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FINAL REPORT

For

WASTE PACKAGE WELD FLAW ANALYSIS

Revision 0

October 13, 2002

Prepared for:
BECHTEL SAIC CO., LLC

On

BECHTEL SAIC PO# 25440860TA00889 MOD.03

Issued To

SENIOR FLEXONICS PATHWAY (SFP)
New Braunfels, Texas

SFP Sales Order H87130
SFP Job Number N390

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1 REFERENCE DOCUMENTS

1.1 Bechtel SAIC Technical Services Statement of Work for Waste Package Weld Flaw Analysis, Revision 3, dated September 23, 2002.

1.2 Bechtel SAIC Technical Services Statement of Work for Waste Package Weld Flaw Analysis, Revision 1, dated October 22, 2001.

1.3 Senior Flexonics Pathway Sketches/Travelers/Procedures File for Sales Order H87130

1.4 SK-0233 (Series of sketches [Sheets 1 thru 9] provided by BSC with the SOW)

2 ABBREVIATIONS and DEFINITIONS

AVL	Approved Vendors List
BSC	Bechtel SAIC Co., LLC
CW	Clockwise
CCW	Counter-Clockwise
ET	Eddy Current Examination
GTAW	Gas Tungsten Arc Welding
M&TE	Measuring and Test Equipment
NDE	Non-Destructive Examination
NIST	National Institute of Standards and Testing
NQAM	Nuclear Quality Assurance Manual
PT	Liquid Penetrant Examination
Q	An activity that must be fully controlled by an audited and approved NQAM
QSC	Quality Systems Certificate
RT	Radiographic Examination
SFP	Senior Flexonics Pathway, New Braunfels, Texas
SOW	Statement of Work
S/T/P File	Sketches/Travelers/Procedures file
UT	Ultrasonic Examination

Coupon Ring: An inner or outer ring that will later be welded into an inner ring – outer ring assembly.

Specimen Ring: The welded assembly of an inner and outer coupon ring.

Flaw: Any discontinuity in the base material, the heat affected zone, or the weld that is detectable by any of the NDE methods utilized on this project.

3 SCOPE OF WORK

3.1 The scope of work as outlined in the SOW was broken down into six major activities:

a) Fabrication of weld coupon specimens and a fixture to hold them during welding.
b) Welding of the specimens.
c) NDE of the specimens including baseline NDE prior to welding and final NDE after welding
d) Mapping of any indications found during examinations.
e) Measurement of surface residual stresses.
f) Metallography

The physical and quality assurance requirements of each of the activities will be described in Section 5 of this report.

3.2 The performance of these activities took place at several locations. The project was managed from the SFP facility in New Braunfels, Texas. Machining and forming was performed at subcontracted shops in San Antonio, Houston, Cyprus (Texas), and Bridgeville (Pennsylvania). The welding of the two setup rings (SU-1 & SU-2) was performed at PCI in Lake Bluff; Illinois with the balance of the welding taking place at SFP in New Braunfels. NDE was conducted at All American Inspection (AAI) in San Antonio, at Ionics, Inc. in Bridgeville, PA and at the SFP facilities in New Braunfels, TX. Surface residual stress measurements (for SU-2) were by Lambda Research conducted in Cincinnati, Ohio, and the metallography was performed by WH Labs in Houston, TX.

4 OBJECTIVES

4.1 The objective of this report is to provide Bechtel SAIC Co., LLC with all of the documentation and analysis required to fulfill the requirements of the Waste Package Weld Flaw Analysis project, as described in the Statement of Work provided to Senior Flexonics Pathway.

4.2 From the SOW, Paragraph II: "The primary goal of this test program was to record weld flaw and residual stress data based on the materials and welding processes (cold wire, narrow groove GTAW) identified in the SOW. It should be stressed that the program is designed to identify flaws in welds with the size ranges stipulated in Appendix 1." The second objective was the compilation of data regarding weld flaw size and distribution in order to predict early failure of waste packages related to weld flaws and their orientation.

5 PROJECT REQUIREMENTS

5.1 Fabrication of the Test Fixture & Coupon Rings

5.1.1 Test Fixture

5.1.1.1 Physical

The fabrication and material control of the test fixture was stipulated to be a non-Q activity (Para. III, SOW). SFP did, however, exercise Quality Program controls to the extent described in the remainder of this section.

Conceptual sketches for the test fixture were provided in the SOW, from which SFP provided detailed manufacturing sketches (ref. SFP S/T/P file). The sketches were submitted to and approved by BSC.

The functional requirements for the fixture found in the SOW (Para. III) and BSC SK-0233 were adhered to exactly; however, there were conceptual changes to the design of the fixture (resulting from changes to the weld specimen coupon design) that were discussed and agreed to between SFP and BSC. These changes will be discussed later in Section 6, "Project Overview".

The size of the fixtures machined dimensions precluded in-house manufacturing at SFP's facilities. The machining of the fixture was sub-contracted to Jet Machine, Houston, Texas. Jet Machine was approved and listed on the SFP AVL prior to utilizing their services.

The dimensional requirements of the fixture were treated as project quality requirements. Dimensional inspections of the fixture during the course of machining and during receipt inspection were treated in the same way as the weld specimen coupons; these were controlled in accordance with the SFP QA Program.

The material utilized for the fixture was not required to meet all ASME Section III requirements. Certified Material Test Reports for the material were obtained and are in the project records files.

