Australian Government

ANSTO

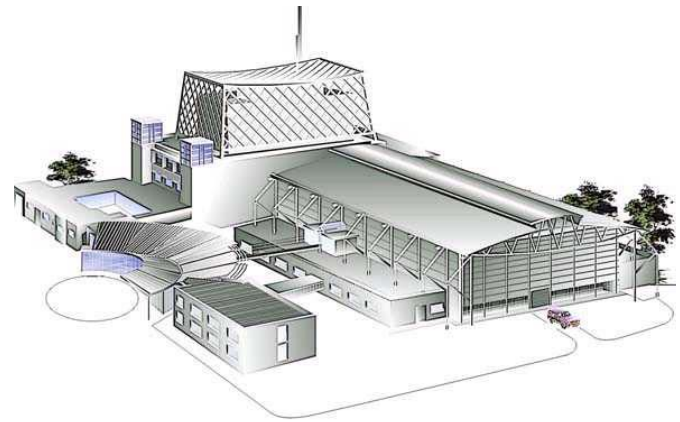
The development of vacuum system engineering guidelines at ANSTO

David Garton, Michael Mann, David Button

Lucas Heights, NSW, Australia

Overview

- ANSTO operates Australia’s only Nuclear Research Reactor
- Have to demonstrate a strong safety culture to regulators and public
- Risk minimisation by adopting tighter controls
- Australian standards for vacuum equipment design only a starting point
- Has impacted on accelerator operations especially in the area of vacuum system design

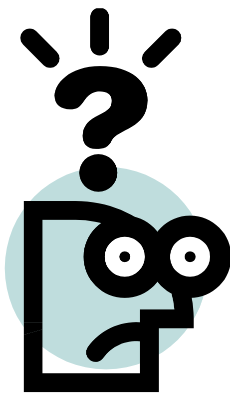


Certification to ensure safety?

- ANSTO meticulously maintains compliance certification for pressure vessels
- ANSTO took the view that vacuum vessels have similar safety risks as positive pressure vessels
- However the maximum pressure on a vacuum vessel is 100 kPa or ~15 PSI
  (half the pressure in a car tyre)
- Australian and International Standards
  have insufficient coverage for vacuum vessels
  like those used around accelerators.

Our engineering department told us …

- In an endeavour to cover the shortfall, ANSTO developed its own standard for vacuum vessels:
  - *All vacuum vessels must be periodically checked and tested by an accredited person,*
  - *All new vacuum equipment, vessels, beam lines must undergo finite elements analysis and have a identification plate attached to each component.*
  - *<u>No one other than the Engineering department</u> can design and manufacture vacuum equipment*



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Then we argued our case

- Australian Standard AS1210 says that there are 5 categories of pressure vessels A to E
- Vacuum vessels less than 3000 litres in volume fall into the lowest category (E) as the maximum pressure is ~100 kPa (~15 PSI)
- Most of the accelerator vacuum equipment is well within this category

