22.033 Core Group- Reactor Core and Secondary Design

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Overview

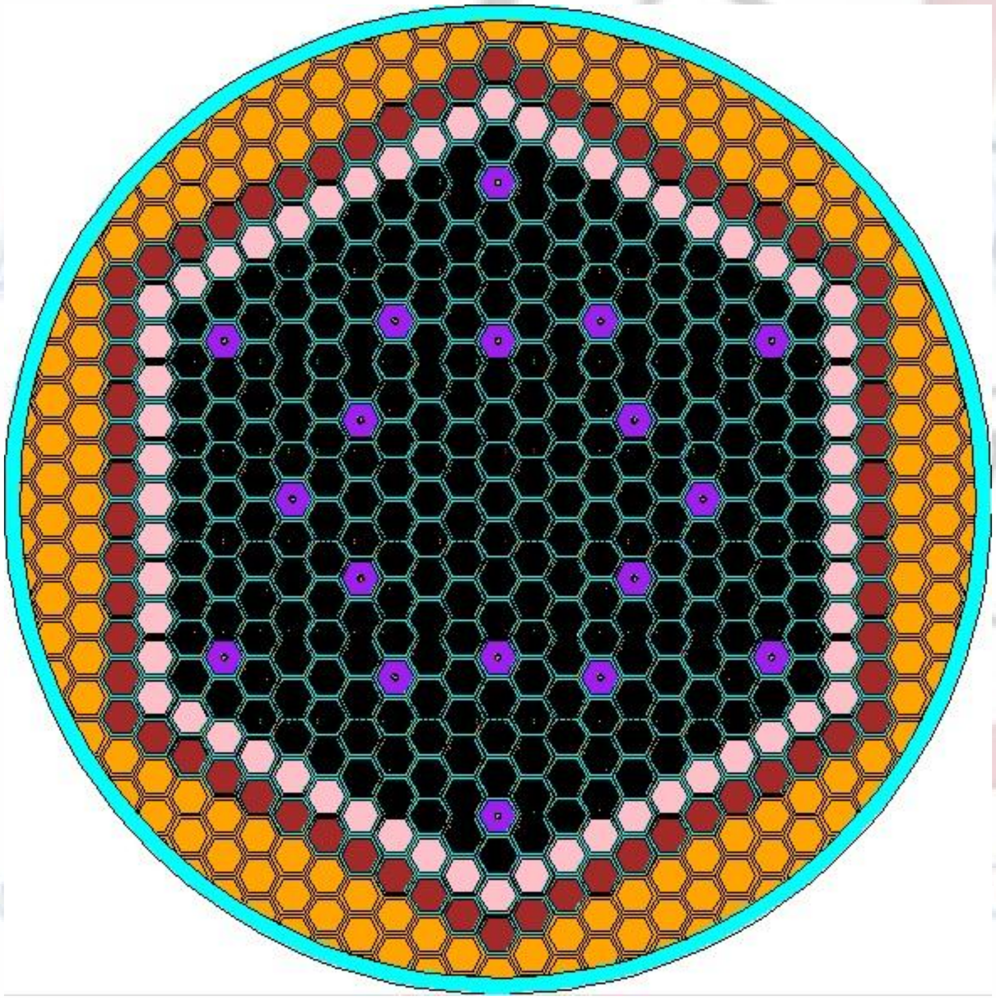
- Proposed Design & Specs
- Core
- Secondary
- Next Steps

