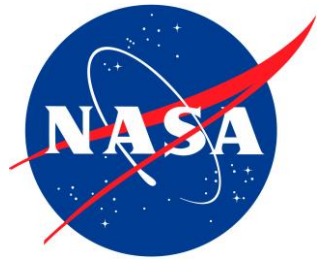


Critical Heat Flux of Liquid Hydrogen, Liquid Methane, and Liquid Oxygen: A Review of Available Data and Predictive Tools

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Paper co-authors: Ali Ghavami², S. Mostafa Ghiaasiaan², and
Alok Majumdar³



Agenda

- Motivation for critical heat flux (CHF) modeling
- Background: pool boiling curve/flow boiling curve
- Availability of pool and flow boiling CHF data for LH_2 , LCH_4 , LO_2
- Results
- Ongoing/Future work

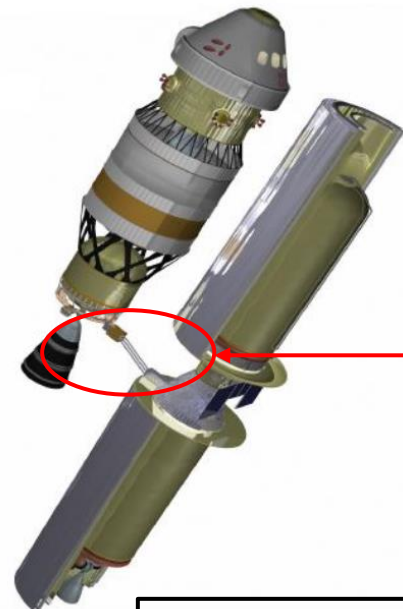
Motivation for CHF Modeling



1. Tank and line chilldown (pool and flow boiling)
2. Avoidance of CHF in “heated-tube” applications (flow boiling)

In-space tank-to-tank propellant transfer line

Application:
-Cryogenic fuel depots



Credit: ULA

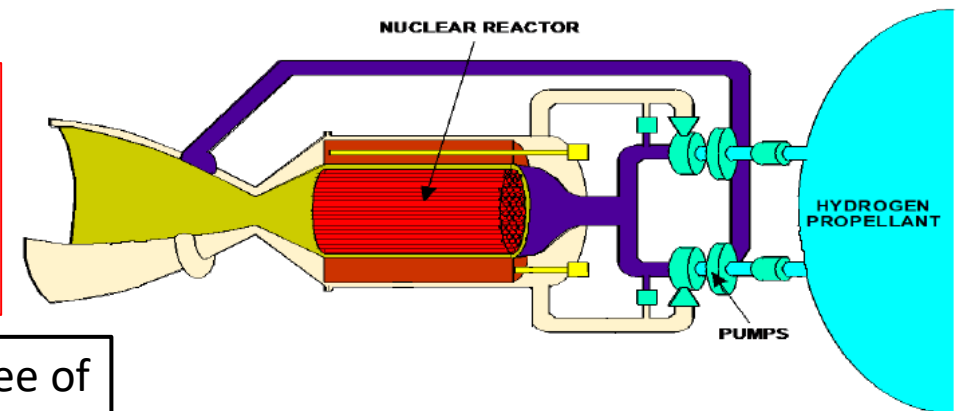
These lines could be on the order of tens of feet or higher in length

