Development of Wolsong Unit 2 Containment Analysis Model

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1. Introduction

The behavior of containment following a pipe break in the primary and secondary heat transport system in the containment building is analyzed to determine the peak pressure & temperature inside containment, the timing of containment pressure dependent signal for containment isolation, differential pressures across the internal walls, and radionuclide release to the environment for the purpose of dose calculation. To be prepared for the full scope safety analysis of Wolsong unit 2 with modified fuel, input decks for the various objectives, which can be read by GOTHIC 7.2b(QA), are developed and tested for the steady state simulation.

A detailed nodalization of 39 control volumes and 92 flow paths is constructed to determine the differential pressure across internal walls or hydrogen concentration and distribution inside containment. A lumped model with 15 control volumes and 74 flow paths has also been developed to reduce the computer run time for the assessments in which the analysis results are not sensitive to detailed thermal hydraulic distribution inside containment such as peak pressure, pressure dependent signal and radionuclide release.

The input data files provide simplified representations of the geometric layout of the containment building (volumes, dimensions, flow paths, doors, panels, etc.) and the performance characteristics of the various containment subsystems. The parameter values are based on best estimate or design values for that parameter. The analysis values are determined by conservatism depending on the analysis objective and may be different for various analysis objectives.

2. Nodalization

As described in the introduction, two nodalization schemes have been prepared. Section 2.1 and Section 2.2 describe the node structure of the Detailed Model and the Lumped Model respectively.

2.1 Detailed Model

This model represents the Wolsong 2 CANDU 6 containment building as a 39 nodes, 92 flow paths. Fig. 1 shows the nodes and flow paths of the Detailed Model.

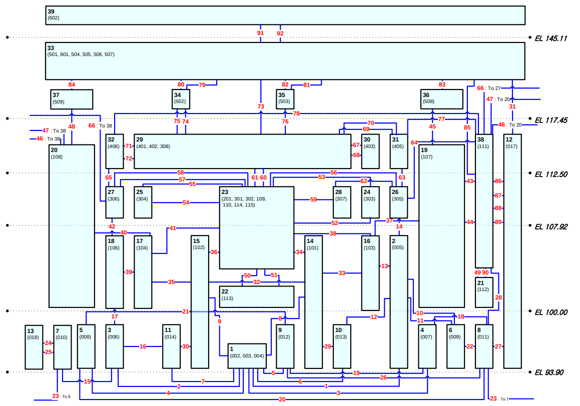


Fig. 1. Control Volume and Flow Path Structure for Detailed Containment Model

In some cases, two or more rooms are combined into one node. This is done in cases where the rooms are connected by large open areas, offering very little flow resistance. Individual rooms are modeled as a single node in cases where the room is a well-defined enclosure with a small passage or door connecting it to adjacent rooms. In this model, every major room except the Spent Fuel Transfer Bay and a few special rooms in the containment building is represented as a separate node, so that the pressure difference on each wall can be determined.

The volume, elevation, height and L/V interface area (assume the same value of floor surface area) of each node are calculated based on information taken from DWG 86-21200-101-1-GA-F to DWG 86-21200-127-1-GA-F [1] and DWG 86-21830-101-1-GA-E to DWG 86-21830-108-1-GA-D [2].

The net free volume of each node is calculated by subtracting the volume of the major equipment located in the node and another small amount of volume to account for miscellaneous items (such as cables, slabs, etc.) from the actual total volume of the node. The volume of the major equipment in each node is approximated by assuming that each piece of equipment is cylindrical in shape based on the dimensions provided in the equipment drawings [3]. The miscellaneous volume is taken to be 1% of the total volume in each node, except for the Nodes 19, 20, and 33 where about 2.3% of the total volume is assumed.

The elevation of the room is the distance between the bottom of the volume and a model reference datum. The height of the volume is the vertical distance from the floor to the ceiling of the room. The node elevation and height of each node are calculated based on the Wolsong 2 drawings [1, 2]. The node hydraulic diameter is used to define the surface area of structures within the volume (walls, vessels, support structures, etc.) that may be wetted by a liquid film. Therefore, the hydraulic diameter should be defined as follows:

$$D_h = \frac{4V}{A_w}$$

where, Dh = hydraulic diameter
Aw = wetted area
V = fluid volume.

