5. REACTOR VESSEL - UPPER CORE SUPPORT STRUCTURES

5.0. SAFETY REQUIREMENTS

5.0.1. Safety functions

The internal structures of the reactor vessel (upper and lower) contribute to the following safety functions:

a) Control of reactivity by ensuring reactor shutdown and by enabling insertion of the core instrumentation,

b) Core cooling by maintaining a geometry enabling core cooling whatever the operating conditions,

c) Containment of radioactive materials by maintaining a vibration amplitude such that the leaktightness of the fuel assemblies is preserved,

d) Integrity of the second barrier by limiting the flux of fast neutrons which may lead to embrittlement of the reactor vessel.

5.0.2. Functional criteria

- Reactivity control

The internal structures of the reactor vessel should enable:

a) absorber control rod clusters to enter the core to ensure reactor shutdown in all circumstances,

b) in-core neutron flux measurement using the “aeroball” system and self-powered neutron detectors (SPND),

c) measurement of temperatures at the core outlet and in the vessel upper head by means of thermocouples

- Decay heat removal

The free circulation of water through and between the fuel assemblies must be maintained under all circumstances.

- Radioactive substance containment:

The vibration amplitude of the internal reactor structures in normal operation must be sufficiently low to prevent any unacceptable stresses on the fuel assemblies.

- Integrity of the second barrier
As well as the functions described in Chapter C.6.5.0.1, the internal structures of the reactor vessel are used in the monitoring programme of the reactor vessel material. The irradiation specimen for this material is contained in capsules inserted into the baskets fixed outside the core barrel. These capsules may be extracted from (and reinserted into) the baskets and thus enable monitoring of vessel material.

5.0.3. Design requirements

5.0.3.1. Requirements from safety classification

5.0.3.1.1. Safety classification

The internal structures of the reactor vessel are classified according to the classification principles presented in the paragraph on the classification of equipment (see Chapter C.2).

5.0.3.1.2. Single failure criterion (active and passive)

Not applicable

5.0.3.1.3. Emergency-supplied power sources

Not applicable

5.0.3.1.4. Qualification in operating conditions

Not applicable

5.0.3.1.5. Mechanical, electrical and instrumentation and control classifications

As far as mechanical integrity is concerned, the internal structures of the reactor vessel are divided into two sub-classes:

- Core support structures (CS) which are necessary for the mechanical integrity of the fuel assemblies,
- Internal structures (EI).

Core support structures must be designed according to the RCC-M (see Chapter B.6) Volume G.

5.0.3.1.6. Seismic classification

The internal structures of the vessel are seismically classified according to the principles presented in the paragraph on the classification of equipment (see Chapter C.2).

5.0.3.2. Other regulatory requirements

5.0.3.2.1. Official texts

Two documents apply to the internal structures of the vessel
5.0.3.2.2. Basic safety rules

Not applicable to UK EPR.

5.0.3.2.3. Technical directives

The general provisions of the technical guidelines apply to the internal structures of the vessel (see Chapter C.1.2).

5.0.3.2.4. Texts specific to EPR reactors

None

5.0.3.3. Hazards

5.0.3.3.1. Internal hazards

Not applicable

5.0.3.3.2. External hazards

The internal structures of the reactor vessel are protected against external hazards, in accordance with the requirements of Chapter C.3.

5.0.4. Tests

It is possible to completely remove the internal structures of the reactor vessel in order to:

- Test the internal structures of the reactor in service,
- Test the internal surface of the reactor vessel.

5.1. GENERAL INFORMATION

The upper internal structures are located above the core, in the region of the vessel which contains the nozzles. They fulfil the following important functions:

- ensure the correct position and alignment of fuel assemblies,
- support the forces exerted by the fuel assemblies on the fuel assembly holddown springs,
- distribute the coolant,
- ensure the correct position and alignment of rod cluster control assemblies [RCCAs],
- guide the level measurement probes,
- serve as a support for the core instrumentation,
- support the dynamic forces produced during PCC-4 events.

