Early LNG Experience in the US

Theodore Lemoff
NFPA

LNG in the U. S. Pre 1940

- First commercial use by the Bureau of Mines in Helium Production.
  - LNG produced was not stored but was re-gasified
- Hope Gas Company, a West Virginia gas utility
  - Built an LNG Pilot Plant in 1940 in Cornwell, W. Va

East Ohio Gas Company

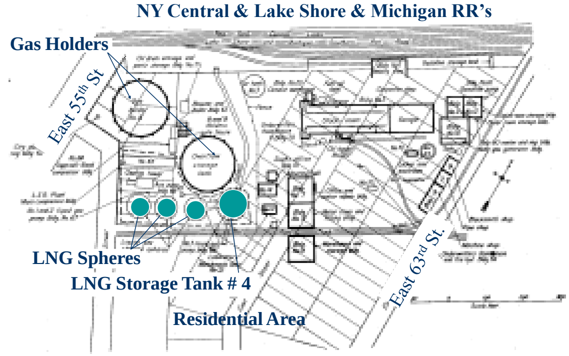
- Purchased gas from West Virginia
  - Four 18" & 20" (450 – 500 mm) lines, 150 miles (240 kM) long
- Jan. 1940 cold wave - gas shortages in the Eastern U. S.
  - Average high, 25° F (Normal 33° F)
  - Average low, 19° F, (Normal 20° F)
  - 15 days with no sunshine
  - Coldest winter in 20 years

East Ohio Gas Company

- East Ohio Gas Co. considered:
  - Extending an existing pipeline to Cleveland ($ 2,500,000)
  - LNG liquefaction and storage plant ($ 750,000)
- LNG Plant built, Sept 1940 – Jan 1941

The Plant

- Located at the No. 2 works, East Cleveland. Site contained:
  - Shops & buildings for the natural gas business
  - Buildings & equipment formerly used for manufactured gas
  - Site had been in use for 50 years



Plan view of No. 2 Works, East Ohio Gas Co, Cleveland, Ohio

Source: Bureau of Mines Report

The Plant

- The location practical
- Plant Capacity:
  - Liquefaction, 4,000,000 ft^3/day
  - Vaporization, 3,000,000 ft^3/day
  - Storage, 3 Spheres
    - 57 ft (17 m) Diameter, ~ 50,000,000 ft^3 each
    - Inner Tank, Low Carbon, 3½ % Nickel Steel*
    - Outer Tank, Carbon Steel
    - Insulation, 3 ft. (1 m) cork – Lower 1/3 Solid, rest granular

Inner Sphere Steel Selection

- Selection of Steel for Sphere Shells recognized the importance of the Charpy Impact Test.
  - Materials considered to have an acceptable Charpy Impact Test at - 50° F (-46 ° C) were copper, bronze, Monel metal, red brass, stainless steel, and steel plate with < 0.09% carbon and >3.5% nickel
    - Oil and Gas Journal 1940 Article cited

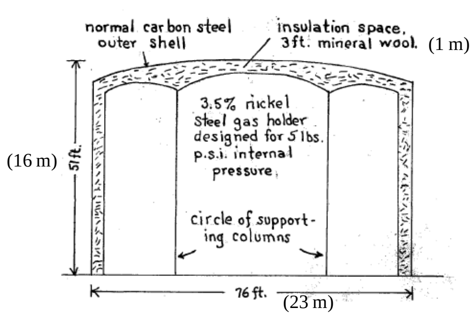
Plant Expansion

- Additional Tank (# 4) added in 1943
  - (2 ½ years later).
- One toro-segmental tank added, capacity 100,000,000 ft^3 (2,800,000 m^3) natural gas
  - Twice the volume of each sphere
  - This type of tank was believed to superior for capacities ≥100,000,000 ft^3 (2,800,000 m^3)
  - Cost was not a factor
  - Flexing of large spheres from filling & emptying was the concern