Preliminary Design

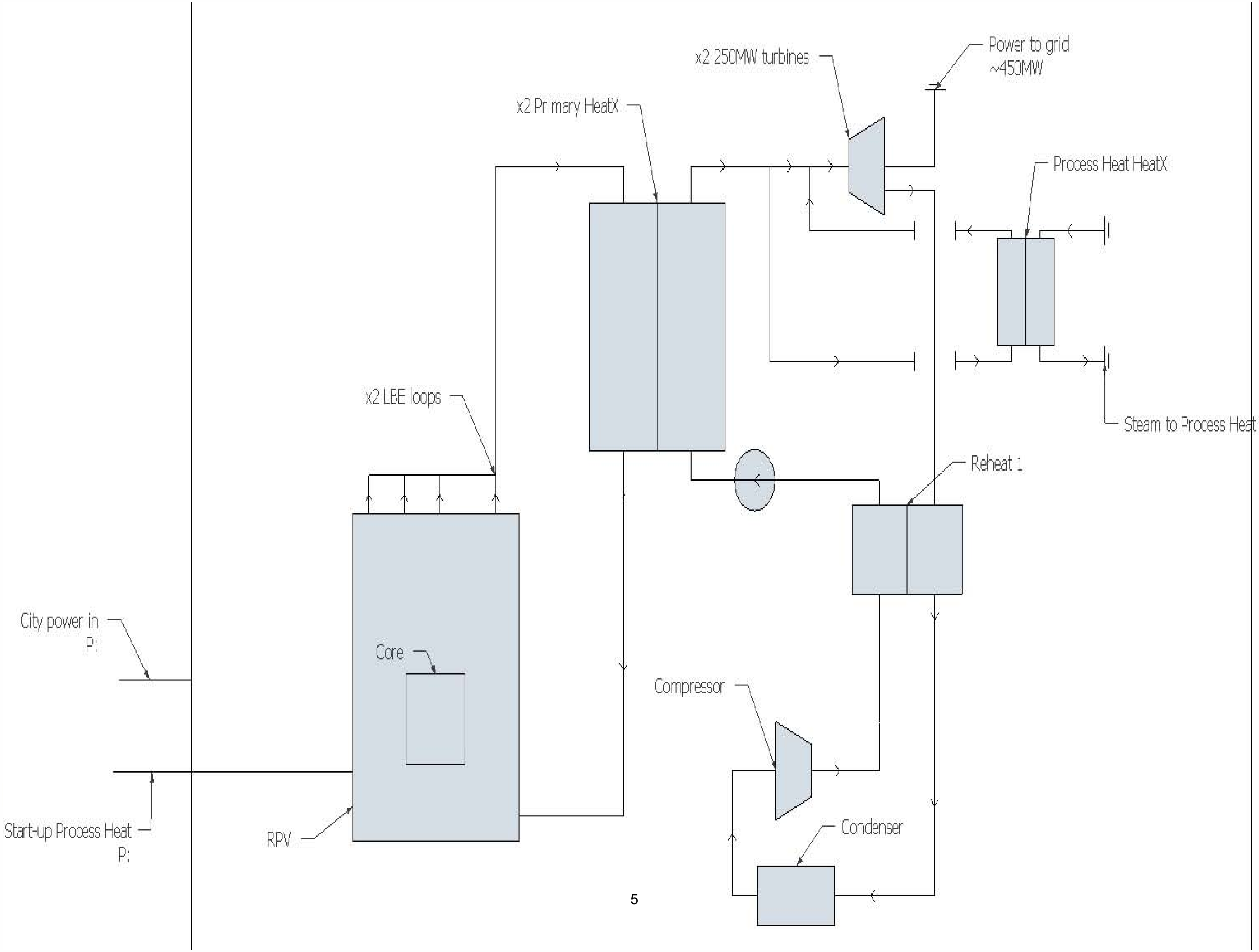
- Lead Cooled Fast Reactor with Supercritical CO_2 Secondary Loop

- 1000 MWt (~450 MWe)
  - Limited by velocity of LBE (2.5-3 m/s) currently we are using 2.5 m/s
  - Subject to changes as ΔT and flow area changes (working on upping it to ~1200 MWt)

Preliminary Design



- Black- Fuel Regions (UO_2)
- Purple- Control Rods (B_4C)
- Beige- Reflector (MgO)
- Red- Shield (B_4C)
- Orange- Coolant (LBE)
- Note the Blue containment is not the actual containment (in reality it is larger)



x2 250MW turbines
Power to grid
~450MW
x2 Primary HeatX
Process Heat HeatX
x2 LBE loops
Steam to Process Heat
Reheat 1
City power in
P:
Core
Compressor
Condenser
Start-up Process Heat
P:
RPV

