SUB-CHAPTER D.2 FUEL DESIGN

This sub-chapter lists the safety requirements related to the fuel assembly design. The main characteristics of the fuel and control rod assemblies which have been used as input data at the present stage of the EPR design, are listed in D.3 TAB 1.

0 SAFETY REQUIREMENTS

0.1 SAFETY FUNCTIONS

The safety functions relevant to fuel assemblies in the reactor core are as follows:

a) control of core reactivity and ability to achieve safe core shutdown in all circumstances.

b) residual heat removal through preservation of a coolable geometry.

c) containment of radioactive materials, in particular fission products, inside the first containment barrier.

0.2 FUNCTIONAL CRITERIA

The mechanical design of the fuel assembly must meet the functional criteria for the safety functions described in the section above. These criteria will be complied with if compatibility is ensured between:

- the fuel assemblies
- the fuel assemblies and their associated fuel elements
- the fuel assemblies and the reactor internals

0.2.1 Core reactivity control

The control rod assemblies are made up of rods which are inserted into the guide thimbles of the fuel assembly (see Chapter D.2.2). Under normal operating conditions, these enable the reactor power to be controlled. Under accident conditions, a control rod drop time compatible with the accident consequences analyses must be achieved.

This functional criterion applies to the following components of the fuel assembly:
Guide thimbles

The guide thimbles shall:

- allow the insertion of the control rod assemblies,
- terminate the drop of the control rod assemblies in an automatic reactor scram.

Grids

These must enable lateral positioning and support of the guide thimbles, even under incident and accident conditions so that the control rod assemblies can always be inserted freely within them.

Fuel assembly bottom nozzle

The bottom nozzle must:

- ensure positioning of the guide thimbles.
- prevent ejection of fuel rods.

Fuel assembly top nozzle

The top nozzle must:

- prevent ejection of fuel rods
- like the bottom fuel assembly nozzle, ensure positioning of the guide thimbles

0.2.2 Decay heat removal

The coolant shall flow at a sufficient rate to remove the heat produced by the fuel.

To this end, the dimensions of the core barrel (distance between the lower and upper core plates, assemblies pitch) and the fuel rods (nominal pitch, outer diameter, nominal height) must be preserved.

This functional criterion applies to the following fuel assembly components:

Fuel assembly

The geometry of the fuel assembly must be maintained through:

- lower support by the lower core plate,
- lateral support using the two alignment pins,
- the hold-down assembly at its upper end which is supported by the upper core plate and prevents the hydraulic pressure from lifting the assembly.

A baffle adds to lateral assembly support and limits the by-pass flow.

Guide thimbles
The guide thimbles must assist in the cooling of associated components and contribute to the structural continuity of the assembly.

### Grids

The grids shall enable:

- the fuel rods to be supported both axially and laterally for all the life of the assembly. The fuel rod support system must adapt to differential expansion between the rods and the skeleton assembly due to differential thermal expansion and irradiation growth,

- the pitch between the fuel rods to be maintained to preserve nuclear and thermal-hydraulic performance of the core. Under incident and accident conditions, the geometry of the core must be deformed as little as possible so that effective core cooling can be maintained,

- effective coolant mixing by creating turbulence (preventing the risk of departure from nucleate boiling), and effective fuel rod heat transfer by minimizing pressure loss.

### Fuel assembly bottom nozzle

The bottom nozzle shall enable:

- lateral positioning of the fuel assembly on to the lower core plate, thus maintaining the required pitch between assemblies,

- correct positioning of the guide thimbles,

- support and transfer of retention forces,

- distribution of the coolant entry flow into the core,

- limited irradiation of the lower core plate,

- support for the anti-debris device.

### Fuel assembly top nozzle

The top nozzle shall enable:

- lateral positioning of the fuel assembly under the upper core plate, maintaining the pitch between assemblies,

- positioning of the guide thimbles,

- support and transfer of the retention forces,

- distribution of the coolant exit flow from the core to the upper core plate while minimizing pressure loss.