Informs insulation design and/or degree of propellant subcooling needed

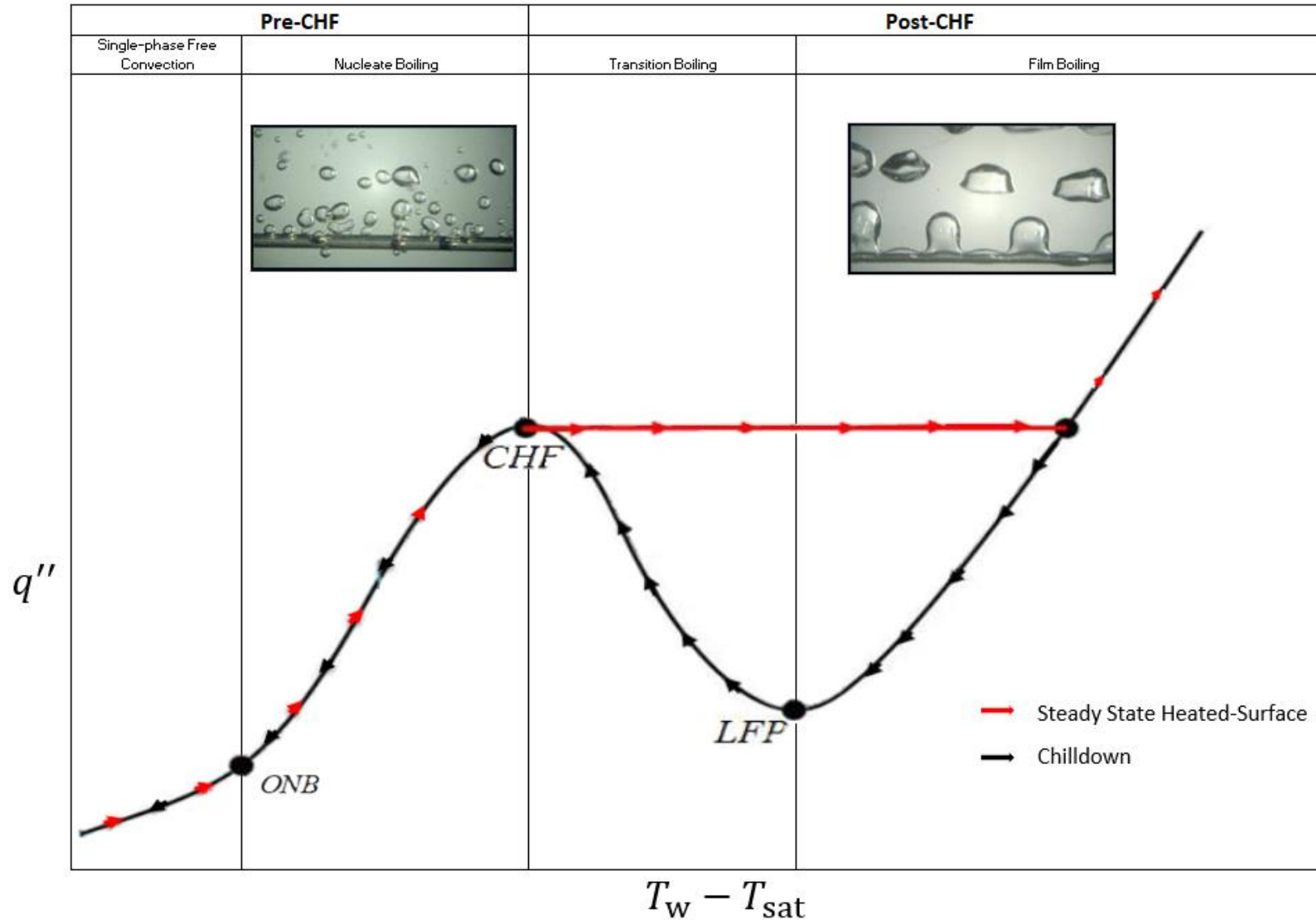
Tank-to-pump propellant feedline

Application:

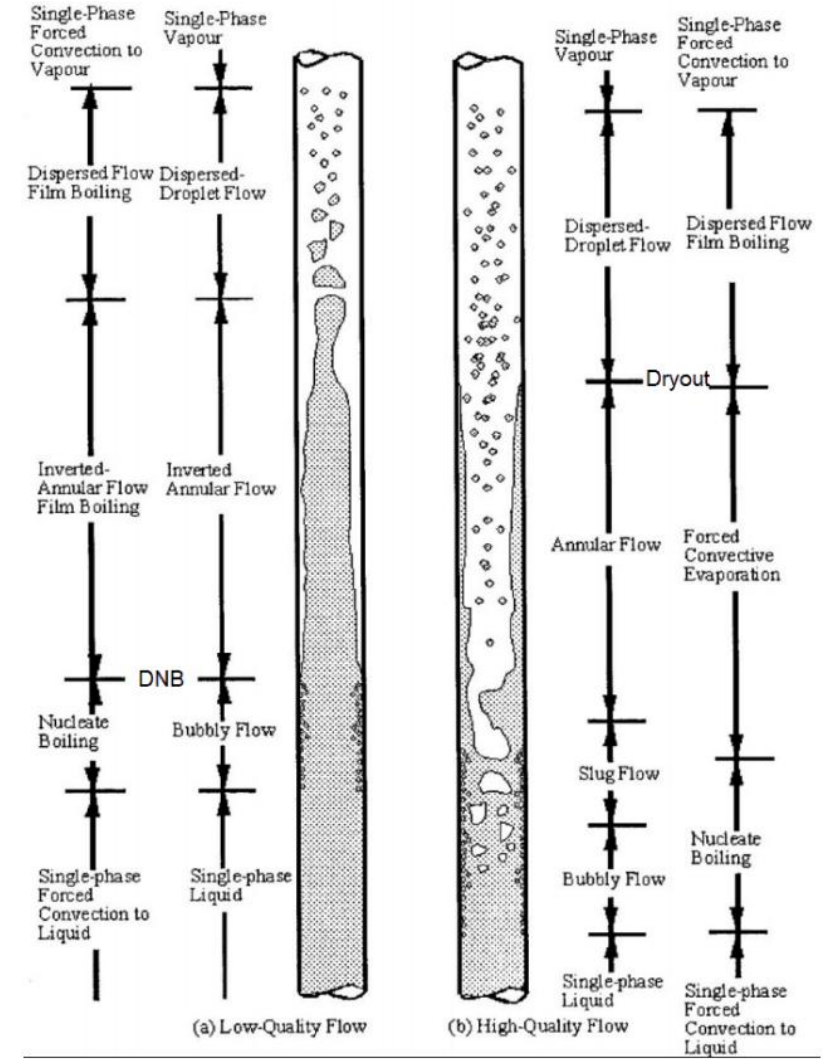
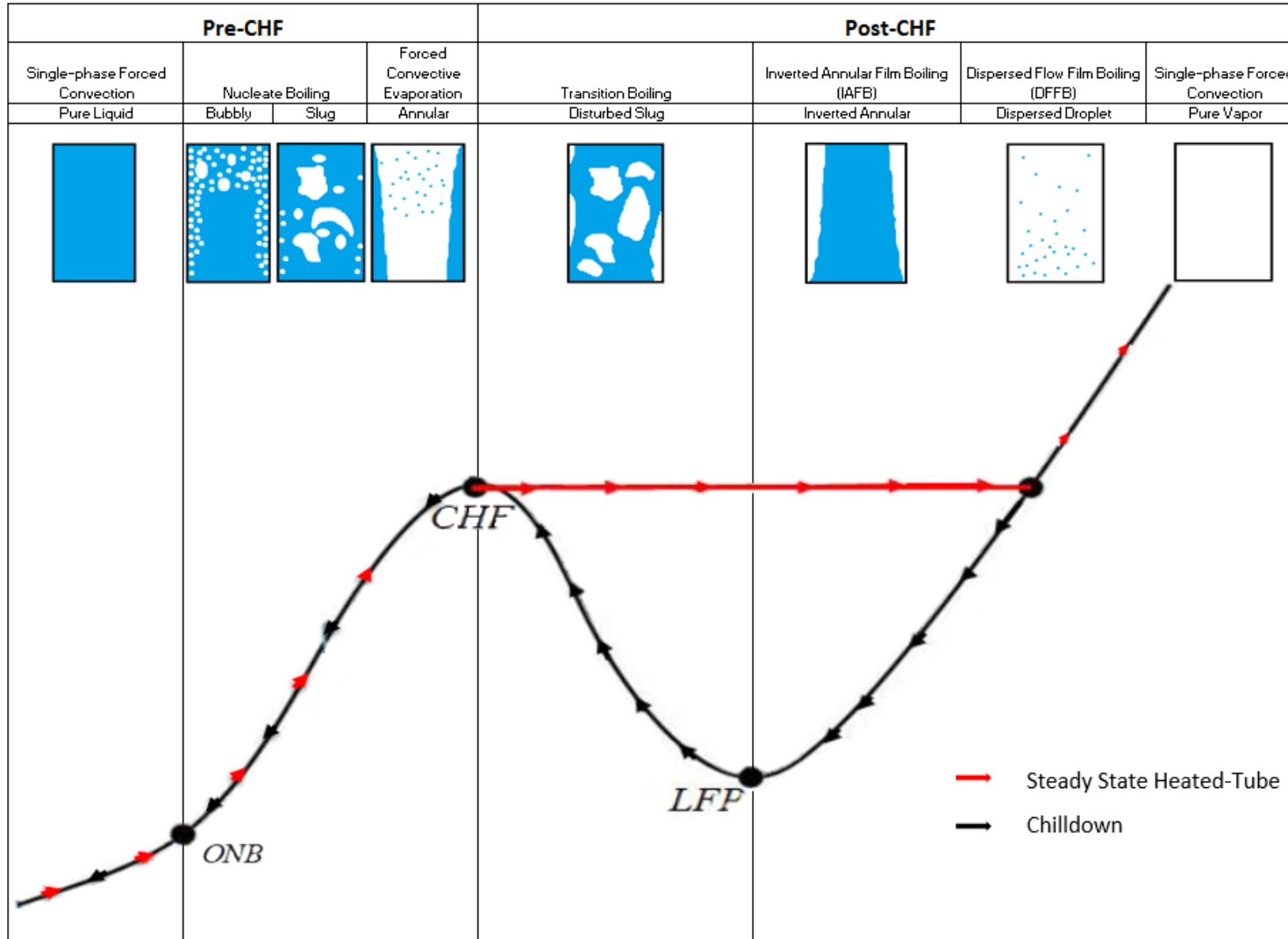
-Ascent and Descent Stages
-Nuclear Thermal Propulsion (NTP)



