# Beam Down Solar Power Tower Concept and its competitiveness with solar PV

P.K. Vijayan
Reactor Design & Development Group, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

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# Contents

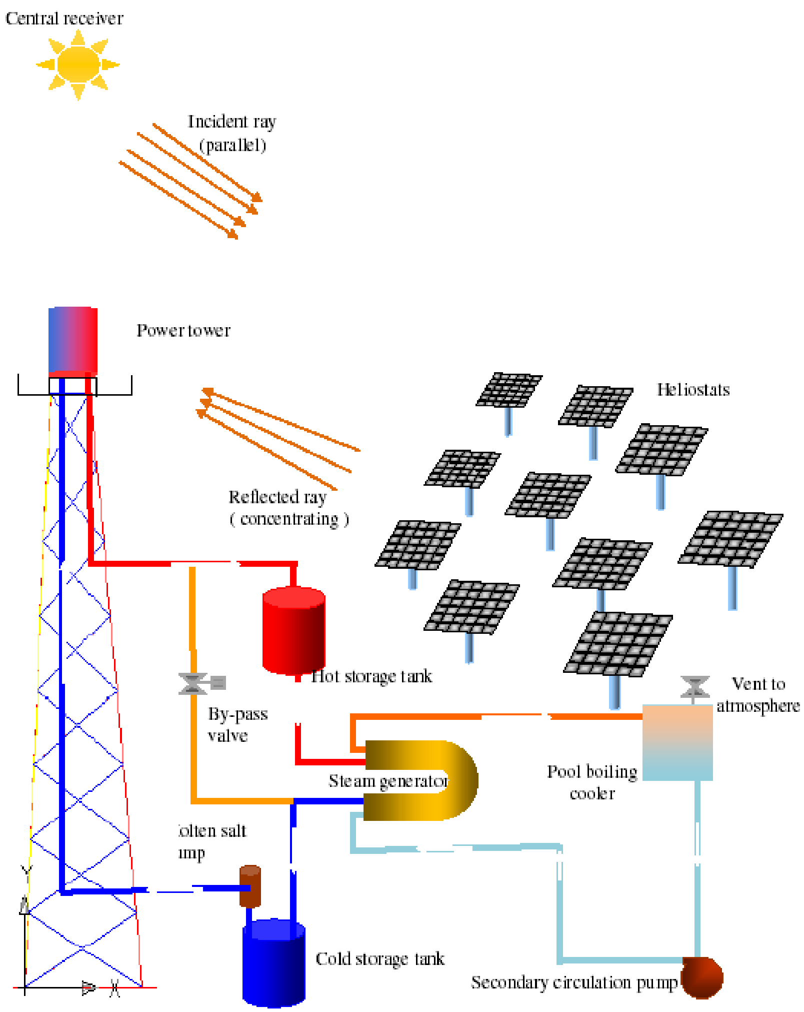
# Introduction

- Solar is abundant
  - Non greenhouse gas generating power source
  - No pollutants emitted
- Dilute and Distributed source
  - Peak solar insolation ~ 1 $kW/m^2$
  - CSP technology is well developed
  - Large land requirement
  - Sun tracking required
- Economically harnessing solar energy is a technological challenge
  - Eliminate or minimise operators
  - Eliminate/minimise components/piping
  - High temperature thermal energy storage
  - Passive systems and controls
  - High technology

# The Power Tower Concept

# The Power Tower Concept

- Main components are
  - Central tower with a receiver
  - Sun tracking heliostats
  - Thermal energy storage system
  - Molten salt heat transport system
  - Steam generating system
  - Turbine and auxiliaries
- Heliostats reflect the solar rays on to a receiver atop the central tower
- The absorbed heat in MSS is transported to the SG
- The generated steam drives the turbine
- Existing power plants based on this concept are PS-10, PS-20, Gemasolar, Crescent Dunes, Ivanpah, etc.




**Schematic of the power tower concept**

# Beam up solar plants

Crescent Dunes Solar Energy Project, USA


Ivanpah Solar Electric Generating System, USA

Heliostat Solar-Field Aperture Area: 1,071,361 m²
Heliostat Aperture Area: 62.4 m²
Tower Height: 540 ft
Receiver Type: External - cylindrical
Heat-Transfer Fluid Type: Molten salt
Turbine Capacity (Gross): 110.0 MW
Output Type: Steam Rankine
Power Cycle Pressure: 115.0 bar
Storage Type: 2-tank direct, 10 hours, raising salt temperature from 550 to 1050 F.

Heliostat Solar-Field Aperture Area: 2,600,000 m²
Heliostat Aperture Area: 15.0 m²
Tower Height: 459 ft
Receiver Type: Solar receiver steam generator
Heat-Transfer Fluid Type: Water
Turbine Capacity 392.0 MW
Output Type: Steam Rankine
Power Cycle Pressure: 160.0 bar
Fossil Backup Type: Natural gas
Storage Type: None

# Beam up solar plants contd..

**Gemasolar Thermosolar Plant, Spain**

Heliostat Solar-Field Aperture Area: 304,750 m²
Heliostat Aperture Area: 120.0 m²
Tower Height: 140 m
Heat-Transfer Fluid Type: Molten salts (sodium and potassium nitrates)
Turbine Capacity 19.9 MW
Cooling Method: Wet cooling
Fossil Backup Type: Natural gas (15%)
Thermal Storage Storage Type: 2-tank direct, 15 hour(s)

**ACME Solar Tower, India**

Heliostat Solar-Field Aperture Area: 16,222 m²
Heliostat Aperture Area: 1.136 m²
Tower Height: 46 m
Heat-Transfer Fluid Type: Water/Steam
Turbine Capacity (Gross): 2.5 MW
Output Type: Steam Rankine, 60.0 bar
Cooling Method: Wet cooling, Cooling Towers
Thermal Storage
Storage Type: None

# Advantages of Power Tower Concept

- High temperature design
  - High temperature process heat applications – competitive economics
    - Hydrogen production by thermo chemical or high temperature electrolysis
  - Metallurgical / material processing industries
    - Why not a solar blast furnace?
- High efficiency power conversion cycles feasible
  - Brayton cycle
  - Supercritical, ultra supercritical or advanced ultra supercritical Rankine cycles
  - Combined cycle
- Thermal energy storage is feasible
  - Base load power station is a possibility
- Could be competitive with solar Photo Voltaic
- Synergy with HTR & MSR

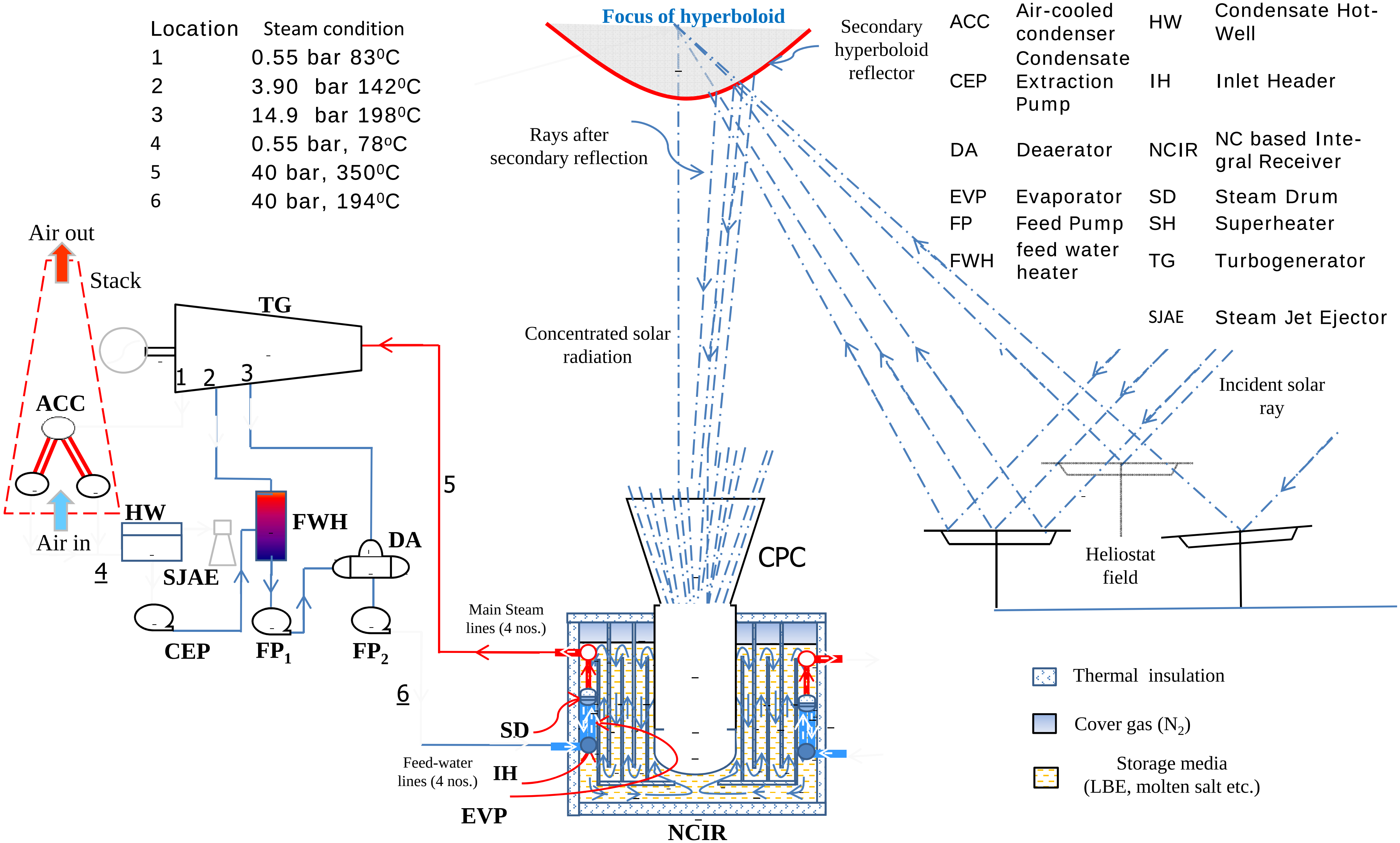
# The Beam Down Concept

Traditionally the power tower concept is
a beam up design

# The Beam Down Power Tower Concept

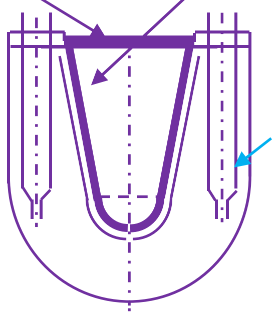
| Location | Steam condition |
|---|---|
| 1 | 0.55 bar 83⁰C |
| 2 | 3.90 bar 142⁰C |
| 3 | 14.9 bar 198⁰C |
| 4 | 0.55 bar, 78⁰C |
| 5 | 40 bar, 350⁰C |
| 6 | 40 bar, 194⁰C |

| | | | |
|---|---|---|---|
| ACC | Air-cooled condenser | HW | Condensate Hot-Well |
| CEP | Condensate Extraction Pump | IH | Inlet Header |
| DA | Deaerator | NCIR | NC based Integral Receiver |
| EVP | Evaporator | SD | Steam Drum |
| FP | Feed Pump | SH | Superheater |
| FWH | feed water heater | TG | Turbogenerator |
| | | SJAE | Steam Jet Ejector |

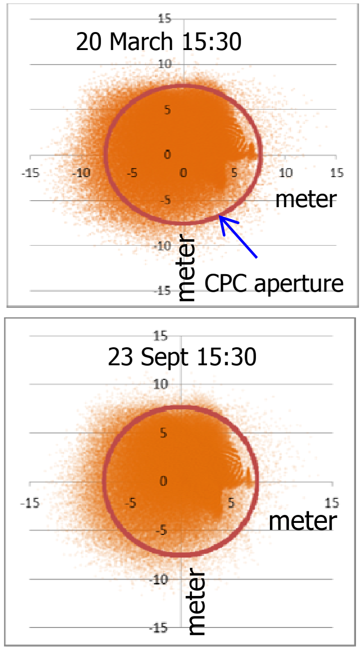


# Advantages of Beam Down Power Tower Concept

- All major equipments are at ground level including the receiver
- Significant reduction in the cost of central tower
- Ease in installation, maintenance and operation
- Natural circulation possible
- Integral receiver design (Receiver cum CPC cum SG cum FWH cum TES) possible (Eliminates pump & piping)
- Spillage can be utilised for feedwater heating
- Retains advantages of power tower design
  - High temperature design
  - Hydrogen production & other process heat applications
  - Metallurgical/material processing feasible
- Hybrids are possible with beam down concept
  - Solar-bio gas hybrid
  - Solar-coal hybrid
  - Solar-nuclear hybrid



