VOLUME 3

TVA WELDING PROJECT
SEQUOYAH PHASE II
REVIEW AND PROGRAMS RESULTS
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TVA SUMMARY OF APTECH REVIEW OF SEQUOYAH WELDS

TVA and its contractor APTECH Engineering Services has performed a review of welding and subsequent preservice and inservice inspection activities at Sequoyah Nuclear Plant for the purpose of determining the suitability for continuing service of welds currently installed at Sequoyah. The basis for this determination is derived from historical records and activities related to the production of quality welds (via an appropriate welding and inspection program) and historical performance of welds during the operating phase of the plant. This review is an adjunct to other TVA activities focused on weld quality determination, weld reinspection, and welding program assessment, problem identification and resolution. The criteria used for determination of suitability for service in this review are:

1. Did the welding and weld-related quality assurance programs contain the control features that are necessary and appropriate for the production of quality welds?

2. To what extent have Sequoyah Section XI welds been inservice and preservice examined?

3. What are the results of the prservice and inservice examinations that indicate weld quality (i.e., indication rate)?

4. To what extent has operation of the plant indicated weld quality (Licensee Event Reports relating to weld quality)?

5. Are the quality indicators or indication rates determined above (3 and 4) acceptable for continued operation and commensurate with accepted industry standards?

This review has been completed and is attached. The results of this review are positive and indicate suitability for service of Sequoyah welds. With respect to the above criteria the APTECH review indicates the following:

1. The Sequoyah welding and weld related quality assurance program did contain the necessary and appropriate control features for production of quality welds.

2. 42.1 percent of Sequoyah ASME Section XI field welds have been examined; 88.4 percent of integrally welded attachments have been examined; 100 percent of Class 1, 2, and 3 hangers have been examined.

3. Indication rates calculated are:

   0.95 percent, piping
   4.79 percent, integrally welded attachments
   0.31 percent, hangers

4. No Licensee Event Reports relating to weld quality have been reported.

5. The above meets or exceeds accepted industry standards.

To support the applicability of this review and for additional information TVA is providing here a discussion of the applicability of preservice and inservice inspection to weld quality determination, and additional detail on all notification of indication documents referenced in the APTECH report including dispositions and supplementary comments. These notification of indication documents are attached at the end of this summary.

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Applicability of Inservice Inspection
Results to Weld Quality Determination

There are essential differences between the purposes, techniques and criteria for inservice inspections and welding inspection at the time of construction. These differences modify and limit the applicability of the inservice results as weld quality indicators. In the case of ASME pressure retaining welds where volometric techniques are employed for post fabrication inspection and subsequent inservice inspection, the ability of inservice to determine weld quality is excellent, especially in the case of radiography and subsequent ultrasonic inspection where the two techniques compliment each other. On ASME welds and integral attachments where only surface examinations are required the techniques and methods are the same for PSI/ISI although the acceptance criteria are different. Both address significent flaws.

The largest differences in purpose, technique and criteria exist in the case of structural support welds and as such imposes some limits on the applicability of inservice inspection results as weld quality indicators for the construction phase. However, from the review of the attached notification of indication documents generated by preservice and inservice inspection of units 1 and 2, it is apparent that this process does, in fact, identify conditions that are quality indicators of welds as originally installed. The reasons the NOI system identifies defects that are not service induced are:

1. Inspectors are responsible to report conditions adverse to quality even when performing inspection for other expressed purposes.

2. Many inspectors have certification in visual inservice and welding inspection.

3. As a practical matter it is difficult or impossible to create inservice inspection criteria which will only identify defects which are service induced.

Since an extensive number of Notification of Indication reports have been examined in conjunction with the APTECH study it is possible to derive other information concerning weld quality which was not in the scope of the APTECH study. There have been several supports which deformed under operating transient conditions which did not result in failure of the welds. In these cases base materials were obviously loaded in excess of yield, sometimes to the point of releasing anchors without causing failures of related welds. Although these are indirect indicators of weld quality they provide some assurance in a practical sense of the adequacy of hanger welding at Sequoyah.

Therefore, in context of all quality indicators examined in the APTECH study and in spite of a possible lack of conservatism of the indication rate for structural welds, the fundamental conclusions are sound.

It is TVA's position that since: (a) Section XI and safety-related pipe welds were originally welded and inspected to the same program; (b) Section XI structurally significant and safety-related structural welds were welded to the same program; (c) a large number of pipe welds have been PSI and ISI examined; and (d) essentially all structural welds in the ISI program have been inspected, then the PSI and ISI results are effective quality indicators of Sequoyah welds, and if systematic, widespread and/or chronic deficiencies existed in Sequoyah welds/welding, this would produce unfavorable PSI/ISI results.

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NOI Number	Systems (Weld Number)	Type Weld	Size	Report Number	Discrepancy	Disposition and Additional Comments
R0082	FDF-4	Field	18"	R0082	Linear Indication 1/2" Long	Removed by grinding. Minimum wall thickness verified Reexamined. MR# A-038177
R0081	RHRS-2	Shop	18"	R0081 R0039	2 Arc Strikes	Removed by grinding. Reexamined to verify removal. MR# A-036818 Reinspection report R-166
R0124	SIF-127	Field	10"	R0124 R0221	Unacceptable Surface Condition for PT Examination	Removed by grinding. Reexamined to verify removal. MR# A-036818 Reinspection Report R-221
R0125	SIF-148	Field	10"	R0125 R0220	1 Arc Strike	Removed by grinding. Reexaminted to verify removal. MR# A-036818 Reinspection Report R-220
R0192	SIS-337	Shop	2.5"	R0192 R0225	Unacceptable Surface Condition for Examination	Removed by grinding. Reexamined to verify removal. MR# A-036818 Reinspection Report R-225
R0193	SIS-338	Shop	2.5"	R1064 R0226	Unacceptable Surface Condition for Examination	Removed by grinding. Reexamined to verify removal. MR# A-036818 Reinspection Report R-226
R0219	UPIF-19	Field	12"	R0219 R520	Linear Indication, 5/8 Long	Removed by grinding. Reexamined to verify removal and minimum wall thickness. MR# A-037009 Reports R-425 and R-520
R0232	SIH-453	Hanger (IA)	8"	R0232 R0334	Linear Indication, 5/32" Long (Appears to be arc strike)	Removed by grinding. Reexamined to verify removal and minimum wall thickness. Report R-334 MR# A-037002

NOI Number	Systems (Weld Number)	Type Weld	Size	Report Number	Discrepancy	Disposition and Additional Comments
SQ0178	RHRF-109A	Field	---	R2540	Linear Indication, 1/4" Long	Removed by grinding. Reexamined to verify removal and minimum wall thickness. Report R-3095 MR# A-520395
SQ0201	FDH-203	Hanger	---	R2714	Weld Missing per as constructed drawing 1-H4-203	Disposition open as of 1-15-86. Instructions to weld pipe to support per GT-11-01A, clean weld area per SQM-17, paint and reexamine. MR# A-520902
---	SIH-17	Hanger	---	MR550488	Weld Missing per as constructed drawing 1-SIH-17	Left as is. Disposition per FCR 3987:revise dwgs 1-SIH-17, and 1-SIH-462 to reflect as built configuration.
SQ0213	SIH-21	Hanger (IA)	---	R2813	Two 3/4" Long Linear Indications	Linear indication due to weld irregularities. Not service induced. Disposition by USQD. MR# A-548376
SQ0212	SIH-20	Hanger (IA)	---	R2812	Two 3/4" Long Linear Indications	Linear indication due to weld irregularities. Not service induced. Disposition by USQD. MR# A-548376
SQ0154	MSH-289	Hanger (IA)	---	R2374	Linear Indication, 5/16"Long	Disposition open as of 1-15-86. Instruction to remove indication per MR# A-543180
SQ0179	RHRH-460	Hanger	---	R2541	Crack-Like Indications on Tack Welds	Removed by grinding. Reinspected to verify removal. Reinspection Report R-2773 MR# A-550460. Are currently inspecting all similar configurations. One indication found on unit 2.

