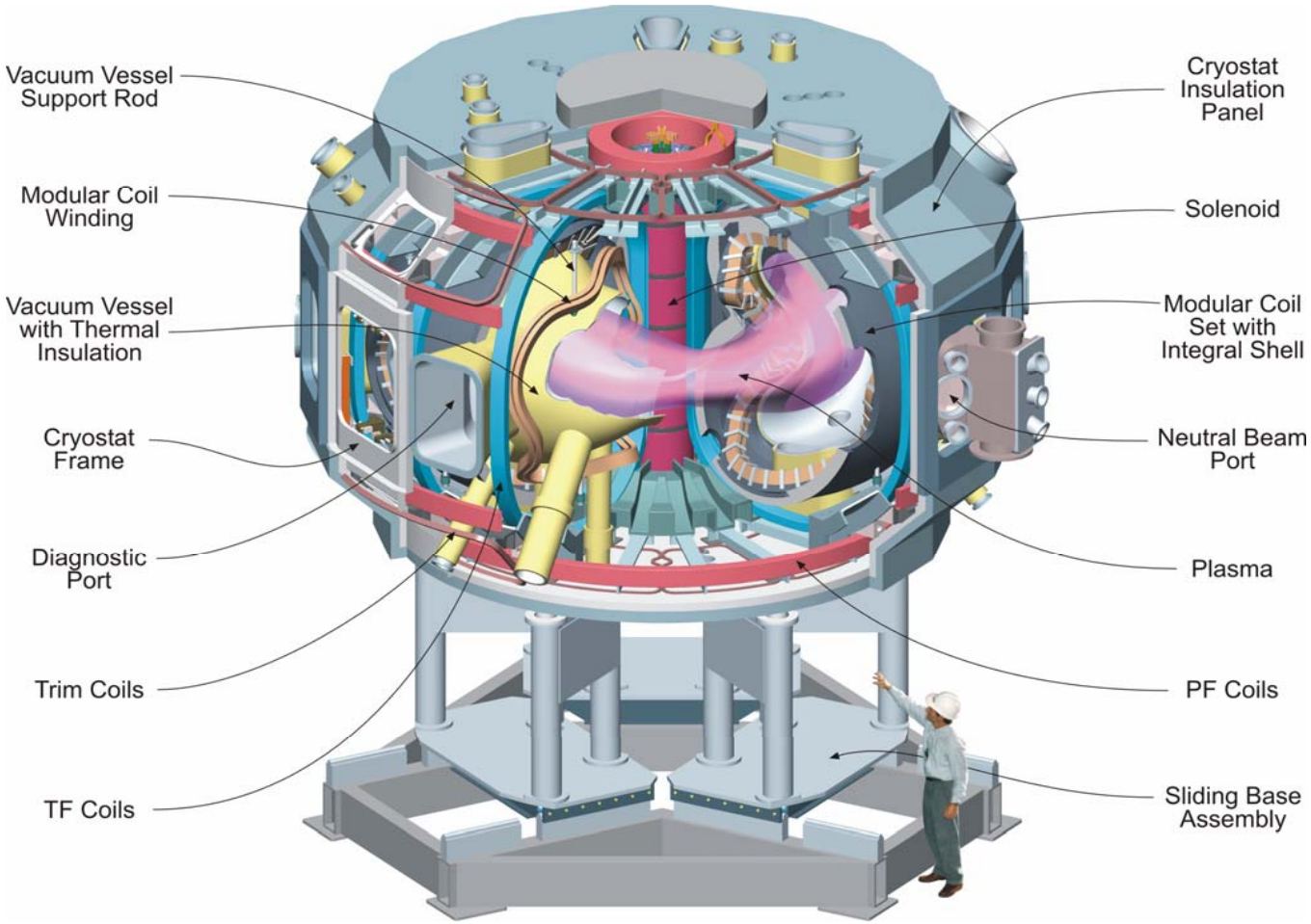
NCSX Modular Coil Welded Interfaces

Presented by the NCSX Engineering Team to the Edison Welding Institute

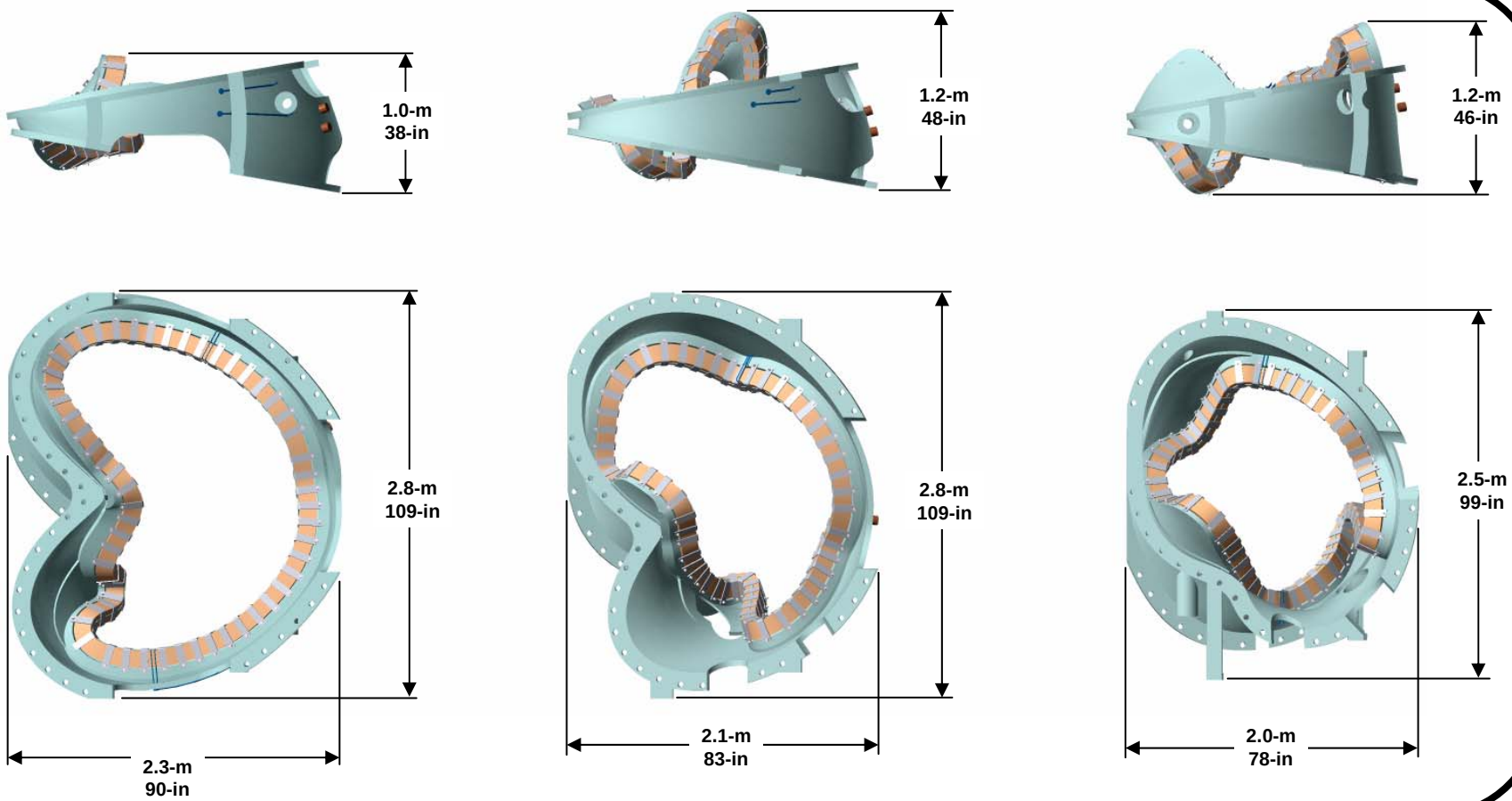
May 30, 2007

NCSX

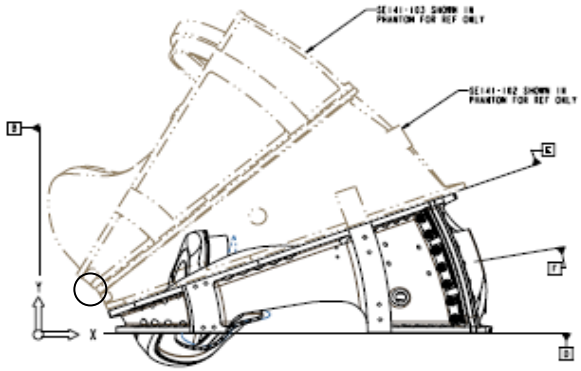

Vacuum Vessel Support Rod
Modular Coil Winding
Vacuum Vessel with Thermal Insulation
Cryostat Frame
Diagnostic Port
Trim Coils
TF Coils
Cryostat Insulation Panel
Solenoid
Modular Coil Set with Integral Shell
Neutral Beam Port
Plasma
PF Coils
Sliding Base Assembly

