5.7 NUCLEAR DESIGN

5.7.1 Introduction

This Section describes the nuclear design of the Reactor Facility and the models used to analyse the reactor core, fuel (described in Section 5.3), shutdown systems (described in Sections 5.4 and 5.5) and irradiation facilities (described in Chapter 11).

The equilibrium cycle is described including the anticipated loading pattern of the fuel assemblies and positions of the CRPs.

Analysis of each core configuration provides information on fast and thermal neutron fluxes, power densities and burnup for various core locations for both Beginning Of Cycle (BOC) and End Of Cycle (EOC) conditions.

Data is also presented on the reactivity worth for various conditions, core feedback coefficients and core dynamic parameters.

Verification is presented on the ability of both shutdown systems to comply with their neutronic design criteria.

5.7.2 Definitions

1. Configuration or core configuration: An arrangement of FAs, moderator, reflector, shutdown systems, structural materials and fixed irradiation rigs.
2. Control Rod Plates (CRPs): Mechanically movable neutron absorbers used to produce reactivity changes in the core.
3. Core configuration changes: Those changes caused by the replacement, removal or insertion of a FA or a fixed irradiation device or the replacement of a CRP plate or the movement of any nucleonic instrumentation.
4. Core state: The state of an operating core, which is completely specified by the temperature, burnup and power of the core.
   a) The working temperature defines different states, two of them being the most significant:
      (i) Cold state: State with the core at room temperature.
      (ii) Hot state: State with the core at operating temperature.
      (iii) The power level determines different states, mainly due to the implied equilibrium level of fission product ^{135}Xe. Two of them are the most significant:
      (i) Clean or without xenon state: There is no ^{135}Xe concentration in the fuel and it is equivalent to zero power.
      (ii) Power state: The ^{135}Xe concentration is in equilibrium and its value depends on the flux (or power) level.
   b) The burnup distribution determines different states, three of them being the most significant:
      (i) Fresh state: All FAs are fresh (no burnup).
      (ii) BOC state: This is the state immediately after FA replacement. Burnup distribution depends on the fuel management strategy. One or more FAs are fresh (just inserted in the core).

(iii) EOC state: This is the state before FA replacement takes place. Burnup distribution depends on the fuel management strategy. There are no fresh FAs.

5. The default state is the hot, power, and BOC state.
6. Reactivity power coefficient: This represents the dependence of the reactivity on total power. Its mathematical definition is:

$$\alpha_p = dR/dP$$

7. Effective multiplication factor (K_{eff}): This is a dimensionless number associated with the core. Mathematically, it is the number that divides the fission source to obtain a steady-state non-zero flux solution without an external neutron source. For a core at constant power K_{eff} is 1.0. Physically, this means the neutron population is constant over time.
8. Irradiation rig: It is a device installed in tubes that penetrate the heavy water reflector to utilise neutron flux and ionising radiation from the core for research, development, isotope production or any other purpose. It can be either a:
   a) fixed irradiation rig: An irradiation rig is designated fixed if it is mechanically fixed, stationary with respect to the core and may be moved only during the reactor shutdown state;
   b) non-fixed irradiation rig: An irradiation rig that may be moved whilst the reactor is at power.
9. Fuel Assembly (FA): Fuel plates and associated components that are installed as a single unit in the reactor core and that are not disassembled during loading and unloading from the reactor core.
10. Normal operation: Operation of the core and associated irradiation rigs within specified operating limits and conditions including start-up, power operation, shutting down, shutdown, maintenance, testing and refuelling.
11. Power peaking factor: Ratio between the maximum heat flux at any point in the core and the average heat flux over the entire core.
12. Reactivity: This is given by the mathematical expression $(K_{eff}-1)/K_{eff}$. It represents the fraction of neutrons created that are in excess of those required to keep the neutron population constant. The reactivity is zero for a critical reactor, positive for a supercritical reactor and negative for a subcritical reactor. The unit generally used is pcm (10^{-5}). There are various different types of reactivity defined, namely:
    a) Reactivity excess (Rexc): This is the reactivity of the core if all the control rod plates were fully withdrawn. If the core configuration and core state are not specified, the following core configuration and core state will be assumed: control rod plates out of the core, reflector vessel filled with heavy water, cold temperatures, no xenon, non-fixed irradiation rigs in their most reactive condition and BOC state.
    b) Reactivity of the first shutdown system (R1SS): This is the reactivity difference between the reactor with the control plates fully extracted and with them fully inserted.
13. Safety reactivity factor: The ratio between the reactivity of all safety plates (R1SS) and the reactivity excess of the core. The mathematical expression is:

SRF = R1SS/Rexc

14. Shutdown system: A system capable of shutting down the reactor. The reactivity balance of the core is controlled by two separate, diverse and independent systems:
    a) FSS: The reactor safety CRPs
    b) SSS: Partial dumping of the reflector vessel heavy water
15. Shutdown margin: The negative reactivity provided in addition to that necessary to maintain the reactor in a subcritical condition without time limit and all fixed and non-fixed irradiation rigs in their most reactive condition.

