# THE SENSITIVITY ANALYSIS FOR APR1400 NODALIZATION UNDER LARGE BREAK LOCA CONDITION BASED ON MARS CODE

by

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**The phenomena of loss of coolant accident have been investigated for long time and the result of experiment shows that the flow condition in the downcomer during the end-of-blowdown were highly multi-dimensional at full-scale. However, the downcomer nodalization of input deck for large break loss of coolant accident used in advanced power reactor 1400 analyses are made up with 1-D model and improperly designed to describe realistic coolant phenomena during loss of coolant accident analysis. In this paper, the authors modified the nodalization of MARS code LBLOCA input deck and performed LBLOCA analysis with new input deck. From original LBLOCA input deck file, the nodalization of downcomer and junction connections with 4 cold legs and direct vessel injection lines are modified for reflecting the realistic cross-flow effect and real downcomer structure. The analysis results show that the peak cladding temperature of new input deck decreases more rapidly than previous result and that the drop of peak cladding temperature was advanced by application of momentum flux term in cross-flow. Additionally, the authors developed a new input deck with multi-dimensional downcomer model and ran MARS code with multi-dimensional input deck as well. By using the modified input deck, the Emergency core cooling system by-pass flow phenomena is better characterized and found to be consistent with both experimental report and regulatory guide.**

*Key word: LBLOCA, PCT, ECC by-pass, MARS code, multi-dimensional, nodalization*

## INTRODUCTION

The emergency core cooling system (ECCS) is the safety system that prevents peak cladding temperature (PCT) increase over design limit during the loss of coolant accident (LOCA) and leakage of nuclear fission product thus guaranteeing core safety. As shown in fig. 1, ECCS provides makeup water to cool the reactor in the event of a loss of coolant from the reactor cooling system. This cooling is needed to remove the decay heat still in the reactor's fuel after the reactor is shutdown.by-passThe phenomena of LOCA have been investigated for long time. The most extensive research project for LOCA was 2-D/3-D program experiments [1]. The results of the 2-D/3-D experiments show that flow conditions in the downcomer during the end-of-blowdown were highly multi-dimensional at full-scale. During the reflood, the distribution of water in the core was one-dimensional. But flow in the core exhibited multi-dimensionality. One-dimen-

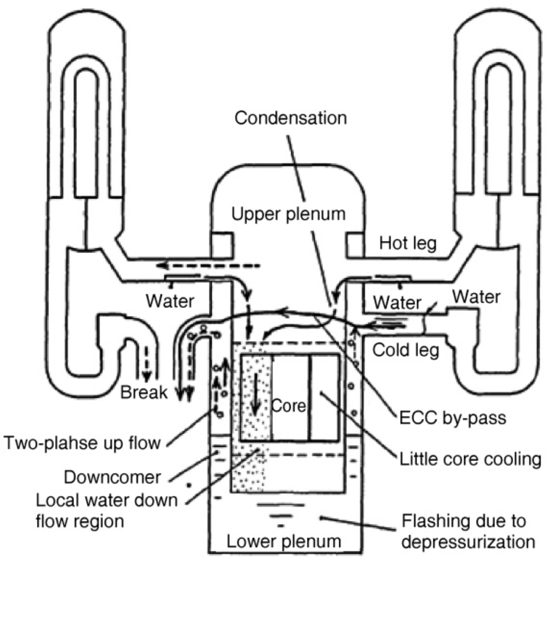


**Figure 1. End of blowdown to lower plenum refill [1]**

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sional manometer oscillation between the downcomer and core was observed. The water level was higher in front of the broken cold leg nozzle than at other azimuthal positions. Flow phenomena at the tie plate were uniform. With the background of 2-D/3-D study, multi-dimensional codes such as TRAC [2], RELAP5-3D [3], CATHARE [4], SPACE [5], MARS [6, 7], and COBRA-TF [8, 9] were developed and applied LOCA application.

But so far, the input deck for LBLOCA used in advanced power reactor 1400 (APR1400) analyses applied 1-D downcomer model and the nodalization of existing input deck was not proper to reflect cross-flow effects within neighboring hydro components. In this paper, the authors developed LBLOCA analysis input deck with new downcomer nodalization and multi-dimensional downcomer model, then performed LOCA analysis with new input decks and compared results with existing analysis results.

## APR1400 LBLOCA ANALYSIS

### Code and methodology

MARS-KS 1.4 Version [10-13] is applied for system thermal hydraulics calculation. Analysis was processed under LBCOCA of 100 % break size of cold leg case.

### New nodalization

In this sensitivity analysis for APR1400 nodalization under LBLOCA condition, the original nodalization was modified in two ways.

