Project De-Brief Presentation

Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks

DOT-PHMSA Contract #693JK32110006POTA

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Photo courtesy of Freeport LNG

This research was funded in part under the Department of Transportation, Pipeline and Hazardous Materials Safety Administration's Pipeline Safety Research and Development Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Pipeline and Hazardous Materials Safety Administration, or the U.S. Government.

Sponsors

- US DOT PHMSA
  - Technical Task Inspector: Katherine Roth
  - Contractual: Dwayne Cross, with Andrea Ceartin

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

Research Project Team Members

- PEMY Consulting, LLC.
  - Philip Myers, Director
  - Andrew Yearwood, Senior Engineer
  - Andy Wong, Mechanical Engineer
- Cost sharing was achieved by additional labor supplied by the project team, as this research project required no material costs.

PEMY CONSULTING

Research Project Background

- LNG is a critical component of US energy infrastructure.
- The LNG infrastructure is aging:
  - Operation planned to continue indefinitely as growth drives demand.
  - The condition, fitness for purpose, and assessment of aging existing facilities is not well defined or understood.
- To address this, DOT-PHMSA funds various research projects to address issues related to energy.
- One research project attempts to address the ongoing integrity of large LNG storage tanks through inspection practices.
  - Project awarded 9/30/2021 to PEMY Consulting, LLC.
- The research work is aimed to address the need for and the types of inspection necessary to maintain and ensure the ongoing mechanical integrity of tanks for cryogenic LNG and liquefied gases.

Primary Objectives

- Scope: US owners/operators' LNG tank systems, > 5000m^3 capacity
- Develop best inspection practices and guidelines
  - Aid SDOs aiming to write inspection and repair standards
  - Reduction of incidents
- Develop recommendations
  - Need to update DOT PHMSA regulations
  - Additional research projects
  - Knowledge transfer to the public domain (i.e., tank owners, operators and industry organizations).

Project Overview

Major Tasks:

- Form Technical Advisory Panel (TAP)
- Standards Review
- Industry Survey
- Tank Design Review and Gap Analysis
- Inspection and Repair Data Review
- System and Component Review
- Classify Damage Mechanisms
- Damage Growth Rate and Interval Assessment
- Inspection Technology Review
- Risk Assessment of Damage and Inspection Effectiveness
- Business and Operational Considerations
- Inspection Records Review
- Draft Inspection Criteria Recommendations

Project Timeline: 2 ¼ Years, Sep 2021 to Dec 2023 (after extensions)

Project Budget: $210,250.00 total, of which $165,000 was funded by DOT PHMSA

Stakeholders

- Filling the gap starts with the current research project.
- The team implementing this work comprised of Technical Advisory Panel (TAP) working with PEMY (research project authors) and special expertise.
  - TAP Stakeholders: Industry, Regulatory, Manufacturers
    - 1 PHMSA
    - 1 FERC
    - 7 LNG tank owner/operators
    - 1 Tank manufacturer
  - Special expertise input from Engineering, Manufacturing, and Inspection stakeholders.
- Consensus meetings for development, review, and approval held over 2 ¼ years; once per quarter
- Work was completed 4th Qtr. 2023

Information and Knowledge Acquisition Methodology

- Establish the Technical Advisory Panel (a group of experts in the domain of interest) and confer with other special expertise
  - Regulatory agencies
  - LNG owners/operators
  - Inspection agencies
  - Cryogenic tank manufacturers
- Literature search
- Survey of TAP and variables associated with their tanks
- Review of incidents
- Internal storage tank and piping expertise

Literature Search

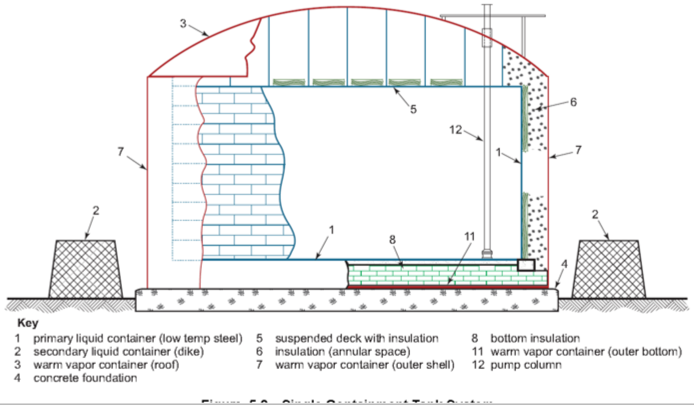
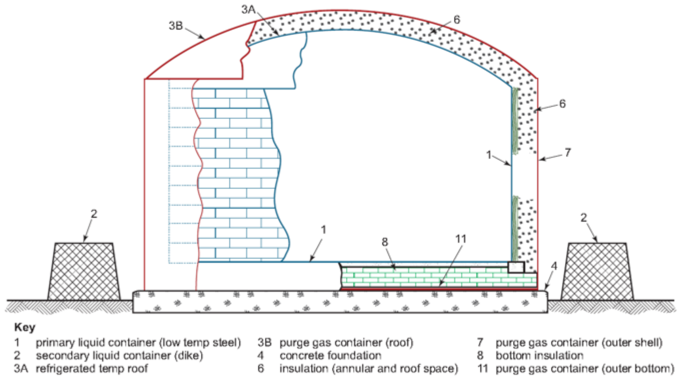
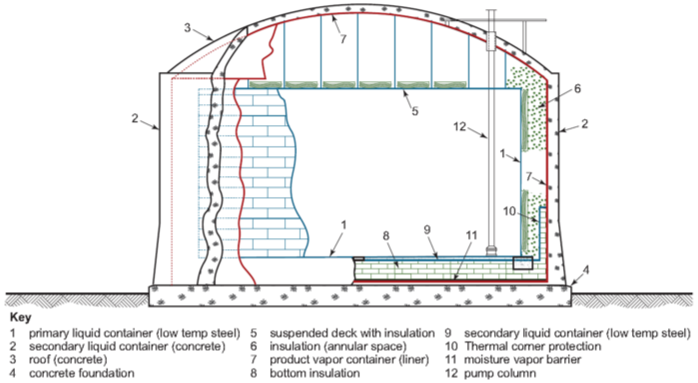
- Review of current standards, practices, regulations in the US
  - Code of Federal Regulations (CFR)
  - API
  - NFPA
- Review foreign standards
  - European (EN, BS, EEMUA)
  - Japanese (JSA)
  - Korean (DATS) and others
- Review of incidents

