

**QPS Fabrication Project  
Work Breakdown Structure (WBS) Dictionary  
Stellarator Core Systems (WBS 1)**

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# QPS WBS Dictionary

## Stellarator Core Systems (WBS 1)

<b>WBS Element: 1</b>	<b>WBS Level: 2</b>
<b>WBS Title:</b>	<b>Stellarator Core Systems</b>
<b>Description:</b>	<p>The QPS Fabrication Project includes all equipment required through first plasma.</p> <p>The Fabrication Project includes all the engineering and physics design efforts starting with the preliminary design phase (Title I) and ending with completion of the Fabrication Project, any of the necessary Research and Development (R&amp;D) to support the design effort that is not completed during conceptual or advanced conceptual design, all component fabrication, assembly, and installation activities, and all system level commissioning and testing. Integrated systems testing of the entire QPS device is covered in Integrated Systems Testing (WBS 73).</p> <p>Stellarator Core Systems include all the systems and related elements that directly provide the confining magnetic fields and the high vacuum enclosure required for first plasma formation and operation.</p> <p>Stellarator Core Systems include:</p> <ul style="list-style-type: none"> <li>• In-Vessel Components (WBS 11),</li> <li>• Vacuum Vessel (WBS 12),</li> <li>• Conventional Coils (WBS 13),</li> <li>• Modular Coils (WBS 14),</li> <li>• Coil Supports (WBS 15),</li> <li>• Coil Services in Test Cell (WBS 16),</li> <li>• Machine Base (WBS 17), and</li> <li>• Stellarator Core Assembly (WBS 18)</li> </ul>

## QPS WBS Dictionary Stellarator Core Systems (WBS1)

<b>WBS Element: 11</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>In-Vessel Components</b>	
<b>Description:</b>	<p>This WBS element consists of all the in-vessel systems required to absorb the heat and particle fluxes from the plasma and to effect divertor operation for neutral recycling and density control. This WBS element also includes all the in-vessel systems that serve to protect the modular coils and in-vessel components from energetic particles and heat fluxes from the plasma. Sub-elements within WBS 11 include the:</p> <ul style="list-style-type: none"> <li>• Limiters (WBS 111);</li> <li>• Divertor (WBS 112); and</li> <li>• PFC local I&amp;C (WBS 113)</li> </ul> <p>For the QPS Fabrication Project, none of these elements are included. However, the conceptual design includes concepts for a simple divertor system that consists of flat targets attached to a cooled pipe immediately above the regions of the plasma “ridges”. The design, fabrication, and installation of these upgrades are outside the scope of the Fabrication Project.</p>	
<b>WBS Element: 111</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Limiters</b>	
<b>Description:</b>	<p>For the QPS Fabrication Project, no local limiters are anticipated. These will be supplied as an upgrade if warranted for protection from the plasma.</p>	
<b>WBS Element: 112</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Divertor</b>	
<b>Description:</b>	<p>For the QPS Fabrication Project, no divertor targets are included. These will be supplied as an upgrade after first plasma.</p>	
<b>WBS Element: 113</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>PFC local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element will provide the local I&amp;C required by all WBS elements included under In-Vessel Components (WBS□1). For the Fabrication Project, no local I&amp;C will be included.</p>	