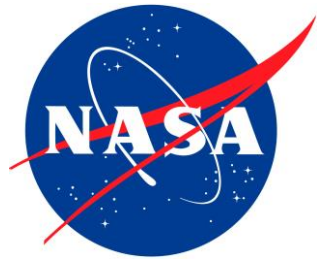
Background: Pool Boiling



Background: Flow Boiling

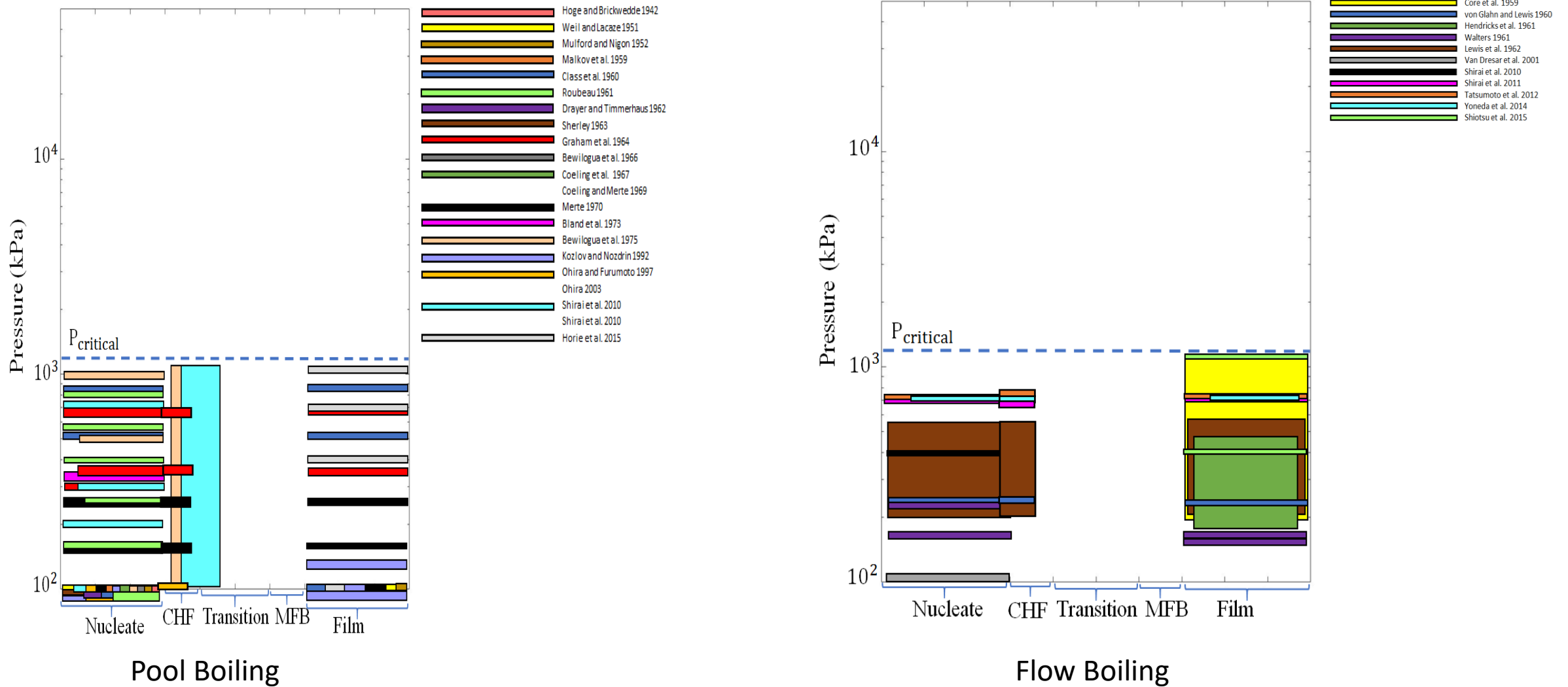
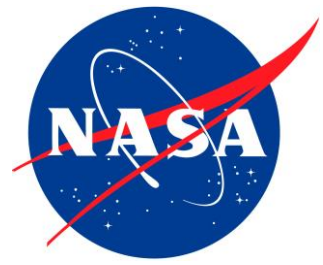


