Fracture Control of Hydrogen Containment Components

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DOE Hydrogen Program

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Pressure vessels and pipelines are important components in the hydrogen energy infrastructure

- Current examples:
  - Cr-Mo ferritic steels
  - <45 MPa H_2 gas
  - <1 pressure cycle/day

- Current examples:
  - C-Mn ferritic steels
  - <15 MPa H_2 gas
  - static pressure

Evolving H_2 containment components will operate outside windows of current service conditions

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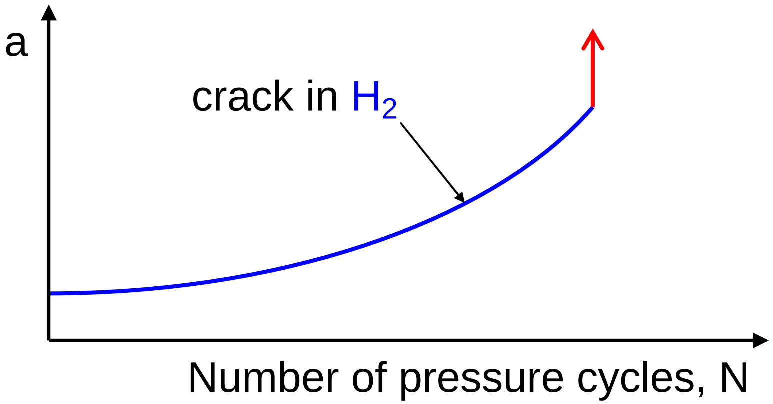
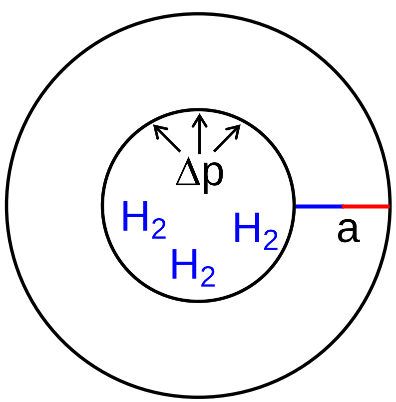
Fatigue crack growth aided by hydrogen embrittlement can dictate component life