Literature Search Findings

- US and worldwide regulations and industry standards reviewed.
- For new LNG tank construction, worldwide standards are modeled after the US standards
  - There is little additional information outside of US codes and standards that is useful.
  - No SDO has yet tackled the problem of standardization of best practices for LNG tank inspection, repair, and mechanical integrity.
- **The existing body of knowledge in both the regulatory and industrial standards arenas are currently insufficient to address what best practices are for the inspection, repair, or ongoing mechanical integrity of LNG storage tanks.**
  - The inspection checklists of the old 1984 AGA standard and the EEMUA standards are lacking in detail and guidance. (The prototype checklist developed for this report fills in the gaps)

TAP Survey General Findings

- The survey provided critical information about the population of large flat bottom LNG tanks in the US.
  - Survey data were anonymized.
- Survey included 36 LNG tanks (>5000m^3)
  - ~35% of the existing tank population.
  - Illustrative of the US LNG tank population.
- Survey focus on tank system types, sizes, construction details, susceptibility to degradation, and inspection and repair practices.
- API 625 system configurations (13)
  - 5.3 (single containment)
  - 5.4 (single containment)
  - 5.9 (full containment)

API 625 Figure Number	Schematics	Comment	% Share
Figure 3—Single Containment Tank System Double Wall with Steel Primary Liquid Container and Steel Vapor Container		Listed in survey as 5.3	52%
Figure 4—Single Containment Tank System Double Wall with Steel Primary Liquid Container and Steel Purge Gas Container		Listed in survey as 5.4	22%
Figure 9—Full Containment Tank System Steel Primary Liquid Container, Concrete Secondary Liquid Container, and Concrete Roof		Listed in survey as 5.9	25%

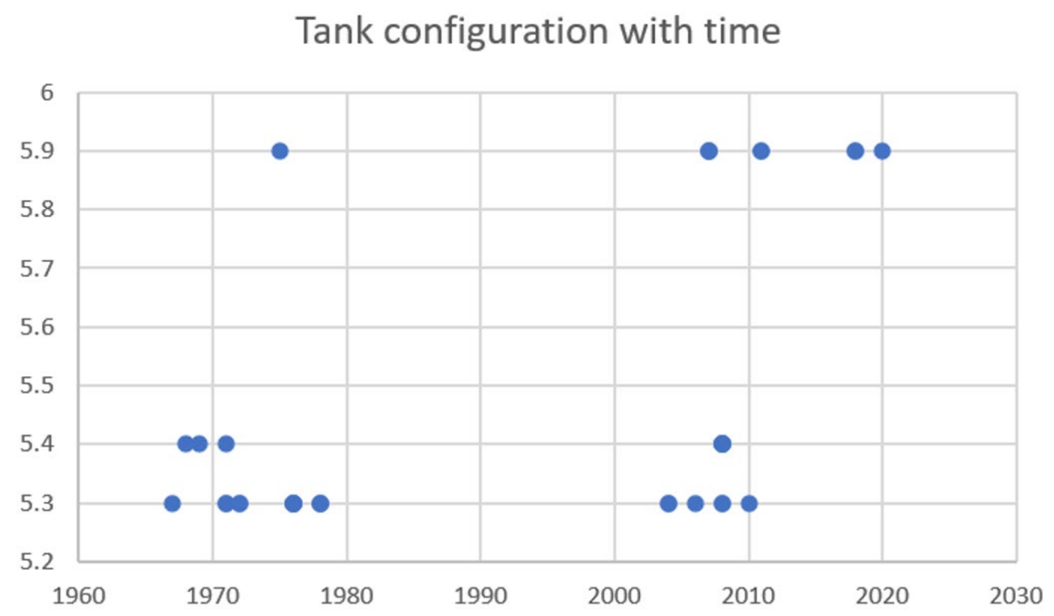
No other tank designs found in TAP tank survey

