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# Fiber Reinforced Composite Pipelines


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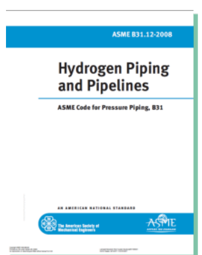



**Project ID #: PD022**
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# Project Overview – FRP for $H_2$ Delivery

**Timeline**

- Project start date:10/2006
- Project end date:10/2017*

* The completion of this project is at the discretion of DOE based on program needs

**DOE Barriers**

- High Capital Cost and Hydrogen Embrittlement of Steel Pipelines
- Safety, Codes and Standards, Permitting

**Budget**

- Funding for FY13 $300K
- Funding for FY14 $350K

**Project Goals**

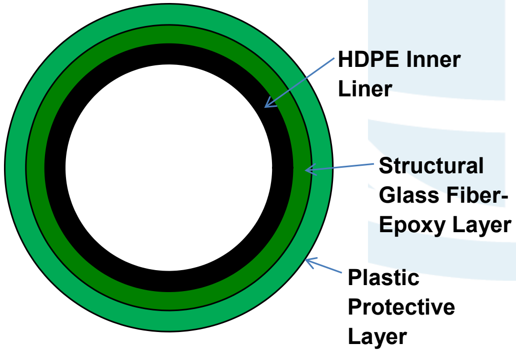
- Provide data to support a technical basis for fiber reinforced piping in hydrogen service.
- Have FRP integrated into the ASME B31.12 Hydrogen Piping and Pipeline Code by 2015

**Partners**

- FRP Manufacturers
- ASME
- ORNL
- University of Hawaii

# Relevance – FRP for $H_2$ Delivery

- **Impact**
  - Composite pipeline technology has the potential to reduce installation costs and improve reliability for hydrogen pipelines.
- **Existing Technology**
  - FRP is an existing commercial technology currently employed in the oil & gas industry.  Commercial products up to 6” diameter and 2500 psig pressure rating are available.
- **Advantages to using FRP**
  - Long lengths can be spooled for delivery reducing installation cost.
  - FRP is not susceptible to hydrogen embrittlement.
  - Superior chemical and corrosion resistance.




FRP Cross Section

FRP Installation



SRNL

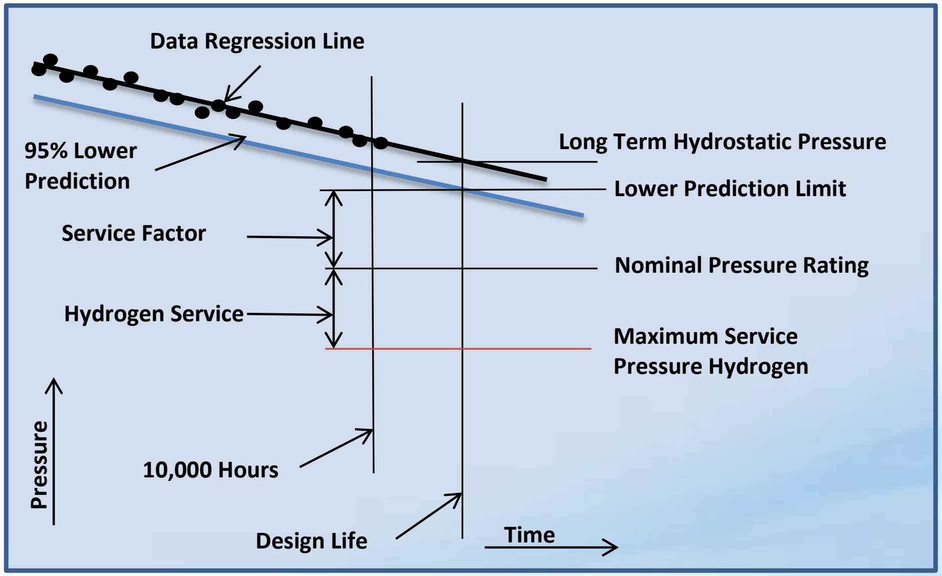
# Approach – FRP for $H_2$ Delivery

- **The SRNL approach towards FRP for hydrogen delivery:**
  - Critically evaluate the current application of available FRP product standards through independent testing.
  - Define changes to the current FRP product standards to meet the ASME Code Methodology.
  - Build a body of data to support codification in the ASME B31.12 Code Hydrogen Piping Code.