Barthélémy, 1st ESSHS, 2006

Maximum number of pressure cycles must be defined for H_2 components

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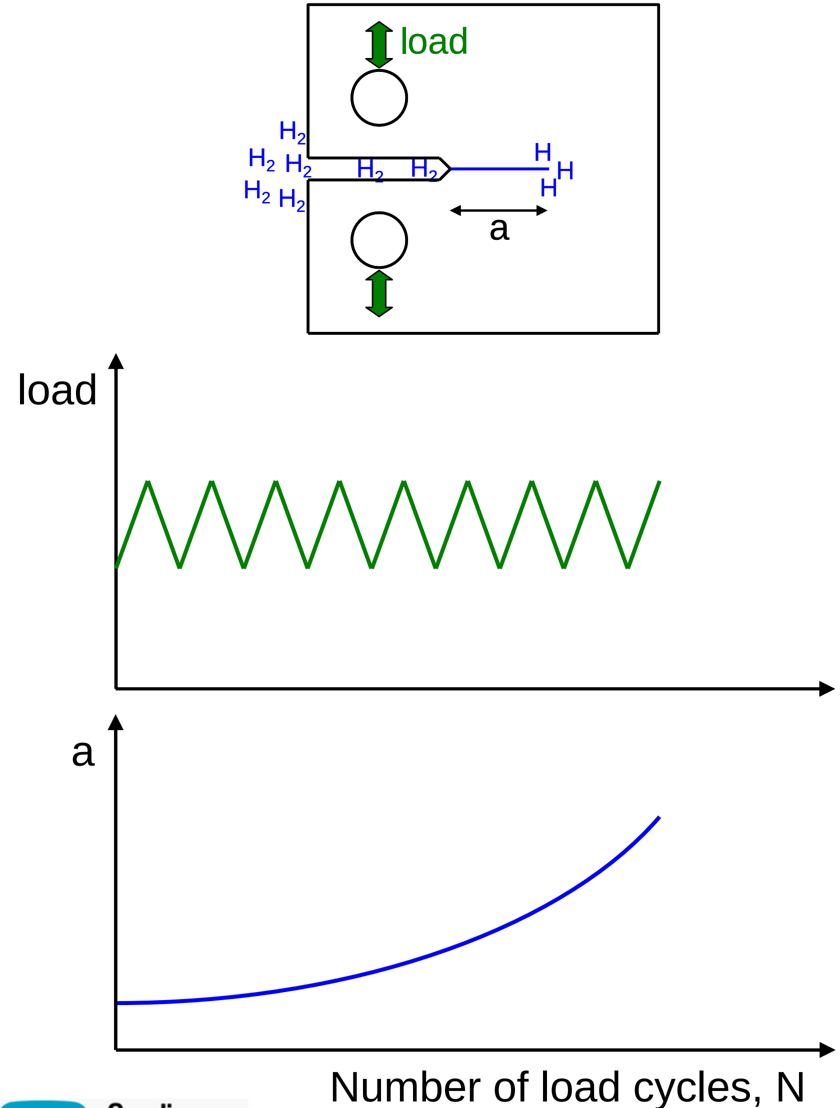
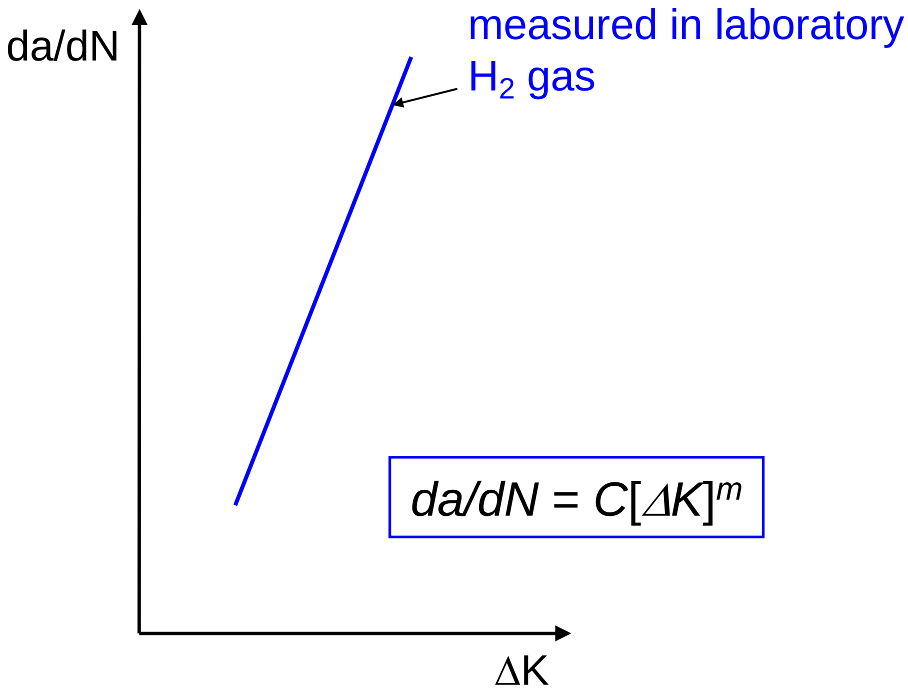
American Society of Mechanical Engineers (ASME) developed design method for H_2 pressure vessels

- Article KD-10 in Section VIII, Division 3 of Boiler and Pressure Vessel (BPV) code
  - "Special Requirements for Vessels in High Pressure Gaseous Hydrogen Service"
  - Mandatory for seamless vessels with H_2 pressure > 41 MPa and welded vessels with H_2 pressure > 17 MPa
  - Allows H_2 pressure up to 100 MPa
  - Design method also considered for H_2 pipelines
  - *Calculate maximum number of cycles by coupling fatigue crack growth data with structural analysis*

