



Horizon 2020
Programme

Ref. Ares(2024)789767 - 02/02/2024

AMHYCO

Research and Innovation Action (RIA)

This project has received funding from the Euratom
research and innovation programme 2014-2018 under
Grant Agreement No 945057

Start date : 2020-10-01 Duration : 48 Months



Data for the generic containment analysis (PWR-W, PWR-VVER, PWR-KWU)

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AMHYCO - Contract Number: 945057

Project officer: PASSALACQUA Roberto

Document title	Data for the generic containment analysis (PWR-W, PWR-VVER, PWR-KWU)
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Number of pages	90
Document type	Deliverable
Work Package	WP2
Document number	D2.1
Issued by	UPM
Date of completion	2024-01-23 09:33:50
Dissemination level	Public

Summary

.

Approval

Date	By
2024-01-23 09:35:54	Dr. Luis E. HERRANZ (CIEMAT)
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Enhancing H₂ & CO Combustion Risk Management

Research and Innovation Action

NFRP-2019-2020

D2.1 – Data for the generic containment analysis (PWR-W, PWR- VVER, PWR-KWU)

Date [22/01/24]

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This project has received funding from the European Union's EURATOM Horizon 2020 research and innovation programme under the Grant Agreement n°945057.

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ABBREVIATIONS AND ACRONYMS

Acronym	Description
CAD	Computer-aided design
CFD	Computational Fluid Dynamics
CV	Control Volume
HS	Heat Structure
KWU	Kraftwerk Union PWR
LP	Lumped Parameter
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
OECD	Organization for Economic Co-operation and Development
PAR	Passive Autocatalytic Recombiner
PORV	Pilot-Operated Relief Valve
PWR	Pressurized Water Reactor
PZR	Pressurizer
RCS	Reactor Cooling System
RPV	Reactor Pressure Vessel
SAMG	Severe Accident Management Guidelines
SFP	Spent Fuel Pool
SG	Steam Generator
SSCs	Systems, Structures and Components
UJA	Containment Building A

UJB	Containment Building B
VVER	Water-Water Energetic Reactor
W	Western-type PWR
WP	Work Package

1. INTRODUCTION

1.1. Background

In the event of a severe accident in a nuclear power plant, combustible gases are released by the core oxidation or by the molten corium-concrete interaction, leading to a potential combustion risk in the nuclear containment building. These gases, predominantly Hydrogen (H_2) and Carbon monoxide (CO), need to be managed to avoid threatening the containment integrity, as a failure of the containment would result in the release of radioactive material into the environment. One of the main objectives of the AMHYCO project is to improve the simulation capabilities of analysis tools – Lumped Parameter (LP), 3D and Computational Fluid Dynamic (CFD) codes – used for combustion hazard evaluation inside the reactor containment [1].

An accurate estimation of the combustion risk relies on a detailed characterization of the distribution of gases - combustible, comburent, and inert agents. Over the years, the trend towards a more detailed description of the combustible gas's spatial distribution has gone hand in hand with the enhanced performance of computers and clusters. Starting from a single averaged value using the LP approach, the information on the gas's distribution was progressively increased by using multi-node LP models, tens of thousands of cells with 3D codes, and up to several million cells with CFD codes [2] [3] [4].

One of the recommendations of the OECD/NEA ISP-47 [2] was to perform “generic plant applications” (analytical benchmarks) to investigate the fundamental differences between different codes and approaches. These activities have been initiated in the framework of SARNET-2 and SAMHYCO [5], using a common database, i.e., nodalization and modelling of the heat structures and junctions, for several LP codes. AMHYCO aims to go one step further by providing a common database also for the 3D and CFD codes, which require more information to define the geometry of the models. Moreover, the nodalization for the LP models will follow the SAMHYCO project approach, and the main hypotheses followed in the definition of the databases will be highlighted to understand the limitations of the nodalizations.

This deliverable explains the methodology using Computer-Aided Design (CAD) tools to develop a generic containment database for LP and 3D models, which will serve as a base for WP4 containment modelling within the AMHYCO project. The objective is to describe the procedure followed in the derivation of generic containment models from public layouts. The database covers the three pressurized water reactor (PWR) nuclear power plant (NPP) designs used predominantly in continental Europe, i.e., the Western PWR design (PWR-W) resembling close the original PWR patent of Westinghouse, the Siemens KWU plant design (PWR-KWU) and the Russian PWR design (PWR-VVER).

The construction of the 3D CAD models for all three plant designs followed a similar approach. All available floor layouts have been imported, sized, digitalized, and extruded in the CAD software. As

the open information of the geometrical details of the containment building is limited, the feedback from AMHYCO partners with previous experience in modelling each specific design was of paramount importance for the model's development. In this regard, the PWR-KWU model and database, which was the first to be accomplished, has relied on a thorough review of the containment characteristics, and has served as a cornerstone for the definition of the methodologies followed in the other two models. This explains the level of detail and the extension of Section 3.1., compared to Sections 3.2. & 3.3.

Once the 3D CAD detailed models were prepared, model nodalizations are proposed and the needed geometrical data are extracted to create the database provided via Excel tables. In WP4, all partners will then share a common arrangement of control volumes and compartments' free volumes, as well as a common database of flow path junctions, heat transfer structures and safety system locations (data needed only for 3D modellers will be specified when necessary).

1.2. Introductory remarks

The generic containment CAD models are built using Autodesk AutoCAD 2021® [6]. A depiction of the main structures is provided for each containment, together with a detailed walkthrough of the different levels. The different floor plans have been superimposed by extrusion from bottom to top, using the different plan views as a reference for each construction level and to extract the altitudes and thicknesses of walls, floors, and ceilings. Furthermore, the containments are enclosed by their liners and concrete walls. More complex geometries, such as equipment parts, have been approximated with some limitations.

Also, the main connections between containment regions are identified and shown. Thus, a complete description of the model geometry is provided, explaining junction dimensions, locations, and shapes in each containment layer. Moreover, a methodology for the extraction of concrete and steel surfaces is reported. This methodology aims to properly characterize each heat structure, depending on its geometry and considering the specifics of each nodalization.

The generic containment specifications of each containment are provided in different subsections. There, the tables gathering the data of control volumes (CVs), junctions, heat structure, or PAR layouts, can be found. Annexes are provided with the collection of public layouts used for each containment. From these layouts, model dimensions are extracted.

Lastly, regarding the PWR-KWU and PWR-VVER, the main information comes from the unfinished Stendal NPP project, which official footage can be found online [7] [8] [9]. For the 1300 MWe PWR-KWU, two cross-section and five plan layouts have been used as the primary source of information, while the PWR-VVER-1000 V320 has relied on one more plan layout and several detailed albums [10] [11]. In the case of the PWR-W, four isometric views and four floor plan layouts have been used, whereas the model has been adapted from the originally developed in [12].

2. METHODOLOGY

An iterative refinement process based on comprehensive reviews performed by different partners was necessary to model geometrical details of the containments to obtain fully developed 3D models. Regarding each containment construction, the extrusion of walls and floors and the disposition of the equipment were made without overlapping volumes and respecting the openings that the possible fluid flows may encounter throughout different levels. Specifically, detail has been put to model stairs, gratings, doors, equipment connections and rooms, aiming to represent the geometrical characteristics of several relevant areas of the containments.

2.1 Volumes and junctions

Once the geometrical models were finished, the main volumes are discretized and their free volume, base elevation, and height were calculated. Also, real structures and flow paths have been merged to limit model complexity. The main geometrical information for the definition of CVs within the containments is schematized in Figure 1. The way in which CV's information has been extracted, follows the approach of the SAMHYCO Generic Containment databases [13].

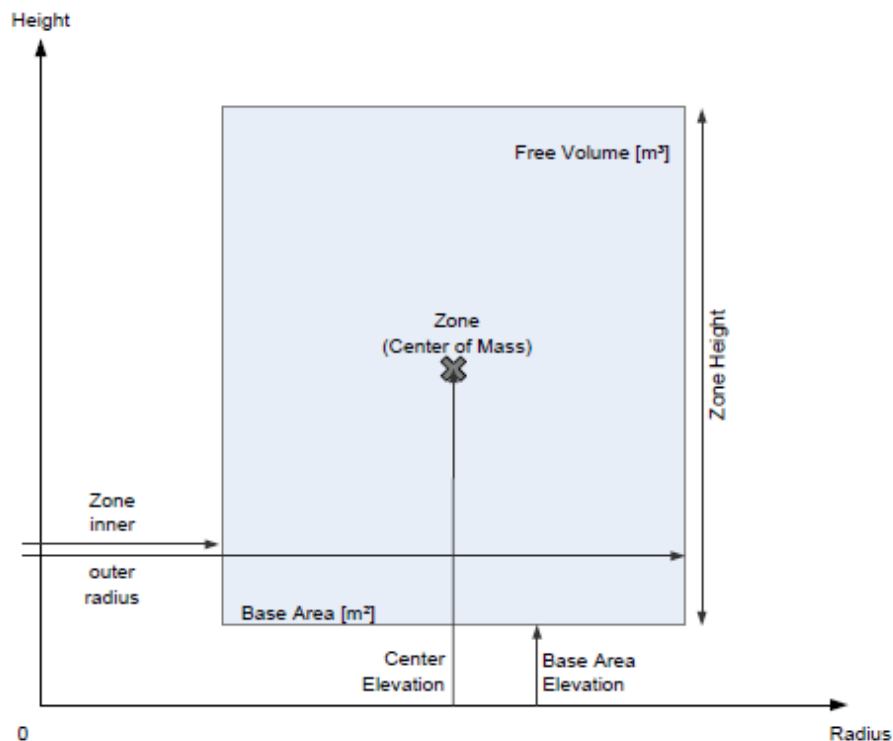


Figure 1. Control Volume geometrical information

For the geometrical definition of horizontal and vertical junctions between CVs, the scheme represented in Figure 2 has been followed. Within the scheme, the junctions are classified by their width, whereas the geometrical parameters for their definition are listed in each case.

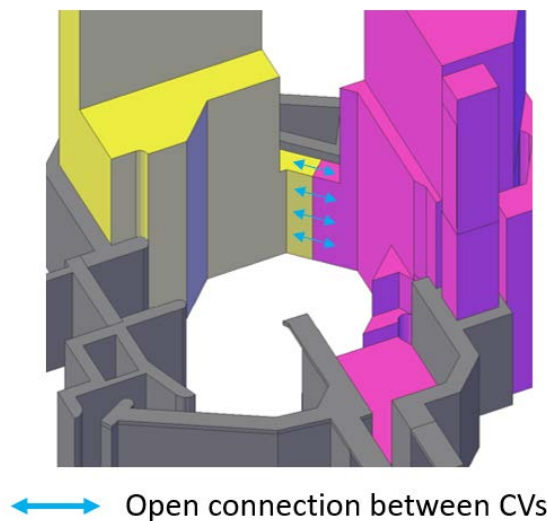
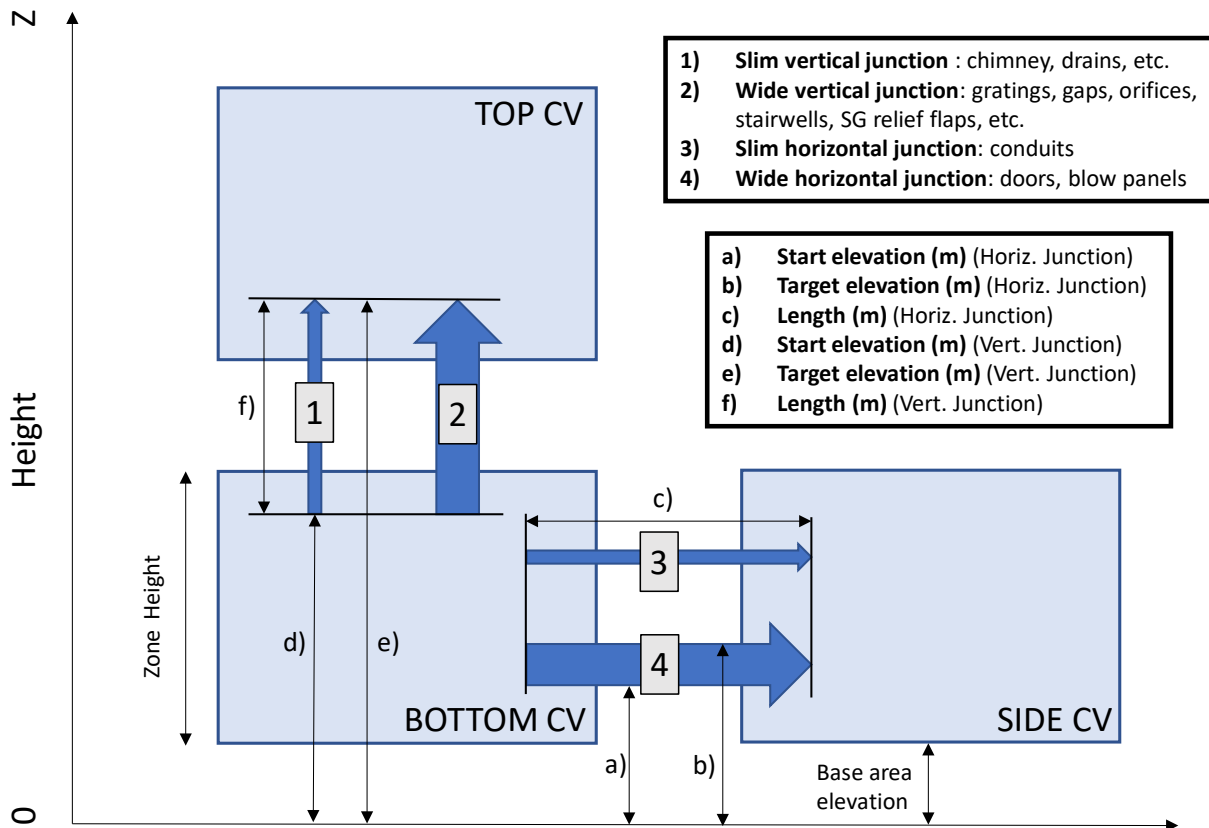


Figure 2. Geometrical characteristics of junctions

A relevant parameter in the definition of geometrical junctions is the pressure or resistance loss coefficients. In general, the pressure loss is defined corresponding to the COCOSYS reference manual [14]:

$$\Delta p = \zeta_{tot} \frac{\rho v^2}{2} = (\zeta_w + \zeta_R) \frac{\rho v^2}{2}$$

with the pressure loss coefficient being a sum of a pipe friction factor ζ_w (major loss), and a resistance coefficient ζ_R (minor loss). The first one is generally calculated code internally, dependent on Reynolds number and following this expression (in case of laminar flow): $\zeta_w = \lambda \frac{l}{d_h} = \frac{64}{Re} \frac{l}{d_h}$.

The second coefficient ζ_R is dependent on the overall junction geometry and is the one listed in Table A.2. Its calculation follows the guidelines of [15].

2.2 Heat structure data extraction

The simulation of heat sinks and sources in a containment needs as a first step the extraction of heat structure (HS) data for each system, structure and component (SSCs). The parameters driving the heat transfer would be the surface area of the structure, directly proportional to the thermal exchange with its surrounding atmosphere, and the thermal inertia of the structure. Nevertheless, the latter parameter must be inferred from the volume of the structure, which can be extracted from the CAD files.

Then, the methodologies used will focus on the extraction and labelling of SSCs of the detailed 3D CAD models, for their classification as HSs in LP and 3D codes (see Annex A). The data is extracted from the CAD model and additional references were used whenever layout's information was insufficient (e.g., thickness of the components of steam generators, pumps, etc.).

SSC geometrical data extraction (volume, area, or thickness) has as a first step the classification of each structure by material (concrete or steel) and disposition (floor/horizontal or wall/vertical type structure). Then, each SSC will be classified by its location within the overall geometry (wall separating two CVs, floor inside the region of a CV, etc.) This differentiation determines the geometrical data extraction method. Finally, the aim is to keep the actual heat transfer surfaces and the volume of the solids (important for the thermal inertia of the model).

Several types of HSs are sketched in Figure 3. Some structures correspond to inner-CV ones ('Internal', 'Gratings') or structures separating adjacent CVs ('Externals'). Table 1 depicts the origin of the geometrical information needed to characterize each type of structure, namely volume, area and thickness. The employed terms for the HS types are loanwords from GOTHIC code methodologies.

In conclusion, the basis of this methodological approach is to group similar SSCs (several walls, columns, or floors) into specific HSs (a single label for the LP model) to simplify the modelling. The

total area of each HS represents all the surface in contact with the fluid (A), whereas the total thickness provided is an estimated value (t_{eff}) adjusted to obtain the volume (V) of all the bodies included in a HS label by simply $V = A \cdot t_{eff}$. This method is based on Reference [16]. More information on the interpretation of the provided data is available in Chapter 3.2.1.3 and Chapter 3.2.2.3. The reader will find clarifications to properly implement the different HSs: (i) heat structures connecting two different control volumes, and (ii) heat structures with an 'adiabatic' side.

Table 1. Extraction of geometrical information for containment structures

	V (m³)	A (m²)	t_{eff} (m)
Columns (type 'I')	CAD	CAD	analytical
Concrete blocks (type 'I')	CAD	analytical	CAD
Equipment (type 'I')	analytical	CAD	references
Gratings (type 'G')	analytical	analytical	references
Externals (Type 'X')	CAD	CAD	analytical

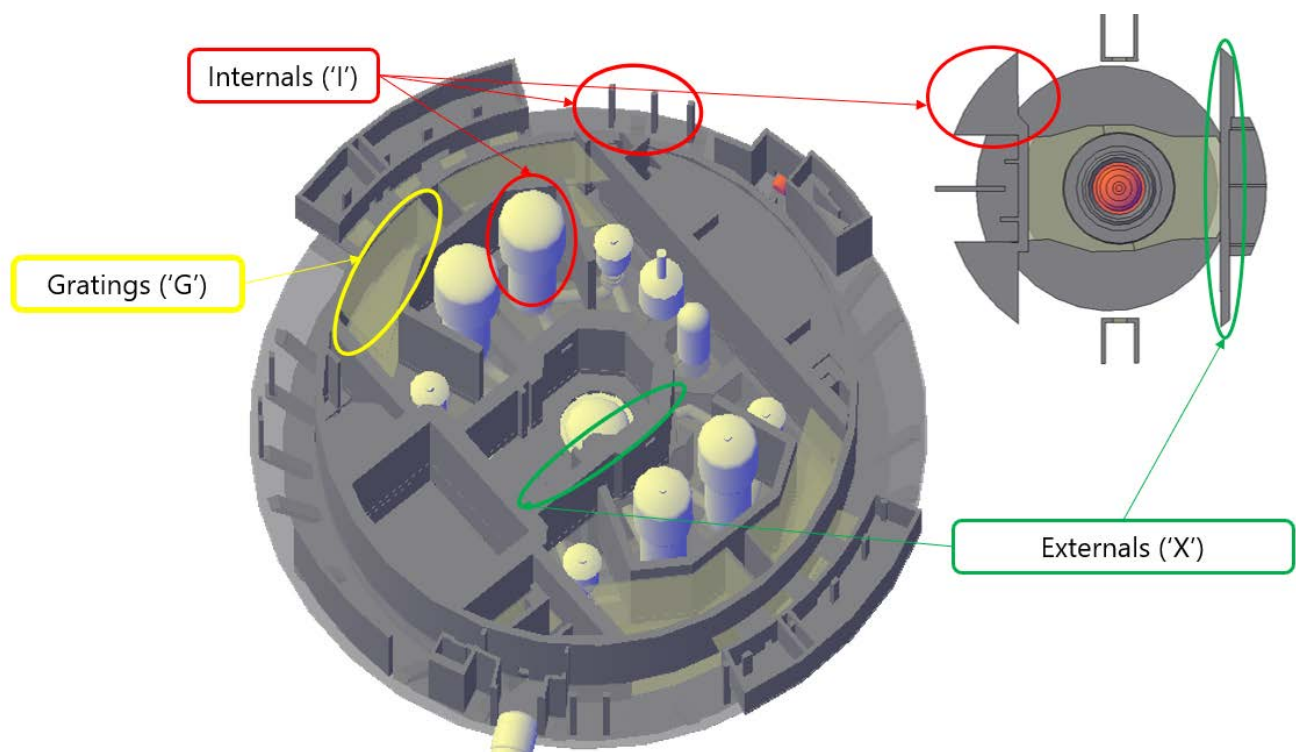


Figure 3. Basic clasification of heat structures (example for PWR-KWU containment)

3. GENERIC CONTAINMENT DATABASE

This section gathers the specifications for the PWR-KWU, PWR-W, and PWR-VVER containments. Each subchapter will provide the 3D CAD construction process followed by the nodalization of the containment volumes. In the nodalization subsections, the tables containing the data related to control volumes, junctions, heat structures and PARs, will be depicted. The nodalization schemes will follow SAMHYCO project approach, with big control volumes defining several zones of the containment buildings. The main hypotheses coming from the nodalization approach, or the model construction, will be stated either in the following subchapters or in Section 5 of this document (where some pending issues to fully characterize the containments are also stated).

Subchapter 3.1 contains some definitions, clarifications or recommendations about the database structure, nomenclature, and content. This, paired with the higher detail in the definition of the complex KWU CAD containment construction and database definition (first one to be accomplished in this project), will make that first subchapter ostensibly larger than the following ones.

3.1 PWR-KWU generic containment

The PWR-KWU model corresponds to a 1300 MWe German NPP with a Konvoi containment type. The containment is a free-standing spherical steel shell that houses the Nuclear Steam Supply System (NSSS). An annular volume separates this steel shell from the outer airplane crash shell, made from heavily reinforced concrete. A project-internal review of the 3D model was performed by FRAMATOME GmbH, from which some geometrical adjustments were made [17].

3.1.1 PWR-KWU 3D CAD model construction

The first region that has been modelled is the inner containment (UJA), which is enclosed by the spherical steel containment and holds the NSSS. In the lower floors, the steel shell is supported by a concrete lower cup (see Figure 4). The second region that has been modelled is the annulus (UJB) (or airplane crash shell), which serves as the last shielding barrier and houses the emergency core cooling systems, protecting them (as well as the steel containment) against external threats like airplane crash or intruders.

Another architectural feature of the PWR-KWU is the shrapnel cylinder within UJA, which encloses the RCS loops and the SFP. This shrapnel cylinder protects the steel containment shell from fast projectiles / fragments impacting from within, e.g., in case of a high-energy pipe break of the RCS. Note, the region between the shrapnel cylinder and the steel containment (i.e., still within the containment) is labelled as “annular rooms”, the region between the steel shell and the airplane crash shell (i.e., outside of the containment) is called the “annulus”.

Prior to the construction of rooms and equipment in the UJA and UJB regions, the main architectural elements were modelled to delimitate spaces and to implement a reference for the coordinates and dimensions of the model (see Figure 4). Those elements are the shrapnel cylinder, lower cup, spherical steel liner, dome, and the UJB enclosure. To recreate the external closure, a hollow cylinder was built, and its height was obtained from the plans of sectional views. A hollow semi sphere which conforms the UJB dome was built over it. In the lower part of the containment a concrete slab floor was added. The sphere is hold by a concrete floor of cylindrical plant whose radius was extracted from the same plans where the sphere radius was obtained.

Lastly, to represent the shrapnel cylinder, a hollow cylinder was built. Since the cylinder is not completely closed nor homogenously isolated from the sphere atmosphere, the cylinder was lifted using the level views for the available heights which represent parts of it (from +6 m to +21.5 m). In this way, it was possible to accurately represent the connections of this containment element between several regions, something of high importance for future analyses of flow distribution. The shrapnel cylinder has an inner diameter of 41.2 m with a concrete thickness of 0.80 m, while the containment steel shell has a diameter of 56 m with a thickness of 38 mm.

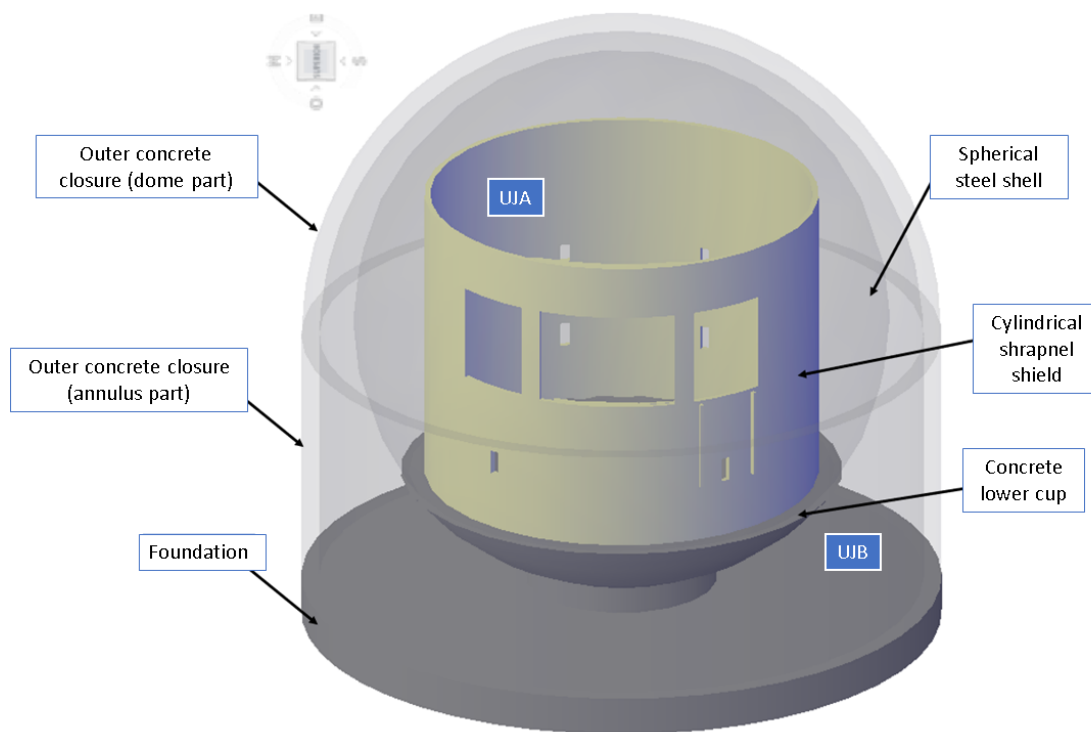


Figure 4. PWR-KWU: Main containment structures of the 3D CAD model

Once the main containment elements were defined and the isometric axes were placed in the CAD model, the bottom-to-top and level-by-level construction process began. Height zero (+0 m) was

placed at the bottom of the RPV. Then, the 2D delimitation of compartments was undertaken. A graphic example of this process is shown in Figure 5, where the construction of the RPV cylindrical walls and the extrusion of walls and gratings of +2 m level is chronologically depicted. The first step is the arrangement of the layout in AutoCAD environment, where the drawing of structures and their extrusion will be made. Then, lines are drawn to represent the projection of the structures, and finally, the 3D volumes are created.

To facilitate the comprehension of the model and the distribution and relationships between compartments, a level-by-level scheme of the construction is presented at the sub-sections below (from Chapter 3.1.1.1 to Chapter 3.1.1.6). The construction has mainly relied upon five floor plan views (-6 m, +2 m, +6 m, +12 m and +21.5 m) and two elevation front sections corresponding to two perpendicular cuts. In the 3D model, UJA walls can be seen in dark grey colour, while grating surfaces and UJB structures are of a dark yellow transparent hue. RCS components and equipment such as the polar crane or the safety injection accumulators are easily identifiable by its lighter colour.

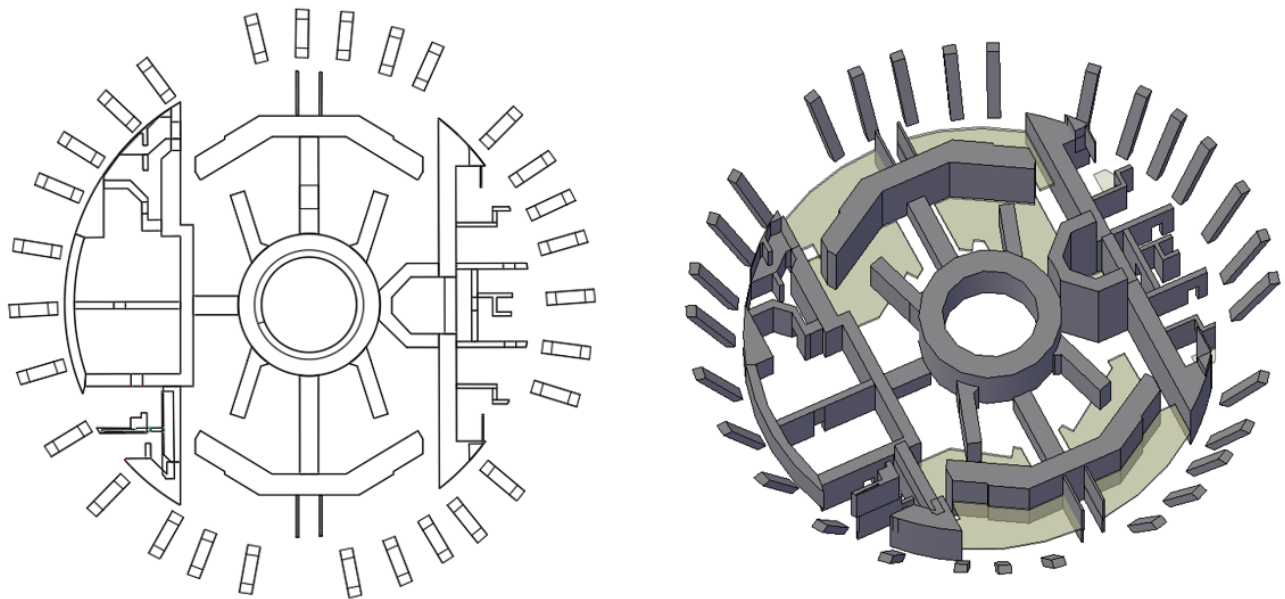


Figure 5. PWR-KWU: Drawing and extrusion process for the CAD model construction.