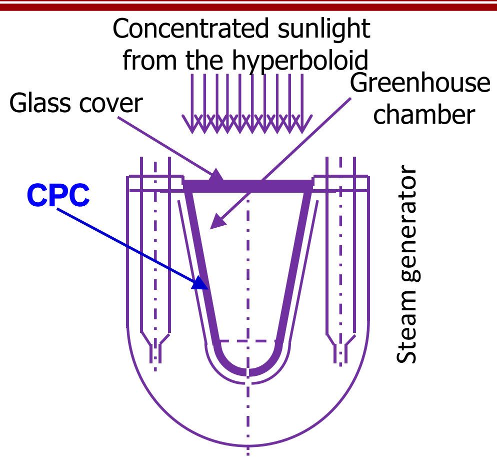

Integral receiver



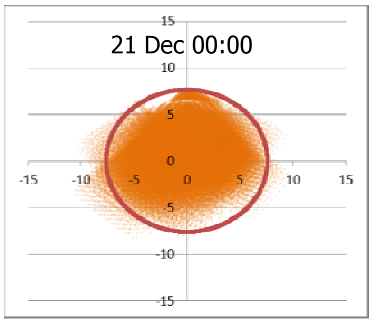

Spillage

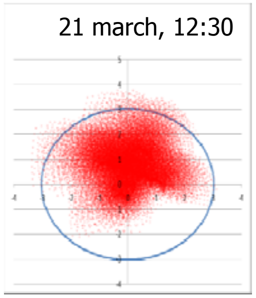
# Challenges of Beam Down Concept

- Additional optical components (hyperboloid mirror & CPC)
- An additional reflection loss at the central hyperboloid mirror
  - Compensated by the greenhouse radiation shields
  - Spillage collection is a bonus
  - High temperature receiver surface is not exposed
- Size optimisation for optical components
  - Secondary reflector
  - Type of Secondary reflector (Flat / hyperboloid)
  - Central receiver (larger spillage for smaller receiver)
- Due to the large area of the hyperboloid mirror, wind load is large
- Maintenance of the hyperboloid mirror is difficult (receiver maintenance in beam up design)
  - Provision to raise and lower on demand for maintenance
  - Cleaning provision required




Integral receiver



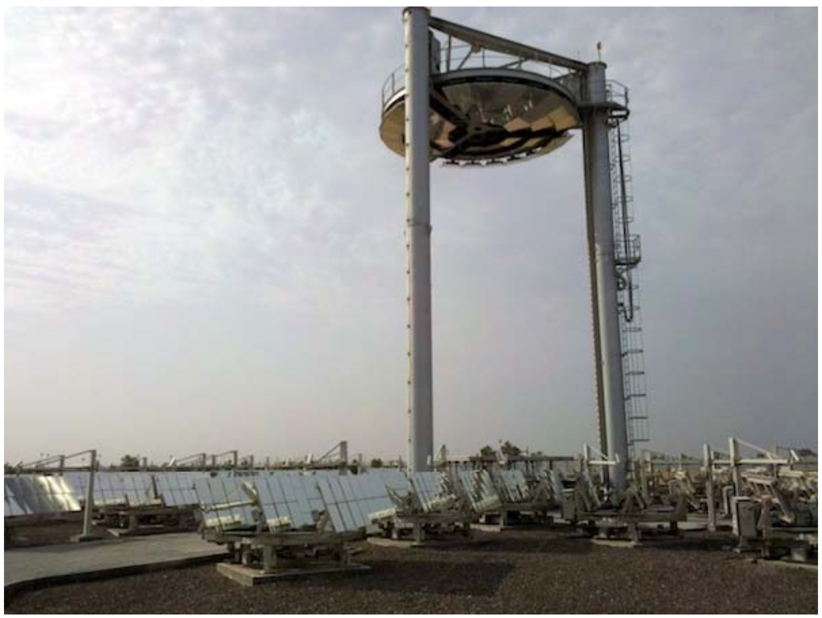




Spillage

# Current status of beam down approach

# Current status of Beam down Plant

- Archimedes is credited with the first use of beam down concept
- The concept of beam-down was proposed by Weizmann Institute in Israel.
- Several designs are reported in literature* up to $100MW_{th}$
- Demonstration plant of $100kW_{th}$ is built at MASDAR, Abu-dhabi, UAE




- 33 ganged-type heliostats of 8.5 $m^2$ each
- 3 fields with 11 heliostats each

**$100 kW_{th}$ Beam Down Demo Plant at Masdar**

* Hiroshi Hasuike , Yoshio Yoshizawa b, Akio Suzuki c, Yutaka Tamaura, Study on design of molten salt solar receivers for beam-down solar concentrator Solar Energy 80 (2006) 1255–1262

# Current status of Beam down plants

- 500 $kW_{th}$ Beam Down plant built at WIS Rehovot, Israel
- Secondary reflector is Monolith hyperboloid mirror of 70 $m^2$
- Receiver works at 1300 °C at 20 Bar pressure air
- CPC is of 2.2 meter aperture diameter and height of 5m

**Beam down tower**

**Solar Air receiver CPC**

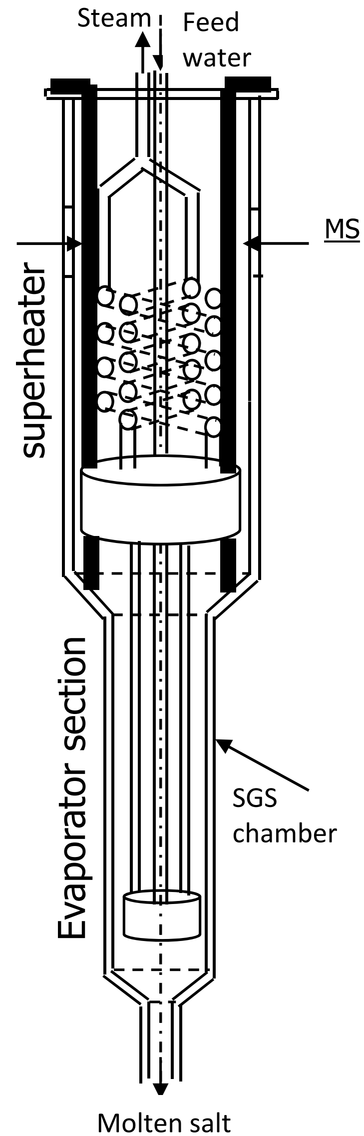
**500 $kW_{th}$ Beam Down Demo Plant**

- Performance validation of Central Hyrperboloid Reflector of higher capacity is yet to be done

# BARC Design of Beam Down Power Tower

# Design Goals of BARC Beam Down Plant

- Integral receiver design
- Natural circulation in MSS as well as SGS
  - Eliminates
    - Molten salt circulation pumps
    - Flow control to suit diurnal power variation
    - Fast stowing down of heliostats
    - Maintenance requirements
- Eliminate/Minimise operator action
  - Natural circulation in MSS as well as SGS
  - Passive controls
  - Self powered heliostats
  - Automatic heliostat cleaning
- Helical coil type superheater
- Passive air-cooled condenser
- Round the clock operation with thermal energy storage (16 h) in molten salt




NC based SGS

# Optical Design

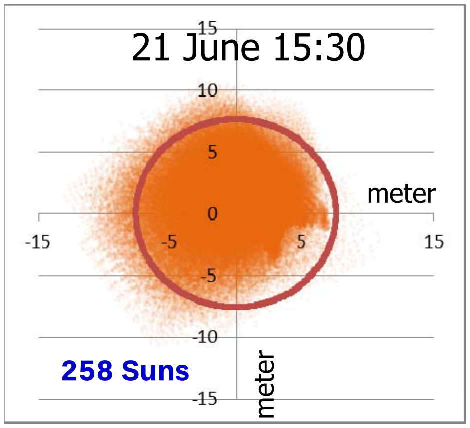
Following information is obtained by optical design

- Hyperboloid size and shape
- Central tower height
- Compound Parabolic Collector dimension
- Receiver aperture
- Heliostat size and curvature
- Heliostat field layout
- Power received by the molten salt fluid
- RAYTRACE code developed for optical design

# RAYTRACE Code for Optical Design

- A computer code 'RAYTRACE' developed for optical design of Solar power plants.
- RAYTRACE computes power obtained from the heliostat field and it can handle multiple towers, uneven terrain, beam up and beam down plants.
- RAYTRACE computes image shape of each heliostat on receiver, cosine losses, flux distribution and spillage losses. It has capability of computing shading and blocking effect also.
- Benchmarking of RAYTRACE has been done with data available in literature achieving close match.
- RAYTRACE is utilized for design and optimizing of Hall-7 roof top facility, Gamma Garden solar facility, SOLTOP-5 plant at Manuguru and SOLTOP-2 power plant at IITJ.

# RAYTRACE Code Features



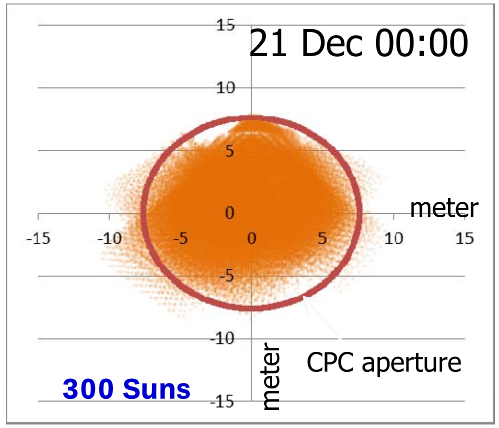




**Image at CPC top on solstice and equinox days**

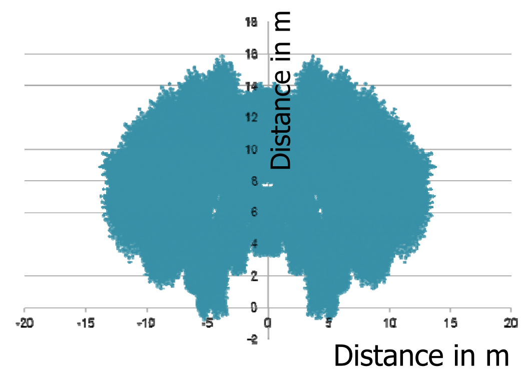



**Image on the hyperboloid for Gamma garden plant**

- Computes Receiver aperture radius & hyperbolic reflector radius
- Computes solar concentration achieved
- Power output with or without storage.
- Computes spillage at the receiver
- Image size on the hyperboloid mirror

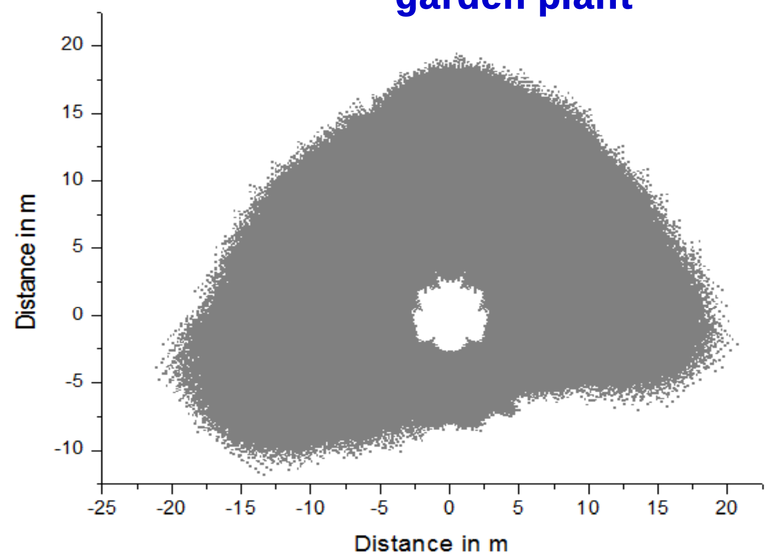



**Image on the hyperboloid for 2 Mwe IITJ plant in the horizontal plane**

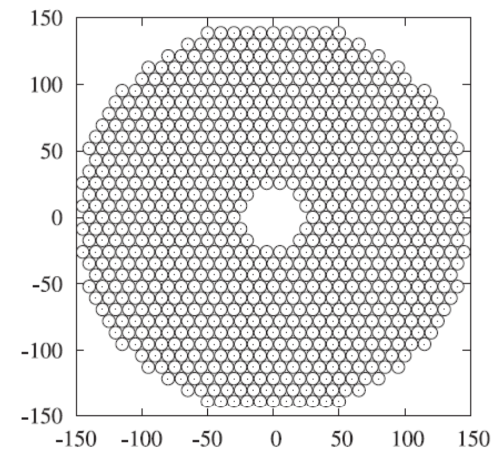
# Computational Procedure for RAYTRACE

- Based on the day and local time, the azimuth and elevation of the sun is computed.
- The heliostat curved surface is divided in several reflective elements.
- Each heliostat surface is oriented so that reflected ray from central element falls on desired focus which provides desired heliostat rotation.
- The reflected ray falls on the hyperbolic mirror which further reflects it to the CPC. Sun shape is also taken into account in all the computations.
- Shading and blocking, flux computations, concentration in CPC are also computed by RAYTRACE code

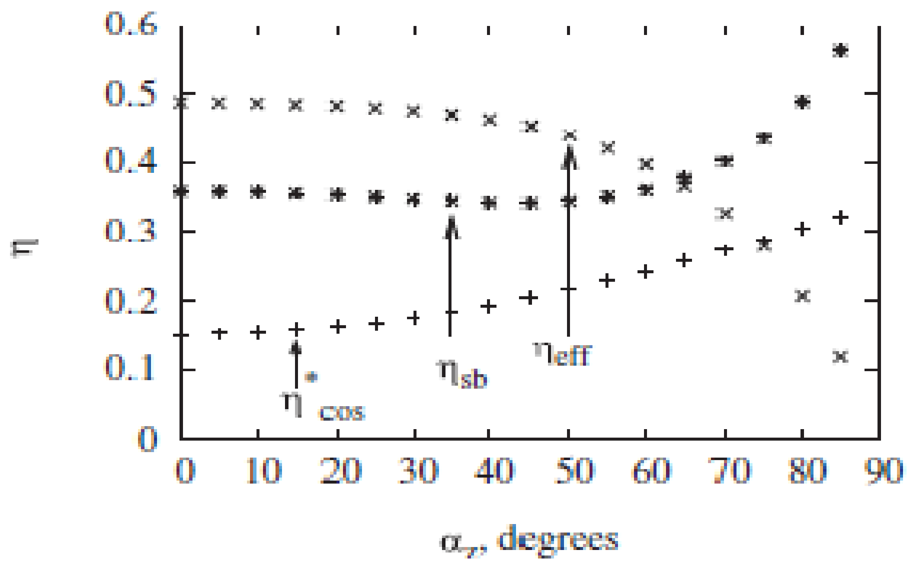
# Benchmarking RAYTRACE Code

(Energy 36 (2011) 4828-4837)

Solar field consists of 786 number of heliostats. Heliostats are circular with radius 5m. Tower height is 50m. Inner radius of the heliostat field is 30m and maximum radius is 140m. Land coverage is 91% in the presented layout.

