National Spherical Torus eXperiment Upgrade

TECHNICAL SPECIFICATION

FOR

CENTER STACK CASING FABRICATION

CAT: ☑ A1 ☐ A2 ☐ A3

UNIQUE PROJECT IDENTIFIER: NSTX-U-SPEC-VVIH-002-09

REFERENCE WORK PLANNING NO: 3019

Revision 9

DATED *November 5th, 2019*

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RECORD OF CHANGES

Rev.	Date	Description of Change(s)	
0	01/17/2019	Initial release	
1	01/23/2019	(§7.3)	Relaxed requirements for performance of critical lifts and references to the PPPL H&R Services procedures
2	02/07/2019	(§4.1.2)	Removed (d), a reference to PPPL H&R Document removed in Revision 1
		(§5.2.2.2)	Added requirements for copper & silver plating on CS Divertor Flange Changed annealing requirements of the rolled tube and forgings provided
		(§5.4.2)	Added use of Plastic Jig (E-DC11126) for installation/removal of HTT Revised installation procedure for HTT Added reference to HTT Installation fixture name per drawing title
		(§5.4.4)	Revised installation procedure for HTP
		(§5.5)	Added detail for silver coating specification
		(§6.2.7)	Removed redundant text "…and stud."
		(§9.4)	Added requirement for delivery timeline of MRR documents
		(§12.0)	Added section references to applicable document deliverables
		(Table 1)	Added reference to HTT/HTP drawings E-DC11198 (HTT Clamp Installation Fixture) and E-DC11126 (Plastic Jig, Center Stack Heat Transfer Tube Installation)
		(Table 2)	Update to be consistent with new HTT/HTP component/assembly part no.
3	02/20/2019	(§5.2.2.2)	Changed (h) to "Nelson Stud or equivalent with…flux tip"
		(§5.4.5)	Removed "install flux loops". To be done at PPPL as part of bellows' ass'y
		(§6.4)	Changed (e) to refer to full bellows' ass'y, not flux loop installation
		(Table 2)	Removed flux loops from PPPL provided material
		(Table 3)	Added dowel pins for bellows' alignment
		(Table 5)	Removed bolt torque placeholder for bellows' bolts. Changed to dowel pins
4	02/22/2019	(Table 2)	Changed Rolled Tubes and Forgings from "PPPL Supplied" (Table 2) to "Subcontractor Supplied" (Table 3)
		(Table 8)	Added CMTR requirements for Rolled Tubes and Forgings
5	06/28/2019	(Table 1)	Added new Drawings E-DC11214 & 11215
		(Table 2)	Removed Drawing Revision Numbers Split into drawings to be made by subcontractor and those for ref. only
		(Table 3)	Updated Items for EDC11210; Corrected Part Names for -9 & -10 Added new Items EDC11214-01 & 11215-01, Microtherm Wraps
		(Figure 1)	Updated part callouts in figure to match new part names
		(§5.4.5)	Removed subcontractor installing bellows insulation; to be done by PPPL

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Rev.	Date	Description of Change(s)	
6	07/19/2019	(§5.2.2.1)	Fixed broken document references §0 to correctly refer to §5.2.3 -1 thru -4)
		(§5.2.2.2a)	Added option for component to be made either as a rolled part or a forging Added minimum yield strength (>65ksi) requirement for divertor flanges
		(§5.2.2.2b)	Added option for component to be made either as a rolled part or a forging
		(§5.2.2.2d)	Added minimum yield strength (>65ksi) requirement for divertor flanges
		(§5.2.2.2g)	Fixed broken document references §0 to correctly refer to §5.2.3
		(§5.2.2.2g)	Added reference to §5.2.3 for magnetic permeability test procedure
		(§6.1.5a)	Fixed broken document references §0 to correctly refer to §5.2.3
		(§6.1.5c)	Added requirement for measurement density for magnetic permeability
		(Table 3)	Corrected part names/quantities for weld studs (EDC11204
7	08/27/2019	(Reference)	Added reference to ASME Y14.5 for clarity
		(Table 1)	Added reference to CS Bellows drawing E-DC1428 Removed "For Reference Only" status of drawing DC11167
		(Table 2)	Changed PPPL provided material to bellows (E-DC1428-1) only Added flux loops Corrected description of COMM part SHC Machine Screw #6-32 UNC × 0.25 LG to Countersink Screw #6-32 × 0.38LG
		(Table 3)	Changed Subcontractor provided material to bellows weldment components (E-DC11167-1 thru 4)
		(Table 5)	Corrected COMM screw length from 0.25 to 0.38
		(Figure 12)	Added callouts for additional welds for bellows weldment assembly
		(§5.2.2.2)	Added material requirements for bellows' flanges and wrap brackets
		(§5.4.5)	Added requirement for subcontractor fabrication of the bellows' assembly and installation of flux loop.
		(§6.1.3g)	Added leak testing requirements for bellows' flange welds
		(§6.2.6)	Added testing procedure of bellows' flange welds
8	09/10/2019	(§6.1.5c)	Restored original measurement density requirement for verifying magnetic permeability
9	11/4/2019	(§2.0)	Added ASME Section V 2015 – *Nondestructive Examination*
		(§2.0)	Added ASTM A388/A388M – Standard Practice for Ultrasonic Examination of Steel Forgings
		(§5.2.2.2)	Added NDT requirements for forgings
		(§6.1.2)	Replaced "capable of Ultrasonic Inspection per AMS-STD-2154 Class A." with "100% NDT inspected per paragraph 6.1.2".
		(Table 6)	Added Calibration Blocks
		(Table 8)	Changed Leak Repair Procedure to "as required"

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LIST OF ACRONYMS

AMS = Aerospace Material Specification
ASME = American Society of Mechanical Engineers
ASTM = American Society for Testing & Materials
CMTR = Certified Mill Test Report
CSASA = Center Stack Angled Section Adapter
CSC = Center Stack Casing
CSFWS = Center Stack First Wall Sleeve
CSVS = Center Stack Vertical Sleeve
GD&T = Geometric Dimensioning & Tolerancing
HTP = Heat Transfer Plate
HTT = Heat Transfer Tube
JHA = Job Hazard Analysis
LG = LonG
MIT = Manufacturing, Inspection & Testing
MRR = Manufacturing Readiness Review
NCR = Non-Conformance Report
NDT = Non-Destructive Testing
NSTX = National Spherical Torus eXperiment
PPPL = Princeton Plasma Physics Laboratory
PQR = Procedure Qualification Records
PTR = Princeton Technical Representative
QA = Quality Assurance
SHC = Socket Head Cap
SST = Stainless Steel
TA = Technical Authority
WPQ = Welder Performance Qualification
WPS = Welding Procedure Specifications

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION & SCOPE

As part of the NSTX-U Recovery Work Plan, this Technical Specification documents all materials, labor, supervision, equipment, etc., required to perform the fabrication of the new NSTX-U Center Stack Casing (CSC) per the drawings outlined below in §3.0. This includes, but is not limited to the following:

a. Fabrication of the Center Stack Assembly
b. Installation of CS Case Divertor Flange-Collar Assemblies
c. Installation of Heat Transfer Tubes and Plates
d. Metrology/Validation of final CSC geometry
e. Acceptance testing (NDT, Leak, Pressure) of all joints/connections

2.0 APPLICABLE DOCUMENTS

[1] AMS 2418 – *Plating, Copper*
[2] AMS 2451 – *Plating, Brush General Requirements*
[3] AMS 2451/13 – *Plating, Brush, Silver*
[4] AMS 2774 – *Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts*
[5] AMS-STD-2154 – *Inspection, Ultrasonic, Wrought Metals, Process for*
[6] ASTM E164-13 – *Standard Practice for Ultrasonic Testing of Weldments*
[7] ASME B31.3 2014 – *Process Piping Code – Category D Fluid Services*
[8] ASME Section V 2015 – *Nondestructive Examination*
[9] ASME Section IX 2015 – *Welding Brazing and Fusing*
[10] ASTM A388/A388M – Standard Practice for Ultrasonic Examination of Steel Forgings
[11] ASTM E498/E498M – *Leaks using Mass Spectrometer Leak Detector or Residual Gas Analyzer*
[12] ASTM A 342-04 – *Standard Test Methods for Permeability of Weakly Magnetic Materials*
[13] ASNT SNT-TC-1A – *Personnel Qualifications and Certification in Nondestructive Testing*
[14] ASTM B443 – *Standard Specification for Nickel-Chromium-Molybdenum Columbium Alloy (UNS N06625) Plate Sheet and Strip*
[15] ASTM B444 – *Standard Specification for Nickel-Chromium-Molybdenum Columbium Alloy (UNS N06625) Pipe and Tube*
[16] ASTM B446 – *Standard Specification for Nickel-Chromium-Molybdenum Columbium Alloy (UNS N06625) Rod and Bar*
[17] ASME SB564 –*Specification for Nickel Alloy Forgings*
[18] ASTM A269 – *Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service*
[19] ASTM A276 – *Standard Specification for Stainless Steel Bars and Shapes*
[20] AWS A5.9 – *Specification for Bare Stainless Steel Welding Electrodes and Rods*
[21] AWS A5.14 – *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes & Rods*
[22] ASME Y14.5 – *Dimensioning and Tolerancing*

3.0 APPLICABLE DRAWINGS

The drawings needed to fabricate the CSC are listed in Table 1 below. Each drawing contains not only the high-level assembly views, but all the necessary sub-component drawing views needed to fabricate the subcomponents, and the overall assembly. Current revisions are indicated, subsequent revisions will be provided to the subcontractor by change order as needed. Should the drawing notes/details conflict with this Technical Specification, the Technical Specification shall take precedence.

*Table 1. List of PPPL Provided Drawings**

Drawing No.	Description
E-DC1428[R]	Center Stack Bellows
E-DC11073[R]	Center Stack Heat Transfer Tube Weldment, Top and Bottom
E-DC11074[R]	Center Stack Heat Transfer Tube Vertical Clamp, Top and Bottom
E-DC11124[R]	Left & Right Heat Transfer Plate Weldment, Top
E-DC11125[R]	Left & Right Heat Transfer Plate Weldment, Bottom
E-DC11126[R]	Plastic Jig, Center Stack Heat Transfer Tube Installation
E-DC11165	Diagnostic Organ Pipe Weldment
E-DC11167	Bellows Weldment, Centerstack
E-DC11173[R]	Gasket, HTP
E-DC11174[R]	Center Stack Heat Transfer Tube Holding Clamps, Top & Bottom
E-DC11198[R]	HTT Clamp Support Welding Fixture
E-DC11204	Center Case Assembly, Protective Tile Weld Stud Locations
E-DC11206	Blank, CS Vertical Sleeve (Material for E-DC11210-5 & -6)
E-DC11208	Forging, CS Angled Section Adapter (Material for E-DC11210-7)
E-DC11209	Blank, CS First Wall Sleeve (Material for E-DC11210-8)
E-DC11210	Center Case Weldment, Center Stack
E-DC11211	Center Case Weldment, Heat Transfer Parts
E-DC11212	Center Case Weldment, Bellows
E-DC11213	Forging, CS Collar Support (Material for E-DC11210-3 & -4)
E-DC11214	Centerstack Assembly, Wrap, Outer Collar
E-DC11215	Centerstack Assembly, Wrap Assembly, Bellows
E-EB1089[R]	Heat Transfer Plate Gas Inlet & Outlet Stub Weldment

* Current revisions of all drawings shall be provided to the subcontractor from PPPL via a contract amendment

[R] Drawing for reference only, components being provided by PPPL

4.0 RESPONSIBILITIES

4.1 PRINCETON PLASMA PHYSICS LABORATORY

4.1.1 PROJECT MANAGEMENT & OVERSIGHT

a. PPPL is responsible for this document, and the requirements outlined within.

b. PPPL will designate a technical contact, the Princeton Technical Representative (PTR) and a Quality Assurance (QA) contact as well as alternate contacts for those individuals at the time of contract award.

c. PPPL will provide staff to oversee and witness various tests, including all leak tests performed as part of this test plan. The Subcontractor should provide a minimum one weeks' notice to PPPL of the anticipated date of testing.