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<b>WBS Element: 12</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Vacuum Vessel</b>	
<b>Description:</b>	<p>The vacuum vessel provides a vacuum boundary around the plasma chamber suitable for high vacuum conditions; structural support for external coils, and access for Auxiliary Systems (WBS□) and Diagnostics (WBS□).</p> <p>This WBS element consists of all the following sub-elements:</p> <ul style="list-style-type: none"> <li>• Vacuum Vessel Assembly (WBS□21);</li> <li>• Centerstack Casing (WBS 122);</li> <li>• Thermal Insulation and Heating Systems(WBS 123);</li> <li>• Vacuum Vessel Local I&amp;C (WBS 124).</li> </ul>	
<b>WBS Element: 121</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Vacuum Vessel Assembly</b>	
<b>Description:</b>	<p>This WBS element consists of the vacuum vessel heads and spool piece, ports, blank port covers, TF and VF coil support interfaces, centerstack interface, and interior support interfaces to modular coils. Modification of the blank port covers to accommodate end users, e.g. Diagnostics (WBS 3), is the responsibility of the primary end user.</p>	
<b>WBS Element: 122</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Centerstack Casing</b>	
<b>Description:</b>	<p>This WBS element consists of the long, racetrack shaped tube that surrounds the centerstack and provides the vacuum boundary at the bore of the machine. It is welded into the end flanges at assembly.</p>	
<b>WBS Element: 123</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Thermal Insulation and Heating System</b>	
<b>Description:</b>	<p>This WBS element covers commercial electric heaters and associated control and external thermal insulation to maintain the vacuum vessel at its desired temperature (up to 150C for bakeout, nominally 40C for normal operation). No heaters are included in the Fabrication Project. This will be added after first plasma.</p>	
<b>WBS Element: 124</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Vacuum Vessel Local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element provides the local I&amp;C required by other WBS elements included under Vacuum Vessel Systems (WBS□2). Local I&amp;C requirements will be determined in the design of these other WBS elements.</p>	

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<b>WBS Element: 13</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Conventional Coils</b>	
<b>Description:</b>	<p>The conventional coils provide background magnetic fields for flexibility in the magnetic configuration, for inductive current drive and plasma shape and position control, and for field error correction.</p> <p>This WBS element consists of the following:</p> <ul style="list-style-type: none"> <li>• TF Coils (WBS 131);</li> <li>• PF Coils (WBS 132);</li> <li>• Centerstack Integration (WBS 133)</li> <li>• External Trim Coils (WBS 134); and</li> <li>• Conventional Coils Local I&amp;C (WBS 135).</li> </ul> <p>Included in these elements are all the engineering and physics design efforts starting with the preliminary design phase (Title I) and ending at first plasma, all coil component fabrication and assembly activities, and all system level commissioning and testing. Final assembly is covered in Test Cell Preparation and Machine Assembly (WBS 7). Integrated systems testing of the conventional coils is also covered in Test Cell Preparation and Machine Assembly (WBS 7).</p>	
<b>WBS Element: 131</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>TF Coils</b>	
<b>Description:</b>	<p>The set of toroidal field coils provide flexibility in the magnetic configuration. This WBS element includes the return legs for the coils and lead connections. The center legs of the coils, which are located in the centerstack assembly, are also included here. There are 12 identical, equally spaced coil return legs. The outboard legs consist of standard copper bus bar, formed to nest in sets of four turns per return leg bundle which are bolted together at standard lap joints. These turns are air cooled. The coils are supported via clamps to the vacuum vessel (WBS 121). The inner turns consist of straight lengths of hollow copper conductor, insulated and integrated with the centerstack.</p> <p>This WBS element consists of the manufacturing design and fabrication of the TF conductor and assembly of the TF leg bundles including interface elements for connections to power and cooling supply at the coils.</p>	
<b>WBS Element: 132</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>PF Coils</b>	
<b>Description:</b>	<p>The poloidal field (PF) magnets produce the poloidal magnetic field within the QPS device. These coils provide inductive current drive and plasma shape and position control. The coil set consists of a solenoid, an inner pair of OH coils, a pair of inner VF coils, a pair of mid VF coils and a pair of outer VF coils. All the coils are symmetric about the horizontal midplane. The solenoid is racetrack shaped and wound in two layers from standard size hollow copper conductor. All the coils except the solenoid already exist and will be re-used. The coils are wound from hollow copper conductor, are water cooled and operate at room temperature. All the coils are supported from the vacuum vessel.</p> <p>The solenoid is racetrack shaped and wound in two layers from standard size hollow copper conductor.</p> <p>This WBS element consists of the design of the solenoid, plus the analysis installation design for all the coils and any refurbishment necessary to re-use the coils.</p>	