5.7.3 Codes and Standards

The core design is guided by a set of design bases, described in the following section, aimed at meeting safe reactor operation conditions.

These design bases will be observed by any core configuration to be operated taking into account its burnup state.

The design bases adopted conform to the following standards and documents:

a) IAEA Safety Series No. 35, Safety Requirements for Research Reactors (draft, February 1999).

b) Criteria for the Design of Nuclear Installations, Regulatory Guideline RG-5, draft, December 1998.

c) Environmental Impact Statement, Final, 1999.

d) Argentine Nuclear Regulatory Authority, Safety Standard AR-4.

5.7.4 Design Bases

The following design bases have been adopted to allow safe operation and shutting down of the reactor. These design bases are summarised in Table 5.7/1:

5.7.4.1 General Design Bases

1. The nominal reactor fission power will be 20 MW.
2. The reactor will have two independent and diverse shutdown systems. The FSS will be a set of absorbing plates built in Hafnium, while the SSS will be a dumping system for the heavy water reflector.
3. The FSS will be an automatic fast-acting system capable of shutting the reactor down for all design-basis fault sequences.
4. The control and regulating system will control core reactivity throughout the operating cycle by means of a regulating plate placed in the centre of the core.
5. Should the reactivity of the safety and regulating plate prove insufficient, assistance will be provided by the remaining plates to compensate for changes in the core reactivity during the operating cycle.
6. The reactivity regulation function will not prevent the operation of the CRP plates in their safety function, which will have priority over the reactivity regulation function.
7. The actuation of the SSS will prevent further withdrawal of any CRP. This last is a safety action and has priority over the CRPs reactivity control function.

5.7.4.2 Reactivity Design Bases

Criterion 1: The total power feedback coefficient shall be negative for any operating condition. All temperature and void coefficients of reactivity associated with the fuel and core will be negative for all operating states and accident conditions unless it is shown that the coefficient has an insignificant effect.

$$\alpha_{ct} < 0,\ \alpha_{cv} < 0,\ \alpha_{ft} < 0,\ \alpha_{p} < 0,\ \alpha_{rt} < 0,\ \alpha_{rv} < 0$$

Criterion 2: The shutdown margin of the FSS should be at least 3000 pcm.

$$\text{SM1SS} \geq 3000 \text{ pcm}$$

Criterion 3: The safety reactivity factor should be at least 1.5.

$$\text{SRF} \geq 1.5$$

Criterion 4: The core shall be subcritical with a shutdown margin of at least 1000 pcm, with any one of the CRPs out of the core.

$$\text{SM-1} \geq 1000 \text{ pcm}$$

Criterion 5: The shutdown margin for the SSS shall be at least 1000 pcm.

$$\text{SM2SS} \geq 1000 \text{ pcm}$$

5.7.4.3 Thermal-hydraulic related Design Bases

Criterion 6: The following relations were adopted within the neutronic and thermal-hydraulic design criteria related to core configuration:

a) The number of FAs shall be 16

$$\text{Nº FAs} = 16$$

b) The power peaking factor shall be lower than 3

$$\text{PPF} * 3$$

c) The thermal power generated shall be lower than the maximum allowed for the different cooling regime:

(i) Forced cooling: The power shall be lower than 20 MW.

$$\text{Power} \leq 20 \text{ MW}$$

(ii) Natural circulation: The power shall be lower than 400 kW.

$$\text{Power} \leq 400 \text{ kW}$$

If any of these previous conditions are not satisfied, a detailed thermal-hydraulic analysis shall be carried out to verify the proper cooling of the core.

5.7.4.4 Operating Condition Design Bases

Criterion 7: Reactor operation requires the minimum reactivity over a cycle to be sufficiently large to compensate for transients and non-fixed irradiation rigs.

$$\text{Reoc} \geq \Sigma\text{Rexn} + \text{Rmtc}$$

There shall be sufficient reactivity margin for transient control (Rmtc) to allow the reactor to return to full power operation 30 minutes after a reactor trip occurs from a spurious event at any time within the operating cycle except during the last 36 hours before a scheduled shutdown.

Criterion 8: The cycle of routine shutdowns for maintenance and/or refuelling will be four or more weeks (in increments of seven days) to accommodate the normal weekly working schedule of the maintenance staff.

$$Tc \text{ (days)} = N * 7 - Tref$$

$$N \geq 4$$

$$0.1{*}Tc \geq Tref \geq 2 \text{ days}$$

5.7.4.5 Irradiation Rig Reactivity Design Bases

The reactivity of each irradiation rig (fixed or not), the total irradiation rig reactivity, the rate of change of reactivity and the total reactivity change are all restricted.

