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Comparison of SPACE and COBRA-TF for the Droplet Field Predictions

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1. Introduction

SPACE is the first safety analysis computer code which has been developed by the Korean nuclear industry. The code has been developed for the purpose of analyzing various accidents in nuclear power plants, but its main use will be the analysis of a large break loss-of-coolant accident (LBLOCA) and KNF has been developing a best estimate LBLOCA evaluation model using the code.

There are several system codes which have been supposed to be a best-estimate code, such as RELAP5 and TRACE. However, most of them don't treat droplet field explicitly and they solve six conservation equations only for liquid and vapor. On the contrary, the SPACE code solves nine conservation equations including three equations for droplet field and that is the unique feature of SPACE compared to other previous best-estimate codes.

In a LBLOCA, especially during the reflood phase, predicting droplet field accurately is very important since the interfacial heat and momentum transfer between droplets and vapor has a significant effect on the core cooling. Information obtained from droplet field equations (amount, velocity, and temperature of droplets) dominates how high the vapor temperature in the core would be and how much droplets would be carried-over to steam generators to make the steam-binding phenomena. Thus validating the droplet field predictions of SPACE is regarded as one of the essential steps of developing a sound LBLOCA evaluation model using the code.

However, it is nearly impossible to validate the droplet field predictions of SPACE using experimental data because there are little LBLOCA experiments in which droplet information was directly measured. That is reason why we chose a rather indirect way of validation to compare the droplet field predictions of SPACE to those of COBRA-TF. COBRA-TF is the only best-estimate code having droplet field equations which has been used for long time for many nuclear applications. This code represents a two-fluid, three-field (continuous liquid, continuous vapor and entrained liquid drop) representation of two-phase flow [1]. In this study, SPACE and COBRA-TF were assessed against the same reflood experiment, and their droplet field predictions were analyzed.

The Rod Bundle Heat Transfer (RBHT) experiment is selected for the assessment of SPACE and COBRA-TF. This experiment was conducted by PSU in 2000 supported by USNRC. The RBHT Test Facility had a test section of with a square geometry of 9.13 cm size. The heater rod bundle in the test section simulated a small portion of the 17x17 reactor fuel assembly. It consisted of 45 heater rods and 4 unheated corner rods having a length of 3.66 m and it had seven mixing vane grids similar to design to a commercial 17x17 fuel assembly. The heater rods had a top skewed power shape with a peak to average power of 1.5 at the 2.77 m (9.0 ft) elevation [2]. Among a number of tests having been conducted up to now, only a representative case having low inlet velocity (Test 1383) was selected for this study.

2. Model and Modeling

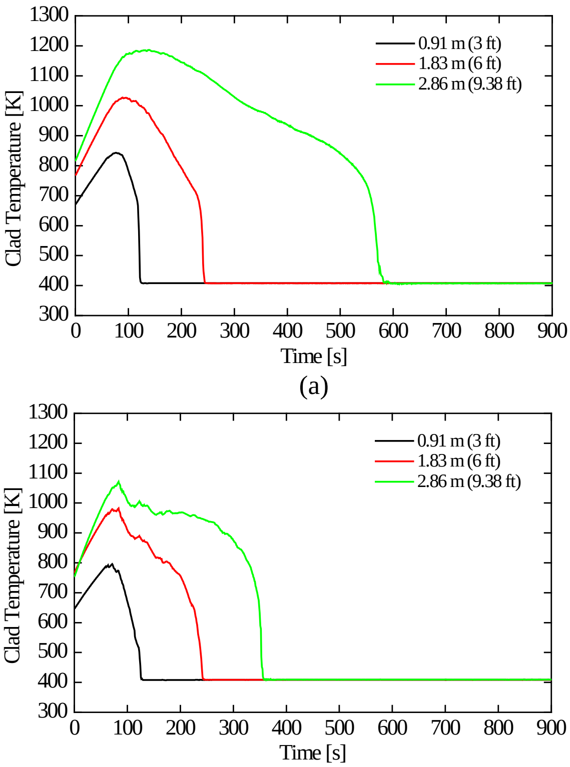
The heated part of the test section is modeled using two radial channels, a channel containing outermost 20 heater rods and channel containing the other 25 heater rods. 47 nodes and 21 sections were used to model the test section axially in SPACE and COBRA-TF calculations, respectively. The same initial and boundary conditions were used in both calculations. The selected test, Test 1383 had a flooding rate of 2.54 cm/s (1 in/sec) and the upper plenum pressure was 2.8 bar (40 psia).

