the coil. The assembly was then attached to a lifting device positioned over the salt bath. A helium line was attached to the hollow tube and the test started by inserting the coil into the 400°F salt bath.

When the coil thermocouples showed that a temperature equilibrium was established the coil was removed from the salt bath and allowed to cool in ambient air. When it was approximately 100°F the leakcheck procedure was repeated.

After the 30th cycle the test assembly was disassembled and washed clean of all evidence of salt. Inspection of the asbestos sheeting showed that the salt had not penetrated to the ID coil. The cleaned coil was then helium leakchecked by the standard technique; no leakage was found. The coil was reassembled and tested without incident to the completion of the 60th cycle. The test assembly was again disassembled, washed clean of the salt, and helium leakchecked by the standard technique. The test coil successfully completed 60 cycles without any helium leakpaths developing.

The outer case of the coil was machined away, exposing the internal Cu wires. All welds of interest were preserved.

The resistance of the Cu windings, measured at 780°F, was found to be 2.32 ohms, a value judged to be adequate under the test conditions. As the protective mica, glass cloth, and Cu windings were removed, the encapsulant coating on the Cu wire showed a gradual change in color, from gray to white, as each layer of Cu was unwound. Samples of the wire were examined and all exhibited excellent ductility. The interior of the coil showed no evidence of heat damage due to the welding processes.

The remaining portions of the coil were then machined to separate the welds of interest. Each weldment was radiographically evaluated for defects. When some indications were found the samples were sectioned for metallographic evaluation.

Of the six weldments evaluated four had defects over the allowable limits set by the governing welding specification. These defects were undoubtedly present before the thermal cycling of the coil, yet it underwent a severe over-stress test without any of these defects propagating to form a leakpath.

Of the four defective weldments, three contained defects (primarily porosity) which could be classified as "less severe."

The one found to be defective far in excess of the allowable limits was the MI cable-to-shell weld; it had excess porosity and undercutting of the bushing (see Figure V-10). The standards set by specification for this weld were no porosity more than 0.013 in. in diameter and no undercut. Although the largest pore was 0.015 in. in diameter and the undercutting had reduced the wall of the bushing by 50%, this joint did not fail when subjected to the overstress test.

While the data represents the thermal overstressing of only one coil, it appears that the weld requirements may have been overly restrictive. It seemed evident that the ability of the metals to prevent the propagation of the defects was of more importance than the presence of the defects.

This test is documented in TI-691-51-001.

K. PROTOTYPE MAGNETIC JACK TEST

The objective of this test was to: establish the magnetic, electrical, and thermal performance characteristics of the modified magnetic jack assembly; verify the ability of the design and assembly processes to maintain coil enclosure seal integrity under operating temperature and pressure conditions in organic; and verify the ability of the coil enclosure to withstand thermal and pressure cycles above and below normal operating conditions without loss of seal integrity. Additional test objectives were verification of the indicator coil enclosure seal integrity, and capability of MI cable to withstand the same test conditions as the prototype magnetic jack.

A prototype magnetic jack was to be assembled from coil assemblies representative of the production units. Six of the coil assemblies were to have simulated rather than actual MI cable for electrical penetrations of the coil enclosures to facilitate leakchecking. Two of the coil assemblies were to use actual production configuration MI cable. One single-coil bobbin and one multicoil-bobbin were to be instrumented to monitor temperature distribution in the coil enclosure. The test assembly was to be subjected to dry static performance tests, followed by wet dynamic performance tests to provide data for the determination of the magnetic, electrical, and thermal performance characteristics of the jack. In addition thermal and pressure cycle tests, including simulated

4-17-68 UNCL

7736-5210

Figure V-10. Defective Mineral-Insulated Cable-to-Shell Weld From Thermal Overstress Test (taken at 40X)

installation and removal transients, were to be performed to verify the integrity of the coil enclosure design and fabrication processes. The test was to conclude with a 1000-hr endurance test, followed by disassembly and inspection of critical areas.

The test was to be performed concurrent with the enclosure integrity test of the indicator coils, which would have subjected these specimens to the same test environment experienced by the prototype magnetic jack assembly.

This test had not been performed at the time of Program termination. The test plan is documented in Reference 17.

L. CONTROL ROD DRIVE ACCEPTANCE TEST

The purpose of this test was to verify the mechanical, electrical, and magnetic acceptability of the control rod assembly.