Criterion 9: The maximum allowed reactivity for any fixed irradiation rig shall be 1200 pcm.

$$Rexf \leq 1200 \text{ pcm}$$

Criterion 10: The maximum allowed reactivity for any non-fixed irradiation rig shall be 200 pcm.

$$Rexn \leq 200 \text{ pcm}$$

Criterion 11: The maximum allowed reactivity for all irradiation rigs shall be 3000 pcm.

$$Rexp \leq 3000 \text{ pcm}$$

Criterion 12: The following relations were adopted for the reactivity rate of the non-fixed irradiation rigs:

a) There is no limit on the reactivity insertion rate for small reactivity perturbations.

$$\text{Any } \frac{dRexn}{dt} \qquad \text{for} \qquad Rexn < 40 \text{ pcm.}$$

b) The reactivity rate should be less than or equal to 10 pcm/sec for Rexn in the range 40 pcm to 200 pcm.

$$\frac{dRexn}{dt} \leq 10 \text{ pcm/sec} \qquad \text{for} \qquad 40 \text{ pcm} < Rexn < 200 \text{ pcm.}$$

5.7.4.6 Core Configuration Change Design Bases

The following criteria are not strictly design criteria for the core but rather conditions that should be met during any core configuration change.

Criterion 13: All core configurations during core reshuffling operations (initial, intermediate and final configuration) should be subcritical with a shutdown margin of at least 3000 pcm.

$$SMref \geq 3000 \text{ pcm}$$

Criterion 14: All core configurations during core reshuffling operations (initial, intermediate and final configuration) shall be subcritical with a shutdown margin of at least 1000 pcm, including the removal of the most effective CRP.

$$SMref\text{-}1 \geq 1000 \text{ pcm}$$

Note that only the initial and final core configurations in a reshuffling sequence are intended to be operated at power.

5.7.4.7 Rate of Insertion of Reactivity Design Bases

These criteria are applicable to the mechanical design of the corresponding systems.

Criterion 15: The FSS should insert a negative reactivity of 2000 pcm in less than 500 milliseconds.

Criterion 16: The SSS should insert a negative reactivity of 3000 pcm in less than 15 seconds.

Criterion 17: The addition of positive reactivity by the regulating and compensating systems should be at an average rate lower than 20 pcm/s.

5.7.5 Description

The Reactor Facility core design consists of a light water moderated core, fuelled with 19.70% enriched U_3Si_2 and surrounded by heavy water that acts as a radial reflector and light water as an axial reflector. The use of light water as a moderator and heavy water as a reflector produces a neutron energy spectrum in which fissions are caused principally by thermal neutrons. The bare core, without reflector and with all control rods removed, is sub-critical so the presence of the reflector is necessary to maintain the nuclear chain reaction.

5.7.5.1 Nuclear Design Description

For the purpose of this Safety Analysis Report (SAR), the equilibrium core is used as a reference core as it will be present for most of the Reactor Facility lifetime. The Reactor Facility will have only one geometrical FA configuration.

Much of the geometrical details and material selection of the fuel, chimney, control rod guide box and CRPs have been influenced by the neutronic design.

From a reactivity point of view the main design parameters are the uranium-235 load, the uranium to water ratio, burnable poison load and other materials present and their mass. The geometry and material of the CRPs has been selected to comply with the design bases with respect to safety and operational aspects.

The excess reactivity at BOC has been kept as low as reasonable and consistent with the cycle duration requirements, the need to compensate xenon and the cold-hot swing as well as to allow for some reactivity to compensate the effects of irradiation facilities.

Particularly important is the use of burnable poison in the FAs to permit the reduction of BOC excess reactivity and correspondingly the reactivity to be compensated by the CRPs along the cycle as well as the reactivity worth requirements on both shutdown systems.

The fuel management strategy determines the equilibrium core.

The neutronic parameters are calculated for the sub cycles at BOC and EOC.

Reactivity margins are calculated for various situations including hot and cold states, full power and without xenon.

There is also reference to the reactivity margins for the CRPs in their normal operating positions and CRPs out during power operations. The CRP normal operating positions have been defined in order to compensate Xenon poisoning for up to 30 minutes after a spurious shutdown (Criterion 7, Section 5.7.4.4). Additional details are given in Section 5.7.5.7.1.

5.7.5.2 Neutron Flux and Power Distribution

The core power distribution is a function of the core configuration design, core loading, CRP pattern and coolant density. Considering the rather small core size, it exhibits a low PPF, which leads to large safety margins from a thermal-hydraulic point of view.

5.7.5.2.1 Neutron Flux and Power Distribution Measurements

Power distribution within the core will be measured using an appropriate technique such as foil or wire activation analysis. Such measurements will only be made during the Physics test state following a few special core or reflector tank configuration changes. These measurements will be used to determine the PPF and the appropriate CRP pattern to be used during Full Power Operation mode in order to comply with the requirement on the value of the PPF. No online power distribution measurements are conducted during other reactor states.