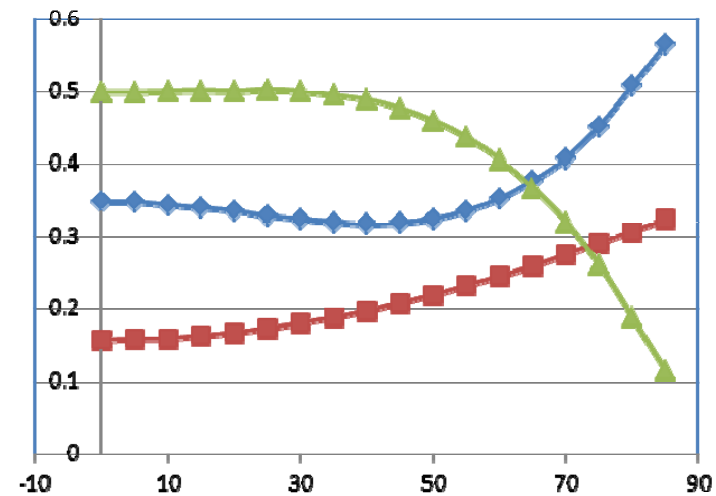



Solar field configuration taken for comparison with CRS4-2 computer code. (Leonardi et al,Energy 36 (2011) 4828-4837)




Computations by CRS4-2 computer code presented in Energy 36 (2011) 4828-4837

Effective fraction, $\eta_{eff,}$ cosine fraction, $\eta_{cos}$ , and shading and blocking fraction, $\eta_{sb}$, as function of $\alpha_z$ at $\phi$=0 , Receiver's height is 50 m and heliostat's radius in 5 m.



Same problem Calculated by RAYTRACE

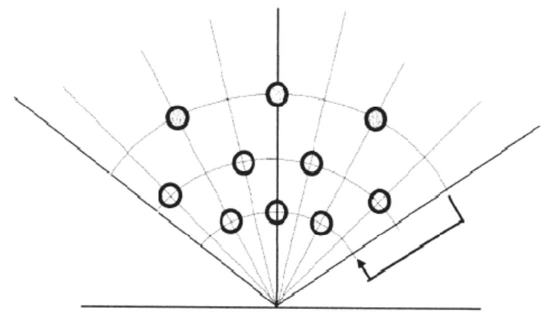
# Heliostat Layout

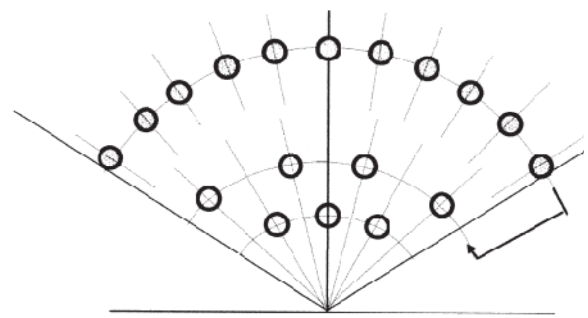
(a) HELFILA code developed for heliostat field layout. The code generates an optimal heliostat layout given the tower height, heliostat size, land area and its orientation Lattitude & Longitude)

(b) Minimum shading and blocking or as specified.

- The criterion selected to base the decision upon is that the land area covered by the reflecting surface should be maximized. The measure of the land use is the mirror density, defined as follows:

$$\delta = \left( \frac{\text{net reflecting surface area}}{\text{land covered area}} \right) = \left( \frac{N_m A_m}{A_f} \right)$$


(a)

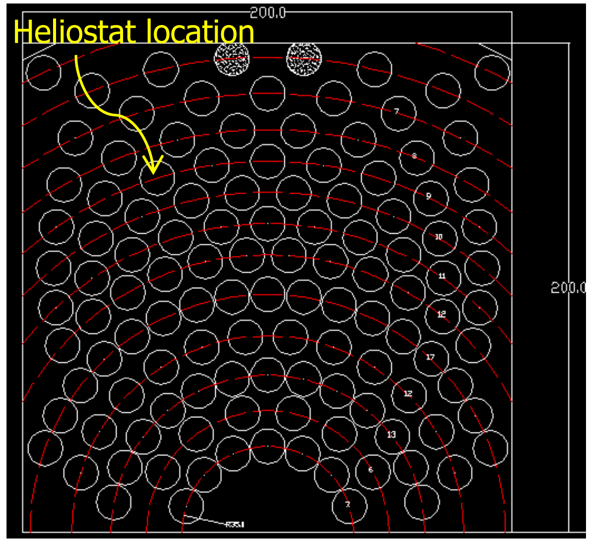

(b)

**Methodology adopted in HELFILA**

# Heliostat field layouts for different plants

**HELFILA Features**

- Multiple heliostat size
- Maximises land utilisation
- Any land orientation

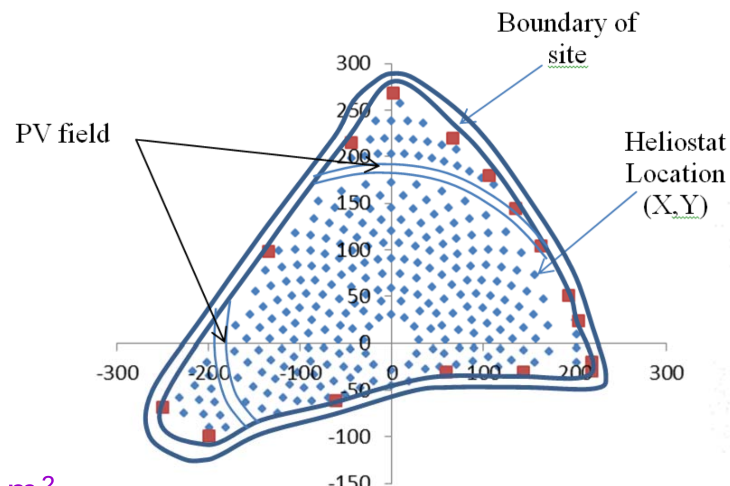



**Manuguru Plant Layout**

- 120 nos. of 10m X 10m heliostat
- 200m X 200m plot
- 30% land utilization
- Average power 3.3 $MW_{th}$

- 14 heliostats of 10mX10m size
- 24 heliostats of 5mx5m size
- Land area 6000 $m^2$

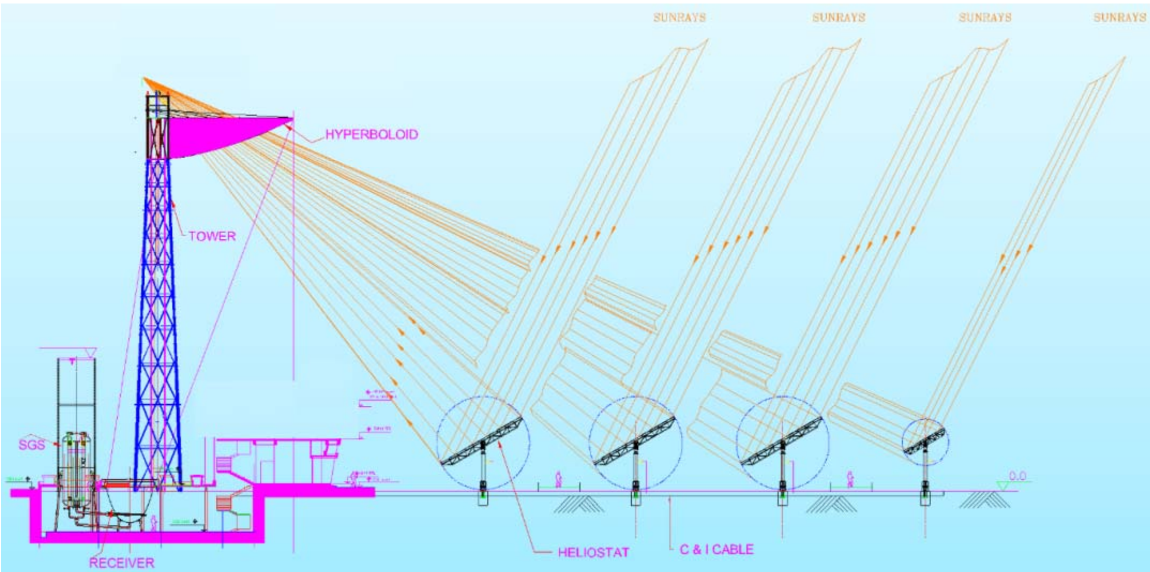
**Gamma Garden Plant**



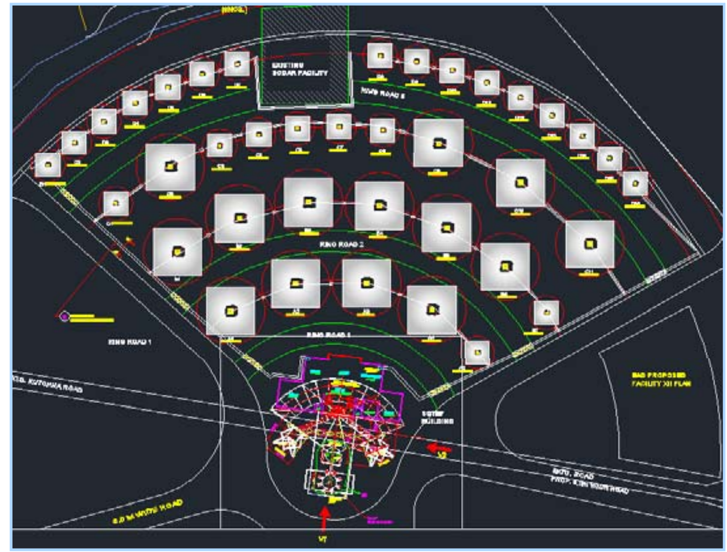

370 10mx10m Heliostats in a 15 acre plot

**Heliostat Field Layout for IITJ Site**

# Gamma Garden Solar Plant




**Elevation**

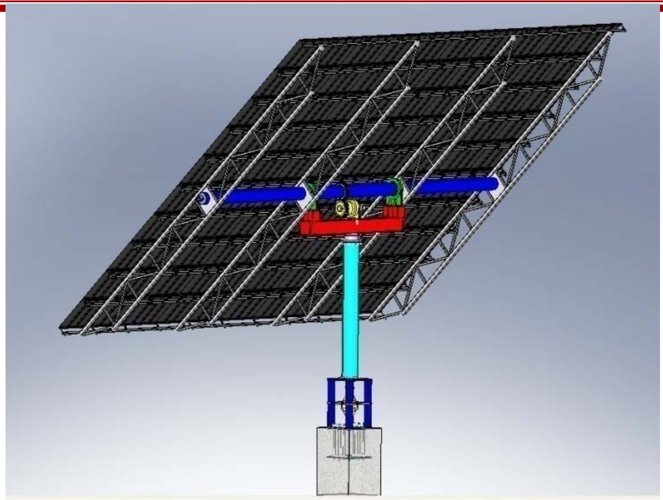


**Plan view**

- Gamma garden plant is a 50 kWe 24 hour operating beam down plant
- Power generation as well as solar hydrogen generation
- Heliostats: 10mx10m (14 No.) & 5mx5m (24 No.)
- Thermal energy storage: 16 h

# Optical Components

- Heliostat, hyperboloid mirror and CPC are the optical components in a beam down plant.
- Sizing of hyperboloid and CPC by the in-house RAYTRACE code
- Heliostat size optimisation
  - 1.5mx1.5m, 3mx3m, 5mx5m, 7mx7m, 10mx10m &12mx12m
  - Cost of control, wind load & structure
  - Designed for operation at 40 kmph & survival at 160 kmph
  - Two axis tracking
  - Powered by solar PV panels
- Central tower also influences the optical design
  - Height
  - Shading and blocking
  - Spillage