NOI Number	Systems (Weld Number)	Type Weld	Size	Report Number	Discrepancy	Disposition and Additional Comments
R235	Stm. Gen.	Shop	---	R235	3/4" Linear Indication	Removed by grinding. Reinspected to verify removal and minimum wall thickness. Reinspection Reports R-496 and R-519 MR# A-038179 and A-037007
R279	RCF-31	Field	---	R279	Arc Strike	Removed by grinding. Reinspected to verify removal. Reinspection Report R-499 MR# A-036818
R00A	SIS-274	Shop	---	R00A	Arc Strike	Removed by grinding. Reexamined to verify removal. Reinspection Report R-426.
R404	RCH-231	Hanger	---	R404	Arc Strike	Removed by grinding. Reexamined to verify removal. Reinspection Report R-428 MR# A-036818
R506	CVCH-291	Hanger	---	R506	Arc Strike	Removed by grinding. Reexamined to verify removal. Reinspection Report R-713 MR# A-036818
R844	RCH-29	Hanger	---	R844	Cracked Weld-2" linear indication in weld connecting I beam to steel plate on wall-confirmed as crack by liquid penetrant exam. Could not be determined whether construction defect or serviced induced.	Weld repaired to comply with design specification. Welded per procedure SM-P-1. MR# A-037876 Reexamined to verify repair. Reinspection Report R-1146.

NOI Number	Systems (Weld Number)	Type Weld	Size	Report Number	Discrepancy	Disposition and Additional Comments
R846	CVCH-44	Hanger	---	R846	Lack of Fusion	Weld repaired to comply with design specification. Welded per procedure SM-P-1. MR# A-037021. Reexamined to verify repair. Reinspection Report R-1145

FD = Feedwater System
RHR = Residual Heat Removal System
SI = Safety Injection System
MS = Main Steam System

UHI = Upper Head Injection System
MR = Maintenance Request
CVC = Chemical and Volume Control
RC = Reactor Coolant

NOI Number	Systems	Type Weld	Size	Report Number	Discrepancy	Disposition and Additional Comments
SQ0007	CVC-1045	Socket	2.0"	R0077 R0527	Linear Indication x 3/16" Long, 14 Rounded indication in a 6 in^2 Area	Reducted to acceptable size by grinding. Reinspection to verify acceptability. Reinspection Report R-0527 MR# A-112052
SQ0008	CVC-1253	Socket	2.0"	R0078 R0528	Linear Indication 1" Long	Removed by grinding per MR# A-112053. Reexamined to verify removal. Reinspection Report R-0528
SQ0025	SIH-219	Hanger Rigid Support	1.5"	R0308 R1177	Separated Weld Previously described as "missing" during meeting with NRC on 1-7-86.	Weld repaired per detail weld procedure SM-P-1. Reexamination to verify repair. Reinspection Report R-1177 MR# A-112057
SQ0126	AFDH-308	Hanger Rigid Support	6"	R1293 R1855	Arc Strikes, Undercut and Porosity	Repaired by grinding and rewelding per MR# A-244588 and detail weld procedure SM-P-1. Reinspected to verify repair. Reinspection Report R-1855
SQ0103	ERCWH-84	Hanager Rigid Support	30"	R1384 R1833	Weld deposit on supporting non-welded area.	Removed per MR# A-295568 Reinspection to verify removal. Reinspection Report R-1833

CVC = Chemical and Volume Control System
SI = Safety Injection System
AFD = Auxiliary Feedwater System
ERCW = Essential Raw Cooling Water System

SEQUOYAH NUCLEAR PLANT UNIT 1 NOI'S
PRESERVICE INSPECTIONS

Report Number	System	Type Weld	Discrepancy	Disposition and/or Additional Comments
R153/153A	RHRS-119	Shop	Linear Indication 0.5" in Length	Reinspection Reports R-1294 and R-1395 find weld acceptable. MR not located.
R885	RCW-25(SE)	Shop	Linear Indication 0.5" Long	Removed by grinding. Reinspected to verify removal.
R1094	TE-68-83	Field	Unacceptable Tack Welds	Removed by grinding. Reinspected to verify removal. Reinspection Report R-1094A

SEQUOYAH NUCLEAR PLANT UNIT 2 NOI'S
PRESERVICE INSPECTIONS

Report Number	System	Type Weld	Discrepancy	Disposition and/or Additional Comments
R-540	RHR-15	Shop	Linear Indication in Fusion Walls of Long Seam E11	Weld removed and replaced with welds RHRF-19B & RHRF-19X. Inspection of new welds to establish baseline. Reports R-2259, R-2257, R-2258, R-2256.
R-743	RHRS-60	Shop	Incomplete Penetration in "T" Longitudinal Weld	Tee removed and replaced. New weld RHRF-38B reinspected to establish baseline. Reports R-2179 and R-2189.
R-1666	RHR-105LS	Shop	Linear Indication in "T," 2-1/2" Long	Tee replaced. New welds RHRF-61A, RHRF-61X, and RHRF-61B inspected to establish baseline. Reports R-2181, R-2190, R-2180, R-2192, R-2178, and R-2191.

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APTECH IS APPLIED TECHNOLOGY

AES 8511598AQ-1

EVALUATION OF QUALITY OF WELDS AT SEQUOYAH NUCLEAR PLANT

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January 1986

VERIFICATION RECORD SHEET

REPORT NO.: 8511598AQ-1

TITLE: Evaluation of Quality of Welds at Sequoyah Nuclear Plant

DATE: January 6, 1986

Originated By: [signature] Project Engineer — 1/6/86 Date

Approved By: [signature] Project Manager — 1/6/86 Date

Verified By: [signature] Verifier — 1/6/86 Date

Quality Assurance Reviewed By: [signature] QA Engineer — 1/6/86 Date

Quality Assurance Approval By: [signature] QA Manager — 1/6/86 Date

APTECH ENGINEERING SERVICES

ABSTRACT

Aptech Engineering Services has performed a review of the welding program at Sequoyah Nuclear Plant, Units 1 and 2 in order to verify that the quality of welds at the plant is sufficient for their intended use. This review consisted of three parts: a review of the welding and quality assurance program to determine whether the necessary controls were in place to ensure quality welds, a review of preservice and inservice inspection results to determine the rate of indications in welds, and a review of the operational history to determine the failure rate due to initial weld quality. Based on this review, there is no evidence that the quality of welds at Sequoyah is less than required for its intended service.

CONTENTS

Section 1
INTRODUCTION

As a result of employee concerns regarding the quality of the welding program at Tennessee Valley Authority's (TVA) Watts Bar Nuclear Plant, the quality of welds made at the Sequoyah Nuclear Plant (SNP) also came into question. The Sequoyah Plant is an operating plant which is currently offline for environmental qualification testing. TVA management decided to take this opportunity to evaluate the welding program at Sequoyah and to reaffirm the quality of the welds. Aptech Engineering Services, Inc. (APTECH) was asked by TVA to review the quality of welds at the SNP Units 1 and 2 to ensure that structurally significant and safety related welds are adequate for their intended service. APTECH developed a program plan to evaluate the quality of welds based upon a three-pronged approach. That approach is illustrated in Figure 1-1 and is described below.