5.7.5.2.2 Neutron Flux and Power Distribution Accuracy

Measurement uncertainties in foil or wire activation and calculation of the resulting power distribution yield uncertainties in the measured PPF. The margin between the calculated and maximum design basis PPF is sufficient to accommodate these uncertainties.

The assessment of the effects on the power distribution indicate that the perturbation of the PPF due to a CNS change of state and the movement of non- fixed irradiation facilities is low, with exception of the iridium loads that introduces a perturbation of a few percents.

5.7.5.2.3 Neutron Flux and Power Distribution Anomalies

Appropriate operational and inspection procedures will be utilised to ensure the correct assembly of the core following fuel loading. A fuel loading error (misplaced FA) is a very unlikely event, but calculations have been performed to determine the effects of such events.

The inherent characteristics of the reactor neutronic design are well suited to limit gross power tilting. The condition requiring that all the reactivity coefficients must be negative provides the core with a stabilising nature and reduces the effects of perturbations (e.g. irradiation target movement) on the power distribution.

The dimensions of the core do not allow excessive local power density increases (e.g. due to burnup effects or CRP pattern) that may lead to an unacceptable power distribution. This characteristic of the core design means that the reactor does not require an online power distribution measurement system. In addition, the design provides a sufficient safety margin on the Power Peaking Factor to allow for any possible power tilt.

The perturbations on the neutron flux and power distributions, including the perturbation on the PPF, have been estimated for the movement of the CRPs along the cycle.

The analysis of the perturbations in the power distribution due to the loading and unloading of irradiation rigs was carried out with the neutronic code CITVAP. The analysis of the perturbation of the neutron flux at the irradiation facilities position due to the loading and unloading of irradiation rigs was carried out with the code MCNP. Irradiation facilities analysed include pneumatic rigs, light loading of iridium-192 production, iodine-131 production, molybdenum-99 production, large volume facilities, and Cold Neutron Source (CNS). The maximum calculated reactivity insertion for these operations is lower than 200 pcm (Section 5.7.5.5.2). The general conclusion of the analysis is that the neutron flux and power distributions, and hence the PPF, in the core are not affected by the loading or unloading of non-fixed irradiation rigs although they can affect the flux of other neighbouring irradiation positions.

Regarding fixed irradiation positions the analysis shows that the heavy loading of iridium-192 production facilities introduces the strongest perturbations in the core reactivity, when the facility is loaded. As these facilities will not be moved during operation the neutron flux and power distribution in the core will remain unaltered during the Power State.

Perturbations introduced by the CNS have been analysed by using the MCNP code. It was found that the perturbations in the flux and power distributions within the core introduced by the change from liquid to gaseous state are negligible.

Further consideration of improper power distributions is given in Chapter 16, Section 16.9.3 where it is concluded that these events may be eliminated as PIEs.

5.7.5.3 Reactivity Feedback Coefficients and Kinetic Parameters

Reactivity feedback coefficients, the rate of change of reactivity produced by changes in core conditions, are useful in calculating the stability and evaluating the response of the core to external disturbances. The initial condition of the system and the postulated events determine which of the various defined coefficients are significant in evaluating the response of the reactor. The coefficients relevant to the response in the case of the reactor are discussed here. Each coefficient was calculated for the hot reactor state and for the cold, without xenon reactor state. It can be seen that all reactivity coefficients are negative as required by criterion 1 (Section 5.7.4.2). Therefore, the power feedback coefficient is negative, as all other feedback coefficients are so.

In calculating the kinetic parameters the difference between the delayed neutron and prompt neutron energy spectrums was taken into account. Delayed neutrons are less energetic than prompt neutrons, so the number of energy groups was increased, mainly in the fast group region, to obtain an accurate estimate of the kinetic parameters.

5.7.5.4 Control Requirements

It will be shown that the designs of the two independent shutdown systems will provide sufficient reactivity to control the maximum excess reactivity anticipated during the plant operation and maintain the reactor shut down without time limit. The rate of insertion of negative reactivity for both systems is also presented and shown to satisfy the design bases.

5.7.5.4.1 Evaluation of Shutdown Systems

5.7.5.4.1.1 First Shutdown System

The reactivity worth of each CRP and of the whole FSS has been calculated. The reactivity worth of the FSS with single failure of one of the CRPs has also been calculated.

Measurements performed on the CRD Prototype (See Section 5.5.3.7) showed that in normal pneumatic actuation system operation the whole bank should reach its full insertion in no longer than 0.425 sec, and that in the case of free fall (failure of actuation system) full insertion will be attained in no more than 0.8 sec.

5.7.5.4.1.2 Control Rod Depletion

The reactivity changes and the efficiencies of the CRPs due to the depletion of the absorber material, hafnium, have been evaluated to estimate the CRP lifetime.