CHF

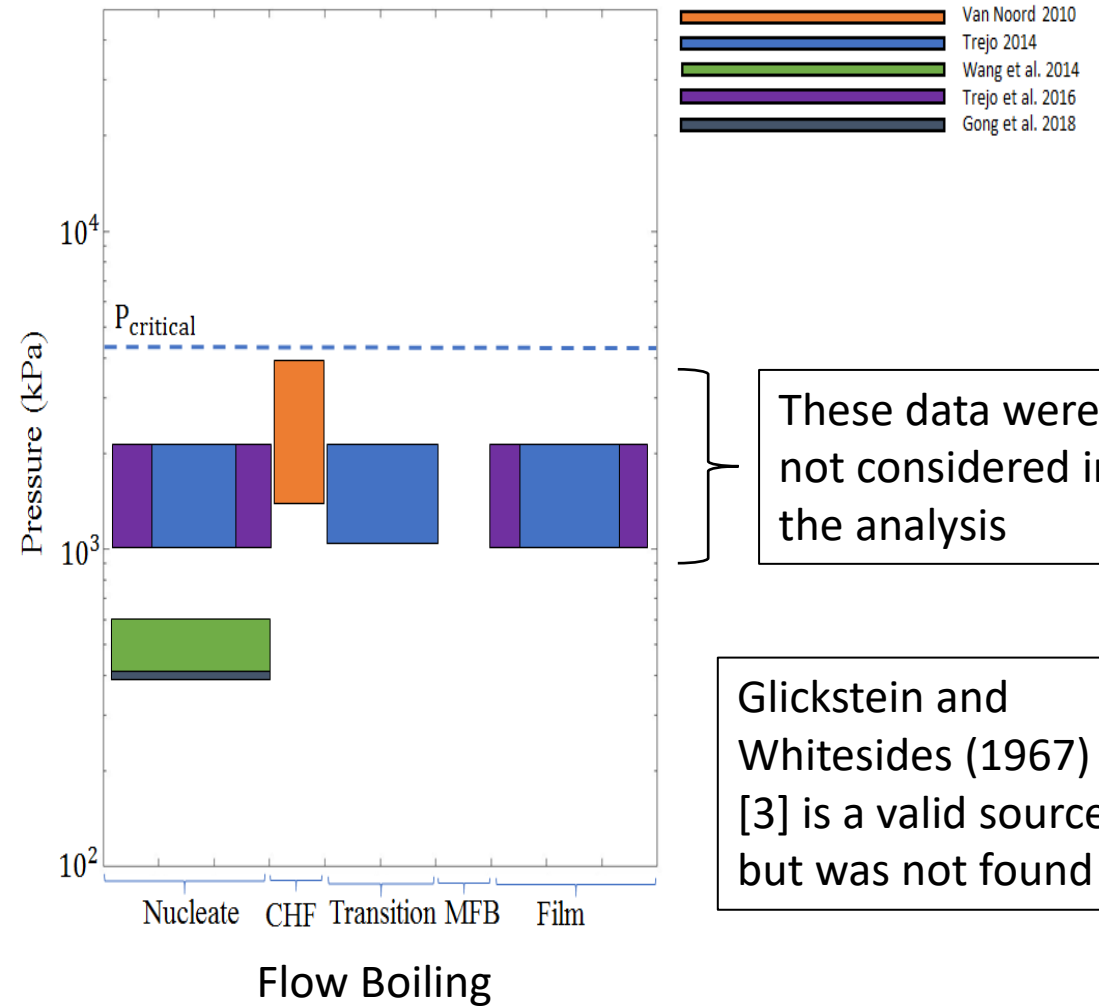
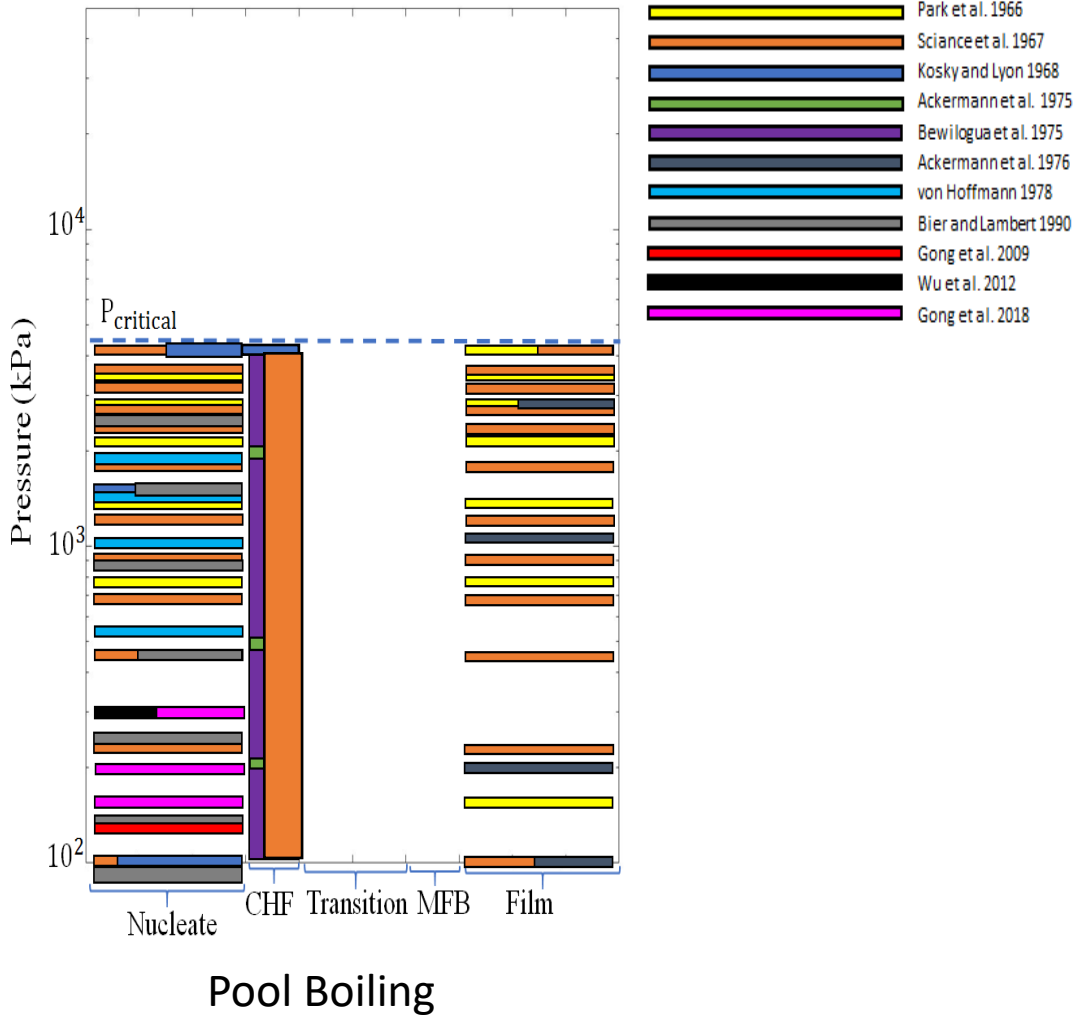
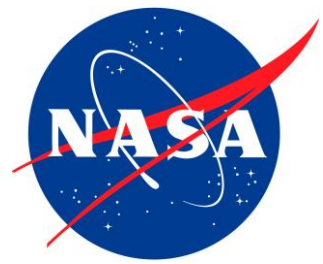