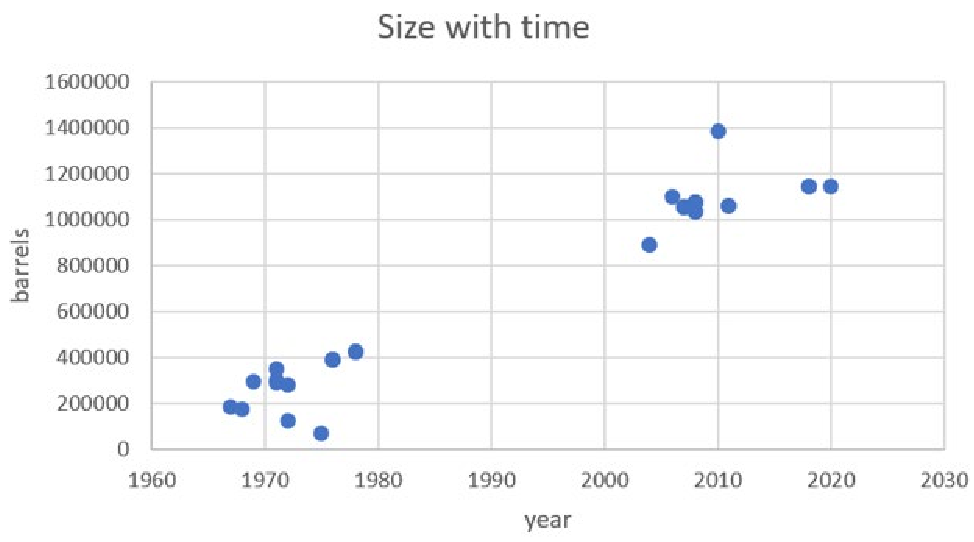
<u>Inner Tank Material</u>

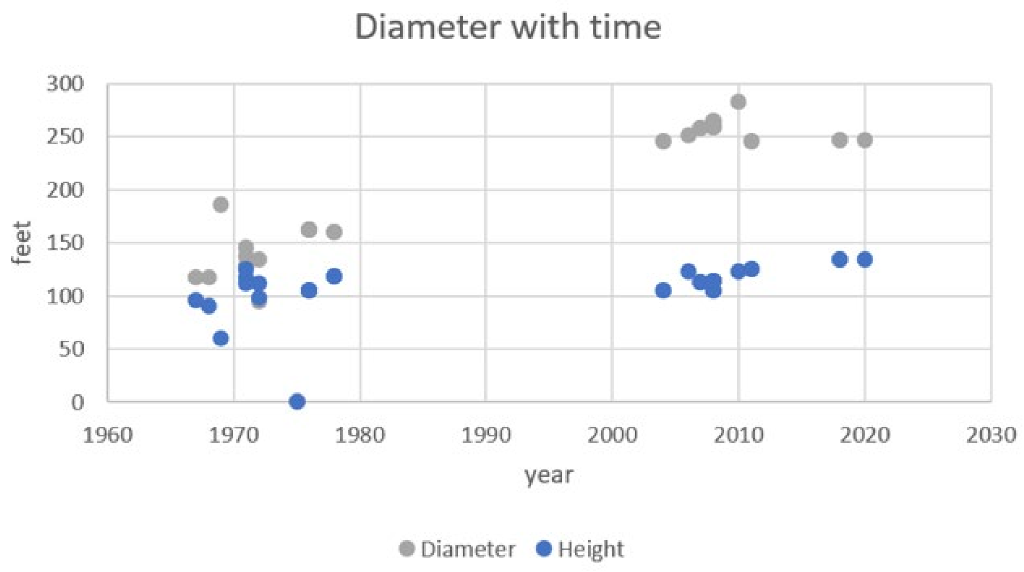
69% 9Ni

28% Al

2% SS







60% of all survey tanks had never been internally inspected;