Heliostat

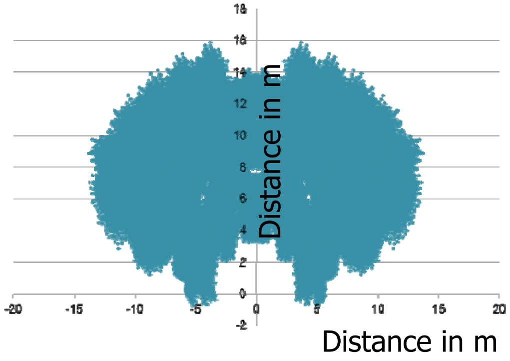
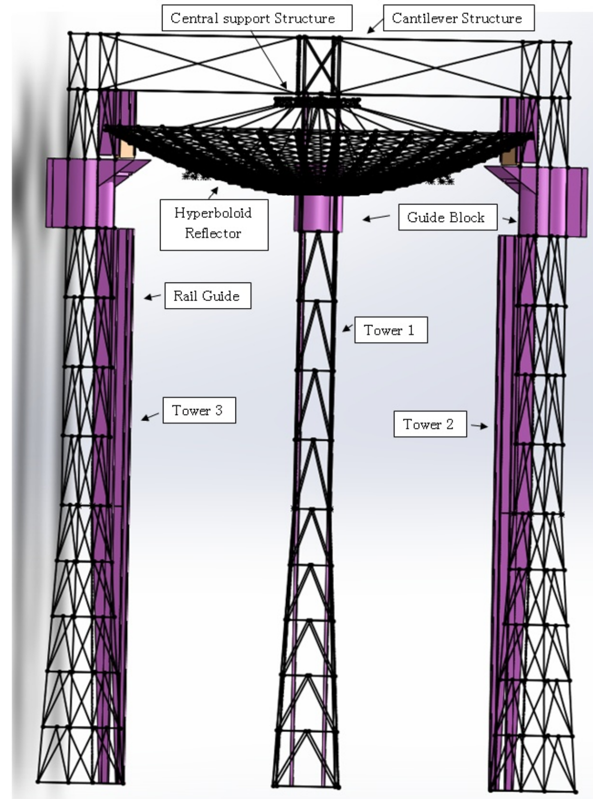



Image at hyperbolic reflector

# Optical Components

- Hyperboloid mirror atop central tower
  - Designed for operation at wind speed of 40 kmph and survival speed of 160 kmph
  - Guide rail to move the mirror up and down
  - Cleaning jets provided along the periphery
  - Total deflection less than 0.5 mrad
- Compound parabolic collector (CPC)
  - Spillage
  - Cooling
- Receiver
  - CPC cum receiver
  - Integral type



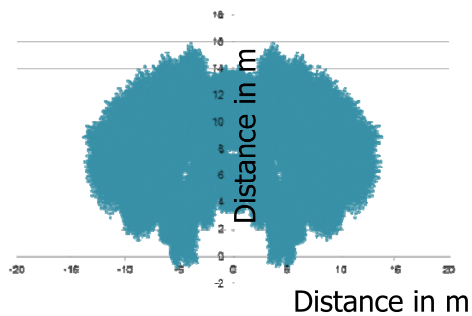
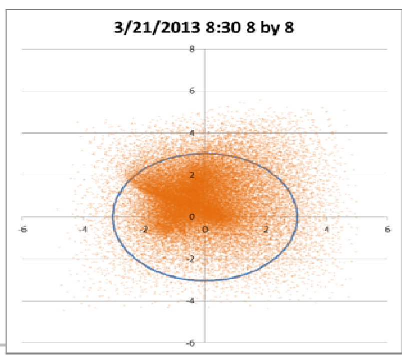




Image at hyperbolic reflector

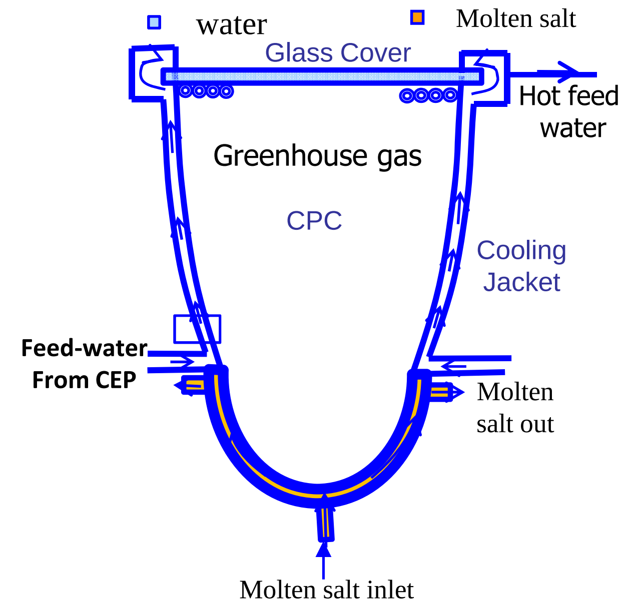



Spillage

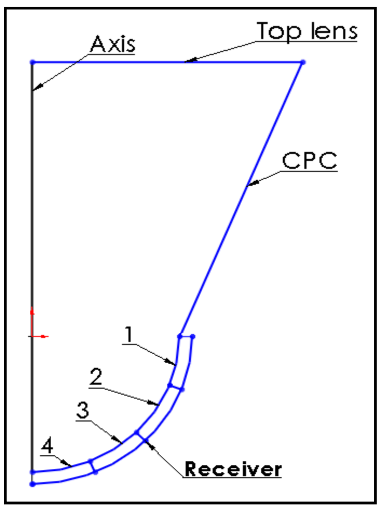
Hyperboloid mirror structure

# CPC cum Receiver

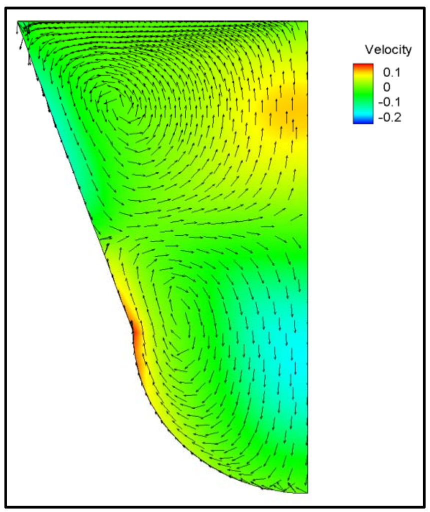
- CPC top glass cover support needs cooling – used for feed water heating
- CPC itself has a cooling jacket
- Greenhouse radiation shield
  - Utilises energy trapped for feed water heating
- Spillage is utilised for feed water heating
- Receiver is subjected to thermal cycling



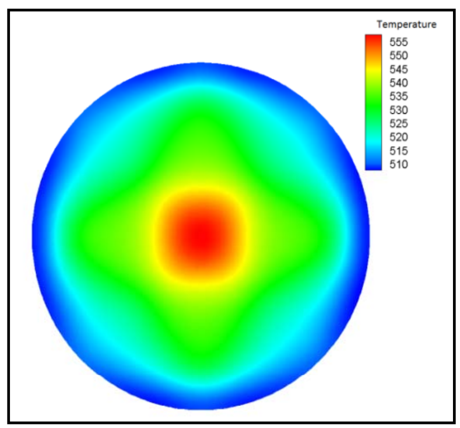

**CPC cum receiver**



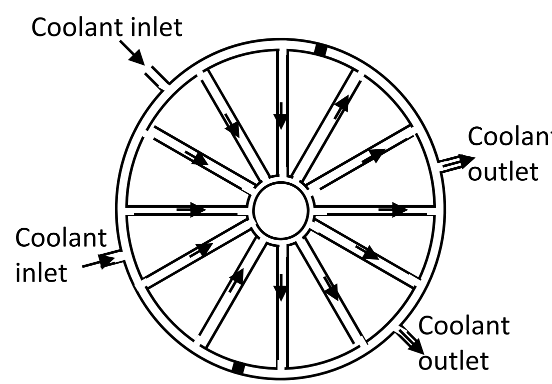

**Receiver geometry & boundary conditions**




**Velocity Profile inside the receiver**



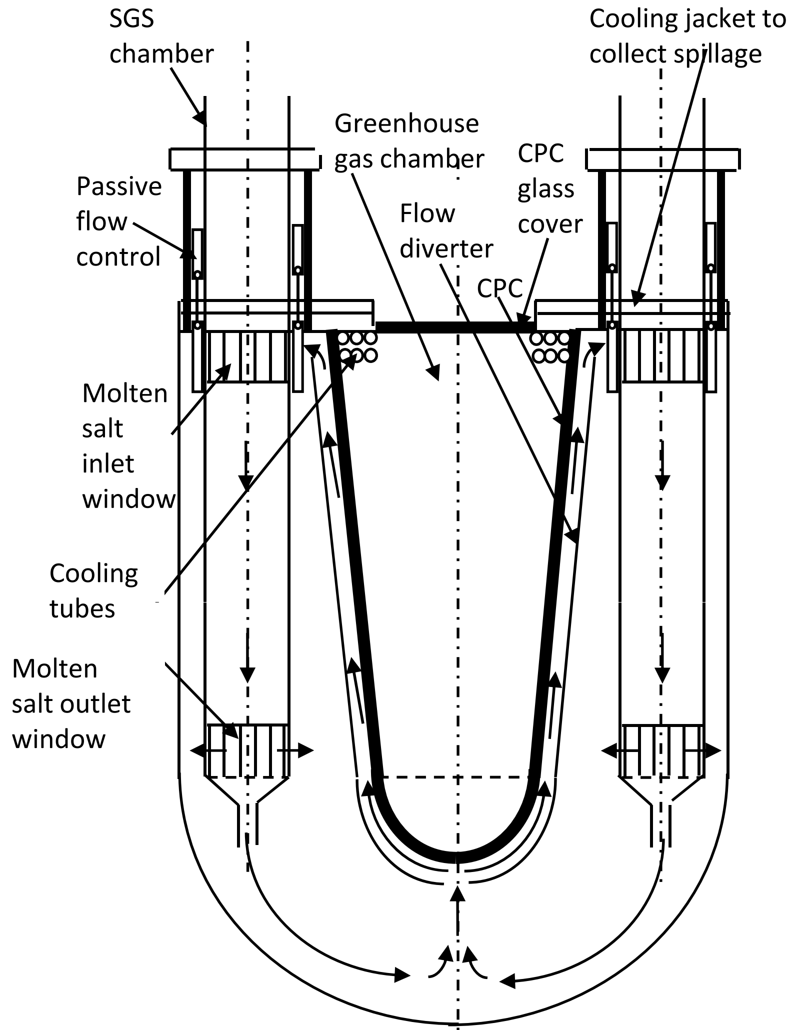

**Receiver cover glass temperature profile**




**Cover glass support structure**

# Integral Receiver

- Integral receiver cum CPC cum FWH cum SG cum TES
  - Eliminates hot and cold storage vessels
  - Eliminates piping and associated heat losses
  - Eliminates separate steam generator system
  - Reduced radiation heat losses compared to beam up design (receiver is insulated from all sides except the beam window)
- Molten salt as well as SGS is natural circulation type
  - Eliminates pump and flow control to account for diurnal variation in solar insolation
- Passive flow control for constant steam generation rate




Integral receiver

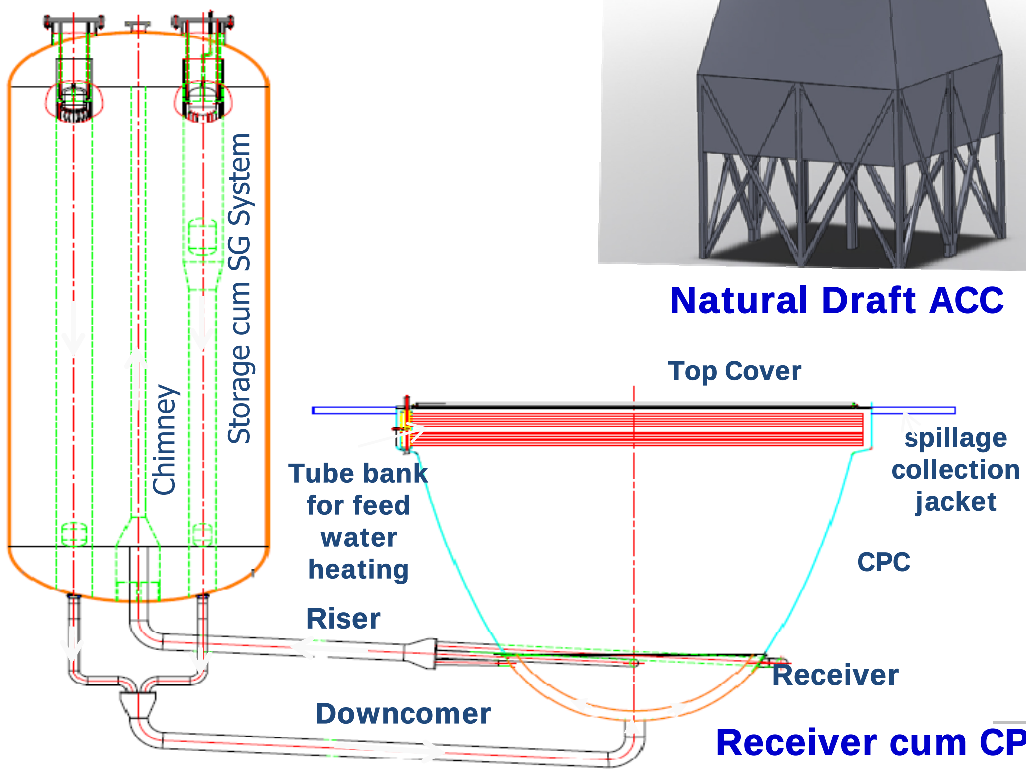
# Major Components of the Plant


**Natural Draft ACC**

| Natural Draft ACC Design Data | |
|---|---|
| No. of units | 4 |
| Air mass flow rate | 248.25 kg/s |
| Face velocity | 3.7 m/s |
| Air heat transfer coefficient | 30 $W/m^2K$ |
| Pressure drop | 10.5 Pa |
| Stack Diameter & height | 8 m & 40 m |

