SNS PPU Cryomodule Pressure & Vacuum Systems

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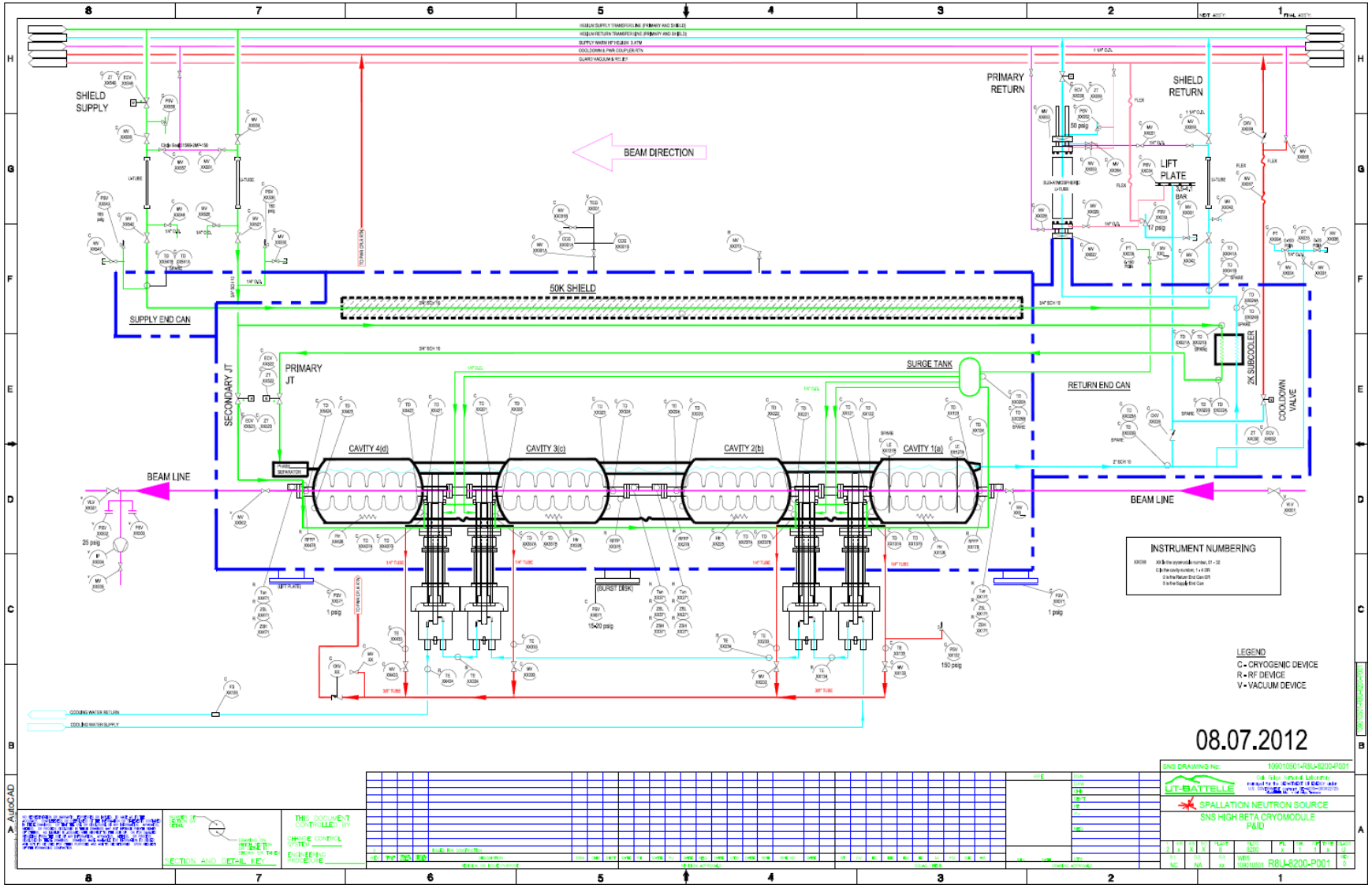
SNS PPU Cryomodule P&ID



