NUCLEAR POWER PART 2

PRESENTED BY ANDREW OHRABLO AND KRISTINE GEHRING-OHRABLO

BIO

- Andrew Ohrablo
  - Bachelor of Science Nuclear Engineering – University of Wisconsin at Madison
    - Senior Thesis – Design of Liquid Metal Fast Breeder Reactor
  - Perry Nuclear Power Plant, Perry, OH 2014-Present
    - Maintenance Electrical Engineer – Current Position
    - Work Week Manager
  - Cooper Nuclear Station, Brownville, NE 1999-2014
    - Shift Technical Engineer
    - Senior Reactor Operator NRC License Number 44337
  - United States Navy Nuclear Electrician – USS Enterprise 1987-1993

BIO

- Kristine Gehring-Ohrablo
  - Masters of Science Radiation Health Physics – Oregon State University
  - Masters of Science Bacteriology – University of Wisconsin at Madison
  - Bachelors of Science Microbiology – Ohio State University
  - Perry Nuclear Power Plant, Perry, OH 2014-present
    - Primary Chemist
  - Cooper Nuclear Station, Brownville, NE 2000-2014
    - Staff Chemist
    - Chemistry Technician

LIGHT WATER REACTORS

- Two designs utilized in the United States
  - Pressurized Water Reactor
    - Davis Besse – 45 miles east of Toledo
    - US Navy Reactors
    - Approximately 2/3 of the 100 plants in the US
  - Boiling Water Reactor
    - Perry – 30 miles east of Cleveland
    - Fukushima Daiichi

REVIEW

- Previously Discussed Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR)
- Coefficients of power – How reactor power changes based on the change of a measurable core parameter
  - In both a PWR and a BWR as temperature goes up, power goes down
  - Other measurables are reactor pressure, reactor void percentage, cladding temperature
- Decay heat is major concern based on reactor needs cooled even after shutdown

OTHER REACTOR DESIGNS

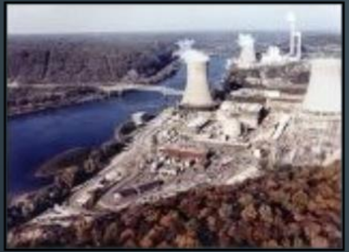
- Liquid Metal Fast Breeder Reactors
- High Temperature Gas Cooled
- Canadian Heavy Water (CANDU)
- Light Water Graphite Moderated (RBMK, Chernobyl)
- Molten Salt Thorium
- Light water small modular reactors
- Ship born reactors (mobile PWR)

GENERATIONS OF REACTORS**

Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics

Generation I

Early Prototype Reactors



- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

Commercial Power Reactors

- LWR–PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

Near-Term Deployment

Generation III+ Evolutionary Designs Offering Improved Economics

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Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Gen I	Gen II	Gen III	Gen III+	Gen IV

1950 1960 1970 1980 1990 2000 2010 2020 2030

GEN I REACTORS

- 1950-1970
- Experimental Breeder Reactor 1 (EBR1) first reactor to generate electricity
- Atom Mirny in Obninsk was first electric plant at 5MW. Early Chernobyl design
- Shippingport, PA (PWR) first commercial US plant
- Dresden 1, Dresden IL (BWR) First privately financed nuclear reactor
- Other designs included the Magnox (He cooled), Fermi 1 (Liquid Metal Breeder Reactor)
- No Gen I reactors in service today, Wylfa closed 12/30/2015

GENERATION II

- All Current US reactors
- Light water reactors, pressurized and boiling water reactors
  - Simple model with large amount of operating years
  - Pressurized water reactor based off of US naval reactor design
- Candu heavy water reactor
- Advance Gas-cooled graphite moderated – England
- Light water graphite moderated – USSR
- Vodo-Vodyanoi Energetichesky Reactor (VVER, PWR) - USSR

GENERATION III

- Passive cooling – Lower theoretical core damage frequency then Gen II reactors
- Designs in service include:
  - GE Advance BWR
  - Korean Power, Chinese and Huolong Advance PWRs
  - Russian VVER (Version of a PWR)
  - Russian Sodium Cooled Fast Breeder Reactor

GENERATION III+

- Advanced versions of the Generation III reactors.
- Additional Designs not yet built:
    - Canadian Advanced CANDU (Heavy Water Reactor)