Fatigue crack growth rate must be measured in high-pressure hydrogen gas





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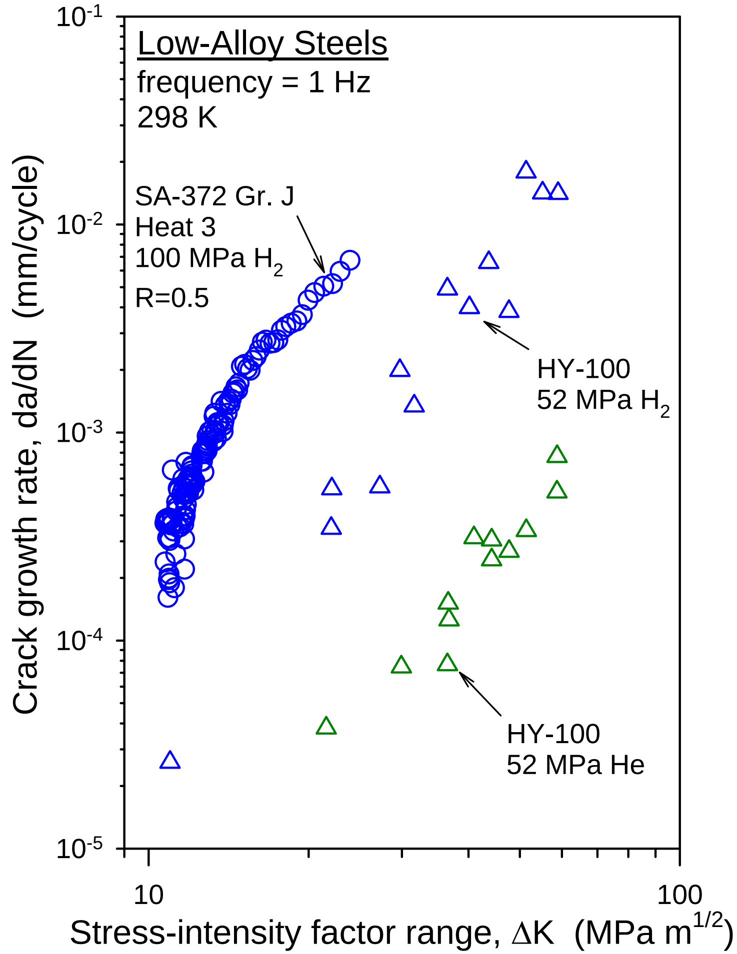
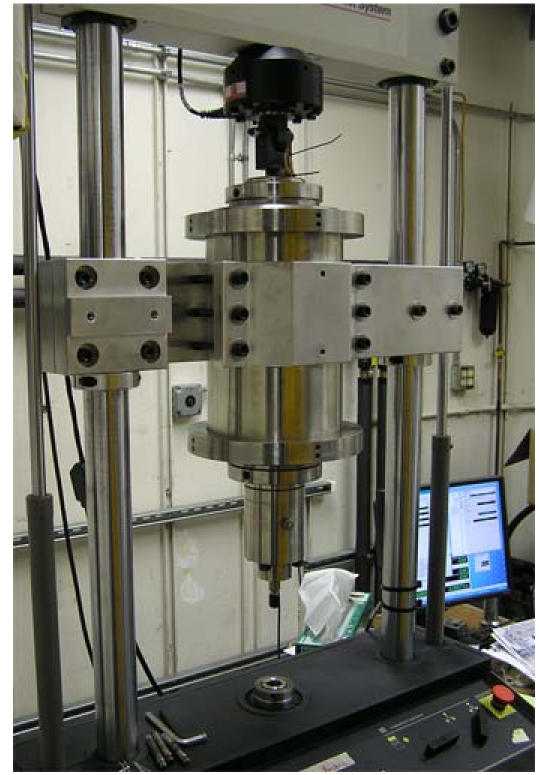
Fatigue crack growth rates measured for Cr-Mo steel SA-372 Gr. J in 100 MPa H_2 gas





Data sets in high-pressure H_2 are rare, in part because measurements are complex

