Design review of pressure vessel manufactured in carbon steel in the 1970's to storage liquid chlorine, in order to prevent brittle fracture.

Argentina, Buenos Aires November, 18 2016

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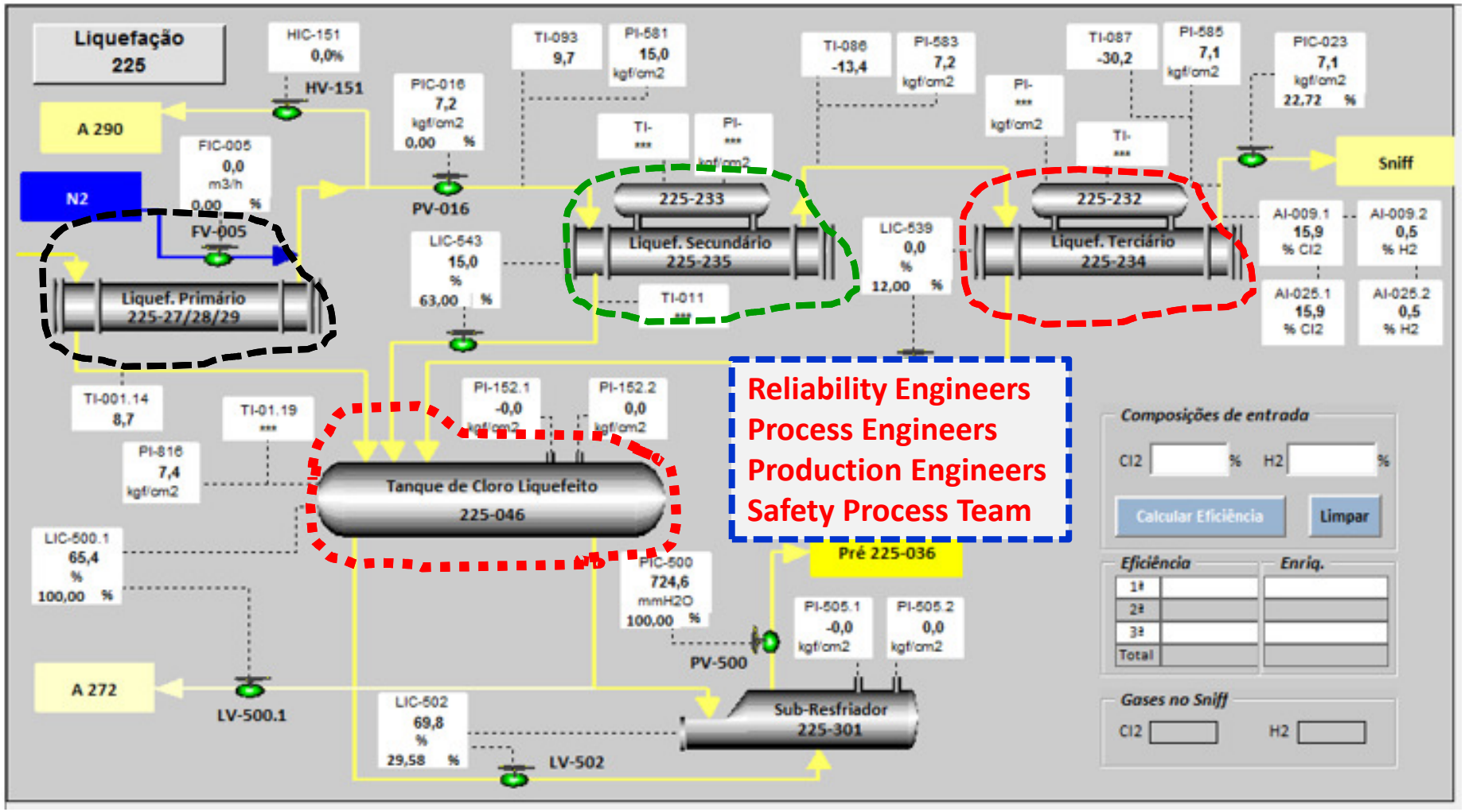

Screen of chlorine liquefaction.

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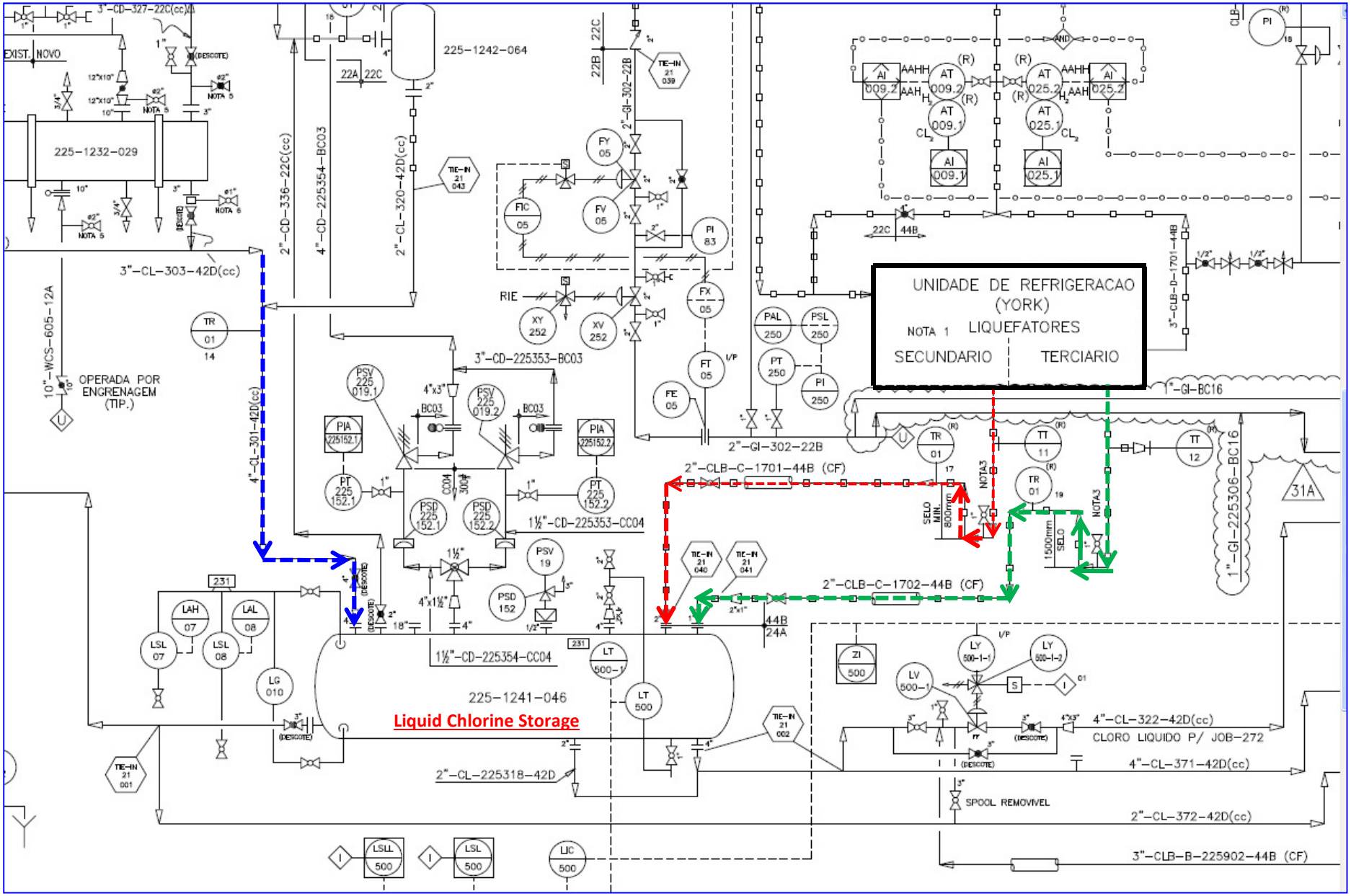

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Old Pressure Vessel - Installed 1977	
Code	ASME SECTION VIII DIV I ED 1971
Service	Liquid Chlorine - Lethal
Volume (m3)	5,845
Design Pressure (Kgf/cm2g)	14,8
Design Temperature (ºC)	-21
Operation Temperature (ºC)	balance between 37 and -21
MDMT (ºC)	Not Informed
RX	FULL
PWHT	YES
Materials: Shell and Heads	SA 285 Gr C PVQ
Fittings	ASME B 16.5 300 PSI
Flanges	SA 181 Gr I
Neck	SA 106 Gr B
Manholle	Neck SA 285 Gr C PVQ
Bolts and Nuts	SA 193 Gr 7 and SA 194 2 H

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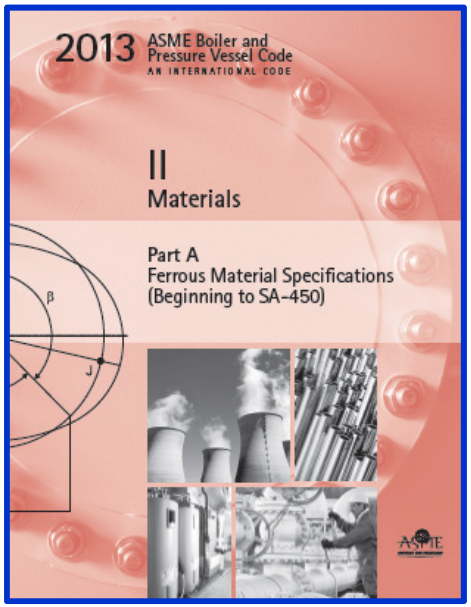
ASME SECTION II - Part D MECHANICAL PROPERTIES		
Material Specification	Allowable Stress @ Tdesign [Mpa]	Yield Stress @ Troom [Mpa]
SA-285 Gr C	95,0	207,0
SA-106 Gr B	103,5	241,0

SPECIFICATION FOR PRESSURE VESSEL PLATES, CARBON STEEL, LOW- AND INTERMEDIATE-TENSILE STRENGTH

SA-285/SA-285M



1.1 This specification covers carbon steel plates of low- and intermediate-tensile strengths which may be made by killed, semi-killed, capped, or rimmed steel practices at the producer's option. These plates are intended for fusion-welded pressure vessels.

1.2 Plates under this specification are available in three grades having different strength levels as follows:

Grade	Tensile Strength, ksi [MPa]
A	45–65 [310–450]
B	50–70 [345–485]
C	55–75 [380–515]

NOTE 1—For killed carbon steels only refer to the following ASTM specifications:

A 299/A 299M Pressure Vessel Plates, Carbon Steel, Manganese-Silicon.

A 515/A 515M Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service

A 516/A 516M Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service.

