NOTES AND REFERENCES

Module 5

GUARANTEED SHUTDOWN STATE

OBJECTIVES:

After completing this module you will be able to:

CRO 5.1 Define *guaranteed shutdown state.* ⇔ *Page 2*

CRO 5.2 List three circumstances in which a reactor would have to be put into a guaranteed shutdown state (GSS), and explain why. ⇔ *Page 2*

CRO 5.3. Explain the purpose of putting a reactor in a GSS, and describe two methods used at your station to achieve a GSS. ⇔ *Page 2*

CRO 5.4 List five reactivity effects whose cumulative effect determines the minimum negative reactivity required to establish a GSS. ⇔ *Page 3*

CRO 5.5 List and explain the importance of four precautions taken while the reactor is in the standard GSS at your station. ⇔ *Page 5*

CRO 5.6 Give the designated position of the GSS Holder of Record, explain why this position is so designated, and give two responsibilities of the GSS Holder of Record. ⇔ *Page 5*

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The GSS is established when the shutdown guarantee is formally accepted by the Operations Manager, who then becomes the GSS Holder of Record. The Shift Supervisor must personally assure the Operations Manager of the integrity of this guarantee before requesting its acceptance.* While the GSS is in effect, the Operations Manager is responsible to ensure that there are no violations of the condition guarantee.

Typically, the SS walks the shutdown guarantee on behalf of the Operations Manager.

In preparation for GSS removal, the Shift Supervisor must review the status of all outstanding work authorizations, and confirm the availability of the regulating and special safety systems. When in a position to assure the Operations Manager that unit conditions are appropriate to exit the GSS, the Shift Supervisor requests the Operations Manager to surrender the shutdown guarantee.

SUMMARY OF THE KEY CONCEPTS

- Three conditions requiring the GSS are:
  1. a shutdown system is unavailable;
  2. the regulating system is unable to control bulk neutron power;
  3. ECI or containment is intentionally made unavailable.
- A reactor is placed in a GSS to prevent a power excursion, which might result in fuel damage, when the regulating and shutdown systems cannot be relied upon to perform this function.
- Isolation of the moderator purification system while in the overpoisoned GSS is necessary to prevent removal of the poison from the moderator. The integrity of the GSS depends absolutely on maintaining the poison concentration at or above the specified minimum.
- Moderator is kept acidic (pH < 6) while the overpoisoned GSS is in effect, to prevent precipitation of the gadolinium poison.
- D_2O addition to the moderator is isolated during the overpoisoned GSS to prevent diluting the moderator poison, and during the moderator drained GSS to prevent introducing D20 to the calandria, and during the moderator dumped GSS to prevent overfilling the dump tank to the extent that D_2O backs up into the core.

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Methods Of Establishing The GSS

The following methods are used to place a reactor in the GSS:*

* Additional variations of the GSS described in station documentation are beyond the scope of this course.

1. **Overpoisoned moderator GSS (not applicable to Pickering-A units).**

   This is the standard GSS, except for Pickering-A units. The overpoisoned moderator GSS is established by adding sufficient neutron absorbing poison (gadolinium nitrate) to a full calandria to ensure subcriticality, then applying condition guarantees (collectively called the *shutdown guarantee*) to prevent poison removal, dilution, and precipitation. Gadolinium nitrate can precipitate out of solution if the moderator pH is not maintained sufficiently acidic (pH < 6).

   The moderator purification system is guaranteed isolated to prevent poison removal. All D_2O addition points are guaranteed isolated to prevent adding any substance which would dilute the poison, and possibly induce poison precipitation by raising pH. The PHT system is maintained cold and depressurized** to reduce the risk of a pressure tube/calandria tube rupture (in-core LOCA), in which case the PHT coolant entering the moderator would dilute the poison, and might even raise pH to the extent that the poison precipitated. Also, the PHT interconnect valves are guaranteed closed to limit the amount of coolant entering the moderator to about one-half the total PHT inventory, in the unlikely event an in-core LOCA did occur.

** Special approval required to pressurize HT coolant

   Sufficient poison is added to the moderator to counteract the total positive reactivity inserted by all of the following effects in concert:*

⇔ *Obj. 5.4*

* These same effects determine the minimum negative reactivity required for the moderator drained GSS and the moderator dumped GSS, except that the moderator temperature coefficient of reactivity and poison dilution effects are irrelevant.

   a) Post-shutdown decay of fission product poisons,

   b) Plutonium buildup,

   c) The net effect of the fuel, coolant and moderator temperature coefficients of reactivity,

   d) All reactivity devices being placed in their most reactive states

   e) Fuel channel voiding and dilution of moderator poison by PHT coolant in case of an in-core LOCA.

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2. Moderator Drained GSS

Operations Manager approval is required to proceed to this non standard GSS. The drained GSS might be used, for example, on the loss (or removal from service) of all automatic shutdown capability. The moderator drained GSS is established by first establishing the overpoisoned GSS, then draining the moderator from the calandria, and applying additional condition guarantees to isolate liquid poison injection (except at Pickering-A), and to establish a 'hole' in the moderator system below calandria level, so that any D_2O entering the moderator system cannot accumulate in the calandria.

The PHT system is maintained cold and depressurized to reduce the risk of an in-core LOCA's increasing reactivity by introducing D_2O to the calandria.