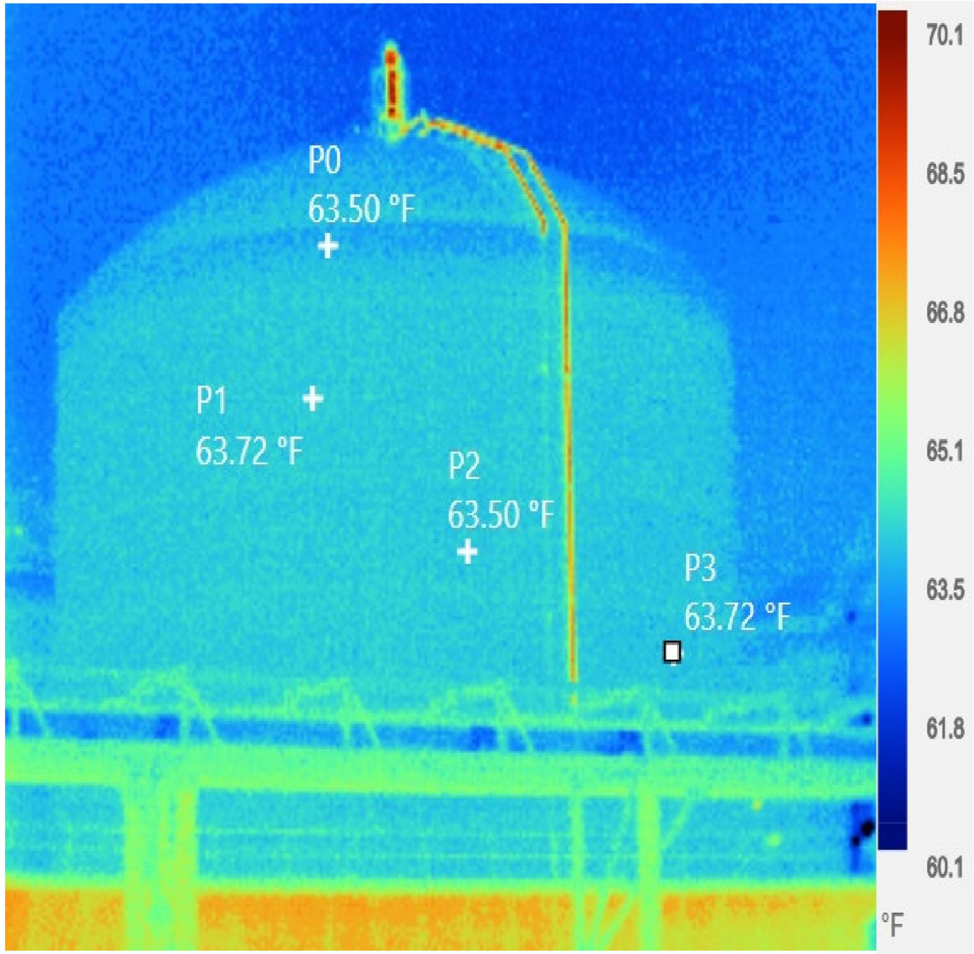
31% for the pre-1980 population

TAP Survey Inspection Findings

- 4/6 respondents performed in-service inspections; 2/6 performed both in- and out-of-service inspections.
- 3/5 base inspection intervals on prescribed intervals; 1/5 on risk-based methods, 1/5 use “many different reasons”.
- 3/6 state motivations for inspection are regulatory; the other 3/6 say they are motivated by concerns of corrosion or equipment status.
- Inspection frequencies of all types vary widely, if they are set; most do not have a set frequency.
- **Conclusion: There is no universal best practice, nor is there consensus on when, how, or why to inspect tanks, nor of when to conduct or not conduct an internal tank inspection**.

Inspection Technology

- Thermal imaging over as much of tank as possible important for inspection.
  - Existing technologies, such as drones equipped with FLIR cameras or laser scanning.
  - Driving emerging technologies (satellite mapping of methane plumes, acoustic imaging).
  - Further tech development refinement needed for practical use with inspections.



Incident Findings

- Only credible source of data is PHMSA “Incident Report – Liquified Natural Gas (LNG) Facilities” (40 CFR 191.3 and 40 CFR 191.15).
- Filtered storage tank-related incidents to 7/32 from Nov 2012 to Feb 2022.
  - MRI (Mean Recurrence Interval) for tank-related incidents: 1.25 yrs
  - None catastrophic and none affecting inner tank
  - Some cracked outer steel tanks from contact with cold liquid
  - Public domain information did not yield reliable information
  - The most infamous incidents (e.g., Staten Island 1973, Skikda 2004, Portland 1969) not directly related to operational storage tanks and therefore not counted.
  - The La Spezia, Italy incident involving a roll over is addressed by this report.
  - The Plymouth incident of 2014 shows that LNG storage tanks can be damaged by projectiles from explosions in other parts of an LNG facility.

Repair Findings

- Most common repairs
  - Painting
  - Insulation
  - Coating
  - Foundation heating systems
  - Topworks, hoisting, spills on dome causing cracking
    - Note: all survey responses were coastal so no correlations between repair frequency and coastal/inland locations can be made.
- No tank settlement repairs
- Incidents caused by repairs
  - Spills on outer tank
  - Temporary repairs

Areas of Susceptibility

- Maintenance activities such as removal of pumps, hoisting objects, replacing valves.
- Temporary repairs were a source of incidents.
- Spillage of cold liquid without sufficient protection from drip pans.
- Insulation failures.
- Concrete foundations and outer tanks subject to cracking and spalling.

