Cast-Iron Hexagons With Cladding for Heat Storage in Sodium, Salt, Lead and Helium Cooled Reactors

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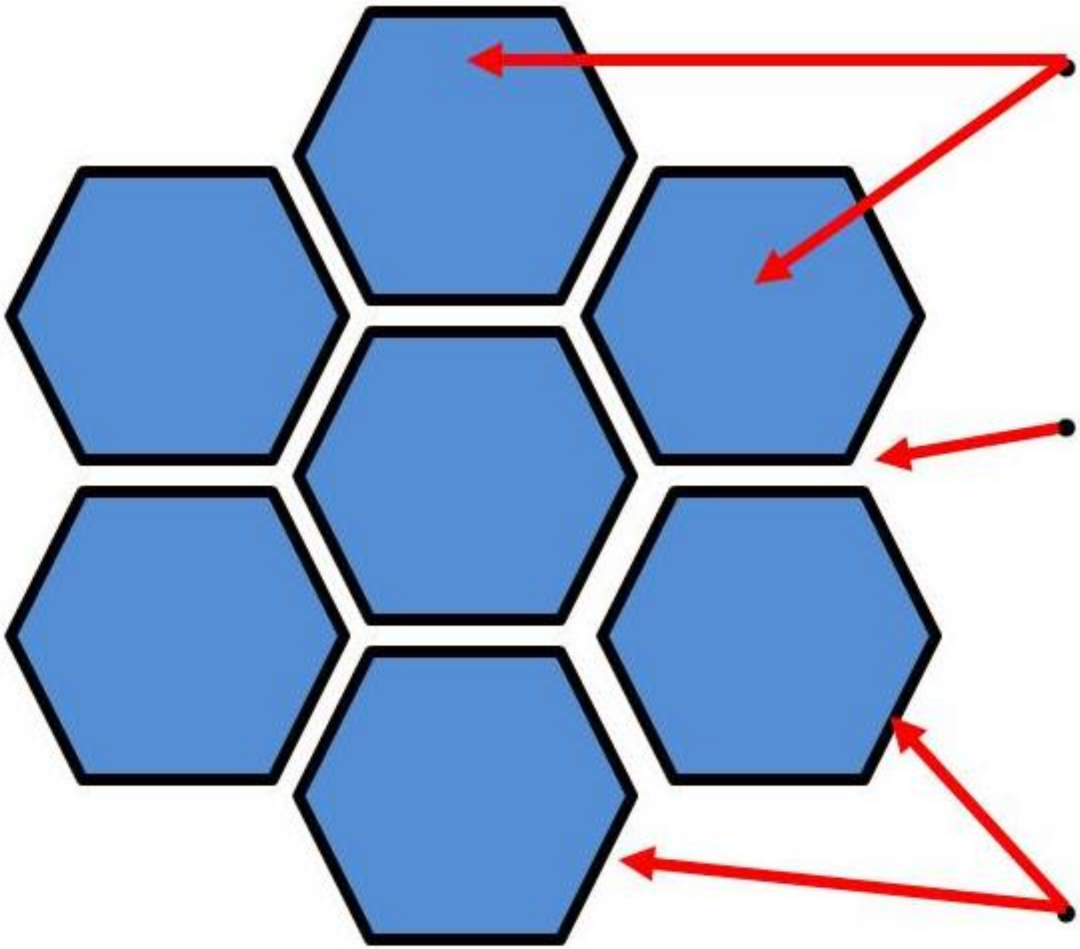
Takeaway Messages

- As a heat storage material, iron is cheap and can operate from 100 to 700/900°C
- Steel cladding can be chosen for helium, sodium, lead or salt (fluoride, nitrate or chloride) environment—universal storage material
- Cast iron sets an upper limit on storage costs for sensible heat storage