A NCSX Modular Coil

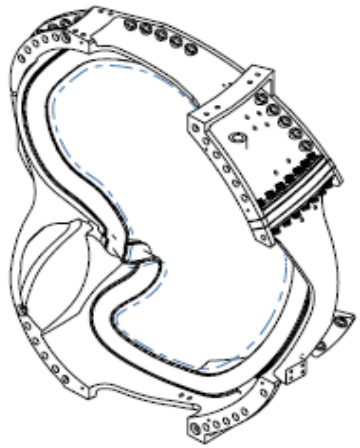
The 3 Types of Modular Coil Castings



Each casting weighs ~6000 lbs.



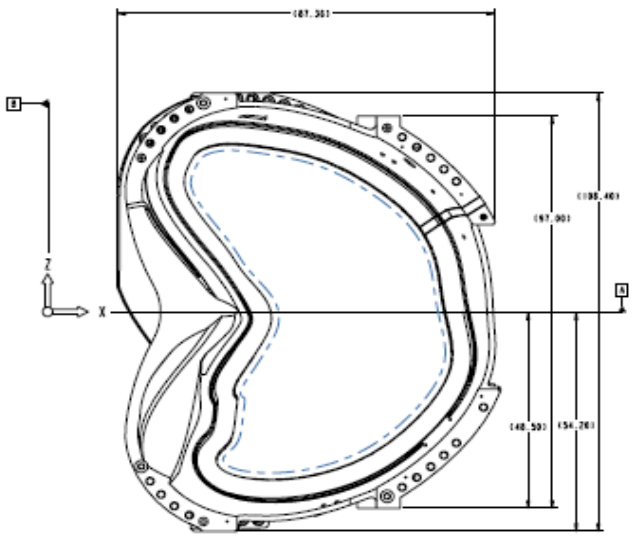
A

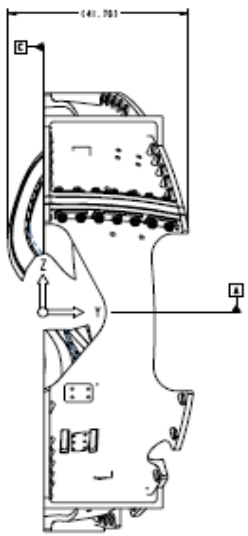


ISOMETRIC VIEW
SCALE 0.10

NOTES:

1. DRAWING PREPARED IN ACCORDANCE WITH ASME Y14.5M-1994.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.
4. DRAWING DEPICTS FINAL MACHINED STATE OF ASSEMBLY DEFINED BY PROVENGINEER FILE SE141-101.PRT.
5. UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE RELATED TO DATUM A- (PRIMARY X-Y PLANE, TOP) DATUM B- (SECONDARY Y-Z PLANE, SIDE) DATUM C- (TERTIARY X-Z PLANE, FRONT)
6. DIMENSIONS APPLY AT TEMPERATURE OF 20-30°C (68-86°F).
7. DIMENSIONS AND TOLERANCES EXCLUDE PROCESS MATERIAL ALLOWANCES WHICH MAY ADD MASS.
8. APPROXIMATE WEIGHT = 4965 LBS
9. MATCH DRILL OR REAM AS REQUIRED TO ACHIEVE RUNNING FIT BETWEEN PARTS AT ASSEMBLY.
3 10. LUBRICATE THREADED SURFACES WITH THRED-GARD ANTI-SEIZE COMPOUND FROM FEDERAL PROCESS CORP, CLEVELAND, OH
11. SEE LATEST REVISION OF SPECIFICATION MCSE-CSPEC-141-03 FOR ADDITIONAL REQUIREMENTS.
12. BOND INSULATING SLEEVE (F/N 5) TO WINDING FORM (F/N 2) USING LOCTITE 411, PER MANUFACTURER'S INSTRUCTIONS.
2 13. ITEM NO. 4 HOLE DIAMETERS TO MATCH OD OF ITEM NO. 6 PLUS .001 TO .002 FOR CLEARANCE FIT.
14. ITEM NO. 7 MAY BE DIVIDED INTO TWO PARTS IF NECESSARY. HOLE DIAMETERS TO MATCH OUTER DIA OF ITEM NO. 5 PLUS .001 TO .002 FOR CLEARANCE FIT.
3 15. TORQUE ITEM NO. 8 TO 1500 +/- 30 FT LBS.

