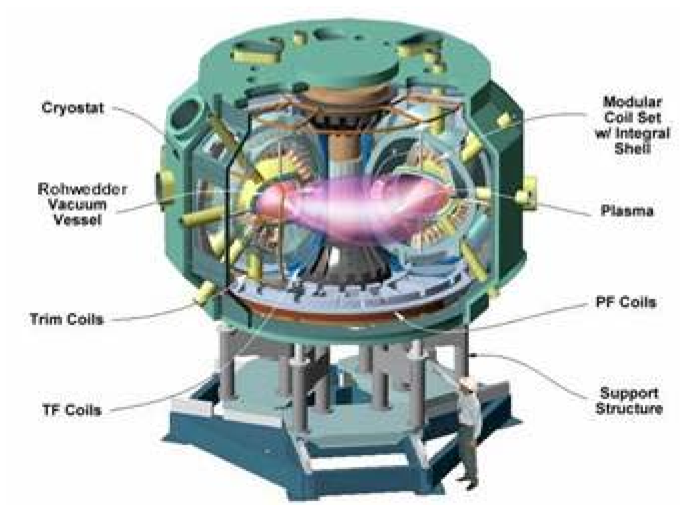
Rohwedder

NVSI

Princeton University
Plasma Physics Laboratory

National Compact Stellarator Experiment (NCSX)

Vacuum Vessel Manufacturing Development and Prototype Fabrication



3.1.1 Manufacturing Methods for Fabricating the VVSA

In Reference to Section 3.1.1 of NCSX-SOW-121-01-01

May 30, 2003

National Compact Stellarator Experiment (NCSX)

Vacuum Vessel Manufacturing Development and Prototype Fabrication

3.1.1 Manufacturing Methods for Fabricating the VVSA In Reference to Section 3.1.1 of NCSX-SOW-121-01-01

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1.0 CAD/CAM

Rohwedder/NVSI will take a full CAD/CAM approach in the engineering, fabrication and inspection of the VVSA, using Pro/E software throughout the manufacturing process. The first step will be to decide on the proper segmentation of the vessel and to create the segments inside the Pro/E models created by PPPL. It is initially anticipated that the segmentation already developed by PPPL will be used unless further investigation by Rohwedder/NVSI determines a more efficient segmentation philosophy. Since Rohwedder/NVSI plans to create the contours of the vessel segments through a forming process, computer models of the necessary die assemblies will then be created matching the profile of the chosen vessel segments. Pro/E Prismatic Milling Software (a CAM package) will be utilized in setting tooling paths, speeds and feeds, and finally to create machine code to control the CNC milling stations that will be used in final machining of the die plates and the vessel segments. The computer modeling and machining of the segment end flanges, port flanges and support hangers as well as the fitting of the port extensions to the contour of the vessel, will be handled in a similar fashion. Throughout the manufacturing process, several inspection points will be inserted for measurement and verification of dimensional tolerances. Data taken from a Coordinate Measurement Machine (CMM) and/or other devices will be compared either to the original Pro/E models or IGES conversions of these models for verification of compliance to PPPL specified tolerances. Using the original file format of the VVSA models (Pro/E) in conjunction with full Computer Aided Manufacturing of the components and assemblies is the most efficient way to complete the manufacture of such complex geometry, while assuring the most dimensionally accurate end product.

2.0 FORMING METHODS

2.1 Forming of Segments

Rohwedder/NVSI will use a series of step dies in forming the various segments of the VVSA. It is anticipated that six (6) step dies sets (male/female) will be needed to form the segments that constitute the repeated 60˚ geometry. The selected segmentation of the vessel will be based on balancing a desire to minimize the number of dies to reduce costs and fabrication time with creating die geometries that minimize distortion and avoid material entrapment. It is also beneficial to reduce the number welds both to decrease the number of set-up and alignment operations necessary and to reduce heat distortion induced by the welding process. As mentioned above, it is initially anticipated that the segmentation already developed by PPPL will be used unless further investigation by Rohwedder/NVSI determines a more efficient segmentation philosophy.

Prior to manufacturing the production die sets, Rohwedder/NVSI will manufacture a prototype die set for a single segment. The test die will be used to qualify our proposed manufacturing and inspection procedures and techniques, material properties and material "spring back" rates, and general tolerance requirements for material pre-cutting and developed length analysis. The step dies will consist of individual carbon steel rib plates aligned in a die enclosure with a ¼" stainless steel or Inconel "scab" plate covering the press surface to eliminate any contamination potential. The plate will be formed to the contour of the rib edges in the die itself and secured using plug welds at points coincident with the edge surface of the underlying rib plates. The individual ribs will be made of ¾" to 1" thick plates set 2" apart along the length of the rib enclosure. The rib and enclosure plates will first be rough cut on a water jet cutting machine, then using Pro-E Prismatic software, a machine code program will be created for 3-axis milling machines to final machine the overall size of the rib and the complex, contoured edge of the rib that will be used to form the Inconel material. The enclosure will be designed using tight tolerances and "key lock" control on the ribs. After the ribs are welded in place in the die enclosure, the enclosure will be filled with concrete approximately two-thirds the height to the lowest point of the die for increased strength. After the concrete is set and the final contour of the die plates has been determined, the scab plate will be added. Currently, alterations to the die set design philosophy are being considered to reduce the difficulty in making additions/modifications to the dies and to allow heat treating the segments while still in the dies. This is discussed in more detail in *3.1.2 Subcontractor Recommendations, Section 3.0 Reusable Die Sets*. When the enclosure is complete, the locking key slot will be machined to match the forming vendor's press machinery. After the segment plates are cut oversized on a water jet machine, they will be placed in the dies and formed using a hydrostatic press.

2.2 Forming of Port Extensions

For some of the vessel ports, it will be necessary to perform simple forming operations. Circular cross sectioned port extensions will be made of purchased seamless tubing. For port extensions with non-circular cross sections, the tubes will be made up of segments that can be created on standard bending equipment, which will then be welded together before machining the extensions to length. During the fabrication of the port extensions, reference points will be added that will aid in the cutting of the extensions to the contour of the vessel and will aid in aligning the ports correctly for fixturing and welding.

2.3 Forming Inspection & QA

Inspection and Quality Assurance for forming of the NCSX will focus on maintaining dimensional tolerances, surface cleanliness and low magnetic permeability. The overall inspection/test plan and quality assurance plan will be within the ISO9001/2000 certified quality manual, the ASME certified quality manual, and the PPPL quality requirements as outlined in NCSX-SOW-121-01-00 and NCSX-CSPEC-121-02-00.

2.3.1 Dimensional Inspection & QA

To maintain dimensional tolerances throughout the manufacturing of the VVSA, physical reference points located on the vessel segments and support hardware to perform verification of tolerance compliance to the original Pro/E models of the segments and die plates. First, reference points will be placed on the precision dies which will be machined and dimensionally verified with a portable CMM against the original Pro/E models of the dies. These points will be in the form of tooling balls, small indentations or precision machined surfaces. These points will then, in turn, be referenced in placing reference points on each segment during or immediately after they are formed. The physical reference points will aid in the machine set-up and dimensional verification for final machining of vessel segments and later for weld fit-up of the segments, port extensions, end flanges and support hangers. Since the reference points will exist in both the model and on the part, it will be possible to align the model of the part with the actual part in the CMM software so that actual location can be compared to nominal when checking tolerances along the dimensional test grid specified in Section 4.2.4 of NCSX-CSPEC-121-02-00.

In order to reduce distortion of the segments due to the high stresses induced into the material when forming the complex shapes with high-tonnage presses, each segment will be stress relieved after it is formed (See *Section 5 Heat Treatment*).

2.3.2 Surface Cleanliness/Magnetic Permeability Inspection & QA

In order to maintain surface cleanliness as well as low magnetic permeability, the press breaks used in the forming process will be thoroughly cleaned per 3.3.2.4 of NCSX-CSPEC-121-02-00 and segregated in an area allowing for separate material receipt and proper material handling/storage for the materials used in the project. The cleaning and forming will only be done when there is a qualified inspector present. If it is determined that the forming must be done during "off hours" to further limit contamination from stray carbon particles, the process will proceed accordingly. Covering the die sets with stainless steel or Inconel "scab plates" will help eliminate any contamination potential from the die ribs themselves.

3.0 MACHINING AND FINISHING

3.1 Machining of Segments

After the vessel segments are formed in the step-dies and stress relieved to reduce distortion, it will be necessary to machine them to final shape for fixturing and welding since the segment plates will be initially cut oversized. The reference points (tooling balls, indentations or precision machined surfaces) that were mentioned in *Section 2 Forming Methods* will be located on each segment using CMM referencing points on the precision machined dies. The reference points will be used to fit the part computer models to the oversized segments. Once aligned, the CMM can find the correct edge locations on the surface of the segments, which will be marked for cutting. The segment edges will then be machined on a milling center and ground, as necessary, during weld fit up to ensure an edge contact between segments to ensure a quality weld seam.

3.2 Fixtures

Stainless steel "cage" type fixtures will be developed and designed to completely capture the VVSA sections after fabrication to allow accurate positioning of the vessel for aligning, welding and machining of the port extensions and when boring out each individual port diameter/shape in the VVSA sections after the ports are cut off. The cage fixtures will be fabricated using stainless steel angle and I-beam stock. The fixtures will be machined after fabrication to provide for precise positioning locations when inserting the fabricated VVSA sections and for precise positioning locations on the machining centers. The position locations will allow for controlled, consistent movement of the VVSA section so that it can be positioned at angles, horizontally, vertically, and flipped in any orientation without losing the control needed to handle the chamber and provide for repeatable results throughout the length and diameter of the chamber. The cage fixtures will be designed to allow unblocked CMM access to all reference points. To aid PPPL in the alignment and re-weld of the port extensions at Princeton, it would be beneficial to have the ability to use the Rohwedder/NVSI cage fixtures. Due to the potential interference of the modular coil units and coil support structure, close cooperation would be required between Rohwedder/NVSI and PPPL to assess the feasibility of designing cage fixtures with this dual functionality. This is addressed in more detail in *3.1.2 Subcontractor Recommendations, Section 4.0 Machining and Weld Fixtures*.

3.3 Machining of Ports

In the machining of the port extensions to the contour of the vessel, a CMM will precisely locate and then indicate the center point for all of the flanges referencing the reference points on the appropriate segments. During initial fabrication, the ports will be oversized so that after they are individually positioned in the cage, welded and axial position is verified to be within tolerance, they can be trimmed to precise length and the flanges welded in place. At this point, the final length of the ports will be intentionally left 1/8" long to account for the material that will be removed when the ports are cut-off for shipping and installation.

To cope the ports to follow the vessel surface geometry, the ports will first be rough cut using a plasma cutter. Then, using Pro-E Prismatic software; a machine code program will be created for 3-axis milling machines to final machine the contoured weld edge of the extension. A CMM, in coordination with the reference points added to the extensions during initial fabrication, will be used to align the port in the milling center for fixturing and to verify the compliance with dimensional tolerances after machining is complete. The port extensions will then be placed in the cage weld fixture, position checked with the CMM, welded and position verified again.

3.4 Machining of Eng Flanges and Support Hangers

To create the VVSA section end flanges and vessel support hangers, their computer models will be imported into Pro/E Prismatic Milling Software (a CAM package) in order to set tooling paths, speeds and feeds, and finally to create machine code to control the CNC milling stations that will be used in final machining of the flanges and hangers. A CMM will be used for verification of part tolerances.

3.5 Machining of Section Spacers

The initial plan for manufacturing the segment spacers is to reverse engineer the final geometry based on the variations in actual manufactured geometry of the VVSA segments. First, the three VVSA sub-sections will be fixtured to match their final assembled positions relative to each other and using a CMM, several data points will be taken from the two section end flanges for each joint to indicate surface and hole locations. The inferred surfaces and hole locations will be used in the creation of computer models of the three custom segment spacers. They will then be manufactured with a CAD/CAM approach similar to that used on the end flanges.

3.6 Containment Control

Rohwedder/NVSI has extensive experience in manufacturing vacuum chambers, and therefore, has a solid knowledge base of vacuum specific cleaning and surface finishing requirements and techniques. Only biodegradable, water based UHV compatible cutting fluids, oils, greases, and hand tapping fluids will be used. A high pressure, high temperature steam cleaner with biodegradable UHV compatible detergent will be used to rinse every component prior to welding/fabrication, and then rinse again after fabrication is complete. Final cleaning will include isopropyl wipe-down using lint-free wipes and drying with oil-free instrument air as per 3.3.2.4 of NCSX-CSPEC-121-02-00.

3.7 Material Finish

It is planned to purchase Inconel material pre-polished with a #4 polish on both sides. This will provide a maximum of a 63 RMS finish on the plates. Rohwedder/NVSI will work with the material vendor and specify the type of grinding/finishing products they can use and the process steps they should take so that we eliminate any contamination potential. After forming, additional polishing and electro-polishing will be performed to meet the 32 RMS on interior surfaces specified by PPPL. After welding, a "weld stripe" concept will be incorporated in the finishing of the internally ground welds on the VVSA. The "weld stripe" concept requires that the fabricator mask a small strip/stripe along the weld seam (typically .5" beyond the farthest grind line on the joint), then the fabricator will blend in a smooth, consistent finish that is at an RMS rating equal to or better than the overall surface finish on the inside body of the chamber. This method, which is used extensively by NVSI on ASME certified stainless steel pharmaceutical steam sterilizers, allows for localized finishing on the joint areas and prevents over finishing and unnecessary blending finishing to large areas inside the chambers.

3.8 Machining and Finishing Inspection & QA

Inspection and Quality Assurance for machining and finishing of the NCSX will focus on maintaining dimensional tolerances, surface finish, surface cleanliness and low magnetic permeability.

3.8.1 Dimensional Control & Verification

As mentioned in *Section 2 Forming Methods*, physical reference points, such as tooling balls will be used throughout manufacture of the VVSA to maintain dimensional tolerances. They will be located on the vessel segments, port extensions, dies and other fixturing to be used in verification of tolerance compliance to the original Pro/E models. The points will be indispensable in assuring proper locating and fixturing of the die-plates for final machining and trimming of the segments after forming. Also, because the reference points will exist in both the model and on the part, it will be possible to align the model of the part with the actual part in the CMM software, so that actual location can be compared to theoretical, when verifying tolerances with the portable CMM after final machining is complete.

3.8.2 Surface Finish Control & Verification

To assure that the surface finish of the vessel complies with those set forth in 3.2.1.2 of NCSX-CSPEC-121-02-00 and ASME B46.1, the finish of incoming raw materials and finished weld joints and sealing surfaces are to be monitored by visual inspections and qualified/verified by a calibrated digital profilometer throughout the manufacturing/fabricating process.

3.8.3 Magnetic Permeability Control & Verification

Magnetic permeability will be controlled through material selection, machining and polishing techniques, use and careful control of proper tooling and consumables. Inconel 625 will be used for the segments and port extensions and ASME/AWS SFA/A 5.14 ERNiCr-3 or ERNiCrMo-3 welding wire, as required by PPPL due to their innate low magnetic permeability. It is expected that Rohwedder/NVSI will also refuse any work from other customers that require the use of carbon steels for the duration of the project. All the finishing tools and consumables used in the finishing processes will be purchased new, and will be segregated, labeled, and secured for use only on this project until the project is complete. Facility maintenance and equipment control will be handled within the procedures detailed in the NVSI ISO9001/2000 certified quality program and manual. Rohwedder/NVSI intends to purchase a Severn Permeability Indicator in order to verify magnetic permeability compliance with the PPPL requirements in the SOW and Product Specification. Calibration and control of the detector will be within the elements of the ISO9001/2000 certified quality program/manual.