5.1.1.2 Quality Assurance

The SOW did not require that the fabrication of the fixture be treated as Quality related except for the dimensional requirements. The design of the fixture (as conceptualized in the sketches provided in the SOW) was intended to "... simulate restraint of the final closure weld of a waste package." (SOW, Para. III). Since the dimensional characteristics were the only feature of the fixture that could impact the objective of the project, they were treated as Quality related. This entailed the following controls:

a) Manufacturing sketches specifying dimensional and tolerancing details were submitted to BSC for approval. Approval was obtained prior to manufacturing.
b) Machining and assembly was performed by facilities approved by SFP and listed on the SFP AVL (see Sect. 5.1.1, third paragraph).
c) The Purchase Order for machining and all applicable requirements of the project were passed on to the sub-tier vendor per the NQAM requirements.
d) Dimensional inspection during machining and at receipt inspection was done with M&TE traceable to the NIST.
e) All records of dimensional inspections were recorded and verified. These records are part of the final documentation package compiled for this project (See Appendix 10.17).
f) All materials were purchased with CMTR's and are part of the final documentation package compiled for this project (See Appendix 10.17).

5.1.2 Coupon Rings

5.1.2.1 Physical

The fabrication and material control of the coupon rings was required to be a Quality activity. Quality controls were exercised as described below and in the following section.

Conceptual sketches for coupon rings were provided in the SOW, from which SFP provided detailed manufacturing sketches (See Appendix 10.17). The sketches were submitted to and approved by BSC.

The requirements for the coupon rings found in the SOW (Para. IV) and SK-0233 were adhered to exactly with three exceptions: there were conceptual changes to the design of the coupon rings that were discussed and agreed to between SFP and BSC; the circularity tolerance found in the SOW was not utilized; and two sets of set-up coupons were manufactured, rather than one. These differences will be discussed later in the "Project Overview" section.

The machining of the coupon rings was sub-contracted to Ionics, Bridgeville, PA. Ionics was approved as a supplier and placed on the SFP AVL prior to utilizing their services.

5.1.2.2 Quality Assurance

The fabrication and control of the coupon rings was entirely controlled under the SFP Nuclear Quality Assurance Program, audited and approved by BSC, which included the following controls:

a) Manufacturing sketches showing dimensional and tolerancing details were submitted to BSC for approval. Approval was obtained prior to manufacturing.

b) Machining and assembly was performed by facilities approved by SFP and listed on the SFP Approved Vendor List (AVL).
c) Dimensional inspection during machining and at receipt inspection was conducted with M&TE traceable to the NIST.
d) Records were kept of dimensional inspections. These records are included in the final documentation package (See Appendix 10.17) compiled for this job.
e) All material was purchased from ASME QSC suppliers listed on the SFP AVL. The material purchasing was controlled as required by the SFP QA Program. CMTR's were provided for all materials. Following receipt of the material, coupons were cut from the material and sent to WH Labs for product analysis and mechanical property evaluation to the requirements of the material specification.

5.2 Welding of the Specimens

5.2.1 Physical

The welding procedure for the specimen's circumferential weld was required to be a narrow groove cold-wire feed GTAW process in compliance with ASME Section IX, 1998 Edition, 2000 Addenda. All other welding procedures used on this project (e.g. the longitudinal seam weld of the specimens) were also in compliance with ASME Section IX, 1998 Edition, 2000 Addenda.

The design of the narrow groove weld preparation was based on BSC's sketch SK-0233 and is shown on the SFP manufacturing sketches for the specimen rings (See Appendix 10.17). Differences between the weld preparation details shown on SK-0233 and the SFP manufacturing sketches will be discussed later in Section 6, "Project Overview".

The welding of the specimen's circumferential weld was required to be a remote process, with the welding operator being visually isolated from the welding, viewing and controlling the weld from not less than thirty feet away.

Details of welding during the course of the project are covered in the "Project Overview" section and in the Weld Data Sheets (Weld Logs) for each individual weld, found in the Data Book for each welded ring assembly (See Appendices 10.1 – 10.16).

5.2.2 Quality Assurance

The welding procedures used on this project were developed by SFP as part of the project and submitted to BSC for approval. BSC approval was obtained prior to welding.

In addition to the procedures and procedure qualifications required by the ASME Code and the SOW, additional operational procedures regarding the operation of the remote welding equipment were submitted for review and approval.

Weld filler material was purchased from Special Metals Corp., a supplier listed on the SFP AVL. Filler material purchasing was controlled as required by the SFP NQAM. Upon receipt of the filler material, coupons were cut and sent to WH Labs (audited, and listed on the SFP AVL) for product analysis and mechanical property evaluation to the requirements of the material specification.

The argon gas utilized for purge and shielding was purchased from a supplier approved in accordance with the requirements of the NQAM. The quality of the gas was verified and documentation is provided with the other Material Certifications (See Appendix 10.17).

5.3 NDE of Each Specimen, Including Baseline Examination

5.3.1 Physical

Four NDE methods were required to be utilized to locate flaws, two being surface methods (PT and ET) and two being volumetric methods (UT and RT). The outer and inner rings were examined prior to being welded together ("Baseline Examination") and the flaws mapped (see Section 6). This baseline flaw mapping was compared to the flaw mapping from NDE performed after welding so that flaws existing prior to welding could be segregated in the data from flaws that developed during welding. RT was not utilized on the baseline examination. Although it was an option to drop RT and possibly PT as NDE methods for examination of specimens, these two examination methods were utilized for the duration of the project.