GENERATION IV REACTORS

- Very High Temperature Reactor – Helium Cooled/Pebble Bed Reactor
- Molten Salt Reactor
- Supercritical Reactor – Higher Pressure PWR
- Gas Cooled Fast Reactor
- Sodium Cooled Fast Breeder Reactor/Integral Fast Reactor
- Lead Cooled Fast Reactor

BENEFITS OF GEN IV

- Able to utilize nuclear waste as fuel
- Passive cooling achieved through laws of physics
- Lower cost through elevated thermal efficiencies
- Potential to utilize natural Uranium or Thorium for fuel, eliminates fuel enrichment cost
- Coolant at atmospheric pressure
- Proliferation resistant
- Potential to load follow/compatible with renewable capacity fluxuation

SMALL MODULAR REACTORS

- Developed after definition of GEN IV Reactor Created
- Electrical Output from 20MWe to 300MWe
- Normally either PWR or BWR on smaller scale
- Lower initial capital investment
- Earlier return on investment
- Smaller or no emergency planning zone
- Either land or ship based
  - Russian built Akademik Lomonosov in service Sept 2019, 70MWe

Key LWR SMR Features*

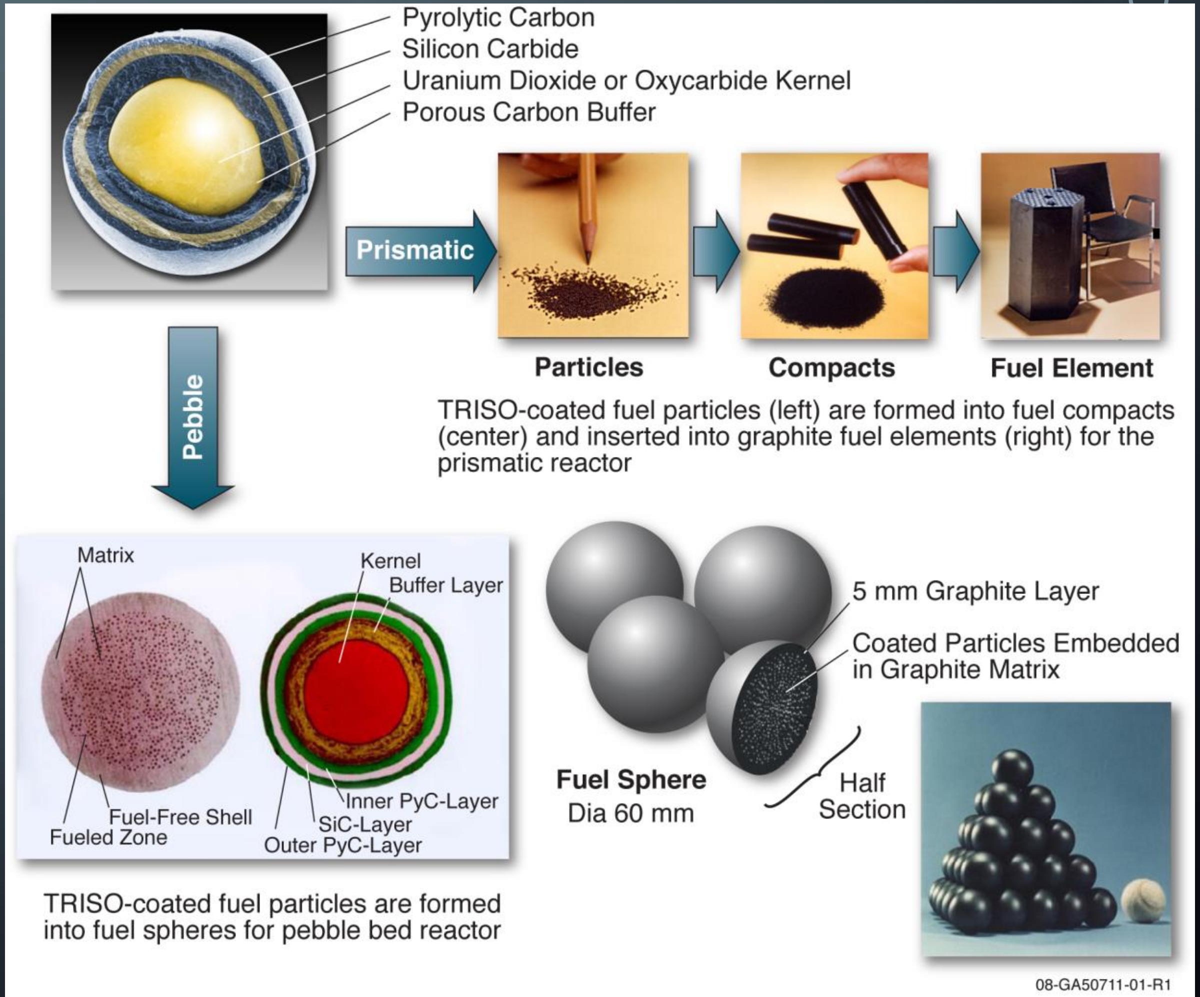
- Modular construction
- Smaller source term
- Integral reactor vessels
- Use of natural circulation
- Internally mounted control rod drive mechanisms
- Reactor and components below ground level
- Large water volume relative to thermal power
- More time for intervention