4.1.2 PPPL DELIVERABLES TO SUBCONTRACTOR

a. All drawings outlined in §3.0.
b. All parts/sub-assemblies and quantities listed in Table 2
c. PPPL Shipping Release Form (Attachment A)

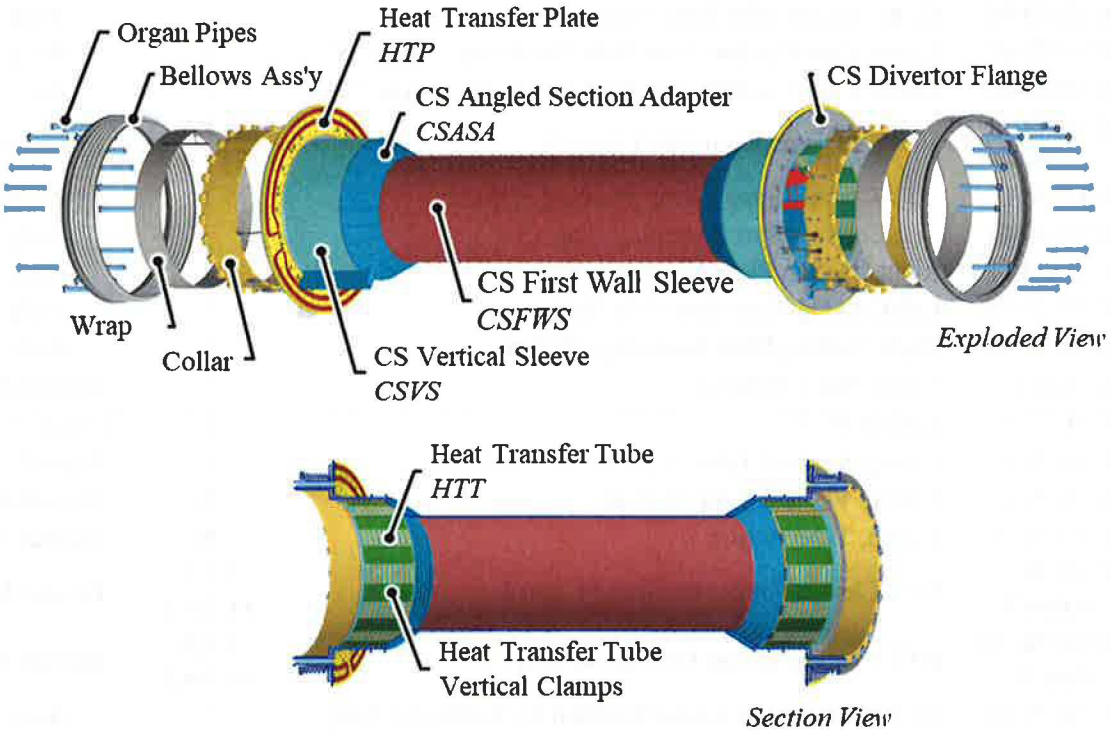

Figure 1. Exploded (top) and Section (bottom) views of the components of the CSC fabrication

4.2 SUBCONTRACTOR

4.2.1 PROJECT MANAGEMENT

The Subcontractor shall provide a single-point of contact and an alternate for any communication between PPPL and the Subcontractor.

4.2.2 DELIVERABLES TO PPPL

The Subcontractor is responsible for providing the physical and document deliverables in §12.0 to PPPL when noted and as required. This final deliverable is an assembly consisting of individual components both provided by PPPL (Table 2) and fabricated by the Subcontractor (Table 3).

4.2.3 MATERIAL ACQUISITION

Unless otherwise noted, the Subcontractor shall be responsible for purchasing all raw and shop materials necessary for the fabrication of all Subcontractor furnished components and subassemblies (Table 3) and assembly of the final deliverable, the CSC (Table 6).

4.2.4 MANUFACTURING

The Subcontractor is responsible for the fabrication of all Subcontractor furnished components/subassemblies (Table 3) and the assembly of the final deliverable, the CSC per the drawings supplied by PPPL, and any other instructions/standards/etc., referenced in this Technical Specification.

Table 2. List of Materials/Equipment Provided by PPPL

Part No.	Description	Quantity	Material
E-DC11073-1	Adapter, Cooling Tube	2	Inconel 625
E-DC11073-04	Heat Transfer Return Tube Assembly	2	Ass'y
E-DC11073-03	Heat Transfer Inlet Tube Assembly	2	Ass'y
E-DC11073-07	Center Case Coolant Tube Stub Weldment – Type "A"	2	Ass'y
E-DC11073-08	Center Case Coolant Tube Stub Weldment – Type "B"	2	Ass'y
E-DC11074-1 thru 24	Vertical Clamp Segments 1 thru 24	1 EA (24 Tot.)	Inconel 625
E-DC11198-01	HTT Clamp Support Ring Welding Fixture	1	Ass'y
E-DC11124-01	Left Cooling Plate Assembly, Top	1	Ass'y
E-DC11124-02	Right Cooling Plate Assembly, Top	1	Ass'y
E-DC11125-01	Left Cooling Plate Assembly, Bottom	1	Ass'y
E-DC11125-02	Right Cooling Plate Assembly, Bottom	1	Ass'y
E-DC1428-1	Center Stack Bellows	2	Inconel 625
E-DC11173-1	Gasket, HTP	4	Grafoil, GTA
E-DC11174-1	Clamp, Vertical Tube, Top	6	Inconel 625
E-DC11174-2	Clamp, Vertical Tube, Bottom	6	Inconel 625
E-DC11174-3	Clamp, Tube Holder	8	Inconel 625
E-DC11174-4 thru 7	HTT Clamps, Upper Position #1 thru 4	1 EA (4 Tot.)	Inconel 625
E-DC11174- 10 thru 13	HTT Clamps, Lower Position #1 thru 4	1 EA (4 Tot.)	Inconel 625
E-DC11174-01	HTT Shim Clamp, Lower Position #6 Weldment Ass'y	1	Ass'y
E-DC11174-02	HTT Shim Clamp, Lower Position #5 Weldment Ass'y	1	Ass'y
E-DC11174-03	HTT Shim Clamp, Upper Position #5 Weldment Ass'y	1	Ass'y
E-DC11174-04	HTT Shim Clamp, Upper Position #6 Weldment Ass'y	1	Ass'y
E-DC11174-16	Feedthru	4	Inconel 625
E-DC11224-1	SHC Machine Screw, Silver Plated, Vented 1/4-28 UNF × 0.75 LG	192	Inconel 625
E-EB1089-01	Divertor Flange Coolant Tube Stub Weldment – Type "A1"	1	Ass'y
E-EB1089-02	Divertor Flange Coolant Tube Stub Weldment – Type "A2"	1	Ass'y
E-EB1089-03	Divertor Flange Coolant Tube Stub Weldment – Type "A3"	1	Ass'y
E-EB1089-04	Divertor Flange Coolant Tube Stub Weldment – Type "A4"	1	Ass'y
COMM	SHC Machine Screw 1/4-28 UNF × 0.63 LG	16	Inconel 625
COMM	Countersink Screw #6-32 UNC × 0.38 LG	12	Inconel 625
COMM	Dowel Pin, 5/8 × 1.22 LG	24	Inconel 625
D-DC11294	Cable Assembly, Flux Loop, Bellows	2	Ass'y

Table 3. List of Vendor Fabricated Components†

Part No.	Description	Quantity	Material
E-DC11165-1	Diagnostic Organ Pipe Weldment	34	Ass'y
E-DC11165-2	2-1/8" Non-Rotatable CF Flange – Blank	34	316 SST
E-DC11165-3	2-1/8" Non-Rotatable Tapped CF Flange – Modified	34	316 SST
E-DC11167-1	Bellows Support Flange, Upper	2	Inconel 625
E-DC11167-2	Bellows Support Flange, Lower	2	Inconel 625
E-DC11167-3	Bracket, Lower Bellows Wrap	24	Inconel 625
E-DC11167-4	Bracket, Upper Bellows Wrap	24	Inconel 625
E-DC11204-1	Weld Stud, 5/16-18 UNC-2A, (.500 LG from wall)	360	Inconel 625
E-DC11204-2	Weld Stud, 5/16-18 UNC-2A, (.625 LG from wall)	96	Inconel 625
E-DC11204-3	Weld Stud, 1/4-20 UNC-2A, (.585 LG from wall)	180	Inconel 625
E-DC11204-4	Weld Standoff, Rogowski, 10-32 UNF-2B (.363 LG from wall)	144	Inconel 625
E-DC11206-1	Blank, CS Vertical Sleeve	2	Inconel 625
E-DC11208-1	Forging, CS Angled Section Adapter	2	Inconel 625
E-DC11209-1	Blank, CS First Wall Sleeve	1	Inconel 625
E-DC11210-1	CS Divertor Flange, Upper	1	Inconel 625
E-DC11210-2	CS Divertor Flange, Lower	1	Inconel 625
E-DC11210-3	Collar Support Assembly, Upper	1	Inconel 625
E-DC11210-4	Collar Support Assembly, Lower	1	Inconel 625
E-DC11210-5	Center Case Vertical Sleeve, Upper (CSVS)	1	E-DC11206-1
E-DC11210-6	Center Case Vertical Sleeve, Lower (CSVS)	1	E-DC11206-1
E-DC11210-7	Center Case Sleeve Adapter Flange (CSASA)	2	E-DC11208-1
E-DC11210-8	Center Case First Wall Sleeve (CSFWS)	1	E-DC11209-1
E-DC11210-9	Dowel Pin, 1/4" Dia × 3/4" LG	4	Inconel 625
E-DC11210-10	Dowel Pin, 3/8" Dia × 1" LG	4	Inconel 625
E-DC11213-1	Forging, CS Collar Support	2	Inconel 625
E-DC11214-01	Wrap, Outer Collar	2	Microtherm‡
E-DC11215-01	Wrap Assembly, Bellows	2	Microtherm‡

† Components listed are part-level only, to be used in higher level (sub-) assemblies per the provided drawing package.

‡ Long lead item

4.2.5 DOCUMENTATION

The Subcontractor shall thoroughly document calibration records, manufacturing plans, personnel certifications and qualifications, and all inspections performed. Inspection reports shall be submitted to PPPL as noted in Table 8 in §12.0. This includes test reports for all NDT, Leak and Pressure tests performed in the completion of the scope of work regardless if a PPPL employee, or designee, is present to witness the test. The report shall include type of test, location or test and results and photos of the setup.

4.2.6 START OF WORK

The actual fabrication work shall not start, until the following are met:

a. PPPL has reviewed, and approved all required documents, including the Subcontractors MIT plan.
b. Successful completion of a Manufacturing Readiness Review per §9.4.
c. PPPL's written approval to proceed with the fabrication.

4.2.7 DIMENSIONAL VERIFICATION

The Subcontractor shall verify all dimensions noted in the drawing package and document the results throughout the component fabrication process, and the final assembly per §6.1.1.

4.2.8 NOTIFICATION REQUIREMENTS

The Subcontractor shall immediately contact PPPL regarding non-compliance or damage to any part or assembly. Details of the damage, including pictures, shall be discussed and documented, and a mitigation plan shall be developed. Work shall not resume on the damaged items, until an approved NCR is issued by PPPL.

4.2.9 TOOLING ACCOUNTABILITY

Any custom tool/fixture fabricated in the execution of the scope, including test fixtures, shall be the property of PPPL. The Subcontractor shall label, and ship these items to PPPL upon CSC completion. The Subcontractor shall make a list of this tooling and should be identified in the applicable step(s) in the MIT Plan. This list shall include the unique identifier for each tool, plus what step, and which part in the manufacturing process, it was used. Pictures shall be taken of the tool(s), showing how the tool was used to make/hold the part. The general requirements outlined in §9.16 apply to all tooling and fixture materials and hardware.

4.2.10 WEEKLY UPDATES

The Subcontractor shall submit weekly updates on the status of fabrication/assembly process. These updates shall include, which part is being worked on, the estimated completion date for each part, any delays, and the reason for the delay. These updates are to be emailed every Monday. The Subcontractor shall schedule a weekly meeting with PPPL to discuss these updates as well.