An NDE report was produced from each examination. These NDE reports are included as part of this Final Report. Each flaw, at the time that it was located during the examination, also had its dimensions and configuration marked on the ring with a low-chloride marker, at the location and on the surface on which it was found (for PT and ET) or at the location and on two surfaces to indicate its depth (for UT and RT).

5.3.2 Quality Assurance

NDE was performed by All American Inspection, Inc. (AAI), a sub-contracted NDE company audited by SFP and listed on the SFP AVL. The Purchase Order for NDE was prepared as required by the SFP NQAM, and the applicable requirements of the project were passed on to the sub-tier vendor.

NDE procedures were submitted to BSC for approval. Approval was obtained prior to performance the NDE examinations.

5.4 Production of Weld Flaw Maps

5.4.1 Physical

The NDE examination of the coupon rings and the specimen rings was as described in Section 5.3.

Each indication found had been physically marked on the specimen using a low-chloride marker, as well as noted on an NDE report. The results of the NDE examinations were then summarized on "Location and Azimuth of Flaws" data sheets. One data sheet was completed for each NDE method for each ring. These data sheets map the location and coordinates of each flaw for each method. For those rings having no flaws, no data sheet is provided.

These data sheets were utilized by the metallographic laboratory and/or the BSC responsible manager (who participated at the laboratory during selected periods of time during the metallographic work) for determining the locations for sectioning the rings for metallographic examination.

The data obtained during metallographic examination was recorded on a "Metallographic Examination Record Sheet". One or more Examination Sheet was completed for each ring examined.

The information provided on the Examination Sheets is summarized on a "Flaw Summarization Form". The Flaw Summarization Form provides the data required to complete the primary objective of the project. (See Appendices 10.1 – 10.16)

5.4.2 Quality Assurance

The compiling of data from the NDE reports on the "Location and Azimuth of Flaws" data sheet was performed by SFP QC personnel. The mapping was performed to a procedure that was written specifically for that purpose, submitted to and approved by BSC.

5.5 Measurement of Residual Surface Stress

5.5.1 Physical

It was determined early in the project that the large grain size of the material precluded the use of x-ray diffraction (XRD) as a viable method for determining the surface residual stresses. One specimen ring (SU-2) was sent to Lambda for examination and confirmed that the material was not suitable for XRD. The report produced by Lambda Research is included as Appendix 10.18 to this report.

5.5.2 Quality Assurance

XRD was performed by a sub-contracted laboratory that had been audited and approved by BSC, DOE, and OCRWM. With BSC permission, SFP placed Lambda Research on the SFP AVL based on the BSC audit. The Purchase Order for NDE was as required by the SFP NQAM, and the applicable requirements of the project were passed on to Lambda Research.

Lambda's procedures were submitted to BSC for approval. Approval was obtained prior to performance of the examinations.

5.6 Metallography

5.6.1 Physical

Following NDE and the completion of mapping each specimen ring, it was shipped to the laboratory for metallographic examination. The requirements of the SOW were not specific as to what the metallography was intended to accomplish or what extent of metallography would be required. This omission was an implied acknowledgement that this was a research project, and some details were best left or necessarily left until a later time. The statement of work, with this in mind, stated that "Specific instructions from [the BSC Responsible Manager] shall be considered part of the contract".

As discussed at the opening meeting held on 10/17/01, the primary task of the metallography was to provide details of any flaws found; in particular, their exact size, location, and orientation with respect to the axis of the weld.

Additionally, the metallographic specimens were polished and etched sufficiently to produce photomicrographs from which the microstructure of the base metal, the heat-affected zone, and the weld could be examined. Specific attention was paid of whether there was a significant presence of phases (sigma, rho, and mu) that are considered detrimental. The photomicrographs (and photomacrographs) are included as part of the final report. (See Appendices 10.1 – 10.16).

5.6.2 Quality Assurance

Metallography was performed by a sub-contracted laboratory audited by SFP and listed on the SFP AVL. The Purchase Order was prepared as required by the SFP NQAM, and the applicable requirements of the project were passed on to this sub-tier vendor.

Preparation and evaluation of metallographic specimens was performed to ASTM E3, ASTM E7, and ASTM E807.

The procedure for measuring, cutting, and documenting the flaws was submitted to BSC for approval. Approval was obtained prior to performance of the examinations.

6 PROJECT OVERVIEW

6.1 Commentary on Fixture Design

The fixture consisted of outer and inner ring concentric rings assembled onto a 3" thick plate. This assembly was placed on a pedestal to raise it to a comfortable working height for fit-up and welding.

The height of the inner and outer fixture rings were adjusted to be appropriate for the reduced height of the coupon rings. Bolts through the sidewalls of the inner and outer fixture rings were used for adjusting the weld prep fit-up of the coupon rings.

During welding of the set-up rings, it was discovered that the loads on the fixture rings which were generated by the coupons thermal distortion during welding were so great that the pins locating the fixture rings on the plate and the bolts holding the fixture rings down on the plate sheared. The pins and the bolts were replaced and approximately 0.020" inch was removed from the fixture rings to allow more clearance between the coupon rings and the fixture rings. This, along with tacking the bottom of the coupon rings before completing the circumferential weld (see Section 7) reduced the distortion problem.