This is how they saw us

http://www.pveng.com/ASME/ASMEComment/ExternalPressure/ExternalPressure.php

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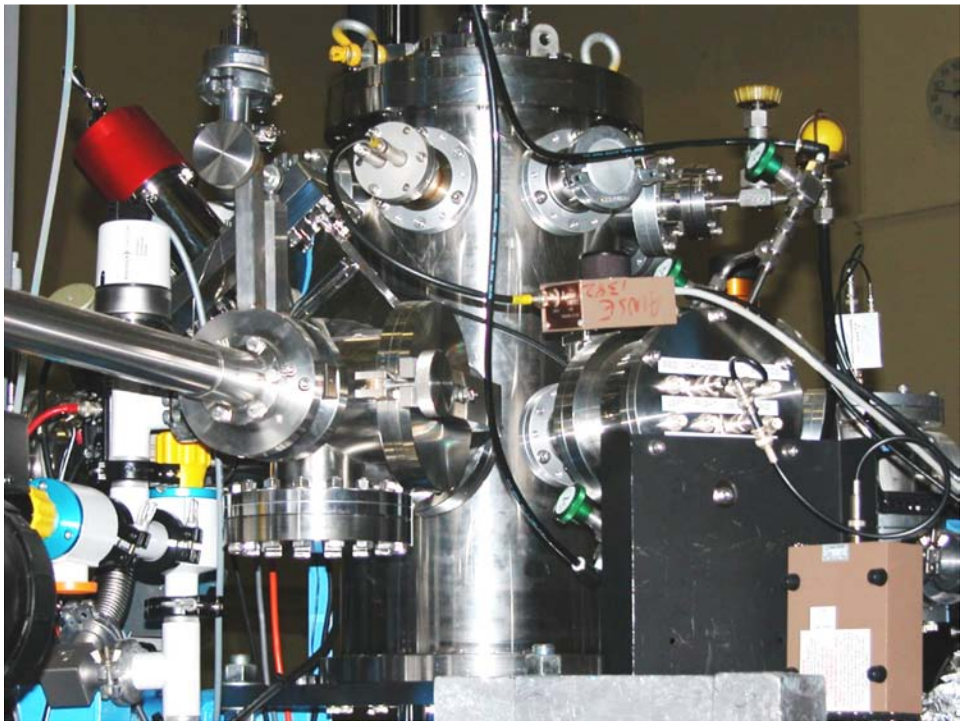
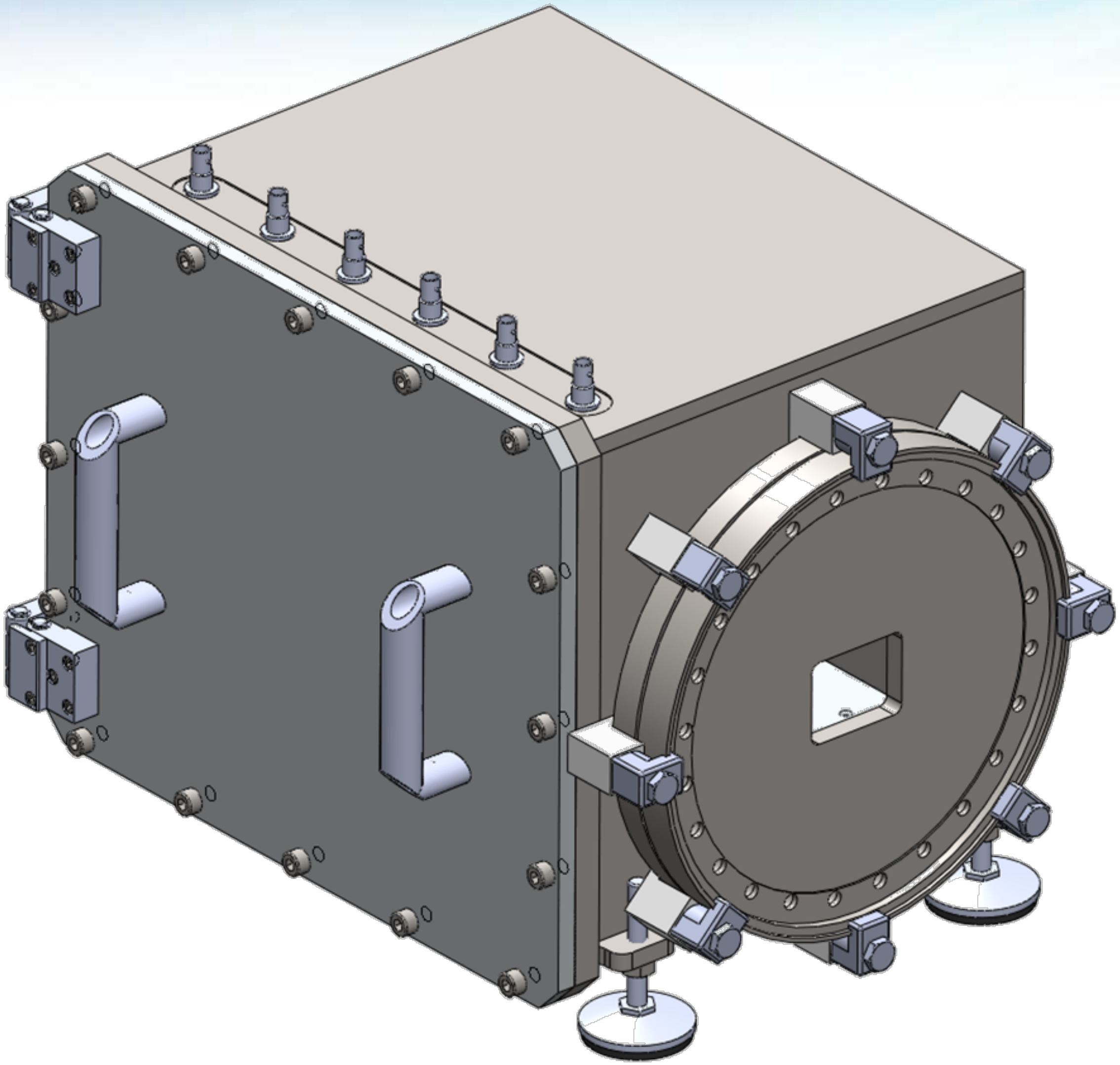
This is how we saw ourselves

