THE FUTURE OF NUCLEAR POWER

ANDREW 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 Engineering Supervisor – Current Position
    - Maintenance Electrical Engineer
    - 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

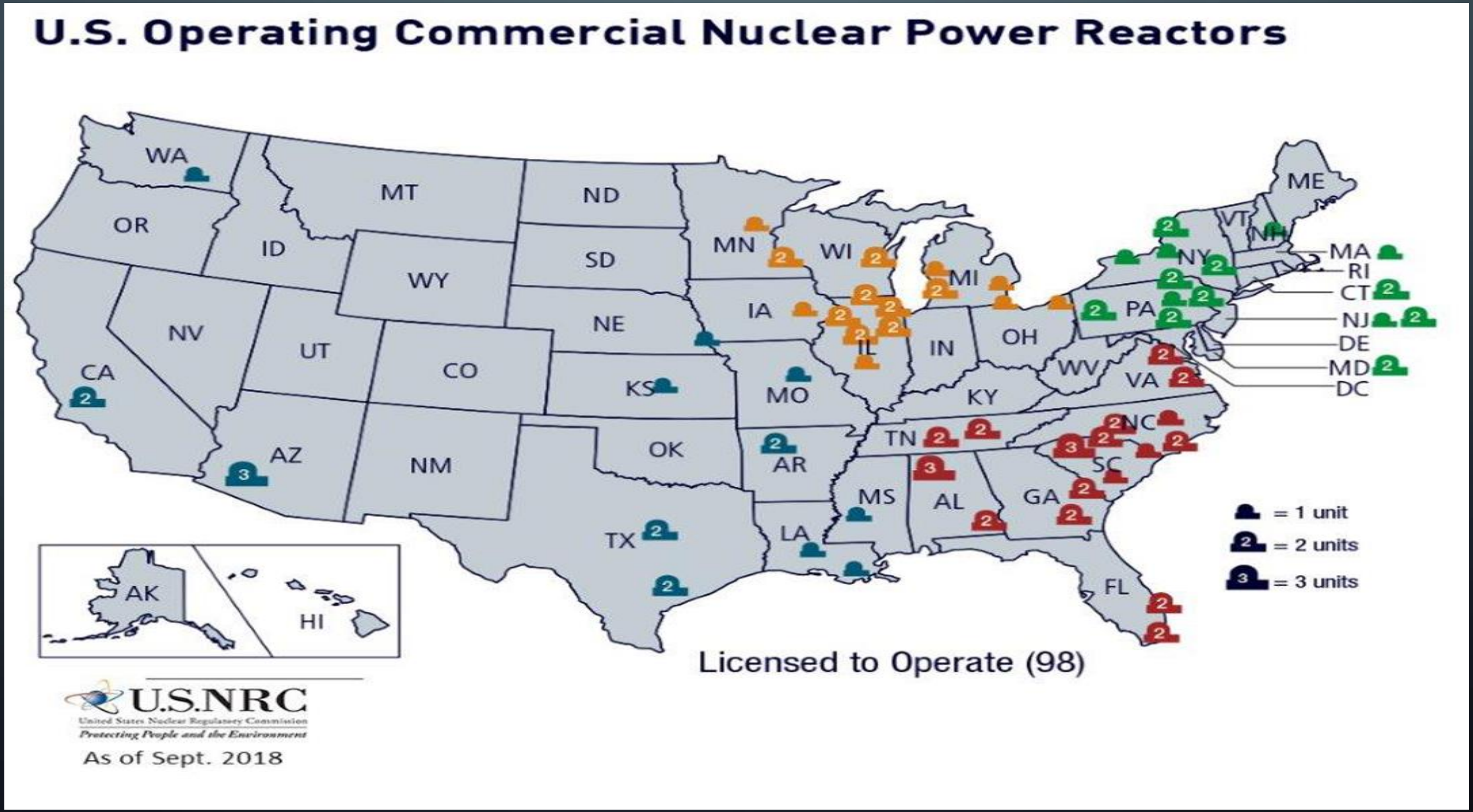
REACTOR SIZES

- Three generally recognized reactor sizes:
  - Large Commercial Reactors:
    - >300MWe
    - Largest operating is Grand Gulf ~1400MWe
    - Currently two 1100MWe reactors under construction in Waynesboro Georgia
  - Small Modular Reactors
    - >5Mwe and <300MWe
    - Does not depend on reactor design, pressurized water, boiling water or advanced design
    - NuScale, Terrapower
  - Micro-reactors
    - <5MWe
    - Commonly referred to as a nuclear battery