## FRP Delivery Program

**ASME Methodology** ⟷ **FRP Product Methodology**

**ASME B31.12 Code**
- Scope
- Materials
- Design
- Fabrication
- Examination
- Testing
- Inspection






SRNL

# SRNL FRP Accomplishments (Prior Years)

- **SRNL in collaboration with ASME developed an FRP Life Management Plan to support Codification of FRP.**
  - **System Design and Applicable Codes and Standards**
    - Complete review of relevant FRP piping and pressure vessel standards.
  - **Service Degradation of FRP**
    - Tested FRP following high and low PH exposure.
    - Evaluated joints for leak integrity.
  - **Evaluated effect of flaws on burst strength and fatigue life.**
    - Burst test flawed and unflawed piping to evaluate design margins.
  - **Fatigue Testing**
    - Evaluated effect of flaws on fatigue life. Will support installation inspections.
    - A primary design fatigue curve has been developed.

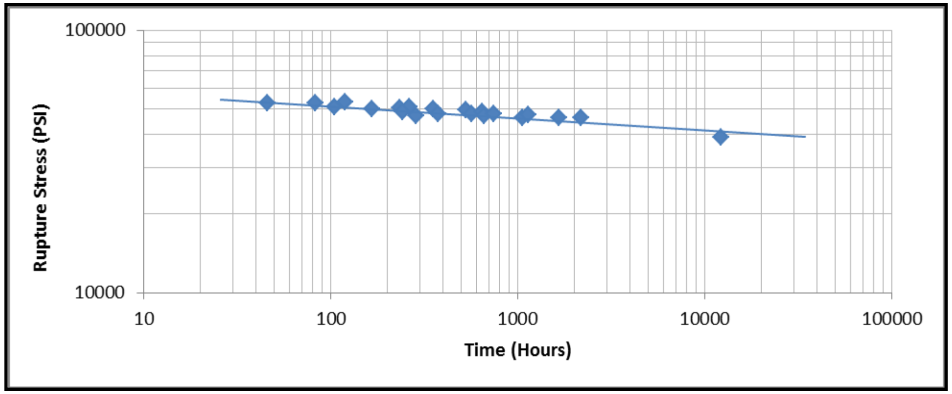
# Fiber Reinforced Composite Pipeline - 50 Year Design Life

- SRNL in collaboration with Fiberspar has evaluated increasing the design life for FRP from 20 to 50 years.
- The 20 year design life was questioned during the first ASME review of the background data. Industrial gas supplier questioned the 20 year design life currently used in FRP standards because pipelines are a large capital investment for a 20 year design life.
- Review of the available glass fiber stress rupture data indicates that only a small increase in design margin is required to support a design life increase to 50 years. This was presented at the 2012 AMR meeting.
- The fatigue testing is now being complete to support a complete evaluation.

# Fiber Reinforced Composite Pipeline - 50 Year Design Life

- A data set from a ASTM D2992 (Hydrostatic Design Basis) test was used to calculate the reduction in design stress to support 50 a year design life.
- The failure data as a function of time illustrates the regression line used to determine the hydrostatic design stress.

- A curve fit to the data results in the following model for rupture stress as a function of time.
- $\sigma_{\text{Rupture Stress}} = 10^{4.814-0.0481\text{Log}_{10}\text{t}}$
- A decrease in the fiber stress level by 4.3% will provide the required increase in design life.
- The required decrease in fiber stress of 6% was calculated using the Robinson strand data.