The distortion of the coupon rings also affected the bolts that were used to set and maintain the weld fit-up. One bolt of each set of two adjusting bolts passed through a hole in a coupon ring. The distortion cause these bolts to bind, and the threads were rendered unusable. This was corrected by turning down the threads of the bolts where they passed through the hole in the coupon.

6.2 Commentary on Coupon Design

The design of the weld specimen coupons shown on the sketches provided with the SOW (SK-0233) was for each outer and inner specimen ring to be 6" high, with a weld prep at the top and bottom . There would be one or two outer/inner ring sets fabricated for trial runs ("set-up rings") and then eight outer/ inner ring sets for acquiring the data for the project. The intent was to place the outer and inner rings in the fixture, perform the weld and subsequent NDE and mapping, then turn the assembly over and perform a subsequent weldment on the opposite side, for a total of sixteen welds.

The concern about "alligatoring" (distortion from heat during welding, manifested as the bottom of the specimen opening up from heat input at the top) was discussed between BSC and SFP at the beginning of the project. There were two concerns

involved with "alligatoring". The first was concern that the specimen might become stuck in the fixture. The second was the potential inability to properly fit up the second-side weld prep due to the distortion.

BSC and SFP agreed to change the design to be sixteen one-sided rings rather than eight two-sided rings to produce the sixteen welds required. The rings were also shortened, with the expectation that they would be easier to remove from the fixture should distortion occur.

The design of the weld preparation on the rings was conceptually available from SK-0233, but due to tolerancing ambiguities on that sketch, the details were still open to discussion.

Because PCI Energy Services had field experience with the type of weld utilized on the project, they were included in the discussions between BSC and SFP in determining the final weld prep design. Three of the major questions were the amount of gap between the inner and outer rings at the root of the weld, the height of the lip at the bottom of the weld preparation, and the amount of clearance under the lip between the outer and inner rings. The input that was received from BSC, SFP, and PCI was used to produce a weld preparation design with dimensions that fell between the extremes of those expressed by the contributing parties (for instance, regarding the gap at the root of the weld: one party's opinion was that the gap should be as small as possible, preferably zero [although it was acknowledged that this was physically problematic], another opinion was 0.118". (The final gap was designed to be 0.02"). Additional welding and evaluations concerning the root gap were performed at SFP.

Special attention was placed on the tolerancing of the coupon rings so that all clearances and locations fell within limits that were reasonable to manufacture while maintaining a good simulation of what would be expected in an actual waste package fabrication.

6.3 Commentary on Welding

The fabrication of the inner and outer rings SU-2A/2B, A1 thru A-17, and B1 thru B16 was done by first rolling and welding plates of suitable thickness into cylinders approximately 63" long (for the outer rings) and 59" long (for the inner rings). The individual rings were then parted from the cylinders. The 59" cylinder was near the maximum length required; it was limited in length by the size of plate that could be manufactured (weight was here the limiting criterion for the material manufacturer's equipment; SFP was advised by the material manufacturer that although their rolling equipment could handle larger lengths of thinner plate, the weight of the thicker plate limited their capability to manufacture a longer length).

The volumetric examination of the inner and outer rings was done prior to the rings being parted from the cylinders. This was for expediency; there was no compromise in

the accuracy of gathering data. Only UT was performed on the cylinders; radiography was not performed on the rolled plate because it would not have produced any meaningful results. The UT reports for the rolled and welded cylinders are included in the quality records binder (Appendix 10.17). No indications were noted in the base material; however, a line of what appeared to be lack of fusion appeared along the length of the weld. This was found during "for information only" RT and UT of the longitudinal seam. BSC advised that the area 1" to either side of the scribed "0" line (the mid-point of the longitudinal seam) would not be recorded as relevant data.

The material distorted during the welding process more than originally anticipated. The sides of the weld preparation were sloped at 3 degrees on the inner ring, and 6 degrees on the outer ring. During the welding, the inner ring (to some degree) and outer ring (to a much greater degree, being half the thickness of the inner ring) drew towards the center of the weld, resulting in the slope of the outer ring actually becoming negative. During the welding of SU-1 and SU-2 (the set-up rings, intended for refining the welding process), the opening at the top of the weld prep closed up to such an extent that the electrode had only 1/32" clearance on each side (the surface of the weld at this point being well below the top surface of the specimen). The proximity of the sidewalls to the tungsten caused problems with the automatic voltage control (AVC), this was not considered severe enough at the time to force stopping the weld. However, NDE performed after welding showed that the weld had voids that were attributed to the AVC not tracking the weld, as it was determined later.

This same phenomenon occurred during the welding of Ring K. However, when controls and video monitors indicated that the AVC was again reading off of the sidewall of the weld prep rather than the weld puddle, and that the arc was being disrupted, the decision was made to stop welding and modify the weld prep in order to correct this problem. The modification consisted of a secondary bevel at 23 degrees (on the outer ring) and 20 degrees (on the inner ring), at the top 0.4" of the weld preps. This secondary bevel was applied to all of the following rings. In addition to the rings used to make up Specimen K (A5 & B1), rings A2 & B2 had to be sent back for re-machining. The baseline NDE had already been performed on these rings; a second PT & ET inspection of just the re-machined surfaces was performed. The NDE reports for these inspections are included in the Ring L binder (Appendix 10.2).

