CAD-based Containment Nodalization for Best-estimate Analysis of Hydrogen Behaviors Using the MELCOR Code

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1. Introduction

Due to the highly complex geometry of reactor containment buildings, generating traditional multi-block meshes for CFD analysis is time-consuming and laborious. Since the late 90s, unstructured auto-meshing techniques have been developed for CFD analysis, and most CFD codes now apply unstructured mesh numerical techniques. Unlike structured meshes, unstructured meshes can be automated, allowing for fast mesh generation with minimal user effort, even for complex geometries such as containment buildings.

To perform hydrogen safety analysis in a nuclear reactor containment building using an integrated lumped-parameter (LP) code, a network of control volumes discretizing the analysis domain must be constructed, similar to CFD. The computational grid for LP analysis is still difficult to automate and therefore relies on manual work.

This manual construction of control volumes (CV) in LP analyses not only increases the time required for input, but is also a major factor in the difficulty of evaluating mesh dependencies (especially number of CVs). Depending on the accident conditions or history, the hydrogen distribution in the containment building may increase the spatial rate of change, but it is difficult to predict, and changing the control volume once configured in the LP analysis requires a lot of time and effort.

Depending on the accident conditions or progress, the rate of spatial variation in hydrogen distribution in the containment building may increase, but it is difficult to predict this with a small number of control volumes, and it is time-consuming to change the control volumes once configured in the LP analysis.

A mesh-dependency study for a hydrogen safety evaluation using an LP code is the first step toward best-estimation. The bottleneck in evaluating mesh-dependency test in MELCOR [1] analyses is the configuration of the analysis CVs. This paper introduces an automated methodology for fast nodalization and its application to the MELCOR analysis for hydrogen safety in APR1400.

2. Methodology

3D computer-aided design (CAD) can be used for control volume construction for LP analysis of a containment building.

By configuring the free volume (analysis area) in the 3D CAD data and cutting the parts that require the control volume using a cutting plane, as many control volumes as the user wants are formed, and a post-processing program can be executed to extract geometric information about CVs and junctions (or flow-paths). Fig. 1 shows a schematic illustrating the procedure.

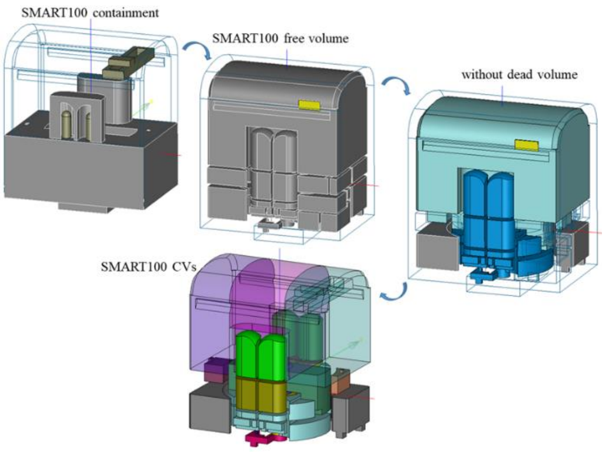


Fig. 1. A procedure for a CAD-based nodalization of a containment free volume.

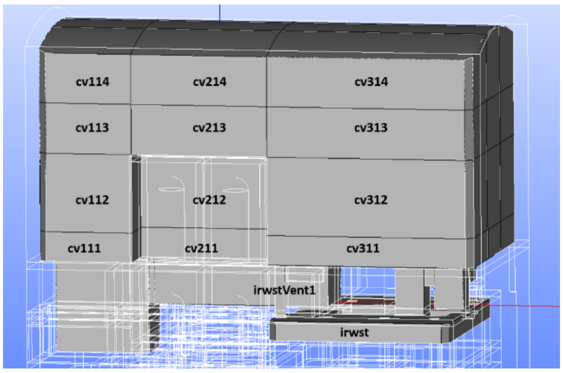


Fig. 2. Control volumes for MELCOR nodalized using a 3D CAD of the containment, 37 CVs (3×3×4 + IRWST) and 77 junctions

Fig. 2 shows an example of control volumes for MELCOR analysis, which uses 3D CAD to construct the control volume of a containment building. A python program has been developed to construct a connectivity of the CVs and calculate geometric data such as volumes, areas, and lengths. The program exports the geometric data in list-type and MELCOR-type files. Table 1 shows the MELCOR flow-path data generated by the developed program, and Table 2 shows geometric data of CVs, junctions, and heat structure in MELCOR format which can be inserted into a Melgen input file.