In the SPACE calculation, a special reflood model (model and correlation package) developed by KNF [3] was applied. The reflood model has been assessed to have much better prediction capability for the overall behaviors of both cladding temperatures and vapor temperatures during reflood than the default model and correlation package.

3. Result and Discussion

Fig. 1 shows clad temperatures at three different elevations; 0.91 m (3 ft), 1.83 m (6 ft) and 2.86 m (9.38 ft). As inflow is coming up from the core bottom, quenching is proceeding and flow condition is changing to normal wall condition.

Fig. 2 shows void fraction comparison between the SPACE and COBRA-TF. In both cases, the core was empty at first then became wet as reflood phase proceeds. A vertical line drawn on each figure of the SPACE and COBRA-TF results mean flow condition change from hot wall to normal wall. According to this change, the SPACE decides whether there would be entrainment or not. Since the SPACE defines entrainment possible region as stratified, annular, reflood flow regimes. The SPACE assumes that there is no possibility that entrainment is occurring in other flow regimes.



(b)

Fig. 1. Hot wall to normal wall condition criteria according to clad temperature at each elevation; (a) SPACE, (b) COBRA-TF

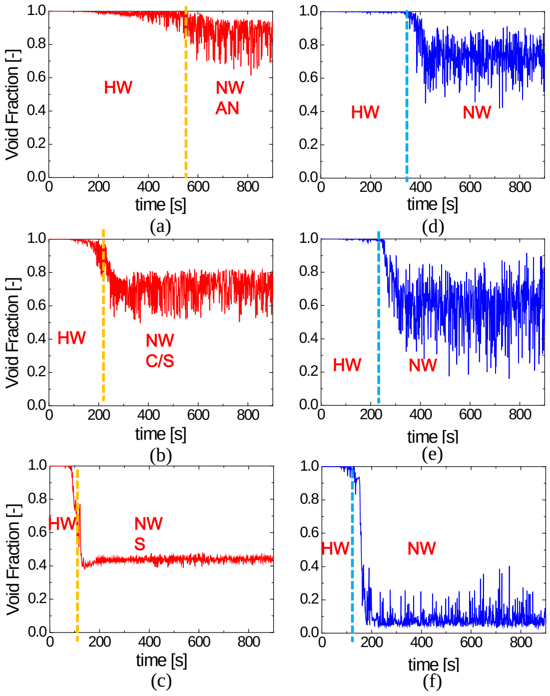


Fig. 2. Void fraction comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node.
HW: hot wall condition, NW: normal wall condition,
AN: annular, C/S: Churn/Slug, S: Slug flow

In Fig. 3 there is a little amount of, less than 0.5%, drop fraction during normal wall region, but it almost disappears as the condition changes. It is hard to be noticed out, but the normal wall condition in Fig. 3(a) and (c), there exist -6 and -12 orders of magnitude of droplet fraction respectively, which is negligible small but still means there exist droplet. Fig. 3(a) seems to be generated by entrainment model in annular flow regime as shown in Fig. 4(a), and Fig. 3(c) seems to be transported from other node since Fig.4(c) doesn't show that there is entrainment.

