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TABLE OF CONTENTS

SUB-CHAPTER 4.5 – FUNCTIONAL DESIGN OF REACTIVITY CONTROL

0. SAFETY REQUIREMENTS

0.1. SAFETY FUNCTION

The safety functional requirements met by the functional design of the reactivity control is to control core reactivity, to enable the chain reaction to be stopped under all circumstances, and to allow the reactor to return to a safe state.

The functional design of reactivity control must ensure these safety functions are achieved under all design basis operating conditions, PCC-1 to PCC-4, and contribute to achieving the safety functions in conditions corresponding to the risk reduction categories RRC-A and RRC-B.

0.2. SAFETY CRITERIA

Core reactivity must be controlled under all normal operating conditions from start-up to shutdown with the use of two diverse means.

The first one consists of the Rod Cluster Control Assembly (RCCA) and the other of variation in the concentration of soluble boron in the coolant.

0.3. DESIGN REQUIREMENTS

The functional design of the reactivity control systems does not fall within design requirements. However, the safety functions that they carry out require the application of a quality assurance program whose aim is to document and monitor activities related to design.

The systems supporting the functions related to reactivity control fall within design requirements. Each system will meet the design requirements as described in the relevant system section.

0.4. TESTING

Compliance of the core with the predictions of the functional design of reactivity control must be verified by physical tests at specified stages in the life of the plant.

1. DESIGN BASES

This section describes the design bases and functional requirements used in the functional design of the reactivity control system.

As stated in section 0.1 of this sub-chapter, safety functions must be fulfilled under all conditions of plant operation.

The four major plant operation categories consist of the normal operational states anticipated for normal plant operation and are enlarged by systematically looking for abnormal events having the potential to disturb safety functions.

These events are divided into four Plant Condition Categories (PCCs), according to their estimated frequency of occurrence (see Sub-chapter 14.0).

The safety criteria are the criteria that must be met in the safety analysis. They are defined in terms of radiological limits.

In practice, in addition to these safety criteria, it is convenient to introduce some decoupling criteria. These decoupling criteria are defined in terms of the integrity of the barriers. When these criteria are met, they provide a good guarantee that the safety criteria, i.e., the radiological limits, will be met (see Sub-chapter 14.6). Generally, for reactivity control functional design, these decoupling criteria will be expressed as a minimum sub-criticality level to be ensured at a given time under normal operation or in an accident[1].

1.1. MAXIMUM CONTROLLED REACTIVITY INSERTION RATE

Basis

The maximum reactivity insertion rate due to withdrawal of rod cluster control assemblies at power or by boron dilution is limited. For normal operation at power, the maximum reactivity variation for accidental withdrawal of control banks is set such that the peak heat generation rate and the departure from nucleate boiling ratio (DNBR) do not exceed the limits at overpower conditions (see Sub-chapter 4.3 – Table 1).

Discussion

Reactivity addition associated with an accidental withdrawal of a control bank (or banks) is limited by the maximum rod speed (or travel rate) and by the worth of the bank(s). The maximum control rod speed (see Sub-chapter 4.3 - Table 1) is such that the maximum rate of reactivity change in an accidental withdrawal of control banks is lower than this limit. During normal operation at power the maximum reactivity change rate is less than the maximum controlled reactivity rate change design value.

The reactivity change rates are conservatively calculated assuming unfavourable axial power and xenon distributions. The peak xenon burnout rate is significantly lower than the maximum reactivity addition rate for normal operation (see Sub-chapter 4.3 - Table 1).

1.2. SHUTDOWN MARGINS

Basis

An adequate shutdown margin or a subcritical state of the core is required in the operating power and shutdown conditions, respectively.

[1] The word "accident" used throughout the sub-chapter refers to any situation other than normal operation.

Discussion

Two independent reactivity control systems are provided, namely control rods and soluble boron in the coolant.

The control rods can compensate for the reactivity effects of the fuel and water temperature changes accompanying power level changes over the range from full-load to no-load. In addition, the control rods provide the minimum shutdown margin under plant condition category events and are capable of making the core subcritical rapidly enough to prevent acceptable fuel damage limits from being exceeded, assuming that the highest worth control rod is stuck out following reactor trip.

Changes in the soluble boron concentration in the reactor coolant can compensate for all reactivity changes due to xenon depletion and also changes in moderator density, and enable the reactor to reach and maintain cold shutdown. Thus, shutdown provisions are provided by a mechanical and a chemical shim control system.

1.3. SUBCRITICALITY

Basis

In shutdown states the core must be maintained sufficiently subcritical to guarantee its safety in case of accidental transients.

When fuel assemblies are in the pressure vessel and the vessel open or the vessel head is about to be removed, the accidental transients considered are boron dilution and the removal of all rod cluster control assemblies.

When the reactor pressure vessel is closed in cold conditions, the accidental transients considered are boron dilution and control rod ejection. In hot conditions, a steam line break must be considered in addition to the two other transients.

