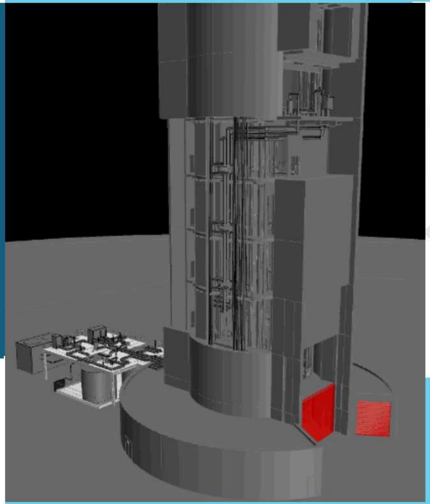
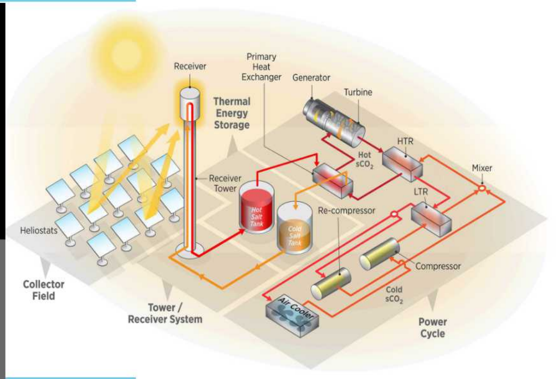
SAND2019-14574C

Design Basis for a 2.0MWth Liquid-HTF Pilot-Scale CSP System





Kenneth M. Armijo, Matthew Carlson, Dwight Dorsey, Joshua Christian, Joe Coventry, Robbie McNaughton & Craig Turchi

Sandia National Laboratories, Albuquerque, NM

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SAND2019-XXXXX

Agenda

Objectives

- Development of a scalable 2.0MWth CSP system using a ternary chloride salt/sodium, with operational temperatures so ~740℃.
- Characterization of a high-temperature molten salt receiver system that can operate efficiently for reliable operation.

Overview

- Gen 3 Liquid-Pathway Program
- Molten Salt Technology-Approach
- System Design
- System Analysis Results

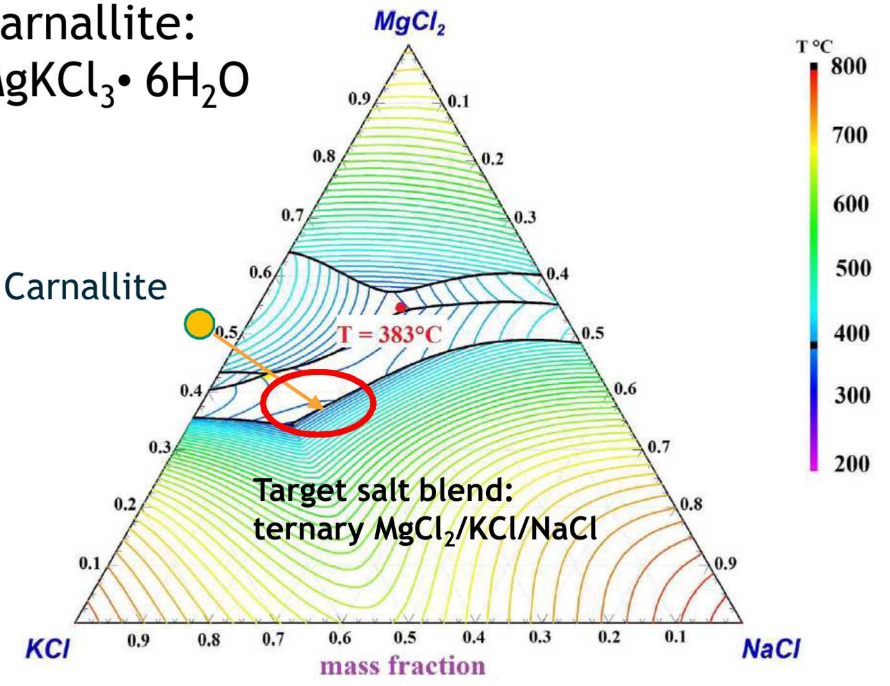
Conclusions & Future work

Transition to Gen 3 CSP Systems

- The limit of traditional solar-salt thermal stability is around 600 °C with ambient air as the cover gas.
- Nitrate molten salt concentrating solar power (CSP) systems are currently deployed globally and are considered to be state-of the art heat transfer fluids (HTFs)
- To fully realize SunShot efficiency goals of $15/kWhth HTFs and an LCOE of 6¢/kWh, molten-salt technologies working at higher temperatures (e.g., 650 °C to 750 °C) will be required as an alternative salt chemistry composition.

Parameter	Solar Salt (Gen2)	Chloride Salt*	Sodium
Mass composition	60% $NaNO_3$ 40% KNO_3	Ternary $MgCl_2$-KCl-NaCl blend	100% Na
Solidification Temp (°C)	238	426	98
Stability Limit (°C)	600	>1418	882
Density (kg/m³)	1770 @ 500°C	1590 @ 700°C	835 @ 700°C
Specific Heat (J/g-K)	1.53 @ 500°C	1.1 @ 700°C	1.26 @ 700°C
Viscosity (cP)	1.30 @ 500°C	1.4 @ 700°C	0.24 @ 700°C
Thermal Cond (W/m-K)	0.54 @ 500°C	0.4 @ 700°C	64.2 @ 700°C

Carnallite: $MgKCl_3 \cdot 6H_2O$



[Mohan et al., Energy Conversion and Management 167 (2018).

Gen3 Liquid Pathway

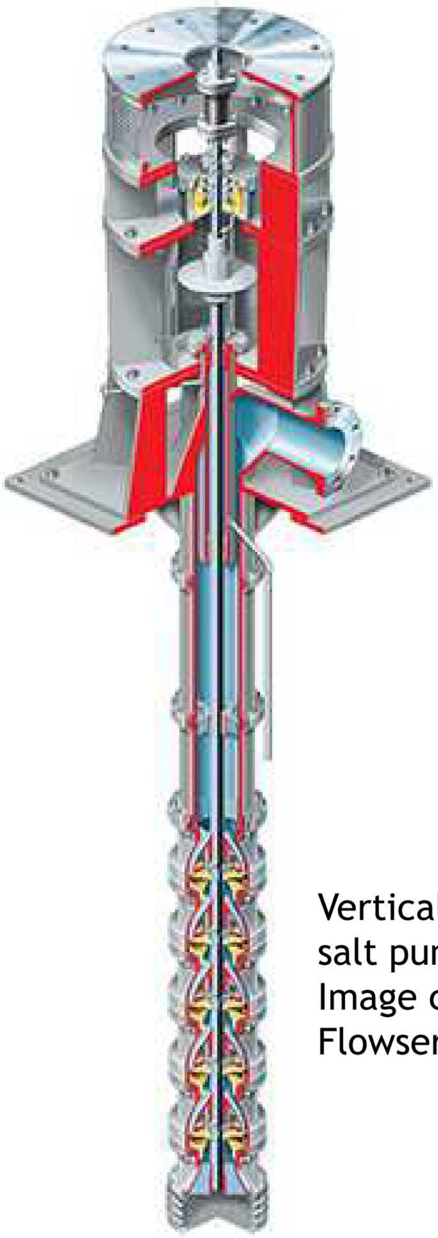
- Leverage expertise with liquid-HTF towers
- Examine two, alternative high-temp liquids
- Use low-cost, thermally stable energy storage media
- Design for sCO_2 Brayton-cycle integration