Core Design Process

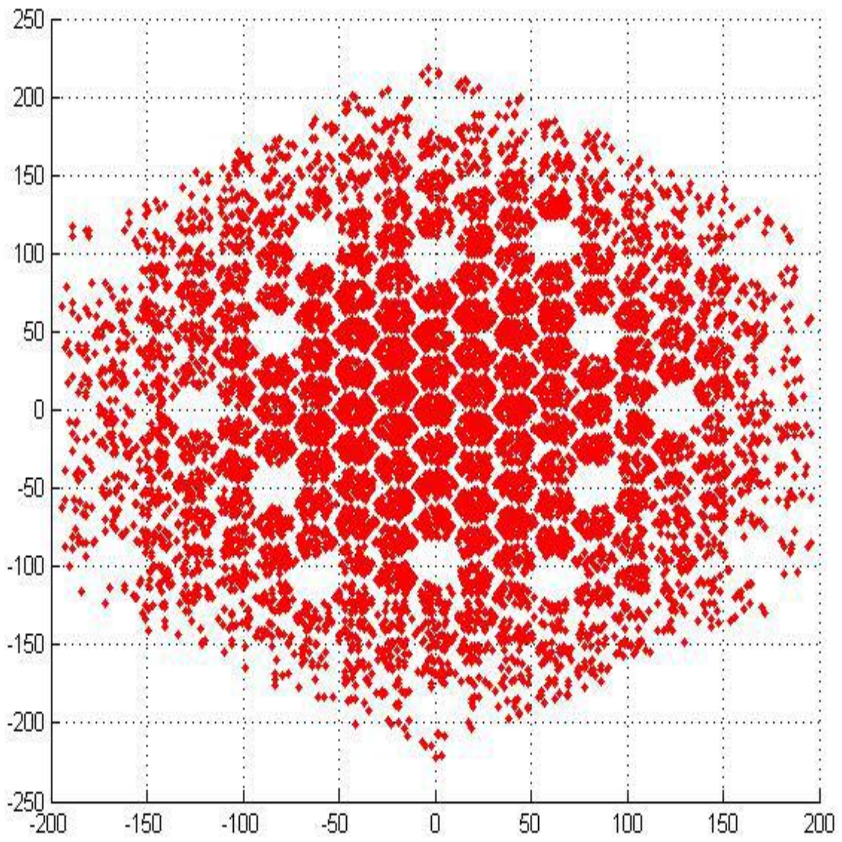
- Used MCNP (Monte Carlo N-Particle) code to design reactor
- Based off of other similar hexagon core shaped liquid metal cooled reactors (STAR-LM, ELSY)
- Design Iterations

Iteration 1

- Version 1.0, looked at a lot of reference designs and created something similar
- See if it were critical
- Fuel Pin design: fuel ➔ LBE gap ➔protective clad ➔ T91 ➔ protective clad ➔ coolant
- It had the whole range of S/D with rods in and supercritical with rods out
  - Needed less reactivity at top of core (helps with S/D margin)
  - Needed less power peaking in the middle

Iteration 1

Control Rods	Keff (+- 0.0005)
In	0.96822
25% out	1.01184
50% out	1.08764
75% out	1.11812
Full Out	1.3265