GEH BWRX-300

*General description, all features may not be applicable to all designs

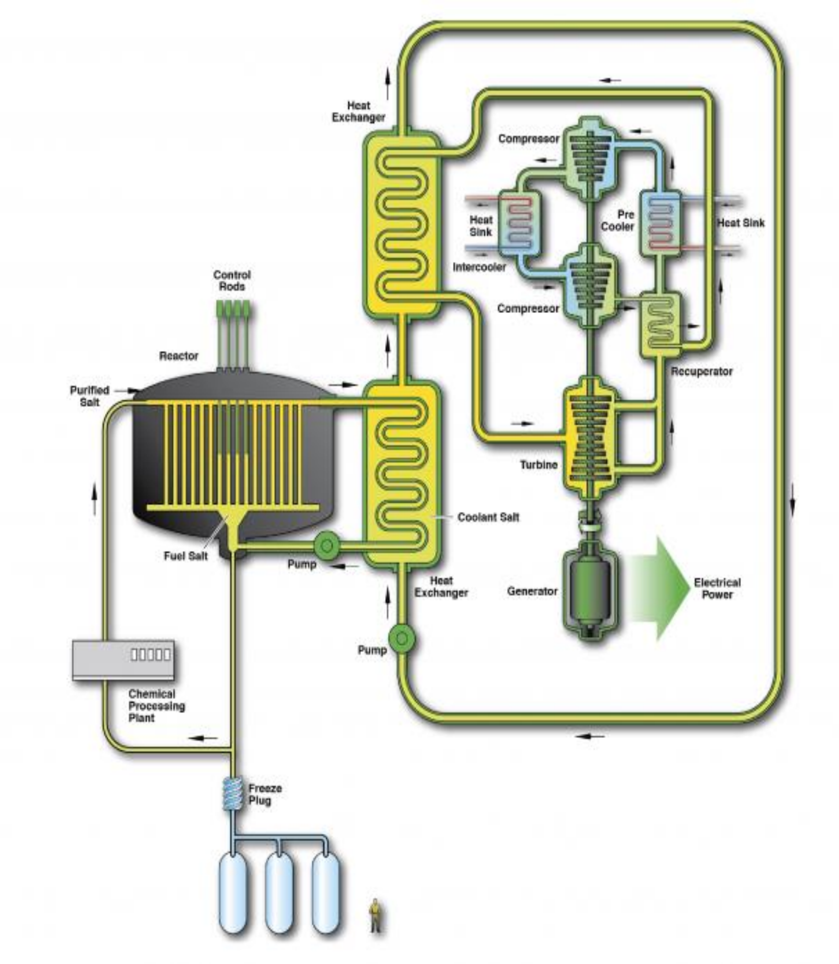
Key Gas Reactor Features

- TRISO fuel provides containment and can withstand temperatures well above accident conditions
- Higher operating temperatures – more efficient
- On-line refueling possible
- Passive decay heat removal