3.1.1.1 First level: -6-meter elevation

The extrusion process for the building of UJB basement compartments can be seen in Figure 6. At this level, only rooms from UJB are present and they are covered by either the sphere or the lower cup. Typical equipment located on this first level are the safety injection pumps as well as the emergency core flooding tanks. The extrusion of the rooms located in the annulus of UJB was lifted to +2 m (the next available layout) and the ones located underneath the concrete lower cup were sliced

by it to form the actual curved walls of those rooms. Once the walls of each compartment were built, the floors that separate this level from the above one were constructed. This process is similar in each level and follows the bottom-to-top construction approach, accounting for any possible floor-to-floor junctions, e.g., stairwells, walking grids (gratings), or equipment hollow compartments.

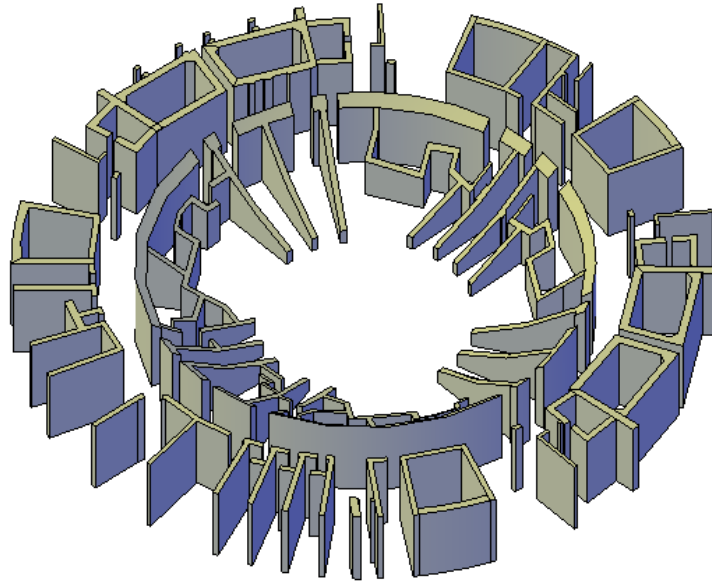


Figure 6. PWR-KWU: Aerial view of UJB of level -6 m

3.1.1.2 Second level: +2-meter elevation

In this plan elevation both UJA walls (in dark grey) and exterior UJB walls and floors can be seen (in lighter grey in Figure 7). In UJA, the columns, and the reactor cavity (coming from -2.1 m) have been extruded and the gap where the vessel will be held is then defined. Interior east and west annular rooms are modelled along with the stairwells that commence to develop at this elevation. Figure 8 depicts the East-West asymmetry that starts to appear at this level when constructing the interior annular rooms (inside the cylinder), which are separated from the RCS and sump regions by thick straight concrete walls with only a few doors as possible openings.

On the other hand, regarding North-South distribution, the location of the RCS loops begins to be clear. It is important to notice that some floors and walking grids are built at slightly different elevations (according to the layouts) as some sub-compartments are connected by stairs in rather complex configurations. Also, with the addition of the lower cup, the containment sump region is totally defined. In the UJB region, three gaps corresponding to stairwells coming from ground zero and elevating up to at least +6 m, can be seen in Figure 9. These stairs are not modelled and any flow there would move in a chimney like volume.

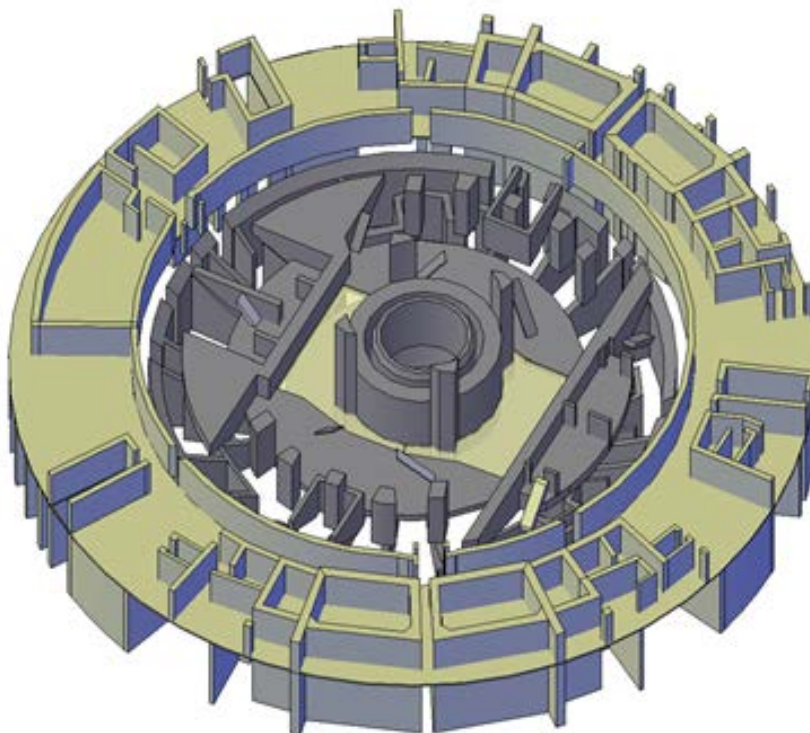


Figure 7. PWR-KWU: Aerial view of UJA and UJB up to level +2 m

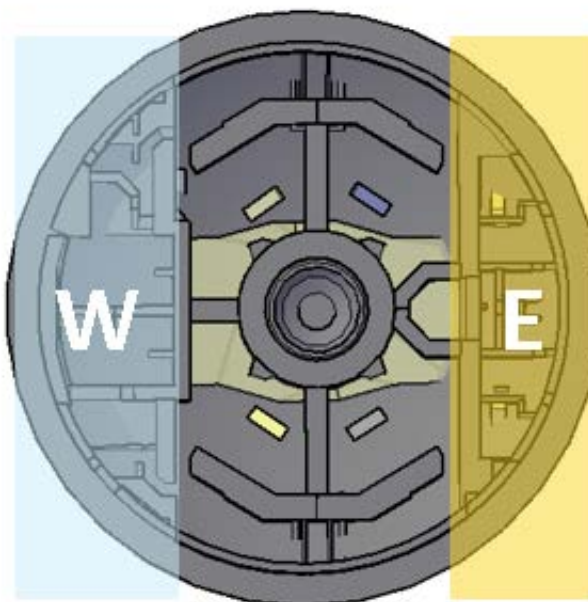


Figure 8. PWR-KWU: East-West room symmetry of the generic containment

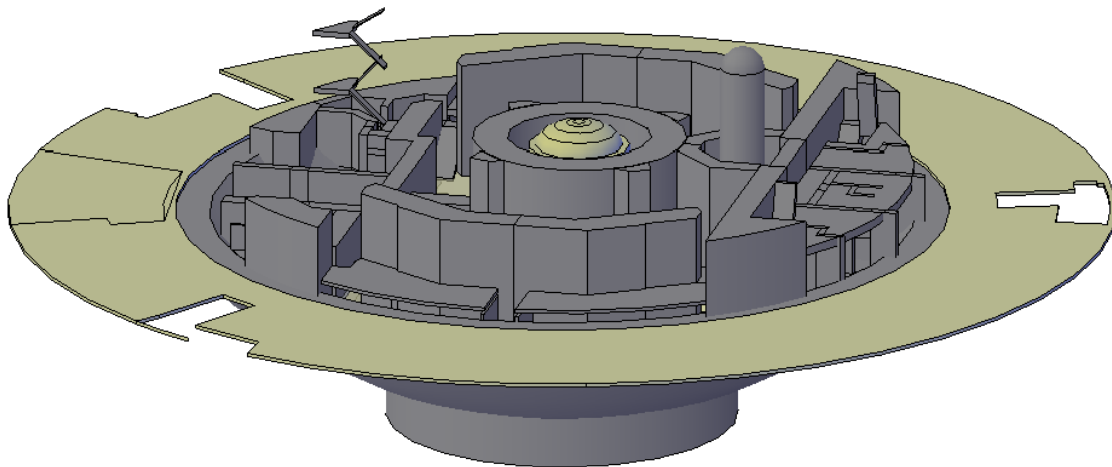


Figure 9. PWR-KWU: Aerial view up to level +6 m

3.1.1.3 Third level: +6 meters elevation and RCS

The construction of walls and floors from +2 m to +6 m allows to see the geometry of the 4 RCS loops, the location of equipment such as the pressurizer (PZR) and the end of the RPV cylinder. Figure 9 portrays the walls of +2 m and +6 m elevations, sustained by the lower cup and surrounded by the floors of UJB's +6 level. A set of stairs pertaining to the interior annular rooms are also shown, along with the RPV and the pressurizer in their respective compartments. Additionally, Figure 10 shows all walls, floors, and gratings of both UJA and UJB regions of the containment.

In UJA, some elements have been coloured to represent specific areas. In orange, the RCS steam generator (SG) housings (made from reinforced concrete) begin to develop at N-S coordinates, as well as the pressurizer compartment at the East, and the reactor cavity walls on top of the support shield surrounding the RPV. In yellow the bottom of the SFP can be seen. The pool is embedded in the western small equipment rooms and will follow up to the level of the service floor, at +21.5 m. Lastly, in pink, the staircases of eastern and western small equipment rooms are highlighted.

These stairwells are flow pathways connecting the sump and the large and small equipment rooms within the shrapnel cylinder. Further, openings and doors from the stairways will connect the annular rooms on the +12 m level and above. In the same figure, in UJA the cylinder is shown up to the +6 level.

Once all walls and floors of UJA were in position at this level, the RCS loops were constructed (SGs, PZR, pumps, hot and cold legs and PZR relief tank). The modelling of the RCS primary equipment has been undertaken to maintain their symmetry, using sweep-extrusion methods and mirror-symmetry

tools. Figure 11 and Figure 12 respectively show the fully developed RCS system and its position embedded within +6 m level structures.

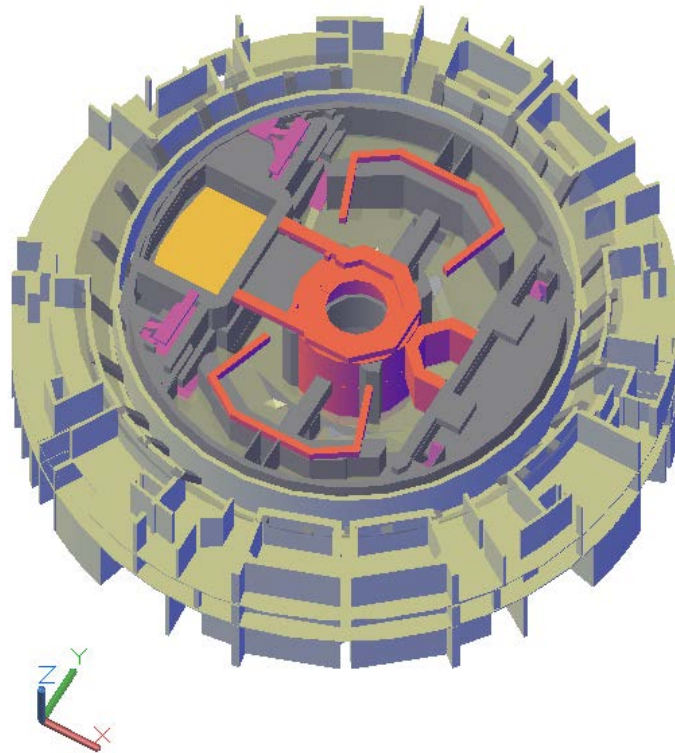


Figure 10. PWR-KWU: Aerial view of UJA and UJB up to level +6 m

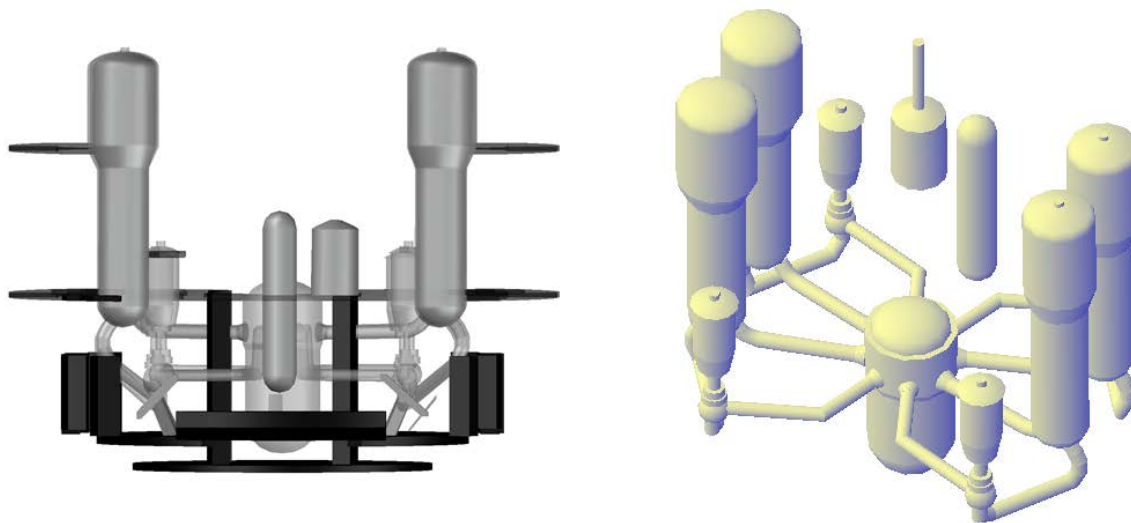


Figure 11. PWR-KWU: RCS loops of the 3D CAD model

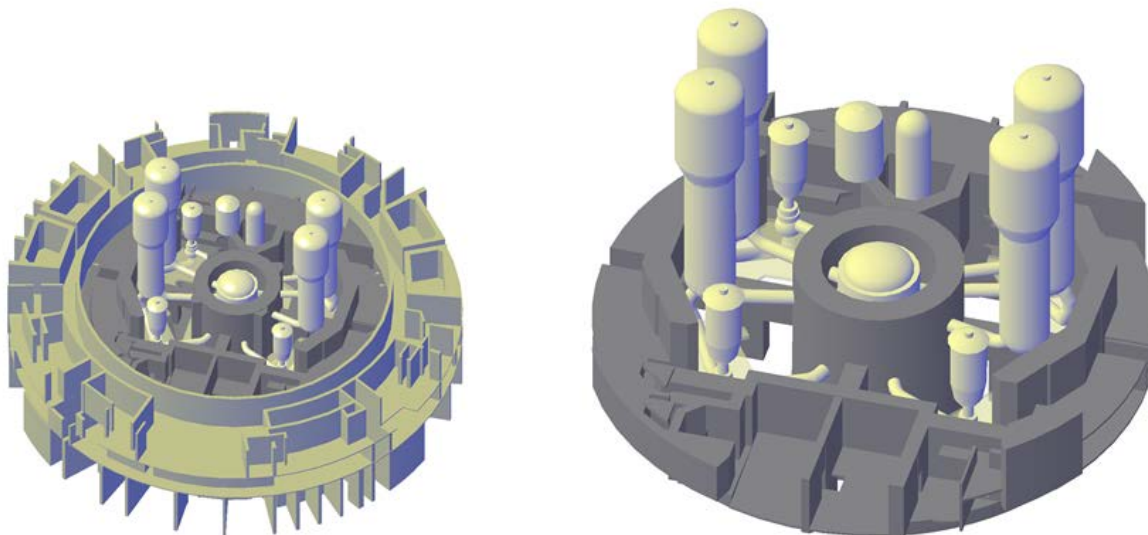


Figure 12. PWR-KWU: Aerial views of level +6 m with the RCS embedded.

3.1.1.4 Fourth level: +12-meter elevation

The fourth-floor plan layout available is that of +12 m and no other intermediate elevation information is available until the +21.5 m service floor level, apart from the information of the two perpendicular full front elevation cuts. For this reason, many walls, columns, and structures are lifted from +6 m to +12 m, both in UJA and UJB regions of the containment. Nevertheless, the geometry of the regions and compartments is maintained. At this point, many openings and junctions between different compartments and regions have been identified and their size and location has been registered for further treatment. Examples are the relief flap windows of the reactor room, shrapnel cylinder penetrations connecting the interior and exterior annulus, a ring opening connecting the exterior annular rooms with the duct for water drainage, and a variety of doors connecting inner compartments.

Figure 13 depicts the UJA geometry up to +12 m. The full body of the SFP and the reactor room above the reactor cavity (housing the RPV) can be seen. The SG compartments still develop at this level, as it is the case for the air supply conduits at the rear part of the SG cages (flanked by pairs of gratings). Some annular rooms, corresponding to ventilation compartments, can be seen outside the shrapnel cylinder, in the annular rooms. Also, two airlocks can be seen: the emergency airlock (in red, at NE), and a personnel lock (in yellow, at SW). Figure 14 shows the fully developed model of UJA, UJB and UJE building up to +12 m. UJE labels the extension of the airplane crash shell over the penetration of the main steam lines through the airplane crash shell, from where they connect to the turbine building of the NPP. Complexity of the compartmentalization of the KWU containment is apparent at this point and extreme care is to be put to not overlap structures.

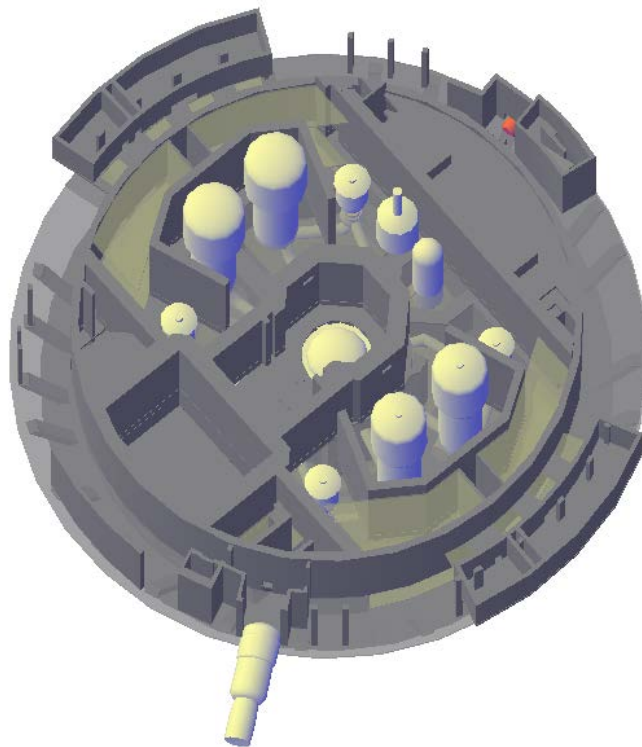


Figure 13. PWR-KWU: Aerial view of UJA up to level +12 m

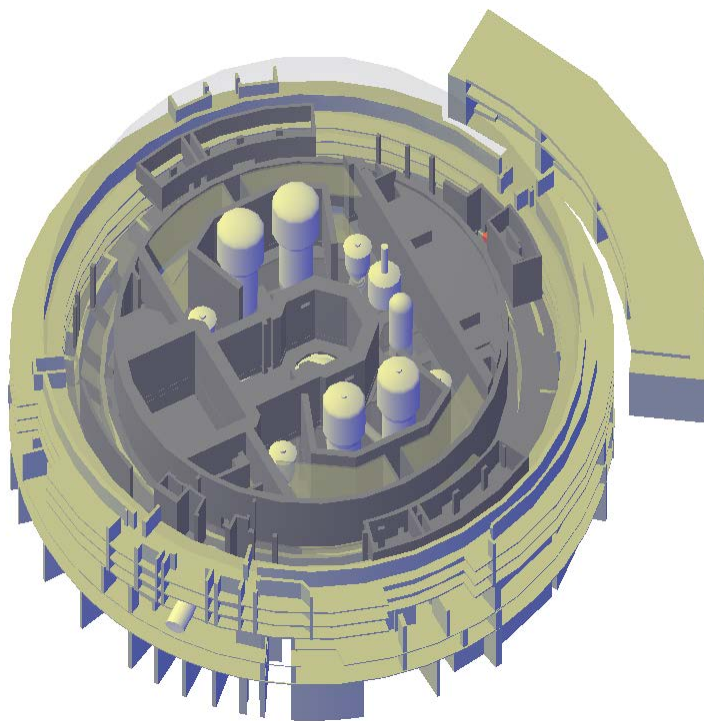


Figure 14. PWR-KWU: Aerial view of UJA and UJB up to level +12 m

3.1.1.5 Fifth level: +21.5-meter elevation

The last floor plan view available gives the information to construct all compartments and floors above the service floor level. This last region goes from +21.5 m up to the top of the containment sphere, forming the dome of the inner containment. The upper part of the shrapnel cylinder has three wide openings at the West, allowing staff full access across this floor elevation, and to transport large components (SG, dry storage casks, etc..) through the material hatch into the inner containment. Some stairwell scaffoldings and banisters surrounding the outer cylinder were identified but not modelled due to lack of proper layouts.

For the UJB region, some floors and rooms are added to complete the annulus. For the UJA region, outside the shrapnel cylinder, important incorporations are the equipment hatch (see Figure 15, equipment in red), the eight vertical accumulators (see Figure 16) and the ventilation rooms.

The main additions in the UJA inner containment are:

- SG compartments end, having pressure relief flaps on top (see Figure 15): the exit of the SG compartments connects with the dome area before the shrapnel cylinder reaches its top elevation. Modelling detail was necessary as it is a crucial area (the plumes of flow coming from a postulated break in the RCS primary loops would ascend through the SG houses, through the relief flaps on top of the SG houses up to the containment dome).
- Fuel handling machine (see Figure 16, equipment in yellow): located above the SFP pool, it has been modelled with an approximate volume due to lack of proper layout views.
- Main steam lines: coming from the top of the SGs and ending in the UJB fin, they have been modelled with a sweep-extrusion method to respect the actual spatial distribution of the steam lines.
- Auxiliary components rooms: located in the East, they house the Pilot-Operated Relief Valves (PORVs) of the PZR as well as heaters and coolers.
- Polar crane: mounted at the top of the cylinder, its modelling has relied upon detailed plans although for simplification reasons, an approximate shape has been implemented while maintaining the actual disposition and dimensions of its rails and platforms.

Figure 15-left shows an aerial view of UJA structures enclosed by the sphere. Figure 15-right shows in more detail the +21.5 m structures and the relief flaps mounted on top of the SG housings.

Figure 16 shows another aerial view of UJA structures up to +21.5 m, including the polar crane and the fuel handling machine (bright yellow), the main steam lines, accumulators, and the equipment hatch (red).

Figure 17 represents the fully developed UJA containment and UJB rooms with all its closures, i.e., sphere, outer concrete annulus and dome, and ground level foundation.

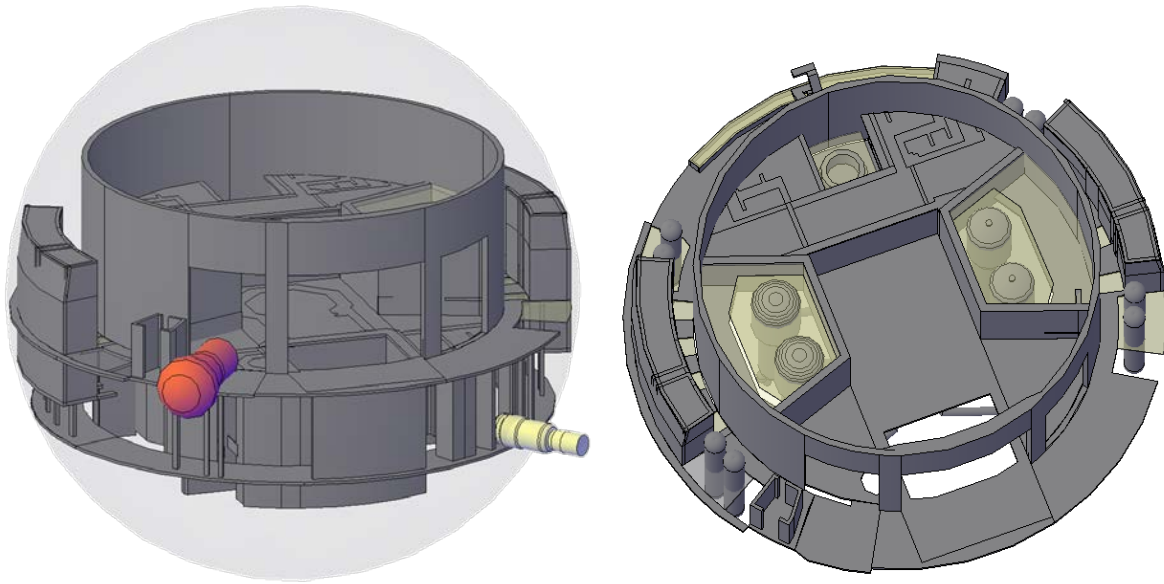


Figure 15. PWR-KWU: Aerial views on to UJA service floor (+21.5 m)

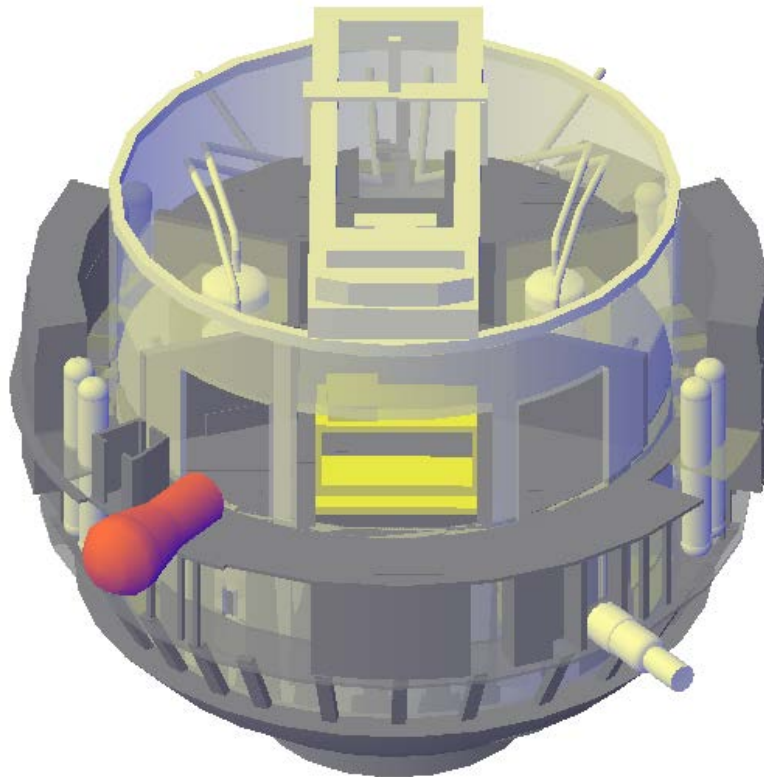


Figure 16. PWR-KWU: Aerial view of UJA level +21.5 m with main equipment

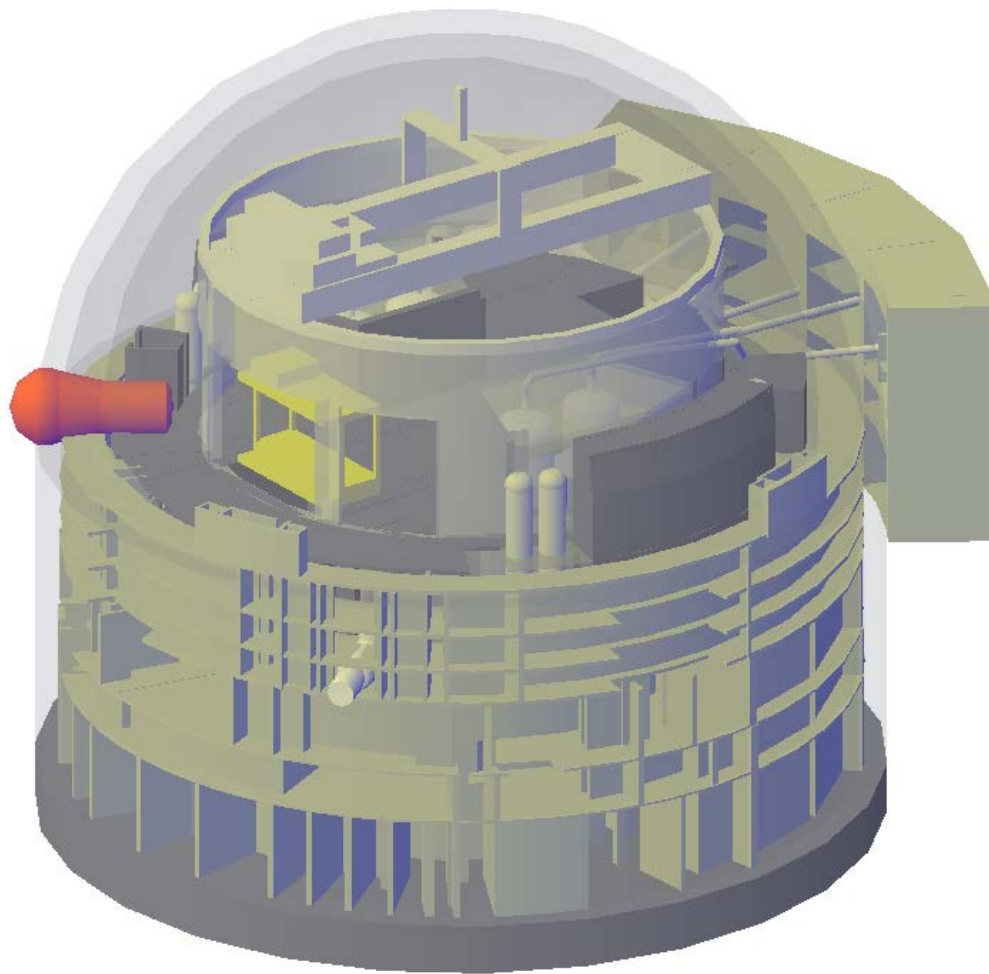


Figure 17. PWR-KWU: Full 3D CAD generic containment model

3.1.1.6 Identification of connections between regions

Using the information available from SAMHYCO-NET, flow paths specified in Reference [13] (for the same PWR-KWU containment type) has been taken into consideration at a first step of the study. Then, during the process of layout interpretation and 3D construction, a variety of connections between compartments have been identified in the containment. Moreover, references provided by some partners during the process of model optimization have become additional sources to understand several containment junctions [18] [19].