The first aspect of this evaluation is a review of the overall welding and quality assurance (QA) program at Sequoyah. This includes a review of welding, construction, and inspection procedures, control of materials and weld consumables, and qualification of welders and inspectors. A properly designed and implemented welding/QA program acts as a series of checks and balances that ensure that high quality welds are being produced. However, high quality welds can be made without a proper QA program. The proof of the quality of the welds lies in the welds themselves, not in the quality of paperwork that accompanies the welds. In order to independently evaluate the quality of the welds, two parallel paths were pursued.

The first approach toward determining the quality of the welds was to evaluate the preservice and inservice inspection (PSI and ISI) results. If the initial quality of the welds were poor, it would be anticipated that the inspection results would indicate an abnormally high rate of detection of weld

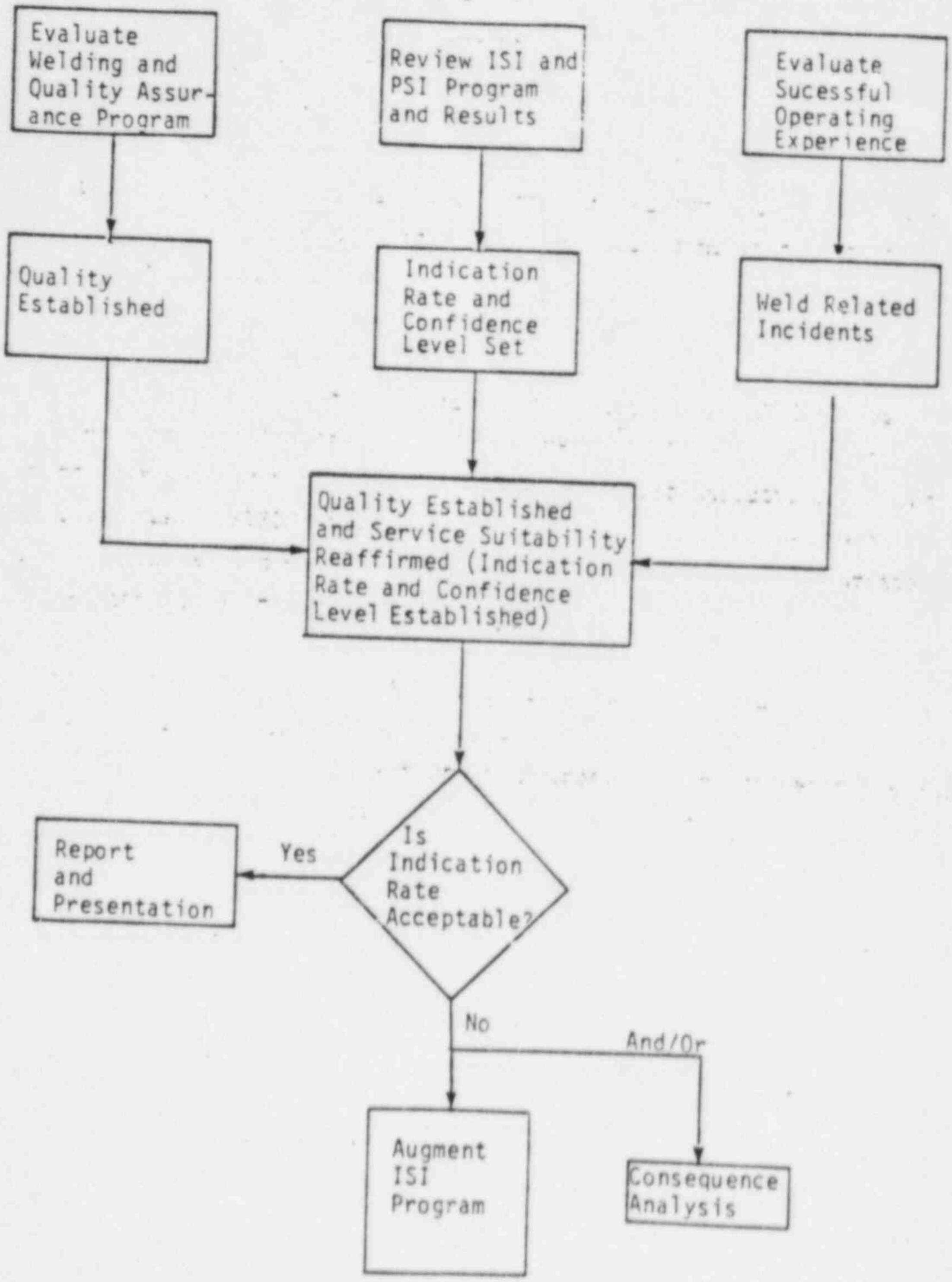

Figure 1-1 - Sequoyah Weld Review Flow Chart indications. As the inspection techniques involved in the PSI and ISI programs are typically different than the construction inspection techniques, these inspections represent an independent measure of the quality of the welds.

The second approach in validating the quality of the welds was to review the successful operating experience of the two units. As both units have over 20,000 reactor hours of operating experience, any initially defective welds should have already been screened out by the natural "infant mortality" period associated with the initial operation of any component. Review of licensee event reports (LER's) would show whether there has been any failures due to poor initial quality of the welds.

The lower half of Figure 1-1 illustrates the process that would be followed after the three separate reviews have been completed and the overall quality of the welds has been determined. If the quality of the welds is determined to be good enough to warrant restart of SNP, then no additional work would be required. However, if the review were to indicate that the welds were not satisfactory for their intended service, then several options would exist, including augmenting the existing ISI program and determining the consequence of failure of specific components. The results of the reviews did show that the welds were satisfactory and therefore no further discussion of consequence analyses or augmentation of the ISI program is included in this report.

The scope of this review was limited to welds made by TVA only. The quality of shop welds made by certified vendors has not been questioned and therefore has not been evaluated. The scope of the review was further limited to structurally significant or safety related welds, such as piping welds, component supports and piping hangers. The basis for the determination of whether a weld was structurally significant or safety related is whether the weld is included in the preservice and inservice inspection plans. The total population of field welds considered was subdivided into two categories: piping welds and structural welds. The basis for this delineation is that piping and structural welds are built to different procedures and acceptance criteria and therefore represent different populations which could have different measures of weld quality. A third population was defined which falls somewhere between the other two categories: integral attachment weldments. The welds on integral attachments are typically performed to structural standards, but as the weld is made to the pressure boundary, inspection criteria are usually similar to those for pressure boundary welds.

Section 2 of this report summarizes the review of the welding and quality assurance programs. Section 3 summarizes the preservice and inservice inspection programs and presents the rate of indications detected to date. This rate is compared with typical reinspection data for similar structures. Section 4 presents the review of the operating experience and any weld related licensee event reports. The results and conclusions of this review are summarized in Section 5.

Section 2

REVIEW OF WELDING AND QUALITY ASSURANCE PROGRAM

The construction of SNP was carried out in accordance with an integrated system of corporate level construction specifications and procedures designed to assure that all regulatory requirements were satisfied and to ensure that the necessary welding quality was achieved. These specifications were implemented at the plant by the use of a series of construction specifications, inspection instructions, and standard operating procedures governing specific aspects of fabrication. This integrated program assured that each phase of work in the welding program was properly controlled.

