ODIN

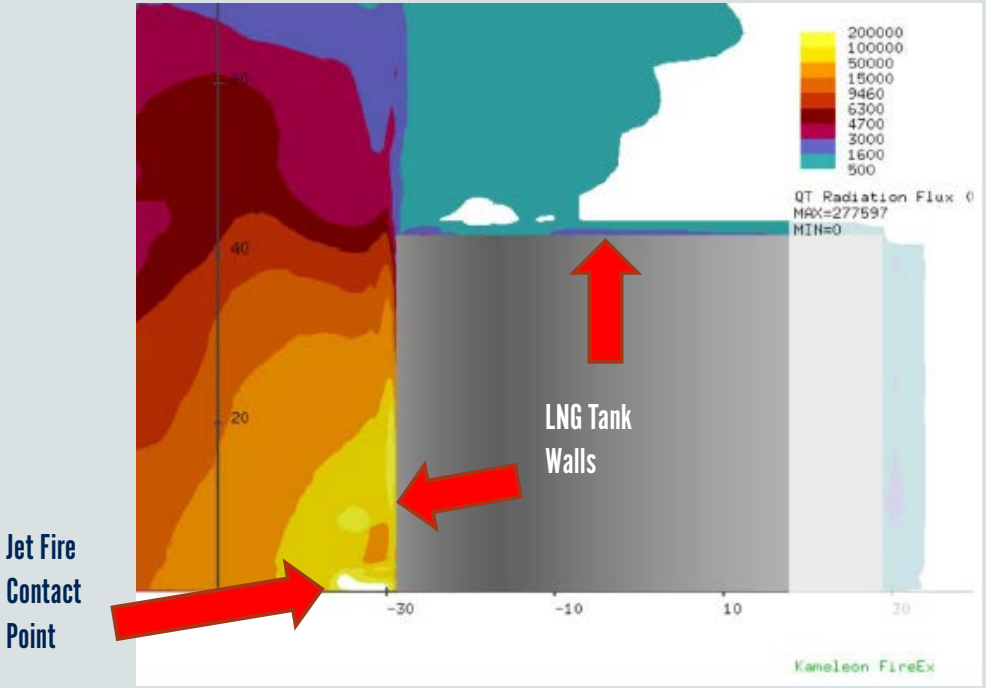
FROM CONCEPT TO COMPLETE

Jet Fire Protection – Field Erected, Bullet, and Trailer Liquefied Natural Gas Tanks

Jet Fires

- What is a Jet Fire?
  - A turbulent diffusion flame, released with significant momentum at temperatures up to 2,012°F.
  - Can arise from the release of gaseous, flashing liquid or pure liquid, including LNG.
  - Enhanced due to pressure >40psi behind the release.

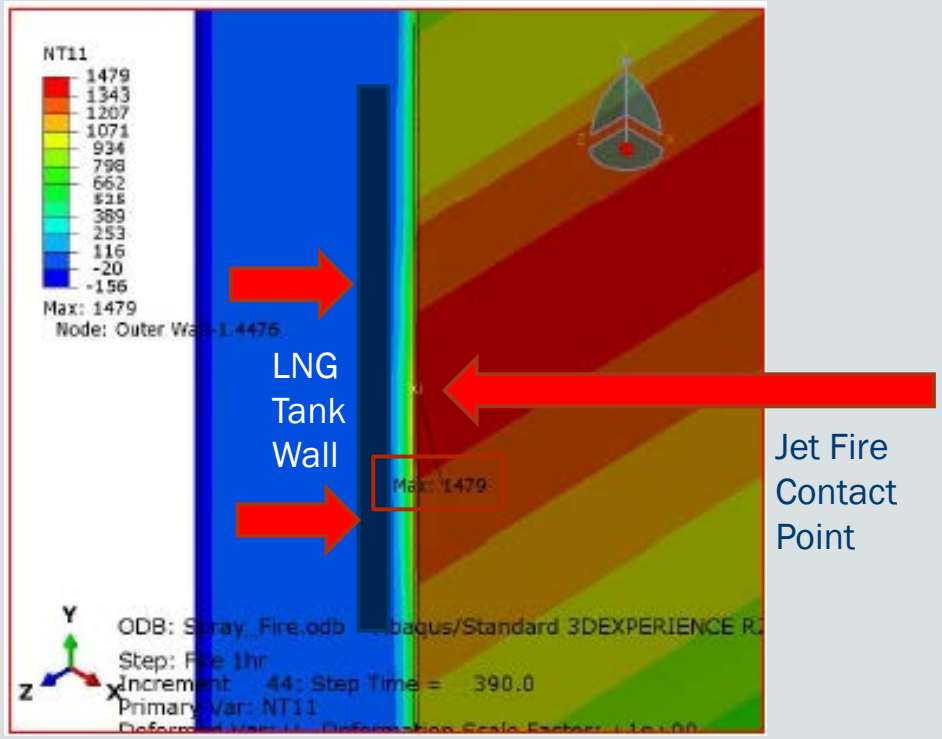
- LNG under pressure presents a higher risk of a serious jet fire in a leak or rupture scenario.