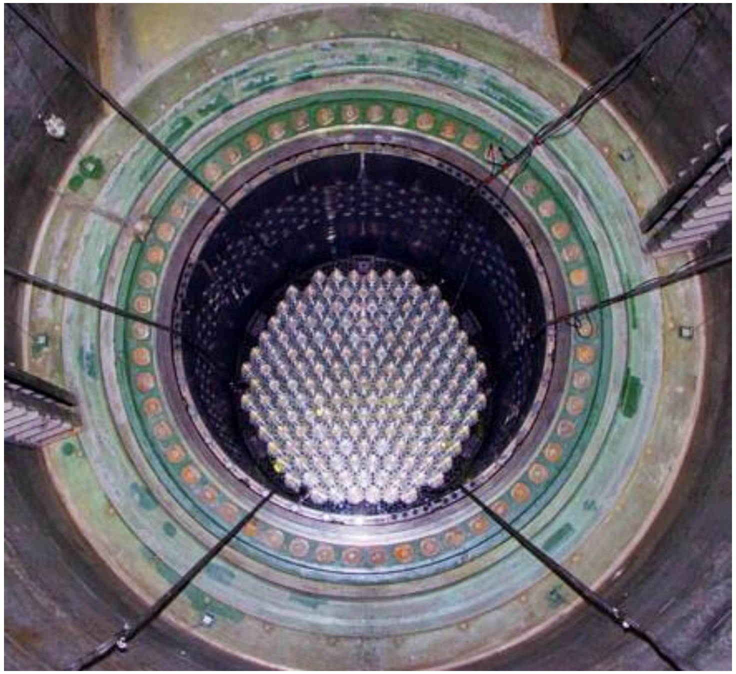
Cast Iron Storage for Any Coolant In Primary or Secondary Loop



- Cast iron hexagons up to 20 meters high, Hundreds of hexagons
- Vertical coolant flow channels
  - Width dependent upon coolant
  - Tabs on assemblies to space array
- Corrosion Resistant Wrapper

Cast Iron Storage In Tank Is Similar to Hexagonal Fuel Assemblies in Sodium and Russian Light Water Reactors

- We know how to design hexagonal structures in close-packed arrays
- Lots of practical experience with different coolants