4.2.11 PHOTOGRAPHS OF PROCESSES, HANDLING, PACKAGING & CRATING

Photographs shall be submitted to PPPL of each step of the various processes (i.e. machining, handling, welding, inspection, packaging, and crating). If the part is moved during the process, new photos shall be taken.

4.2.12 SHIPPING RELEASE FORM

Before shipping, the Subcontractor must complete the Shipping Release Form, see §9.21 and Attachment A, and send it to PPPL's QA department. The Subcontractor shall not ship the physical deliverables back to PPPL until PPPL returns the signed form and provides written authorization.

5.0 REQUIREMENTS

5.1 DESIGN PERFORMANCE REQUIREMENTS

5.1.1 PERFORMANCE CHARACTERISTICS

a. All components installed on the CSC shall be positioned to within the tolerances defined in the drawing package.

b. All welded joints/connections shall pass all non-destructive testing, leak and pressure tests as outlined in §6.1.

c. Conformance to the dimensions outlined in the drawing package is priority. It is the Subcontractors responsibility to design and fabricate any jig or fixture required for fabrication/installation to fall within the required tolerance range. Prior to fabricating the jig or fixture, the Subcontractor shall submit a design and explain the need for the device to the PTR for approval. These fixtures shall also be included as part of the MIT Plan.

5.2 EQUIPMENT DEFINITION

5.2.1 SPECIFICATION AND STANDARDS

A copy of the most recent calibration certificates for each of the machining, metrology and other appropriate equipment/instruments that will be used for critical measurements or manufacturing processes shall be submitted for PPPL approval, at least a week prior to the beginning of fabrication. The Subcontractor must maintain the equipment calibration throughout the duration of the scope of work. The calibration standards must be traceable to the National Institute of Standards and Technology (NIST) or equivalent.

5.2.2 SUBCONTRACTOR SUPPLIED MATERIALS

5.2.2.1 General Requirements

a. All materials shall meet the magnetic permeability limits outlined in §5.2.3.

b. Misc. Hardware – All hardware shall meet requirements defined in the associated drawings and shall incorporate a locking device (locking-washer, or tack weld) depending on accessibility and as noted on the drawings. All hardware must also meet the requirements outlined in §9.16.

5.2.2.2 Specific Requirements

a. CSFWS – Shall be either: (1) Inconel 625 plate meeting ASTM B443. Raw material shall be annealed per AMS2774 and prior to rolling, the annealed yield strength shall be $\geq$ 65 ksi OR (2) a forging of Inconel 625 per ASME SB564, UNS 06625 forged, seamless, annealed per AMS 2774, 100% NDT inspected per paragraph 6.1.2 and rough machined to at least RMS 250 finish. The annealed yield strength shall be $\geq$ 65 ksi.

b. CSVSs – Shall be either: (1) Inconel 625 plate meeting ASTM B443. Raw material shall be annealed per AMS 2774 and prior to rolling, the annealed yield strength shall be ≥ 65 ksi OR (2) a forging of Inconel 625 per ASME SB564, UNS 06625 forged, seamless, annealed per AMS 2774, 100% NDT inspected per paragraph 6.1.2 and rough machined to at least RMS 250 finish. The annealed yield strength shall be ≥ 65 ksi.

c. CSASA – shall be made out of a forging of Inconel 625 per ASME SB564, UNS 06625 forged, seamless, annealed per AMS 2774, 100% NDT inspected per paragraph 6.1.2 and rough machined to at least RMS 250 finish. The annealed yield strength shall be ≥ 65 ksi.

d. CS Divertor Flanges – shall be machined out of Inconel 625 plate meeting ASTM B443. The annealed yield strength shall be ≥ 65 ksi. The flange shall host three small pad locations on the outboard side of each flange plated with copper and a thin layer of silver per drawing E-DC11210 and as outlined in Table 4 below. The copper shall be electroplated per AMS 2418 or brush plated per AMS 2451 with 100% IACS oxygen free copper. The silver top coating shall be applied per §5.5.

e. CS Divertor Flange Collar – shall be made out of a forging of Inconel 625 per ASME SB564, UNS 06625 forged, seamless, annealed per AMS 2774, 100% NDT inspected per paragraph 6.1.2 and rough machined to at least RMS 250 finish. The annealed yield strength shall be ≥ 65 ksi.

f. Diagnostic Organ Pipes – shall be Inconel 625 tube meeting ASTM B444.

g. Conflat Flanges – shall be 316 SST meeting ASTM A276 and meet the magnetic permeability limits outlined in §5.2.3.

h. PFC Studs – Shall be Inconel 625 studs from Nelson Stud or equivalent, with an applied aluminum oxide flux tip.

i. Weld Filler – Shall meet the AWS A5.9 or AWS A5.14 specifications for steel and Inconel 625 weldments respectively.

j. Bellows' Support Flanges, Upper and Lower – shall be made out of Inconel 625 plate meeting ASTM B443. The annealed yield strength shall be ≥ 65 ksi.

k. Bellows Wrap Brackets – shall be made out of Inconel 625 plate or sheet meeting ASTM B443.

Table 4. Plating Requirements for CS Divertor Flange

	Copper Plate	Silver Coat
Material	100% IACS	316 Silver Coatalyte
Thickness (in)	0.002	0.001
Flatness (in)	0.002	0.002
Roughness (µin)	8	8

5.2.3 ELECTROMAGNETIC INTERFERENCE AND SUSCEPTIBILITY

All work performed in the execution of this Technical Specification shall meet the magnetic permeability limits listed on the drawing. If the drawings do not list a magnetic permeability limit, then use the following:

Base Material:

- $\leq 1.2\mu$ for 316SST
- $\leq 1.02\mu$ for all other materials

Welds:

- $\leq 1.2\mu$ for 316 Stainless-to-Stainless
- $\leq 2.0\mu$ for 316 Stainless-to-Inconel
- $\leq 1.02\mu$ for Inconel-to-Inconel
- $\leq 1.2\mu$ for all other welds, and attaching hardware (e.g. nuts, bolts, etc.)

Magnetic permeability shall be measured utilizing the test procedure in §6.1.5.

5.2.4 IDENTIFICATION AND MARKING

Add identifications and markings per the supplied drawings.

5.2.5 WORKMANSHIP

a. General shop cleanliness and housekeeping shall be adequately maintained to prevent tracking contamination of vessel components.
b. Careful handling of the CSC is required so as not to damage machined surfaces.
c. All fabricated parts shall be free from sharp edges and burrs.
d. In the event of ferritic contamination of stainless steel, pickling and passivation shall be required.
e. The all parts and assemblies shall be free from weld spatter.
f. Tubing shall be bent with care to avoid kinking.

5.2.6 CLEANING

a. All surfaces shall be cleaned to remove all oil, grease, dirt, loose mill scale, residue from protective covering and other foreign substances as the assembly operates in an ultra-high vacuum environment. Steam cleaning shall be performed first, then a cleaning sequence of acetone and then followed-up with alcohol.

5.2.7 SUBCONTRACTOR USE OF EQUIPMENT

It is the Subcontractor's responsibility to qualify/calibrate all equipment necessary to perform the work outlined in this document.

5.3 WELDING

a. Unless otherwise noted on the drawing, all full penetration weld joints shall be of the double-beveled joint type with a minimum included angle of 45 degrees. The sequence of the welding shall be performed to allow easy access to view the weld root prior to applying the second weld. For example, when welding the CSC sleeves, the inner diameter should be welded first and the root background from the outside until sound metal is visible. Exceptions require written PPPL approval prior to performing the work.

b. Edges or surfaces of parts to be joined by welding shall be prepared by machining, grinding, or plasma arc cutting.

c. Where thermal cutting is used, all scale must be removed by grinding. Any grinding shall be performed using rubber or resin bonded aluminum oxide or silicon carbide grinding wheels. The grinding wheels shall not have been previously used on other than stainless steel materials and identified accordingly (e.g. color coded).

d. All filler material must be compatible with the base metals of the components that shall be welded together and have equal or greater strength than the base material and meet the specifications outlined in §5.2.2.2i. Filler material must be added in all weld passes. Filler materials which are dirty, damaged or inadequately identified shall not be used. Filler material shall be stored in a clean and dry space. The filler material shall be properly identified by type or grade.

e. Magnetic permeability may increase at the base material because of thermal processing. If the permeability increase exceeds the criteria of §5.2.3, additional grinding will be required.

f. Welding shall be accomplished per the welding standards listed in §2.0.

g. Welding sequence and techniques shall be closely controlled in order to minimize distortion. Subcontractor's welding sequence and distortion control methodology shall be provided to PPPL for review and approval as part of the Manufacturing/Inspection/Test Plan. Subcontractor may propose alternate methods of welding and weld types (e.g. MIG) other than those indicated on the drawings. These alternate methods must be fully documented and approved by PPPL prior to use. The method proposed should maximize position and tolerance control.

h. The Subcontractor shall provide, as part of their MIT plan, their proposed methodology for weld distortion control. This explanation shall be reviewed by the PTR prior to the start of work. Detailed designs of any fixtures or jigs for control for each weld shall be submitted to the PTR for review prior to performing the specific weld step.

i. Prior to performing welds, the Subcontractor shall prepare and weld a test coupon to qualify their weld process. The Subcontractor shall submit photos to PPPL of the coupon at each weld root pass and the final weld for approval.

j. Prior to welding, the joint edges and immediate weld area of the parts to be joined shall be cleaned of all oil, grease, scale or other foreign materials. For degreasing, swab the weld region with acetone or other PPPL approved solvent. No residual cleaning compounds shall be left on the surfaces prior to welding. These steps shall be documented in the MIT plan described in §9.6.

k. All welds shall be subject to non-destructive testing per §6.1.2. Additionally, leak and pressure testing shall be performed on vacuum-boundaries and pressure lines as outlined in §6.1.3 and §6.1.4.

1. After successfully passing weld inspections, but prior to the performance of leak and pressure testing, all welds shall be post machined to achieve the features/geometry noted in the GD&T of the associated drawings (e.g. fillets, corner radii, etc.).

5.4 PROPOSED MANUFACTURING SEQUENCE

The following sequence of operations is the recommended fabrication and installation sequence for the assembly of the new Center Stack Casing highlighting key steps. The Subcontractor shall provide a process flow via their MIT plan which shall be submitted to PPPL for approval prior to the start of work. All welded joints associated with the fabrication and installation below are subject to the testing outlined in §6.1. PPPL required hold points for this process are listed in §6.3. All field fit and welds shall be performed according to the dimension and welding specification detailed in this technical specification.

5.4.1 FABRICATION AND ASSEMBLY OF THE CENTER STACK SLEEVE ASSEMBLY

The Subcontractor shall fabricate the CSFWS, CSVSs and CSASA and Divertor flange assemblies at the quantities outlined in drawing E-DC11210. Post machining of the CSC can be performed if necessary to meet the GD&T requirements outlined in the drawings. For all welds, when switching between the inner and outer passes, back grinding shall be performed in order to achieve the desired full penetration welds. It is recommended that the outer ring of HTP mounting holes and the organ pipe holes on the divertor flange are machined after weldment to the CSC to avoid potential distortion during welding.

5.4.2 INSTALLATION OF THE HEAT TRANSFER TUBE

The subcontractor shall field fit HTT top and bottom inlet (E-DC111073-03) and outlet (E-DC111073-03) tube assembly weldments into the groove on the ID of the upper and lower CSVSs respectfully utilizing the supplied plastic jig (E-DC11126). The fit shall be performed to ensure that the bent ends at the top of the inlet and outlet assemblies sit in the groove in the outer surface and through the windows on the divertor flange. Once the proper orientation has been achieved, the unfinished (bottom) ends of the inlet and outlet tubes shall be cut to remove any overlap and leave a gap for the installation of the cooling tube 3/8"-to-1/4" adapter (E-DC11073-1). The subcontractor shall then remove the inlet and outlet assemblies from the CSC and slide on the provided HTT Shim Clamp upper and lower weldment assemblies, E-DC11174-01 & 02 on the lower HTT and E-DC11174-03 & -04 on the upper. The subcontractor shall next weld together the inlet, outlet and tube adapters to form the top and bottom Heat Transfer coil assemblies per the drawings. These assemblies shall be subjected to NDT and leak tested per §6.1.2 and §6.1.3 prior to reinserting into the CSC. Once the leak test is passed, the subcontractor shall reinsert the Heat Transfer Coil assemblies into the CSC again feeding the bent ends into the groove and windows of the divertor flange. The subcontractor shall then weld the coolant tube stub weldments (E-DC11073-07 & -08) onto the exposed ends of the HTT assemblies. The whole assembly shall then be subjected to NDT, leak and pressure testing per §6.1.2 through §6.1.4 and the parts reworked as necessary.