The "alligatoring" (see Paragraph 6.1.1) did prove to be a problem, even with the half-height specimens. The removal of Ring K from the fixture was very difficult. Two measures were taken to correct the problem: first, material (approx. 0.03") was removed from the inner and outer surfaces of the outer and inner fixture rings (respectively); second, the specimens were turned up-side down and tacked in eight places, equally spaced, at the bottom. They were then turned weld-prep-side up and installed in the fixture.

The tack welds at the bottom performed another favorable service: during welding of the root pass, the cameras indicated that the initial distortion of the material opened up the

gap at the root of the weld significantly, from its original 0.020" to almost 0.1". The tacks at the bottom reduced this significantly.

6.4 Commentary on NDE

The weld flaw data was obtained by performing non-destructive examination on sixteen welded specimen rings, each specimen ring consisting of an inner ring and an outer ring that were welded together circumferentially. It was BSC's intent to duplicate as closely as possible the actual closure weld of a nuclear waste package. The inner and outer rings were designed to have characteristics (e.g. material, dimensions, thermal characteristics, weld prep geometry) similar to the actual design of a nuclear waste package. The weld procedure, process, and welding equipment were to be essentially similar to that which will be used on the final closure of a nuclear waste package.

Following the welding of the specimens, non-destructive examinations were performed. The data from each examination, including the size, depth, and orientation of each flaw is recorded on the NDE Reports and Continuation Sheets provided in the "Welded Ring NDE" tab in the data books of Appendices 10.1 – 10.16. After mapping the flaws on the NDE Reports and Continuation Sheets, the location of each flaw was marked on the ring using a low-chloride marker, with care taken to assure that the marks were outside the zone where the flaw was expected to be. These marks were those used as guides by the laboratory to cut the section containing the flaw from the ring. The precaution of making the marks outside the zone where the flaw was expected to prevent a flaw from inadvertently being eliminated. The location of the marks were recorded and mapped on a "Location and Azimuth of Flaws" data sheet and provided to the lab for reference.

Surface indications revealed by PT and ET examination were evaluated and considered non-relevant; they consisted of non-welding related indications such as tooling marks. A note regarding the disparity between the data produced by PT and those produced by ET (reference the "Location and Azimuth of Flaws" data sheets): Relatively broad, shallow discontinuities (such as would be made by a chuck mark) were revealed by ET examination, but not PT examination. Sharp indentations were revealed by PT examination, but not by ET examination.

During the evaluation of the various NDE methods, some indications were interpreted as non-relevant indications. Due to the nature of this project, SFP recorded these indications as those that were to be investigated further by metallography which resulted in a negative finding.

6.5 Commentary on Metallography

Upon receipt of each ring at the laboratory, visual examination of the surface indications revealed none that were considered relevant; they appeared to be the result of

processes other than welding, e.g. tooling marks. Only volumetric indications were considered relevant for metallographic examination.

Each welded ring specimen was metallographically examined. Full sized mountings of the weld were prepared from sections selected from the circumference of the specimen. Selection of the location of the specimen was based on the following criteria: (1) Flaws identified during NDE and considered relevant were examined; (2) up to six additional locations away from known NDE indications were chosen at random for examination; (3) If no flaws were noted on a given specimen, then six locations were chosen at random.

Samples of flaws were taken by removal of the flaw, as close as possible to each end of the flaw. The sample was mounted in an epoxy resin matrix, and rough ground on a 60 – 100 grit wheel. The polishing process was as follows: 240 grit – 320 grit – 400 grit – 600 grit – 2000 grit silicon carbide – 3 micron – 1 micron diamond suspension – 0.05 micron alumina paste. The metallographic specimen was then electrolytically etched at 0.5 to 1.0 amps per square inch, with 95% hydrochloric 5% oxalic acid by weight for 15 seconds to remove cold work artifacts. The sample was then repolished using 1 micron diamond suspension and 0.05 micron alumina paste, then electrolytically etched at 0.5 to 1.0 amps per square inch with the hydrochloric acid/oxalic acid for 35 seconds to display the weld and base material microstructure, from which photomicrographs were produced. Subsequent etching with the hydrochloric acid/oxalic acid mixture for 1 to 2 minutes was used when necessary to provide macroetched structures. Photomicrographs of the base material, HAZ, weld, and the weld root were produced. Photomicrographs and photomacrographs of selected specimens are included in Appendices 10.1 – 10.16 of this report.

Ring K: The process for determining the locations for metallographic examination on Ring K was to first identify the flaws from the "Location an Azimuth of Flaws" data sheets. These were identified as K1 through K4. K1 was subsequently eliminated as it was determined to be a non-relevant surface indication. Flaws K2 through K4 were indications reported through UT examination. The selection of the random locations as a series (K5 through K10) was considered appropriate as a "random" selection. (Subsequent rings, however, were sampled by taking two adjacent samples from three locations 120 degrees apart. The only caveat was that the location of the initial cut was not to be duplicated on any two rings.)

The flaws in Ring K were determined to be a result of the interruption of welding and re-machining of the weld prep without a complete removal of the previously deposited weld metal that was resultant from the AVC wandering due to the ring base material distortion referred to in paragraph 6.3.

Ring L: A total of eleven gas bubbles were found; one was approximately 0.02" in diameter, the remainder were less than 0.001" diameter.

Ring M: A total of fourteen gas bubbles were found, all 0.003" or less in diameter.

Ring N: A total of twenty gas bubbles were found, all 0.003" or less in diameter.

