

# Cryogenics

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ACADEMIC-INDUSTRY  
LIQUID ROCKET SYMPOSIUM **2023**



# Cryogenics

## Texas A&M University Dewar Explosion



ref. <http://www.tdi.texas.gov/fire/documents/fmred022206.pdf>

- Hazards, Personal Protection Equipment
- Properties of Interest
  - BLEVE
  - Transferring
  - Boiling and Vapor Production

The information provided in the seminar is not meant to be inclusive of all information needed to understand cryogenics. The information provided is meant as a guide to assist in education. The referenced information as is not inclusive of all pertinent information about cryogenics. VES holds itself harmless from any action that results from the use of this information. VES holds itself harmless from any errors provided in this seminar. The information in this seminar is incomplete without the oral portion of the presentation.

# Hazards

- Cold
  - Frostbite, cryo burns
  - Eye damage
- Vapor generation
  - Oxygen depleted clouds and spaces (LN2)
  - Oxygen enriched clouds and spaces (LO2, covered by O2 presentation)
  - Explosive and flammable atmosphere (LNG, LCH4, LH2)
- Trapped cavities
  - Overpressure and rupture of equipment, valve traps, ball valves, others
  - BLEVE
- Uninsulated LH2 surfaces produce oxygen enriched air liquification, fire hazard

# Personal Protection Equipment

## Typical Cryo PPE

Goggles/splash protection  
Face shield  
Cryo gloves  
Cryo apron/smock  
Footwear  
Ear protection  
No exposed skin

Other related equipment  
Oxygen sensor  
Flammable gas sensor  
Grounding



<https://www.aps.anl.gov/files/APS-Uploads/SECTOR29/Cryo.pdf>

# Boiling Liquid Expanding Vapor Explosion (BLEVE)

- Thermal energy is absorbed by contained fluid
- Fluid pressure rises to vessel burst pressure
- Vessel rupture lowers the fluid pressure
- State changes generate large amounts of gas
- Expanding vapors produce work
- Work  $\sim$  explosion



Grover Shoe Factory Explosion, 1905  
(660 lbm dynamite equivalent)

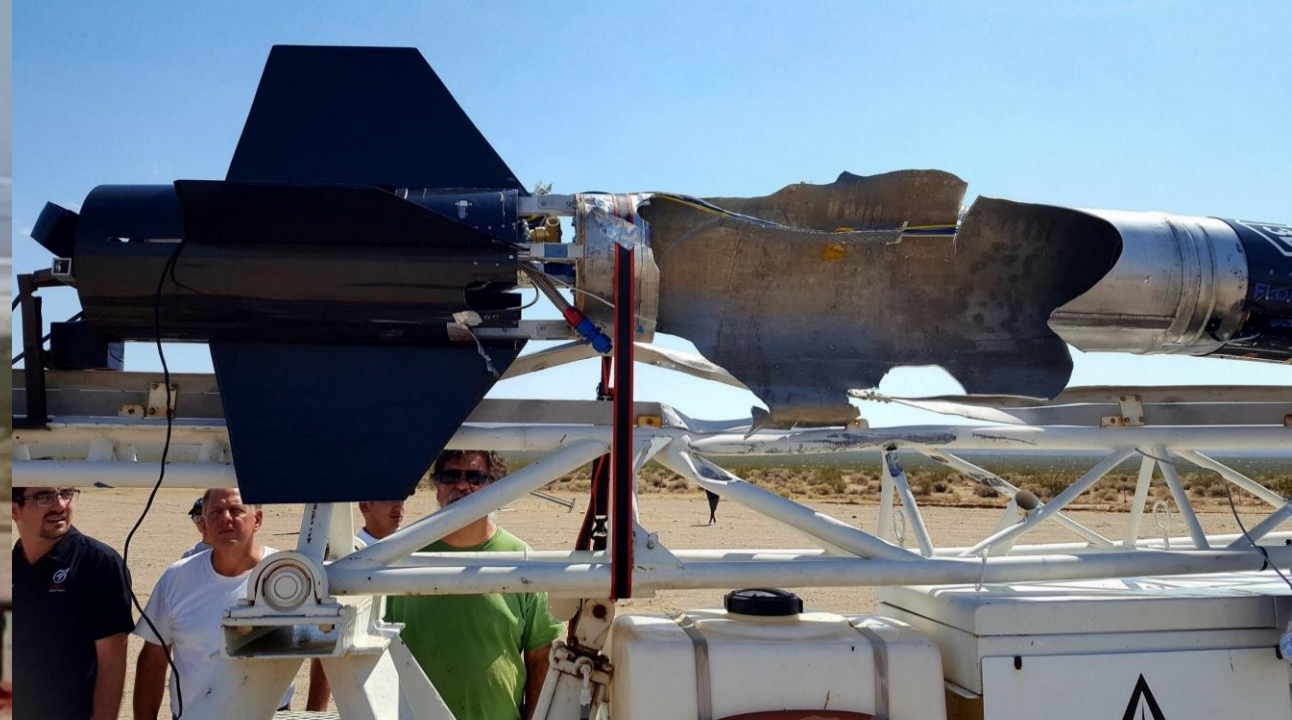
[https://en.wikipedia.org/wiki/Grover\\_Shoe\\_Factory\\_disaster](https://en.wikipedia.org/wiki/Grover_Shoe_Factory_disaster)