After the parts pass all testing, the subcontractor shall insert and weld the HTT Vertical Clamps (E-DC11074-1 thru 24) in the order noted on the drawings. The vertical clamps shall be installed utilizing the provided HTT Clamp Support Welding Fixture (E-DC11198-01) applying the appropriate torque per Table 5 to each 1-8 UNC x 3.00" LG screw. The subcontractor shall also weld the remaining individual clamps (E-DC11174-4 thru 7 and 10 thru 13) and the clamps preinstalled on the tubes (E-DC11174-01 thru -04) per the installation drawing E-DC11211. If warping/dimpling occurs due to the welding of any of the clamps, the outer diameter of the CSVSs shall be turned after welding to meet the tolerance requirements. The Subcontractor shall then install the lower vertical tube clamps (E-DC11174-2) using #6-32 × 0.25" LG fasteners. Finally the subcontractor shall install the tube holders (E-DC11174-3) on the divertor flange using the 1/4-28 × 0.63" LG fasteners. All fasteners shall be torques per Table 5 and per the associated drawing.

5.4.3 Installation of the Organ Pipes

The Subcontractor shall weld the organ pipes to the CSC. Once welded, the Subcontractor shall perform all necessary NDT and leak testing per this Technical Specification.

5.4.4 Installation of the Heat Transfer Plate and Feedthrus

The Subcontractor shall first place the Grafoil gaskets on the divertor flanges and then loosely install the upper and lower pairs (left and right) HTP assemblies (E-DC11124-01 & -02 and E-DC11125-01 & -02) on the CSC divertor flanges utilizing the associated modified 1/4-28 UNF × .75" LG machine screws (C-DC11224-1). The subcontractor shall then use metrology to align the HTPs to achieve the perpendicularity and concentricity requirements specified on the installation drawing, E-DC11211. In order to achieve the perpendicularity, additional Grafoil shims, .005" thick, may be inserted as necessary. Once aligned, the feedthrus (E-DC11174-16) shall be inserted over the HTP tube adapters and into the hole on the divertor flange and tack welded in place (Note: the alignment must allow the feedthru to be inserted properly into the divertor flange hole without bending the tube adapters). The subcontractor shall then remove the HTPs and fully weld the feedthrus on the inboard (vacuum) side of the divertor flange per the drawing. Once welded, the tack welds shall be removed and the feedthru weld shall be subject to NDT and leak testing per §6.1.2 and §6.1.3. After passing all tests, the HTP shall be reinstalled again using metrology to confirm perpendicularity and concentricity and torqued per Table 5. The Grafoil gasket and shims shall be reinstalled as well. With the HTP installed, the HTP tube adapters shall be welded to the feedthrus, and the weld shall be subjected to NDT and leak design per §6.1.2 and §6.1.3. The HTP Coolant Tube Stub Weldments (E-EB1089-01 through -04) shall then be welded to the exposed ends of the HTP tube adapters, and the welds subjected to NDT, leak and pressure testing per §6.1.2 through §6.1.4. Once all welding and testing is completed, a layer of insulation shall be installed around the stub weldment surfaces per the drawing. Finally, the shear pin holes in the HTP and divertor flange shall be match-machined to achieve the appropriate diameter and positioning, and the pins shall be inserted and tack welded in place.

5.4.5 INSTALLATION OF THE BELLOWS

The Subcontractor shall fabricate and install the bellows assembly per drawings D-DC11167 and E-DC11212. A magnetic wire loop, the "flux loop", shall be provided by PPPL to the subcontractor for installation into the bellows assembly prior to installation on the divertor flange. The flux loop shall be attached and held to the bellows lower support flange using a series of shim stock tabs that straddle the loop and are welded to the flange on either side.

5.4.6 INSTALLATION OF PFC STUDS

The Subcontractor shall install all CSC studs per drawing E-DC11204 using a properly calibrated stud gun. Prior to installing any studs on the CSC, three test samples shall be pulled to breaking to evaluate the strength. The Subcontractor shall also perform pull and bend tests on studs on a test plate to demonstrate the quality and repeatability of the stud welds. All test results and photos shall be submitted to PPPL for approval and approved in writing prior to proceeding with actual stud welding. When starting the installation process and at each shift change during installation, the Subcontractor shall perform an additional pull and bend test on a test plate to re-verify the quality and repeatability of the stud welds. All weld fillets shall complete 360° around the perimeter of the stud.

Table 5. Fastener Torque values for the HTT/HTP Component Installations

Fastener	Torque
1/4-28 UNF × 0.75 LG (E-DC11224-1) per §5.4.4	5.0 ft-lb
1/4-28 UNF × 0.63 LG (COMM), HTT Clamps per §5.4.2	7.0 ft-lb
#6-32 UNC × 0.38 LG (COMM) per §5.4.2	9.6 in-lb
1-8 UNC × 3.00 LG (COMM),part of E-DC11198-01 per §5.4.2	17.0 ft-lb

5.5 SILVER PLATING

Silver plating shall be performed using a professional portable plating unit and Silver coatalyte #316, or an equivalent means and method approved by the PTR. In all cases, the silver shall be electrodeposited from a silver brush plating solution in accordance with processing instructions from the solution manufacturer and per AMS2451. Prior to application of the plating, the surface shall be cleaned with an abrasive pad to remove oxidation and wiped down with ethanol and a clean cloth. The plating shall be tested utilizing Rapid Electroplating No. 26 Test Solution. The plating shall also be mechanically tested by rubbing or the use of an abrasive per a methodology and acceptance criteria approved of by the PTR. If the plating is removed or damaged after applying the solution or during mechanical testing, the plating is considered defective and shall be reapplied. The subcontractor shall apply the plating to a test coupon prior to applying to the CSC. The results of the application test, including photos/images, shall be submitted to the PTR for approval.

6.0 TEST AND INSPECTION REQUIREMENTS

6.1 PERFORMANCE TESTS

The Subcontractor shall perform each test in the sequence outlined in §6.2, unless suggested changes are submitted and approved in writing by PPPL. All sub-assemblies fabricated on a bench shall be tested on the bench ***prior*** to installation into the CSC assembly to facilitate repairs as necessary.

6.1.1 DIMENSIONAL INSPECTION

Tolerances are indicated on the manufacturing drawings. Strict adherence to these dimensions and tolerances are critical to the assembly and performance of the subject equipment. All dimensional measurements shall be performed in a temperature controlled environment.

On all large surface features (e.g. the outer surface of the CSFWS), the measurements shall be taken with a maximum allowable spacing of 2" between measured points. For all remaining surfaces/features, it is the Subcontractors responsibility to provide adequate point density to verify the drawing tolerances have been achieved.

The Subcontractor shall include the sequence and measurement methodology as part of their MIT Plan. The Subcontractor shall also note what best-fit methodology is used to confirm compliance with the drawing tolerances.

Dimensional inspections shall be performed at the following steps:

a. Pre-Weld/Component Measurements – inspect all components per their respective drawings and document the results.

b. Post-Weld Measurements – inspect the weldments per their respective drawing and document the results.

c. Final Metrology Survey Data – when all other weld, leak and other inspections have been completed, take a final metrology point cloud of the finished work to confirm GD&T compliance with all drawings. The positional accuracy of all assembled components shall fall within the tolerances specified in the associated drawings.

6.1.2 NON-DESTRUCTIVE TESTING

a. All forgings examined as part of this technical specification shall be subjected to non-destructive testing in accordance with ASTM A388/A388M Standard Practice for Ultrasonic Examination of Steel Forgings with the following Acceptance Criteria:

- Straight Beam: In accordance with ASTM A388/A388M Par. 12.3.1.5; No indications exceeding the reference level specified in the DGS method, with a length or width $\geq$ 2.5mm.
- Angle Beam: In accordance with ASTM A388/A388M Par. 12.3.2; No indications exceeding the 100% of the amplitude reference line, with a length or width $\geq$ 2.5mm.
- Ultrasonic calibrations and examinations for acceptance shall be witnessed by the PPPL UT Level III designee. All calibration blocks become the property of PPPL so that future calibrations can be performed.

b. All welds performed as part of this technical specification shall be subjected to non-destructive testing in accordance with the severe cyclic condition acceptance criteria of ASME B31.3. Unless otherwise noted on the drawing, all welds performed in the execution of this technical specification shall be subjected to visual inspections. Additionally, the seam welds between the CSFWS, CSASA, CSVS and other vacuum boundary welds shall be subjected to Ultrasonic Inspection per ASTM E164-13. No surface weld defects, such as lack of fusion, overlap, undercut, porosity, or inclusion are acceptable

6.1.3 LEAK TESTING

Leak testing is performed on all vacuum-air-boundary or process pipeline welds as noted in the drawings. All Helium Leak testing shall be performed following ASTM E498/E498M utilizing Test Method A. The maximum allowable helium leak rate, unless otherwise noted, is 1×10^{-9} ATM cc/sec (air equivalent). It is required that a global test of the entire weldment with 1 atmosphere of helium be completed (see §10.8 of ASTM E498/498M). Helium detection shall be performed utilizing a Helium Mass Spectrometer Leak Detector (HMSLD).

All leak testing shall be witnessed by a qualified PPPL employee (as designated by PPPL). The Subcontractor shall give one week's notice to PPPL for any upcoming leak tests. This testing shall be performed on all welded joints including, but not limited to the following:

a. CSC sleeve and divertor flange seams (E-DC11210)
b. Bellows Support Flange, Lower to Divertor Flanges (E-DC11212)
c. All joints part of HTT assemblies (E-DC11211)
d. HTP Puck to Divertor Flanges (E-DC11211)
e. HTP Assembly to HTP Puck (E-DC11211)
f. HTP Assembly to HTP Tube Stub Weldments (E-DC11211)
g. Bellows to Bellows' flanges (E-DC11167)

6.1.4 PRESSURE TESTING

Pressure testing shall be performed on all pressurized pipelines. All Pressure testing shall be done to 2 times the maximum expected operating pressure, which exceeds the requirements of to ASME BPVC and to the acceptance criteria of ASME B31.3 after performance of any required leak testing. The test shall be conducted for 8 hours, or overnight.

a. For all joints of the HTT, pressure testing shall be performed to 2 times the maximum operating pressure: 120PSIG × 2 = 240PSIG.
b. For all joints of the HTP, pressure testing shall be performed to 2 times the maximum operating pressure: 300PSIG × 2 = 600PSIG.

Failure of connections tested cause damage/debris to be ejected to the surround area. The Subcontractor shall be required to have a clean work area in which to perform the tests, and include such provisions in their Job Hazard Analysis (JHA). This testing shall be performed on the following joints:

a. All joints part of HTT assemblies (E-DC11211)
b. HTP Assembly to HTP Tube Stub Weldments (E-DC11211)

The Subcontractor shall give one week's notice to PPPL for any upcoming pressure tests.

6.1.5 MAGNETIC PERMEABILITY TEST

To verify conformance, magnetic permeability shall be measured in accordance with the requirements of ASTM A 342, Test Method No. 3.

a. The magnetic permeability limits shall be per §5.2.3.

b. Testing shall use a Severn Engineering Low Mu Permeability Indicator (Available from Severn Engineering Co. Auburn, Alabama), which has been calibrated within the past 12 months.

c. The drawing shall designate where to measure permeability. If the drawing does not designate where to measure permeability, then contact the PPPL PTR for clarification. Record on the drawing only those values, and their locations, that are out-of-tolerance. Include dimensions to the nearest edge/surface so that it can be double-checked by the PTR or designee.

d. Unless otherwise specified on the drawing, all welds shall be checked every 1/2" (both inside and outside surfaces wherever possible). Actual values shall be recorded only for any out-of-tolerance conditions.