**ASTM D2992 Data set for FRP**

| Years | Time (hours) | Rupture Stress (psi) |
|---|---|---|
| 1 | 8,760 | 42113 |
| 20 | 175,200 | 36465 |
| 50 | 438,000 | 34894 |

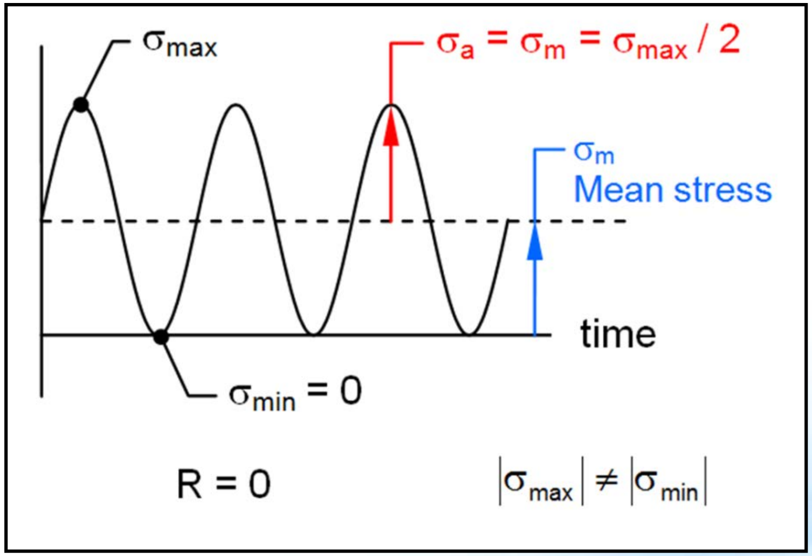
**Stress Levels vs. Time**



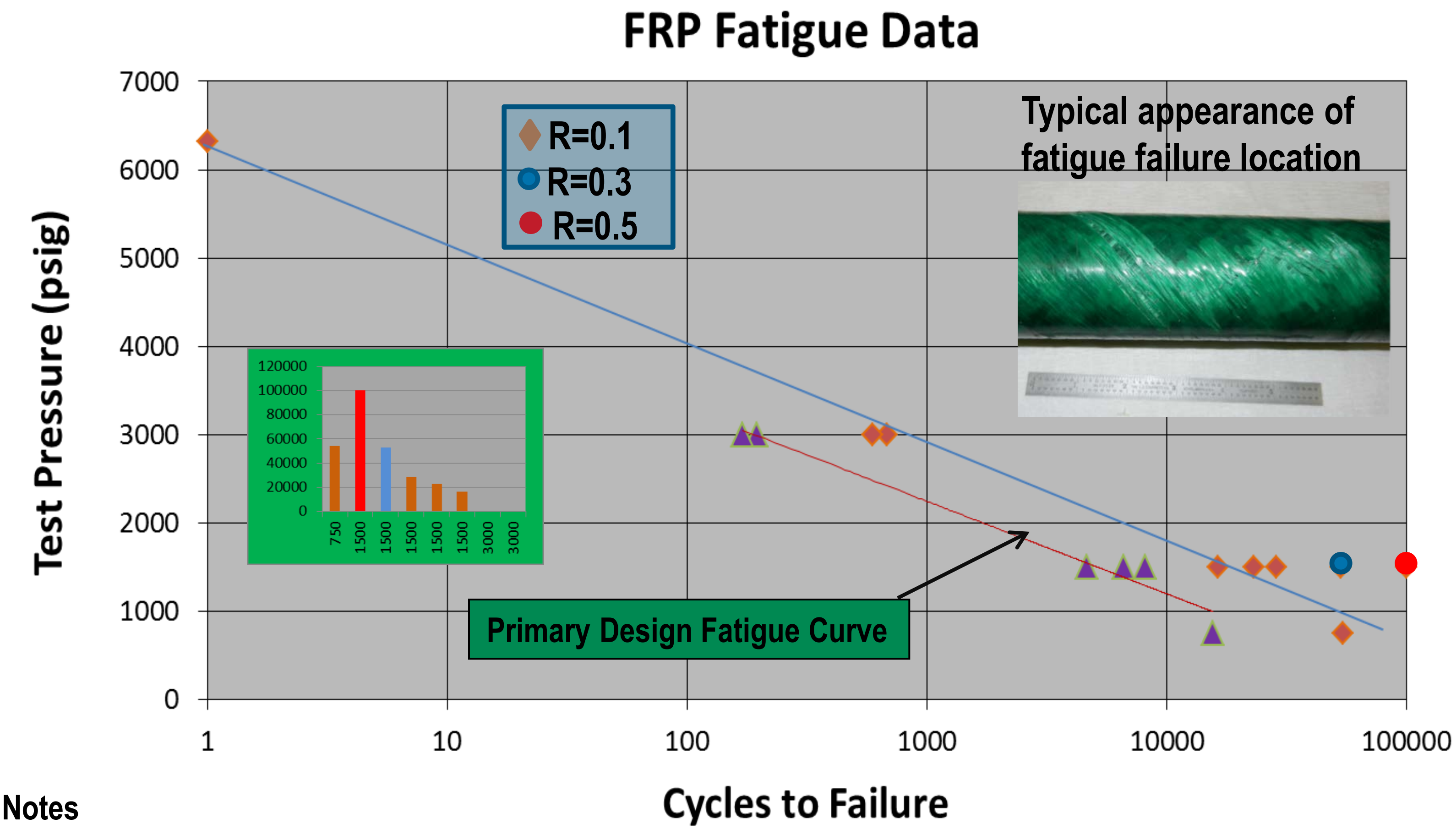
SRNL

# SRNL FRP - Fatigue Testing

- Fatigue testing of FRP was started at SRNL during FY 2012 and is continuing during FY 2014. The fatigue test data directly support both FRP codification and the evaluation of a 50 FRP design life.
- During FY 2013 six fatigue tests were completed at pressure levels ranging from 750 psi to 3000 psi. The pressure levels ranges from half to twice the rated pressure of the FRP product test samples. All these tests were performed at a stress of R- ratio of 0.1.
- The Stress Ratio R = $\sigma_{min}/\sigma_{max}$
- During FY 2014 two additional samples were tested. The maximum pressure for each test was 1500 psi, the rated FRP sample pressure. These tests were performed at a stress ratio or R-ratio values of 0.3 and 0.5. The FY 2014 fatigue tests show that the FRP product is sensitive to R-ratio.



# Fiber Reinforced Composite Pipeline - Fatigue Testing




Notes
1 Single cycle test represents burst test data