3. Moderator dumped GSS (Pickering-A only)

This is the standard GSS for Pickering-A units. The moderator dumped GSS is established by applying condition guarantees to prevent moderator pump-up from the dump tank to the calandria, and to isolate all moderator D_2O addition points. The shutdown guarantee isolates the cover gas compressors, and guarantees the regulating valves open, so that the pressure differential between dump tank and calandria cover gases, which is essential to support moderator in the calandria, cannot be developed. The interconnect valves between PHT loops are guaranteed closed to limit the amount of coolant which could enter the calandria/dump tank system in case of an in-core LOCA, to roughly one-half the total PHT inventory. This action, together with observance of the limits on total combined inventory in the HT D_2O storage tank and moderator dump tank, ensures that the dump tank will not overfill, with D_2O backing up to the calandria.

Note that in both the moderator drained GSS and the moderator dumped GSS, the "ultimate heat sink" is removed from the calandria. But this becomes a problem only in the extremely unlikely event that all other shutdown heat sinks, including ECI, are lost. Even then, the option remains to refill the calandria with light or heavy water (after closing the 'hole' in the case of the drained GSS, of course).

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Precautions Observed In The GSS

The following precautions are taken while the reactor is in the GSS, in order to protect the integrity of the respective shutdown guarantees:*

* This list is not complete. Refer to station documentation for an exhaustive list of constraints and precautions.

⇔ *Obj. 5.5*

All GSS's

- The positions of all guaranteed devices are checked periodically (typically daily), to confirm the integrity of the shutdown guarantee.
- Neutron flux indication must be maintained continuously via either regulating system or start-up instrumentation.
- Except in the case of the drained state, at least one SDS is kept in service.*
- The PHT system is maintained cold and depressurized, unless Operations Manager approval is obtained to deviate from this state.

* Even in the drained state, at some stations where the calandria contains some residual D_2O, SDS1 remains in service with the shutoff rods partially inserted, but *poised above* the water surface.

Overpoisoned GSS:

- Moderator poison concentration is measured frequently (typically twice per shift), to ensure that the specified minimum required concentration is met.
- Moderator pH is measured frequently (typically twice per shift), to confirm sufficient acidity (pH < 6) to prevent precipitation of the gadolinium poison.
- The moderator is circulated continuously around the moderator circuit, to maintain uniform poison concentration in the calandria, and to maintain moderator temperature control.

Moderator Dumped GSS (Pickering-A only):

- Levels in the PHT D_2O storage tank and Moderator dump tank are monitored to confirm that total combined inventory is within limits.

Responsibilities of GSS Holder of Record

The integrity of the GSS is critically important to nuclear safety—eg, the regulating system or a shutdown system may be unavailable when the GSS is applied. The responsibility to ensure the integrity of the GSS is therefore assigned to the Operations Manager as the highest operations authority at the station.

⇔ *Obj. 5.6*

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Purpose Of The Guaranteed Shutdown State

Obj. 5.1 <>

Definition: **A guaranteed shutdown state (GSS)** is a state in which enough subcriticality in the event of any process failure, and condition guarantees are in effect to prevent net removal of negative reactivity.

Obj. 5.2 <>

A reactor must be placed in a GSS whenever any of the following occurs:

1. The Regulating System is unavailable to control neutron power.

2. A shutdown system is impaired, and cannot be returned to service within the grace period specified in operating instructions.

3. Containment or ECI is intentionally made unavailable. At some stations, the GSS is required if either of these systems becomes impaired, unless repairs can be completed within the specified grace period; at others, it is sufficient to shut down and cool down the PHT system. At all stations, the availability of containment and ECI is a prerequisite for *removing* the GSS.

Obj. 5.3. <>

Establishing a GSS is a special case of controlling reactor power. The purpose of putting a reactor into a GSS is to prevent a power excursion which might result in fuel damage, when the regulating and shutdown systems cannot be relied upon to perform this function. Nevertheless, for maximum defense in depth, the preferred state for the Regulating and Special Safety Systems is to be available and poised, even with GSS in effect. In particular, special approvals are required to remove all automatic shutdown capability during the GSS.

The rationale for applying the GSS as a prerequisite to removing ECI or Containment from service, is to reduce the risk of a power excursion while either of these mitigating system is unavailable. Removing a special safety system from service reduces the defense in depth; placing the unit in the GSS is a compensating stratagem to increase defense in depth.

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- Two responsibilities of the GSS Holder of Record are to ensure the integrity of the shutdown guarantee, and to ensure that conditions are appropriate for removal of the GSS before surrendering the shutdown guarantee.

- The Operations Manager is the Holder of Record because ensuring the integrity of the GSS is critically important to nuclear safety

ASSIGNMENT

Carefully prepare detailed answers to the Module 5 learning objectives.

1. The overpoisoned GSS is established by adding sufficient neutron poison to the moderator to ensure subciticality. List the various positive reactivity effects which must be considered in establishing the required concentration of neutron poison.

2. Once an overpoisoned GSS has been established, a number of conditions must be closely monitored. Identify four of these conditions, and *for each one* state why the monitoring is required.

3. CANDU reactors are potentially dangerous when shut down because of the large amounts of excess reactivity they may contain. List three sources of this excess reactivity, and explain how it is safely handled during a reactor shutdown. Include in your explanation the roles of the regulating and shutdown systems and the additional requirements if these systems become disabled.

4. State the measures that are typically taken to ensure that the concentration of poison required for the overpoisoned GSS is maintained.

5. Briefly explain why it is preferable to keep at least one shutdown system poised when the reactor is in the Overpoisoned Guaranteed Shutdown State.