Vast Solar Jemalong
Sodium-HTF pilot facility (Australia)

SolarReserve Crescent Dunes
Molten-salt HTF plant (USA)

Gen 3 Liquid-Pathway System

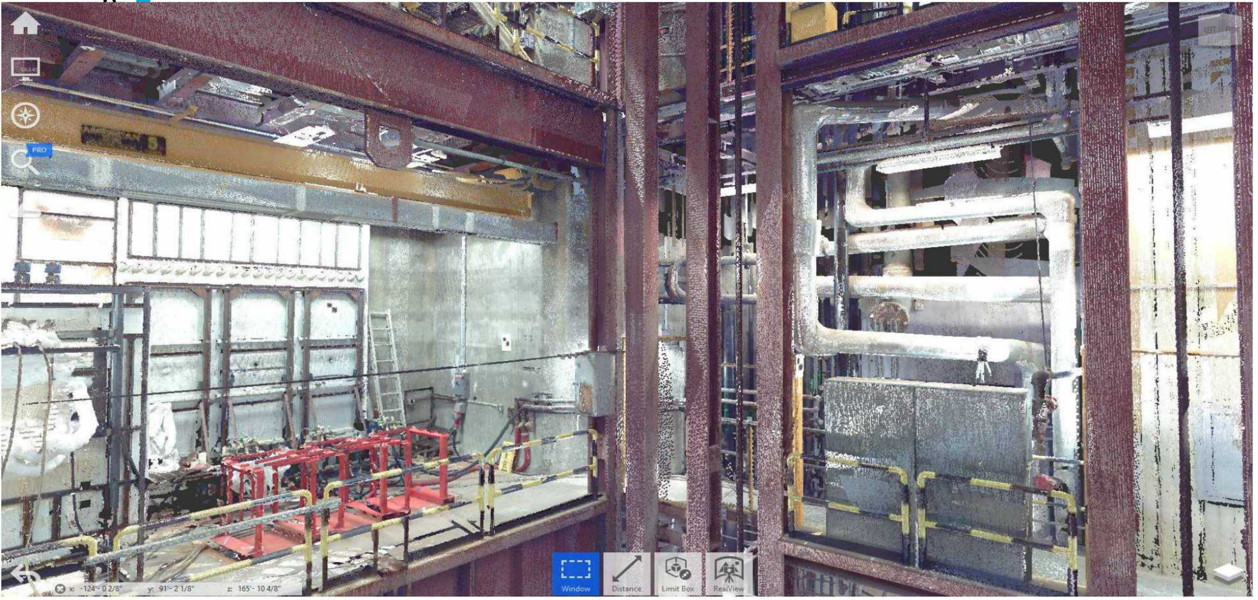
- 2.0MWth Pilot-scale CSP plant design is developed to assess thermodynamic performance potential for operation up to 720 ℃.
- Molten salt system HTF/TES with sCO_2 power block.
- 6 hours of TES with charging/discharging cycles over 2 days.
- Established approaches for piping, pump, valve, and heat exchanger design (including the receiver).
- High energy and exergy efficiency of storage (direct TES)
  - Flexible dispatch because solar collection and power generation are decoupled.
- Recognized and accepted by industry and financiers.



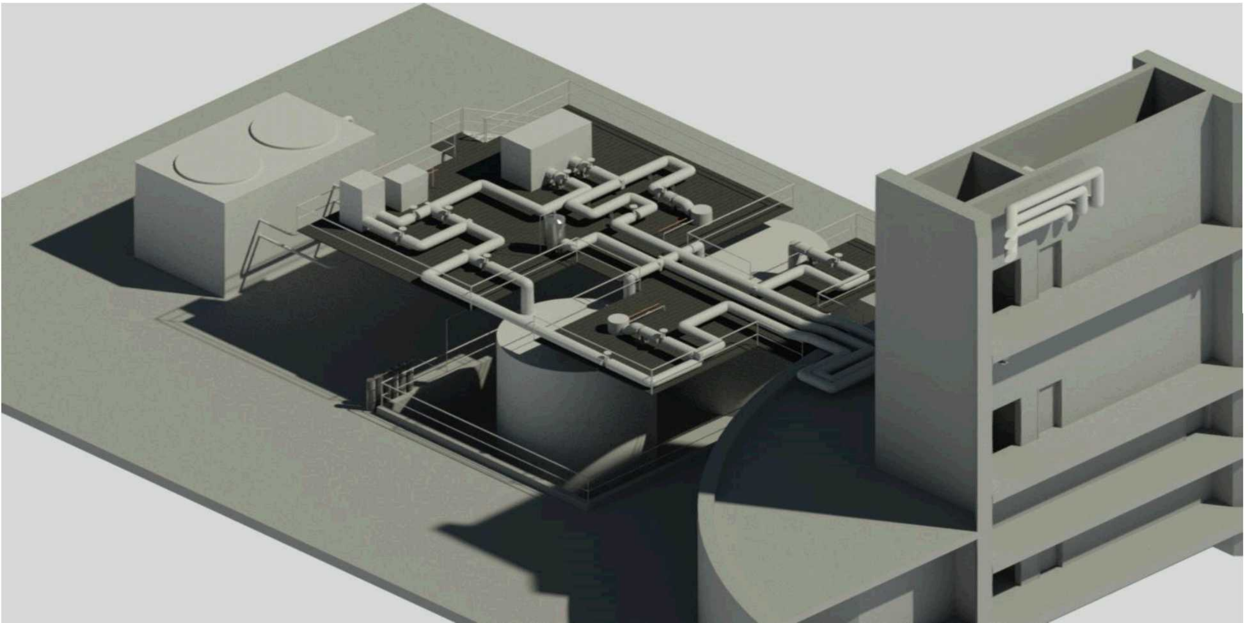
Vertical turbine salt pump. Image courtesy Flowserve.

Need robust, high-temperature molten salt system capable of achieving temperatures above 720℃ to achieve DOE 2020 SunShot Targets.