### Hold down assembly

The hold-down assembly shall enable the fuel assembly to:
resist hydraulic pressure forces,
- absorb relative height variations.

In the first case, during reactor operation, the assembly must maintain contact with the lower core plate. In order to ensure this, the hold-down assembly and fuel assembly weight must exert a restraining force greater than the sum of the corresponding buoyancy force and the hydraulic pressure produced by the coolant fluid.

In the second case, the hold-down assembly must absorb the variations between the length of the fuel assembly and the distance between the lower and upper core plates. These variations are due to:
- differential thermal expansion,
- irradiation growth

Connections

Rod/grid and guide thimble/grid connections must ensure:
- structural continuity of the fuel assembly,
- dimensional stability of the fuel assembly.

The fuel assembly is made up of several components. The role of the connections is to link the components together so that each component can carry out its functions in a satisfactory and safe manner.

The choice and implementation of the connections must comply with the assembly dimensional requirements i.e. the alignment of grids and nozzles, the axial positions of the grids and the radial positions of the guide thimbles.

0.2.3 Containment of radioactive products

The barrier known as the first containment barrier which isolates the primary coolant fluid from the fuel and fission products must remain leaktight.

This functional criterion applies to the following components of the fuel assembly;

Fuel rod

The fuel rod cladding must maintain its integrity to keep the fissile material in a given configuration so as to contain fission products generated by the fuel pellets and avoid contamination of the coolant by activation of corrosion products.

This functional criterion must be complied with under Plant Condition Categories 1 and 2 (transients related to normal operation and anticipated operational occurrences).
For Plant Condition Categories 3 and 4 (incidents and accidents), clad deformation is permitted but a coolable geometry must be maintained. Under these conditions, the level of activity is calculated to check that the authorized discharge limits are complied with.

**Grids**

The grids shall facilitate core loading operations and fuel handling operations in such a way that contact with the fuel rod cladding does not threaten fuel integrity.

**Fuel assembly bottom nozzle**

The bottom nozzle shall facilitate core loading operations and fuel handling operations in such a way that contact with the fuel rod cladding does not threaten fuel integrity.

**Fuel assembly top nozzle**

The upper nozzle shall enable the gripping of the assembly by a handling tool during core loading operations and fuel handling operations in such a way that contact with the fuel rod cladding does not threaten fuel integrity.

### 0.3 DESIGN REQUIREMENTS

#### 0.3.1 Requirements derived from safety classifications

a) Safety classifications

   No safety class is attributed to fuel assemblies.

b) Single failure criterion

   Not applicable.

c) Emergency power supply

   Not applicable.

d) Qualification for operating conditions

   Not applicable.

e) Mechanical, electrical and instrumentation and control classifications

   Not applicable.

f) Seismic classification

   Although no level of safety classification is attributed to the fuel assembly, its mechanical design must take the effects of earthquakes into account.
g) Periodic checks

Not applicable (however, monitoring during operation will detect any leak in a fuel assembly).

0.3.2 Other regulatory requirements

The safety functions fulfilled by the fuel assemblies require the application of specific design rules. This information is not yet available.

0.3.3 Hazards

Not applicable.

0.4 TESTS

0.4.1 Pre-operational testing

Tests using mock-ups and prototypes

Fuel continues to be tested using mock-ups and through more representative tests under normal operating conditions, to validate computer codes and/or check the correct mechanical operation of the fuel assemblies in the reactor.

These tests address various aspects, including the effects of irradiation and mechanical strength.

The results of these tests will allow be applied to the planned fuel design.

Handling tests

Fuel handling tests are performed using dummy assemblies.

0.4.2 Inspection during operation

Monitoring for fuel assemblies leaktightness is carried out using measurements of radiological activity in the primary fluid during reactor operation which should reveal any fuel failures and enable monitoring of their development.

0.4.3 Periodic tests

Not applicable.
1 DESIGN DESCRIPTION OF THE FUEL

Each fuel assembly consists of 265 fuel rods and 24 guide thimbles which can either be used for control rods or for core instrumentation. They are arranged in a 17 x 17 rod array (see D.2 FIG1). The main characteristics of the fuel assembly are listed in table D.3. TAB 1.

