NUCLEAR POWER ACCIDENT ANALYSIS

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

REVIEW

- Terms:
    - Scram - Shutdown of reactor by insertion of control rods
    - Reactivity Coefficient – Change in neutron population for a change in reactor parameter
        - Positive coefficient power goes up when parameter goes up
        - Negative Coefficient power goes down when parameter goes down
    - Reactivity – change of power for change of parameter

REVIEW CONTINUED

- Automatic Scram signals (not all inclusive)
  - High water level
  - Low water level
  - High reactor pressure
  - Closure of Main Steam Isolation valves
  - High reactor power
  - High drywell pressure
  - Turbine trip

EVENT CATEGORIZATION

- Incident of Moderate Frequency – once per 20 years
- Infrequent Incidents – once between 20 to 100 years
- Limiting Fault – Never expected to occur
- Abnormal Operating Transient – Analysis of both Moderate and Infrequent events
- Special Event – Events not postulated until reactors were built

* Presentation is based upon USAR Chapter 14 of Cooper Nuclear Station a ~800MWe boiling water reactor with a mark 4 containment

ABNORMAL OPERATIONAL TRANSIENTS

- Pressure Increase
- Moderator Temperature Decrease
- Addition of Positive Reactivity
- Reactor Vessel water inventory Decrease
- Reactor Core Flow Decrease
- Reactor Core Flow Increase
- Reactor Water Inventory Increase
- Reactor Water Coolant Temperature Increase

ABNORMAL OPERATION TRANSIENT SAFETY DESIGN BASIS

- Radioactive release rates below normal operating limits (10CFR20)
- No fuel failures
- No coolant system parameters above normal piping stress limits
  - No challenge to the reactor coolant system

SPECIAL EVENTS

- Shutdown From Outside of Control Room
- Shutdown Without Control Rods
- Anticipated Transient Without Scram
- Station Blackout

Safety Design Basis

- Special Event Terminated

ACCIDENTS

- Total of five but only one that will be discussed
  - Loss of Coolant Accident Concurrent with a Station Blackout
- Safety Design Basis
  - Radioactive release below EPA standards
  - Fuel Cladding Failure will not occur based on mechanical or thermal performance
  - Piping stress below accident requirements
  - Containment stress below accident requirements
  - No overexposure of Control Room Operators

PRESSURE INCREASE

Concern because pressure increase results in immediate power increase

- Turbine Stop Valve Closure
- Turbine Governor Valve Closure
- Main Steam Isolation Valve Closure * (MSIV)

Mitigated by:

- Scram on Turbine Trip or MSIV closure

*Worst case scenario

MODERATOR TEMPERATURE DECREASE

Concern because temperature drop results in power increase

- Loss of Feedwater Heating
- Loss of Shutdown Cooling
- Inadvertent initiation of High-Pressure Coolant Injection*

Mitigated by:

- Reactor Water High Level Scram or Operator Action

ADDITION OF POSITIVE REACTIVITY

- Continuous Control Rod Withdrawal during operation* (~30% power)
- Continuous Control Rod Withdrawal during Start Up
- Control Rod Withdrawal Shut Down
- Incorrectly loaded fuel cell during refueling

Mitigated by:

- Control Rod Block (no Scram)

REACTOR VESSEL WATER INVENTORY DECREASE

- Pressure controller fails high – Opens bypass valves*
- Inadvertent opening of safety valve
- Loss of feedwater flow
- Loss of auxiliary power – loss of condensate pumps

Mitigated by:

- MSIV closure and water injection via HPCI and RCIC systems
- Notes:
  - low reactor water level scram not credited
  - Power response limited by voiding of core to lower power

REACTOR COOLANT FLOW DECREASE

- Recirc flow controller failure
- Trip of one Reactor Coolant Pump
- Trip of both Reactor Coolant Pump Motor Generators
- Reactor Coolant Pump Seizure

Mitigated by:

- Nature of the design

REACTOR COOLANT FLOW INCREASE

- Recirc flow controller failure*
- Start of one Reactor Coolant Pump

Mitigated by:

- Design of rate of change of flow controller
- High Power Scram

REACTOR WATER INVENTORY INCREASE

- Reactor Feedwater flow controller failure
- Results in excessive subcooling of feedwater
- Results in excessive inventory

Mitigated by:

- Reactor Water High Level Scram

REACTOR WATER COOLANT TEMPERATURE INCREASE

- Loss of Shutdown Cooling

Mitigated by:

- Operator Action
- Can only occur when shutdown and depressurized
- Operators re-establish shutdown cooling

SPECIAL EVENTS

- Shutdown Outside Control Room
  - Mitigated by:
    - Shutting down reactor with local controls
- Anticipated Transient Without Scram (ATWS)
  - Mitigated by:
    - Manual Scram insertion
    - Initiation of Boron injection

SPECIAL EVENTS

- Shutdown Without Control Rods
  - Mitigated by:
    - Initiation of Boron Injection
- Station Blackout (loss of offsite power and Diesel Generators fail to start)
  - Mitigated by:
    - Remove pressure using safety relief valves and steam turbines (HPCI, RCIC)
    - Maintain level with steam driven pumps (HPCI, RCIC)
    - Black out response systems are battery operated