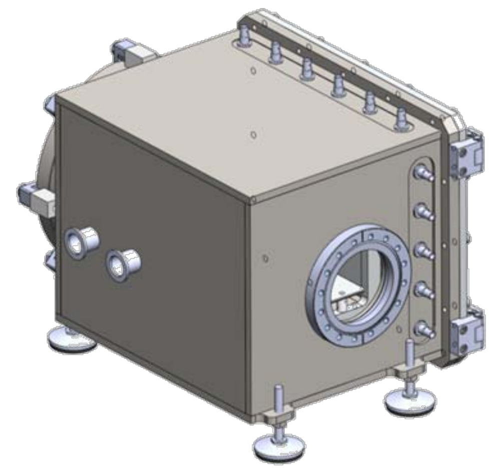


- Engineering's knowledge of vacuum technology not adequate
- The Australian Standard covers industrial type vacuum equipment but falls short of smaller scientific type vacuum equipment
- We sought to demonstrate that we already have a vacuum system standard

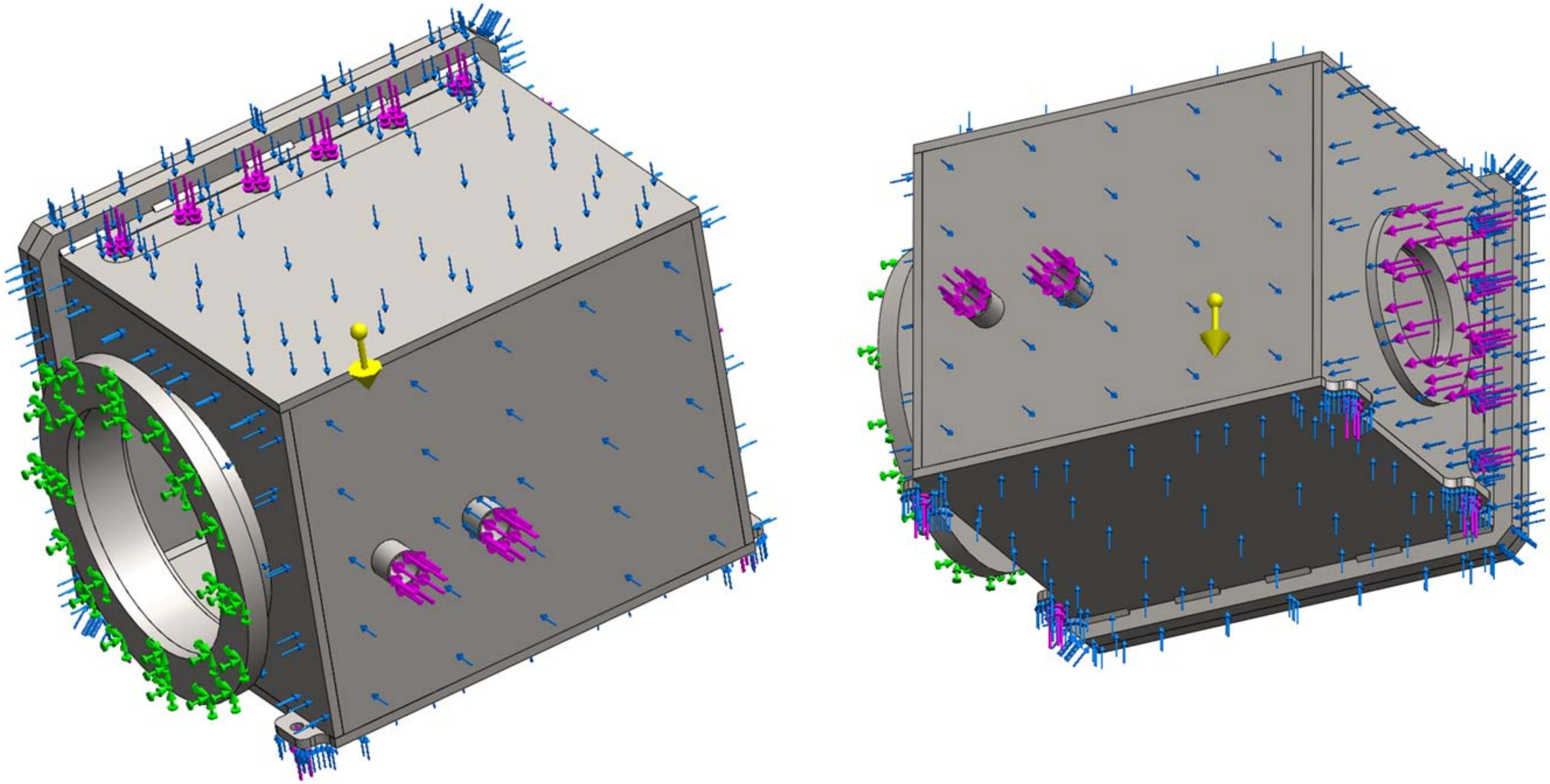
Acceptance that we know what we are doing