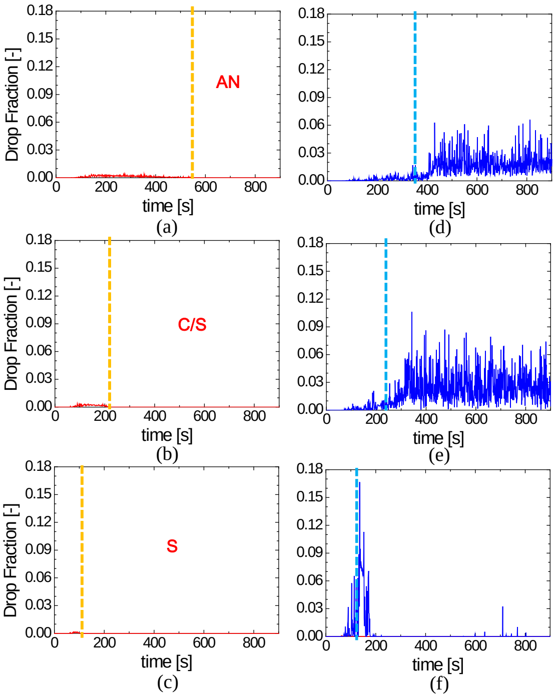
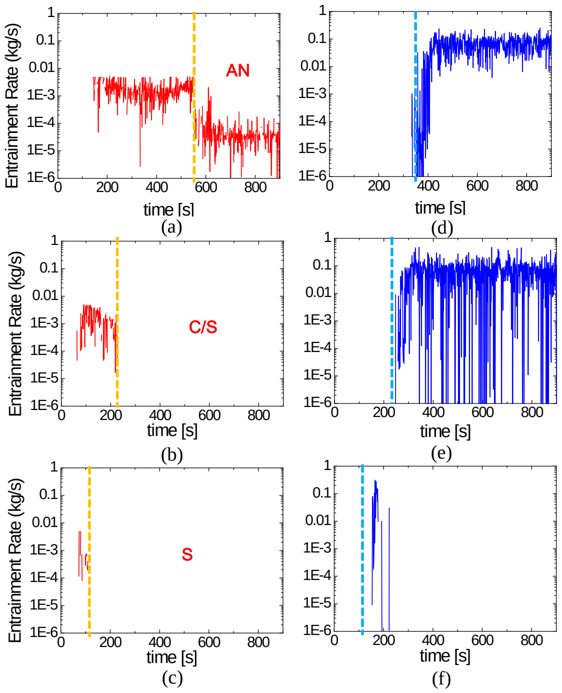


Fig. 3. Drop fraction comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node.

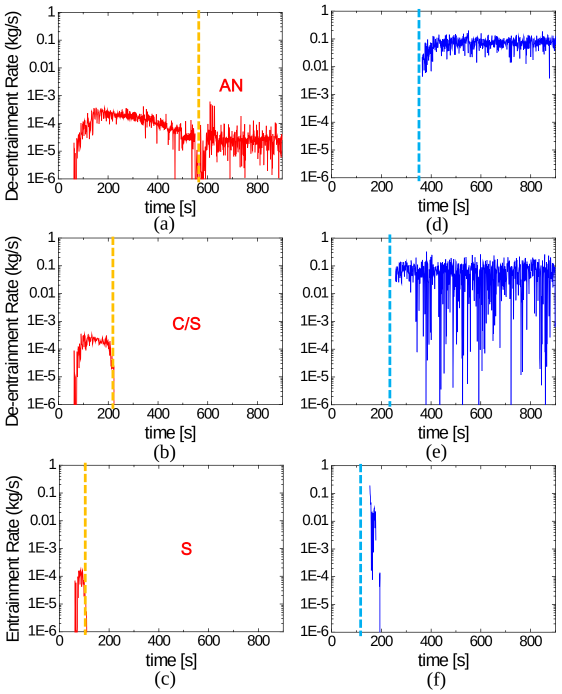
In Fig. 4(a) and Fig. 5(a), there is very small amount of drop fraction even in the normal wall region. This is because it is normal wall condition but also annular flow regime. Fig. 4 and Fig. 5 also show that entrainment and de-entrainment occurs only in hot wall condition or annular flow regime region.

In the COBRA-TF cases, however, the assessment results show different behavior. Fig. 3(d), (e), (f) represent the COBRA-TF drop volume fraction. It presents that there exist a certain amount of drop fraction while it is under hot wall condition, but most of drop fraction appears when it is under normal wall condition. This behavior is opposite to that of the SPACE. In Fig. 4 and Fig. 5, it can be seen that only in the normal wall condition, when the rod cooled down to the saturation temperature, droplet starts to entrain and de-entrain. The y-axes on those figures are logarithmic to show the magnitude of entrainment and de-entrainment rate of the COBRA-TF and those of the SPACE differ by an order of magnitude. The amount of entrained and de-entrained droplet in the COBRA-TF is much larger.



