New Nuclear Design for Electric Power Systems

Senior Design Team 30

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Project Background

- Nuclear power has been a significant part of the power generated in the United States since about the 1970s, but many of the reactors are becoming outdated and are being retired.
- Previous reactor and plant designs were very costly and financially risky.
- The world is moving towards more carbon-neutral solutions to power generation.
- The ability to supplement solar and wind power with a carbon neutral solution would be majorly beneficial for renewables.

Project Overview

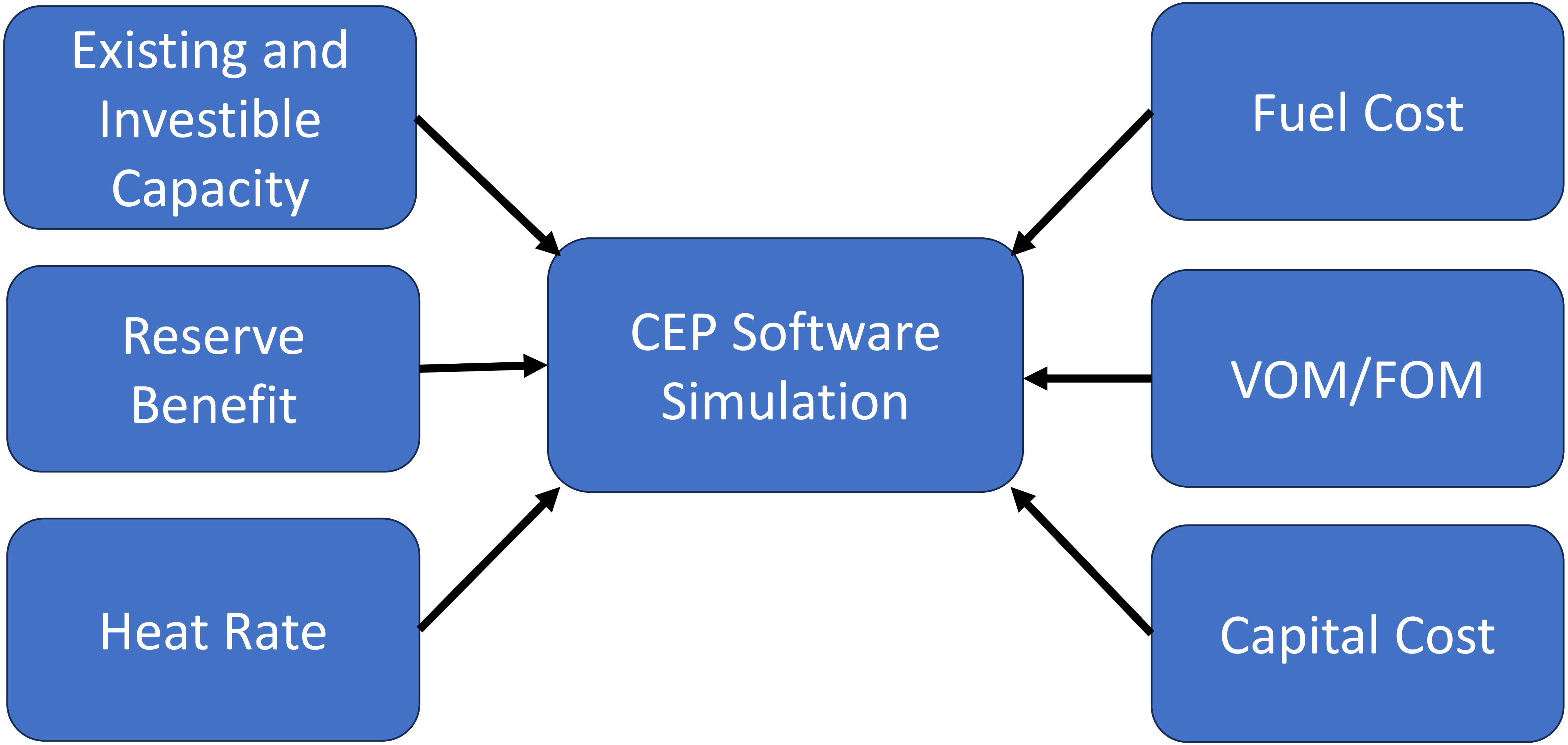
- Identify a “new nuclear” design that provides the highest benefit to cost ratio under a high renewables future.
  - 1. Identify all reasonably practical “new nuclear” designs that have been suggested so far. Develop a summary report of these technologies that identifies their strengths and weaknesses. Estimate the Benefit to Cost ratio of each design.
  - 2. Identify a “recommended design” (RD). The RD could be one of the technologies surveyed, or it could be an extension of one of them, or it could be an integration of two or more of them.
  - 3. Identify any significant problems with the design and describe solutions for these problems. Provide a convincing argument that the RD’s Benefit to Cost ratio is better than all other designs considered.
  - 4. Identify and evaluate tools useful in designing and assessing the performance of the nuclear power plant.

