DESIGN REPORT ON THE GUIDE BOX- REACTIVITY AND SAFETY CONTROL PLATES FOR MPR REACTOR UNDER NORMAL OPERATION CONDITIONS.

M. Markiewicz
Nuclear Fuel Design Group
Nuclear Engineering Department
Centro Atómico Bariloche
ARGENTINA

ABSTRACT

The reactivity control system for the MPR reactor (Multi Purpose Reactor) is a critical component regarding safety, it must ensure a fast shut down, maintaining the reactor in subcritical condition under normal or accidental operation condition. For this purpose, this core component must be designed to maintain its operating capacity during all the residence time and under any foreseen operation condition.

The mechanical design of control plates and guide boxes must comply with structural integrity, maintaining its geometric and dimensional stability within the preestablished limits to prevent interferences with other core components. For this, the heat generation effect, mechanical loads and environment and irradiation effects were evaluated during the mechanical design.

The reactivity control system is composed of guide boxes, manufactured from Aluminium alloy, located between the fuel elements, and control absorber plates of Ag-In-Cd alloy hermetically enclosed by a cladding of stainless steel sliding inside de guide boxes. The upward-downward movement is transmited by a rod from the motion device located at the reactor lower part.

The design requirements, criteria and limits were established to fulfill with the normal and abnormal operation conditions. The design verifications were performed by analitical method, estimating the guide box and control plates residence time.

The result of the analysis performed, shows that the design of the reactivity control system and the material selected, are appropiate to fulfill the functional requirements, with no failures attributed to the mechanical design.

1- INTRODUCTION

This report describes the design of the reactivity control system for the MPR reactor (Multi Purpose Reactor), consisting of control plates and guide box, evaluating the stresses both components shall be subjected to during normal operation conditions.

The control system is a critical component regarding safety. Its correct operation when required must be ensured. For this purpose, both components must maintain their operating capacity during all their residence time and under any foreseen operation condition.

The mechanical design must comply with structural integrity, and maintain its geometric and dimensional stability within the preestablished limits to prevent interferences with other core components.

2- PURPOSES

The mechanical loads and environment effects under normal operation conditions had to be evaluated for the guide box - control plates system mechanical design.

This report defines the requirements and design criteria. The design verifications were made by using analytical calculation methods in order to determine, from the mechanical point of view, the components residence time inside the reactor core.

3- DESIGN REQUIREMENTS

The operation requirements for the MPR reactor reactivity control system, both control plates and guide boxes, must comply with are detailed in this section. The specified requirements are applicable for normal as well as abnormal operation conditions.

Considering the reactivity control system is extremely important for the reactor safety, it must ensure a fast shut down, maintaining the reactor in subcritical condition under normal or accidental operation condition.

From the operation point of view, the reactivity control system must comply with the following functions:

- Compensate for reactivity changes under normal operation conditions, including start up, shut down, fuel burnup effect.
- Shut down the reactor in case of abnormal operation condition.

The six control plates in the MPR reactor are classified functionally as four control plates and two shut down plates. All of them are geometrically identical.

To fulfill the operation capacity, the control plates and guide boxes mechanical design must guarantee that the reactivity control system shall not fail when required. For this purpose, both components must maintain the following capacities during their residence time:

- The control plates and guide boxes must maintain their mechanical integrity.
- The geometric and dimensional variations of both components must be within the tolerances defined in the design, so as to prevent mechanical interferences which may delay or impede the control plates axial motion.
- The tolerances required for manufacturing and mounting at the reactor must ensure an appropriate alignment of both components.

4- DESIGN CRITERIA
4.1- CONTROL PLATES

The following effects are considered in the control plates mechanical design:

a) Heat generation effect.

- Risk of reaching the absorber alloy fusion temperature.
- Reduction of the control plate - guide box gap due to thermal expansion difference between both components.

b) Irradiation effect

- Swelling of absorber material due to alloy elements conversion processes.
- Changes in the mechanical properties of the control plate cladding.

c) Chemical interaction with the coolant.

- Corrosion of control plate cladding.

d) Mechanical loads.

- Wear effects on the surfaces where the control plates and guide box are in contact.
- Tensile stresses in the cladding due to internal gas overpressure.

4.2- GUIDE BOX

The reactivity control absorber plates guide box is an important component of the MPR reactor core regarding safety, since it must ensure a correct operation of the reactivity control primary system and not interfere with the other core components under predictable reactor operation conditions.

For this reason, the guide boxes mechanical design must fulfill the following operation requirements:

a) Maintain their structural integrity against the loads required under any operation condition.
b) Maintain their geometric and dimensional stability, to prevent mechanical interferences with other core components.