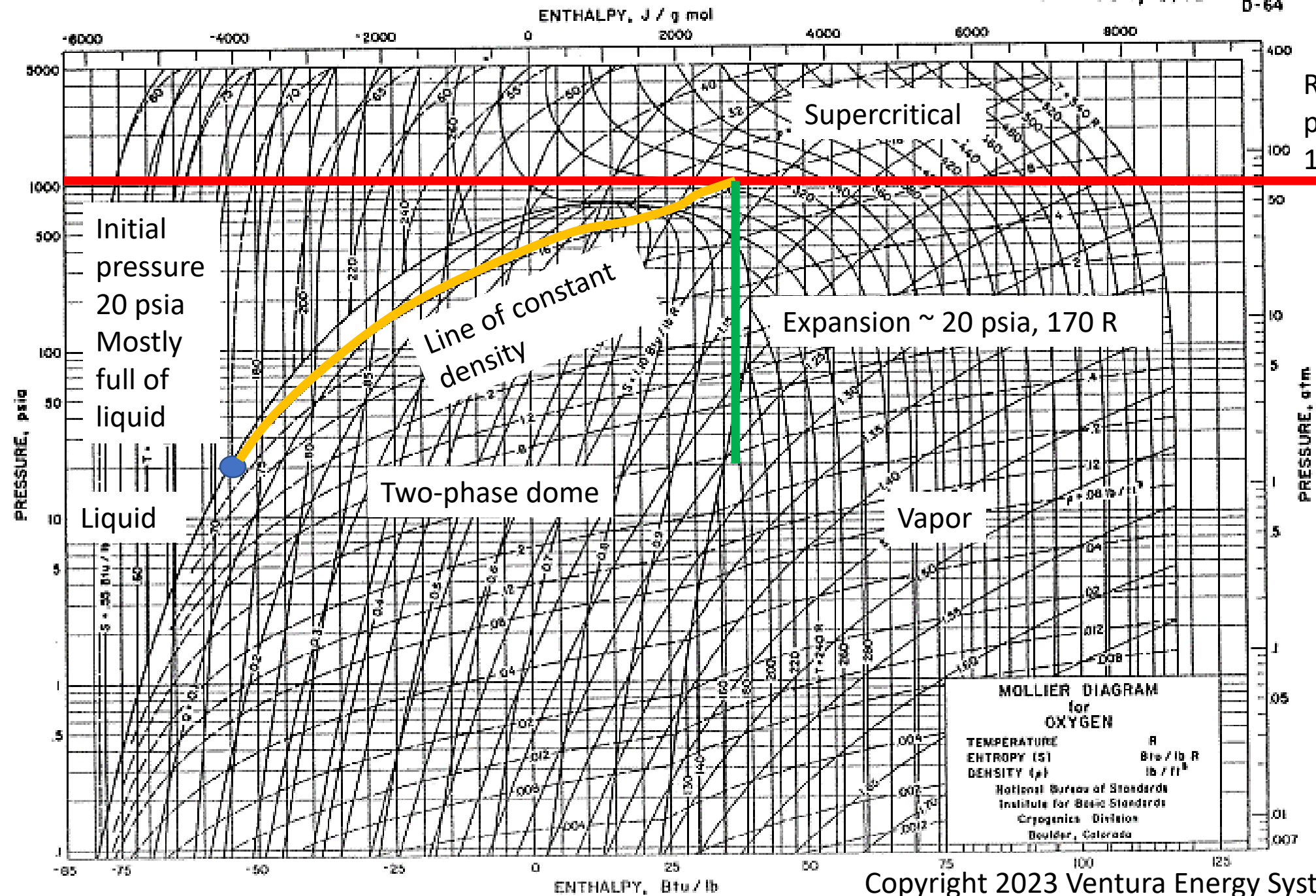




# BLEVE

## Example at FAR

