1. INNER CONTAINMENT WITH STEEL LINER

1.0 SAFETY REQUIREMENTS

The safety requirements for the steel lined inner containment are given in Chapter C.5.0.

1.1 DESCRIPTION OF THE STEEL LINER

1.1.1 General configuration

The containment for the EPR reactor is a double-walled structure founded off a reinforced concrete foundation raft.

The inner containment wall is constructed using pre-stressed reinforced concrete, with a steel liner plate covering its internal surface, walls, dome and support slab. This continuous membrane provides a leaktight surface.

The outer containment wall is constructed using reinforced concrete. It ensures protection against external hazards such as aircraft crash and explosion pressure waves.

The containments are separated by a 1.80 m wide annulus between the inner and outer structures. The annulus is maintained at sub-atmospheric pressure to collect any leakage through the inner containment. Any leakage is filtered, before being vented to the environment.

This double wall structure provides an effective environmental radiation protection under forecast incident and accident conditions, including severe accidents.

The foundation raft is a reinforced concrete structure, described in Chapter C.5.5.

The steel liner plate is located between the common foundation raft and the internal structure support slab.

The containments internal volume (approximately 80,000 m³) provides the necessary free volume compatible with the conditions generated by severe accidents (hydrogen deflagration and pressurisation).

Provision is made for sufficient clearance to enable the polar crane to handle the largest items of equipment (e.g. single piece steam generators).

1.1.2 Inner containment

Geometry

The pre-stressed reinforced concrete inner containment is comprised, from bottom to top, of a:

- cylindrical gusset,
- truncated section,
- cylindrical section called the "inner containment skirt". 
- torispherical dome connected to the skirt by a ring.

It includes:

- On its internal side, a steel leak tight liner anchored to the concrete,
- Support brackets for the polar crane girder beam,
- On its external side there are three vertical ribs for anchoring the horizontal prestressing tendons,
- Bosses and strengtheners around the transfer tube sleeve and equipment hatch.

Concrete

The concrete used for the inner containment is High Performance Concrete (BHP). The principle characteristics of the concrete are given in the ETC-C.

Pre-stressing

The inner containment cylindrical shell and the dome are pre-stressed concrete structures.

Pre-stressing is provided by an arrangement of steel tendons.

Each horizontal tendon makes a complete loop of the containment and is anchored within a buttress. Each horizontal tendon is tensioned on both ends.

The vertical tendons form two main groups:

- The “gamma” tendons,
- The “pure” vertical tendons.

The “gamma” tendons are vertical tendons which are returned to the dome and which are tensioned at both ends. The upper end is anchored at the dome ring and the lower end is anchored in the vertical tendons pre-stressing gallery, located underneath the support slab.

The “pure” vertical tendons are tensioned at their upper end located in the dome ring and are passively anchored in the gallery beneath the support slab.

Steel liner plate

The steel liner plate fully covers the inside surface of the containment structure walls, dome and top surface of the support slab. This continuous membrane provides a containment boundary against which leak tightness criteria is applied. For this reason, the steel liner plate is located between the top of the foundation raft and the internal structure support slab.

The steel liner is designed to ensure leak tightness under normal operating conditions, during tests on the containment and in accident conditions.

The steel liner is used as a form for the construction of the inner containment concrete wall.

Anchorage system
A continuous anchoring system is integrated into the concrete and welded to the steel liner plate. It comprises continuous steel anchors crossing at right angles to form a mesh. In each of the meshes there are stud anchors.

The role of the anchoring system is to stiffen the steel liner plate and ensure stability of the liner during construction and operation.

The continuous anchorages transmit concrete deformation to the steel liner plate. They limit the movement of the steel liner plate in case of differences of thickness, temperature or elastoplastic conditions, between two adjacent meshes in the steel liner plate. In addition, they provide the liner with sufficient rigidity during its assembly and during the construction phase.

The localized anchorages prevent the grid from buckling. The spacing of the anchorages is such that local bending, which may occur in the steel liner plate during prestressing or when heated, due to geometrical manufacturing defects, remains within acceptable limits.

Reinforcing steel

In addition to pre-stressing, the cylindrical wall and dome are reinforced to limit the opening of cracks and to resist thermal bending during accident conditions.

1.1.3 Foundation Raft

The foundation raft for the internal containment is common foundation raft for the nuclear island buildings.