- Critical heat flux is a vital point in the boiling curve
- If CHF occurs, heat transfer plummets and the structural integrity of the heated surface could be compromised
- In all propellant transfer applications where a heated-tube boiling situation is present, CHF is to be avoided at all cost.

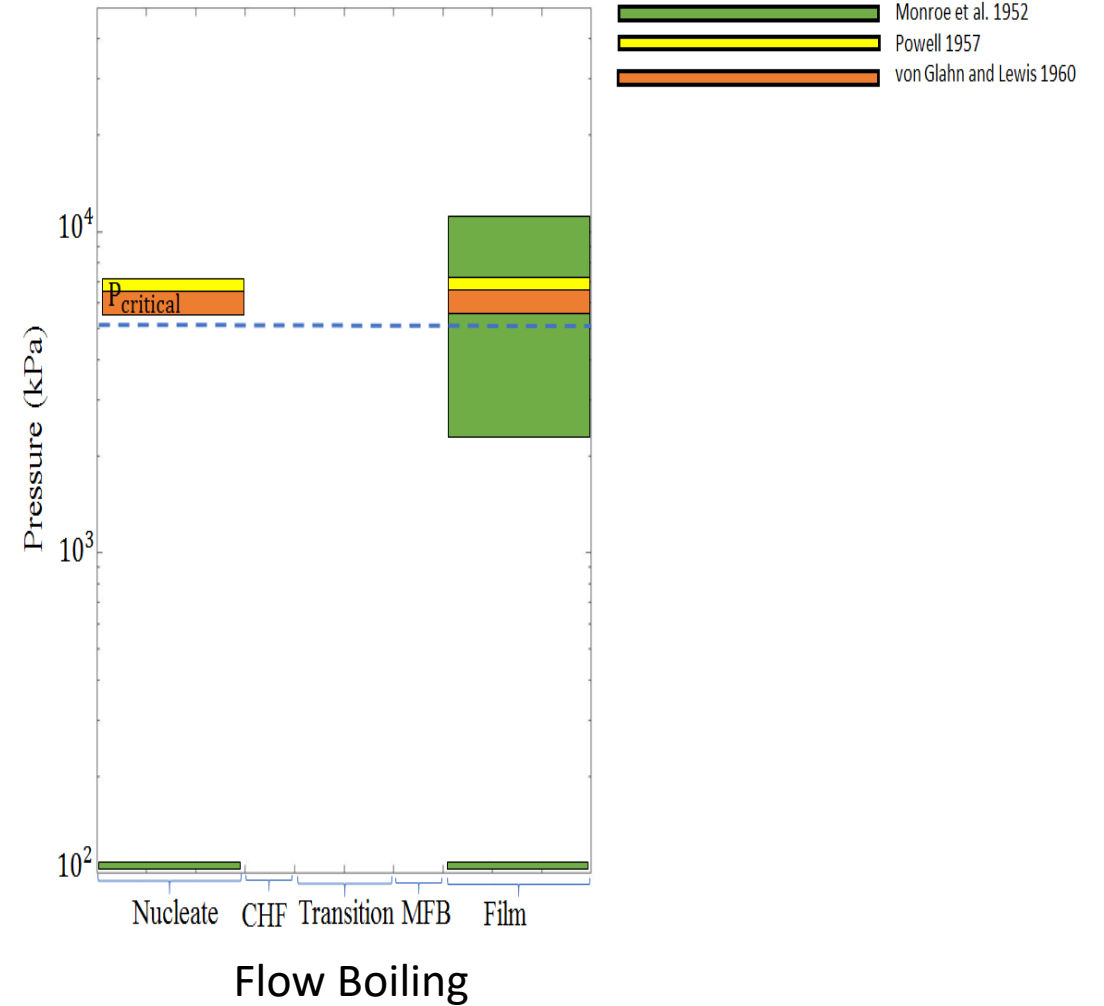
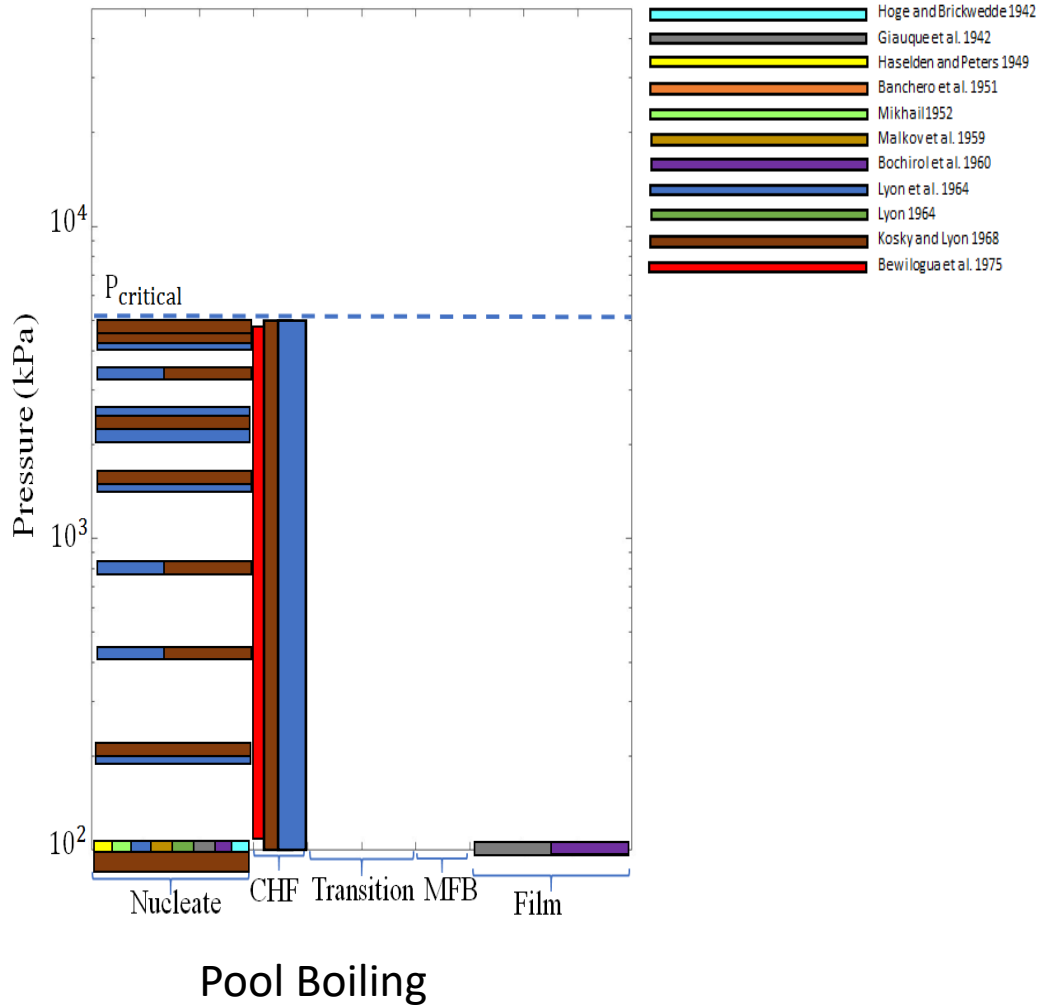
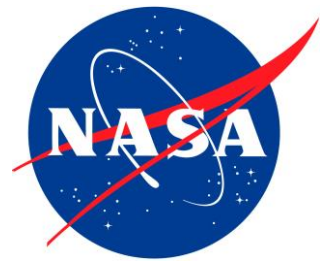
State of available CHF data for H₂ [2-3]



