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Original Article

Method of estimating break size in piping loop systems

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A R T I C L E I N F O

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Loss of coolant accident (LOCA)
Temperature difference
Break size
MAAP5
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A B S T R A C T

The approach for determining the break size of recirculation loops in a multiple-loop power plant in the event of a loss of coolant accident (LOCA) is presented in this study. In this study, the MAAP5 simulation program was used. An approach to measuring the size of a crack or break in the cooling system is the temperature difference between the recirculation loops. This method does not require any additional facilities; it compares the temperatures of the cooling loops to determine which one has a rupture. The best data source was the loop monitoring system, which sends temperature data for analysis to the main control room. A real operating power reactor training simulator and the FSAR are applied to evaluate MAAP5, the methodology's engine. The results of the MAAP5 simulation code were consistent with those of the power plant simulator. Therefore, MAAP5 could produce enough analytical data to create the relationship diagram between temperature difference and break size.

The study hypothesized that there exists a maximum value of temperature difference corresponding to each break size and suggested that applying the absolute maximum temperature difference can aid in identifying the break size. This approach proposes an assistive method for determining the size of a fracture or break in the recirculation system by leveraging the temperature difference between each loop.

This approach eliminates the need for additional facilities, as temperature data from the recirculation loops can be transmitted to the main control room. After the reactor scram, operators can monitor the maximum temperature differences at the inlet to estimate the break size. Although the fitting curve used to preliminary estimate the Large Break Loss of Coolant Accident break size may overestimate the break size, it still provides valuable insights. This novel tool offers a rapid and comprehensive method for detecting LOCA events in the recirculation loops.

1. Introduction

A significant nuclear safety concern in the safety analysis of nuclear reactors is the loss of coolant accident (LOCA). LOCA is defined as the break or crack of the reactor pressure boundary or the valve being opened accidently; therefore, it causes the coolant to flow out of the reactor pressure vessel (RPV). That results in a decrease in the coolant inventory and even causes a severe accident to melt down the reactor core. When there is a break or crack in the pressure boundary of a nuclear reactor with high temperature and high pressure, the pressure, temperature, and flow rate of the system will be quickly out of balance, and the emergency core cooling systems (ECCS) will inject cooling water into the active region of the core, consequently avoiding the core heat-up or collapse. In general, peak cladding temperature (PCT) is frequently used as an evaluation index in the traditional LOCA analysis, as is cooling water loss from the rupture of the primary loops [1–4]. The full spectrum of the break size to the PCT in LOCA analysis showed that the break size is related to the PCT [5]. The ROSA-III Experimental Program utilized the THYDE-BI code to assess the results of computer codes for boiling water reactors (BWR). The summary of integral simulation test results is described on thermal-hydraulic behavior during a LOCA of a BWR and on the effectiveness of the emergency core cooling system (ECCS). The PCT value is influenced by the size of the break, initiation of ECCS injection, and initiation of Automatic Depressurization System (ADS) venting and etc. The JAERI-1307 report describes how the ROSA program conducted integral simulations and tests for BWR LOCA/ECCS. It established Break Area Spectrum Tests for the recirculation loop pump suction line, inlet section, and break sizes ranging from 0 to 200 %. The measured PCTs ranged were lower than the licensing criterion present. The size of the break, the initiation of ECCS injection, the initiation of Automatic Depressurization System (ADS) venting, etc. [6]. The experience with a large break LOCA (LB-LOCA) showed that there was a

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significant difference between the default input data for computer code models and the predicted or calculated PCT [7].

According to Hou et al., research showed that when LOCA occurs, the temperature changes at the inlet and outlet ends of the cooling loop were related to the size of the break [8]. They utilized the RELAP5 program to investigate the impacts of different sizes of breaches in the coolant loop on the safety systems, drawing from the large break incident in the cold-leg pipeline at the CNP plant for simulation and analysis purposes. The total simulation duration for the system was 1000 s, with the transient break initiated at 200 s following the attainment of a steady state. The paper presented the variations in flow rate, pressure, temperature changes with time, within the intact loop and the broken loop following a LOCA. The results indicate that the larger the break, the faster the decrease in coolant inlet temperature.

In JAERI-Conf. 99-005, Yasuharu Kawabe et al. compared the MAAP code and the RELAP code, which showed” both codes had almost the same tendencies even in the case when accident management measures were not used.” [9,10].