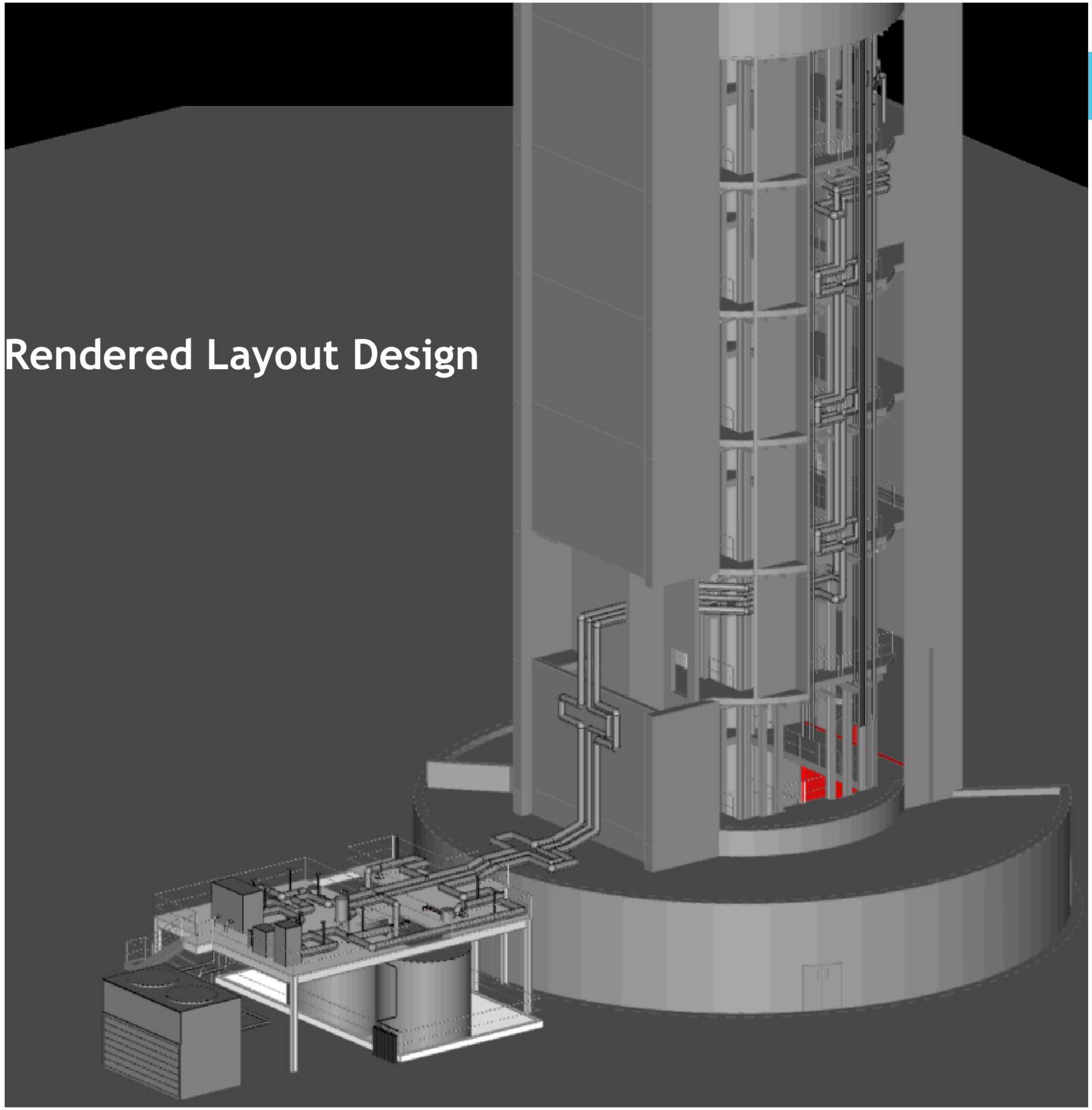
220 ft Point Cloud Tower Level

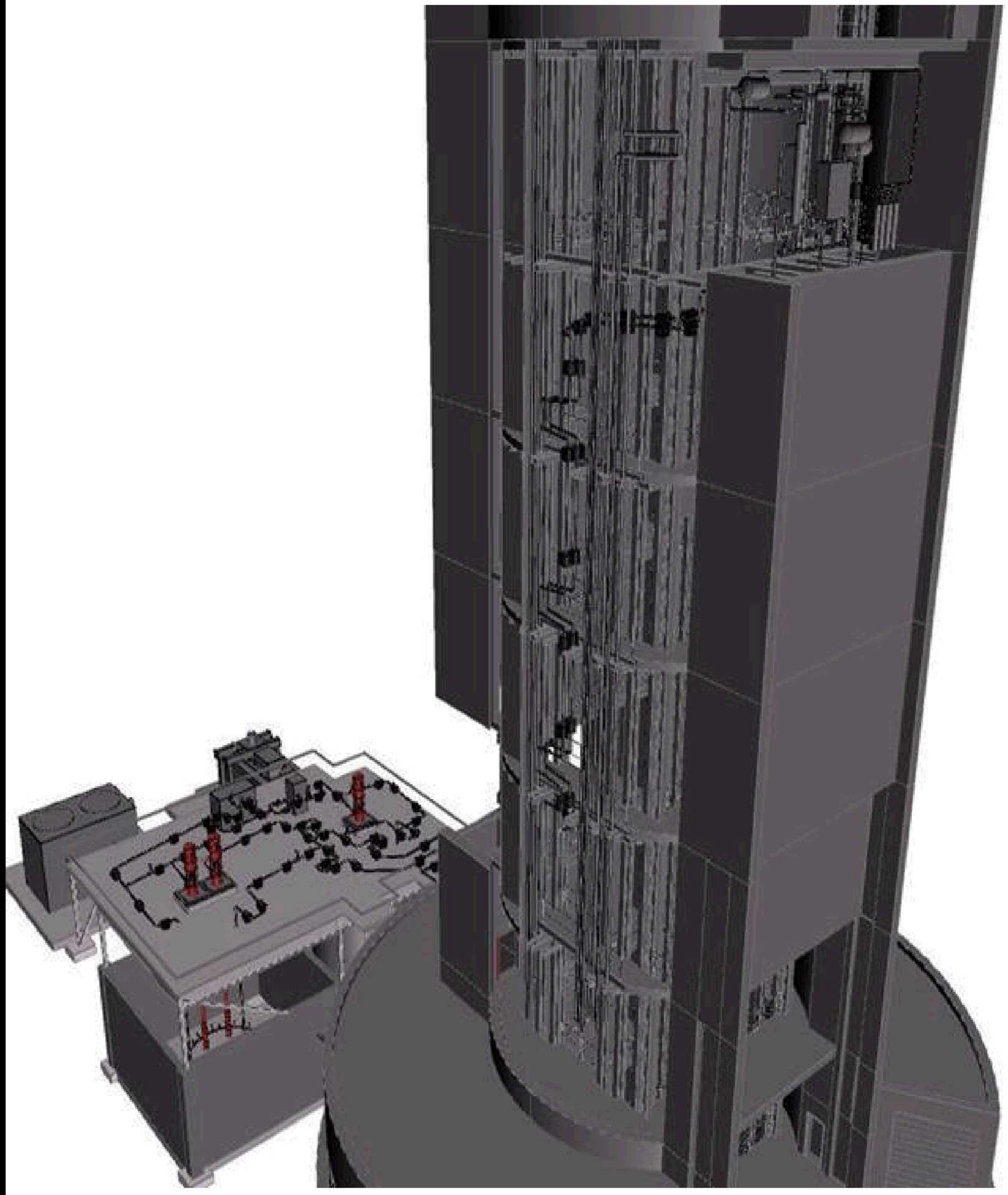


Rendered Revit 3D Model



Rendered Layout Design





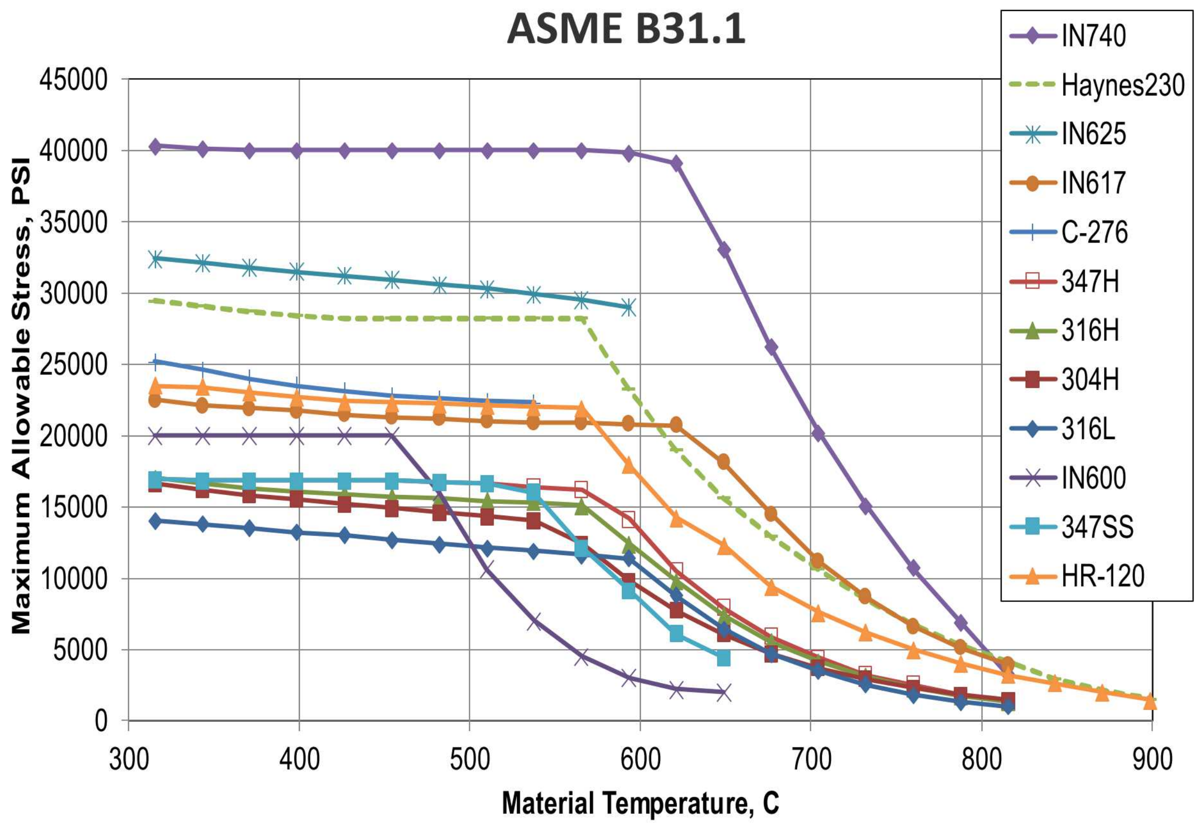
Design Considerations - Materials Selection

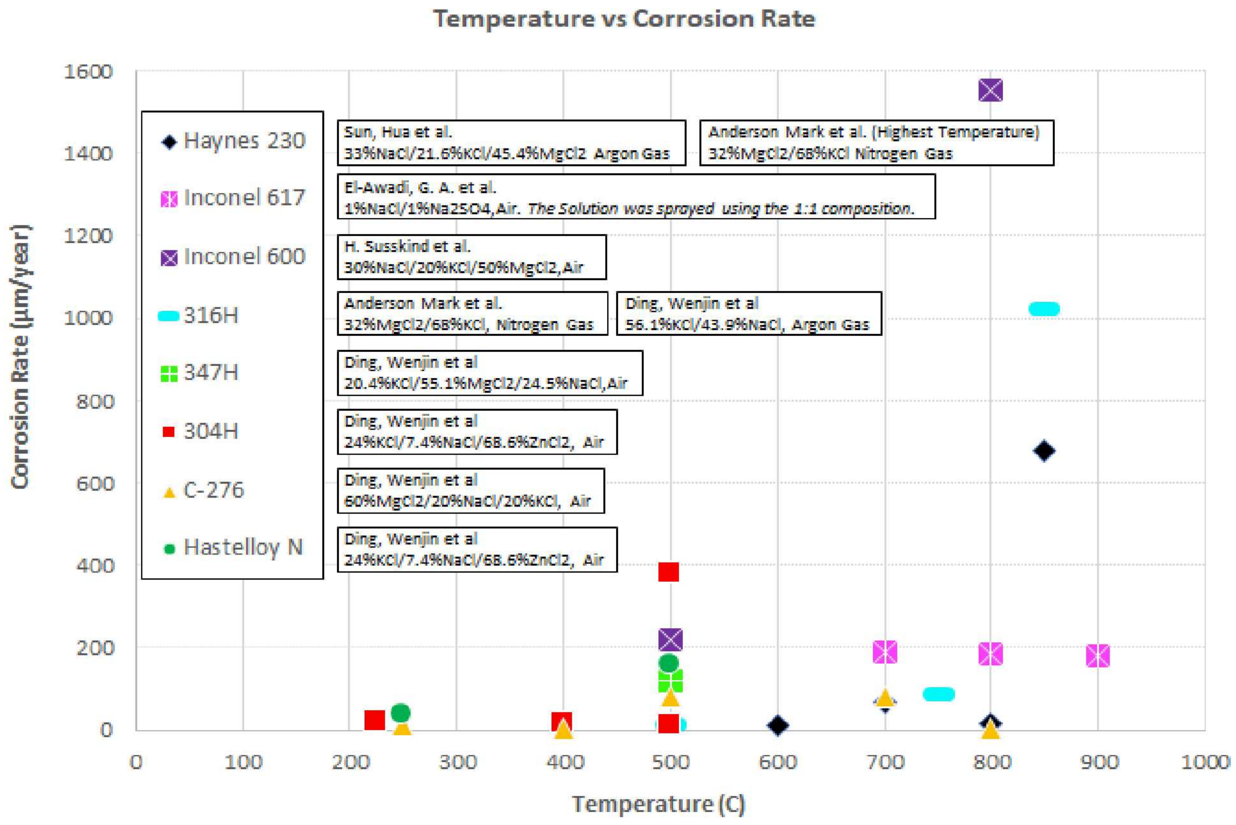
- Piping and component material selection based on project alloy selection critieria.
- Recommended alloys satisfy specifications for corrosion, cost, mechanical strength and joinability for salt-wetted components.
- The target hot piping design fluid state is 750°C and 73 psi, and the cold piping design fluid state is 500°C and 160 psi.