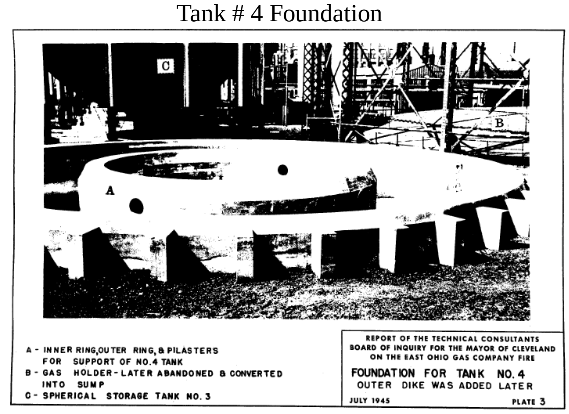
Tank Design

- The tank designers recognized that 3.5% Nickel Steel was brittle at - 260° F (-162° C)
  - "A sledge might be driven through it"
  - Other brittle materials had been used in construction successfully (i.e. the spheres)

Tank # 4

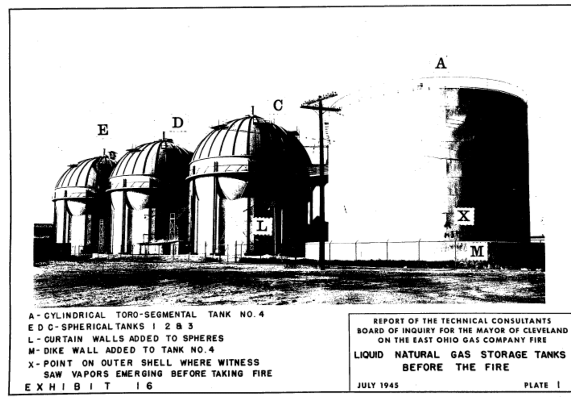


Tank # 4 Foundation



Tank Design

- Tank Dimensions:
  - Inner Tank: 42 ft (13 m) high, 70 ft (21 m). Diam.
  - Outer Tank: 51 ft (16 m) high, 76 ft. (23 m) Diam.
  - Insulation: 3 ft (1 m) Rockwool
- Tank Support:
  - Circular footings, 34 ft (10 m) & 70 ft (21 m) Diam
  - 30 12 in x 12 in (300 x 300 mm) Douglas fir posts



Startup

- Initial cooling of Tank # 4 via fill line
- Resulted in a crack in the bottom
  - Crack entirely in one plate
  - Repaired by cutting section of plate & replacement
- Added ¾ in. (19 mm) copper tubing rings
  - Holes to disperse liquid
  - Additional thermocouples for monitoring
- Second cool-down successful

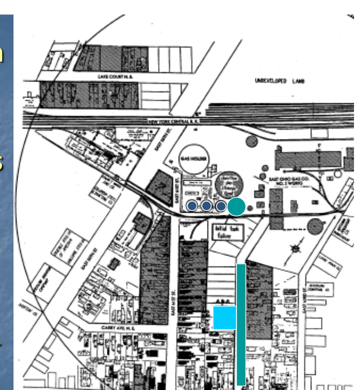
Leak Control

- Concrete dams added to spheres and tank # 4 for minor leaks
  - Spheres: 18 m diam, 1.4 m high;
    - Skirt on Dam
  - Tank # 4: 26 m diam, 7 2.1 m high
    - Skirt on Dam
- Overflow holding in old gas receiver
- Tank builder commented that dams & skirts could compromise tank design

Friday October 20, 1944

- The LNG tanks were filled, and topping-off was in progress
  - At about 2:00 PM shut-down began
- At 2:40 PM tank # 4 failed
  - Observers at AGA Labs, 180 m S saw vapor/liquid prior to tank collapse
  - Slight earth tremor reported
  - Fire observed
- 1.1 Million gallons (4,800 m^3) of LNG released

- Liquid ran down 62nd St. – entered sewers
- Vapor in sewers mixed with air and ignited
- Innumerable sources of ignition nearby i.e., labs, meter shop, homes