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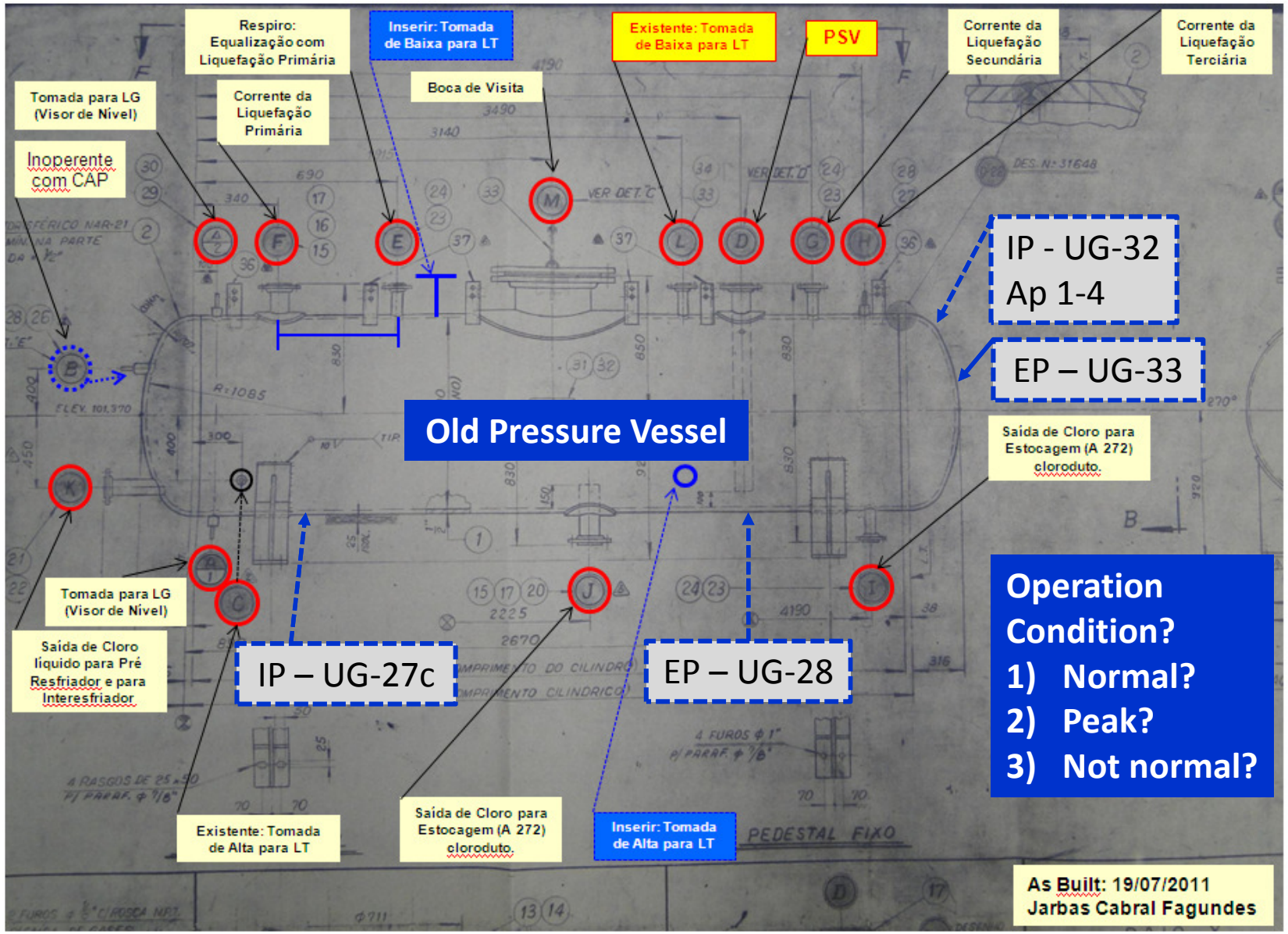

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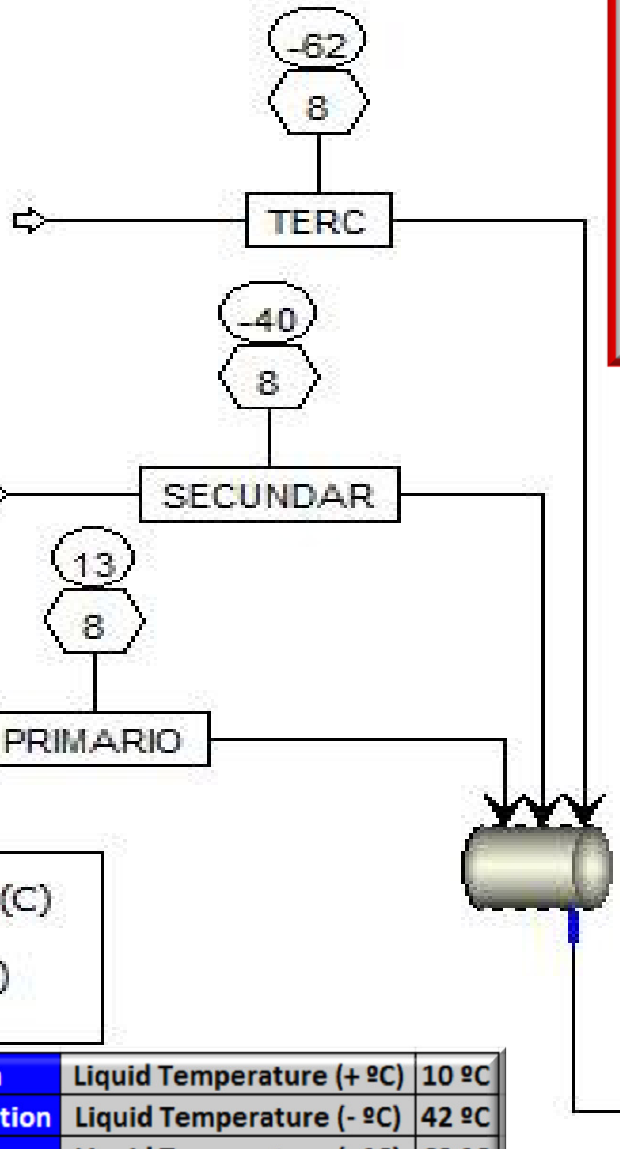
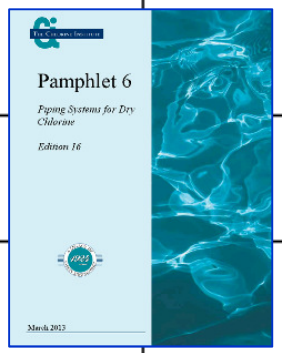


Starting condition of the Unit: Inventory with liquid chlorine at - 45ºC (-49ºF) which can cause flashing.

Nozlle F - Inlet - Primay Liquefaction	Liquid Temperature (+ ºC)	10 ºC
Nozlle G - Inlet - Secundary Liquefaction	Liquid Temperature (- ºC)	42 ºC
Nozlle H - Inlet - Terciary Liquefaction	Liquid Temperature (- ºC)	62 ºC

Pamphlet 6 – Piping System for Dry Chlorine

Service Class	Fluid State	Design Pressure	Design Temperature
Class I	Gas Only	Vacuum to 150 PSIG (1034 kPa)	-20°F to 300°F (-29°C to 149°C)
Class II	Gas Only	Vacuum to 150 PSIG (1034 kPa)	-50°F to 300°F (-46°C to 149°C)
Class III	Gas Only	Vacuum to 150 PSIG (1034 kPa)	-150°F to 300°F (-101°C to 149°C)
Class IV[1]	Gas or Liquid	Vacuum to 300 PSIG (2068 kPa)	-20°F to 300°F (-29°C to 149°C)
Class V[1]	Gas or Liquid	Vacuum to 300 PSIG (2068 kPa)	-50°F to 300°F (-46°C to 149°C)
Class VI[1]	Gas or Liquid	Vacuum to 300 PSIG (2068 kPa)	-150°F to 300°F (-101°C to 149°C)



[1] Piping classes corresponding to the fluid state "gas or liquid" are to be used for all liquid-only lines and gas lines where the possibility of liquid entry exists or where there is the possibility that gas in a line may liquefy.

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ASME B 16.5 - Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard

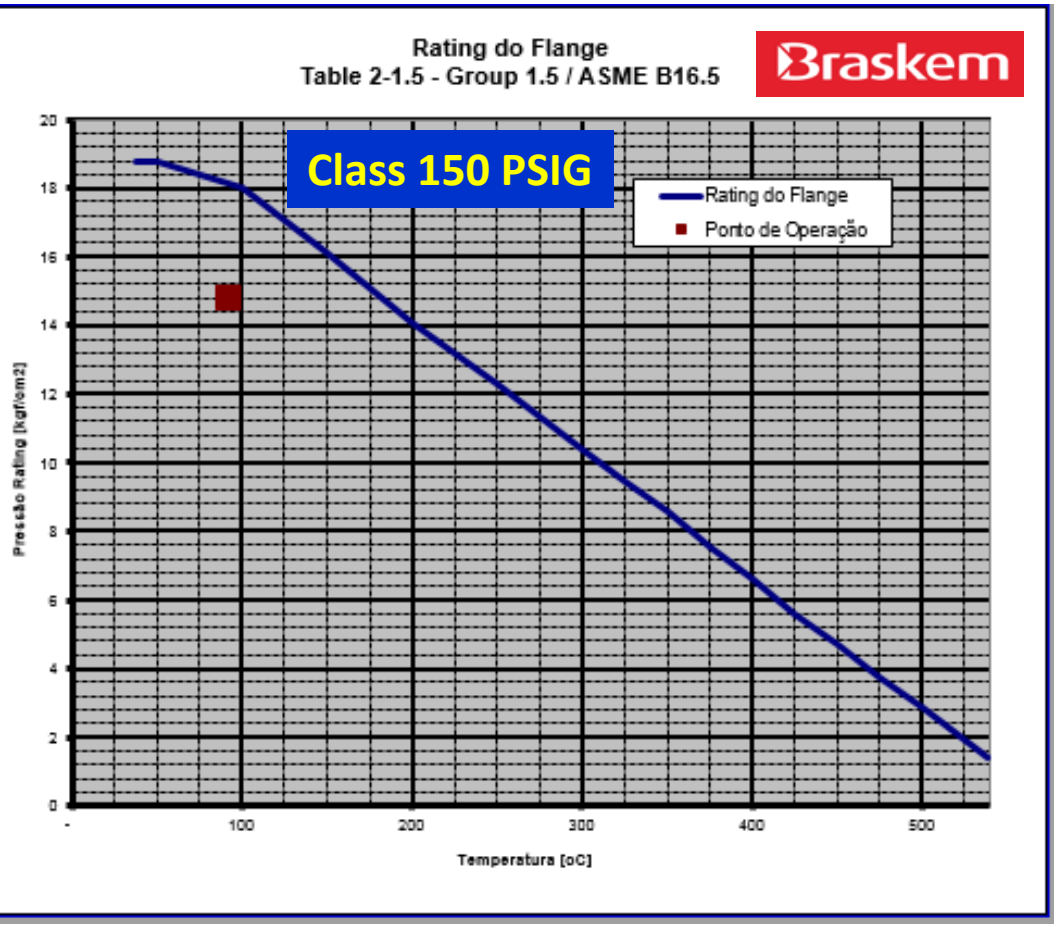
Table 2-1.5 Pressure-Temperature Ratings for Group 1.5 Materials

IDENTIFICAÇÃO DA TUBULAÇÃO →	Pressure Vessels 225 I241046	
MATERIAL DO FLANGE →	SA 387 Gr F1	
CLASSE DE PRESSÃO DO FLANGE →	150	#
CONDIÇÕES DE OPERAÇÃO DA TUBULAÇÃO		
PRESSÃO MÁXIMA →	14,8	[kgf/cm²]
TEMPERATURA MÁXIMA →	93,0	[°C]
CONDIÇÕES LIMITES DO ASME B16.5		**ACEITÁVEL**
PRESSÃO DO RATING @ Tmax	18,1	[kgf/cm²] SIM
LIMITE DE TEMPERATURA DO F	538,0	[°C] SIM