4.0 WELDING AND WELD REPAIR

The design of the weld joints will facilitate a metal to metal contact of the segments and end flanges when they are fitted together for the welding process, reducing the amount of heat and weld wire needed to fabricate the VVSA sections. This will aid in reducing distortion and tolerance shifting and eliminate the problem of holding the individual segments “in the air” to prep and weld the joints. Adjustable internal spreaders/spiders will also be used that are designed to and verified against the PPPL assembly models as well as the incremental step die shapes, and the tolerance requirements of the overall VVSA project. Additionally, it is planned to use small Inconel 625 bridge tacks on the outside skins of the segments to help support the VVSA sections as they are wrapped around the internal spreaders and the joints are fit together.

After each VVSA section is completely welded including end flanges, support hangers and port extensions, the VVSA section(s) will be stress relieved to eliminate stresses induced during the welding/fabrication process.

During the welding of the support hangers, end flanges and port extensions to the vessel and when welding the flanges to the ends of the port extensions, the reference points will be used to verify tolerance compliance to the original Pro/E models. As mentioned in *Section 2 Forming Methods*, it will be possible to import part models into the CMM software to align the reference points of the part model with the actual part, allowing verification of tolerances during weld fixturing and after welding is complete. Following the welding operation, port extensions will be cut with a plasma cutter and labeled for correlation to vessel location for re-weld at Princeton. The most logical cutting approach will be determined for each port in order to ensure no port stub will extend past 1" from the vessel surface to allow for fit-up of the modular coil units. Either straight angle cuts or one following the surface contour will be used, depending on the size of the port and the local vessel contour. As mentioned in *Section 3 Machining and Finishing*, the extra 1/8" left in the port length initially, will be removed during the cutting process, allowing the length of the ports at final assembly at Princeton to be within the Port Assembly Length tolerance specified in NCSX-12-122002-PH.

4.1 Weld Inspection & QA

Inspection and Quality Assurance for welding of the NCSX will focus on maintaining dimensional tolerances, surface finish, surface cleanliness and low magnetic permeability.

Welding and NDE of the NCSX VVSA will follow the guidelines dictated by the ASME "U" and "R" certification held by NVSI, Section 4.2.6 of NCSX-CSPEC-121-02-00 and all documents specified within. A Weld Procedure Specification (WPS) will be generated, which will detail general joint details, procedures for welding wire, backing gas, backing materials, welding machine settings, torch controls, welder position requirements, etc. All welders working on this project will be qualified in a 6G position to the project WPS. This means each welder will be tested by an ASME certified independent testing facility to determine if they qualify or "pass" welding in any position (6G certification) while following the procedures and welding the materials necessary per the WPS for this project.

Following ASME guidelines, a weld map will be generated for fabrication of the VVSA sections. In a weld map, each joint is detailed on a print and is assigned a specific number which is used for identification to the welders, internal inspectors, customer representatives, and to any independent inspection facilities. The individual joint is defined by the required procedure in the WPS and a sign-off is required by the weld map supervisor and by the person who fabricated/welded the joint. The individual weld number sequence supports in-process review of individual performance that can be performed at any time. A series of formal and informal inspection hold points will be incorporated into the VVSA fabrication process that will include visual and/or radiographic inspections of the weld seams. These inspection hold points must be signed off before any further work can commence. The inspections will only be done by approved quality inspectors within our quality system or, when required, by certified independent testing facilities/inspectors.

All required formal NDE will be done by independent testing facilities. Independent review helps to confirm our performance and provide assurance to the customer/end user that the work is being done in full accordance/compliance with the SOW and Product Specification.

Developing the most efficient and effective weld joint configuration possible will also reduce the final magnetic permeability of the VVSA. Minimum weld length (joint length) will result in less welding induced magnetism within the VVSA sections.

5.0 HEAT TREATMENT

The initial Rohwedder/NVSI heat treating (stress relief) plan is for a two-step process. First, the individual rough formed segments will be heat treated to remove any stresses induced by forming. Second, the entire fabricated 120˚ assembly will be heat treated prior to final machining after installation into the stainless steel cage fixture and positioned for final machining and port location. It is not certain how feasible the plan of "double" stress relief will be, so an initial test run will be performed on sample pieces prior to initiating the production process.

The planned method of stress relieving is to place each component or assembly in an inert gas (Argon) furnace and heat to 1600 Fahrenheit, hold the temperature for one hour and oven cool until it reaches ambient temperature. It must be noted that through the stress relieving, the tensile strength of the Inconel will drop from 155,000psi to 144,000psi.

6.0 VACUUM TESTING

Vacuum testing of the vessel and the port extensions shall be conducted in accordance to Section 3.2.1.1 of NCSXCSPEC-121-02-00 and the ASTM E498 specification referenced within. All surfaces will be thoroughly cleaned per Section 3.3.2.4 prior to initiating leak check procedures. To leak check the main vessel shell sub-assemblies, custom blank-offs will be manufactured and mounted to VVSA. The vessel will be pumped down using a turbomolecular pump to a < $1x10^{-7}$ torr and leak checked at a detection sensitivity of 10^{-10} scc/sec He, with a mass spectrometer leak detector connected to the turbo pump foreline. The ports will be similarly blanked-off and leak checked prior to cutting away the ports and boring the port extension holes in the vessel shell. All leaks will be documented in nonconformance repots and repaired.

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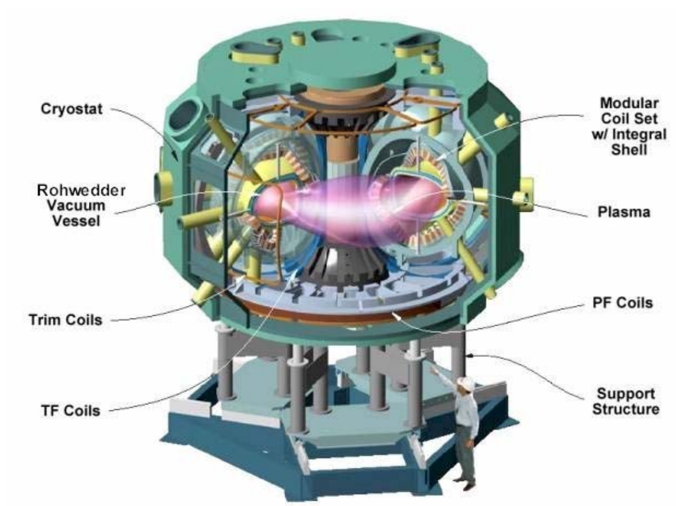

3.1.2 Subcontractor Recommendations

In Reference to Section 3.1.2 of NCSX-SOW-121-01-01

May 30, 2003

National Compact Stellarator Experiment (NCSX)

Vacuum Vessel Manufacturing Development and Prototype Fabrication

3.1.2 Subcontractor Recommendations
In Reference to Section 3.1.2 of NCSX-SOW-121-01-01

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1.0 ELECTRO-POLISHING OF VESSEL INTERIOR SURFACES

Section 3.2.1.2.1 of NCSX-CSPEC-121-02-00 requests electro-polish of all interior surfaces of the VVSA. Due to the size and complex shape of the system, electro-polishing will most likely have to take place on individual segments prior to welding them together to form the vessel shell. A significant amount of welding, machining and surface finishing will take place after that point, which will reduce the final effectiveness of the electro-polishing. Areas around each weld seam would not have as high a quality surface finish as the electro-polish will provide on the segment and port extension surfaces. As a result of these circumstances, Rohwedder has discussed the usefulness of this specification with Princeton Plasma Physics Lab (PPPL) in previous correspondence. It was stated that this was not a rigid requirement and was open for discussion, however, the conversation did re-emphasize the UHV base pressure (10^{-9} torr range) at which PPPL plans to operate the NCSX. The reduced surface area associated with the electro-polish will reduce pump-down times and pumping speed necessary to maintain base pressure.

Because of the UHV nature of the system, Rohwedder Inc does recommend that the interior surfaces of the VVSA be electro-polished even if the effectiveness is somewhat reduced due to the amount of area around weld seams that would not receive electro-polish. Rohwedder will include pricing of the VVSA with and without electro-polishing in the report *3.1.4 Budgetary Cost and Schedule Estimate for the VVSA* to allow PPPL to weigh the benefits vs. cost for this process step. Rohwedder will also investigate the feasibility of electro-polishing a full 120˚ vessel shell segment, reducing the area without electro-polish to the weld seams at the connection of the port extensions to the vessel shell, thereby increasing the effectiveness of the procedure.

2.0 SPACER MANUFACTURE APPROACH

An area of the manufacturing process of the VVSA that is not yet completely defined by the NCSX Statement of Work or Product Specification is the design and manufacturing of the section spacers. The variance that will occur between the computer models of the vessel surfaces and the actual end product, and even between the three fabricated segments dictates that even if the surfaces are within tolerance (+/- 0.188") and even with proper fit-up of the segment end flanges, a single segment designed prior to the completion of the vessel segment manufacturing will not suffice. The build-up of tolerances in the fabrication of the segments would undoubtedly prevent the bolt holes from aligning or the segments from sealing with the spacer surfaces. As explained in *3.1.1 Manufacturing Methods for the VVSA Section 3 Machining and Finishing,* the initial plan for manufacturing the segment spacers is to reverse engineer the final geometry of each spacer based on the variations in actual manufactured geometry of the VVSA segments to assure proper fit-up. First, the three VVSA sub-sections will be fixtured to match their final assembled positions relative to each other and using a CMM, several data points will be taken from the two respective section end flanges for each joint to indicate surface and hole locations. The inferred surfaces and hole locations will be used in the creation of computer models of the three custom segment spacers. The computer models of the spacers will then be imported into Pro/E Prismatic Milling Software (a CAM package) in order to set tooling paths, speeds and feeds, and finally to create machine code to control the CNC milling stations that will be used in final machining of the flanges and hangers. A CMM will be used for verification of part tolerances.

The fit-up and design of the segment spacers could be a difficult and critical process step in the manufacture of the VVSA that, at this point, is not addressed in the prototype segment. Therefore, Rohwedder/NVSI would like to propose including a segment spacer fabrication development program in parallel with the PVVS program. This would not involve an addition or modification to the proposed prototype segment, but a separate prototype of the segment joint area (end flanges and spacers), scaled down both in size and in geometric complexity. This would provide the opportunity to develop a solution, including testing the feasibility of the reverse engineering approach proposed by Rohwedder/NVSI. The geometry chosen for the prototype end flanges would be simplified in respect to the actual VVSA end flanges to reduce costs, yet would be complex enough to assure test results are applicable to the joint design of the VVSA. To represent the joint area of two VVSA segments, two prototype end flanges would be placed in fixtures designed to provide 6 DOF adjustments independently to each flange. Multiple test configurations of the relative positioning of the two end flanges could be created and the planned manufacturing approach tested for each. A verification of fit-up and compliance to dimensional tolerances set by PPPL for the prototype assembly would be performed. The prototype end flanges could also be designed to allow for pump-down and leak checking of the joint seals. Rohwedder/NVSI will create a budgetary estimate for this development effort.

3.0 REUSABLE DIE SETS

PPPL has expressed their desire for prototype segment (PVVS) forming dies that will be usable in the forming of the full vessel segments (VVSA) to reduce costs for the fabrication of the VVSA, if it is at all possible. Rohwedder/NVSI has looked into methods to partially reuse the prototype die sets on the full assemblies. Rohwedder/NVSI is not optimistic that a die could be created for the PVVS in which new "sections" can be added at a later date to create a die set that is usable on the larger sections of the VVSA. The die design and fabrication procedures described in *3.1.1 Manufacturing Methods for the VVSA Section 2 Forming Methods*, are based on the recommendations of forming houses and conform to standards in the forming industry, however, they are not conducive to simple modifications or additions that would allow the prototype dies to be used in forming the larger segments of the VVSA. With the present approach, the die ribs and enclosure are welded together, the spaces between ribs are partially filled with concrete and the scab plate is welded in place on the contact surface. These features would make additions difficult and some components like the prototype segment-sized scab plates would have to be scrapped and replaced completely. The reuse of only some components may still be a cost savings, however, it may be found that the design and labor costs that would go into salvaging prototype die components will exceed the material savings of component reuse. Rohwedder/NVSI is currently looking into alternate die designs that will allow for easier additions and modifications to make the prototype segment die sets more conducive to reuse on the VVSA, such as bolted assemblies that use removable cross bracing instead of concrete for reinforcement. It is not clear at this point if such designs are feasible either in functionality or cost-effectiveness. Rohwedder/NVSI will advise PPPL as soon as a more informed recommendation of die reuse feasibility can be made.

4.0 MACHINING AND WELD FIXTURES

Stainless steel "cage" type fixtures will be developed and designed to completely capture the VVSA sections after fabrication to allow accurate positioning of the vessel for aligning, welding and machining of the port extensions and when boring out each individual port diameter/shape in the VVSA sections after the ports are cut off. The cages will also be used to fixture the three VVSA sub-sections in their final assembled positions relative to each other for the reverse engineering and fabrication of the section spacers. Fixtures will be necessary in the alignment and re-weld of the port extensions at PPPL, and for cost-efficiency, it would be beneficial to use the Rohwedder/NVSI cage fixtures during this process. However, at the time of the re-weld procedure at PPPL the modular coil units and coil support structure will be in place, undoubtedly interfering with the support beams and vessel interface points of the weld fixtures. The coil units will also cover the reference points placed throughout the vessel shell that would be used in initial alignment of the fixtures and, later, the alignment of the ports themselves. Accommodations in the geometry of the modular coil units and coil support structure would be necessary for utilization of weld fixtures. The support beams of weld fixtures used in the port re-weld process will also have to be offset further from the vessel surface than would be standard, potentially increasing location errors. It may not be feasible to create cage fixtures that can be effectively used during the Rohwedder/NVSI fabrication of the VVSA and during the re-weld process at PPPL. Close cooperation between Rohwedder/NVSI and the PPPL design engineers responsible for integration on-site (and the required support equipment) will be necessary to assess the feasibility of designing cage fixtures with this dual functionality and to ensure access to the VVSA reference points critical for alignment of the port extensions during the re-weld process.