Ring O: A total of seventeen gas bubbles were found, all 0.003" or less in diameter.

Ring P: A total of seventeen gas bubbles were found, all 0.003" or less in diameter.

Ring Q: Thirty-five gas bubbles were found, all 0.003" or less in diameter. One gas bubble, 0.003" x 0.004", was noted, and one gas bubble 0.009" x 0.011" was noted.

Ring R: Ring R had three volumetric flaws identified. All were described as lack of fusion, and all were located near the bottom of the weld, near where the radius at the root of the weld prep met the straight edge of the sidewall (0.8" – 0.9" from the top surface of the specimen). All had major axes that were parallel with the circumference of the weld.

As it was mentioned earlier that the location of the flaws as determined by NDE was not exact. Upon removing the sections for Flaws R1 and R3, it was discovered that, on each of them, one of the saw cuts had gone into the flaw. Another cut was then made on the ring, creating another specimen that contained the other half of the flaw. This is reflected on the Metallographic Examination Record Sheets as the suffix "a" and/or "b" after the flaw identification. Flaw R1 is contained in specimens R1Fa (containing the section from 18-1/8" to 18-11/16" CW from the zero point) and R1F (containing the section from 18-7/8" to 19-7/8" CW from the zero point). The gap from 18-11/16" to 18-7/8" is the saw kerf. Flaw R3 is contained in specimens R3Fa (containing the section from 47-1/8" to 48" CW from the zero point) and R3Fb (containing the section from 48-1/8" to 49-1/16" CW from the zero point). The gap from 48" to 48-1/8" is the saw kerf.

Flaw R1 had a total length of about 1-1/16" along the weld prep near the bottom, and had a breadth of 0.002" and width of about 0.05". Flaw R3 was a roughly triangular (in cross-section) void about 1-5/8" long, each side of the triangle being about 0.03". Flaw R5 extended less than ½" along the circumference of the weld, and was also roughly triangular (isosceles) in cross section, the equal legs being about 0.02" long.

Ring S: Radiographic examination revealed two possible indications and ultrasonic examination revealed one possible indication on Ring S. None of these indications were located or verified during metallographic examination. (See Section 6.4, last paragraph) A total of thirty-five gas bubbles were found. Thirty-four are 0.003" or less in diameter. One is 0.011" x 0.014".

Ring T: A total of forty-two gas bubbles were found, all 0.003" or less in diameter due to gas coverage loss at the start of the root pass.

Ring U: A total of forty-seven gas bubbles were found all 0.003" or less in diameter. One flaw was reported by UT and RT NDE.

Ring V: A total of forty gas bubbles were found, all 0.003" or less in diameter.

Ring W: A total of twenty-seven gas bubbles were found. Twenty-five are 0.003" or less in diameter. One is 0.003" x 0.004" and one is 0.015" x 0.020".

Ring X: A total of thirty-five gas bubbles were found all 0.003" or less in diameter.

Ring Y: A total of twenty-seven gas bubbles were found. Twenty-five are 0.003" or less in diameter. One is 0.010" x 0.015" and one is 0.008" x 0.006".

Ring Z: A total of twenty gas bubbles were found all 0.003" or less in diameter.

7 DATA

7.1 Set-up Rings SU-1 and SU-2

Data was gathered on the two set-up rings, SU-1 and SU-2, in the same manner as with the test rings K thru Z, with the exception of the UT examination of the inner and outer rings that comprise SU-1; the inner and outer rings for this set-up specimen were not cut from the cylinder discussed in Section 7. They were rolled as individual rings and UT examined individually.

All of the NDE data for the inner rings used for the set-up specimens (SU-1A and SU-2A) and outer rings for the set-up specimens (SU-1B and SU-2B) is found in the data books for the set-up specimens, entitled SU-1 and SU-2. This data is essentially "for information only" and is retained in the SFP QA records and not submitted with this report.. The NDE was performed and the data gathered as a trial run for specimens K thru Z. The data from SU-1 and SU-2 is not used in the final compilation of the data.

7.2 Baseline Data from NDE Examination of Coupon Rings

The PT and ET NDE data for the inner and outer rings prior to welding is found in the sixteen binders identified as Appendices 10.1 thru 10.16. These binders contain PT and ET examination reports for baseline documentation. The UT examination reports for the cylinders from which the inner and outer rings were cut are found in the binder identified as Appendix 10.17. No indications were noted on the UT examination conducted on the cylinders prior to the individual rings being parted from them.

Ring A3 had six PT indications on the outer surface of the ring, and are irrelevant to the data being gathered for this report. Notes by the inspectors (here summarized from notes found amongst the various NDE reports) report that these indications examined under magnification and appeared to be a result of either chuck marks from the machining operation or raised/smeared metal, again a result of machining. This

observation applies to all of the indications noted below that are found on the outer surface of the outer ring and the inner surface of the inner ring.

Another relevant observation regards the apparent discrepancy between PT and ET examinations. PT and ET did not replicate or confirm the other's findings. Again from notes provided by the NDE inspectors, this was due to the nature of the irregularities responsible for the indication; for instance, a relatively broad, shallow discontinuity with no clear edges might show up on ET (the result of an edge effect), but not on PT. Similarly, smeared material might show on PT, but not on ET. It is for this reason that these indications are not reported in the NDE reports for rings K thru Z.

Ring A5 had two PT indications on the outer surface of the ring, and are considered irrelevant to the data being gathered for this report.