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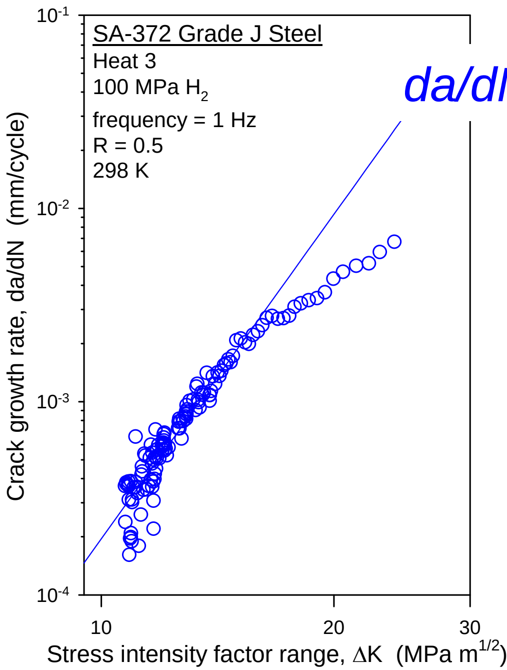
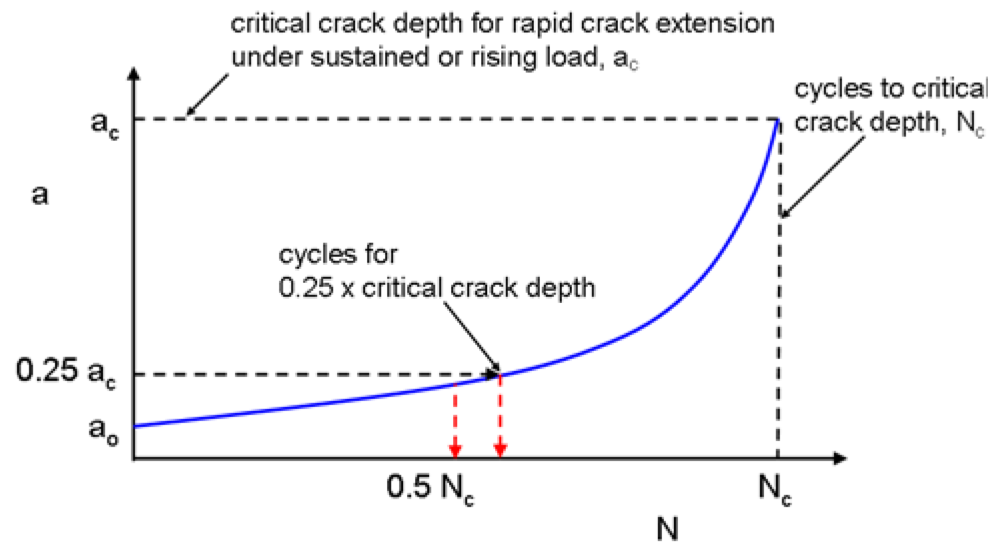
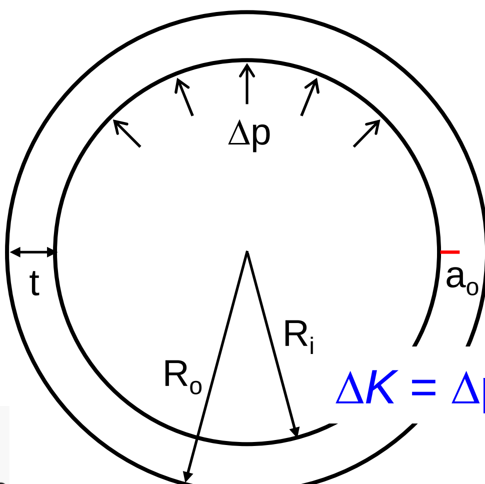
Fatigue crack growth rate data enable determination of maximum number of pressure cycles