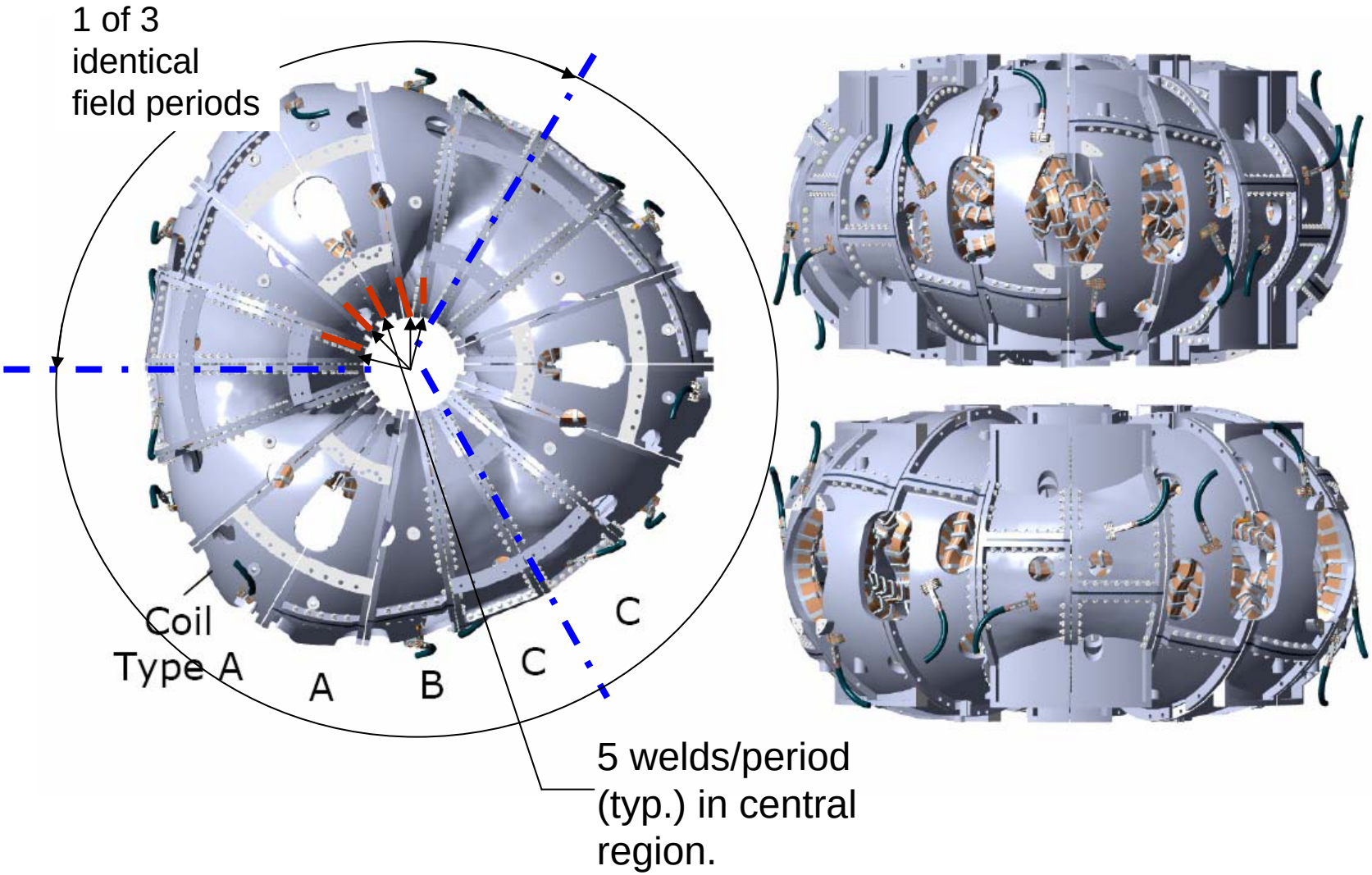




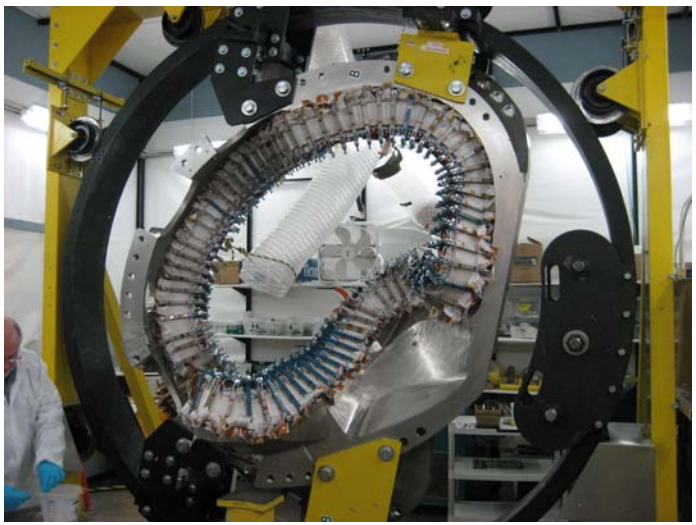
RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting Jerry Siegel

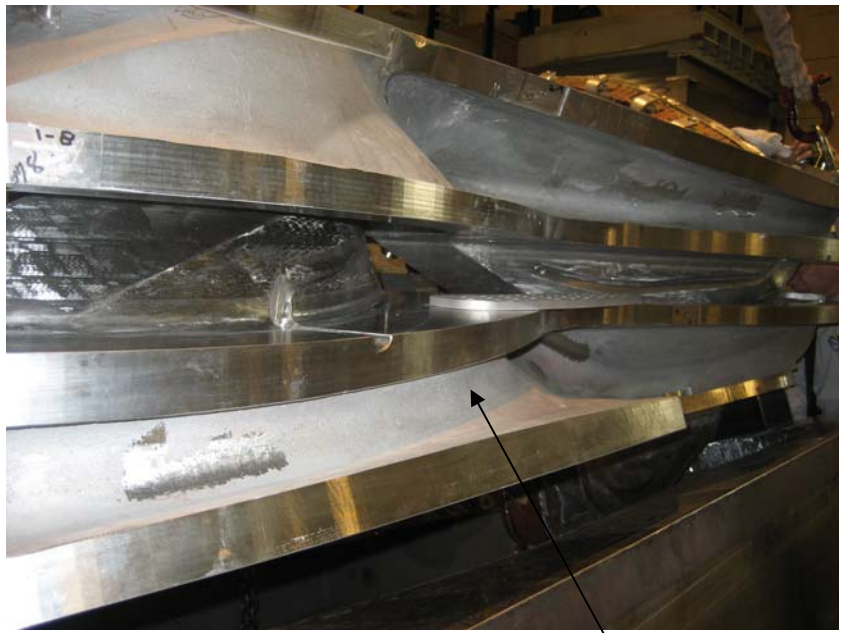
3	2		SE141-142	BEARING PLATE - LONG		10
	4		SE141-141	BEARING PLATE - SHORT		9
	14		95141-960	NUT, 12PT HEX 1.375-6UNC-2B		8
2	2		-7	INS SHEET, 26 X 3 X .063 THK	NEMA GRADE G-11CR	7
	7		95141-936	STUD, 1.375-6UNC-2A X 9.5 LG		6
	14		-5	INS BUSHING, 1.63 OD X 1.38 ID X 1.7 LG	NEMA GRADE G-11CR	5
	1		-4	INS SHEET, 15 X 32 X .063 THK	NEMA GRADE G-11CR	4
	1		SE141-948	POL BREAK SHIM ASSEMBLY TYPE-A		3
	1		SE141-114	PRODUCTION WINDING FORM TYPE-A		2
AR	X		-1	MOD COIL WINDING FORM ASSEMBLY TYPE-A		1
SIZE	-1	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	FIND NO
			NEXT ASSEMBLY	PARTS LIST		

The Inner “Legs” of the Central Coils in a Field Period are Welded – Outer 2/3 of Perimeters are bolted.



Photos of A Winding Form





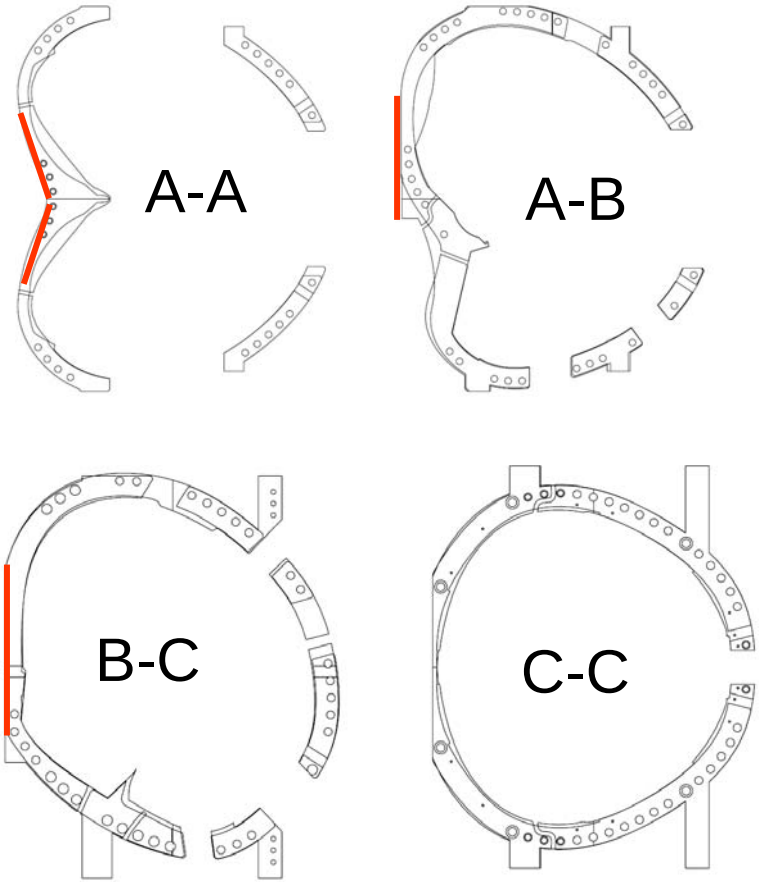
The photo above shows the A-A weld region as the upper casting is being lowered onto the mating casting.