## Turbine design data for IITJ

- Inlet steam Pressure: 40 bar
- Steam temperature: 350°C
- Steam flow rate: 12.7 tph
- Power: 2MWe at generator terminals
- Cycle efficiency:
  - 20.2 % (water cooled)
  - 19% (Air-cooled)
- Efficiency can be increased (2-3%) by regeneration




**Receiver cum CPC**

## Integral Receiver for IITJ

- Natural circulation based receiver.
- Integral storage cum SGS
- Maximum Surface temp. 650°C.
- One hour thermal storage (9 $MW_{th}$)
- Average heat flux 0.15 $MW/m^2$ .
- Max. thermal loss 10%
- Steam at 350 °C & 40 bar

# Analysis of Steam Generating System

## Energy equation for fluid

$$\frac{\partial T}{\partial t} - \alpha \frac{\partial^2 T}{\partial s^2} + \frac{W}{A_{in}\rho_0}\left(\frac{\partial T}{\partial s}\right) = \frac{-4h_{in}(T - T_w)}{\rho_0 D_{in}\ C_p}$$

## Momentum equation for fluid

$$\frac{\Delta s_i}{A_{in}} \frac{dW}{dt} = \rho_0 g (1 - \beta (T_i - T_0)) \Delta z_i$$

$$- \frac{f_i \Delta s_i}{D_{in.i}} \left( \frac{W}{2\rho_0 A_{in,i}^2} \right) - k_i \left( \frac{W^2}{2\rho_0 A_{in,i}^2} \right) - \Delta p_i - \Delta p_{acc,i}$$

## Conduction equation for the wall

$$\frac{\partial T_w}{\partial t} - \alpha_w \frac{\partial^2 T_w}{\partial S^2} = -\frac{4h_{in}(T_w - T)}{\rho_w Cp_w}\left(\frac{D_{in}}{(D_o^2 - D_{in}^2)}\right)$$

$$-\frac{4h_o(T_w - T_x)}{\rho_w Cp_w} + \frac{4q}{\rho_w Cp_w}\left(\frac{D_o}{(D_o^2 - D_{in}^2)}\right)$$

subscripts

- $in \Rightarrow$ inside the loop
- $a \Rightarrow$ ambient
- $o \Rightarrow$ outside the loop
- $w \Rightarrow$ wall
- $s \Rightarrow$ secondary (cooler) side
- $i \Rightarrow i^{th}$ node

- LBENC Code for NC analysis developed in-house
- It can take different fluids
- Coupled analysis possible

*Where,*

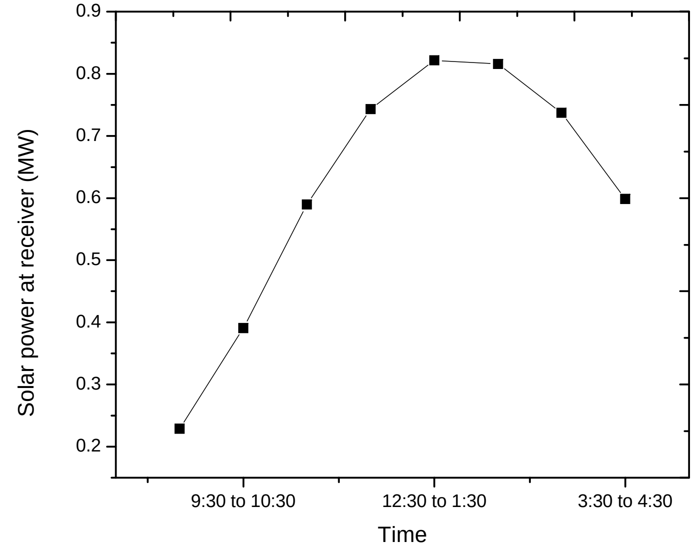
*for pipes* $T_x = T_a$, $h_o = h_a$ *and* $q = 0$

*for cooler* $T_x = T_s$, $h_o = h_s$ *and* $q = 0$

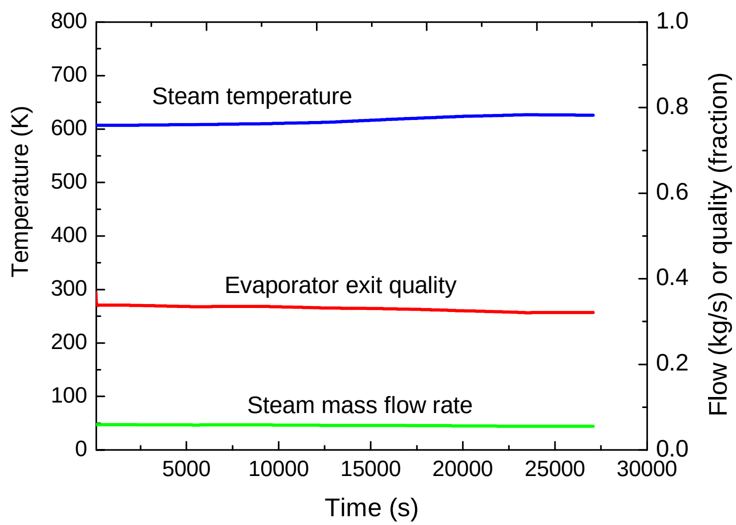
*for heater* $h_o = 0$ *and* $q$ *specified*

# Integral Receiver Performance

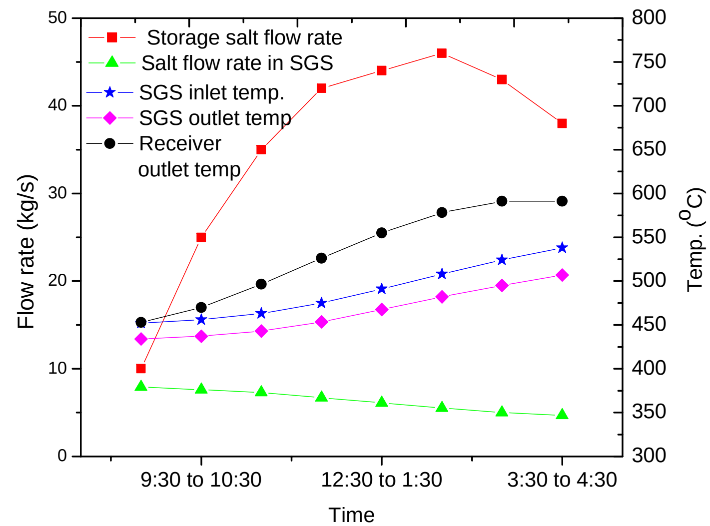
- In-house developed code for NC analysis
- Power collected varies with the time of the day
- MS temperatures and flow rates also vary with time
- Steam generation rate is nearly constant with passive flow control
- The loop circulation rate is one-fourth of the circulation rate in the SGS tank




**Receiver power**



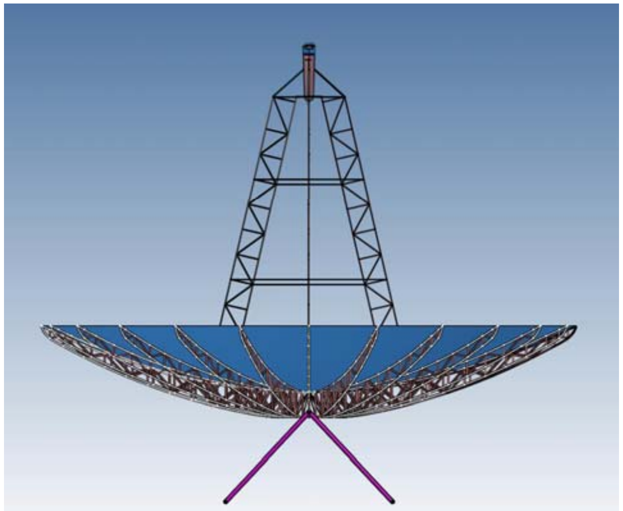

**SGS performance**

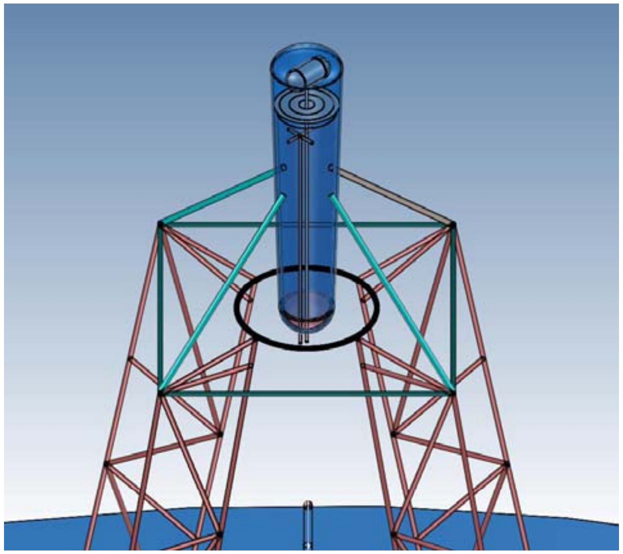



**MSS performance**

# Hybrids with solar power tower

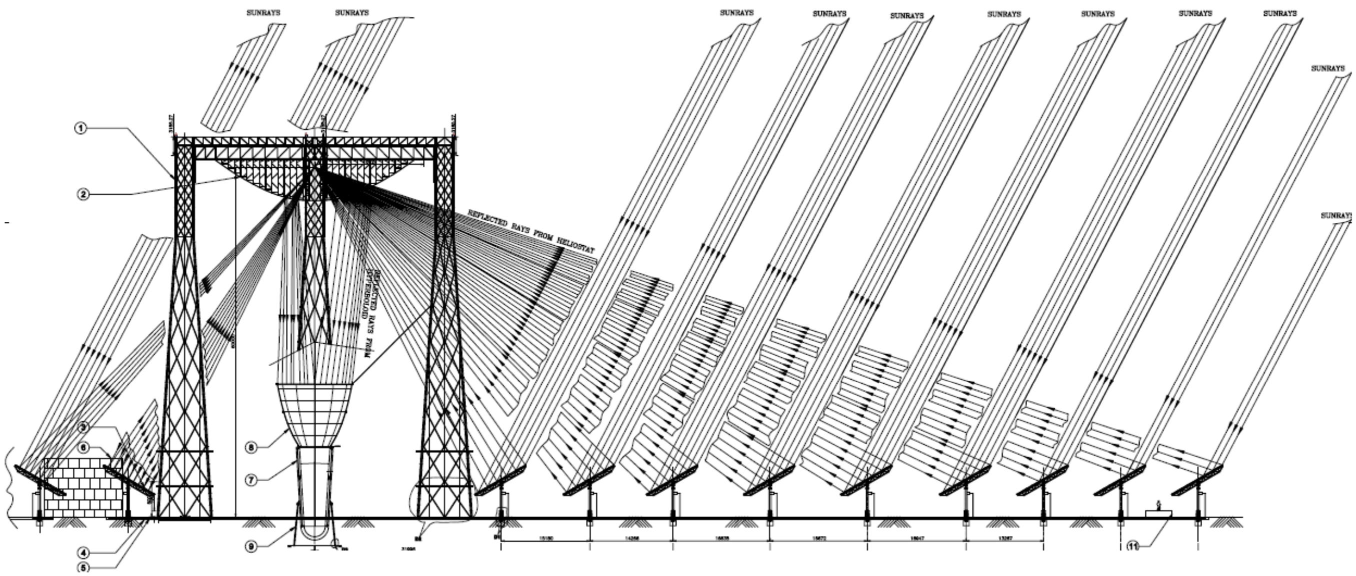
- High temperature solar thermal power technologies are necessary for increased efficiency and high temperature process heat applications.
- High temperature solar power plants needs to be operated continuously to avoid thermal cycling and to prolong plant life.
- Generally, continuous operation is achieved either by hybridisation or by providing thermal energy storage.
- Thermal energy storage is not economic as the main cost in a power tower concept is in the heliostats whose number has to be enhanced tremendously.
- Several different types of hybrids are proposed.
  - Solar-biogas hybrid
  - Solar-fossil hybrid
  - Solar-nuclear hybrid
- A single dish solar-biogas hybrid has been designed