The lifetime is defined as the period after which the CRP reactivity worth reaches the minimum reactivity worth needed to satisfy the design bases. The calculation was done at the BOC of each operation sub cycle in the cold without Xenon state.

CRPs are anticipated to be replaced every 12 years. The results show that depletion at that time will be less than 7% of the CRPs giving sufficient margin.

5.7.5.4.1.3 Second Shutdown System

The reactivity worth of the SSS was calculated using the neutron transport code MCNP. The heavy water level as a function of time was measured in a mock up of the SSS.

The calculations show that the negative reactivity provided by the SSS within 15 s complies with the requirements.

5.7.5.4.2 Reactivity Variations

Small reactivity variations due to normal operation of the reactor will be accommodated by the safety and regulating plate. Larger reactivity changes will be compensated by the safety and compensating plates. Movement of CRPs is commanded by the RCMS when performing its reactivity regulating function. The logic of the RCMS allows only one CRP to move at a time.

During power operation the four lateral CRPs will be introduced into the core only a small percentage of their length and the central cruciform CRP, the safety and regulating plate, will be used to compensate the core reactivity change along the cycle. The safety and regulating plate will be almost completely inserted at BOC and withdrawn at EOC. The safety and compensating plates are kept partially introduced to provide a reactivity margin to start up after a trip. This reactivity is enough to compensate the negative reactivity introduced by xenon for up to 30 minutes after the trip occurred except during the last 36 hours of the cycle.

5.7.5.5 Variations in the Neutronic Parameters Induced by Various Situations

5.7.5.5.1 First Core and Intermediate Cores

The first core will be built by using different types of FAs. One of them is the standard FA, while the others are geometrically identical to the standard.

A series of intermediate configurations will be reached by applying the fuel management strategy. Subsequent cores will be assembled by loading standard FAs after removing the corresponding spent FAs. Fuel cycles of intermediate cores will be either 26 or 33 FPD long.

Neutrons for first core start up will be provided by an external Am-Be source. After sufficient burnup is reached, the core will be capable of being started up with the photo-neutrons produced in the heavy water surrounding the core.

5.7.5.5.2 Changes on the Irradiation Rig Conditions

Irradiation rig movements introduce changes in the reactivity of the reactor. A perturbation analysis has been carried out to calculate the magnitude of those changes.

It is observed that while irradiation rig positions fully loaded with iridium could produce a reactivity change of about 170 pcm, the effect of any of the other facilities is smaller. The changeover time from one state to the other is at least several minutes.

5.7.5.5.3 Heavy Water Degradation

Calculations were made to evaluate the effects of heavy water degradation (accumulation of light water as an impurity in heavy water) on the flux distribution and core reactivity. The model used to obtain the results was a simplified 3D model at BOC. The analysis was performed by varying the light water molar content from 0.10% to 0.50%, calculating the corresponding macroscopic cross sections for the degraded heavy water and then recomputing the fluxes and reactivity of the core.

It is concluded that these negative reactivity variations can be accommodated by the reactivity excess of the core and regulated by the CRPs.

5.7.5.5.4 Anticipated Operational Occurrences

Anticipated operational occurrences and postulated accidents resulting from FA movements are:

a) Refuelling error: Two situations are considered here. First, the insertion of a fresh FA in an incorrect position is considered maintaining the average burnup constant, that is, interchanging the positions of the fresh FA with a burned FA. Second, it is assumed that the three most burned FAs are replaced by three fresh FAs.

b) Insertion of a fresh FA without burnable poison: Two cases are considered. First, it is assumed a FA without burnable poison (e.g. due to a manufacturing error) is inserted. The second situation considered is the insertion of three fresh FAs without burnable poison into the replacement positions.

c) FA falling down over the core: It is assumed a fresh FA without burnable poison falls over the core. The aluminium non-active length of the fresh FA is neglected. The FA maximum feasible inclination is thirteen degrees due to the geometrical constraints imposed by the core chimney and the CRGB.

d) Dropping of a FA during transfer from the reactor pool to the service pool.

e) Inadvertent FA ejection and subsequent reinsertion of a FA in the core grid during reactor operation.

The last three items are considered in Chapter 16, Section 16.8.2 where it is shown that they can be eliminated as DBAs by inherent design provisions. For the first three items, the core reactivity and PPF changes have been analysed for the reference core at BOC. It can be seen that the reactivity worth of the FSS is sufficient to safely shut down the reactor for these postulated situations. The PPF changes can be safely accommodated by the design.

5.7.5.5.5 Manufacturing tolerance

An analysis was performed on the effect of uncertainties due to various sources of tolerances in the manufacture of FAs. This analysis included the following tolerances:

a) Fuel assembly loading: this allows for extreme changes on fuel loading and burnable poison loading.

b) Fuel assembly dimensions and position: this takes into account variations in

   (i) fuel meat width and thickness

(ii) burnable poison width, thickness and position.