First, nodalizaion connections between the downcomer region and the hot and cold legs were modified to reflect real downcomer structure. As shown in fig. 2, the downcomer region of original region is divided into 6 azimuthal sectors to accommodate 4 cold legs (CL) and 2 hot legs (HL). Four direct vessel injection (DVI) lines are connected to the middle of upper downcomer. Although cold legs and DVI lines are connected to downcomer in horizontal direction as shown in fig. 3, cold legs and DVI are connected to the top face of downcomer. The cross-flow option [3, 14] at cross-flow junction connection with neighboring downcomer components is not used either. The middle point of axial locations of components connected to cold leg and DVI are modified to correspond with the middle point of cold leg and DVI. Cold legs and DVI form outside face of downcomer components are reconnected as shown in fig. 4.

Secondly, azimuthal sectors of downcomer region were increased from 6 to 12 to enhance the model accuracy. The nodalization has the most important effect on code calculations as it influences their accuracy

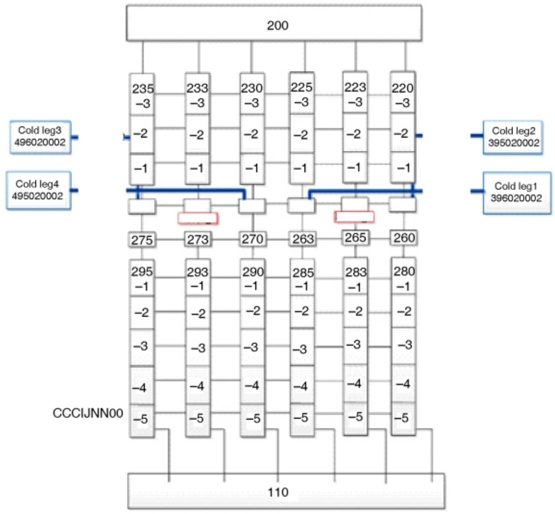



**Figure 2. MARS nodding scheme of vessel in KREM**

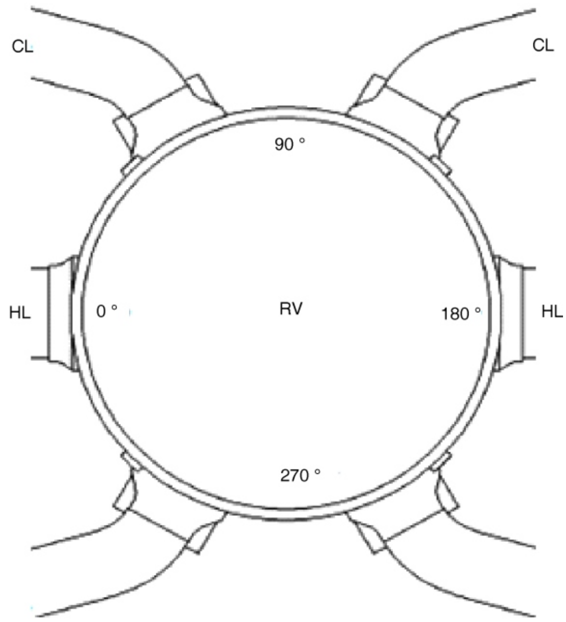



**Figure 3. Section through vessel nozzles**

and determines their feasibility. In general, calculations performed with finer nodalization will yield results that are in better agreement with experimental data. However, a finer nodalization requires longer computing time and, therefore, costs more [14]. In early LBLOCA analyses, 2 sectors were used for the downcomer and 6 sectors are used in the current LBLOCA analyses. Furthermore, 12 sectors are used in the current study. The authors increased azimuthal sectors from 6 to 12 and reassigned axial heights and volumes of each component with maintaining same total volumes. For example, the heights of components connected to cold leg are modified to internal diameter of cold leg nozzle. The modified steady-state input deck was run and mass velocity of coolant through cold leg was chcked. For maintaining same pressure