State of available CHF data for CH₄ [2-3]



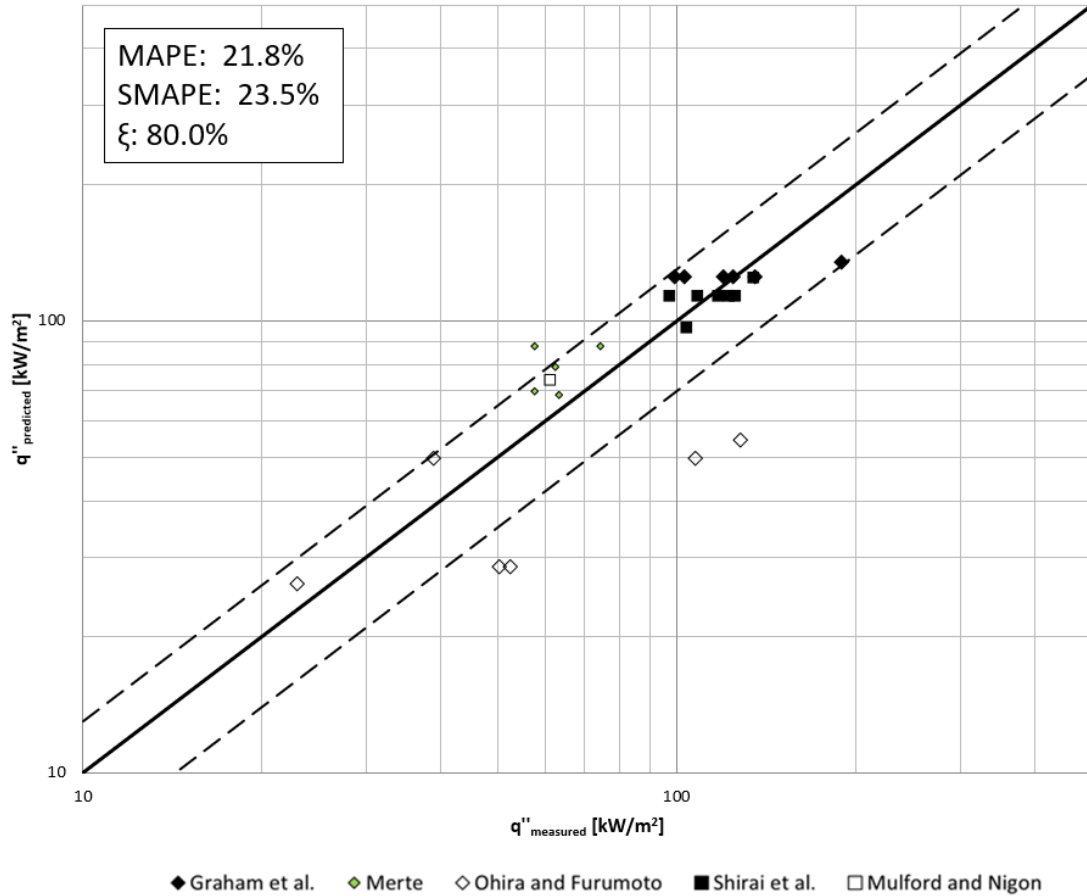
State of available CHF data for O₂ [2-3]