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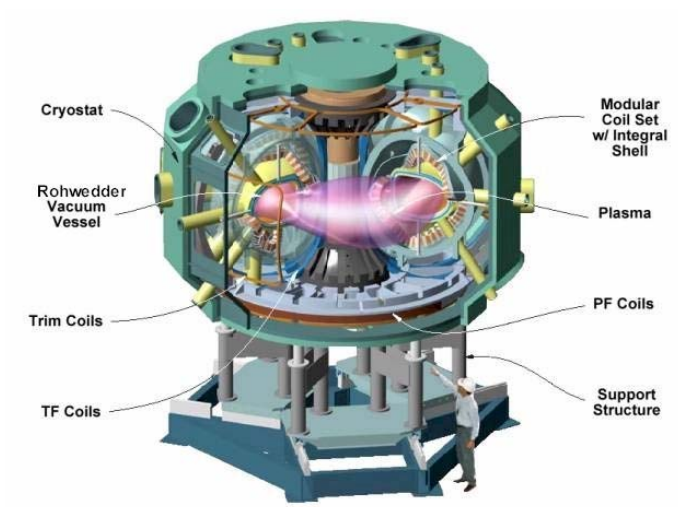

3.1.3 Preliminary MIT and QA Plans for the VVSA

In Reference to Section 3.1.3 of NCSX-SOW-121-01-01

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In Reference to Section 3.1.3 of NCSX-SOW-121-01-01

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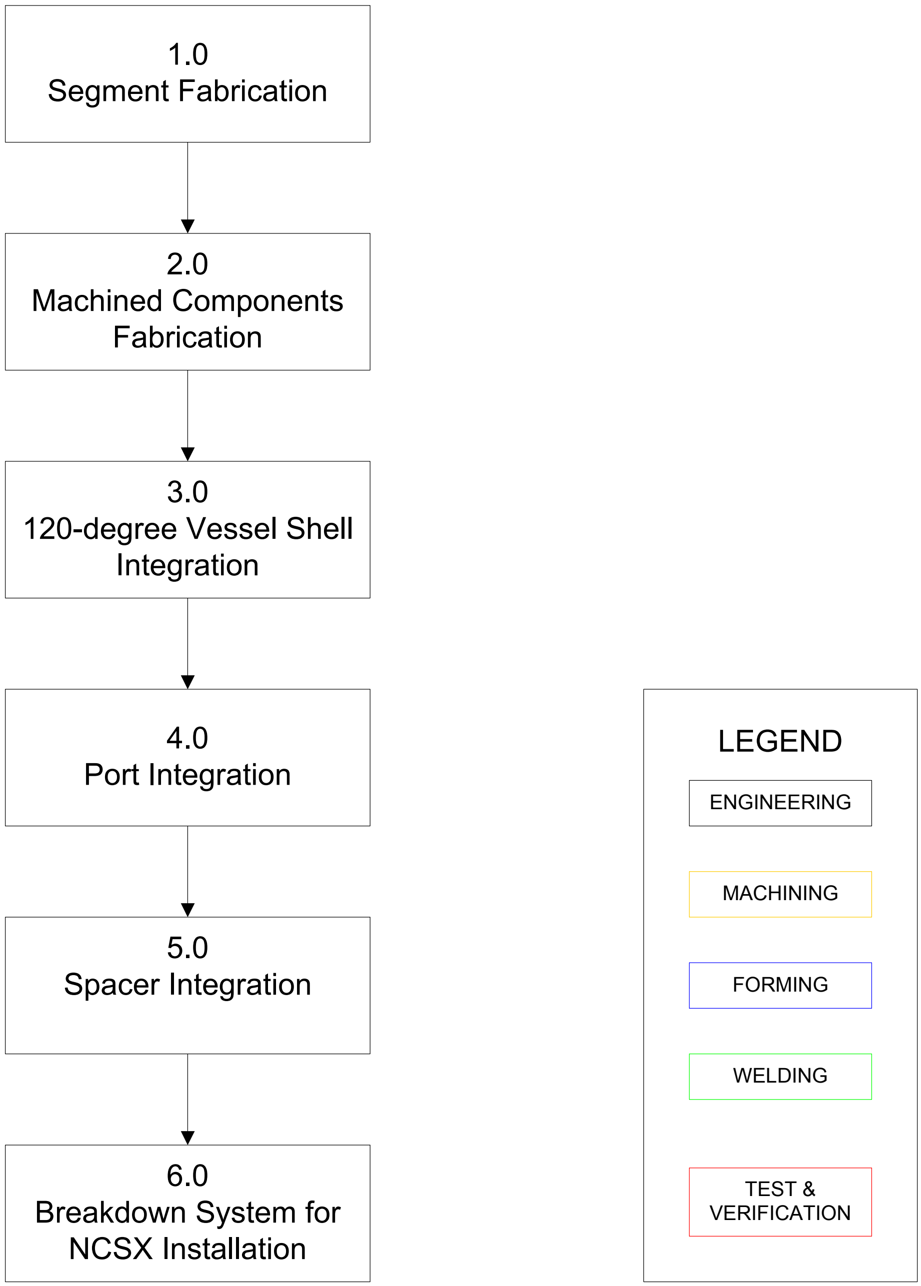
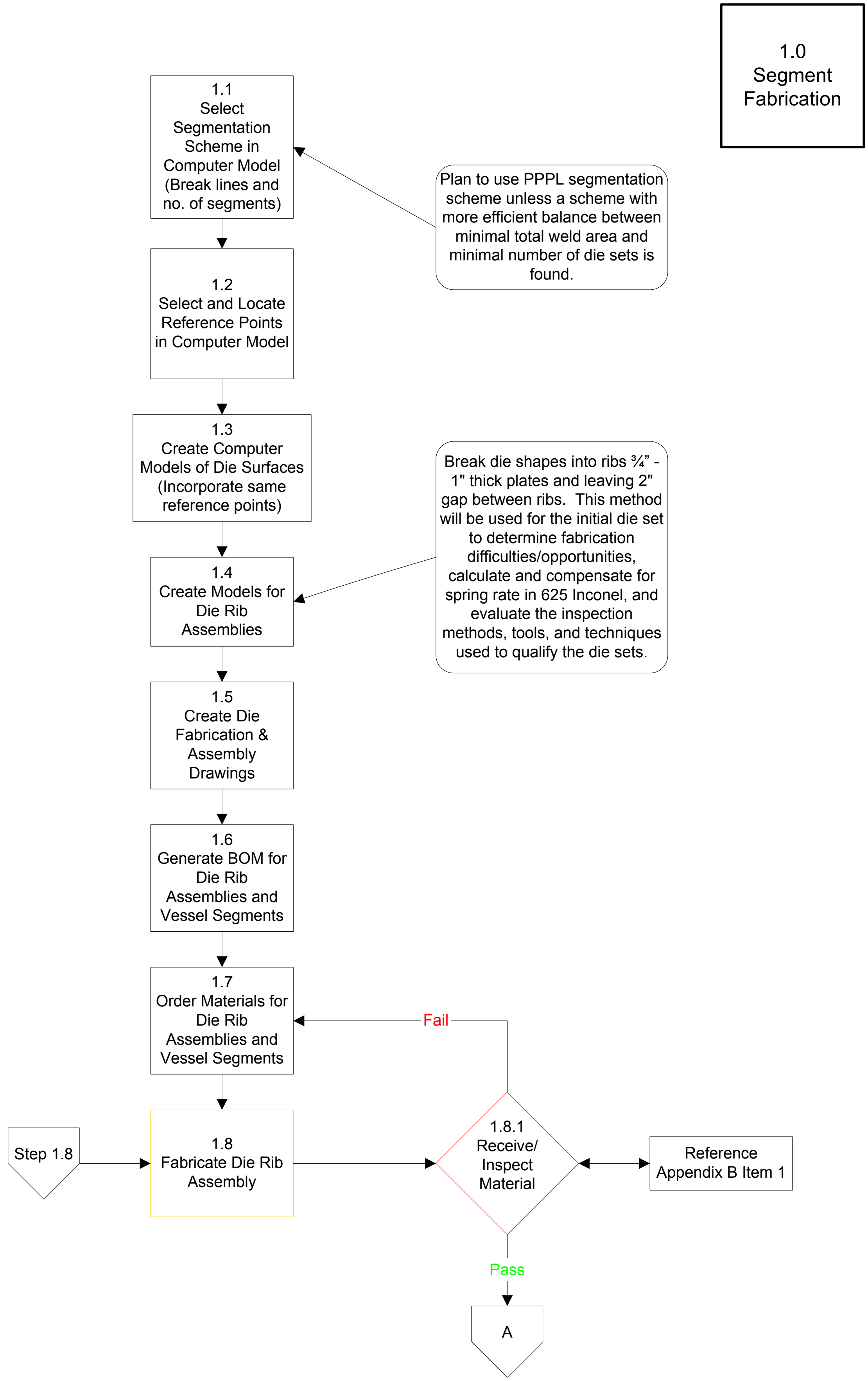
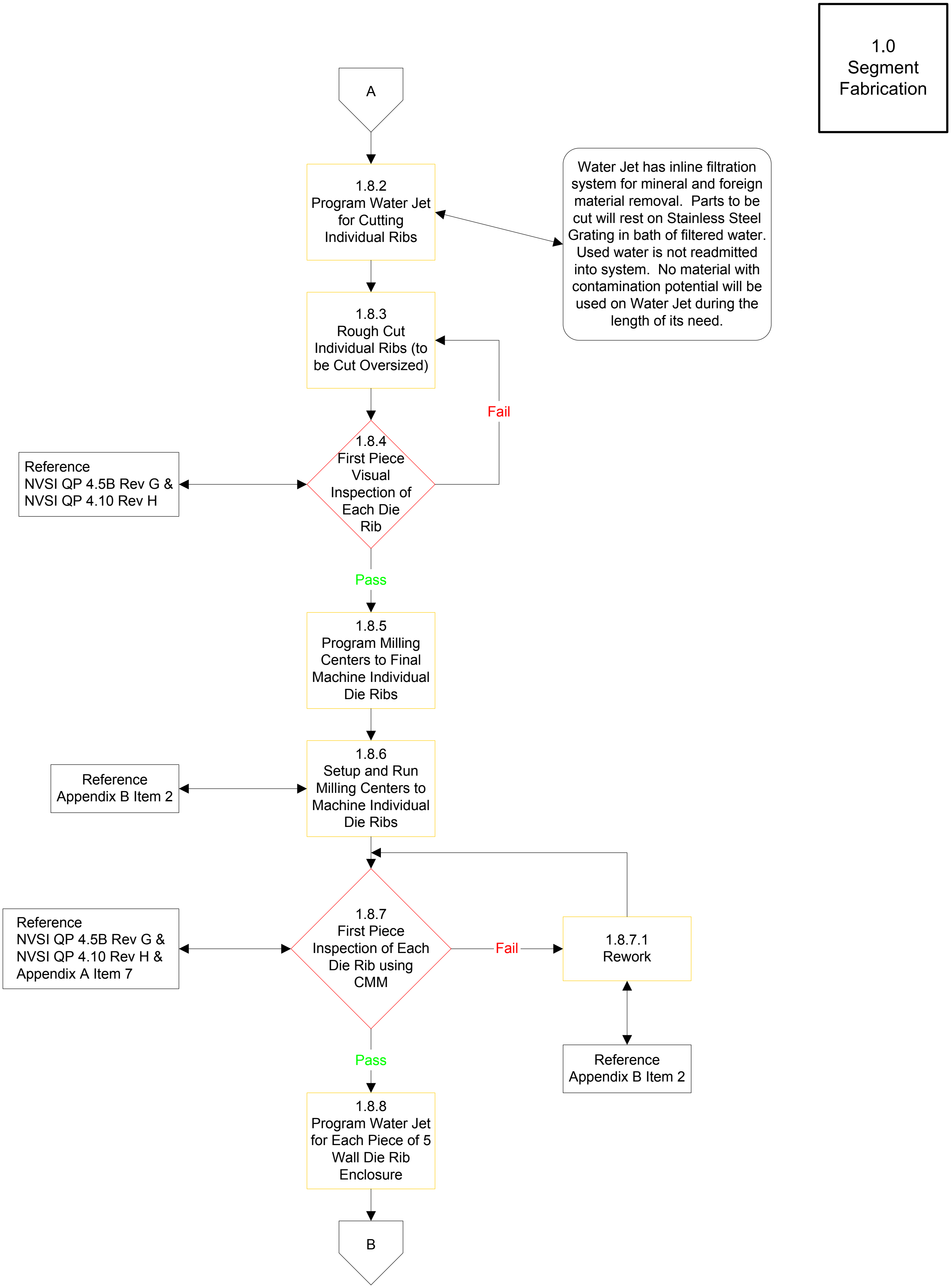
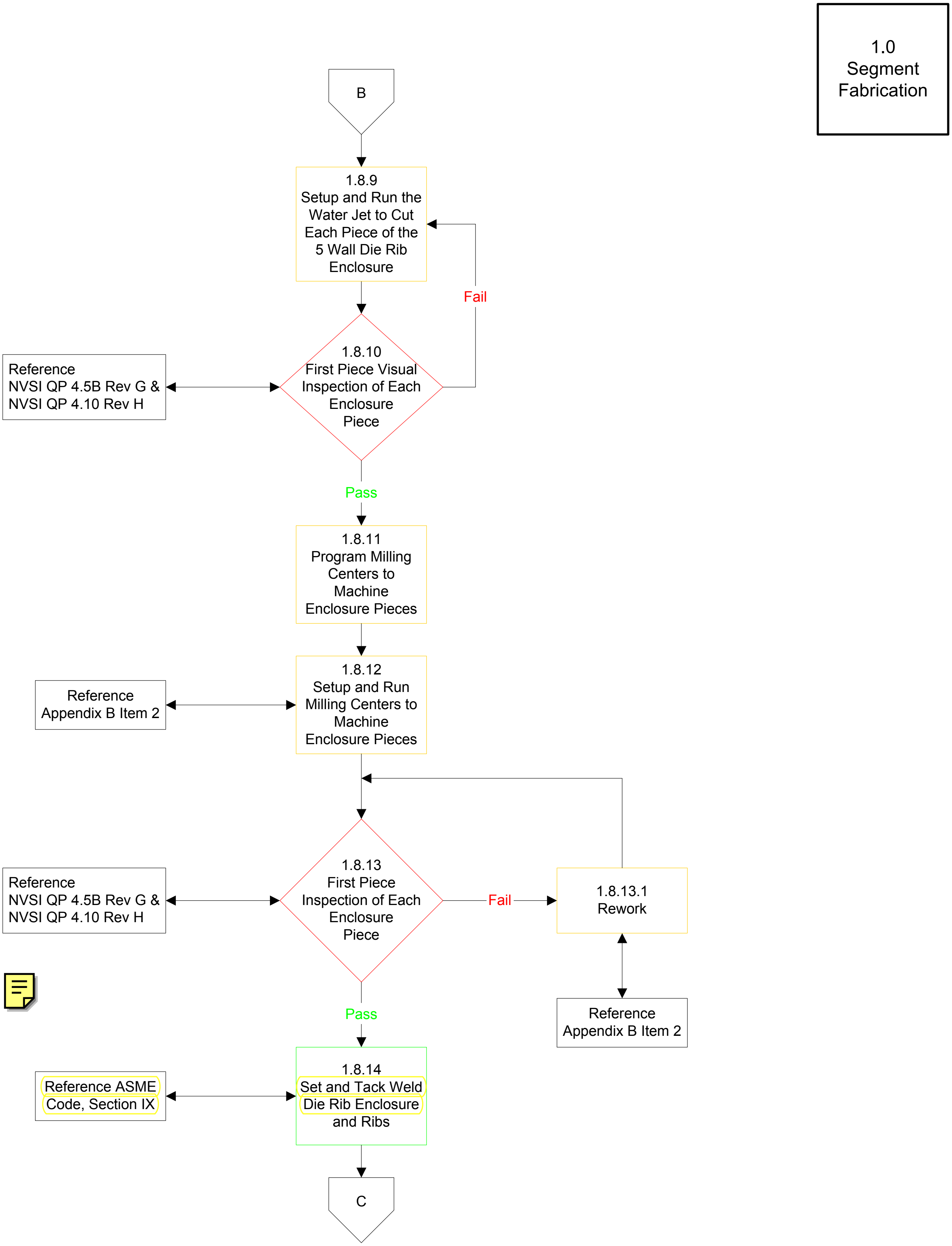
NuVacuum Systems