2 750 psig fatigue test was terminated at 54160 cycles without a structural failure
3 The fatigue tests for R = 0.3 failed at 53020 cycles. The fatigue tests for R = 0.5 has not failed

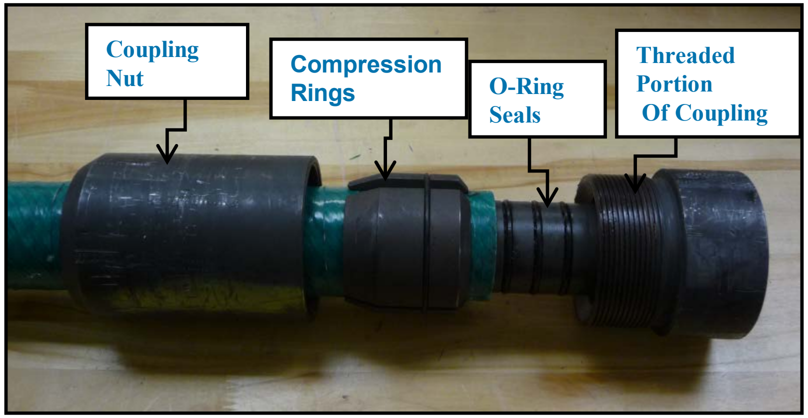
# Fiber Reinforced Composite Pipeline - 50 Year Design Life

- The stress rupture data for both the ASTM D2992 data and the Robinson glass fiber stress rupture data support a 50 year design life with a less than 10% reduction in fiber stress.
- The results for the fatigue testing to date shows that for the current FRP product tested, the fiber stress level will have to be reduced if pipeline operation at full pressure cycles (low R ratio) is required.
- Piping systems that can be operated at a higher R ratio can be constructed with the current FRP products available today, with reduction in fiber stress of the same order of magnitude as required for the stress rupture life. It is noted that hydrogen pipelines are operated today with approximately constant operating pressure with very few fatigue cycles.
- The current data supports an increase in design life to 50 year for FRP with a 5% decrease in fiber stress and a limit on fatigue life of 28500 cycles at an R ratio of 0.5.