Damage Mechanisms

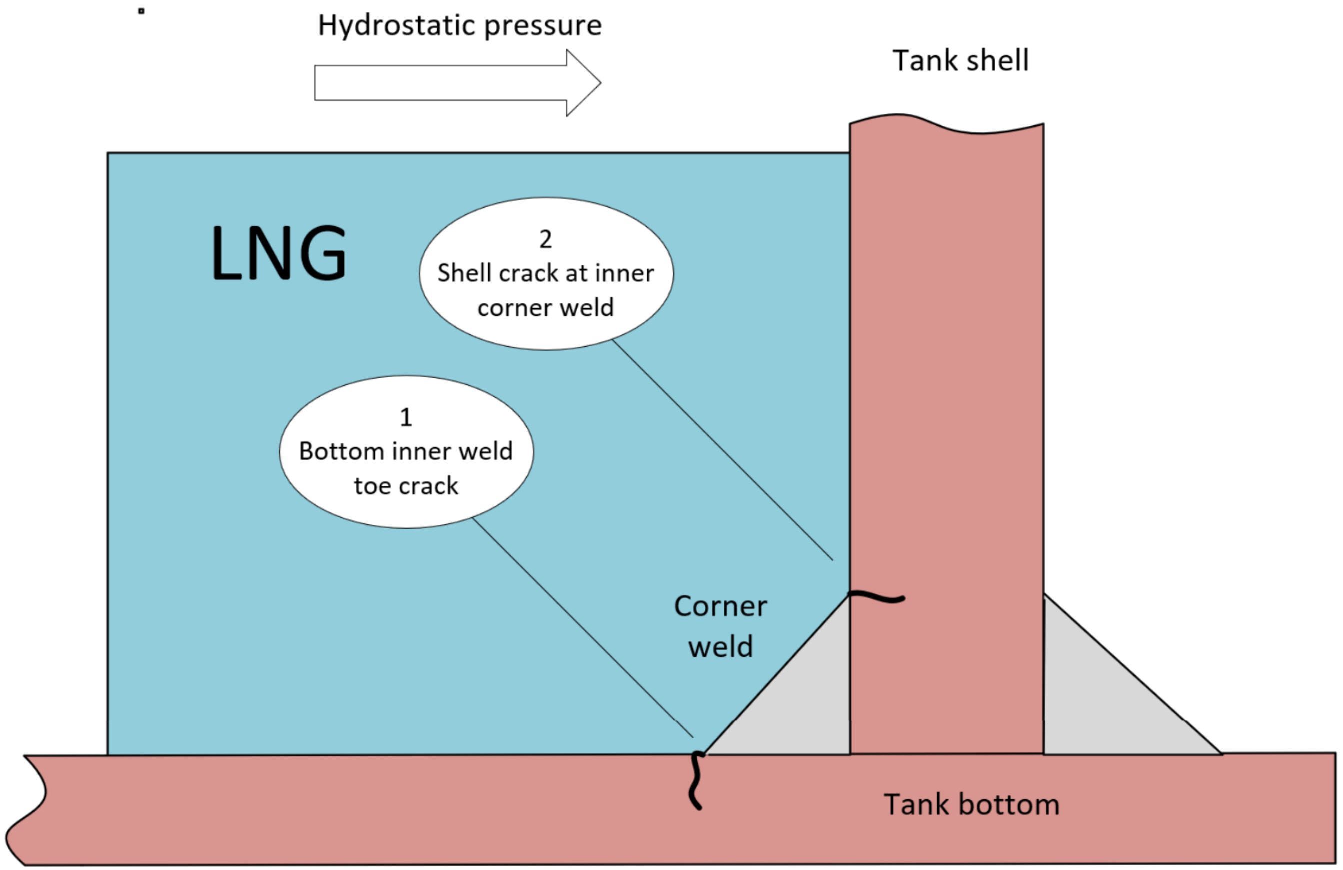
- Construction management
  - Materials, welding, NDE
- Inspection Program
  - Excessive pressure
  - Excessive vacuum
  - Tank distortions
  - Settlement
- Fitness for Service (per API 579)
  - Mechanical impact
  - Thinning
  - Gouging
  - Fatigue (next slide)
  - Excessive external loads
  - Fire damage

Important note: Inspection is only a subset of overall tank integrity management and may not address issues associated with faulty construction, overfills, improper operations, management of change, and other scenarios.