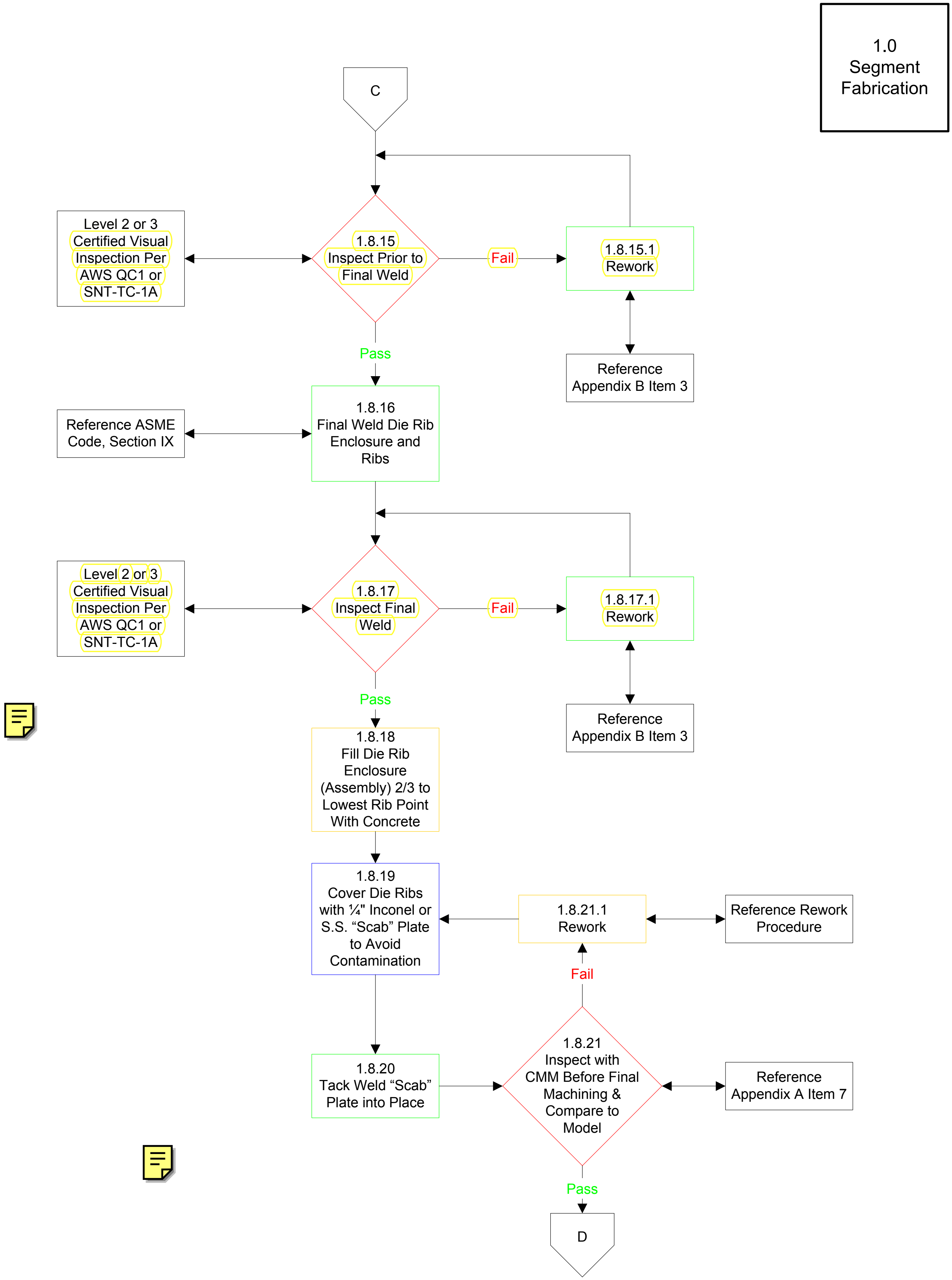
3.1.3 Preliminary MIT and QA Plans for the VVSA



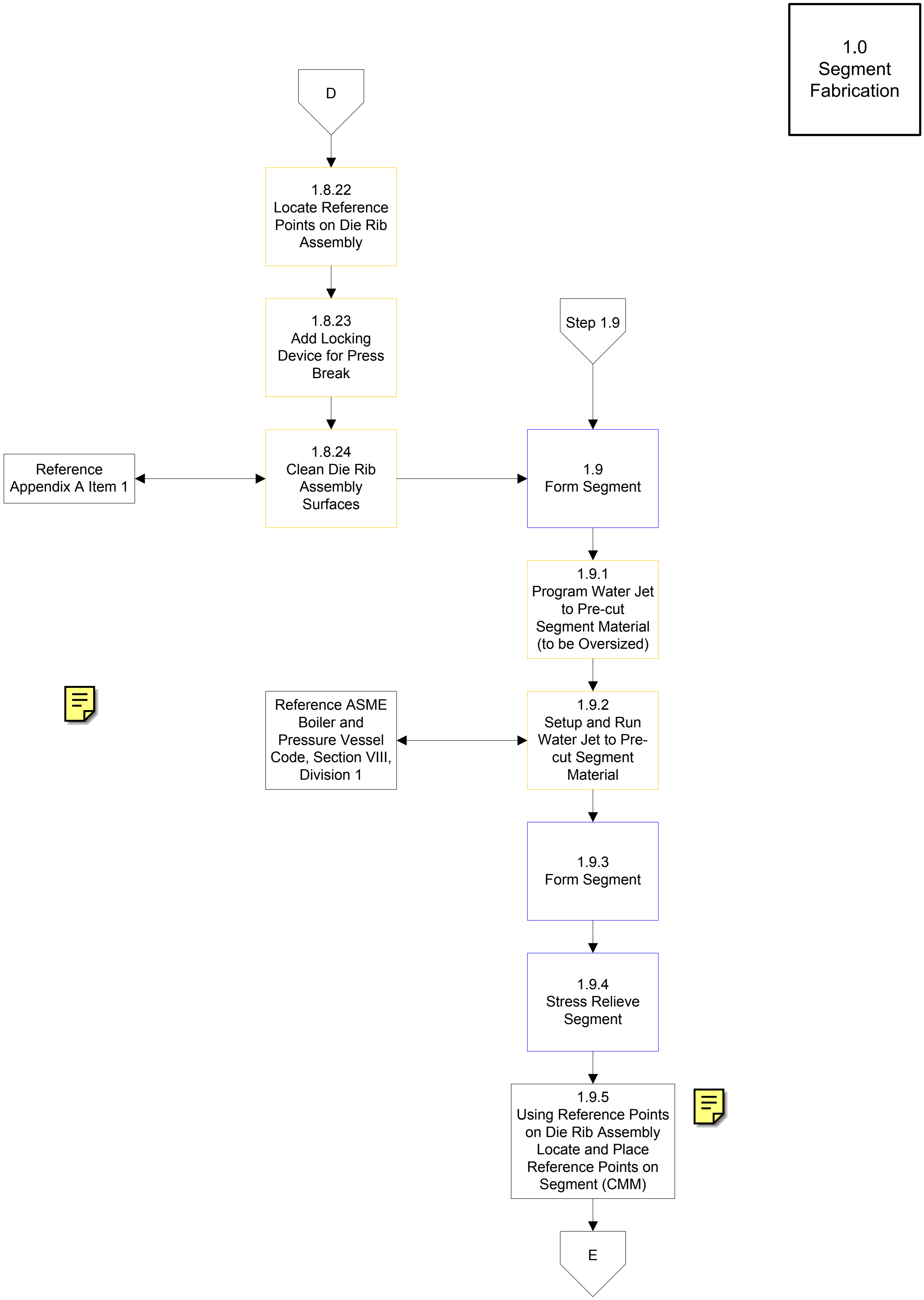

1.0
Segment
Fabrication
1.1
Select
Segmentation
Scheme in
Computer Model
(Break lines and
no. of segments)
Plan to use PPPL segmentation scheme unless a scheme with more efficient balance between minimal total weld area and minimal number of die sets is found.
1.2
Select and Locate
Reference Points
in Computer Model
1.3
Create Computer
Models of Die Surfaces
(Incorporate same
reference points)
Break die shapes into ribs ¾" - 1" thick plates and leaving 2" gap between ribs. This method will be used for the initial die set to determine fabrication difficulties/opportunities, calculate and compensate for spring rate in 625 Inconel, and evaluate the inspection methods, tools, and techniques used to qualify the die sets.
1.4
Create Models for
Die Rib
Assemblies
1.5
Create Die
Fabrication &
Assembly
Drawings
1.6
Generate BOM for
Die Rib
Assemblies and
Vessel Segments
1.7
Order Materials for
Die Rib
Assemblies and
Vessel Segments
Fail
Step 1.8
1.8
Fabricate Die Rib
Assembly
1.8.1
Receive/
Inspect
Material
Reference
Appendix B Item 1
Pass
A

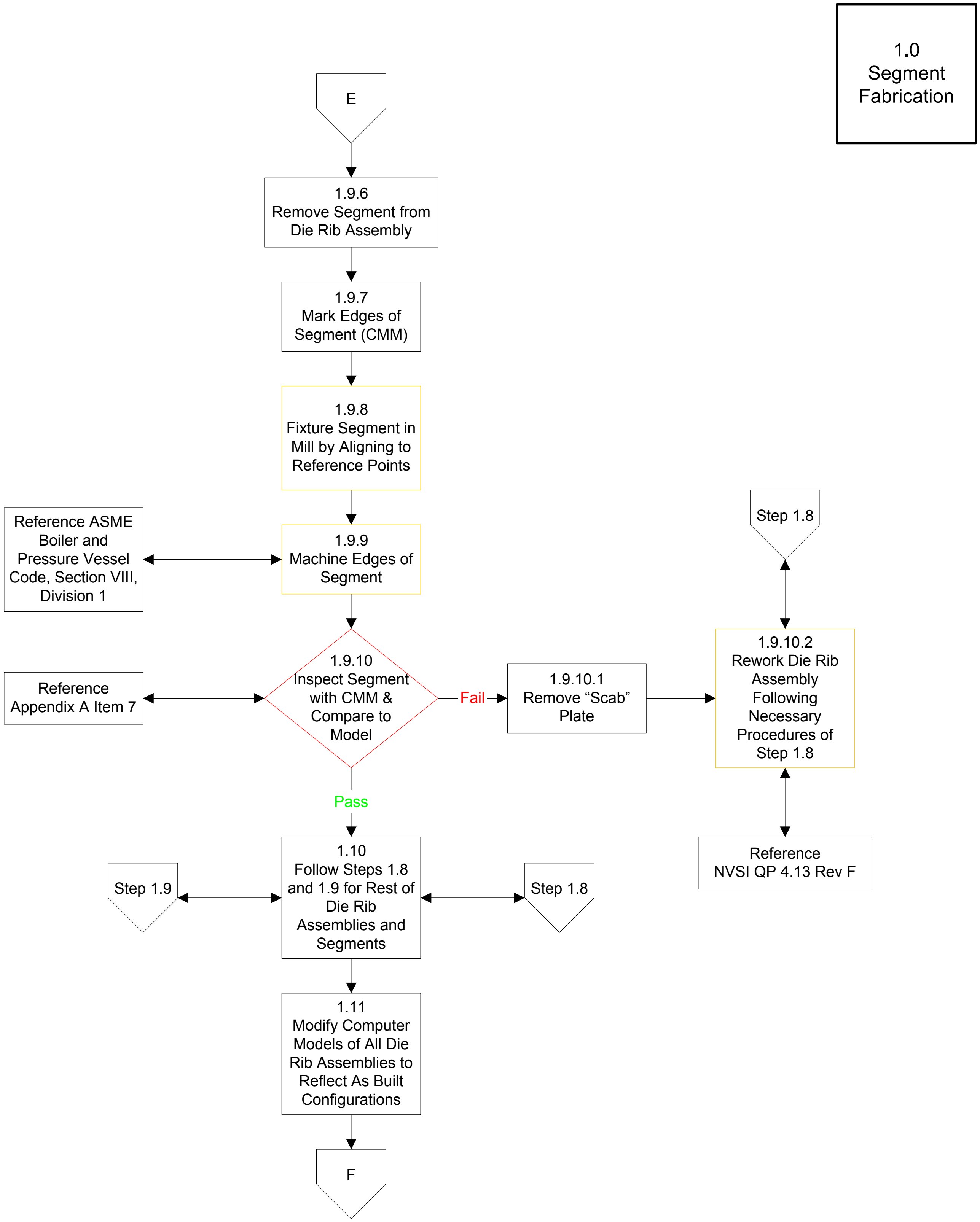

1.0 Segment Fabrication
A
1.8.2 Program Water Jet for Cutting Individual Ribs
Water Jet has inline filtration system for mineral and foreign material removal. Parts to be cut will rest on Stainless Steel Grating in bath of filtered water. Used water is not readmitted into system. No material with contamination potential will be used on Water Jet during the length of its need.
1.8.3 Rough Cut Individual Ribs (to be Cut Oversized)
Fail
Reference NVSI QP 4.5B Rev G & NVSI QP 4.10 Rev H
1.8.4 First Piece Visual Inspection of Each Die Rib
Pass
1.8.5 Program Milling Centers to Final Machine Individual Die Ribs
Reference Appendix B Item 2
1.8.6 Setup and Run Milling Centers to Machine Individual Die Ribs
Reference NVSI QP 4.5B Rev G & NVSI QP 4.10 Rev H & Appendix A Item 7
1.8.7 First Piece Inspection of Each Die Rib using CMM
Fail
1.8.7.1 Rework
Reference Appendix B Item 2
Pass
1.8.8 Program Water Jet for Each Piece of 5 Wall Die Rib Enclosure
B

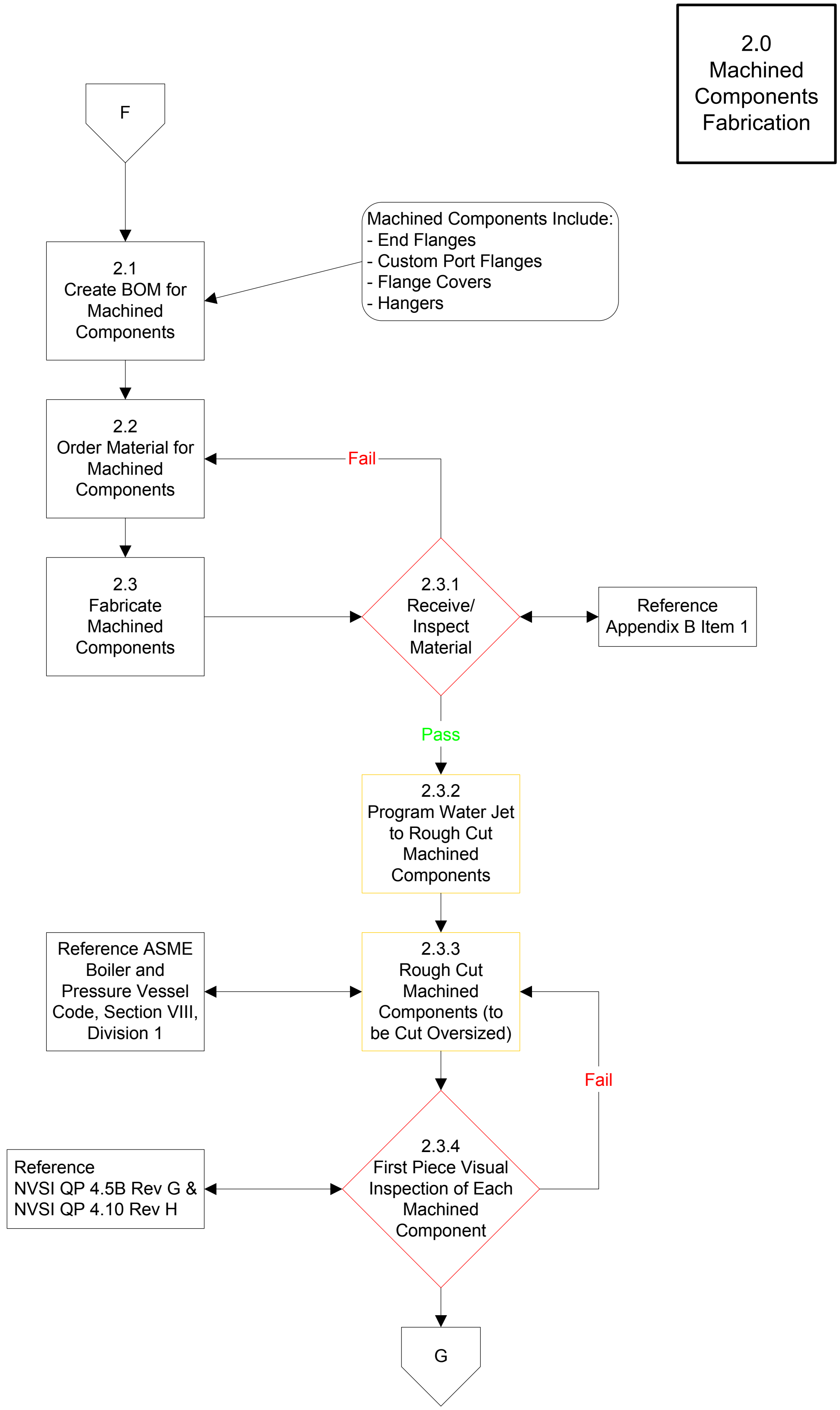

1.0
Segment
Fabrication
B
1.8.9
Setup and Run the Water Jet to Cut Each Piece of the 5 Wall Die Rib Enclosure
Fail
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H
1.8.10
First Piece Visual Inspection of Each Enclosure Piece
Pass
1.8.11
Program Milling Centers to Machine Enclosure Pieces
Reference
Appendix B Item 2
1.8.12
Setup and Run Milling Centers to Machine Enclosure Pieces
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H
1.8.13
First Piece Inspection of Each Enclosure Piece
Fail
1.8.13.1
Rework
Pass
Reference
Appendix B Item 2
Reference ASME Code, Section IX
1.8.14
Set and Tack Weld Die Rib Enclosure and Ribs
C