Nominal Designation	Forgings	Castings	Plates
C-½Mo	A 182 Gr. F1 (1)	...	A 204 Gr. A (1)
C-½Mo	...	...	A 204 Gr. B (1)

Working Pressures by Classes, bar

	Class						
Temp., °C	150	300	400	600	900	1500	2500
-29 to 38	18.4	48.0	64.0	96.0	144.1	240.1	400.1
50	18.4	48.0	64.0	96.0	144.1	240.1	400.1
100	17.7	47.9	63.9	95.9	143.8	239.7	399.5
150	15.8	47.3	63.1	94.7	142.0	236.7	394.5
200	13.8	45.8	61.1	91.6	137.4	229.0	381.7
250	12.1	44.5	59.3	89.0	133.5	222.5	370.9
300	10.2	42.9	57.0	85.7	128.6	214.4	357.1
325	9.3	41.4	55.0	82.6	124.0	206.6	344.3
350	8.4	40.3	53.6	80.4	120.7	201.1	335.3
375	7.4	38.9	51.6	77.6	116.5	194.1	323.2
400	6.5	36.5	48.9	73.3	109.8	183.1	304.9
425	5.5	35.2	46.5	70.0	105.1	175.1	291.6
450	4.6	33.7	45.1	67.7	101.4	169.0	281.8
475	3.7	31.7	42.3	63.4	95.1	158.2	263.9
500	2.8	24.1	32.1	48.1	72.2	120.3	200.5
538	1.4	11.3	15.1	22.7	34.0	56.7	94.6



Pamplhet 6 – Piping Systems for Dry Chlorine – Edition 15 – The Chlorine Institute, Inc

Class V	Gas or Liquid	Vacuum to 300 PSIG (2068 Kpa)	-50ºF to 300ºF (-46ºF to 149ºC)

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ASME B 16.5 - Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard

Table 2-1.5 Pressure-Temperature Ratings for Group 1.5 Materials

IDENTIFICAÇÃO DA TUBULAÇÃO	*Pressure Vessels 225 I241 046*	
MATERIAL DO FLANGE →	*SA 182 Gr F1*	
CLASSE DE PRESSÃO DO FLANGE	*300* #	
CONDIÇÕES DE OPERAÇÃO DA TUBULAÇÃO		
PRESSÃO MÁXIMA →	*14,8* [kgf/cm²]	
TEMPERATURA MÁXIMA →	*300* [°C]	
CONDIÇÕES LIMITES DO ASME B16.5		**ACEITÁVEL**
PRESSÃO DO RATING @ Tmax	48,8 [kgf/cm²]	*SIM*
LIMITE DE TEMPERATURA DO R	538,0 [°C]	*SIM*

Nominal Designation	Forgings	Castings	Plates
C-½Mo	A 182 Gr. F1 (1)	...	A 204 Gr. A (1)
C-½Mo	...	...	A 204 Gr. B (1)

Working Pressures by Classes, bar

	Class						
Temp., °C	150	300	400	600	900	1500	2500
-29 to 38	18.4	48.0	64.0	96.0	144.1	240.1	400.1
50	18.4	48.0	64.0	96.0	144.1	240.1	400.1
100	17.7	47.9	63.9	95.9	143.8	239.7	399.5
150	15.8	47.3	63.1	94.7	142.0	236.7	394.5
200	13.8	45.8	61.1	91.6	137.4	229.0	381.7
250	12.1	44.5	59.3	89.0	133.5	222.5	370.9
300	10.2	42.9	57.0	85.7	128.6	214.4	357.1
325	9.3	41.4	55.0	82.6	124.0	206.6	344.3
350	8.4	40.3	53.6	80.4	120.7	201.1	335.3
375	7.4	38.9	51.6	77.6	116.5	194.1	323.2
400	6.5	36.5	48.9	73.3	109.8	183.1	304.9
425	5.5	35.2	46.5	70.0	105.1	175.1	291.6
450	4.6	33.7	45.1	67.7	101.4	169.0	281.8
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500	2.8	24.1	32.1	48.1	72.2	120.3	200.5
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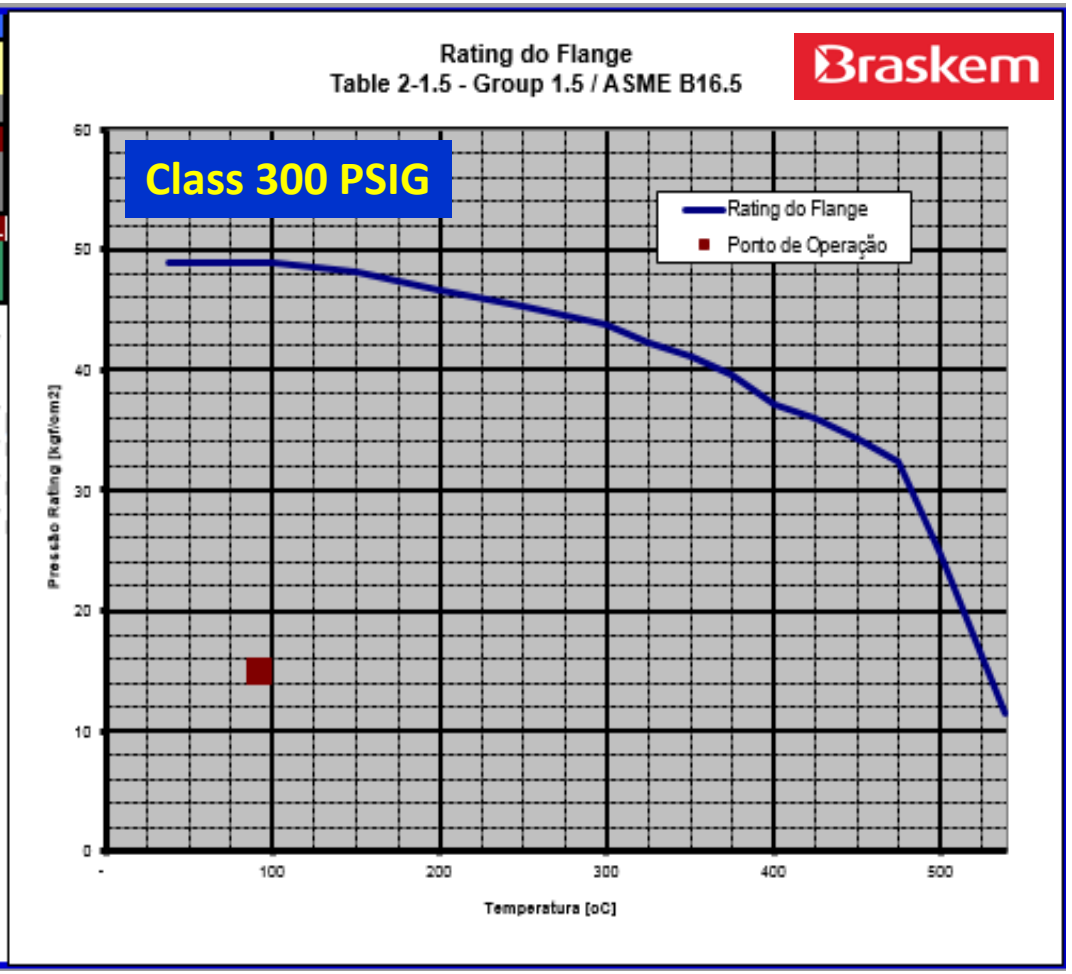

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Class V	Gas or Liquid	Vacuum to 300 PSIG (2068 Kpa)	-50ºF to 300ºF (-46ºF to 149ºC)

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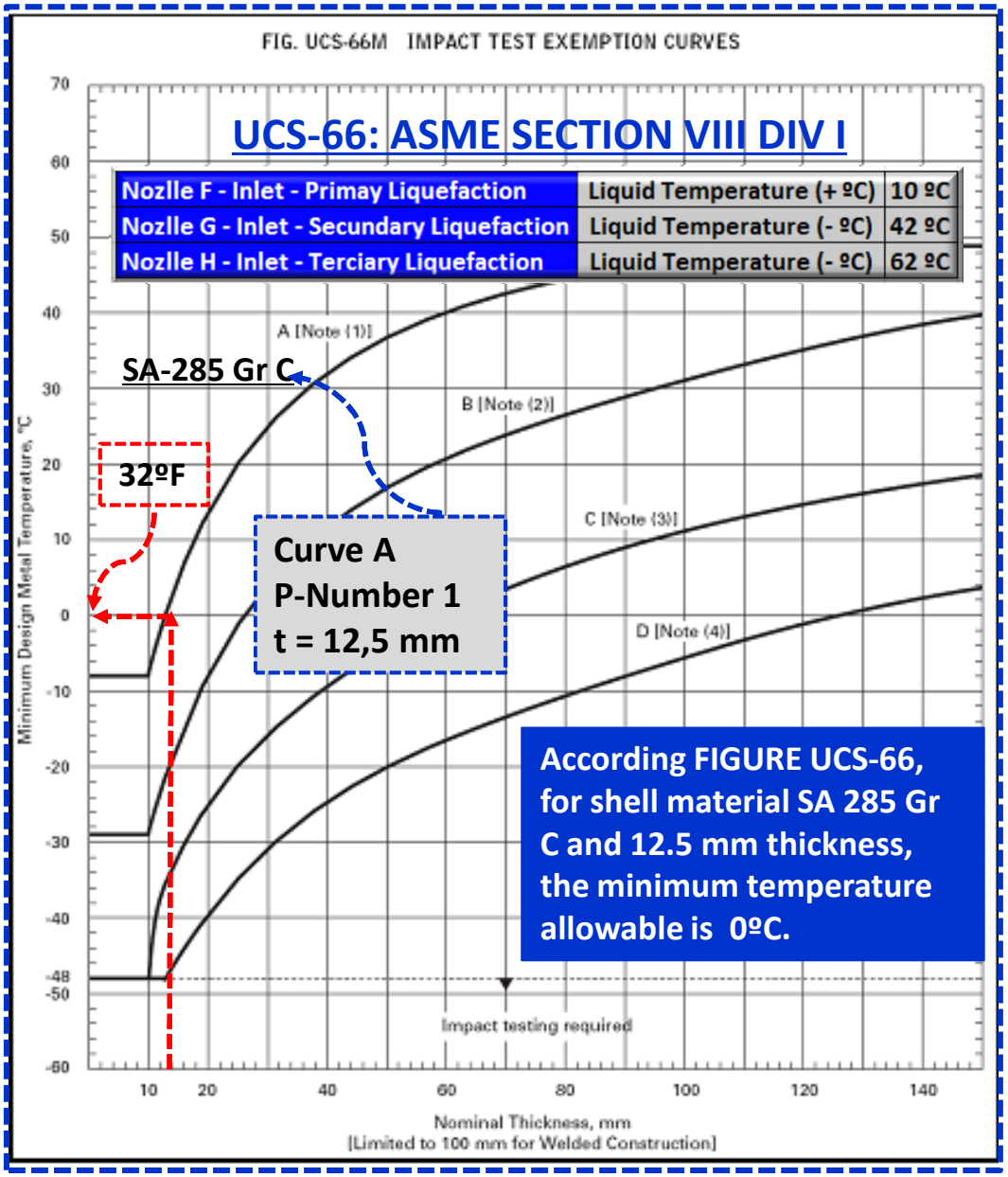

According figure UCS-68 (c) we will have the temperature reduction associated with figure UCS-66. The reduction in function of the PWHT.