Using that information, the main characteristics regarding the separation of compartments in this containment have been identified. Firstly, in PWR-KWU plants, a clear separation between accessible and equipment rooms exists. Thereby accessible and equipment refers to the possibility for personnel to access these rooms during power operation. In the accessible rooms, service and maintenance works

can be performed, as well as preparations for the outage. The accessible rooms include mainly the reactor service floor, as well as the annular rooms outside of the shrapnel cylinder and the staircases. The equipment rooms hold the primary loop equipment. Due to the N16 activation during normal operation, the radiation levels in these rooms is too high to allow access of personnel. One further distinguishes between the large equipment rooms, which hold the large equipment like RPV, SG, or the sump, and the small equipment rooms, which house smaller equipment like volume control system or fuel pool purification system.

In normal operation, the accessible and equipment rooms are strictly separated, and the non-accessible rooms are kept at a small sub-pressure to prevent any airborne activity transport to the accessible rooms.

Figure 21 depicts the separation into equipment rooms (red) and accessible rooms (green). The blue areas are escape routes, where workers can reach the personnel hatch or the emergency hatch from the staircases even in case of a fire / smoke in the accessible rooms. Further, all doors in the staircases are usually in closed position, as the staircases are fire escape routes. These doors, however, may open due to excessive differential pressure in case of a high-energy pipe break.

In an accident scenario, the separation of the containment into two compartments is not beneficial. Therefore, large pressure relief openings are installed on the ceilings of the SG towers. In some plants these ceilings are realized as flaps, in other plants as rupture foils.

The identified junctions are possible flow pathways in case of an accidental scenario and thus, their identification, nature, and sizing are vital to understand the thermal-hydraulic phenomenology of the different flows moving across the containment's free volume. Examples of those 3D openings are vertical doors connecting rooms or regions, wall penetrations, large windows, staircases, corridor-like spaces connecting adjacent openings, floor-to-floor apertures such as stairwell landings or trapdoors, gratings and structural walking grids. The complete list of junctions identified in the PWR-KWU containment can be found in Section 3.1.2. Figure 18 to Figure 20 depict the openings identified inside the containment:

- **Connections up to the third level:** regarding the floors at the +2 m and +6 m levels, a series of connections between the stairwells, the containment sump and the small equipment rooms have been identified, mostly doors. Figure 18 depicts a floor view of the containment sump (bluish surfaces north and south inside the shrapnel cylinder), of the small equipment rooms (in light yellow at the western and eastern wings of the sump) and the lowest annular room, the so-called duct (identifiable by the support columns and its position outside of the shrapnel cylinder). The doors, indicated as yellow straight arrows, are considered to be closed during normal operation. The staircases connect to the upper floor (indicated by the red arrows).

The duct further has four penetrations (two per annular rooms wing, marked by curved yellow arrows) that connect it to the sump. These flaps shall ensure the drainage of water from the annular rooms back into the containment sump in case the normal plant drainage system gets clogged in case of a loss of coolant accident. These flaps can open due to the differential pressure caused by a high-energy pipe break or by hydrostatic water pressure when water accumulates in the duct.

Also, the small equipment rooms have a drainage opening to the sump (orange arrows), to prevent the accumulation of cooling water in these rooms in case of a loss of coolant accident. These openings are closed in normal plant operation, but open by differential pressure or hydrostatic pressure.

- **Connections at the fourth level:** Figure 19 show the identified junctions at the +12 m level. Inside the shrapnel cylinder, the reactor room has two flaps that connect this compartment with the large equipment rooms. These flaps are for ventilating the reactor room (i.e. open in normal plant operation), and especially for cooling the control rod drives on top of the RPV head. There are further (normally closed) access doors from the staircases to the large equipment and to the small equipment rooms.

There is a small distance between the floor of the +12 m annular room (= ceiling of the +6 m duct) and the spherical steel containment shell. This shall prevent any interference / local stress for the structures. This gap, however, also allow the drainage of water from the +12 m annular room level down to the duct (where the water can eventually drain into the sump). The ventilation rooms located in the annular rooms also have doors that can be considered closed in normal operation. Despite being outside the shrapnel cylinder, these ventilation rooms belong to the equipment rooms. Via ducts, air is extracted from the upper large equipment rooms, filtered, cooled, and then re-injected via ducts into the containment sump. For simplicity, these duct connections are not shown in Figure 19.

- **Connections at the fifth level:** the service floor located at +21.5 m level, is connected to the large equipment rooms via the relief openings (closed in normal operation) located at the top of the SG towers. In case of an accident, with the rise of pressure in the equipment rooms, these flaps will open, allowing for a decompression of the equipment rooms into the accessible rooms. In that case, hot gases will rise as plumes into the containment dome and fill the upper regions of the containment. The flaps are represented in Figure 20, where the flow streamlines are represented with orange curved arrows. Another connection between this region and the lower RCS levels is a small floor-to-floor opening located in the Pressure Operated Relief Valves (PORVs) room (orange ring inside the cylinder area), a dead-end compartment located just above the PZR. The shrapnel cylinder, that rises to the elevation of the polar crane (only obstacle on the way to the dome), has three major openings in the western wall, allowing staff passage and equipment transportation. In the floors outside the cylinder. A series of walking grids (e.g., around the eight accumulator tanks)

connect the service floor level with the +12 m level annular rooms below (see orange rings in Figure 20). Finally, the ventilation rooms doors are also accounted for in this level.

On the other hand, a series of door-type junctions were identified. These doors have the particularity of being sensitive to a determined overpressure, from which they would open in a transient scenario. Examples are the doors of the HVAC rooms, the fire protection doors at the anterooms of the personnel hatches, or the doors connecting the accessible areas inside the cylinder with the rooms at the annulus outside it. A list of the generic containment door- junction data can be found in Section 3.1.2. They are listed to ease the definition of sensitivity simulations where some of the doors may be considered opened or closed.

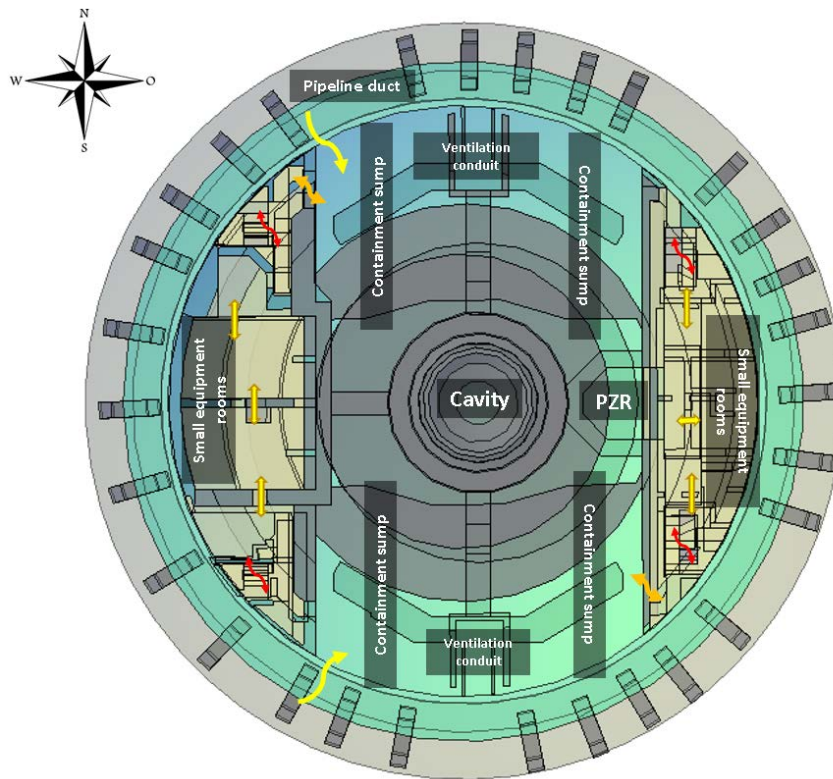


Figure 18. PWR-KWU: Containment inner connections up to the third-floor plan layout

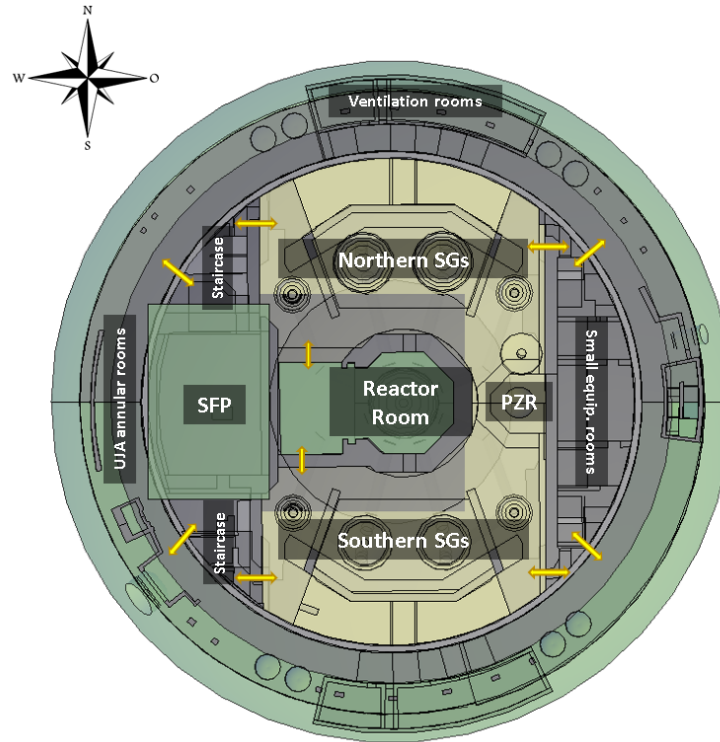


Figure 19. PWR-KWU: Containment inner connections at the fourth-floor plan layout

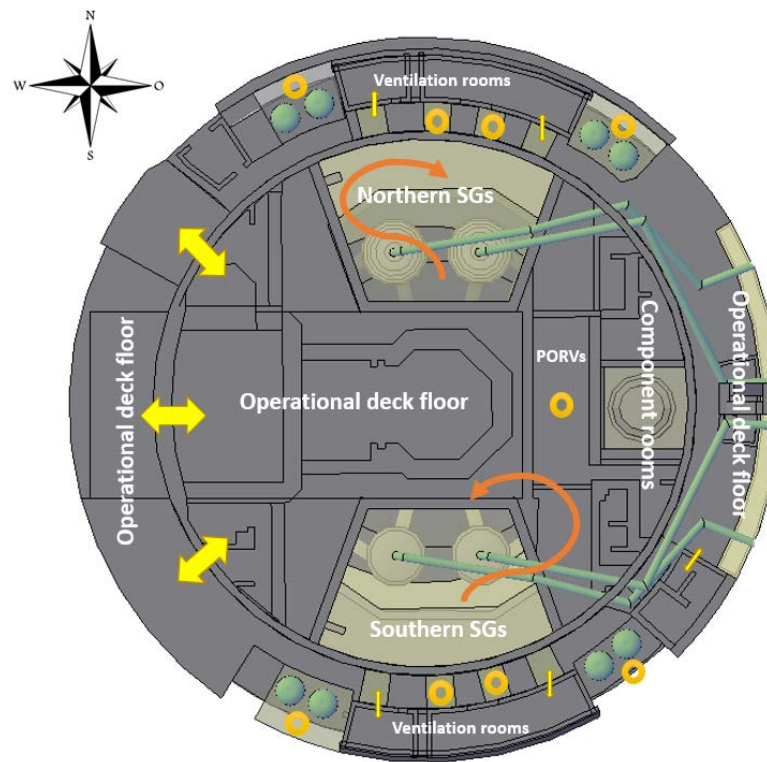


Figure 20. PWR-KWU: Containment inner connections at the fifth-floor plan layout

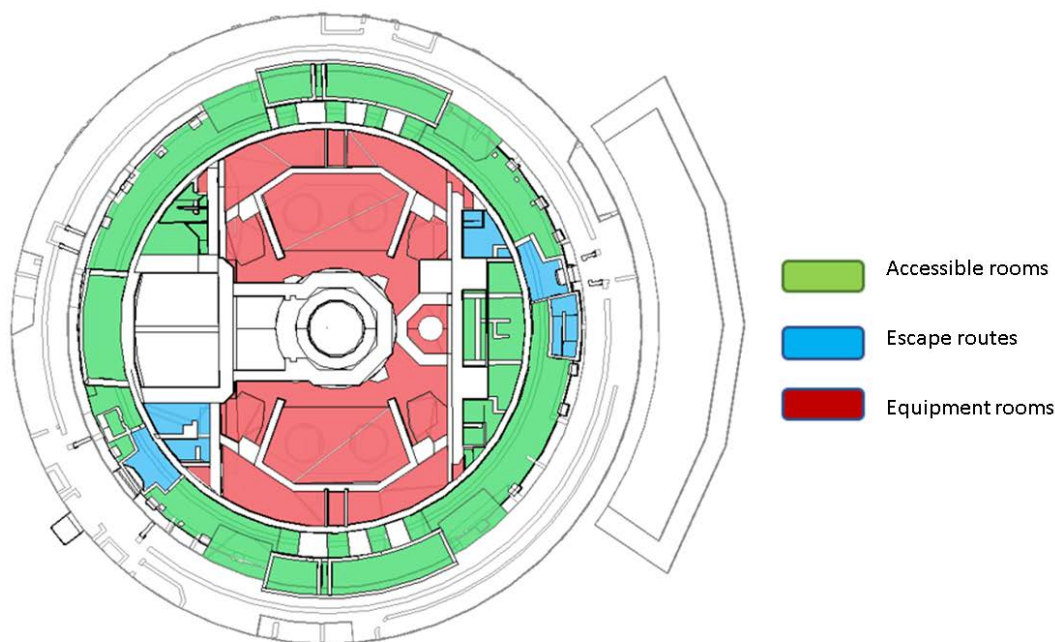


Figure 21. PWR-KWU: Accessible and non-accessible areas inside containment

3.1.2 PWR-KWU LP nodalization and database

The simulation of each physical room and junction within the containment can be a challenge regarding the numerical capacities of LP codes. Therefore, as simplification, several rooms, which could behave similar under accident conditions, are grouped together in so-called control volumes.

For the PWR-KWU, the rooms and compartments of the UJA containment have been grouped into 10 CVs (or zones) to generate a simple generic nodalization. This room grouping reduces the complexity of the containment down to 24 open junctions, 24 door-type pressure-sensitive junctions and 71 HSs. Also, a CV for the UJB containment building has been included. This last volume will account for the main heat loss of the containment in case of a severe accident.

The nodalization arrangement follows the same approach of the SAMHYCO-NET project PWR-KWU model [20], although a volume is added for the Spent Fuel Pool, and another volume is considered for the reactor room above the RPV (flooded during the fuel outage, dry during power operation). As in the SAMHYCO-NET model, the loops have been grouped in two steam generator zones (SG-N and SG-S). The reactor cavity as well as the pipe duct are represented by separated CVs, and there are a common dome and sump regions. Finally, the small equipment rooms and the annular rooms outside the shrapnel cylinder have been grouped as two CVs (eastern and western annular rooms) up to the level of the service floor. Above the service floor, all rooms not belonging to the SG towers are merged

into the containment dome volume. Figure 22 depicts the division of CVs in the UJA containment 3D model and in the elevation layouts.

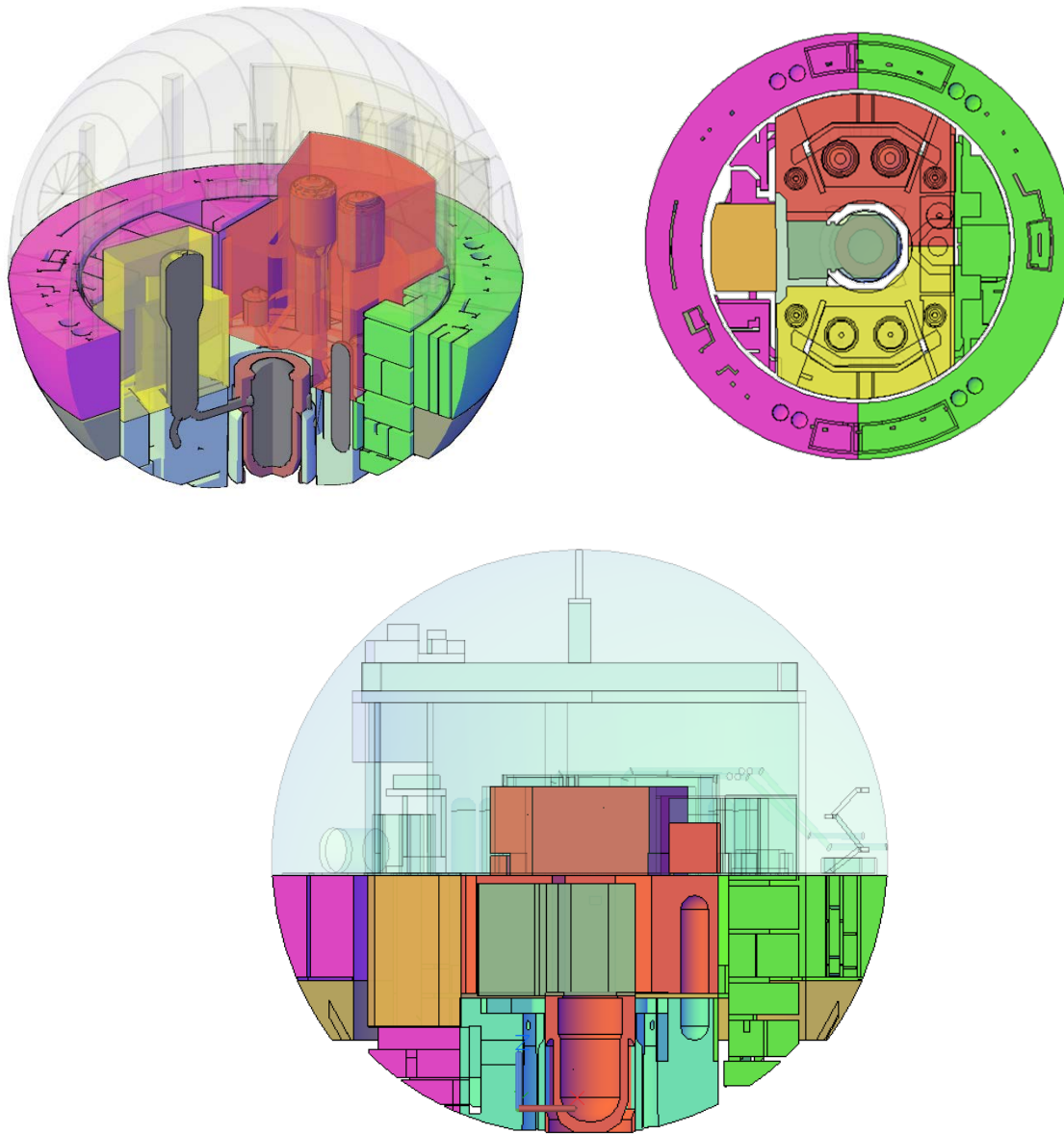


Figure 22. PWR-KWU: Generic Containment proposed nodalization.

This LP nodalization represents a reasonable simplification. However, some simplifications also have certain disadvantages.

- The representation of the sump as one large volume over-estimates the pool-atmosphere heat exchanges, which might result in significant deviations in the long run. An example of this situation would be after a pipe break or during MCCI, hot gases enter the upper region of the sump CV, where they would physically ascend to the SG towers without much interaction with

the water in the containment sump. However, as a lumped parameter code does not recognize a temperature gradient within the gas phase of a CV, the entire CV equally heats up, and this may lead to an over-estimation of the water heat up.

- The representation of the sump as well as the dome as large volume underestimates high local concentrations of combustible gases as the LP-approach foresees an instantaneous dilution of any gases within a CV. Thus, the larger the CV, the higher the chances for such underestimations.
- The merging of the small equipment rooms and the staircases with the annular rooms leads to a disruption of the building water drainage paths, an enhancement of mixing rates, and the consideration of the whole set of walls as a joint energy sink for the containment atmosphere. This approach will likely distort the thermal scenario in the long run. Further, normal building emergency draining occurs via drainage of water from the service floor to the annular rooms down to the duct, where then flaps open, draining the duct into the sump. When merging the small equipment rooms with the annular rooms, in the LP logic, water drains instantaneously into the bottom of the CV, i.e., into the small equipment rooms, bypassing the duct. Thus, water cannot accumulate in the duct, and thus, no hydrostatic pressure is available to open the duct flaps into the sump.

These kinds of disadvantages must be taken into account when using the above stated nodalization.

3.1.2.1 PWR-KWU Control volumes data

Table 2 gathers CV specifications, including the floor and top elevations. For CVs with rounded shape, the inner and outer radii are given (minimum and maximum distance from the RPV axis). The UJA containment free volume is **73944** m³, whereas the UJB free volume is **49255** m³. Also, an environment arbitrary volume is defined.

Table 2. PWR-KWU: Generic containment control volumes

Zones UJA	Identifier	Free Volume [m³]	Base Elevation	Top Elevation	Height	Inner radius	Outer radius	Geometrical shape
			[m]					
CAVITY	1	205	-1.90	8.90	10.80		4.10	CYLINDER
SUMP	2	5132	-1.90	10.50	12.40		20.20	SPHERICAL CAP
DUCT	3	2668	6.20	11.40	5.20	21.00	26.20	RING SHAPE
SG-N	4	4551	10.50	29.30	18.80		20.00	
SG-S	5	4489	10.50	29.30	18.80		20.00	
ANN-E	6	6091	1.84	30.40	28.56			CYLINDRICAL SHELL
ANN-W	7	5783	0.35	30.40	30.05			CYLINDRICAL SHELL
SFP	8	1327	7.45	21.50	14.05			POOL
RROOM	9	1044	10.30	20.50	10.20			POOL
DOME	10	42654	21.50	51.00	29.50		29.11	SPHERICAL CAP
UJA		73944						
UJB	11	49255	-6.00	57.00	63.00	25.00	31.00	ANNULUS
ENVIRONMENT	12	2*10^9	0.00	500.00	500.00			

3.1.2.2 PWR-KWU Junctions data

The generic containment zones are connected by means of 24 junctions between CVs and 24 additional door-type pressure-sensitive junctions located inside several CVs. The latter are treated separately, allowing the partners using 3D codes to consider each one as opened or closed in their simulations (depending on the transient scenario).

Table 3 gathers all information relative to the geometrical junctions. For vertical and horizontal junctions, an equivalent circular area is given as the flow path effective cross section area. For vertical junctions, an effective height is provided, being the difference between its highest elevation in the target zone and the lowest one in the start zone (elevations are extracted from the blocks in the detailed model). Also, for horizontal junctions, a minimal default length is provided (based on local concrete thickness).

Regarding water accumulation in the form of pools in the CVs, it is not expected in the zones except for the SUMP CV. Thus, gas carrying junctions should not be submerged by definition. Another relevant physical information gathered in Table 3 is the resistance loss coefficient defined for each junction. This coefficient is dependent on flow direction, so a +/- mark will indicate the positive and negative flow directions if the values are different. The methodology followed for deriving the loss coefficient factors is explained in Section 2.1 of this document.

Finally, all junctions are defined by an identifier, **J-X-Y-Z**, where the first letter indicates a CV-to-CV junction, the next two indicate the CV zone identifier (from Table 2) and the last letter numbers the junctions (2-digit number) by order of appearance (clockwise and bottom-to-top ordination in the PWR-KWU 3D CAD model). As for the KWU LP junction names, a quick glossary would be the following:

- **Flap:** burst (rupture) disks or relief flaps, e.g., SG cage's relief flap panels.
- **Chimney:** slimmer-than-thick junctions connecting various levels.
- **Door:** 1.9 m high door-type connections that connect rooms.
- **Drain:** horizontal or vertical water drainages connecting different regions of the containment.
- **Grating:** walking grids on floors, or structural gratings, in a level where they separate CVs. Not to be confused with other gratings in areas not connecting different nodalization volumes. These latter gratings are structural grids or inner openings.
- **Open Connection:** integrated area of the geometrical connection of juxtaposed CVs, e.g., area delimiting north and south SG CVs (J-4-5-01).
- **Orifice:** generally horizontal small junctions, normally the cross section of a tube-like structure, e.g., HVAC conduits, RCS piping penetrations.

- **Stairs:** stairwell openings connecting CVs.

Commentaries are provided for some junctions to clarify its characteristics and location:

- **J-3-2-01:** Drainage connecting duct and sump, with rupture foils in loops 1&4 with a 100-mbar air & hydrostatic pressure opening.
- **J-4-9-01, J-5-9-01:** Relief flaps (burst discs) of the Reactor Room. These flaps are open in normal plant operation for ventilating the reactor room.
- **J-4-10-01, J-5-10-01:** SG relief flaps with a variable opening pressure (flaps are made of several parts which allows for a gradual opening depending on the pressure build-up). A value of 30 mbar (+/- 20%) is chosen as a first approach to their modelling. The material specifications mark that they should resist temperatures up to 80°C.
- **J-6-2-01, J-7-2-01:** equipment-rooms small rupture foils into the sump. They open at 50 mbar pressure differential (air or hydrostatic) and are located 0.5 m above the floor.
- **J-10-6-01, J-10-7-01:** Merging of several openings from gratings, floor gaps or stairwells.
- **J-4-6-01, J-5-6-01, J-4-7-01, J-5-7-01:** Connecting accessible areas inside the shrapnel cylinder with the SG regions. Their opening would be subjected to the characteristics of the simulated transient. Failure pressure in opening direction of 100 mbar. Against opening direction 350 mbar [18]. Their junction length (horizontal) must be greater than 0.5 m (concrete wall thickness). Their resistance loss coefficient can be set to $\zeta_R = 1$.
- **J-8-10-01:** This open connection represents the free surface of the pool of water contained in SFP CV. It connects to the operational floor with a +10 cm upstand around it (no condensation draining from the service floor into the SFP). This description has been achieved through consultation with engineers who are expert on the containment layout [21].

Table 4 gathers the data for the additional 24 door-type pressure-sensitive junctions. They are doors connecting rooms in the accessible areas of the containment and always inside the same CV. They are of interest only for the partners modelling the containment in 3D environments. In other words, in LP models they are not geometrically included as they do not connect different CVs in this nodalization scheme. Instances of these doors are fire-protection doors in the personnel hatches, entrances to the shrapnel cylinder from the annulus, or the HVAC rooms doors in the annulus region.