The MAAP5 program is used to generate the different break size to obtain the temperature difference when LOCA happened. By using the MAAP5 program to simulate the phenomenon described in Hou et al. and decide if this phenomenon exists. Consequentially, it can be confirmed that this phenomenon is not accidental and is a common case. As early as ITOYA et al.’s chart data in many research reports on the ROSA-III experiment, it can be seen that the temperature at the inlet of the cooling loops does change after LOCA occurs [9,10]. According to 10 CFR 50.46, which modifies realistic or best-estimate approaches for LOCA safety analysis, other realistic LOCA transient simulations must be run in order to conduct a realistic analysis [11]. The MAAP5 program was verified by the Final Safety Analysis Report (FSAR) report and the training simulator records.

The goal is to estimate the break size that occurred at the recirculation loops by building a break size spectrum using the verified MAAP5 program. The result was then contrasted with the break spectrum constructed in the K. Nikitin KKM reactor and ROSA-III by PCT [5,6,12–14].

2. Method and verification

This study utilizes the MAAP5 program to simulate the reactor and subsequently compares the obtained results with both FSAR design values and the recorded values from the operator training simulator to validate the installation of the MAAP5. Therefore, the verification process will proceed in the sequence of first comparing against FSAR, followed by comparison against the simulator. The MAAP5 program, upon completion of verification, will be utilized to establish spectrum, for break size and temperature difference. A detailed analysis of the process will be provided separately in the following sections.

The first part aimed to confirm that the MAAP5 simulation program was followed by the initial settings of a power plant. The FSAR design values were compared with the simulated results of the MAAP5 program in order to verify the accuracy of the simulations.

By following these procedures, it is possible to achieve the goal:

To verify the consistency between MAAP5 and the reactor behavior, initially, the data obtained from the simulated reactor under steady state conditions should match the design values of the reactor’s FSAR. First, a steady-state calculation was performed using the nominal thermal power, and the second was involved in the LOCA simulation using the MAAP5 software. Then, the transient computation could be carried out. Initially, a 24000 s real-time run was conducted, incorporating the built-in control system governing vessel level, recirculation pump speed, and core mass flow rate. The results were compared with the FSAR report. After that, each experiment consisted of a 100-s full-power steady-state operation that behaved steadily up until the recirculation loop’s suction inlet broke. The comparison of the results of MAAP5 and the FSAR is shown in Table 1, demonstrating that the relative error between them are less than 1 %, meeting the requirements of the computer program simulation. The errors for each response were less than 1 % of the FSAR-designed values, satisfying the model’s allowable range [15]. Table 1 lists the reactor pressure at the steam line, the inlet temperature, the water level, the flow rate, and the deviation of each parameter consistent with the designed value. This indicates that this MAAP5 program deck can adequately represent this power plant.

Table 1
The MAAP5 code simulated an operating reactor at full power 3001MW$_t$.

	Designed	simulated	error[a]
RPV steam pressure (psi)	1040	1038	−0.19 %
Lower plenum temperature (K)	551	549	−0.36 %
Shroud head water level (m)	14.16	14.15	−0.071%
Core flow-rate (Kg/S)	10650	10571	−0.74 %

[a] Error is defined as: [(simulated-designed)/designed] × 100.

Next, the steady-state operation results of MAAP5 will be compared with the data recorded by the operator training simulator. In the normal operation of a reactor, the simulator indicated that the temperature at the recirculation loops were 550K (277 °C), while the temperatures calculated by the MAAP5 were 549.9K (276.9 °C); and the reactor pressure was 72.14 bar (1046 psi). and the flowrate at the recirculation loops were listed in Table 2. The list of the simulator’s parameters corresponding to the MAAP5 code is provided.

Based on the comparisons outlined in Table 1 for MAAP5 versus FSAR and Table 2 for MAAP5 versus the simulator under steady-state conditions, the results demonstrate consistency among the MAAP5, FSAR, and the simulator sources at the steady-state. Therefore, transient experiments can be conducted to further validate the MAAP5 program. In this regard, Station Blackout (SBO) and LOCA experiments were selected on the simulator for verification against MAAP5 simulations.

Fig. 1 is a schematic diagram of the relevant locations and corresponding parameters where the experiments will be carried out in this study.