Assembly of the modified CRD was controlled by AI Process Specification ST0620NA0052, "Control Rod Drive Assembly, Assembly of Piqua Modifications" (Reference 18). Throughout the assembly sequence, various tests such as coil insulation resistance, static performance, loop resistance, etc., were to be performed to verify CRD acceptability.

Since no control rods were assembled at the time of Program termination, these tests were not performed.

M. LEAD PRODUCTION DRIVE TEST IN REACTOR

The lead production drive test was to be the first for the complete Mark III (modified) control rod drive and the first in which reactor flow conditions were to be duplicated. This test was to establish final drive operating levels. In addition, the lead production drive was to (1) undergo an endurance run to establish the wear characteristics of the Mark III design, and (2) be subjected to handling thermal transients to verify its ability to accommodate them. Testing of the drive was to start the final checkout of the power supply and position-indication system modifications.

The lead production drive was to be installed in the reactor and its jumper connected. The reactor vessel was to be closed and pressurized and coolant

flow begun. The drive was to be operated with the full complement of coils and with each of the redundant sets energized. The parameters of concern were to have been consistency in the number of steps for full travel and the ability to maintain position under sustained holding operation. These parameters were to be investigated over the temperature range of 350 to 550°F and pressure from atmospheric to 135 psig. Thermal cycling was planned through pump heating and cyclic use of the heat exchangers. During full-flow operation, minimum pressure would have been limited by pump NPSH requirements. The scram capability of the drives was to be established at both extremes of the temperature range. The drive coil current settings were to be varied and the drive operated to determine the minimum current values consistent with acceptable operation. These values would have been used for testing the production drives. The lead production drive was to have been operated on each of the three drivers at the site.

After completing the initial testing, the lead production drive was to have been subjected to an endurance run of a minimum of 1000 full-travel cycles and 60 scram cycles. Following this, it was to have undergone 10 cycles of transfers between the reactor and the control rod thimble in the spent-fuel storage pool. Finally the drive would have been disassembled for examination of the armature for wear and inspection for damage due to thermal transients.

At the time of Program termination this test had not been performed. The test plans are documented in References 19 and 20.

N. PRODUCTION DRIVE TESTS IN REACTOR

All production drives were to be tested to assure that they attained performance levels established by the lead production drive tests. This testing was also to complete the final checkout of the power supply and position-indication system modifications.

The tests were to be conducted in the Piqua reactor vessel, with no fuel in the reactor core. Flow, temperature, and pressure conditions of normal reactor operation of the drives were to have been established within the limitations of noncritical reactor operation.

As the production drives arrived at the site they were to have been installed in the reactor for testing. Each was to be tested to demonstrate its compliance with the performance levels established by these tests. The minimum test duration and operation requirement for each production drive was:

- 1) Twelve full-travel cycles plus 10 scram cycles at 350°F;
- 2) Twelve full-trave cycles plus 10 scram cycles at 550°F;
- 3) Two operating-to-refueling-temperature cycles; and
- 4) Eight pressure cycles.

These tests were not performed because of Program termination.

O. READOUT INSTRUMENTATION ACCEPTANCE TEST

The objective of this test was to demonstrate the functional integrity of the CRD position-indication readout instrumentation. It was also designed to verify the correctness of wiring and the operability of switches and equipment-adjusting devices.

The readout instrumentation was to have been interconnected as it would have been in service at PNPf. Simulated inputs were to be utilized for the position coil bridge, indicator coils, and scram devices. The entire circuit was then to be operated under simulated PNPf operating conditions.

At the time of Program termination, this test had not been performed. The test procedure is documented in Reference 21.