Russian VVER Core

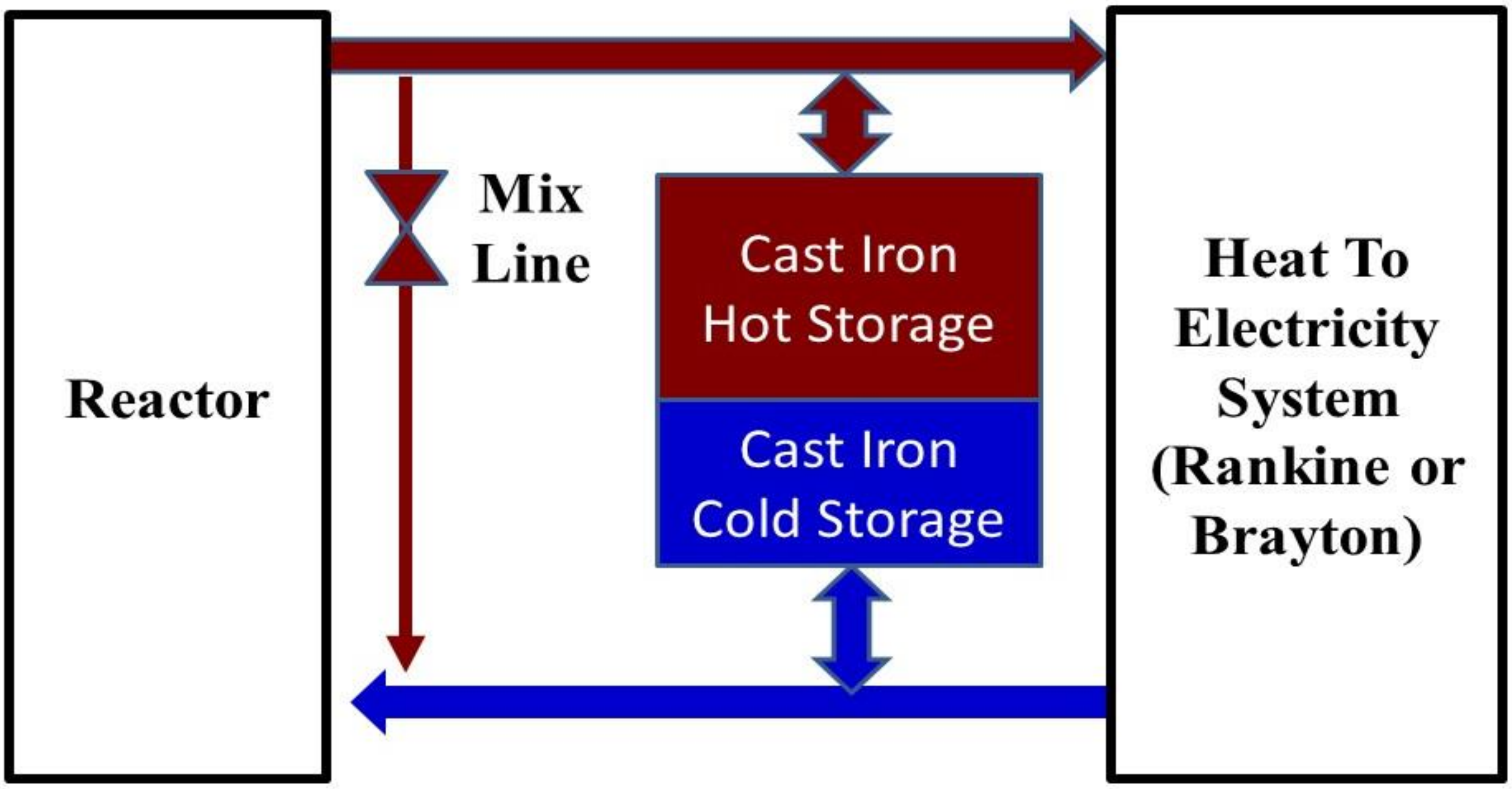
Characteristics of Cast Iron Storage

- Sensible heat storage with cast iron. Clad metal chosen for corrosion resistance to primary or secondary reactor coolant (sodium, salt, lead or helium)
- Temperature range from 100 to 700/900°C
- Low cost
- Layout: hexagonal assemblies 10 to 20 meters high in close-pack array
  - Maximize storage heat capacity with >95% of volume in hexagonal solid assemblies
  - Minimize primary or secondary coolant fraction to minimize cost and maximize safety (sodium case)