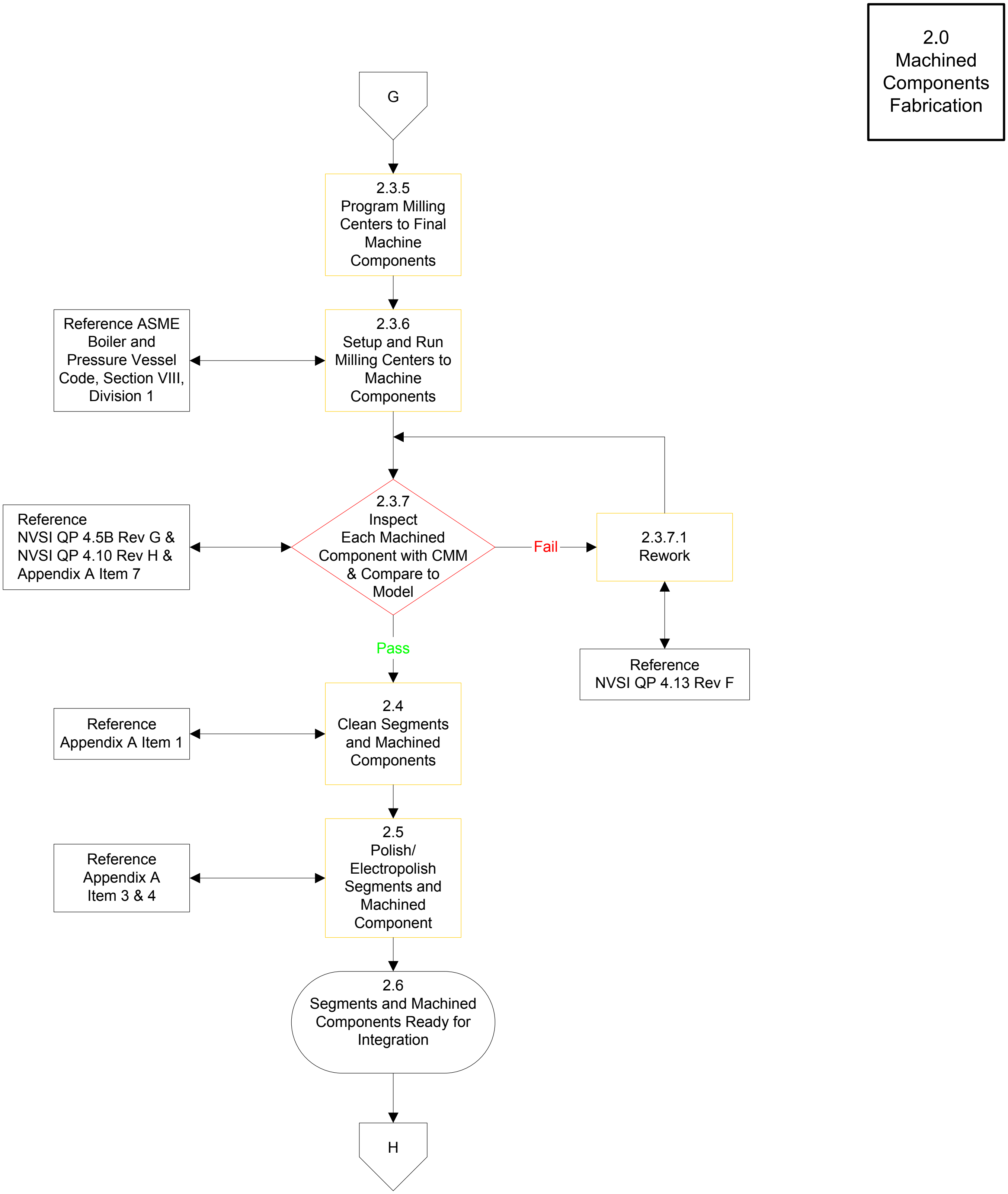

1.0
Segment
Fabrication
C
1.8.15
Inspect Prior to
Final Weld
Level 2 or 3
Certified Visual
Inspection Per
AWS QC1 or
SNT-TC-1A
Fail
1.8.15.1
Rework
Reference
Appendix B Item 3
Pass
1.8.16
Final Weld Die Rib
Enclosure and
Ribs
Reference ASME
Code, Section IX
1.8.17
Inspect Final
Weld
Level 2 or 3
Certified Visual
Inspection Per
AWS QC1 or
SNT-TC-1A
Fail
1.8.17.1
Rework
Reference
Appendix B Item 3
Pass
1.8.18
Fill Die Rib
Enclosure
(Assembly) 2/3 to
Lowest Rib Point
With Concrete
1.8.19
Cover Die Ribs
with ¼" Inconel or
S.S. "Scab" Plate
to Avoid
Contamination
1.8.21.1
Rework
Reference Rework
Procedure
Fail
1.8.20
Tack Weld "Scab"
Plate into Place
1.8.21
Inspect with
CMM Before Final
Machining &
Compare to
Model
Reference
Appendix A Item 7
Pass
D

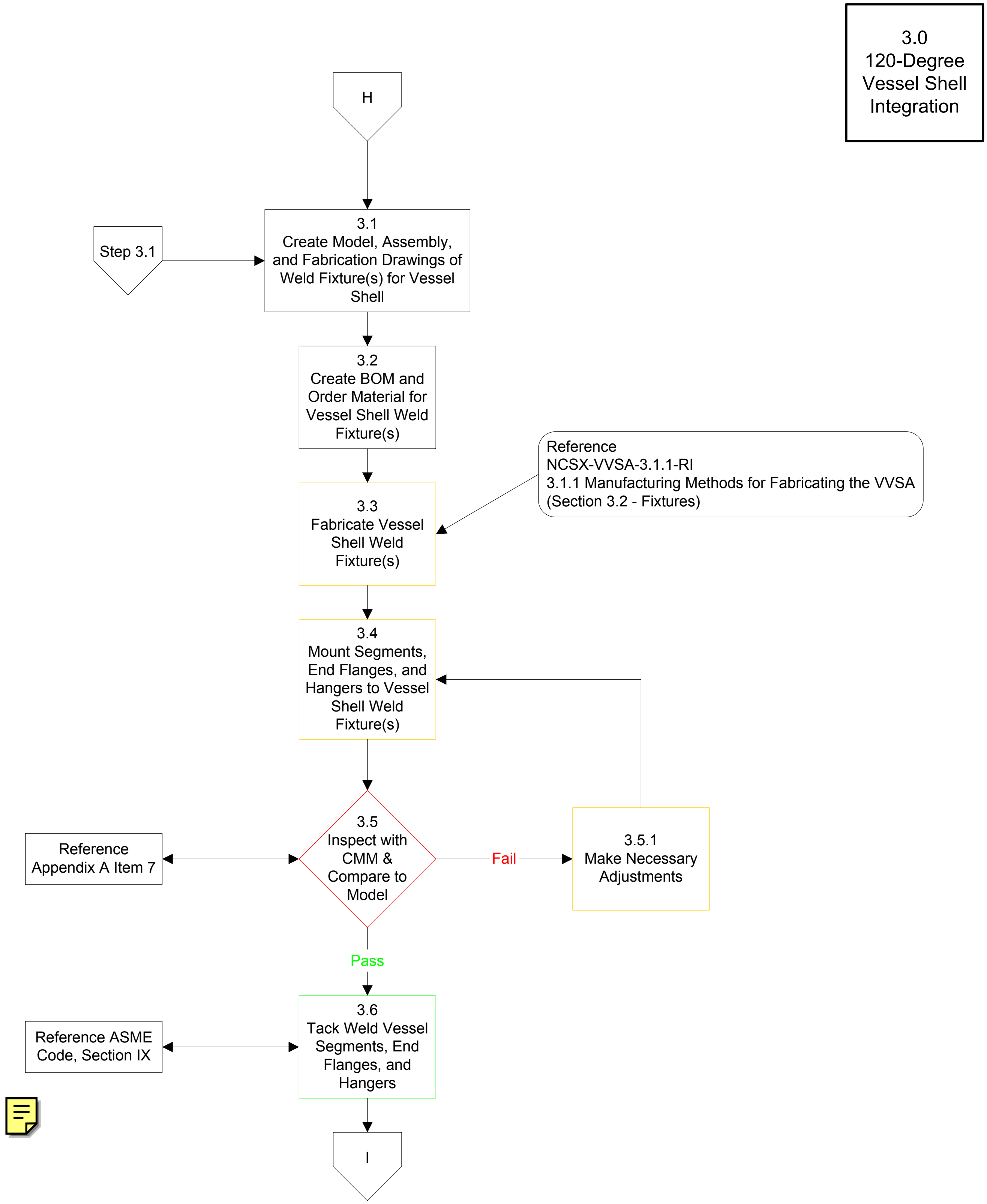
NUVAC INPUT


1.0
Segment
Fabrication
D
1.8.22
Locate Reference Points on Die Rib Assembly
1.8.23
Add Locking Device for Press Break
Step 1.9
Reference Appendix A Item 1
1.8.24
Clean Die Rib Assembly Surfaces
1.9
Form Segment
1.9.1
Program Water Jet to Pre-cut Segment Material (to be Oversized)
Reference ASME Boiler and Pressure Vessel Code, Section VIII, Division 1
1.9.2
Setup and Run Water Jet to Pre-cut Segment Material
1.9.3
Form Segment
1.9.4
Stress Relieve Segment
1.9.5
Using Reference Points on Die Rib Assembly Locate and Place Reference Points on Segment (CMM)
E

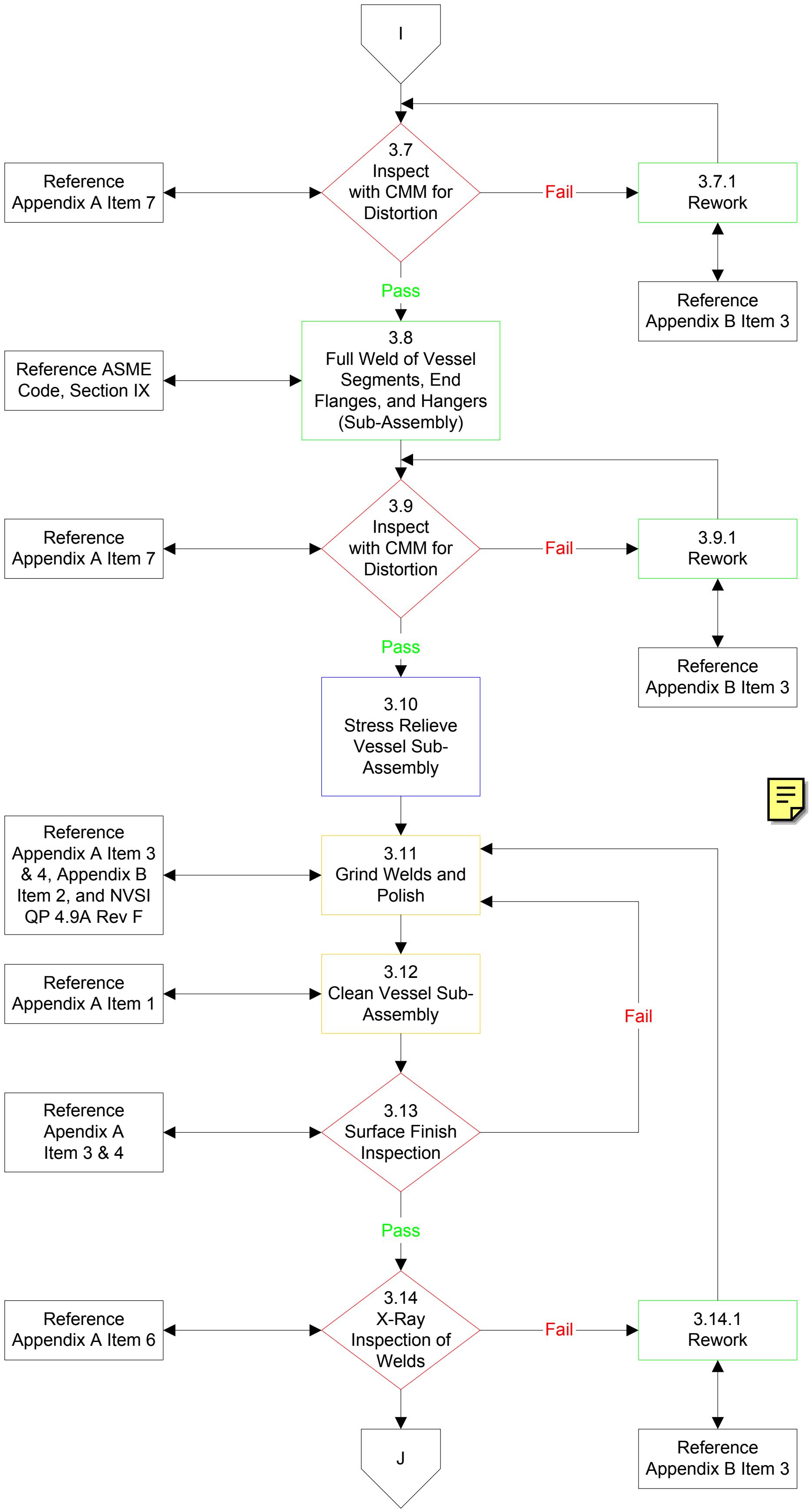

1.0
Segment
Fabrication
E
1.9.6
Remove Segment from
Die Rib Assembly
1.9.7
Mark Edges of
Segment (CMM)
1.9.8
Fixture Segment in
Mill by Aligning to
Reference Points
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
1.9.9
Machine Edges of
Segment
Step 1.8
Reference
Appendix A Item 7
1.9.10
Inspect Segment
with CMM &
Compare to
Model
Fail
1.9.10.1
Remove "Scab"
Plate
1.9.10.2
Rework Die Rib
Assembly
Following
Necessary
Procedures of
Step 1.8
Pass
Reference
NVSI QP 4.13 Rev F
Step 1.9
1.10
Follow Steps 1.8
and 1.9 for Rest of
Die Rib
Assemblies and
Segments
Step 1.8
1.11
Modify Computer
Models of All Die
Rib Assemblies to
Reflect As Built
Configurations
F


2.0 Machined Components Fabrication
F
2.1 Create BOM for Machined Components
Machined Components Include:
- End Flanges
- Custom Port Flanges
- Flange Covers
- Hangers
2.2 Order Material for Machined Components
Fail
2.3 Fabricate Machined Components
2.3.1 Receive/ Inspect Material
Reference Appendix B Item 1
Pass
2.3.2 Program Water Jet to Rough Cut Machined Components
Reference ASME Boiler and Pressure Vessel Code, Section VIII, Division 1
2.3.3 Rough Cut Machined Components (to be Cut Oversized)
Fail
Reference NVSI QP 4.5B Rev G & NVSI QP 4.10 Rev H
2.3.4 First Piece Visual Inspection of Each Machined Component
G

