

Development of Closure Bolt Analysis Rules on Design of ASME Section III, Division 3 Containments

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The ASME BPV Code Subcommittee responsible for Section III Division 3 is currently revising Subsections WB and WC and developing Subsection WD. Subsections WB and WC contain rules for the material, design, fabrication, examination, testing, marking, stamping, and preparation of reports by the Certificate Holder for Class TC transportation containments and Class SC storage containments, respectively, for spent nuclear fuel and high-level radioactive waste and materials. Subsection WD, which is under development, contains rules similar to those in Subsections WB and WC, but for internal supports inside the transportation and storage containments. The Working Group on the Design of Section III Division 3 Containments is addressing design issues, i.e., rules and/or guidance, for the bolted joints beyond the current Subsections WB and WC (and WD) limits. Further development of closure bolt analysis rules has been identified as a priority. As a member of the ASME BVP Code Subcommittee and the Working Group, Argonne National Laboratory has been tasked to assist in the further development of the closure bolt analysis rules.

Three tables have been created to compare the bolting rules between Subsections WB and WC, and between the rules in the mandatory Appendices XIII and XIV and Article WB-3000. The bolting rules in Subsections WB and WC are compared in Table 1 and the results were presented at the Working Group meeting in May 2012. The mandatory Appendices XIII and XIV to Section III Division 1 of the ASME BPV Code also contain bolting design analysis rules in Article XIII-1000, "Design Based on Stress Analysis," and Article XIV-1000, "Design Based on Fatigue Analysis." Although the rules in these two appendices are only applicable to the design of Class 2 vessels, they could be considered for use for containments meeting the requirements of WC-3200. The design rules and guidance in these two appendices are compared in Tables 2 and 3, respectively, against those in Subsection WB, for potential incorporation into Article WC-3000.

Subsection WB addresses the design stress limit for bolted closures under Level A and Level D service limits to ensure integrity of the bolted flange. Properly applied bolt preloads introduce clamping force in the bolted joint, ensuring leak-tightness of the transportation and storage casks. Work has begun in reviewing the bolting analysis rules in NUREG/CR-6007 "Stress Analysis of Closure Bolts for Shipping Casks" and the current practices for installing bolt preloads in the closure joints of transportation casks for hazardous and radioactive materials in ASME PCC-1, "Guidelines for Pressure Boundary Bolted Flange Joint Assembly."

Future Work

Evaluation of the bolting analysis rules will continue, along with literature review of bolting analyses and practices for used fuel storage and transportation casks with bolted closures. Current practices for installing bolt preloads will be examined and finite-element analyses may need to be performed to determine preload uncertainties and scatters resulting from the different bolting-up methods.

The closure integrity of the storage and transportation casks in service is also affected by other factors such as aging and/or vibration during storage and transport, as well as the performance of seals. Aging effects on the bolted closure of storage and transportation casks could lead to a loss of preload due to

stress relaxation and self-loosening, or loss of bolting material due to corrosion and fatigue. Therefore, the impact of aging effects on the closure bolts and seals, and aging management programs and practices for bolted closures in storage and transportation casks should be evaluated.

Managing aging effects on the closure bolts of storage and transportation casks requires an aging management program (AMP) to prevent, mitigate, and detect aging effects, by condition and/or performance monitoring. One AMP titled “Bolted Canister Seal and Leakage Monitoring Program” has been developed for inclusion in Chapter IV of the report by O.K. Chopra, et al. [1]. The effectiveness of this AMP will be assessed against the operating experience from the storage and transportation casks with bolted closures in the future.

Reference

- 1) O.K. Chopra, et al., *Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel*, FCRD-USED-2012-000119 (ANL-12/29), June 30, 2012.