UCS-68(c) – If postweld heat treating is performed when it is not otherwise a requirement of this Division, a 30ºF (17ºC) reduction in impact testing exemption temperature may be given to the minimum permissible temperature from Fig. UCS-66 for P-No. 1 materials. The resulting exemption temperature may be colder than – 55F (-48ºC)

Minimum temperature of equipment will be – 17ºC (+1,4 ºF).

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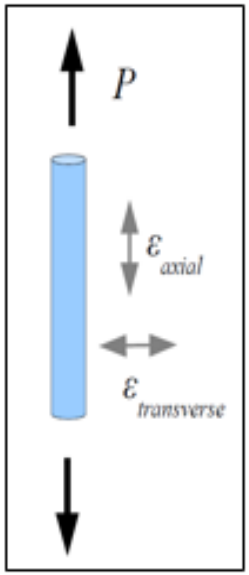

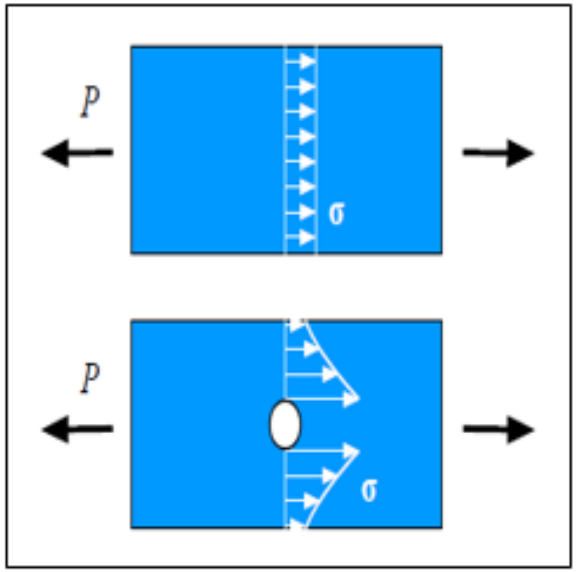

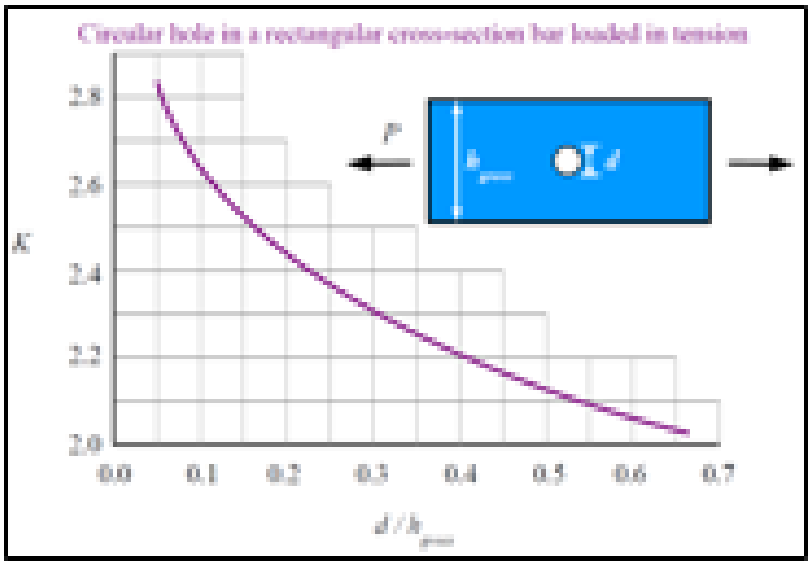

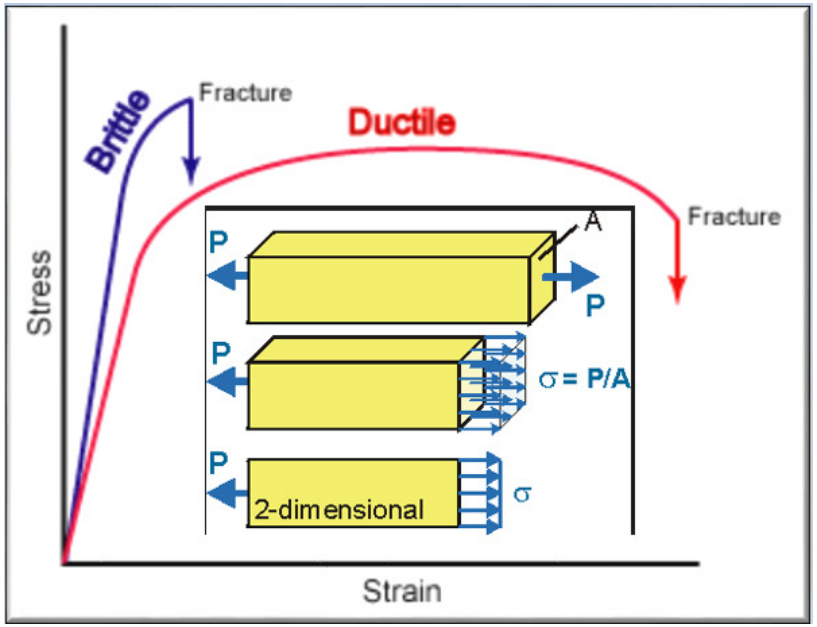

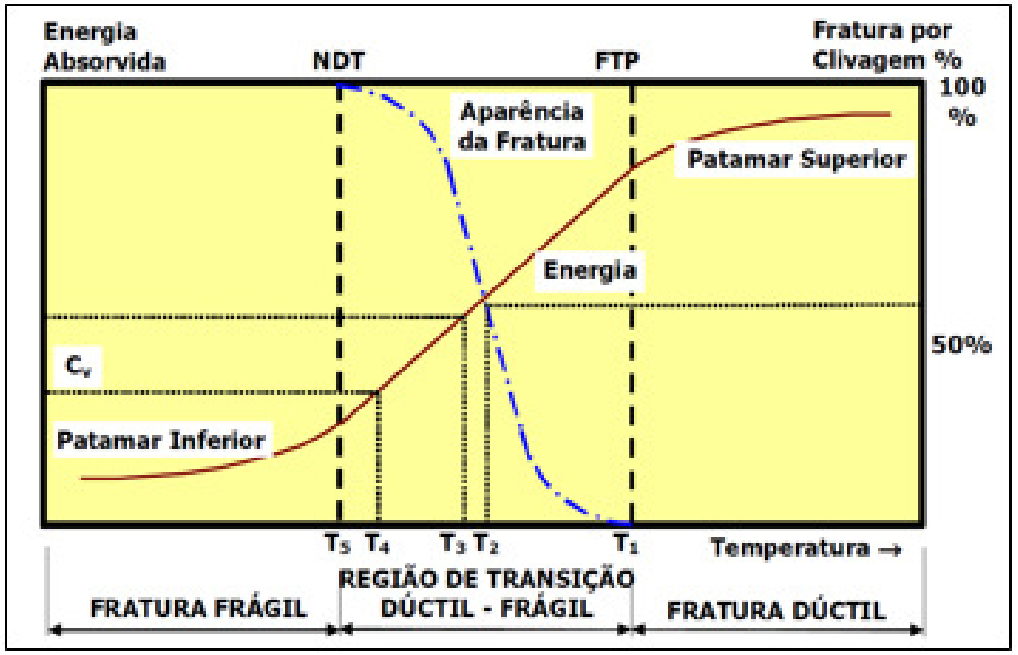

Primary Stress - Membrane

§3.4 CYLINDRICAL VESSELS

$$\sigma_\theta = \frac{pr}{t}$$

$$\sigma_x = \frac{pr}{2t}$$

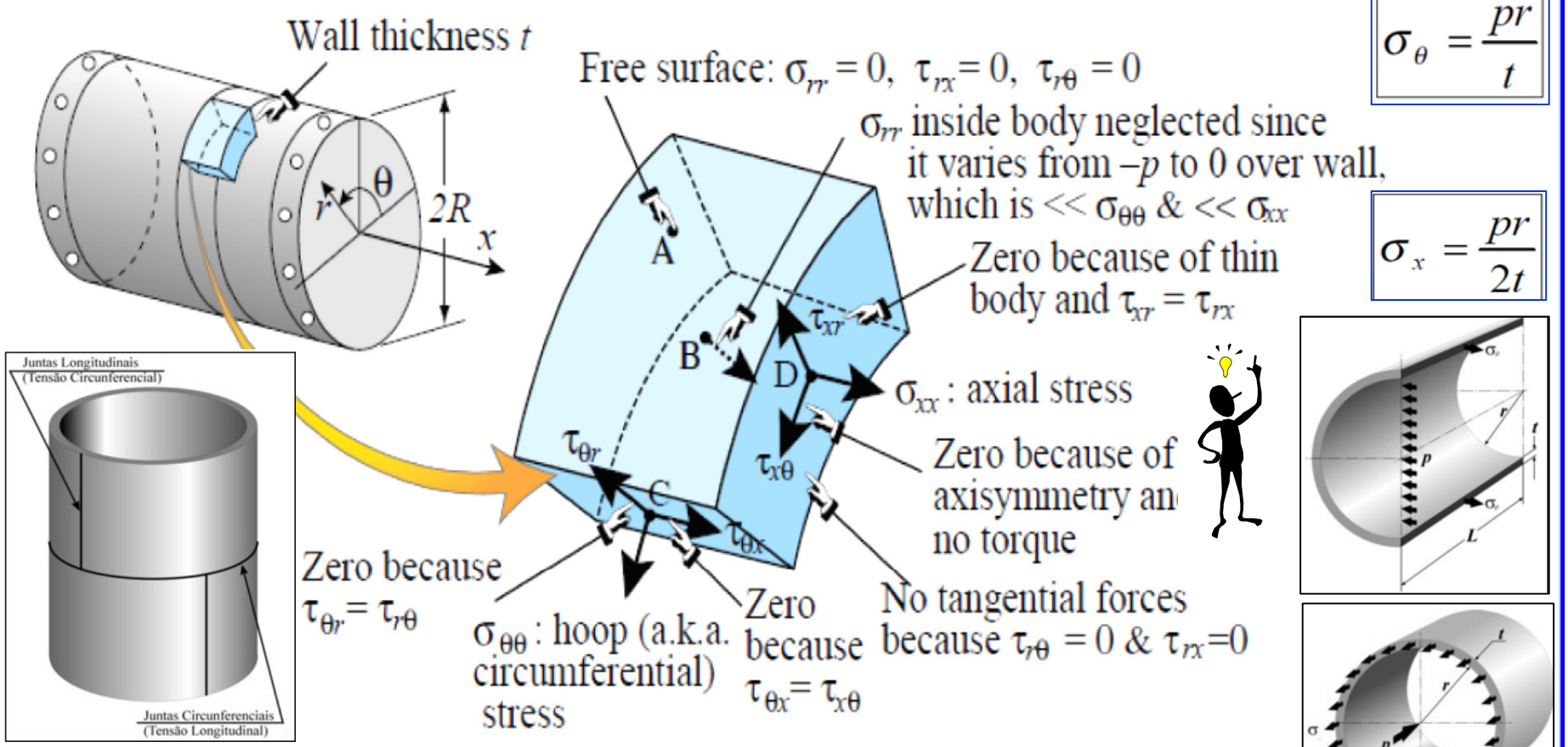

FIGURE 3.2. Wall material element of a pressurized cylindrical vessel referred to cylindrical coordinates. Note that thickness is grossly exaggerated for visibility.

