FLARE LINE FAILURE CASE, WHAT HAVE WE LEARNED?

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Overview

- Background
- Flare System Overview
- Event Sequence
- Root Causes / Corrective Actions
- Brittle Fracture Discussion
- Other Follow Up Actions
- Learning / Conclusions

Background

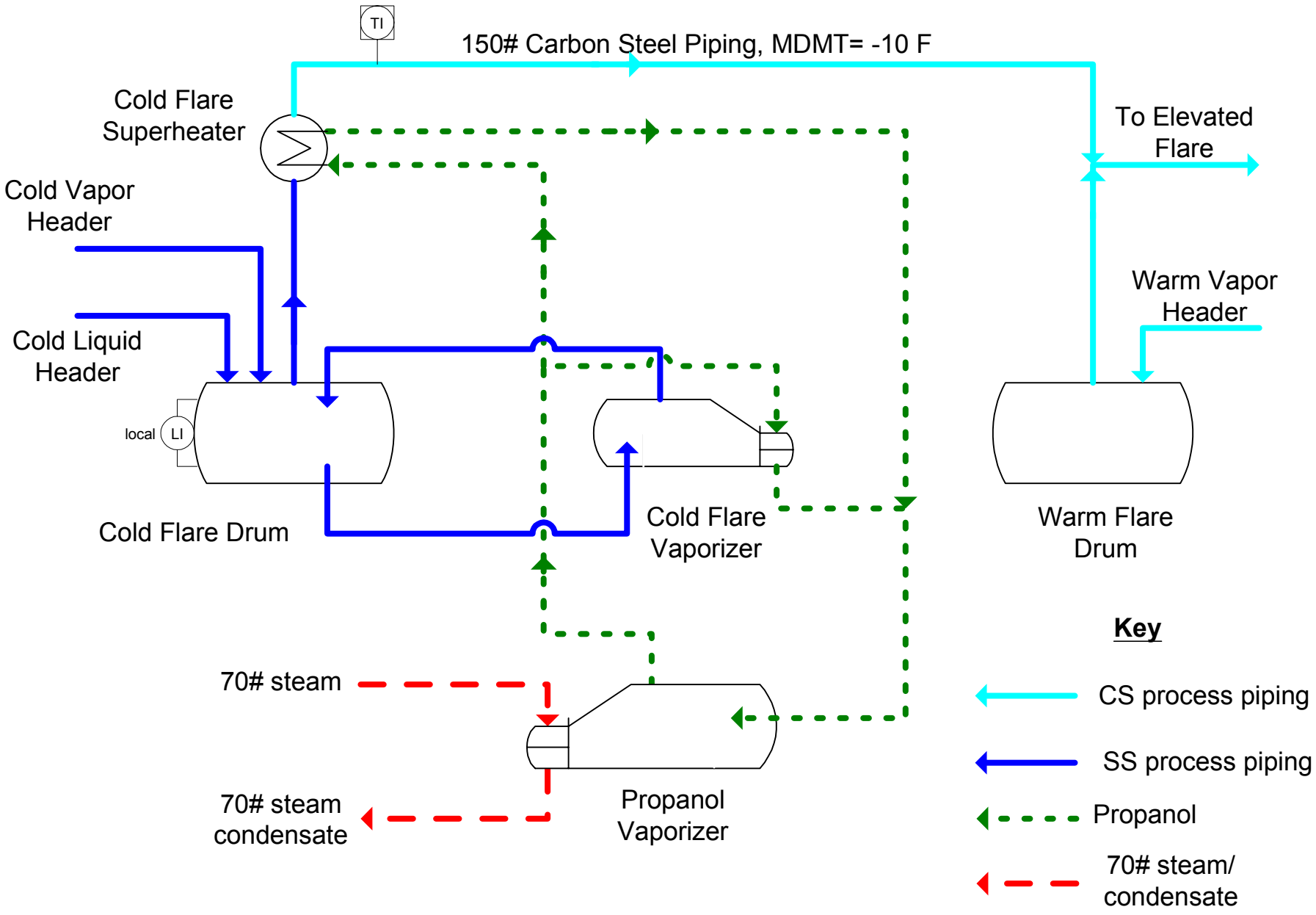
- The Westlake Petro 1 plant is a “demethanizer first” ethane cracker with a back end acetylene converter
- An off-spec event on 1/4/02 at the acetylene converter led to flaring of liquid ethylene product via the unit cold flare drum
- Through a sequence of events, the cold flare drum overhead line fell to below its minimum design metallurgy temperature
- On 1/5/02, the cold temperatures led to brittle fracture of the cold flare drum overhead line, loss of hydrocarbon containment, and ultimately an explosion and fire