Pressure Circuits in SNS PPU Cryomodule

Four pressure circuits

1. Upstream to the JTs

- Starts with the primary supply bayonet and ends at the upstream sides of the JT valves. Major components include the JT valves, heat exchanger supercritical helium coil and connection pipes in between these components.
- Guarded by a pressure relief with its set pressure being 150 psig.
- Design & fabrication to observe 2016 ASME B31.3. Design temperature: 2-300K, Design pressures: 165 psia internal and 45 psia external.

2. Downstream to the secondary JT

- Consists of 4x coupler 5K flanges that have cooling channels, the surge tank, 4x coupler's outer conductors that have trace-cool channels and multiple segments of piping: from the secondary JT to coupler flanges, in-between coupler 5K flanges, from coupler 5K flange to the surge tank, from the surge tank to pressure transducer on the return end can, from the surge tank to all 4 couplers' outer conductors and from the exits of coupler outer conductors to coupler helium gas return line.
- Guarded by a pressure relief with a set pressure of 150 psig.
- Design & fabrication to observe 2016 ASME B31.3. Design temperature: 2-300K, Design pressures: 165 psia internal and 45 psia external.

Pressure Systems in SNS PPU Cryomodule (Cont'd)

3. Downstream to the primary JT

- Consists of 4x helium vessels, 4 x cavities, top & bottom interconnection headers between HVs, heat exchanger return gas coil, piping between the 1st HV and primary JT, after the last HV all the way up to the relief stacks, through the heat exchanger to the primary helium return bayonet and to the upstream side of the cooldown valve in the return end can.
- LHe primary circuit is guarded by two pressure reliefs with set pressures of 17 psid and 51-59.5 psia, respectively.
- Helium vessel design & fabrication to observe 2017 BPVC. Design pressures & temperatures: 5 atm/75 psia internal @ 2K, 2.2 atm/33 psia internal and 45 psia external @ 300K.
- Niobium cavities are not covered by ASME BPVC. Refer to JLab ES&H Manual 6151 Pressure and Vacuum Systems Safety Supplement Part 3 Equivalent Measures for guidelines. Cavity design shall observe 2017 BPVC. Design pressures & temperatures: 5 atm/75 psia external @ 2K, 2.2 atm/33 psia external and 40 psia internal @ 300K.
- Helium vessel and cavity design shall consider tuner's effect.
- Piping, bellows and hoses design & fabrication per 2016 ASME B31.3. Design pressures & temperatures: 5 atm/75 psia internal @ 2K, 2.2 atm/33 psia internal and 45 psia external @ 300K.

Pressure Systems in SNS PPU Cryomodule (Cont'd)

4. Shield Circuit

- Consists of the single-pass cooling pipe mounted onto the thermal shield and relevant piping in the supply & return end cans.
- Guarded by a pressure relief with a set pressure of 185 psig.
- Design & fabrication to observe 2016 ASME B31.3. Design temperature: 35-300K, Design pressures: 200 psia internal and 45 psia external.

Category III Vacuum Systems in SNS PPU Cryomodule

Three category III vacuum systems

1. **Vacuum Vessel (VV)**
2. **Supply end can (SEC) shell**
3. **Return End Can (REC) shell**

- The above three systems' design & fabrication shall comply with 2017 ASME BPVC rules. Needs ASME stamp.
- Guarded by 2x 1.0 psig lift plate pressure reliefs and 1x 15-20 psig burst disk, which carries ASME stamp.
- Design temperature: 300K. Design pressures: 3 atm/45 psia internal (MAWP is 22 psig) and 1 atm/15 psia external, respectively.
- Note that these systems always have 1 atm external pressure.
- Need to register using PS-4 form.