Source: Bureau of Mines Report

The Fire

- 20 Minutes later, Sphere # 3 fails
  - Held about ½ the amount of LNG as Tank # 4
- Major fire underway
  - Area was industrial and residential
  - Many homes exploded from gas entering from sewers
  - Significant radiated heat reported.
  - Panic was reported (newspaper)
  - Extensive police, fire, & military response
    - 95 % of Cleveland's apparatus responded

The Fire

- An observer 1000 ft (300 m) away estimated flames at 2800 ft. (850 m)
- Injured taken to hospitals
  - 50 Ambulances incl. Army, Navy, Police, and Private
- Red Cross found shelter for the homeless


CLEVELAND PLAIN DEALER

CLEVELAND, SATURDAY MORNING, OCTOBER 21, 1944 — 22 PAGES — FOUR CENTS

3,600 HOMELESS, 10 KILLED, 200 INJURED IN GAS BLAST

PRIZED AIRFIELD FALLS ON LEYTE, IS REPORT AS 250,000 POUR ASHORE

Great Invasion Armada of 600 Ships Unloads Force Said to Rival D-Day Stormers of Normandy; Bewildered Japs Rally for Bitter Resistance; Filipinos Get Call From MacArthur

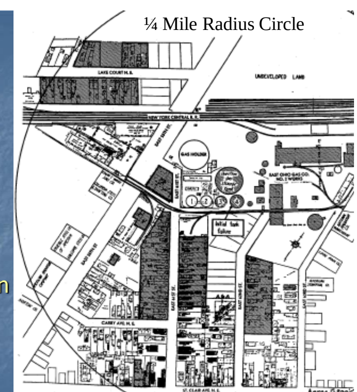
By the Associated Press

FLAMES HURLED OVER E. 55TH-ST. CLAIR AREA; LOSS RUNS IN MILLIONS

Fire Razes 150 Houses and Continues Unchecked After Eight Hours; 10,000 Families in Adjoining Areas Forced to Evacuate for Safety; at Least Six Explosions Occur at Storage Plant

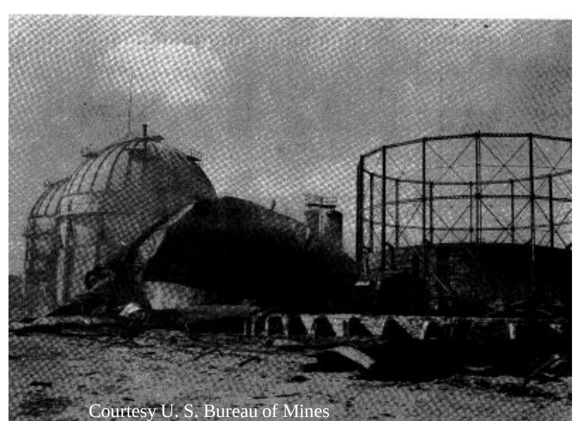
Ten persons were known to be dead, 11 had suffered perhaps fatal burns and 180 others

- Fire controlled on Saturday, October 21
  - Buildings within 300 ft (91 m) destroyed
  - Burned areas shown shaded in drawing



Source: Bureau of Mines Report


Source: International News Photo


Courtesy U. S. Bureau of Mines

Source: Acme

Clean-up

- Sunday October 22, 1944
  - Gas Co. employees and tank designer arrive.
  - Spheres # 1 & 2 survived essentially intact
    - Vent line burning venting gas
    - Smoke issuing from top of Sphere # 2
  - Vent re-piped, and smoke attributed to burning cork.
    - Liquid and solid CO_2 smothered cork fire.
  - Steam from locomotives vaporize LNG in Spheres. 3 week process.