Table 1. Geometric data of CVs and junctions for MELCOR analysis.

CV0	CV1	area	length	Dh
cv111	cv121	305.576	9.457	15.399
cv111	cv211	28.256	33.522	2.885
cv111	cv112	281.75	19.786	14.944
cv211	cv221	241.426	12.069	9.669
cv211	cv212	522.875	17.562	19.028
cv121	cv221	28.256	32.974	2.885
cv121	cv122	281.75	19.786	14.944
cv221	cv222	522.875	17.031	19.028
cv112	cv122	616.5	14.486	24.709
cv112	cv212	335.307	31.592	16.059
cv212	cv222	1048.05	14.817	31.928
cv212	IRWSTvent0	1.2	22.031	1.091
cv122	cv222	335.307	31.592	16.059
cv222	IRWSTvent1	1.2	22.031	1.091

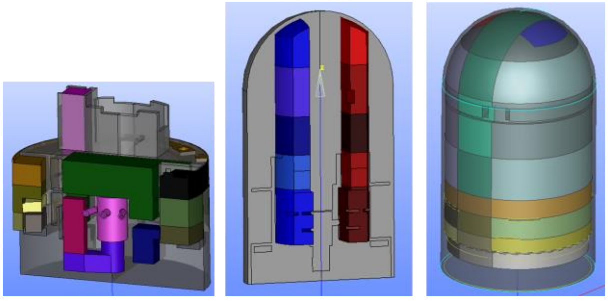
Table 2. Geometric data of CVs, junctions, and heat structure in MELCOR format.

```
****************************************
*     SG1_z0
****************************************
CV80000     SG1_z0     2        2        8
CV800A0     3
CV800A1     TATM     325.15     PVOL     101700.0
CV800A2     MLFR.4     0.79     MLFR.5     0.21     RHUM     0.6
CV800B1        -5.283          0.000
CV800B2        11.786      1951.609
****************************************
*     SG_z0L_SG1_z0
****************************************
FL80000     SG_z0L_SG1_z0     810     800          1.761          3.047
FL80001        114.023          14.590          1.000          3.226          3.226
FL80002     3        0        0        0
FL80003          1.000          1.000
FL800S0        114.023          14.590          14.590
****************************************
*     SG_z0R_SG1_z0
****************************************
****************************************
*     SG2_z0_wall80155
****************************************
HS80155000     5        1        0
HS80155001     'SG2_z0_wall80155'
HS80155002          0.127     -1.0e-7
HS80155100     -1        1              0.000
HS80155102          0.250     2
HS80155103          0.500     3
HS80155104          0.750     4
HS80155105          1.000     5
HS80155200     -1
HS80155201     'CONCRETE'     4
HS80155300     0
HS80155400     1        805     'EXT'          0.500          0.500
HS80155500          3.178          1.783          1.783
HS80155600     0
```

3. Application

A containment building node constructions (CVs and junctions) for MELCOR analysis are traditionally performed manually and can be partially assisted by a spreadsheets such as Excel. This manual node construction typically takes several months. On the other hand, the CAD-based node construction of the containment building can be performed in graphical mode, and can be completed in a matter of days if 3-dimensional CAD data of the containment is already developed.