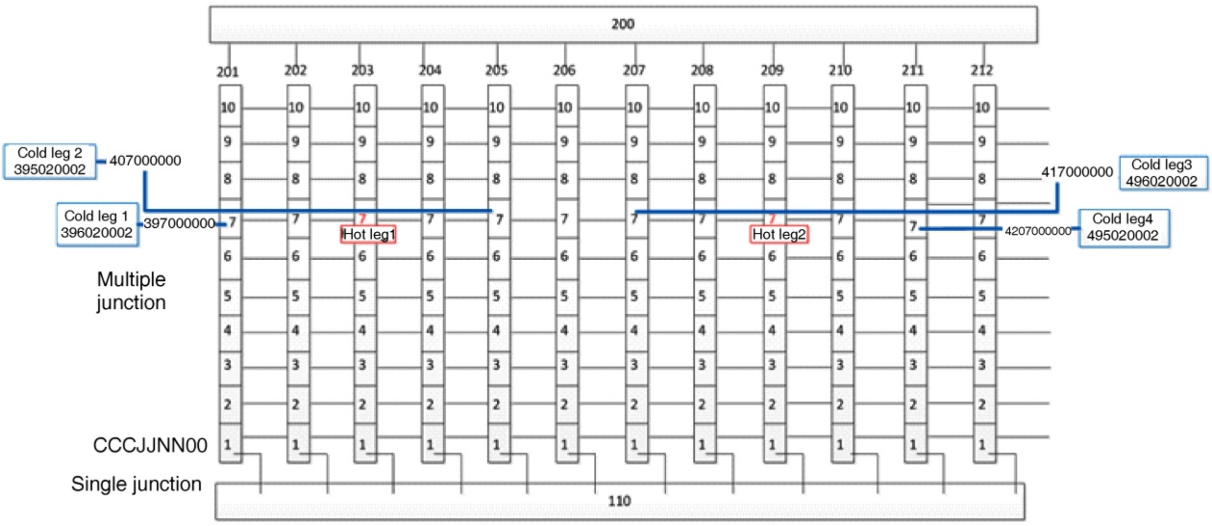



**Figure 4. Downcomer nodalization with 12 radial components (cold legs: SIT injection point, hot legs: break point)**

drop in downcomer with original input deck, the loss coefficients in junctions connecting each component were modified until mass velocity of cold leg became equal to mass velocity of cold leg of input deck used in APR1400 analyses during the steady state.

### Multi-dimensional flow model

Korea Atomic Energy Research Institute (KAERI) developed the multi-dimensional system code by integrating the one dimensional RELAP5/MOD3 code and the multi-dimensional COBRA-TF code. Although COBRA-TF module can handle the multi-channel flow, there were limitations for the application of shear terms and cylindrical coordinate system.

A new multi-dimensional component in MARS has been developed to overcome these limitations, to get the more flexible 3-D capabilities in the system code, and to allow the user to model more accurately the multi-dimensional hydrodynamic features of reactor operation, primarily in the vessel (*i. e*., core, downcomer) and steam generator. The multi-dimensional component (indicated by MULTID in the input cards) defines a one, two, or three dimensional arrays of volumes and the internal junctions connecting these volumes. The geometry can be either Cartesian or cylindrical. The full 3-D convection and diffusion terms are implemented in the momentum equation.

The downcomer region of existing input deck is composed by ANNULUS components considered one-dimensional components. So, the authors replaced the downcomer area from ANNULUS options to multi-dimensional option (MULTID) with cylindrical coordinates system [15, 16] from new nodalization input deck.

For checking effects of multi-dimensional option, dimensional values like heights and volumes of downcomer components remained the same as new input deck. For maintaining the same pressure drop in downcomer with original input deck, the loss coefficients in junctions connecting each component were also modified in the same method of developing new input deck with 12 radial components.

## RESULTS AND DISCUSSION

### Results of existing and new input deck

Even though the best way to check whether new input deck could describe more realistic coolant phenomena during LBLOCA is comparing results with LBLOCA experimental data, there were difficulties to get experiment data and perform comparative analysis. So the authors compared coolant flow phenomena from new nodalization input deck and multi-dimensional model with LBLOCA analysis results from existing input deck instead.

As shown in fig. 5, PCT from new input deck decreased more speedily compared to that from existing input deck. The second PCT peak point from new input deck is lower than that from original input deck. The safety injection tank (SIT) injection and break flow rate from break cold leg shows similar tendency. The water level in the core of original input deck kept low level during the high and low SIT injection and kept high fluctuation during the refill period. The water level in downcomer also shows high fluctuation during the refill period.

The core flow rate have been changed. Especially during the reflood period, when core flows from new input deck shows lower fluctuation than the original deck.

### The effects of cross-flow option

MARS Code solves below momentum equation [6] to calculate the coolant flow in hydro components