Analysis of Failure

- No evidence of metal fragments to indicate a pressure explosion
  - Small number found, probably from ammonia or ethylene cylinders
  - Four large sections of the bottom ring (1-2 tons each) found 200 – 300 ft (61 - 91 m) from Tank # 4
- Fragments from Tank # 4 typical of low-temperature embrittlement
- Evidence of failure at welds

Possible Causes

- Event external to Tank # 4
    - Gas leakage ignites
  - No evidence to support this
- Explosive shock from burst ammonia cylinder
    - Such explosion occurred, based on fragments found
  - Location indicates this occurred after Tank # 4 failed

Possible Causes

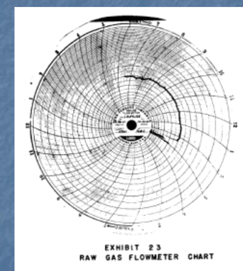
- Abnormal shock from failure in liquefaction plant
    - Charts show increased pressure about time of failure
  - Pressure increases probably caused by intense heat in compressor building due to fire.
- Abnormal shock from sudden pressure release
    - Broken vent-gas line could have been source
  - Witness accounts do not validate this

Possible Causes

- Seismic shocks
    - Vibrations: railroad trains & stamping plant
    - Cork supported spheres would be somewhat protected from vibrations & shocks
  - Impossible to prove or disprove
- Crack, strain, or metal flaw
    - Frost spots on Tank # 4 may have indicated a small leak
  - Not believed to be probable

Possible Causes

- Superheating of liquid
    - Known as "rollover", due to temperature stratification
  - No fluctuation in liquid level gauge



Source: Cleveland Mayor's Report

Bureau of Mines Conclusions

- Definitive cause of disaster not possible
  - No evidence of operating or personnel failure
  - No evidence of gas-air explosion
  - No evidence of other operations to cause disaster
  - No evidence of sabotage
- Contributing factors
  - Improper design (wood support of inner tank)
  - Use of steel subject to brittle failure
  - Flaw in tank or welding

Observations

- Many reports explain the use of 3.5 % nickel steel to wartime shortages
  - Known to be brittle at LNG temperature
  - Bureau of Mines report does not mention this
  - It appears to have been recognized by tank designer and not considered a reason not to use 3.5 % nickel steel

Major Recommendations

- LNG plants be isolated from other facilities
- Dikes must be provided
- Low temperature properties of metals be investigated and published

Major Recommendations

- Cryogenic liquids Storage not be made of 3.5 % nickel steel unless brittle failure is determined not to be the cause of Tank # 4 failure
- Extreme caution be taken to prevent spilled LNG from entering sewers

What Happened Next?

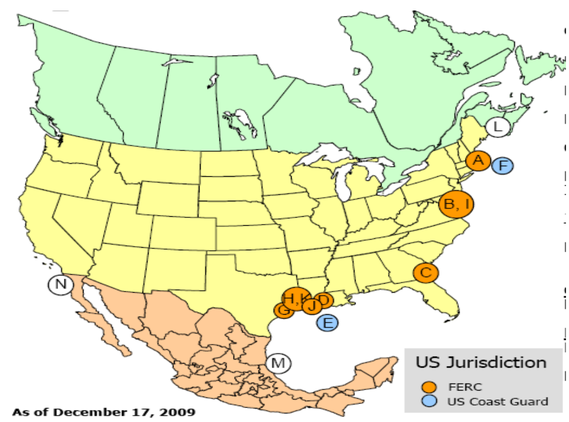
- Not much.
- No interest in LNG for 10 – 15 years
- Economics and supply considerations revive interest in peak shaving in the late 1950's.
- AGA forms committee in 1960 to develop draft LNG standard
  - Recommends NFPA issue standard in 1964

NFPA 59A

- First edition in 1967
  - Required dikes
  - Required 9 % Nickel Steel, Aluminum, or Concrete
  - Separation

The Next Wave

- A number of LNG peak shaving plants were built at points along the natural gas pipeline system
- Today, over 100 are operating.
- 4 LNG import terminals were built in the "first wave", and 7 additional in North America added recently



As of December 17, 2009

What is the Long Term Forecast for LNG Worldwide?

- Difficult to predict:
  - The availability of Natural Gas
  - The needs for Natural Gas

Thank you

Questions?

Ted Lemoff
tlemoff@nfpa.org