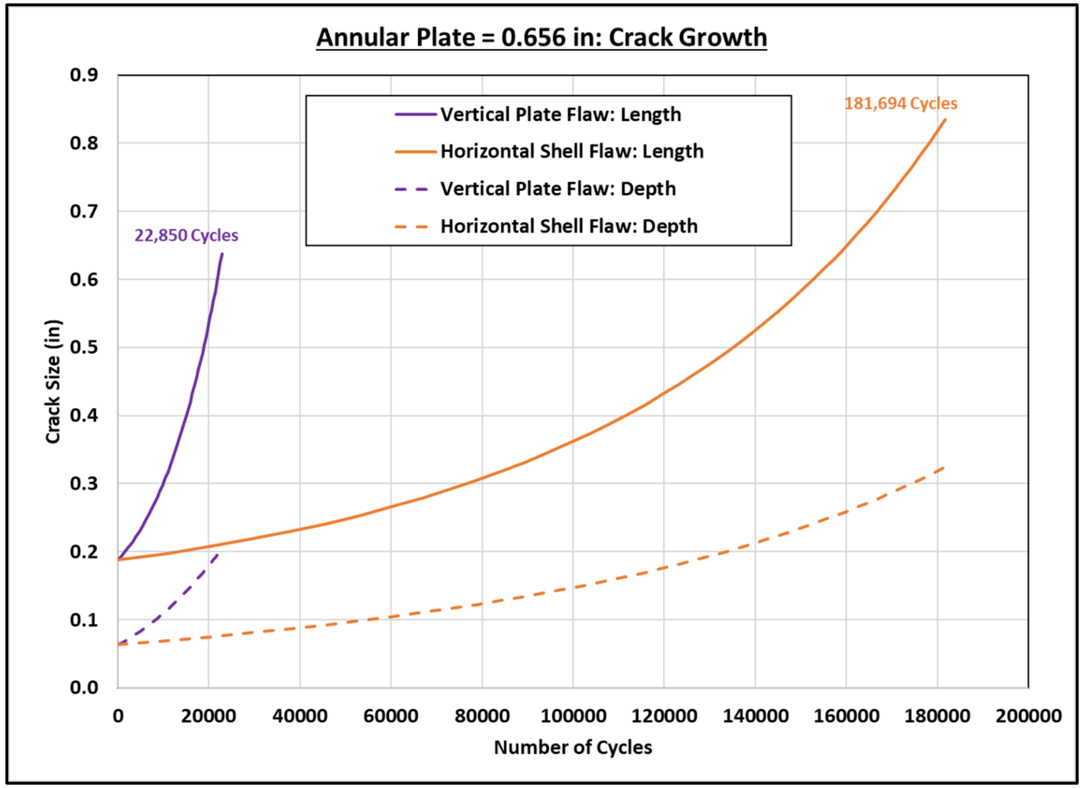
Fatigue Life Case Study

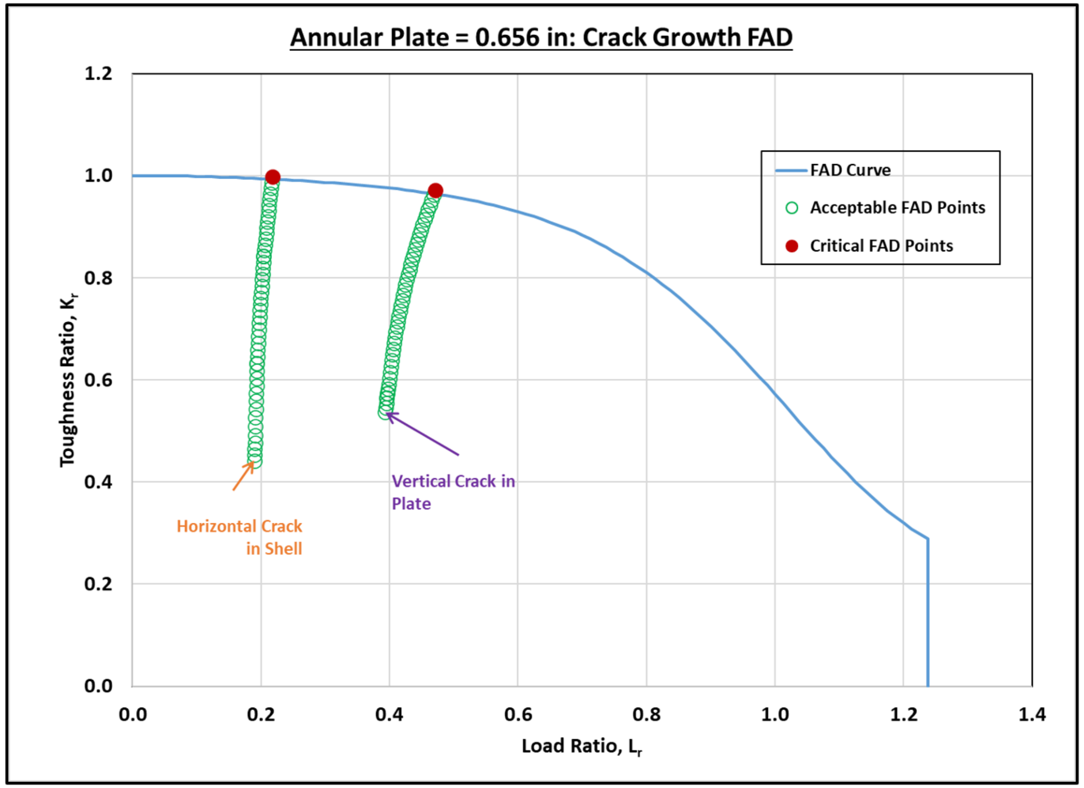
- Thermal fatigue may not be an issue
- Fill-empty fatigue is a concern
  - API 620 lists 1000 fill cycles (outdated and not analyzed for at least 30 yrs)
- Two tank sizes for case study were analyzed:
  - 255 ft ID, 1M bbl
  - 164 ft ID, 300k bbl
- A553 9Ni steel
- Elastic material behavior
- API 579 crack growth assessment using Paris' Law
- Reference flaw size (1/16 inch depth X 3/16 inch length) with crack size sensitivity analysis
- Fatigue assessment using crack growth model permits inspection, repair, and restoration of fatigue life on existing tanks. SN fatigue assessment does not.