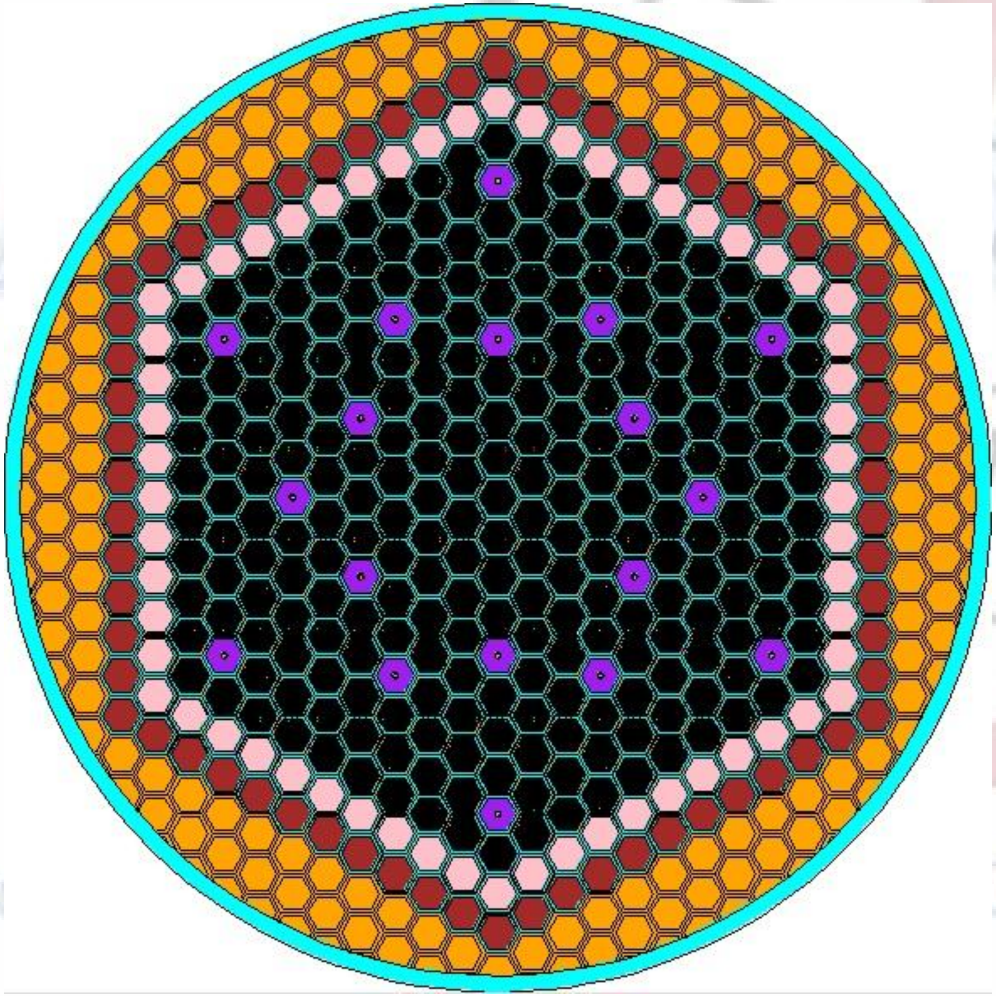


Iteration 2

- Added Axial Zoning to fix the large excess reactivity (20% enriched Lower, 15% enriched Middle, 10% enriched bottom)
- Added Radial Zoning to get a flatter flux profile (Added 5% to the outer rings)

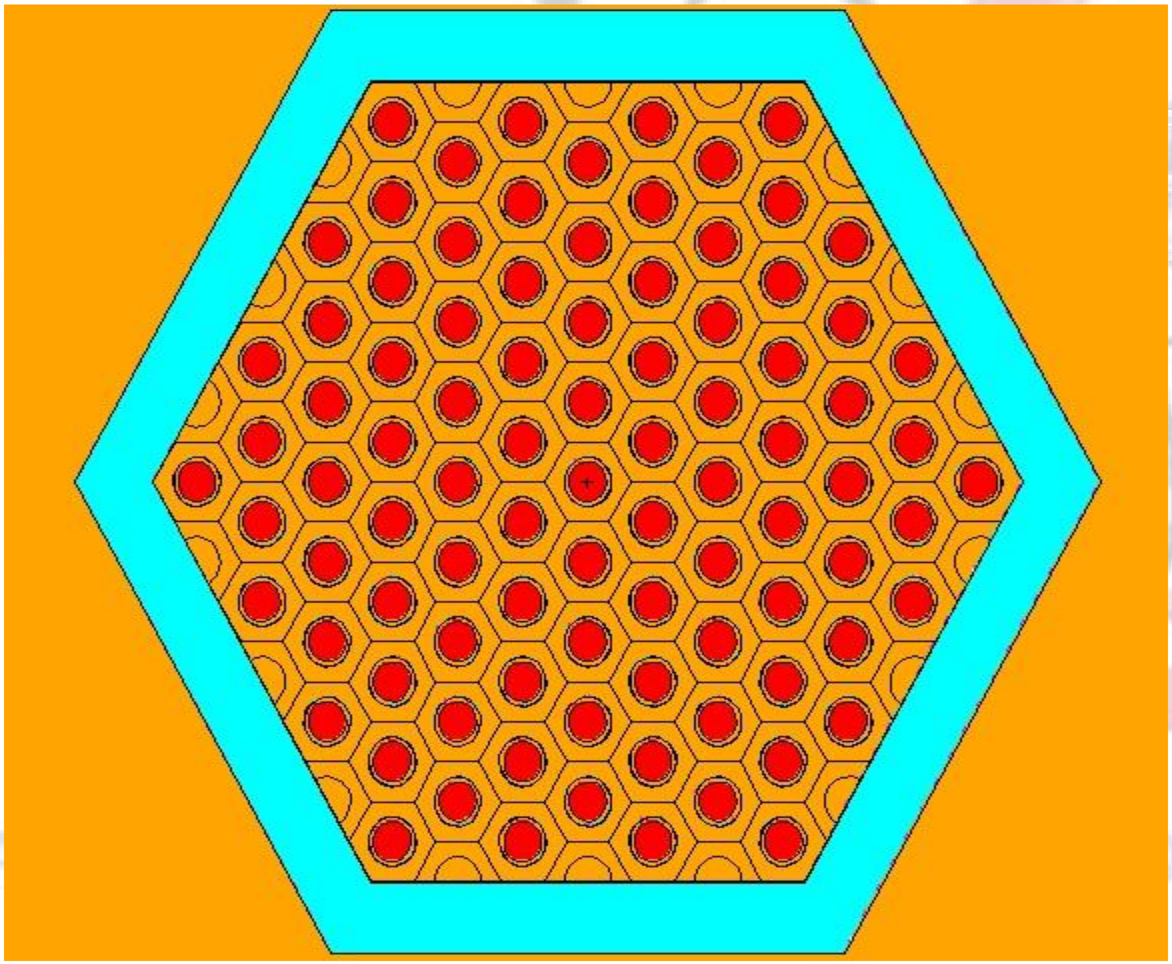
Control Rods	In	0.25	0.5	0.75	Out
Keff	0.95387	1.08059	1.15039	1.16142	1.16144