Metric	Success Value	Assessment Tool	Metric Justification
Corrosion rate	< 15 um/year	Corrosion rate defined in electrochemical or immersion tests in the defined salt composition and relevant temperature.	DOE target for system corrosion based on SunShot assumption for plant life.
Cost/strength at target use conditions	Alloy(s) recommended for each wetted part that minimize component and system cost of the life of the plant	Parametric study with System Model(s) developed under Task 10.	Alloy selection affects CAPEX, OPEX, and system life. A full system model is needed to assess the long-term impacts of different material selections. Performance based on laboratory testing; material costs estimated from vendors.
Weld strength and corrosion resistance	No worse than native alloy	Corrosion rate defined in electrochemical or immersion tests in the defined salt composition and relevant temperature.	DOE target for system corrosion based on SunShot assumption for plant life. Note that no testing is funded under this project; data most be referenced from other work.

Materials Selection

- Allowable stress values for seamless piping for each candidate from ASME code as function of temperature.
- Most data exist for SS, C-276 and Haynes 230. No corrosion found for Inc. 617 or 740H in MgCl2 salt.
- Recommended that plant be constructed of C-276 on cold side and H230 on hot side.

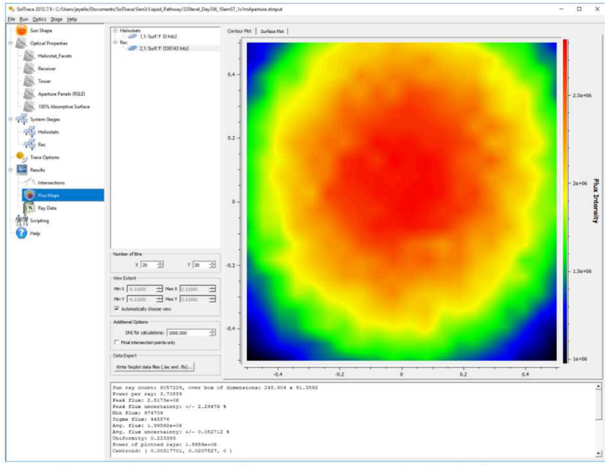




Design Considerations - Component Selection

Salt Receiver:

- Absorbed thermal energy = 2 MWth.
- 30 psig pressure drop.
- Freeze-protection and recovery design provisions.
- SolTrace studies for day 172 @10AM (conservative)
  - Single Aim Point
  - Multiple Aim Points

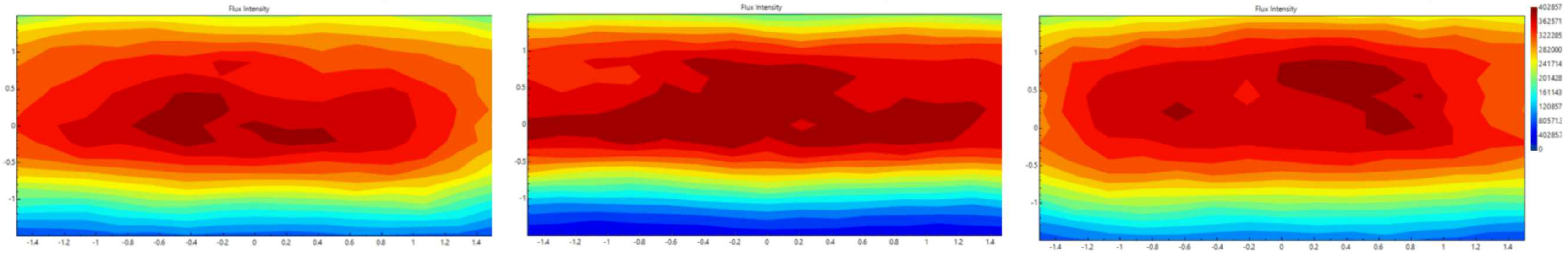


Peak irradiance = 2810 suns
Power = 2.0 MW

-3 Hours Before Solar Noon
4.25m x 1.3m Heliostat Spread

Solar Noon
5.5m x 1.1m Heliostat Spread

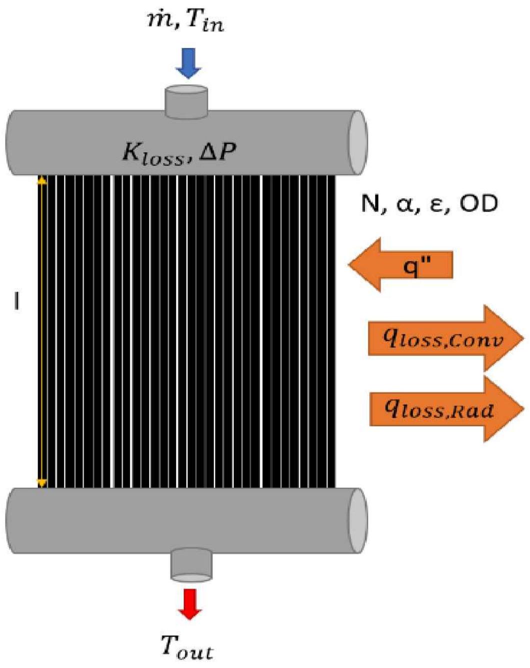
+3 Hours After Solar Noon
4.25m x 1.3m Heliostat Spread



Receiver Flux Distributions on Day 172, 212 heliostats

Receiver Model

- Parametric analysis was performed for a simple tubular receiver with a single-pass design.
- Required receiver flux and efficiencies calculated for ~2.56 m^2 aperture area
- Performed with the NSTTF heliostat field and the 120 ft. test section of the solar tower.
- Model developed with 40 single-pass tubes that were 0.5 NPS Sch. 10, constructed of an H230 material.
- Assessment performed to compare receiver performance between multiple HTFs with operation up to 735 ℃.
- Receiver model considers a panel with N number of tubes to allow a mass flow rate and a pressure drop. Also considers uniform heat flux, uniform flow through the tubes with grey properties approximated for the tubes.



$$Q_c = \frac{2\pi L k}{\ln(OD/ID)}\left(T_{s,OD} - T_{s,ID}\right)$$

$$q_{loss} = h_\infty\left(T_{s,OD} - T_\infty\right) + \varepsilon\sigma\left(T_{s,OD}^4 - T_\infty^4\right)$$