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<b>WBS Element: 133</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Centerstack Integration</b>	
<b>Description:</b>	<p>The centerstack is an assembly that includes the OH solenoid windings, the inner TF coil legs, and the vacuum casing that surrounds these components. The casing is a 160 inch long stainless steel tube, also with a racetrack cross-section. Pins extend between the coil windings from one side of the casing to the other to restrain the magnetic loads on the solenoid as well as the 1 atm internal pressure. This element consists of the integration of these components.</p> <p>This WBS element consists of the assembly design and manufacturing integration of the centerstack components.</p>	
<b>WBS Element: 134</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>External Trim Coils</b>	
<b>Description:</b>	<p>For the QPS Fabrication Project, no external trim coils are included. These will be supplied as an upgrade if warranted to reduce low poloidal mode number (m) resonant errors that may result from manufacturing or assembly errors in the modular coil geometry.</p>	
<b>WBS Element: 135</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Conventional Coils Local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element provides the manufacturing design and fabrication of the local I&amp;C components required by the WBS elements under Conventional Coils (WBS 13). Local I&amp;C requirements will be determined in the design of these WBS elements, and may include strain gages, RTDs, and voltage taps.</p>	

<b>WBS Element: 14</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Modular Coils</b>	
<b>Description:</b>	<p>This WBS element consists of all the following:</p> <ul style="list-style-type: none"> <li>• Modular Coil Winding Forms (WBS 141)</li> <li>• Modular Coil Winding and Assembly (WBS 142); and</li> <li>• Modular Coils Local I&amp;C (WBS 143);.</li> </ul> <p>This WBS element consists of the design and fabrication of the modular coil components, including any supporting R&amp;D necessary for the design and fabrication of these components. Modular coil assembly and installation in a field period is covered in Stellarator Core Assembly (WBS 18). Integrated systems testing is covered under Core and Facility Integration (WBS 7).</p>	
<b>WBS Element: 141</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Modular Coil Winding Forms</b>	
<b>Description:</b>	<p>This WBS element consists of the design and fabrication of the modular coil winding forms. There are five different coil types but only 3 different winding forms that are repeated for a total of 10 winding forms. Each winding form is fabricated as a casting. Due to the complexity of the shape, the pattern geometry is assumed to require at least two iterations by a pattern maker. After stress relieving the castings in a fixture, all structural interface features are machined. After the coils are wound, the winding forms are bolted together, to form two complete field periods. During final assembly, the two field periods are bolted together to form the completed modular coil assembly.</p>	

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<b>WBS Element: 142</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Modular Coil Winding and Assembly</b>	
<b>Description:</b>	<p>This WBS element consists of the design and fabrication of the modular coil windings and coil assembly. The modular coil set consists of two field periods with 10 coils per period, for a total of 20 coils. Due to symmetry, only five different coil shapes are needed to make up the complete coil set. Within the modular coil envelope, a thick web supports each multi-turn winding pack. The design concept uses flexible, copper cable conductor that has been compacted into a rectangular cross-section and wrapped with Kapton and glass tape insulation. The conductor is wound in a double pancake on the side of the structural web. Copper cladding consisting of copper sheet formed to the surface of the winding form and outside of winding pack (or a different arrangement to be determined during design) is provided for coil cooling. After winding is complete, the final geometry is verified and the assembly is vacuum pressure impregnated with epoxy to complete the insulation system. The epoxy fills the voids within the cable conductor so the winding pack becomes a monolithic copper-glass-epoxy composite. Auxiliary clamping brackets are then installed. This element includes the conductor, insulation, winding, integral cooling components (e.g. chill plates), epoxy impregnation, clamp brackets, inspection and electrical testing.</p>	
<b>WBS Element: 143</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Modular Coils Local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element consists of the design and fabrication of the modular coil local I&amp;C components. The modular coil set requires several types of sensors at each coil that may include strain gages, RTDs, and voltage taps.</p>	