Category II Vacuum Systems in SNS PPU Cryomodule

1. **Beam line components**
   - Includes cavities, warm to cold transition beam pipes at supply and return ends, inter-cavity beam pipes & bellows, and couplers' outer conductor/ceramic window/antenna formed vacuum section connecting to beam pipe.
   - Guarded by two burst disks with crack pressure of 25 psig.
   - Design & fabrication per 2017 ASME BPVC.
   - Design parameters for components other than cavities:
     - Design temperature: 2-300K.
     - Design pressures: 40 psia internal and 45 psia external.
   - Although the beamline burst disc set pressure exceeded 15 psig, the probability of these burst disks cracking is deemed to be extremely low. Therefore these components are treated as category II vacuum systems.
   - On Commercial Off-The-Shelf (COTS) components, such as ion-pumps, gate valves, check pressure ratings to see if they meet pressure/vacuum system requirements.

Pressure Reliefs

- There are 7x spring loaded pressure reliefs, including 4 x commercial PRVs and 3x lift plate style PRVs.
  - the 4x commercial PRVs need ASME stamp.
  - The 2x 1 psig lift plate PRVs mounted on the VV do not need ASME stamp
  - The primary return 51-59.5 psia lift plate PRV needs ASME certification (ORNL certified this type of PRV?)
    - Alternative is to install an ASME certified burst disk in parallel to the lift plate.
  - Need to fill out PS-5 forms for all.

- There are 3x burst disks. The burst disk on VV shall carry ASME stamp.
- Relief sizing
  - Refer to JLab ES&H Manual 6151 Pressure and Vacuum Systems Safety Supplement Part 4: Overpressure Protection.
  - Failure modes to consider include, loss of insulating vacuum, loss of beamline vacuum, prolonged external fire condition.
  - Design guidance can be found from American Petroleum Institute standard API 521 and Compressed Gas Association CGA S-1.3.
  - Need to review past relief sizing calcs if exist. Otherwise, redo the relief sizing calcs.

Pressure & Vacuum System Design Guideline

Material Properties

- All B31.3 piping: use ASME B31.3 material data for the lowest temperature range
- Vacuum Vessel and End Can outer shells: use ASME BPVC room temperature data
- Helium vessel: use 2K properties from literature and BPVC data for the lowest temperature range for the room temperature analysis
- Niobium cavity: use 2K and room temperature data from literature.
- Other components governed by BPVC: use BPVC data for the lowest temperature range.

Design Requirements

- All pressure systems and category III vacuum systems identified require design analysis per applicable ASME, API, CGS codes or standards.
- B31.3 piping typically require stress and system flexibility analysis, refer to 2016 ASME B31.3.
- VV and SEC & REC shells are analyzed by ORNL. Need to review their reports to determine if amendments are needed.
- HV and cavity pressure safety analyses, if ORNL do not have them, need to be done per ASME BPVC S8D1 or S8D2 rules. Past experience tells that HV and cavity, and the stiffening from tuner shall be considered all together. Design scenarios need to be identified prior to analysis. Refer to relevant JLAB TNs and FNAL's work on ILC and LCLS-II dressed cavities.
- Once the pressure & vacuum system components drawings are made, a table with design parameters (fluid service, design temperature, design pressure) associated with specific components can be made.

Pressure & Vacuum System Design Refernces

- References on Material Properties
  1. Material properties from ASME BPVC and B31.3 tables.
  2. BNL Selected Cryogenic Data Notebook.
  3. NIST Cryogenic Material Properties
  4. NIST Thermophysical Properties of Fluid System
  5. JLAB-TN-09-002, On Niobium in Construction of Cryogenic Pressure Vessel Systems.
  6. FNAL Specification ED0371110 – Material Properties for Engineering Analyses of SRF Cavities.

- References on Pressure/Vacuum Systems Design
  1. JLAB tech notes on SNS CM design and C100 pressure systems design.
  2. ORNL engineering notes on spare CM design
  3. FNAL ILC and LCLS-II dressed cavity, pressure system engineering notes.
  4. FNAL TD-09-005, Guidelines for the Design, Fabrication, Testing and Installation of SRF Nb Cavities.

