Sodium receivers

DOE Virtual receiver and reactor workshop

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February 15, 2024

Australian National University

ASTRI
Australian Solar Thermal Research Institute

Gratefully acknowledging that this work was carried out under the Australian Solar Thermal Research Institute (ASTRI) program, supported by the Australian Government through the Australian Renewable Energy Agency (ARENA)

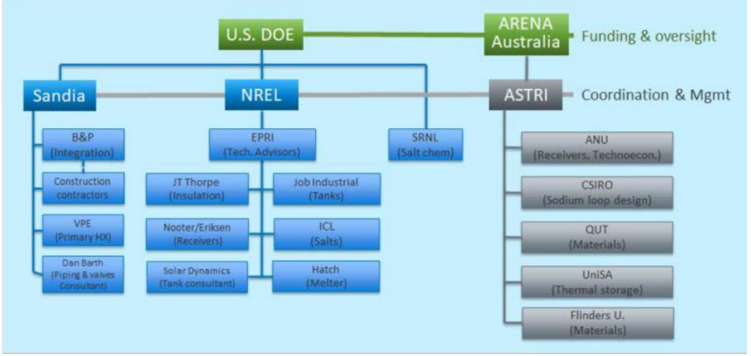
Content

Gen3 CSP – sodium receivers design for 700°C power cycles (Joe Coventry)

- Conceptual design of a full-scale cylindrical sodium receiver for the CSP Gen3 Liquids Pathway project
- Design and construction of the ASTRI 700kWth receiver

Vast Energy – experience ramping up for commercial deployment of sodium receivers (Kurt Drewes)

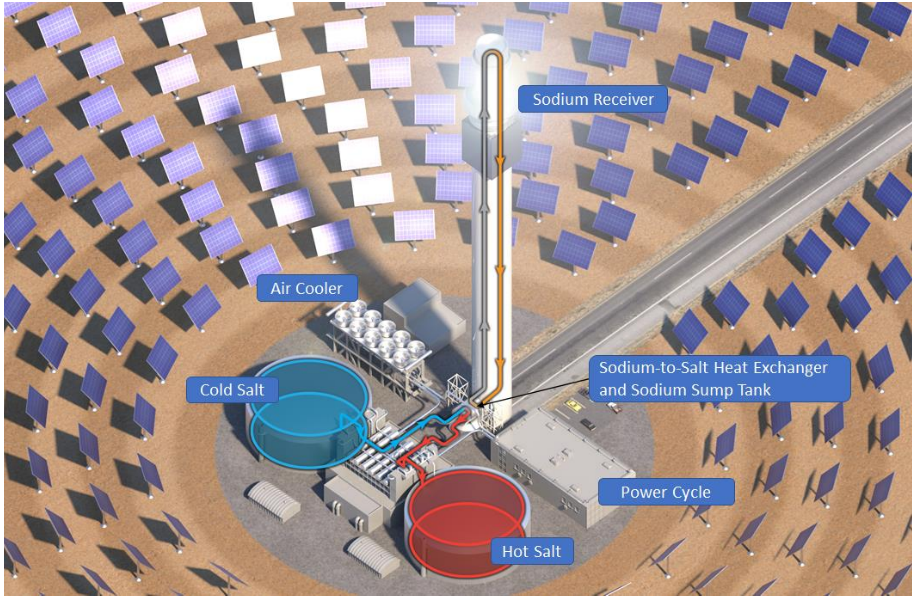
- Lessons learned



Gen3 Liquid Pathway team (left) and final report (right)

Gen3 CSP Liquids Pathway system configuration

- Proposed Gen3 design incorporated:
  - Sodium receiver operating at 740°C
  - Liquid-liquid heat exchanger
  - Two-tank molten-chloride salt storage system (540-720°C)
  - sCO2 power cycle at 700°C
- Why sodium in the receiver not chloride salt?
  - Lower LCOE (11.4%)
  - Significant benefits due to sodium's superior thermophysical properties versus the chloride salt
    - Lower melting point (98°C vs. 400°C)
    - Lower volume change on freezing/melting (3% vs. ~20%)
    - Lower viscosity (~10x lower)
    - Greater thermal conductivity (64 vs. 0.4 W/m-K).
  - Only slightly higher risk



Sodium/Salt Gen3 system showing on-sun charging of the salt storage system. Scale is 50 Mwe.