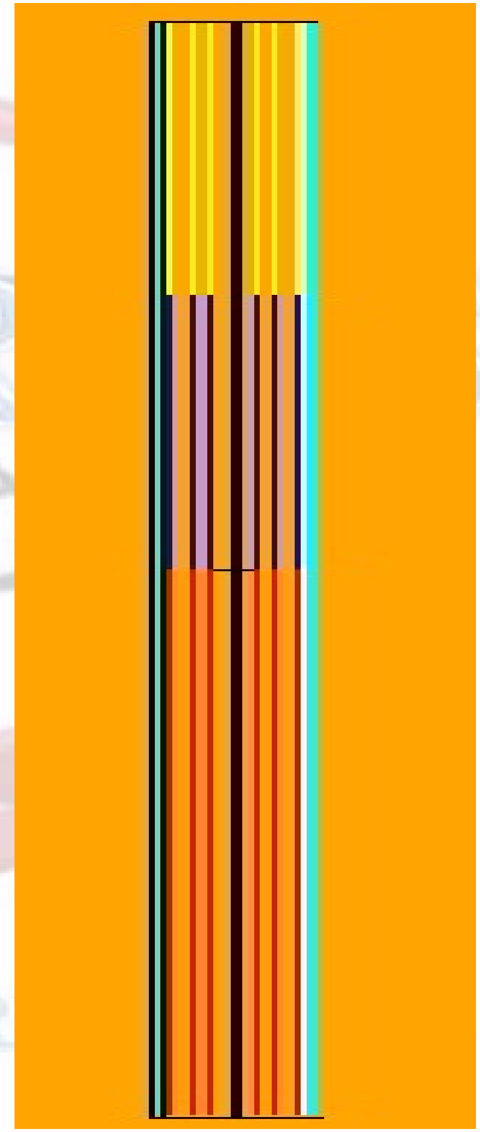
Iteration 2



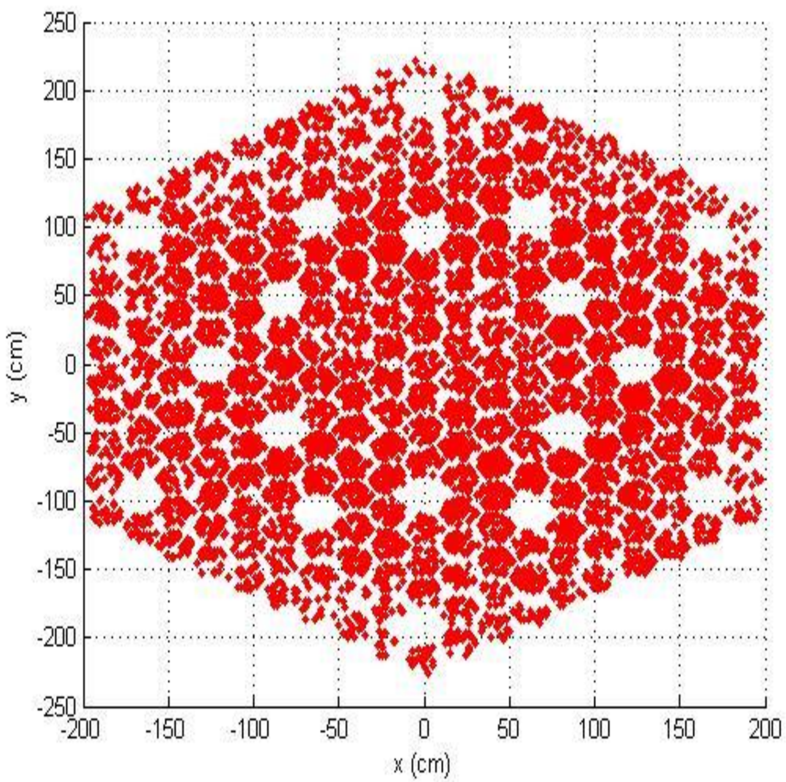
- Black- Fuel Regions (UO_2)
- Purple- Control Rods (B_4C)
- Beige- Reflector (MgO)
- Red- Shield (B_4C)
- Orange- Coolant (LBE)
- Blue- Cladding (T91 stainless steel, protective outer layer)
- Note the Blue containment is not the actual containment (in reality it is larger)