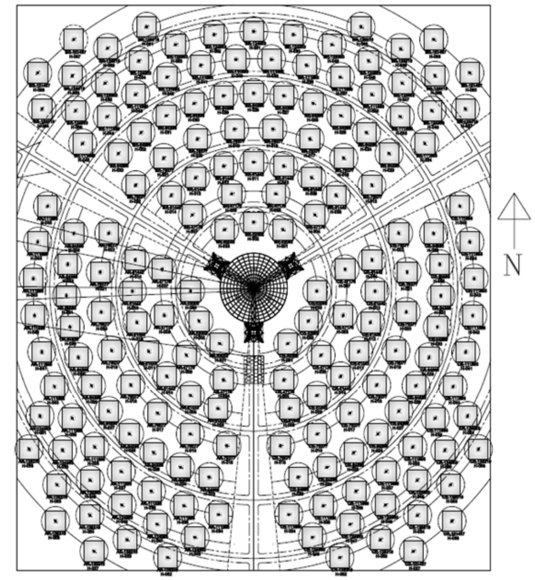


**Solar Biogas hybrid**

# Solar-coal hybrid plant at Manuguru



**Elevation view**

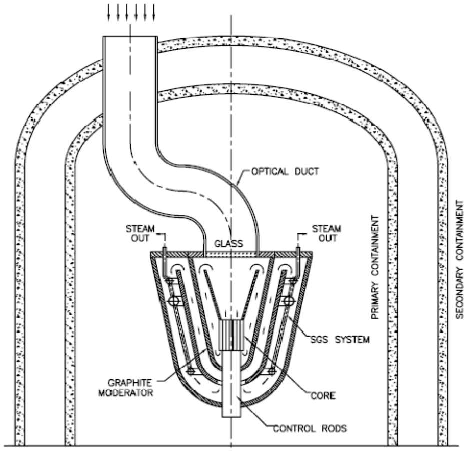



**Plan view**

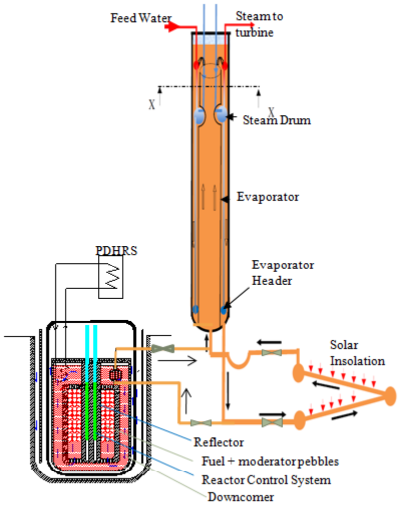
Heliostat Solar-Field Aperture Area: 18,400 m²
Heliostat Aperture Area: 100.0 m²
Tower Height: 60 m
Thermal power generated 5 $MW_{th}$
Heat-Transfer Fluid Type: Molten salts (sodium and potassium nitrates)
Thermal Storage Molten salt, Integral with the receiver

# Solar-Nuclear Hybrid

- In most instances, hybridisation is proposed with fossil fuels which generates greenhouse gasses.
- Maximum capacity factor for solar is only 20%.
- Nuclear power is cheaper than solar thermal today.
- A solar-nuclear hybrid is possible with the power tower concept if the beam down approach is adopted.
- Nuclear reactor operates during non-solar hours.
- Decay heat is a boon rather than a curse.




Solar – nuclear hybrid




10 $MW_{th}$ Solar –Nuclear Hybrid System

Solar-nuclear hybrid

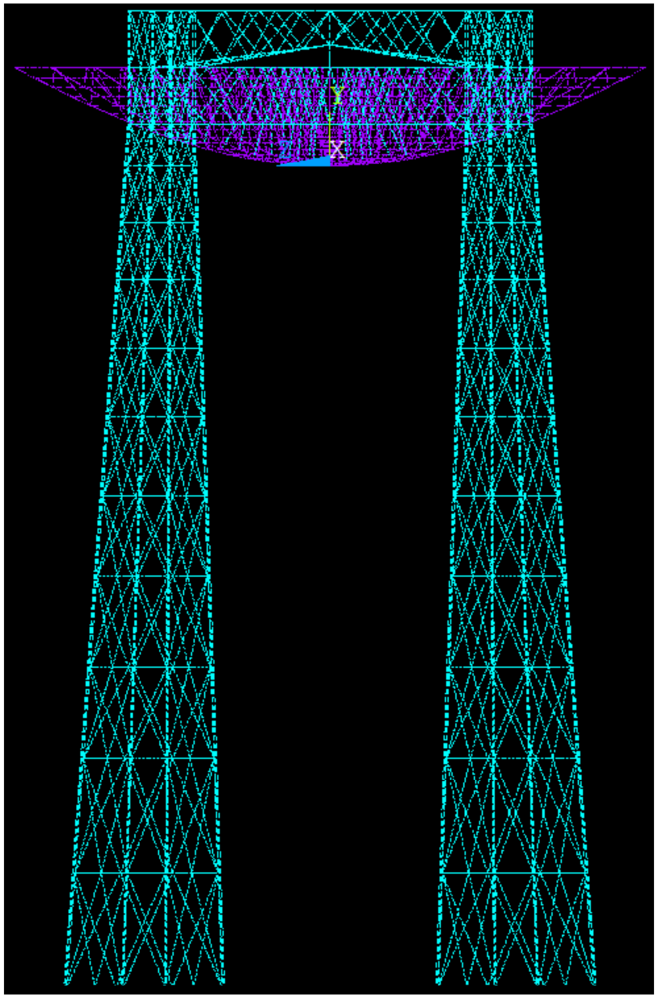
# Research Directions of a Beam Down Plant

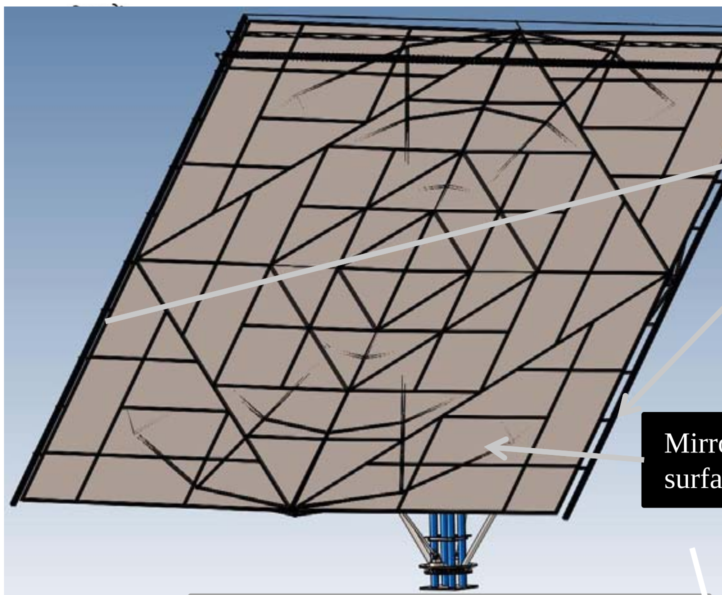
- Reduction in optical losses
- Validation of optical design code
- Integral receiver cum storage cum steam generator design validation
- Direct solar energy absorption in transparent molten salts
- Hydraulic heliostats
- Greenhouse radiation shield development
- High efficiency power conversion cycles
- High temperature thermal energy storage
- High temperature structural material development
- Development of solar selective coating & its characterisation
- Passive air-cooled condenser development

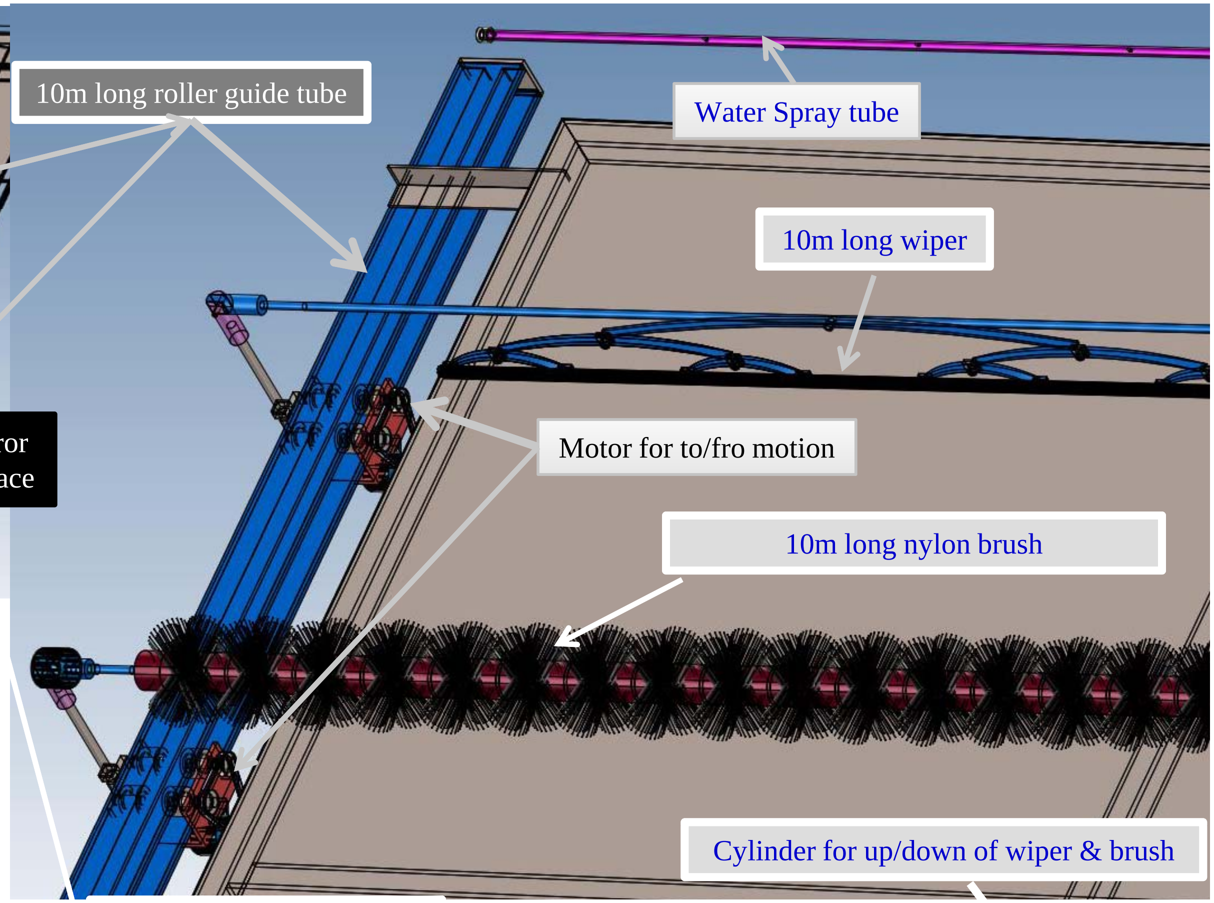
Roof top test facility for validation

# Reducing Optical Losses

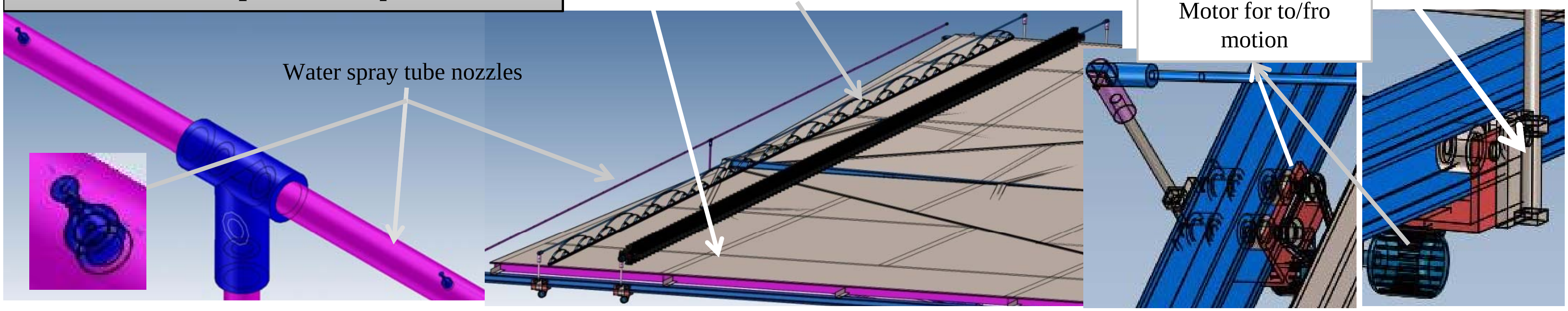
- Reduction in cosine losses (18-25%)
  - Increase in tower height reduces cosine losses
  - Heliostat layout
  - Heliostat field orientation
- Automatic heliostat and hyperboloid mirror cleaning
- Increasing the height of tower
- Hyperboloid mirror versus flat mirror
  - Planar mirrors are much easier to construct
  - Smaller image at ground level
  - Precise control of curvature not required
  - Planar mirrors ideal for smaller plants
  - Hyperboloid mirror is ideal for larger plants
- Validation of optical design code
  - Joint work in progress with ICT






Design feature : Low Cost light structure, Dust cleaning Water washing & Mopping - No manpower required




# Automatic Heliostat Cleaning System

# Design Validation- Rooftop Solar test facility

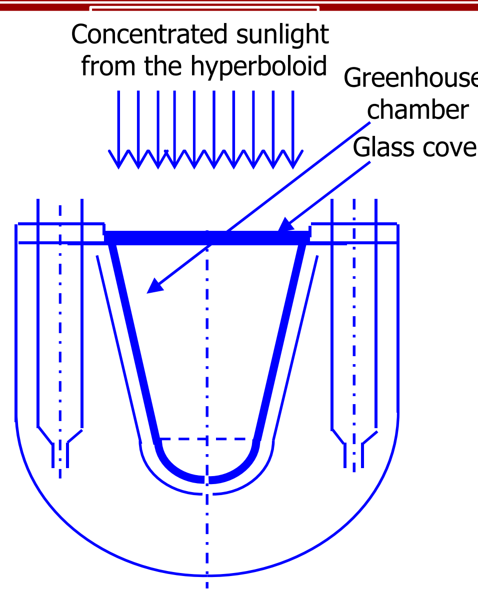
**Objectives:**

- ❖ Performance validation
  - ➢ Heliostat
  - ➢ Integral Receiver
  - ➢ Tracking mechanism
  - ➢ Air cooled condenser
- ❖ Demonstration of the desired molten salt temperature
- ❖ Demonstration of steam generation at the desired conditions for power generation