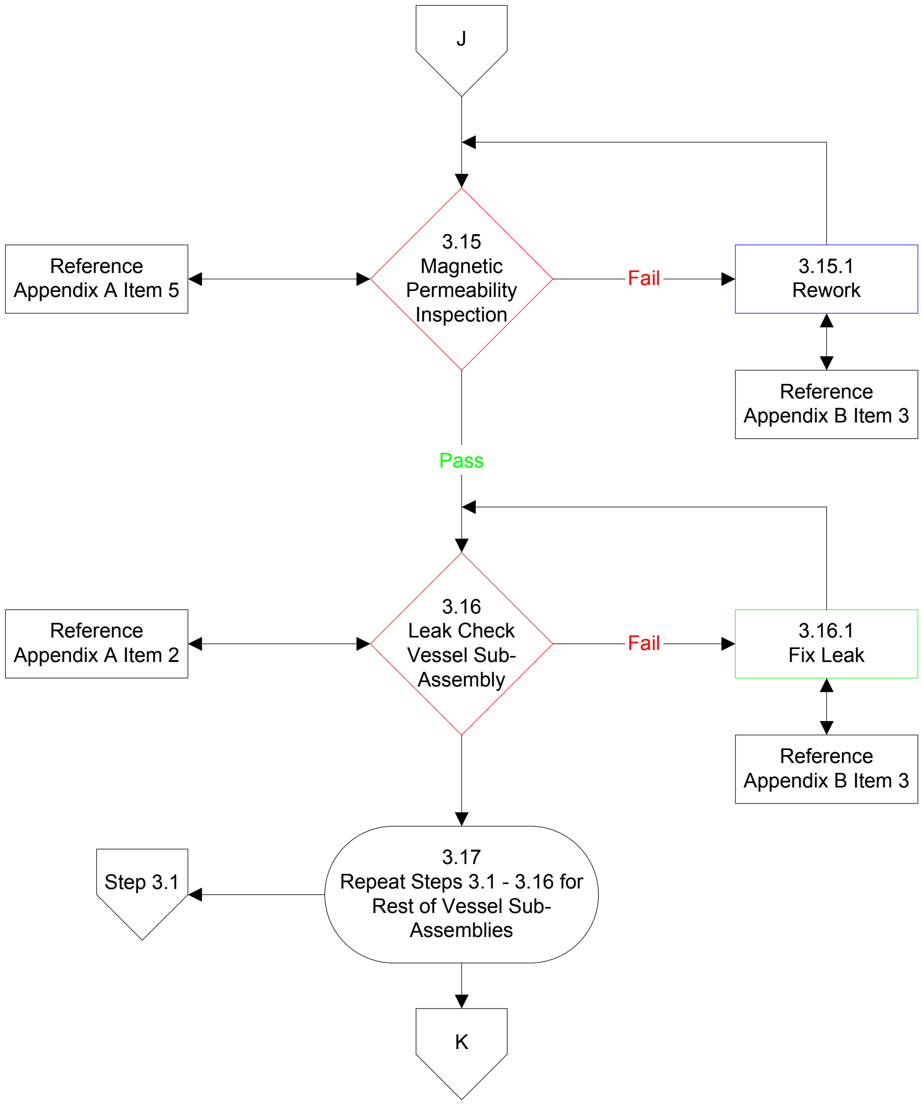

2.0
Machined
Components
Fabrication
G
2.3.5
Program Milling
Centers to Final
Machine
Components
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
2.3.6
Setup and Run
Milling Centers to
Machine
Components
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H &
Appendix A Item 7
2.3.7
Inspect
Each Machined
Component with CMM
& Compare to
Model
Fail
2.3.7.1
Rework
Pass
Reference
NVSI QP 4.13 Rev F
Reference
Appendix A Item 1
2.4
Clean Segments
and Machined
Components
Reference
Appendix A
Item 3 & 4
2.5
Polish/
Electropolish
Segments and
Machined
Component
2.6
Segments and Machined
Components Ready for
Integration
H

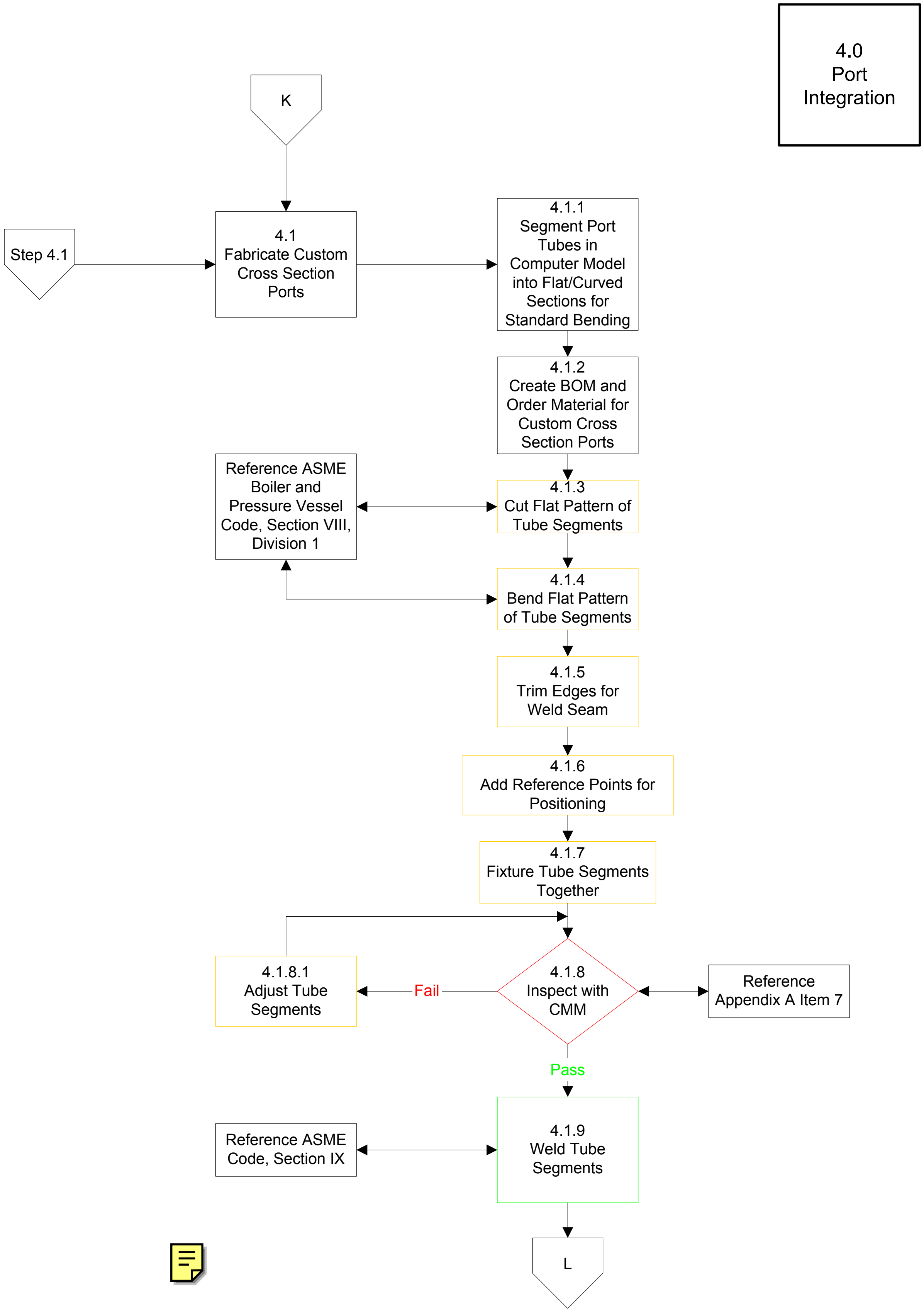

3.0
120-Degree
Vessel Shell
Integration
H
Step 3.1
3.1
Create Model, Assembly, and Fabrication Drawings of Weld Fixture(s) for Vessel Shell
3.2
Create BOM and Order Material for Vessel Shell Weld Fixture(s)
Reference
NCSX-VVSA-3.1.1-RI
3.1.1 Manufacturing Methods for Fabricating the VVSA
(Section 3.2 - Fixtures)
3.3
Fabricate Vessel Shell Weld Fixture(s)
3.4
Mount Segments, End Flanges, and Hangers to Vessel Shell Weld Fixture(s)
Reference
Appendix A Item 7
3.5
Inspect with CMM & Compare to Model
Fail
3.5.1
Make Necessary Adjustments
Pass
Reference ASME Code, Section IX
3.6
Tack Weld Vessel Segments, End Flanges, and Hangers
I