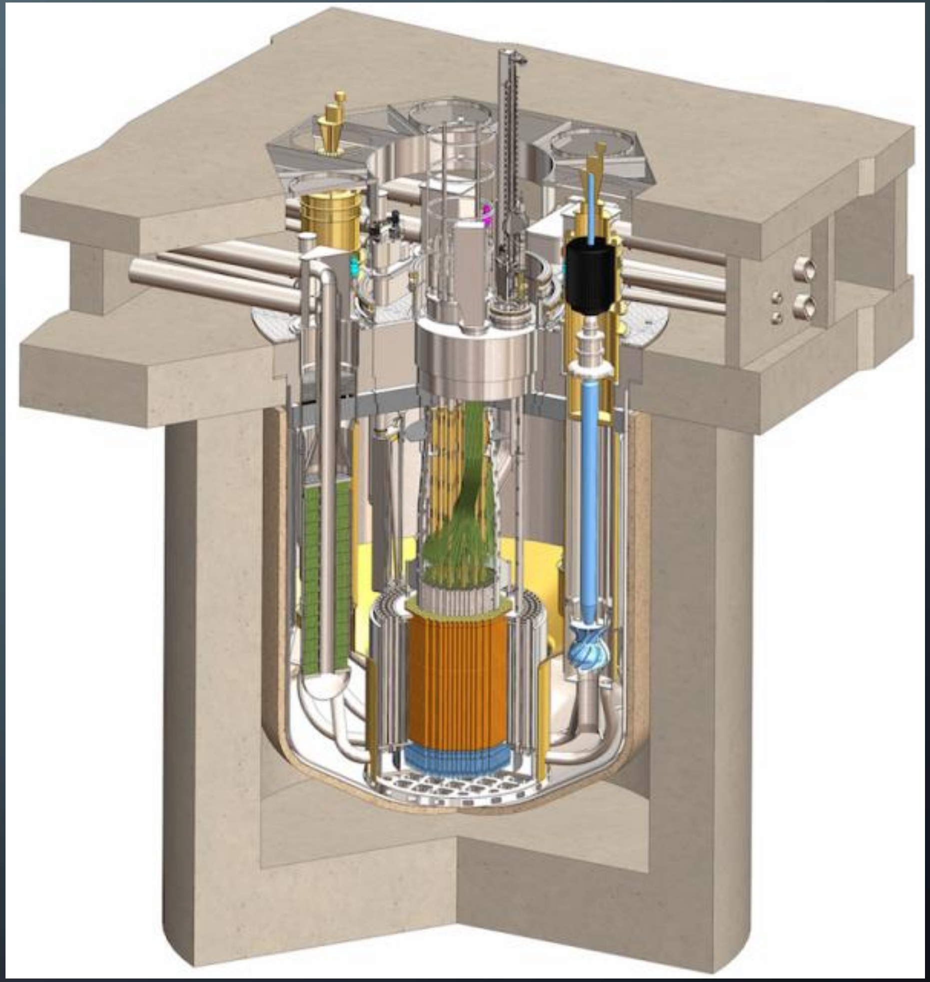
Key Molten Salt Reactor Features

- Operates at close to atmospheric pressure
- Two fuel versions: Fuel dissolved in salt and solid TRISO fuel
- Passive decay heat removal
- Higher operating temperatures – more efficient
- On-line refueling and longer cycle lengths
- Potential to utilize used fuel from existing fleet as fuel



Key Liquid Metal Reactor Features

- Operates at close to atmospheric pressure
- Passive decay heat removal
- Potential for longer cycle lengths
- Potential to utilize used fuel from existing fleet as fuel



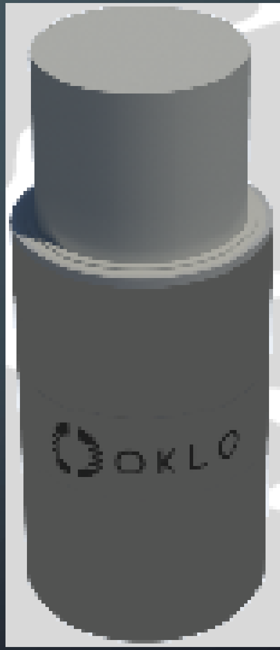
Example: TerraPower Traveling Wave Reactor

MICRO REACTORS

- 1MWe to 20MWe
- Passive components
- 10 year life cycle without refueling
- Completely factory built and delivered via semi-truck
- Lower initial capital investment
- Earlier return on investment
- Smaller or no emergency planning zone

Key Micro-Reactor Features*

- Very small size
  - Site <0.1 acres
  - Building ~size of a house
  - Reactor fits in shipping container
- Very small potential consequences
  - Radionuclide inventory extremely low
  - Fail-safe: shuts itself off, cannot meltdown
- Operational simplicity
  - Potential for automatic and remote operations
  - Minimal maintenance
  - Few to zero moving parts