They constitute the upper part of the reactor core and house the absorber rods and the lances for the core and other instrumentation.

The upper internal structures are comprised of:
- the upper support plate with its wall and flange,
- the upper core plate,
- the rod assembly guide columns,
- the rod assembly guides,
- normal columns,
- columns for the level measurement probes: (LMP),
- guide tubes for the instrumentation lance thimbles,
- centring pins for the rod assembly guides,
- upper centring pins for the fuel assemblies.

5.2. DESCRIPTION

Chapter C. 6.5 Fig I and 2 illustrate the design of the upper internal structures.

- **Upper support** -

The upper support (in the form of an inverted top hat) separates the upper plenum from the upper head. It is the major structural component of the upper internal structures. It is connected to the upper core plate by the rod assembly guide columns, the normal columns and the LMP columns.

The upper support includes the upper support plate, a flange and a cylindrical wall. The cylindrical wall is connected to the plate by means of a full penetration weld.

The upper end of the holes in the rod assembly guide locations is closed by a connection flange to the rod assembly guide and by the connection flange to the upper cover of the rod assembly guide. The lower end is closed by a connection flange to the rod guide column.

For level measurement positions, the LMP column is connected by a flange to the lower face of the plate. The hole, which is much smaller than the one described above, is closed at the upper face of the plate by a flange guiding cone to facilitate the insertion of the level measurement probes.

The alignment pins are used to position the head, the vessel, and the lower and upper internal structures. They are comprised of two parts fixed respectively to the flange of the core barrel and the flange of the upper support.

The adjusting ring is between the upper internal structure flange and the core barrel flange.
- Upper core plate

This plate is connected to the upper support by the rod assembly guide columns, the normal columns and the LMP columns. These columns ensure the correct spacing between the upper plate of the core and the upper support. The other parts on the upper core plate are the centring pins for the fuel assemblies and the centring pins for the rod assembly guides.

The fuel assembly centring pins and the rod assembly centring pins ensure accurate positioning of the rod assembly guides in relation to the corresponding fuel assemblies.

Accurate alignment between the upper core plate and the heavy reflector (i.e. the core cavity) is obtained by means of four centring pins fixed to the heavy reflector and which insert into four sets of inserts fixed to the plate.

The upper core plate is equipped with square holes for the rod assembly guides, unlimited flow holes and holes above which the lower flanges on the normal columns and LMP columns are located.

- Support columns -

A distinction is made between the three types of support column:

- rod assembly guide columns,
- normal columns,
- LMP columns

The rod assembly guide columns are located above those fuel assembly positions which are equipped with an absorber rod cluster. The rod assembly guides are located inside these columns.

Each rod assembly guide column is connected to its lower flange by brackets. These brackets pass through the lower open section between the rod assembly guide column tube and the connection flange to the upper core plate. This system of brackets enables passage of the primary flow.

The peripheral portion of the upper core plate which is outside the core is connected to the upper support by the normal columns and the LMP columns.

- Rod assembly guides (GDG)

The GDG ensure correct alignment and the characteristics of the control rod drop into the core.

The GDG are mainly comprised of hangers and guide cards. In the lower section of the rod assembly guide column which is open, the guide cards are, in addition, connected by split tubes (C-shaped tubes), in which each rodlet in the control rod cluster can slide freely.

The rod cluster control assemblies are protected from the flow by the rod assembly guide columns.

The GDG are screwed to the top of the upper support plate. The correct position in relation to the fuel assembly is obtained by centring the lower GDG card on the four centring pins fixed to the upper core plate.
The upper section of the GDG is closed in the upper head. The housing plate at the top of the GDG within the upper head is equipped with a hole which, due to a predetermined gap between the plate and the control rod, ensures a specific flow. The resulting pressure in the head is less than the pressure in the centre of the upper plenum and greater than the pressure around the upper plenum. In these conditions, the “hot” coolant flows from the upper plenum through the central rod assembly guide columns into the head where it is mixed with the “cold” by-pass flow from the annular space between the vessel and the core barrel via the spray nozzles. The mixed fluid then flows from the upper head to the upper plenum through the surrounding rod assembly guide columns.