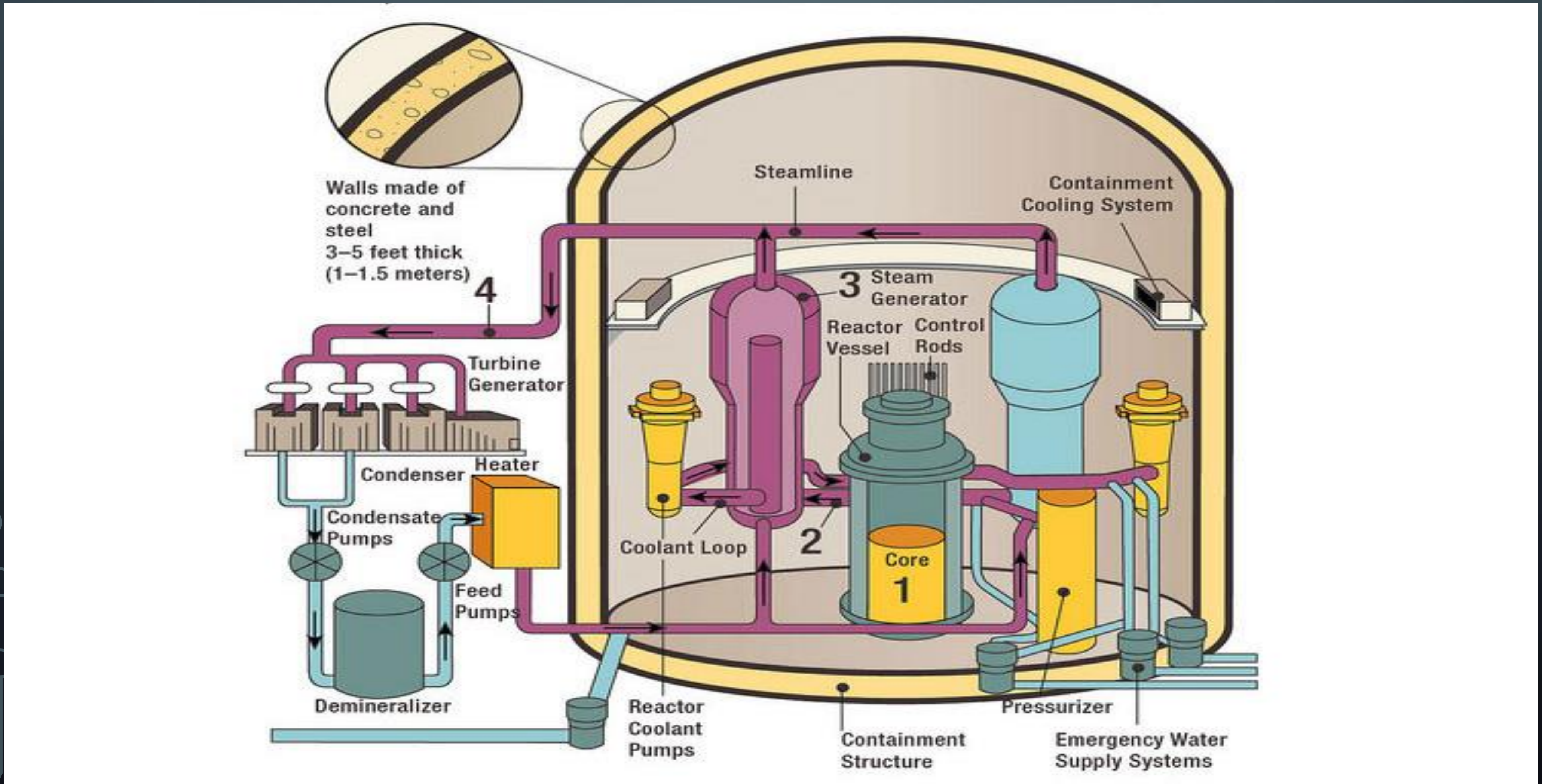
OTHER REACTOR DESIGN

- Liquid Metal Fast Breeder Reactors
- High Temperature Gas Cooled
- Canadian Heavy Water (CANDU)
- Light Water Graphite Moderated (RBMK, Chernobyl)
- Molten Salt Thorium