Fig. 3 shows the control volumes created by the tool applying for the APR1400 containment building, which consists of 50 control volumes. As shown in the figure, the control volume can be configured to reflect the geometry of the expected flow paths and compartments in the containment building, and the control volume can be subdivided as needed. Fig. 3 (a) shows the annular compartment under the APR1400 operating deck, the cavity below the reactor, and the lower compartments, including the corium chamber, split into their respective control volumes. Fig. 3 (b) shows the height-wise subdivision of the two steam generator compartments and (c) shows the control volume subdivision for the region above the operating deck and the dome region.



(a) (b) (c)

Fig. 3. Construction of control volumes for MELCOR analysis of APR1400.

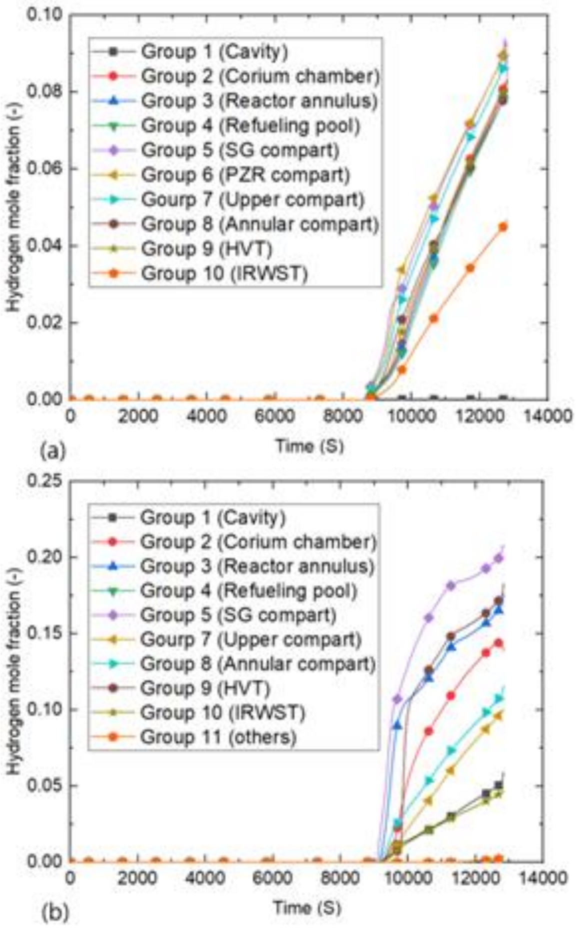


Fig. 4. Change of hydrogen concentrations in CVs from MELCOR analysis of the APR1400 SBO accident, (a) 11 CVs used, (b) 50 CVs used.

This CAD-based control volume nodalization tool analyzes the geometric information of the created control volumes and outputs it as CV (control volume), FL (flow path), HS (heat structure), etc. of the MELCOR code, which can be used as input to MELCOR.

Fig. 4 shows the results of the MELCOR analysis of an SBO accident at APR1400. The simulation conditions assume a 3-way valve switch at severe accident entry to change depressurization from the IRWST to the steam generator compartment and hydrogen generation at 100% active core oxidation until reactor vessel failure.

In Fig. 4 (a), the containment building free volume was discretized with 11 CVs and in the figure (b) with 50 CVs. It can be seen from the figures that as the number of CVs increases, a large spatial gradient is formed in the hydrogen distribution in the containment building.

4. Conclusions

In this study, a tool for CAD-based containment nodaliztion has been developed for a mesh-dependency test of a MELCOR analysis in a nuclear reactor containment This methodology can reduce the amount of time spent on constructing CVs and junctions. This method is expected to help best-estimation of hydrogen safety.

ACKNOWLEDGMENTS

This work was supported by the Korea Foundation of Nuclear Safety (KOFONS) (No. 2106007) and the National Research Foundation of Korea (NRF) (No. 2017M2A8A4015277).

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[1] L.L. Humphries, B.A. Beeny, F. Gelbard, D.L. Louie, J. Phillips, "MELCOR Computer Code Manuals Vol. 1: Primer and Users' Guide Version 2.2", USNRC, 2017