Model Schematic and Crack Planes



Crack Growth Assessment

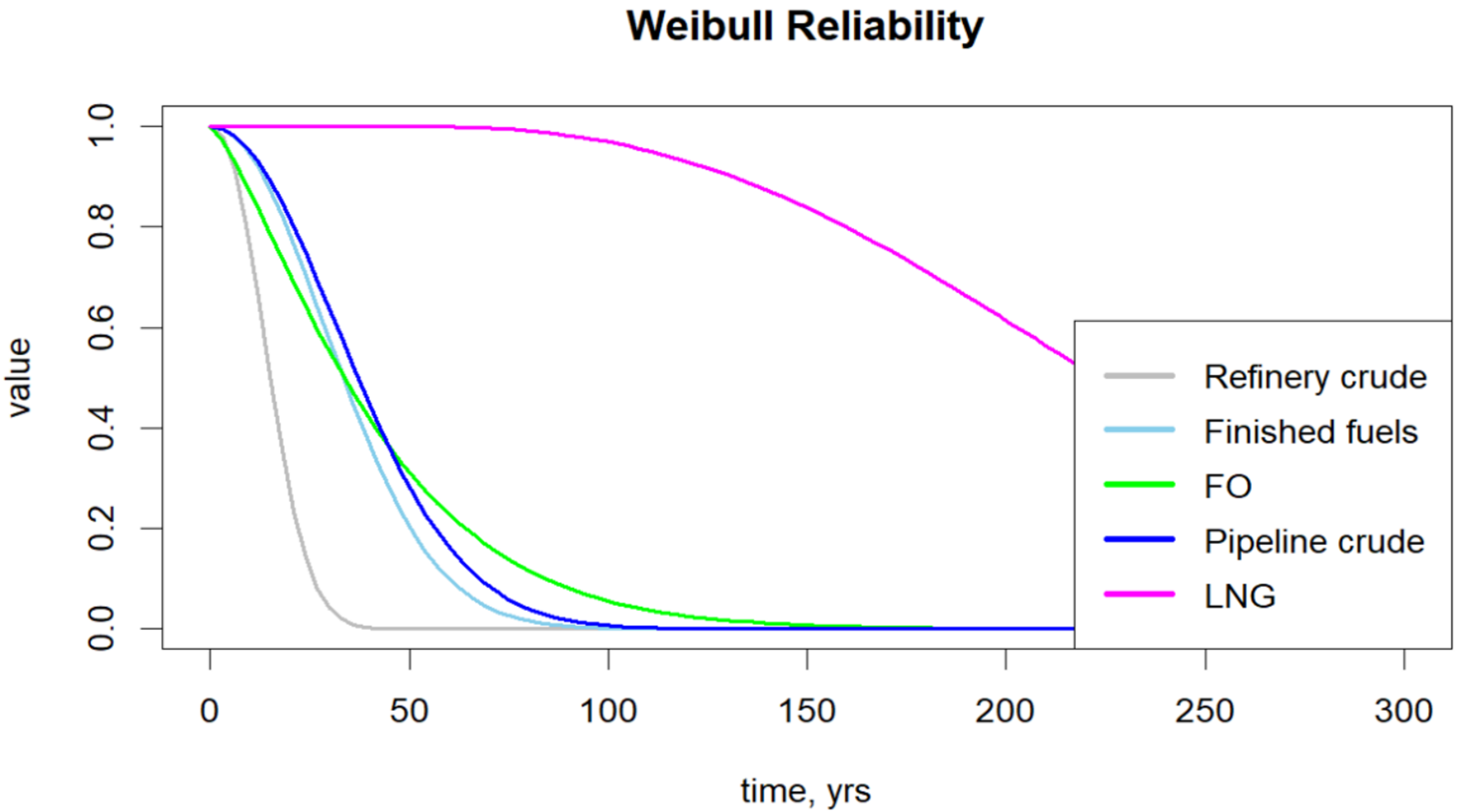




Radial and circumferential crack growth rates are of concern because they appear to indicate a hidden failure mode (i.e., break-before-leak). More studies on the design of the chime, the annular plate, and the shell joining detail may provide better ways to control failure.

LNG Tank Reliability

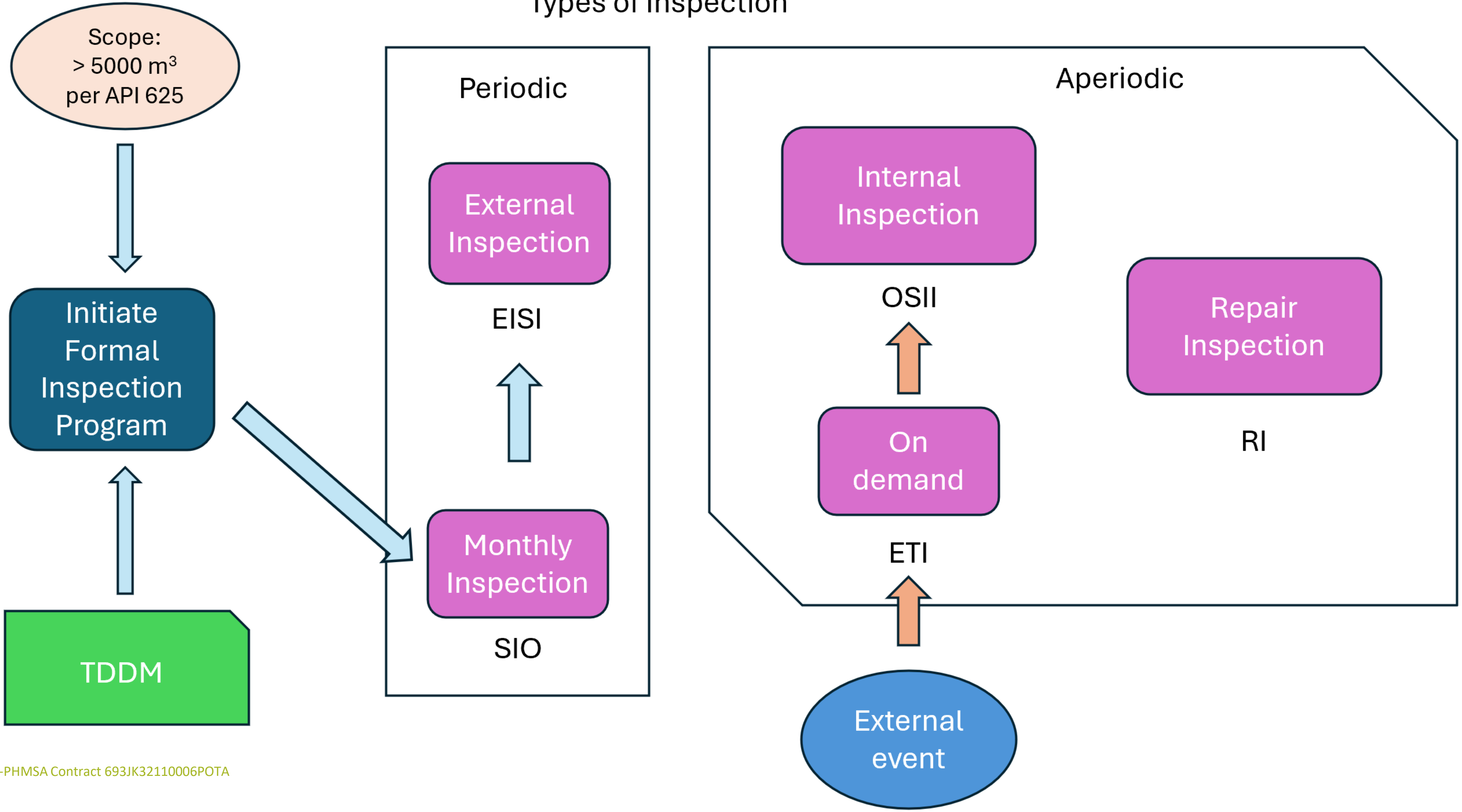
- Inspections/repairs to outer tanks typically can be done quickly, but for inner tanks any inspection represents a major and long business interruption.
- Inner tank inspections require cool down and warm up which are thermal shocks to the systems and may cause some material damage. They should not be conducted unless needed.
- Reliability does not decay sufficiently before a 100-year operating interval, but more research is needed to determine what the criteria for periodic internal inspection should be based on parametric fatigue analyses research.
- The inner tank reliability of LNG tanks is far superior to that of conventional petroleum tanks based on Weibull analyses (see next slide)
- Routine internal inspections would cause a need for a slightly increased LNG tank population simply based on the tank duty cycle.