Iteration 2





Iteration 2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y (cm)
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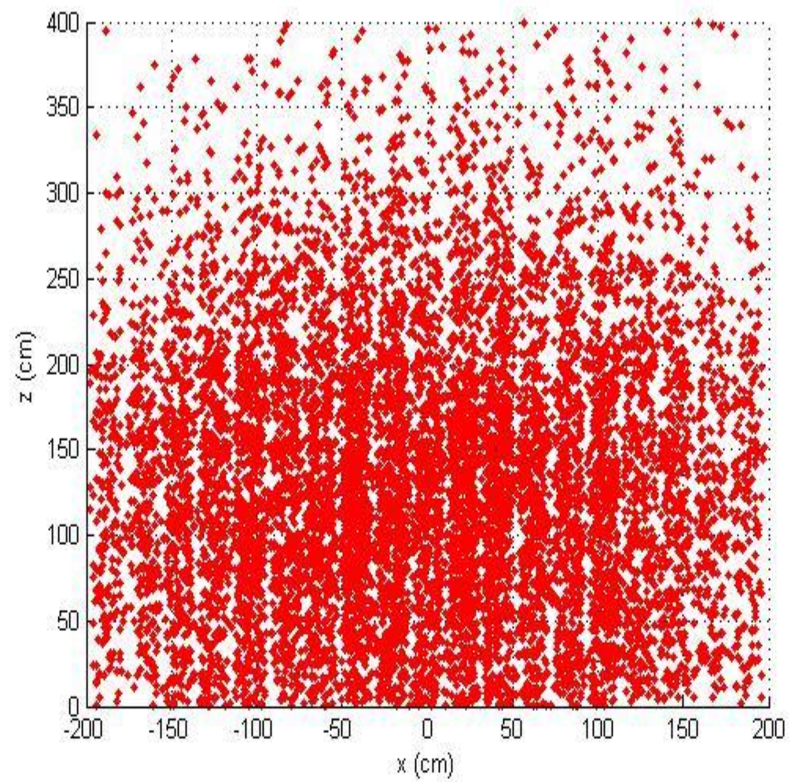
400
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Power Calculation

- Used Power= $\dot{m}\, c_p\, \Delta T$
- Where $\dot{m} = \rho\, v\, A$
- Where v is limited at 2.5 m/s, rho is 10500 kg/m^3 , A is the cross sectional coolant flow area, c_p is 150 J/kg·K and ΔT is the temperature change across the core
- Directly proportional to A and ΔT

