

Principles of Nuclear Safety



Module 4

The 3C's: CONTROL, COOL & CONTAIN

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Golden Rule of Reactor Safety

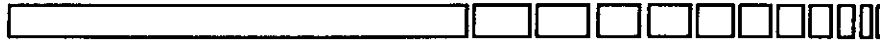


- There is no threat to public safety as long as
 - reactor power is controlled
 - the fuel is cooled
 - radioactivity is contained
- the 3C's are *essential* under *all* operating conditions:
 - at all power levels
 - during normal operation, shutdown or upset

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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

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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 *must* be put in GSS to prevent Loss of Regulation Accident (LORA)

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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

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Basic Requirements to Maintain Fuel Integrity



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

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Setback and Stepback

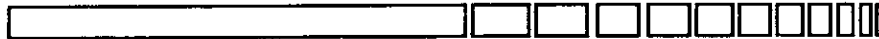


- second line of defence against fuel overheating
- various parameters monitored by each system
- fuel heat production is reduced when
 - operating limit reached indicating actual or potential mismatch between heat production and removal
- Examples:
 - Boiler pressure high (setback some stations)
 -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

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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

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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

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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)

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Containment



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