Principles of Nuclear Safety

Module 4

The 3C's:
CONTROL, COOL & CONTAIN

Golden Rule of Reactor Safety

- There is no threat to public safety as long as
  - reactor power is controlled
  - the fuel is cooled
  - radioactivity is contained
- the 3C's are ***essential*** under ***all*** operating conditions:
  - at all power levels
  - during normal operation, shutdown or upset

Control: Defence Hierarchy

1) ***RRS*** -normal process control
2) ***Setback*** -automatic power ramp-down using normal RRS control devices
3) ***Stepback*** -sudden power reduction via CA full or partial drop
4) ***SDS1*** -sudden, deep shutdown via SA drop
5) ***SDS2*** -sudden, deep shutdown via LISS

Reactor Regulating System (RRS)

- First line of defence against fuel overheating
- Accepts set point from:
  - Operator in ***Reactor Leading*** mode
  - BPC in ***Reactor Lagging*** mode
- Compares actual power with demanded power
- Manipulates reactivity mechanisms to reduce power error = actual power - demanded power
- If RRS impaired, unit *<u>must</u>* be put in GSS to prevent Loss of Regulation Accident (LORA)

What if Fuel Cooling is Inadequate?

- Fuel overheats
- Fission product gases released from ceramic
- gas pressure increases inside sheath
- sheath softens as temperature nears melting point
- sheath balloons & ruptures
- fission products released into coolant

Basic Requirements to Maintain Fuel Integrity

- fuel heat production ≤ heat removal
  - Heat production = fission heat + decay heat
  - Fission heat is proportional to neutron power Pn
  - Decay heat production depends on core power history
  - Even if Pn is off-scale low, need heat sink for decay heat
- temperature well below melting point
  - Primary and back-up heat sinks must <u>*always*</u> be available

Setback and Stepback

- second line of defence against fuel overheating
- various parameters monitored by each system
- fuel heat production is reduced when
  - operating limit reached indicating actual or potential mismatch between heat production and removal
- *Examples:*
  - Boiler pressure high (setback some stations)
  - Boiler level low (setback backed up by trip)
  - High Rate Log N (stepback backed up by trip)

SDS1 and SDS2

- Final lines of defense to reduce fuel heat production via automatic protective action
- If either SDS is unavailable, then the GSS is mandatory
- Examples of trips protecting against excessive heat production:
  - neutron overpower, high rate log N, coolant high pressure
- Examples of trips protecting against impaired heat removal:
  - boiler low level
  - LOCA trips: RB pressure high, coolant pressure low, moderator level high, coolant flow low, core differential pressure low

Control Room Neutron Power Indication

Required at *all* times to confirm:

- during normal operation, that neutron power is within heat sink capability
- during accident conditions, that neutron power is responding predictably

Preferred Unit State for Fuelling

- reactor critical and at high power
- local reactivity changes compensated by RRS via Liquid Zone Control System
- zone levels monitored for unusual reactivity effects by ANO
- No such capability with reactor power <15% FP
- Shutdown fuelling requires Manager's approval

Factors Affecting Fuel Cooling

Under Operator control:

- Reactor thermal (fission + decay) power
- coolant inventory
- subcooling/saturation margin to dryout
- coolant flow
- heat sink availability and capability

Primary & Backup Heat Sink Availability Requirements

- Primary & backup are an OP&P requirement
  - total loss of heat sink results in fuel failures

  Exception: no backup full power heat sink available
- Backup *independent* of primary
  - including the power supply
  - single equipment failure cannot disable both
- O&M planned to keep backup heat sink available
- seismically qualified heat sink (except PNGS-A)

Containment

- last line of defence against releases
- If **CONTROL** and **COOL** fail, resulting in fuel failures, public safety depends absolutely on **CONTAIN**ment integrity
- barrier to chronic and acute tritium releases