Table 1 Comparison Matrix of Bolting Rules in Subsections WB and WC

WB - BOLTING	WC - BOLTING	COMMENTS
ARTICLE WB-2000 MATERIAL	ARTICLE WC-2120 MATERIAL	
<p>WB-2100 GENERAL REQUIREMENTS FOR MATERIAL</p> <p>WB-2120 CONTAINMENT MATERIAL</p> <p>WB-2125 Bolting Material</p> <p>(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.</p> <p>(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.</p>	<p>WC-2100 GENERAL REQUIREMENTS FOR MATERIAL</p> <p>WC-2120 CONTAINMENT MATERIAL</p> <p>WC-2128 Bolting Material</p> <p>(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Table 4, Section II, Part D, Subpart 1. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Table 4, Section II, Part D, Subpart 1.</p> <p>(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.</p>	<p>WB and WC are identical.</p>
<p>WB-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL AND DUCTILE CAST IRON</p> <p>WB-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL AND FOR DUCTILE CAST IRON</p> <p>WB-2224 Location of Coupons</p> <p>(b) For bolting materials, test shall be made of either full-size bolts or test coupons are required by the base specification. The gauge length of the tension specimens and the area under the notch of Charpy specimens shall be at least one diameter or</p>	<p>WC-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL AND DUCTILE CAST IRON</p> <p>WC-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL AND FOR DUCTILE CAST IRON</p> <p>WC-2224 Bars and Bolting Material</p> <p>WC-2224.3 Bolting Material</p> <p>For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the</p>	<p>WB and WC have different requirements for test coupons and tests.</p>

WB - BOLTING	WC - BOLTING	COMMENTS
<p>thickness from the heat treated end.</p>	<p>applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.</p>	
<p>WB-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL</p> <p>WB-2310 MATERIAL TO BE TOUGHNESS TESTED</p> <p>WB-2311 Material for Which Toughness Testing Is Required</p> <p>(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;</p> <p>WB-2320 IMPACT TEST PROCEDURES</p> <p>WB-2322 Test Specimens</p> <p>WB-2322.1 Location of Test Specimens</p> <p>(a) ...When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.</p>	<p>WC-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL</p> <p>WC-2310 MATERIAL TO BE IMPACT TESTED</p> <p>WC-2311 Material for Which Impact Testing Is Required</p> <p>(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;</p> <p>WC-2320 IMPACT TEST PROCEDURES</p> <p>WC-2322 Test Specimens</p> <p>WC-2322.1 Location of Test Specimens</p> <p>(a) ...When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.</p>	<p>WB and WC are identical.</p>
<p>WB-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS</p>	<p>WC-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS</p>	<p>WB and WC are similar except for the test temperature.</p>