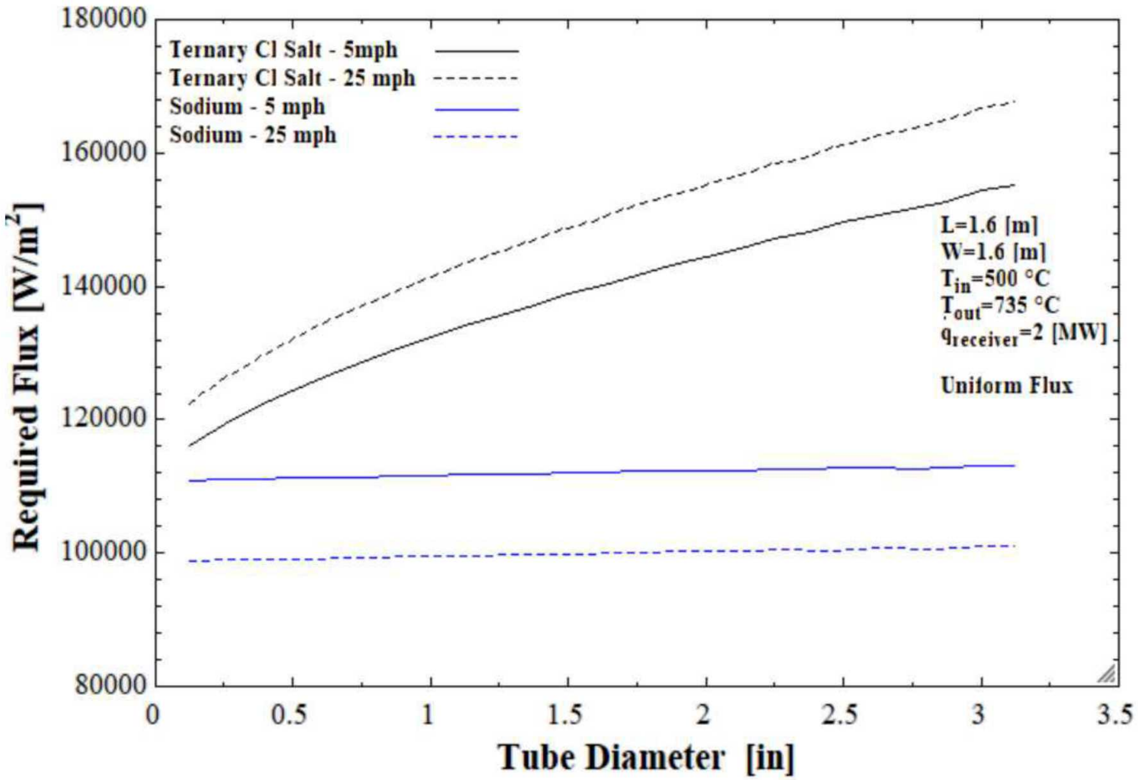
$$q_{abs,tube} = \frac{\alpha q_{in}}{N}$$

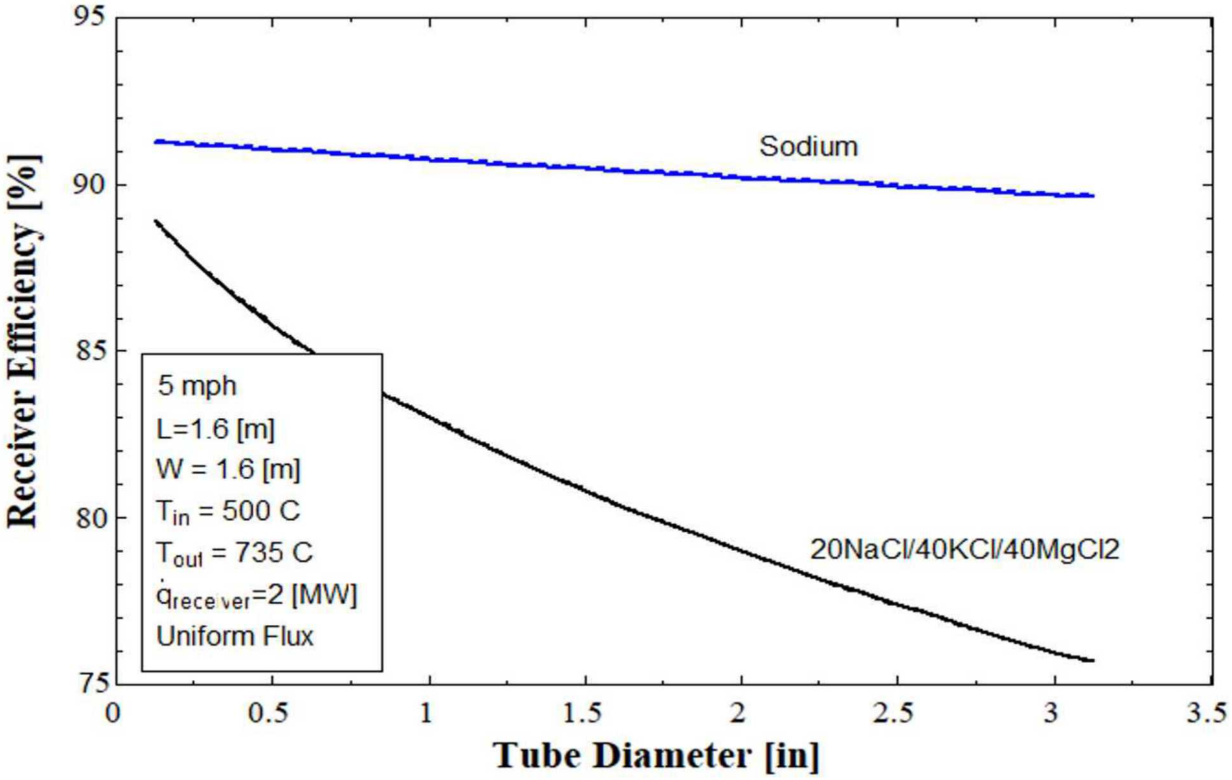
$$\Delta P = \left(f\frac{L}{ID} - \sum K\right)\frac{\rho U^2}{2}$$

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\epsilon/ID}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Receiver Results

- Results indicate that as the peak flux of the receiver increases for a uniform flux distribution and tube geometry, receiver efficiency sensitivity due to wind also increases.
- Ternary chloride salt not only had the highest overall required flux values, but it had a much larger increase in required flux between 0.125in OD and 3.125in OD.
- Liquid sodium requires a much lower flux to heat to the desired temperature, regardless of wind speed and tube diameter.
- Receiver efficiency was found to be overall higher for sodium over the ternary chloride salt by an average of 10.1% more than the ternary chloride salt, possibly due to higher k_{cond}.