Those components that were covered by the quality assurance program were delineated on TVA Division of Engineering Design approved drawings and in TVA SNP Construction Specification N2-G-877 "Identification of Structures, Systems, and Components Covered by the SNP Quality Assurance Program". Fabrication of specific components (e.g., structural steel, or seismic supports) was governed by construction procedures, which prescribed additional construction procedures for detailed steps in the fabrication process (e.g., weld procedure assignment). Table 2-1 lists the SNP construction procedures related to welding. These procedures also cover the qualification, certification, and QA training of personnel.

These construction procedures also include by reference the AISC, AWS, ANSI, and ASME Codes (1-4) as well as TVA's general construction specifications, such as G-29 ("Process Specifications for Welding, Heat Treatment, Nondestructive Examination, and Allied Field Fabrication Operations"). The G-29 specification is broken into several sections, such as G-29C (structural), G-29M (piping), and G-29E (electrical). The G-29M specification is written to be consistent with the ASME and ANSI Codes for piping, whereas the G-29C specification is written to be in accordance with the AISC and AWS

Table 2-1

WELD RELATED CONSTRUCTION PROCEDURES

C2	Erection & Inspection of Structural Steel
E3	Installation & Inspection of Seismic Supports for Conduit & Lighting Fixtures
G1	Fabrication & Installation of Seismic Supports
G3	Erection of Piping & Instrument Lines
G4	Surveillance of Site Contractors
I5	Fabrication, Installation, & Inspection of Seismic Instrument Line Supports & Wall Mounted Panels
M1	Procurement, Storage, Issue, and Control of Welding Materials
M2	Welder & Welding Operator Performance Qualification
M3	Welding Surveillance & Weld Procedure Assignment
M5	Certification of Nondestructive Examination Personnel
M7	Erection & Documentation Requirements for QA Piping Systems
M15	Post Weld Heat Treatment
M19	Cleanliness of Fluid System Piping and Components
M20	Pipe Support Installation & Documentation
M23	Fabrication, Installation, & Inspection of HVAC Duct Supports
M28	Arc Strike Removal
P2	Handling Nonconformances
CP3	Procurement, Storage, Issue, & Control of Welding Materials
P3	Reporting and Documenting Conditions Adverse to Quality
CP4	Welder & Welding Operator Performance Qualification
P8	Preparation, Review, Handling & Storage of QA Records
P9	Responding to NRC Inspection Items & QA Audit Findings
P10	Control of QA Documents
P11	Control & Documentation of Permanent Material Field Fabrications
P12	Storage of QA Material
P13	Release for Drilling, Chipping, Cutting, Welding, Sandblasting, & Rework of Permanent Structures
P14	Installation & Inspection of Embedded Material & Equipment
P16	Certification of Nondestructive Testing Personnel
P30	Fabrication and Installation of Seismic Supports
P33	Certification of Inspectors
P34	Heat Number Validation
P41	Handling Allegations
P48	Personnel QA Training
P50	Stop Work & Restart
W1	Procurement, Storage, Issue, & Control of Welding Material
W2	Welder & Welding Operator Performance Qualification
W3	Weld Procedure Assignment & Welding Surveillance
W4	Base Metal Repair
W5	Arc Strike Removal
W6	Post Weld Heat Treatment
W7	Repair of Welds

Codes. As a result, the acceptance criteria are slightly different for structural welds than for piping welds. This fact, plus the fact that structural welds are typically made using different techniques than piping welds indicates that the quality of structural welds is likely different than the quality of piping welds. As a result, they will be treated as two separate populations in the statistical evaluation of the inspection results in Section 3.

In order to ensure that the construction procedures were followed properly, a series of inspection instructions were utilized. These govern prewelding inspections as well as post weld inspection. Table 2-2 lists the SNP Inspection Instructions related to welding. Standard operating procedures are also defined to prescribe procedures not specifically covered by construction procedures or inspection instructions. Weld related standard operating procedures are listed in Table 2-3.

Briefly, the construction procedures imposed the following controls over the welding program: base metals and welding materials were controlled from procurement through final use including receipt, storage, issue and in process fabrication. No requirements were placed on traceability of a heat number of an electrode to a particular joint, as all of the electrodes were purchased, stored, and issued to the same quality standards. Welders were trained, tested, certified, and had their continuity (recent experience) maintained as required. Welds were made by qualified welders whose certifications were verified on a continuous basis. Welding was performed to qualified welding procedures which were assigned by knowledgeable personnel. Welding inspections were assigned, conducted, evaluated, and documented as dictated by the procedures.

The welding and QA program described above has all of the characteristics of a good program. It provides for personnel qualification and training, procurement and control of welding materials, and written procedures for welding and inspecting the quality of the welds. The program has been audited and approved by both internal and external auditing and regulatory bodies.

Table 2-2

WELD RELATED INSPECTION INSTRUCTIONS

II-D5	Piping & Supports Walkdown Procedure
II 34	Surveillance of Contractor Site Activities
II 38	Inspection of Site Fabricated Assemblies
II 39	Heat Code Transfer
II 41	Hydrostatic Test of Piping Systems
II 63	Piping Inspection
II 66	Inspection of Supports
II 67	Vacuum Box Testing
II 70	Inspection of Base Metal Repairs
II 71	Inspection of Post Weld Heat Treatment
II 72	Ferrite Content
II 73	Arc Strike Removal
II 74	Fitup & Cleanliness Inspection
II 75	Visual Examination of Weld Joints
II 76	Liquid Penetrant Examination
II 77	Magnetic Particle Examination
II 78	Ultrasonic Examination
II 79	Radiography Examination
II 85	Installation Verification & Pressure Test of Instrument Lines
II 91	Pneumatic Test of Piping Systems

Table 2-3

WELD RELATED STANDARD OPERATING PROCEDURES

SOP 102	Conduit Hanger Installations
SOP 300	Reporting of Field Discrepancies
SOP 301	Qualification of Inspectors
SOP 302	Releases to Drill, Chip, Cut, Weld, or Sandblast
SOP 318	Resolving & Documenting Items Identified in NRC Exit Meetings or Inspection Reports
SOP 319	Work Suspension & Restart Procedure
SOP 321	Weld Map Status Program Operation & Maintenance
SOP 400	Mechanical Hanger Installation, Inspection, & Documentation
SOP 401	Weld Maps
SOP 405	Requirements for Pipe Bends, Threaded Pipe Connections, Weld Location, Piping Bolted Connections, & Valves
SOP 550	Review of QA Records
SOP 601	Receipt Inspection of Permanent Plant Material
SOP 650	Walkdown of Permanent Plant Features
SOP 700	Weld Surveillance
SOP 703	Welding Inspection Unit Weekly Report
SOP 704	Procurement of Welding Inspection Unit Materials
SOP 901	Supplementary Welding Instructions for Heavy Members

This implies that the program, if properly implemented, is capable of producing quality welds. However, an early audit by the Atomic Energy Commision (AEC) Directorate of Regulatory Operations discovered several violations in SNP's welding program (5). As a result of this audit, several changes were made to the welding program, including revising construction procedures, increasing the QA training, and additional weld surveillance. Standard operating procedure Number 700 "Weld Surveillance" was implemented subsequent to this audit as a check on the quality of welding. This program requires a minimum of two complete surveillance tours of each inspection area each shift to ensure that correct procedures are being followed. The surveillance inspections served as a major control feature for the Sequoyah construction welding program, although other controls, including internal and external audits, were also utilized.