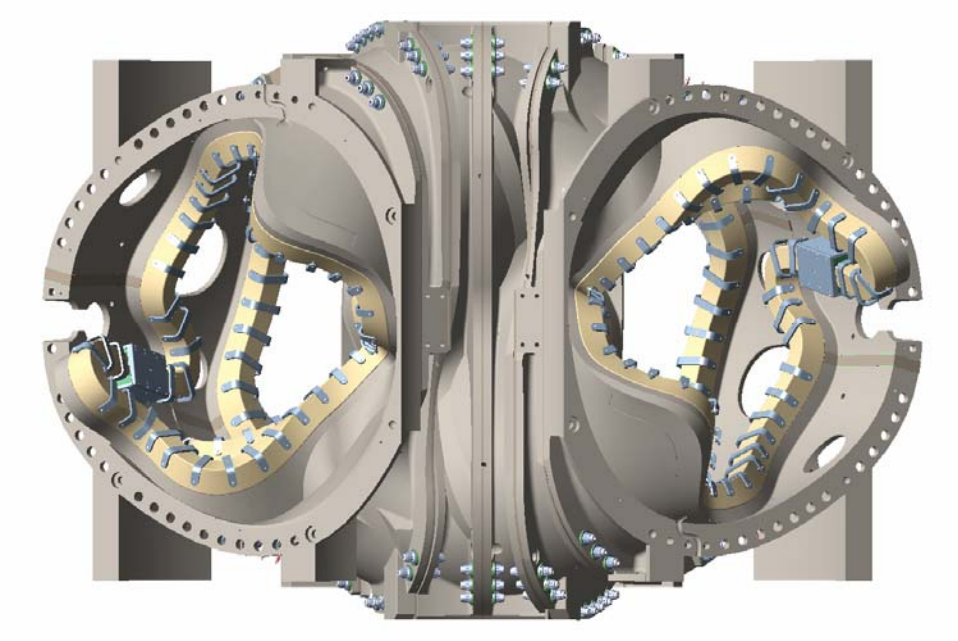
½” shim plate

Inner Leg Weld Regions

Major weld load:

Up to ~ 4.5 kips/inch of running load.



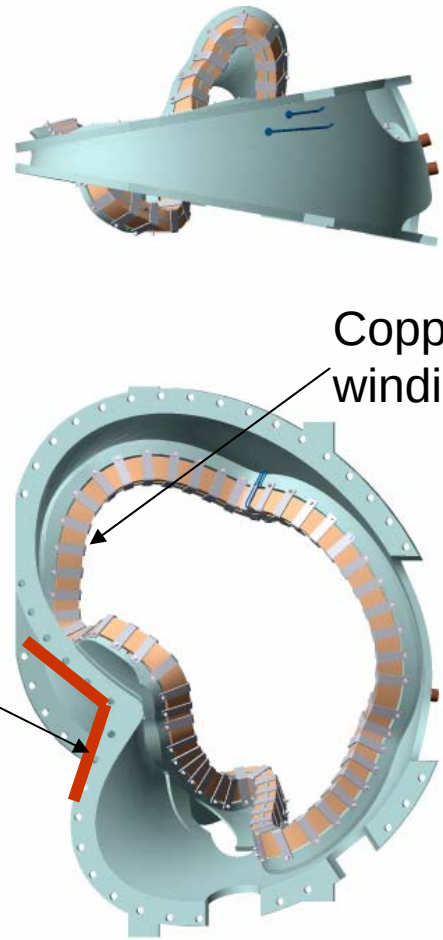


Red indicates weld; note that C-C is not welded.

Issues

- Weld distortion. (See figure on right.)
  - *Preliminary analysis suggests a weld of 0.5 inch is sufficient*
- Permeability of welds must be <1.02.
- Fatigue life of welds. (4 X 130,000 pulses req'd.)

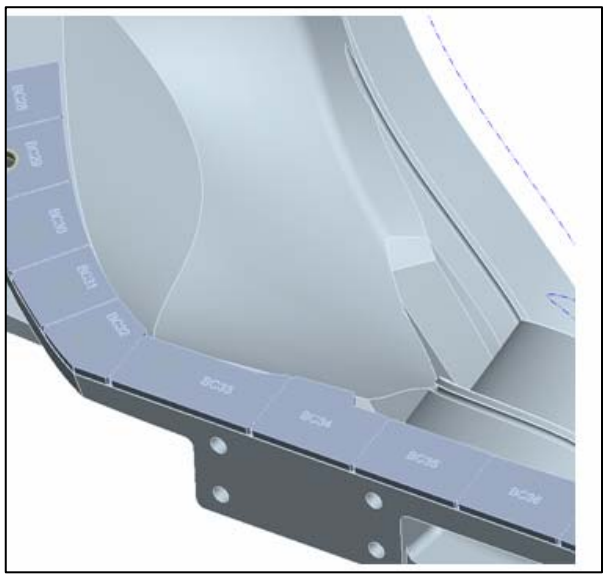
Primary Issue: Will welds here result in distortion >0.010" at the copper windings??