Technical or Peer Review

Technical/peer review of the design of all SNS PPU CM pressure/vacuum systems identified will be held and JLab ES&H Manual 6151 Pressure and Vacuum Systems Safety Supplement Mandatory PS-3 form will be signed off.

TECHNICAL/PEER REVIEW RECORD		FORM PS-3	
Pressure System Number			
Component(s) (if applicable)			
Design Authority (DA)			
DA Group/Division			
Note: Excluded Elements require a Peer Review. Peer Review must be completed by one or more DAs not associated with the project. Technical Review is applicable to code compliant components and can be performed by any DA.			
Type of Review (check)	___Technical Review	___Peer Review	
Description:			
Scope of Review:			
Applicable Code(s):			
The undersigned have reviewed the calculations and/or design specifications listed above and verify accuracy and compliance with JLAB requirements, national consensus codes, or equivalent measures.			
Reviewer Name	Signature	Date	Group/Division
Comments:			

Special Topics: Fracture Toughness

- All pressure/vacuum systems in SNS PPU CM that contains components that will see cryogenic temperatures < -20 °F (-29°C) shall be examined for whether Charpy Impact testing is required.
- JLab Pressure System DA toolbox has a policy on Fracture Toughness Testing Requirements. Apply the latest (dated 6/16/2017).
- Note that the SNS PPU CM cryogenic circuits components are typically made of 316L stainless steel and welded by gas tungsten arc welding (GTAW) method. If material thickness is greater than 0.099" (2.5 mm), impact test might be required. For example, 1" IPS steel pipe with schedule 10 has a wall thickness of 0.109" that exceeds the 0.099" limit.
- Also note that if impact test is required, ASME BPVC S8D1 UHA-51 "Impact Tests" (a)(3)(a)(1) requires type 316L filler material shall have a Ferrite Number (FN) not greater than 10, along with other requirements. UHA-51 does give alternatives if (a)(3)(a) cannot be met.

Pressure & Vacuum System Procurement Specifications

A comprehensive SOW is a good start point. SOW is a powerful contractual documents between JLab and vendors. For the pressure/vacuum systems in SNS PPU CM, the following elements shall be included in the procurement SOW:

- ✓ Applicable ASME code
- ✓ Material certs are required. Mater index table links certs and parts is needed.
- ✓ Welder qualification records, WPS, WPQ and PQR shall be submitted and approved.
- ✓ Impact toughness testing (if required) related: base and HAZ materials impact test, weld filler material ferrite number <= 10, required impact testing for WPQ.
- ✓ Cold shock (just spraying is insufficient, must soak), then pressure test, and leak check after cold shock and pressure test. SOW must detail the testing requirements.
- ✓ Vendor needs to develop in-process weldmap(s), keep welding records on which weld is performed by which welder (sign/stamp) per what WPS on what date.
- ✓ Parts serialization is necessary. SOW sets forth the format of SNs and where to etch SNs.
- ✓ If there are fasteners, fastener torque specification and QC requirements must be included in the SOW.
- ✓ If Loctite is required, a fastener Loctite specification (what type, QC requirements)
- ✓ JLab has the right to do unannounced vendor visit. Critical tests must be witnessed by JLab.
- ✓ Deliverables and delivery schedule. Some documents, such as test reports, need to be submitted to JLab for approval before shipping.
- ✓ Shipping configuration shall ensure the integrity of parts. Vendor is fully responsible for any damages.