Fig. 2 demonstrates an NPP under an SBO accident simulated by the training simulator, wherein the temperature difference between the two loops is represented by a yellow line, which coincides with a horizontal line. Due to the absence of a break at the recirculation loops, there was no temperature difference between the two loops. It is clear that the temperature at each recirculation loop inlet is close and stays at the same value when there are no breaks in each loop. The data of BBA92 (an intact loop) is represented by the green line, and the data of BBA59 (a broken loop) is represented by the blue line. The lines in blue and green are nearly identical to one another. The temperature difference between loops BBA59 and BBA92 is nearly zero, as indicated by the yellow line.

In this scenario, the nuclear power plant experiences n scram solely due to SBO, thus, there is no occurrence of temperature difference between the recirculation cooling loop.

Another experiment, LOCA, was conducted to compare the previous scenario of a SBO with a broken pipe in recirculation loop A (BBA59). The results of this experiment are demonstrated in Fig. 3, which shows the record of the simulator at an LOCA. The reactor was in normal operating condition at 14:36:14 p.m. before the LOCA occurred. Fig. 3

Table 2
Partial parameters in the simulator correspond to the MAAP5.

Parameters in the NPP	Simulator output	MAAP5 output
Reactor pressure vessel, Pressure	AEA84/1046psi	PEX0(1)/1038psi
Temperature at the recirculation loop A	BBA59/277.11 °C	TWRCS(12)/ 277 °C
Temperature at the recirculation loop B	BBA92/277.11 °C	TWRCS(14)/ 277 °C
Flow rate at the recirculation loop A	BBA05/17.63 kg/s	WW(12)/19.0 kg/s[a]
Flow rate at the recirculation loop B	BBA06/18.29 kg/s	WW(14)/19.0 kg/s[a]

[a] The power of the reactor has been uprated [16], the flowrate can be changed.