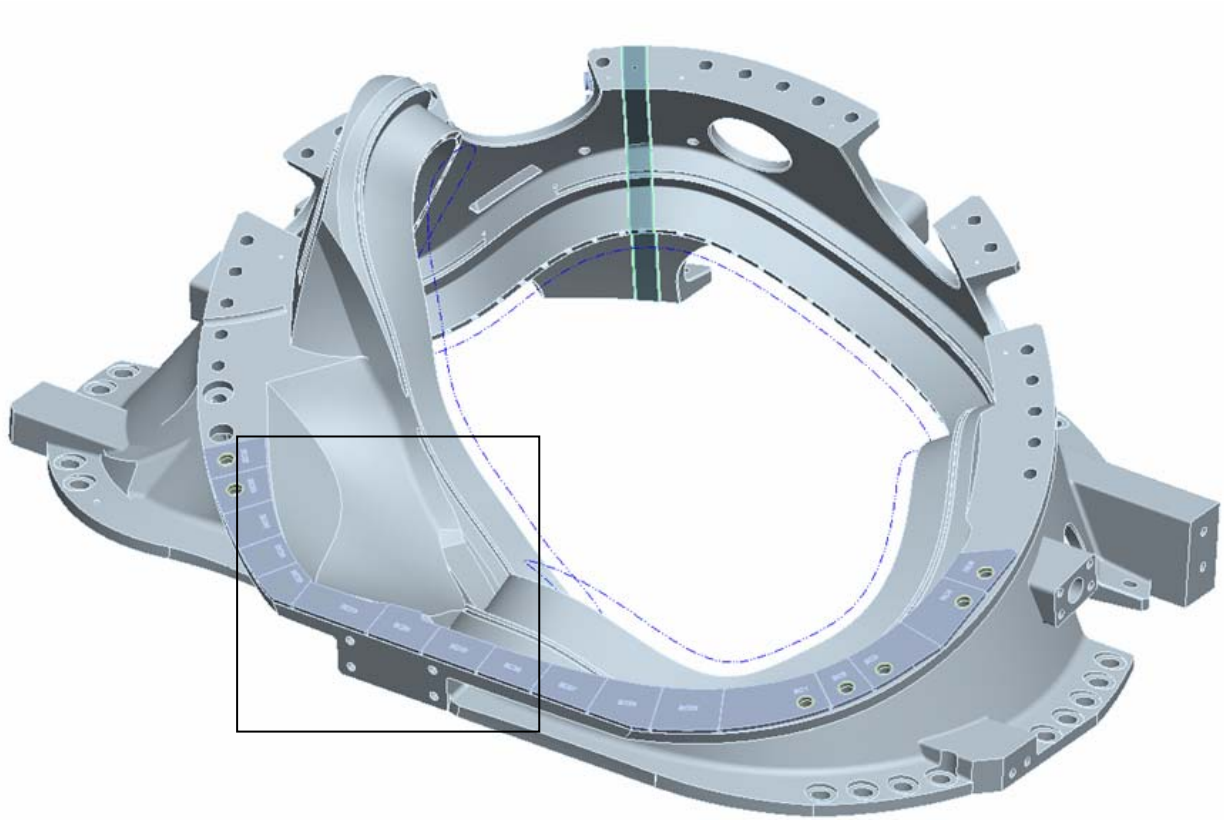


Preliminary analysis suggests a weld of 0.5 inch is sufficient

Inboard shims are cut to shape and thickness

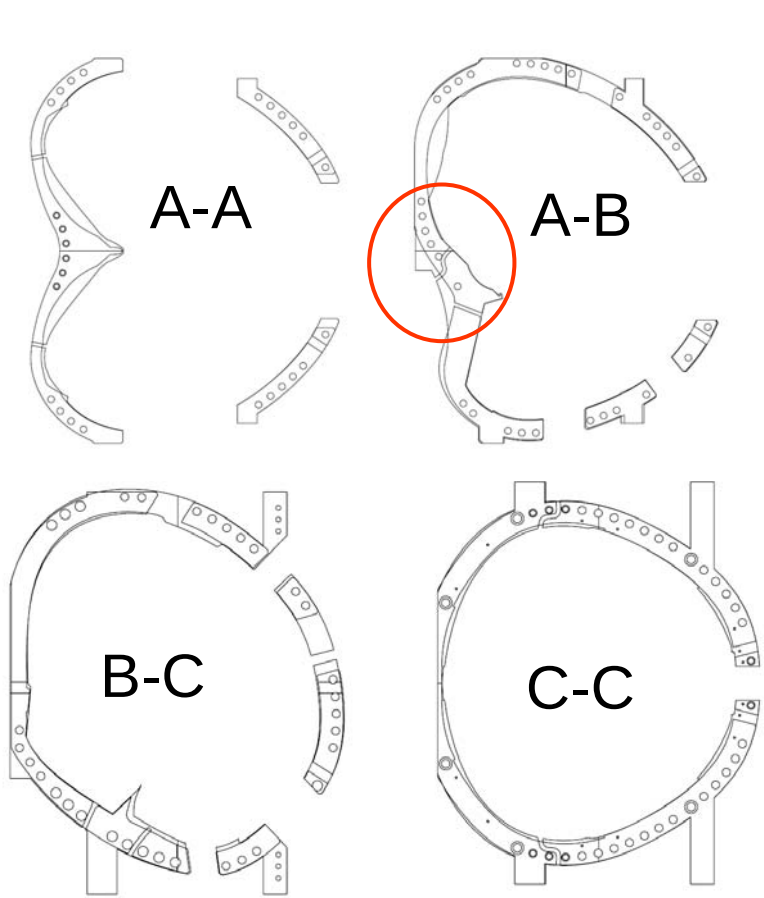
- Shim profile cut on water-jet and one side milled or ground flat
- Other side milled to thickness at assembly
- Shims made from stellalloy
- Shims welded with Metaltek casting repair wire for low permeability

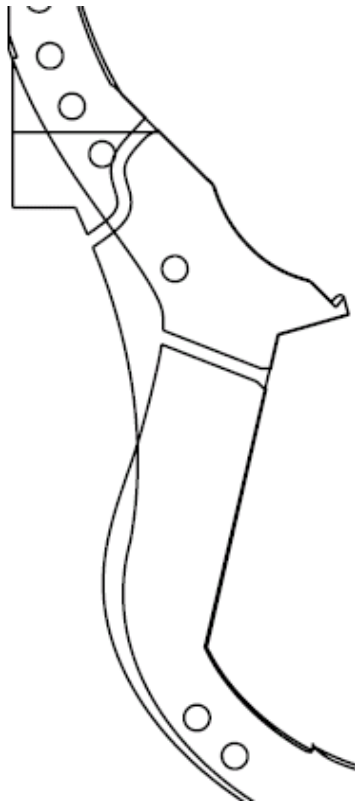


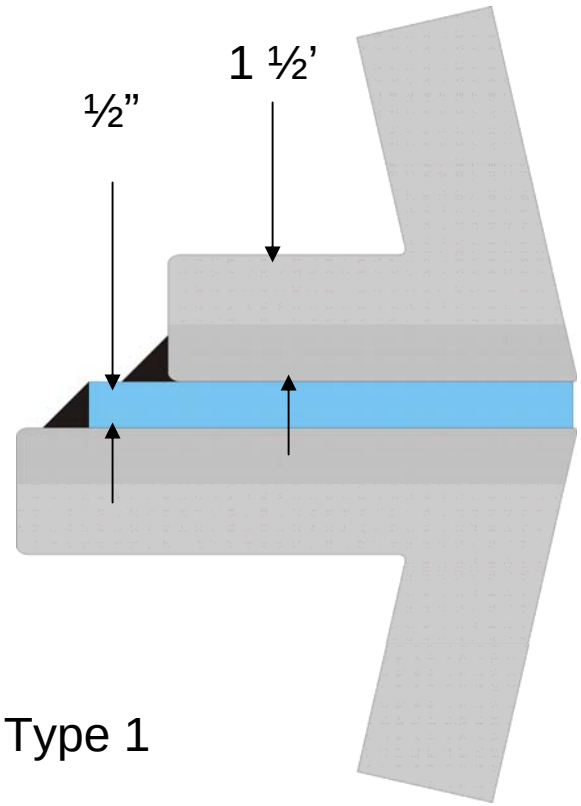


Weld design options depend on location

- Flanges do not match up in some locations



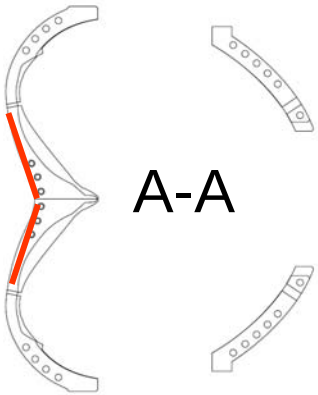


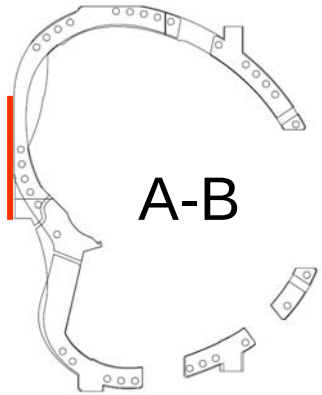


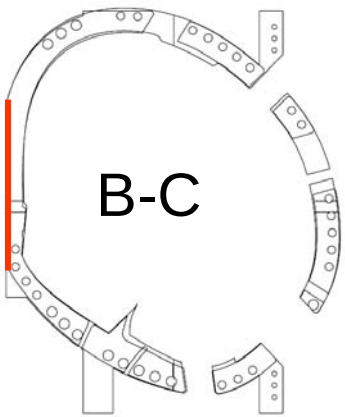
Type 1

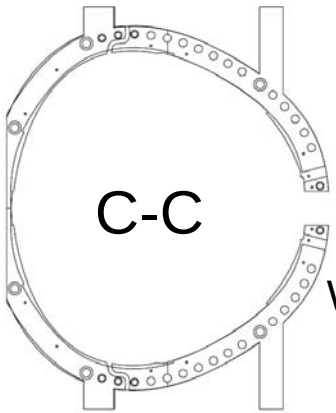
Weld design options depend on location

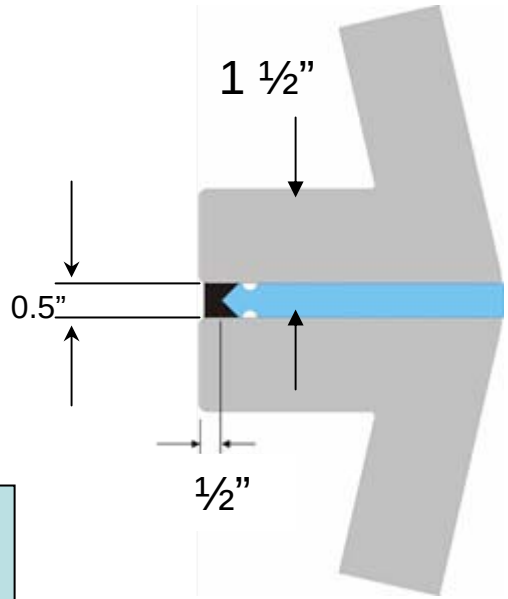
- Flange edges abut solenoid in some areas, shim must be flush