WB - BOLTING	WC - BOLTING	COMMENTS																								
<p>WB-2333 Bolting Material</p> <p>For bolting material, including studs, nuts, and bolts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is less. All three specimens shall meet the requirements of Table WB-2333-1.</p> <p style="text-align: center;">Table WB-2333-1 Required C_v Values for Bolting Material</p> <table border="1" data-bbox="94 581 739 834"> <thead> <tr> <th>Nominal Diameter, in. (mm)</th> <th>Lateral Expansion, mils (mm)</th> <th>Absorbed Energy, ft-lb (J)</th> </tr> </thead> <tbody> <tr> <td>1 (25) or less</td> <td>No test required</td> <td>No test required</td> </tr> <tr> <td>Over 1 to 4 (25 to 100), incl.</td> <td>25 (0.64)</td> <td>No requirements</td> </tr> <tr> <td>Over 4 (100)</td> <td>25 (0.64)</td> <td>45 (61)</td> </tr> </tbody> </table>	Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)	1 (25) or less	No test required	No test required	Over 1 to 4 (25 to 100), incl.	25 (0.64)	No requirements	Over 4 (100)	25 (0.64)	45 (61)	<p>WC-2332.3 Bolting Material</p> <p>For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The tests shall be performed at or below the Lowest Service Metal Temperature, and all three specimens shall meet the requirements of Table WC-2332.3-1.</p> <p style="text-align: center;">Table WC-2332.3-1 Required C_v Values for Bolting Material Tested in Accordance with WC-2332.3</p> <table border="1" data-bbox="819 548 1463 800"> <thead> <tr> <th>Nominal Diameter, in. (mm)</th> <th>Lateral Expansion, mils (mm)</th> <th>Absorbed Energy, ft-lb (J)</th> </tr> </thead> <tbody> <tr> <td>1 (25) or less</td> <td>No test required</td> <td>No test required</td> </tr> <tr> <td>Over 1 through 4 (25 through 100)</td> <td>25 (0.64)</td> <td>No requirements</td> </tr> <tr> <td>Over 4 (100)</td> <td>25 (0.64)</td> <td>45 (61)</td> </tr> </tbody> </table>	Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)	1 (25) or less	No test required	No test required	Over 1 through 4 (25 through 100)	25 (0.64)	No requirements	Over 4 (100)	25 (0.64)	45 (61)	
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<p>WB-2340 NUMBER OF TOUGHNESS TESTS REQUIRED</p> <p>WB-2345 Bolting Material</p> <p>One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed the following:</p> <table border="1" data-bbox="94 1133 787 1295"> <thead> <tr> <th>Diameter</th> <th>Weight</th> </tr> </thead> <tbody> <tr> <td>1-3/4 in. (44 mm) and less</td> <td>1,500 lb (680 kg)</td> </tr> <tr> <td>Over 1-3/4 in. to 2-1/2 in. (44 mm to 64 mm)</td> <td>3,000 lb (1350 kg)</td> </tr> <tr> <td>Over 2-1/2 in. to 5 in. (6 mm to 127 mm)</td> <td>6,000 lb (2700 kg)</td> </tr> <tr> <td>Over 5 in. (127 mm)</td> <td>10,000 lb (4500 kg)</td> </tr> </tbody> </table>	Diameter	Weight	1-3/4 in. (44 mm) and less	1,500 lb (680 kg)	Over 1-3/4 in. to 2-1/2 in. (44 mm to 64 mm)	3,000 lb (1350 kg)	Over 2-1/2 in. to 5 in. (6 mm to 127 mm)	6,000 lb (2700 kg)	Over 5 in. (127 mm)	10,000 lb (4500 kg)	<p>WC-2340 NUMBER OF IMPACT TESTS REQUIRED</p> <p>WC-2345 Bolting Material</p> <p>One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed the following:</p> <table border="1" data-bbox="819 1133 1512 1295"> <thead> <tr> <th>Diameter</th> <th>Weight</th> </tr> </thead> <tbody> <tr> <td>1-3/4 in. (44 mm) and less</td> <td>1,500 lb (680 kg)</td> </tr> <tr> <td>Over 1-3/4 in. to 2-1/2 in. (44 mm to 64 mm)</td> <td>3,000 lb (1350 kg)</td> </tr> <tr> <td>Over 2-1/2 in. to 5 in. (6 mm to 127 mm)</td> <td>6,000 lb (2700 kg)</td> </tr> <tr> <td>Over 5 in. (127 mm)</td> <td>10,000 lb (4500 kg)</td> </tr> </tbody> </table>	Diameter	Weight	1-3/4 in. (44 mm) and less	1,500 lb (680 kg)	Over 1-3/4 in. to 2-1/2 in. (44 mm to 64 mm)	3,000 lb (1350 kg)	Over 2-1/2 in. to 5 in. (6 mm to 127 mm)	6,000 lb (2700 kg)	Over 5 in. (127 mm)	10,000 lb (4500 kg)	<p>WB and WC are identical.</p>				
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WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-2500 EXAMINATION AND REPAIR OF CONTAINMENT MATERIAL</p> <p>WB-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS</p> <p>WB-2581 Requirements</p> <p>ALL bolting material shall be visually examined in accordance with WB-2582. Normal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle or the liquid penetrant method. In addition, nominal sizes greater than 2 in. (50 mm) but not over 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with WB-2585 and nominal sizes greater than 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with both WB-2585 and WB-2586.</p> <p>WB-2582 Visual Examination</p> <p>The areas of threads, shanks, and heads of final machined parts shall be visually examined. The requirements of WB-5520 do not apply to personnel performing this examination. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.</p> <p>WB-2583 Magnetic Particle Examination (for Ferritic Steel Bolting Material Only)</p> <p>WB-2583.1 Examination Procedures. All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method in accordance with ASTM A 275. If desired, the supplier may perform liquid penetrant examination in accordance with WB-2584 instead of magnetic particle examination. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved).</p>	<p>WC-2500 EXAMINATION AND REPAIR OF CONTAINMENT MATERIAL</p> <p>WC-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS</p> <p>WC-2581 Requirements</p> <p>ALL bolting material shall be visually examined in accordance with WC-2582.</p> <p>WC-2582 Visual Examination</p> <p>Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.</p>	<p>WB and WC are significantly different.</p>

WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-2583.2 Evaluation of Indications</p> <p>(a) All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular or elliptical with the length equal to or less than three times the width.</p> <p>(b) All indications are not necessarily relevant: leakage of magnetic fields and permeability variations may produce indications that are not relevant to the detection of unacceptable discontinuities. Indications with major dimensions of 1/16 in. (1.5 mm) or less are not relevant.</p> <p>(c) Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning.</p> <p>(d) Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.</p> <p>(e) As an alternative to magnetic particle reexamination, other nondestructive examination means (such as liquid penetrant examination for surface discontinuities) may be used to determine relevancy.</p> <p>WB-2583.3 Acceptance Standard. Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.</p> <p>WB-2584 Liquid Penetrant Examination</p> <p>WB-2584.1 Examination Procedure. All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by a liquid penetrant method in accordance with the methods of Section V, Article 6. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after</p>		

WB - BOLTING	WC - BOLTING	COMMENTS
<p>heading (if involved).</p> <p>WB-2584.2 Evaluation of Indications. All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular to elliptical with the length equal to or less than three times the width. All penetrant indications are not necessarily relevant. Surface imperfections such as machining marks and scratches may produce indications that are nonrelevant to the detection of unacceptable discontinuities. Broad areas of pigmentation, which could mask indications of defects, are unacceptable. Indications with major dimensions of 1/16 in. (1.5 mm) or less are not relevant. Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning. Any area of pigmentation also shall be reexamined after recleaning or light surface conditioning, as appropriate. Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.</p> <p>WB-2584.3 Acceptance Standard. Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) long are unacceptable.</p> <p>WB-2585 Ultrasonic Examination for Sizes Greater Than 2 in. (50 mm)</p> <p>All bolts, studs, and nuts greater than 2 in. (50 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading in accordance with the following requirements:</p> <p>WB-2585.1 Ultrasonic Method. Examination shall be carried out by the straight-beam, radial-scan method in accordance with Section V, Article 23, SA-388.</p>		

WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-2585.2 Examination Procedures. Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit area not to exceed 1 in.² (650 mm²).</p> <p>WB-2585.3 Calibration of Equipment. Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.</p> <p>WB-2585.4 Acceptance Standard. Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.</p> <p>WB-2586 Ultrasonic Examination for Sizes Over 4 in. (100 mm)</p> <p>In addition to the requirements of WB-2585, all bolts, studs, and nuts over 4 in. (100 mm) nominal bolt size shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the following requirements:</p> <p>WB-2586.1 Ultrasonic Method. Examination shall be carried out by the straight-beam, longitudinal-scan method.</p> <p>WB-2586.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit having a circular cross section with a diameter not less than ½ in. (13 mm) nor more than 1-1/8 in/ (29 mm).</p> <p>WB-2586.3 Calibration of Equipment. Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A 3/8 in. (10 mm) diameter by 3 in. (75 mm) deep flat-bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance-amplitude curve shall be established by scanning from both ends of the test bar.</p>		

WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-2586.4 Acceptance Standard. Any discontinuity that causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance-amplitude curve is not acceptable.</p> <p>WB-2587 Time of Examination Acceptance examinations shall be performed after the final heat treatment required by the basic material specification.</p> <p>WB-2588 Elimination of Surface Defects Unacceptable surface defects on finished bolts, studs, and nuts are not permitted, and are cause for rejection.</p> <p>WB-2589 Repair by Welding Weld repairs of bolts, studs, and nuts are not permitted.</p>		

WB - BOLTING	WC - BOLTING	COMMENTS
ARTICLE WB-3000 DESIGN	ARTICLE WC-3000 DESIGN	
<p>WB-3100 GENERAL DESIGN</p> <p>WB-3130 GENERAL DESIGN RULES</p> <p>WB-3134 Leak Tightness</p> <p>The leak tightness requirements for each containment shall be set forth in the Design Specification.</p>	<p>WC-3100 GENERAL DESIGN</p> <p>WC-3130 GENERAL DESIGN RULES</p> <p>N/A</p>	<p>No similar paragraph exists in WC.</p>
<p>WB-3200 DESIGN RULES FOR CONTAINMENTS</p> <p>WB-3220 STRESS LIMITS FOR OTHER THAN BOLTS</p> <p>N/A</p>	<p>WC-3200 DESIGN RULES FOR CONTAINMENTS</p> <p>WC-3220 DESIGN CONSIDERATIONS</p> <p>WC-3225 Flat Heads and Covers</p> <p>Discusses both welded and bolted flat heads and covers, but does not address the design of the bolts</p> <p>WC-3225.1 Nomenclature</p> <p>Addresses nomenclature applicable to flat heads and closures.</p>	<p>No similar paragraph exists in WB.</p>
<p>N/A</p>	<p>WC-3225.2 Equations for Minimum Thickness</p> <p>Provides equations for minimum thickness of flat heads and closures.</p>	<p>No similar paragraph exists in WB.</p>
<p>N/A</p>	<p>Fig. WC-3225-2</p>	<p>No similar paragraph exists in WB.</p>

WB - BOLTING	WC - BOLTING	COMMENTS
	Provides illustrations of some acceptable types of unstayed flat heads and covers.	
<p>WB-3230 STRESS LIMITS FOR BOLTS</p> <p><i>This paragraph discusses general aspects of stress limits for bolts.</i></p> <p>The evaluation of bolting requires a number of analysis considerations, including (a) through (f) below and the criteria specified in this subsubarticle for the loads imposed.</p> <p>(a) When gaskets are used for preservice testing only, the design is satisfactory if WB-3231 requirements are satisfied for $m = y = 0$, and the requirements of WB-3232 are satisfied when the appropriate m and y factors are used for the test gasket.</p> <p>(b) The membrane and bending stresses in the bolt produced by thermal expansion due to differences in the temperature or thermal expansion coefficients shall be treated as primary stresses in bolting analysis.</p> <p>(c) The bolting analysis shall consider the effects of loading eccentricities due to puncture loads and eccentric impact loads.</p> <p>(d) The bolting analysis shall consider prying effects, which cause amplification of the bolt loads due to rotation of the closure surfaces.</p> <p>(e) Bolting analysis shall consider bolt preload application methodology and resulting bolt forces.</p> <p>(f) Gasket characteristics and leak tightness requirements shall be considered in the bolting analysis.</p>	N/A	No similar paragraph exists in WC.

WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-3231 Design Limits</p> <p><i>This paragraph provides instructions to determine the number and cross-sectional area of bolts.</i></p> <p>The number and cross-sectional area of bolts required to resist the Design Pressure shall be determined in accordance with the procedures of Division 1, Appendix E, using the larger of the bolt loads, given by the equations of Division 1, Appendix E, as a Design Mechanical Load.</p> <p>The stress limits shall be the values given in Section II, Part D, Subpart 1, Table 4 for bolting material.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3232 Level A Service Limits</p> <p><i>This paragraph addresses stresses in bolts for Level A Service Limits.</i></p> <p>Actual stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the values given in Section II, Part D, Subpart 1, Table 4.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3232.1 Average Stress</p> <p>Provides requirements to handle average bolt stresses.</p> <p>The maximum value of stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part D, Subpart 1, Table 4.</p>	N/A	No similar paragraph exists in WC.

WB - BOLTING	WC - BOLTING	COMMENTS
<p>WB-3232.2 Shear Stress:</p> <p>Provides requirements to handle average bolt shear stresses.</p> <p>The average bolt shear stress expressed in terms of available shear stress area shall not exceed 1.2 S_m (at temperature) from Section II, Part D, Subpart 1, Table 4.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3232.3 Maximum Stress</p> <p>Provides requirements for handling maximum stress in bolts.</p> <p>The maximum value of stress, except as restricted by WB-3232.4(b), at the periphery of the bolt cross section resulting from direct tension plus bending, and neglecting stress concentrations, shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means that minimize residual torsion.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3232.4 Fatigue Analyses of Bolts</p> <p>Provides requirements for handling fatigue analyses in bolts. Contains parts (a) through (e).</p> <p>Unless the components on which they are installed meet all the conditions of WB-3222.9(d) and thus require no fatigue analysis, the suitability of bolts for cyclic service shall be determined in accordance with the procedures of (a) through (e) below. Thermal stress ratchet shall be evaluated in accordance with WB-3222.9(a).</p> <p><i>(a) Bolting Having Less Than 100.0 ksi (689 MPa) Tensile</i></p>	N/A	No similar paragraph exists in WC.

WB - BOLTING	WC - BOLTING	COMMENTS
<p><i>Strength.</i> Bolts made of material which has specified minimum tensile strength of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of WB-3222.9(e), using the applicable design fatigue curve of Division 1, Appendix I, Figs. 1-9.0 and an appropriate fatigue strength reduction factor [WB-3232.4(c)].</p> <p><i>(b) High Strength Alloy Steel Bolting.</i> High strength alloy steel bolts and studs may be evaluated for cyclic service by the methods of WB-3222.9(e) using the design fatigue curve of Division 1, Appendix I, Figs. 1-9.4 provided:</p> <p>(1) the maximum value of the stress (WB-3232.3) at the periphery of the bolt cross section, resulting from direct tension plus bending and neglecting stress concentration, shall not exceed $2.7Sm$ if the higher of the two fatigue design curves given in Division 1, Appendix I, Figs. 1-9.4 is used. The $2Sm$ limit for direct tension is unchanged.</p> <p>(2) threads shall be of a Vee-type having a minimum thread root radius no smaller than 0.003 in. (0.08 mm).</p> <p>(3) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.</p> <p><i>(c) Fatigue Strength Reduction Factor (WB 3213.17).</i> Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall be not less than 4.0. However, when applying the rules of WB-3232.4(b) for high strength alloy steel bolts, the value used shall be not less than 4.0.</p> <p><i>(d) Effect of Elastic Modulus.</i> Multiply S_{alt} (as determined in WB-3216.1 or WB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of</p>		

WB - BOLTING	WC - BOLTING	COMMENTS
<p>the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the cyclic service being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.</p> <p><i>(e) Cumulative Damage.</i> The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor U, as determined in WB-3222.9(e)(5), does not exceed 1.0.</p>		
<p>WB-3234 Level D Service Limits</p> <p>This paragraph addresses stresses in bolts for Level A Service Limits.</p> <p><i>(a)</i> The rules contained in Division 1, Appendix F may be used in evaluating loadings for which Level D Service Limits are specified, independently of all other loadings.</p> <p><i>(b)</i> If leak tightness of the closure is required by the Design Specification, the analysis of the bolting shall demonstrate that no yielding occurs in the bolt or sealing surface materials. This requirement may be satisfied by using the rules of WB-3232.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3235 Testing Limits</p> <p>Bolts shall not yield for test conditions.</p>	N/A	No similar paragraph exists in WC.
<p>WB-3236 Design Stress Intensity Values</p> <p>States where Design Stress intensity values may be found.</p>	N/A	No similar paragraph exists in WC.