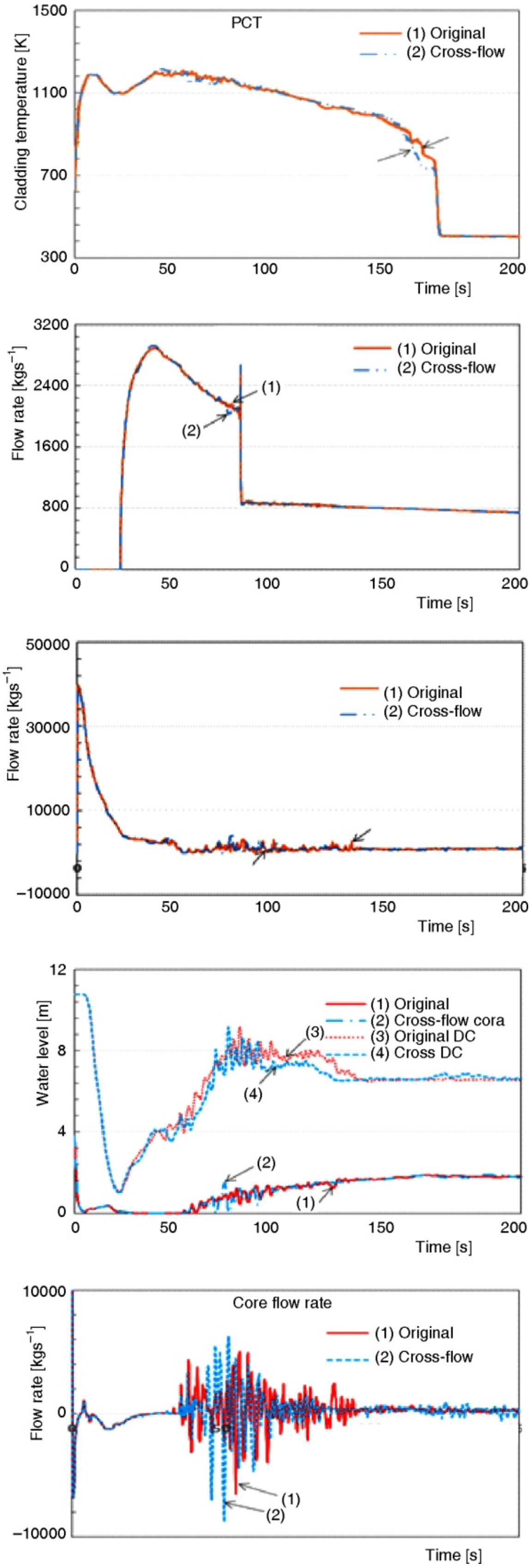



**Figure 5. Results of existing and new input deck**

$$\rho \frac{\partial \bar{v}}{\partial t} \quad \bar{v} \quad \bar{v} \qquad P \quad \bar{\sigma} \quad \rho \bar{f} \qquad (1)$$

In the existing input deck, the momentum flux term $((\bar{v} \quad \bar{v})$ is not applied to the cross-flow junctions

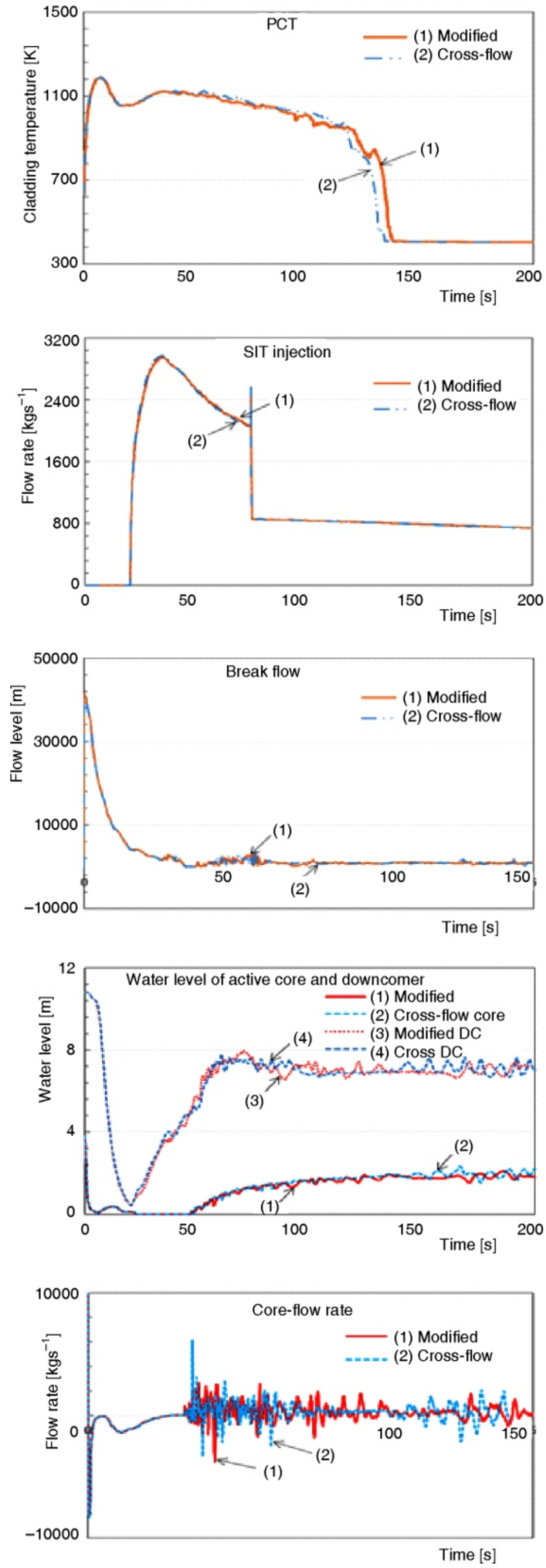



**Figure 6. Results of existing input deck and deck with cross-flow option**

to calculate the cross-flow within each downcomer components. For realistic safety analysis, the authors checked the effects of cross-flow option in MARS for LBLOCA analysis. From original and new input decks, the authors changed cross-flow option to use momentum flux in both to and from volume and two