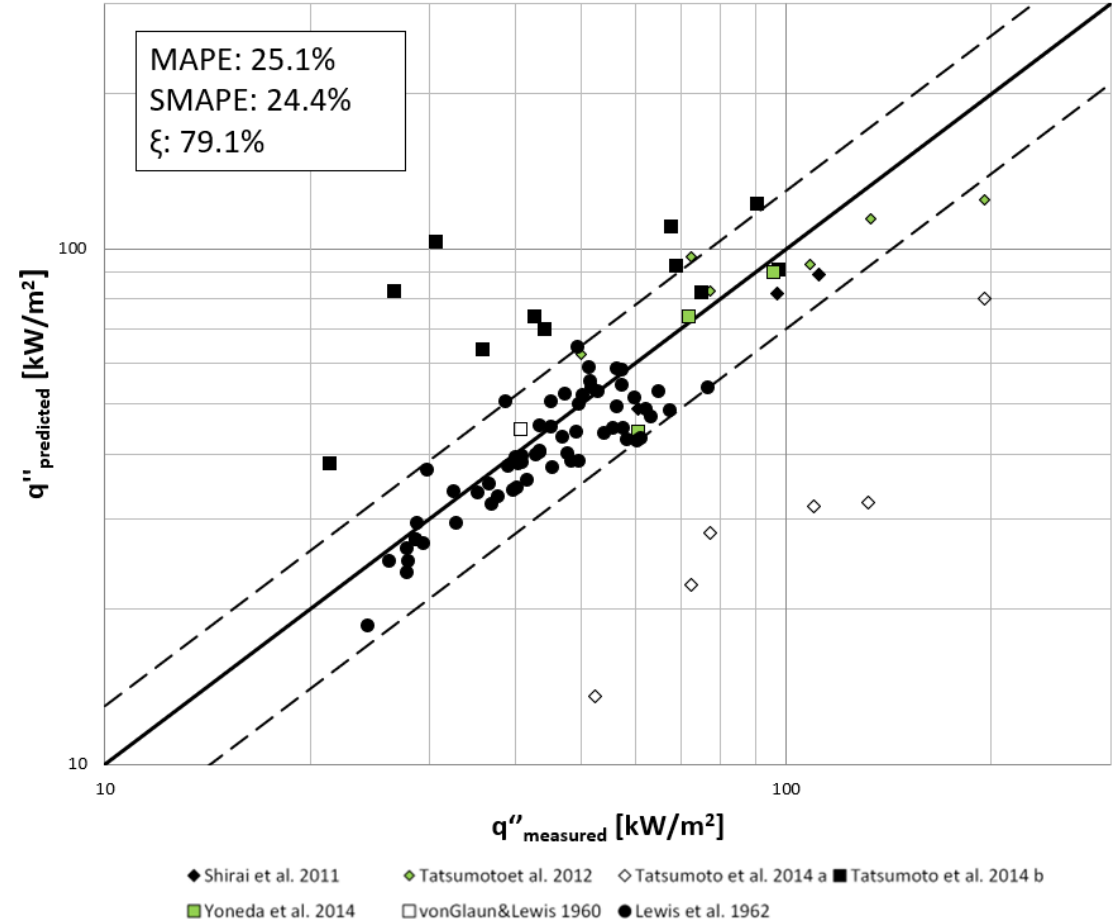
Correlations Considered

- Zuber (1961) or Kutateladze (1952)- seemingly identically derived correlations
- Lurie and Noyes (1964)
- Sun and Lienhard (1970)
- Kandlikar (2001)
- Von Glaun and Lewis (1960)- water and cryo data
- Katto and Ohno (1984)- R-12 data
- Shah (1987)- many fluids
- Mudawar and Maddox (1990)- FC-72 data
- Katto (1992)
- Hall and Mudawar (2000)- water data

Hydrogen CHF Recommendations

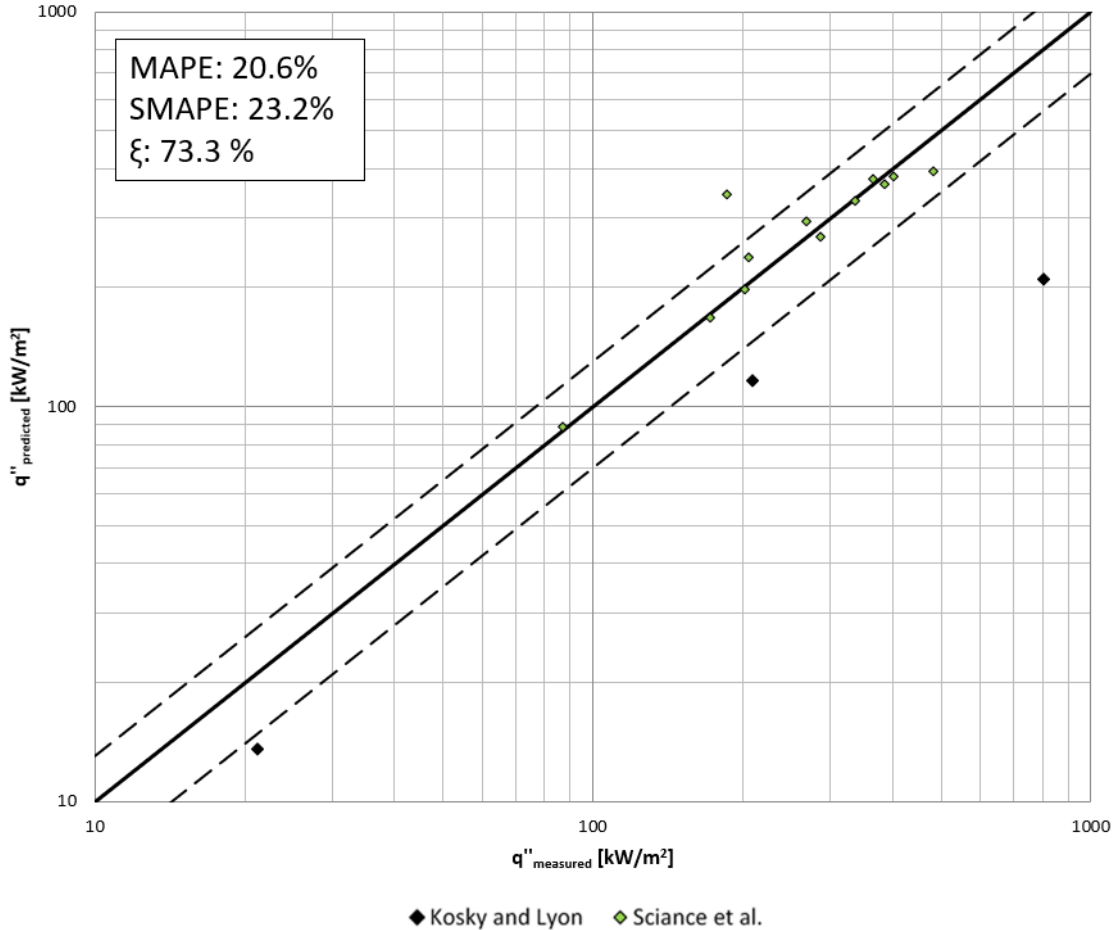
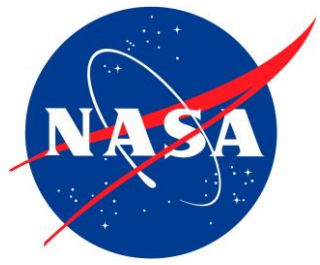