Sodium in industry

Sodium is a commodity

- Sodium production and consumption is well over 100,000 tonnes/year, mainly in China
- Chemical uses
  - A substantial amount is used in sodium alkyl sulfates as the principal ingredient in synthetic detergents
  - Manufacture of indigo dyes, for dyeing cotton along with manufacturing denim
  - Deoxidant and reducing agent for producing Ca, Zr, Ti and other transition metals
- Largest producers are Nippon Soda, Lantai, Wanji, Yinchuan, Tiantai, and MSSA

Sodium in nuclear

- Since the 1950s RD&D in power generation has been linked to funding for Fast Breeder Reactor (FBR) programs
- Today sodium-cooled FBRs operate in Russia, India and China
- Overall, there are over 400 years cumulative operation of sodium-cooled FBRs in plants at scales of 10s to 100s of MWe
- Sodium is a safe heat transfer fluid to use when handled properly

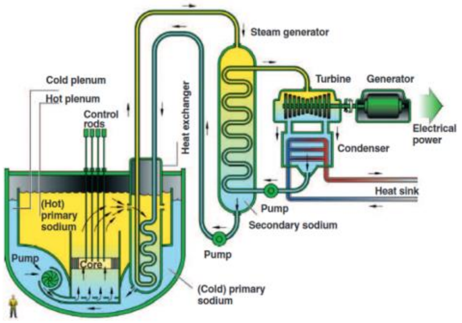
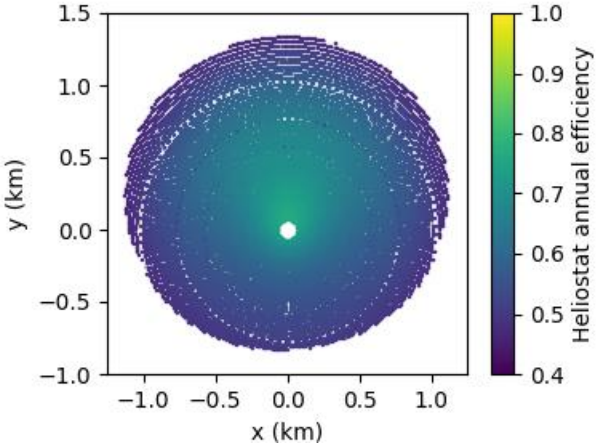
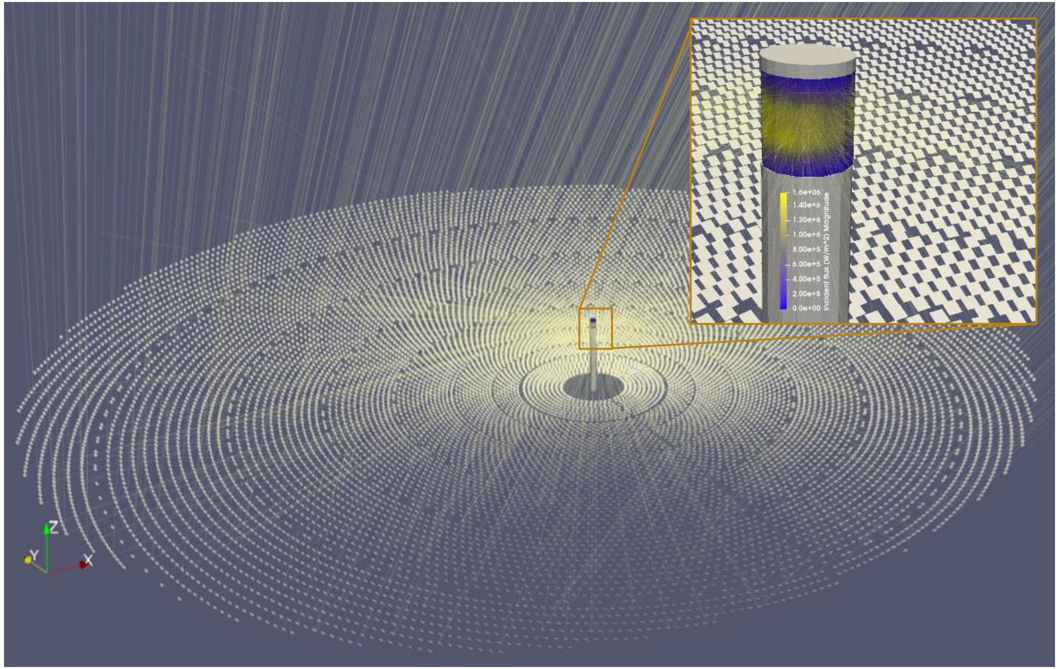