When the drive rod is disconnected, the housing plate at the top of the GDG within the upper head maintains the rod almost in the vertical position. This facilitates insertion of the drive rod in the adapter when the vessel head is lowered onto the vessel.

- **Level measurement columns**

The columns for the level measurement probes (LMP) are comprised mainly of two parts: the column itself and an entrance part. The entrance part is installed on the top of the upper support plate.

The column itself is a tube. Its top is fixed by a flange under the upper support plate. Its lower end is fixed to the upper core plate.

- **Guide tube for core instrumentation**

The guide tubes for the core instrumentation are fixed by means of supports to the rod assembly guide columns. These supports are welded to the tubes and screwed to the rod assembly guide columns.

The upper end of the guide tubes is inserted into a hole in the upper support plate. A gap is left for thermal expansion.

### 5.3. MECHANICAL DESIGN

- **Design requirements**

For forthcoming work, the requirements will be those of the RCC-M (see Chapter B.6).

- **Functional requirements**

The service life of the vessel internal structures is 60 years.

Based on the loading conditions defined and according to the rules of the RCC-M (see Chapter B.6), the mechanical design ensures the integrity of the vessel internal structures for all operating conditions PCC-1 to -4 and RRC-A.

The vessel internal structures are structurally designed for the permanent loads and the transients of normal and accident operation resulting from temperature transients, external accidents and a loss of coolant accident (LOCA). The design ensures the cooling capacity and the shutdown of the reactor in all circumstances.

The design analysis takes account of the following loads for normal operating and accident conditions:
- mechanical loads due to weight, to permanent flow, to vibrations, to rod assembly acceleration and deceleration forces,

- thermal load due to differential thermal expansion of the individual parts and gamma-induced internal heating,

- the vibrations and impact forces caused by a loss of coolant accident and external events, taking into account local conditions as regards the extent and the frequency.

The resistance of the internal structures to cyclical forces (fatigue curves and parts’ endurance limit) is checked by calculating and measuring vibrations.

The vessel internal structures are divided into two sub-classes:

- ES for components functioning as core support,

- EI for the other components.

As regards upper internal structures, the ES components include for example the upper core plate, the upper support plate and the GDG support columns.

- **Materials**

The following characteristics, concerning the quality of the materials defined for the manufacture of upper internal structures, are taken into account:

- qualification (for example: material manufacturer’s experience, his references)

- manufacturing process used (for example: welding, hot or cold forming)

- chemical compositions (for example: carbon content, alloy elements, associated and elements and traces of elements)

- mechanical properties during operating life (for example: toughness, resistance to ambient temperature and to higher temperatures, fatigue)

- resistance to corrosion mechanisms corresponding to the specific situation

- reduction in the irradiation level in the nuclear plant (for example Cobalt content)

### 5.4. HYDRAULIC DESIGN

**Hydraulic design of upper internal structures**

The hydraulic resistance and the sections where the coolant flows between the region of the upper head and the upper plenum are important in ensuring the conditions of a warm closed upper head.

There are different flowpaths from the upper head to the upper plenum:

- flow through the housing plate and the GDG,

- flow through the guide tubes protecting the instrumentation lance thimbles for the aeroball system, the self-powered neutron detectors (SPND) and the thermocouples.
- flow through the thimble passage holes for the level measurement probes (LMP).

In addition, the route from the core to the upper plenum is taken into account.

This is the flow through the upper core plate:

- at the control rod positions,
- at the control rod plugs,
- in the annular space between the core barrel and the upper core plate.

The instrumentation guide tubes for the aeroball system, SPND and thermocouples are located in this region. The flowpath geometries in the various types of guide tubes are identical.