PLANT LOCATIONS IN THE UNITED STATES



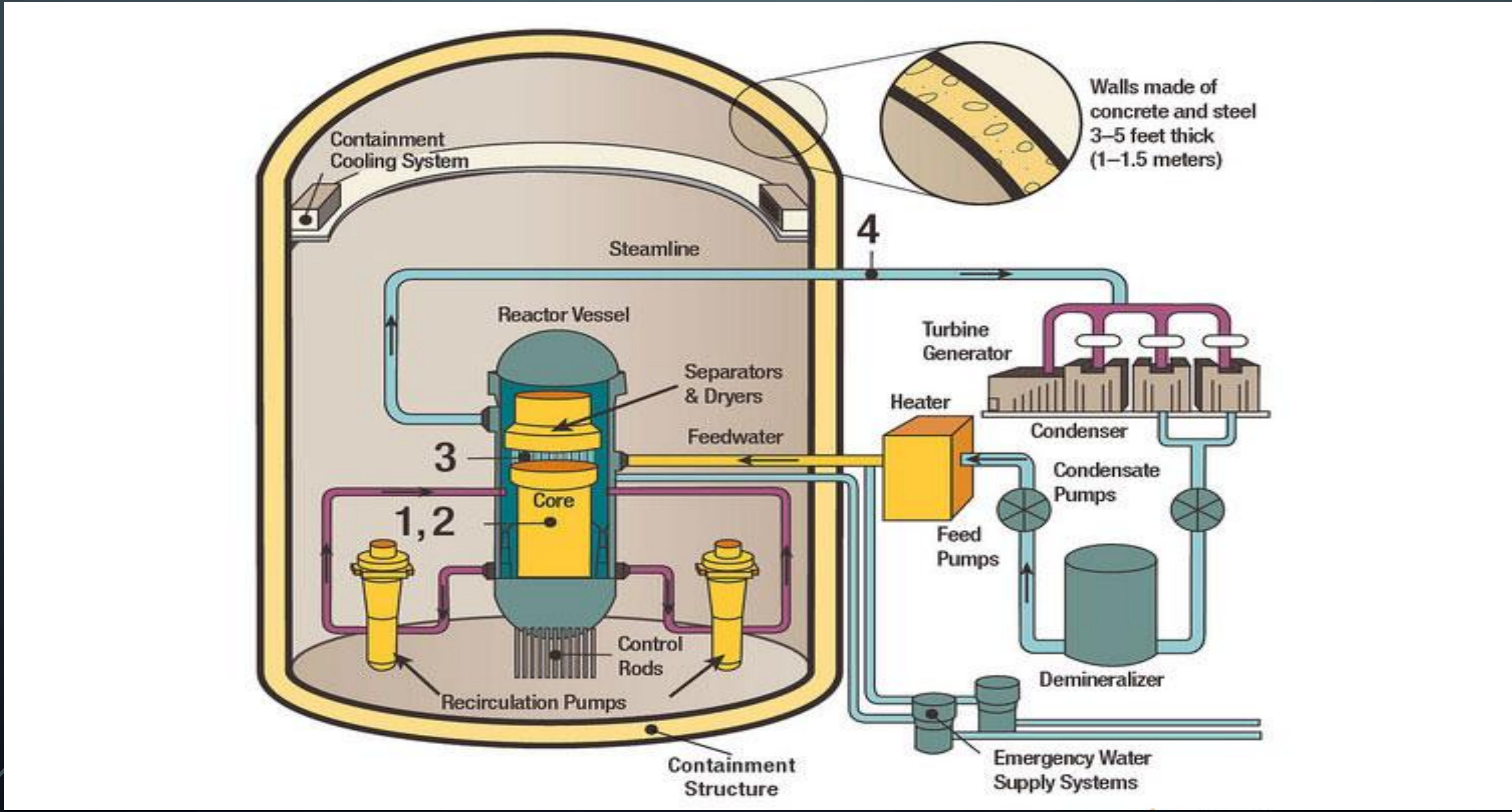
PRESSURIZED WATER REACTORS



PRESSURIZED WATER REACTOR

- Reactor Pressure can be around 2000 psig
- Reactivity (power) controlled by boron concentration
- Primary Coolant never exits containment structure – lower dose