(a) (d)
(b) (e)
(c) (f)

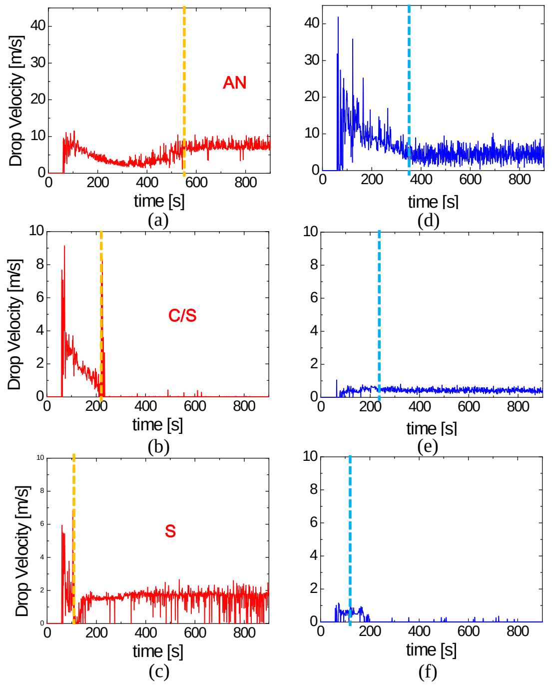
Fig. 4. Entrainment rate comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node.



(a) (d)
(b) (e)
(c) (f)

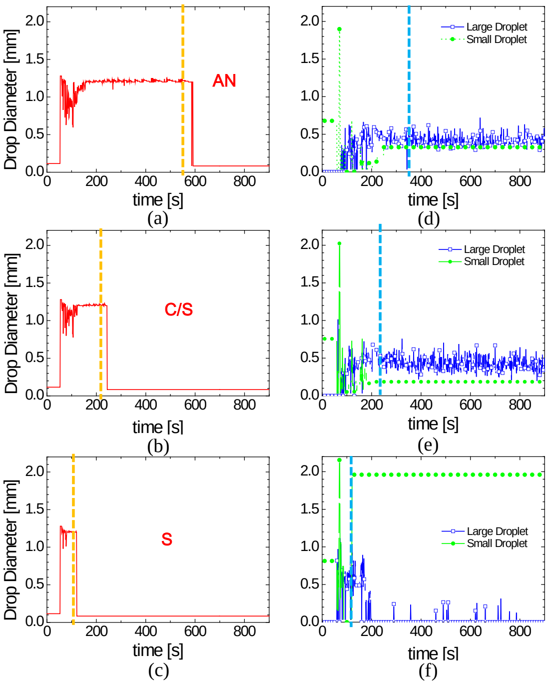
Fig. 5. De-entrainment rate comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node

Fig. 6 presents droplet velocity comparison between the SPACE and COBRA-TF. Fig. 7 shows drop size of each code. The SPACE defines most droplet sizes as a value, and assumes that when the wall condition becomes cold, the droplet size becomes very small as shown in Fig.7 (a).



(a) (d)
(b) (e)
(c) (f)

Fig. 6. Drop velocity comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node.



(a) (d)
(b) (e)
(c) (f)

Fig. 7. Drop size comparison; SPACE (a) 3ft, (b) 6ft (c) hot node, COBRA-TF (d) 3ft, (e) 6ft, (f) hot node.

4. Conclusions

To validate the ability of droplet behavior prediction of the SPACE code, RBHT experiment was assessed and compared to the COBRA-TF code's assessment result. Two codes define entrain/de-entrain occurring region differently, so that the region where the droplet is dominantly generated was different. The magnitude of entrainment/de-entrainment was shown an order of magnitude difference. Velocity and size also behave differently. More detail analysis based on model and code comparison is remaining in future work.

REFERENCES

[1] COBRA/TRAC- A Thermal-Hydraulics Code for Transient Analysis of Nuclear Reactor Vessels and Primary Coolant Systems, NUREG/CR-3046 PNL-4385 Vol.1.
[2] RBHT Reflood Heat Transfer Experiments Data and Analysis, NUREG/CR-6980.
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