The L/V interface area is used to define the interfacial area for calculating heat and mass transfer between the liquid and vapor phases in lumped parameter volumes. The L/V interface area of each node is set to the node floor surface area.

2.2 Lumped Model

This model is composed of 15 nodes and 74 flow paths for the Wolsong 2 containment building. Fig. 2 shows the node and flow paths of the Lumped Model.

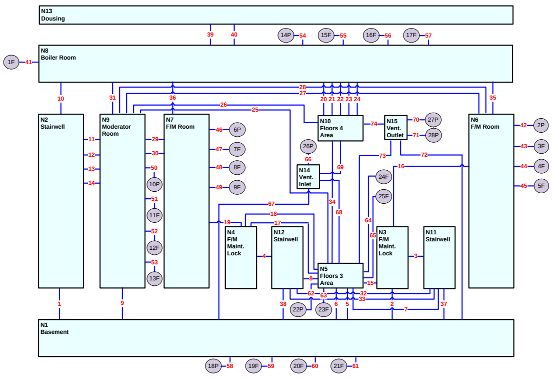


Fig. 2. Control Volume and Flow Path Structure for Lumped Containment Model

In contrast with the Detailed Model, many rooms are combined into one node for the Lumped Model, except for some of the important rooms. The node volume and L/V interface area are calculated by adding the individual values in the Detailed Model.

3. Flow Paths

3.1 Detailed Model

For this model, all of the blowout panels, doors or openings are considered as flow paths. The blowout panels used to separate the accessible and inaccessible areas have a rupture pressure of 6.9 kPa(d)(design value). The model uses the analysis values, which include an instrument uncertainty and an operational flexibility. There are five types of doors inside containment. The first type is shielding doors, which are assumed to be strong enough to withstand all pressure loads. The second type is doors in which blowout panels are located. This type of door is modeled to rupture the blowout panel only when the differential pressure across the door reaches a threshold pressure of 8.9 kPa(d). The third type is doors which are designed to blow open when the latch holding the door closed breaks at a differential pressure of 1.2 - 1.7 kPa(d) [1, 4]. These doors are modeled to rupture at 1.7 kPa(d). The fourth type is doors which have a louvered grille. This type of door is assumed to be always open (the grille provides an open pathway between the two rooms). The last type is sealed, solid doors which do not have blowout panels or louvered grilles incorporated into the door design. In addition, the door latch is not designed to release for any differential pressure. Therefore, these doors are assumed to be permanently closed and to withstand all pressure loads (similar to shielding doors). Reference 4 describes the door locations, types, size, etc. in detail.

Flow path end heights define the vertical distance occupied by the connection of a flow path to a node. Flow path end elevations are used to calculate the gravitational head across the flow path, the gravitational head within the volumes, and to determine whether the flow path end is above or below the liquid pool in the volume. The elevation and height of each flow path are modeled considering actual position and geometry of the blowout panels, doors and openings. The flow cross-sectional area of each flow path is calculated by evaluating the minimum opening area between two nodes. In some cases, an allowance for equipment or stair restriction in the flow path is made by reducing the flow area by a factor of 0.6 to 0.8. The hydraulic diameter of each flow path is used to calculate the wall friction head in GOTHIC7.2b and calculated using following equation:

$$D_h = \frac{4A}{P_w}$$

where, Dh = hydraulic diameter of flow path
A = flow area
Pw = wetted perimeter.

The friction length is taken as the actual distance of the flow path (i.e. the door thickness, the thickness of the orifice or thickness of concrete walls between two areas) and the inertia length is calculated using approximated formula.