Table 3. PWR-KWU: Junctions between control volumes

LP Junction	ID	Start Zone	End Zone	Circ. Area	Start Elev.	Target Elev.	Horiz. Length	Vert. Length	Loss coef ζ_R	dP
				[m ²]	[m]				[-]	[mbar]
DRAIN	J-3-2-01	DUCT	SUMP	1	6.4	6.4	1	0.5	2	100
FLAP	J-6-2-01	ANN-E	SUMP	0.5	1.84	1.84	1.7	0.3	1.5	50
FLAP	J-7-2-01	ANN-W	SUMP	0.5	0.35	0.35	1.7	0.3	1.5	50
ORIFICE	J-1-2-01	CAVITY	SUMP	1	7.5	7.5	2	1	3	
OPEN CONN.	J-2-4-01	SUMP	SG-N	46.81	10.1	10.5		0.4	2.2	
OPEN CONN.	J-2-5-01	SUMP	SG-S	46.81	10.1	10.5		0.4	2.5	
OPEN CONN.	J-4-5-01	SG-N	SG-S	43.9	15.65	15.65	1	11.1	2.7	
DRAIN	J-9-2-01	RROOM	SUMP	0.1	9.8	11.7		1.9	2	
OPEN CONN.	J-6-3-01	ANN-E	DUCT	12	11.85	12.15		0.3	3.3	
OPEN CONN.	J-7-3-01	ANN-W	DUCT	12	11.85	12.15		0.3	3.3	
OPEN CONN.	J-6-7-01	ANN-E	ANN-W	60.12	16.6	16.6	1	9.2	3.4	
OPEN CONN.	J-6-7-02	ANN-E	ANN-W	60.12	16.6	16.6	1	9.2	3.4	
FLAP	J-4-9-01	SG-N	RROOM	0.75	19.4	19.4	1.7	0.75	1.5	
FLAP	J-5-9-01	SG-S	RROOM	0.75	19.4	19.4	1.7	0.75	1.5	
DRAIN	J-10-2-01	DOME	SUMP	0.2	21.5	6.1		15.4	2	
GRATING + STAIRS	J-10-6-01	DOME	ANN-E	77.42	21.5	21.8		0.3	3(+) / 1.9(-)	
GRATING + STAIRS	J-10-7-01	DOME	ANN-W	69.1	21.5	21.8		0.3	2.7(+) / 1.8(-)	
FLAP	J-4-10-01	SG-N	DOME	169.83	29	29.5		0.5	1.5(+) / 2.2(-)	30
FLAP	J-5-10-01	SG-S	DOME	165.17	29	29.5		0.5		
DOOR	J-4-6-01	SG-N	ANN-E	2.66	11.45	11.45	1	1.9	1	100(+)/3 50(-)
DOOR	J-5-6-01	SG-S	ANN-E	2.66	11.45	11.45	1	1.9	1	
DOOR	J-4-7-01	SG-N	ANN-W	2.66	11.45	11.45	1	1.9	1	
DOOR	J-5-7-01	SG-S	ANN-W	2.66	11.45	11.45	1	1.9	1	
OPEN CONN.	J-8-10-01	SFP	DOME	94.5	21.5	21.5		0.1	0	

Table 4. PWR-KWU: Door-type pressure-sensitive junctions

ID	Start Zone	Target Zone	Circular Area	Start Elevation	Target Elevation	Height	Loss coef ζ_R
			[m ²]	[m]	[m]	[m]	[-]
D-6-6-01	ANN-E	ANN-E	2.35	12	14.5	2.5	1
D-7-7-01	ANN-W	ANN-W	2.35	12	14.5	2.5	1
D-6-6-02	ANN-E	ANN-E	2.35	12	14.5	2.5	1
D-7-7-02	ANN-W	ANN-W	2.35	12	14.5	2.5	1
D-6-6-03	ANN-E	ANN-E	1.9	12	13.9	1.9	1
D-6-6-04	ANN-E	ANN-E	1.9	12	13.9	1.9	1
D-6-6-05	ANN-E	ANN-E	2.66	12	13.9	1.9	1
D-7-7-03	ANN-W	ANN-W	1.9	12	13.9	1.9	1
D-7-7-04	ANN-W	ANN-W	1.9	12	13.9	1.9	1
D-6-6-06	ANN-E	ANN-E	1.33	12	13.9	1.9	1
D-6-6-07	ANN-E	ANN-E	1.33	16.5	18.4	1.9	1
D-6-6-08	ANN-E	ANN-E	1.9	21.5	23.4	1.9	1
D-6-6-09	ANN-E	ANN-E	1.33	21.5	23.4	1.9	1
D-6-6-10	ANN-E	ANN-E	1.33	16.2	18.1	1.9	1
D-6-6-11	ANN-E	ANN-E	1.33	21.5	23.4	1.9	1
D-6-6-12	ANN-E	ANN-E	1.33	16.2	18.1	1.9	1
D-7-7-05	ANN-W	ANN-W	1.33	21.5	23.4	1.9	1
D-7-7-06	ANN-W	ANN-W	1.33	21.5	23.4	1.9	1
D-7-7-07	ANN-W	ANN-W	1.33	16.2	18.1	1.9	1
D-7-7-08	ANN-W	ANN-W	1.33	16.2	18.1	1.9	1
D-7-7-09	ANN-W	ANN-W	1.33	21.5	23.4	1.9	1
D-7-7-10	ANN-W	ANN-W	1.33	21.5	23.4	1.9	1
D-7-7-11	ANN-W	ANN-W	1.33	16.2	18.1	1.9	1
D-7-7-12	ANN-W	ANN-W	1.33	16.2	18.1	1.9	1

3.1.2.3 PWR-KWU Heat Structures

To capture the total heat capacity and the heat transfer area of all concrete and steel surfaces in the containment, 71 heat structures (HSs) have been identified. Table 5 gathers the HS data, separating between floors and walls made of concrete or steel structures (see Section 4 for the material properties). For each HS label, the total heat transfer surface and the characteristic thickness (defined as total volume divided by total surface) is provided, together with the lowest elevation where the heat surface is present and the total height of that surface (integrated from the detailed 3D model). In general, the thickness provided is a characteristic value and does not correspond to a specific structure of the containment or to its specific elevation. This means that the product of thicknesses with the total areas provided gives the actual volume of material that correlates to that specific HS connection. The methodology followed to extract the HS data by type of structure is explained in Annex A of this report, although some clarifications ought to be made for the sake of clarity with respect to the interpretation of the table:

- When there is a set of heat transfer surfaces that belong only to a single CV (such as an internal wall), both left and right sides of the HS are assigned to the same CV. To avoid misunderstandings, only the left side area is provided in the tables, representing the total surface area in contact with the fluid. Therefore, multiplying the given thickness to the given area, delivers the actual volume of heat sink/source of material: $V = A_{left} * t_{charac}$
- Gratings are included with specific HS identifiers and its heat exchange is considered as steel wall type.
- Equipment such as the RCS or the main steam pipes is not included as steel HSs due to the lack of proper information to model them as heat sources (internal development of the fluid temperature inside the equipment structures).
- Some HSs are defined for the containment steel shell, thermally coupling the UJA rooms and the UJB building. The steel liner is made of carbon steel (see Section 4. of this report for the material properties).
- A specific HS represents the airplane crash shell between the UJB building and the environment (ENVIRONMENT). In Table 5, only Side A area is given, which accounts for the concrete surface inside the UJB building (see HSs with a -* mark at Side B column). If a code user needs to model the outer side surface (direct contact with the environment), the same area must be used.

In total, the following values of heat exchange surfaces are obtained for the KWU generic containment (UJA and UJB buildings):

- Horizontal concrete surface: **20674 m²**
- Vertical concrete surface: **51956 m²**

- Vertical steel surface: **18688 m²**
- Grating steel surface: **21341 m²**

Table 5. PWR-KWU: Heat structures

Structure ID	Composition	Type	Side A	Side B	Side A Area (m ²)	Side B Area (m ²)	Thickness (m)	Volume (m ³)	Elevation (m)	Height (m)
CAV-01	CONCRETE	WALL	CAVITY	CAVITY	357.480	-	0.347	124.220	-1.31	7.62
CAV-02	CONCRETE	WALL	CAVITY	SUMP	475.660	475.660	1.400	665.924	-1.90	10.80
CAV-03	CONCRETE	FLOOR	CAVITY	CAVITY	37.750	-	0.620	23.390	-1.90	0.62
CAV-04	CONCRETE	FLOOR	CAVITY	RROOM	30.349	30.349	1.400	42.489	7.50	1.40
SUMP-01	CONCRETE	WALL	SUMP	SUMP	1791.090	-	0.627	1123.013	0.43	10.07
SUMP-02	CONCRETE	WALL	SUMP	ANN-E	234.368	234.368	1.569	367.723	0.16	10.34
SUMP-03	CONCRETE	WALL	SUMP	ANN-W	205.753	205.753	1.380	283.939	-0.40	10.50
SUMP-04	CONCRETE	WALL	SUMP	DUCT	197.610	197.610	0.800	158.088	5.90	4.20
SUMP-05	CONCRETE	WALL	SUMP	SFP	9.303	9.303	1.400	13.024	7.50	2.60
SUMP-06	CONCRETE	FLOOR	SUMP	SUMP	1436.926	-	2.911	4183.190	-1.90	9.10
SUMP-07	CONCRETE	FLOOR	SUMP	SG-N	193.700	193.700	1.800	348.660	8.70	1.80
SUMP-08	CONCRETE	FLOOR	SUMP	SG-S	193.700	193.700	1.800	348.660	8.70	1.80
SUMP-09	GRATING	WALL	SUMP	SUMP	4335.685	-	0.005	21.678	0.00	6.70
SUMP-10	GRATING	WALL	SUMP	SG-N	530.195	530.195	0.010	5.302	10.10	0.40
SUMP-11	GRATING	WALL	SUMP	SG-S	530.195	530.195	0.010	5.302	10.10	0.40
DUCT-01	CONCRETE	WALL	DUCT	DUCT	715.950	-	0.216	154.330	6.20	5.40
DUCT-02	CONCRETE	WALL	DUCT	SG-N	44.129	44.129	0.800	35.303	10.10	1.60
DUCT-03	CONCRETE	WALL	DUCT	SG-S	43.980	43.980	0.800	35.184	10.10	1.60
DUCT-04	CONCRETE	WALL	DUCT	ANN-E	196.513	196.513	0.800	157.210	6.20	5.20
DUCT-05	CONCRETE	WALL	DUCT	ANN-W	170.054	170.054	0.800	136.043	6.20	5.20
DUCT-06	CONCRETE	WALL	DUCT	SFP	49.232	49.232	0.800	39.385	7.45	3.95
DUCT-07	CONCRETE	FLOOR	DUCT	DUCT	406.560	-	0.200	81.312	6.20	0.40
DUCT-08	CONCRETE	FLOOR	DUCT	ANN-E	300.430	300.430	0.300	90.129	11.70	0.30
DUCT-09	CONCRETE	FLOOR	DUCT	ANN-W	317.330	317.330	0.300	95.199	11.70	0.30
DUCT-10	STEEL	WALL	DUCT	UJB	967.610	967.610	0.038	36.769	6.20	5.20
SG-N-01	CONCRETE	WALL	SG-N	SG-N	1085.730	-	0.285	309.433	10.50	18.00
SG-N-02	CONCRETE	WALL	SG-N	ANN-E	336.810	336.810	0.910	306.497	10.50	11.10
SG-N-03	CONCRETE	WALL	SG-N	ANN-W	237.016	237.016	0.874	207.152	10.50	11.10
SG-N-04	CONCRETE	WALL	SG-N	RROOM	213.255	213.255	1.376	293.439	10.56	9.94

SG-N-05	CONCRETE	WALL	SG-N	DOME	549.066	549.066	0.776	426.075	21.50	7.80
SG-N-06	CONCRETE	FLOOR	SG-N	SG-N	279.360	-	0.236	66.030	20.50	2.80
SG-N-07	CONCRETE	FLOOR	SG-N	DOME	76.440	76.440	1.000	76.440	25.00	1.00
SG-N-08	GRATING	WALL	SG-N	SG-N	5598.724	-	0.005	27.994	10.50	18.80
SG-S-01	CONCRETE	WALL	SG-S	SG-S	1034.109	-	0.288	297.823	10.50	18.40
SG-S-02	CONCRETE	WALL	SG-S	ANN-E	326.266	326.266	0.880	287.114	10.50	11.10
SG-S-03	CONCRETE	WALL	SG-S	ANN-W	232.647	232.647	0.874	203.333	10.50	11.10
SG-S-04	CONCRETE	WALL	SG-S	RROOM	213.255	213.255	1.376	293.439	10.56	9.94
SG-S-05	CONCRETE	WALL	SG-S	DOME	536.908	536.908	0.818	439.191	21.50	7.80
SG-S-06	CONCRETE	FLOOR	SG-S	SG-S	261.056	-	0.256	66.770	20.50	2.80
SG-S-07	CONCRETE	FLOOR	SG-S	DOME	76.290	76.290	1.000	76.290	25.00	1.00
SG-S-08	GRATING	WALL	SG-S	SG-S	5638.958	-	0.005	28.195	10.50	18.80
ANN-E-01	CONCRETE	WALL	ANN-E	ANN-E	2703.858	-	0.257	694.892	1.84	28.56
ANN-E-02	CONCRETE	FLOOR	ANN-E	ANN-E	1748.318	-	0.609	1064.726	1.84	28.56
ANN-E-03	CONCRETE	FLOOR	ANN-E	DOME	354.710	354.710	0.456	161.748	20.70	9.70
ANN-E-04	STEEL	WALL	ANN-E	ANN-E	15.030	-	0.100	1.500	12.27	1.45
ANN-E-05	STEEL	WALL	ANN-E	ANN-E	207.340	-	0.080	16.587	13.45	8.05
ANN-E-06	STEEL	WALL	ANN-E	UJB	835.660	835.660	0.038	31.755	11.40	9.50
ANN-E-07	GRATING	WALL	ANN-E	ANN-E	732.161	-	0.005	3.661	16.20	0.30
ANN-E-08	GRATING	WALL	ANN-E	DOME	307.388	307.388	0.010	3.074	21.40	0.10
ANN-W-01	CONCRETE	WALL	ANN-W	ANN-W	2685.140	-	0.276	741.099	0.35	30.05
ANN-W-02	CONCRETE	WALL	ANN-W	SFP	256.687	256.687	0.743	190.817	7.45	14.05
ANN-W-03	CONCRETE	FLOOR	ANN-W	ANN-W	1432.650	-	0.736	1054.290	0.35	30.05
ANN-W-04	CONCRETE	FLOOR	ANN-W	SFP	96.620	96.620	2.000	193.240	7.45	1.80
ANN-W-05	CONCRETE	FLOOR	ANN-W	DOME	323.760	323.760	0.636	205.911	20.70	9.70
ANN-W-06	STEEL	WALL	ANN-W	ANN-W	61.680	-	0.100	6.170	12.04	3.09
ANN-W-07	STEEL	WALL	ANN-W	ANN-W	207.340	-	0.080	16.587	13.45	8.05
ANN-W-08	STEEL	WALL	ANN-W	UJB	835.660	835.660	0.038	31.755	11.40	9.50
ANN-W-09	GRATING	WALL	ANN-W	ANN-W	737.120	-	0.005	3.686	16.20	0.30
ANN-W-10	GRATING	WALL	ANN-W	DOME	312.160	312.160	0.010	3.122	21.40	0.10
SFP-01	CONCRETE	WALL	SFP	RROOM	161.470	161.470	1.368	220.891	10.10	10.40
RROOM-01	CONCRETE	FLOOR	RROOM	SUMP	46.393	46.393	1.400	64.950	8.90	1.40
RROOM-02	CONCRETE	FLOOR	RROOM	DOME	232.920	232.920	1.000	232.920	20.50	1.00
DOME-01	CONCRETE	WALL	DOME	DOME	5656.584	-	0.316	1790.149	21.50	15.80
DOME-02	CONCRETE	FLOOR	DOME	DOME	806.100	-	0.222	178.587	21.50	8.90
DOME-03	STEEL	WALL	DOME	DOME	2351.300	-	0.049	115.214	21.50	29.50

DOME-04	STEEL	WALL	DOME	UJB	5284.000	5284.000	0.038	200.792	21.50	29.50
DOME-05	GRATING	WALL	DOME	DOME	938.620	-	0.005	4.693	22.80	4.00
UJB-01	CONCRETE	WALL	UJB	ENVIRONMENT	6059.830	-*	3.800	23027.354	0	54.5
UJB-02	CONCRETE	WALL	UJB	UJB	14426.820	-	0.500	7213.410	-6.00	31.5
UJB-03	CONCRETE	FLOOR	UJB	UJB	6276.670	-	0.300	1883.001	2.2	19.6
UJB-04	CONCRETE	FLOOR	UJB	ENVIRONMENT	3504.000	-*	1.000	3504.000	-7	1

* For HSs connecting with the environment, only side A area is given, accounting for the surface inside the building. In case the surface in contact with the environment wants to be simulated, the same area must be used.

3.1.2.4 PWR-KWU PAR layout

The PAR distribution inside the PWR-KWU Generic Containment zones is summarized in Table 6 and represented in Figure 23 to Figure 25. PAR elevation refers to the global elevation of the PAR geometric centre, i.e., with respect to the containment coordinate system. Their geometrical features are summarized in Section 4.2 of this report. The PAR sizing and location is based on IAEA's recommendations (*Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants, TecDoc 1661, 2011*) [22]. Thus, 40 recombiners will be a priori implemented in the containment compartments. Two PAR types, Framatome FR-1500 and FR-960, will be used to achieve a representative global nominal recombination rate for this type of containment.

Note that the PAR distribution in this generic containment may not represent the actual PAR placement in a nuclear power plant. It is merely a representative possible realization of a PAR system.

The recommendations to locate the PARs have been the following:

- All the CVs except the Cavity and the SFP have at least one PAR.
- Dead-end compartments should have a PAR.
- Several groups of N number of PARs are located in each elevation, one per loop (N-loop "symmetry"). For example, at a certain elevation, one PAR should be located in each one of the SG cages.
- Spaces close to H₂/CO releases have a higher number of PAR (RCS).
- Spaces where combustible gases may ascent to (i.e., the containment dome) shall be equipped with a higher number of PARs.

Table 6. PWR-KWU: PAR layout

Zones	PAR type	Number of PARs	PAR Elevation [m]
CAVITY	-	0	-
SUMP	FR-960	4	+8.0
DUCT	FR-1500	4	+10.0
SG-N	FR-1500	2	+12.0
	FR-960	3	+16.0
SG-S	FR-1500	2	+12.0
	FR-960	3	+16.0
ANN-E	FR-1500	2	+13.0
	FR-960	2	+13.0
ANN-W	FR-1500	2	+13.0
	FR-960	2	+13.0
SFP	-	0	-
R-ROOM	FR-960	1	+12.0
DOME	FR-1500	4	+23.0
		4	+40.0
	FR-960	1	+23.0
		4	+26.0

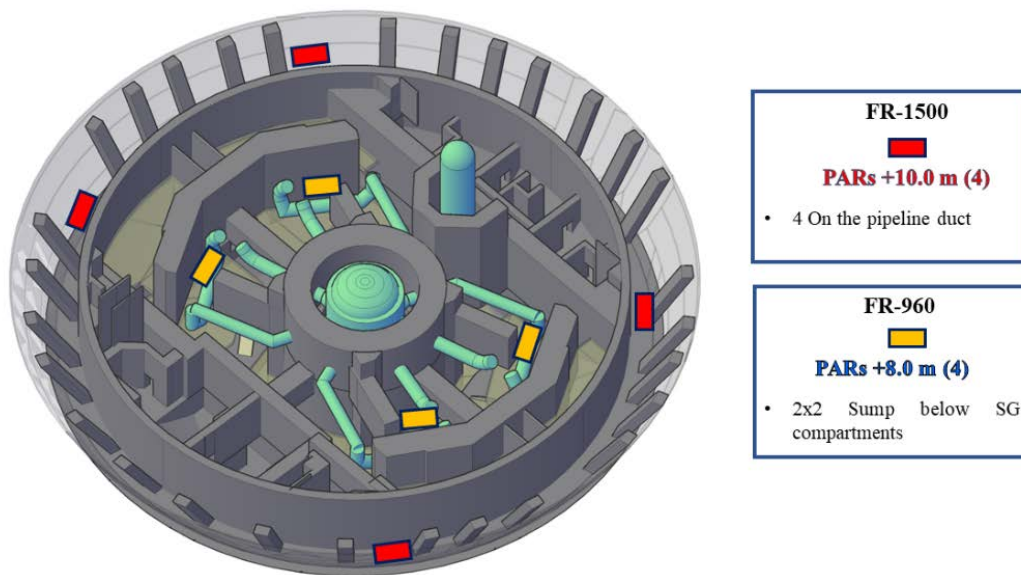


Figure 23. PWR-KWU: PAR positioning in the SUMP and DUCT CV

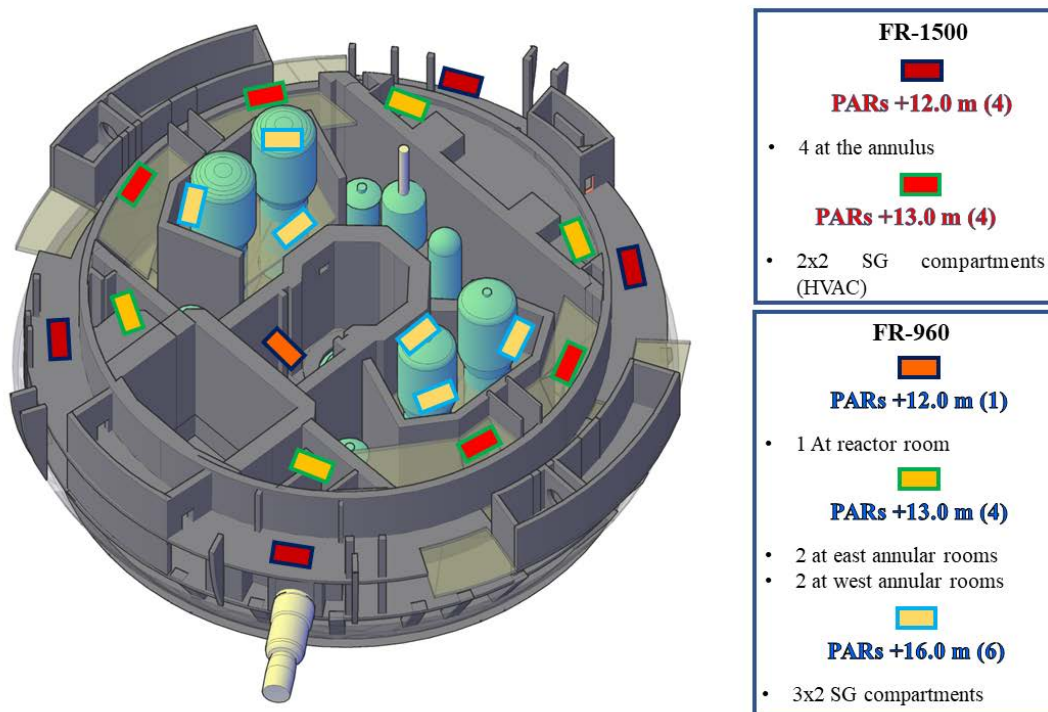


Figure 24. PWR-KWU: PARs at SG-N, SG-S, RROOM, ANN-E and ANN-W CVs

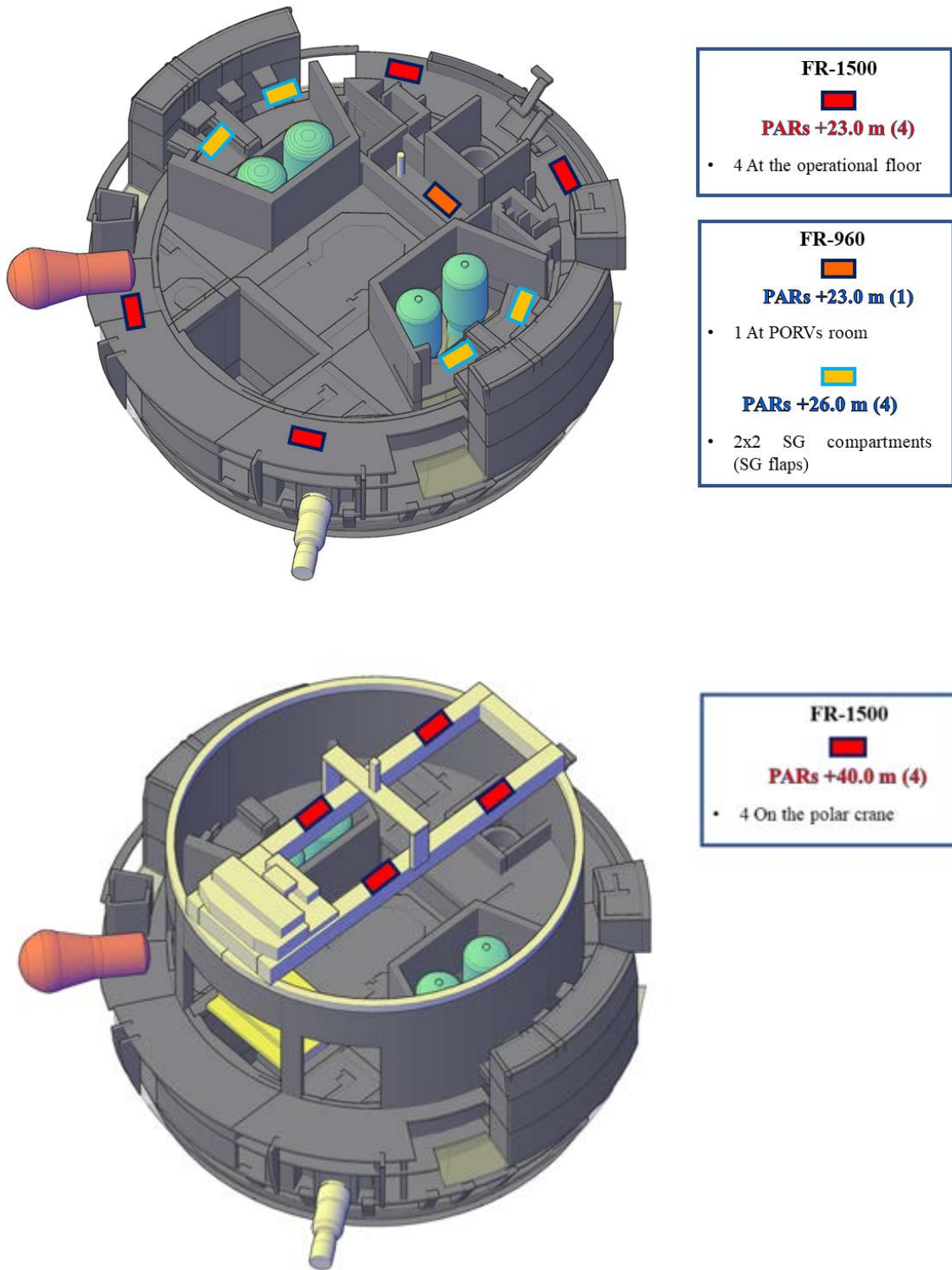


Figure 25. PWR-KWU: PAR positioning in the DOME CV

3.2 PWR-W generic containment

The containment of the generic PWR-W is a steel-lined post-tensioned reinforced concrete structure, which accommodates a Westinghouse 3-loops PWR. It was designed to withstand a pressure up to 3.75 bar and a temperature up to 149 °C induced by a LBLOCA at approximately 3000 MWt. The heavily reinforced concrete structure has a vertical cylindrical wall and a toroidal/spherical dome with a reinforcement ring (Ring-Girder) above the main cylinder, all supported by a mostly flat concrete floor.

The construction of the CAD model relied on an extended database of layouts that are not publicly available. However, traceable references to the containment geometry can be found in previous publications [12] [23].

3.2.1 PWR-W 3D CAD model construction

The first structures drawn in the CAD model were the steel-lined vertical cylinder and the toroidal/spherical dome, i.e., the structures visible from outside. The containment structure has an inside diameter of 40 m. The bend line of the dome 59 m above the top of the main foundation floor (the bottom of the steam generator compartments). The cylindrical wall is 1.15 m thick, the dome is 1 m thick, and the basement is 2.75 m thick. The steel liner has a constant thickness of 6.5 mm. The liner covers the internal surface of all the concrete structure, and it is covered by an extra layer of concrete on the main foundation floor.

The building process continues with the definition of the operational floor, a thick slab of concrete with a thickness of 1.2 m and a diameter of 37.8 m (there is a small gap between the floor border and the liner), located 13 m above the top of the basement's floor. This structure separates the containment in two regions, and for the containment analysis, it is the main obstacle to reach a homogeneous distribution of the gases in the containment.

The construction of the regions located above and below the operational floor are explained in two separated subsections.

3.2.1.1 Space below the operational floor

The internal structures located below the operational floor, also known as primary and secondary shielding, separate this space in three regions (see Figure 26): (i) the reactor cavity, located inside the primary shielding; (ii) the Steam Generators (SG) and Pressurizer (PZR) compartments, between the primary and secondary shielding; and (iii) and the Outage Pool, the region of the containment filled with water during the fuel reloading. These areas are built as follows:

Primary Shielding

The primary shielding envelopes the reactor vessel cavity. Furthermore, the cavity space of the containment is extended up to 9 m below the basement floor, as can be seen in the sketch of Figure 27. The primary shielding has six supporting structures for accommodating the reactor vessel and the hot/cold legs of the reactor cooling system. Below the annular gap between the reactor vessel and the primary shielding, there is a corridor for all the in-core instrumentation lines. The corridor has a horizontal and a vertical section, which ends in the instrumentation room (outside the primary shielding, Figure 28). The concrete walls located below the basement are lined.

The presence of the cavity modifies the shape of the main concrete building. This was the region of the containment modelled with the lower level of details from the layouts. Eventually, a good approximation of the actual geometry was built based on the location of the vertical part of the instrumentation tunnel (Figure 26), the exact elevation of the floor of the horizontal part of the instrumentation tunnel, and the available data of the free volume of these spaces.

Secondary Shielding

The spaces included within the secondary shielding are identified and labelled in Figure 26. Although the SGs and the PZR are not visible at the elevation of the figure, the bottom of the compartments that house the main equipment of the nuclear steam supply system are easily identified. Each steam generator compartment is connected to a ventilation corridor, which starts at the containment basement and will end in the open space of the dome. These corridors have several air conduits and mechanical systems to circulate the air from the open space of the dome to all the rooms located below the operational floor. All these equipment is not represented in the CAD model, but only the main connections between the bottom of the compartments and the dome expected to be open in accidental conditions. Figure 26 helps to show that all the main compartments have open connections at this elevation. In fact, the same is not true at higher elevations, as it is shown in Figure 28, where the SG compartments 2 and 3 are not connected anymore. Indeed, the only connection between the SG compartments and the air corridors are close to the basement floor. The connection of the instrumentation corridor and the instrumentation room is also displayed in Figure 26.

Each compartment also has a connection with the space located outside the secondary walls, the external ring. These connections are extended up to the operational floor in Figure 28. At the external ring, there are other small rooms, the east/west stairs, the elevator, and the containment sump.