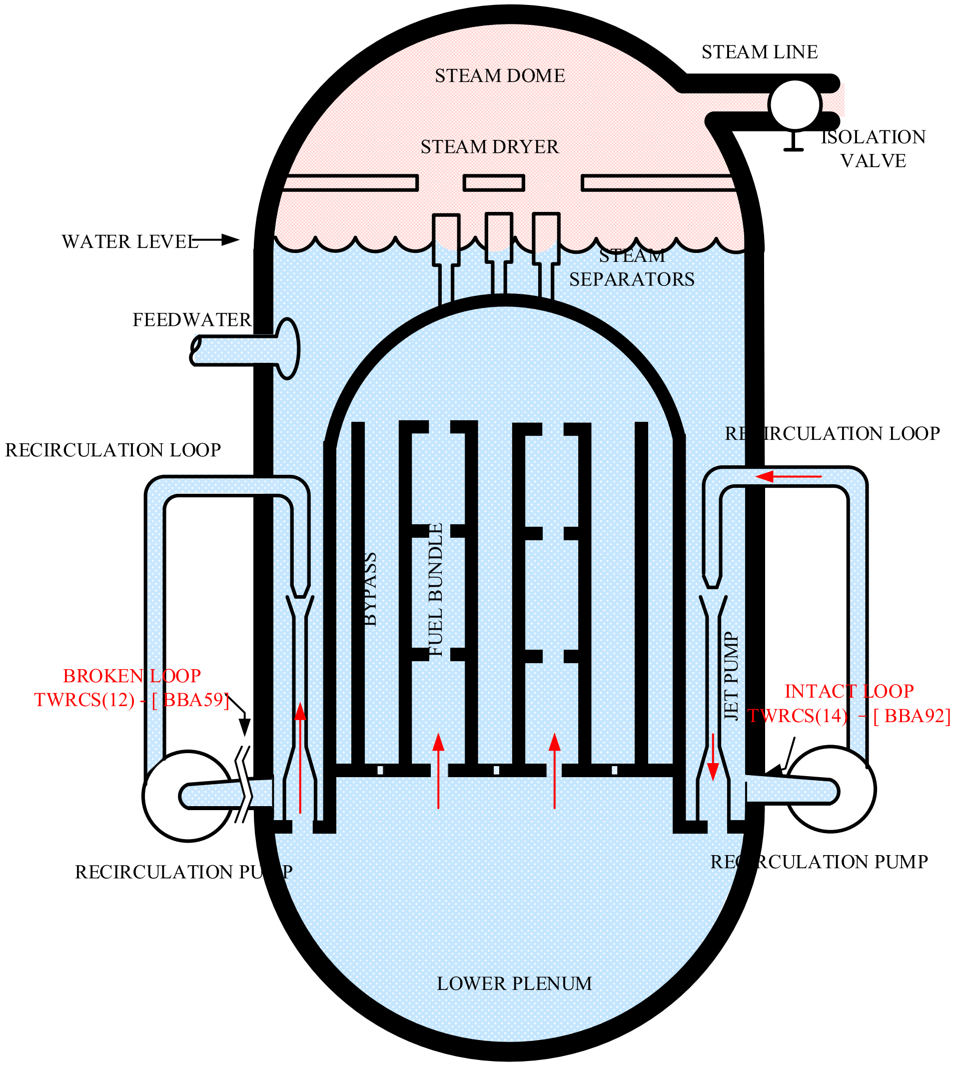

Fig. 1. The relevant locations and the parameters of the experiment.

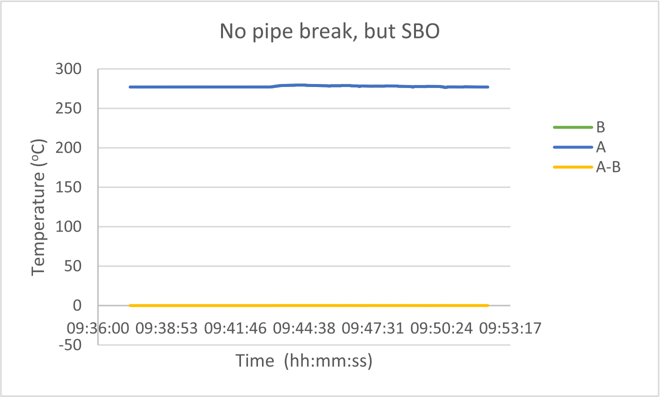

Fig. 2. Shows the temperature difference between the two loops of the training simulator during an SBO accident without any loop ruptures.

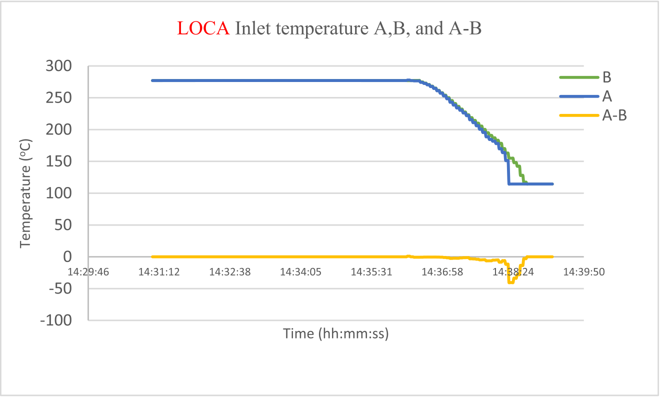

Fig. 3. The simulated temperature at the inlet of loop A and B, when an LOCA accident occurred by the training simulator.

was an extracted result of the simulator to an LOCA. The inlet temperature at loop A (BBA59) was different from the inlet temperature at loop B(BBA92). Where the green line is the intact pipe (BBA92), the blue line is the broken pipe (BBA59), and the yellow line is the temperature difference between the two loops. According to the result of the simulator, the temperature difference between loop A (BBA59) and loop B (BBA92) began at time 14:36:14 and lasted until 14:38:47, and the temperature gap was up to 40 °C. The results of the simulator indicated that the pipe break can lead to a temperature difference between the intact loop and the broken loop.

In Fig. 3, the reactor scrammed at 14:36:31, and the temperature difference between the inlet recirculation loops began to increase until

14:38:49; the duration was about 200 s. The temperature difference between the inlets can be obtained after the reactor scram, as demonstrated by the simulator in Fig. 3. It is found that the temperature difference is a temporary situation, and operators can follow the operation procedure guidance while paying a little attention to the temperature changes between the recirculation loops. Figs. 2 and 3 respectively illustrate the differences in temperature difference between the recirculation cooling loop of the reactor training simulator during SBO and LOCA scenarios. It is confirmed that the temperature difference was caused by the broken pipe. On the simulator, the temperature difference phenomenon resulting from a LOCA caused by a break in the recirculation piping loops can be clearly distinguished. The concern lies in whether this phenomenon can be accurately simulated by the MAAP5 program.