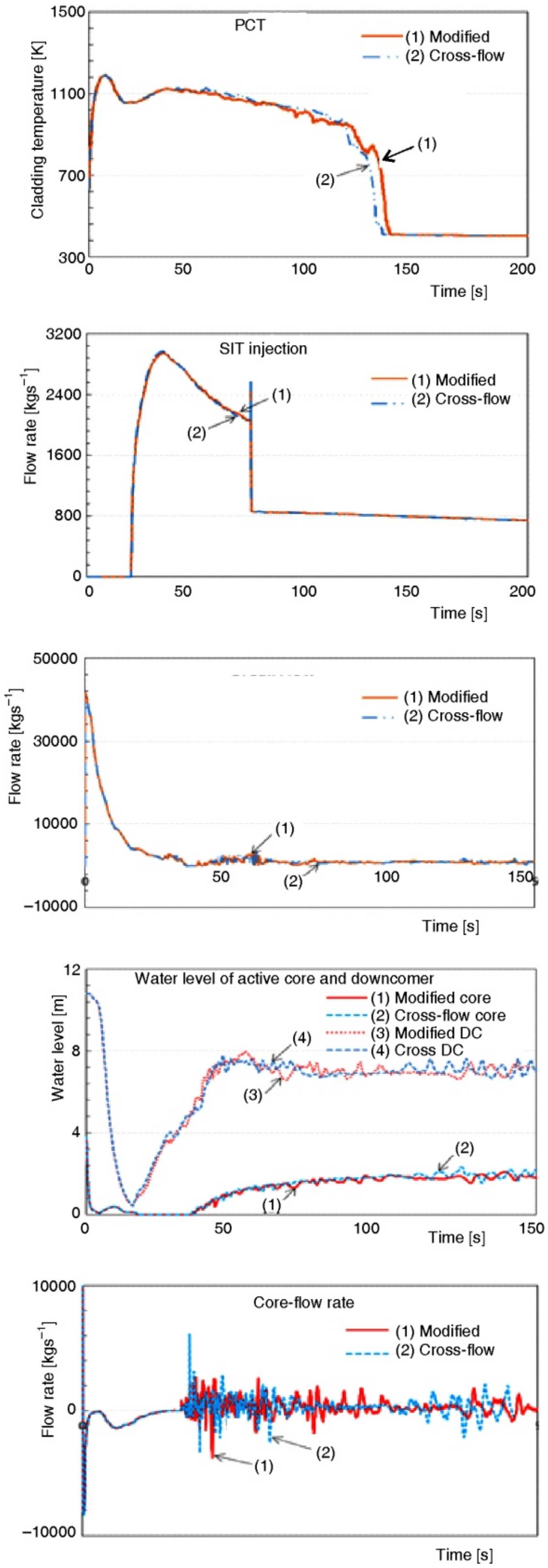
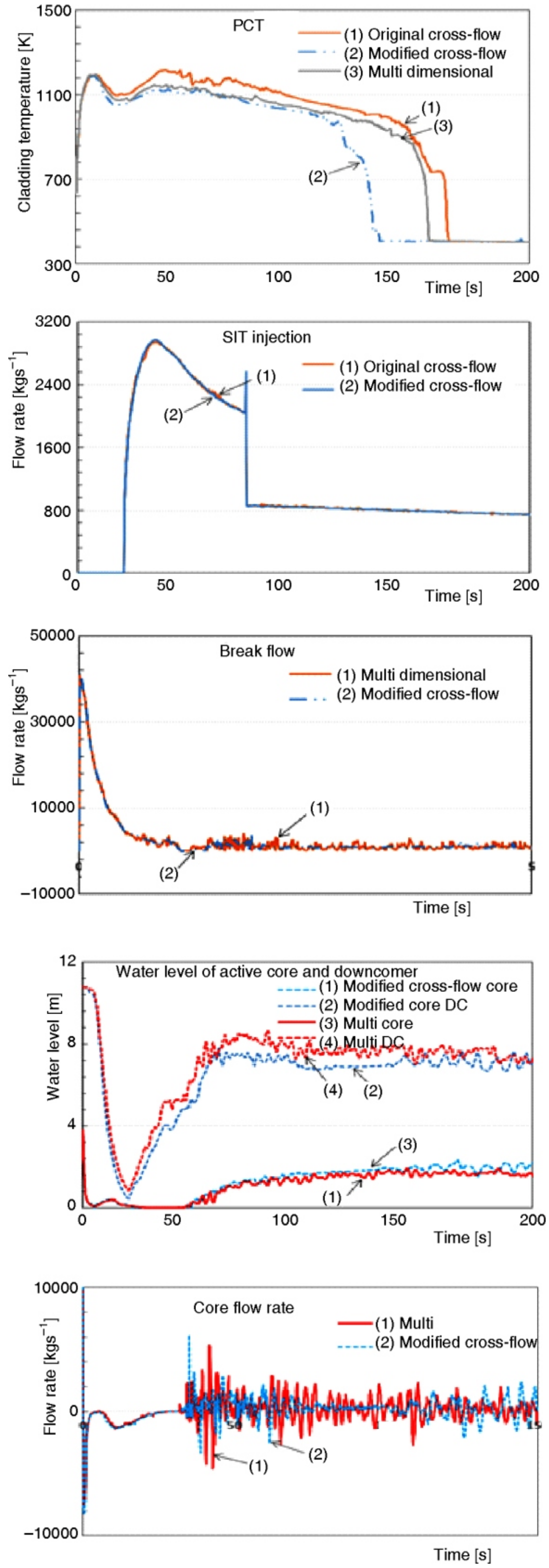