| Years | Equipment Maintenance Demand | | Refueling Station Demand | |
|---|---|---|---|---|
| | Fatigue Life (@1 Cycle per Month) | Fatigue Life (@2 Cycle per Month) | Fatigue Life (@1 Cycles per Day) | Fatigue Life (@2 Cycles per Day) |
| 1 | 12 | 24 | 365 | 730 |
| 20 | 240 | 480 | 7,300 | 14,600 |
| 50 | 600 | 1200 | 18,250 | 36,500 |

# Fiber Reinforced Composite Pipeline - Fatigue Testing

- **FRP Connectors -** The connectors are all metallic with elastomer O-ring seals. To form the connection the internal diameter of the polyethylene liner is machined to a specified diameter. The machined portion of the liner is where the O-rings in the metallic connector interface with the composite piping to form the fluid seal. The outer nut of the connector is tightened, mechanically compressing ferrules on the piping, resulting in compression of the seals.



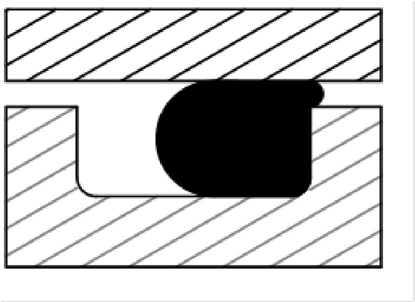
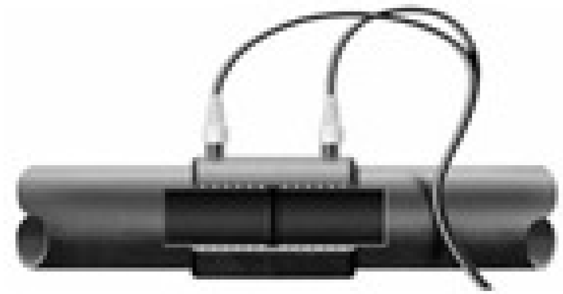



**Illustration of O-Ring Extrusion Failures from FY 2013 Fatigue Testing**

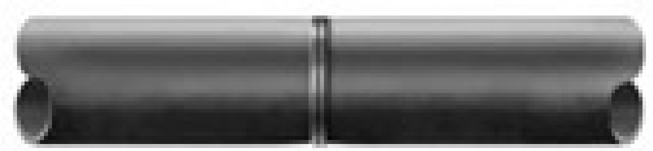
- The extrusion failures were resolved by increasing the O-ring hardness level to approximately 75 durometer M.
- During discussions with ASME pipeline operators expressed a concern over the use of mechanical joints that may require maintenance.

# Fiber Reinforced Composite Pipeline - Joint Concepts

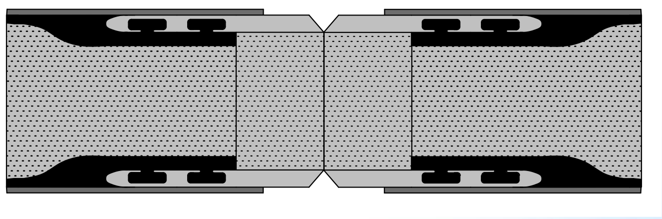
- Existing technology was reviewed to provide new concepts for FRP Joints.
- Electro fusion joining is a welding method for joining polyethylene piping utilizing fittings that have built-in electric heating elements used to weld the joint forming a permanent bond.
- Heat fusion jointing is a welding method used to join polyethylene piping . In this method both pieces of the piping are simultaneously heated. Pressing the piping together during cooling forms a permanent bond.
- The welded joint utilizes a metallic component formed into the polyethylene liner. The joint is then formed using standard welding methods.