As a check on the implementation of the program, APTECH selected at random two welds for detailed examination of the documentation supporting those welds. An integral welded attachment from Unit 1 (SIH-21) and a field piping weld from Unit 2 (UHIF-55) were selected. Complete documentation was provided by TVA for both welds, includ g piping drawings, construction procedures, weld history records, material certifications, welder qualifications and continuity, inspection procedures, inspector qualifications and certification, PSI and ISI results, and NDE equipment calibration. The PSI examination of the structural weld was performed by outside contractors (Lambert, MacGill and Thomas, Inc.), therefore providing an independent assessment of the quality of the weld. All other NDE was performed by TVA personnel.

This review did not address the technical adequacy of the construction procedures in detail, as they relied heavily on existing codes and standards. In some cases the acceptance criteria for SNP were more stringent than comparable codes, and in some cases, they were more lenient. However, those cases that we observed to be more lenient than the Code of record were consistent with current codes and technical justification existed for deviations from the Code of Record (6).

In summary, APTECH has reviewed the welding/QA program at Sequoyah and has found that subsequent to the 1974 AEC audit, the program contains the necessary checks and balances to ensure high quality welding. As a result of the 1974 audit, steps were taken to evaluate the quality of welds made prior to the audit, and it is felt that there is no reason to question the quality of these welds further. A spot check of the implementation of the program uncovered no deficiencies in documentation of the program.

Section 3
REVIEW OF PRESERVICE AND INSERVICE INSPECTION RESULTS

The best way to measure the quality of field welds at Sequoyah Nuclear Plant is to reinspect the welds using some form of sampling plan to ensure high confidence in the inspection results, short of inspecting 100% of the welds, which may be impossible to do because of problems of accessibility. The preservice and inservice inspections required by Section XI of the ASME Code represent independent reinspections of the quality of the welds. The PSI and ISI examinations are performed by different personnel (in some cases outside contractors) than those involved in the fabrication of the welds, and the techniques and procedures are different, ensuring an evaluation which is independent of the original construction inspections. Thus, the PSI and ISI results will be used as quality indicators for the welds at SNP. If chronic deficiencies existed in the welding program at SNP, it would be expected that an unusually high number of defective welds would be detected in the PSI and ISI programs. The rate of generation of Notices of Indications (NOI's) will be used here as a measure of weld quality.

Preservice Inspection Results

The results of the PSI program were taken from the PSI summaries (7, 8). The type of weld was determined from the weld identification number. Field piping welds were identified by an "F" suffix after the system number. Socket welds were identified by four digit weld numbers. It is possible that additional socket welds exist that are not designated by four digit numbers. The result of these unknown welds would be to increase the population size, therefore decreasing the indication rate for a known number of indications. Thus, the effect of not counting these unknown socket welds in the total population is conservative. Hangers were identified by an "H" suffix, and those hangers that are integrally welded attachments were subsequently indentified by the hanger type "IA". The number of PSI examinations for each category are summarized in Table 3-1. There were 1101 Class 1 and 2 field welds examined during the PSI program (including socket welds). Most of the subsequent ISI examinations represented reinspection of those welds examined in the PSI program and thus this number represents the total number of piping welds inspected. The total number of Class 1 and 2 field welds (representing the entire population) determined by TVA from a review of construction drawings is 2618, thus the PSI's on Units 1 and 2 covered 42.1% of the total field weld populations. These counts are used in another section of this report to estimate the NOI rate.

The only hangers inspected in the PSI program were integral attachments. The number of integrally welded attachments (IA's) inspected during the PSI program (61) represents less than half of the total population (146). Some of the IA's inspected in the PSI program were subsequently reinspected during the ISI program. The values shown in Table 3-1 represent only those IA's which were not subsequently inspected during the ISI program. This number (39) will be added to the number of IA's inspected during the ISI examinations to provide the total number of integral attachments inspected during PSI/ISI.

A summary of notices of indications reported as a result of the PSI on Unit 1 and 2 is given in Table 3-2. Only one significant NOI was reported for all the categories of field welds inspected. There were five NOI's on shop welds. "Significant NOI's" in this case refers to indications which were unacceptable per ASME Section XI and required repair and re-inspection. The NOI's generated as a result of the PSI examinations are described in more detail in Tables 3-3 and 3-4. The only field weld containing an indication was Weld Number TE-68-83, which is a reactor coolant main loop temperature element weld.

Slightly under 10% of the field welds were inspected by penetrant (PT). The remaining 90% were inspected ultrasonically (UT), which is a more rigorous

Table 3-1

SUMMARY OF PRE-SERVICE INSPECTIONS (PSI's)

	Unit 1	Unit 2
Field Piping Welds	473	484
Field Socket Welds	20	124
Integrally Welded Attachments	25	14

Table 3-2

PRE-SERVICE NOI's ON FIELD WELDS

	Unit 1	Unit 2
Field Piping Welds	1	0
Field Socket Welds	0	0
Integrally Welded Attachments	0	0

Note: 2 NOI's on Shop Welds Unit 1
3 NOI's on Shop Welds Unit 2

Table 3-4

SEQUOYAH UNIT 2 NOI's - PRE-SERVICE INSPECTIONS

Report Number	System	Type Weld	Discrepancy
R-540	RHR-15	Shop	Linear Indication in Fusion Walls of Long Seam Ell
R-743	RHRS-60	Shop	Incomplete Penetration in "T" Longitudinal Weld
R-1666	RHR-105LS	Shop	Linear Indication in "T", 2-1/2" Long

Table 3-3

SEQUOYAH UNIT 1 NOI's - PRE-SERVICE INSPECTIONS

Report Number	System	Type Weld	Discrepancy
R153/153A	RHRS-119	Shop	Linear Indication 0.5" in Length
R885	RCW-25(SE)	Shop	Linear Indication 0.5" Long
R1094	TE-68-83	Field	Unacceptable Tack Welds

volumetric examination than PT, which is primarily a surface examination. The lack of significant numbers of NOI's from the PSI is a strong indicator that the quality of the welds is high.

Inservice Inspection Results

Although inservice inspection is directed at finding defects caused by operating factors, the inspection findings are also a measure of the initial weld quality. This will become apparent below as some of the indications detected during ISI are construction related defects. The number of ISI's performed on Unit 1 through three fuel cycles and on Unit 2 through two fuel cycles are listed in Table 3-5. This table also includes the number of Class 1, 2 and 3 hangers which were visually inspected. Field welds and IA's were all inspected by UT, PT, RT or MT, or a combination of two inspections by these methods. The total number of ISI's on field welds (piping and socket welds) for both units is 456. As these are mostly repeats of the welds inspected in the PSI program, these welds are not included in the total number of inspections used to establish an indication rate below. Ninety hanger IA's have been performed to date in the inservice inspection program. The total population of Class 1, 2, and 3 hangers according to a TVA count is 2,580 and all were inspected at least once during a total of 3,150 ISI examinations.