The flow resistance coefficient, k is estimated based on the geometry of the flow path. The following Equations are used to determine the resistance coefficients (k) [5, 6].

a. Sudden contraction from A_1 to A_0

$$K = 0.5\left[1 - \frac{A_0}{A_1}\right]$$

b. Sudden expansion from A0 to A2

$$K = \left[1 - \frac{A_0}{A_2}\right]^2$$

c. Thick orifice of area A_0 in a transition from A_1 to A_2

$$K = 0.5\left[1-\frac{A_0}{A_1}\right]+\left[1-\frac{A_0}{A_2}\right]^2+\tau\sqrt{1-\frac{A_0}{A_1}}\left(1-\frac{A_0}{A_2}\right)+fL/D$$

3.2 Lumped Model

The Lumped Model has 74 flow paths. Among these flow paths, only 38 flow paths are for simulating actual fluid flow in the containment. The rest 36 flow paths are for modeling containment subsystems such as containment spray system, D2O vapor recovery system and ventilation system. Because several rooms are merged into one node, there may be several flow paths connecting the upstream and downstream node (or nodes). In that case, the several flow paths are combined into one flow path, if the characteristics of the flow paths are similar to each other.

4. Thermal Conductor

Thermal conductors are used to model the heat capacity of solid structures, heat transfer between the fluid and these structures, radiation heat transfer among structure surfaces, heat transfer through solid structures separating volumes, and heat sources associated with the structures. Conductors are intended to model concrete walls and structural steel in a containment building, although they are not limited to these geometries and materials. All conductors are defined with two surfaces. Conduction in conductors is modeled by one-dimensional heat transfer, perpendicular to the two conductor surfaces. Total 35 conductor types are defined in this model according to the combination of material type and conductor thickness. The conductor is typically modeled by dividing the conductor into a number of one-dimensional regions through the thickness. The number and location of temperature nodes through the conductor required for an accurate solution depends on the material properties, conductor thickness, heat transfer coefficient and rate of change in the fluid temperature.

The concrete surface areas calculated in this section are used to determine heat transfer to the walls. The calculated concrete surface areas are based on Wolsong 2 concrete arrangement drawings [7, 8]. For the purpose of pressure dependent signal analysis, surface area is increased by 10%.

The steel surface area is also used for heat transfer and molecular iodine plateout calculations.

The outer layer of the external concrete wall and dome are allowed to have heat transfer to the ambient atmosphere. For conservatism, a low value of 5 W/(m^2K) is assumed for the heat transfer coefficient on the outer surface of the perimeter wall. The heat transfer coefficient at the surface of an internal wall or the inner surface of a perimeter wall is modeled using “Direct” and “XOR” or “ADD” option of GOTHIC7.2b. For the condensation heat transfer, the Uchida heat transfer correlation [9] is selected. The heat transfer coefficient varies from 1,578 W/(m^2K) to 11 W/(m^2K) for pure steam to pure air conditions respectively.

5. Subsystem Model

5.1 Air Cooler Model

Only the local air coolers and associated fans supplied by Class IV and Class III power in the fuelling machine rooms and steam generator room are assumed to be available and functioning and all the other air coolers supplied by Class IV power only are ignored for some objectives of the containment analysis. For the assessment of timing of pressure dependent signal, all of the 35 coolers are assumed to be available and operating. The capacity of the coolers to condense steam in an air and steam environment is computed on the basis of laboratory tests of a Bruce A NGS air cooler [10, 11] and theoretical work[12].

The operating range of RCW is from 18℃ to 35℃. In order to obtain the analysis value of the RCW temperature, an instrument uncertainty and an analysis uncertainty should be added to the RCW temperature. Thus, 14℃ or 39℃ is used for the analysis value of RCW temperature according to specific analysis objectives.

5.2 Additional Heat Source

Additional heat sources due to lighting, motors, the reactor face, etc. are modeled using “Heater” component model in GOTHIC7.2b code. During normal operation, they are balanced by the heat removal capacity of the local air coolers (LACs).

5.3 Dousing System

The dousing spray is modeled using one additional node, two flow paths, one “Spray nozzle” component, and one “Valve” component with trip logics in GOTHIC7.2b code. The additional node represents the dousing tank and the flow paths are to simulate the piping and flow between dousing tank and containment atmosphere. The valve represents isolation valve for simulating cyclic operation of the spray system. The dousing spray is modeled as flow rate is the maximum when dousing tank is full and decreases as the level of dousing tank decreases.