- We sent a copy of our vacuum standard to engineering to help them understand our dilemma
- They were very supportive and now realise the problem of testing and name plating several 100 separate vacuum components
- A realistic approach was agreed to

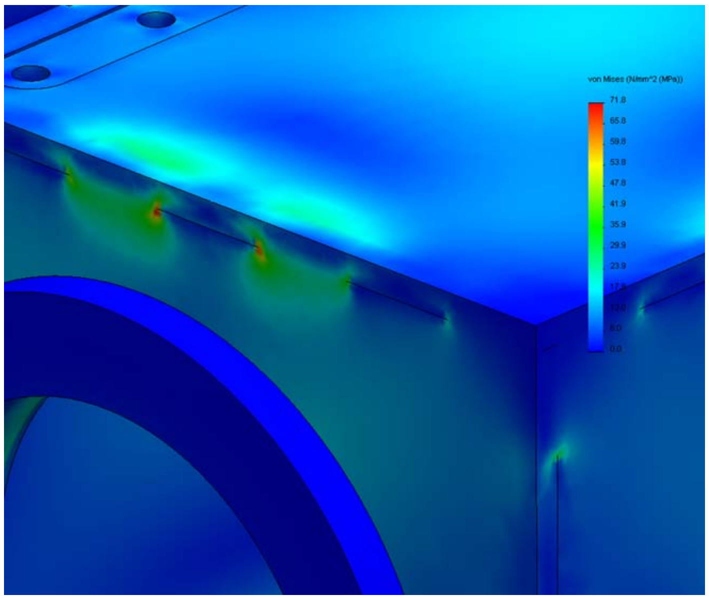


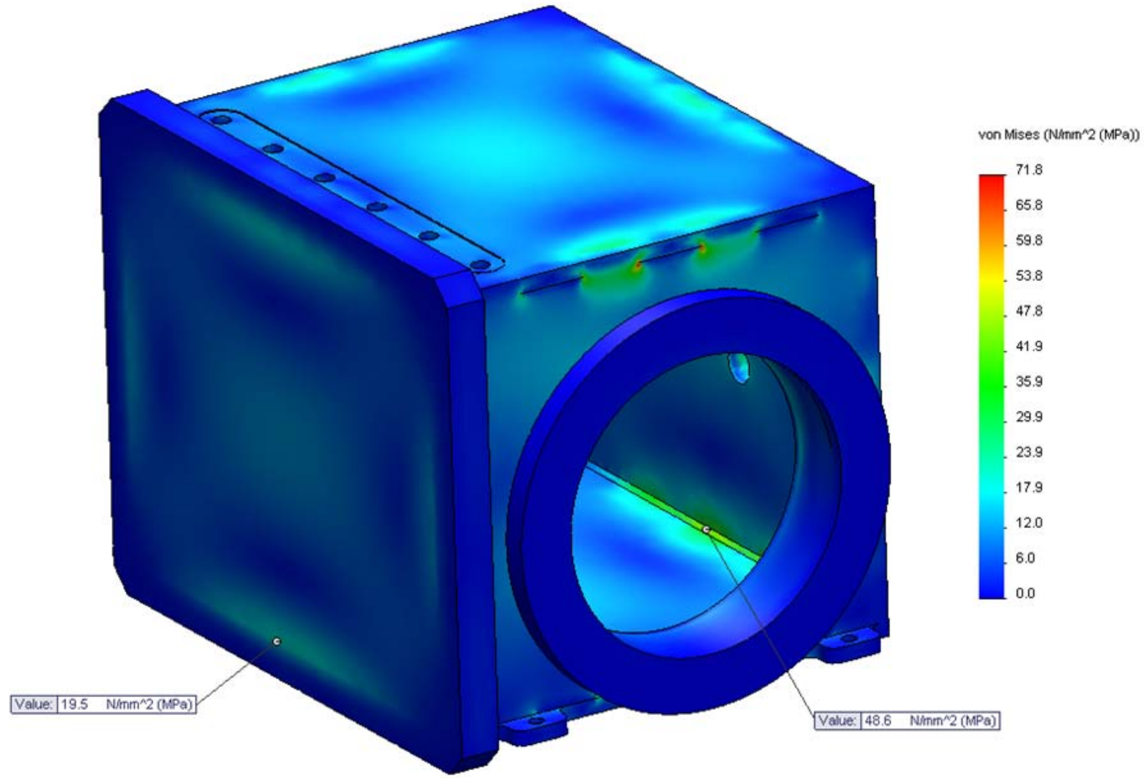


Design

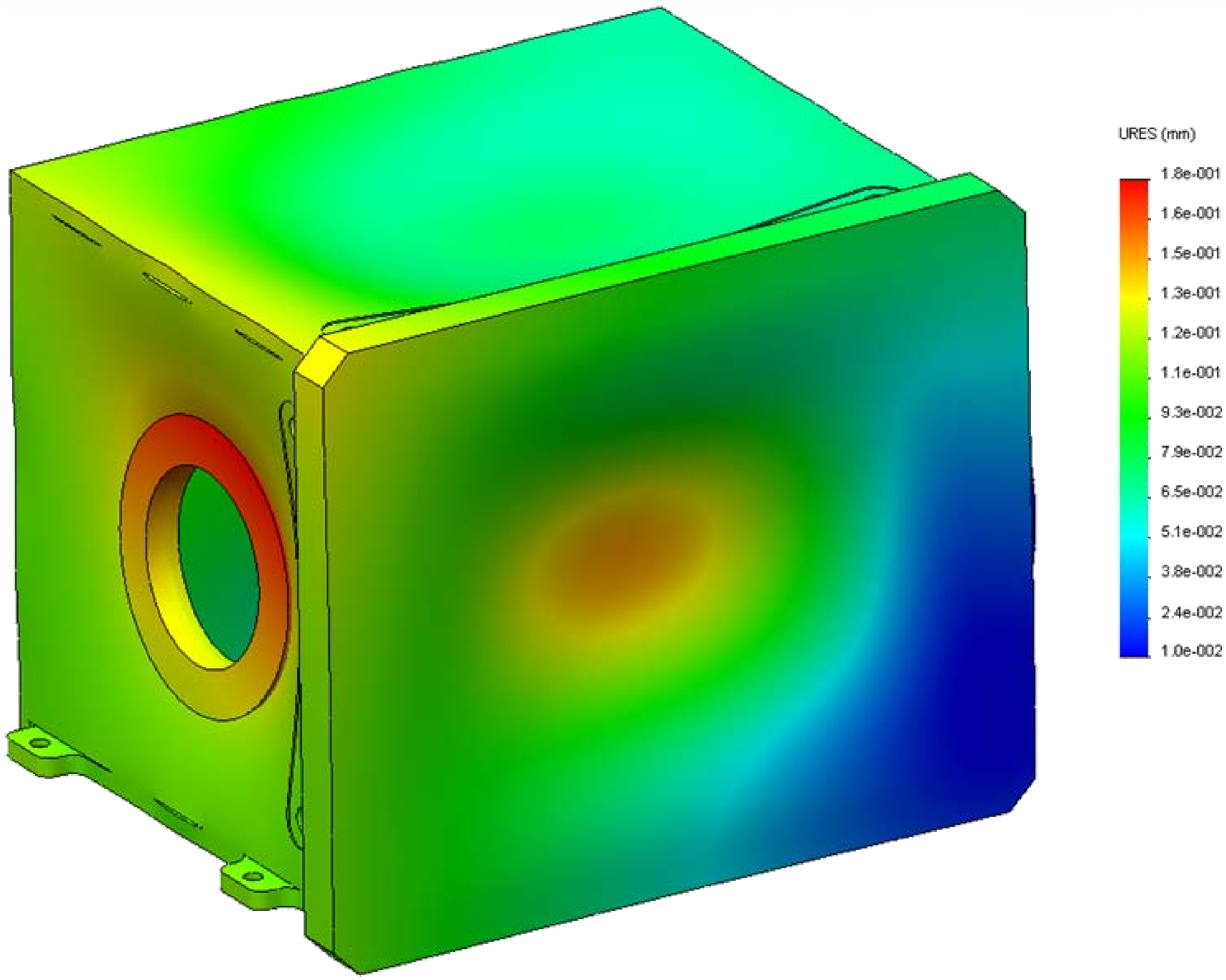


Material stresses





Weld stresses



Deformation

Accelerator Area Vacuum standards

- Developed from best engineering practises used in our accelerator area for 50 years
- Tested against experience and consultation with other vacuum users in Australia
- Measured against the Australian Standards
- This led to the development of an in-house document: *Vacuum Technology and Vacuum Design Handbook for Accelerator Technicians*

Accelerator Area Vacuum standards

Document covers:

1. Basic design
2. Welds
3. Surface finishes
4. Flanges
5. Seals
6. Screws
7. Feedthroughs
8. Lubricants, vacuum greases and epoxies
9. Mounting
10. Access
11. Testing
12. Operation and Continued Monitoring

Document also includes:

- Design Criteria, Information and Philosophies for Vacuum Systems