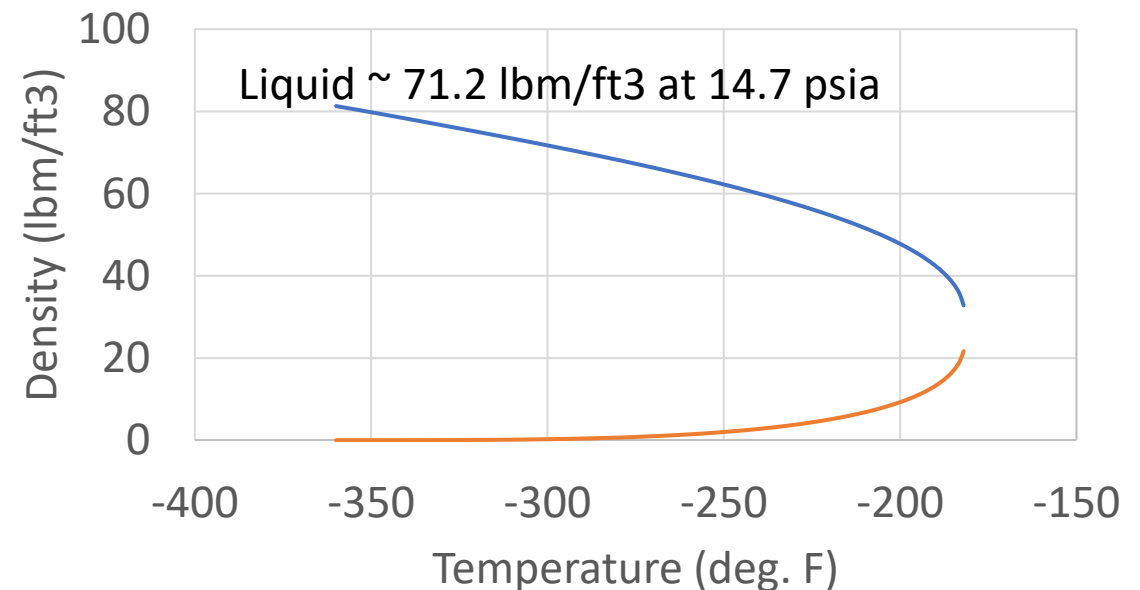
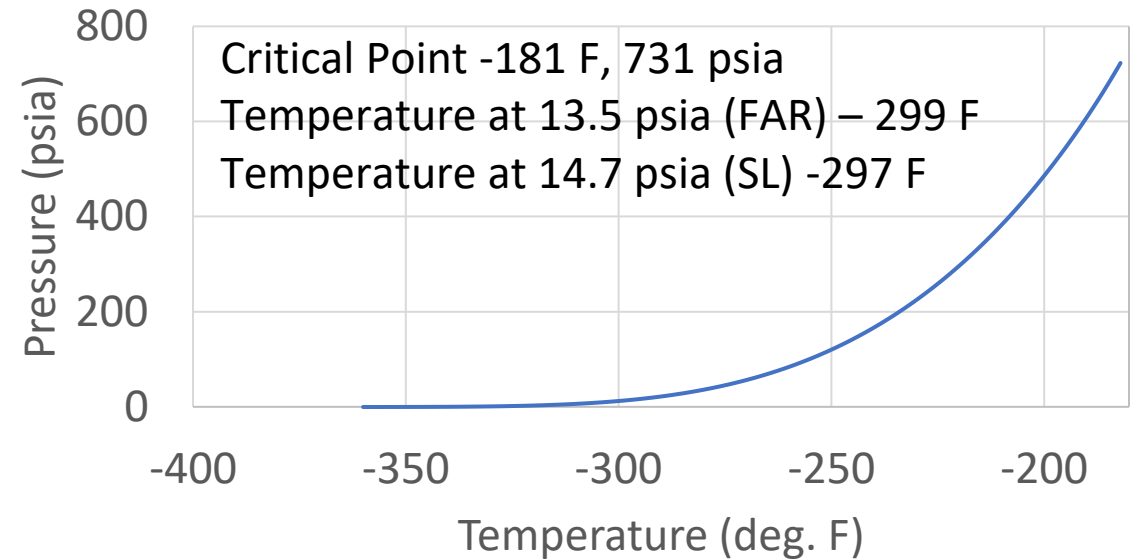