Cast Iron Constraints

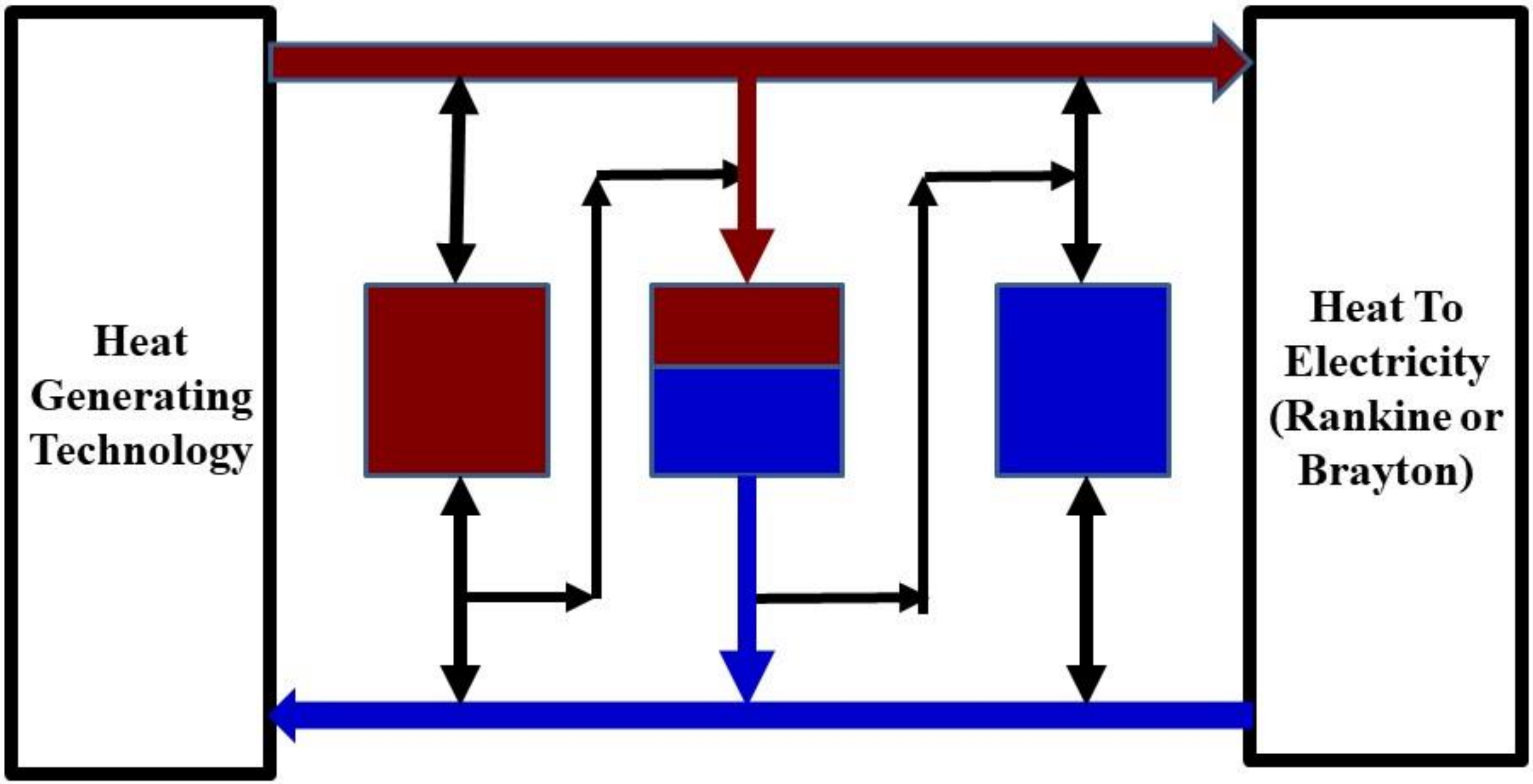
- Peak temperature limit is a tradeoff between performance and cost
  - Cast iron (iron + carbon) phase change with significant expansion 727 °C
  - Pure iron phase change at 917°C
  - Loose strength at higher temperatures
- Minimizing costs requires design with fabricator where minimum-cost design may depend upon fabricator facilities—manufacturing cost determines design

Cast Iron Storage with Small Temperature Drop Across Reactor and Large Temperature Drop Across Cast Iron to Minimize Storage Cost