BOILING WATER REACTOR



BOILING WATER REACTORS

- Normal operating pressure around 1000 psig
- Reactivity (power) controlled by control rod position or reactor coolant flow
- Cooling water is also heat transfer medium

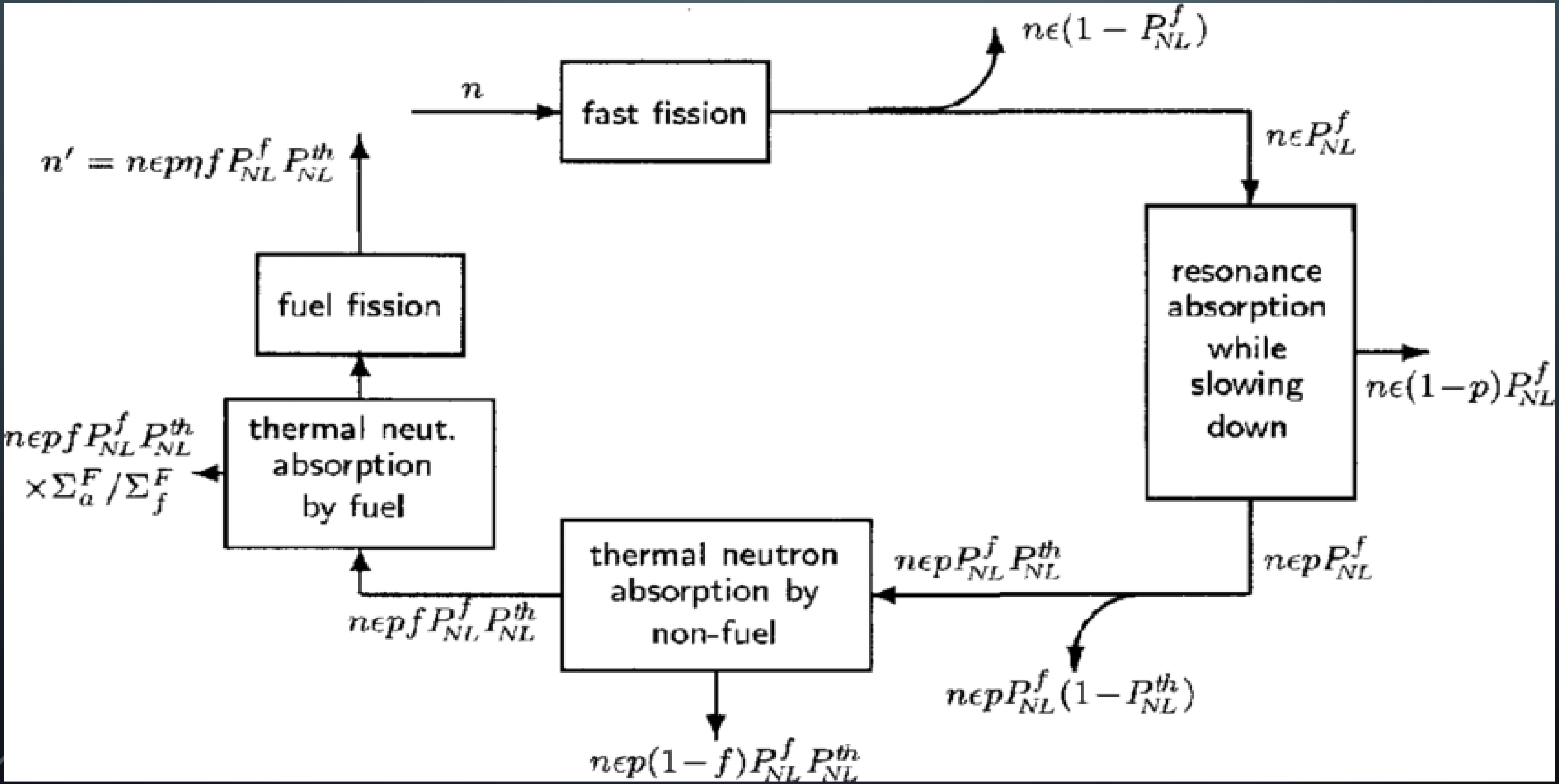
TERMS

- 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

NEUTRON LIFE CYCLE



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