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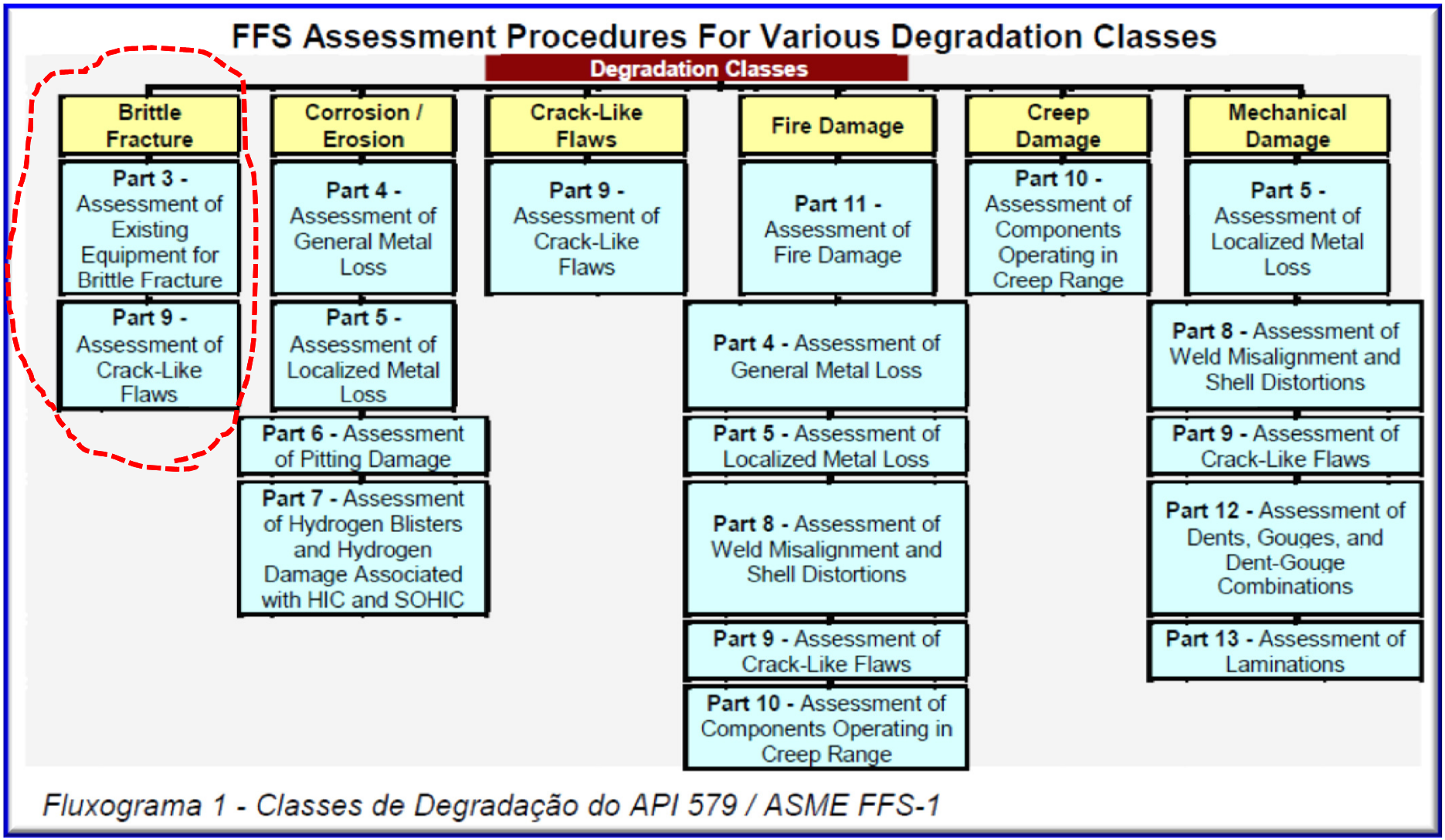

Fluxograma 1 - Classes de Degradação do API 579 / ASME FFS-1

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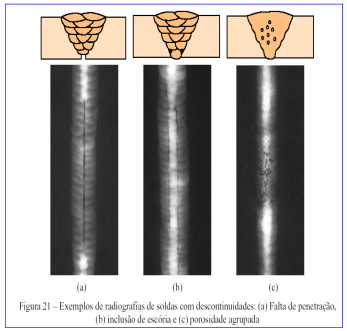

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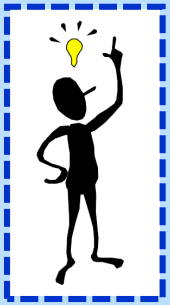
Risk is Time-Dependent



Review Inspection Program?
News NDT? TOFD? EA?
Review of project?
Thermal Model – FEM? CFD?

FAD – Failure Assessment Diagram for devolop Structural Integrity Analysis?

Next Year

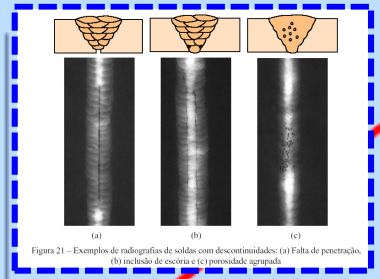
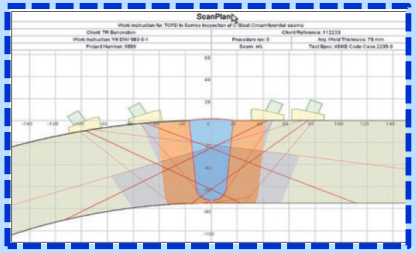


Figura 21 – Exemplos de radiografias de soldas com descontinuidades: (a) Falta de penetração, (b) inclusão de escória e (c) porosidade agrupada

Today



Risk, Events per Year

Time, t

Fitness-for-Service Assessments are quantitative engineering evaluations which are performed to demonstrate the structural integrity of In-Service componente containing a flaw or demage.

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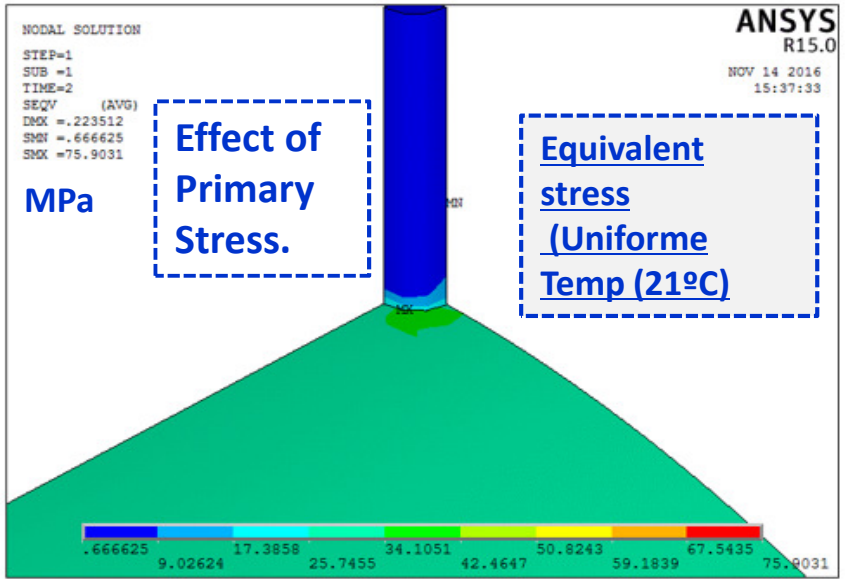
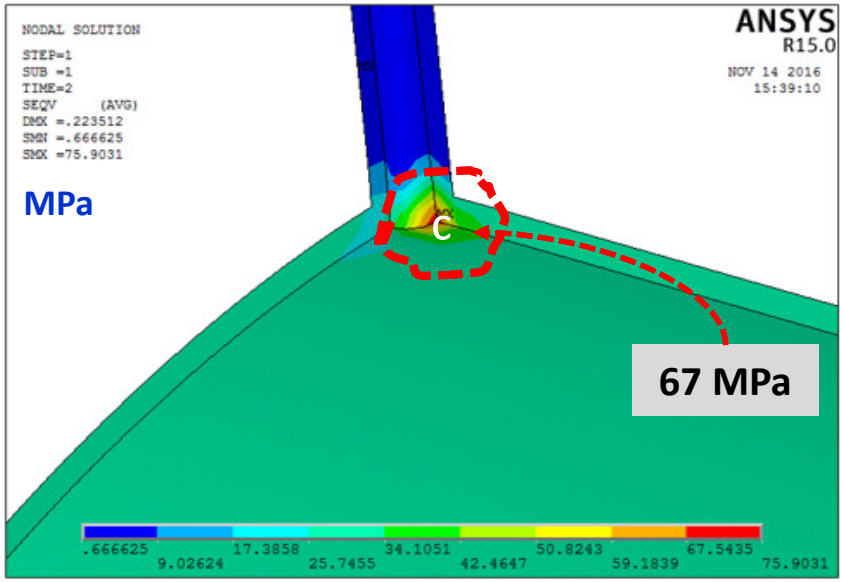


MPa

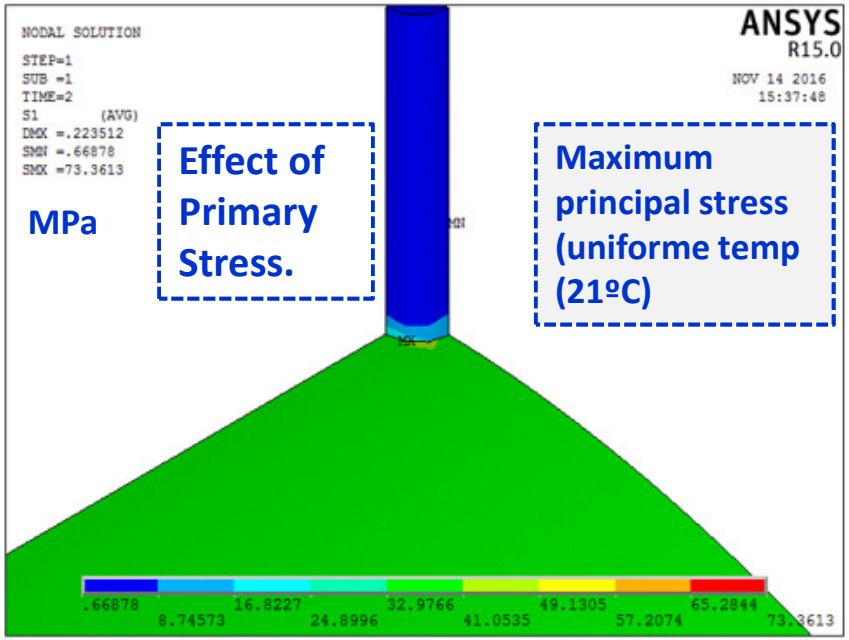
Effect of Primary Stress.