As a result of the ISI program a total of 22 NOI's were written on welds (including shop welds) on Units 1 and 2. These are summarized in Table 3-6 under the appropriate category. Not all of these NOI's were considered to be significant NOI's. Notices of Indications for Unit 1 are listed in Table 3-7. Only linear indications, missing welds and cracks are considered significant defects. There were three significant NOI's on field welds (FDF-4, UPIF-19 and RHRF-109A); four NOI's were written on hanger IA's (SIH-453, SIH-20, SIH-21 and MSH-289); five NOI's were written on hangers (FDH-203, SIH-17 and RHRH-460, RCH-29 and CVCH-44). All were adequately repaired as determined by re-inspection. Table 3-8 shows the five significant NOI's for Unit 2 after two fuel cycles. Two were associated with field socket welds (CVC-1045 and CVC-1253) and are considered significant. The other three which were written

Table 3-5

SUMMARY OF WELD ISI's

	Unit One			Unit Two	
	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2
Field Piping Welds	90	1[illegible]	85	65	3
Field Socket Welds	63	0	60	76	0
Integrally Welded Attachments (IA)	26	9	26	29	0
Hangers*	683	752	463	710	544

*Class 1, 2, and 3

Table 3-6

SUMMARY OF WELD NOI's

	Unit One			Unit Two	
	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2
Piping Field Welds	7		1		
Field Socket Welds				2	
Integrally Welded Attachments	1		3		
Hangers	2		3	1	2

Table 3-7

NOI DESCRIPTIONS - SEQUOYAH UNIT 1

NOI Number	Systems (Weld No.)	Type Weld	Size	Report Number	Discrepancy
R0082	FDF-4	Field	18"	R0082	Linear Indication 1/2" Long
R0081	RHRS-2	Shop	18"	R0081 R0039	2 Arc Strikes
R0124	SIF-127	Field	10"	R0124 R0221	Unacceptable Surface Condition For PT Examination
R0125	SIF-148	Field	10"	R0125 R0220	1 Arc Strike
R0192	SIS-337	Shop	2.5"	R0192 R0225	Unacceptable Surface Condition For Examination
R0193	SIS-338	Shop	2.5"	R1064 R0226	Unacceptable Surface Condition For Examination
R0219	UPIF-19	Field	12"	R0219 R520	Linear Indication, 5/8" Long
R0232	SIH-453	Hanger (IA)	8"	R0232 R0334	Linear Indication, 5/32" Long (Appears to be arc strike)
SQ0178	RHRF-109A	Field	---	R2540	Linear Indication, 1/4" Long
SQ0201	FDH -203	Hanger	---	R2714	Weld Missing
----	SIH-17	Hanger	---	MR550488	Weld Missing
SQ0213	SIH-21	Hanger (IA)	---	R2813	Two 3/4" Long Linear Indications
SQ0212	SIH-20	Hanger (IA)	---	R2812	Two 3/4" Long Linear Indications
SQ0154	MSH-289	Hanger (IA)	---	R2374	Linear Indication, 5/16" Long
SQ0179	RHRH-460	Hanger	---	R2541	Crack-Like Indications on Tack Welds

(Table 3-[illegible] - Continued)

NOI Number	Systems (Weld No.)	Type Weld	Size	Report Number	Discrepancy
R235	Stm. Gen.	Shop	---	R235	3/4" Linear Indication
R279	RCF-31	Field	---	R279	Arc Strike
R00A	SIS-274	Shop	---	R00A	Arc Strike
R404	RCH-231	Hanger	---	R404	Arc Strike
R506	CVCH-291	Hanger	---	R506	Arc Strike
R844	RCH-29	Hanger	---	R844	Cracked Weld
R846	CVCH-44	Hanger	---	R846	Lack of Fusion

FD = Feedwater System
RHR = Residual Heat Removal System
SI = Safety Injection System
MS = Main Steam System
UHI = Upper Head Injection System
MR = Maintenance Request
CVC = Chemical and Volume Control
RC = Reactor Coolant

Table 3-8

NOI DESCRIPTIONS - SEQUOYAH UNIT 2

NOI Number	Systems	Type Weld	Size	Report Number	Discrepancy
SQ0007	CVC-1045	Socket	2.0"	R0077 R0527	Linear Indication > 3/16" Long, 14 Rounded Indication in a 6 in^2 Area
SQ0008	CVC-1253	Socket	2.0"	R0078 R0528	Linear Indication 1" Long
SQ0025	SIH-219	Hanger Rigid Support	1.5"	R0308 R1177	Missing Weld
SQ0126	AFDH-308	Hanger Rigid Support	6"	R1293 R1855	Arc Strikes, Undercut and Porosity
SQ0103	ERCWH-84	Hanger Rigid Support	30"	R1384 R1833	Unacceptable Weld Deposition

CVC = Chemical and Volume Control System

SI = Safety Injection System

AFD = Auxiliary Feedwater System

ERCW = Essential Raw Cooling Water System on hangers (SIH-219, AFDH-308 and ERCWH-84) are also considered significant because of their linear indications, missing weld, undercut, porosity and unacceptable weld deposition.

The ISI program plan requires only 25% of the piping welds and 100% of the hangers to be inspected in the first ten year inspection interval. However, SNP has inspected in four years far more welds than required to be inspected in ten years. This is a good indication that SNP personnel are concerned about the quality of their welds.

Indication Rates

The PSI and ISI results are summarized are in Table 3-9. Since the ISI's on field welds were essentially a repeat of those in the PSI's, the latter number is taken as the sample size. This makes the resulting indication rate conservative since the addition of any ISI's to this sample number will increase the sample number above 1101 and decrease the defect rate. For the integral attachments, the PSI's are added to ISI's to give the total sample size of 129. All duplicate inspections were deleted (this is conservative as described above). For hangers, 3044 ISI examinations were performed on a total of 2689 different hangers. However, only 2588 hangers were included in the ISI program plan. This means that all of the hangers in the ISI program plus many others have been inspected. Since all hangers in the ISI population were inspected once, we are 100% confident that the NOI rate is:

$$\frac{8}{2588} \times 100 = 0.31\%$$

For field welds and integral attachments, the indication rate for a partial sampling program was calculated using the hypergeometric distribution theory. This is used for the same situations as the binomial distribution except that when the proportion of OK's cannot be assumed to be constant after the sample is drawn, the hypergeometric distribution is used. A more detailed description of this theory is in Appendix B. The estimated rate of significant indications for the field weld population is 0.95% with a confidence/probability level greater than 95%/95%. The estimated rate of

Table 3-9

SIGNIFICANT INDICATION RATE

	Total Population	PSI	ISI	%Examined	NOI's	NOI Rate (%)***
Field Piping Welds (Includes Socket Welds)	2618	1101	456	42.1	6	0.95
Integrally Welded Attachments	146	39	90	88.4	4	4.79
Hangers (Class 1. 2. and 3)	2588	0	2689	100	8	0.31

* ISI Examination Mostly Repeated PSI. Total Number of Welds Examined is 1101.

** Includes IA's not Subsequently Reinspect in PSI.

*** Probability Level at Greater Than 95% Confidence.

significant indications for the hanger IA's is 4.79% which is also greater than the 95% confidence/95% probability levels. Another way of describing the IA indication rate is, "we are more than 95% confident that the estimated indication rate will not exceed 4.79%".

All of the individual indication rates (and therefore the cumulative indication rate) provide greater confidence in the quality of the welds than the 95% confidence/95% probability level that is common in the nuclear industry. Use of a statistical confidence limit is necessary because no inspection technique is capable of detecting 100% of the defects with 100% confidence. Therefore there will be a finite probability that defects will be detected in a component even if it has already been inspected and no known defects were left in the component. For comparison purposes, a complete re-evaluation of 254 radiographs of Class 1 piping at Millstone Unit 3 that had previously been interpreted as being free from defects revealed a 1.6% reinspection indication rate (9). The 0.95% indication rate for field piping at Sequoyah compares favorably with this value. For structural welds, there is very little data available for comparison, however, limited reinspection data of structural welds in offshore platforms indicate a reinspection indication rate of nearly 5% (10, 11, 12). Thus, the rate of indications in the reinspections at Sequoyah are comparable with similar data for similar types of welds.