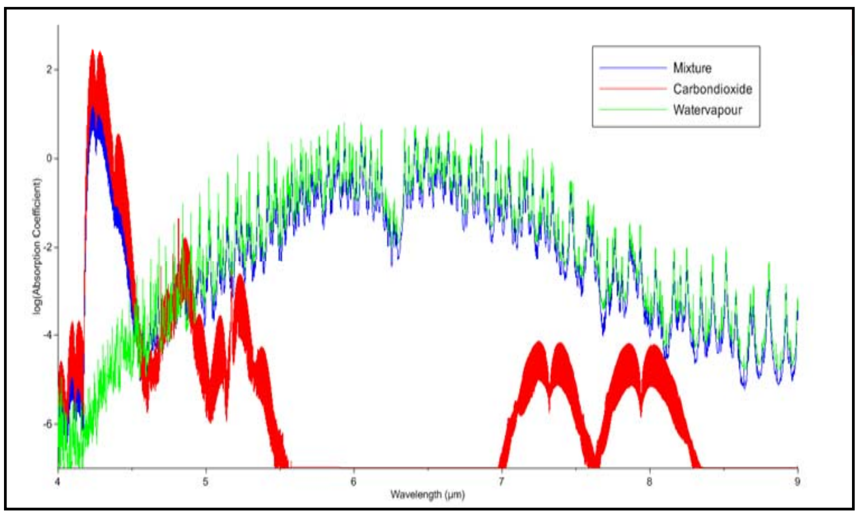

Molten salt receiver

# Greenhouse Radiation Shield Development

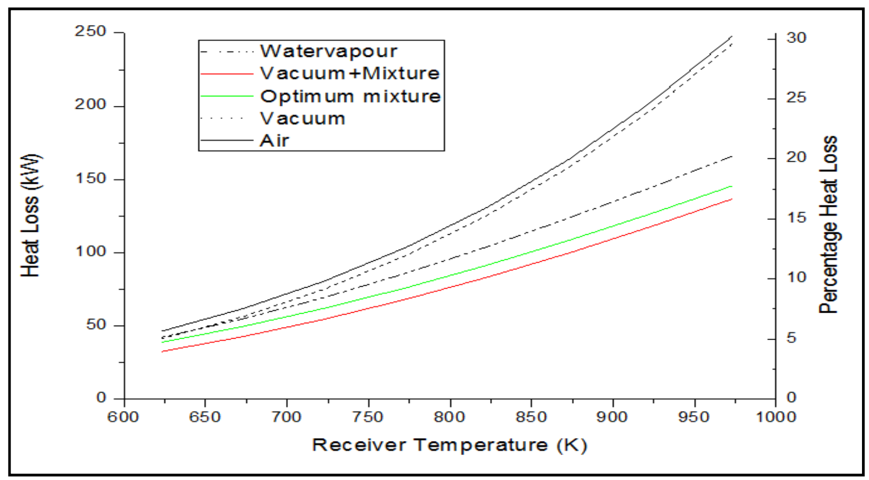
- Greenhouse gases are transparent to solar radiation and opaque to the radiation emitted by the receiver.
- Greenhouse gas reduces radiation loss from the receiver surface
- Calculations show ~8% saving which is roughly the same as lost due to additional reflection at the hyperboloid surface
- Additional savings looks possible with mixture of gases
- Spillage can be collected to heat feed water.




Greenhouse radiation shield



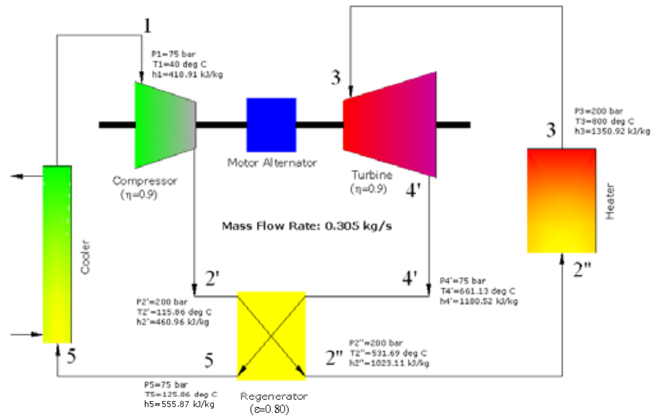

Absorption coefficient Vs wavelength for individual gases and mixture



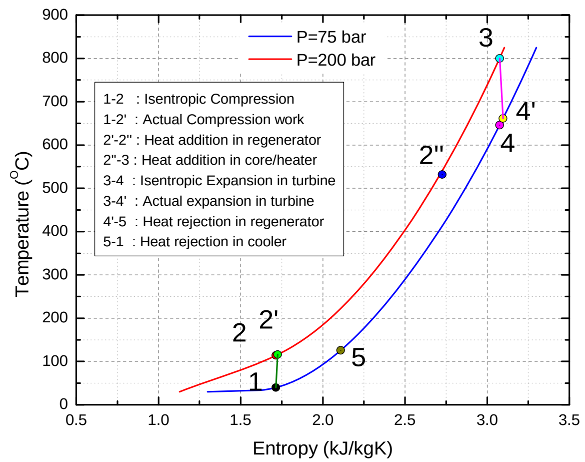

Heat loss variation with greenhouse gas radiation shield

# Development of High Efficiency Power Conversion Cycle

- Brayton cycle is cheaper and simpler than Rankine cycle
- With Supercritical $CO_2$, overall cycle efficiency of 35-50%
- Critical temperature of $CO_2$ is ~$31^0$C and pressure ~ 7.4 MPa avoiding two-phase region
- Compact size components compared to steam cycle
- Compressor work is less for SC $CO_2$
- High rotational speed
- Joint work in progress with academic institutes & industry participation



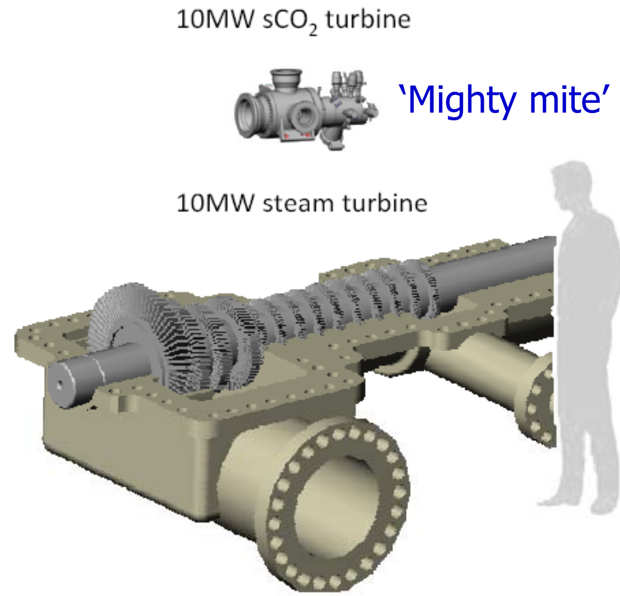

**Brayton cycle Power Conversion System**



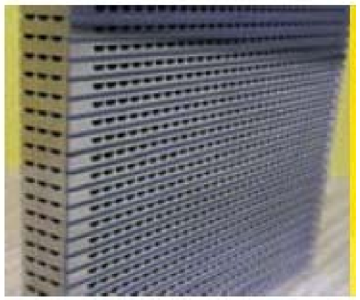

**T-S diagram for Brayton cycle Power Conversion System**

# Advantages of SCBC

- The SCBC power conversion system is promising for advanced nuclear reactors, solar, geothermal or fossil fuel systems. The main advantage of a SCBC are:
  - Reduced compression work:
    - Efficiency improvement.
  - Simplified cycle:
    - Single compressor without inter-cooling stages.
    - High pressure: compact heat exchangers and turbines.
  - Significantly fewer turbine compressor stages than helium based Brayton cycle
  - SCBC with air cooled HX eliminates water requirement (attractive for desert sites)
  - Small overall size:
    - Smaller footprint,
    - Better economics (~18% less cost compared to traditional Rankine cycle).




Ref: M/s. Ecogen Power Systems

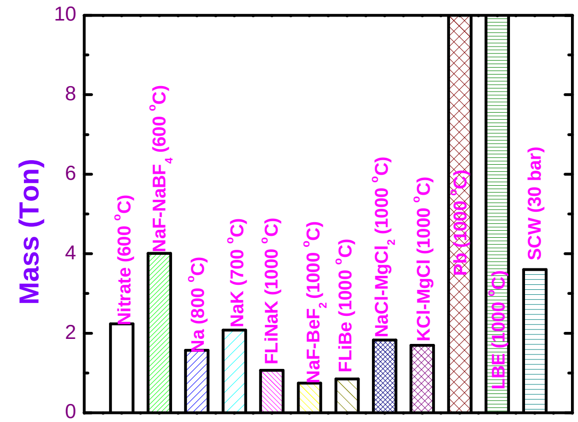


**PCHE Block Section**

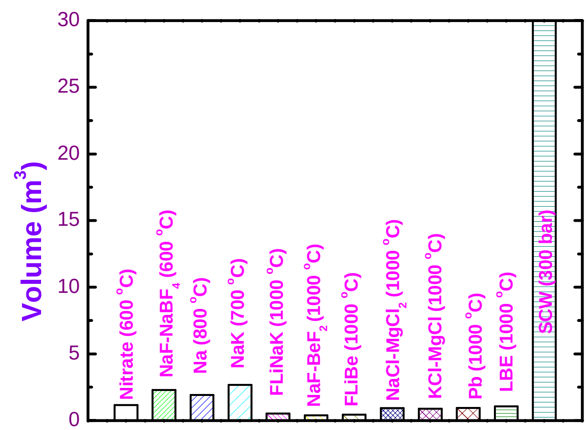
Ref: V. Dostal et. al., "A S-CO2 Brayton Cycle for Advanced Reactor Applications," *Transactions of the American Nuclear Society,* 85, ( 2001).

# High Temperature Thermal Energy Storage

- Required for power tower
- Only liquids are considered as heat extraction to generate steam is easier
- Candidate fluids considered are molten metals, molten salts and supercritical water
- The volume is directly related to the size of the vessel
- Molten salts and molten liquids can be stored at low pressure compared to SCW
- Molten salts and liquid metals are excellent high temperature TES media




**Mass required to store 1 GJ**




**Volume required to store 1 GJ**

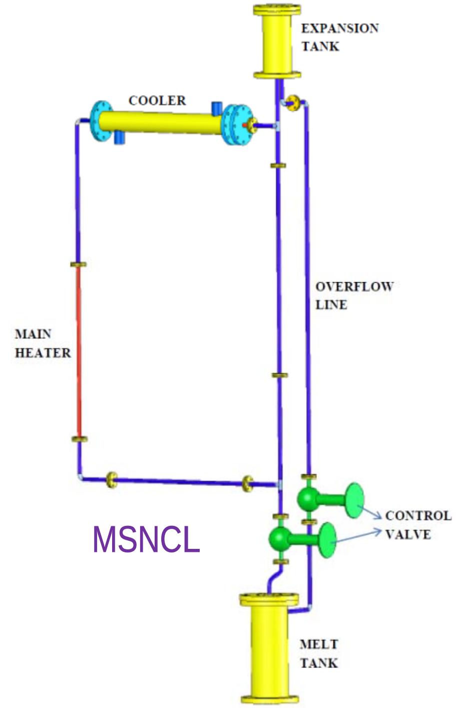
# Molten Salt Natural Circulation Loop (MSNCL) and Molten Salt Corrosion Test Facility (MOSCOT)

**Molten Salt used for experiment:**
- 60:40 mixture of $NaNO_3$ and $KNO_3$
- Tests planned with FLiNaK

**Experiments performed:**
- Steady state NC performance at different powers

**Operating conditions**
- Cooling media: Air
  - Max. power: 2kW

**Loop Geometry**
- Inside diameter: 14 mm
- Height of the loop: 2m
- Total circulation length: 6.8m



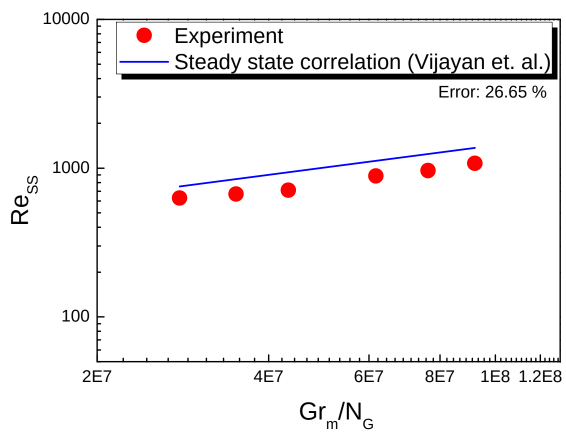

MSNCL

Photograph of MOSCOT Facility

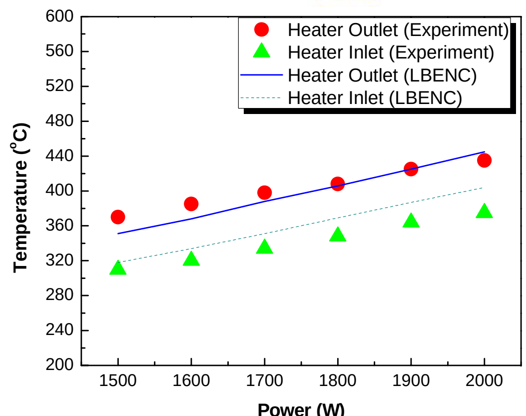
**Molten Salt used for corrosion study:**
- Eutectic mixture of LiF-NaF-KF