Equivalent stress (Uniforme Temp (21ºC)



MPa

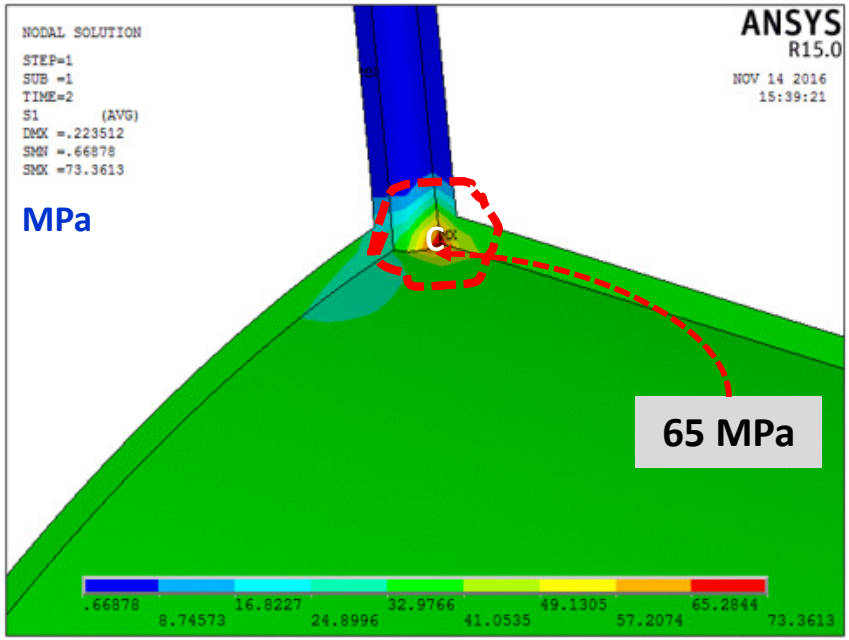
67 MPa



MPa

Effect of Primary Stress.

Maximum principal stress (uniforme temp (21ºC)



MPa

65 MPa

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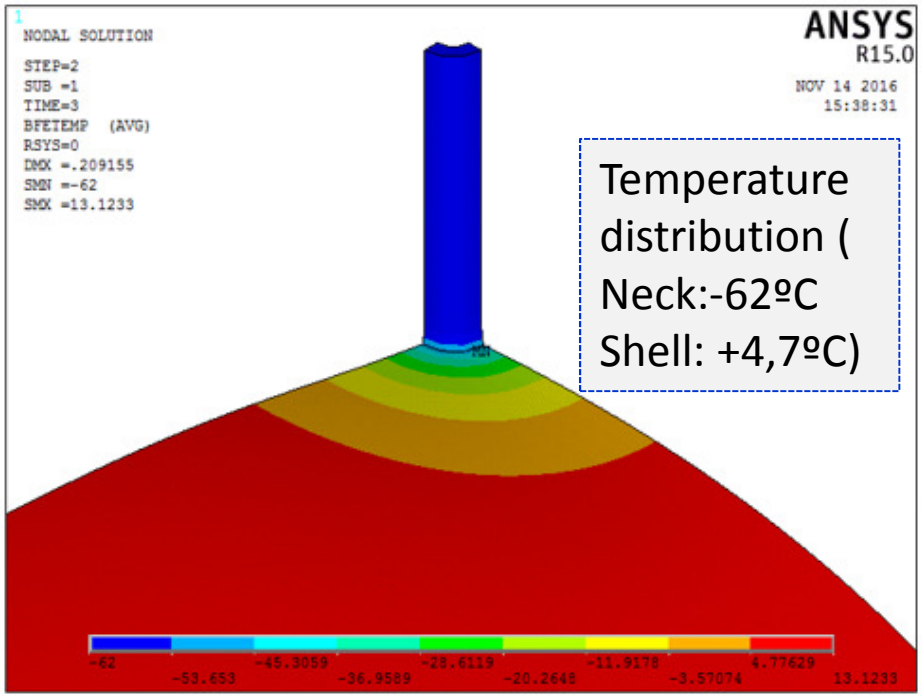
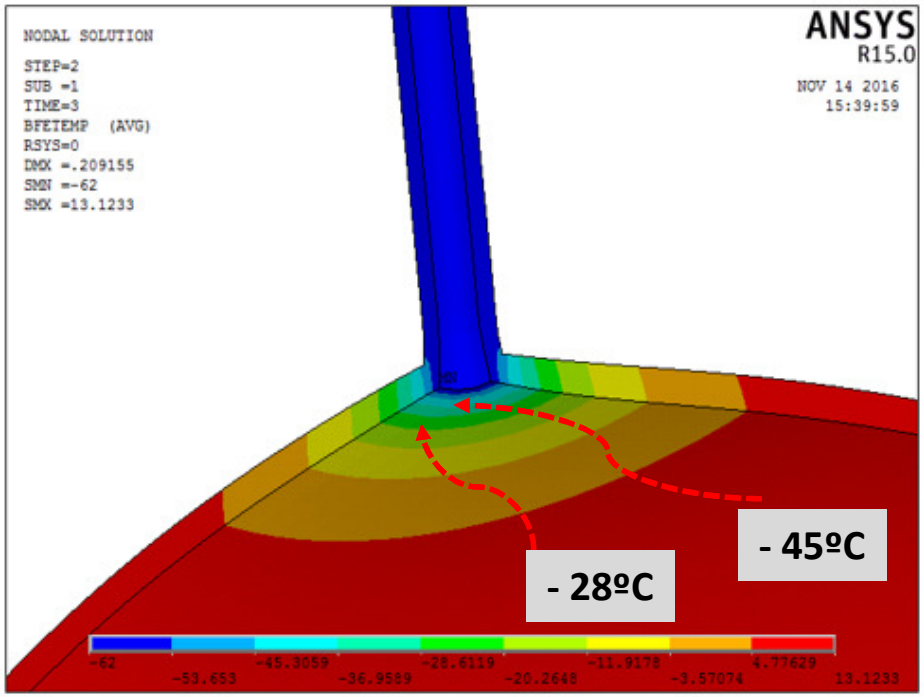


Temperature distribution (Neck:-62ºC Shell: +4,7ºC)



Very important the reliability engineer Analyse the distibution of temperature at nozlles using "CFD" or "FEM".

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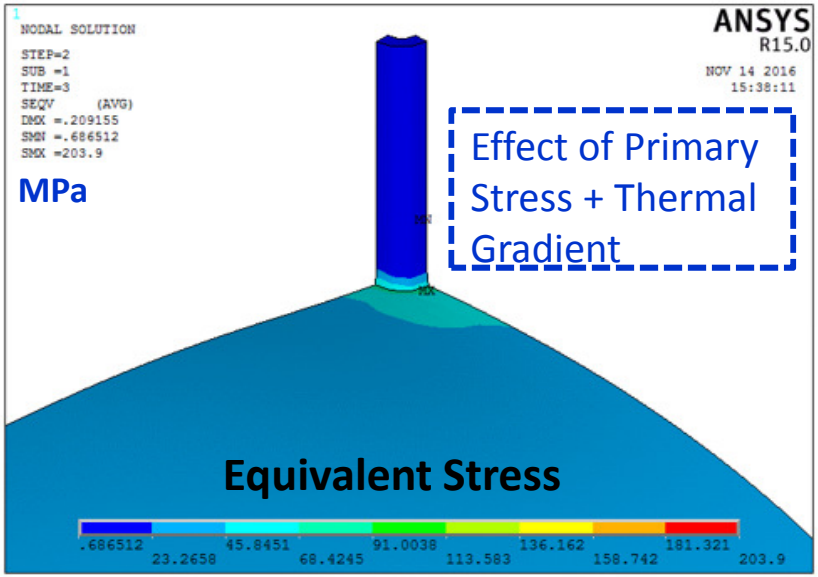