Section 4
REVIEW OF OPERATIONAL EXPERIENCE

Sequoyah Nuclear Plant Units 1 and 2 have seen a combined service life of 46,430 critical hours of operation. This amount of service should be enough to identify any welds which are not of sufficient quality for their intended service. Once a plant is in operation, any failures would be reported to the Nuclear Regulatory Commission (NRC) as Licensee Event Reports (LER's). The LER's associated with SNP were reviewed looking for any events related to welds or welding. The results of that review are summarized below.

Sequoyah Unit 1 started commercial operation on July 1, 1981 and to date the system has 24,445 critical reactor hours. These critical reactor hours represent a total of 2.79 years of continuous operation. During this period only five LER's related to welds were sent to the NRC. These LER's are summarized in Table 4-1. No failures can be attributed to poor quality of field welds.

Sequoyah Unit 2 went into commercial operation on June 1, 1982. When shut down on August 21, 1985, the reactor had achieved 21,985 critical hours of operation representing 2.51 years of continuous operation. There were no LER's relating to welds sent to the NRC (Table 4-2). Therefore, these two Sequoyah units have 5.3 years of critical operation with no failure related to poor quality of field welds.

Table 4-1

SEQUOYAH UNIT ONE OPERATION EXPERIENCE

Date of Commercial Operation: July 1, 1981

Hours Reactor Critical: 24,445

Capacity Factor (Cumulative): 59.5%

LER's Concerned With Welds:

LER Number	Date	Event
80-156	10-5-80	Nozzle Failure on CVC Seal Water Injection Line - Vibration or Physical Damage
80-141	08-29-80	Seal Weld Failure on CRDM - Westinghouse Defect
80-150	09-27-80	Check Valve Stuck Open - Tack Weld Interferred With Disc and Valve Body (Vendor Defect)
81-17	02-12-81	Welder Blew Pin Hole in Pipe - Restricted Access
82-97	08-03-82	Door Latch Connecting - Rod Broken at Weld - Fatigue

Weld Record:

- No Failures Due to Poor Quality of Field Welds

Table 4-2

SEQUOYAH UNIT 2 OPERATION EXPERIENCE

Date of Commerical Operation:	June 1, 1982
Hours Reactor Critical:	21,985
Capacity Factor:	69.2%
LER's Concerned with Welds:	

LER Number	Date	Event
None	---	---

Weld Record:

- No Failures Due to Poor Quality of Field Welds

Section 5
SUMMARY AND CONCLUSIONS

APTECH has performed a review of the welding/QA program at Sequoyah Nuclear plant and has evaluated the quality of welds through a review of the preservice and inservice inspection results and Licensee Event Reports related to welding. The following conclusions have been developed based upon these reviews:

- The welding program contains the necessary controls to ensure high quality welds (after the 1974 AEC audit).
- SNP evaluated the quality of welds made prior to the 1974 audit through reinspection and repair where required. Those welds made prior to the 1974 audit can now be considered to be satisfactory despite a breakdown in the QA program.
- The rate of significant indications detected during the preservice and inservice inspections is less than 5% with greater than 95% confidence.
- No Licensee Event Reports have been generated which relate to poor quality field welds.

Based upon these conclusions, there is no evidence that the quality of welds at Sequoyah Nuclear Plant are not fit for their intended service.

REFERENCES

1. American Institute of Steel Construction "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings".

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3. American National Standards Institute, "Power Piping", ANSI B31.1.

4. American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code", Sections I, III, and VIII.

5. "Corrective Action Report for Welding at SNP", November 4, 1974 (ECD-11).*

6. Memorandum from G.H. Kimmons, to H.N. Culver, "Watts Bar Nuclear Plant - Technical Justification of Contrasts of AWS D1.1 and General Construction Specification G-29C", December 15, 1982 (ECD-23).

7. Summary of Preservice Inspection at Sequoyah Nuclear Plant Unit 1 (ECD-2).

8. Summary of Preservice Inspection at Sequoyah Nuclear Plant Unit 2 (ECD-3).

9. Feiereisen, Thomas J., Peter D. Hedgecock, and Geoffrey R. Egan, "Radiographic Review of Piping Welds at Millstine 3 Nuclear Power Plant", APTECH report AES 8501521AQ-1.

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* Externally generated controlled documents are denoted by (ECD-n).

Appendix A
PRE-SERVICE INSPECTION

Table A-1

UNIT ONE PSI FIELD WELD INSPECTIONS

RCF	RCF	UPIF	SIF	SIF	RHRF	RHRF	RC
13	63	19	2	147B	4A	88	1
14	63A	20	3	148	6A	89	2
15	64	21	4	149	10A	90	3
16	65	22	7	150	12	90A	4
17	66	23	8	150A	14	91	5
18	66B	24	10	160	15	92	6
19	67	25	12	162	16	93	7
20	68	26	14	163	17	106	8
21	69	27	19	166	18	107	9
22	70	28	36	167	19	107A	10
22A	70A	29	87	168	20	108	11
23	71	30	88	169	23	109	12
24	72	31	89	170	25	109A	13
24A	73	32	118	170A	26	109B	15
24B	74	33	119	170B	29	109C	16
24C	75	34	120	171	31	109D	17
24D	76	35	121	175	34	109E	18
24E	77	36	121A	176	38	109F	19
24F	77A	37	122	177	39	110	20
24G	78	38	125	178	40	111	21
24H	79	39	125A	179	41	111A	22
24P	80	40	126	182	42	112	23
25	81	41	127	183	43	122	24
26	82	44	128	184	44	123	25
26A	83	45	128A	185	45	124	26
26B	84	46	129	186	46	124A	27
26C		47	130	186A	48	124B	28
26D		48	130A	186B	50	125	29
27		49	130B	187	51		30
29-X1		50	131	193	52		31
30		51	132	194	53		32
30A		52	133	194A	54		33
30B		53	135	195	55		34
30C		54	137	196	58		35
30D		55	138	197	59		1 (SE)
31		56	138A	198	60		2 (SE)
36		57	139	201	61		3 (SE)
42		58	142	202	63		8 (SE)
45		59	143	202A	64		9 (SE)
49		60	144	203	65		10 (SE)
49A		61	145	204	66		11 (SE)
50		62	145A	205	67		16 (SE)
							17 (SE)

(TABLE 1 - Continued)

RCF	UPIF	SIF	SIF	RHRF	RC
51	63	146	206	85	18 (SE)
51A	64	147		86	19 (SE)
52	65	147A		87	24 (SE)
53					25 (SE)
54					26 (SE)
55					27 (SE)
					32 (SE)
					1-TE-68-1
					1-TE-68-1C
					1-TE-68-18
					1-TE-68-24
					1-TE-68-24C
					1-TE-68-41
					1-TE-68-43
					1-TE-68-43C
					1-TE-68-60
					1-TE-68-65
					1-TE-68-65C
					1-TE-68-83
					1-TE-68-318