Image: CEA

Commercial sodium receiver

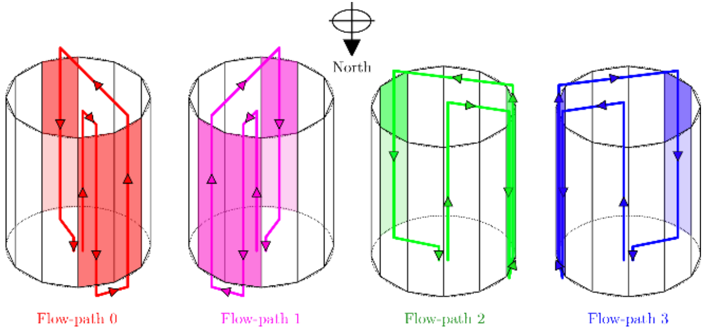
- **"Conventional" cylindrical sodium receiver concept, similar to molten salt receivers**
  - System design output 50 MW_e
  - Solar multiple ~3.0
  - Temperature range: 520°C to 740°C.
  - Receiver 14.5 m high x 14 m diam.
  - Nominal receiver output: 350 MW_{th}

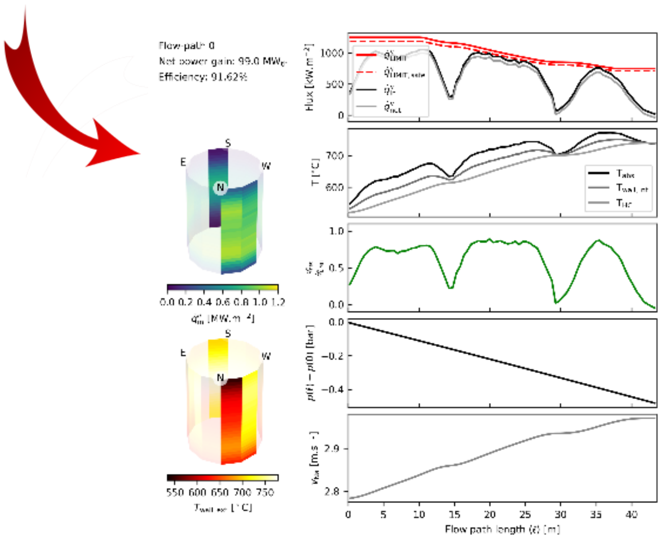




Performance Summary

- Receiver sizing based on annual performance simulation
- Flow-path adapted to liquid sodium properties
- Flux controlled to remain below limits determined by creep-fatigue behaviour of the tube material (1)
- Efficiency consistently high throughout the year





