

Phase Change
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**Strategic Research to Enable NASA's
Exploration Missions**

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Phase Change Processes in Space Systems

- Recent workshops to define **strategic research** on critical issues in microgravity fluids and transport phenomena in support of **mission orientated needs** of NASA and many technical conferences over the years in support of **fundamental research** targeting NASA's long range missions goal have identified several phase change processes needed to design advanced space and planetary based systems for long duration operations
- Recommendation noted that phase change processes are profoundly affected by gravitational environment

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Space Systems Requiring Phase Change Processes

- Closed loop life support systems: Humidity control, drying, wastewater processing
- Thermal management: Heat rejection systems (heat pipes, radiators) for power generating units, habitats, vehicles
- Power generation using Rankine cycle
- Thermal energy storage, transient thermal management using phase change materials
- In space depot: Storage, acquisition and transport of cryogenic fluid in space
- In situ production, liquefaction and storage of cryogenic fluids (life support, propellants)

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Phase change processes affected by gravitational environment

- **Boiling:** Pool and flow boiling in geometrical configurations and surfaces of practical applications, flow boiling in conduits from inception to post dry-out conditions, boiling in porous media and from prepared surfaces
- **Condensation:** Drop wise and film condensation on surfaces, conduits, porous media, screened surface, membranes; direct contact condensation on subcooled droplets and agitated interface

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Phase change processes affected by gravitational environment

- **Evaporation:** Evaporation from plane and screened surfaces, porous media, at solid-liquid-vapor contact line with and without forced flow
- **Melting and solidification:** Void formation, void location, growth and migration of void bubble as function of material properties, thermal conditions and geometric configurations

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State of Knowledge of Phase Change Processes in Microgravity

- Presentations by leading experts in the afternoon sessions will provide most current state of information on respective topics
- Visual and quantitative data from numerous experiments on pool boiling in short and long durations reduced and microgravity environments. Findings are often contradictory. Useful information but it could not be compiled into a form useful for design purposes.

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State of Knowledge of Phase Change Processes in Microgravity

- Limited number of flow boiling experiments in short duration microgravity. High velocity results are insensitive to microgravity. Need to define quantitative criteria for high and low velocities. Need to describe flow boiling independent of pool boiling in microgravity.
- A good number of short duration two phase flow experiments to identify and characterize flow regimes and experiments involving liquid vapor interface configurations
- Number of short and long durations experiments with systems utilizing phase change processes (mostly with heat pipes) some fluid mixing and interface condensation

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Strategic Research on Phase Change Processes

- Phase change heat and mass transfer processes are very efficient but complicated. Except for a few idealized cases they cannot be solved from first principles. Resolution of critical issues associated to these phenomena through comprehensive understanding has been the goal of fundamental research supported by OBPR. This goal may or may not be realized in time to support NASA's current mission plans.
- Phase change processes are highly gravity dependent but we must make use of these efficient processes to design essential subsystems, such as evaporators, condensers for Advanced Closed Loop Life Support Systems, thermal management and power generation systems.

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Strategic Research on Phase Change Processes

- Performance and operation of these units may be significantly affected by the microgravity and partial gravity environments if these units are not designed, either to be gravity insensitive or the effects of gravity on processes are accounted for through appropriate scaling parameters and validated design equations

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Useful Design Specific Information

- **Pool boiling:** Analytical description of pool boiling in microgravity, prediction of critical heat fluxes if they exist, liquid superheat excursion (on-orbit start up failure of cpl due to high liquid superheat), boiling in the presence of vapor or gas bubble.
- **Flow boiling:** Saturated/subcooled flow boiling in single and multiple channels, with and without porous wicking materials for fluid properties encompassing range of cryogenic to liquid metals to quantify:
 - Inception of boiling
 - Critical heat fluxes and the wall superheats at critical conditions
 - Boiling heat transfer coefficients (Flow regime specific)
 - Minimum flow velocity needed to sustain the boiling process
 - Effect of dissolved gas

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Useful Design Specific Information

- **Condensation:** Condensation on hydrophobic and hydrophilic surfaces, condensation on porous media and propagation of condensation front, steady and transient direct contact condensation including the effects of non-condensable, stability of condensation in multiple channels
- **Evaporation:** Evaporation from screened surface, porous media; from interface due to sudden depressurization
- Phase change materials for thermal management: Melting and solidification, void formation, growth and departure in confined geometry in microgravity

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Strategic Research Questions on Phase Change Processes

- Can we develop design equations or compile information into system specific design guides valid for a limited range of operating parameters of practical applications in time to support NASA's current mission plans even though the necessary fundamentals are not understood to a desired level?
- Can we design systems utilizing phase change processes from existing body of knowledge based on normal gravity experience and limited microgravity data in a way such that their performance in microgravity will remain unaffected or if affected it can be described by appropriate scaling parameters, equations?



Strategic Research Questions on Phase Change Processes

- Can we make use of unique geometrical configuration that eliminates gravity dependence and makes effective utilization of capillary and inertia forces?
- Can we establish limiting design criteria ?
- How can we conclusively verify the gravity insensitivity and certify performance in microgravity without experimental validation in microgravity?

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Strategic Research Questions on Phase Change Processes

- If flight experiment is a must how can we optimized the need for microgravity data?
- Do we need to develop experiment protocol (e.g. well defined procedure for surface preparation for boiling experiment) to obtain much needed data?
- Multi-scale, multi-dimensional numerical models for multiphase systems make use of mechanistic models for CHF, boiling inception, dry-out conditions, interface transfer etc. If microgravity data is needed should we follow a well defined experiment protocol?

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