Ring A6 had one PT and six ET indications. The PT indication was not one of the indications found with ET. All of the indications were on the outer surface of the ring, and are considered irrelevant to the data being gathered for this report.

Ring A11 had one indication noted by both PT and ET on the surface of the weld prep, about 7/8" from the top surface of the ring, and 0.012" CW from the scribe line. This indication did not re-appear after welding (Ring T).

Ring A15 had two ET indications, both of which were on the outer surface of the ring, and are considered irrelevant to the data being gathered for this report.

Ring B9 had one PT and four ET indications. The PT indication was not one of the indications found with ET. All of the indications were on either the inner surface or bottom surface of the ring, and are considered irrelevant to the data being gathered for this report.

Ring B11 had one indication noted by both PT and ET on the surface of the weld prep, about 5/16" from the top surface of the ring, and ½" CW from the scribe line. This indication did not re-appear after welding (Ring T).

Ring B12 had three PT indications. One was on the outer surface (below the weld prep), one was on the inner surface, and one was on the surface of the weld prep, ½" from the top of the ring, and 3/8" CW from the scribe line. The indication on the surface of the weld prep did not re-appear after welding (Ring X). These indications did not appear with ET examination. The indications on the inner surface and outer surface (below the weld prep) are irrelevant to the data being gathered for this report.

Ring B13 had one PT indication noted on the surface of the weld prep, about ¼" from the top surface of the ring, and ¼" CW from the scribe line. This indication did not re-appear after welding (Ring Z).

The significance of the baseline NDE was the confirmation that no relevant indications existed in the material prior to the inner and outer rings being welded together.

7.3 Data from NDE Examination of Specimen Rings

Ring K was assembled from Outer Ring A-5 and Inner Ring B-1. It was noted in Section 7 earlier that the sides of the weld prep pulled in during welding. The three indications that appeared both on UT & RT in the NDT report for Ring K are a result of the interruption of the welding when the ring was re-machined half-way through the weld, and the weld completed after the secondary bevel was machined. The indications appear to be a result of a spot that didn't clean up during the machining of the original weld surface/weld prep sidewall junction. The indications are precisely where the first welding/second-welding junction is. In the WH Labs' *Introduction* to Ring K, this is reported as "weld repair". For this reason, these flaws were not analyzed extensively. It should be noted that UT1 (K2) was not found during metallography. A total of four gas bubbles were found.

Ring L was assembled from Outer Ring A-2 and Inner Ring B-2. No indications were noted.

Ring M was assembled from Outer Ring A-3 and Inner Ring B-4. There were no volumetric indications. There were six PT and three ET indications on the inner and outer surfaces that were considered non-relevant to the data, and one PT indication at the toe of the weld, 1/32" CW from the scribe line. This indication was removed from consideration because of its proximity to the "0" datum (see Section 7).

Ring N was assembled from Outer Ring A-7 and Inner Ring B-3. No indications were noted.

Ring O was assembled from Outer Ring A-6 and Inner Ring B-5. There were no volumetric indications. There were eight ET indications on the outer surface that were considered non-relevant to the data, and two PT indications, one at the toe of the weld, well removed from the scribe line, and one located 1/8" in from the outside, on the top surface.

Ring P was assembled from Outer Ring A-17 and Inner Ring B-9. No indications were noted.

Ring Q was assembled from Outer Ring A-8 and Inner Ring B-6. No indications were noted.

Ring R was assembled from Outer Ring A-12 and Inner Ring B-14. Three volumetric indications were determined to be lack of fusion. These indications were located near the bottom of the weld possibly caused by a jump in the weld head. Three indications were noted by RT and UT NDE.

Ring S was assembled from Outer Ring A-15 and Inner Ring B-15. Three indications were noted, one by UT NDE and two by RT NDE.

Ring T was assembled from Outer Ring A-11 and Inner Ring B-11. No indications were noted.

Ring U was assembled from Outer Ring A-14 and Inner Ring B-8. No indications were noted.

Ring V was assembled from Outer Ring A-16 and Inner Ring B-10. No indications were noted.

Ring W was assembled from Outer Ring A-9 and Inner Ring B-16. One indication was noted by RT and UT NDE.

Ring X was assembled from Outer Ring A-10 and Inner Ring B-12. One indication was noted by RT and UT NDE.

Ring Y was assembled from Outer Ring A-4 and Inner Ring B-7.No indications were noted.

Ring Z was assembled from Outer Ring A-1 and Inner Ring B-13. No indications were noted.

8 DATA SUMMARY

Spherical gas pores identified through metallography but not identified by NDE are not considered to be flaws relevant to the data. They are reported in the metallographic data (See Appendices 10.1 thru 10.16).

