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Life Extension of Tanks for High Pressure Hydrogen Storage Vessels

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Agenda

1) Recap **project scope & project plan** (15 minutes)
2) Receive feedback on **project plan**
3) I would like pathways forward by end of meeting on:
   a) Actual pressure cycle histories in industry
   → This seems to be the missing link needed!!
   b) **Targeted flaw sizes for NDE inspections**
   → Initial thoughts: 0.5 mm (0.02") deep x 1.5 mm (0.06") long
   * Baseline for recertification should be what is used for original design of vessels (Assuming no crack extension during service)

Invitation List

Sandia	Joe Ronevich Chris San Marchi John Emery
Fiba Tech	John Felbaum
Air Products	Dave Farese
Praxair/Linde	Kang Xu Mahendra Rana
Becht Eng.	Eileen Chant Bob Sims Greg Epremian
Digital Wave	Brian Burks
NASA-WSTF	Charles Nichols
Luna Inc.	Matt Webster
UC Davis	Prof. Mike Hill

Issue: Type 2 composite-wrapped tanks reaching end of life criteria far sooner than anticipated

Design life: 37,500 cycles or 20 year (whichever comes first)

Pressure range: 13,500 psi (93 MPa) to 8,900 psi (61.3 MPa)

Reached **<u>cycle life</u>** in ~ 7 years

17”OD, 14’6” length with bores of 1.5” or 2-3/4”.

No current NDE method to inspect metal liner of type 2 tanks, therefore tanks are retired

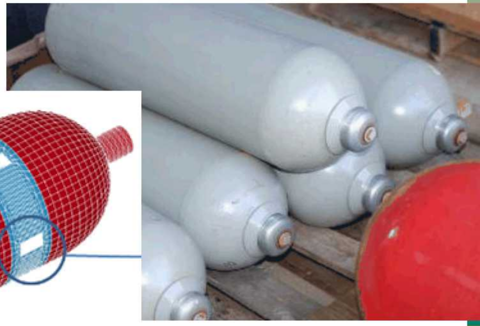
Project Objectives / Plan

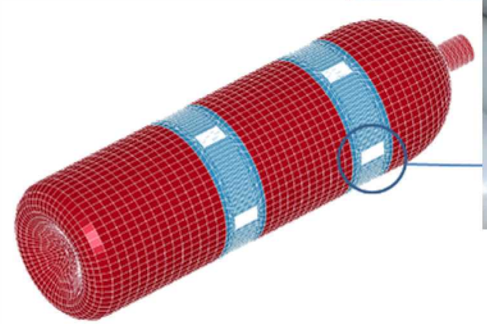
1) Develop understanding of opportunity space for life extension:

- Influence of cycle range on estimated life – Sandia & Becht
- Perform ΔK_{th} testing in high pressure H_2 – Sandia
- Obtain industry data - **???**

2) Assess defect population in end of life vessels

- Develop techniques for NDE for Type II tanks – Digital Wave & NASA
- Proof of principal - metal liner measurements using eddy current on Type 1 tanks with internal manufactured defects - NASA
- Inspection of Type 2 carbon-fiber – Digital Wave





Project Objectives / Plan…

3) Develop guidelines and protocols for life extension

- Could range from predictive tool that operators could employ to generic guidance on what cycles can be dismissed
  - → Oversight/Input needed from industry on what this would look like

4) (*Stretch goal)* Experimental validation of life extension practice

- Pressure cycling of miniature vessels with engineered defects followed by NDE?

Result of this effort will be science-based justification for tank life-extension which can be adopted by industry and standards.

Other items to consider

Does spectrum loading have a measurable effect on tank life?

How do we capture evolution of residual stress in these vessels?

→ How does it evolve or diminish with cycling, with crack extension?

Risks in Project

1) NDE technique to inspect steel liner of Type 2 tank not currently available
- Response Plan: Possibly perform destructive evaluation if NDE is not identified

2) ΔK_{th} measurements in 100 MPa H_2 is challenging and time consuming
- Response Plan: Modify pressures / frequencies to measure high fidelity ΔK_{th}