ACCIDENTS

Only Discussing one: Loss of Coolant Accident (LOCA) with loss of offsite power (LOOP)

Assumptions:

- Double guillotine shear of recirc pump suction piping
- Loss of offsite power
- Leak is large enough that reactor depressurizes and high pressure injection sources do not have a steam supply to drive the turbines
- One additional failure at time of accident:
  - Worst case scenario is failure of a diesel generator

ACCIDENT RESPONSE

- T-14 seconds:
  - Recirc pump suction line shears and completely displaces
  - Offsite power trips
  - Initiation of LOOP-LOCA signal to start emergency systems
  - One train of emergency systems fails to start
- T-0 seconds:
  - One DG starts
  - Signal to one RHR pump to start
- T+5 seconds:
  - Second RHR pump starts
  - Service water pump starts to cool the diesel and suppression pool
- T+10 seconds
  - Core spray pump starts

CONCLUSION

- Nuclear reactors are designed to mitigate a wide arrange of events from abnormal operational transients, special events and accidents.
- Nuclear Reactors cannot be licensed without being able to demonstrate that there will be no release of fission products to the public for AOTs or special events
- Nuclear Reactors cannot be licensed without being able to demonstrate that there will be no release of fission products above accident limits for Accidents

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

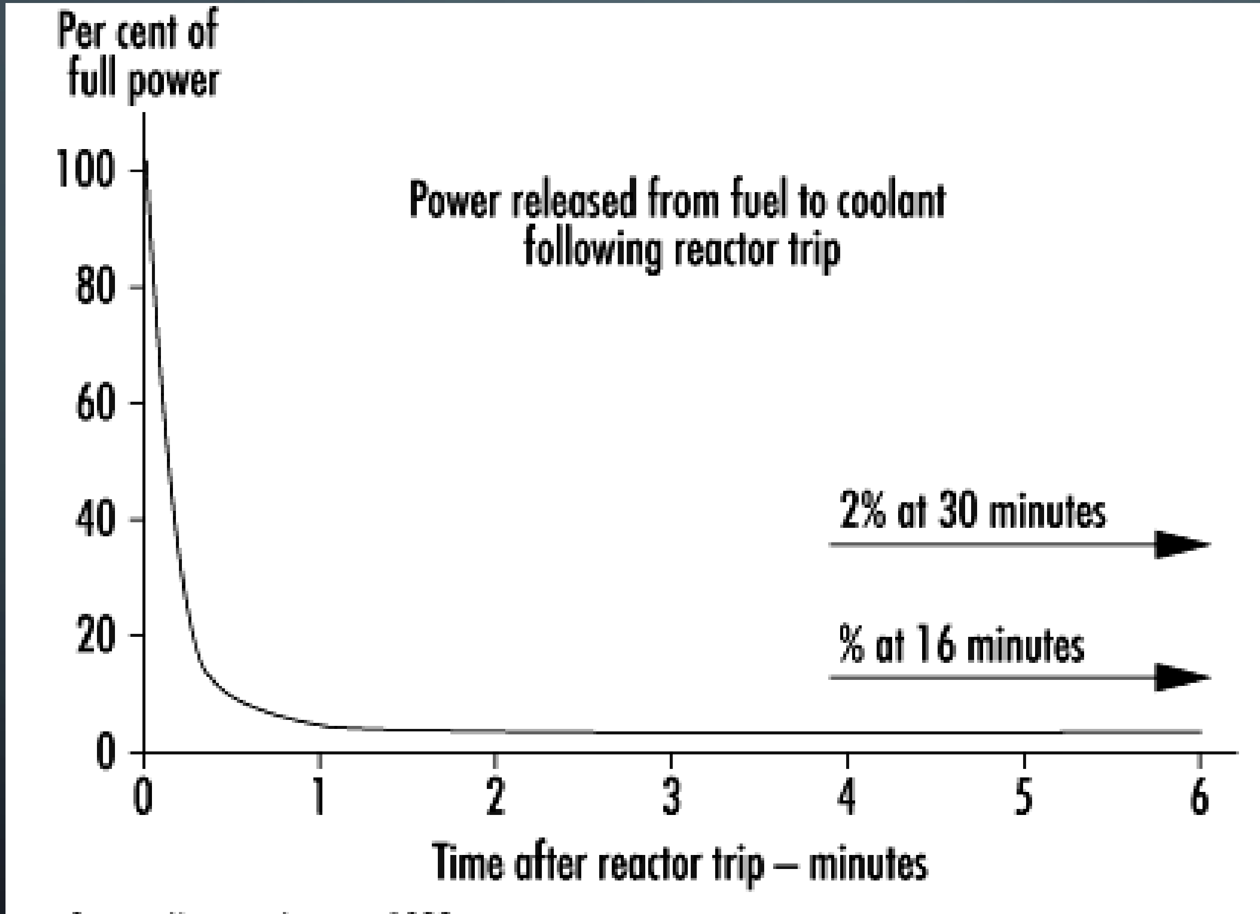
TERMS (CONTINUED)

- 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

DECAY HEAT



Source: Uranium Institute 1988.

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