CVCF	SI	RCW	FDF	SIW	SWIW	UPIW	MSF	SIH	RCH
163	1575	1	4	1	1968A	9	3	2	15
163A	1588	2	10	2	1968B	10	11	7	27
164	1631	3	11	3	2040A	11	31	20	70
165	1643A	4	18	4	2040B	13	38	21	125
166	1664	5	21	5	2098A	14	39	22	126
167	1669	6	22	7	2098BX	16	46	24	140
158	1681A	7	128	8	2158A	17		71	188
169	1719	8	130	9	2158B	19		79	232
170	1732	9	131	10		20		164	288
171	1734A	10	140	1734		22		318	
172		12	141	1772A				320	
209B		13							
210		14							
210A		22							
210B									
211									
211A									
211B									
212									
213									
214									
242B									
243									
243A									
243B									

(TABLE 1 - Continued)

CVCF
244
244A
245
246
246A
246B
247

CVCH	RHRH	RHRW	CVCW	UHIH	CSF	UHI
6	3	1	1	34	1	1 UHI 0030X2
14	4	2	2	37	2	2 UHI 0039
32	5	3	3		3	
106	7	183C	4		14	
136					15	
296						
302						

Table A-2

UNIT TWO PSI FIELD WELD INSPECTIONS

RHRF	RHRF	SIF	SIF	RCF	RCF	UPIF	UPIF	CVCF
4A	60	1	168	13	66	17	62	163
5A	61A	2	169	13A	67	17A	63	164
6A	61B	3	170	14	68	17B	64	165
6C	61X	5	171	15	69	18	65	166
7	62	11	176	16	70	19		167
10A	64	12	177	16A	70A	20		168
12	65	13	178	16B	71	21		169
13	66	18	179	17	71B	22		170
14	67	36	182	18	72	23		171
16	85	87	182A	19	73	24		172
16A	86	88	183	20	74	25		209B
17	87	90	184	21	75	26		210
18	88	118	185	22	76	27		210A
19	89	121	186	23	77	28		210B
19B	90	121A	187	24	78	29		211
19X	90A	121B	193	24A	79	30		211A
20	91	122	194	24C	80	31		212
22	92	125	194A	24D	81	32		213
23	93	125A	194B	25	82	33		214
24	94	126	195	26	83	34		242B
25	104	127	196	26A	84	35		243
26	105	128	197	26B		36		243A
27	106	129	198	26C		37		244
28A	106A	130	201	26D		38		244A
28B	107	131	202	27		40		244B
30	107A	132	202A	29		41		245
32	108	135	202B	30		42		246
33	109	136	203	30A		43		246A
34	110	137	204	30B		44		247
35	111	138	205	30C		45		
36	111A	139	205A	30D		46		
37	111C	142	206	31		47		
38B	112	143	206A	36		48		
40	113	144	206B	42		49		
41	114	145		45		50		
42	120	145A		56		51		
43	121	146		56B		52		
44	122	147		57		53		
45	123	148		58		54		
46	124	149		59		55		
47	124A	150		60		56		
49	125	161		61		57		
53		162		62		58		
56		163		63		59		

(TABLE 2 - Continued)

RHRF	SIF	RCF	UPIF
57	166	63A	60
58	167	64	61
		65	

SI	CVC	RC	RC	FDF	CSF	RCW	MSF	CVCW	UPIW	SIW
1129	1017	1	1234	2	1	1	2	1	10	1
1130	1031	2	1250	5	2	2	5	2	11	2
1136	1039	3	1268	6	3	3	10	3	13	3
1142	1040	4	1269	10	14	4	14	4	14	4
1148	1049	5	1284	11	15	5	17	1057A	16	5
1161	1056	6	1348	15	16	6	18	1057B	17	7
1162	1057	7	1368	16		7	20	1069	19	8
1822	1069	8	1379	20		8	24	1091B	20	9
1829	1072	9	1386	21		9	30	1169B		10
1830	1086	10	1412	22		10	32	1236		
1848	1087	11	1413	125		12	35	1236B		
1856	1094	12	1430	127		13	39			
1864	1103	13	1449	128		14	41			
1865	1104	14	1450	130		22	43A			
1866	1116	15	1460	131			44			
1870	1128	16	1466	134						
1876	1129	17	1477	140						
1890	1139	18	1495	141						
1897	1143F	19	1510							
1898	1148	20	1511							
1906B	1149	21	1523							
1915	1164	22	1542							
1916	1169	23	1543							
1921	1177	24	1561							
1926	1188	25	1585							
1940	1189	26	1586							
1950	1200	27	1592							
1951	1207	28	1607							
1984A	1213	29	1618							
1993	1225	30	1626							
2057	1237	31	1644							
2098	1241	32	1651							
2115	1251	33	1652							
2187	1252	34	1661							
2193	1259A	35	1671							
2255	1272	1 (SE)	1672							
2256		2 (SE)	1675							
2270		3 (SE)	1729							
		8 (SE)	1745							
		9 (SE)	1761							
		10 (SE)	1762							

(TABLE 2 - Continued)

RC	RC
11 (SE)	1767
16 (SE)	1772
17 (SE)	
18 (SE)	
19 (SE)	
24 (SE)	
25 (SE)	
26 (SE)	
27 (SE)	
32 (SE)	
2-TE-68-1	
2-TE-68-1C	
2-TE-68-18	
2-TE-68-24	
2-TE-68-24C	
2-TE-68-41	
2-TE-68-43	
2-TE-68-43C	
2-TE-68-60	
2-TE-68-65	
2-TE-68-65C	
2-TE-68-83	
2-TE-68-318	

UHI	SIH	RCH	RHRH	UHIH	CVCH	RHRW
1261	2	15	2	34	296	1
1265	7	91	3		302	2
1272	20	125	4			3
	21	126	5			
	22	140	7			
	24	188				
	71	232				
	79	288				
	161					

Appendix B

THE HYPERGEOMETRIC PROBABILITY DISTRIBUTION

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THE HYPERGEOMETRIC PROBABILITY DISTRIBUTION

The hypergeometric probability distribution is used to calculate the probability of finding I defects in a sample size of Q, when there is a finite population of N items and there are R defects in the total population. The equation for this distribution is:

$$P\left(\frac{I}{Q}\right) = \sum_{I=0}^{K} \frac{\binom{R}{I}\binom{N-R}{Q-I}}{\binom{N}{Q}} \quad (1)$$

Where, $P\left(\frac{I}{Q}\right)$ = Probability that a sample of Q items will contain I defective items

R = Number of defects in total population

I = Number of defects in sample

N = Total popluation

Q = Sample size

The pertinent terms in the above equation are:

$$\binom{R}{I} = \frac{R!}{I!\,(R-I)!}$$

$$\binom{N}{Q} = \frac{N!}{Q!\,(N-Q)!}$$

$$\binom{N-R}{Q-I} = \frac{(N-R)!}{(Q-I)!\,((N-R-(Q-I))!}$$

In order to calculate the probability of finding I defects in the sample and relating this to confidence limits the above equation is set equal to 1-C where C is the confidence level as a decimal:

$$P\left(\frac{I}{Q}\right) = \sum_{I=0}^{K} \frac{\binom{R}{I}\binom{N-R}{Q-I}}{\binom{N}{Q}} = 1-C \qquad (2)$$

The use of this equation requires an iterative process. A value for R is assumed and the confidence is computed. Our normal confidence level in nuclear work is 95%. Therefore R values are assumed until the summation from I = 0 to I = K defects is as near equal to the 95% confidence level as possible. Note that only whole numbers are possible for R, the number of defects in the total population. The justification for equation (2) comes from a similar development for the binomial distribution (B-1).

B-1. Amstedter, Bertram L., Reliability Mathematics, McGraw-Hill Book Company, Page 247.