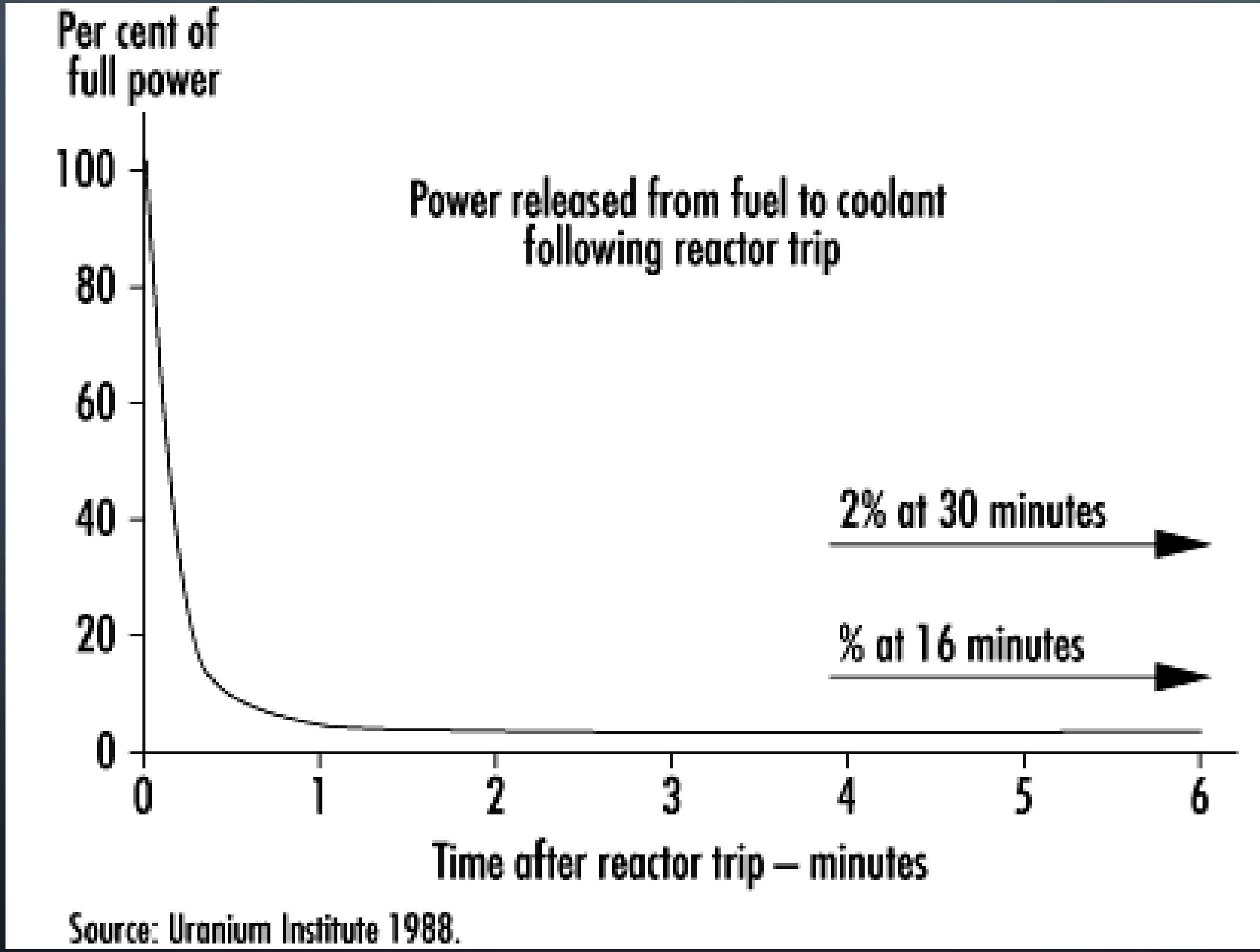
BENEFIT OF LIGHT WATER REACTORS

- Negative temperature coefficient
  - As temperature rises, power drops
- Negative Void Coefficient
  - As water is turned to steam and voids are created, power drops
- Doppler Coefficient
  - As the fuel heats up it vibrates more and non-fuel components absorb more neutrons
- Light Water Reactors are inherently safe