The resistances in the GDG, in the instrumentation lance conduits and in the upper core plate have been evaluated and taken into account in by-pass flow studies.

- **Hydraulic design of the upper head**

The upper support plate, which separates the upper head and the upper plenum, is not a leaktight barrier between the hot water exiting the core and the mixed water from the upper head. This is due to the fact that the control rod assemblies must be able to be raised and lowered and therefore a gap with sufficient clearance is necessary for the drive rod at the housing plate (top of the GDG cover).

To control the core by-pass flow which cools the upper head, the holes are equipped with spray nozzles. These by-pass nozzles are uniformly distributed around a circumference whose average diameter is between the outer diameter of the adjusting ring and the contact zone of the upper internal structures with the vessel head.

The resulting by-pass pressure in the head is less than the pressure in the centre of the upper plenum and greater than the pressure around the upper plenum. In these conditions, the “hot” coolant flows from the upper plenum through the central GDG columns into the head where it is mixed with the “cold” by-pass flow. The fluid then flows back from the upper head via the housing plates through the peripheral GDG columns to the upper plenum.

The thermal-hydraulic design of the head requires a certain minimum value for the downflow coefficient in the GDG in order to ensure the correct flow and thus temperature of the closure head.

### 5.5. SIZING CALCULATIONS

The basis for preliminary estimation of the ability to resist applied loads is obtained by considering the forces applied to the support columns for various cases and from the results of experimental or analytical stress analyses. A three-dimensional analysis of fluid-structure interactions in the event of a loss of coolant accident has been carried out. The support columns can withstand a complete guillotine break of the surge line with an opening time slightly greater than 1 ms. The exact opening time of the break will be determined from a dynamic analysis of the whipping of the pipe during the detailed design.

The dimensions of the upper internal structures are checked by means of an analysis of the main structures and comparison of the results with the applicable standards (RCC-M, see Chapter B.6). It has been shown that the upper internal structures meet the functional requirements.
5.6. INSPECTABILITY AND REPAIRABILITY

In-service visual inspection of the upper internal structures is possible. The upper internal structures can be replaced as a whole or element by element. The design of the GDG, the instrumentation and the upper centring pins of the fuel assemblies is such that replacement is possible.

5.7. OPERATING EXPERIENCE

The structural and hydraulic design of the upper internal structures is based on the principles and equipment already implemented in operating power plants. The GDG and the GDG columns are similar to those in Konvoi. The support structure and the arrangement of the closure head are a French standard.

5.8. CORE INSTRUMENTATION

- General information

The mechanical design of the core instrumentation meets the requirements imposed by:

- correct operation,
- load conditions,
- correct selection and use of materials,
- good manufacturing practices,
- ease of maintenance’

and by taking account of the interaction between these requirements.

Core instrumentation is comprised of the following components:

- instrumentation lances,
- thimbles for the neutron detector (SPND) and the thermocouples (temperature measurement at the core outlet),
- thimbles with aeroball,
- level measurement probes,
- instrumentation penetrations in the vessel head, located above the core periphery,
- temperature sensors for temperature measurements in the upper head,
- penetration close to the vessel head centre to measure the temperature in the upper head.
The design of these components is based on the experience acquired with the core instrumentation in German PWR plants. These proposals are presented below with the main dimensions.

All the instrumentation is inserted into the vessel via the head. This is instrumentation "fixed from above".

- **Description**

**Instrumentation lances for the aeroball system, fixed neutron detectors in the core (SPND) and thermocouples**

The mechanical design of the instrumentation lances is fundamentally the same as the instrumentation lances used in German power plants.

Each instrumentation lance includes a vertical lance rod with a lance head, a horizontal beam lying on the upper surface of the upper support plate and the thimbles fixed to the horizontal beam.