6.1.6 METROLOGY

Prior to shipping, PPPL requires a metrology data set (e.g. a point cloud) of the finished work confirming GD&T compliance with all drawings. The positional accuracy of all assembled components shall meet or exceed the tolerances specified in the associated drawings. This final metrology must be performed with the CSC in its vertical orientation. Additional metrology steps may be required throughout the fabrication process in order to verify the dimensional tolerances outlined in the drawing package of individual components and subassemblies.

6.2 TESTING SEQUENCE

The Subcontractor shall perform all of the tests outlined in this test plan in the following sequence. Should the Subcontractor's approved MIT plan conflict with this sequence, the Subcontractor shall contact PPPL to discuss and receive written approval for any changes

6.2.1 TESTS AFTER PERFORMING CSC WELDS

The subcontractor shall perform UT NDT per §6.1.2 and leak testing per §6.1.3 at all seam welds, see Figure 2:

a. Weld 1 – CSVS to CSASA, upper and lower
b. Weld 2 – CSVS-CSASA Assemblies (Step a.) to CSFWS, upper and lower
c. Weld 3 – CS Divertor Flange-Collar Assemblies to CS Sleeve Assemblies, upper and lower

The leak testing requires a fixture to enclose the entire inner volume of the CS Sleeve Assembly.

Prior to welding the divertor flange assembly to the CS Sleeve assemblies, the Subcontractor shall perform NDT on the CS Divertor Flange-Collar weld, see Figure 3.

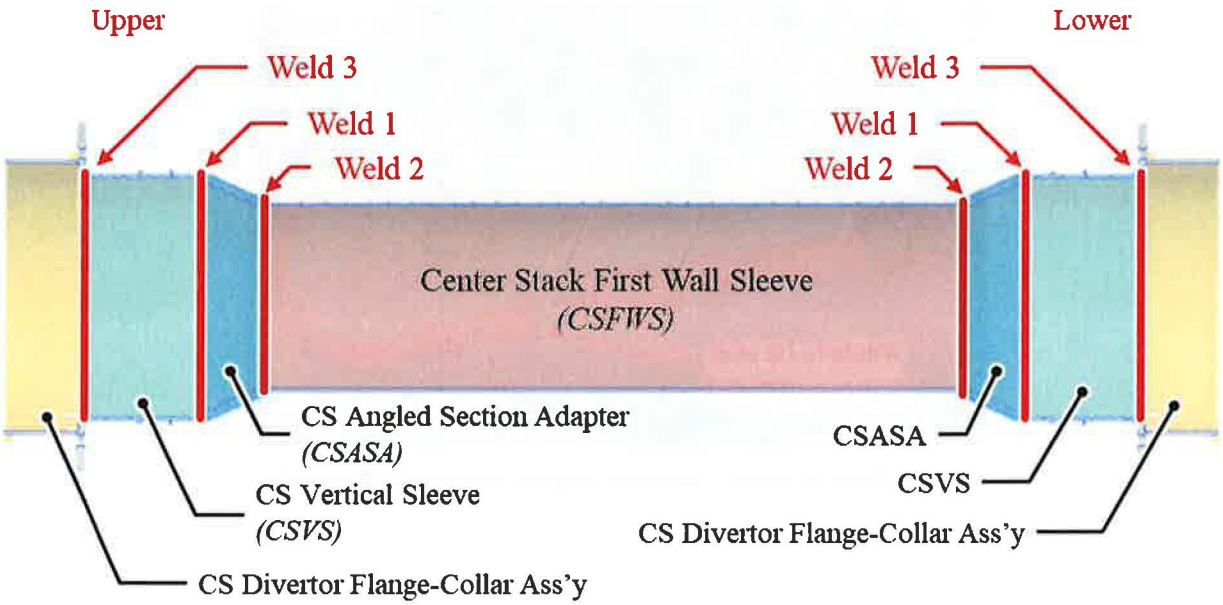

Figure 2. Vacuum-Air Boundary Welds to be NDT and leak tested on the CSC

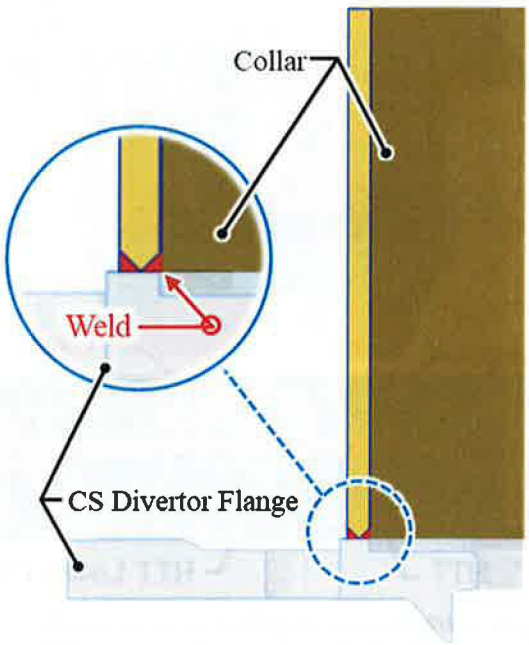

Figure 3. Weld to be tested between the divertor flange and collar

6.2.2 TESTS AFTER HTT INSTALLATION

The Subcontractor shall perform a visual inspection per §6.1.2, leak testing per §6.1.3 and pressure testing per §6.1.4 on the HTT return tube to tube adapter welds, see Figure 4. The clamps used to hold the tube in the CSVS groove shall only be subject to visual inspection per §6.1.2, see Figure 5.

The HTT to HTT Stub Assemblies, see Figure 6, shall be subject to visual inspection per §6.1.2, leak testing per §6.1.3 and pressure testing per §6.1.4.

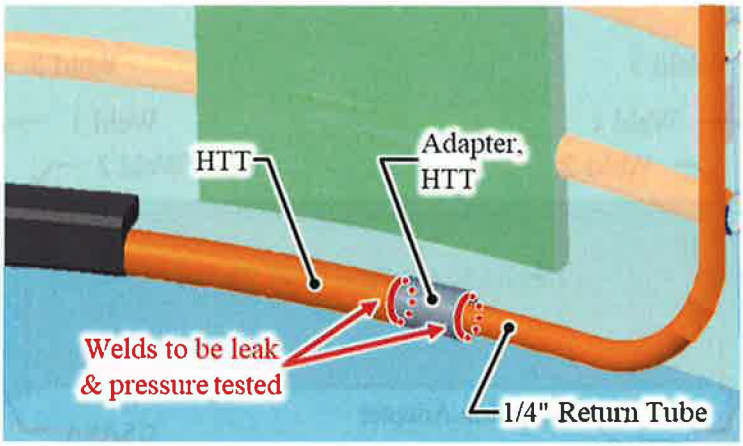

Figure 4. Welds to be tested during the installation of the HTT Return Tube

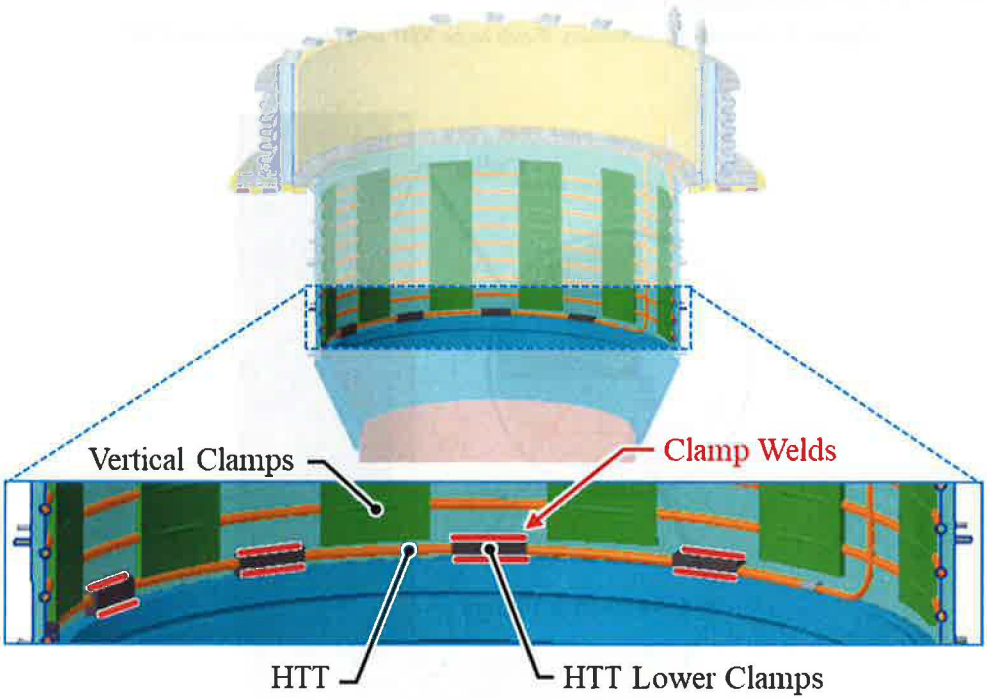

Figure 5. HTT Lower Clamp Welds to be subjected to NDT

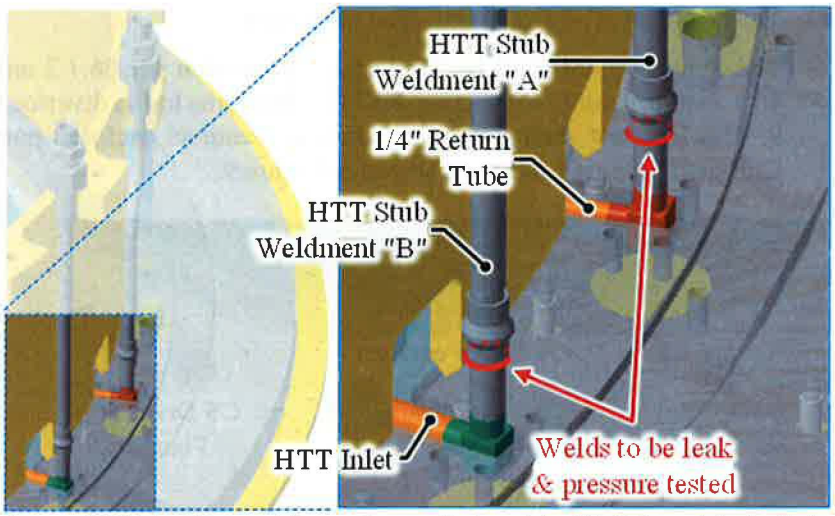

Figure 6. Welds to be tested during the installation of the HTT Inlet and Outlet Stubs

6.2.3 TESTS AFTER ORGAN PIPE INSTALLATION

The Subcontractor shall perform visual inspection per §6.1.2 and leak testing per §6.1.3 on each weld between the diagnostic organ pipe tubes and Conflat Flanges, see Weld 1 of Figure 7.

The Subcontractor shall then perform visual inspection per §6.1.2 and leak testing per §6.1.3 on each weld between the diagnostic organ pipe assemblies and the divertor flange, see Weld 2 of Figure 7.