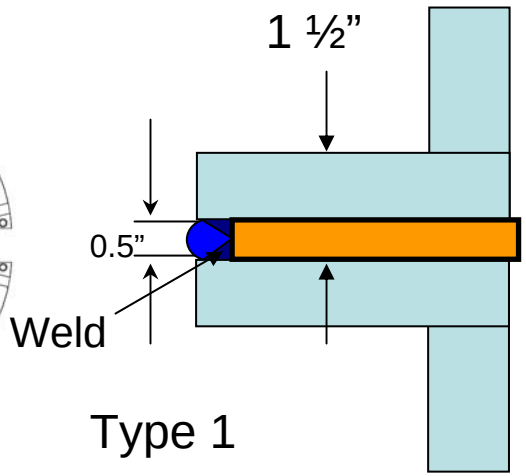








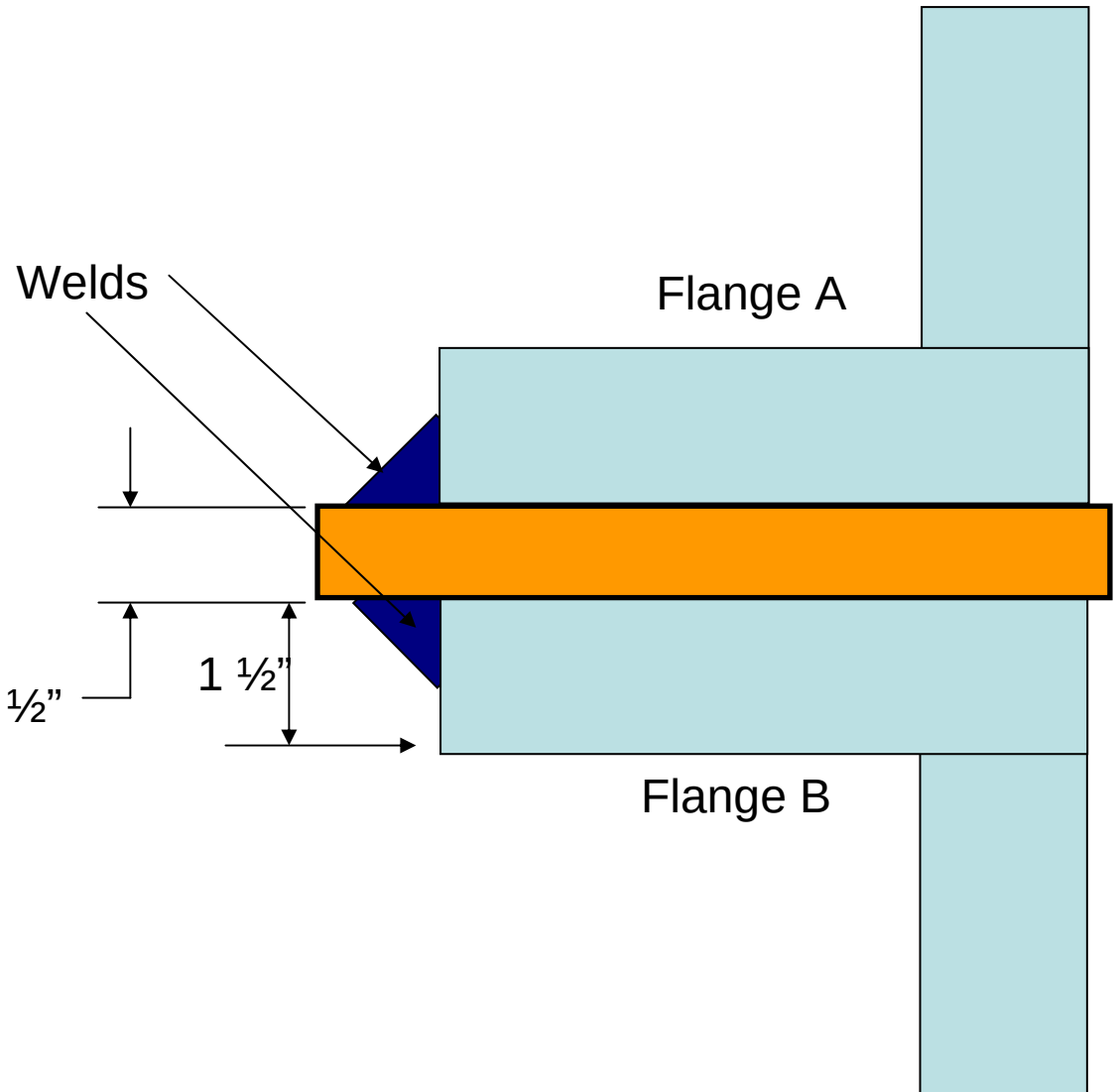
Type 1A

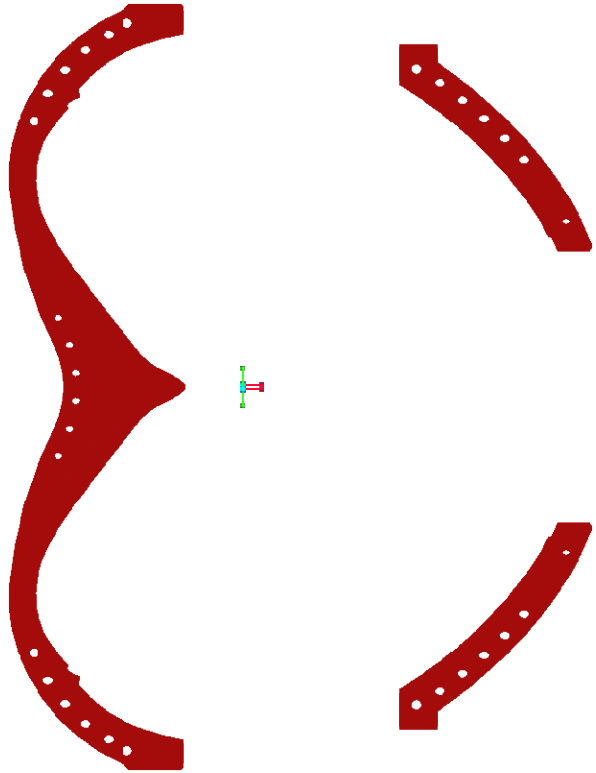


Type 1

(not analyzed yet)