Westlake Petro 1 Flare Drum System Overview

- The cold flare drum contents are vaporized and superheated with a closed loop propanol system
- Heat is supplied to the propanol system with 70# steam (~270 F)
- The vaporizer and superheater heats the cold flare drum material from cryogenic temperatures to above the minimum design metal temperature of the cold flare drum carbon steel overhead piping @ -10 F

Westlake Petro 1 Flare Drum System Overview

Original System



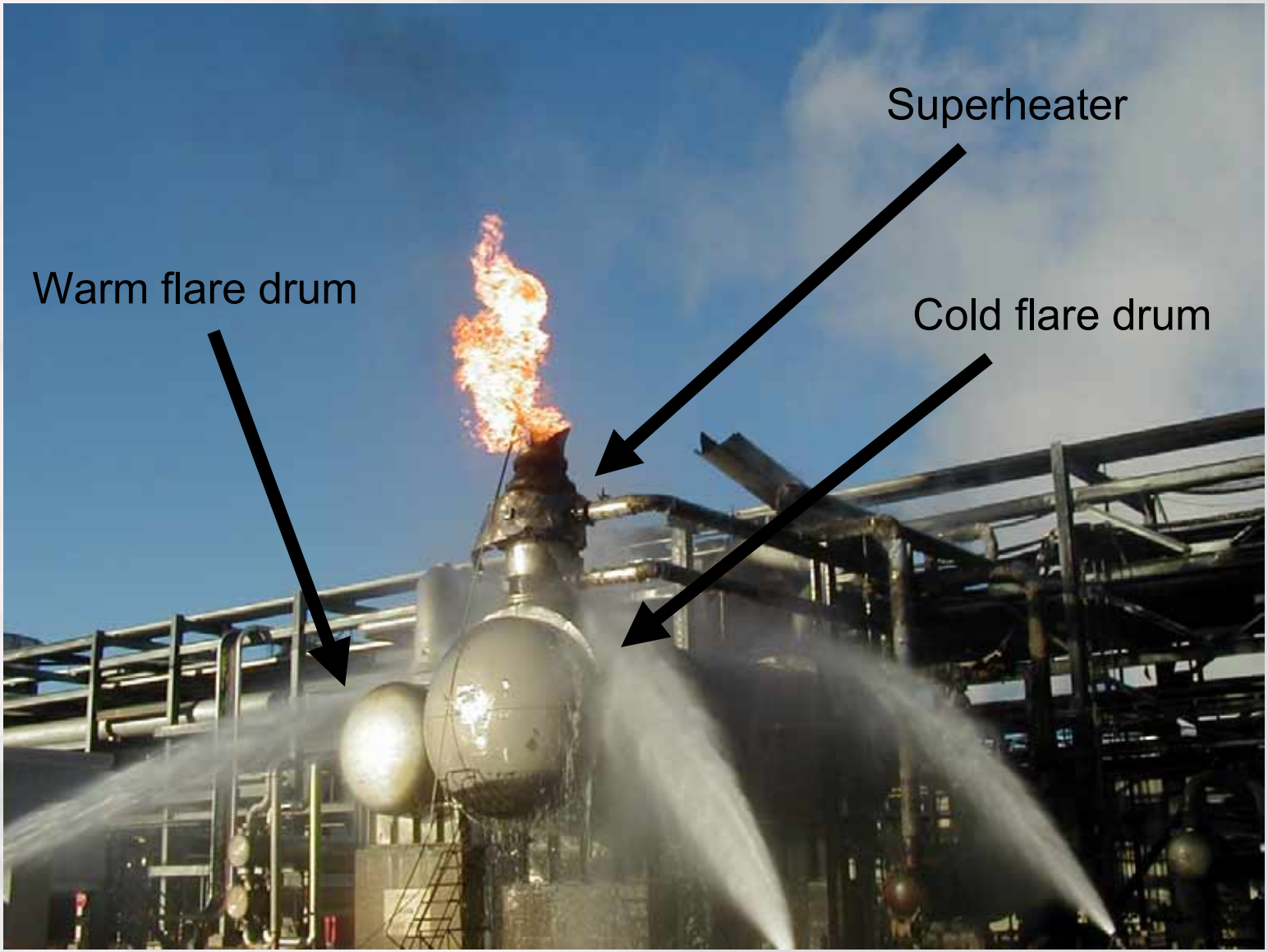
Event Sequence

- The Westlake Petro 1 ethylene product went off spec on acetylene, initiating flaring of liquid ethylene product
- Acetylene converter outlet analyzer was in error which allowed the ethylene splitter inventory to be contaminated with acetylene prior to corrective action being taken
- A portion of the off spec liquid ethylene product was consumed by internal Westlake customers, with the balance being flared via the cold flare drum
- Malfunction of the cold flare drum vaporizer and superheater allowed the cold flare drum overhead line temperature to fall sharply

Event Sequence, Cont...

- A low temperature alarm sounded as the overhead line temperature fell to 0 F, and the thermocouple “went bad” at a value of -13 F
- With the cold flare drum overhead line running below its minimum design temperature of -10 F, the pipe ruptured, resulting in loss of hydrocarbon containment
- The hydrocarbon released found an ignition source, resulting in an explosion and fire

Cold Flare Drum Overhead Line Fire



Root Causes of the Fire

- Vaporizer/superheater exchanger fouling had reduced heat transfer capacity of the cold flare system
- Once flaring began, the cold flare drum overhead line experienced low temperature
- Brittle fracture of cold flare drum overhead piping due to operation below the minimum design temperature of the carbon steel line

Root Cause #1: Vaporizer/Superheater Malfunction

- After the event, it was determined that fouling had compromised the operation of the vaporizer and superheater exchangers

Corrective Actions:

- 2 LI's installed on cold flare drum w/ DCS hi alarms @ 10%
- Heavy oil pull down system installed to allow removal of heavy oil from the cold flare drum
- Cold flare drum superheater replaced with 50% larger exchanger and propanol piping was replaced to handle higher throughput

Root Cause #2: Cold Safety Awareness/Management

- Once flaring began, the cold flare drum overhead line low temperature was not recognized

Corrective Action:

- Plant wide training conducted to re-emphasize cold safety awareness, including root causes and corrective actions for cold flare line event