- Overview of Basic Vacuum Technology

Extract

tabled in "Hazard Levels of Pressure Equipment" in Section 2, Hazard Levels of Pressure Equipment in Australian Standard AS 4343-2005.

- The vacuum equipment designed by/for the accelerator area maintains a Hazard level of E. All pressure equipment with a $pV \leq 30$, pressure (p in MPa) x volume (litres) ≤ 30 is classed as Hazard level of E. For vacuum equipment in Hazard Level E the de-rating value of 0.1 is applied, ie $0.1pV \leq 30$. Note the amount of stored energy at this level is very small. For example a Ø 1000 mm chamber, 1000 mm high will have a pV for vacuum equal to 7.85.
- AS 4343-2005, Section 2.1.2 Typical hazard levels, part (d), states for Hazard Level E, "This equipment is usually exempt from special regulatory control but is covered by general plant safety regulations". See Appendix 7.

- All designs of chambers excluding general beam lines and fittings should be checked for structural integrity using finite elements analysis. Sound designs with acceptable structural integrity will be released for manufacture. A copy of the design acceptance tests must be filed with the project file. The standard finite element analysis can be performed utilising Solidworks. (Modelling for irregular shaped chambers, calculations Appendix 1 where appropriate for regular shapes)
- Stainless steel (304 or 316) will be used to construct chambers, beam lines and general fittings unless it is a *special* requirement to use other metals. Do not choose substances that

The Agreement

ANSTO agrees that we can continue to design our own vacuum equipment on the understanding that:

- All vessels are less than 300 litres volume
- Cylindrical in shape (preferred)
- Wall thicknesses must be ≥ the values as referenced in the tables within the ANSTO guide, "Design and Fabrication of Vacuum Vessels"
- Undertake finite elements analysis (FEA) of vessels

Extract from ANSTO Guide:

Design and Fabrication of Vacuum Vessels

For handling and economy, minimum thickness of each part is desirable, provided it is not less than that determined from the following sections.

.2 Minimum Thickness for Corrosion and Abrasion

Assume = 0.5 mm for materials in a non-corrosive environment on both sides.
Thickness for other reasons will always cover this for normal ANSTO vacuum equipment. for strength.