Pool Boiling: Sun and Reinhard (1970)

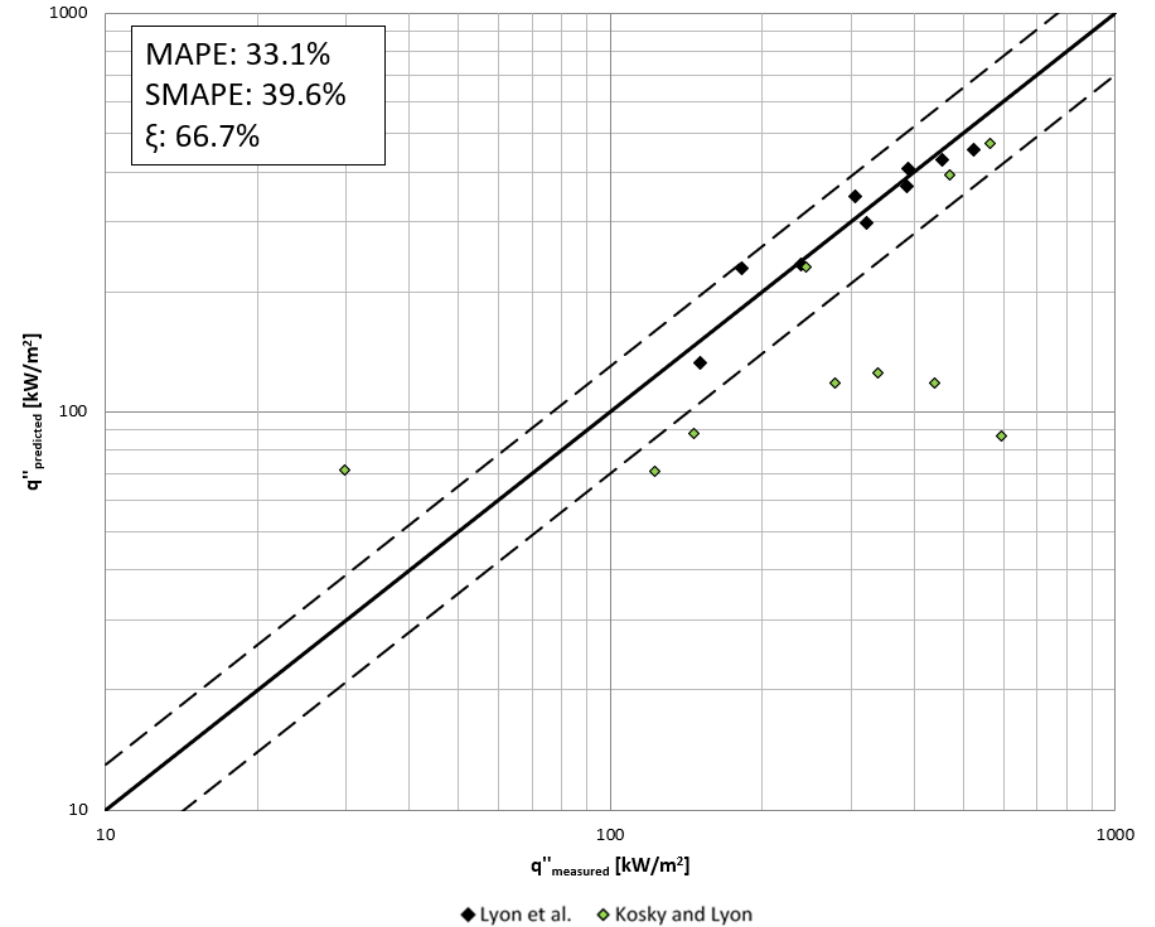


Flow Boiling: Katto and Ohno (1984)

Methane and Oxygen Pool CHF Recommendations

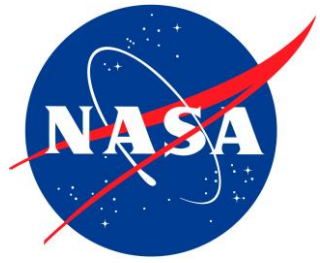


Methane: Lurie and Noyes (1964)



Oxygen: Sun and Lienhard (1970)

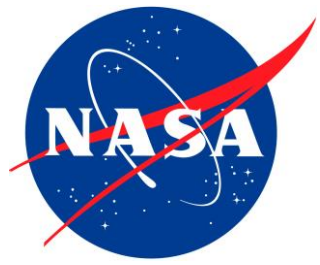
Methane and Oxygen Flow CHF Recommendations



(This chart was intentionally left blank)

Ongoing/Future Work

- Continuing to collect quality datasets (primarily flow CH_4 and O_2)
 - Ones we missed, e.g. Glickstein and Whitesides (1967) methane
 - Future data sets
- Please let us know if you are aware of any data sets we missed
 - Michael.r.Baldwin@nasa.gov
- A flow boiling O_2 experiment to capture pre-CHF HTC, post-CHF HTC, CHF data, and two-phase pressure drop data has been discussed and proposed as future work to be conducted at NASA MSFC or NASA GRC



References

- [1] Sherley, Joan E. "Nucleate boiling heat-transfer data for liquid hydrogen at standard and zero gravity." *Advances in Cryogenic Engineering: Proceedings of the 1962 Cryogenic Engineering Conference University of California Los Angeles, California August 14–16, 1962*. Springer US, 1963.
- [2] Baldwin, Michael, et al. "Pool boiling in liquid hydrogen, liquid methane and liquid oxygen: A review of available data and predictive tools." *Cryogenics* 115 (2021): 103240.
- [3] Baldwin, Michael, et al. "Flow boiling in liquid hydrogen, liquid methane and liquid oxygen: A review of available data and predictive tools." *Cryogenics* 116 (2021): 103298.