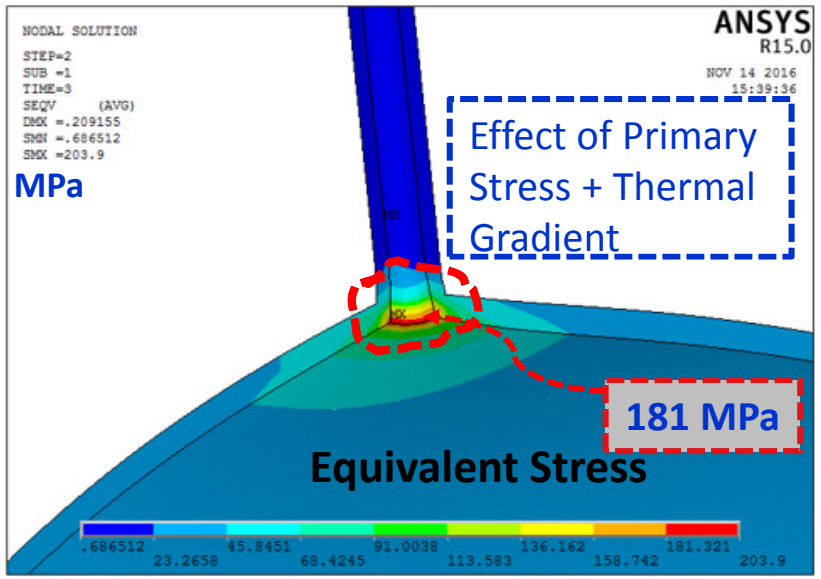

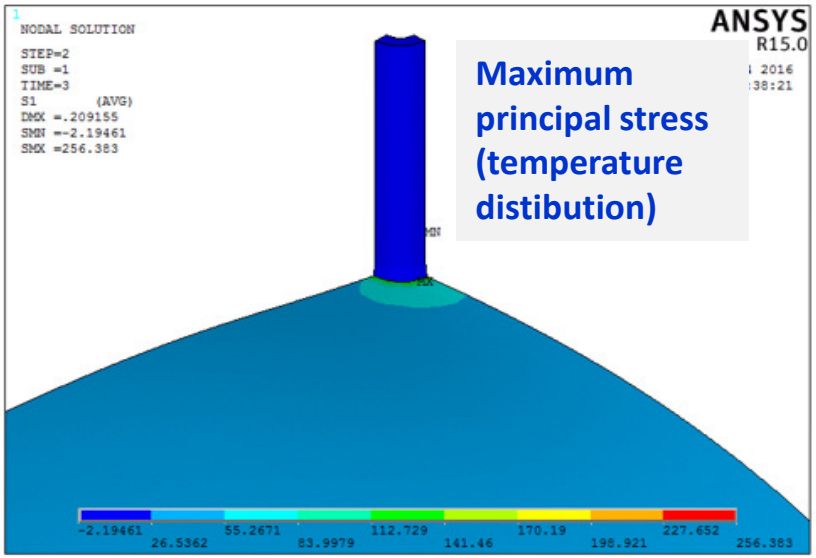

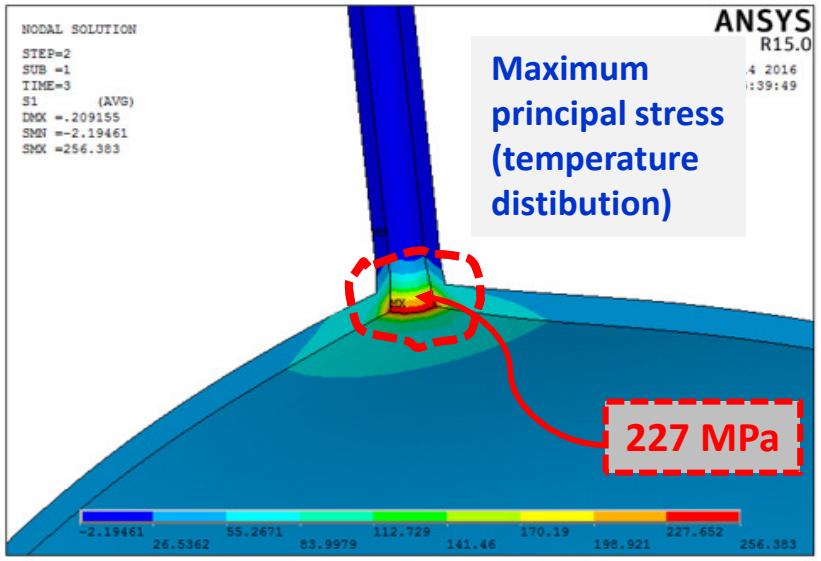

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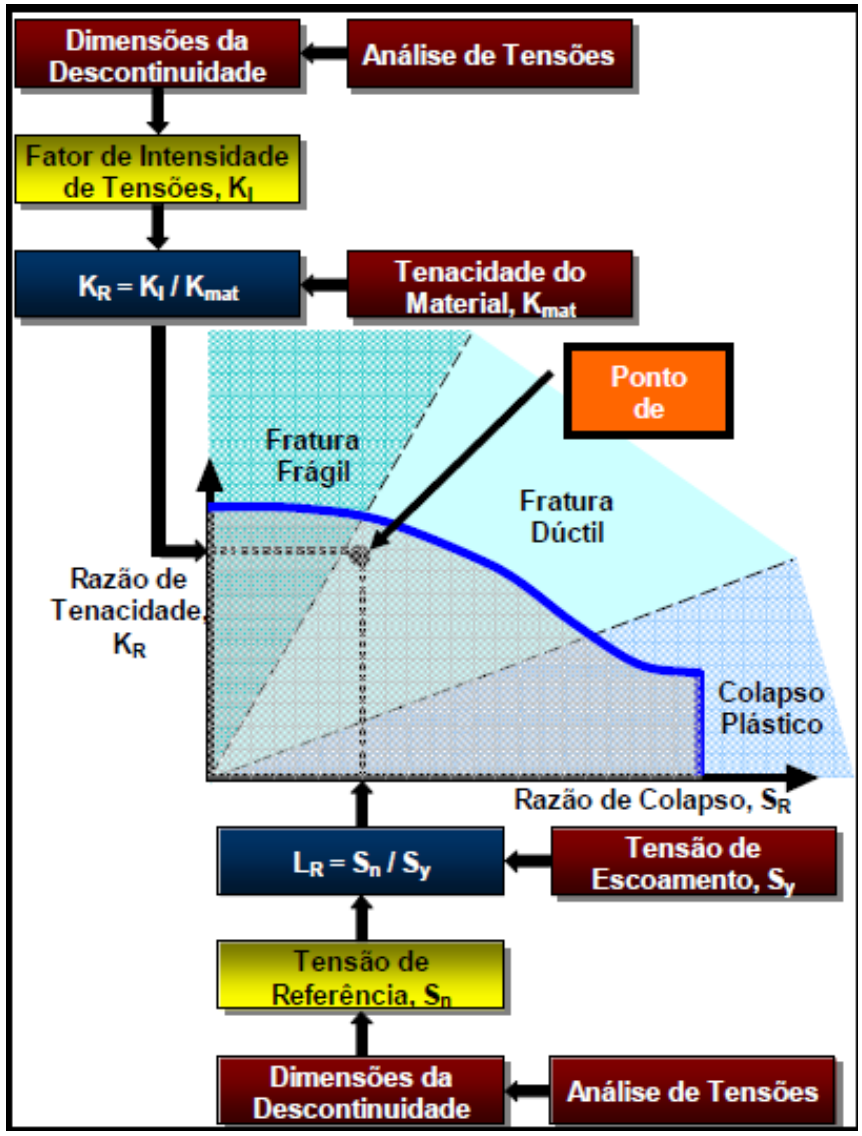
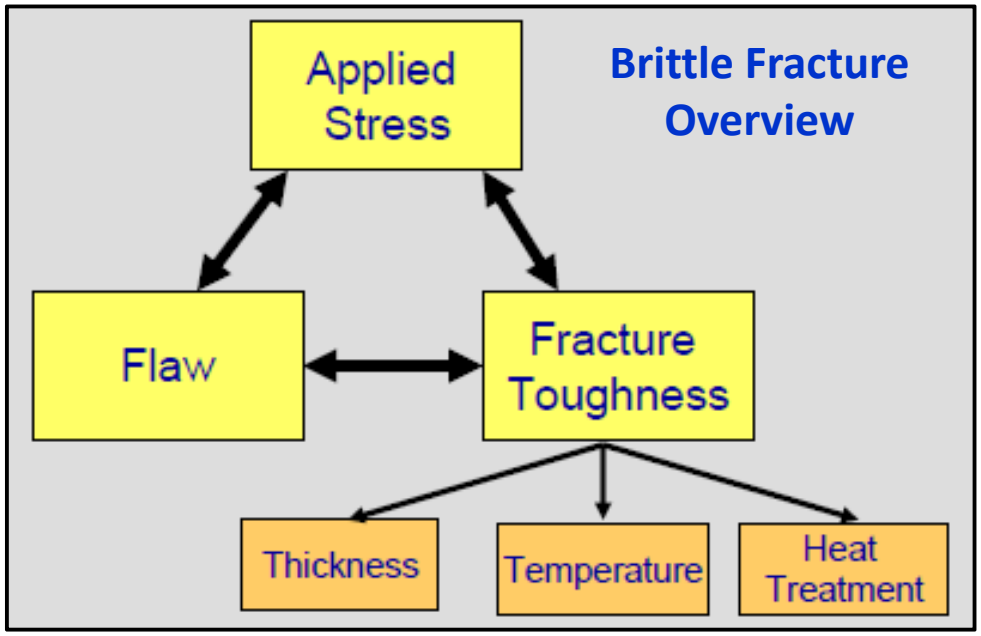
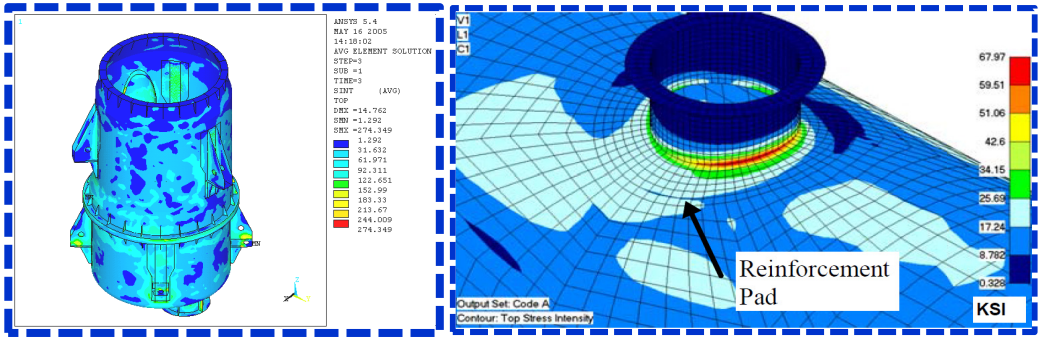


FAD - Failure Analysis Diagram



Factors Affecting Material Toughness



Design review of pressure vessel manufactured in carbon steel in the 1970's to storage liquid chlorine, in order to prevent brittle fracture.

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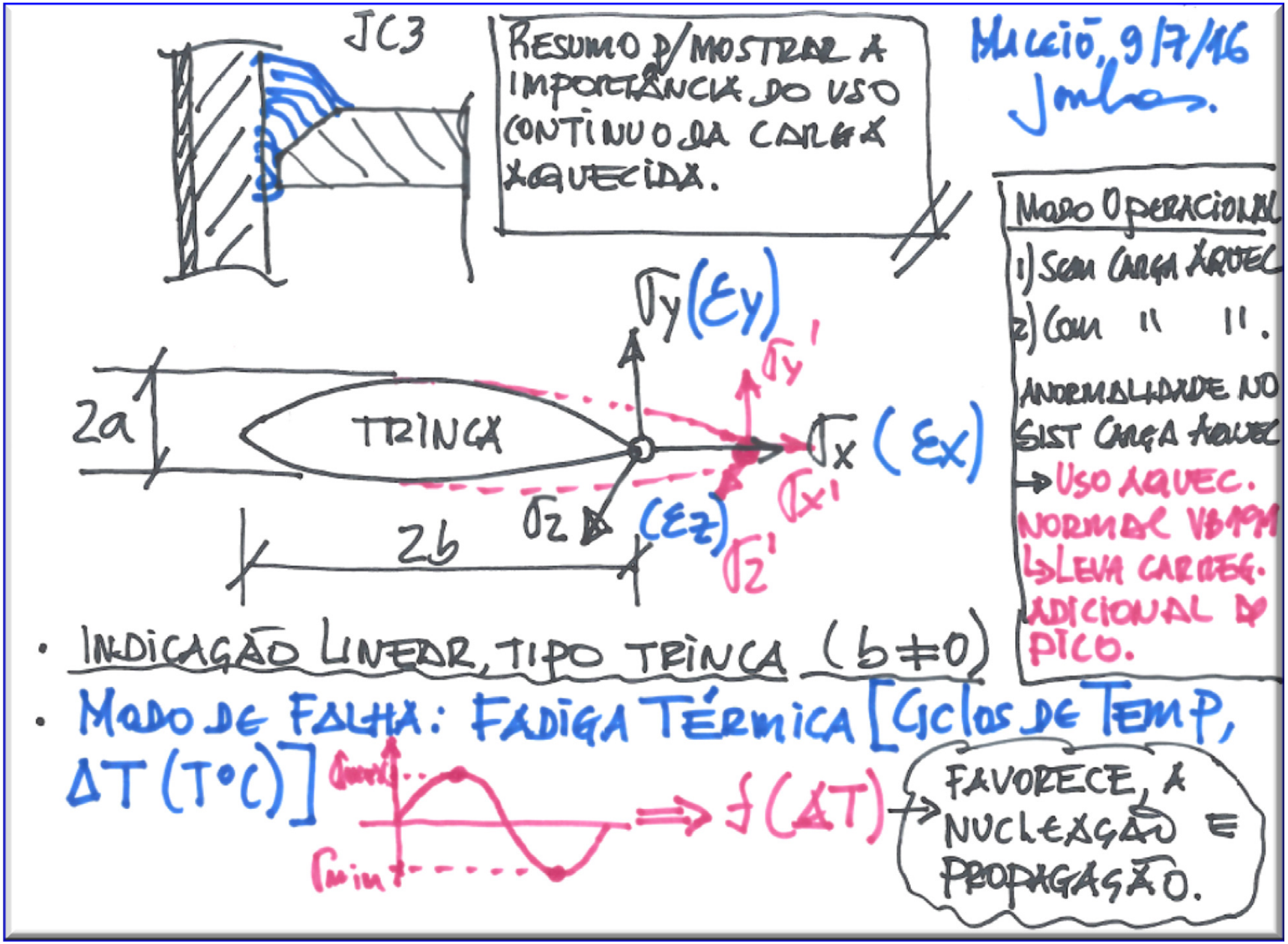

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New Pressure Vessels - Installed 2012	
Code	ASME SECTION VIII DIV I ED 2007 ADD 2008
Service	Liquid Chlorine - Lethal
Volume (m3)	5,845
Design Pressure (Kgf/cm2g)	14,8
Design Temperature (ºC)	-45
MDMT (ºC)	-46
RX	FULL
PWHT	YES
Materials: Shell and Heads	SA 516 Gr 70 N, Charpy in according ASME SECTION VIII DIV I UCS66
Fittings	ASME B 16.5 300 PSI
Flanges	SA 350 LF3 - Nozlles G and H
	SA 350 LF2 - Others Nozlles
Neck	SA 333 Gr 3 and SA 333 Gr 6
Manholle	SA 516 Gr 70 N with Impact Test according UCS66
Bolts and Nuts	SA 320 Gr L7 and SA 194 GR 4

Primary Liquefaction: + 13ºC
Secundary Liquefaction: - 40ºC
Terciary Liquefaction: - 62ºC

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ASME SECTION II - Part D MECHANICAL PROPERTIES		
Material Specification	Allowable Stress @ Tdesign [Mpa]	Yield Stress @ Troom [Mpa]
SA-516 Gr 70 N	137,0	262,0
SA-333 Gr 6	117,0	241,0

SA-516/SA-516M

SPECIFICATION FOR PRESSURE VESSEL PLATES, CARBON STEEL, FOR MODERATE- AND LOWER-TEMPERATURE SERVICE

1.1 This specification covers carbon steel plates intended primarily for service in welded pressure vessels where improved notch toughness is important.