Design Process

- Field of 15 potential recommended designs narrowed down to 6.
- Designs are evaluated based on the following criteria:

Reactor Type	Power Output (MWe)	Overnight Cost (First in Class and nth type)	Estimated Construction period	Refueling Cycle
Benefit to Cost Ratio	Operational Date	Important/Unique features	LCOE	Thermal Efficiency

Co-optimized expansion planning (CEP)



CEP Software Simulation

Each plant evaluated on 3 separate buses:

Bus	Conditions
Bus #1	• Capacity equivalent to 1 plant preexisting • No investible capacity
Bus #2	• No preexisting capacity available • Capacity equivalent to 1 plant available for investment
Bus #3	• Capacity equivalent to 1 plant preexisting • Capacity equivalent to 1 plant available for investment

CEP Analysis: Natrium

All available investible capacity utilized

- Natrium had the 2nd lowest Capital expenditure ranking (2.9 Billion $ / GW)

All existing/preexisting capacity was utilized in each time interval

- At 41% thermal efficiency, Natrium has the highest efficiency of the SMRs tested

CEP Analysis: VOYGR

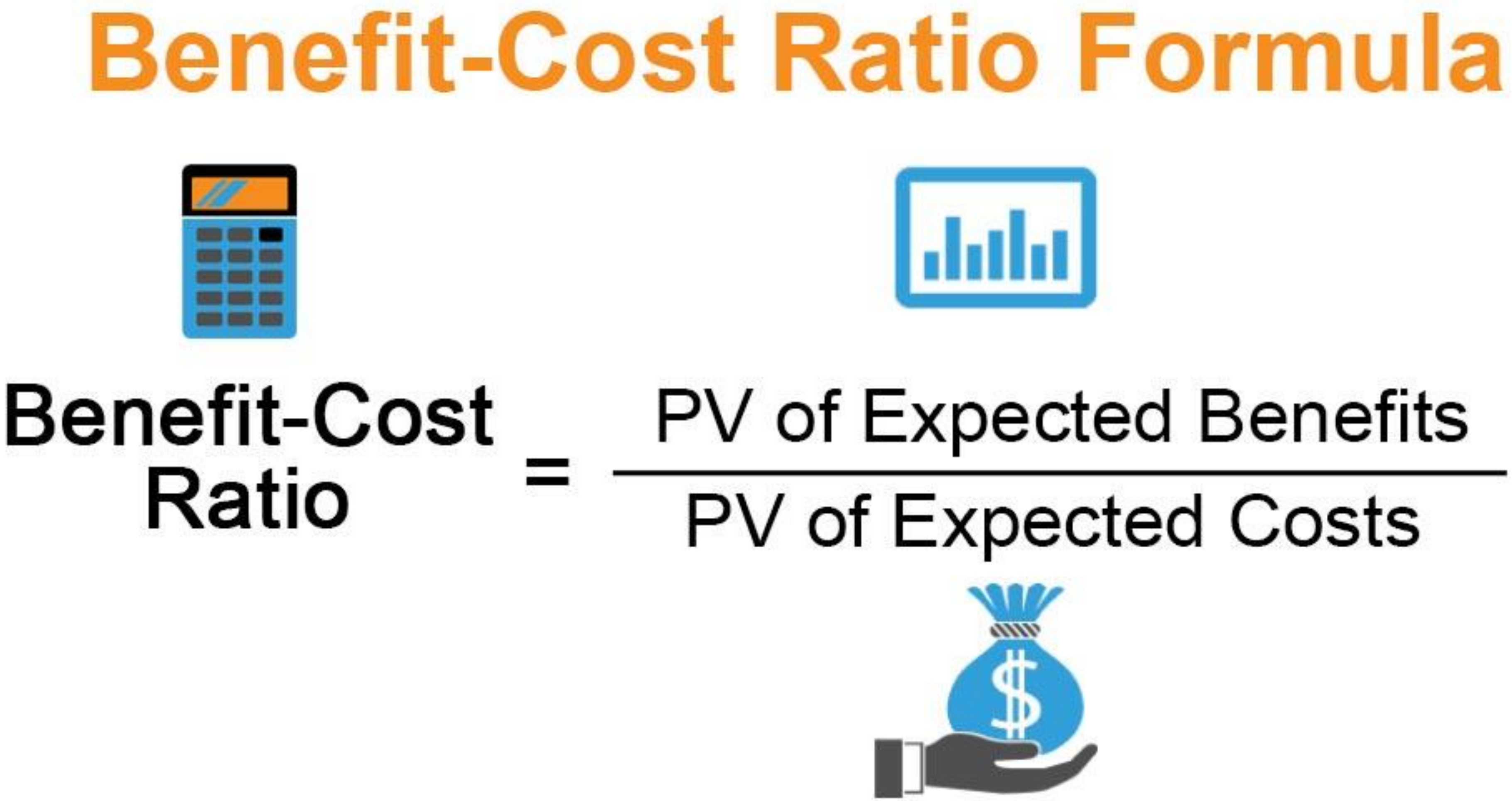
No new investments made into VOYGR

- VOYGR had the highest Capital expenditure rating of all SMRs tested (7.79 Billion $ / GW)

Preexisting capacity not utilized fully in first time interval

- With a thermal efficiency of 30%, VOYGR tied for the lowest efficiency of the SMRs tested.

Benefit-Cost Calculations



Variables Considered

Benefits

- Sale of Energy
- Regulating Reserve
- Spinning Reserve
- Supplemental Reserve
- Capacity Benefit

Numbers pulled from historical MISO data

Costs

- Fuel Costs
- Fixed O&M
- Variable O&M
- Overnight Cost

Numbers pulled from company websites, historical data, etc.

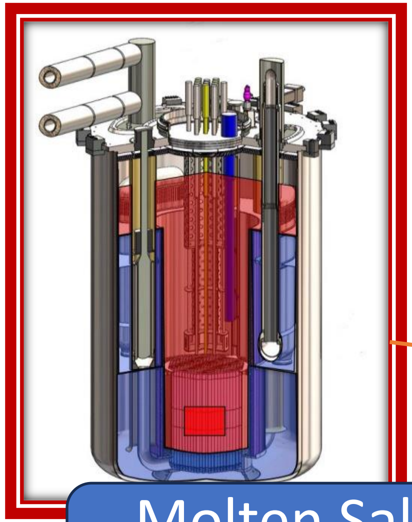
Benefit-Cost: Results

Reactor	1st Build Benefit-Cost Ratio	Nth-Build Benefit-Cost Ratio
Natrium by TerraPower	0.85	2.33
VOYGR by NuScale	0.98	1.94
PRISM by GE Hitachi	0.99	1.68
SMR-160 by Holtec	1.39	1.39
BWRX-300 by GE Hitachi	2.14	2.62
ARC-100 by ARC	1.91	1.91