Outage Pool

The outage pool, a key space for the fuel reload, is represented in Figure 28. During normal operation, it does not contain water and is covered by a concrete slab, visible in Figure 29 (6b). The pool is mostly isolated from all the other spaces of the containment, however, there is a small gap between the reactor vessel head and the cavity region, and between the concrete slab and the dome.

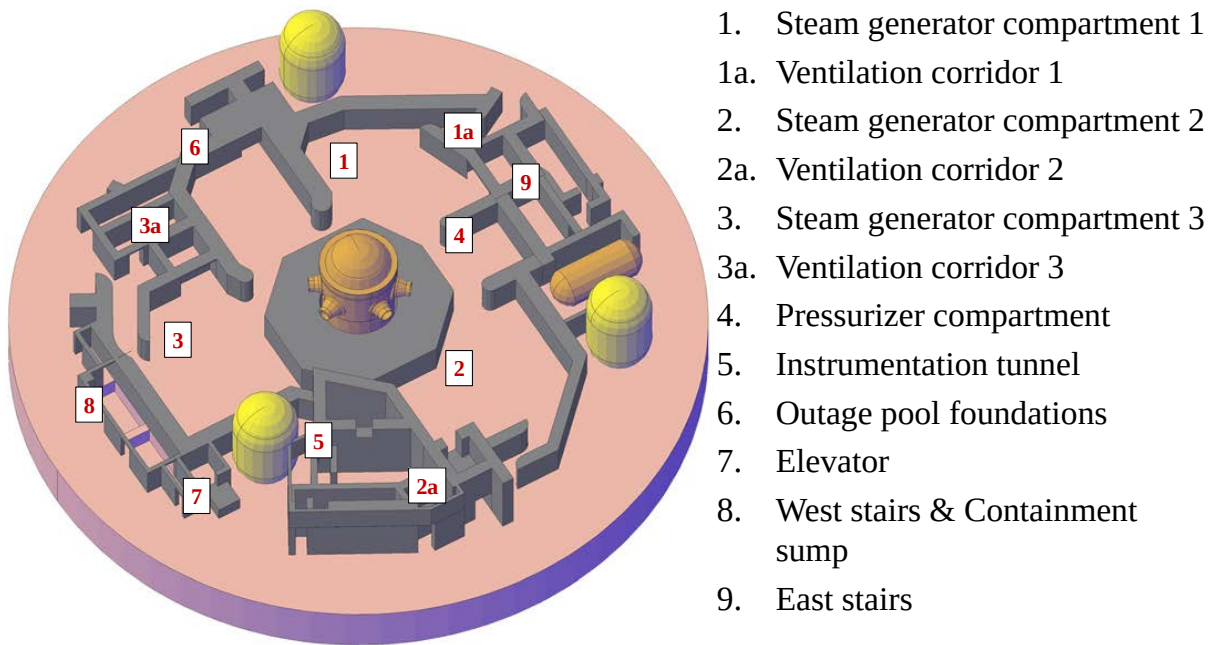


Figure 26. Isometric view and labelling of the compartments at the bottom of the containment.

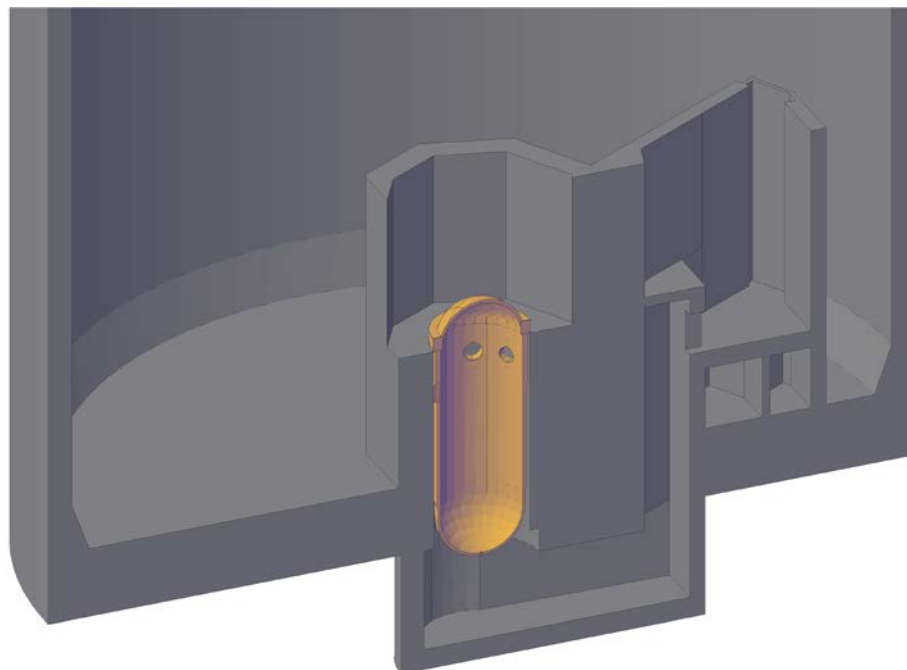
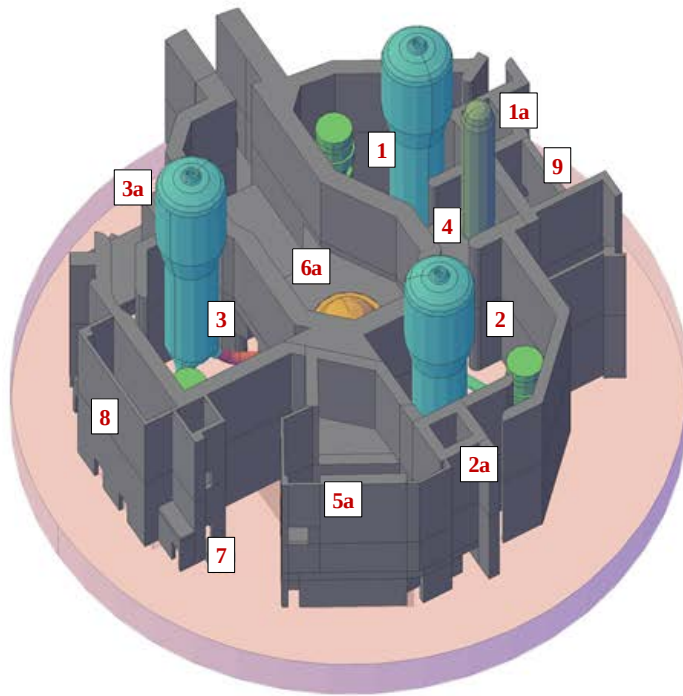
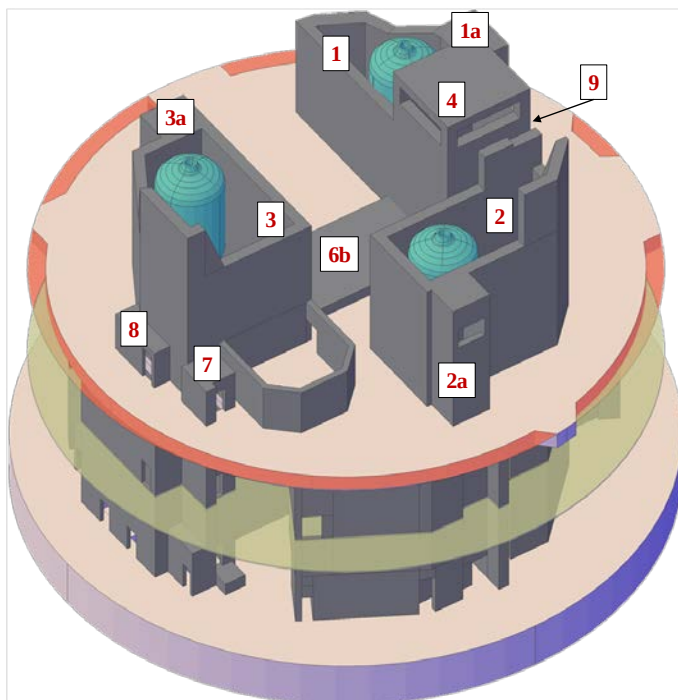


Figure 27. Cross section of the spaces connected to the cavity.



1. Steam generator compartment 1
- 1a. Ventilation corridor 1
2. Steam generator compartment 2
- 2a. Ventilation corridor 2
3. Steam generator compartment 3
- 3a. Ventilation corridor 3
4. Pressurizer compartment
- 5a. Instrumentation room
- 6a. Outage pool
7. Elevator
8. West stairs
9. East stairs

Figure 28. Isometric view and labelling of the compartments within the secondary shielding and the outage pool.



1. Steam generator compartment 1
- 1a. Ventilation corridor 1
2. Steam generator compartment 2
- 2a. Ventilation corridor 2
3. Steam generator compartment 3
- 3a. Ventilation corridor 3
4. Pressurizer compartment
- 6b. Vessel missile shield
7. Elevator
8. West stairs
9. East stairs

Figure 29. Isometric view and labelling of the walls above the operational floor. The open space between the liner and the operational floor is highlighted in red.

3.2.1.2 Space above the operational floor

The space above the operational floor represents approximately 75% of the free volume of the containment, and it is known as the dome. The main concrete walls of the dome are those of the PZR compartment, and the SG compartments with their ventilation corridors. Figure 30 shows the main steam lines and the polar crane, also located in the containment dome. This figure also shows the thin metallic liner, which envelopes all the structures described above. Although not represented in the figures, most of the safety systems of the containment building (most of the PARs, the spray system, and the FCVS) operate at the dome.

One of the most important insights for a comprehensive description of the containment geometry, is to understand the possible paths to transport the fluid from the space above the operational floor to the space below it. The two main mixing paths are visible in Figure 29 (highlighted in red) and Figure 30, i.e., the exits of each SG compartment, and the annular gap between the liner and the operational floor. Alternatively, there are six smaller flow paths that can be understood as vertical corridors that have connections with both the dome and the basement of the containment: each of the three corridors of the SG compartments, the east and west stairs, and the elevator. Besides their small surface, the geometry of the last 6 connections makes the transport of relevant quantities of fluid from the dome to the lower elevations unlikely.

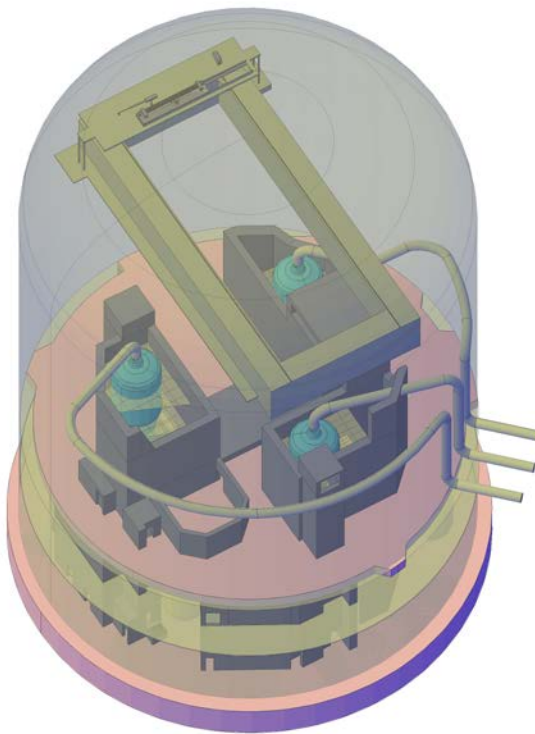


Figure 30. Isometric view including all the internal walls and components enclosed by the containment steel liner.

3.2.2 PWR-W LP nodalization and database

The nodalization arrangement follows the same approach of SAMHYCO-NET project [20]. The volume of the containment has been grouped into 11 control volumes (or zones) to generate a simple generic nodalization. To create the nodalization, the containment was separated in big compartments where differentiated thermo-hydraulic conditions may be expected. As in the generic containment of SAMHYCO-NET, a simple nodalization eases the modelling process and help to minimize potential user induced errors in the implementation of the models. Since the number of rooms and compartments of the PWR-W is lower than in the PWR-KWU, the criterion used to delimitate the different regions depend on the main structures of the building (primary shielding, secondary shielding, and operational floor). In total, there are 31 junctions and 70 heat structures.

The space within the secondary shielding has been grouped in three Steam Generator zones (SG-1 (green), SG-2 (yellow), and SG-3 (magenta) in Figure 32), and a separated volume for the PZR compartment. The reactor cavity as well as the instrumentation channel are represented by a separated control volume (dark blue, Figure 31). The space outside the secondary shielding has been separated into two control volumes (pink and brown, Figure 32 - right). The stairs, also outside the secondary shielding, have two separated control volumes since these are mostly separated from the rest of the containment and connect the lower and upper part of the containment. Lastly, all the space above the operational floor not included in the main compartments is modelled with a single CV, the Dome.

3.2.2.1 PWR-W Control Volumes

The rooms and compartments of the reactor containment building have been grouped into 11 control volumes to generate a simple generic nodalization (see Table 7). The total free volume of the generic containment is **61293 m³**. Below the ground floor level of the containment the first CV is identified, the cavity. This region not only includes the volume where the vessel is located but an instrumentation channel. In Figure 31 the CV and the connection between the cavity and the channel is shown.

Following the geometry of the internal structures located between the primary and the secondary shielding we can separate this space in five regions (see Figure 32): three CVs for the steam generator compartments, one for the PZR compartment, and one for the outage pool. This distribution follows the naturally separated areas of the containment. Each steam generator has a separate CV, since the junctions between each SG compartment and the junctions with the dome are small compared with their free volume. This geometrical distribution may create differentiated thermal-hydraulic conditions during high mass and energy releases. The Outage Pool is surrounded by the SGs compartments. This region is contained in its own CV as it is mostly separated from the other regions of the containment.

The space located below the operational floor and between the secondary shielding and the liner is separated in two annular control volumes. Although these external rings relate to the steam generator

compartments and the dome, the size of these connections is small respect to their free volume. This justifies the creation of separated CVs. Furthermore, splitting this region in two halves may allow representing the flow circulation between these regions. Differently to the PWR-KWU, two CVs containing the stairs located on the sides were added (see figure 32, right). Staircases could work as a fluid transport path from bottom the bottom of the containment to the top, above the operational floor (see figure 33). Consequently, these CVs will allow to represent this behaviour on the lumped parameter model. Finally, as it was explained in 3.2.1.1 and 3.2.2.2, to separate the spaces below and above the operational floor, a final CV is added to the model, representing the volume over the operational slab (see figure 34). The dome contains the largest fraction of the containment free volume.

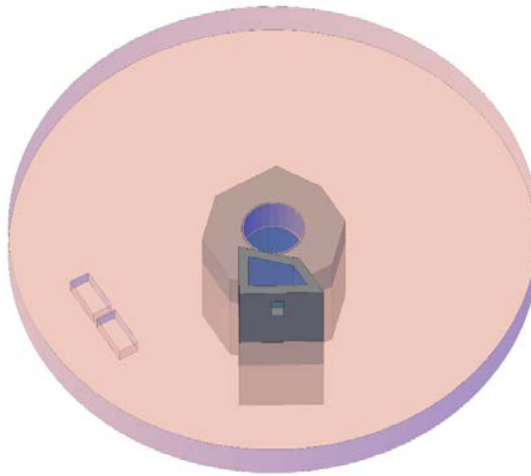


Figure 31 Isometric view of the cavity control volume in the PWR-W containment

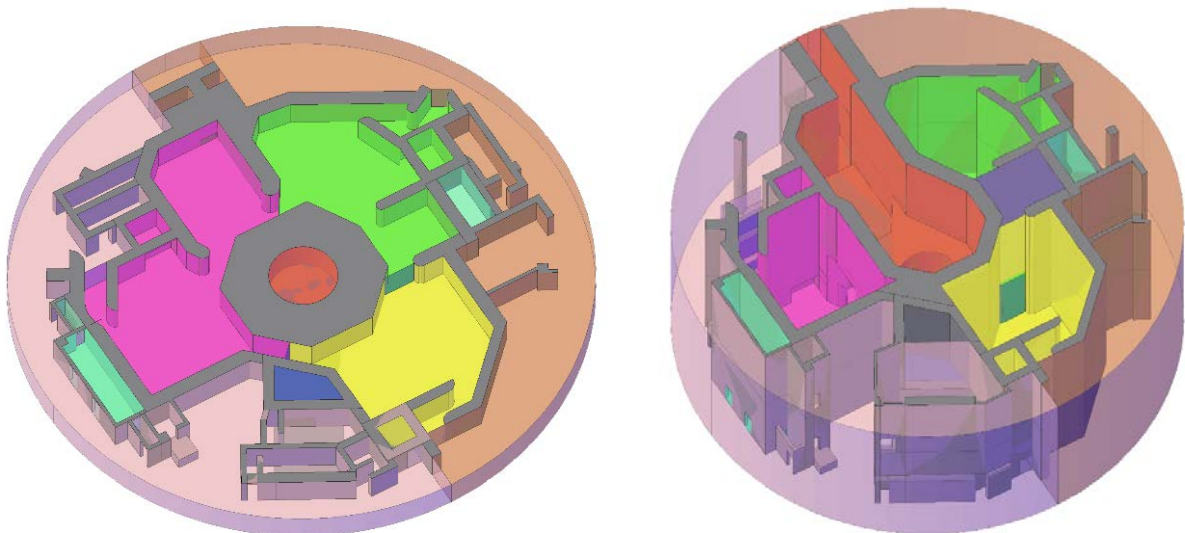


Figure 32 Isometric views of the control volumes for the PWR-W geometry. The bottom view (left) and the top view (right) show that the space is separated respecting the different regions naturally located in the containment.

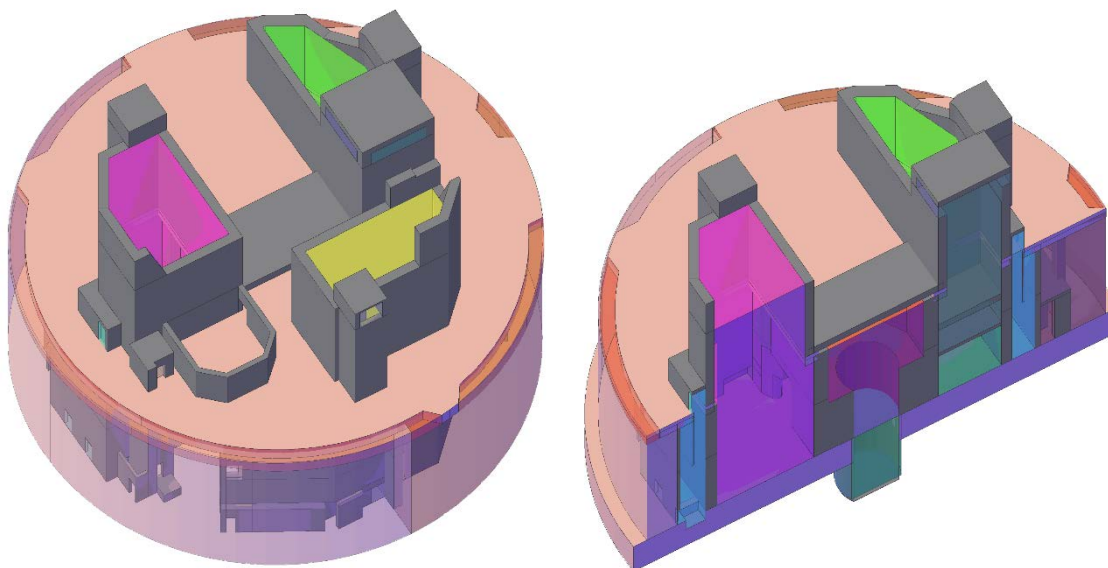


Figure 33. Isometric view of the control volumes above the operational floor for the PWR-W geometry and a cutaway of the full lumped parameter model.

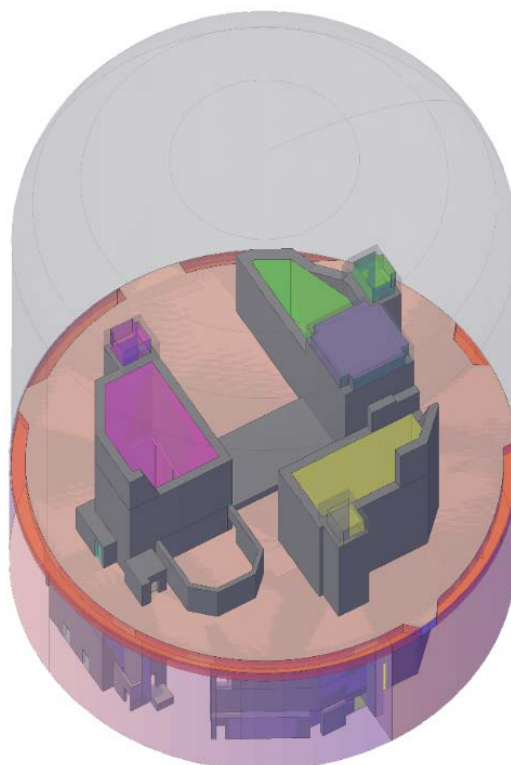


Figure 34. Isometric view of the PWR-W with the Dome CV.

3.2.2.2 PWR-W Junctions

The generic containment zones are connected by means of 32 junctions between CVs. Table 8 gathers all information relative to these junctions. The same criteria used for the PWR-KWU was used to determine these connections. For vertical and horizontal junctions, an equivalent circular area is given as the flow path effective cross section area. For vertical junctions, an effective height is provided, being the difference between its highest elevation in the target zone and the lowest one in the start zone (elevations are extracted from the blockages in the detailed model). Also, for horizontal junctions, a minimal default length is provided (based on local concrete thickness).

Another relevant physical information gathered in Table 8 is the resistance loss coefficient defined for each junction. This coefficient is dependent on flow direction, so a +/- mark will indicate the positive and negative flow directions if the values are different. The methodology followed for deriving the loss coefficient factors is explained in Section 2.1 of this document. The identification of junctions follows the same rules as in PWR-KWU (see Section 3.1.2.2).

3.2.2.3 PWR-W Heat Structures

To capture the total heat capacity and the heat transfer area of all concrete and steel surfaces in the containment, 68 heat structures (HSs) have been identified. Table 9 gathers the HS data, separating between floor and wall, concrete, and steel structures. For each HS label, the total heat transfer surface and the characteristic thickness (defined as total volume divided by total surface) is provided, together with the lowest elevation where the heat surface is present and the total height of that surface (integrated from the detailed 3D model). In general, the thickness provided is a characteristic value and does not correspond to a specific structure of the containment or to its specific elevation. This means that the product of thicknesses with the total areas provided gives the actual volume of material that correlates to that specific HS connection.

The methodology followed to extract the HS data by type of structure is explained in Annex A of this report, and some clarifications can be consulted in Section 3.1.2.3:

There is a special HS label for the thermal connections with the environment through the liner (see HSs with a -* mark at Side B column). The *liner* material type consist of a 1.157 m concrete thickness to which 6.5 mm of carbon steel are added (see Section 4. of this report for the material properties). Thus, in Table 9 only Side A area is given, which accounts for the liner surface inside the containment. If a code user needs to model the outer side surface (direct contact with the environment), the same area must be used.

In total, the following values of heat exchange surfaces are obtained for the PWR-W generic containment:

- Horizontal concrete surface: **3928 m²**
- Vertical concrete surface: **10060 m²**
- Horizontal steel surface: **1181 m²**
- Vertical steel surface: **10424 m²**
- Liner surface: **7754 m²**

3.2.2.4 PWR-W PAR layout

The PAR distribution inside the PWR-W Generic Containment zones is summarized in Table 10 and represented in Figures 35 to 38. PAR elevation refers to the global elevation of the PAR geometric centre, i.e., with respect to the containment coordinate system. Their geometrical features are summarized in Section 4.2 of this report. The PAR sizing and location is based on IAEA's recommendations (*Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants, TecDoc 1661, 2011*) [22]. Thus, 40 recombiners will be a priori implemented in the containment compartments. Two PAR types, Framatome FR-1500 and FR-960, will be used to achieve a representative global nominal recombination rate for this type of containment. Note that the PAR distribution in this generic containment may not represent the actual PAR placement in a nuclear power plant. It is merely a representative possible realization of a PAR system.

The recommendations to locate the PARs have been the following:

- Dead-end compartments should have a PAR.
- Several groups of N number of PARs are located in each elevation, one per loop (N-loop "symmetry"). For example, at a certain elevation, one PAR should be located in each one of the SG cages.
- Spaces close to H₂/CO releases have a higher number of PAR (RCS).
- Spaces where combustible gases may ascent to (i.e., the containment dome) shall be equipped with a higher number of PARs.

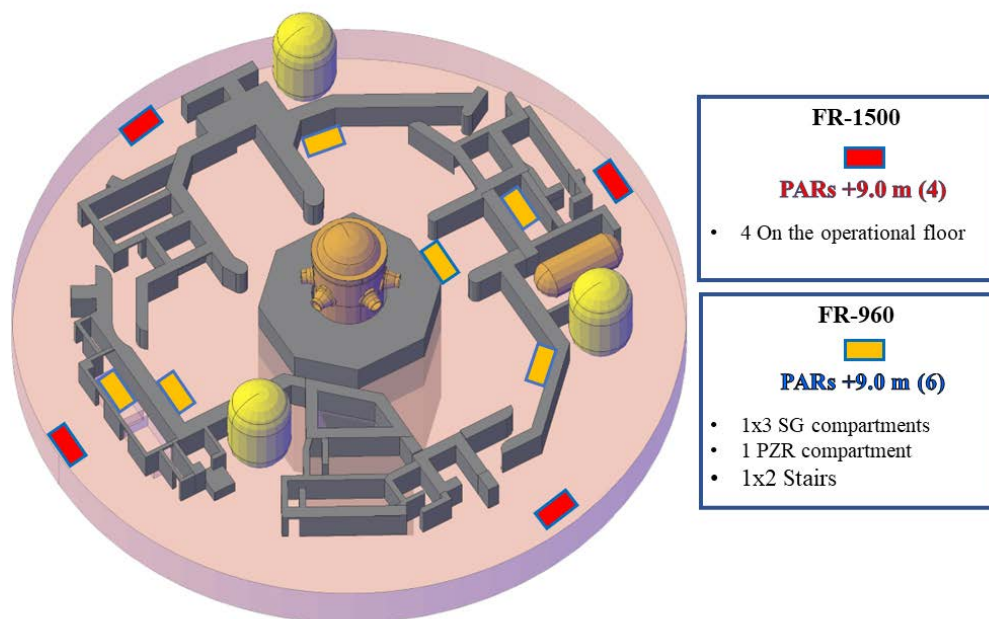


Figure 35. PWR-W PAR layout up to +42.8 m (1)

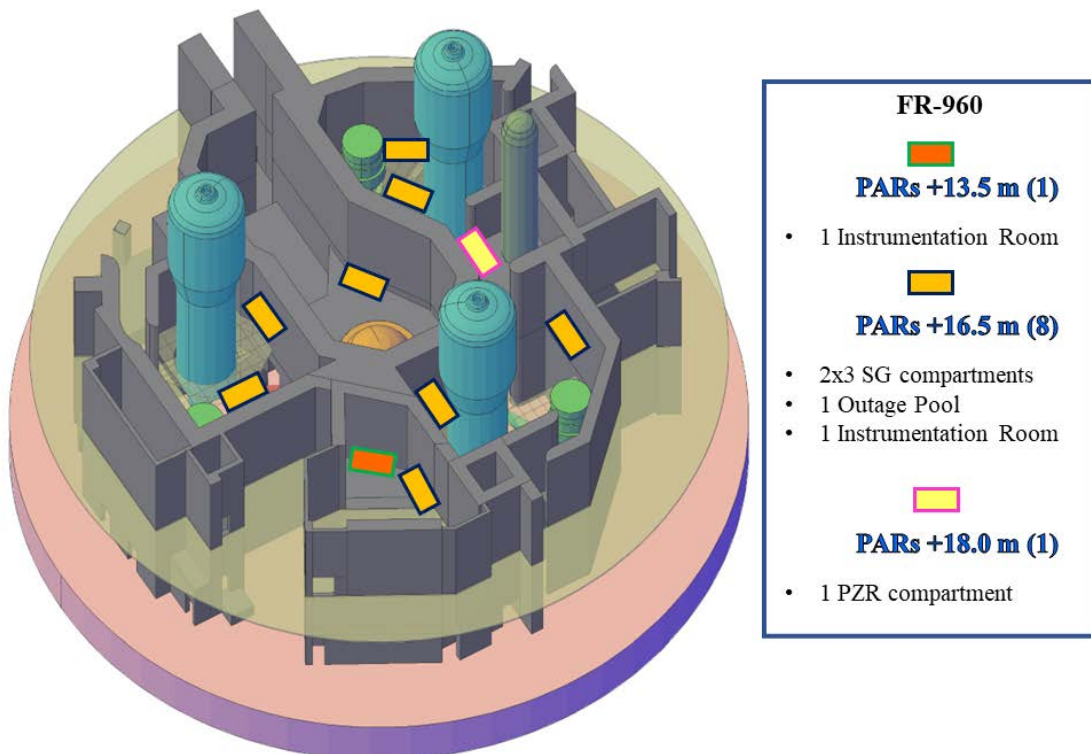


Figure 36. PWR-W PAR layout up to +42.8 m (2)