<b>WBS Element: 15</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Coil Supports</b>	
<b>Description:</b>	<p>This WBS element consists of all the following:</p> <ul style="list-style-type: none"> <li>• Mod coil shear panel and shims (WBS 151);</li> <li>• TF crown structure (WBS 152); and</li> <li>• TF and PF brackets (WBS 153)</li> <li>• Support Structure Local I&amp;C (WBS 154)</li> </ul> <p>The support structures provide the interfacing mechanism between coil components and interface with the machine base support structure (WBS 172). No R&amp;D is anticipated for this WBS element. Fit-check of these components is covered in this element, but final installation is covered under WBS 18. Integrated systems testing is covered under Test Cell Preparation and Machine Assembly (WBS 7).</p>	
<b>WBS Element: 151</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Mod Coil Shear Panels and Shims</b>	
<b>Description:</b>	<p>This WBS element consists of design and fabrication of the modular coil shear panels and the shims between winding forms.</p>	
<b>WBS Element: 152</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>TF Crown structure</b>	
<b>Description:</b>	<p>This WBS element consists of the design and fabrication of the TF crown structures that support out-of-plane loads on the upper and lower TF coil regions.</p>	
<b>WBS Element: 153</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>TF and PF brackets</b>	
<b>Description:</b>	<p>This WBS element consists of the design and procurement of the brackets that connect the TF and PF coils to the vacuum vessel.</p>	

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<b>WBS Element: 154</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Support Structure Local I&amp;C</b>	
<b>Description:</b>	This WBS element consists of the design and procurement of the local I&C sensors for the coil support structures.	

<b>WBS Element: 16</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Coil Services in Test Cell</b>	
<b>Description:</b>	<p>This WBS element consists of all the following:</p> <ul style="list-style-type: none"> <li>• Modular coil cooling system</li> <li>• Conventional coil cooling system</li> <li>• Electrical leads</li> <li>• Coil protection system</li> <li>• Coil services local I&amp;C</li> </ul> <p>The coil services provide overall coordination of the cooling, electrical leads, and coil protection systems for the coil components. At this time, no R&amp;D is anticipated for this WBS element. Assembly and installation of these coil services systems is covered in Core Assembly (WBS 18). Integrated systems testing is also covered under Test Cell Preparation and Machine Assembly (WBS 7).</p>	

<b>WBS Element: 161</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Modular Coil Cooling System</b>	
<b>Description:</b>	This WBS element consists of the design and fabrication of the manifolds and cooling pipes to connect the modular coils to the cooling system in the pit (WBS 6).	

<b>WBS Element: 162</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Conventional Coil Cooling System</b>	
<b>Description:</b>	This WBS element consists of the design and fabrication of the manifolds and cooling pipes to connect the conventional coils to the cooling system in the pit (WBS 6).	

<b>WBS Element: 163</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Electrical Leads</b>	
<b>Description:</b>	This WBS element consists of the design and fabrication of the coaxial coil electrical leads, which connect the coils to the power supply bus or cables in the pit.	

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<b>WBS Element: 164</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Coil Protection System</b>	
<b>Description:</b>	<p>This WBS element consists of the development of the overall coil protection system logic and limitation and the design and fabrication of the any coil protection system-specific sensors (e.g., temperature sensors, etc.) not specified in other WBS elements. This design will borrow heavily on that being developed for NCSX. The overall design and fabrication of the coil protection system is divided among three major WBS elements as follows:</p> <ul style="list-style-type: none"> <li>• WBS 164 – as described above;</li> <li>• WBS 4 - provides the digital coil protection system and ground fault detection system for the Modular, PF, and TF coil systems and will be designed to include the trim coils as an upgrade. The digital coil protection system uses the coil current measurements as input and declares a fault if electrical, thermal, or mechanical limits are exceeded. The ground fault detection system declares a fault if excessive ground current flow is detected.</li> <li>• WBS 5 – provides DC current transformer (DCCT) signal conditioners and interface with the control computer and hardwired control circuits. Provides signal transmission from C-Site to D-Site, including temperature of the coils and actual voltages across the coil. The Field Coil Power Convertors (FCPC) computer will perform real time calculation of coil impedances.</li> </ul>	
<b>WBS Element: 165</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Coil Services Local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element provides the thermocouples required by other WBS elements included under Coil Services in Test Cell (WBS□2). This element includes the sensors and their installation. Signal conditioning is included in WBS 5.</p>	