Weibull Reliability
value
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
time, yrs
Refinery crude
Finished fuels
FO
Pipeline crude
LNG

Inspection Guidelines

- Developed guidelines for inspection, including:
  - A checklist for record keeping and document management (TDDM)
  - Tank Inspection Guidelines inspection types, categorized as:
    - Periodic: Self Inspection by Owner (SIO) and External In-service Inspection (EISI)
    - Event triggered: Event-Triggered Inspection (ETI) and Repair Inspection (RI)
    - Out-of-Service Internal Inspection (OSII). No fixed interval requirement (default 100 yrs) or when triggered by ETI.
    - Checklists for each type of inspection.
- Only an SDO such as API is qualified for producing consensus-based standards or recommended practices for inspections and repairs of these tanks.

Tank Inspection Guidelines
Types of Inspection



Conclusions

- There is currently no best practice or appropriate inspection and repair standard for cryogenic and LNG tanks, and the practices among owners/operators varies widely.
- Although the fatigue life of the two case studies PEMY analyzed show a fatigue life in the hundreds of years or longer based on frequent fill-empty cycles, the study did not consider other tank designs, configurations, and materials, especially relevant to the older tank population.
- While the principles used to establish the inspection guidelines here were based on LNG storage tanks, they can be adapted to other cryogenic liquefied gas tanks.

Recommendations

- Notify the American Petroleum Institute of the need for an LNG tank inspection and repair standard.
- Update 49 CFR 193 to include the latest edition of NFPA 59A as the currently applicable edition is out-of-date and holds back technological development.
- Conduct a parametric research study on fatigue of LNG tank configurations for various tank system configurations and designs, sizes, and different materials to help establish when and under what conditions internal inspections of the inner tank are advised. Include thermal fatigue analysis.
- Conduct a long-term study on the world population of LNG tanks and an industry project to collect and maintain incident data similar to that currently in use by PHMSA. This would allow probabilities and estimates to be made and align regulations to be in proportionate control of the actual risk.

PHMSA Public Page for Project

- PHMSA Public Page Link https://primis.phmsa.dot.gov/matrix/prjhome.rdm?prj=949
- PHMSA Final Report Download Link https://primis.phmsa.dot.gov/matrix/FilGet.rdm?fil=19267&s=6137372E40034B26A2EA214A412D7BCF&c=1

Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks

Main Objective

The primary objective of this project is to outline the current best practices associated with inspection and testing to ensure the integrity of aboveground cryogenic storage tanks such as liquified natural gas tanks. It also entails recommendations for these tanks which may involve new technology and to organize the information so that it can be transferred to the public domain so that tank owners, operators and industry organizations can use this information to reduce the potential for incidents through inspection and testing.

Public Abstract

The primary objective of the research project is development of a set of inspection recommendations that is based on industry experience, underpinned by sound domain knowledge, supported by stakeholders, and reflects current state of the art and best available technologies. The recommendations could be included in federal regulations or industry standards. The regulations/standards will provide immediate benefit in terms of standardization. Over time, well written recommendations will foster a strong, healthy market for cryogenic tank inspections and public confidence in the safe and environmentally sound operation of cryogenic tanks.

Fast Facts	
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Contract #:	693JK32110006POTA
Project #:	949
Researcher Contact Info:	Philip E. Myers 925-302-6707 phil @ pemyconsulting.com
Downloads of Project Reporting	
Since Jan 1, 2017	5406
Financial and Status Data	
Project Status:	Completed
Start Fiscal Year:	2021 (09/30/2021)
End Fiscal Year:	2024 (12/31/2023)
PHMSA $$ Budgeted:	$165,000.00

FINAL REPORT

LNG Inspection Public Final Report

LNG_INSPECTION_PUBLIC_FINAL_REPORT_240207.PDF (17,107,726 bytes) [VIEW] [DOWNLOAD/SAVE...]

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