The next step is to verify if the training simulator exhibits the same behavior as the reactor and if the MAAP5 program can be used to simulate SBO or LOCA events. Using the MAAP5 program to simulate the break pipe experiment at the loop, as Fig. 4 shows, the temperature difference between the two loops was then determined. The temperature at TWRCS(12) and TWRCS(14) represented the temperature at the recirculation loop A (TWRCS(12)) and loop B (TWRCS(14)). If the break occurred at loop A (TWRCS(12)), the consequence indicated that the temperature at the intact loop is higher than that at the broken loop, and the temperature difference varies with time. And, as expectedly there was no temperature difference also between the recirculation loops in an SBO event, that simulated by the MAAP5.

Simulation data by MAAP5 or the simulator demonstrate that the broken pipe is the source of the temperature difference between the recirculation loop inlets during a reactor's LOCA accident. The temperature at the broken loop is obviously lower than the temperature at the intact loop when the recirculation loop breaks. This same appearance can be seen in both the MAAP5 program and the training simulator, as in Figs. 3 and 4.

A simulator that replicates the accident progression process brought on by malfunctioning or damaged components is used for staff education and training. The primary goal of a simulator is to teach operators how to respond to different accident scenarios by following procedure guidelines. For this reason, it is crucial to remember that the LOCA is only one of the topics covered in training programs that teach operators how to handle emergency facilities in the event that there is a risk to the power plant's safety and how to comply with regulations. Consequently, there cannot obtain enough data for the experiment from the training simulator.

Even though the break's size is adjustable, the open valve can never exactly match the actual break size. Since it is impossible to confirm the precise size of individual fractures, the maximum open valve value is the only value that can be chosen as a representative of the LOCA break size. In general, the demarcation between large and medium breaks in a main coolant pipe is defined as the break size equal to 10 % of the pipe's cross-section area, and the demarcation between medium and small break is defined as the break size equal to 2 % of the main pipe's cross-section area [8]. The design of the LOCA break simulation experiment was assumed to follow this rule. It assumed that the training simulator's large break on the recirculation cooling loop represents a 10 % of the pipeline break area.

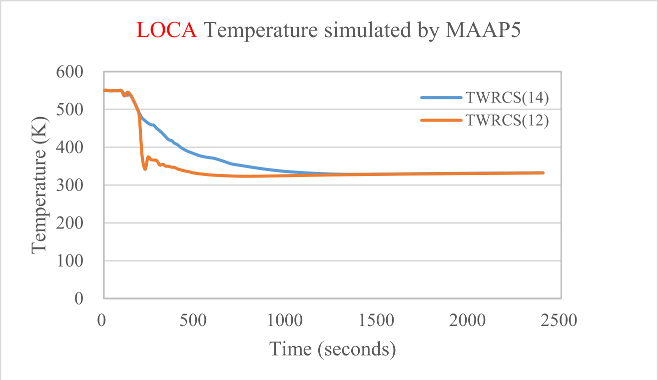

Fig. 4. The temperature at the recirculation loops, which simulated by MAAP5 program.

In reality, there is only one option for the LB-LOCA's break size 10 % (~203 cm^2) of the cross-section in this training simulator. In Fig. 3, the maximum temperature difference between the inlets was approximately 40 °C, based on the data that the simulator obtained. In MAAP5 calculations, it was found that when the break size is 10 %(204 cm^2), the temperature difference in the recirculation loop is 36 °C. The deviation between the MAAP5 calculated and the simulator obtained is 10 %. Temperature difference calculated by the MAAP5 program is 36 °C, while in the simulator, it is 40 °C, indicating that that assumption is reasonable. Based on this, it can confirm that the relationship between the break size and temperature difference established by the MAAP5 program calculated data for the recirculation loop is feasible.

The data built by MAAP5, as demonstrated in Fig. 5, the break sizes from a 2-cm square to a 2000-cm square rupture at the recirculation loop A, and the temperature differences varied with time. Here, the area of the break described by a percentage of the entire size of the recirculation loops (20 inches in diameter) of the break. However, it seemed that the temperature differences are roughly related to the broken size. This irregularity could indicate complexities in the system or interactions between different variables that affect the temperature. Sampling at different times may lead to different consequences when estimating based on temperature differences, so far the sampling time was 2400 s.