**Figure 7. Results of new input deck and deck with cross-flow option**




**Figere 8. Results of multi-dimensional input deck**

more calculations were achieved. Then the authors compared the results of both cases; the results of original inputdeck with cross-flow option and without cross-flow option, result of new inputdeck with cross-flow option and without cross-flow option.

In case of original input deck and new input deck, there was no critical change of PCT trend by using cross-flow option as shown in fig. 6, fig. 7. But PCT trends of both cases show rapid drop at end of PCT drift curve and new input deck shows more rapid drop. The downcomer is divided into 6 at the original

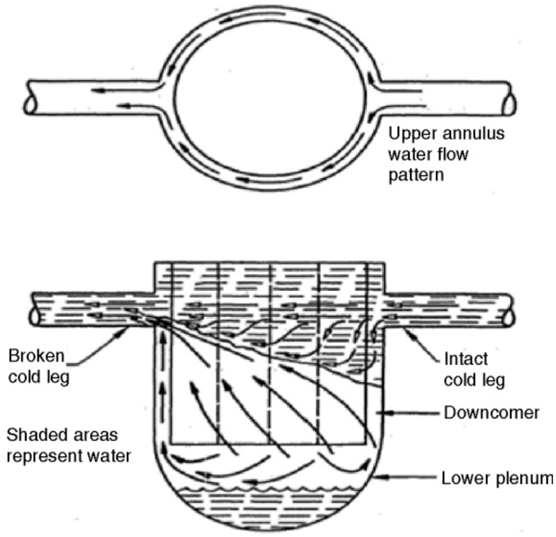



**Figure 9. ECC by-pass with ECC injection [15]**

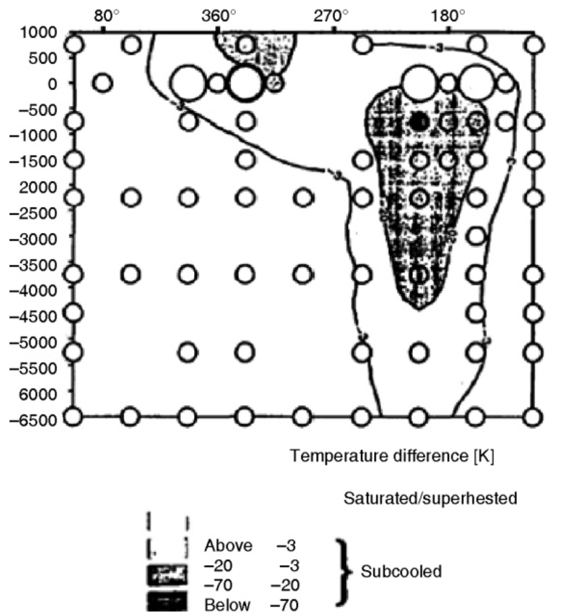



**Figure 10. End of blowdown phase – ECC by-pass [1]**

input deck and 12 at the new input deck. So, the new input deck has double number of cross-flow junctions applied the cross-flow options. It can be inferred that cross-flow option has more effects on PCT trend with new radial 12 divided nodalization.

In both cases, flow rates of SIT injection and break flow show similar trends regardless of using cross-flow option. There were some changes in water level of active core and downcomer and core flow rate. The clear relation between these changes and rapid drop of PCT was not found.

## The results of multi-dimensional flow model

In case of multi-dimensional downcomer model, PCT decreased more quickly than original input deck and PCT decreased more slowly than new input deck as shown in fig. 8. During high SIT flow period, PCT of multi-dimensional input deck show more similar trend with new input deck than the original deck. This is because the new input deck and multi-dimensional model share same dimensional values (volume, height) of downcomer. The PCT drop is delayed by using the multi-dimensional flow model.