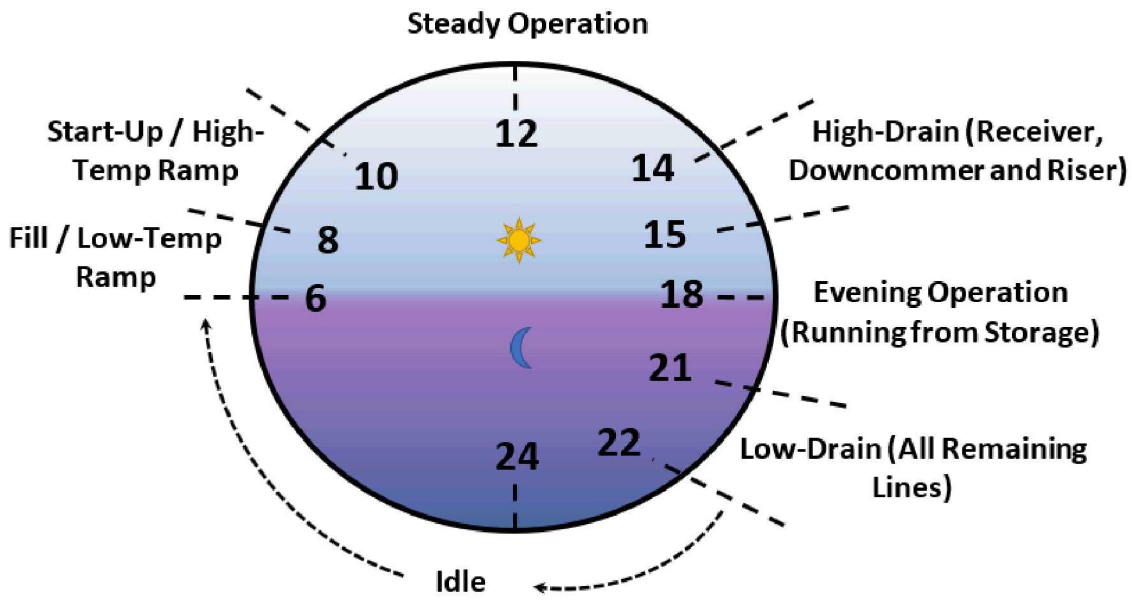




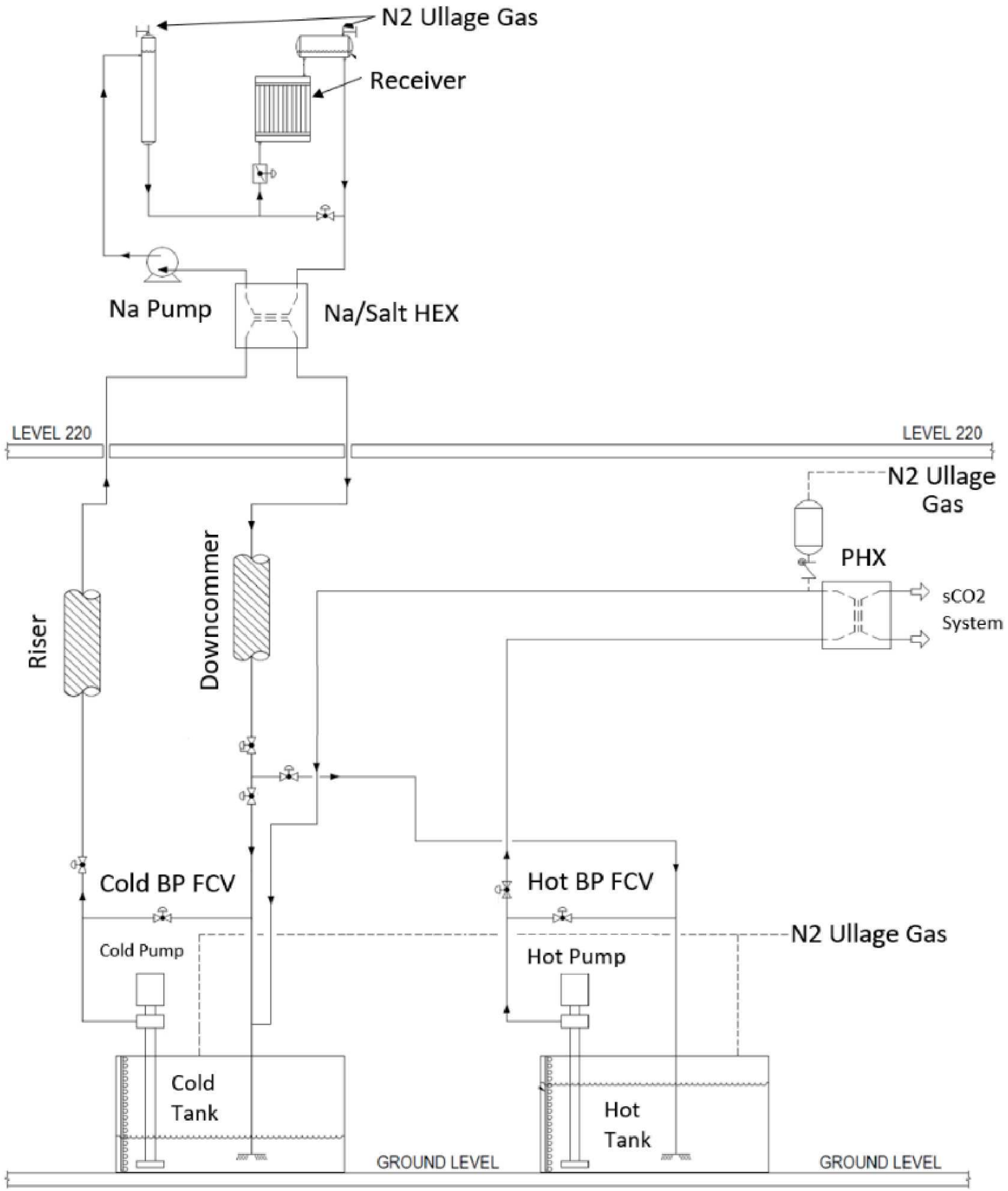
Gen 3 Liquid-Pathway Operation

Charging Operational Modes. Pilot-system operational modes consist of:

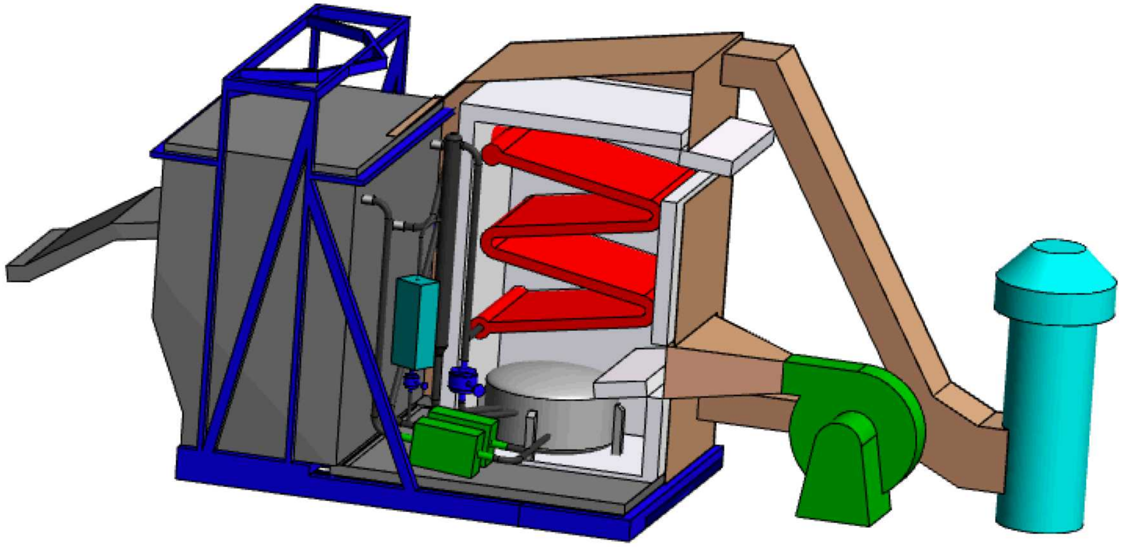
1. Fill of the riser, downcommer and receiver with low-temperature ramp-up.
2. Start-up and high-temperature ramp-up of systems and components.
3. Attemporation of Primary Heat Exchanger (PHX).
4. Steady operation.
5. Drain-down of system high-level lines and receiver.
6. Drain of all lower-level system lines.
7. Idle operation of cold tank and remaining wet components.