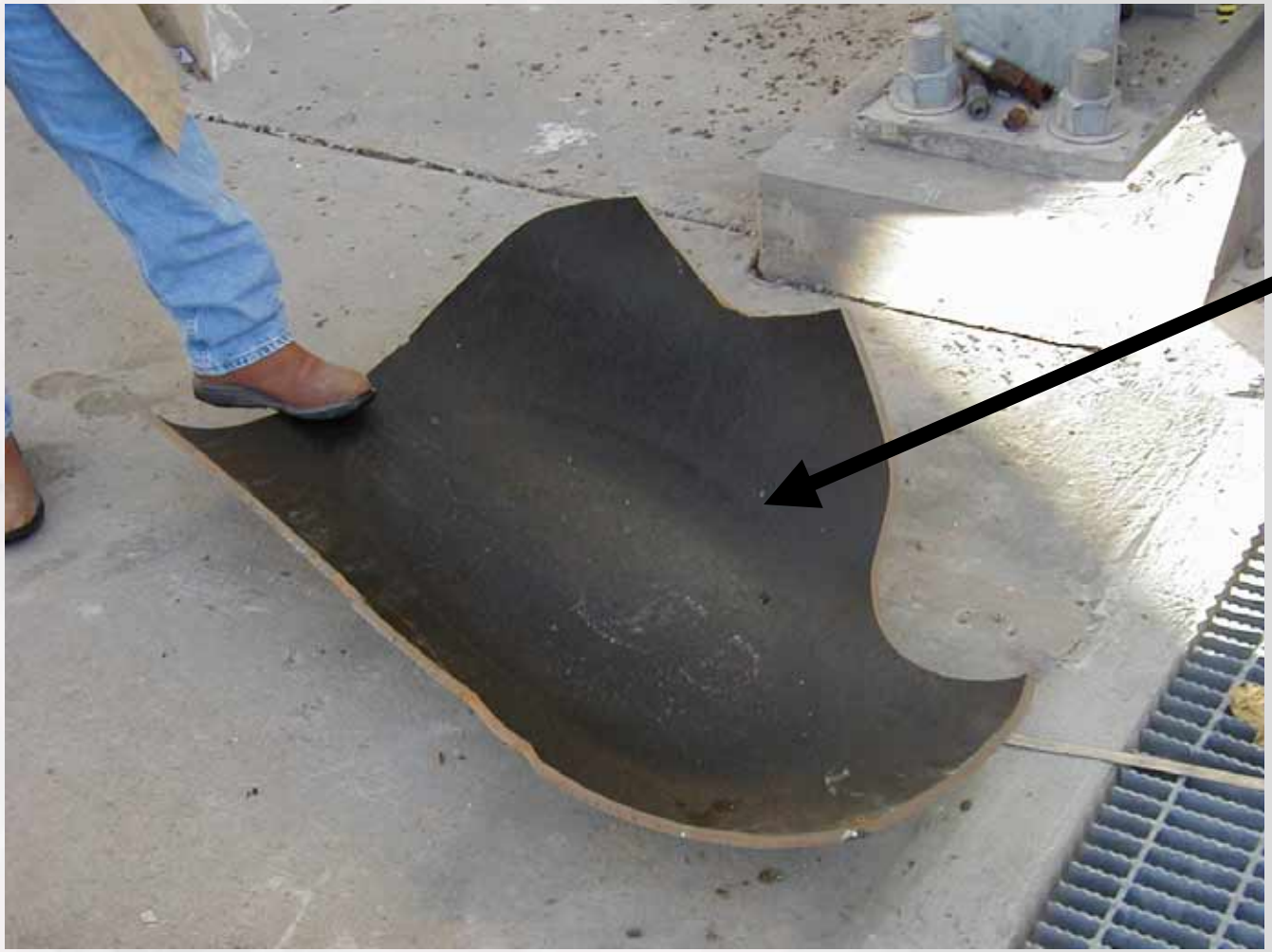
Root Cause #3: Brittle Fracture

- The “final stress” that ultimately caused the brittle fracture of the piping has not been identified, but could have been any number of internal or external stresses
- External stress - Hard rain that came at the time of event?
- Internal stress - Contraction of the cold flare line due to temperature gradient?

Corrective Actions:

- Carbon steel flare system piping replaced with stainless steel, ~100' downstream of warm/cold flare drum tie-point
- Thermocouple installed on new stainless steel piping upstream of SS to CS transition
- Stress analysis on the new flare line, FEA on flare drum
- See “Flare Drum System Modifications” diagram