The Heat Flux Contour Plot above shows the effects of a 21kg/s jet fire on an LNG tank. According to a DNV report done on the effect of thermal stresses on LNG tanks, the maximum heat flux experienced is 277,597 W/m2 or approximately 87,998 BTU/ft2-hr.

Failure Time of Steel When Exposed to Jet Fire

- Pressurized process areas adjacent to LNG tanks increase the risk of the tank's exposure to jet fires.
- If Emergency Shutdowns devices or fire protection systems fail due to mechanical or human error, LNG tanks can be exposed to jet fires for extended periods of time.
- The example here shows the results of a DNV test where jet fire temperature was hot enough to fail steel at **6.5 minutes!**



Temperatures resulting in structural failure of an LNG trailer at 6.5 minutes under Spray/Jet Fire conditions. According to a DNV report done on the effect of thermal stresses on LNG tanks, the maximum temperature is seen to be 1479°C (melting point of ASTM A131 Steel) at the metal contact point which is the center of the graphic.

FERC, ASME, and NFPA Guidance with Respect to Jet Fires

- FERC's requirements for fire protection for vessels and tanks
  - "Fire protection [should be provided] for pressure vessels within 4,000 BTU/ft2-hr, steel atmospheric tanks within 4,900 BTU/ft2-hr, and concrete atmospheric tanks within 10,000 BTU/ft2-hr".

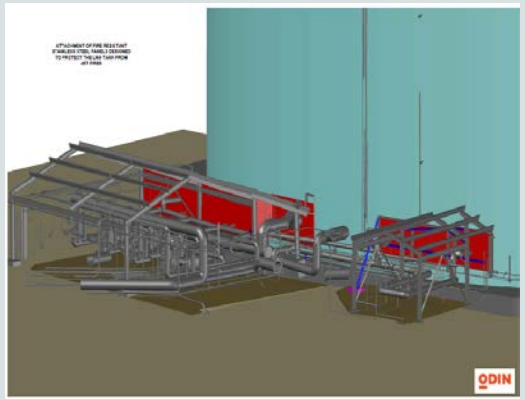
- ASME Boiler and Pressure Vessel Code (BPVC) and ASME B31.1 Process Piping
  - "prolonged exposure of 4,900 BTU/ft2-hr can result in temperatures that results in a 50% loss in material strength, which would put it above the allowable stress limits and yield points of that material."

- From NFPA 59A-2019 Section A.6.6.4
  - "Carbon structural steels begin to have a noticeable loss of strength at 570°F - 650°F, lose approximately one-third of strength at 840 °F - 900°F, and lose approximately one-half of strength at 1,000°F – 1,100°F. The temperatures associated with one-half and one-third losses of strength correspond to when structural steel begins to exceed allowable stresses and yield strengths and suffers possible structural damage based on allowable stress/strength designs in structural and mechanical design codes."
  - "The temperatures associated with losses of strength [mentioned above] would correspond to [thermal fluxes] of approximately 2,000 Btu/ft2-hr, 4,900 Btu/ft2-hr, and 7,750 Btu/ft2-hr, respectively."
  - NFPA would seems to guide Field Erected Tank protection at thermal fluxes of 4,900 Btu/ft2-hr.

Jet Fire Protection Systems

- Primary
  - Emergency Shut-Off Device (ESD) Controls

- Secondary/Complementary
  - Deluge Systems / High Expansion Foam – Pool Fire Protection
  - Shrouding – Deterrent to Jet Fire – At Source
  - Thermal Barrier – Deterrent to Jet Fire – At Target