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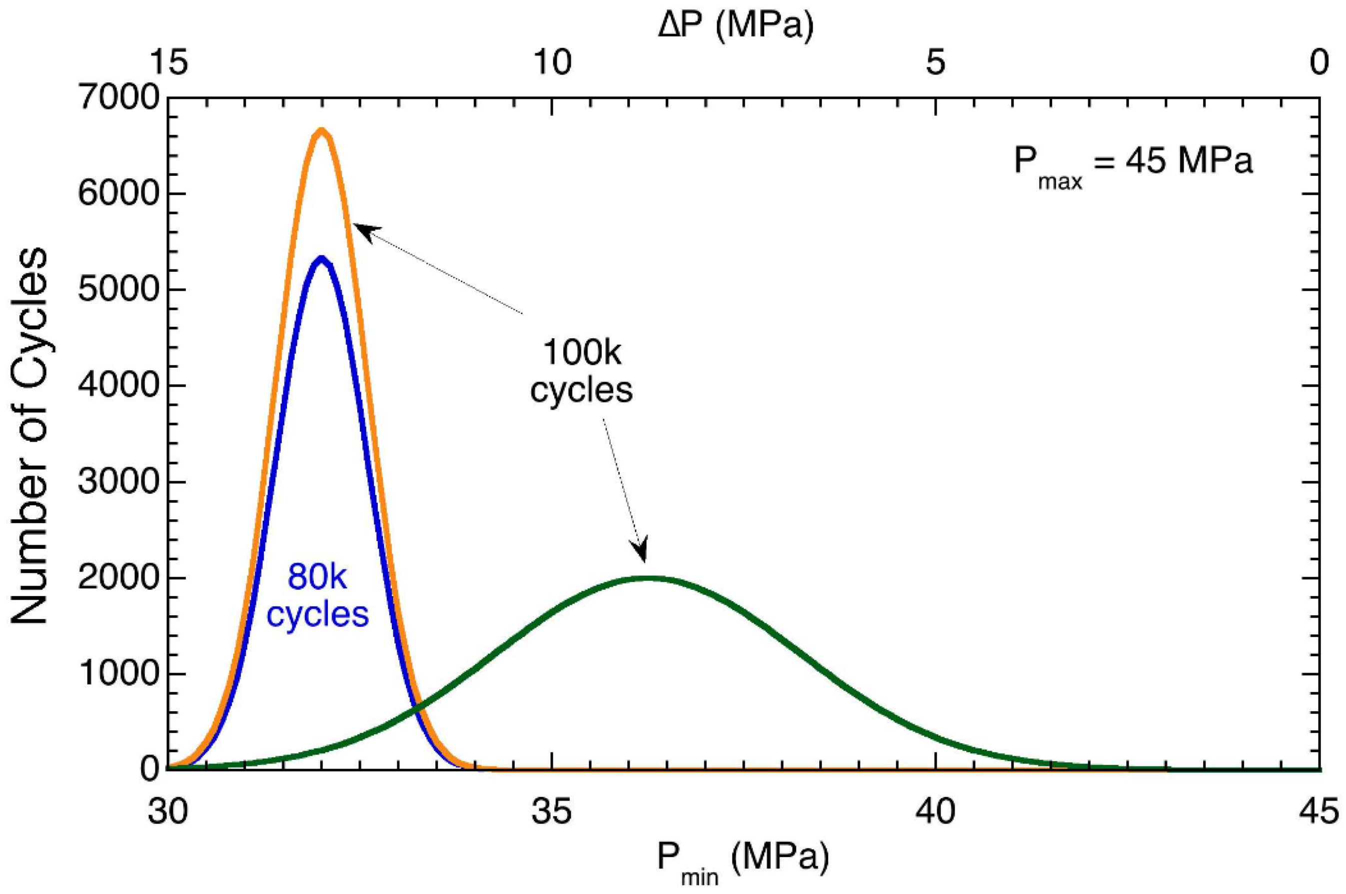
Initial calculations for a Type 1 tank operated at different pressure ranges