(iii) water volume

(iv) aluminium volume

A stochastic method was used in this case to take into account random variations in the mechanical dimensions of the FA.

c) Fuel plate impurities: this considers the presence and level of impurities in meat and cladding.

Variations in the core reactivity due to changes in these parameters were estimated to result in a variation of less than 300 pcm in the core reactivity.

5.7.5.6 Criticality During Refuelling and Maintenance

During Refuelling and Maintenance States the reactor is maintained in a sub-critical state at all times with the five CRPs in the fully inserted position.

The calculated shutdown margin during refuelling and the calculated shutdown margin during refuelling with the most effective CRP out satisfy the relevant design bases. Calculations were performed assuming cold and without xenon core states for BOC conditions.

The reflector vessel will be emptied for particular maintenance cases where the negative reactivity worth of the CRPs is altered. This will ensure sufficient shutdown margin in such cases.

It is anticipated that FAs will be removed from the core prior to any CRP replacement operation.

5.7.5.7 Stability

5.7.5.7.1 Xenon Transients

Instabilities induced by xenon oscillations are not present in reactors with compact cores, such as is in the case of the Reactor Facility.

The negative reactivity introduced by xenon poisoning was calculated. Such reactivity changes can be safely compensated (that is, maintaining the shutdown margins) by the CRPs.

In case the reactor has been operating at full power and is shut down it will be possible to startup again within 30 minutes except during the last 36 hours of the cycle. This is accomplished by appropriate placement of the safety and compensating plates to balance xenon poisoning.

5.7.5.7.2 Thermal-hydraulic Stability

The compliance of the Reactor Facility nuclear design with the criteria set forth in the thermal-hydraulic related design bases (Section 5.7.4.3) assures that no thermal-hydraulic instabilities, discussed in Section 5.8 such as the flow instability phenomenon, departure from nucleate boiling or low flow burn out phenomenon, will be induced by the neutronic behaviour of the core.

The limits on the core configuration, power and PPF not exceeding the value of 3 allows the uncoupling of neutronic and thermal-hydraulic calculations. The Automatic Reactor

Power System Control loop parameters are such that the power will be smoothly controlled.

5.7.6 Neutronic Calculation Line

This section describes the steps followed to perform the neutronic calculations for the reactor. These calculations include reactivity worth of the shutdown systems, fuel management strategy, core power distribution, reactivity coefficients etc. Code details are provided in Section 5.10.

5.7.6.1 Calculation Methodologies

The calculations necessary for the design of the Reactor Facility are performed in several steps with various codes, summarised in a calculation line.

The MTR_PC system was used to perform many of the calculations for the nuclear design. It is an integrated system composed of several of the codes used for the reactor design calculations.

The calculation line for Reactor Facility is divided into three different methodologies:

a) Calculation using macroscopic cross sections. This methodology is used for almost all the neutronic parameters. The equilibrium core burnup distribution is the most important calculated parameter.

b) Calculation using microscopic cross sections. This methodology is used for the calculation of the kinetic parameters and time dependent calculations.

c) Monte Carlo code. This calculation methodology is used for the verification of several neutronic parameters.

The first two methodologies are divided into 3 steps:

a) library generation

b) cell calculation

c) core calculation

The last methodology is divided into 2 steps:

a) library generation

b) Monte Carlo calculation

5.7.6.2 Working Library Generation

This step is done using several codes integrated into a system. The primary inputs are the Evaluated Nuclear Data files. The output is the working library that is used as input in the next step.

The INVAP calculation line uses ESIN and MCNP type working libraries, which are periodically updated with the most recent nuclear data.

The ESIN type library is extracted from the WIMS library (with some updates from ENDF-B/VI) and from the commercial code HELIOS.

The MCNP type working libraries are extracted from ENDF-B/VI.

5.7.6.3 Cell Calculation

A cell calculation is performed using the CONDOR code and ESIN type libraries to generate a homogenised macroscopic (or microscopic) cross-section set for each component of the core.

These cross sections are used as input for the next step.

5.7.6.4 Core Calculation

This step is done with the CITVAP code, an improved INVAP version of the CITATION II code. The outputs of this step are the neutronic parameters.

5.7.6.5 Nuclear Data and Neutronic Design Codes

5.7.6.5.1 Nuclear Data Library

Primary data for the ESIN type nuclear data, with 69 groups, results from the WIMS library, which has good thermal detail as well as resonance parameters. Moreover, it has isotopes added from the HELIOS library for control rod material (Hafnium isotopes).

A new set of isotopes was added from the ENDF/B-VI library, for Ir and Te, using the NJOY system.

The primary data for HELIOS is from the ENDF/B-VI library. The library has three different group structures: 190, 89 and 34 groups.

5.7.6.5.2 Neutronic Design Codes

Description of the codes and their validation is provided in Section 5.10.

5.7.7 Design Evaluation

The neutronic design of the Reactor Facility has been performed by following all applicable codes and standards (Section 5.7.3) and applying international best practice.

