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LBNF Target Containment Code Compliance

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- FESHM Has chapters on Pressure Vessels, Low Pressure Vessels, Vacuum Vessels, and Piping Systems.
- What applies to the LBNF target containment?
- Features of the Target containment include:
 - Pressurized with helium gas at greater than 15 psig (> 1 bar).
 - Purpose is to remove beam deposited heat from target and transfer it to the flowing helium gas.
 - Includes a part with a transverse dimension greater than 6 inches in diameter.
- These features exclude low pressure vessels and vacuum vessels leaving only FESHM 5031 (Pressure vessels) and 5031.1 (Piping) as potentially governing FESHM chapters.

Consider 5031 – Pressure Vessels

- FESHM 5031 uses ASME section VIII to determine when this chapter applies:

This chapter applies to any vessel used at Fermilab that falls within the scope of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), Section VIII, excluding those vessels falling within the scope of the following FESHM chapters:

- 1) Fermilab Environment, Safety, and Health Manual (FESHM) 5031.6 Dressed Niobium SRF Cavity Pressure Safety
- 2) FESHM 5032.2 Guidelines for the Design, Review, and Approval of Liquid Cryogenic Targets
- 3) FESHM 5035 Mechanical Refrigeration Systems.

- What does Section VIII say?

- The Introduction, U-1 Scope identifies when the code can be applied and excludes some applications.
- None of the exclusions appear to apply the target containment at first read.
- However....a careful read of U-1 (c) (2) (-e) describes the large diameter portion of the target containment.

Consider 5031 – Pressure Vessels

(-e) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, and fittings, and the pressure-containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, *distributing*, and metering or controlling flow, provided that pressure-containing parts of such components are generally recognized as piping components or accessories;

- The one portion of the target containment that is greater than 6 inches in diameter can be considered to provide a flow distributing function from the clearly piping portion (Helium supply and return) of the system to the small (< 6 inches) tube surrounding the target where the heat exchange occurs.

Consider 5031 – Pressure Vessels

- The preceding page demonstrates that the LBNF target containment is outside of the scope of FESHM 5031 (Pressure vessels).
- The helium piping and the target containment are better covered by FESHM 5031.1 (piping) and specifically B31.3 as described next:

Consider 5031.1 – Piping Codes

- FESHM 5031 recognizes many piping codes. The code most appropriate to this service is B31.3, Normal Fluid Service.
- Helium is refrigerant 704 per ASHRAE

5.7 Table 1: Applicable code guidance for common systems at Fermilab.

Piping Service or Application	Applicable Code or National Standard											
	ASME B31.1	ASME B31.3 Normal Fluid Service or EN13480	ASME B31.3 Cat. D Fluid Service or EN13480	ASME B31.3 High Purity Fluid Service or EN13480	ASME B31.5	ASME B31.8	ASME B31.9	NFPA 13	NFPA 24	ASME A17.1	ANSI Z223.1	Illinois Plumbing Code, Title 77 Part 890
Building Sump Pump Discharge							X					
Non-Cryogenic System: Compressed air/inert gas (non-cryogenic)							X					
Cryogenic System: Liquid or Gas		X	X									
Domestic Potable Water												X
Elevator and Lift Hydraulic Systems										X		
Fire Protection								X				
Flammable Gas		X										
Fuel Gas Piping from point of delivery to burner											X	
Fuel Gas Transmission Piping						X						
House Vacuum							X					
Industrial Cooling Water external to buildings									X			
Industrial Cooling Water internal to buildings							X					
Inner Pipe of Vacuum Insulated Cryogenic Piping		X										
Low Conductivity Water		X	X									
Non-flammable Scintillator				X								
Pond Water Cooling Systems							X					
Radioactive Water		X										
Refrigerant for HVAC					X							
Refrigerant for Process Systems		X										
Sewer Piping												X
Steam for Heating Applications							X					
Steam for Power Generation	X											
Vacuum Jacket of vacuum insulated piping			X									

Consider 5031.1 – Piping per B31.3 – and complex parts:

- From B31.3 Chapter 1, Scope and Definitions Part 300 (c), (3):
 - (3) The Code generally specifies a simplified approach for many of its requirements. A designer may choose to use a more rigorous analysis to develop design and construction requirements. When the designer decides to take this approach, the designer shall provide to the owner details and calculations demonstrating that design, construction, examination, and testing are consistent with the design criteria of this Code. These details shall be adequate for the owner to verify the validity and shall be approved by the owner. The details shall be documented in the engineering design.
- The relative complex geometry which is not covered by the simplified approach is permitted and can be addressed with FEA as described in the section on Unlisted components in Part 304.7.2:
 - (b) experimental stress analysis, such as described in ASME BPVC, Section VIII, Division 2, Annex 5.F.
 - (c) proof test in accordance with ASME B16.9, MSS SP- 97, or ASME BPVC, Section VIII, Division 1, UG-101.
 - (d) detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 2, Part 5. The basic allowable stress from Table A-1 or Table A-1M shall be used in place of the allowable stress, S , in Division 2 where applicable. Load design factors used in a Division 2 evaluation shall be consistent with the design bases in para. 302.3.2. At design temperatures in the creep range, additional considerations beyond the scope of Division 2 may be necessary.
- Use of the piping chapter is not precluded by the complexity of some of the components of the LBNF target containment.