WB - BOLTING	WC - BOLTING	COMMENTS
<p>The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Table 4 for bolting. Values for intermediate temperature may be found by interpolation.</p>		
<p align="center">ARTICLE WB-4000 FABRICATION</p>	<p align="center">ARTICLE WC-4000 FABRICATION</p>	
<p>WB-4700 MECHANICAL JOINTS</p> <p>WB-4710 BOLTING AND THREADING</p> <p>WB-4711 Thread Engagement</p> <p>The threads of all bolts or studs shall be engaged in accordance with the design.</p>	<p>WC-4700 MECHANICAL JOINTS</p> <p>WC-4710 BOLTING AND THREADING</p> <p>WC-4711 Thread Engagement:</p> <p>The threads of all bolts or studs shall be engaged in accordance with the design.</p>	<p>WB and WC are identical.</p>
<p>WB-4712 Thread Lubricants</p> <p>Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any <u>containment</u> material in the system.</p>	<p>WC-4712 Thread Lubricants</p> <p>Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any <u>component</u> material in the system.</p>	<p>WB and WC are identical except that the word containment is used in WB, and the word component is used in WC. This difference is acceptable.</p>
<p>WB-4713 Removal of Thread Lubricants</p> <p>All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.</p>	<p>WC-4713 Removal of Thread Lubricants</p> <p>All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.</p>	<p>WB and WC are identical.</p>
<p>WB-4720 Bolting Flanged Joints</p> <p>This paragraph discusses bolting of gasketed flange joints.</p>	<p>WC-4720 Bolting Flanged Joints</p> <p>This paragraph discusses bolting of gasketed flange joints.</p>	<p>WB and WC are identical.</p>

WB - BOLTING	WC - BOLTING	COMMENTS
<p>In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used.</p> <p>All flanged joints shall be made up with relatively uniform bolt stress.</p>	<p>In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used.</p> <p>All flanged joints shall be made up with relatively uniform bolt stress.</p>	

Table 2 Comparison of Requirements for Design Based on Stress Analysis of Bolts in ASME Section III, Subsection WB-3000 and Appendix XIII

	Article WB-3200	Article XIII-1100
Stress Limits & bolt and gasket requirements	<p>WB-3230 Stress Limits for Bolts</p> <p>The evaluation of bolting requires a number of analysis considerations, including (a) through (f) below and the criteria specified in this subsubarticle for the loads imposed.</p> <p>(a) When gaskets are used for preservice testing only, the design is satisfactory if WB-3231 requirements are satisfied for $m = y = 0$, and the requirements of WB-3232 are satisfied when the appropriate m and y factors are used for the test gasket.</p> <p>WB-3231 Design Limits</p> <p>The number and cross-sectional area of bolts required to resist the Design Pressure shall be determined in accordance with the procedures of Division 1, Appendix E, using the larger of the bolt loads, given by the equations of Division 1, Appendix E, as a Design Mechanical Load. The stress limits shall be the values given in Section II, Part D, Subpart 1, Table 4 for bolting material.</p>	<p>XIII-1180 BOLTING</p> <p>XIII-1181 Bolt and Gasket Requirements</p> <p>(a) The number and cross-sectional area of bolts required to resist internal pressure shall be determined in accordance with the procedures of Mandatory Appendix XI. The allowable bolt design stresses, as used in the equations of Mandatory Appendix XI, shall be the values given in Section II, part D, Subpart 1, Table 4 for bolting materials. When sealing is affected by a seal weld instead of a gasket, the gasket factor m and the minimum design seating stress y may be taken as zero.</p> <p>(b) When gaskets are used for preservice testing only, the design is satisfactory if the above requirements are satisfied for $m=y=0$ and the requirements of XIII-1182 are satisfied when the appropriate m and y are used for test gasket.</p>
Maximum Service Stress	<p>WB-3232.1 Average Stress</p> <p>The maximum value of stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part D, Subpart 1, Table 4.</p> <p>WB-3232.3 Maximum Stress</p>	<p>XIII-1182 Allowable Maximum Service Stresses in Bolts</p> <p>It is recognized that actual service stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the values given in Section II,</p>