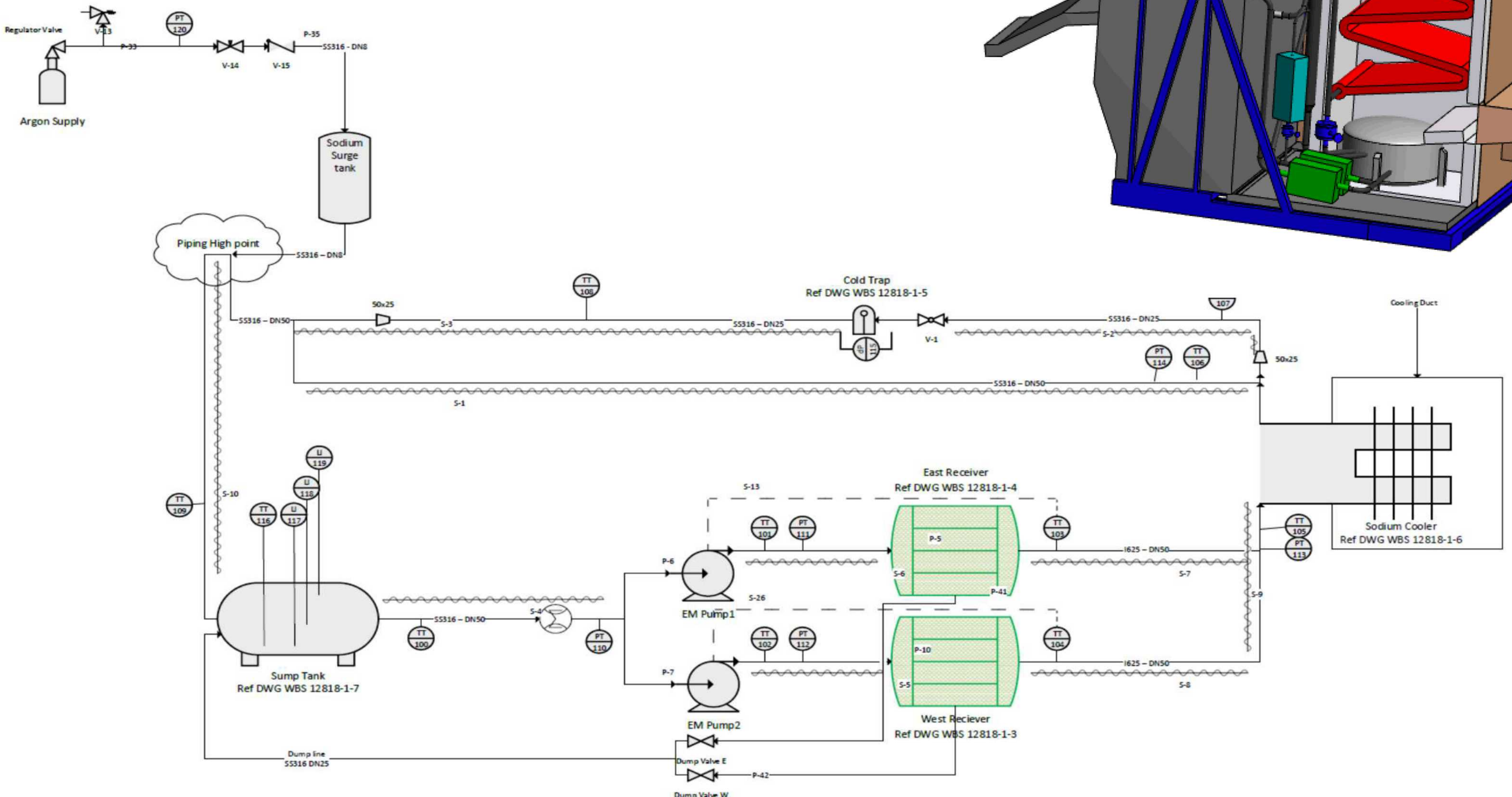


Gen 3 Sodium/Salt System



Sodium System Design - CSIRO





Conclusions & Future Work

- A system layout for a 2-MWth sodium/chloride molten-salt test loop is presented, including a thermodynamic system model developed using EES to model operational states during various operational modes.
- A ternary chloride molten salt chemistry was compared to a sodium HTF with respect to required flux and efficiencies to achieve system design criteria including cold and hot tank temperatures of 500℃ and 720℃.
- Receiver efficiency was found to be overall higher for sodium over the ternary chloride salt by an average of 10.1% more than the ternary chloride salt, possibly due to higher k_{cond}.
- Materials down-selection was made for SS316 Sodium, H230 (Salt Hot-Side) and C-276 (Salt Cold-Side).
- The results suggest a minimum Cv of 60 required for both cold and hot throttle recirculation valves for the operational pump speeds between 1800 and 2400 RPM.
- Future studies will include receiver flux distributions and transient operational modes.
- Future receiver model development will later consider accepting SolTrace incident beam information from the SNL NSTTF Heliostat field with transient contributions and flux distributions in two dimensions.

Acknowledgements

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kmarmij@sandia.gov

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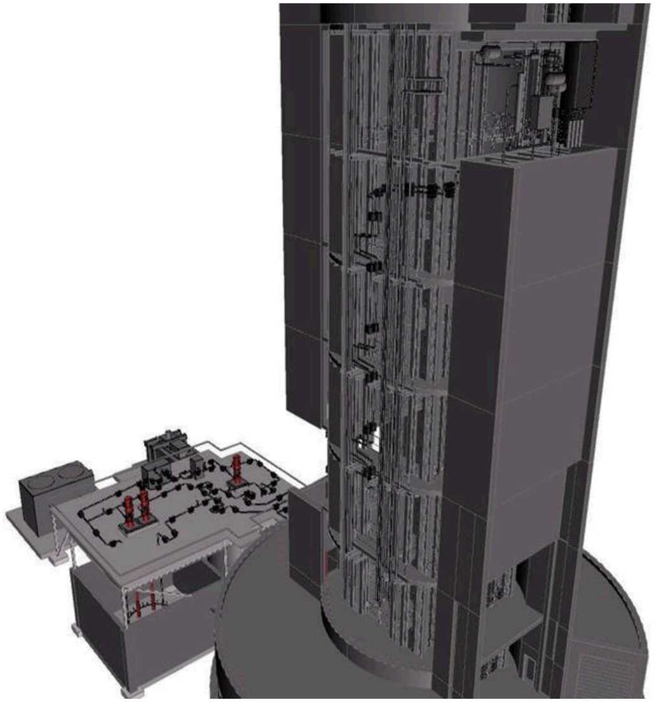

Thank you.