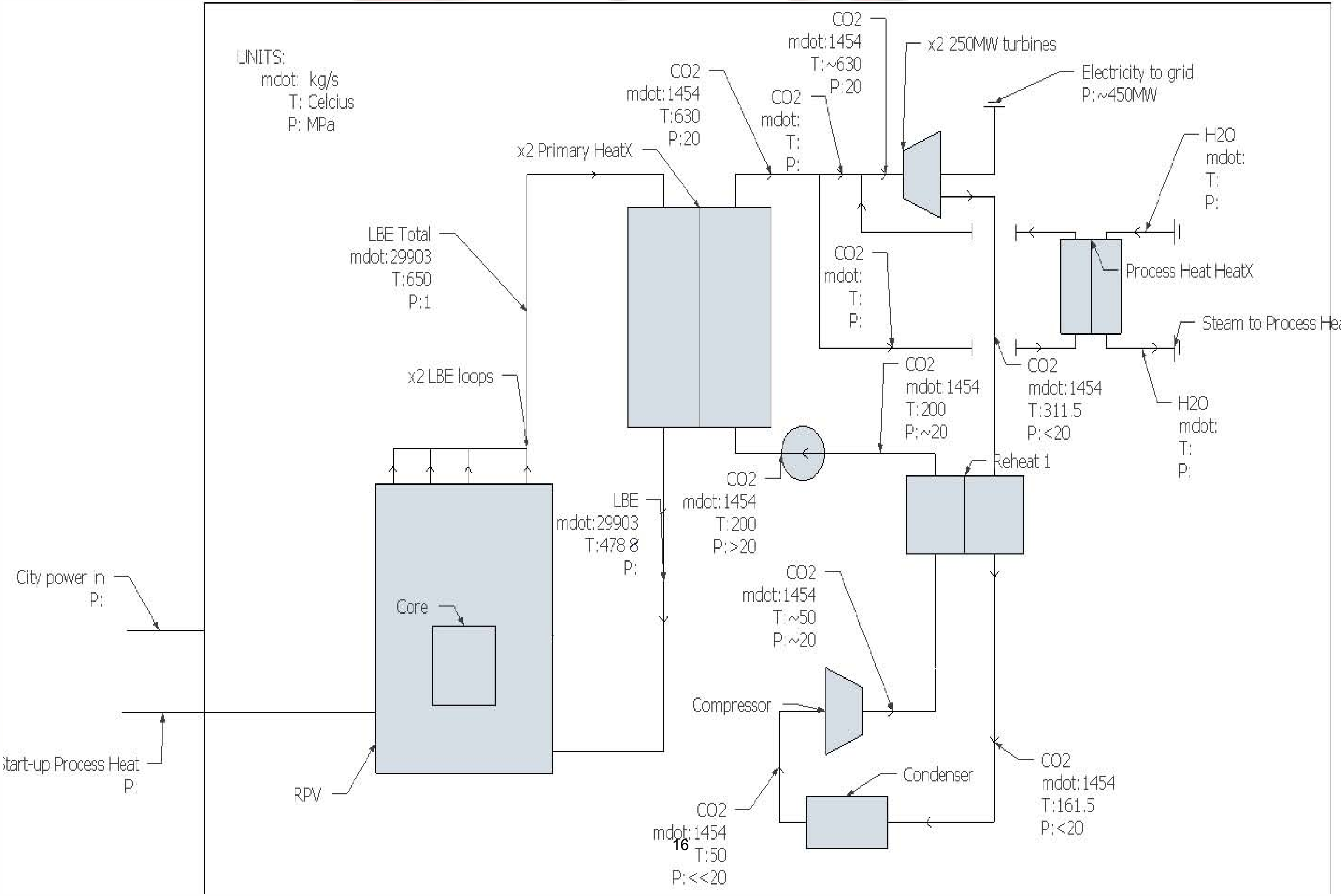
Decay Heat Removal

- After a month of shutdown from long operation still producing about 3 MWt of energy
- After a month of shutdown from 1 month of operation still producing 400 kWt of energy
- Need to see how much power produced is sufficient to keep LBE liquid and then work with process heat

Secondary System

- Modeled in EES
  - Temperature and mass flow calculations
- Initial Assumptions Made
  - Heat exchanger input and output for S-CO_2
  - Low end temperature after condenser
- Allows for faster optimization in the future