The lance head forms a watertight penetration into the vessel head for the aeroball system tubes, the SPND cables and the thermocouples. With the penetration closure device, the lance head constitutes the sealed joint for the instrumentation penetration.

The tubes and cables are routed through the lance rod to the horizontal beam on the upper support plate from where they continue horizontally to their respective thimble.

The instrumentation thimbles are fixed to the horizontal beam and are guided from this position to the guide-tubes of the fuel assemblies. At the upper end of the fuel assembly, over a short distance, they are not guided. This is because the core outlet temperature is measured in this zone. The corresponding thimbles contain holes in this zone to enable direct flow of the coolant to the thermocouples.

Inside the fuel assemblies, the thimbles are inserted into guide-tubes normally used for the control rod assemblies.

The instrumentation lance thimbles containing the SPND can be replaced individually.

During refuelling shutdown, all the plugs and threaded connections are removed and protected by a leaktight tube (cap). After removing the sealing joints from the instrumentation penetrations, the vessel head can be raised or lowered above the lances.

The lances themselves are removed from the upper support structure using a special tool (lance gripping tool). They are inserted using other special tools (guide loading funnels).

There are different types of instrumentation lances:

- **Vessel level measurement probes**

A vessel level measurement probe is used to determine that a sufficient level of water is present in the upper plenum. This measurement, particularly useful in the event of a loss of coolant accident, aims to indicate potential uncovering of the core.
The vessel level measurement probes are located in the LMP columns around the upper plenum. A special device fixed to the lower end of the columns is used to supply the measurement system with low flow water conditions (KONVOI system). Holes for circulation of this water are machined in the upper section of the LMP column, under the upper support plate.

The probe is comprised of the following elements:

- a penetration in the vessel head similar to that for the instrumentation lances. A centring cone of geometry specific to the vessel level measurement probes is fixed to the lower part of these penetrations in the vessel head
- thermocouples in the upper part to measure the temperature in the upper head (see below) for one of the probes
- sensors to measure the vessel level in the upper plenum
- a cone in the lower part of the sensor to ensure correct insertion into the guide tube screwed to the upper support plate

- Thermocouple probes

A thermocouple probe measures the temperature of the environment inside the upper head, the volume under the vessel head.

For the EPR, there are three thermocouples at different levels above the level of the vessel/head flange.

The probe is comprised of the following elements:

- a leaktight tube
- a thermocouple head
- a probe thimble
- guide tubes inside the leaktight tube and the probe thimble

For the thermocouple located near the centre of the head, the penetration is a vent tube. The two other thermocouples, associated with one of the four vessel level measurement probes, use its penetration in the vessel. The thermocouple probe heads are used for sealed penetration into the vessel head for the thermocouples cables and are placed at the level of the cable run. This height makes maintenance easy. The thermocouples can be replaced individually.

The thermocouple cables run inside the vertical guide tubes from the probe head to the measurement point in the upper head. It is not necessary to sinter the guide tubes.

The probe thimble and the guide tubes contain holes at the elevation of the temperature measurements to enable direct flow towards the thermocouples.

- **Arrangement of penetrations**

16 instrumentation penetrations above the core periphery are necessary for the core instrumentation and the vessel level measurement probes.
An additional penetration near the centre of the vessel head is necessary for temperature measurement in the highest part of the upper head.

The instrumentation penetrations are sealed at the position of the lance heads and probe head by means of capping devices.

- **Functional requirements**
  - Fuel assembly guide tubes

The guide-tubes used have been selected in accordance with the following three requirements:

a) Minimum inner diameter to house the instrumentation lance thimbles

b) The aeroball system and SPND thimbles must be distributed as uniformly as possible throughout the core,

c) Reduced intervals for the guide tube support slats in the upper support structure

As the central guide tube only meets one of these requirements, it has not been used.

- Thermocouples for temperature measurement at the core outlet

The number of measurement points results from the number of thimbles with the SPND.

Three thermocouples are installed in each thimble.

The thermocouples are located at the upper end of the fuel assembly.