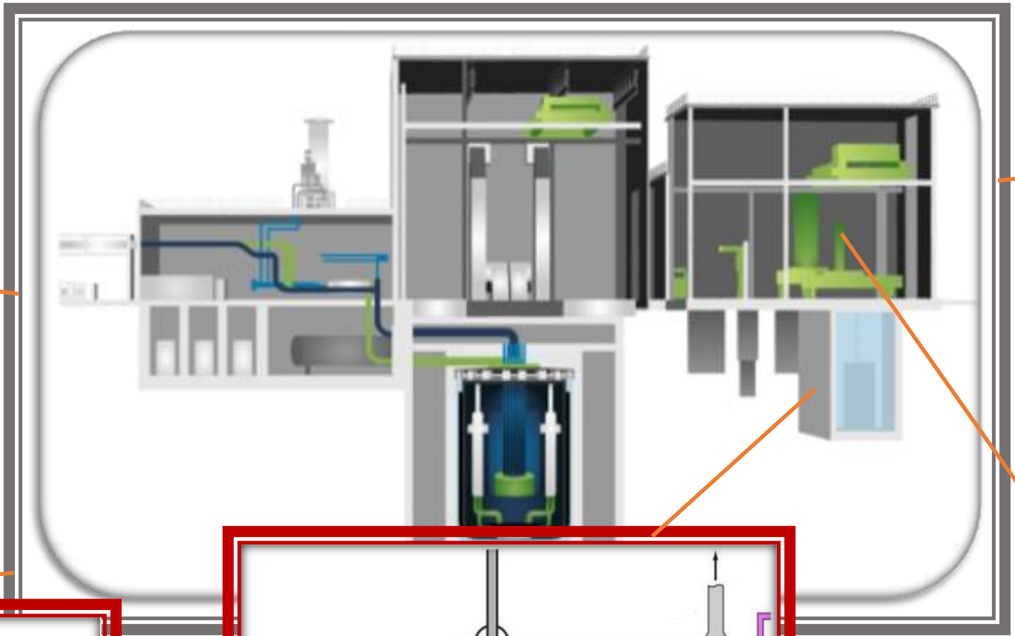
Several don't make sense for the 1st build, but all become economically viable by the nth build