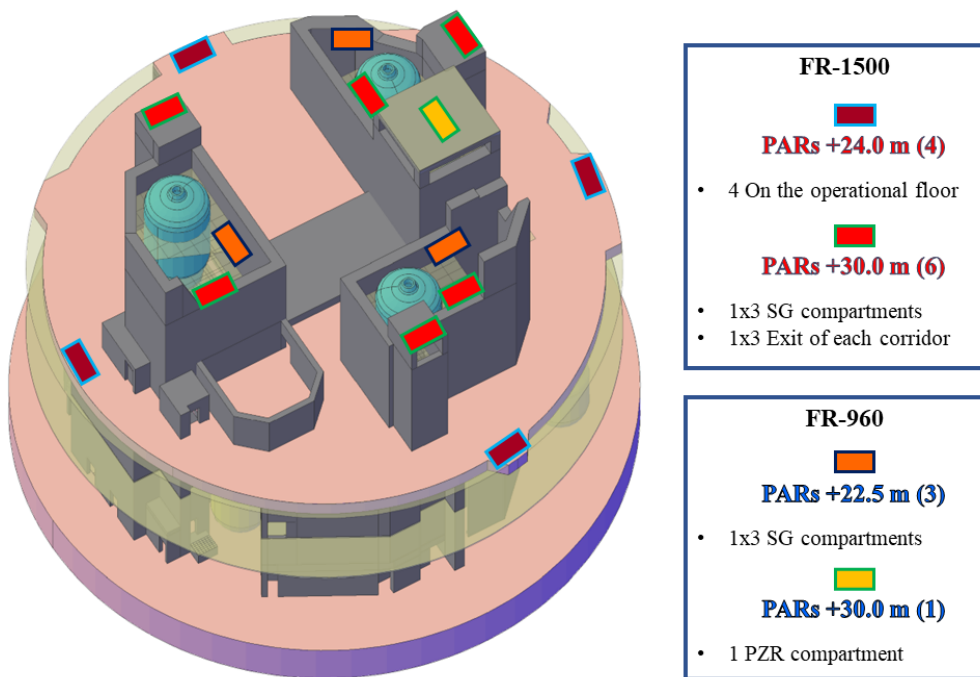


Figure 37. PWR-W PAR layout up to +60 m

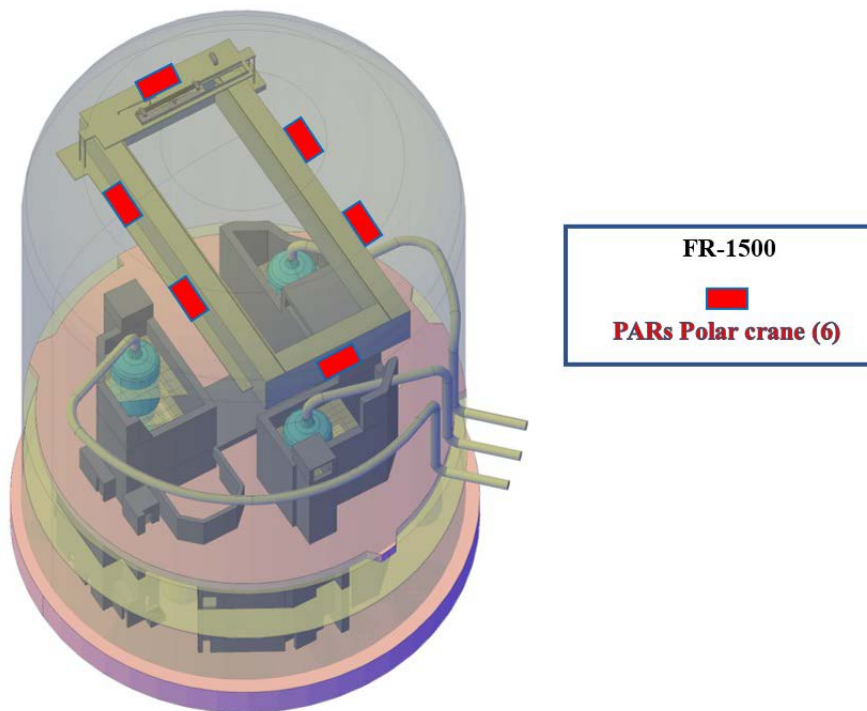


Figure 38. PWR-W PAR layout in polar crane region

Table 7. PWR-W: Generic containment control volumes

Zones	Id.	Free Volume	Base Elevation	Height	Top Elevation	Inner radius	Outer radius	Geometrical shape
		[m ³]	[m]					
CAVITY	1	775	-1.00	22.70	22.85		2.50	CYLINDER
SG-1	2	1469	7.50	22.35	29.85			PRISM SHAPE
SG-2	3	1717	7.50	24.35	31.85			PRISM SHAPE
SG-3	4	1906	7.50	24.35	31.85			PRISM SHAPE
ANN-E	5	3306	7.50	14.35	21.85	10.5	19.74	RING SHAPE
ANN-W	6	3458	7.50	14.35	21.85	10.5	19.74	RING SHAPE
PZR	7	411	7.50	25.85	33.35			CUBIC SHAPE
STAIRS-E	8	111	7.50	16.85	24.35			CUBIC SHAPE
STAIRS-W	9	218	7.50	16.85	24.35			CUBIC SHAPE
OP	10	1178	7.50	14.35	21.85			POOL
DOMES	11	46744	21.85	44.71	66.56		19.99	HEMISPHERE SHELL
TOTAL		61293						

Table 8. PWR-W: Junctions between control volumes

LP Junction	ID	Start Zone	End Zone	Circ. Area	Start Elevation	Target Elevation	Length (horizontal FLs)	Height	Loss coef ζ_R
				[m ²]	[m]				[-]
DOORS	J-1-6-01	CAVITY	ANN-W	2.21	13.65	13.65	0.75	2.00	7.00
GAP	J-1-10-01	CAVITY	FTP	2.47	7.50	7.50		0.01	3.00
GAP	J-1-2-01	CAVITY	SG-1	0.06	11.88	11.88	1.50	0.89	3.00
GAP	J-1-3-01	CAVITY	SG-2	0.06	11.88	11.88	1.50	0.89	3.00
GAP	J-1-4-01	CAVITY	SG-3	0.06	11.88	11.88	1.50	0.89	3.00
OPEN CONNECTION	J-2-3-01	SG-1	SG-2	12.78	10.23	10.23	1.00	5.45	2.50
OPEN CONNECTION	J-2-4-01	SG-1	SG-3	4.84	8.58	8.58	1.25	2.17	2.50
OPEN CONNECTION	J-2-5-01	SG-1	ANN-E	18.68	14.08	14.08	1.00	13.15	2.50
OPEN CONNECTION	J-2-7-01	SG-1	PZR	16.97	17.00	17.00	1.00	7.30	2.50
OPEN CONNECTION	J-2-11-01	SG-1	DOME	31.76	29.85	29.85		0.01	2.00
CHIMNEY	J-2-11-02	SG-1	DOME	4.00	29.26	29.26	0.40	1.50	2.05
OPEN CONNECTION	J-3-4-01	SG-2	SG-3	8.88	10.74	10.74	1.00	6.49	2.50
OPEN CONNECTION	J-3-5-01	SG-2	ANN-E	18.41	14.08	14.08	1.00	13.15	2.50
OPEN CONNECTION	J-3-7-01	SG-2	PZR	17.12	17.00	17.00	1.00	7.30	2.50
OPEN CONNECTION	J-3-11-01	SG-2	DOME	46.82	31.85	31.85		0.01	2.00
CHIMNEY	J-3-11-02	SG-2	DOME	4.00	29.26	29.26	0.40	1.50	2.05
OPEN CONNECTION	J-4-5-01	SG-3	ANN-E	0.89	7.82	7.82	0.46	0.64	

OPEN CONNECTION	J-4-6-01	SG-3	ANN-W	22.93	14.08	14.08	1.00	13.15	2.50
OPEN CONNECTION	J-4-11-01	SG-3	DOME	67.59	31.85	31.85		0.01	2.00
CHIMNEY	J-4-11-02	SG-3	DOME	4.00	29.26	29.26	0.40	1.50	2.05
CHIMNEY	J-7-11-01	PZR	DOME	28.10	32.60	32.60	0.75	1.50	1.50
OPEN CONNECTION	J-5-11-01	ANN-E	DOME	39.45	21.85	21.85		1.20	2.00
OPEN CONNECTION	J-6-11-01	ANN-W	DOME	63.74	21.85	21.85		1.20	2.00
DOORS	J-8-5-01	STAIRS-E	ANN-E	1.60	8.50	8.50	0.50	2.00	1.00
DOORS	J-8-5-02	STAIRS-E	ANN-E	1.54	15.61	15.61	0.50	1.93	1.00
DOORS	J-8-11-01	STAIRS-E	DOME	2.50	23.10	23.10	0.20	2.50	1.00
DOORS	J-9-6-01	STAIRS-W	ANN-W	1.60	8.50	8.50	0.25	2.00	1.00
DOORS	J-9-6-02	STAIRS-W	ANN-W	2.00	8.50	8.50	0.25	2.00	1.00
DOORS	J-9-6-03	STAIRS-W	ANN-W	2.00	8.50	8.50	0.25	2.00	1.00
DOORS	J-9-6-04	STAIRS-W	ANN-W	1.60	8.50	8.50	0.25	2.00	1.00
DOORS	J-9-11-01	STAIRS-W	DOME	2.50	23.10	23.10	0.20	2.50	1.00
GAP	J-10-11-01	OP	DOME	6.00	20.50	23.00		1.50	3.00

Table 9. PWR-W: Heat structures

Structure ID	Composition	Type	Side A	Side B	Side A Area (m ²)	Side B Area (m ²)	Thickness (m)	Volume (m ³)	Elevation (m)	Height (m)
CAV-01	CONCRETE	WALL	CAVITY	CAVITY	162.228	-	2.500	405.570	0.00	8.35
CAV-02	CONCRETE	WALL	CAVITY	SG2	35.068	35.068	0.713	25.013	7.50	13.88
CAV-03	CONCRETE	WALL	CAVITY	ANN-W	376.275	376.275	0.570	214.477	11.35	10.03
CAV-04	CONCRETE	WALL	CAVITY	ENVIRONMENT	92,457	-*	2,500	231.144	0.00	3.80
CAV-05	CONCRETE	FLOOR	CAVITY	CAVITY	218.161	-	1.315	286.858	-1.00	16.50
CAV-06	CONCRETE	FLOOR	CAVITY	ANN-W	53.345	53.345	0.850	45.344	10.50	0.85
CAV-07	CONCRETE	FLOOR	CAVITY	DOME	58.680	58.680	1.200	70.416	20.65	21.85
CAV-08	CONCRETE	FLOOR	CAVITY	ENVIRONMENT.	26,775	-*	2,500	66.938	3.80	1.15
SG1-01	CONCRETE	WALL	SG1	SG1	306.323	-	0.633	193.902	7.50	13.88
SG1-02	CONCRETE	WALL	SG1	ANN-E	320.085	320.085	0.681	218.100	7.50	13.88
SG1-03	CONCRETE	WALL	SG1	PZR	51.484	51.484	0.750	38.625	21.85	10.00
SG1-04	CONCRETE	WALL	SG1	DOME	273.831	273.831	0.723	197.998	21.85	10.00
SG1-05	CONCRETE	WALL	SG1	SG3	15.815	15.815	1.641	25.957	7.50	2.17
SG1-06	CONCRETE	WALL	SG1	PZR	55.277	55.277	0.695	38.420	7.50	13.88
SG1-07	CONCRETE	WALL	SG1	OP	74.547	74.547	1.239	92.397	14.65	6.73
SG1-08	CONCRETE	FLOOR	SG1	DOME	42.527	42.527	1.144	48.641	20.65	10.85
SG1-09	CONCRETE	FLOOR	SG1	ENVIRONMENT.	116,380	-*	3,360	391.037	4.14	3.36
SG1-10	GRATING	WALL	SG1	SG1	1187.670	-	0.005	5.938	11.80	17.25
SG2-01	CONCRETE	WALL	SG2	SG2	363.878	-	0.727	264.499	7.50	13.88
SG2-02	CONCRETE	WALL	SG2	ANN-W	15.906	15.906	0.475	7.558	7.50	13.88
SG2-03	CONCRETE	WALL	SG2	OP	44.728	44.728	1.239	55.438	14.65	6.73
SG2-04	CONCRETE	WALL	SG2	DOME	403.495	403.495	0.698	281.545	21.85	10.00
SG2-05	CONCRETE	FLOOR	SG2	DOME	46.730	46.730	1.162	54.312	20.65	10.85
SG2-06	CONCRETE	FLOOR	SG2	ENVIRONMENT.	101,360	-*	3,360	340.570	4.14	3.36
SG2-07	GRATING	WALL	SG2	SG2	1253.577	-	0.005	6.268	11.80	17.25

SG2-08	CONCRETE	WALL	SG2	ANN-E	188.868	188.868	0.828	156.460	7.50	13.88
SG3-01	CONCRETE	WALL	SG3	SG3	327.223	-	0.966	316.229	7.50	13.88
SG3-02	CONCRETE	WALL	SG3	ANN-W	472.812	472.812	0.859	406.025	7.50	13.88
SG3-03	CONCRETE	WALL	SG3	OP	112.666	112.666	1.159	130.594	7.50	13.88
SG3-04	CONCRETE	WALL	SG3	DOME	512.279	512.279	0.608	311.582	21.85	10.00
SG3-05	CONCRETE	FLOOR	SG3	OP	52.161	52.161	1.062	55.417	9.67	4.32
SG3-06	CONCRETE	FLOOR	SG3	DOME	10.386	10.386	1.000	10.386	30.50	1.00
SG3-07	CONCRETE	FLOOR	SG3	ENVIRONMENT.	146,650	-*	3,360	492.744	4.14	3.36
SG3-08	GRATING	WALL	SG3	SG3	1207.913	-	0.005	6.040	11.80	17.25
ANN-E-01	CONCRETE	WALL	ANN-E	ANN-E	672.235	-	0.254	170.806	7.50	13.88
ANN-E-02	CONCRETE	FLOOR	ANN-E	ANN-E	39.603	-	0.200	7.921	12.80	0.40
ANN-E-03	CONCRETE	FLOOR	ANN-E	OP	58.144	58.144	1.334	77.574	8.14	3.18
ANN-E-04	CONCRETE	FLOOR	ANN-E	DOME	378.490	378.490	1.200	454.188	20.65	1.20
ANN-E-05	CONCRETE	FLOOR	ANN-E	ENVIRONMENT.	266,965	-*	3,360	897.002	4.14	3.36
ANN-E-06	LINER	WALL	ANN-E	ENVIRONMENT.	942,500	-*	1,157	1089.978	7.50	14.35
ANN-E-07	STEEL	WALL	ANN-E	ANN-E	175.929	-	0.040	7.037	7.50	7.00
ANN-E-08	GRATING	WALL	ANN-E	ANN-E	2230.744	-	0.005	11.154	15.10	6.05
ANN-E-09	CONCRETE	WALL	ANN-E	PZR	135.831	135.831	0.902	122.584	7.50	13.88
ANN-W-01	CONCRETE	WALL	ANN-W	ANN-W	737.724	-	0.213	156.990	7.50	13.88
ANN-W-02	CONCRETE	WALL	ANN-W	OP	104.365	104.365	1.239	129.356	14.65	6.73
ANN-W-03	CONCRETE	FLOOR	ANN-W	ANN-W	48.084	-	0.200	9.617	10.85	0.40
ANN-W-04	CONCRETE	FLOOR	ANN-W	DOME	388.290	388.290	1.200	465.948	20.65	1.20
ANN-W-05	CONCRETE	FLOOR	ANN-W	ENVIRONMENT.	299,175	-*	3,360	1005.228	4.14	3.36
ANN-W-06	LINER	WALL	ANN-W	ENVIRONMENT.	942,500	-*	1,157	1089.978	7.50	14.35
ANN-W-07	STEEL	WALL	ANN-W	ANN-W	87.965	-	0.040	3.519	7.50	7.00
ANN-W-08	GRATING	WALL	ANN-W	ANN-W	2780.727	-	0.005	13.904	15.10	6.05
PZR-01	CONCRETE	WALL	PZR	DOME	159.416	159.416	0.778	124.046	21.85	10.00
PZR-02	CONCRETE	WALL	PZR	OP	29.819	29.819	1.239	36.959	14.65	6.73

PZR-03	CONCRETE	FLOOR	PZR	PZR	100.166	-	0.300	30.050	12.95	4.35
PZR-04	CONCRETE	FLOOR	PZR	DOME	38.226	38.226	0.788	30.135	31.85	2.20
PZR-05	GRATING	WALL	PZR	PZR	767.236	-	0.005	3.836	22.60	8.35
STAIRS-E-01	CONCRETE	WALL	STAIRS-E	STAIRS-E	74.350	-	0.144	10.742	7.50	14.35
STAIRS-E-02	CONCRETE	FLOOR	STAIRS-E	STAIRS-E	82.320	-	0.299	24.626	7.50	14.35
STAIRS-E-03	CONCRETE	FLOOR	STAIRS-E	ENVIRONMENT.	9,640	-*	3,360	32.390	4.14	3.36
STAIRS-W-01	CONCRETE	WALL	STAIRS-W	STAIRS-W	107.418	-	0.100	10.742	7.50	14.35
STAIRS-W-02	CONCRETE	FLOOR	STAIRS-W	STAIRS-W	143.872	-	0.171	24.626	7.50	14.35
STAIRS-W-03	CONCRETE	FLOOR	STAIRS-W	ENVIRONMENT.	6,150	-*	3,360	20.664	4.14	3.36
STAIRS-W-04	GRATING	WALL	STAIRS-W	STAIRS-W	280.237	-	0.005	1.401	9.30	0.05
OP-01	CONCRETE	FLOOR	OP	OP	68.500	-	2.335	159.933	10.75	3.24
DOME-01	CONCRETE	WALL	DOME	DOME	451.544	-	0.214	96.830	21.85	14.50
DOME-02	LINER	WALL	DOME	ENVIRONMENT.	5869,070	-*	1,106	6488.561	21.85	44.71
DOME-03	STEEL	FLOOR	DOME	DOME	1181.000	-	0.150	177.150	49.25	4.44
DOME-04	GRATING	WALL	DOME	DOME	452.155	-	0.005	2.261	22.60	0.05

* For HSs connecting with the environment, only side A area is given, accounting for the surface inside the building. In case the surface in contact with the environment wants to be simulated, the same area must be used.

Table 10. PWR-W: PAR layout

Zones	PAR type	Number of PARs	PAR Elevation [m]
CAVITY	FR-960	2	+13.5 (1) +16.5 (1)
SG-1	FR-1500	2	+30.0 (2)
	FR-960	4	+9.0 (1) +16.5 (2) +22.5 (1)
SG-2	FR-1500	2	+30.0 (2)
	FR-960	4	+9.0 (1) +16.5 (2) +22.5 (1)
SG-3	FR-1500	2	+30.0 (2)
	FR-960	4	+9.0 (1) +16.5 (2) +22.5 (1)
ANN-E	FR-1500	2	+9.0 (2)
ANN-W	FR-1500	2	+9.0 (2)
PZR	FR-960	3	+9.0 (1)
			+18.0 (1)
			+30.0 (1)
STAIRS-E	FR-960	1	+9.0 (1)
STAIRS-W	FR-960	1	+9.0 (1)
O.P.	FR-960	1	+16.5 (1)
DOME	FR-1500	10	+24.0 (4)
			+ 50.5 (6)

3.3 PWR-VVER generic containment

The containment built for the PWR-VVER model corresponds to a 1000 MW_e V320-type reactor. It contains four RCS loops enclosed and a cylindrical steel liner, which is surrounded by a concrete building. The details on the internal parts of the containment can be consulted in Annex C, which contains a collection of public layouts. An official review of the 3D model was performed by LLC ENERGORISK, from which some geometrical adjustments were made.

3.3.1 PWR-VVER 3D CAD model construction

Prior to the construction of the different containment floors and walls, the main structures that form the containment boundaries are built within CAD (see Figure 39). These architectural elements are modelled to separate spaces and to select and implement a coordinate reference for the model. All dimensions are extracted from the different cross-section and floor plans, extracted from public domain.

The VVER-1000 V320 containment consists of a cylindrical concrete building closed by an elliptical dome. This cylinder has an inner diameter of 45.05 m and a thickness of 1.47 m (slightly thicker at the personnel hatches that penetrate the containment, found at +19.2 and +36.9 m elevations). Dome's altitude reaches 66.45 m, and its concrete thickness is 1.1 m (1.9 m average considering the concrete crown at its base). The foundation concrete slab, that serves as "zero ground" point, has a thickness of 2.4 m and ends at +13.2 m elevation. Inside the cylinder, a cylindrical steel liner encloses all the containment's free volume. The liner then is the first structural barrier, being separated from the cylindrical concrete wall by an air gap of approximately 0.27 m and having a steel thickness of 8 mm.

Then, inside the liner, all the Nuclear Steam Supply Systems are modelled throughout the different levels that form the containment. Neither outer auxiliar compartments nor basement levels are modelled.

Once the main containment elements were built and the isometric axes were placed, the bottom-to-top and level-by-level construction process began. Height zero is placed at the centre of +13.2 m concrete slab (foundation), beneath the RPV compartment.

To facilitate the comprehension of the model and the distribution of compartments, a level-by-level portrayal of the construction is presented at the sub-sections below (from 3.3.1.1 to 3.3.1.6). The construction has mainly relied upon seven floor plan views, while the equipment has been mainly built based on the data extracted from auxiliar layouts. In the 3D model, grating surfaces are of a dark yellow transparent hue, while steel surfaces are of light grey colour.

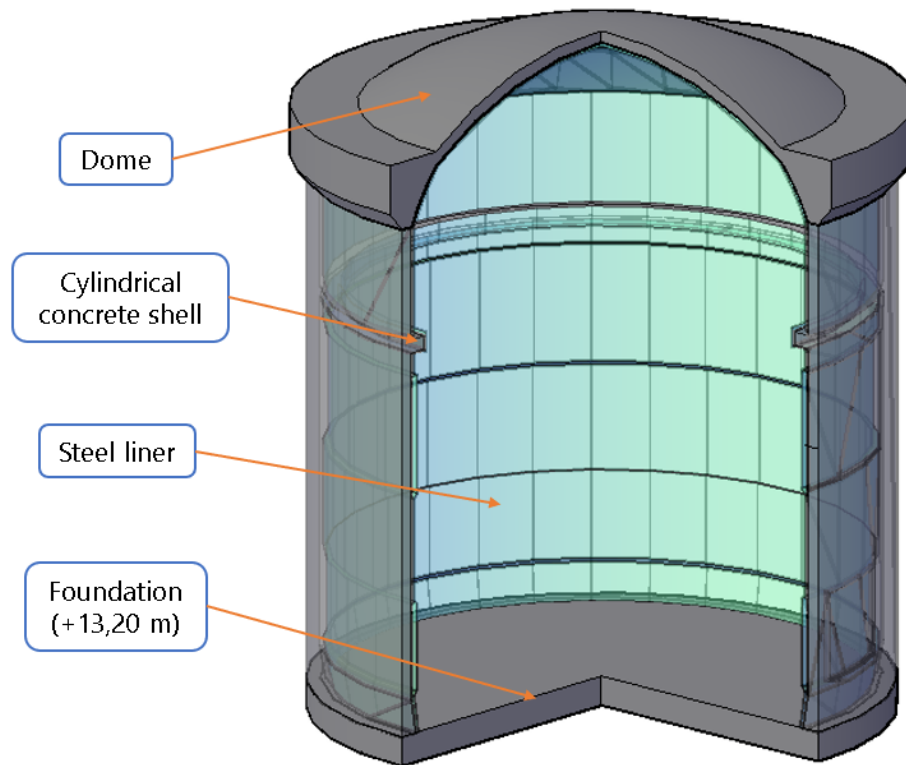


Figure 39. Main containment structures of the PWR-VVER 3D CAD model

3.3.1.1 First level: +13.20 meters elevation

Over the foundation slab, a sump floor of 0.4 m thickness is elevated. From this floor, all walls from this first level are extruded up to +16.5 m. At the centre, the reactor cavity is lifted, and a channel is opened towards the RPV inspection equipment room. The RPV well has a higher floor, as well as in the case of the well of the reactor internals revision pool (heavy concrete floor). Surrounding the RPV, several rooms start to develop: elevator cavity and machine compartments, MCP oil tank compartment, pipelines and valves compartments, I&C rooms, transport hatch, ventilation systems, and filters-containers compartments. The maintenance system cranes and wagons are modelled, whereas several concrete columns and steel penetration pipes are lifted in the valves compartments. A corridor surrounds all the aforementioned rooms.

Figure 40 shows an aerial view of this first level, together with a coordinate reference (typical coordinates and VVER layout quadrants).

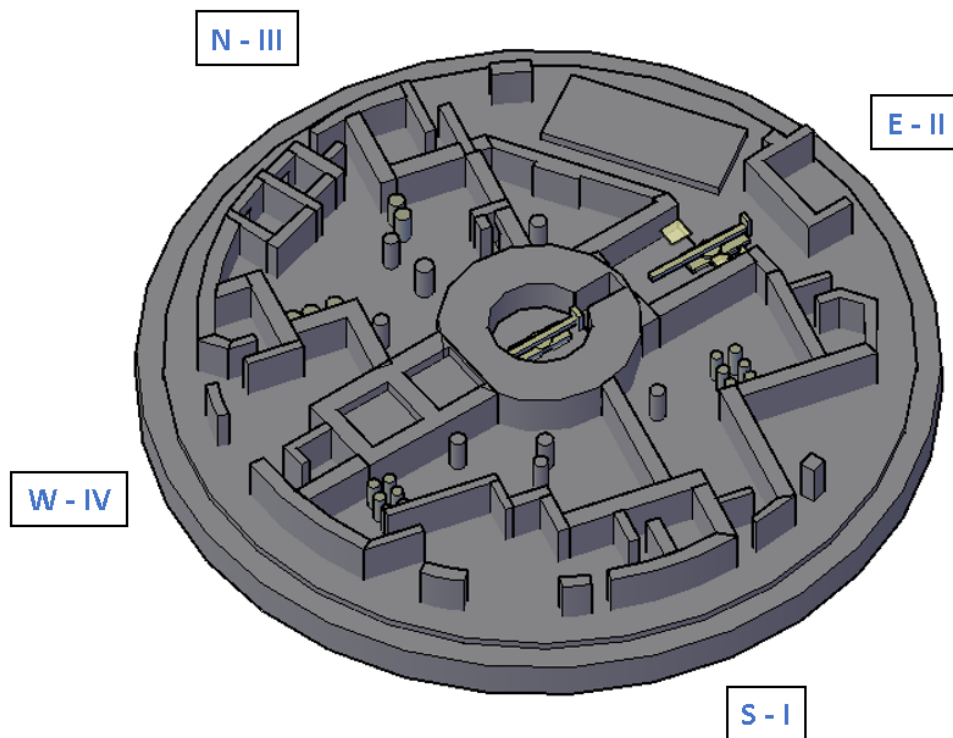


Figure 40. PWR-VVER+13.20 m level and coordinate references.

3.3.1.2 Second level: +16.50 meters elevation

The walls of the first level are re-extruded in this second floor towards the third level floor. Thus, the compartments listed in the first level, continue to be developed here. An important addition lies above the annular corridor, where another corridor floor serves as base for several cable penetration compartments. These compartments are sealed by fire protection doors and have concrete floor and ceiling, while the rest of the corridor is made of grating. No more concrete floors are encountered at this level, although some gratings are located at +16.00 m, supported by the valve compartment's columns. Figure 41 shows an aerial view of the second level, where the reactor vessel has been also included for reference.

3.3.1.3 Third level: +19.20 meters elevation

The floor of this level covers with concrete almost all the plan surface, where many new walls begin to be developed. Two concrete slabs with different thicknesses are lifted, the thicker being the one at the steam generator compartments and in the PZR compartment. Several openings pierce the floor that surrounds the main RCS compartments. These openings vary in size, from the small landings of the stairwells or the HVAC conduits penetrations, to bigger ones such as the transport hatch compartment

opening. Also, several gratings surround the annular floor. The cavity concrete shield, the spent fuel storage pool and the reactor internals revision pool, follow its development. Next to this last pool, the heat exchangers compartment is now present for the first time. Lastly, a personnel steel hatch is built at the north. Figure 42 shows an aerial view of the containment up to the third level. The ventilation fans are also visible at the ventilation system compartments (surrounding the RCS compartments).

3.3.1.4 Fourth level: +24.60 meters elevation

Walls of the third level are extruded up to +28.8 m, with slight modifications in some elevations in the inspection pool and in the RPV cylindrical shield. Some concrete floors are built in the annular corridor compartments, such as the pump's floors. Also, there are some openings with gratings at the corridor, (e.g., at the accumulators). At this level, the main equipment of the RCS is modelled, namely the steam generators, primary piping, pumps and pressurizer. Also, the main steam lines. The accumulators and the quench tank are modelled. Walls, floors, and equipment at this level are shown in Figure 43.