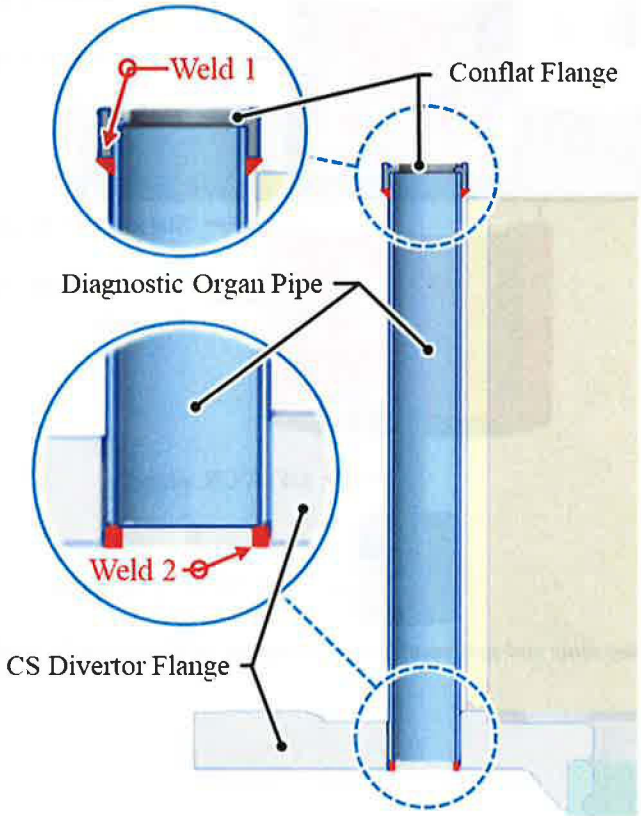

Figure 7. Welds to be tested during the fabrication and installation of the organ pipes

6.2.4 TESTS AFTER HTP FEEDTHRU INSTALLATION

The Subcontractor shall perform visual inspection per §6.1.2 and leak testing per §6.1.3 on the welds connecting the HTP feedthrus to the divertor flange, see Figure 9. This leak test shall require a fixture to create an enclosed pump-down volume. One such proposed fixture is shown in Figure 9.

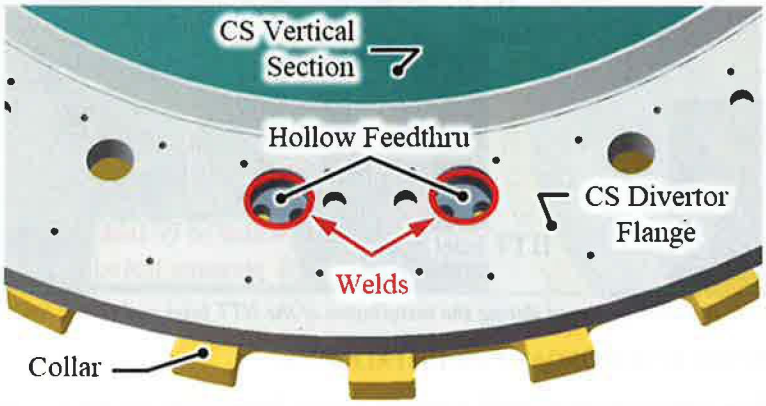

Figure 8. Welds between the HTP feedthrus and the casing flange to be tested

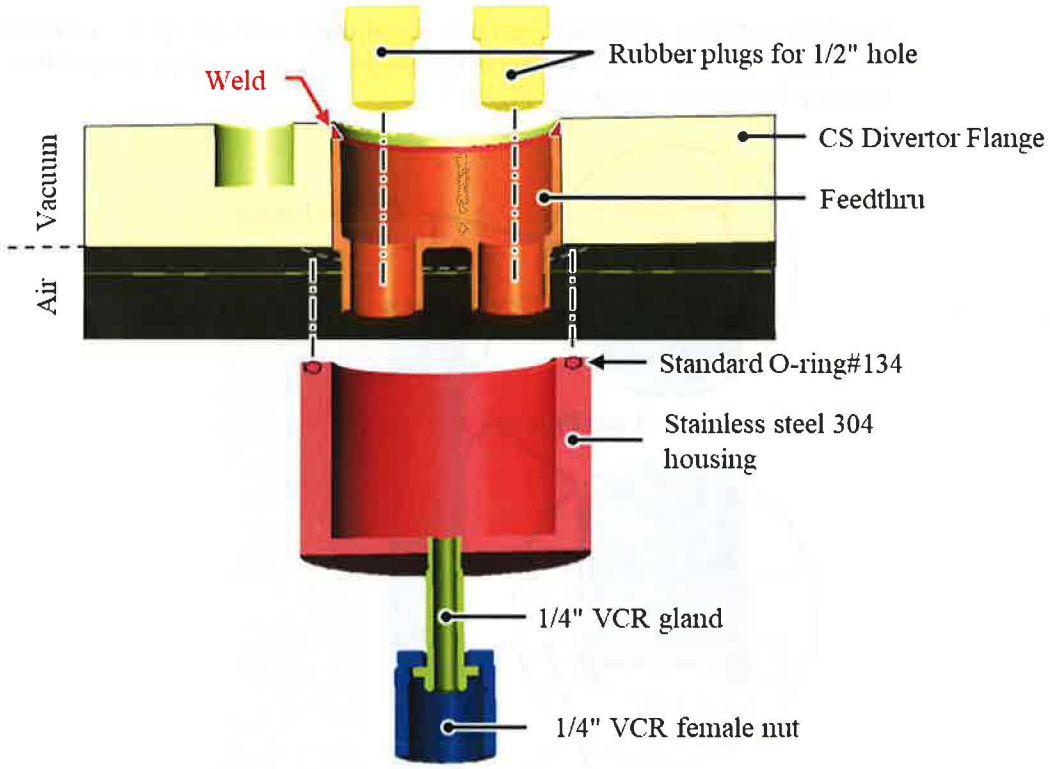

Figure 9. Proposed leak testing setup and equipment for qualifying the weld between the feedthrough and divertor flange

6.2.5 TESTS AFTER HTP INSTALLATION

The Subcontractor shall perform visual inspection per §6.1.2 and leak testing per §6.1.3 on the welds joining the HTP tube adapters to the feedthrough installed on the CS Divertor Flange, see Figure 10.

The Subcontractor shall then perform visual inspection per §6.1.2, leak testing per §6.1.3 and pressure testing per §6.1.4 on the HTP tube stub weldments to the HTP tube adapters see Figure 11.

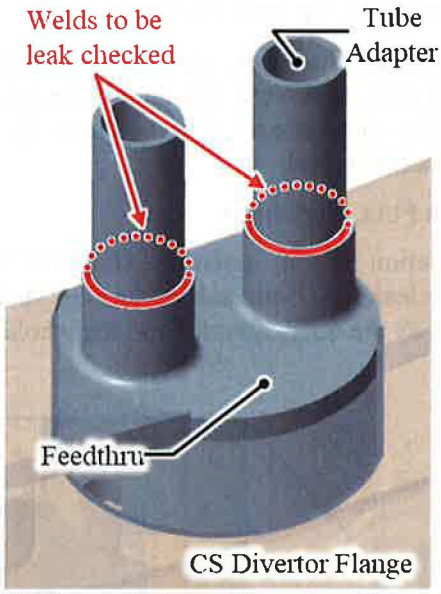

Figure 10. Welds to be leak tested during installation of the HTP

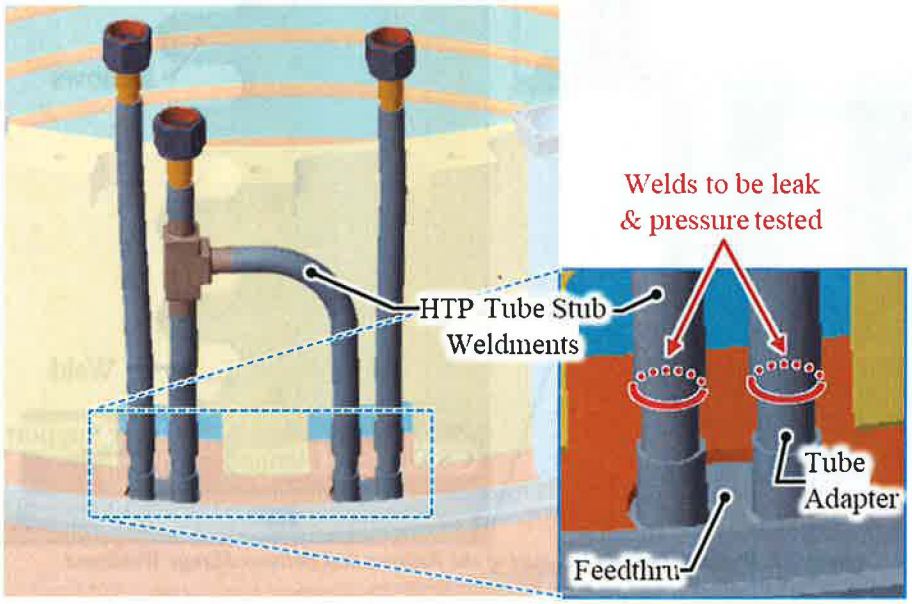

Figure 11. Welds to be tested during the installation of the HTP Inlet and Outlet Stubs

6.2.6 TESTS AFTER BELLOWS INSTALLATION

The subcontractor shall perform visual inspection per §6.1.2 and leak testing per §6.1.3 on the welds joining all of the components of the bellows weldment assembly prior to installation on the divertor flange.

The subcontractor shall then perform visual inspection per §6.1.2 and leak testing per §6.1.3 on the weld between the bellows' assembly and the divertor flange, see Figure 12.

6.2.7 TESTS AFTER PFC STUD INSTALLATION

After installing each stud on the CSC, the Subcontractor shall perform a visual inspection of each stud weld and be reinforced as necessary with additional weld passes. The alignment of each stud shall meet the GD&T provided on the associated drawing for both the stud.

6.2.8 TESTS AFTER FULL ASSEMBLY

Upon completion of the assembly (E-DC11204-01), the entire CSC shall be subjected to a leak test. Both ends of the CSC shall be capped with fixtures designed and provided by the Subcontractor and the whole volume shall be pumped down.

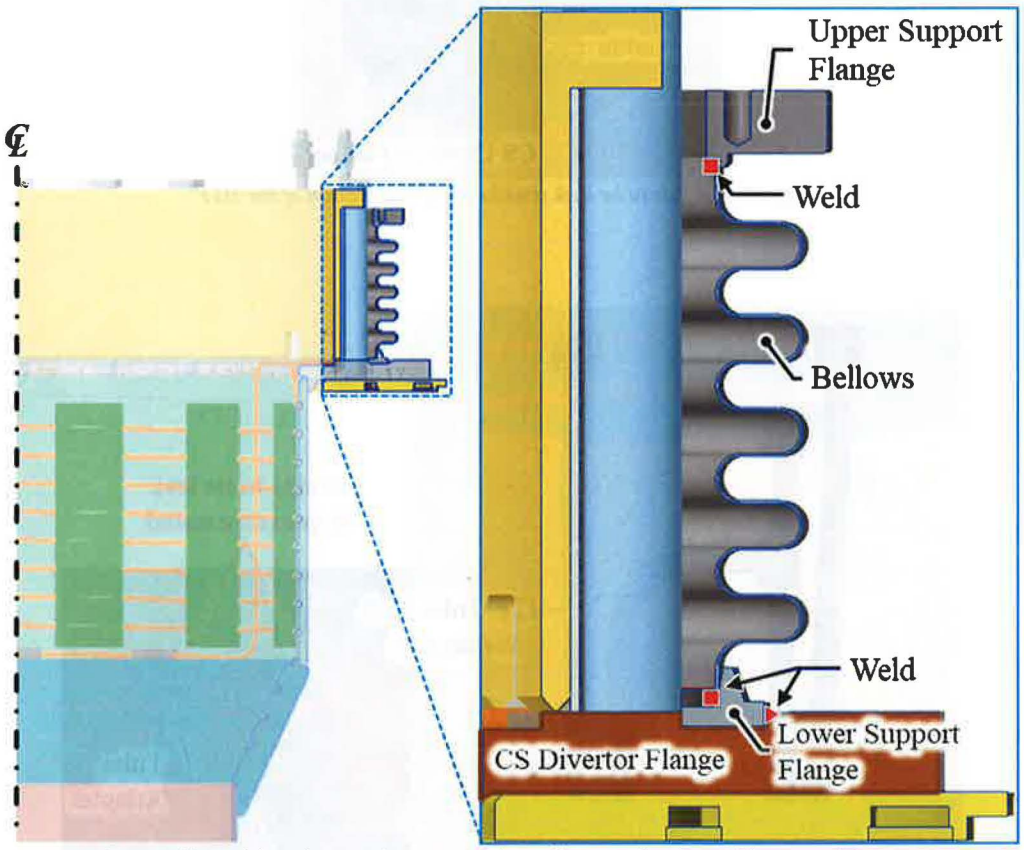

Figure 12. Welds to be tested as part of the Bellows and Bellows Flange Weldment

6.4 SUBCONTRACTOR HOLD POINTS

Hold work and contact PPPL for inspection/approval prior to proceeding at the following process steps:

a. After fabrication/machining of the CSFWS, CSASA, CSVS as part of a trial fit-up including tacking in place.
b. After welding the divertor flange to the CSC Sleeve Assembly and machining surfaces.
c. After testing of the Organ Pipe, Puck and HTT installation welds
d. After testing the HTP tube to puck welds
e. After installing bellows
f. After the testing the bellows weld
g. After performing the preliminary testing of the entire CSC assembly
h. Before final packing and crating
i. After final packing and crating when ready for shipment

7.0 QUALIFICATIONS

7.1 GENERAL REQUIREMENTS

Personnel are required to be trained in the operation of the equipment such that time is not lost, and material is not damaged, due to preventable mistakes. A copy of training certifications for Personnel performing the operations listed below shall be provided, and approved by PPPL, in writing, before the manufacturing work begins. The training must be up-to-date and maintained by each individual throughout the fabrication performed in the execution of this scope. The certifications shall be per the requirements listed in §2.0, or by a PPPL approved alternative.

a. Welders
b. Non-Destructive Testing Operators
c. Magnetic Permeability
d. Leak Tester
e. Pressure Tester

7.2 WELDING

7.2.1 SPECIFICATIONS

Welding Procedure Specifications (WPSs), Welding Procedure Qualification Records (PQRs), and Welding Personnel qualifications (WPQs) shall be provided for all work being performed during the execution of the scope of work outlined in this Technical Specification. All documentation must be approved by PPPL prior to the start of welding.