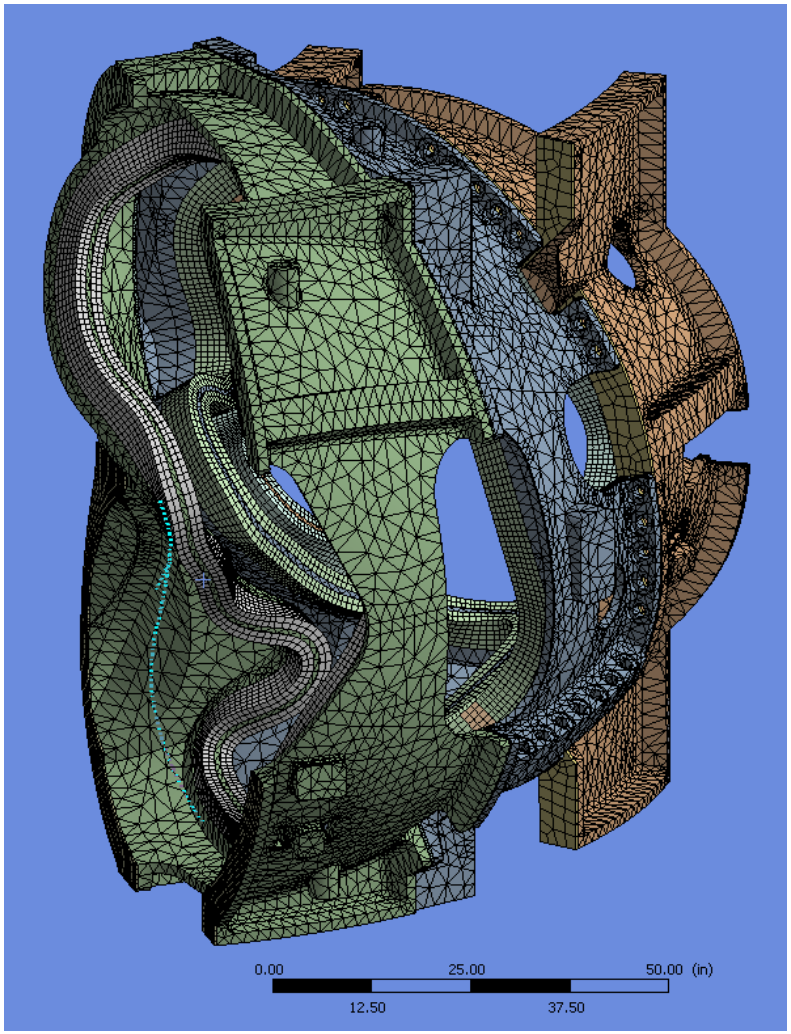
Type 3

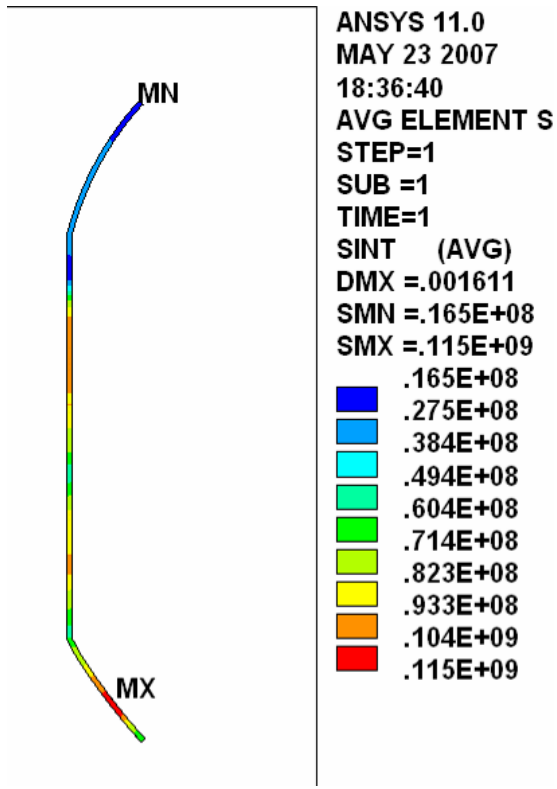




This can be used on non straight sections AA

Weld Stresses Calculated with ANSYS Global Model





Peak Stress of 19,246 psi

Chemical Composition of Casting Alloy and Weld Wire

	C	Mn	Si	Cr	Ni	Mo	P	S	N
Min. %	.040	2.3	--	18.0	13.0	2.1	--	--	.24
Max. %	.070	2.8	0.7	18.5	13.5	2.5	0.035	0.025	.28

Table 3-1 Weight % of Chemical Constituents in Casting Alloy

	C	Mn	Si	Cr	Ni	Mo	P	S	Cu	N
Min. %	--	5.0	--	19.0	15.0	2.5	--	--	--	--
Max. %	0.03	9.0	1.0	22.0	18.0	4.5	0.03	0.02	0.3	0.3

Table 3-2 Weight % of Chemical Constituents of Bare Weld Wire

Casting Alloy Mechanical Properties

Temperature	77K	293K
Elastic Modulus	21 Msi (144.8 Gpa)	20 Msi (137.9 Gpa)
0.2% Yield Strength	72 ksi (496.4 Mpa)	30 ksi (206.8 Mpa)
Tensile Strength	95 ksi (655 Mpa)	78 ksi (537.8 Mpa)
Elongation (Casting)	32%	36%
Elongation (Weld Material)	25%	28%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	50 ft-lbs (67.8 J)

Table 3-4 Minimum Mechanical Properties

Measured Properties of Actual Castings and Weld Wire

updated 2/15/07

AVERAGES

Type C

Casting Compariso		77K (-320F)						293K (RT)						
Property	**Required**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Required**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Elastic Modulus	21 Msi (144.8 Gpa)	23.3	25.5	24.9	26.5	30.2	28.8	20 Msi (137.9 Gpa)	23.1	22.7	21.6	23.1	27.3	24.1
0.2% Yield Strength	72 ksi (496.4 Mpa)	98.4	93.2	97.1	97.8	102.5	99.5	34 ksi (234.4 Mpa)	35.1	36.6	38.3	37.4	38.8	44.5
Tensile Strength	95 ksi (655 Mpa)	170.3	163.8	163.1	164.8	170.9	159.9	78 ksi (537.8 Mpa)	83.7	82.4	82.7	83.1	87.0	83.7
Elongation	32.0%	55.7%	54.3%	55.7%	54.0%	42.4%	42.3%	36.0%	52.0%	53.5%	52.5%	55.7%	58.0%	40.3%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	77.7	84.3	99.7	86.7	80.3	85.3	50 ft-lbs (67.8 J)	142.0	150.7	157.3	175.7	139.0	152.3

Type A

Casting Compariso		77K (-320F)						293K (RT)						
Property	**Required**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**Required**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**
Elastic Modulus	21 Msi (144.8 Gpa)	25.5	25.3	26.7	28.9	26.4	27.9	20 Msi (137.9 Gpa)	21.7	22.2	21.9	22.9	23.1	22.6
0.2% Yield Strength	72 ksi (496.4 Mpa)	97.3	99.9	98.9	100.0	101.0	103.2	34 ksi (234.4 Mpa)	36.6	43.3	43.2	43.8	42.4	44.5
Tensile Strength	95 ksi (655 Mpa)	166.3	165.3	166.0	165.9	165.2	163.0	78 ksi (537.8 Mpa)	82.4	83.7	82.6	84.6	82.2	89.2
Elongation	32.0%	56.0%	56.3%	51.0%	46.0%	48.7%	38.3%	36.0%	53.2%	56.0%	53.3%	50.3%	50.0%	49.0%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	78.7	79.0	87.3	76.7	70.3	73.0	50 ft-lbs (67.8 J)	163.7	164.0	158.0	150.3	146.3	126.7