During their residence time inside the reactor core, the guide boxes are subjected to different types of loads. Under normal operation conditions, the loads they are exposed to may be divided into:

a) Mechanical loads, produced by the coolant flow (difference of dynamic pressure on both sides of the guide box wall), interaction with the control plates (friction and wear).

b) Environmental effects, including corrosion phenomenon and damage due to irradiation.

The analysis and evaluation of these effects makes it possible to determine the residence time for this component of the reactor core, under normal operation conditions.

5- CONCEPTUAL DESIGN DESCRIPTION

The MPR reactor reactivity control system is composed of the following elements, lodged in the core:

a- Guide boxes for the control absorber plates.

b- Control absorber plates

Two (2) guides boxes are considered in the reactor core design. They are located between the fuel elements (F.E.) and parallel to the fuel plates.

There are three (3) control plates inside each guide box. This ensures the plates are guided from end to end and the correct performance of the control system. Each guide box is located by two (2) lateral guides, placed on two (2) opposite walls of the chimney and its lower end supported by the reactor grid. The upper part is fixed by two (2) lateral locks.

The upward-downward sliding of each control plate is transmitted by a circular rod from the motion device, located at the reactor lower part.

6- DEMANDS AND DESIGN LIMITS
6.1- GUIDE BOX
6.1.1- COOLANT INTERNAL OVERPRESSURE

According to the MPR reactor core thermohydraulic design, the coolant flow velocity in the channel formed between FE and guide box is faster than the flow velocity inside the guide box (region without control plate).

These speed differences result in a higher pressure inside the guide box. This produces a deflection of the channel lateral walls, being also a deformation process depending on time.

6.1.2- ELASTIC DEFLECTION AND MAXIMUM STRESS

A third of the guide box width is treated as a rectangular section straight beam, with built in ends and stressed by an uniformly distributed load and a concentrated load in the half of its length for calculating stresses and the lateral wall deflection.

6.1.3- CREEP DEFORMATION

An analysis was made to estimate the deformation of the lateral wall in terms of time.

Considering infinitesimal deformations, the ratio between the elastic deflection and the creep deformation of the beam was calculated

The creep deflection is proportional to the elastic deflection and it increases with the neutron irradiation.

The maximum lateral wall deflection was calculated and therefore the guide box residence time, to prevent interferences with other core components.

6.1.4- COOLANT INDUCED VIBRATIONS

The guide box is a slender structure, oriented parallel to the coolant flow direction, and so the hydrodynamic loads due to cross flow may be considered negligible.

The flow induced vibrations remain at a very low level under normal reactor operation conditions. It may then be expected that the amplitude of the fluid induced cyclical stresses remain below the stress given by the material fatigue curves.

6.1.5- WEAR DUE TO INTERACTION WITH THE CONTROL PLATE

The magnitude of the friction stress and location of the contact points change during reactor operation, as a consequence of the control plate axial motion and slight geometric and dimensional modifications of both components.

The guide box channels internal design, with longitudinal projections for guiding the control plates, produce an alignment of both components (due to the reduced tolerances) and thus reduces the contact stress.

6.1.6- IRRADIATION DAMAGE

Regarding mechanical design, the most relevant effects of neutronic irradiation on the structural components are:

- Changes in the mechanical and physical properties.
- Generation of new deformation mechanisms such as growth, creep, swelling.

These effects were considered in the mechanical design.

Since the MPR is a high flux reactor, it may be expected that the damages due to irradiation may be a limiting factor for the residence time of the structural elements which shall operate continuously in the core.

6.1.7- CORROSION EFFECTS

The Aluminium corrosion rate and corrosion type depends mainly on the water quality, the reactor core materials characteristics, and the components design.

Regarding design, the most important characteristics which affect the corrosion behaviour in structural materials are the correct selection of materials which are in contact (so as to prevent galvanic couples) and an appropriate design of the components to prevent water stagnation

Two different mechanisms may be identified regarding the localized corrosion phenomenon: pitting and galvanic corrosion. The first type is associated to impurities contained in the water such as chlorides and heavy metals. To prevent the consequences of corrosion mechanisms, it is necessary to control strictly the water chemistry during the reactor life time, together with a careful cleaning of the components introduced in the reactor core.

Galvanic corrosion results as a consequence of the union of dissimilar materials in presence of a conductive medium. This type of corrosion is prevented by an appropriate materials selection and a correct design of the contact areas, preventing for instance water stagnation, which may lead to local variations in the medium conductivity.