The guide thimbles provide the channels for insertion of a rod cluster control assembly. In the present concept, the instrumentation lances use guide thimbles in the core fuel assemblies which are not used for control rod assembly insertion.

The fuel rods are maintained within a supporting structure consisting of the 24 guide thimbles, top and bottom nozzles and 10 grid assemblies distributed regularly over their height. The fuel rods are loaded into the fuel assembly structure so that there is clearance between the fuel rod ends and the top and bottom nozzles.

Each fuel assembly is installed vertically in the reactor vessel and stands upright on the lower core plate, which is fitted with a device to locate and orient the assembly. After all fuel assemblies are set in place, the upper support structure is installed. Alignment pins, built into the upper core plate, engage and locate the upper ends of the fuel assemblies. The upper core plate then bears downward against holddown springs on the top nozzle of each fuel assembly to hold the fuel assemblies in place.

Visual confirmation of the position of the fuel assemblies within the core is provided by an identification number.

1.1 FUEL RODS

Fuel rods are composed of slightly enriched uranium dioxide pellets with or without burnable poison (Gadolinium) or MOX (uranium plus plutonium) contained in a closed tube made of M5, hermetically sealed at its ends.

Plena are provided, at the top end and at the bottom end whose function is to contain fission gases.

The fuel pellets are held in place by a spring bearing on the top end of the pellet stack.

The extremities of each pellet are dished in order to compensate for the differential deformation between the centre and the periphery.

The gap between the pellets and the cladding, the initial pressurization, and the density of the pellets are calculated so as to minimize the interaction between the pellet and the cladding.

1.2 FUEL ASSEMBLY STRUCTURE

The fuel assembly structure consists of a bottom nozzle, top nozzle, guide thimble, and grids.

1.2.1 Bottom nozzle

The bottom nozzle serves as the bottom structural element of the fuel assembly and directs the coolant flow to the assembly. Made of stainless steel type AISI 304, the bottom nozzle consists of a plate perforated and supported through four legs with bearing plates. These legs form a plenum for the inlet coolant flow to the fuel assembly.
Coolant flows from the plenum in the bottom nozzle upward through the penetrations in the plate to the channels between the fuel rods. The perforations in the plate are positioned between the rows of the fuel rods.

The bottom nozzle is equipped with an anti-debris device and a positioning device to fix its position on the lower core plate.

### 1.2.2 Top nozzle and hold down system

The top nozzle assembly functions as the upper structural element of the fuel assembly and provides a partial protective housing for the rod cluster control assembly or other components. It consists of a top plate and an adapted plate which are linked by a square enclosure, and holddown springs mounted on the top plate. It allows rotation of the fuel assembly by 90°, 180° or -90° to provide flexibility for optimising the reload pattern.

The square adapter plate is provided with penetrations to permit the flow of coolant upward through the top nozzle. The top plate has a large square hole in the centre to permit access for control rods.

The top nozzle contains the identification marks of the fuel assembly, which are used to avoid incorrect positioning of fuel elements.

### 1.2.3 Assembly grids

The fuel rods are supported at intervals along their length by 10 assembly grids which maintain the correct lateral spacing between the rods.

Each fuel rod is supported within each grid by a combination of support dimples and springs. The magnitude of the grid restraining force on the fuel rod is set high enough to minimize possible fretting without overstressing the cladding at the points of contact between the grids and fuel rods. The grid assemblies also allow axial thermal expansion of the fuel rods without imposing a restraint sufficient to cause buckling or distortion of the fuel rods.

Two types of grid assemblies are used in each fuel assembly. One type has integral mixing vanes projecting from the trailing (upper) edges of the straps into the coolant stream. This type (8 grids) is used in the high heat flux region of the fuel assemblies to promote mixing of the coolant. The other type (2 grids), located at either end of the bundle, does not contain mixing vanes on the internal grid straps and serves only to support and locate the fuel rods.