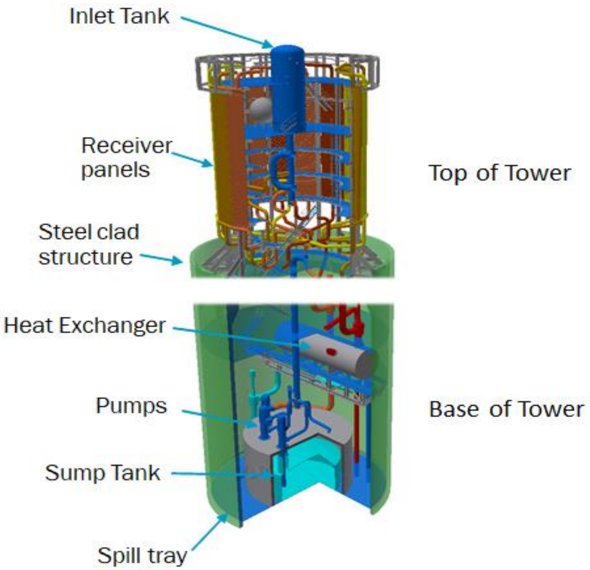
Design point

	Summer			Equinox				Winter		
	Noon	Noon +2h	Noon +6	Noon	Noon +2h	Noon +4h	Noon +5h	Noon	Noon +2h	Noon +4h
DNI (W/m2)	950	930	520	980	950	805	590	930	875	510
Field efficiency	0.647	0.632	0.416	0.639	0.618	0.539	0.420	0.590	0.562	0.369
Intercept efficiency	0.978	0.972	0.962	0.968	0.955	0.961	0.957	0.952	0.957	0.950
Solar absorption efficiency	0.987	0.987	0.987	0.987	0.987	0.987	0.987	0.987	0.987	0.987
Thermal efficiency	**0.923**	**0.924**	**0.830**	**0.921**	**0.922**	**0.906**	**0.846**	**0.920**	**0.913**	**0.792**
Receiver efficiency	**0.912**	**0.912**	**0.819**	**0.909**	**0.910**	**0.895**	**0.835**	**0.908**	**0.901**	**0.782**
Receiver and intercept efficiency	**0.891**	**0.886**	**0.788**	**0.881**	**0.869**	**0.860**	**0.799**	**0.865**	**0.862**	**0.743**
Overall efficiency	**0.577**	**0.560**	**0.328**	**0.563**	**0.537**	**0.463**	**0.335**	**0.511**	**0.484**	**0.274**

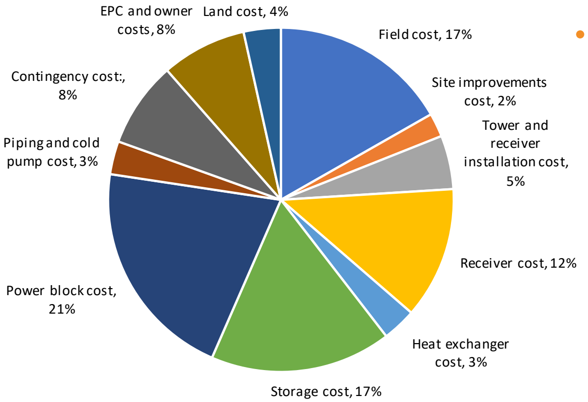
(1) Wang, C-A. Asselineau, W.R. Logie, J. Pye, J. Coventry, Solar Energy, Vol 225, 2021

System components

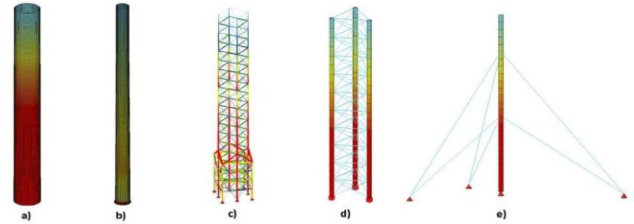
- Key sodium components are available commercially
  - Sump tank
  - Inlet vessel
  - Purification skid (cold trap)
  - Argon tank, cryogenic tank, atmospheric heater
  - 4 x 33% pump configuration, each 4-stages
- Shorter towers may provide cost reduction opportunities



Sodium loop components (source: John Cockerill)



- Details of the capital cost breakdown in the final report NREL/TP-5700-79323

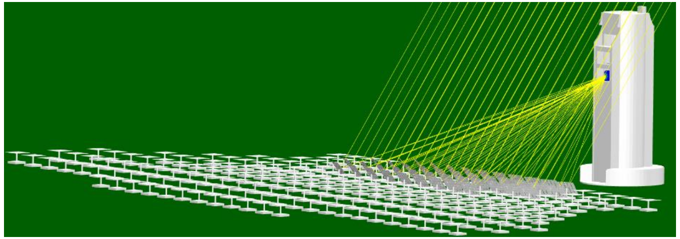


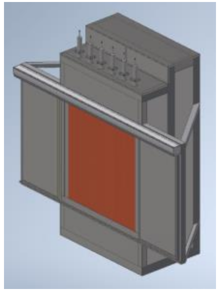
spb compared several tower designs

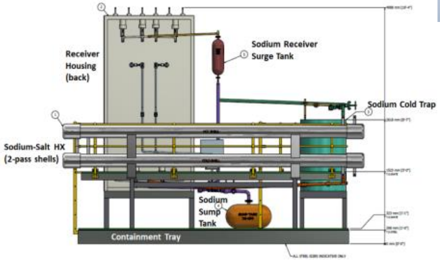
De-risking by testing

- Sodium receiver operation is not new *however* successful demonstration is required at the Gen3 CSP temperatures
- A 1 MWth "billboard" style receiver was designed for Phase 3 of the Gen3 CSP Liquids Pathway project.
- The Australian Solar Thermal Research Institute is testing a 740°C prototype sodium receiver this year