.3 Minimum Thickness for Reasonable Handling

a) Normal service: $t = 0.1\sqrt{D_o}$ for Do =/< 225 mm [AS 1210 Table 3.4.3]
and tmin = 1.5 mm for Do =/< 1000 mm

e.g.

D_o = mm	50	100	200	400	500
t = mm	0.7	1	1.4	1.5	1.5

b) Special service: If protected, the above thickness may be halved provided thickness is adequate for vacuum.

.4 Minimum Thickness of Cylindrical Shells, Nozzles and Piping Under Vacuum (P = 0.101 MPa)

a) $t = \frac{P_e D_m}{2EA}$; and $P_e = 3P = 0.3$ MPa [AS 1210 Clause 3.9.3]

Note: Elastic buckling only applies here

$$= \frac{P_e D_m}{2E} \quad \frac{D_m^{0.5} L}{1.3t^{1.5}}$$

$$t = \sqrt[2.5]{\frac{0.3 D_m^{1.5} L}{2 \times 200{,}000 \times 1.3}}$$

$t = 0.0032\,(D_m^{1.5} L)^{0.4}$

where D_m = mean diameter, mm
L = length between ends or rings, mm
E = Young's Modulus at 20°C
= 200,000 MPa - carbon steel
= 193,000 MPa –stainless "
= 69,000 MPa –aluminium alloys

e.g. For carbon steel D_m = 100 mm; L = 100 mm, t = 0.32 mm
D_m = 400 mm; L = 400 mm; t = 1.3 mm

b) For other materials or temperatures multiply above $t \times \left(\frac{200{,}000}{E}\right)^{0.4}$

e.g for stainless steel x 1.015; and for aluminium alloys x 1.53 at 20°C

c) Maximum radial deformation under vacuum of vessels complying with the above will be less than 0.1 mm

.5 Minimum Thickness for Spherical Shells Under Vacuum

a) $t = D_m \sqrt{\frac{P_e}{4.84E}}$ where $P_e = \frac{P}{0.07}$ [AS 1210 Eq 3.9.4.1]

$t = 0.005\, D_m$ approx for carbon steel

b) For other materials or temperatures multiply above $t \times \left(\frac{200{,}000}{E}\right)^{0.5}$

e.g for stainless steel x 1.02; and for aluminium alloys x 1.73

c) Deflection is similar to that in .4a) above.

b) Special service: If the vessel outer shell is protected, the above thickness may be halved to the following provided thickness is adequate for vacuum.

Do (mm)	10	30	50	100	200	300	500	1000
t (mm)	0.16	0.28	0.35	0.50	0.70	0.75	0.75	0.75

For a given diameter, the greater of:
1) the minimum thickness values from tables a) and b) above, or
2) the minimum thickness values from the following tables shall be used.
Grey highlight is applicable for normal service. Yellow highlight is applicable only for special protected service. Blank boxes mean that minimum thickness from tables a) or b) above appl

Table 2: Minimum Thickness of Cylindrical Shells, Nozzles and Piping Under Vacuum

L = shell length; all dimension in mm; see also notes at the end of the Tables.

Carbon steel

	Dm =	10	30	50	100	200	300	500	1000
L =	30								0.79
L =	50								0.97
L =	100							0.84	1.27
L =	200						0.82	1.11	1.68
L =	300				0.50	0.75	0.96	1.30	1.98
L =	500		0.30	0.40	0.61	0.92	1.18	1.60	2.43
L =	1000	0.20	0.39	0.53	0.80	1.22	1.55	2.11	3.20

Stainless Steel

	Dm =	10	30	50	100	200	300	500	1000
L =	30								0.80
L =	50								0.98
L =	100							0.85	1.29
L =	200						0.83	1.12	1.71
L =	300				0.50	0.76	0.97	1.32	2.01
L =	500	0.16	0.30	0.41	0.62	0.94	1.19	1.62	2.46
L =	1000	0.20	0.40	0.54	0.82	1.24	1.58	2.14	3.25

Aluminium alloys

	Dm =	10	30	50	100	200	300	500	1000
L =	30							0.79	1.20
L =	50							0.97	1.48
L =	100					0.74	0.95	1.29	1.95
L =	200	0.16	0.31	0.43	0.65	0.98	1.25	1.70	2.57
L =	300	0.19	0.37	0.50	0.76	1.15	1.47	2.00	3.03
L =	500	0.23	0.45	0.62	0.93	1.41	1.80	2.45	3.71
L =	1000	0.31	0.60	0.81	1.23	1.86	2.38	3.23	4.90

Extract from ANSTO Guide:

Design and Fabrication of Vacuum Vessels

Table 3: Minimum Thickness for Spherical Shells Under Vacuum

All dimension in mm; see also notes at the end of the Tables.