### 1.2.4 Guide thimbles

The guide thimbles are structural members which also provide channels for the neutron absorber rods, neutron sources or instrumentation devices. Each thimble consists of a Zircaloy tube. The tube diameter at the top section provides the annular area necessary to permit rapid control rod insertion during a reactor trip. The lower portion of the guide thimble is made with a smaller inner diameter to reduce diame tri cal clearances and produce a dashpot action near the end of the control rod travel during trip operation.
2 DESIGN DESCRIPTION OF THE CONTROL ROD ASSEMBLIES

The rod cluster control assemblies are used for shutdown and control purposes to offset fast reactivity changes.

A rod cluster control assembly is comprised of a group of individual neutron absorber rods fastened at the top end to a common spider assembly.

At the present stage of the design, the absorber materials chosen for the control rods are AIC and B4C. This is the assumption used to perform neutronic core calculations, but different materials may be used in the final design.

The AIC bars and B4C pellets bars are sealed in a stainless steel tubes. The lower end plug of the tube is stainless steel. The absorber rods are fastened securely to the spider.

The overall length is such that when the assembly is fully withdrawn, the tips of the absorber rods remain engaged in the guide thimbles so that alignment between rods and thimbles is always maintained. Since the rods are long and slender, they are relatively free to adapt to any small misalignments with the guide thimble.

3 DESIGN EVALUATION

The fuel assemblies, fuel rods, and in-core control components are designed to satisfy the performance and safety criteria given in Chapter D.2.0.

3.1 CLAD

Evaluation of the design of the fuel rod clad will consider the following aspects:

a) vibration and wear
b) Fuel rod internal pressure and cladding stress
c) materials and chemical evaluation
d) fretting
e) stress corrosion
f) cycling and fatigue
g) rod bowing
h) consequences of a power/coolant mismatch
i) stability of the clad under irradiation
j) creep collapse and creep down
3.2 FUEL MATERIAL

Evaluation of the design of the fuel material will consider the following aspects:

a) dimensional stability of the fuel
b) chemical interaction potential
c) thermal stability
d) irradiation effects

3.3 FUEL ROD PERFORMANCE

The performance of the fuel rods will be demonstrated, focusing on the following points:

- pellet and clad temperature
- pellet and clad interaction
- pellet densification
- irradiation effects

Demonstration of the performance will be met through analytical models and/or experimental data collected either in test programs or commercial power plants.

3.4 SPACER GRIDS

The strain levels on the fuel assembly elements must be limited by the design of the grids.

3.5 FUEL ASSEMBLY

The ability of the fuel assembly to withstand various types of load will be demonstrated. The loads to be accounted for are as follows:

- the loads applied by the core restraint system
- analysis of accident loads
- loads applied during fuel handling and shipping

3.6 REACTIVITY CONTROL SYSTEMS

The evaluation of the design of the reactivity control system (control rods) will address the following points:

a) internal pressure and strain on the clad in normal, transient and accident conditions
b) thermal stability of the absorber material, including during phase changes and thermal expansion

c) stability under irradiation of the absorber material

d) chemical interaction potential

4 TEST AND CONTROL PROGRAMME

In general, the manufacturing and examination operations are performed in agreement with the fuel assembly supplier and in accordance with the appropriate rules (see Chapter B.6).

The fuel assembly contractor and its subcontractors are required to develop a quality assurance program whose aim is to document and monitor activities related to design, study and fabrication of fuel assemblies and their associated components.

The program must cover all the activities which might affect the quality of the product from design to development, to procurement, to materials handling, to fabrication, tests, examinations, storage, and transportation.

The examinations are either carried out at 100% (important structural elements such as assemblies or rods) or on a statistical quality control basis. The principle used for statistical quality control is that, unless otherwise indicated, examinations guarantee at a 95% confidence level that at least 95% of fabrication conforms to specifications (95 x 95).

This confidence level is based on experience acquired during previous core fabrication and from operating results. The statistical distribution of the main parameters is determined during fabrication and compared with the design distribution.
4.2 FIG 1: RADIAL DESCRIPTION OF A FUEL ASSEMBLY

- FUEL ROD
- GUIDE THIMBLE