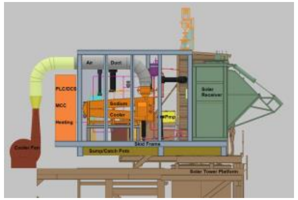
Source: ABC News

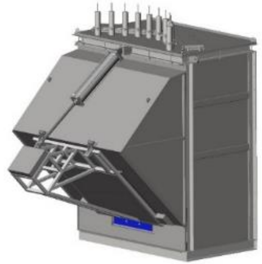






The 1 MWth receiver and sodium loop was designed for Phase 3 prototype testing at Sandia National Laboratories

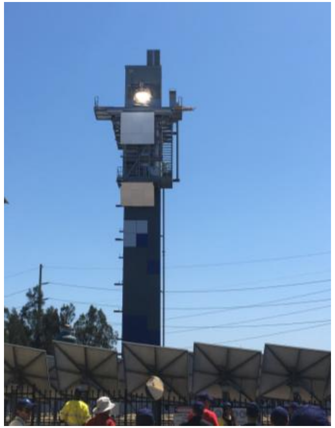




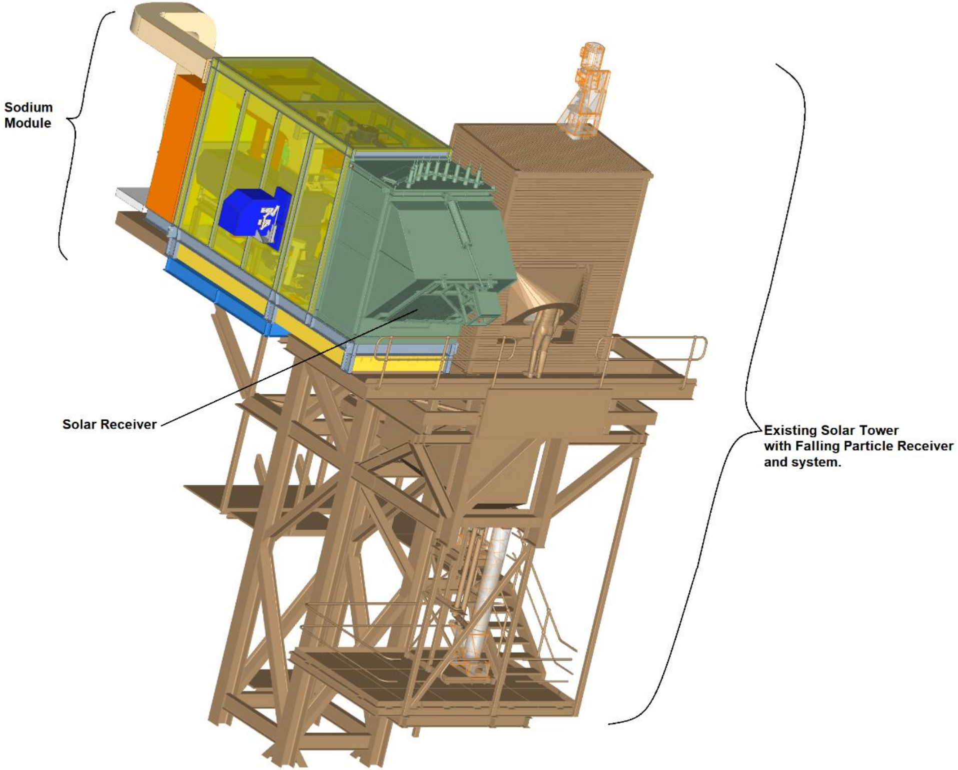
The 700 kWth receiver to be tested in 2024 by ASTRI at CSIRO Newcastle, will operate at a temperature range compatible with next-generation CSP (520-740°C)

ASTRI program

- Australian Solar Thermal Research Institute (ASTRI): developing high-temperature CSP technologies to complement development of the supercritical CO_2 Brayton cycle
- Two pathways: liquid sodium and solid particles
- A strong focus on demonstration for the final year of the ASTRI program (2024)