7.2.2 PERSONNEL QUALIFICATIONS

All welders, welder operators and welding procedures shall be qualified in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section IX, and this scope of work. Welding procedure qualification test results shall demonstrate that the resulting weldments are compatible with the base materials and meet or exceed the base material mechanical properties, with relative magnetic permeability less than or equal to 1.7.

7.3 CRITICAL LIFTS

Due to the criticality of the work executed as part of this scope (Category A1), all rigging & lifts of the CSC shall follow best practices and meet all OSHA requirements. Any lifts that require unusual handling should be discussed with the PPPL PTR and lift engineer prior to performing the lift.

8.0 ENVIRONMENT, SAFETY, AND HEALTH

8.1 SAFETY

Work shall be performed under an established safety program including documented policies and procedures subject to PPPL review. Workers shall be trained to these policies and procedures and records of their training shall be auditable.

8.2 NOTIFICATION REQUIREMENTS OFF-NORMAL EVENTS & ISSUES

The Subcontractor is required to provide, for PPPL review and approval, a procedure that details Subcontractor's process in the case of an off-normal event with safety implications. This procedure may be incorporated into the Quality Assurance Oversight Plan.

8.3 OVERSIGHT

Supplier shall allow scheduled access to their facility to review manufacturing processes and perform inspections at the discretion of PPPL. Supplier shall work with the PPPL PTR and PPPL visitors to identify the hazards of the work to be reviewed and the hazards of unrelated work in the facility that could affect the visitors, and the safety protocols (including but not limited to training and personal protective equipment) that will apply to protect visitors from the hazards. Supplier shall provide any required training to PPPL visitors to assure observance of the supplier's safety rules and prevent exposure to any hazard at supplier's facility.

8.4 SAFETY AND HAZARD MITIGATION PLAN

The Subcontractor shall perform a Job Hazard Analysis (JHA) to prior to the execution of the tests outlined in this plan and discuss the results with PPPL. The JHA shall identify the hazards of the test and the safety protocols (including but not limited to training and personal protective equipment) that will apply to protect workers and visitors from the hazards. A sample safety and mitigation plan is shown below using the pressure testing as an example:

Pressure Testing:

a. Before approaching the pressurized system to examine the system for a leak, the system test pressure must be reduced to the design pressure (or 15 psig, whichever is less).

b. Each member of the test team shall wear goggles, a full face shield and ear protection whenever pressure is applied to the system being tested.

c. Each valve which has been closed to contain the pressure shall be appropriately tagged to prevent inadvertent operation and assure that it will be returned to its normal position after the test.

d. The area where the test is being performed shall be roped off to prevent access to the general work force with signs posted on the ropes warning about the test.

e. Joints in the system which would be subjected to failure or flexible tubing shall be restrained during the test to prevent personnel injury.

9.0 QUALITY ASSURANCE REQUIREMENTS

9.1 INSPECTION/ SURVEILLANCE/AUDIT BY PPPL

Authorized representatives of PPPL and the U.S. Government shall have the right at all reasonable times to visit the Subcontractor's premises and those of Subcontractor's suppliers during the performance of the procurement for the purposes of inspection, surveillance, audit and/or obtaining any required information as may be necessary to assure that items or services are being furnished in accordance with specified requirements. Such visits shall be coordinated with the Subcontractor's personnel to minimize interference with the normal operations of said premises. The Subcontractor shall make available records and documentation necessary for this function and shall provide all reasonable facilities and assistance for the safety and convenience of PPPL and/or U.S. Government representatives in the performance of their duties. PPPL and the U.S. Government recognize the Subcontractor's right to withhold information concerning proprietary processes.

9.2 SUBCONTRACTOR'S RESPONSIBILITY FOR CONFORMANCE

PPPL's review and/or approval of Subcontractor's documents nor PPPL's inspection of Subcontractor's items or services shall not relieve the Subcontractor of responsibility for full compliance with requirements of the purchase order/contract.

9.3 SUBCONTRACTOR QUALITY ASSURANCE PROGRAM

The Subcontractor shall establish and maintain an effective Quality Assurance Program to assure that the Subcontractor's work meets the required level of quality and is performed in accordance with contractual requirements.

Subcontractor's quality assurance function shall be organized to have sufficient authority and independence to identify quality problems, verify conformance of supplied items or services to specified requirements and obtain satisfactory resolution of conflicts involving quality.

9.4 MANUFACTURING READINESS REVIEW

The Subcontractor shall prepare for and participate in a Manufacturing Readiness Review with PPPL prior to the start of work. This review shall include the proposed process in order to effectively execute the tasks outlined in this Technical Specification, including equipment, work flow and scheduling. As part of this review the Subcontractor shall be prepared to provide the necessary deliverables, including but not limited to the following:

- Tooling and fixture conceptual drawings and/or methodologies
- MIT Plan and associated procedures
- Personnel Certifications/Qualifications
- Safety Plan/JHA
- QA Plan
- List of Subcontractor Supplied Materials

All of required materials are to be submitted to PPPL a maximum of two (2) weeks after contract award. The Subcontractor shall be responsible to respond to and/or execute any comments provided by the PTR prior to the scheduled MRR. After successful completion of the MRR, PPPL will authorize the start of fabrication in writing.

9.5 QUALITY ASSURANCE PLAN

The subcontractor shall submit a Quality Assurance (QA) plan describing the specific quality assurance and quality control procedures and practices, including special process training and qualifications, which will be in force to meet the requirements of this specification. The QA plan and any revisions require review and approval by PPPL prior to the start of design or manufacturing of the equipment under this specification.

9.6 MANUFACTURING, INSPECTION AND TEST PLAN

The Subcontractor shall submit a Manufacturing, Inspection and Test (MIT) plan for PPPL approval prior to the start of manufacture. The MIT must delineate the sequence of all processes and operations affecting quality, including in-process and final acceptance inspections and tests. The plan shall identify parts; show their integrated flow into end items; identify critical manufacturing operations; and show inspections and the characteristics/dimensions to be inspected. The Plan may include flow chart(s), Process Sheets, Shop Travelers, and inspection sheets, etc. Equipment to be used for all fabrication, inspections and tests shall be specified, including but not limited to the following:

- Equipment to be used for all fabrication, inspections and tests
- Part(s) being made.
- Integrated flow into end items
- Critical manufacturing operations
- Cleaning steps
- Inspections and the characteristics/dimensions to be inspected
- Sign-off and date by designated inspection personnel at specified process, inspection, and test points.
- How the signoffs are traceable to the items being fabricated.
- PPPL designated Hold/Witness Points

The witness/hold points are steps where the manufacturer will temporarily stop work on this particular part in the Technical Specification, until PPPL has had a chance to review the data, and approves continuing with the fabrication. Subcontractor shall notify PPPL a minimum of five (5) working days in advance of these witness points. Revisions or changes to the approved MIT, or its alternate, shall be reviewed and approved by PPPL prior to use including flow chart(s), process and inspection sheets, and shop travelers.

A traveler, whether integral to the MIT Plan or a separate document, shall be used for data entry and operation sign-offs. Relevant data for inspections and tests includes equipment ID and calibration status; acceptance values, actual values obtained, and pass/fail determination. PPPL will designate selected steps as mandatory "witness" points. Subcontractor shall notify PPPL a minimum of five (5) working days in advance of these witness points. Revisions or changes to the approved MIT or traveler shall be reviewed and approved by PPPL prior to use.

9.7 CHANGES TO PPPL APPROVED DOCUMENTS

Revisions or changes by the Subcontractor to documents approved by PPPL shall be reviewed and approved by PPPL prior to use.

9.8 NONCONFORMANCE & CORRECTIVE ACTIONS AND NOTIFICATION OF PPPL

Nonconforming items or services shall be positively identified, and, where possible, segregated to prevent use. The Subcontractor shall document each nonconformance. The written approval of PPPL is required in the form of a signed NCR prior to the use or continued fabrication of the nonconforming item or service. The Subcontractor's system shall provide not only for timely resolution of nonconformance but also for analysis of nonconformance to determine causes and to implement appropriate and effective corrective actions.

9.9 MEASURING AND TEST EQUIPMENT

Inspections and tests shall be performed using properly calibrated measuring and test equipment. Calibration standards shall be traceable to the National Institute for Standards and Technology (NIST) or equivalent. Where such standards do not exist, the basis used for calibration shall be documented. Standards used for calibration shall not be used for shop inspections, but instead shall be protected against damage or degradation.

9.10 SUBMITTAL OF MATERIAL CERTIFICATIONS

The Subcontractor shall submit the manufacturer's Certified Mill Test Reports (CMTR) showing actual relevant chemical, mechanical, and electrical properties of all parts fabricated by the subcontractor, including raw materials and weld material. Materials from arrival all the way to the completion need to be labeled and traceable to the mill test report (numbered, painted, etched, etc.). Submitted CMTRs must be linked to the specific part by referencing the parts list on the drawing. One copy is to be submitted to PPPL upon Subcontractor acceptance for use. Note: For specialty materials, typically non-metals, where test reports are not readily available from the manufacturer, their certificate of analysis or certificate of grade, as appropriate, may suffice, subject to PPPL concurrence.

Subcontractor shall provide high strength fasteners (tensile strength equal to or greater than 100 ksi) in accordance with the Fastener Quality Act. Fasteners shall exhibit grade marks and the manufacturer's identification symbol (head stamp) as specified in the referenced Material Specification. Fasteners having a head mark shown on the suspect fastener list (see ATTACHMENT B) will not be accepted. Certified Mill Test Reports (CMTR), showing actual material composition and physical properties and traceable to the actual fasteners, are required for each lot supplied. Results must be on the original letterhead of the entity performing the tests and not transferred to alternate letterhead. Where high strength fasteners are not required, it is recommended that they not be used. If used, the requirements above shall be implemented.

9.11 DOCUMENT TRACEABILITY AND RECORDS

The Subcontractor shall maintain a system of documentation whereby the results of required operations, inspections, examinations, and tests is systematically compiled, indexed and stored. Such objective evidence may include "travelers"; and material test, certification, inspection, examination, test and discrepancy reports; which shall be complete, legible, signed, and dated and shall be traceable to subject items.

9.12 INSPECTION AND TEST CONTROL

Inspections and tests shall be performed by personnel independent of those doing the work inspected or tested. They shall be performed in accordance with written procedures referencing criteria for acceptance or rejection. Adequate records shall be maintained and available for PPPL's review.