OKLO

*General description, all features may not be applicable to all designs

OHIO POWER PLANT STATUS

- Davis Besse – 2,817MW thermal pressurized water reactor near Toledo Ohio
  - Operating license issued 4/22/1977
  - License renewed 12/08/2015
  - Current license expires 4/22/2037
- Perry – 3,758MW thermal boiling water reactor near Cleveland Ohio
  - Operating license issued 11/13/1986
  - License expires 3/18/2026
  - License extension project in progress to extend license to 3/18/2046

LICENSE EXTENSIONS

- Nuclear power plants originally licensed to 40 years due to potential degradation of the reactor pressure vessel due to neutron embrittlement
- With current experience due to years of operation, neutron embrittlement does not degraded the reactor pressure vessel after an initial embrittlement
- Over 90 plants have applied and been given a license extension for an additional 20 years
- Several plants have submitted additional license extensions to extend plant life an additional 20 years for a total license of 80 years
- With proper maintenance, theoretically, a plant could extend its license indefinitely

OHIO HOUSE BILL 6

- HB 6 titled “Creates Ohio Clean Air Program”
- Passed by Senate on 7/17/19 and the House on 7/23/19
- Signed by Governor on 7/23/19
- Became effective on 10/22/19
- Provides $150M/year to a nuclear generation fund for electricity generated from nuclear power
- Provides for $20M/year for renewable energy fund
- Lowers electric user rates by eliminating efficiency standards after 2021
- Funds will be for years from 2021 to 2027, when the bill expires
- Challenge to law dropped and bill enacted as written

RECENT DEVELOPMENTS (DECEMBER 2018)

- Turkey Point received additional License extension to 80 years to 2052 and 2053
- OKLO Microreactor received Department of Energy Site Use Permit for Idaho National Laboratory location
- Department of Energy awarded $3.5M to X-Energy for development of a pebble bed high temperature gas cooled reactor
- Terrestrial Energy's Integral Molten Salt Reactor undergoing joint technical review by US Nuclear Regulatory Commission and Canadian Nuclear Safety Commission
- NRC to issue Early Site Permit for Clinch River site in Tennessee for Small Modular Reactor 12/17/19
- NRC makes available for comment rule making for variable size Emergency Planning Zones for Small Modular and Advance Reactors
- Challenge to HB6 dropped.

CONCLUSION

- Generation I reactors were the initial test reactors and early commercial reactors
- Generation II reactors are the current electric power reactors in the US. These are boiling water or pressurized water reactors
- Generation III reactors are more accident resistant designs that are based on generation II designs.
- Generation IV reactors are passively cooled reactor designs that do not need human interaction for accident response
- Small modular and microreactors in process of being developed for construction

CITATIONS

- * NEI Briefing “SMRs and Other Advanced Reactors” for the Department of Homeland Security December 3, 2019, Nuclear Energy Institute 2019
- **Generation map Wikipedia https://en.wikipedia.org/wiki/Generation_IV_reactor#/media/File:GenIVRoadmap-en.svg

QUESTIONS?

TERMS

- Critical – status of nuclear reactor where the number of neutrons in one generation is equal to the number of neutrons in the previous generation – power is remaining constant
- Reactivity – Relative departure from critical for a nuclear reactor
- Sub-Critical – status of nuclear rector where the number of neutrons in one generation is less then the number of neutrons in the previous generation – power is going down
- Super-Critical – status of nuclear rector where the number of neutrons in one generation is more then the number of neutrons in the previous generation – power is going up

TERMS (CONTINUED)

- Barns – measure of cross section of a nucleus for a specific reaction – higher barns means a nucleus is more likely to react
- Absorption – nuclear reaction where an incident particle is absorbed into the nucleus
- Capture – Nuclear reaction where an incident particle remains in the nucleus following absorption
- Fission – nuclear reaction where an incident particle results in the mother nuclear splitting into two or more nuclei
- Beta Decay – where an excited nucleus releases energy in the form of a positron or electron and a nucleon is changed from a proton or neutron to bring the nucleus to a lower energy state
- Alpha decay – where an excited nucleus releases an alpha particle to bring the nucleus to a lower energy state
- Alpha Particle – Essentially a helium atom without the electrons. Two protons and two Neutrons

COEFFICIENTS OF POWER

- A coefficient of power is a change in the physical properties of the reactor and how it affects the neutron life cycle
- A positive coefficient of power will result in a rise in neutron population from one generation to the next. A power increase.
- Coefficients of power
  - Temperature
  - Pressure
  - Voids
  - Doppler
  - Poisons