Discussion

The boron concentration required to meet the refuelling shutdown criteria is specified in the section related to nuclear design (see Sub-chapter 4.3 - Table 4).

2. FUNCTIONAL DESIGN DESCRIPTION OF THE SYSTEMS

The functional design of reactivity control impacts the design of a large number of systems, and the design bases for these systems must reflect these impacts. The affected systems are listed below, along with the impact of reactivity control functional design on their design bases.

Information on the combined performance of reactivity systems is also presented below.

2.1. CONTROL ROD DRIVE SYSTEM (CRDS)

The Control Rod Drive System (CRDS) responds to actuation signals, which may be generated by the reactor control and protection system (see section 2 of Sub-chapter 7.4) or through operator action. These actuation signals must enable rod motion by de-energising the coils of the Control Rod Drive Mechanisms (RGL [CRDM]) (see section 4 of Sub-chapter 3.4).

The CRDS enables the core to be taken subcritical in a very short time regardless of the initial power level. For most of the PCCs (except Loss Of Coolant Accidents (LOCAs) and Steam Line Breaks (SLBs)) the control rods are sufficient to reach sub-criticality.

2.2. CHEMICAL AND VOLUMETRIC CONTROL SYSTEM (RCV [CVCS]) / EXTRA BORATION SYSTEM (RBS [EBS])

The RCV [CVCS] responds to the actuation signals which may be generated by the reactor control system or through operator action (see section 2 of Sub-chapter 9.3). It enables the boron concentration to be adjusted to the required value for the core to be critical at power or subcritical by the required margin in shutdown states.

Because the RCV [CVCS] is not a safety classified system, the function of reactivity control in the safety analysis of PCC-1 to 4 events is provided by the RBS [EBS].

The RBS [EBS] responds to the actuation signals through operator action, except for the Anticipated Transients Without Scram (ATWS) signal which actuates it automatically (see Sub-chapter 6.7).

The RBS [EBS] ensures that the core remains subcritical in the long term over the range of PCCs. It enables the safe shutdown state to be achieved for all PCCs except LOCA, and is needed to reach the controlled state in the case of a SLB.

2.3. SAFETY INJECTION SYSTEM (RIS [SIS])

The RIS [SIS] responds to actuation signals generated by the reactor protection system or by operator action (see Sub-chapter 6.3).

Among other functions, it ensures core sub-criticality in the long term after a LOCA and enables the controlled and safe shutdown states to be reached.

2.4. INFORMATION FOR COMBINED PERFORMANCE OF REACTIVITY SYSTEMS

Reactor trip (RT) combined with RBS [EBS] ensures core sub-criticality in controlled and safe shutdown states for PCC-2 to PCC-4 situations, except for LOCAs and SLBs (see Chapter 14). In the case of a LOCA, in addition to RT, the RIS [SIS] is required to achieve both the controlled and safe shutdown states. In the case of an SLB, the RBS [EBS] is required to reach the controlled state. Note that in the analysis of transients no credit is taken for the boration capabilities of the Chemical and Volume Control System (RCV [CVCS]) (see Chapter 14).

Information on the capabilities of the RCV [CVCS] is provided in the relevant PCSR section (see section 2 of Sub-chapter 9.3). Adverse boron dilution possibilities due to the mal-operation of the RCV [CVCS] are investigated in the relevant accident analysis (see Sub-chapter 14.3). Correct prior operation of the RCV [CVCS] has been presumed as an initial condition in the analysis of transients: appropriate technical specifications will be prepared to ensure correct operation or remedial action.

3. DESIGN EVALUATION

The design evaluations of the individual systems impacted by the functional design of reactivity control are addressed in the relevant chapters.

The only aspect addressed here is the evaluation of combined performance of the different systems.

The evaluation of PCC-2 to PCC-4, which assumes the combined actuation of the CRDS and the RBS [EBS] by the reactor protection system and operator action, is presented in the accident analysis chapter (Chapter 14). Reactor trip signals for these events are generated from redundant equipment (sensors, logic train) and actuate redundant means of reactivity control. The reactor trip is obtained from the action of redundant trip breakers that interrupt the RGL [CRDM] power supply, which cause the 89 control rods to drop into the core by gravity. After RT, the RBS [EBS] is manually initiated in compliance with the accident management procedure. It consists of two totally redundant trains (2* 100% of function).

LOCA analysis assumes the combined actuation of the CRDS and the RIS [SIS] by the reactor protection system. Safety injection signals are generated from redundant sensors and logic trains. The RIS [SIS] consists of four independent, strictly separated trains in the reactor coolant loops and located in the four safety divisions.

It should be noted that the RBS [EBS] is automatically actuated in case of an ATWS to ensure core sub-criticality as a separate means of shutdown from the CRDS. Measures are taken to limit the consequences of an ATWS (see Sub-chapter 16.1).