**Electro Fusion Joint**

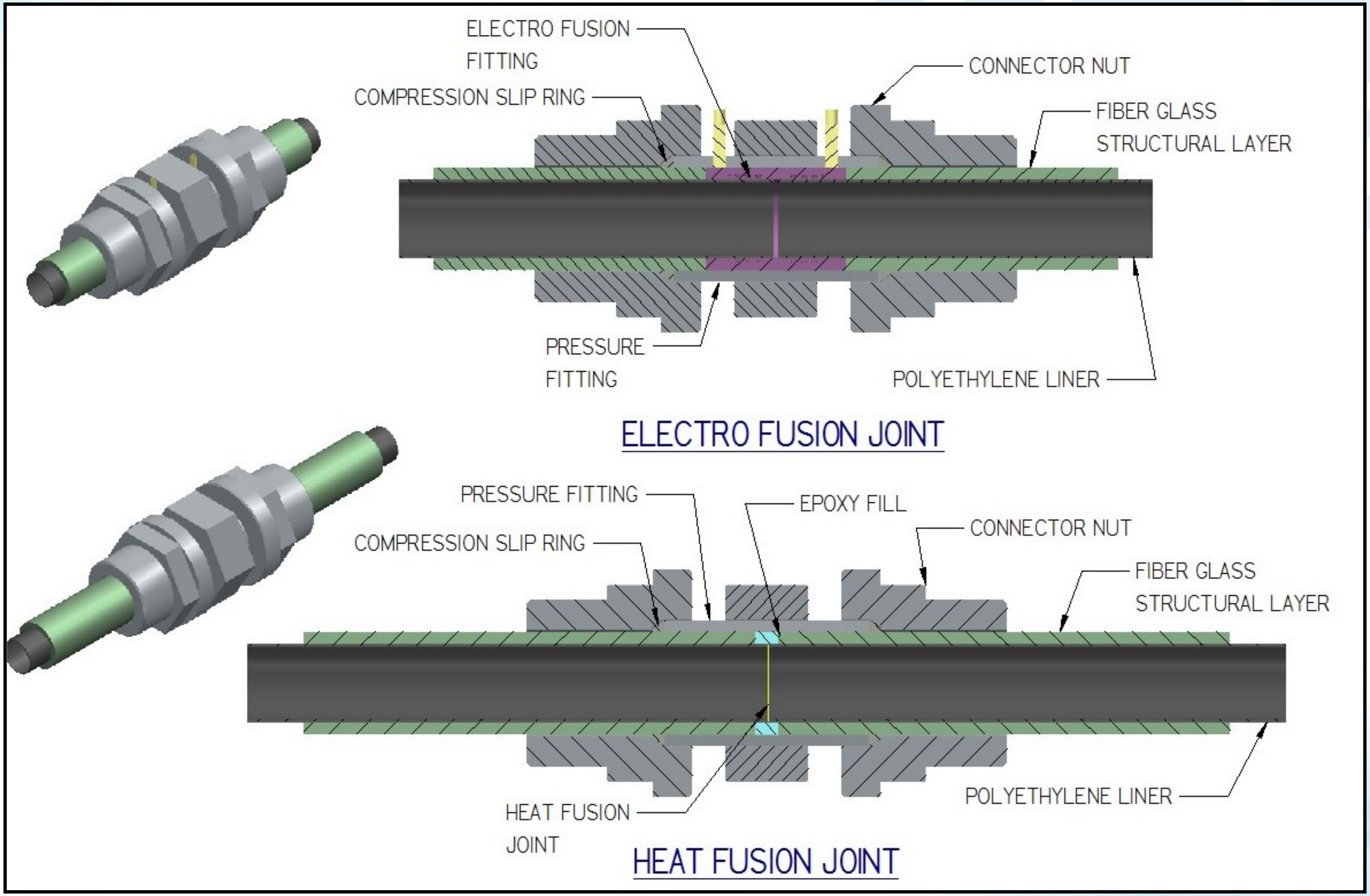


**Heat Fusion Joint**



**Welded