On-sun testing of ASTRI's falling particle receiver during the SolarPACES 2023 tour to CSIRO Newcastle



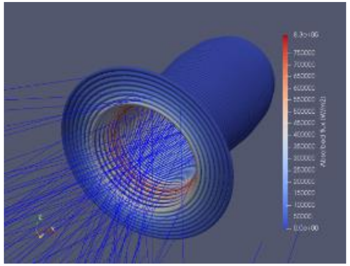
Planned position for the sodium receiver testing on the CSIRO Newcastle tower

Concept design

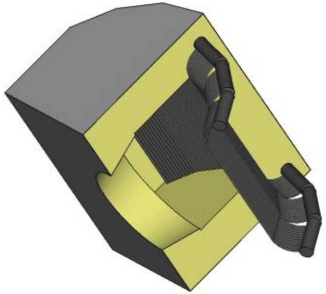
- Operating temperature range was set to match the Gen3 CSP Liquids Project at 520-740°C

Design criteria

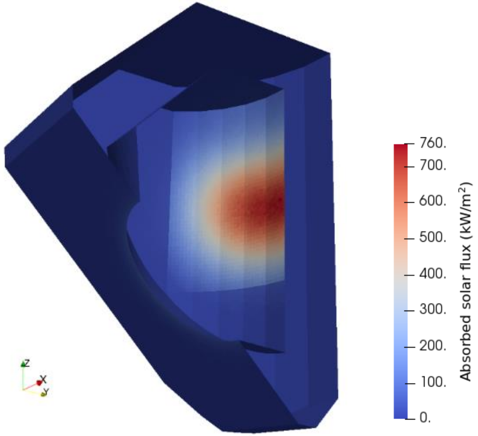
- Successful operation and integration of a 700kW$_{th}$ sodium cavity receiver
- A design that is simple, scalable, and durable, supporting the objective of lowering the cost of CSP
- Validation of receiver performance models using experimental data
- Increased understanding of receiver design interfaces with system balance of plant
- Demonstration of a receiver efficiency greater than 86%



ANU-led cylindrical cavity receiver



CSIRO-led tilted panel cavity receiver



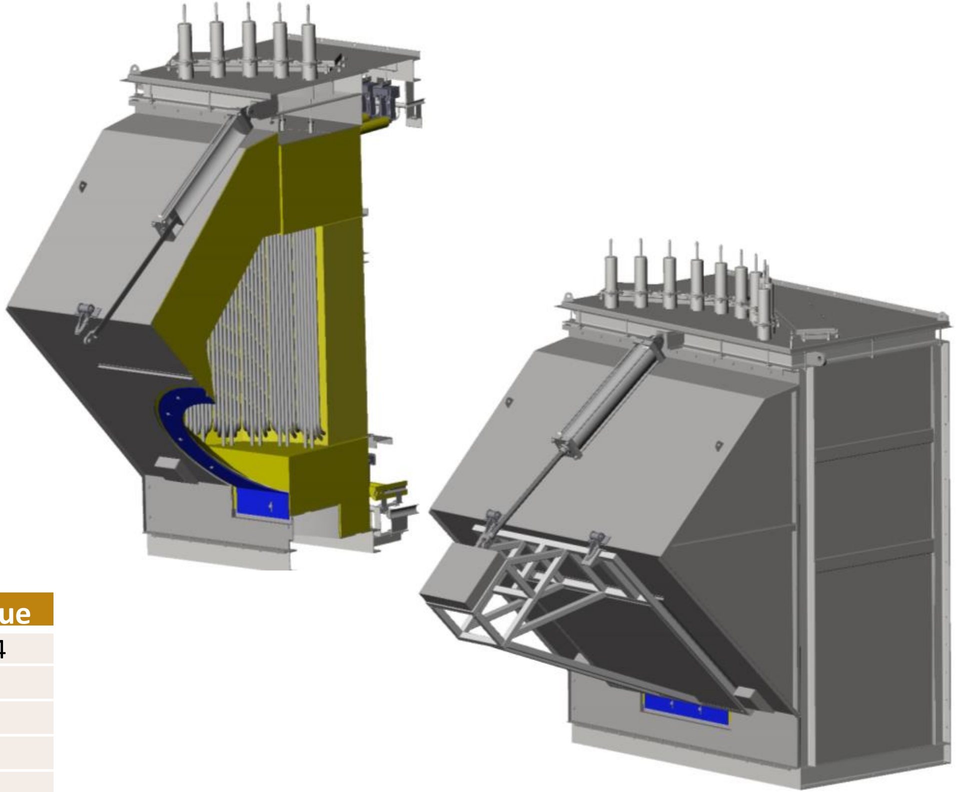
Heliosim 3D surface model, with predicted absorbed solar flux at design point.