<b>WBS Element: 17</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Machine Base</b>	
<b>Description:</b>	<p>This WBS element consists of all the following:</p> <ul style="list-style-type: none"> <li>• Machine Base Columns (WBS 171).</li> <li>• Machine Base Local I&amp;C</li> </ul> <p>The machine base structures provide the columns that hold up the machine and the interface elements at the top of the columns. No R&amp;D is anticipated for this WBS element. Fit-check of these components is covered in this element, but final installation is covered under WBS 18. Integrated systems testing is covered under Test Cell Preparation and Machine Assembly (WBS 7).</p>	
<b>WBS Element: 171</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Machine Base Columns</b>	
<b>Description:</b>	<p>This WBS element consists of the design and fabrication of the base support structure. The base support structure consists of the base column assemblies, interconnecting beams and column base hardware.</p>	
<b>WBS Element: 172</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Machine Base Local I&amp;C</b>	
<b>Description:</b>	<p>This WBS element consists of the design and procurement of the local I&amp;C sensors for the machine base.</p>	

## QPS WBS Dictionary Stellarator Core Systems (WBS1)

<b>WBS Element: 18</b>		<b>WBS Level: 3</b>
<b>WBS Title:</b>	<b>Stellarator Core Assembly</b>	
<b>Description:</b>	<p>This WBS element consists of all the following:</p> <ul style="list-style-type: none"> <li>• Inspection and general oversight (WBS 181);</li> <li>• Base assembly (WBS 182);</li> <li>• Centerstack Assembly (WBS 183);</li> <li>• VF coils and tank head assembly (WBS 184);</li> <li>• TF Coil assembly (WBS 185);</li> <li>• Modular coil assembly (WBS 186)</li> <li>• Cooling and buswork assembly (WBS 187</li> <li>• Tooling Design and Fabrication (WBS 188); and</li> <li>• Measurement Systems (WBS 189)</li> </ul> <p>The two field periods will be pre-assembled adjacent to the pit prior to final assembly in the QPS Test Cell. This WBS element covers the both the field period subassembly and the final assembly of the stellarator core components.</p>	
<b>WBS Element: 181</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Inspection and general oversight</b>	
<b>Description:</b>	This WBS element includes receiving inspection and planning for the assembly of the stellarator core.	
<b>WBS Element: 182</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Base assembly</b>	
<b>Description:</b>	The WBS element covers the assembly of the base.	
<b>WBS Element: 183</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Centerstack assembly</b>	
<b>Description:</b>	This WBS element covers the assembly of the integrated centerstack subassembly into the stellarator core.	
<b>WBS Element: 184</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>VF Coils and tank head assembly</b>	
<b>Description:</b>	The WBS element consists of the activities associated with mounting the PF coils to the vessel and installing the vessel	
<b>WBS Element: 185</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>TF coil assembly</b>	
<b>Description:</b>	The WBS element consists of the activities associated with assembling the TF coils and mounting them to the vessel	
<b>WBS Element: 186</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Modular coil assembly</b>	
<b>Description:</b>	The WBS element consists of the activities associated with assembling the two field periods and mounting them on the columns.	

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**Stellarator Core Systems (WBS1)**

<b>WBS Element: 187</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Cooling and buswork assembly</b>	
<b>Description:</b>	This WBS element consists of those activities associated with connecting the coax electrical leads and water lines to the coils. Instrument lead connections are covered under WBS 3.	
<b>WBS Element: 188</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Tooling Design &amp; Fabrication</b>	
<b>Description:</b>	This WBS element consists of the activities associated with the design and fabrication of tooling required during assembly operations. Only lifting beams and jacks are anticipated.	
<b>WBS Element: 189</b>		<b>WBS Level: 4</b>
<b>WBS Title:</b>	<b>Measurement Systems</b>	
<b>Description:</b>	This WBS element consists of those efforts required to design and procure a commercial measurement system for assembly of the stellarator core.	