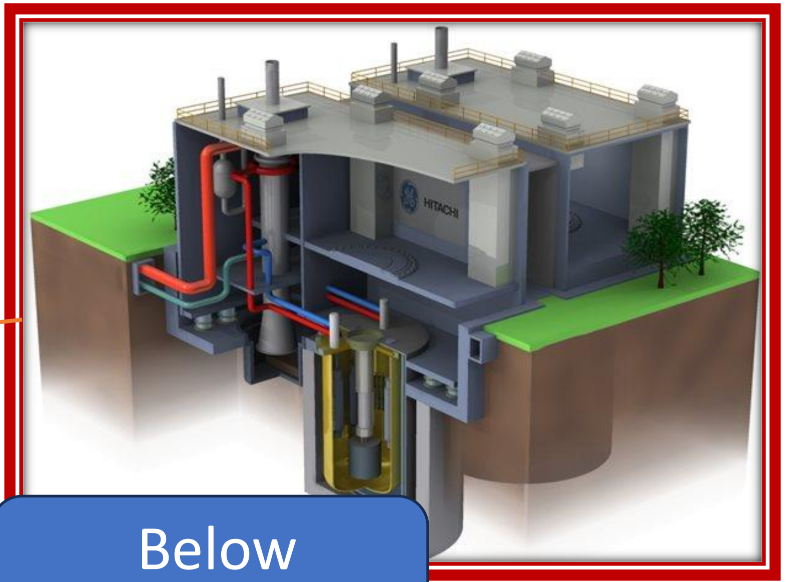
BWRX-300 and Natrium stand at the top

Recommended Design

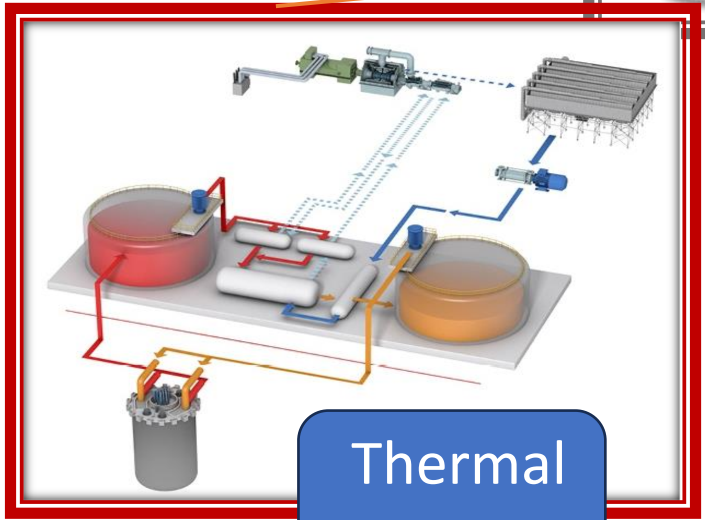


Molten Salt Fast Reactor

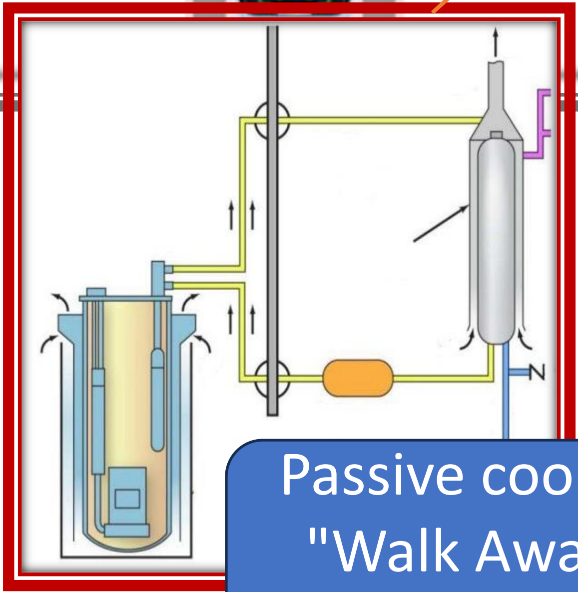




Below Ground Level

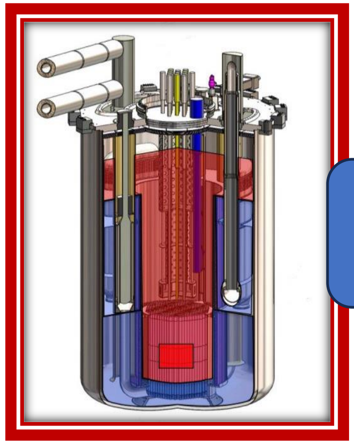


Thermal storage



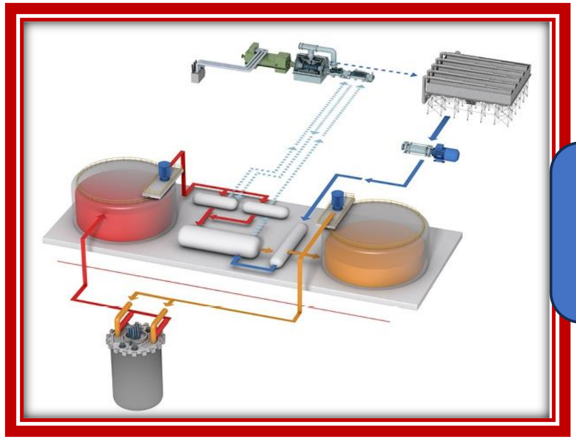
Passive cooling "Walk Away" system

Conventional Fuel, U-235



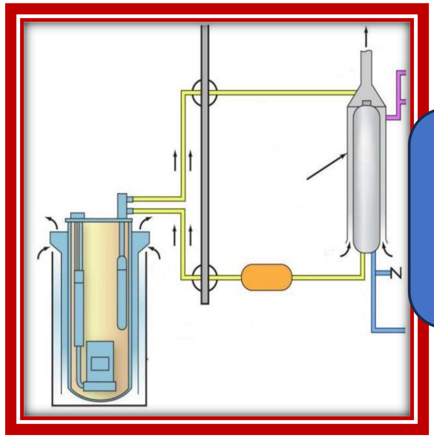
Molten Salt Fast Reactor

- Sodium fast-cooled reactor.
- Liquid sodium as a coolant (Excellent heat transfer properties).
- Does not undergo heat changes like boiling water reactor.
- Operate at near atmospheric pressure.