6.2- CONTROL PLATE

6.2.1- HEAT GENERATION EFFECT

As a consequence of the neutronic capture and other types of radiation, a certain quantity of heat is produced in the control plates, which is removed by the coolant flow along the guide box.

The heat transference mechanisms considered are:

- Heat conduction in the absorber material, with internal heat source.
- Heat conduction in the gap absorber material - cladding.
- Heat conduction in the cladding.
- Forced convection in the cladding surface (liquid phase).

The control plates operation temperature is determined mainly by the heat conduction in the gap absorber material - cladding, which depends on the gap size and the filling gas (helium) thermal conductivity.

To ensure the control plate geometric and dimensional stability during its residence time in the core, it is necessary to limit these parameters:

- Maximum absorber material temperature.
- Control plate thermal expansion.

The design criterion to limit the absorber material maximum temperature is to prevent, under any operation condition, the fusion of the alloy (Ag, In, Cd), which starts to form a liquid phase at temperatures of around 800 øC.

The control plate thermal expansion, in the direction of its thickness, may produce a mechanical interference with the guide box, delaying or even preventing the axial sliding.

During its operation in the reactor core, the initial gap is progressively reduced, due to the difference of thermal expansion of the absorber material at higher temperature and its swelling effect induced by irradiation.

If the absorber alloy is in contact with the cladding, additional volume increases may develop tensile stress and possibly the cladding rupture. Besides, the deformations produced may cause mechanical interference with the guide box.

To prevent these effects, the conservative design limit of the MPR reactor control plates consists in preventing contact between both components. According to this, the maximum increase of the absorber alloy in any of its directions must be lower than the initial gap thicknesses specified in the design for the same directions.

6.2.2- IRRADIATION EFFECT

Due to the neutronic capture, the elements Ag, In and Cd experience transmutations which produce a volume increase in the absorber alloy. This effect is given by the Sn and Cd atoms increase in the Ag fcc structure

Regarding mechanical design, the maximum permitted neutronic fluence must be specified, to prevent dimensional instability of the control plates due to swelling.

6.2.3- MECHANICAL LOADS

The reactivity control system is designed so that the control plates may support the mechanical loads which may occur under any reactor operation condition. The most important mechanical effects on the control plates performance are:

- Wear mechanisms due to contact with the guide box, due to friction stress during axial sliding.
- Tensile stresses in the cladding due to possible internal overpressure of the control plates filling gas, due to the temperature and reduction of initial volume caused by absorber alloy swelling.
- Mechanical loads produced during fast reactor shut down (scram).

The design limit for the control plates, regarding wear effects, consists in limiting the maximum wear mark to a depth where the equivalent stress is lower than the minimum cladding yield strength when irradiation starts.

In the same way, the stresses produced by overpressure and dynamic loads must be lower than the cladding yield strenght.

7- DESIGN VERIFICATION

7.1- GUIDE BOX

The guide boxes mechanical design verification makes it possible to predict their residence time under normal operation conditions, so as to prevent mechanical interferences with other core components and ensure fast reactor shut down.

The items considered in the mechanical design verification were:

- MECHANICAL PROPERTIES
  yield strength
  ultimate strength
  modulus of elasticity
  Poisson's modulus
- STRESSES AND ELASTIC DEFLECTION CALCULATION
- CALCULATION OF IRRADIATION INDUCED SWELLING
- SCREWED JOINT CALCULATION
- CORROSION BEHAVIOUR

7.2- CONTROL PLATE

- ABSORBER MATERIAL MAXIMUM TEMPERATURE CALCULATION

The temperatures in the following points were previously determined:
- Control plate cladding external surface.

- Control plate cladding internal surface.
- Absorber material surface.

- CALCULATION OF ABSORBER MATERIAL THERMAL EXPANSION

- CALCULATION OF IRRADIATION INDUCED SWELLING

- CALCULATION OF INTERNAL PRESSURE EVOLUTION WITH THE NEUTRON FLUX

- STRESSES CALCULATION

8- CONCLUSIONS

This report presents an analysis of the MPR guide box - control plate system behaviour for normal operation conditions.

The analysis results indicate both components' mechanical design and the materials selected are appropriate to fulfill the main functional requirements: structural integrity and geometric stability.

The calculations performed under conservative considerations show that after 4 years' reactor operation, the nominal gap between the guide box and the adjacent fuel elements is reduced in 80%.

The residence time estimated for the control plates is about 6 years.

If any consideration justifies extension of the permanence inside the reactor, it is recommended to inspect the component's dimensional and structural stability.