According to the consequence of the simulation by MAAP5, the distribution of temperature difference varied with time. The vertical red dash line indicated the 200 s after reactor scrammed, as shown in Fig. 5. Despite the duration of the lasting time of the temperature difference of MAAP5 is longer than by the training simulator, but they demonstrate a same trend that the temperature difference is related to its break size. Herein, the temperature difference is defined as the intact loop temperature minus the broken loop temperature, the positive value means that the temperature at the broken loop is lower than at the intact loop. At the same time, there appears to be a pattern: the temperature difference at the inlet of the recirculation loop is associated to the size of the break size. Specifically, the larger the break size and the higher the temperature differences are. Hou et al. thought that the temperature difference between the broken loop and the intact loop was because of the recirculation pumps out of service, then the coolant flow slowed down and the coolant was overcooled in the heat exchanger leading to the inlet temperature decrease [8].

Therefore, a brief conclusion is obtained that the inlet temperature difference has the potential to assess the break size of the recirculation loops within a few seconds after a reactor scram. The operators only have to pay attention to the temperature difference at the inlet of the recirculation loops shortly after the reactor scram. Although the consequence of the previous figures has demonstrated that the temperature difference at the inlet can connect to the size of the break at the recirculation loop. However, it is still a complicated process, and that needs further analysis to clearly highlight the relationship between the temperature and the break size.

3. Result and disccssion

Based on the GE drawing of this power plant, the inner diameter of the pipe of the recirculation loop is 20 inches, with a cross-section of 2027 cm^2. The scenario was established as follows: while the reactor is operating under normal conditions at full power, at t = 100 s, a pipe rupture occurs at the recirculation loop A. After the LOCA accident, the reactor safety injection systems started sequentially to perform their functions according to the originally set points for the system. Herein,

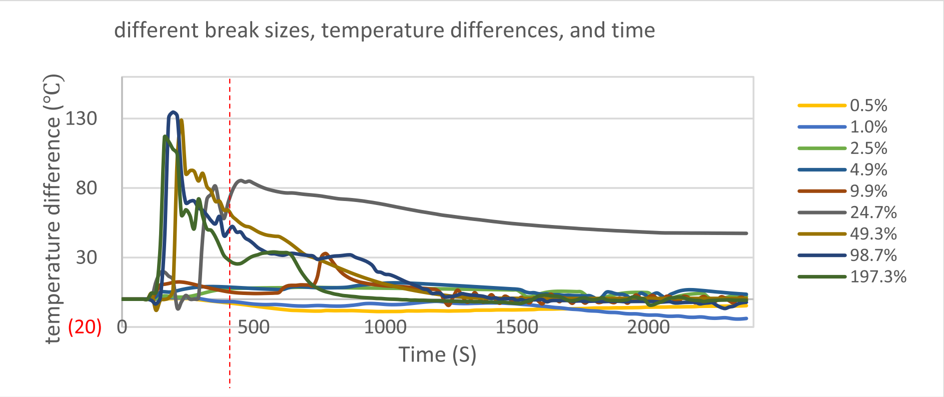

Fig. 5. Demonstrating the temperature difference (°C) between the TWRCS(14) and TWRCS(12), and with the break size from ~0.1 %(2 square centimeter) to 198 % (4000 square centimeters).
*If double-ended guillotine break (DEGB) is taken into account i.e. the break size is equal to 200 %.

the cross-section of the break size was represented by 0.1 %, 0.2 %, 0.5 %, 1 %, 2 %, 5 %, 10 %, 25 %, 50 %,100 %, and 200 %; as K. Nikitin et al. [5].

Approaching the qualitative analysis of this temperature difference data collected through observations and interpreting it. When the pipeline pressure continues to drop, the flowrate of the coolant leakage from different break sizes in the pipeline should have individual limits. A hypothesis suggests that there is a maximum temperature difference for individual break size after the scram. By taking the absolute value of the maximum temperature difference for each break size, a spectrum can be built by the break size to its corresponding temperature difference; and the result is demonstrated in Fig. 6. Herein, the break size was described by the percentage of the pipe cross-section of the recirculation loop to the corresponding temperature difference. Based on this, the responses of the other break sizes can still be ascertained in order to construct the break size spectrum.