Corrosion rate of different structural materials in 'mpy'

| Temp °C | Inconel 600 | Inconel 617 | Inconel 625 | Incoloy 800 |
|---|---|---|---|---|
| 550 | 6.2 | 10.0 | - | 17.4 |
| 600 | 12.2 | 18.2 | 6.1 | 30.1 |
| 650 | 25.9 | 22.7 | 5.0 | 31.2 |
| 700 | 25.4 | 33.9 | 71.3 | 45.4 |
| 750 | 15.8 | 97.9 | 127.6 | 33.2 |

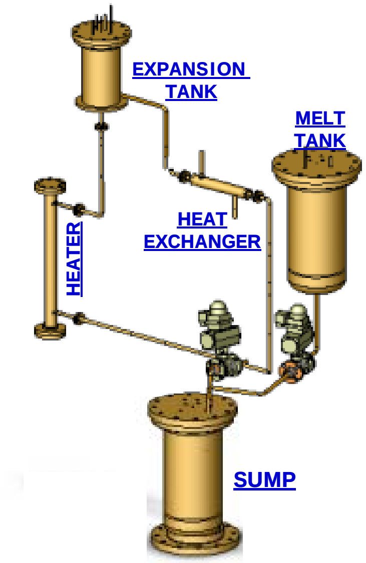



Steady state performance of MS NCL




Steady state temperatures of MS NCL

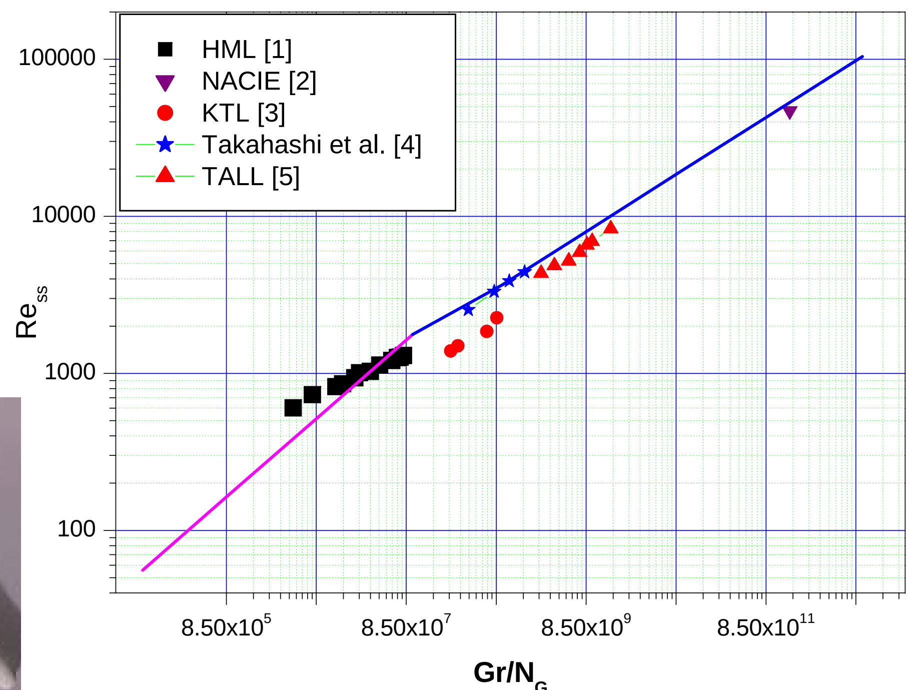
# Thermal hydraulic Studies for LBE Coolant




Liquid Metal Loop (Up to 550 °C)

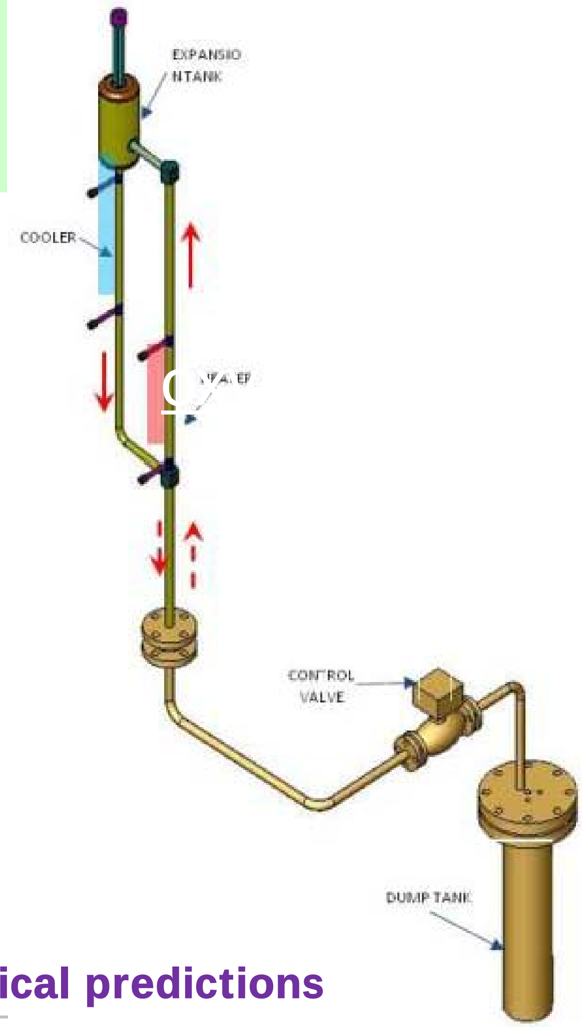
**Major areas of development**

- Analytical studies and code development
- Liquid metal loop for experimental studies
  - Loop at 550 °C operating since 2009
  - KTL established and operated up to 1000 °C
- Steady state and transient tests carried out
- In-house developed code validated




**Steady state data compared with analytical predictions**

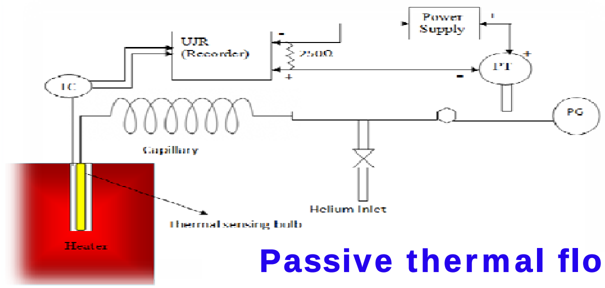
Isometric of Kilo Temperature Loop (KTL)



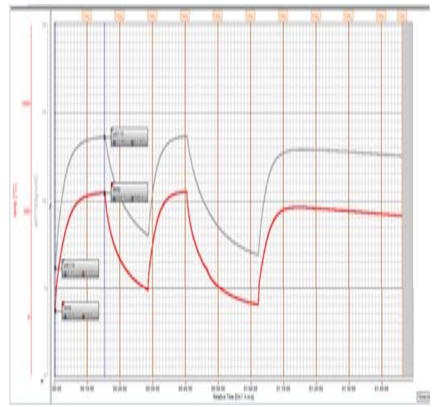

Oxygen sensor

# Development of Passive Controls

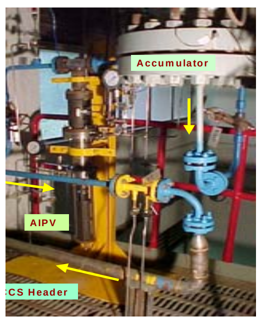
- Passive controls by definition do not use any external power source
  - Derives power from the system based on natural physical laws such as buoyancy and gravity
- Passive controls involve the use of
  - Passive sensors (pressure, delta-P and level)
  - Self powered sensors (e.g. thermocouples)
- Typical passive controls under development
  - Passive temperature control,
  - Passive flow control and
  - Passive level control using PPPT
- Passive valves under development
  - Several PVs developed for AHWR



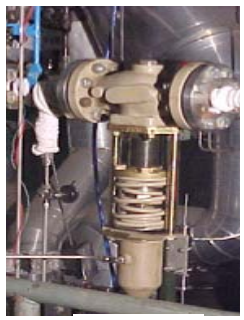

**Passive thermal flow control test setup**



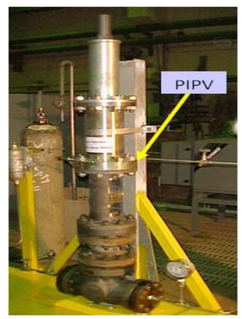
**Thermal flow control valve test facility and valve response**




**HSPV**



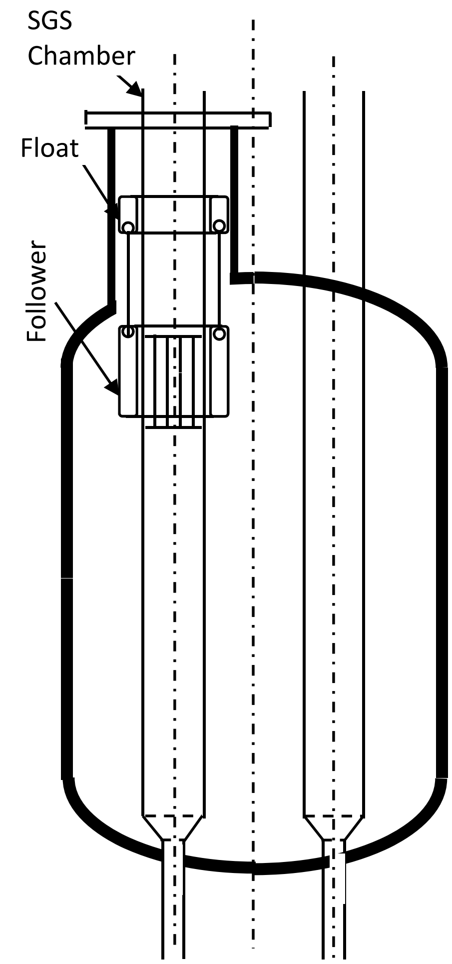
**AIPV**




**PPIV**

# Passive Flow Control

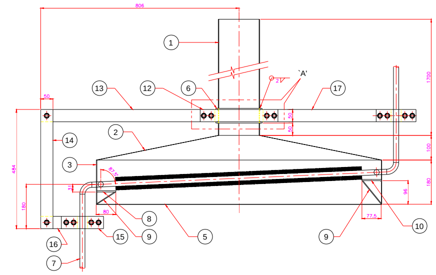
- Float and follower is used to achieve passive flow control
- As more heat is stored, the MS level increases due to temperature increase
- The level increase raises the float and the follower blocks the slot area
- The blocking of the slot reduces the flow maintaining the heat extracted by the SGS constant.
- To enhance the level increase, a narrow portion of the vessel head is elevated.




Passive flow control
in SGS cum TES vessel

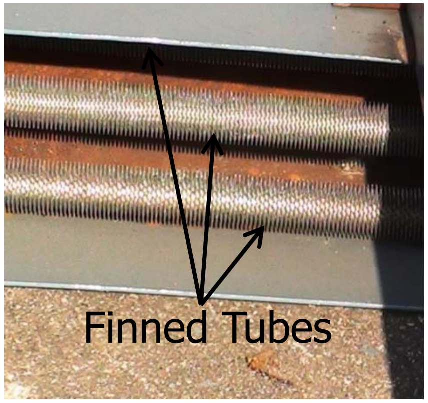
# Passive air cooled Condenser Development

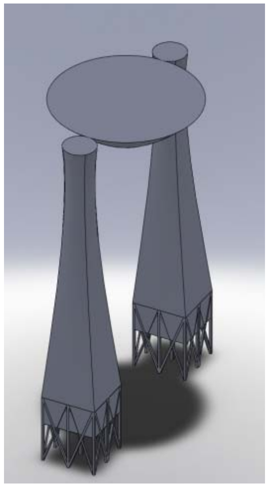
- Passive air cooled condensers enable solar power towers to be sited in deserts
- Also enables nuclear power plants to be sited in deserts
- Leads to some efficiency loss
- Low land cost
- Studies are in progress to enhance heat transfer using nano fluids



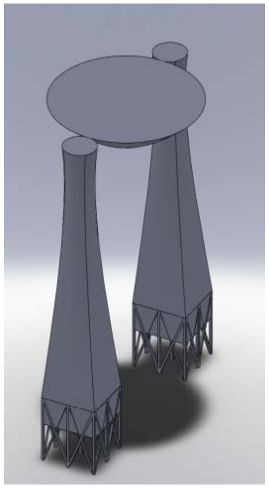
Schematic of ACC test facility

Air cooled condenser test facility



**The central tower supporting the hyperboloid mirror can be used as passive air cooled condenser**



**Passive air cooled condenser**

# Concluding Remarks

- Beam down concept has several advantages
- Technology developments required are identified and in progress. Important among them are
  - High efficiency power conversion system
  - Optimisation of optical components
  - Benchmarking of optical design
  - Passive air cooled ultimate heat sink
  - Passive controls
- Performance validation of integral receiver is required
- To be cost effective with solar PV, we need overall cycle efficiency to be more than 28%.
- Harnessing solar thermal energy economically is a technological challenge and requires advanced technology


Thank You
Wake up to the
technological challenge to
preserve the environment