The foundation raft has a thickness of 3.95 m underneath the reactor building. A prestressing gallery for tensioning the inner containment vertical tendons is located underneath the foundation raft. This gallery is not structurally linked to the foundation raft.

The internal structures are set on a foundation slab, which is referred to as “the internal structures’ support slab”. This slab is located on the common foundation raft. The interface between the foundation raft and the internal structures’ support slab is comprised of a leak tight steel liner. This liner ensures continuity of leak tightness with the steel liner plate and the bottom surface of the internal containment.

1.1.4 Outer containment

The outer containment is discussed in Chapter C.5.4.

The outer containment is formed by a cylindrical section and a reinforced concrete dome. The dome and upper section of the cylinder are directly exposed to the external environment, and form part of the outer shield building. The lower part of the cylinder is protected by the surrounding buildings.

1.1.5 Penetrations

The penetrations are described in Chapter C.5.2.

The containment comprises miscellaneous penetrations, including the:

- Equipment access hatch,
- Personnel and emergency hatch,
Mechanical (fluids) penetrations,
- Electrical penetrations,
- Fuel transfer tube.

These penetrations connect the BR (Reactor Building) with other buildings and systems. Each penetration is fitted with an active or passive leak tight device which enables the containment to be isolated in case of an accident (see Chapters C.5.2 and F.2.3).

1.2 DESIGN BASIS FOR THE INNER CONTAINMENT

1.2.1 Applied regulations and procedures

The preliminary containment analysis was performed in accordance with ETC-C.

The preliminary analysis of the reinforced concrete structures and pre-stressing was undertaken in accordance with the limit state method.

The analysis principles are based on the Eurocodes listed in the ETC-C. A specific ETC-C section gives the procedure for the design of the steel liner.

1.2.2 Loads and load combinations

The loads cases and combinations considered are compliant with both the ETC-C and Chapter C.5.0.

The inner containment is designed so that it can resist hazards, test conditions for the unit’s lifetime and accident conditions.

1.2.3 Design procedure

Using the defined action combinations considered as part of the design of the containments inner shell, the major stages are as follows:

- Design of the shell pre-stressing ensuring containment and reinforcement,
- Design of the steel liner plate,
- Analysis of the structures behaviour under accident thermodynamic stresses (P and T),
- Analysis of the behaviour under earthquake conditions,
- Analysis to verify containment leak tightness at a pressure greater than the design pressure.

The planned design conditions are as follows:
The design calculations for the steel liner plate are based on 3 successive stages whose aim is to supply increasingly detailed information on the behaviour of the steel liner plate:

**Stage 0**: calculations of the deformations and restrictions in the steel liner plate in order to identify the plasticized areas (major deformations) using a non-linear method performed in the elasto-plastic field and by assuming that the steel liner plate deformation follows that of the concrete on all points.

**Stage 1**: more in depth analysis of the behaviour of the steel liner plate and the anchorages (stress structure) by zoning the containment:

- Truncated cone
- Cylindrical section
- Polar crane brackets
- Dome, torispherical section and Equipment hatch
- Personnel access

**Stage 2**: Steel liner plate behaviour analysis taking into consideration the mechanical role of the anchor points. This analysis is concentrated around a grid defined in the ETC-C, taking into consideration the potential breakage of one or more studs in normal service or in an accident situation. This analysis enables verification of the steel liner plates buckling behaviour.

A further analysis is considered in addition to the 3 steel liner design stages, this assess the liners reaction in relation to a hydrogen deflagration incident, corresponding to a localised heating of around 450°C for 100 s in the most exposed area (the dome).
1.3 PRELIMINARY STRUCTURAL ANALYSIS

The inner containment design (concrete structure and steel liner plate) is assessed under normal, accident or exceptional conditions which the structures may be subject to, and contains margins with respect to safety requirements.

For reinforced and pre-stressed concrete shell, the standard zones comprise steels with a wider diameter on the outer surface than on the inner surface. The singular zones are treated by locally increasing the reinforcement in a way which absorbs the traction forces.

The steel liner plate deformations remain compatible with ETC-Cs design criteria, even if the plasticity limit is partially achieved during the normal operating conditions and is nearly fully achieved in an accident situation. The compression forces which generate buckling and blistering are considered in the design.

The main finding from the results of the preliminary analysis, is that the component parts of the structure satisfy the resistance criteria for severe accident conditions, with design margin in reserve.