# Transferring Cryogenics

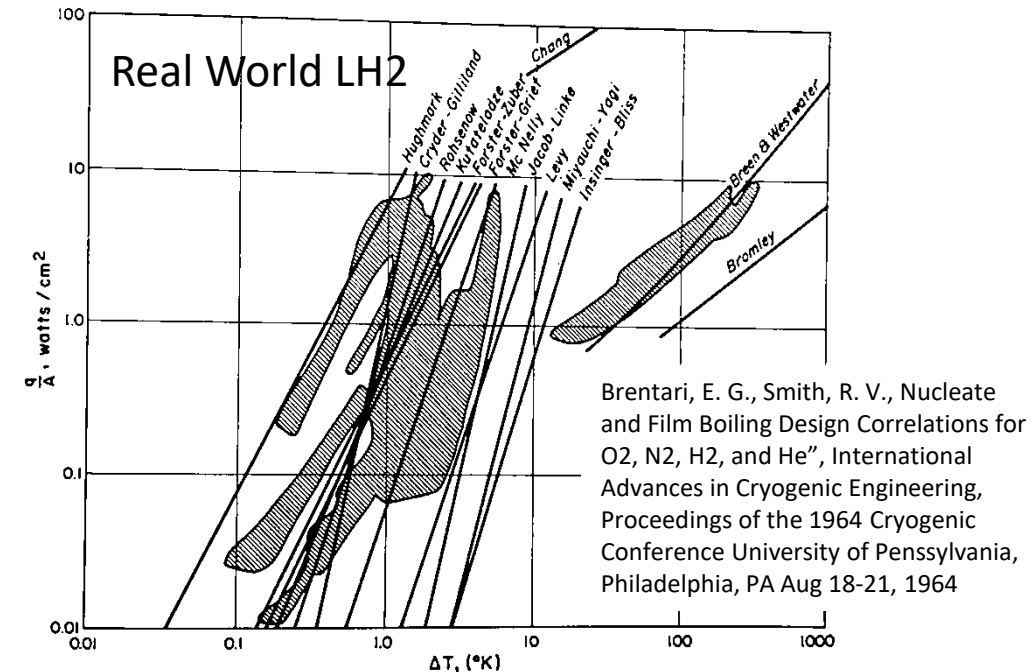
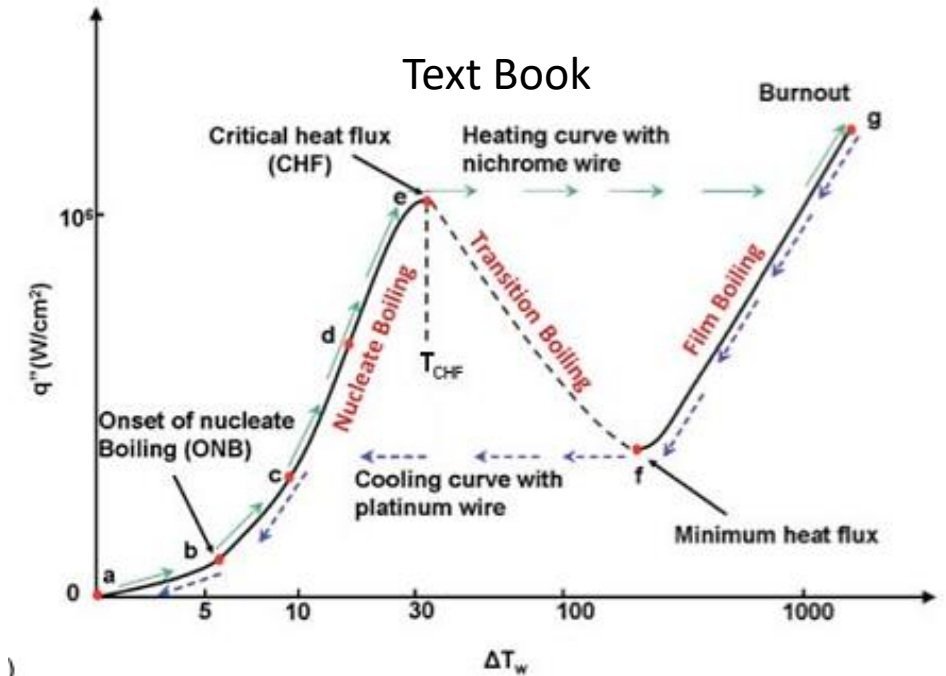
- Liquid is typically saturated at the storage container pressure
- Fluid flow has a negative pressure gradient and flows from a cold soaked system to a hot system
- Fluid flow is transient, and multi-phase, typically two-phase: liquid/vapor
- Small amounts of vapor dramatically change the hydrodynamic behavior of two-phase flow
- Process entails large amounts of vented gases to absorb the heat of the hot equipment
- Vent systems need to be designed to allow this vent rate, too small of a vent system will limit fill rate and resulting bulk density