## Coolant flow phenomena during refilling

ECC by-pass flow phenomena occure during the coolant refill period as shown in figs. 9 and 10.

After 30 s of cold leg "Break", coolant mass flow velocity vectors for each cases were checked. The velocities on junctions of each downcomer components are extracted and scattered on rectangle dimension as shown in figs. 11, 12, and 13.

Compared to original and new input deck, coolant flow of multi-dimensional model with cross-flow option shows more clear ECC by-pass phenomena (fig. 13). In case of original input deck, cold legs are connected to upper face of downcomer components and downcomer is divided by 6 azimuthal sectors. As shown in fig. 11, there is no clear by-pass trend from original input deck. Each coolant flow shows different flow patterns and there is no clear continuity of flow.

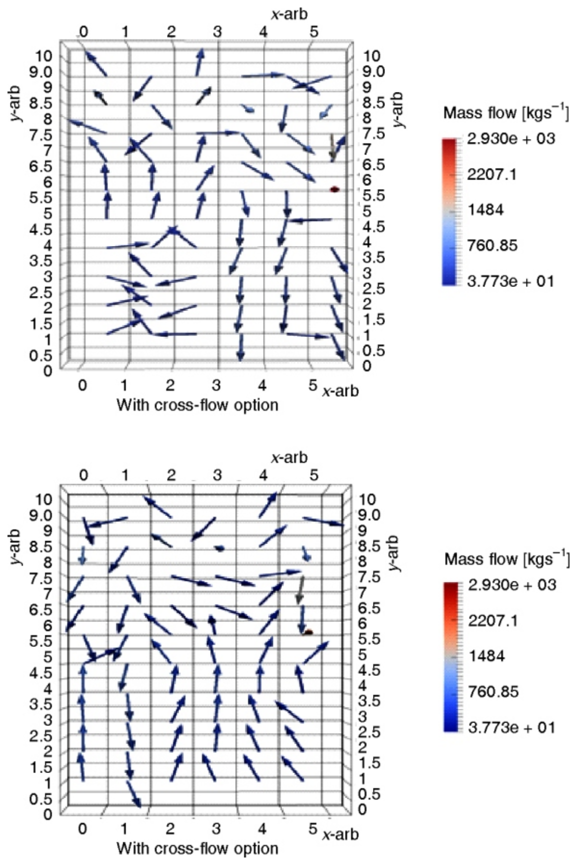



**Figure 11. Coolant flow of original input deck durign refill**

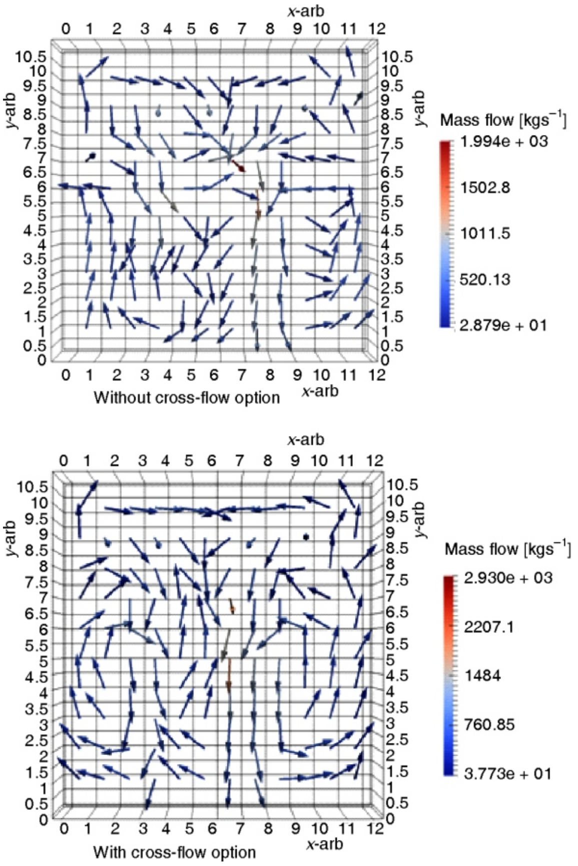



**Figure 12. Coolant flow of new input deck during refill**

Especially, flow patterns at the left bottom side looks irregular and flow patterns of the top region do not show ECC by-pass flow.

By using modified input deck, the ECC by-pass flow phenomena is better characterized and found to be consistent with both experimental report [1] and regulatory guide [14]. In case of multi-dimensional input deck (fig. 13), velocity vectors near break cold leg are heading for break cold leg location. ECC by-pass flow trend became clearer from multi-dimensional input deck. More velocity vectors are facing to break cold leg location and trend of by-pass flow velocity vectors on upper area flows very speedily.