Overhead Line Brittle Fracture

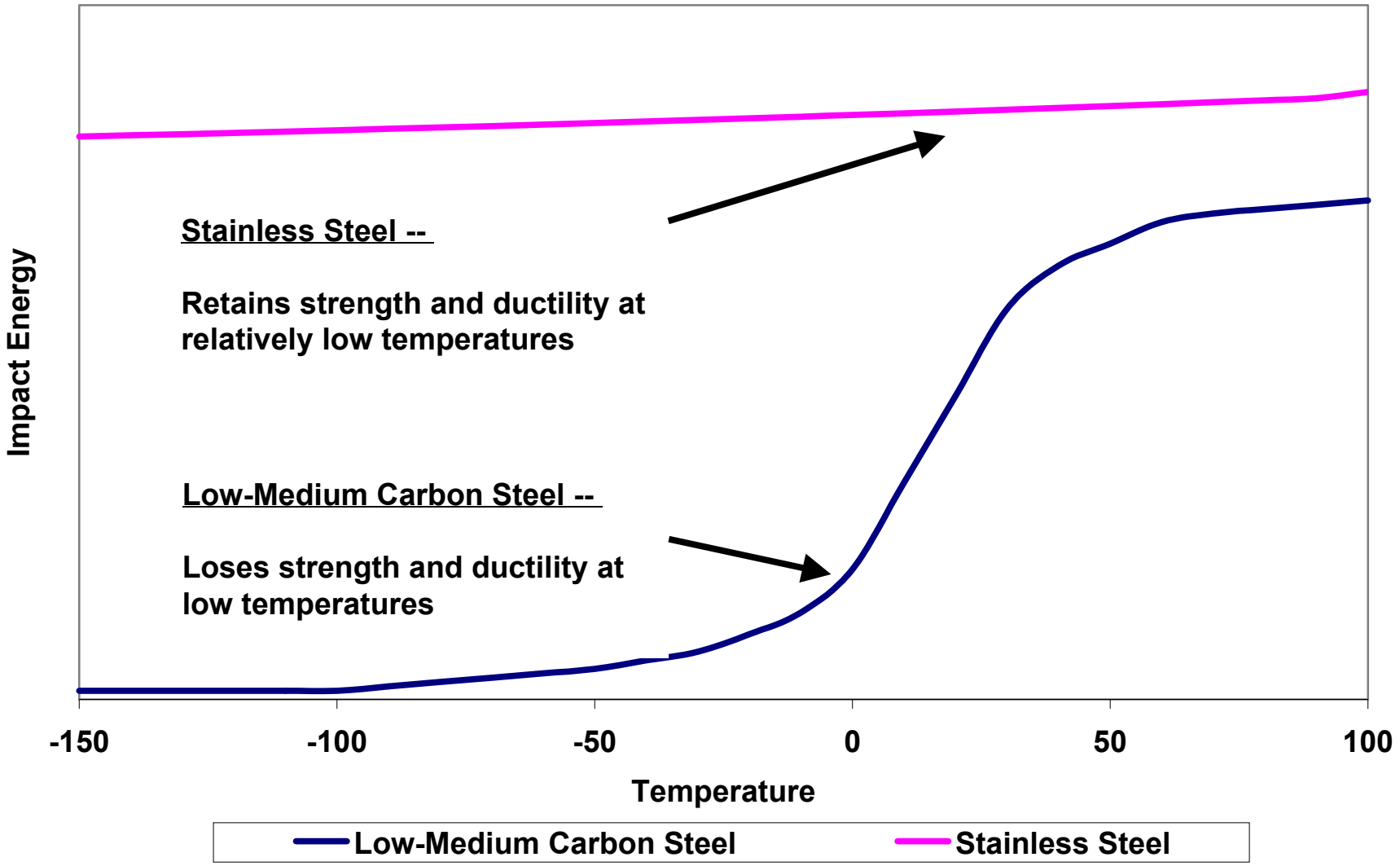


30” cold flare drum overhead line failure due to brittle fracture

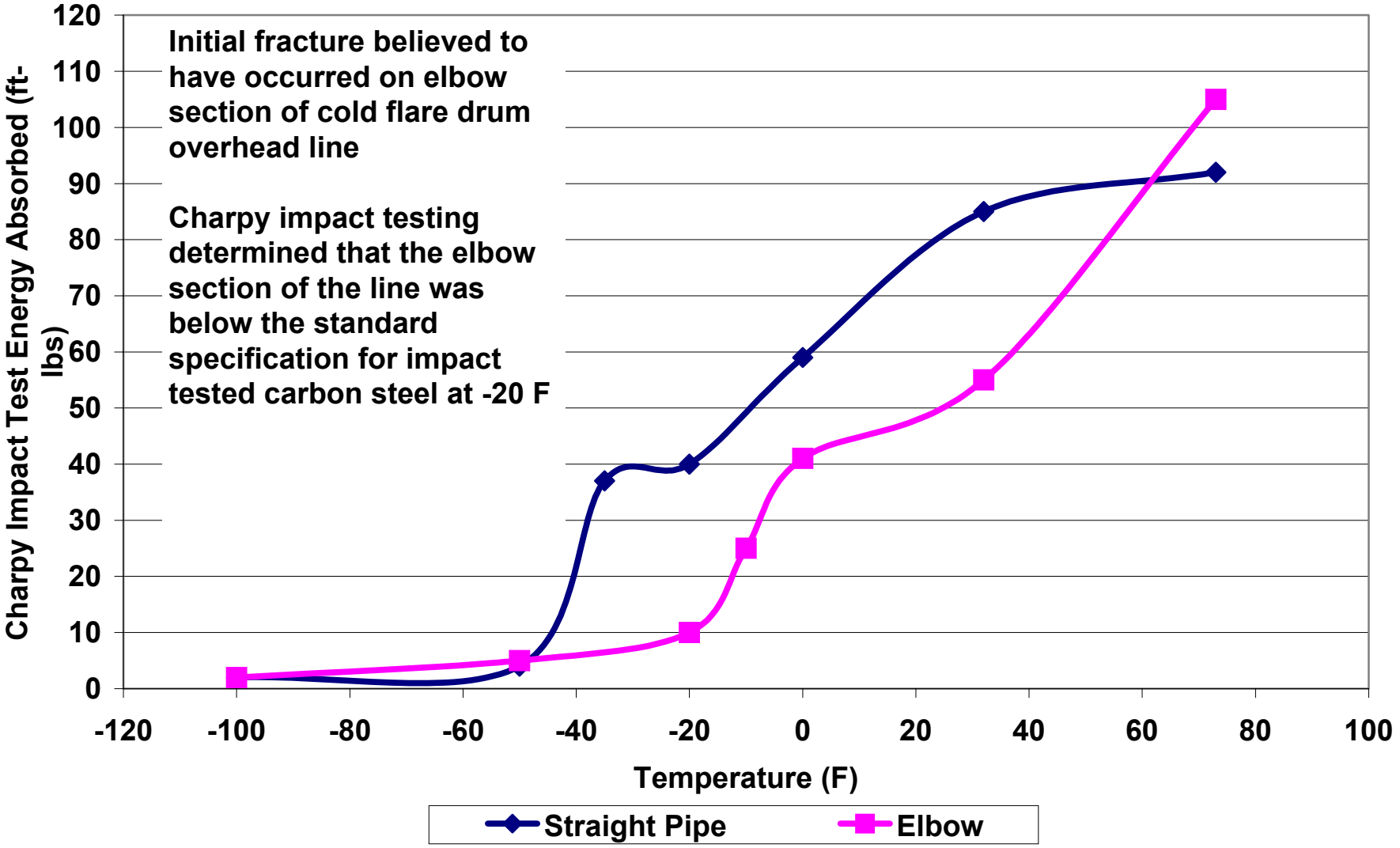
Carbon Steel Brittle Fracture Discussion

- Carbon steel piping is typically used in services w/ temperatures above -10 to -20 F
  - Impact testing can certify the use of carbon steel piping in services as cold as -55 F (i.e. “killed carbon steel”)
- At temperatures below -10 to -20 F normal carbon steel loses ductility and strength
  - The metal becomes brittle and can be susceptible to brittle fracture
- Three main factors influence the onset of brittle fracture:
  - Temperature
  - Flaw size (notches, scratches, etc…)
  - Stress