5.4 Initial Condition

For the assessment of timing of pressure dependent signal objective, the containment pressure is assumed to be -2.5 kPa(g). For the other objectives the containment pressure is assumed to be 0.0 kPa(g). For the assessment of peak pressure, pressure differential and radionuclide release, dry condition is assumed, to minimize the heat removal capacity of dousing and the local air coolers, thus maximizing the peak pressure rise in containment and leakage (from containment). For the assessment of pressure dependent signals, 100% relative humidity is assumed to maximize the heat removal capacity of the local air coolers.

5.5 Instrument Air

The instrument air discharge into containment is modeled based on several design values and assumptions provided in reference 13. The assumed instrument air ingression is simulated using “Flow Boundary Condition” and “Forcing function” of GOTHIC7.2b code.

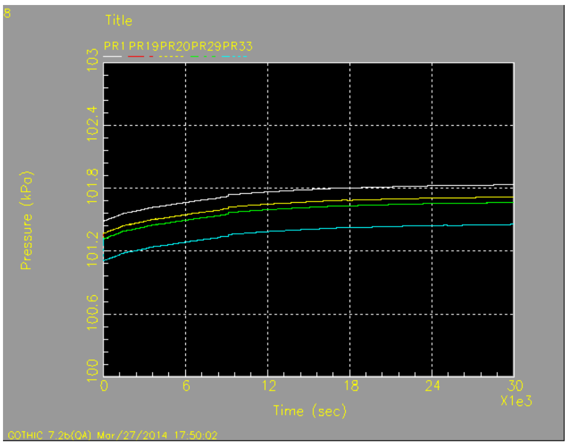
5.6 Leakage through wall

For analyses in which minimum containment pressure or maximum releases from containment is desired, then building leakage should be modeled. Thus, leakage is modeled only for the objectives of PS and RR. For these cases, Reference 14 suggests that building leakage be modeled as 5% of the containment building volume per day at the design pressure of 124 kPa(g). For conservatism, the volume of all nodes not bordered by the perimeter wall is also included in the leakage calculation by adjusting the leakage rate of the nodes which are modeled to leak.

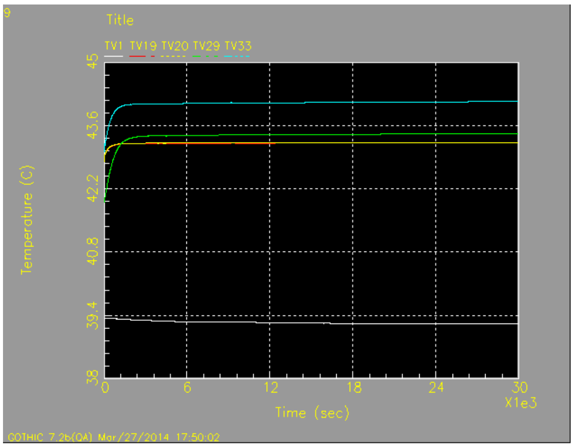
6. Steady State Simulation

Steady state calculation of input deck for the each analysis objective was done and the results are shown in this section.

Fig. 3 shows the null transient calculation results of detailed model for the differential pressure assessment. The pressure of each node reflects the difference in head according to the elevation of each node. The ‘PR1’ is pressure of node1 representing basement and the ‘PR33’ is pressure of node33 representing steam generator room.