Jet Fire Protection Systems – Deluge

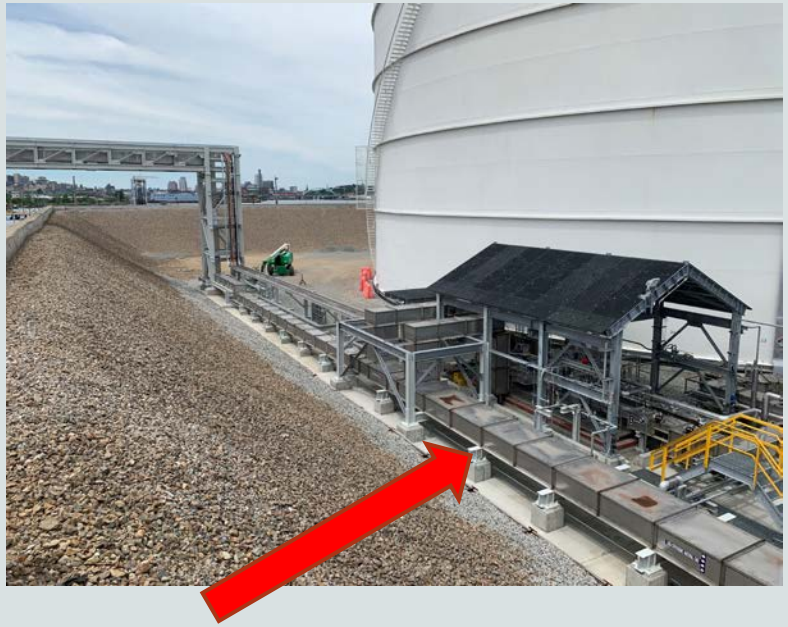
- What is a Deluge System?
  - An unpressurized dry piping system with open sprinkler heads, directly connected to a water supply.
  - A deluge valve is activated by a heat or smoke detector and releases water, to lower the temperature of the tank.

- Are there issues with a Deluge system?
  - Mechanical failure to the system would result in little to no protection to an LNG tank in the event of a jet fire.
  - Requires large amounts of water and all sprinklers release at once, while only cooling the tank. Does not extinguish a jet fire.
  - Time of protection is limited to the water supply.

Jet Fire Protection Systems – Shrouding

- What is Shrouding?
  - A stainless steal barrier placed around piping to cause LNG to pool in the event of a leak.

- Are there issues with Shrouding?
  - Eliminates the possibility of visual inspection.
  - Difficult and high cost to install on existing piping.
  - Makes maintenance more difficult.
    - Shrouding must be removed before work can be done on piping or instrumentation.

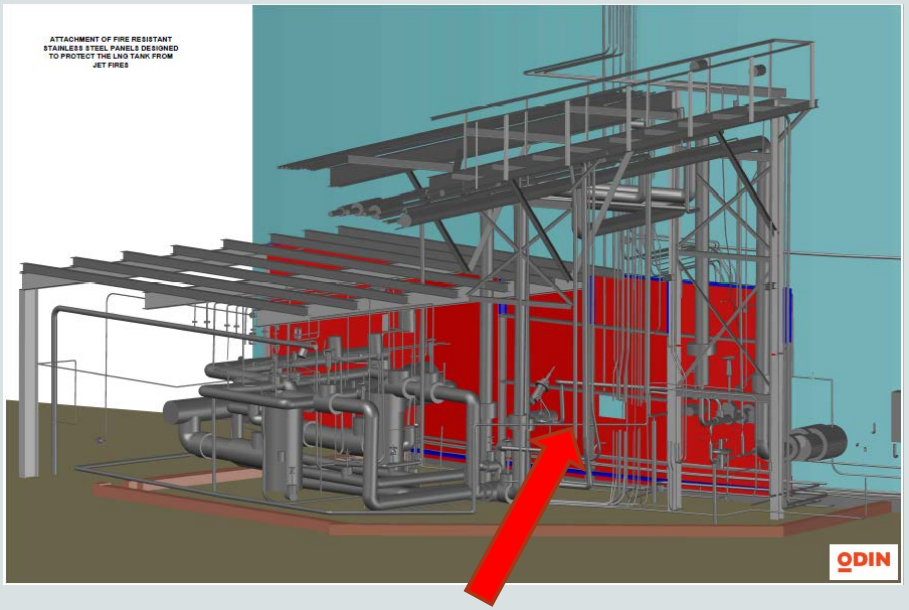


Shrouding at LNG process area next to LNG storage tank

Jet Fire Protection Systems – Thermal Barrier

- What is a Thermal Barrier?
  - Physical barrier between a jet fire from an LNG process area under pressure and an area of desired protection including an LNG tank, shown here, or an LNG truck loading area.