Joint**

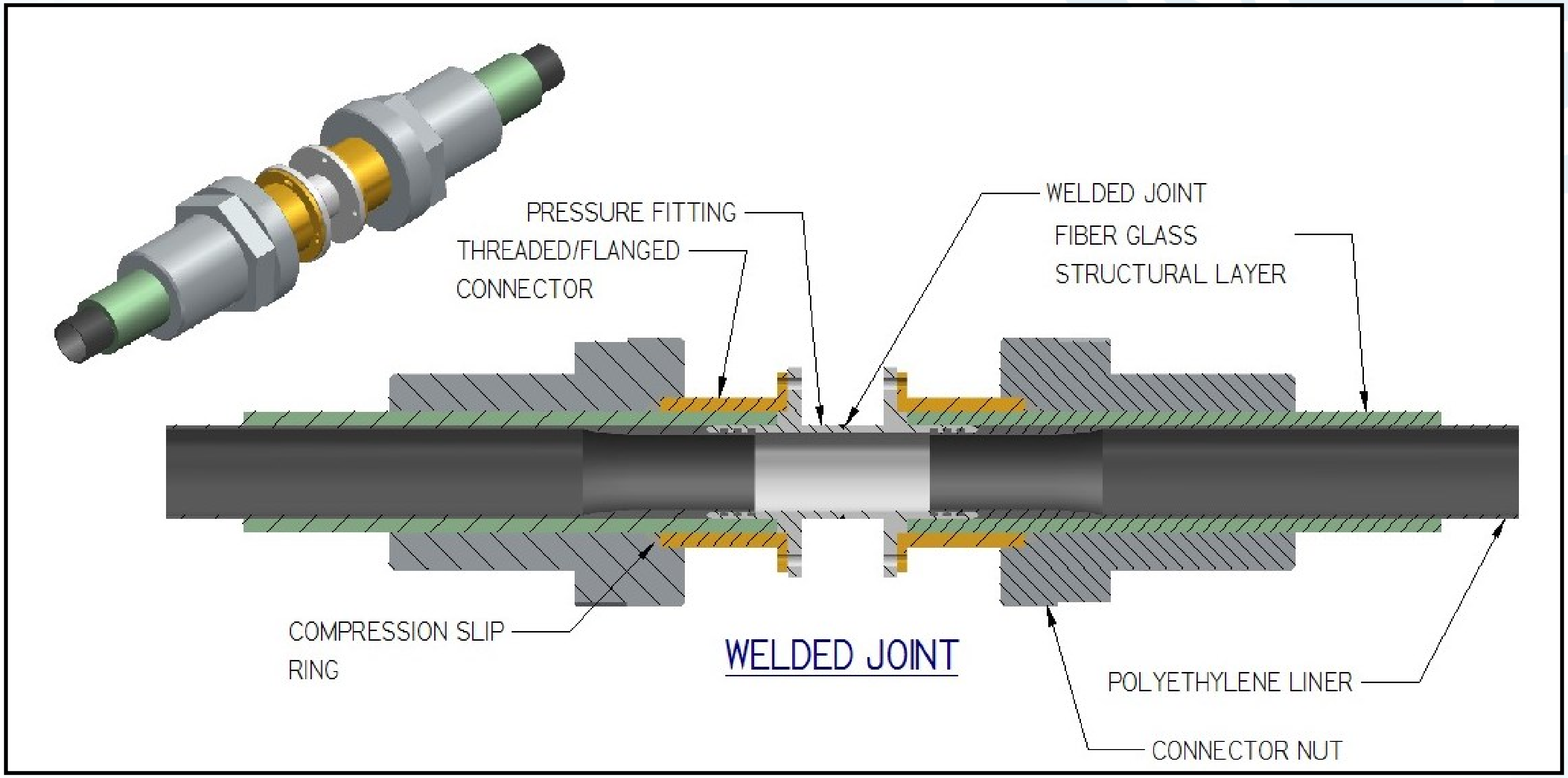
# Fiber Reinforced Composite Pipeline - Joint Concepts