$$da/dN = C[\Delta K]^m$$





$$\Delta K = \Delta p[f(a, t, R_o, R_i)]$$

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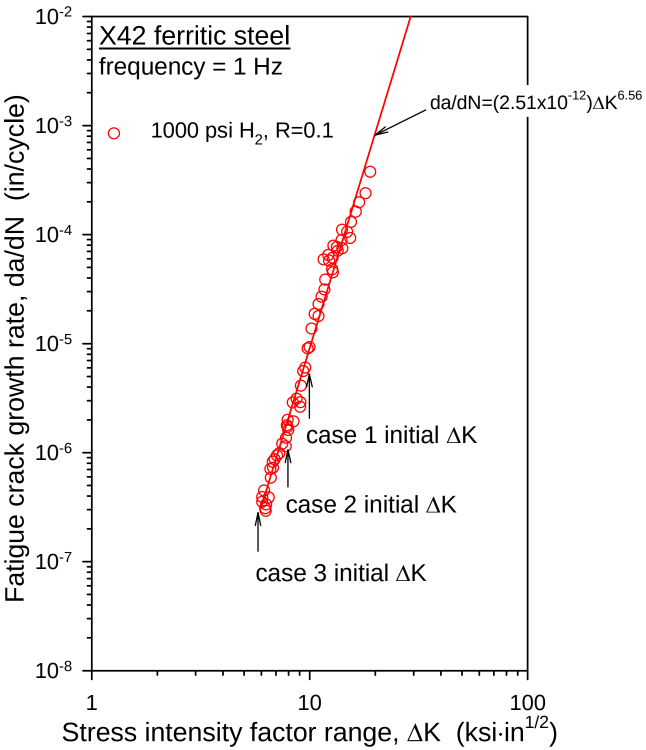
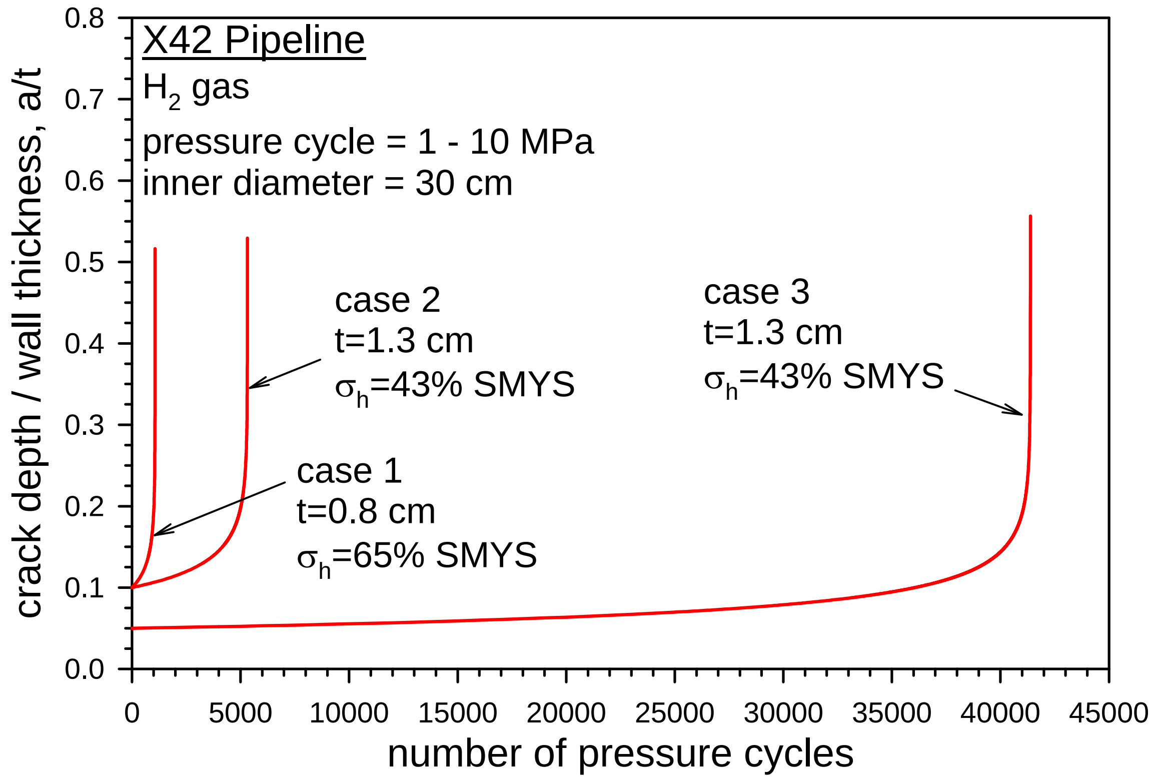
Example: crack depth *vs* number of cycles calculations for three component variations





Design life depends on both fatigue crack growth rate response *and* component features