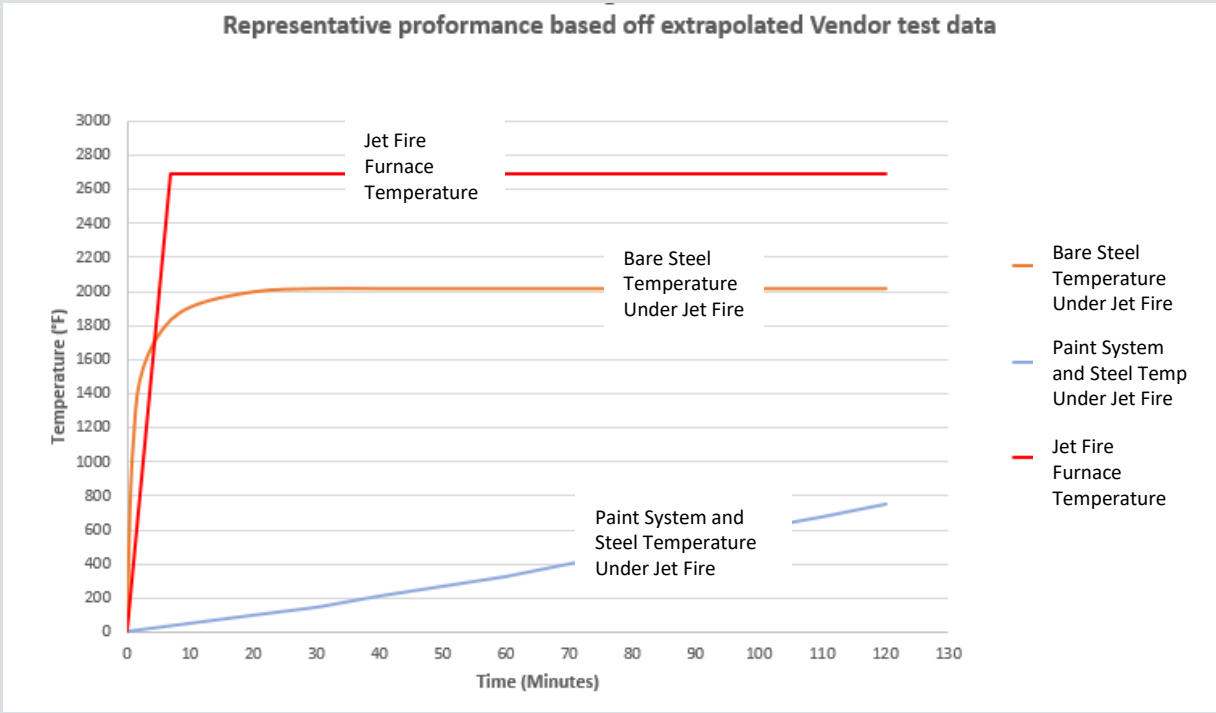
- Are there issues with a Thermal Barrier?
  - Low cost of installation and maintenance .
  - Provides up to 3 hours of protection dependent on paint thickness.
  - Needs protection from cold weather cracking.



A proposed thermal barrier "in RED" between an LNG tank and LNG process area.

Jet Fire Protection Systems – Thermal Barrier Details

- What is a type of Thermal Barrier?
  - Meets ISO 22899-1 test standard.
  - ¼” stainless steel plate with a paint-on coating of two products designed to withstand an LNG release before the ignition of a jet fire.
  - First part is a cold barrier that adheres to a stainless-steel plate and provides protection before ignition.
  - Second part is thermal protection for the temperatures associated with jet fires.
  - Additionally, a weatherproofing sealant is applied to resist cold weather cracking.
  - Application at different thicknesses will provide varying levels of protection against LNG release and jet fire for potentially multiple hours.



The graph above shows the thermal protection provided by paint-on coating, using a DNV report done on the effect of thermal stresses on LNG tanks and data extrapolated from vendor testing. A protective base paint thickness of 0.3” reduces the temperature behind a steel barrier to 752 °F.

Jet Fire Protection Systems – ISO 22899-1 Test Standard

- Overview
  - Test is designed to give an indication of how passive fire protection material will withstand to a jet fire.
  - Temperature is measured throughout the testing from the front and back of the fire protective barrier with thermocouples.

- Flame Properties
  - Propane is delivered at a steady flow rate of 0.66 lb./s or greater as a vapor without a liquid fraction.
    - Propane has a higher BTU generation than LNG and therefore burns hotter.

- Thermal Flux
  - The test will produce a heat flux between 79,250BTU/ft2 and 101,440BTU/ft2 and the test notes that this flux is of “medium scale”.

Jet fire test done on 2-part paint system, being performed to ISO 22899-1 test standards.

Jet Fire Protection Recommendation – Thermal Barrier

- Barrier can be installed as new infrastructure, or it may be installed with minimal modifications, utilize any existing ice-shield infrastructure.
- The product manufacturer has a standard warranty of 5 to 10 years, and the paint has a projected useful life of 20+ years.
- The 2-part paint system requires minimal yearly maintenance.
  - It is resilient coating that is difficult to chip or damage, only substantial damage resulting in missing chinks of paint or cracks down to the steel will require recoating.
  - Small and medium size cracks are not required to be fixed, though should be resealed due to possible water damage.
- Tank Failures due to jet fire could be potentially extended from 6 minutes to 2 hours!
  - Benefit to the protection of life safety.
  - Provide time to react with alternative preventative measures.

ODIN

FROM CONCEPT TO COMPLETE