Liquid Oxygen Saturation Pressure



# Boiling & Clouds

- Boiling is hard to understand without experiential test data due to large dispersions in the boiling curve
- Cryogenic operations require an understating and analysis of how to manage vapors, oxygen deficient, oxygen enriched, and flammable vapors
- Vapors are clear, visible vapors are from water condensation which is highly variable based on the air specific humidity and thermodynamic state of the air
- Visible vapor clouds do not represent a good proxy for the actual vapor cloud due to large dispersions in water condensation behavior

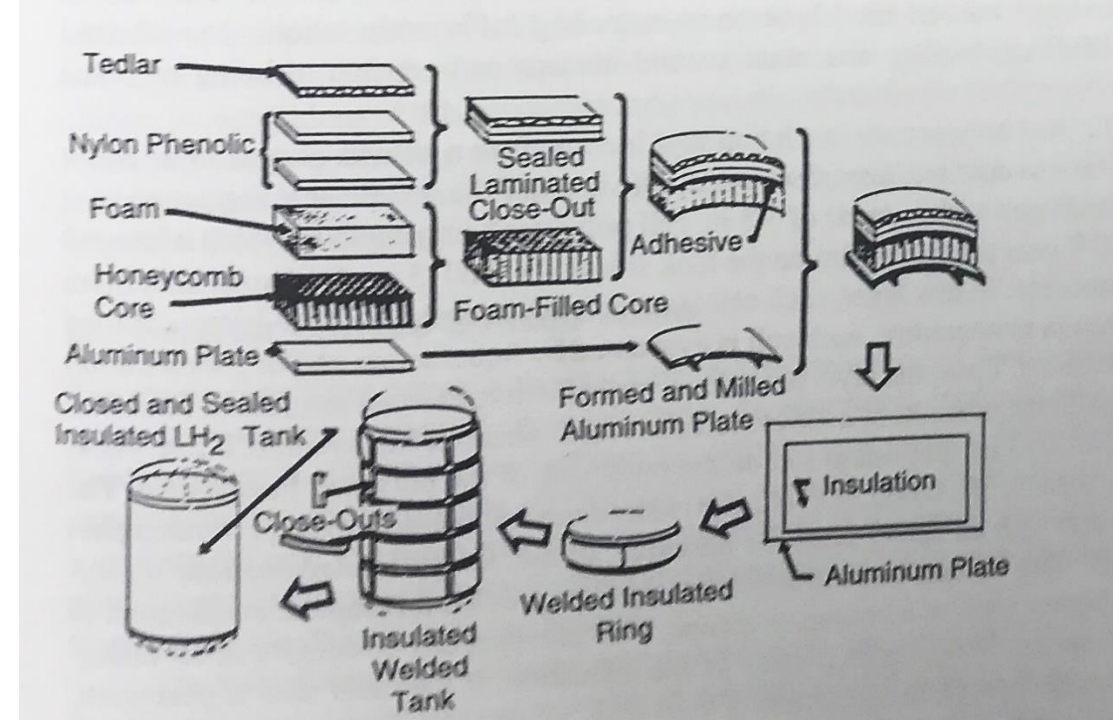
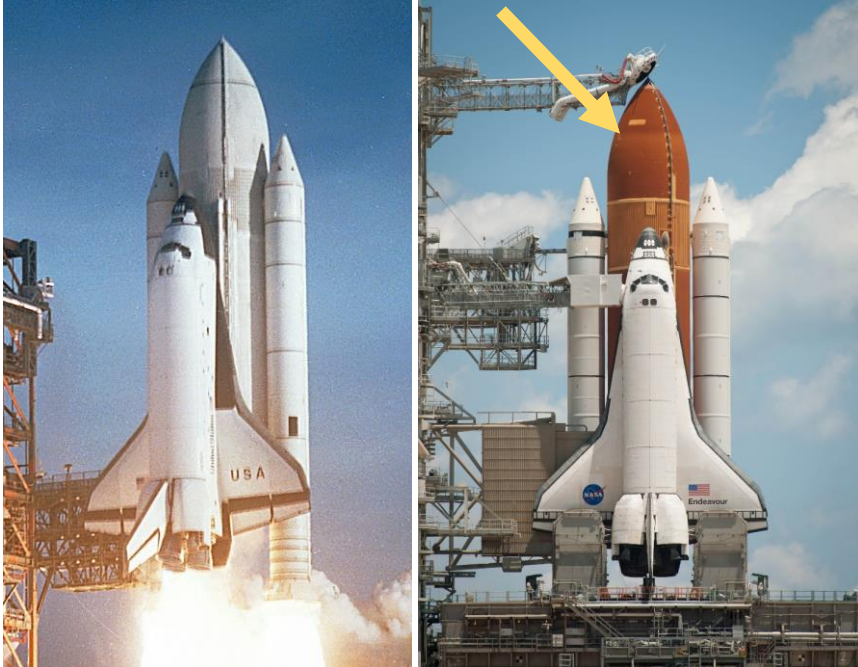