In-process QC/QA & System Examination

- Cleanroom and cryomodule assembly travelers shall include QC check points at various work stations and data/reports to be collected.
- After a cryomodule final assembly, perform a mechanical system examination and fill up PS-6 form

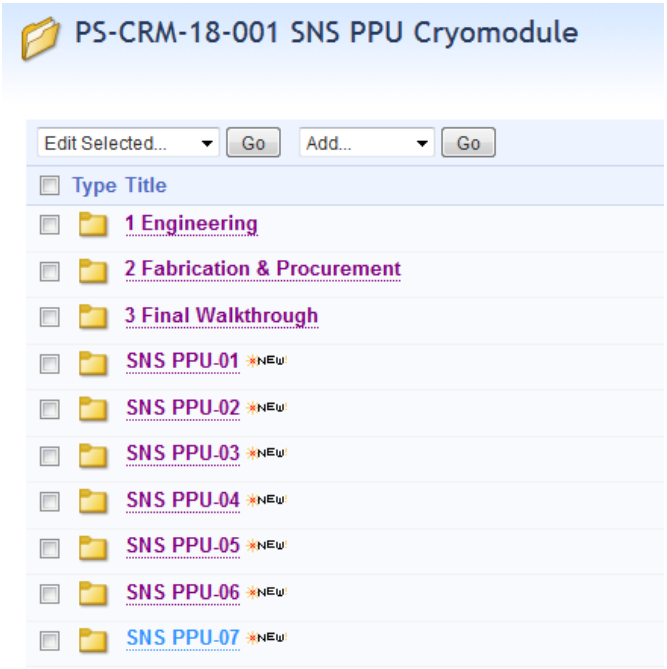
FINAL MECHANICAL EXAMINATION	FORM PS-6
Pressure System Number:	
Pressure System Name:	
Design Authority:	
CHECK IF COMPLETE, N/A IF NOT APPLICABLE:	
	Materials, components and products meet specifications and the requirements of engineering design
	Applicable procedures for assembly, glue bonding, etc.
	Assembly of threaded, bolted and other joints conforms to Code and engineering design
	Alignment, supports and/or cold spring meet engineering design
	Dimensional checks of components and materials meet Code and engineering design
Comments:	
Examiner name and signature:	Date:

Pressure & Vacuum System Testing at JLab

- The 4 pressure circuits need to be pressure tested respectively after final assembly by closing relevant valves to establish isolated pressure systems. Pressure tests are to be done at room temperature with helium/nitrogen gas, observing ASME B31.3 and BPVC rules on pressure/leak testing.
- SNS requires a helium leak test at LN2 temperatures or colder. For the helium circuits, i.e., all four pressure circuits in a SNS PPU cryomodule,
  - Run LN2/LHe through helium circuits to perform cold shock test
  - Leak test after warm up to see if there are any leaks developed during cold shock
  - pressure test after the first round of leak test
  - repeat the leak check after or during the pressure test to check if leaks developed during pressure test.
- Category III vacuum systems, i.e. VV and end can shells, are tested by vendors. JLab will not test VV and end cans for internal pressure.
- Category II beam line vacuum system components, except COTS items and cavities, that are outside of the vacuum boundary need to be pressure tested **individually** for their capability to hold internal & external pressures. They WILL NOT be pressure tested after final assembly to avoid the risk of contaminating beam line UHV. No plan to test coupler interior vacuum space.
- Cavities WILL ONLY be tested for its external design pressure at warm after final assembly.
- In case that certain welds cannot be pressure tested, consider alternative tests such as radiography like what LCLS-II does.
- For all pressure tests, develop test procedures, evaluate stored energy and prepare OSP if needed. PS-7 forms need to be filled up for any pressure tests performed.

Pressure System Number and Folder

- The pressure system ID for SNS PPU Cryomodule is PS-CRM-18-001, which needs to appear on pressure/vacuum system drawings (mainly on assembly drawings).
- Pressure system folder is structured so that folders common to all 7 CMs stay at the root level and cryomodule specific documents will be stored under sub-folders corresponding to each production cryomodule.



PS-8 & PS-9 Forms

- PS-8 to be filled after all cryomodule work is complete, perform a final walk-through before shipping and finish this form for each cryomodule to be sent away.
- PS-9 to be filled after delivery of a module to ORNL.