- Thermocouples for temperature measurement in the upper head

One thermocouple must be mounted near the centre of the upper head.

- Aeroball system

All the radial positions of the fuel assemblies where control rod assemblies are not inserted must be monitored by at least two probes.

The number of aeroballs required is based on the above requirements.

- Level measurement

In order to prevent the probes being subjected to significant loads during a possible loss of coolant accident, the level measurement probes are placed in zones of low flow inside the vessel between the coolant outlet nozzles.

- Core self-powered neutron detectors (SPND)

The thimbles containing the neutron detectors are inserted in the fuel assembly guide tubes for the control rod assemblies.

- **Design data and interfaces**
  - Seismic design
Parts in the pressurise boundary inside the reactor are seismic class 1.

- Life of the lance with tube but without detector: 60 years
- Interfaces

The following elements are concerned:

- vessel head including penetrations
- vessel internal structures including control rod assembly guides
- fuel assemblies
  - head equipment, i.e. the cable run and connection panels
- electrical equipment and control and instrumentation devices
- reactor control system
- nitrogen supply circuit
- fuel assembly cap assembly.

- Ease of repair and replacement
- In-service inspection
  - Inspection can be carried out by verifying the measurement made during reactor operation.
- Maintenance and repair operations

The space required to insert the instrumentation lances inside the vessel is available in the fuel assembly guide tubes which are not occupied by the drive rods. The thimbles are inserted in these guide tubes to prevent any damage during insertion and withdrawal.

The lance sits freely in the dead flow zone above the upper support plate. The thimbles are guided by the tubes over their whole height. This ensures reliable insertion of the lances and, during reactor operation, protects the thimbles against the flow forces of the coolant which may cause vibrations.

The aeroball tubes and the tubes carrying the motor gas are together on the horizontal beam and exit from the lance head which is sealed with the penetration. Above the lance head a removable screwed joint is installed on the tubes. The tubes are protected from the water by a cap when the reactor cavity is full.

Any instrumentation lance removed from the reactor because it contains faulty detectors can be replaced routinely during plant maintenance using the lance gripping tool and special tools. The defective thimbles are temporarily stored in the reactor cavity until final removal.
Vessel level measurement sensors can be rapidly replaced during a plant outage (for example due to a broken sensor) using a special grab. For this replacement, the sealing device to be opened is of identical design to that of the control rod drive mechanisms. As such, the special gripping tool used for replacement is the same. The replacement probes are temporarily stored in the cavity.

A defective upper head temperature measurement thermocouple can be replaced during a plant outage from the cable platform when the vessel head is on its storage stand.

- Reference technologies

The instrumentation lance was first installed in the Stade nuclear power plant in 1971. Since then, all other light water reactors built by KWU have been fitted with this instrumentation system. Due to conclusive operating experience, only small improvements have been made and the basic design has not been changed.

The systems have operated with an operational availability of 100% over the 260 years of accumulated operation in 16 power plants.

The vessel level measurement sensors, with their proven design, have been installed since 1983 in 15 Siemens PWRs, with excellent feedback.

The mechanical design of the thermocouple sensor is based on the design of the core instrumentation used without any problems in the KWU PWR plant since 1968.
FIG 1: UPPER INTERNAL STRUCTURE ASSEMBLY

- GDG upper cap
- Housing plate
- Upper support
- Upper internal structures alignment pin
- Roto-lock
- Normal column
- Upper core plate
- Guide support column
- LMP column
FIG 2: UPPER INTERNAL STRUCTURES WITH THE INSTRUMENTATION

- Penetration for instrumentation lance
- Penetration for vessel level measurement probe
- Presence of two thermocouples on one of the vessel level measurement probes
- Upper GDG cap
- Horizontal beam for instrumentation lances
- Upper support
- GDG column
- Instrumentation lance guide tube
- LMP column
- Vessel head
- Core barrel
- Vessel level measurement sensors