Secondary System



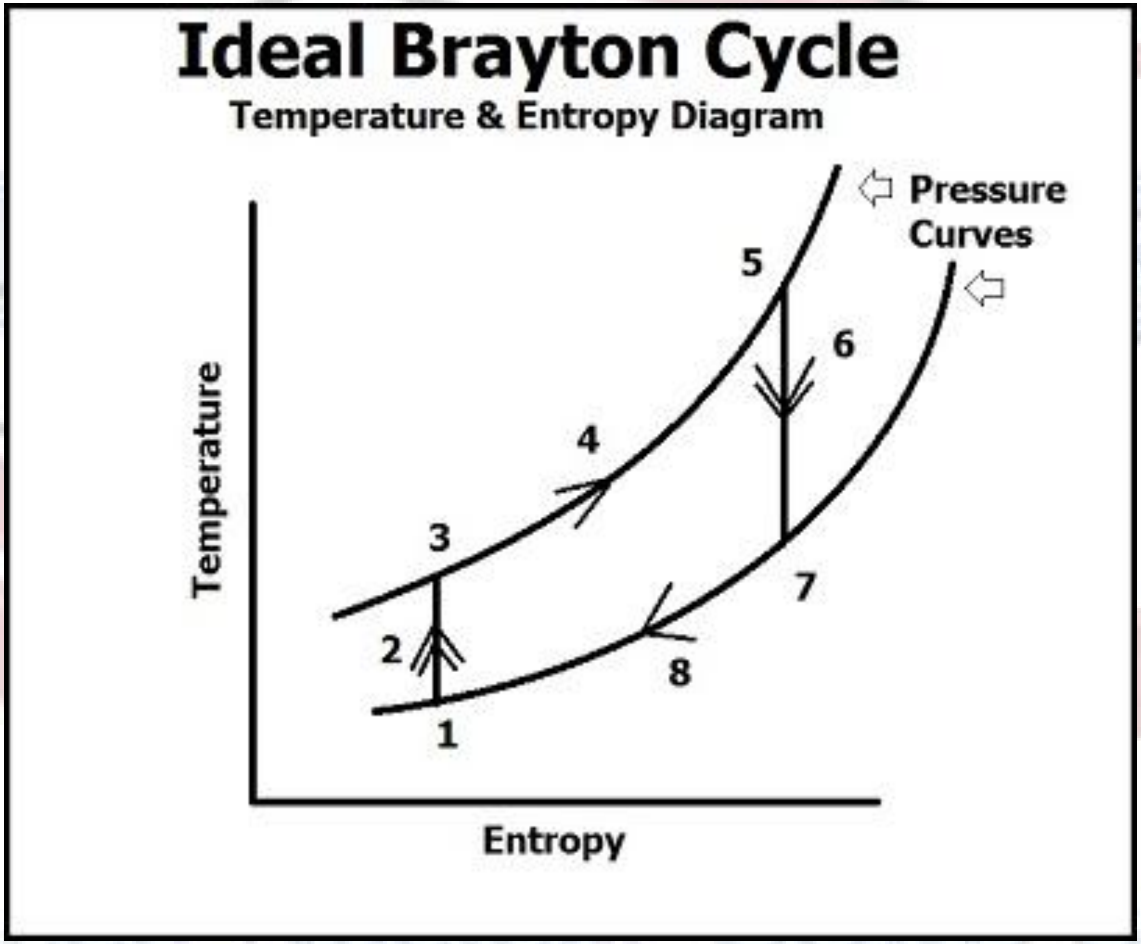
Secondary System

- More S-CO_2 data required to perform analysis of pressure changes.
  - Enthalpy Tables

- Possible second loop with an added re-heater and compressor to account for changes in specific heat

- Energy diverted to Process-Heat needs to be accounted for
  - Only majorly effects electricity generated

Brayton Cycle: Quick Overview



Source: UC Davis ChemWiki, license CC BY-NC-SA 3.0

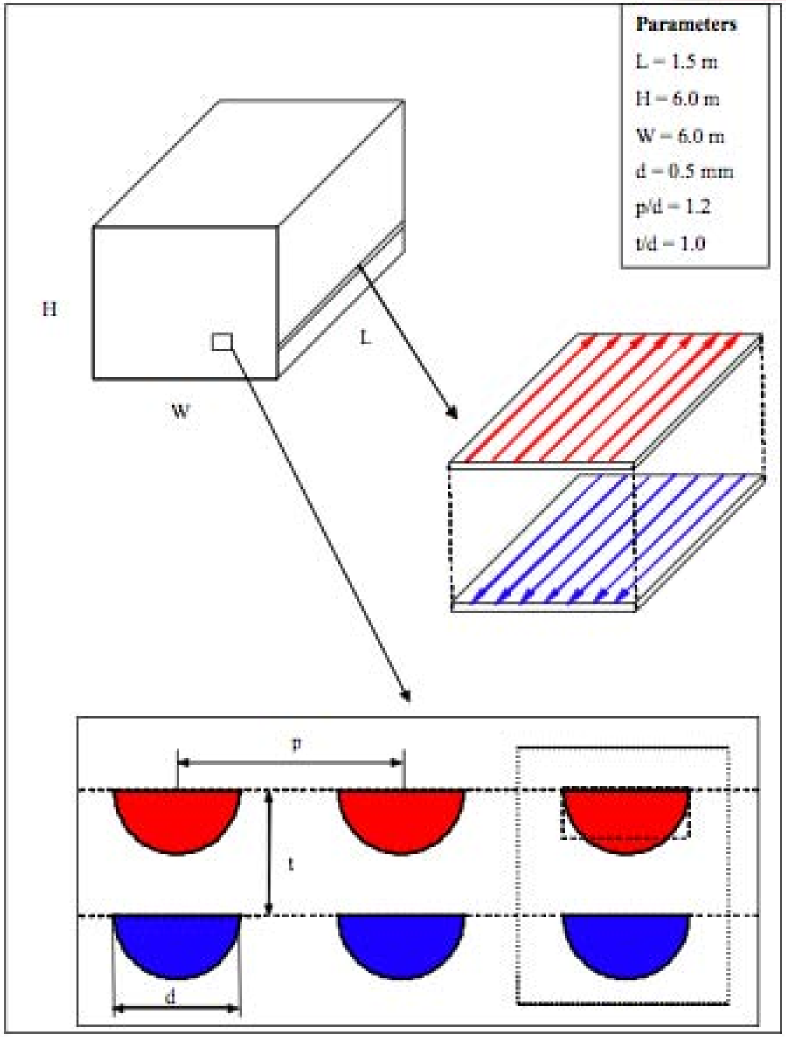
http://chemwiki.ucdavis.edu/@api/deki/files/13235/=TS_Curve.jpg

LBE & S-CO_2 Heat Exchanger

http://www.heatric.com/

- Printed Circuit Heat Exchanger (PCHE) vs. Shell-and-Tube Heat Exchanger

PCHE



- Compact design
- Competitive Efficiency
- Friction Factor for LBE becomes obstacle

Shell-and-Tube Heat Exchanger

- Simple design (easy to make, low cost, etc.)
- Larger than PCHE
- Competitive efficiency

http://www.thermopedia.com/content/1211/?tid=104&sn=1410

Next Step

- Secondary: Better data, more accurate values, possible second re-heater/compressor loop, and process heat removal

- Core: Natural Circulation, Decay heat work, continue optimizing core zoning, thermal analysis of fuel

QUESTIONS?

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