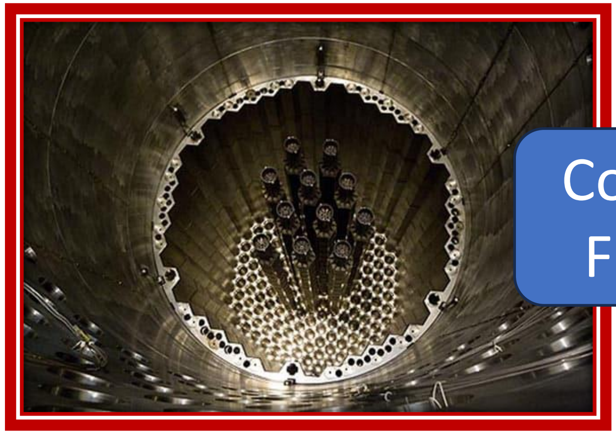
Thermal storage

- A feature from the Natrium reactor design.
- Load-following ability.
- The system uses the excess heat generated by the reactor, storing thermal energy,
- Can then be used to generate electricity during higher load demand.



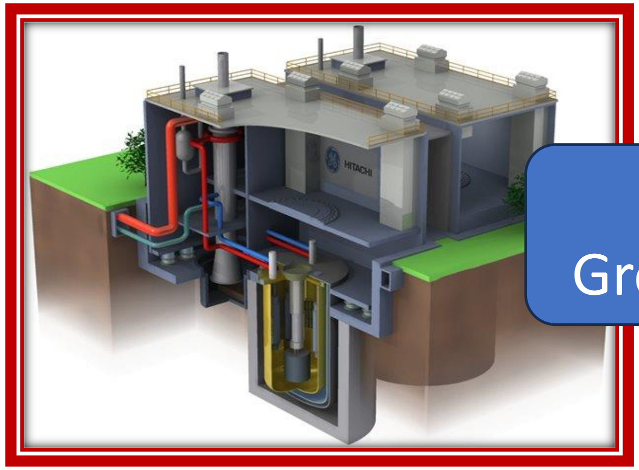
Passive cooling "Walk Away" system

- Passive safety feature
- The system rely on natural processes, such as gravity and convection to cool the reactor in the event of an accident.
- Allows the reactor to automatically shut down and cool itself
- Without any operator intervention or external power sources.



Conventional Fuel, U-235

- Conventional fuel which is typically U-235 isotope concentration.
- Considered low-enriched uranium (LEU).
- Abundant, readily available, and cheap to be used.