Computational programs used in the design have already been adequately validated and verified (Section 5.10). The cross section libraries utilised to construct macroscopic cross sections (Section 5.7.6.2) are used extensively world-wide and have also been validated.

Limiting values and conditions have been set to ensure safe reactor operation and that no damage will occur to fuel plates in accordance with the results obtained in Section 5.8. Table 5.7/2 shows the compliance with the nuclear design bases.

In order to comply with reactivity addition rates for non-fixed experiments, the removal and insertion of irradiation rigs containing uranium-235 should be done by means that ensure compliance with the 10 pcm/s limit.

The lifetime of CRPs has been defined by providing a design margin thus the necessary shutdown margins for the FSS are ensured.

In particular the reactivity worth of both shutdown systems under all conditions complies with the design bases with ample margins.

The maximum PPF provides a large margin to the design value of 3 used in the thermal-hydraulic design of the core. This margin is sufficient to allow for calculation uncertainties as well as effects from irradiation facilities and other factors not accounted explicitly.

End of Section

Table 5.7/1 Summary of Design Bases

Criterion	Limit Value	Applicable
1	α_{ct}, α_{cv}, α_{ft}, α_{p}, α_{rt}, α_{rv} < 0	Always
2	SM1SS ≥ 3000 pcm	During operation
3	SRF ≥ 1.5	During operation
4	SM-1 ≥ 1000 pcm	During operation
5	SM2SS ≥ 1000 pcm	During operation
6	N° FA = 16 PPF ≤ 3	Core at full power
7	Reoc ≥ ΣRexn + Rmtc	Core at full power
8	Reoc≥1200 pcm	Core at full power
9	Tc (days) = N * 7 – Tref N ≥ 4 0.1*Tc ≥ Tref ≥ 2 days	Core at full power
10	Rexf ≤ 1200 pcm	During operation
11	Rexn ≤ 200 pcm	During operation
12	Rexp ≤ 3000 pcm	During operation
13	Any Rexn rate Rexn rate ≤ 10 $pcms^{-1}$	In operation and for Rexn < 40 pcm In operation and for 40 pcm < Rexn < 200 pcm
14	SMref ≥ 3000 pcm	Any core configuration change
15	SMref-1 ≥ 1000 pcm	Any core configuration change
16	SM1SS ≥ 2000 pcm in 0.5 s	Always.
17	SM2SS ≥ 3000 pcm in 15 s	Always.
18	Average reactivity insertion rate < 20 pcm/s	Always (during operation).