WHY CONCERN FOR ACCIDENTS

- Unlike fossil fuels, when the reactor is shut down, fission product decay continues to generate heat.
- During normal operation, fission product heat (decay heat) is approximately seven percent of power.
- One minute following shutdown, decay heat is approximately three percent power.
- Ten minutes following shutdown, decay heat is approximately one percent of power.

DECAY HEAT



Per cent of full power
100
80
60
40
20
0
Power released from fuel to coolant following reactor trip
2% at 30 minutes
% at 16 minutes
0
1
2
3
4
5
6
Time after reactor trip – minutes
Source: Uranium Institute 1988.

WHY CONCERN FOR ACCIDENT

- Assume that 1/100th of power of decay heat at 6 hours
- Reactor power at 100% can be 1300 MW
- Therefore 1300MW X 0.0001 = 130 kW at 6 hrs
- Average house uses 1kw an hour

EMERGENCY SYSTEMS BOILING WATER REACTORS

- High Pressure Injection sources – Reactor Core Isolation Cooling, High Pressure Coolant Injection – Used for small leaks that do not depressurize the reactor (at least two systems per reactor) – steam or electric pumps
- Low Pressure Injection – Residual Heat Removal, Core Spray – Used for large leaks that depressurize reactor (four to six systems per reactor) - electric pumps
- Diesel Generators – supply electricity to emergency pumps when offsite power is lost (two to three per reactor)

ADDITIONAL WATER SOURCES

- Control Rod Drive Pumps – two per reactor
- Standby Liquid Control Pumps – two per reactor
- Feedwater Pumps – two per reactor – high pressure injection
- Condensate Booster Pumps – three per reactor – medium pressure injection
- Condensate Pumps – three per reactor – low pressure injection
- Fire Protection – diesel driven or electric driven – low pressure injection
- River/Lake Water – designed cross tie to allow for injection to reactor – low pressure injection

DOSE CONCERNS

- Four potential effects on cells due to radiation:
  - Radiation passes through cell without damage occurring
  - Cell repairs itself and no further damage occurs
  - Cell dies – This occurs millions of times a day even without radiation
  - Cell does not repair itself and replicates in the damaged form
    - Body identifies and eliminates
    - Potential to cause cancer
    - Potential to pass to next generation

DOSE LIMITS* (10CFR20)

- Radiation Worker
  - Whole Body – 5 Rem/yr
  - Any Organ – 50 Rem/yr
  - Lens of Eye – 15 Rem/yr
- Member of Public
  - 100 mRem/yr
  - 1,000 mrem = 1 Rem
- Data shows that high doses of radiation may cause cancers. But there is no data to establish a firm link between cancer and doses below about 10,000 mRem (10,000 mRem – 100 times the NRC limit). *
  - Average US resident receives annual exposure of about 620 mrem/yr

IMMEDIATE EFFECTS OF RADIATION**

- 0-10 Rem No observable effect
- 10-100 Rem Slight to moderate decrease in white blood cell counts – no observed long term effects
- 100-200 Rem Significant blood cell count reduction, nausea, vomiting, rarely fatal
- 200-500 Rem Nausea, vomiting, hair loss, severe blood damage, fatalities

Compare to occupational limit of 5 Rem/year

CONCLUSION

- Two major designs utilized in the US – Boiling Water and Pressurized Water Reactors
- Definitions Associated with Nuclear Reactors
- Coefficients of Power
- Benefits of Light Water Reactors
- Injection Systems Available at a Boiling Water Reactor
- Effects of radiation on cells

CITATIONS

- * NRC regulations 10CFR20 & https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html
- **BC Campus, College Physics Biological effects of Ionizing Radiation https://opentextbc.ca/physicstestbook2/chapter/biological-effects-of-ionizing-radiation/

QUESTIONS?