Grade U.S. [SI]	Tensile Strength, ksi [MPa]
55 [380]	55–75 [380–515]
60 [415]	60–80 [415–550]
65 [450]	65–85 [450–585]
70 [485]	70–90 [485–620]

KILLED STEEL: Completely deoxidized steel due to the addition of elements such as Silicon and Aluminum. It has good internal quality due to the homogeneity of the structure and the chemical composition.

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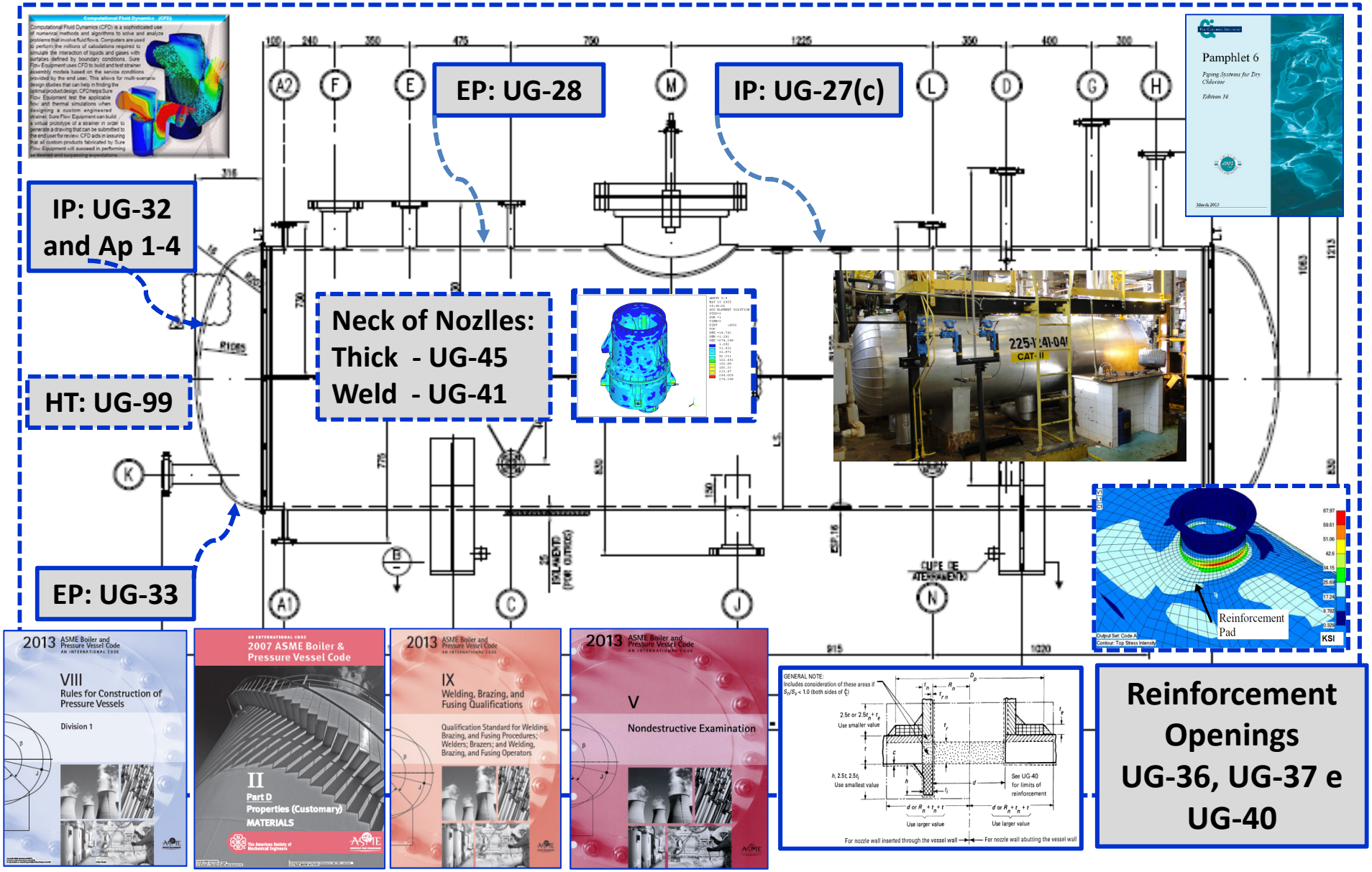
New Pressure Vessel - High Reliability – High Safety Process



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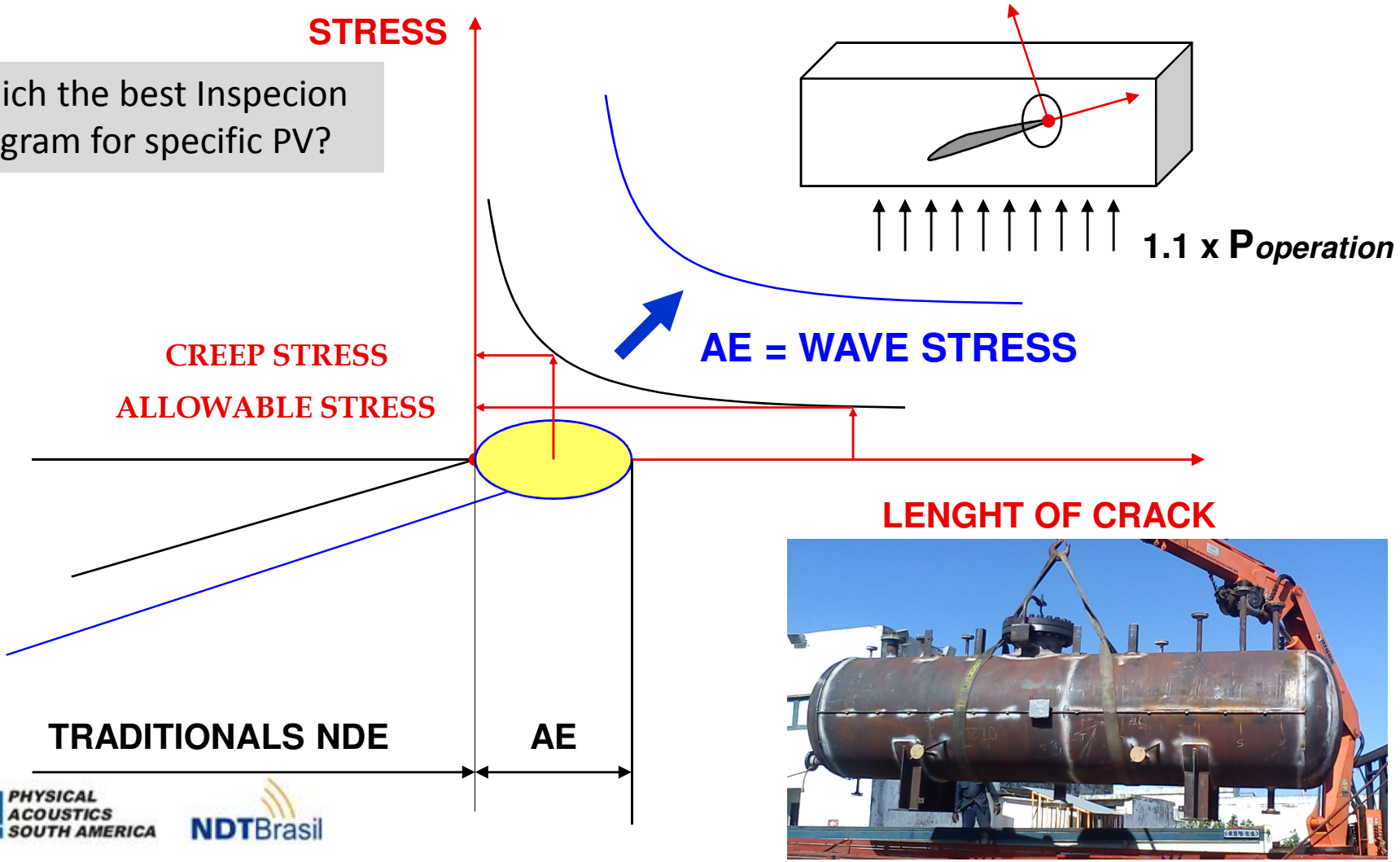
ACOUSTIC EMISSION – ACTIVE AREAS

Which the best Inspecion Program for specific PV?



PHYSICAL ACOUSTICS SOUTH AMERICA

NDTBrasil

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Requirements that the Project Codes always contemplate

- ✓ *Specification of materials*, defining minimum required properties, chemical composition, additional quality requirements and manufacturing process.
- ✓ Definition of the safety factors and allowable stress to be applied in the design for temperatures below and above the creep regime.
- ✓ Rules for the definition of pressurized components for internal and external pressure conditions.
- ✓ Rules for definition and verification of regions of geometric discontinuities, such as insertion of nozzles with the equipment, transition between nozzles with shell regions of conical transitions.
- ✓ Rules for reinforcements of openings isolateds, multiple openings and large openings.
- ✓ Criteria for analysis of stress in specific regions of the equipment, with the identification of the type of stress and their respective allowable values.
- ✓ ***Minimum fracture toughness requirements to be required for materials exposed to low temperatures, including recommendations and design details in critical regions of the equipment.***
- ✓ Design rules for operation under the action of cyclical loads.
- ✓ Details of manufacturing to be attended to.
- ✓ ***Inspection requirements (particularly for welded joints).***
- ✓ Efficiency of welded joints and quality factors.
- ✓ **Recommendations for PWHT after welding**, when required.
- ✓ Requirements for Welding Procedures and Qualification of Welders.

For pressure vessels designed and manufactured before 1975 a good practice to do a review of project for critical vessels, and to plan a Integrity Evaluation , qualitative and quantitative for more reliability.

Design review of pressure vessel manufactured in carbon steel in the 1970's to storage liquid chlorine, in order to prevent brittle fracture.

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Jarbas Cabral Fagundes

- ✓ Mechanical Engineer – UFPB Brasil – 1983
- ✓ Reliability Specialist Engineer of Braskem
- ✓ 30 years of experience with Chemical and Petrochemical Plants
- ✓ Specialist in Materials Selection and Corrosion
- ✓ Specialist in Maintenance Engineering and Reliability
- ✓ Specialist in Cryogenic System (Storage Etylene Tank – API 620 Ap Q)
- ✓ Specialist in ASME SECTION VIII DIV I
- ✓ Specialist in API 579-1 / ASME FFS-1 FITNESS-FOR-SERVICE
- ✓ Specialist in API RP 571 – Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
- ✓ ASME Membership 675574
- ✓ NACE Membership 834200
- ✓ ABENDI Membership
- ✓ ABRACO Membership
- ✓ ABCM Membership

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Thanking you Very Much