End of Tables

Figure 5.7/1 First Shutdown System Reactivity Worth as a Function of Time

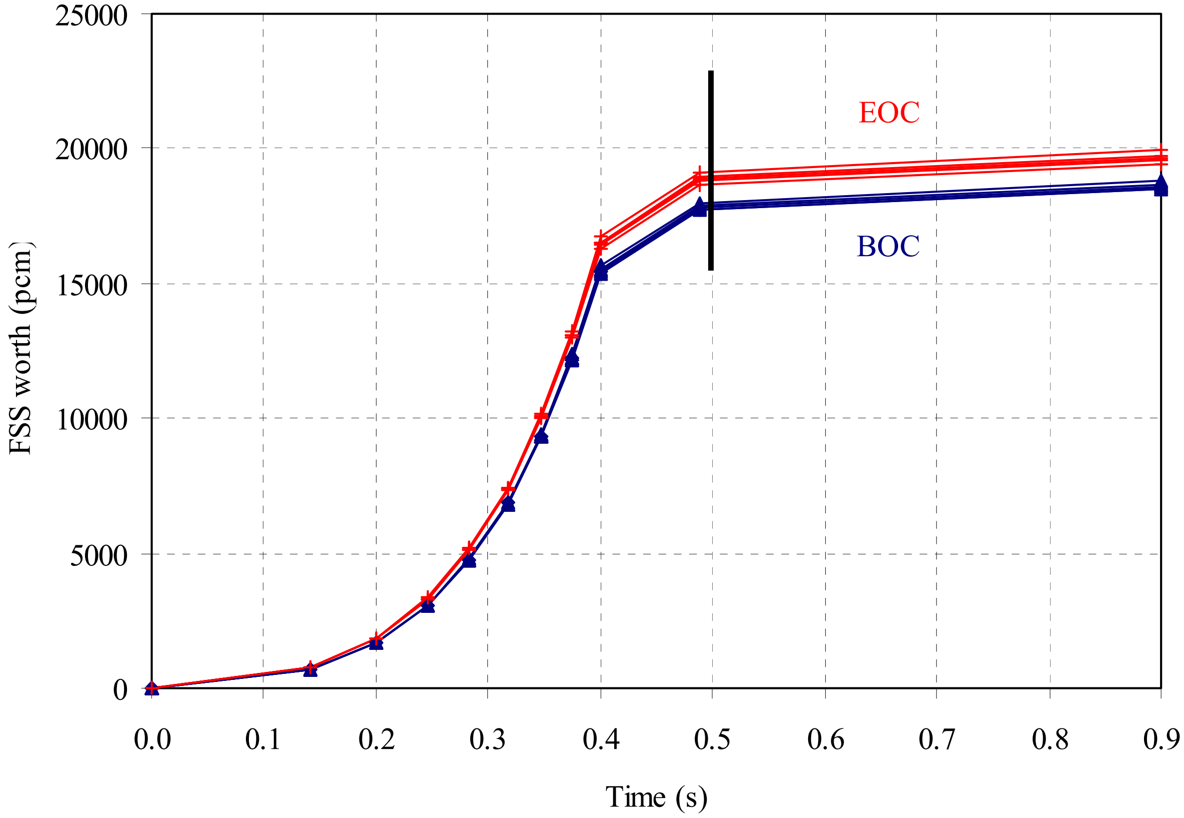
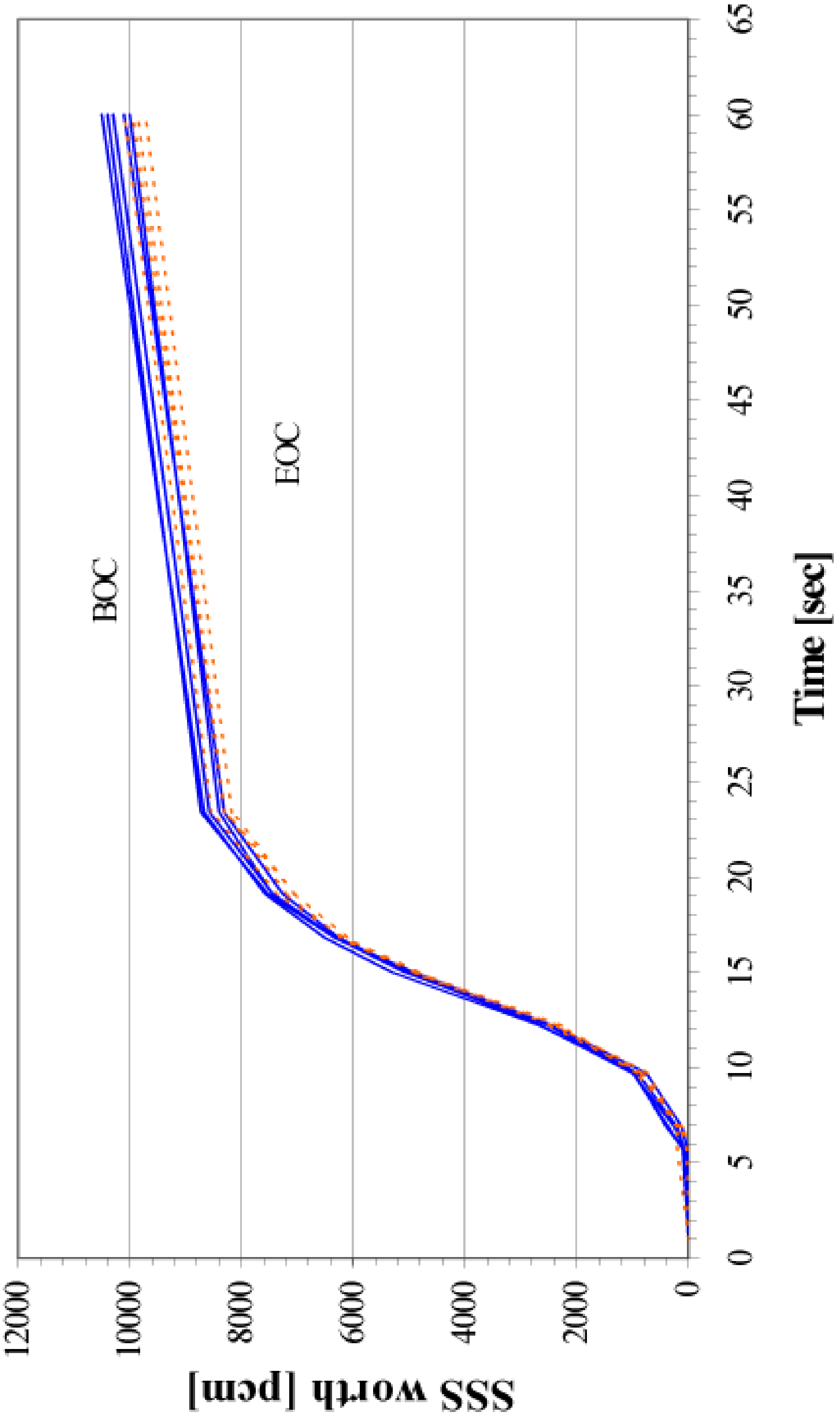


Figure 5.7/2 Second Shutdown System Reactivity Worth as Function of Time



End of Figures