(a) Pressure



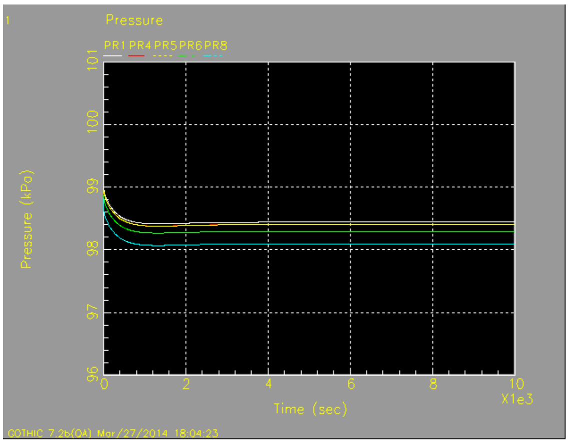
(b) Temperature

Fig. 3. Steady state of the detailed model for differential pressure assessment

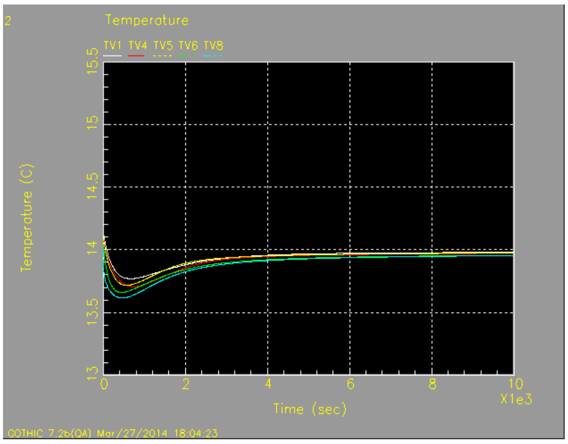
The temperature of each node reflects the balance of the heat added by additional heat source and removed by air coolers in each node. The ‘TV1’is temperature of node1 which has not any heat source decreases at the beginning of calculation and gets stable. The temperature of the other nodes which have heat source and coolers increases at the beginning and gets balanced stable state.

Fig. 4 shows the null transient calculation results of lumped model for the timing of pressure dependent signal. The stable state of the calculation matches well the initial condition assumed for the analysis objective.

Fig. 5 shows the steady state calculation results of lumped model for the peak pressure and temperature assessment. On the contrary to the analysis objective of pressure dependent signal, the pressure gets stable at the pressure a little bit higher than 0.0 kPa(g), but it is more conservative at the point of analysis objective of peak pressure and temperature.

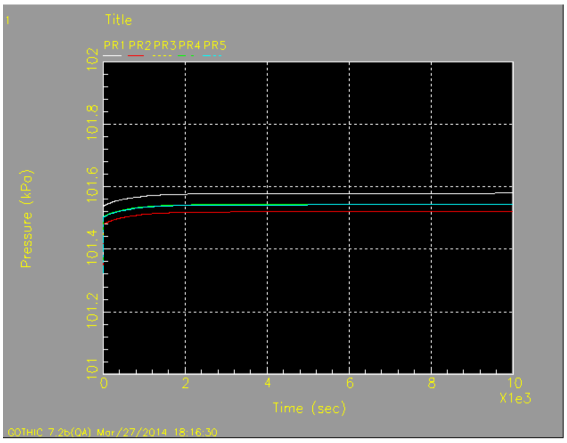


(a) Pressure

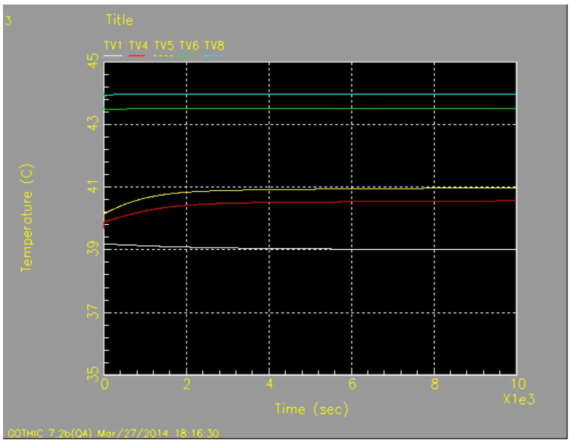


(b) Temperature

Fig. 4. Steady state of the lumped model for determining of the timing of pressure dependent signal



(a) Pressure



(b) Temperature

Fig. 5. Steady state of the lumped model for peak pressure and temperature assessment

7. Conclusion

Basic input decks of Wolsong unit 2 were developed for the various analysis purposes with GOTHIC 7.2b(QA). Depend on the analysis objective, two types of models are prepared. Detailed model models each confined room in the containment as a separate node. All of the geometric data are based on the drawings of Wolsong unit 2. On the other hand, lumped model is developed by merging several nodes which are connected with relatively large openings into a node. Subsystems such as air coolers, dousing spray, heaters, instrument air ingression, trip and controls are modeled and tested its proper operation also. Initial conditions are determined differently for each analysis objective. Developed containment models are simulating the steady state well to the designated initial condition. These base models will be used for Wolsong unit 2 in case of safety analysis of full scope is needed.

REFERENCES

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