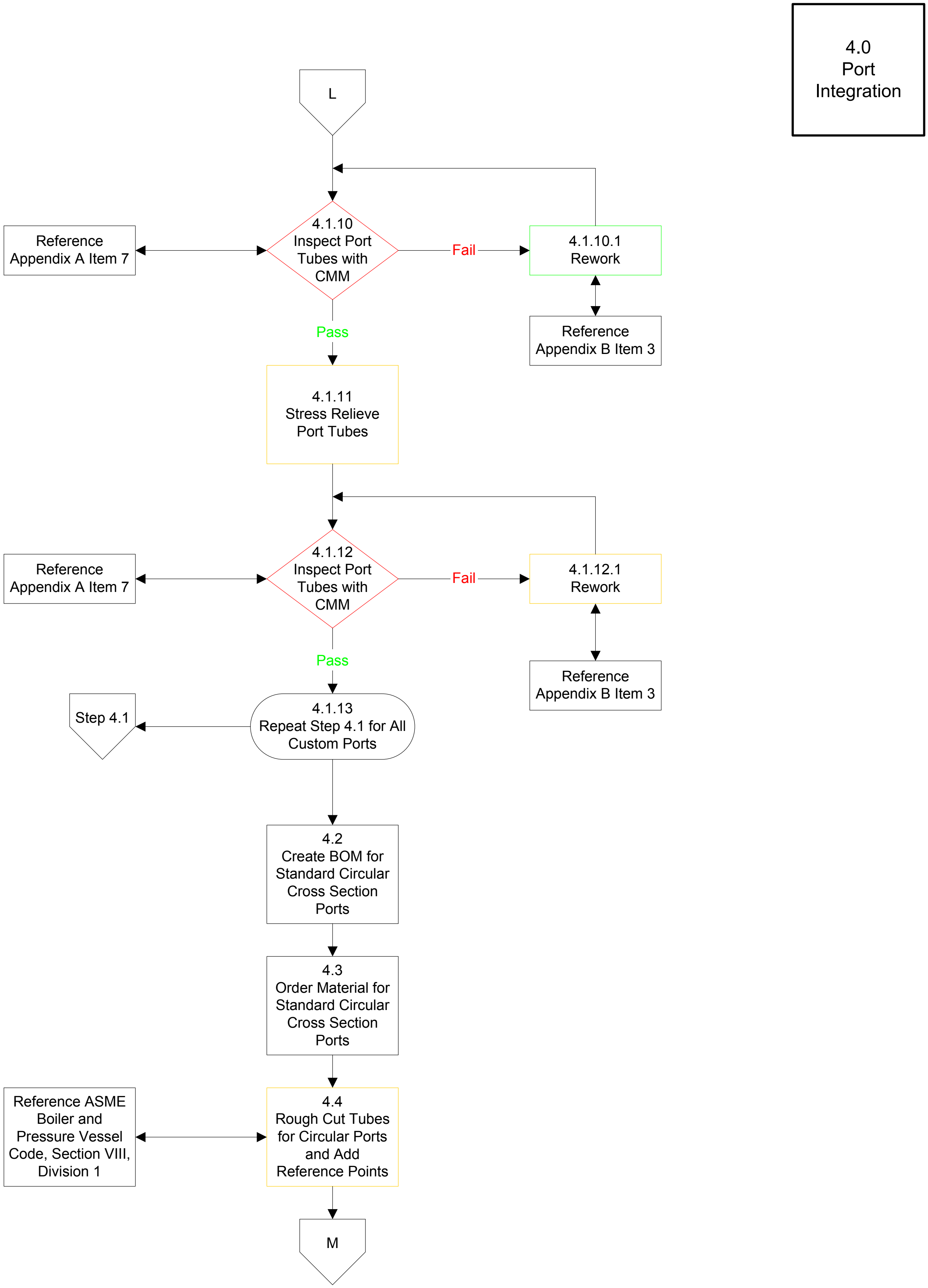
3.0
120-Degree
Vessel Shell
Integration

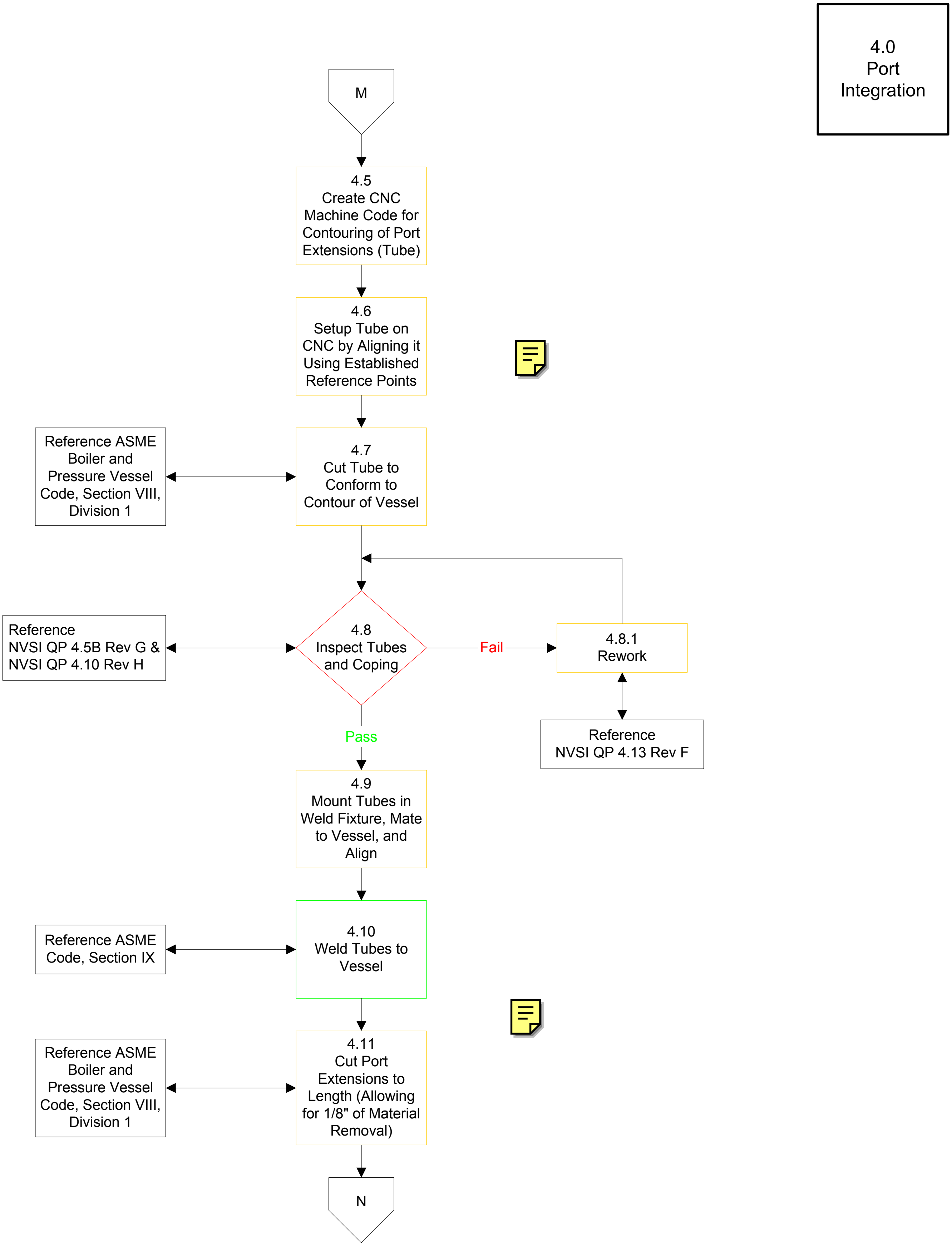


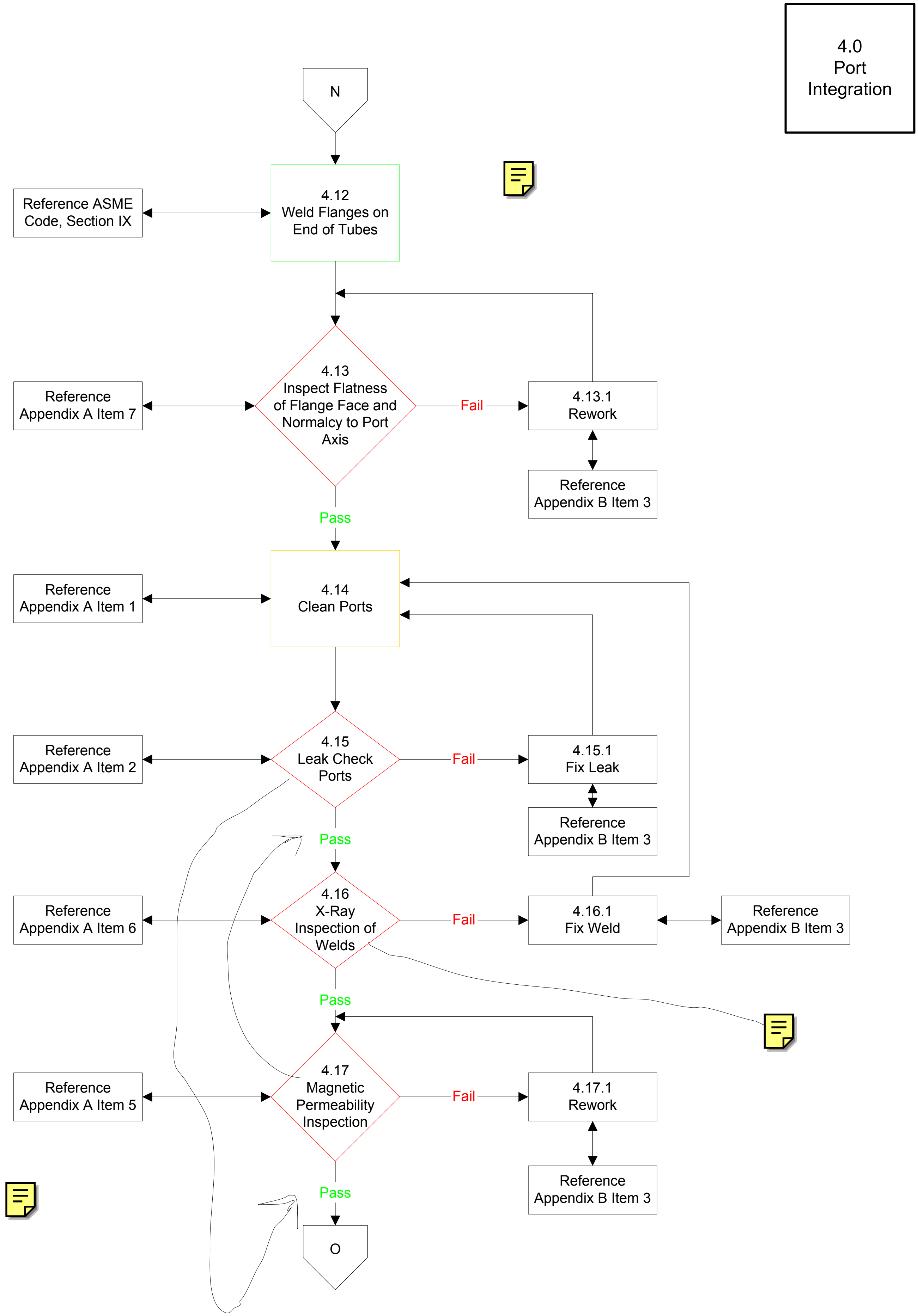
3.0
120-Degree
Vessel Shell
Integration

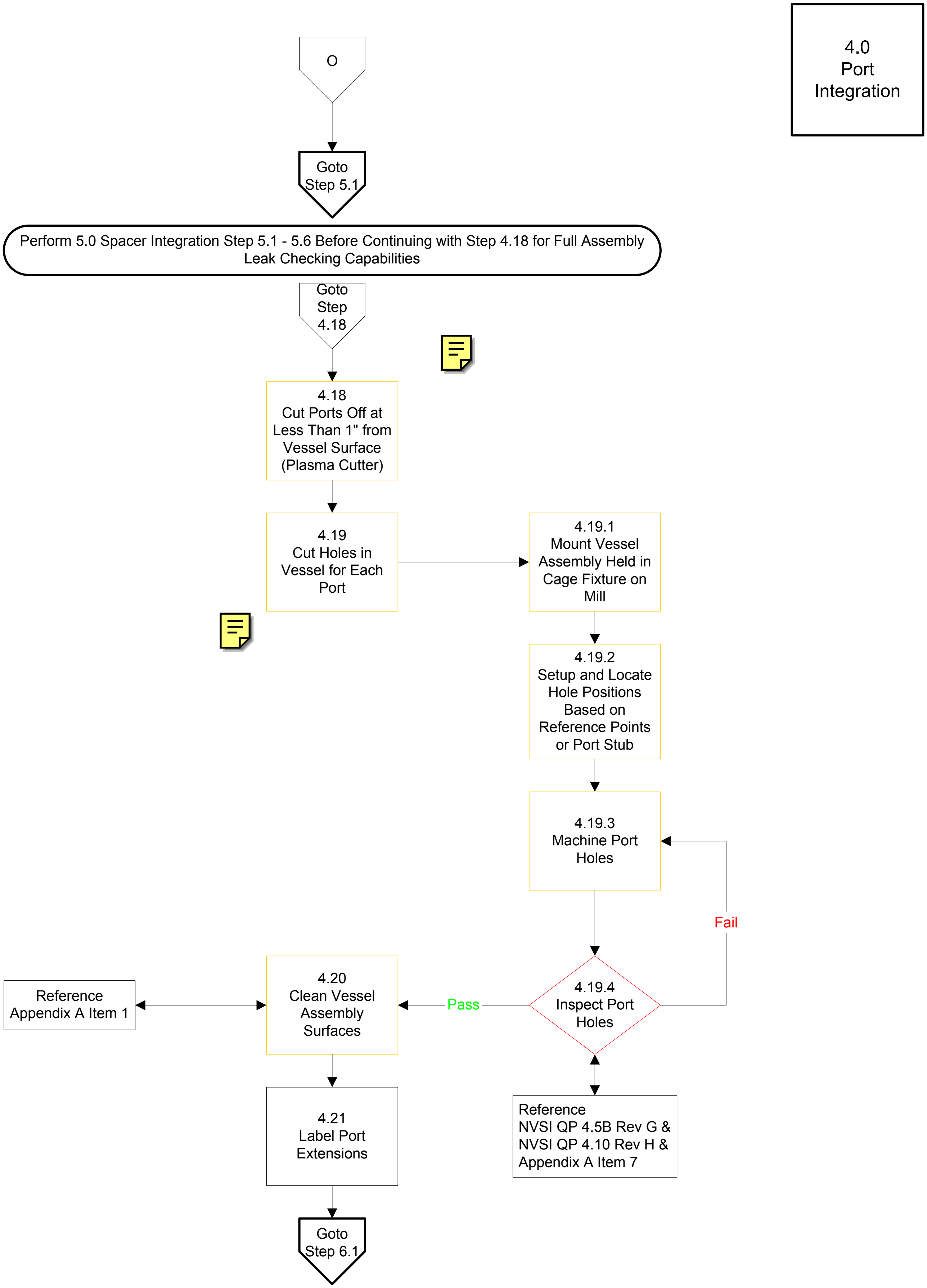


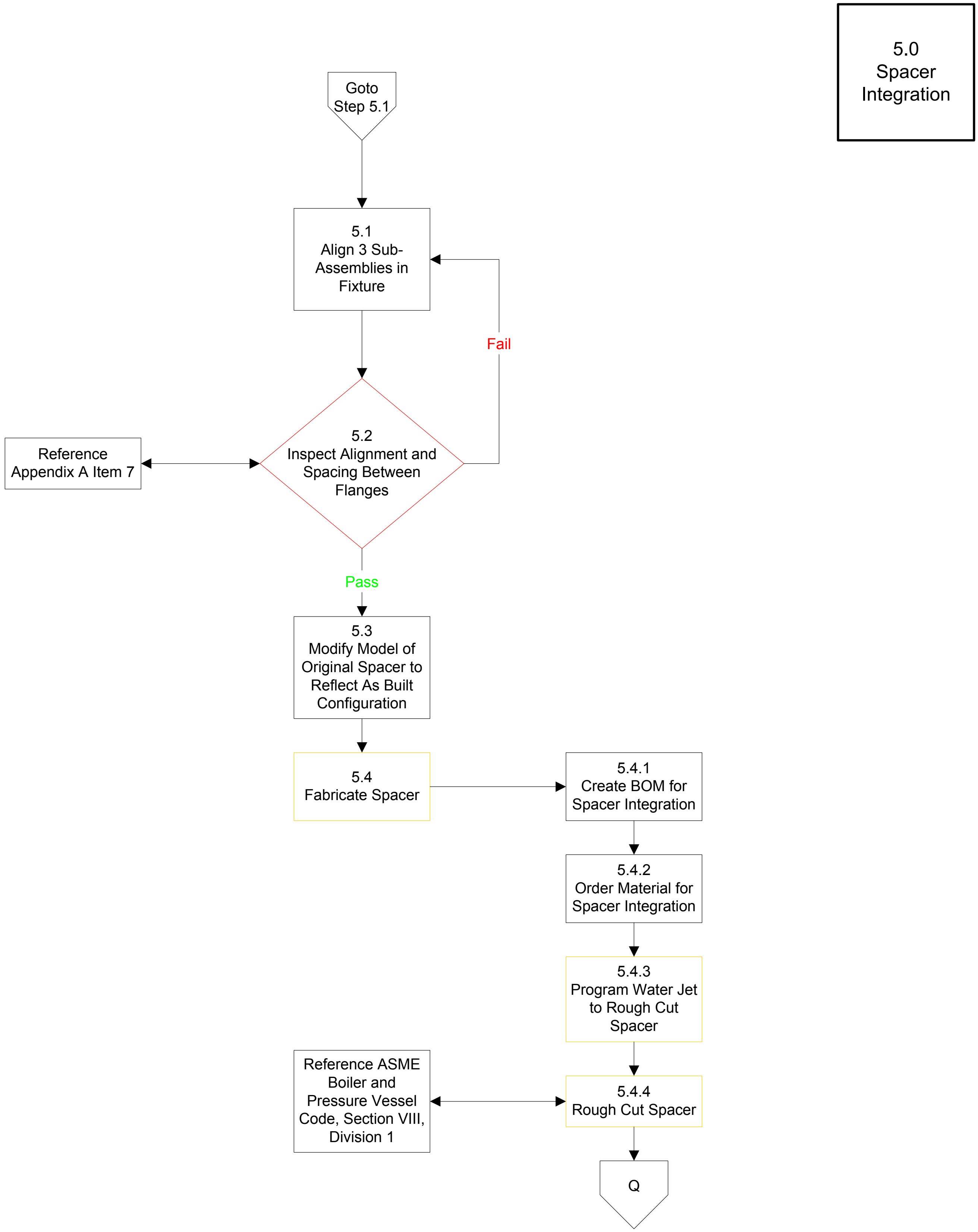

4.0
Port
Integration
K
Step 4.1
4.1
Fabricate Custom
Cross Section
Ports
4.1.1
Segment Port
Tubes in
Computer Model
into Flat/Curved
Sections for
Standard Bending
4.1.2
Create BOM and
Order Material for
Custom Cross
Section Ports
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
4.1.3
Cut Flat Pattern of
Tube Segments
4.1.4
Bend Flat Pattern
of Tube Segments
4.1.5
Trim Edges for
Weld Seam
4.1.6
Add Reference Points for
Positioning
4.1.7
Fixture Tube Segments
Together
4.1.8.1
Adjust Tube
Segments
Fail
4.1.8
Inspect with
CMM
Reference
Appendix A Item 7
Pass
Reference ASME
Code, Section IX
4.1.9
Weld Tube
Segments
L

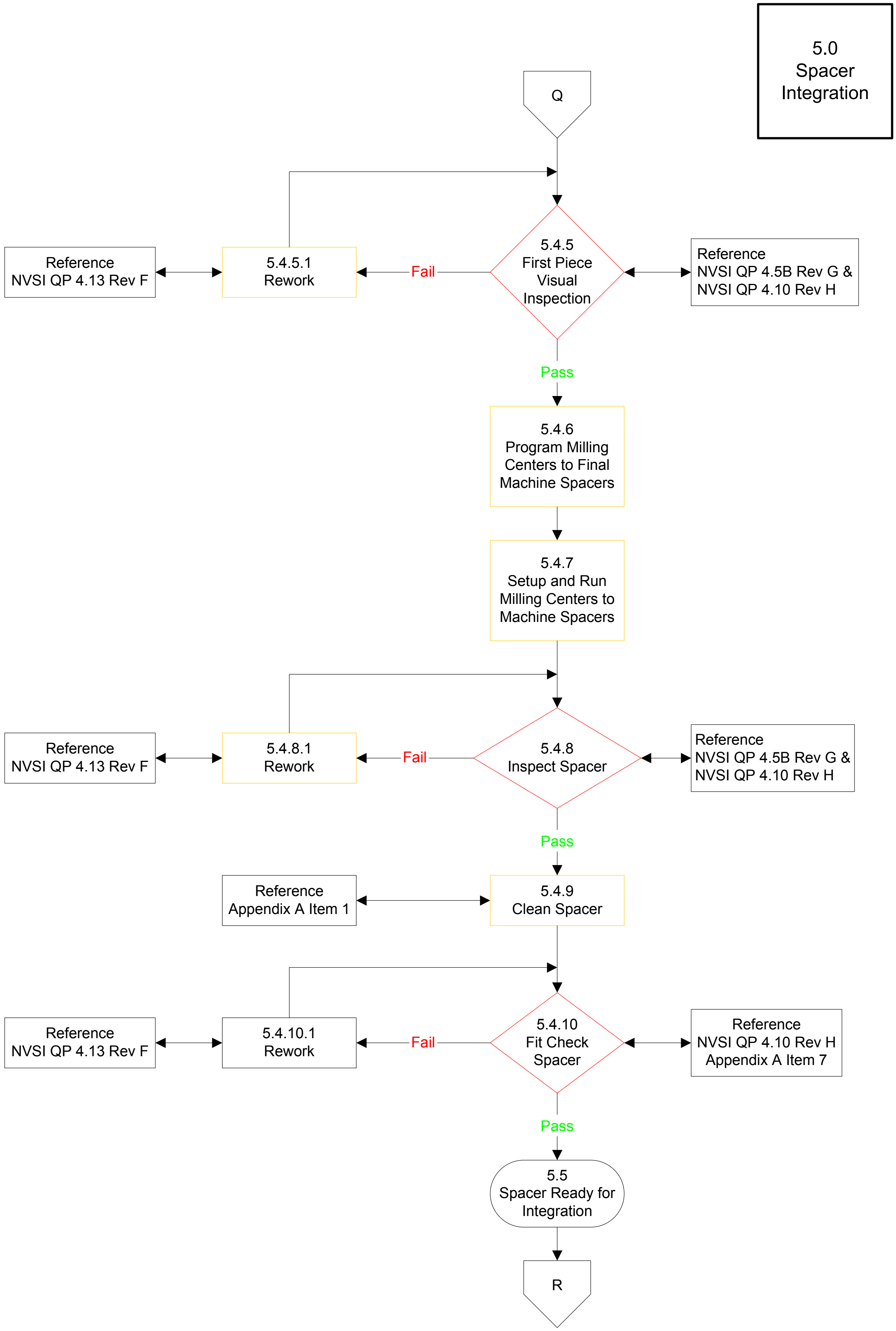

4.0
Port
Integration
L
4.1.10
Inspect Port
Tubes with
CMM
Reference
Appendix A Item 7
Fail
4.1.10.1
Rework
Reference
Appendix B Item 3
Pass
4.1.11
Stress Relieve
Port Tubes
4.1.12
Inspect Port
Tubes with
CMM
Reference
Appendix A Item 7
Fail
4.1.12.1
Rework
Reference
Appendix B Item 3
Pass
4.1.13
Repeat Step 4.1 for All
Custom Ports
Step 4.1
4.2
Create BOM for
Standard Circular
Cross Section
Ports
4.3
Order Material for
Standard Circular
Cross Section
Ports
4.4
Rough Cut Tubes
for Circular Ports
and Add
Reference Points
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
M