This temperature difference of the simulator when the valve fully opened is 40 °C, which corresponds to a break size of 12 % (or 227 cm^2). The polynomial function was utilized to fit the data, exhibiting the correlation between the temperature difference and the break size. The sampling period is extended to 300 s to establish the relationship between the break size and the absolute temperature difference. Based on the equation, the estimated break size is approximately 227 cm^2, and the error of this break size is overestimated at approximately 12 %. This is not a very good result, but from an experimental perspective, it is consistent with the trend. The size of the break at the recirculation loop's inlet section can be estimated from the MAAP program's results because they can conform to the simulator's changing trend under LOCA.

In Fig. 6, even if the sampling time interval of Hou et al.'s experiment is changed to 1000 s, the results are the same. The maximums absolute temperature difference and its corresponding break size was written in the following form by the EXCEL.

$$y = -268.55x^2 + 402.96x - 1.8402 \tag{1}$$

And.

x represents the break size in percentage to 2027 cm^2, it must less than 100 %
y represents the absolute maximum temperature difference, in °C

It is convenient for the operators to have a quick preliminary estimate of the break size. It must be emphasized here that equation (1) formula will have a different correspondences depending on the specific unit of the power plant.

Operators can preliminarily estimate LOCA break size using the fitting curve equation (1).

Here below are some examples of a regular operating NPP, which suffered under a LOCA accident, after the reactor scrammed.

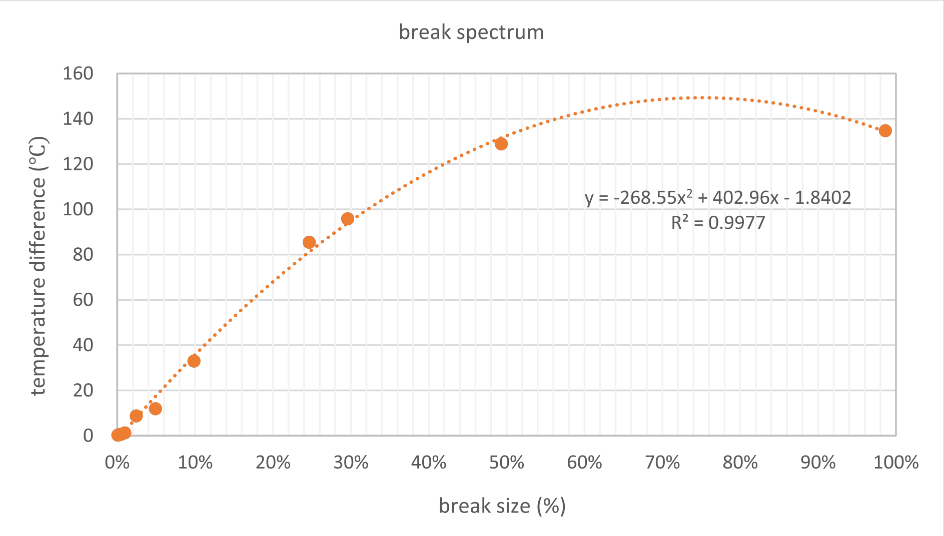

Fig. 6. The absolute maximum temperature difference between the broken loop and the intact loop.

Case1.

According to the data obtained by the simulator, the maximum temperature difference between the inlets was about 40 °C (Fig. 3).

Here, if the training simulator of the valve is fully opened the break area is equal to 10 % of the cross-section area of the main pipe. This means that the break size is about 203 cm^2. If the break size is 203 cm^2 in the MAAP5 program, the obtained temperature difference is 36 °C.

According to Equation (1), this temperature difference corresponds to the break size 11.2 % (or 227 cm^2), which means the error of this break size is 12 %. Even though the break size calculated using Equation (1) is only 11.2 % of the cross-section area of the main pipe, with an error of 12 %, it demonstrates the feasibility and accuracy of estimating the breach size using this method.

Case2.