Carbon steel (t = 0.005 x Dm)

Dm =	30	50	100	200	300	500	1000
t =			0.5	1	1.5	2.5	5

Stainless Steel

Dm =	30	50	100	200	300	500	1000
t =			0.51	1.02	1.53	2.55	5.09

Aluminium alloys

Dm =	30	50	100	200	300	500	1000
t =		0.44	0.87	1.74	2.61	4.35	8.70

Table 4: Minimum Thickness Dished Ends Under Vacuum

All dimension in mm; see also notes at the end of the Tables.

a) Spherical ends – same as for spherical shells above

b) Torispherical ends - same as spheres but use Dm = 2 x CR

CR = Crown radius (mm) = inside radius of torispherical end (often 2 x vessel diameter)

Carbon steel (t = 0.005 x 2 x CR)

	2Do =	60	100	200	400	600	1000	2000
	Do =	30	50	100	200	300	500	1000
CR min =	Do/2	15	25	50	100	150	250	500
CR =	30	0.3						
CR =	50	0.5	0.5	0.5				
CR =	100	1	1	1	1			
CR =	150			1.5	1.5	1.5		
CR =	200			2	2	2		
CR =	250				2.5	2.5	2.5	
CR =	300				3	3	3	
CR =	500				5	5	5	5
CR =	1000					10	10	10

Stainless Steel

	2Do =	60	100	200	400	600	1000	2000
	Do =	30	50	100	200	300	500	1000
CR min =	Do/2	15	25	50	100	150	250	500
CR =	30	0.31						
CR =	50	0.51	0.51	0.51				
CR =	100	1.02	1.02	1.02	1.02			
CR =	150			1.53	1.53	1.53		
CR =	200			2.04	2.04	2.04		
CR =	250				2.55	2.55	2.55	
CR =	300				3.05	3.05	3.05	
CR =	500				5.09	5.09	5.09	5.09
CR =	1000					10.18	10.18	10.18

Aluminium alloys

	2Do =	60	100	200	400	600	1000	2000
	Do =	30	50	100	200	300	500	1000
CR min =	Do/2	15	25	50	100	150	250	500
CR =	30	0.52	0.52					
CR =	50	0.87	0.87	0.87				
CR =	100	1.74	1.74	1.74	1.74			
CR =	150			2.61	2.61	2.61		
CR =	200			3.48	3.48	3.48		
CR =	250				4.35	4.35	4.35	
CR =	300				5.22	5.22	5.22	
CR =	500				8.70	8.70	8.70	8.70
CR =	1000					17.40	17.40	17.40

c) Ellipsoidal ends (2:1 only)

Carbon steel

Do =	30	50	100	200	300	500	1000
t =		0.45	0.90	1.80	2.70	4.50	9.00

Stainless Steel

Dm =	30	50	100	200	300	500	1000
t =		0.46	0.92	1.83	2.75	4.58	9.16

Aluminium alloys

Dm =	30	50	100	200	300	500	1000
t =	0.47	0.78	1.57	3.13	4.70	7.83	15.66

Table 5: Minimum Thickness for Flat Plates

What was found

- This was always going to be difficult as the standards found in other countries had insufficient detail on calculating minimum wall thickness for scientific type equipment
- Australian Standard was no different
- ASME Boiler and Pressure vessel code Section VIII, Division 1, came close
- Some labs reference other labs (blind leading the blind???)

Conclusion

- This issue is not unique to ANSTO
- As the world becomes more *safety aware,* regulators may look closer at codes for designing and maintaining vacuum vessels
- Investigate whether you are complying with your country's equivalent pressure/vacuum standard
- Be ahead of the game and adopt a minimum design standard for your facilities

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