SRNL

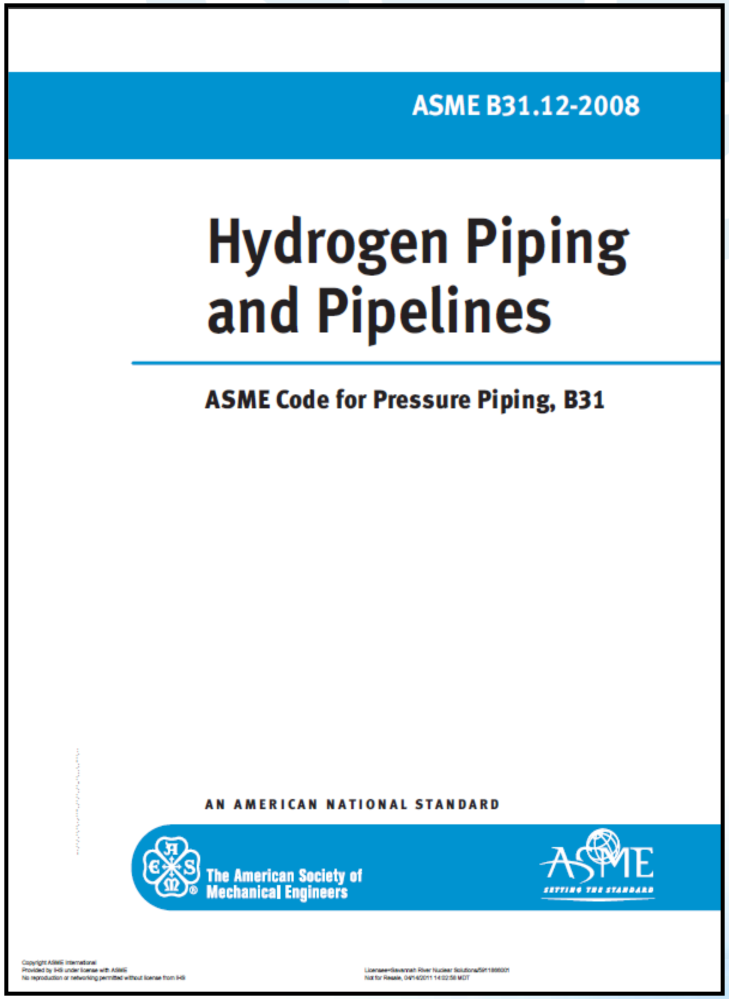
# Fiber Reinforced Composite Pipeline - Joint Concepts




Adapted from Hexagon Lincoln Tuffshell tank boss design.

# Fiber Reinforced Composite Pipeline – Codification

- **ASME B31.12 Code**
  - The initial proposal (Code Language) for codification into ASME B31.12 was presented to the Code Committee at a meeting March 2014.
  - A project team to review the technical report for codification was determined at the March 2014 Meeting.
  - The report summarizing the FRP testing by SRNL and ORNL has been completed with the current available data. The report will become the basis for ASME Codification of FRP.



# Summary

- The deign life evaluation supports that an increase in design life from 20 years to 50 years is feasible for FRP.
- The codification of FRP will proceed with a recommendation for a 50 year design life. The proposed fatigue testing provided in the B31.12 Code proposal is well suited to address the required fatigue life.
- Fatigue testing over the range of 750 psig to 3000 psig was completed following the 2013 AMR Project Review Meeting. The data provides an indication on the fatigue life of FRP. The FY 2013 tests were performed at a stress of R- ratio of 0.1.
- Fatigue testing continued in FY 2014. The first fatigue test at an R ratio of approximately 0.5 has been tested to 100,000 cycles without failure. The second test with an R ratio of approximately 0.3 has been tested to 53,020 cycles. The testing shows that the FRP has a significant sensitivity to R-ratio.
- The initial proposal (Code Language) for codification of FRP into ASME B31.12 was presented to the Code Committee at a meeting in March 2014.

# Proposed Future Work – SRNL Scope for FRP

- Complete the FRP Codification into ASME B31.12
- Complete collaboration with Fiberspar to determine the variability in the fatigue data and effect of cycle frequency.
- Collect and document available service history data for FRP from literature and FRP manufacturers.
- Continue the evaluation of non-mechanical joints for FRP application.
- Development an in-service inspection criteria for FRP.
- Continue to support the development of an FRP demonstration project.