9.13 PERFORMANCE AND DOCUMENTATION OF INSPECTIONS AND TESTS

Each item to be delivered to PPPL shall be inspected and tested by the Subcontractor to verify that they meet PPPL's requirements. All produced parts must be inspected and tested unless an alternate plan is agreed upon with PPPL in writing. Results shall be documented and reported to PPPL. Any exceptions to PPPL requirements must be approved by PPPL in writing.

The inspection/test report(s) shall indicate the results of all tests and compliance with all drawing notes. Actual values for all drawing dimensions, including Basic, but excluding Reference, must be reported. Either a drawing copy or an inspection report may be used as the report, but the drawing zone and actual measured values must be clearly indicated. Regardless of format, the report must be dated and signed.

The following values should be measured and recorded:

a. All non-reference drawing dimensions, including Basic Dimensions
b. Compliance with drawing notes
c. Measurements taken in §6.1.1

9.14 SUBMITTAL OF COMPLETED INSPECTION AND TEST REPORTS

Reports shall be provided of all required inspections and tests, showing actual values, properly validated by authorized personnel. NDE reports shall meet the requirements of ASME V. All reports shall include the raw data files (e.g. point clouds) for verification.

9.15 SUBMITTAL OF ACCEPTANCE TEST PROCEDURES FOR PPPL APPROVAL

The Acceptance Test Procedures (ATPs), including pass/fail criteria, required to demonstrate conformance to PPPL's requirements shall be submitted to PPPL for review and approval prior to use of such procedures.

9.16 GENERAL REQUIREMENTS

Material(s) and/or product(s), including those components, parts, and materials that are permanently installed into systems, sub-systems, and/or assemblies, etc. furnished under this purchase order/subcontract shall be new. Parts and components that have been rebuilt, refurbished, or modified are specifically prohibited unless approved by PPPL in writing. Evidence of deliberate misrepresentation of any item(s)/component(s)/material(s) provided under this order may result in an investigation by the Office of the Inspector General, U.S. Department of Energy. Examples of such misrepresentation include the following:

- Remanufactured, rebuilt, or used parts represented as new
- Counterfeit parts (fraudulently labeled or marked with another manufacturer's name).
- Misrepresented parts.

9.17 PPPL RECEIVING/INSPECTION

PPPL will perform Receiving Inspection on items or services supplied by Subcontractor, using either a sampling plan or 100% inspection. Discrepant items or services will be rejected and returned to Subcontractor or reworked by PPPL.

9.18 PROCESS SEQUENCE

The Subcontractor shall maintain a system to define the sequence and document the performance of manufacturing, inspection, installation, and test activities. These shall provide for signoff and date by designated inspection personnel at specified process, inspection, and test points and shall be traceable to the items.

9.19 EQUIPMENT/MATERIAL IDENTIFICATION AND STATUS

Material and equipment identification shall be maintained throughout processing and be traceable to the records. Status of acceptability shall be readily discernible through the Subcontractor's use of tags, stamps, serial numbers or other positive means.

9.20 CONTROL OF SPECIAL PROCESSES

Subcontractor shall use trained and qualified personnel and qualified written procedures in accordance with specified requirements for the performance of certain special processes, including but not limited to, soldering, electronic assembly, brazing, welding, plating, heat treatment, nondestructive examination, etc. Copies of special process procedures and qualifications shall be available for review by PPPL and submitted to PPPL for acceptance if requested.

9.21 SUBMITTAL OF COMPLETED RELEASE FOR SHIPMENT FORM

Subcontractor shall not ship without a "Product Quality Certification and Shipping Release" Form (Attachment A) signed by PPPL's Representative. Subcontractor shall complete and sign the certification section, fax or email the form to PPPL's Quality Assurance (QA) Representative, and hold shipment until PPPL signs and returns the form, authorizing shipment. A copy of the fully executed form shall accompany each full or partial shipment.

10.0 SHIPPING STORAGE AND HANDLING

The Subcontractor shall be responsible for packing crating and shipping the CSC. A Packing and Shipping plan shall be included in the MRR. This plan shall include details to maintain the cleanliness of the assembly, and prevent damage due to road hazards during shipment. The CSC shall be shipped in a closed container and be secured by its end flanges such that the sleeve and studs are not damaged. Crating shall include shock indicators. Once assembly and crating is complete, and PPPL has performed a final inspection, PPPL will sign the Shipping release form (Attachment A).

11.0 ATTACHMENTS

A. *Product Quality Certification & Shipping Release Form*

B. *Department of Energy Suspect/Counterfeit Headmark List*

12.0 DOCUMENTATION & DELIVERABLES

RFI / PO / Subcontract / BOA / BPA #: _____

Table 6. List of Subcontractor Required Deliverables to PPPL

#	Physical Deliverables Required	Date Required	Received (✓)
1	Fully Assembled Center Stack Casing per Drawing E-DC11204-01	C	
2	All Fixtures, Jigs and Calibration Block made as part of this scope	C	

Exceptions: None

Table 7. List of Required Meetings between the Subcontractor and PPPL

#	Meetings Required	Date Required	Complete (✓)
1	Manufacturing Readiness Review	PS	
2	NCR Meeting	D	
3	Weekly Status Update (for duration of executing scope)	D	

Exceptions: None

Table 8. List of Subcontractor Document Deliverables

#	Document Deliverables Required	Date Required	Format	Storage Location	Rcvd (✓)
1	Training Certifications of Personnel (§7.0)	PS	E	Ops Center	
2	Manufacturing, Inspection & Test Plan (§9.6)	PM	E	Ops Center	
3	Quality Assurance Plan (§9.5)	PM	E	Ops Center	
4	Oversight Form (§8.3)	PS	E	Ops Center	
5	Leak Test Procedure (§6.1.3)	PS	E	Ops Center	
6	Acceptance Test Procedures (§9.15)	PM	E	Ops Center	
7	Sequence of Assembly	PS	E	Ops Center	
8	Magnetic Permeability Procedures (§6.1.5)	PS	E	Ops Center	
9	Forming and Material controls procedures	PS	E	Ops Center	
10	Weld Procedures and Welder Qualifications (§7.2.2)	PS	E	Ops Center	
11	Weld Sequence & Distortion Control Procedure (§7.2.1)	PS	E	Ops Center	
12	Cleaning Procedures (§5.2.6)	PS	E	Ops Center	
13	Radiography and Visual Examination Procedures (§6.1.2)	PS	E	Ops Center	
14	Leak Repair Procedure	D	E	Ops Center	
15	Quality Assurance Manual (§9.3)	PS	E	Ops Center	
16	Packing and Shipping Plan (§10.0)	PS	E	Ops Center	

#	Document Deliverables Required	Date Required	Format	Storage Location	Rcvd (✓)
18	Design & Drawing Details for Auxiliary Components (e.g. Lift Fixtures, Leak Test Fixtures/jigs, etc.)	N	E	Ops Center	
19	Evidence of Conformance	C	E	Ops Center	
20	CMTR – Divertor Flanges	PS	E	Ops Center	
21	CMTR – Bellows Flange	PS	E	Ops Center	
22	CMTR – Organ Pipe Tube	PS	E	Ops Center	
23	CMTR – Organ Pipe Conflat Flange	PS	E	Ops Center	
24	CMTR – Weld Filler Material	PS	E	Ops Center	
25	CMTR – Rolled Tubing	PS	E	Ops Center	
26	CMTR – Forgings	PS	E	Ops Center	
27	Non-conformance Reports (§9.8)	D	E	Ops Center	
28	Leak Pressure and Non-destructive Test Reports (*as required*)	N	E	Ops Center	
29	Metrology Survey Reports with Point Cloud Data (*as required*)	N	E	Ops Center	
30	Weld Stud Pull Test Report	N	E	Ops Center	
31	Product Quality Certification & Shipping Release Form (§9.21)	C	E	Ops Center	
32	Fabrication Drawings	C	E	Ops Center	
33	Marked record drawings	C	E	Ops Center	
34	Process History	C	E	Ops Center	

Legend

N = Notice to Proceed Requirement
PM = Prior to MRR
PS = Prior to Start of Construction
C = Project Completion
P,E = Paper or Electronic
D = During Construction/As Required

Princeton Technical Representative: _____

(Sign-off and provide to the Operations Center when job is completed and deliverables are dispositioned and placed/filed in Operations Center (or other Project, Department or Division designated file center).

ATTACHMENT A. PRODUCT QUALITY CERTIFICATION & SHIPPING RELEASE

To be completed by supplier and submitted to PPPL with the Documentation package. Shipment (full or partial) is not authorized until PPPL returns this form signed.

Completed by Supplier

PPPL SUBCONTRACT/ ORDER #	ITEM #(s)	QUANTITY SHIPPED
ITEM DESCRIPTION	SUPPLIER REFERENCE #	SHIPMENT #

SUPPLIER'S CERTIFICATION

This is to certify that the products and services identified herein have been produced under a controlled quality assurance program and are in conformance with the procurement requirements including applicable codes, standards and specifications as identified in the above-referenced documents unless noted below. Any supporting documentation will be retained in accordance with the procurement requirements.

SIGNED:_____ DATE:_____

TITLE:_____ COMPANY: _____

Completed, signed, and returned by PPPL before shipment

PPPL (AUTHORIZED REPRESENTATIVE) SHIPPING RELEASE

This is to certify that evidence supporting the above Supplier's Certification statement has been reviewed and no product/service non-conformances from procurement requirements have been identified unless noted below. This product/service is hereby released for shipment.

This section serves as the Quality Assurance release for the above described product for shipment. It does not constitute an acceptance thereof and does not relieve the Supplier, Manufacturer or Contractor of any and all responsibility or obligation imposed by the purchase contract. It does not waive any rights the Purchaser may have under the purchase contract, including the Purchaser's right to reject the above described material upon discovery of any deviations from requirements of the purchase contract, drawings and specifications.

NONCONFORMANCES FROM PROCUREMENT QUALITY REQUIREMENTS:

REMARKS/PRODUCT SERIAL NUMBERS:

BY PPPL QA REPRESENTATIVE (OR DESIGNEE)	DATE

Rev. 1 November 15, 2010

ATTACHMENT B. DEPARTMENT OF ENERGY SUSPECT/COUNTERFEIT HEADMARK LIST

DOE Headmark List

ANY BOLT ON THIS LIST SHOULD BE TREATED AS DEFECTIVE WITHOUT FURTHER TESTING.

ALL GRADE 5 AND GRADE 8 FASTENERS OF FOREIGN ORIGIN WHICH DO NOT BEAR ANY MANUFACTURERS' HEADMARKS:

 **GRADE 5**  **GRADE 8**

GRADE 5 FASTENERS WITH THE FOLLOWING MANUFACTURERS' HEADMARKS:

	MARK	MANUFACTURER		MARK	MANUFACTURER
	J	Jinn Her (TW)		KS	Kosaka Kogyo (JP)

GRADE 8 FASTENERS WITH THE FOLLOWING MANUFACTURES' HEADMARKS:

	MARK	MANUFACTURER		MARK	MANUFACTURER
	A	Asahi Mfg (JP)		KS	Kosaka Kogyo (JP)
	NF	Nippon Fasteners (JP)		RT	Takai Ltd (JP)
	H	Hinomoto Metal (JP)		FM	Fastener Co of Japan (JP)
	M	Minamida Sieybo (JP)		KY	Kyoei Mfg (JP)
	MS	Minato Kogyo (JP)		J	Jinn Her (TW)
	Hollow Triangle	Infasca (CA TW JP YU) (Greater than 1/2 inch dia.)			
	E	Dalai (JP)		UNV	Unytite (JP)

GRADE 8.2 FASTENERS WITH THE FOLLOWING HEADMARKS:

	MARK	MANUFACTURER
	KS	Kosaka Kogyo (JP)

GRADE A325 FASTENERS (BENNETT DENVER TARGET ONLY) WITH THE FOLLOWING HEADMARKS:

	MARK	MANUFACTURER
Type 1 	A325 KS	Kosaka Kogyo (JP)
Type 2 		
Type 3 		

Key: CA-Canada, JP-Japan, TW-Taiwan, YU-Yugoslavia