Materials:

- Grade 2 and Grade 9 Titanium are likely materials of construction.
 - B31.3 provide maximum stress values for several grades of titanium including grade 2.
- An unspecified ceramic material is described in the Proposed Structural Integrity Assurance Procedure Document.
- Unlisted materials including grade 9 Titanium and the ceramic are addressed in section 323.1.2 (Next Page)

Table A-1M Basic Allowable Stresses In Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/Grade	UNS No.	Class/Condition/Temp	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa
1	Ti	Smls. & wid. tube	B338	1	R50250	Annealed	51	...	-59	240	138
2	Ti	Smls. pipe	B861	1	R50250	Annealed	51	...	-59	240	138
3	Ti	Wld. pipe	B862	1	R50250	Annealed	51	...	-59	240	138
4	Ti	Smls. & wid. tube	B338	2	R50400	Annealed	51	...	-59	345	275
5	Ti	Smls. pipe	B861	2	R50400	Annealed	51	...	-59	345	275
6	Ti	Wld. pipe	B862	2	R50400	Annealed	51	...	-59	345	275
7	Ti	Smls. & wid. tube	B338	3	R50550	Annealed	52	...	-59	450	380
8	Ti	Smls. pipe	B861	3	R50550	Annealed	52	...	-59	450	380
9	Ti	Wld. pipe	B862	3	R50550	Annealed	52	...	-59	450	380
10	Ti-Pd	Smls. & wid. tube	B338	7	R52400	Annealed	51	...	-59	345	275
11	Ti-Pd	Smls. pipe	B861	7	R52400	Annealed	51	...	-59	345	275
12	Ti-Pd	Wld. pipe	B862	7	R52400	Annealed	51	...	-59	345	275
13	Ti-0.3Mo-0.8Ni	Smls. & wid. tube	B338	12	R53400	Annealed	52	...	-59	485	345
14	Ti-0.3Mo-0.8Ni	Smls. pipe	B861	12	R53400	Annealed	52	...	-59	485	345
15	Ti-0.3Mo-0.8Ni	Wld. pipe	B862	12	R53400	Annealed	52	...	-59	485	345
16	Ti	Plate, sheet, strip	B265	1	R50250	Annealed	51	...	-59	240	138
17	Ti	Plate, sheet, strip	B265	2	R50400	Annealed	51	...	-59	345	275
18	Ti	Plate, sheet, strip	B265	3	R50550	Annealed	52	...	-59	450	380
19	Ti-Pd	Plate, sheet, strip	B265	7	R52400	Annealed	51	...	-59	345	275
20	Ti-0.3Mo-0.8Ni	Plate, sheet, strip	B265	12	R53400	Annealed	52	...	-59	485	345
21	Ti	Fittings	B363	WPT1	R50250	Annealed	51	...	-59	240	138
22	Ti	Forgings	B381	F-1	R50250	Annealed	51	...	-59	240	138
23	Ti	Fittings	B363	WPT2	R50400	Annealed	51	...	-59	345	275
24	Ti	Forgings	B381	F-2	R50400	Annealed	51	...	-59	345	275
25	Ti	Fittings	B363	WPT3	R50550	Annealed	52	...	-59	450	380
26	Ti	Forgings	B381	F-3	R50550	Annealed	52	...	-59	450	380
27	Ti-Pd	Fittings	B363	WPT7	R52400	Annealed	51	...	-59	345	275
28	Ti-Pd	Forgings	B381	F-7	R52400	Annealed	51	...	-59	345	275
29	Ti-0.3Mo-0.8Ni	Fittings	B363	WPT12	R53400	Annealed	52	...	-59	485	345
30	Ti-0.3Mo-0.8Ni	Forgings	B381	F-12	R53400	Annealed	52	...	-59	485	345
31	Ti	Bar	B348	1	R50250	Annealed	51	...	-59	240	138
32	Ti	Bar	B348	2	R50400	Annealed	51	...	-59	345	275
33	Ti	Bar	B348	3	R50550	Annealed	52	...	-59	450	380
34	Ti-Pd	Bar	B348	7	R52400	Annealed	51	...	-59	345	275
35	Ti-0.3Mo-0.8Ni	Bar	B348	12	R53400	Annealed	52	...	-59	485	345
36	Ti	Castings	B367	C-2	R52550	...	51	(14)(44)	-59	345	275
37	Ti	Castings	B367	C-3	R52550	...	52	(14)(44)	-59	450	380
38	Ti-Pd	Castings	B367	C-7	R52700	...	51	(14)(44)	-59	345	275

Unlisted Materials:

323.1.2 Unlisted Materials. Unlisted materials may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the requirements of this Code. See also ASME BPVC, Section II, Part D, Appendix 5. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.

- Use of titanium grade 2 and grade 9 and ceramics does not preclude the use of B31.3 as the design code for the LBNF target containment.
- Using FESHM 5031.1 and the B31.3 piping code the allowable stress values avoids the 0.8 allowable stress factor required when using the pressure vessel chapter 5031.

ASME Certification, Accreditation, etc.

- Manufactures of parts used in piping systems are not accredited or certified by ASME. Piping does not have a code stamp.

Welding Procedure Specification & Qualifications:

- Both B31 and Section VIII require that welding (or brazing) be performed per a written procedure (WPS), the procedure qualified (PQR), and personnel performing the procedure be qualified to perform the procedure (WPQ). These are spelled out in ASME section IX.
 - Electron beam welds are covered by Section IX, and table QW-260 lists the essential and non-essential variables to be addressed in the WPS.
- Use of qualified welders, performing documented and qualified procedures will be necessary to shown the target containment meets the requirements of B31.3 and FESHM 5031.1
 - Any reputable electron beam welding shop should already be performing EB welds per a qualified procedure and have documented the qualifications of the personnel performing the work.
 - Collecting welding documentation should not be a significant additional effort.

ASME Certification, Accreditation, etc.

- Inspection and Examination of welds is required by B31.3 in chapter 6. This sets the minimum requirements and addresses requirements for severe cycle conditions (fatigue).
- Since the Proposed Structural Integrity Assurance Procedure Document already addresses performing significant inspections including CT scans of the target containment, the requirements of B31.3 are largely met with existing plans.