Impact Energy vs. Temperature for Carbon and Stainless Steel



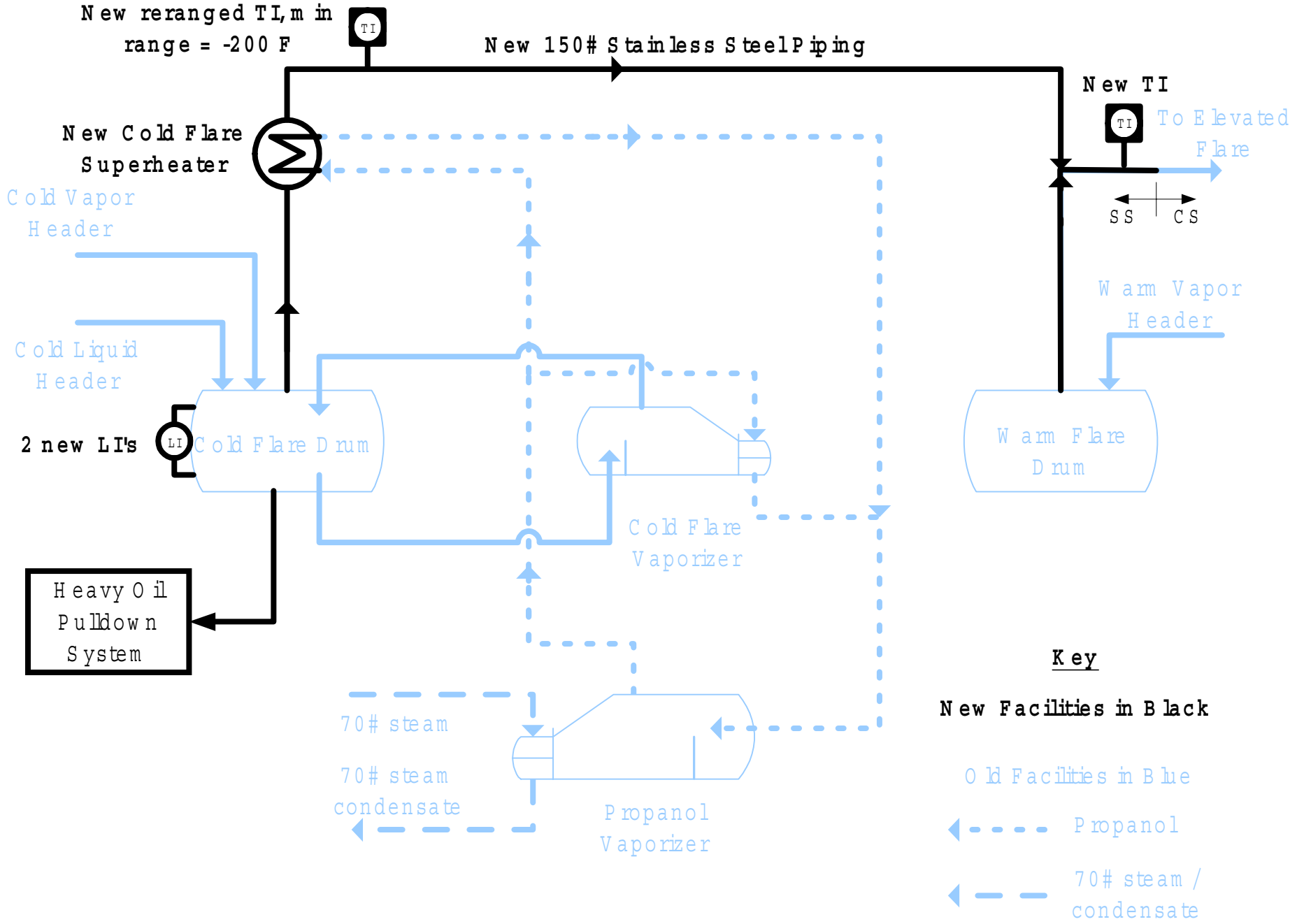
Westlake Charpy Impact Testing on Cold Flare Drum Overhead Line



Other Follow Up Actions

- Study conducted to identify and replace carbon steel components in cryogenic service
  - Bimetallic demethanizer tower upgraded to stainless steel during 2003 T/A
  - Demethanizer tower reboiler piping upgraded from killed carbon steel to stainless steel during 2003 T/A
  - Ethylene splitter bottoms piping upgraded from killed carbon steel to stainless steel during 2003 T/A
- Install new cold flare line overhead thermocouple with a minimum range to -200 F

Westlake Petro 1 Flare Drum System Modifications



Safety/Environmental Impact

- The state police, the Local Emergency Planning Commission (LEPC), and the National Response Center (NRC) were notified of the event.
- No first aid or recordable injuries
- The fire was contained within a few hours, but it was not completely extinguished for 1 week
- The plant was shut down for 1 month while repairs were made to the unit

Key Learnings

- Event specific
  - Heavy liquid introduced to the cold flare drum should be removed in a timely manner
  - Cyclopentadiene (CPD) and other components in deethanizer bottoms streams can polymerize to foul cold flare heat exchangers
  - Cold flare system fouling may not be readily identified due to infrequency of use
- General
  - Unit upsets will tend to find the “weak link” in management systems, facilities, and personnel
  - Cold safety should remain a focus for all ethylene plants