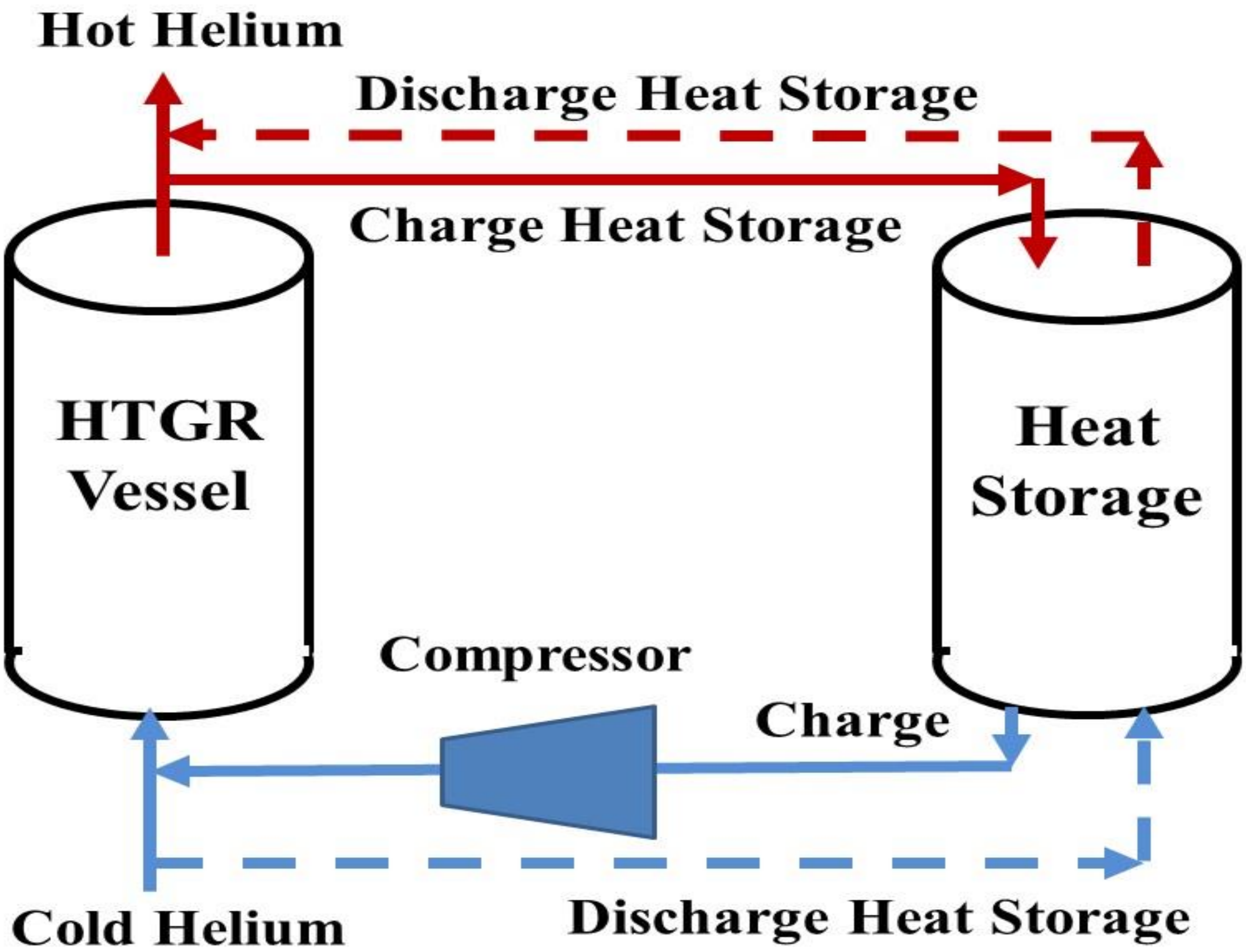


Sodium or Salt-Cooled Reactor Intermediate Loop

Cast Iron Heat Storage Can Be Placed in Series to Minimize Conductive Heat Loses in the Vertical Direction