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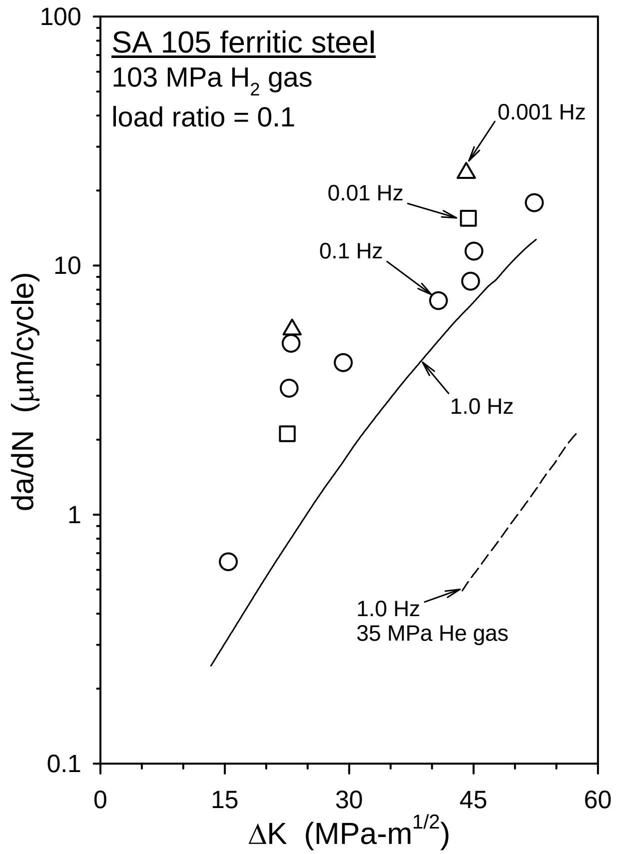
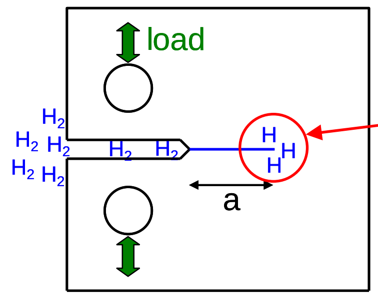
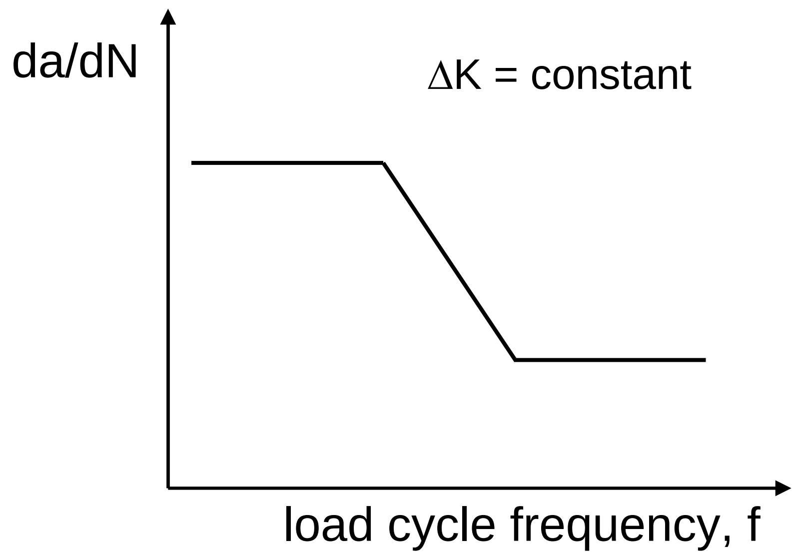
Fatigue crack growth measurements for component design must consider *environmental similitude*



Walter and Chandler, Effects of Hydrogen on Behavior of Metals, 1975



Environmental similitude: crack-tip H concentration



Environmental similitude affected by variables such as H_2 pressure and *load-cycle frequency*

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Summary

- Fatigue crack growth aided by hydrogen embrittlement can dictate service life of H_2 containment components
  - Maximum number of pressure cycles must be defined
- Maximum number of cycles calculated by coupling fatigue crack growth data with structural analysis
  - Framework established in ASME codes
- Measurements of fatigue crack growth rates in high-pressure H_2 gas in progress
  - Initial data for Cr-Mo steel SA-372 Gr. J in 100 MPa H_2
  - Must address effects of load cycle frequency and wave form on fatigue crack growth rates in H_2