Type B

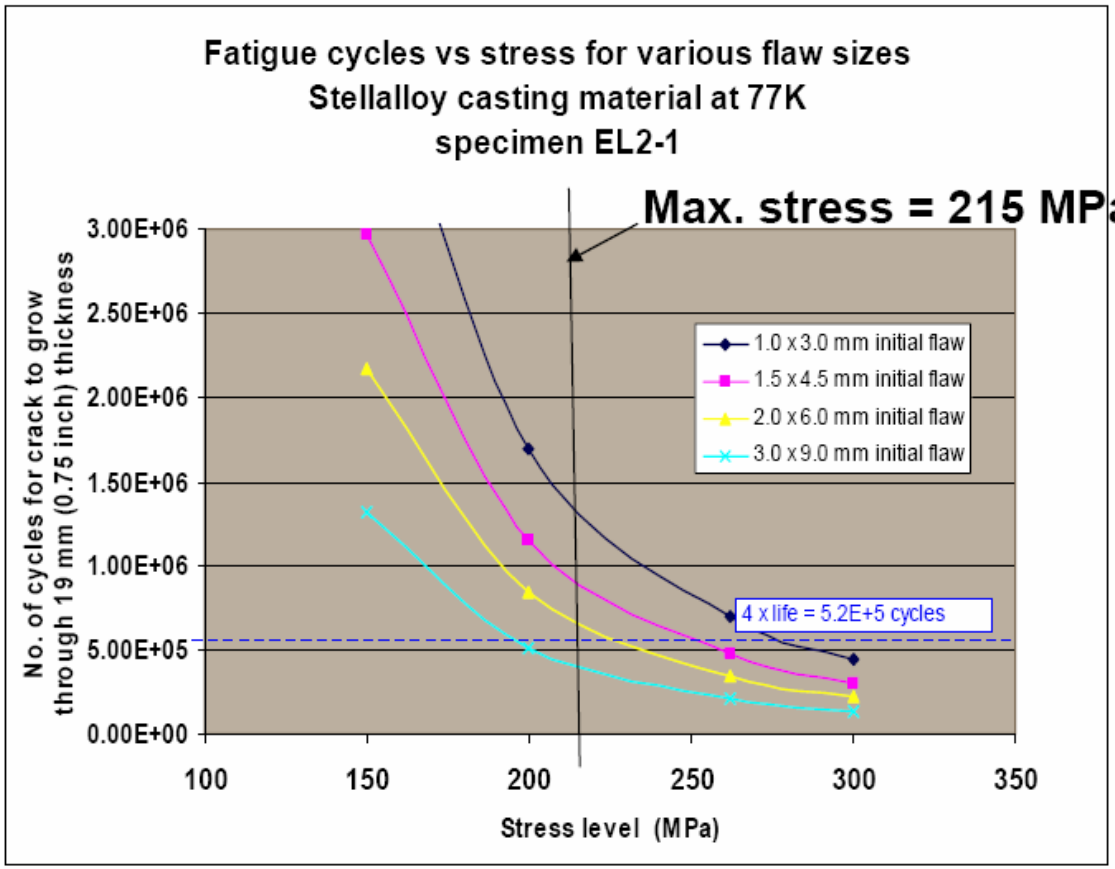
Casting Compariso		77K (-320F)						293K (RT)						
Property	**Required**	**B-1**	**B-2**	**B-3**	**B-4**	**B-5**	**B-6**	**Required**	**B-1**	**B-2**	**B-3**	**B-4**	**B-5**	**B-6**
Elastic Modulus	21 Msi (144.8 Gpa)	25.9	27.4	29.3	25.3	29.3		20 Msi (137.9 Gpa)	22.7	22.5	22.6	22.8	22.6	
0.2% Yield Strength	72 ksi (496.4 Mpa)	98.7	103.9	107.4	100.2	107.4		34 ksi (234.4 Mpa)	43.3	58.9	42.7	42.6	42.7	
Tensile Strength	95 ksi (655 Mpa)	164.9	177.5	172.5	166.1	177.5		78 ksi (537.8 Mpa)	86.0	86.6	84.1	85.6	84.1	
Elongation	32.0%	46.3%	50.3%	56.3%	53.3%	56.3%		36.0%	47.3%	49.5%	44.7%	43.5%	44.7%	
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	88.0	63.7	74.7	65.7	74.7		50 ft-lbs (67.8 J)	146.7	135.7	115.0	119.7	115.0	

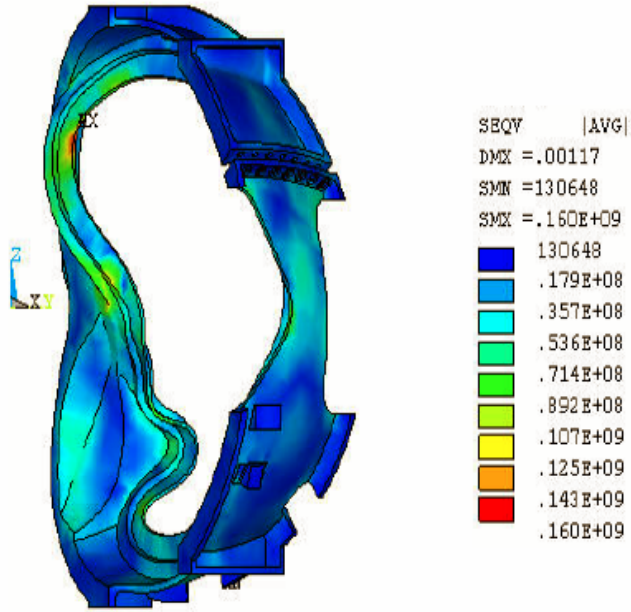
Weld Material		77K (-320F)						293K (RT)							
Property	**Required**	**Lincoln 3018926/78309**	**Lincoln Lot # 3012668/82743**	**Lincoln 3018513/78308**	**Lincoln Lot # 3017006/72262**	**Metrode Lot # WO21735**	**Metrode Lot # WO19711**	**Required**	**Lincoln 3018926/78309 Doc #10**	**Lincoln Lot # 3012668/82743 see previous info -->**	**Lincoln 3018513/78308**	**Lincoln Lot # 3017006/72262**	**Metrode Lot # WO21735**	**Metrode Lot # WO19711**	**Previously Reported Heat/Lot # 3012668/82743**
Elastic Modulus	21 Msi (144.8 Gpa)	23.3	27.1 Doc#9	27	23.2	24.3	26.4 Doc#9	20 Msi (137.9 Gpa)	24.5 Doc 10	22.6	23.4	24.9	23	23.1 Doc#10	25.5 Doc#10
0.2% Yield Strength	72 ksi (496.4 Mpa)	114.3	126.3 Doc#9	128.2	112.4	102.1	109.5 Doc#9	34 ksi (234.4 Mpa)	56.9 Doc #10	57.4	65.2	54.9	54.8	63.9 Doc#10	56.5 Doc#10
Tensile Strength	95 ksi (655 Mpa)	157.5	187.7 Doc#9	182.1	176.4	166.6	166.9 Doc#9	78 ksi (537.8 Mpa)	93.9 Doc #10	93.7	95.2	92.1	88.2	98.1 Doc#10	85 Doc#10
Elongation	32%	16.0%	33% Doc#9	34.0%	48.0%	38.0%	34% Doc#9	36.0%	42% Doc #10	41.5%	38.0%	42.5%	37.5%	54% Doc#10	55% Doc#10
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	36.33	51 Doc#11	54	53	48	48 Doc#11	50 ft-lbs (67.8 J)	100 Doc #10	98	103	117	93	111 Doc#12	102 Doc#12

Derivation of S_m

- Per the NCSX Structural Design Criteria, Sm shall be the lesser of 1/3 of the ultimate strength or 2/3 of the yield strength at temperature.
- Since the weld region includes the Stelalloy casting, weld metal, HAZ, and shims made of 316-LN, the strength values shall be the lesser of these.
- At this time, 316-LN for the shim material has not been finalized, so for the present we shall use the lowest values between the Stellalloy and the weld material at 77K. For the yield, this is 93.2 ksi for the C2 casting; 2/3 of yield =61.5 ksi. **The lowest ultimate strength is 157.5 for the weld wire; 1/3 of this =52.5, so this is what we shall use.**
- A weld efficiency factor factor of 0.55 shall be applied to this, since it is a *butt joint*. ***Therefore, the Sm=0.6*52.5=28.9ksi.***
- ***Issue: What is required for fatigue?*** What stress concentration factor should be used for this type of weld?

Stellalloy has Good Fatigue Properties





Stress in the Type A Castings