FINAL SYSTEM WALKTHROUGH AND DOCUMENTATION REVIEW	FORM PS-8
Pressure System Number:	
Pressure System Name:	
Design Authority:	
CHECK IF COMPLETE, N/A IF NOT APPLICABLE:	
Form PS-1 Pressure System Project Cover Sheet is complete and filed.	
Form PS-2 complete and filed if applicable.	
Review of construction documentation including: ○ Review of pressure/leak test documentation, completed and filed (Form PS-7) ○ Technical and Peer Reviews have been performed and filed (Form PS-3). ○ Ensure that welding and brazing inspections have been performed and filed ○ Ensure that mechanical examinations have been performed and filed (Form PS-6) ○ Ensure that applicable fabrication documents have been filed.	
Review of P&ID critical elements (i.e. relief devices, vessels, relief paths, etc.).	
Conspicuous and durable Jefferson Lab specific tags are installed on pressure vessels and boilers	
Forms PS-4 and PS-5 are filed for vessels and their relief valves	
General physical system condition and readiness.	
Checks on all relief devices providing overpressure protection.	
Through direct visual examination, relief devices (providing overpressure protection) are installed and that the relief paths are free (e.g. stop valves are locked open, test plugs removed etc.) and direction of discharge is safe.	
Comments:	
Owner's Inspector name and signature:	Date:

PRESSURE SYSTEM TURNOVER	FORM PS-9
Pressure System Number:	
Pressure System Name:	
OPERATING REQUIREMENTS:	
MAINTENANCE REQUIREMENTS:	
IN-SERVICE INSPECTION REQUIREMENTS:	

	Piping	Vessels	Relief Valves	Component	Component
ISI Category					
ISI Type					
ISI Frequency					

Special ISI Requirements:	
System Owner name and signature:	Date:
Design Authority name and signature	Date

Summary of the Application of Mandatory Forms

- PS-1 is the pressure system cover sheet. It is common to all 7 SNS PPU CMs.
- PS-2 overpressure by system design does not apply to this project.
- PS-3 is technical/peer review records. It's common to all modules.
- PS-4 Pressure vessel registration. It is cryomodule specific since each cryomodule has its own set of pressure & vacuum systems.
- PS-5 Pressure relief device data sheet. Each cryomodule has its own specific set of reliefs
- PS-6 Final mechanical examination shall occur to each production cryomodule
- PS-7 Pressure/leak test record. Need to keep a set of PS-7s for each CM.
- PS-8 Final system walkthrough and documentation check. Need to do this for each module prior to shipping.
- PS-9 Pressure system turnover. Need to do this for each CM after delivery.
- PS-10, -11, -12 do not apply since ORNL has their own policy.

Summary of SNS PPU CM Pressure System Related Work

- Engineering
  - Review ORNL calcs and determine their compatibility with JLab ES&H 6151 policy.
  - Make new/revise existing drawings that do not comply with JLab ES&H 6151 policy.
  - Perform pressure & vacuum systems engineering analysis if not existing
  - Hold technical/peer reviews.
  - Fill PS-1 & PS-3 forms.
- Procurement
  - SOTRs write SOW following guidelines mentioned earlier
  - Vendor welding documents need to be reviewed by JLab CWI or Authorized Inspector
  - SOTRs may review vendor's fabrication drawings if vendor chooses to make them.
  - SOTRs arrange to visit vendor to witness critical tests.
  - SOTRs check vendor submitted test procedures, material certs, test reports, etc.
  - SOTRs need to prepare incoming inspection travelers.
- Fabrication
  - Develop weldmaps, keep welding records.
  - Execute in-process QC.
  - Develop cold shock, pressure and leak test procedures if not existing. Develop OSPs.
  - Fill forms PS-4, PS-5, PS-6, PS-7, PS-8 and PS-9.