	<p>Provides requirements for handling maximum stress in bolts.</p> <p>The maximum value of stress, except as restricted by WB-3232.4(b), at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means that minimize residual torsion.</p>	<p>Part D, Subpart 1, Table 4. The maximum of such service stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part 1, Table 4. Except as restricted by XIV-1322(b), the maximum value of such service stress as the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means that minimize residual torsion.</p>
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Table 3 Comparison of Requirements for Analysis of Cyclic Service of Bolts in ASME Section III, Subsection WB-3000 and Appendix XIV

	Article WB-3232.4	Article XIV-1300
Bolts with less than 100 ksi tensile strength	WB-3232.4(a) Requires appropriate fatigue strength reduction factor	Requires that fatigue strength reduction factor not be less than 4
High-strength bolting	WB-3232.4(b) does not specify material	Specifies materials: SA-193 Grade B7 or B-16 SA-320 Grade L-43 SA-540 Grades B-23 and B-24
Maximum value of stress intensity at the periphery of bolt cross section	WB-3232.4(b)(1)	XIV-1322(b) The requirements are exactly the same.
Thread type and fillet radii	WB-3232.4(b)(2) and (3)	XIV-1322(c) and (d) The requirements are exactly the same.
Fatigue strength reduction factor	WB-3232.4(c) ¹	XIV-1324 Both articles require that the factor not be less than 4 unless a lower value can be justified.
Effect of elastic modulus	WB-3232.4(d)	Not considered.
Cumulative damage	WB-3232.4(f)	XIV-1323 The requirements are exactly the same.

¹The last statement in WB-3232.4(c) is confusing. It states, “However, when applying the rules of WB-3232.4(b) above for high strength alloy steel bolts, the value used shall not be less than 4.0.” This statement is not included in the above comparison.

FCT Quality Assurance Program Document

Appendix E FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	Used Fuel Disposition (UFD) Year End Letter Report – FY2012
Work Package Title and Number	ST Transportation - ANL
Work Package WBS Number	FT-12AN081301
Responsible Work Package Manager	Yung Liu
	(Name/Signature)

Date Submitted 9/11/2012

Quality Rigor Level for Deliverable/Milestone	<input checked="" type="checkbox"/> QRL-3	<input type="checkbox"/> QRL-2	<input type="checkbox"/> QRL-1 <input type="checkbox"/> Nuclear Data	<input type="checkbox"/> N/A*
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This deliverable was prepared in accordance with Argonne National Laboratory
(Participant/National Laboratory Name)

QA program which meets the requirements of
 DOE Order 414.1 NQA-1-2000

This Deliverable was subjected to:

Technical Review

Technical Review (TR)

Review Documentation Provided

- Signed TR Report or,
- Signed TR Concurrence Sheet or,
- Signature of TR Reviewer(s) below

Name and Signature of Reviewers

Yung Liu

Peer Review

Peer Review (PR)

Review Documentation Provided

- Signed PR Report or,
- Signed PR Concurrence Sheet or,
- Signature of PR Reviewer(s) below

*Note: In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity along with the Document Cover Sheet is sufficient to demonstrate achieving the milestone. QRL for such milestones may be also be marked N/A in the work package provided the work package clearly specifies the requirement to use the Document Cover Sheet and provide supporting documentation.