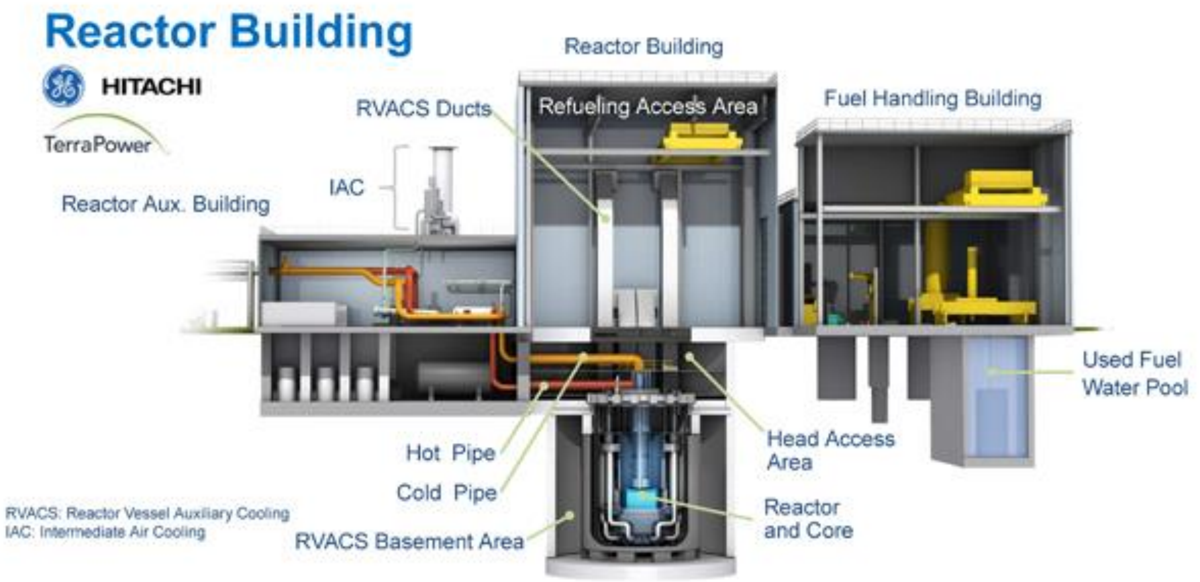


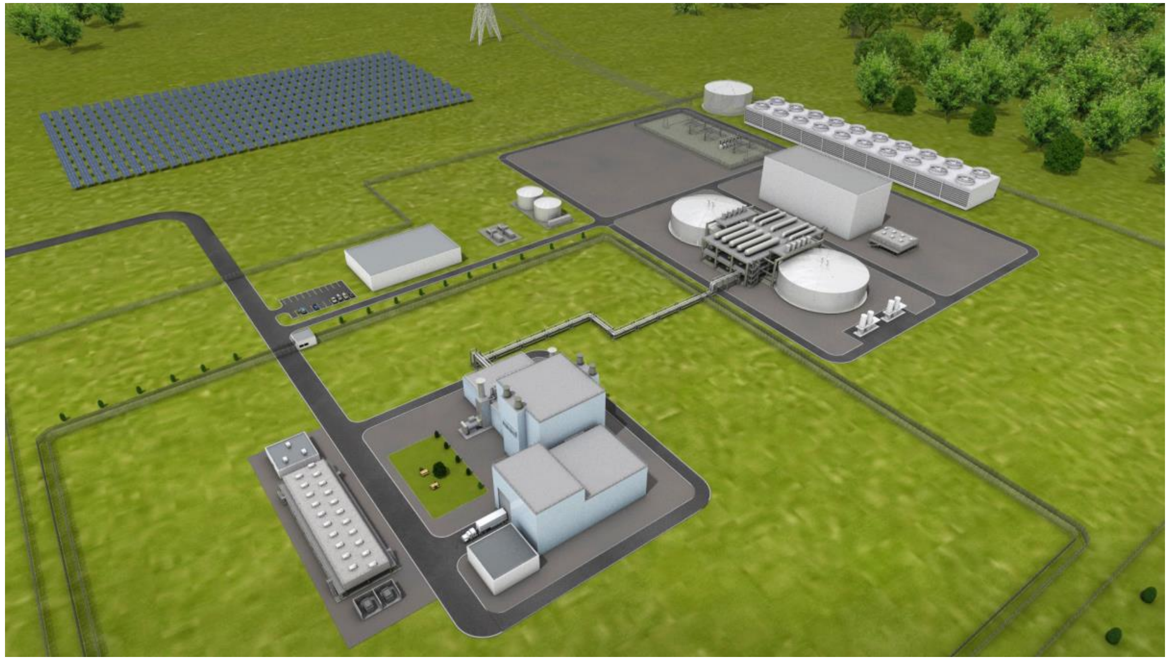
Below Ground Level

- Locating the reactor underground provides an additional barrier against external threats.
- E.g. aircraft impacts, and natural disasters.
- Enhancing the overall safety and security of the plant.

Suggesting One SMR Design As Our Recommended Design

- Natrium from TerraPower.





Questions?

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