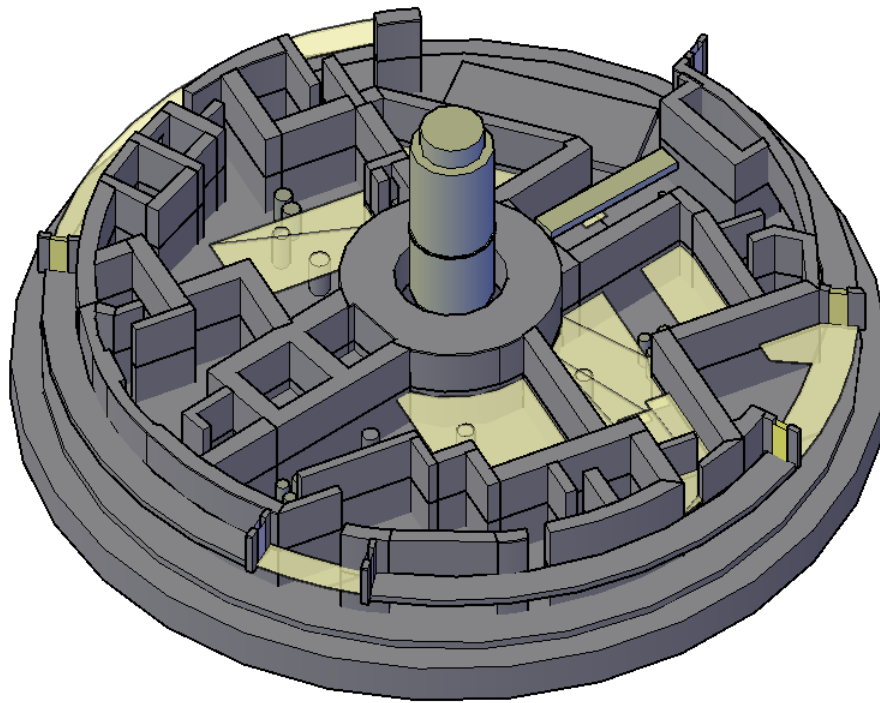


Figure 41. PWR-VVER +16.50 m level and reactor vessel

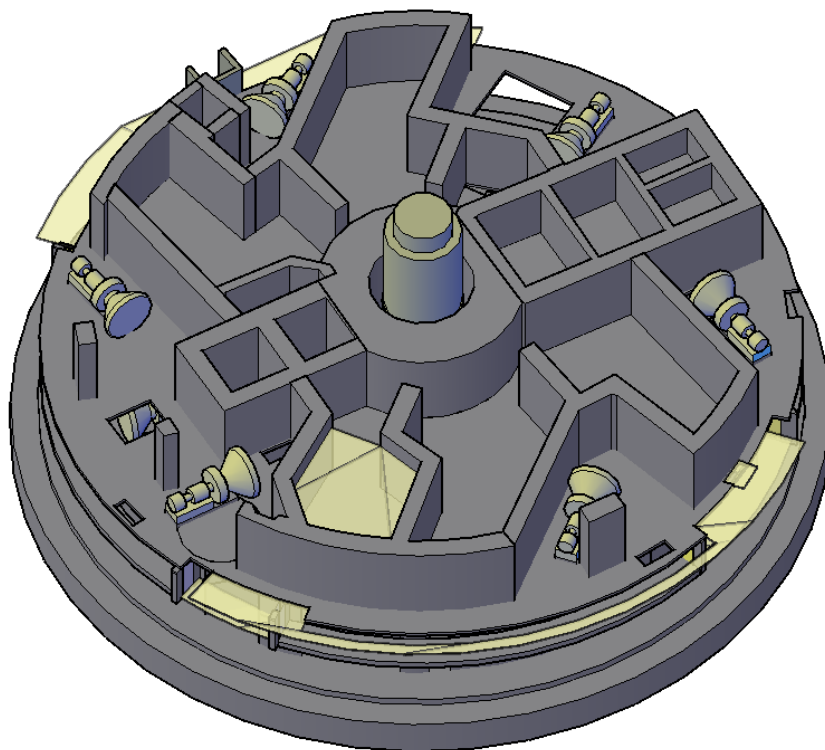


Figure 42. PWR-VVER +19.20 m level and ventilation fans

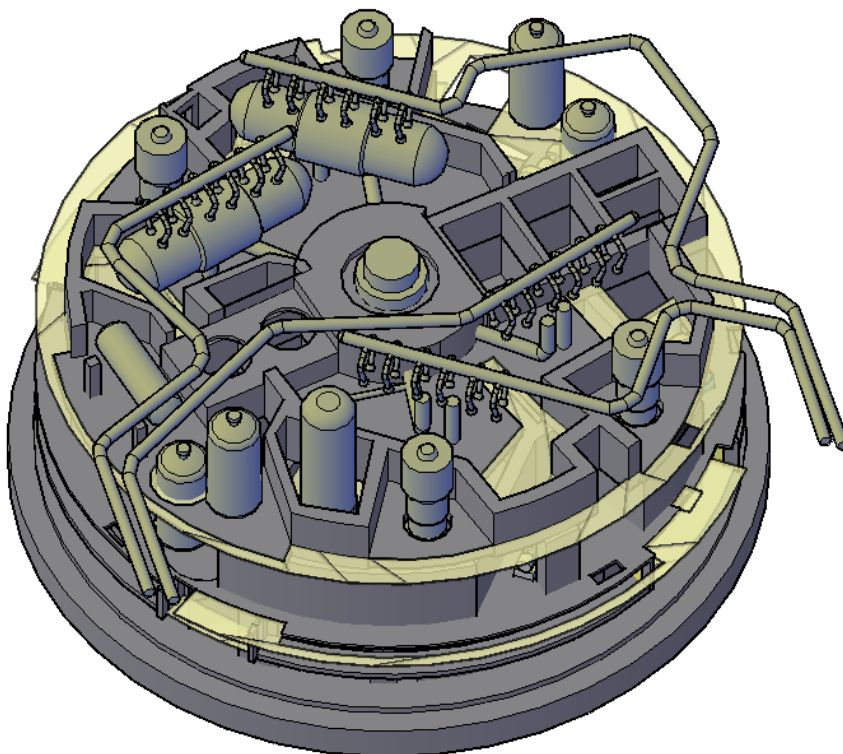


Figure 43. PWR-VVER +24.60 m level and RCS equipment

3.3.1.5 Fifth level: +28.80 meters elevation

At this level and up to the operational floor slab, the compartments housing the ECCS, MCP pumps and the SGs, are extruded with the shape of the fourth level walls. Nevertheless, several openings are performed in these walls, as shown in the detailed layouts. The pools and the cavity shield get their last change in geometry at this level. Two cable penetration corridor rooms, housing control rod instrumentation and reactor control instrumentation, are created. The refuelling-machine-rods-revision compartment is built adjacent to the southern one.

The cavity concrete cylinder has two doors leading to cable corridors with ex-vessel instrumentation. Next to the accumulators at quadrant IV, a concrete slab is built for the upper unit revision compartment. Figure 44 shows an aerial view of the containment up to this point.

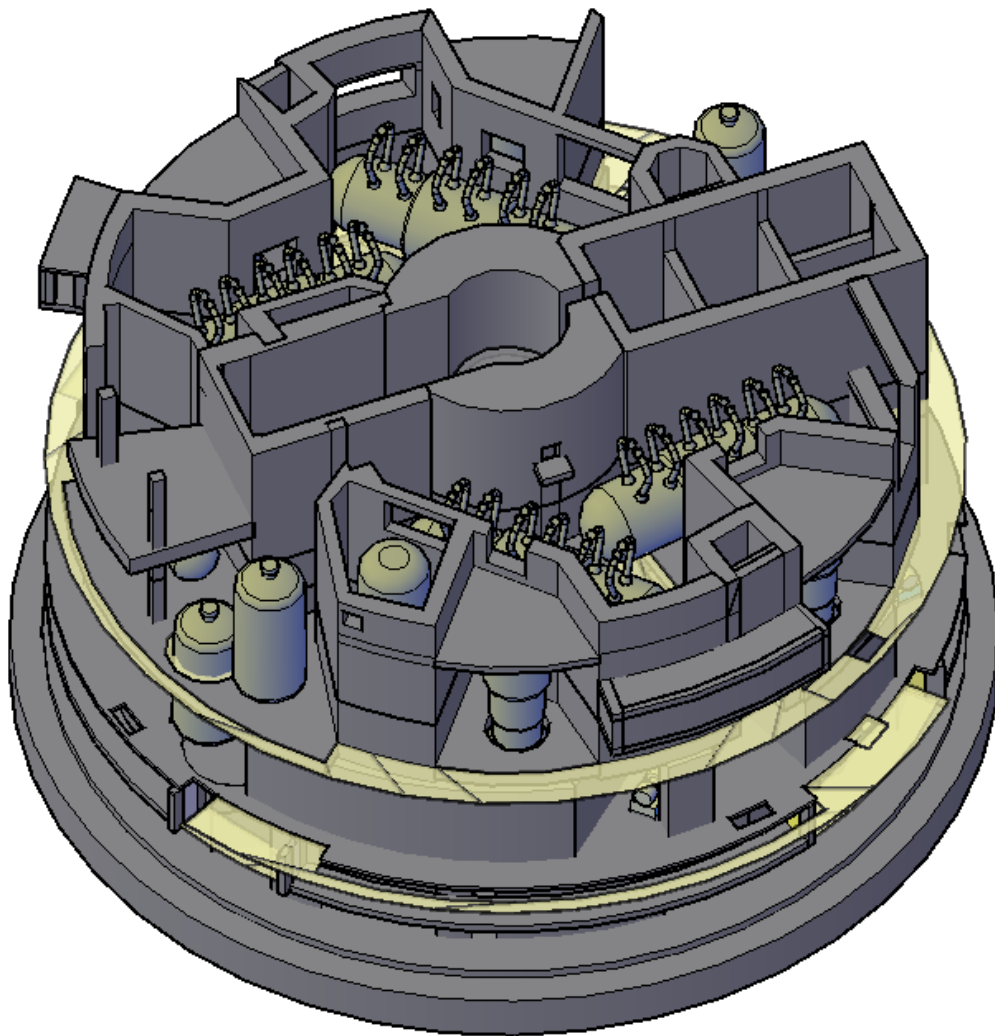


Figure 44. PWR-VVER +28.80 m level

3.3.1.6 Sixth level: +36.90 meters elevation

The last level of the containment corresponds to the operational (or service) floor deck. This floor has a 1 m thickness, starting at +35.90 m and ending at +36.9 m. Two small compartments rise at this elevation, housing the iodine and aerosol filters. Also, the elevator cavity compartment ends here. A personnel hatch is modelled at the north, having the same dimensions that the one found at +19.34 m. Moreover, three ventilation system fans are modelled at this elevation.

The operational floor has a particular shape. A considerable surface is made of grating and several openings allow to see floors at different levels. The pools are open to the dome volume and an annular gap separates the floor and the steel liner of the containment. Figure 45 shows the development of the containment up to this last level. Figure 46 shows the complete model, enclosed by the liner and the dome.

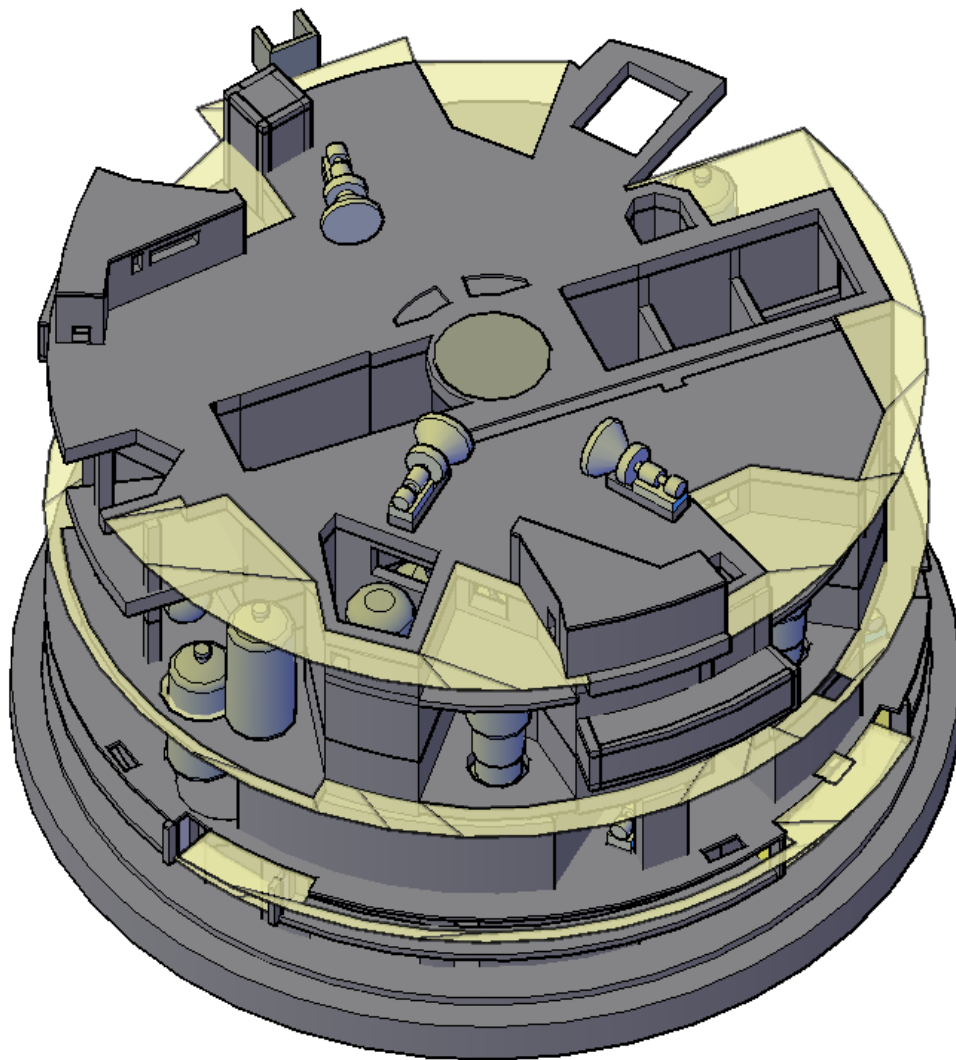


Figure 45. PWR-VVER +36.90 m level and operational floor

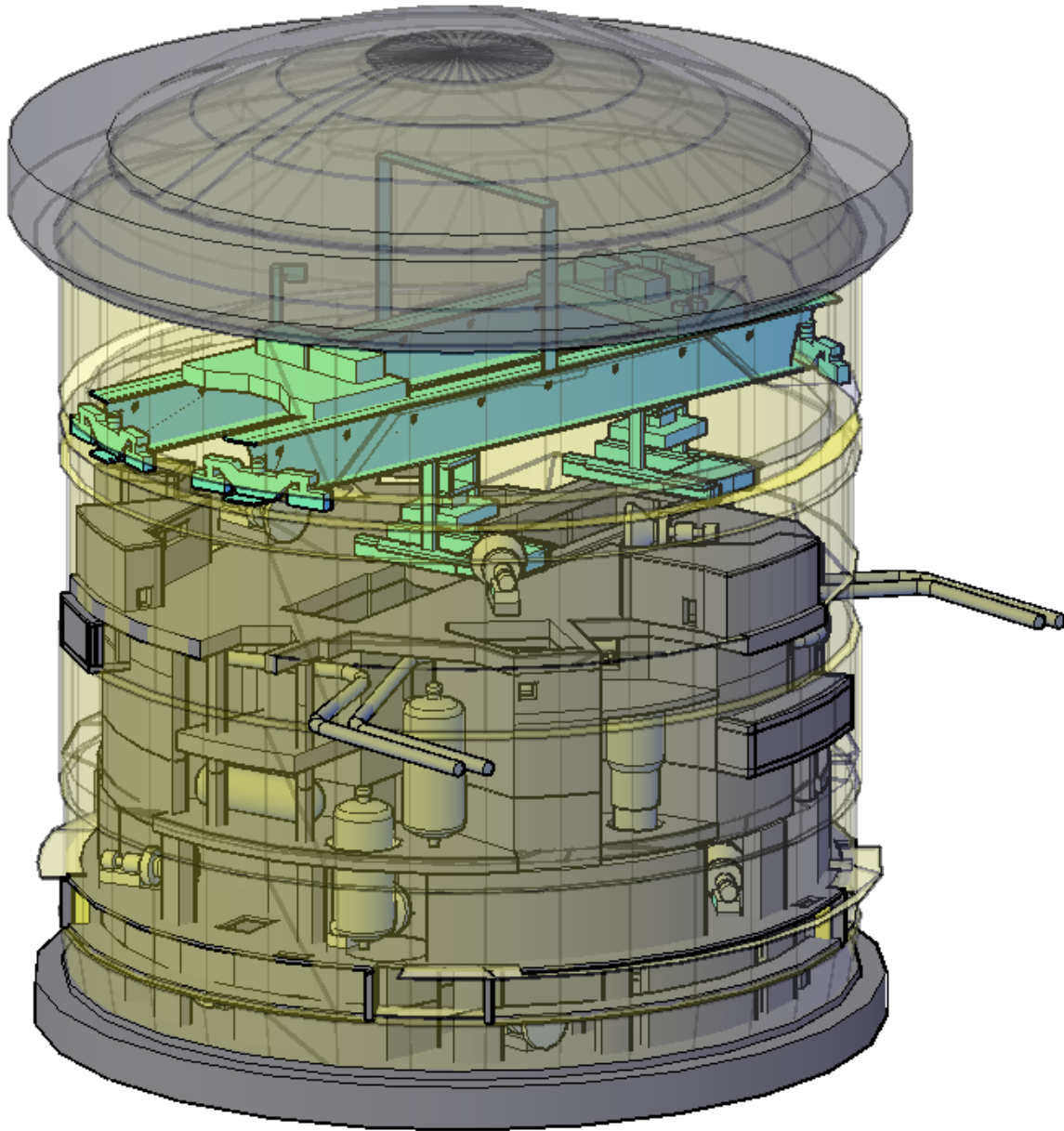


Figure 46. PWR-VVER full 3D model

3.3.1.7 Reactor Coolant System equipment

Figure 47 shows the Reactor Coolant System (RCS), consisting of the vessel, the steam generators, the pumps and the pressurizer. From their CAD model representations, the relevant steel information can be extracted, namely the surfaces. The steel thicknesses of the equipment could be extracted from references [10] [11]. Thus, the vessel thickness for a PWR-VVER-1000-V320 is 192.5 mm, the thickness of a SG is 105 mm at its minimum and 120 at its maximum (112.5 mm average), the PZR average thickness is 165 mm, the pumps' thickness is 185 mm on average, the accumulators' is 80 mm, the

pipes from the primary system have a thickness of 70 mm (with a 5 mm insulation), and the MSLs have a steel thickness of 25 mm.

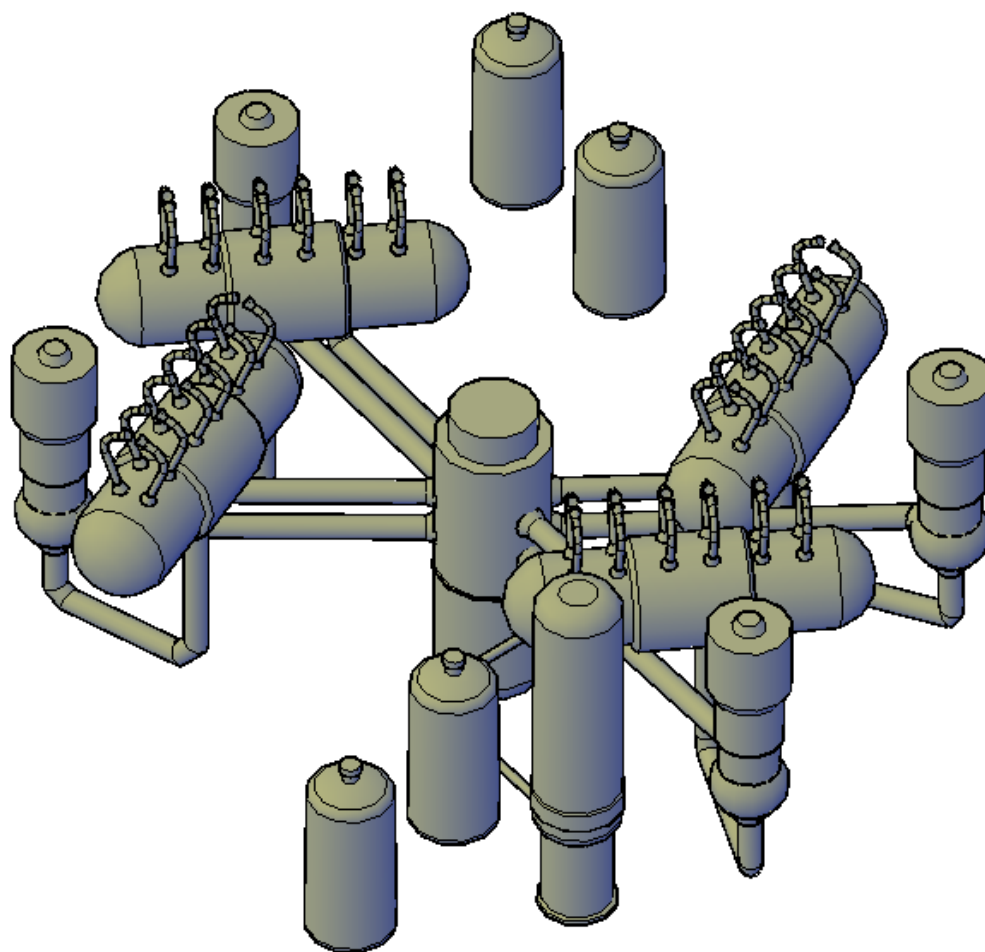


Figure 47. PWR-VVER RCS system and accumulators

3.3.1.8 Auxiliary equipment

Finally, the main cranes of the containment have been represented in the CAD model. Due to their steel mass these structures are relevant inside the containment. This auxiliary equipment consists of the SFP twin cranes, shown in Figure 48, and the polar crane, that can be seen in Figure 49. The average steel thickness of the cranes is extracted from references and compared to the volume-to-area ratio extracted from the CAD model, with positive results.

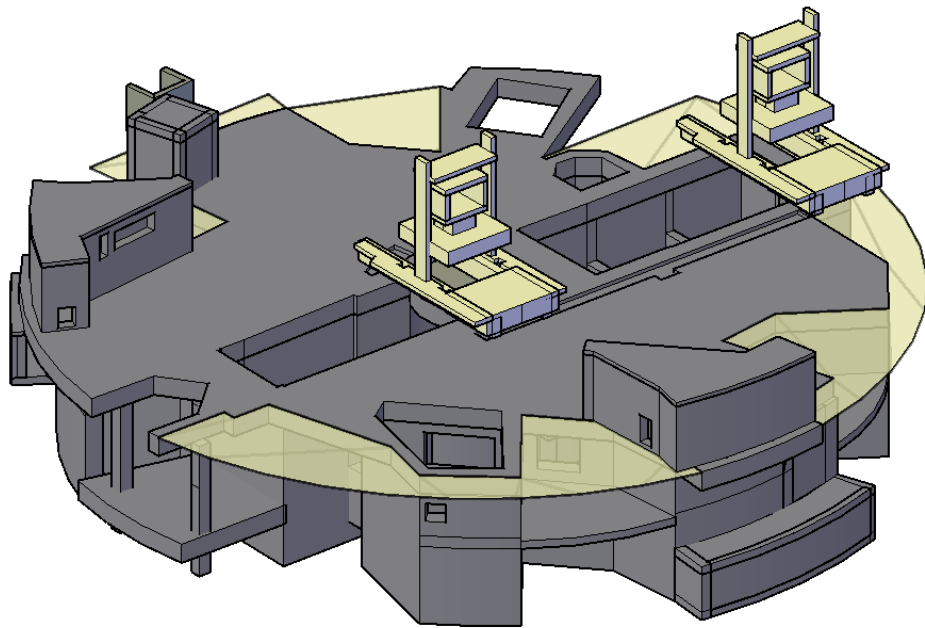


Figure 48. PWR-VVER fuel handling machine (in its maximal travel positions)

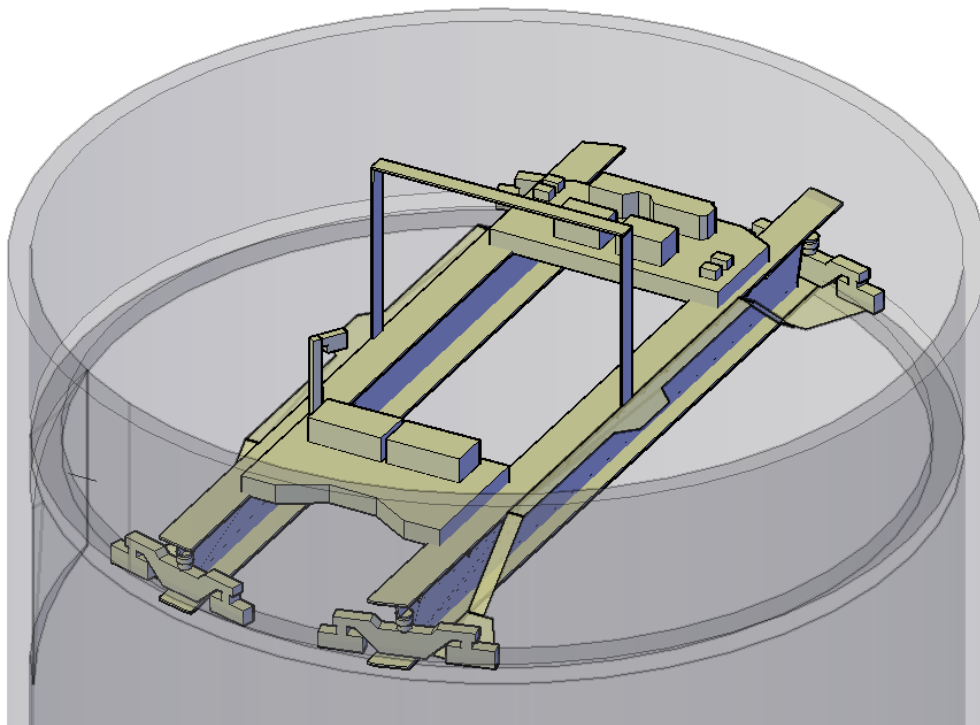


Figure 49. PWR-VVER polar crane

3.3.2 PWR-VVER LP nodalization and database

3.3.2.1 PWR-VVER Control Volumes

The rooms and compartments of the reactor containment building have been grouped into one control volume in order to generate a simple generic nodalization. The total free volume of the generic containment is **62223 m³**.

3.3.2.2 PWR-VVER Heat Structures

Table 11 gathers the Heat Structure (HS) data, separating between floor and wall, concrete and steel structures.

The thermal connection of the PWR-VVER containment with the environment consists of a concrete layer followed by an air gap and the containment liner (8 mm of carbon steel, see Section 4. of this report for the material properties). Only the steel liner is accounted for, and it is included under the 'Steel Vertical' total HS.

For each HS label, the effective heat transfer area and the characteristic thickness is provided. The methodology followed to extract the HS data is explained in Annex A. Gratings (walking grids) are included as a specific HS (its heat exchange is considered as wall type).

Table 11. PWR-VVER: Integrated heat structures

	Total Heat Transfer Area (m²)	Characteristic thickness (m)	Volume of material (m³)
Concrete_Horizontal	4405	0.669	2946.95
Concrete_Vertical	11290	0.601	6785.29
Steel_Horizontal	984	0.020	20.54
Steel_Vertical	9420	0.032	300.47
Steel_Vertical_Gratings	9537	0.005	47.68

4. MATERIAL PROPERTIES AND PAR SPECIFICATIONS

4.1 Containment material properties

In order to provide a common basis for the material properties, this section includes the concrete and steel specific heat capacity, conductivity and density for all PWR containments included in this report (see Tables 12 to 14). Steel properties are gathered from the publicly available MELCOR Manual [24]. For the steel liners, polar cranes, accumulators, and other equipment, the properties of carbon steel are considered. Also, we provide material properties for stainless steel, this is ONLY for parametric studies. For all analyses in WP4, carbon steel properties should be used.

For the concrete, as it is not a standardized material, a set of justifiable values which lay within a best-estimate range have been taken from accepted references [25] [26] [27]. The goal is to find a reasonable average property of high-strength high-reinforced concrete in NPPs. It is understood that many codes need tabulated values for the concrete properties, and not numerical correlations. It lies within the task of the simulating parties to generate the respective tables, most suitable for their used codes. An example concrete properties set is given in Table 12.

Concrete properties are specified in the following:

- Specific heat: bounding limits are extracted from EUROCODE 3.3.2 [25]. They do not consider moisture evaporation content (i.e., dry concrete) both for siliceous and calcareous aggregates:

$$c_p(T) = 900 \left[\frac{J}{kg \cdot ^\circ C} \right] \quad \text{for } 20^\circ C \text{ to } 100^\circ C$$

$$c_p(T) = 900 + (T - 100) \left[\frac{J}{kg \cdot ^\circ C} \right] \quad \text{for } 100^\circ C \text{ to } 200^\circ C$$

$$c_p(T) = 1000 + 0.5 * (T - 200) \left[\frac{J}{kg \cdot ^\circ C} \right] \quad \text{for } 200^\circ C \text{ to } 400^\circ C$$

$$c_p(T) = 1100 \left[\frac{J}{kg \cdot ^\circ C} \right] \quad \text{for } 400^\circ C \text{ to } 1200^\circ C$$

- Thermal conductivity: upper limits are extracted from EUROCODE 3.3.3. [25] to take into account the rebar content:

$$\lambda_c = 2 - 0.2451 * \left(\frac{T}{100} \right) + 0.0107 * \left(\frac{T}{100} \right)^2 \left[\frac{W}{m \cdot ^\circ C} \right] \quad \text{for } 20^\circ C \text{ to } 1200^\circ C$$

- Density: an upper limit value of $2500 \left[\frac{kg}{m^3} \right]$ is chosen (it is normally in the range of 2300 to 2500), as it has been studied that rebar content within concrete increase overall density. Density temperature dependency is ignored for easier interpretation of code-internal handlings.