REFERENCES, SECTION V

1. "Electrical Feed-Through Insulator Evaluation," AI-66-TDR-7
2. "Piqua Control Rod Bearing Evaluation in Santowax OMP at 500°F," NAA-SR-TDR-12320
3. "Final Report - Mockup Magnetic Jack Development Tests Piqua Control Rod Drive," TR-691-51-003
4. "Piqua Control Rod Drive Mark II Configuration S/N 11 Dry Performance Test," DTP-691-51-008
5. "Piqua Control Rod Drive Highlights," Internal Letter, Smith to Morgan, Atomics International, 7-15-67
6. "Static Dry Test - Piqua Control Rod Drive - Mark II Configuration," DTP-691-51-009
7. "The Brittleness of Annealed Copper," Transactions of the American Chemical Society, (1916) 29, 515
8. "Test Plan, Piqua Control Rod Drive Power Coil Performance in Organic (Defective Coil Test)," TP-691-51-001
9. "Developmental Test Procedure Piqua Control Rod Drive - Power Coil Performance in Organic (Defective Coil Test)," DTP-691-51-001
10. "Test Report, Development, Performance of Unsealed Piqua Control Rod Drive Power Coils," TR-691-51-001
11. "Effect of Organic Environment on Coil Insulation," DTP-691-51-010
12. "Coil Analysis Investigation, Piqua Control Rod," TI-691-22-007
13. "Wet Operation of Piqua Control Rod Coils," Internal Letter, Nakae to Morgan, Atomics International, 12-14-67
14. "Cable Assembly (MI) Hermetically Sealed, Qualification Test," ST0403NA0039
15. "Effect of Organic Environment on Coil Terminations," DTP-691-51-011
16. "Thermal Analysis of Piqua CRD Pull and Grip Coils," Internal Letter, Beiriger to Jetter, Atomics International, April 11, 1967
17. "Prototype Magnetic Jack Developmental Test Plan Piqua Control Rod Drive," TP-691-51-004

18. "Control Rod Drive Assembly, Piqua Modification, Assembly of,"
ST0620NA0052
19. "Test Plan, Lead Production and Production Drive Testing in the Piqua
Reactor Vessel," TP-691-51-006
20. "Test Procedure for Testing the Lead Production and Production Mark III
Control Rod Drives in the Piqua Reactor Vessel (Preliminary),"
DTP-691-51-006
21. "Readout Instrumentation, Reactor Control, Acceptance Test,"
ST0203NA0068

VI. STATUS AT TERMINATION

At the time of Program termination, parts fabrication, development activity, and the test program were well underway. All engineering drawings and specifications had been issued and were under baseline control. Development activity, with the exception of that associated with the MI cable-to-shell weld, was complete. The test program had reached the point where only design verification testing was to be completed.

The total program interrelationship and status at the time of Program termination is shown graphically in Figure VI-1. Work to the left of the vertical line had been completed; that to the right was in progress. Two constraints are worth noting. The first constraint was the completion of weld qualification. The difficulty here was in qualifying the MI cable-to-shell weld (see Section IV). This constraint was in turn holding completion of the prototype magnetic jack.

The second constraint was connected to the first: No closure welds would be made to the production magnetic jack coils until the prototype magnetic jack fabrication was complete and the unit had successfully passed dry static and thermal cycling tests. This latter constraint was necessary to avoid any risk of assembling the production CRD's and then finding rework was necessary.

Figure VI-2 shows the status of the modified CRD parts at the time of Program termination. As can be seen, parts fabrication was about 46% complete. All parts have been protected against corrosion and are stored at AI pending the resolution of final disposition.

1

2

3

4

4-18-68 UNCL

Figure VI-1. Total Control Rod Development Program Status at the Time of Program Termination

7736-5213

4-18-68 UNCL

7736-5214

Figure VI-2. Modified Control Rod Development Production Parts Status at the Time of Program Termination

VII. CONCLUSIONS

Conclusions related to the PNPF Control Rod Drive Modification Program are as follows:

- 1) Design effort associated with the control rod modification program was complete. All engineering drawings and specifications were under baseline control. The selected modifications were arrived at after consideration of possible alternates, and were based upon operating experience and sound analytical engineering principles.
- 2) Coil winding and fabrication techniques had been satisfactorily developed. The necessary production and quality assurance programs had been put into effect to provide high product quality.
- 3) All welds except the MI cable-to-shell had been successfully developed and qualified. That weld presented considerable difficulty, and several approaches to developing a qualified weld technique were being evaluated at the time of program termination.
- 4) The results of testing completed before program termination confirmed design adequacy. Thermal-cycling tests on one sample coil indicated that a more than adequate design margin existed. Component tests in organic environment had verified the necessity to keep the coils leak-tight throughout their design life. Unfortunately, no prototype or system tests were made before program termination; only component tests verified force capabilities.
- 5) At the time of program termination the prototype magnetic jack was about 90% complete, and production parts fabrication about 40% complete. All parts have been protected from corrosion and are stored at AI pending final disposition.