## CONCLUSIONS

The sensitivity analysis for APR1400 nodalization based on MARS code was conducted with MARS-KS 1.4 Version. The analysis was processed under the LBCOCA of 100 % break size of cold leg case. The authors developed input deck with new downcomer nodalization and multi-dimensional downcomer model.

For sensitivity analysis under LBLOCA condition, we changed the original nodalization into finer nodalization; From 6 azimuthal sectors of downcomer region to 12 azimuthal sectors, and junction connections with 4 cold legs and DVI lines were modified for reflecting realistic cross-flow effect and real downcomer structure, then performed LOCA analysis with new input decks and compared with existing analysis results. PCT from new input and multi-dimensional input deck shows similar PCT trend from original input deck, where more rapid drop of PCT from new and multi-dimensional input deck than original input deck occured.. It can be concluded that no acceptance criteria [17] issue occurred even though new and multi-dimensional input deck are applied to LBLOCA analysis.

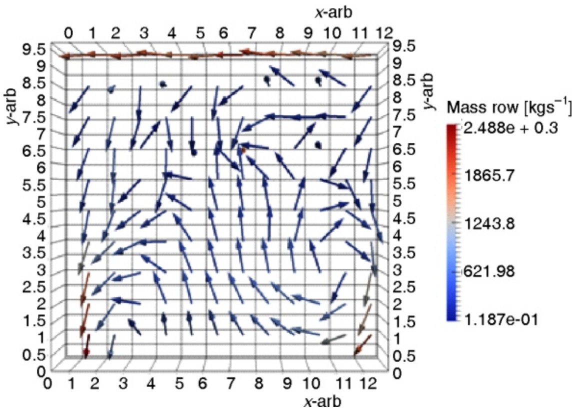



**Figure 13. Coolant flow of multi-dimensional input deck during refill**

The analysis of the effects of cross-flow option in MARS for LBLOCA was conducted. The cross-flow option has more effects on new radial 12 divided azimuthal sectors than 6 azimuthal sectors because 12 azimuthal sectors nodalization has double number of cross-flow junctions which apply the cross-flow options than that of 6 azimuthal sectors. ECC by-pass occurred during this refill period [14]. From this study, it can be inferred that the ECC by-pass flow phenomena from new input deck is better characterized and found to be consistent with both experimental report [1] and regulatory guide [14]. The authors verified that more realistic LBLOCA analysis could be conducted by new and multi-dimensional input deck.

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## AUTHORS' CONTRIBUTIONS

Theoretical analysis carried out by S.-Y. Lee. The manuscript was written, and the figures were pre pared by H.-W. Jang. All authors analyzed and discussed the results.

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## ИСТРЖИВАЊЕ ОСЕТЉИВОСТИ РЕЗУЛТАТА АНАЛИЗЕ АКЦИДЕНТА УСЛЕД ГУБИТКА ХЛАДИОЦА У ДОВОДНОМ ЦЕВОВОДУ APR1400 РЕАКТОРА У ЗАВИСНОСТИ ОД НОДАЛИЗАЦИЈЕ РАСХЛАДНОГ СИСТЕМА У MARS РАЧУНАРСКОМ ПРОГРАМУ

Појаве акцидената губитка хладиоца дуго се истражују и резултати експеримента показују да је стање протока хладиоца у доводном систему цевовода током завршетка тока акцидента у пуном обиму изразито мултидимензионално. Међутим, нодализација доводног система цевовода хладиоца у улазним подацима за случај целиког лома (LBLOCA акцидент) коришћен у досадашњим анализама АПР1400 реактора моделована је једнодимензионалном нодализацијом која је неодговарајућа да опише реалне појаве у хладиоцу током такве LOCA анализе. У овом раду, аутори су модификовали нодализацију главног расхладног система у LBLOCA улазним подацима MARS рачунарског програма и спровели анализу LBLOCA са новим улазним подацима. Уместо оригиналног LBLOCA пакета улазних података, нодализација главног доводног система хладиоца и разводних веза са 4 хладне гране и директним убризгавајућим цевоводима у суд реактора модификована је да прикаже реално дејство унакрсног протока хладиоца и праву структуру главног доводног система за хлађење. Резултати анализе показују да са новим улазним подацима максимум температуре кошуљице горива опада брже него у досадашњим анализама и да је смањење максимума температуре кошуљице последица примењеног побољшања услед допуне члана импулса флукса унакрсног тока хладиоца. Поред тога, аутори су развили нови пакет улазних података са мултидимензионалним нодализованим моделом главног доводног система хладоца и применили га у MARS програму. Коришћењем модификованог пакета улазних података, деловање интервентног система хлађења у случају акцидента боље је описано и утврђено је да је у складу и са експерименталним резултатима и са регулаторним упутствима.

*Кључне речи: LBLOCA, максимум температуре кошуљице, интервентни систем хлађења језгра, MARS код, вишедимензионална нодализација*