Table 12. Material properties: Concrete

Properties	T [°C]	$c_p \left[\frac{kJ}{kg \cdot ^\circ C} \right]$	$\lambda \left[\frac{W}{m \cdot ^\circ C} \right]$	$\rho \left[\frac{kg}{m^3} \right]$
Concrete	0.00	0.90	2.00	2500.00
	20.00	0.90	1.95	2500.00
	40.00	0.90	1.90	2500.00
	60.00	0.90	1.86	2500.00
	80.00	0.90	1.81	2500.00
	100.00	0.90	1.77	2500.00
	120.00	0.92	1.72	2500.00
	140.00	0.94	1.68	2500.00
	160.00	0.96	1.64	2500.00
	180.00	0.98	1.59	2500.00
	200.00	1.00	1.55	2500.00
	240.00	1.02	1.47	2500.00
	280.00	1.04	1.40	2500.00
	320.00	1.06	1.33	2500.00
	360.00	1.08	1.26	2500.00
	400.00	1.10	1.19	2500.00
	500.00	1.10	1.04	2500.00
	600.00	1.10	0.91	2500.00
	700.00	1.10	0.81	2500.00
	800.00	1.10	0.72	2500.00
	900.00	1.10	0.66	2500.00
	1000.00	1.10	0.62	2500.00
	1100.00	1.10	0.60	2500.00
	1200.00	1.10	0.60	2500.00
	2000.00	1.10	0.60	2500.00
	5000.00	1.10	0.60	2500.00

Table 13. Material properties: Carbon steel

Properties	T [°C]	$c_p \left[\frac{kJ}{kg \cdot ^\circ C} \right]$	$\lambda \left[\frac{W}{m \cdot ^\circ C} \right]$	$\rho \left[\frac{kg}{m^3} \right]$
Carbon Steel	0.00	0.44	45.44	7752.90
	100.00	0.48	44.23	7752.90
	200.00	0.52	42.68	7752.90
	300.00	0.56	40.79	7752.90
	400.00	0.60	38.57	7752.90
	500.00	0.67	36.00	7752.90
	600.00	0.75	33.10	7752.90
	650.00	0.82	33.10	7752.90
	700.00	0.92	29.85	7752.90
	750.00	1.13	29.85	7752.90
	760.00	1.34	29.85	7752.90
	800.00	0.84	29.85	7752.90
	803.65	0.84	26.14	7752.90
	850.00	0.73	26.14	7752.90
	900.00	0.73	27.10	7752.90
	950.00	0.69	27.10	7752.90
	1000.00	0.69	28.10	7752.90
	1076.67	0.69	28.10	7752.90
	1100.00	0.69	29.10	7752.90
	1200.00	0.71	30.10	7752.90
	1300.00	0.72	31.10	7752.90
	1400.00	0.73	32.10	7752.90
	1500.00	0.74	33.10	7752.90
	1537.75	0.75	33.48	7752.90
	1537.76	0.75	33.48	7752.90
	4726.85	0.75	33.48	7752.90

Table 14. Material properties: Stainless steel 304

Properties	T [°C]	$c_p \left[\frac{kJ}{kg \cdot ^\circ C} \right]$	$\lambda \left[\frac{W}{m \cdot ^\circ C} \right]$	$\rho \left[\frac{kg}{m^3} \right]$
Stainless Steel 304	0.00	0.51	13.00	8025.00
	26.85	0.51	13.00	8025.00
	50.00	0.51	13.00	8003.00
	100.00	0.51	13.00	7981.00
	126.85	0.53	14.60	7981.00
	150.00	0.53	14.60	7958.00
	200.00	0.53	14.60	7936.00
	226.85	0.54	16.20	7936.00
	250.00	0.54	16.20	7914.00
	300.00	0.54	16.20	7891.00
	326.85	0.55	17.80	7891.00

	350.00	0.55	17.80	7869.00
	400.00	0.55	17.80	7847.00
	426.85	0.57	19.40	7847.00
	450.00	0.57	19.40	7824.00
	500.00	0.57	19.40	7802.00
	526.85	0.58	21.10	7802.00
	550.00	0.58	21.10	7780.00
	600.00	0.58	21.10	7757.00
	626.85	0.59	22.70	7757.00
	650.00	0.59	22.70	7735.00
	700.00	0.59	22.70	7713.00
	726.85	0.61	24.30	7713.00
	750.00	0.61	24.30	7690.00
	800.00	0.61	24.30	7668.00
	826.85	0.62	25.90	7668.00
	850.00	0.62	25.90	7646.00
	900.00	0.62	25.90	7623.00
	926.85	0.64	27.50	7623.00
	950.00	0.64	27.50	7601.00
	1000.00	0.64	27.50	7579.00
	1026.85	0.65	29.10	7579.00
	1100.00	0.65	29.10	7534.00
	1126.85	0.66	30.80	7534.00
	1200.00	0.66	30.80	7489.00
	1226.85	0.68	32.40	7489.00
	1300.00	0.68	32.40	7445.00
	1326.85	0.69	34.00	7445.00
	1400.00	0.69	34.00	7400.00
	1426.85	0.70	35.60	7388.00
	1426.86	0.80	17.80	6926.00
	1526.85	0.80	18.10	6862.00
	1626.85	0.80	18.50	6785.00
	1726.85	0.80	18.80	6725.00
	1826.85	0.80	19.10	6652.00
	1926.85	0.80	19.40	6576.00
	2026.85	0.80	19.80	6498.00
	2126.85	0.80	20.10	6416.00
	2226.85	0.80	20.40	6331.00
	2326.85	0.80	20.70	6243.00
	2426.85	0.80	21.10	6152.00
	2526.85	0.80	21.40	6058.00
	2626.85	0.80	21.70	5961.00
	2726.85	0.80	22.00	5861.00

4.2 PAR specifications

In this subsection the different PAR specifications are gathered, together with the public reference from which they are collected. In Figure 50, the dimensions of the PAR (as listed in Table 15, [28]) are defined.

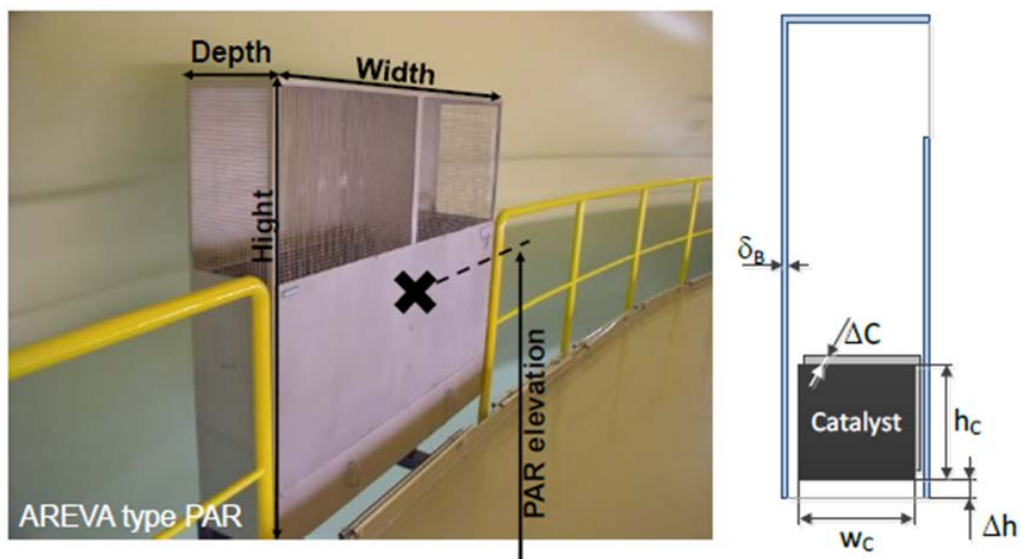


Figure 50. PAR geometric characteristics

Table 15. PAR specifications

RECOMBINER	Width (m)	Depth (m)	Height (m)	Number of plates	Area of plates (m ²)	Recombination rate (kg/h) *
FR90/1-1500	1.550	0.326	1.40	150	0.0392	5.36
FR90/1-960	1.010	0.166	1.00	96	0.0225	1.20

* The recombination rates were calculated from a flow of 4% H₂, 0% steam, with a pressure of 1.5 bar and an inlet temperature of 60°C.

5. FINAL REMARKS

The construction of databases for the simulation of three PWR containments has been the basis of this report. Having a common geometry and an agreed set of geometrical and thermophysical datasets, the user errors in the benchmarking of different code approaches can be minimized. Moreover, the methodologies used to extract all relevant data for the generic containment models, have been a priori defined to maintain coherence in the data extraction process. Also, the construction of detailed 3D CAD models has allowed to gather more accurate data, from more precise heat structure surfaces to the better definition of several junctions. Nevertheless, each containment still presents some uncertain parameters that need to be pointed out and studied in the future.

PWR-KWU

- Regarding the containment geometry, further insight in the HVAC conduits is needed. These connect some accessible and non-accessible regions, and a proper simulation of the ventilation system would require dedicated layouts to model it. Also, another part of the geometry that needs further refinement is the free volume of the sump region, namely below the +2 m floors, where containment sump pumps are allocated.
- Regarding the definition of junctions, the parameters of the relief flaps of the SGs need to be reviewed. Namely, the differential pressure at which they open is not homogeneous throughout the whole flap, as is now considered. Then, a realistic simulation of the flap opening in the first stages of the accidents would require a discretization of the junction domain, to account for the parts of the flap that will actually remain in position.
- Regarding the definition of pressure-sensitive doors for the 3D simulation models, the doors of the HVAC rooms or the anteroom hatches have not a well-defined opening pressure. Modellers will have to decide during WP4 if these doors remain open during the whole transients or if a differential pressure needs to be implemented in some of them to accurately represent the connections between compartments.

PWR-W

The geometry presented in this report is based on one specific PWR-W. It is important to note that, within this category, there are multiple designs with significant geometrical differences. Indeed, the partners of AMHYCO have used 2-loop, 3-loop, and 4-loops Western PWRs during WP2 for calculating the sequences that will be used during WP4. Nevertheless, the obvious separation of two zones in the containment space, above and below the operational floor, is a common feature of all the PWR-W designs. This shared geometrical characteristic might be enough to give some overall insights into the homogeneity/heterogeneity of the combustible gases' distribution in the PWR-W containments for

different sequences. The definition of a basic scaling process to adapt the sequences of the different designs to the 3-loops 3000 MWt PWR is a pending issue that should be addressed in WP4.

The scope of this report has been limited to the presentation of the main geometrical characteristic of the reference PWR-W. However, the calculations planned for WP4 require further information to model the safety systems of the containment (PAR, FCVSs, Spray, and Fan Coolers). The operating conditions of the safety systems will not use the characteristics of a specific design, but conditions as representative as possible for all the different types of PWR-W.

One particularity of the PWR-W used as a geometrical reference to build the CAD presented in this report is the safety concept of containment cooling since the cooling requirements are equally shared by the spray system and the fan coolers, class 1E safety systems. Unfortunately, there is not enough information available to configure the system in 3D models. Furthermore, the fan coolers are not class 1E safety system for other PWR-W designs. Therefore, the role of the coolers can be studied with the generic LP PWR-W model but not in 3D or CFD. To have appropriate comparisons between the three modelling approaches there will be two different specifications for the spray system: (i) a spray system designed to meet 50% of the cooling requirements (combined with the fan coolers); (ii) a spray designed to meet the 100% of the cooling requirements.

PWR-VVER

Further feedback is needed to characterize:

- The exact location and shape of some connections between compartments. Thus, a detailed list of CVs and junctions inside and between CVs is not provided in this report.
- A suitable and simplified nodalization scheme to provide a database of HS connecting different CVs and a PAR layout.

6. REFERENCES

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ANNEX A: Heat structure data extraction methodology

Data extraction: structure type 'I'

Under this type of structure, both metallic and concrete SSCs are included, and every face/side of the structures are assigned to the same CV. On one hand, concrete type 'I' SSCs that will be lumped into a single heat structure having an average thickness. For this reason, a proper characteristic thickness for the total area of concrete in the CV must be defined. On the other hand, metallic type 'I' surfaces, namely equipment components, must be characterized by its actual steel wall thickness (obtained from references), which multiplied by a realistic superficial area would bring a consistent steel volume in each CV.

Concrete columns

They are generally concrete support structures with usually four faces in contact with the fluid. Also, their heating profile is of heat sink. Thus, it is necessary to define a characteristic thickness to properly account for the column volumetric contribution to the total of structures in the same region. So, as all faces are included in the area calculation, the accounted thickness is a fraction of the real one (generally $\frac{1}{4}$ of the actual thickness). Figure A-1 shows an example of geometrical data extraction from a CAD column to an Excel file. The equations and the origin of the variables used, are respectively the following:

	A (m ²)	V (m ³)	t* (m)
Equation	$\sum_1^4 A_i$	V	$\frac{V}{\sum_1^4 A_i}$
Origin	CAD	CAD	analytical

Concrete blocks

These are concrete structures of larger volume and width located at the bottom of the containment. Considering their real volume would impact the calculation of a representative thickness of the walls in the same CV.

Figure A-2 shows an example of geometrical data extraction from a CAD concrete block to an Excel file, together with the equations and the origin of the variables used. In their calculation, to obtain a representative volume, first the block surfaces in contact with the fluid are extracted (yellow surfaces in Figure A-2). Then, the thicknesses and areas of neighbouring common walls are obtained to calculate a regional characteristic thickness (t*). If the thicknesses are extracted with the actual volumes of the blocks and the exposed block surface (both values from the CAD geometry), big thickness values would arise. For example, in Figure A-2, blocks #9 and #11 would have thicknesses of 4.91 and 4.99 m,

respectively. By using the areas and thicknesses of the neighbouring SSCs, thicknesses are lower and this way, thermal inertia in these regions will not be overestimated.

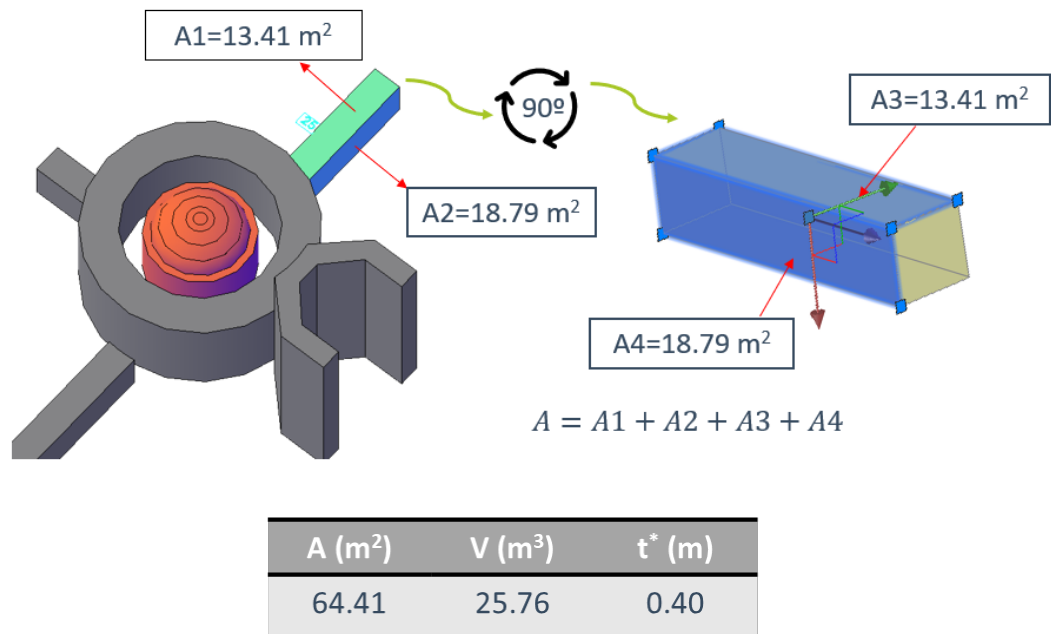


Figure A 1. Example of geometrical data extraction from a CAD column

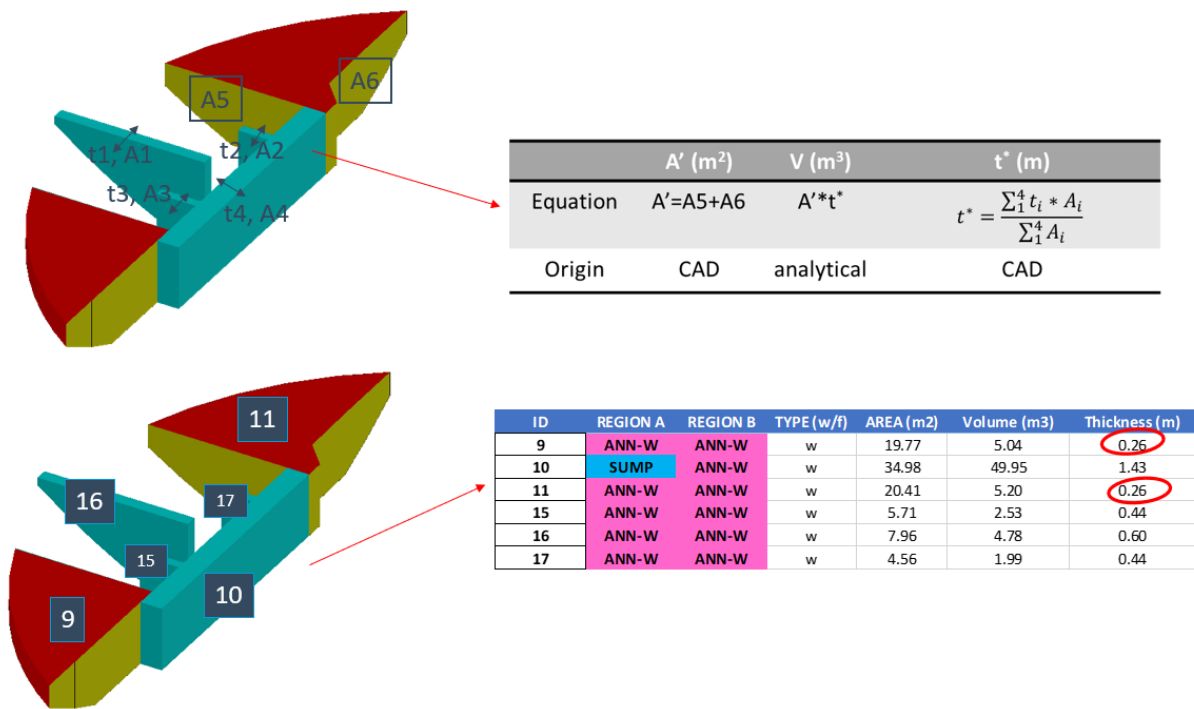


Figure A 2. Example of geometrical data extraction from a CAD concrete fin

Equipment

For equipment like the NSSS systems, accumulator, cranes, etc., and for metallic surfaces like hatches or banisters, it is necessary to a priori know the wall thickness to calculate a realistic steel volume. The only CAD exportable data in this case is the superficial equipment area. The thickness is obtained from references.

Data extraction: structure type 'G'

Under this label, gratings are characterized. In this wall type steel structures, the representative heat transference takes place when the fluid pass through the grid cells, so the area calculation must consider the inner steel faces. Thus, the geometrical characterization precise specific approaches. Based on the grating type, the equations and hypotheses used to calculate t , A and V will come from certain references. The only data that can be extracted from the layouts, and therefore from the CAD, is the cross-sectional area and the grating height (see Figure A-3).

To calculate realistic grating steel area and volume parameters, external references are employed [29]. Also, when defining the grating type, not only the grid nature is considered, but also the existence of the support structure. This is done using general recommendations on grating area and mass values provided by FRAMATOME GmbH.

Then, we need two sets of information to calculate the areas and volumes of grating grids. One is the geometrical information related to the grating structure, and the other is the geometrical characteristics of one cell contained inside the grating (see Figure A-4). To calculate the needed variables, ad-hoc equations are adapted from the references. It is also assumed that the grating and cell grid is square-shaped (width = length; $a = b$).

The general equation used to calculate grating steel area is the equation (4) (see below). Grating steel surface is the lateral cell area multiplied by the number of cells, while the spacing is the distance between cell centres (thus, this parameter includes the thickness). The equation used to calculate the grating volume is equation (6). Steel volume is calculated with the cell area, the grid thickness, the width, and the spacing. To avoid counting twice the volume of steel coming from the faces of adjacent cells (e.g., by multiplying $t \cdot A$ first at the left side and again on the cell at the right side), the total volume equation has been adapted.

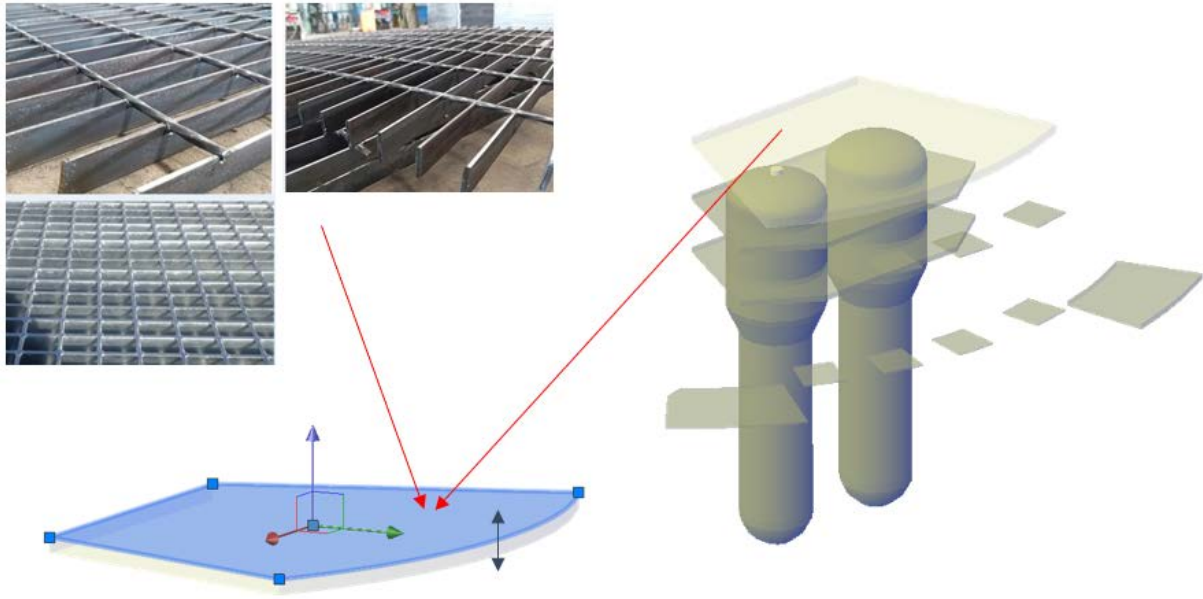


Figure A 3. Grating geometry

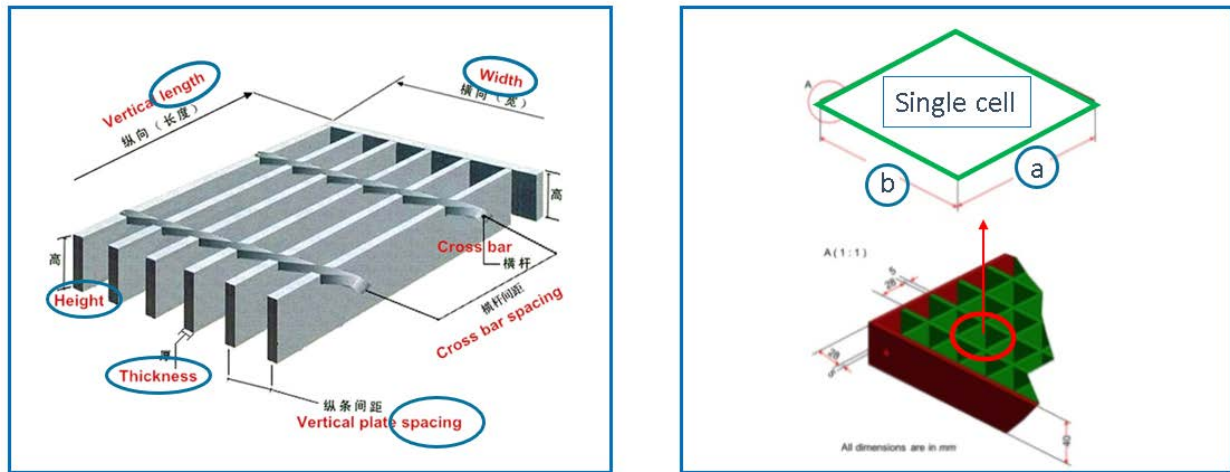


Figure A 4. Grating grid parameters

$$Area_{steel} = cell\ number * cell\ area \quad (1)$$

$$cell\ area = 4 * height * a \quad (2)$$

$$cell\ number = \frac{width}{spacing} * \frac{lenght}{spacing} = \frac{grating\ area}{spacing^2} \quad (3)$$

$$Area_{steel} = \frac{grating\ area}{spacing^2} * 4 * height * a \quad (4)$$

$$If\ spacing \cong a \rightarrow Area_{steel} = \frac{grating\ area}{a} * 4 * height \quad (5)$$

$$V_{steel} = \frac{Area_{steel}}{grating\ area} * spacing^2 * t * \left(3 + \frac{5}{2} \left(\frac{width}{spacing} - 2 \right) + \frac{1}{2} \left(\frac{width}{spacing} - 2 \right)^2 \right) \quad (6)$$

The previous equations are valid for box type gratings. Although KWU gratings are bar-rod type, we can use the same expression to estimate the grid area for bar-rod type gratings. That is, the area correlation between bar-rod and box types is 1:1. Nevertheless, this expression does not consider the area of the support structure of the bar-rod grid, so a factor $\approx *2$ is required to determine the total grating area for the bar rod type gratings. For the volume, the grid steel volume of a bar-rod type can be also calculated from the box type grating parameters. Once the support structure of the bar-rod type is considered, the total steel mass has a factor $\approx *4$, so the total grating volume of a bar-rod type can be calculated from the box type grating parameters. Then, the total grating steel area and volume of a bar-rod type can be calculated from the box type grating parameters by using the next equations:

$$Area'_{steel} \sim 8 * \frac{grating\ area}{a} * height \quad (7)$$

$$V'_{steel} \sim 4 * \frac{Area_{steel}}{grating\ area} * spacing^2 * t * \left(3 + \frac{5}{2} \left(\frac{width}{spacing} - 2 \right) + \frac{1}{2} \left(\frac{width}{spacing} - 2 \right)^2 \right) \quad (8)$$

Data extraction: structure type 'X'

These structures are characterized for separating fluid regions. To extract their data, the area of both faces is added up and the whole structure volume is obtained also from the CAD. Then, **the characteristic thickness is half of the actual CAD structure thickness**. Figure A-5 shows the equations used for extracting the data of a type 'X' structure, together with the origin of the parameters used and an example of these type of structures.

Each CV has many types of 'X' SSCs. Thus, to obtain the characteristic area and thickness of the floor and wall heat structures which encompass the 'X' structures in a CV, the following calculation is done:

$$Area_{CV} = \sum_1^n 2 * A_i \quad ; \quad Volume_{CV} = \sum_1^n V_i \quad ; \quad t^* = V_{CV} / A_{CV} \quad (9)$$

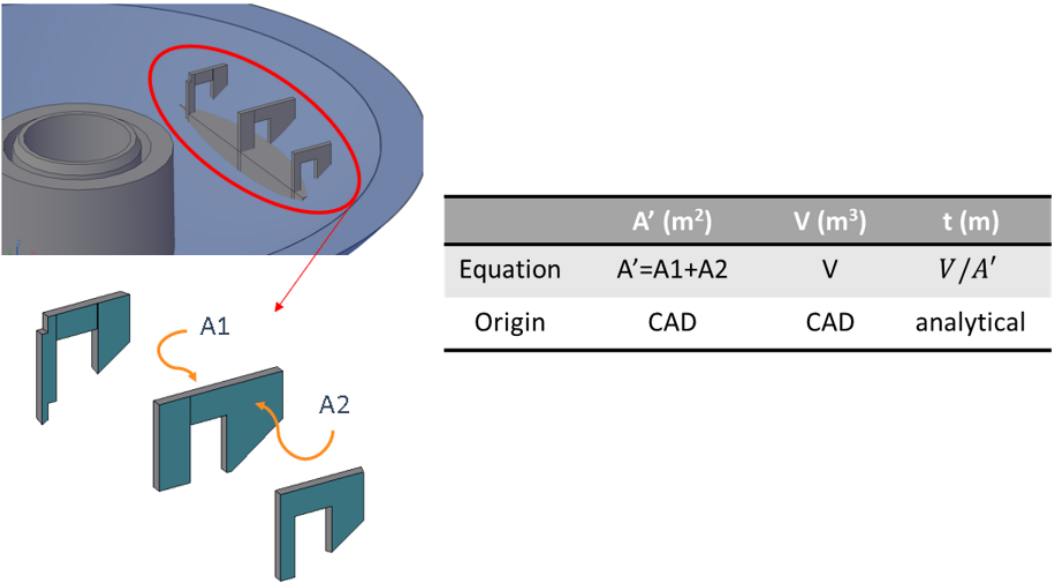


Figure A 5. Example of geometrical data extraction from CAD type 'X' SSCs