9 Contract Personnel and Sub-Tier Suppliers

9.1 Senior Operations, Inc.
Senior Flexonics Pathway
2400 Longhorn Industrial Drive
New Braunfels, TX 78130

Terry O'Connell	Director of Quality Assurance	(830) 629-8080 x 233
Gene Woelfel	QC Manager/Welding Engineer	(830) 629-8080 x 230
Steve Woolery	QC Chief Inspector/NDE Level III	(830) 629-8080 x 227

9.2 Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, NV 89144

Primary Contact:	Doug Smith (BSC Responsible Manager)
Title:	Senior Engineer/Scientist
Phone No.:	(702) 295-7588
Cell Phone No.:	(702) 525-1673
Fax No.:	(702) 295-4496
E-mail address:	Doug_Smith@notes.ymp.gov

Secondary Contact:	Jerry Cogar
Title:	Section Manager
Phone No.:	(702) 295-6599
Fax No.:	(702) 295-4438
E-Mail Address:	Jerry_Cogar@notes.ymp.gov

Commercial Contact:	Kim Davis
Title:	Senior Buyer
Phone No.:	(702) 295-5596
Fax No.:	(702) 295-2639
E-Mail Address:	Kim_Davis@notes.ymp.gov

9.3 Subcontracted organizations and other suppliers

The following organizations were either subcontracted to perform activities directly related to the production and compilation of data, or provide other services and/or material necessary for the completion of the contract.

All of the organizations listed below have been approved by SFP and are included on the SFP Approved Vendor List (AVL). The records are not included in this report, but are available upon request at SFP for the duration of the records retention requirement found in the Statement of Work (three years).

Subcontracted Organizations

1) All American Inspections, Inc. (AAI)
119 West Rhapsody
San Antonio, TX 78216

Primary contact (contracts): Gary Fox — Phone: (210) 525-0421, E-mail: Gary@aaindt.com

Primary contact (technical): Bryan Lancon — Phone: (210) 525-0421, E-mail: Bryan@aaindt.com

Scope of supply: NDT services to conduct UT, RT, PT, & ET examinations and provide reports as required for baseline flaw data from inner and outer rings prior to welding, and final flaw data from welded specimens. Work was conducted at Ionics' shop in Bridgeville, Pennsylvania, at SFP facilities in New Braunfels, Texas, and at AAI facilities in San Antonio, Texas.

2) Ionics, Inc.
3039 Washington Pike
Bridgeville, PA 15017

Primary contacts: Bill Henderson
Adam Figura
Phone: (412) 257-2029

Scope of supply: Machining of inner and outer specimen rings to sketches provided by SFP

3) PCI Energy Services
3039 Washington Pike
Lake Bluff, IL 60044

Primary contact: Mike Peterson
Phone: (847) 680-810

Scope of supply: Provide automated welding equipment and technicians to operate it for welding specimens. Welding of set-up rings was performed at PCI facilities in Lake Bluff, Illinois. Balance of welding was performed at SFP facilities, New Braunfels, Texas.

4) WH Laboratories, Inc.
8450 Rayson Road
Houston, TX 15017

Primary contact: Loyd Taylor
Phone: (713) 895-7504

Scope of supply: (1) Provide laboratory services for conducting product analysis and conducting all other testing required by the material specifications for material used on this project (as required), including weld filler material. (2) Provide metallography services for sectioning welded specimen rings, mounting, polishing, and microphotography of metallographic samples as directed by BSC Responsible Manager. Work to be performed at WH Laboratories in Houston.

Other Suppliers

1) Jet Machine Works
1107 Aldine
Houston, TX 77039

Primary contact: Doug Couey Phone: (281) 449-0046

Scope of supply: Machining and assembly of fixture (except the fixture base, which was manufactured by SFP) to sketches provided by SFP.

2) Tex-Fab, Inc.
23138 US 290
Cypress, TX 77429

Primary Contact: Roger Phone: (281) 373 0855

Scope of supply: Roll SB-575 622 plates into cylinders that will later be parted into inner and outer rings. (Note: welding of longitudinal seam was performed later by SFP at SFP facilities using welding procedures approved by BSC for use on this contract.)

3) Rothe Development Inc.
Metrology Services Division
4614 Sinclair Road
San Antonio, TX 78222-2099

Primary Contact: Pete Stemmermann Phone: (210) 648-3131

Scope of supply: calibration of digital thermometer

4) Precision Calibration & Repair
3130 Farrell Road
Houston, TX

Primary Contact: Charles Ashley Phone: (281) 209-9000

Scope of supply: calibration of measuring and test equipment

5) National Institute of Standards and Technology (NIST)
100 Bureau Drive Stop 2322
Gaithersburg, MD 20899

Primary Contact: Christina Phone: (301) 975-6776
Scope of supply: density strip

6) Laboratory Testing, Inc.
2331 Topaz Drive
Hatfield, PA 19440

Primary Contact: Arnie Horoff Phone: (800) 219-9095

Scope of supply: UT/ET Calibration blocks

7) 3D Welding
3016 Hwy 123
San Marcos, TX 78666

Primary Contact: Greg Davis

Scope of supply: Argon and bulk tank used for this project

8) Special Metals Corporation
3200 Riverside Drive
Huntington, WV 25705

Primary Contact: Jim

Scope of supply: SB-575 622 material for SU-2 and test rings K thru Z

9) Corrosion Materials
P.O. Box 62868
New Orleans, LA 70162

Primary Contact: Rhonda

Scope of supply: SB-575 622 material for SU-1 (setup ring # 1)

10) Special Metals Corporation
1401 Burris Rd
Newton, NC 28658

Primary contact: Paige Martin

Scope of supply: weld filler material

11) Universal Steel
13123 W. Hardy Rd.
Houston, TX 77060

Primary contact: Randy

Scope of supply: SA-516 Grade 70 plate for fixture base

12) TriVis, Inc.
2976 Pelham Parkway, Suite B2
Pelham, AL 35124

Primary Contact: Steve Andrews

Scope of supply: project logistics co-ordination services