# Heat Transfer, Insulation

- Fluid operations are always transient
- Ice adds weight, heat lowers bulk density
- Condensable species, LH2 special case

PU/SOFI insulation



- Cold surfaces can cryopump moisture
- Creates partial pressure gradient
- Can infiltrate valves and causing jamming

Flynn, T., Cryogenic Engineering, Marcel Dekker, New York, 1996

# Common Problems

- Fluid system pressure drop and back pressure create a fill pressure balance
- Process is two-phase and transient
- Two-phase flow pressure drop is not easy to predict
  - It can be very large
  - Unsteady
  - Changes with time
- Valve freezing from residual water or other condensable species
  - Valves can freeze in various states, open, closed, partially open
- Dewar vacuum jackets can be degraded, variable dewar boil-off
- Fill rate needs to be fast enough to overcome heat transfer
- Tank back pressure controls tank saturation conditions and tank average density
- Axial and radial density gradients effect bulk density and are always transient
- BLEVE demo

Start reading  
these authors

- R. V. Smith
- E. G. Brentari
- P. J. Giarratano
- And people they co-author with

- Advances in Cryogenic Engineering  
1960's +/- 20 years
- NBS Technical Notes, various same  
time period

NIST Refprops source data, plus a lot  
more

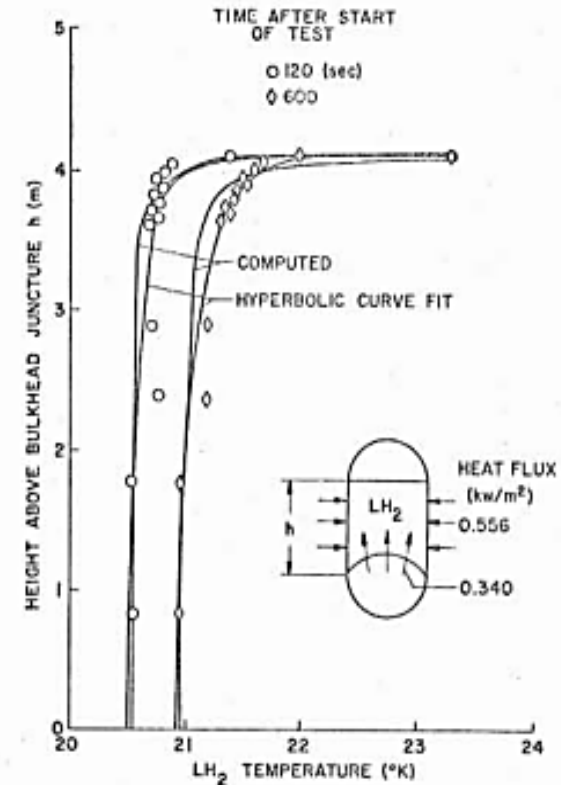
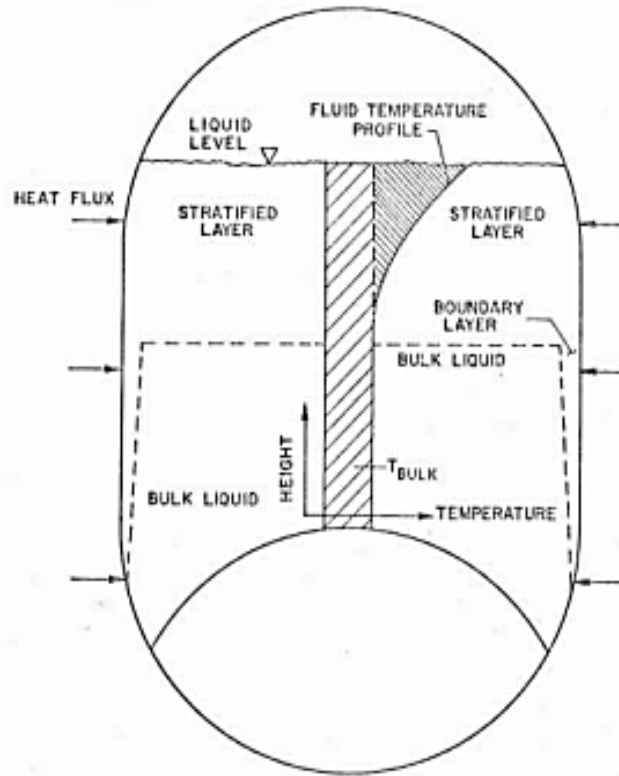
# Questions

- What is the difference between para and ortho hydrogen?
- What happens to uninsulated LO2 equipment? And LH2 equipment? How are they the same and different?
- For a tank loaded with a single cryogenic fluid saturated at local ambient pressure, what percentage of the tank fill maximizes the explosive BLEVE energy?
- What thickness of polyurethane foam reduces the heat load into a cryogenic tank by a factor of ten versus an uninsulated tank?
- Are the mole/mass fractions of LNG species the same in a saturated state for liquid and vapor?
- Does LNG species blend change during transfer?
- What happens if you mix liquid oxygen with kerosene?