Detailed design

The receiver consists of:

- Tube banks (painted with Pyromark 2500)
- Receiver frame and cladding
- Panel mounting system (on spring hangers)
- Instrumentation (thermocouples)
- A mechanical door (for standby or incident)
- Spill tray (can contain full 85L sodium inventory)
- Interconnecting piping, including fill and drain lines and valves
- Heat tracing
- Insulation (Superwool Plus)

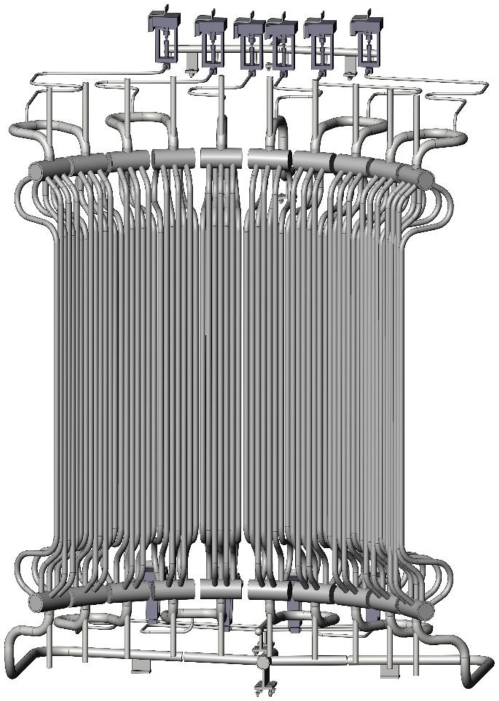
Item	Unit	Value
Receiver tube outer diameter	mm	25.4
Receiver tube separation	mm	0.7
Receiver tube count per tube bank		7
Tube banks per flow path		5
Flow paths		2
Relative azimuth angle between adjacent tube banks	degrees	12
Irradiated length per pipe	mm	1300



3D model of the sodium receiver

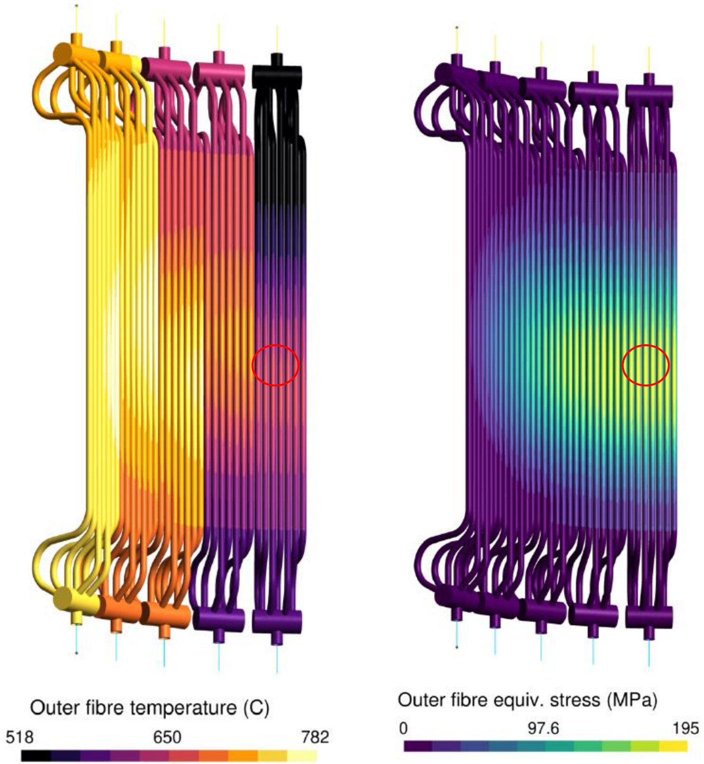
Detailed design

- Designed to Australian Standard AS1210 2010 Class 1
- Operating pressure 200 kPa (gauge)
- Creep design life is 1000 h and number of design thermal cycles is 500,
- Top headers were supported via a dummy leg, supported by spring hangers
- Tube bends allow deflection, stress relief, weld access
- Drain and fill lines also allow gravity drain in case of incident, with sodium returning to the drain tank



Tube bank arrangement, including the drain and fill lines.