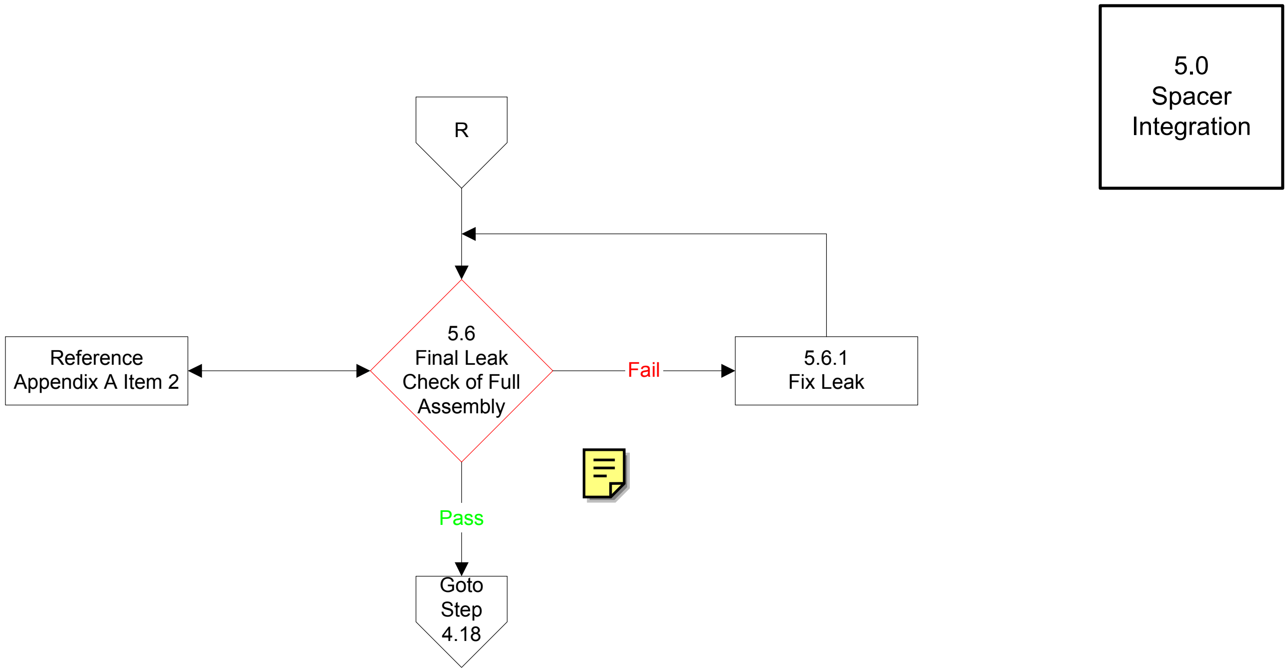

4.0
Port
Integration
M
4.5
Create CNC
Machine Code for
Contouring of Port
Extensions (Tube)
4.6
Setup Tube on
CNC by Aligning it
Using Established
Reference Points
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
4.7
Cut Tube to
Conform to
Contour of Vessel
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H
4.8
Inspect Tubes
and Coping
Fail
4.8.1
Rework
Reference
NVSI QP 4.13 Rev F
Pass
4.9
Mount Tubes in
Weld Fixture, Mate
to Vessel, and
Align
Reference ASME
Code, Section IX
4.10
Weld Tubes to
Vessel
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
4.11
Cut Port
Extensions to
Length (Allowing
for 1/8" of Material
Removal)
N

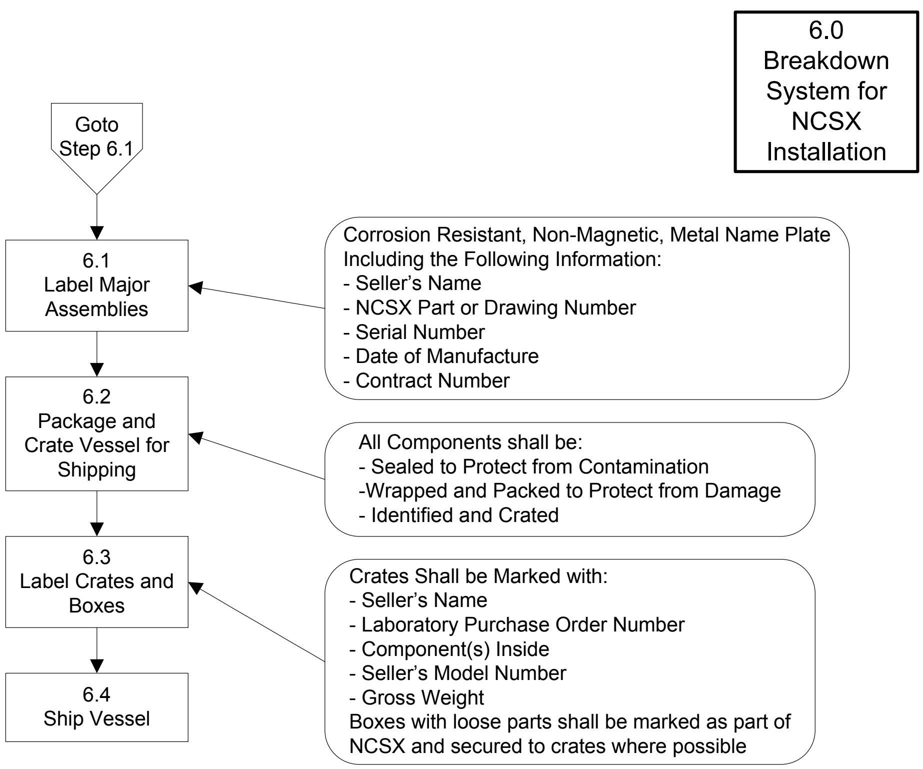

4.0
Port
Integration
N
4.12
Weld Flanges on
End of Tubes
Reference ASME
Code, Section IX
4.13
Inspect Flatness
of Flange Face and
Normalcy to Port
Axis
Reference
Appendix A Item 7
Fail
4.13.1
Rework
Reference
Appendix B Item 3
Pass
4.14
Clean Ports
Reference
Appendix A Item 1
4.15
Leak Check
Ports
Reference
Appendix A Item 2
Fail
4.15.1
Fix Leak
Reference
Appendix B Item 3
Pass
4.16
X-Ray
Inspection of
Welds
Reference
Appendix A Item 6
Fail
4.16.1
Fix Weld
Reference
Appendix B Item 3
Pass
4.17
Magnetic
Permeability
Inspection
Reference
Appendix A Item 5
Fail
4.17.1
Rework
Reference
Appendix B Item 3
Pass
O


4.0
Port
Integration
O
Goto
Step 5.1
Perform 5.0 Spacer Integration Step 5.1 - 5.6 Before Continuing with Step 4.18 for Full Assembly Leak Checking Capabilities
Goto
Step
4.18
4.18
Cut Ports Off at Less Than 1" from Vessel Surface (Plasma Cutter)
4.19
Cut Holes in Vessel for Each Port
4.19.1
Mount Vessel Assembly Held in Cage Fixture on Mill
4.19.2
Setup and Locate Hole Positions Based on Reference Points or Port Stub
4.19.3
Machine Port Holes
Fail
4.19.4
Inspect Port Holes
Pass
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H &
Appendix A Item 7
4.20
Clean Vessel Assembly Surfaces
Reference
Appendix A Item 1
4.21
Label Port Extensions
Goto
Step 6.1


5.0
Spacer
Integration
Goto
Step 5.1
5.1
Align 3 Sub-
Assemblies in
Fixture
Fail
Reference
Appendix A Item 7
5.2
Inspect Alignment and
Spacing Between
Flanges
Pass
5.3
Modify Model of
Original Spacer to
Reflect As Built
Configuration
5.4
Fabricate Spacer
5.4.1
Create BOM for
Spacer Integration
5.4.2
Order Material for
Spacer Integration
5.4.3
Program Water Jet
to Rough Cut
Spacer
Reference ASME
Boiler and
Pressure Vessel
Code, Section VIII,
Division 1
5.4.4
Rough Cut Spacer
Q


5.0
Spacer
Integration
Q
Reference
NVSI QP 4.13 Rev F
5.4.5.1
Rework
Fail
5.4.5
First Piece
Visual
Inspection
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H
Pass
5.4.6
Program Milling
Centers to Final
Machine Spacers
5.4.7
Setup and Run
Milling Centers to
Machine Spacers
Reference
NVSI QP 4.13 Rev F
5.4.8.1
Rework
Fail
5.4.8
Inspect Spacer
Reference
NVSI QP 4.5B Rev G &
NVSI QP 4.10 Rev H
Pass
Reference
Appendix A Item 1
5.4.9
Clean Spacer
Reference
NVSI QP 4.13 Rev F
5.4.10.1
Rework
Fail
5.4.10
Fit Check
Spacer
Reference
NVSI QP 4.10 Rev H
Appendix A Item 7
Pass
5.5
Spacer Ready for
Integration
R


5.0
Spacer
Integration
R
5.6
Final Leak
Check of Full
Assembly
Reference
Appendix A Item 2
Fail
5.6.1
Fix Leak
Pass
Goto
Step
4.18


6.0
Breakdown
System for
NCSX
Installation
Goto
Step 6.1
6.1
Label Major
Assemblies
Corrosion Resistant, Non-Magnetic, Metal Name Plate
Including the Following Information:
- Seller's Name
- NCSX Part or Drawing Number
- Serial Number
- Date of Manufacture
- Contract Number
6.2
Package and
Crate Vessel for
Shipping
All Components shall be:
- Sealed to Protect from Contamination
-Wrapped and Packed to Protect from Damage
- Identified and Crated
6.3
Label Crates and
Boxes
Crates Shall be Marked with:
- Seller's Name
- Laboratory Purchase Order Number
- Component(s) Inside
- Seller's Model Number
- Gross Weight
Boxes with loose parts shall be marked as part of
NCSX and secured to crates where possible
6.4
Ship Vessel

Appendix A

1. Cleaning Procedure
   - Use High Pressure Steam Cleaner with biodegradable UHV compatible detergent to remove oils, grease, and die lubricant residues resulting from handling.
   - Wipe down surfaces with solvent (e.g. Ethanol).
   - Blow dry surfaces with oil free instrument air.
   - Use lint free wipes.

2. Leak Check Procedure
   - Testing shall be done in accordance with NVSI Qp4.10 Rev H/ASTM E498.
   - Ports and assemblies shall be cleaned in accordance with Item 1 Cleaning Procedure above.
   - VVSA shall be leak checked a minimum of times after cycling between room temperature and 200 C.
   - Ports should be evacuated using a mechanical pump and turbo molecular pump to a base pressure equal to or less than 1.0 E-7 Torr and have a total helium leak rate equal to or less than 1.0E-9 sccm/s (7.6E-10 Torr-L/s).
   - Sub-assemblies and full assembly should be evacuated using a mechanical pump and turbo molecular pump to a base pressure equal to or less than 1.0 E-7 Torr and have a total helium leak rate equal to or less than 1.0E-9 sccm/s (7.6E-10 Torr-L/s).
   - Leaks shall be documented on nonconformance reports and repaired.

3. Interior Surface Finish Procedure
   - VVSA interior surfaces, including ports, shall be mechanically ground and electropolished to a 32 micro inch finish or better per ASME B46.1.
   - All finishing tools used shall be nonferrous ceramics or nonmagnetic stainless steel and must be new or previously used on Inconel or austentic steel only.

4. External Surface Finish Procedure
   - Mill Finish Acceptable
   - Gouges greater than 0.06" shall be weld repaired and ground smooth.

5. Magnetic Permeability Requirements
   - Magnetic permeability measurements shall meet requirements of ASTM A800 Supplementary Requirement S1.
   - Measurements shall be relative permeability rather than ferrite content.
   - All features and surfaces shall be measured with a Severn Permeability Indicator1.
   - The VVSA shall be measured over a 6" X 6" grid.
   - All welds shall be measured every ½", inside and outside wherever possible.
   - Overall relative magnetic permeability of all components fabricated of nickel chromium alloy shall not exceed 1.01.
   - Overall relative magnetic permeability of all components fabricated of 316 LN stainless steel shall not exceed 1.02.
   - Overall relative magnetic permeability in all welds (and heat affected zones) joining 316 LN stainless steel to nickel chromium alloy shall not exceed 1.2.

Appendix A

6. Weld Inspection Procedure
   - Weld Inspections shall meet the requirements of NVSI ASME Quality Manual 2nd Edition Revision A Section 11 and 12/NVSI QP 4.10 Rev H

7. CMM Dimension and Tolerance Verification
   - Reference NVSI QP 4.5B Rev B and NVSI QP 4.10 Rev H
   - VVSA measurements shall be done pre and post port cut off.
   - All features and surfaces shall be checked on a grid with less than or equal to 1" centers.
   - All measurements shall be compared to applicable models and drawings.

Appendix B

1. Materials
    - All sheet, strip, and plate metal shall be annealed Alloy UNS N06625 and meet ASTM B 443 Requirements.
    - All piping and tubing shall be seamless or welded alloy UNS N06625 and meet ASTM B 444 or ASTM B 705 requirements.
    - All bar and structural shapes shall be annealed alloy UNS N06625 and meet ASTM B 446.
    - All conflat flanges shall be fabricated of austentic stainless steel and meet ASTM A 240 requirements.
    - Weld filler metal shall meet the applicable requirements of ASME SFA Specifications or AWS A Series Specifications. ASME SFA or AWS A 5.14 requirements and ERNiCr-3 or ERNiCrMo-3 filler metal shall be used when welding stainless steel conflat flanges to UNS N06625 ports.
    - Conflat flange bolts shall be, 12-point silver plated, ASTM A 193 - Grade B8.
    - Standard copper seals shall be used where metal seals are necessary.
    - Viton A O-Rings shall be used where o-ring seals are necessary.

2. Material and Tooling Selection/Control
    - Material and Tooling Selection/Control shall meet the requirements of NVSI ASME Quality Manual 2nd Edition Revision A Section 8/NVSI QP 4.5B Rev G

3. Weld Repair Procedure
    - Weld Repairs shall meet the requirements of NVSI ASME Quality Manual 2nd Edition Revision A Section 11, 12, and 14/NVSI QP 4.10 Rev H & NVSI QP 4.13 Rev F