# Liquid Level, Stratification, and Densification

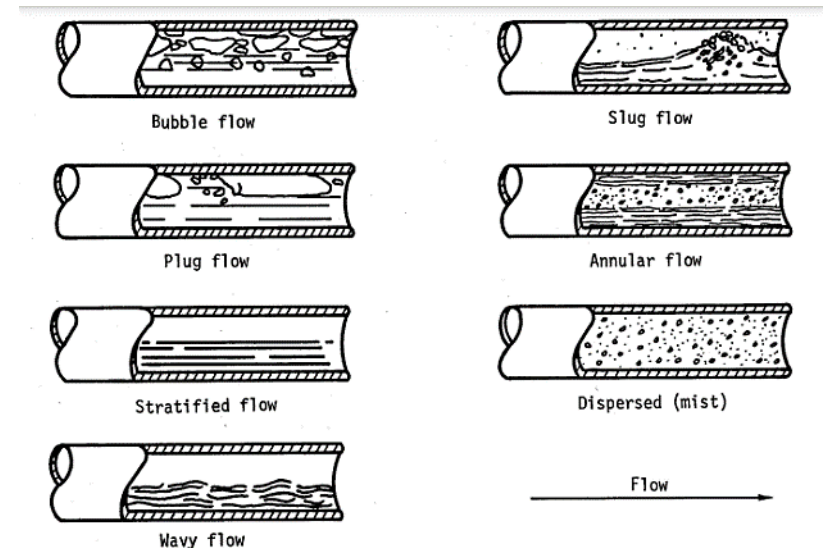
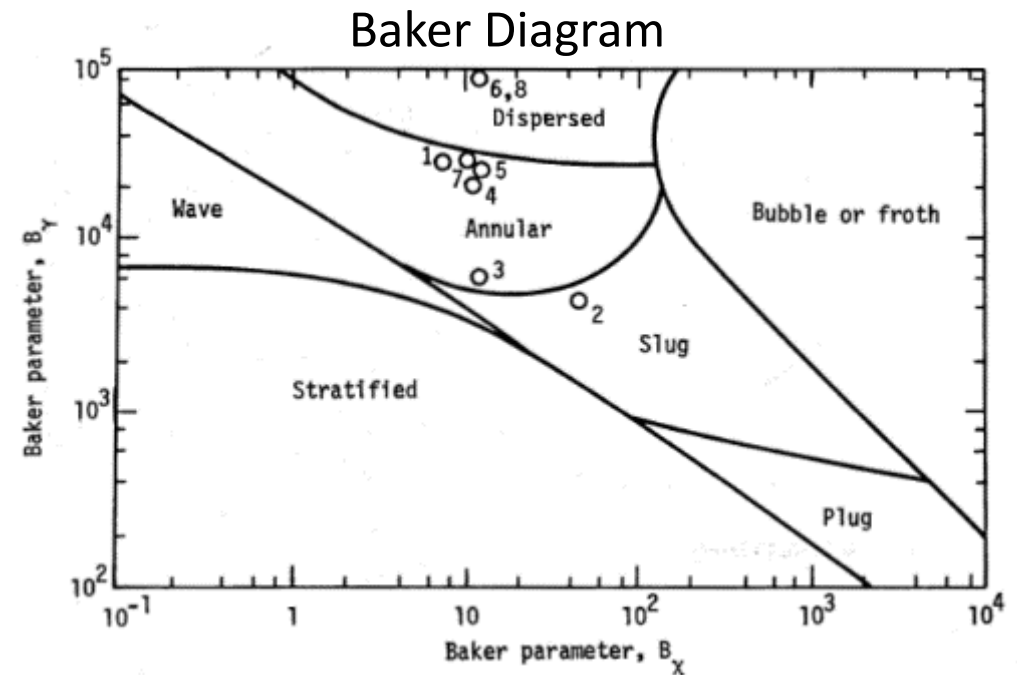
- A filled tank will be at some pressure between the loading pressure and ambient pressure aka a saturated fluid at a higher vapor pressure than ambient
  - Liquid will boil until it self-cools to lower saturation pressure
  - Self-cooling lowers saturation pressure/temperature and increases density
- Tank internal density is non-uniform and time dependent (stratification)
- Liquid surface level and location is unsteady and non-uniform



Woods, C., A REVIEW OF CRYOGENIC TECHNOLOGY ASPECTS OF SPACE FLIGHT, INVITED PAPER for THE INTERNATIONAL CRYOGENIC ENGINEERING CONFERENCE Kyoto, Japan April 9 - 13, 1967

# Multi-phase flow

- Very hard to perform accurate engineering calculations, modeling, and simulation
- Flow regime dependent, typical operations have multiple regimes
- Inherently unsteady, pulsating
- Geometry, scale, fluid, species mixture, and orientation dependent
- Develop experiential data on systems, control variables and learn
- Multiple sources of analytic tools and methods



# Embrittlement

- Some materials structurally unsuitable at low temperatures
- Material becomes brittle and will fracture
- Materials to avoid
  - Steels
  - Plastics
- Materials that work better
  - 300 series stainless steels
  - Teflon, however Teflon will cold flow under load
  - Polymers will go through the glass transition and become brittle
- H<sub>2</sub> will also cause chemical embrittlement which is different but also common in cryogenics due to LH<sub>2</sub>
  - Exposure to H<sub>2</sub> cause migration of H<sub>2</sub> into certain materials which change their physical properties and some become brittle



LNG Facility Failure – East Ohio Gas Co., 1944

128 deaths

Cause unknown

Possibly due to brittle tank material

<https://uspas.fnal.gov/materials/21onlineSBU/Cryo/2021%20USPAS%20Lecture%2016.pdf>