Highest flux is 0.76 MWm^{-2} (corresponding to bulk sodium temp 555°C, max surface temp 668°C)



Outer fibre temperature (left), and outer fibre equivalent stress (right) at design point (equinox solar noon).

Construction

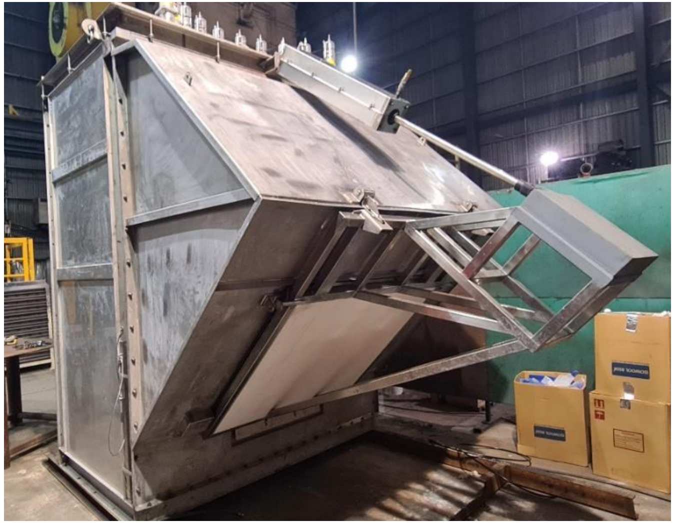
- The receiver tubes were bent and welded to the headers to form the tube banks by MCM Manufacturing
- The receiver enclosure and door were fabricated Performance Engineering Group, who also mounted the tube banks, and welded on the interconnecting pipework and valves.

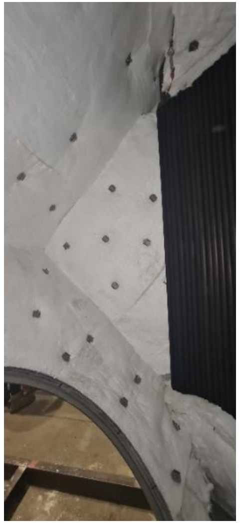
The sodium receiver in various stages of construction showing (top) the completed tube banks and (bottom) the tube banks welded to the interconnecting piping.

Construction

Challenges

- The Alloy 625 material was not a simple material to weld. Weld rectification work was required for many of the welds in order to pass the NDT requirements.
- Sourcing of Alloy 625 grade 2 in the small quantities required for the prototype.






The sodium receiver in various stages of construction showing from left to right: the completed receiver from the front, from the back, the insulation inside the enclosure, and the cavity opening (with the door locked out)

Conclusions

- Fabrication of the sodium receiver was completed in July 2022
- The receiver interfaces with a new sodium loop designed by CSIRO and Vast Energy
- The receiver and loop were joined in mid 2023, and have on-ground commissioning is complete
- Lifting up to the tower at CSIRO Newcastle, and on-sun testing will occur during 2024

The receiver and sodium loop mounted on a skid, on route from the fabricator in Newcastle to Vast Solar's Jemalong site for sodium fill and on-ground commissioning steps

The sodium receiver and loop back on the ground at CSIRO Newcastle, re for lifting onto the tower.

Thank you!

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Acknowledgement

I would like to acknowledge the contributions of all the Australian (ASTRI) team who contributed to the Gen3 Liquids Pathway project and the ASTRI sodium receiver project, included John Pye, Charles-Alexis Asselineau, Felix Venn, William Logie, Armando Fontalvo, Shuang Wang, Robbie McNaughton, Wil Gardner, Daniel Potter, Wes Stein, Dominic Zaal, Ted Steinberg and Geoffrey Will. Further thanks to the extended ASTRI community, including the team at Vast Energy, FE Consulting, and many others!

ANU's sodium research is supported by the Australian Solar Thermal Research Institute (ASTRI), a program supported by the Australian Government through the Australian Renewable Energy Agency (ARENA)