Assumption:
- Pressure cycles are normally distributed.
- P_{max} = constant

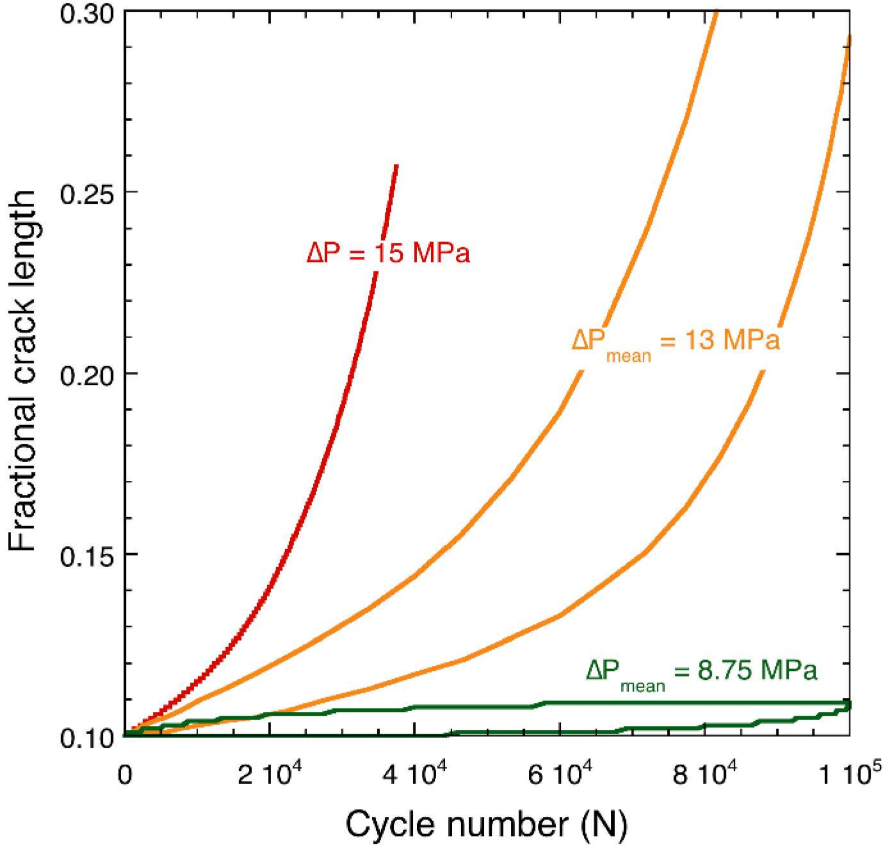
Courtesy of Chris San Marchi



Two distributions are considered in this plot:
- ΔP_{mean} = 13 MPa
  (two curves are shown with total number of cycles of 80k and 100k respectively)
- ΔP_{mean} = 8.75 MPa

Lower mean = longer life AND lower ΔP earlier = longer life

Assumption:
- Cylinder: 238 x 15.9 mm (OD x t)
- Maximum pressure = 45 MPa
- ΔP is determined from distributions provided
- Initial defect is 6% of wall (a/t = 0.06)
- Life = cycles to grow defect to a/t = 0.25
- da/dN follows "master curves" for H2



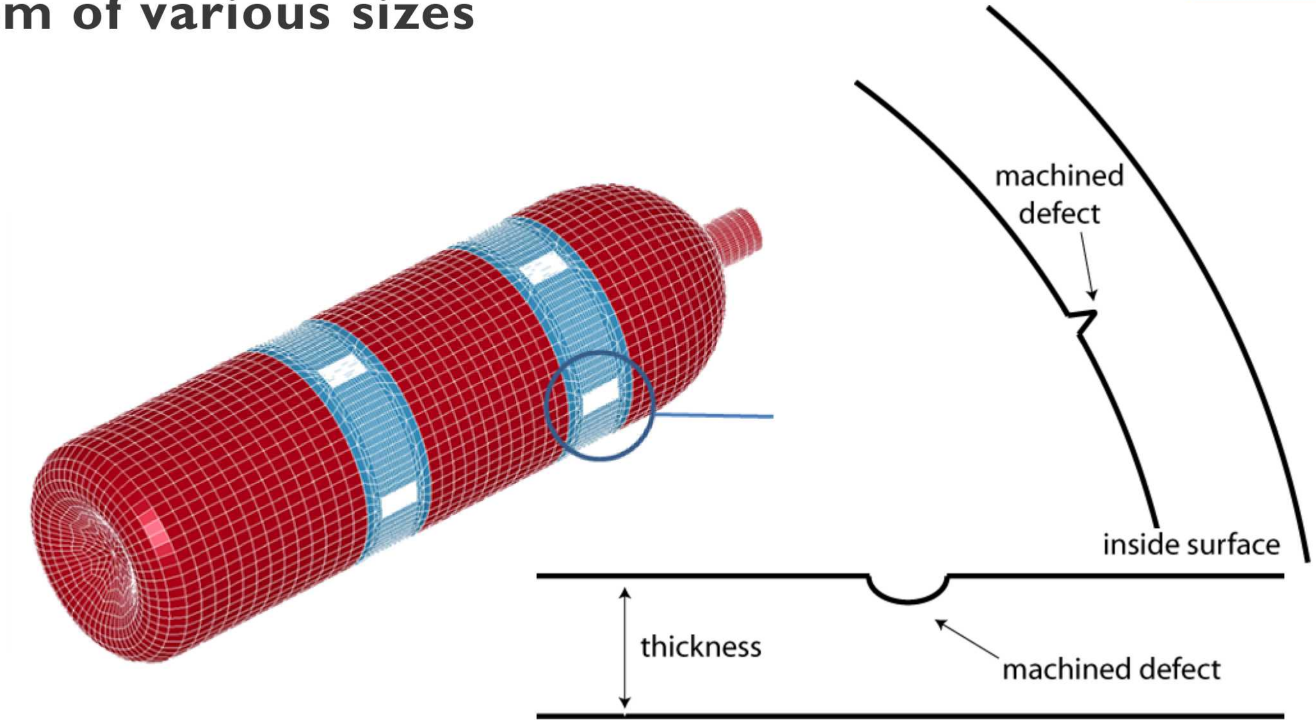
Outcome:
- Red curve represents constant ΔP = 15 MPa
- Two curves are shown for each distribution (estimated to be bounding behavior)
- Crack extension is strongly dependent on ΔP and its distribution
- In this case, worst case = ~34k cycles (constant ΔP), but cycle life is 2 to >5 (?) times greater for lower ΔP

Notes:
- Crack growth is dependent on order of application of pressure cycles
  - Here we assumed either accumulation of cycles from low to high ΔP (slower), or from high to low ΔP (faster)
  - Planning to calculate with random application of ΔP (within an assumed distribution)

Additional tanks could be used for development work – all steel (no overwrap)

9 tanks with machined defects in them of various sizes

Steel pressure vessels



Calibration block with machined defects