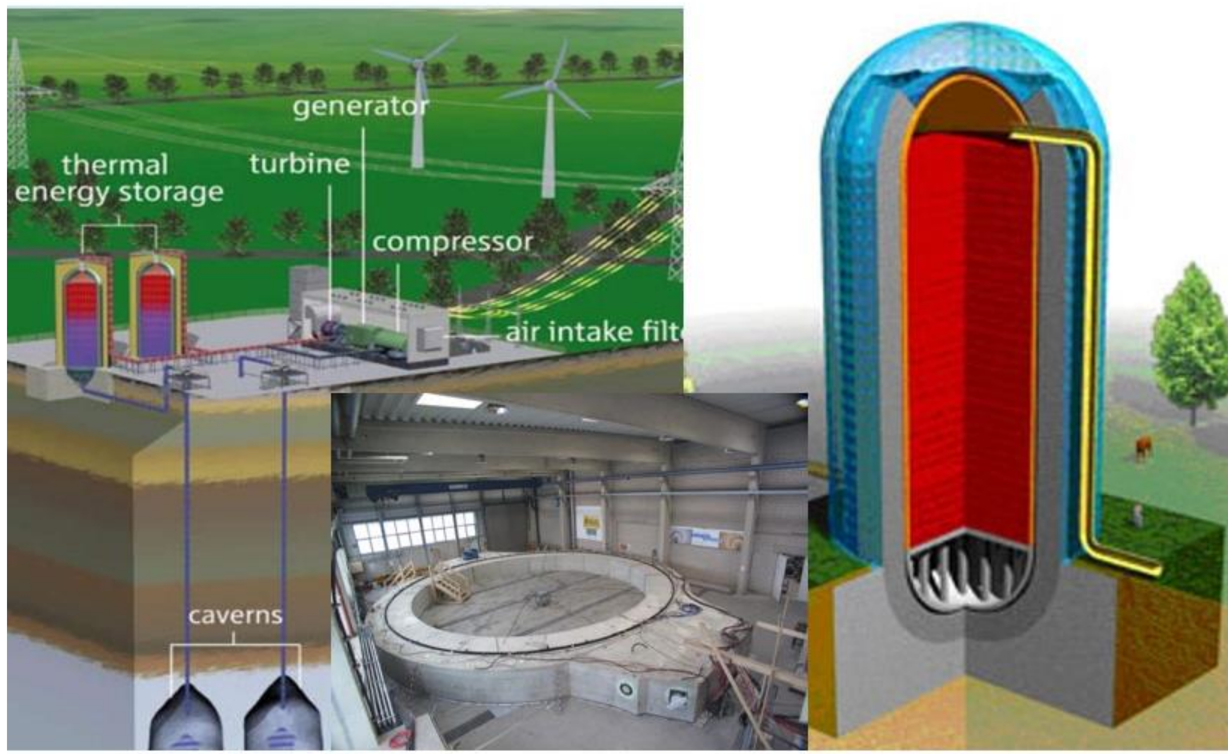


Integrating Cast Iron With Primary Helium in High-Temperature Gas-Cooled Reactor



Large Pressure Vessels Being Developed for Adiabatic Compressed Air Storage

- Primary system minimizes temperature losses
- Fast response to variable electricity prices
- Steam or Brayton cycle



Project Adele system, laboratory section of prestress pressure vessel and schematic of the pressure vessel. Courtesy of General Electric, RWE AG, and Zublin

Size and Cost of Cast Iron Heat-Storage System is Reasonable

- Gigawatt-hour of cast iron with 100°C Delta T
  - 80,000 metric tons
  - 10,000 m^3
  - If 15 meters high, Diameter 29 m
- Cast iron capital cost: $500/ton (plus cladding and system)
  - $40/kWh if 100°C Delta T
  - $13/kWh if 300°C Delta T

Can the Steel Clad Be Filled with Other Heat Storage Materials?

- Potentially other storage materials
  - Firebrick, alumina, phase-change, etc.
  - Requires thicker steel cladding (container) to provide support
- Cast iron with cladding fabrication: Integrated piece
  - Cast iron
  - Fit cladding over cast iron
  - Pull vacuum and heat to bond into single structure (other fabrication options exist)

Conclusions

- Cast iron storage is compatible with all coolants if use appropriate cladding
- Cast iron
  - Can be used in primary or secondary loop of reactor
  - Minimizes risk by minimizing total inventory of reactive coolants such as sodium (reduced inventory)
  - Reduces cost if expensive coolant (sodium, many salts)
- Brute force, low technology option
- No detailed engineering studies

References

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3. C. Forsberg and P. Sabharwall, *Heat Storage Options for Sodium, Salt and Helium Cooled Reactors to Enable Variable Electricity to the Grid and Heat to Industry with Base-Load Operations*, ANP-TR-181, Center for Advanced Nuclear Energy, Massachusetts Institute of Technology, INL/EXT-18-51329, Idaho National Laboratory
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5. C. Forsberg, K. Dawson, N. Sepulveda, and M. Corradini, *Implications of Carbon Constraints on (1) the Electricity Generating Mix for the United States, China, France and the United Kingdom and (1) Future Nuclear System Requirements*, MIT-ANP-TR-184 (March 2019)