In another case, if the maximum temperature difference is detected to be 90.2 °C, then according to equation (1), the estimated break size is a 27.2 % (or 551 cm^2) break; actually, the preliminary break size is set at a 32 % (or 650 cm^2) break. In Fig. 6, the fitting curve to the break size has an 5 % deviation. As shown in Fig. 6, it's evident that for an LB-LOCA or larger break sizes, the preliminary estimated break size may have a little underestimated.

Case3.

If the sensors at the inlet of the recirculation loops observe a maximum temperature difference of 11.9 °C. The operators can take this data 11.9 °C onto the left side of Equation (1) or as shown in Fig. 6 and then they can obtain a preliminarily break size whose cross section area is approximately 3.5 % (or 70.8 cm^2). This is only within 200 s after the scram.

It is possible to predict the size of a rupture in recirculation pipes based on the temperature difference, without the need for additional tools or technologies. Based on the aforementioned CASE study, the following conclusions can be succinctly listed: if the temperature difference is less than 7 °C, the break is considered small; if the temperature difference exceeds 36 °C, it indicates a large break.

The deviation in the estimated break sizes indicates that the results are within a reasonable range of the estimation, even though the estimated preliminary large break sizes can overestimate or underestimate. The curve fitting for the break size against the temperature difference is satisfactory. The most important thing is that this method does not require any installing components; just watch the recirculation inlet temperature measured device within a short time period after the reactor scram.

However, each component or device has its own error when measuring an actual temperature. According to Ho's report [17], which associated to the guidance for the temperature measurement devices, the acceptance criteria for resistance temperature devices (RTD) is as follows:

Every RTD was checked during each refueling process. The acceptance criteria for RTDs used in nuclear power plant cooling loops dictates that measurement results should not exceed or fall below 0.28 °C from the average value of other 24 RTD devices of the same type. Therefore, 0.28 °C can be considered as its deviation. The standard deviation of the subtraction operation is 0.28 °C multiplied by the square root of 2, yielding 0.4 °C as the standard deviation of the RTD. Any measured data less than 0.4 °C can be regarded as error or noise. Upon examination of the data in this study, it is observed that when the break size is less than 0.5 %, the temperature difference between the two circuits remains below 0.4 °C. Therefore, it can be inferred that this method can reliably identify breaks above 0.5 %.

While there may be some inaccuracies by the temperature difference method used to determine the LOCA break size in the recirculation loop, it is an easy method that does not require any extra tools. The operator only needs to monitor the temperature difference at the recirculation loops after the reactor scrams. In the event that there is no temperature difference between the loops, LOCA is not the source of the scram. The recirculation loop must have broken if there is a temperature difference, and the break may not have been larger than what the fitting curve shows.

Here we compare the difference between using PCT to estimate the break and using temperature difference to estimate. These data were caught by a GetData Graph Digitizer program [18] to gets raw data of visual graphs for analytical purposes at TASAKA ROSA III and K. Nikitin KKM reactor. Both KKM and ROSA result demonstrated the PCT spectrum with the break size that relates to a logarithm. The distribution of TASAKA break size in Fig. 7 displayed the PCT closely to 800 K, the regularity of KKM is not obvious. In comparison, the relationship between the maximum temperature difference and the crack size is more obvious, as shown in Fig. 6. Thus, the temperature difference between the inlet section can be an assistance parameter to the PCT in determining the break size.

Although KKM experiment demonstrated the highest and the lowest PCT changed as high as 1000K, its rules are not obvious; and the ROSA experiment PCT was only around 800K.

4. Conclusion

This study employed recorded data from a nuclear reactor training simulator to validate the results of the simulation code MAAP5 for a rupture at the recirculation loop pipe LOCA. Rather than relying solely on physical experimentation, this method makes effective use of computer programs to produce insightful results. Verifying the response to the MAAP5 program with the FSAR and the training simulator consistency was the initial goal of this comparison. An aligned MAAP5 program is an important tool for research due to the difficulty of achieving the scenarios through practical experiments. Then, the MAAP5 program helps to build the break spectrum at the recirculation loops. This study showed the temperature differences between cooling loops during a LOCA. It was confirmed that the temperature difference at the inlet of the coolant recirculation loop is related to the LOCA break size but not a SBO. This study proposes the bold hypothesis that there exists a maximum temperature difference for each break size, and we assume that applying this absolute maximum temperature difference can identify the corresponding break size. Determining the LOCA break size based on the maximum temperature difference at the recirculation water inlet offers several benefits.

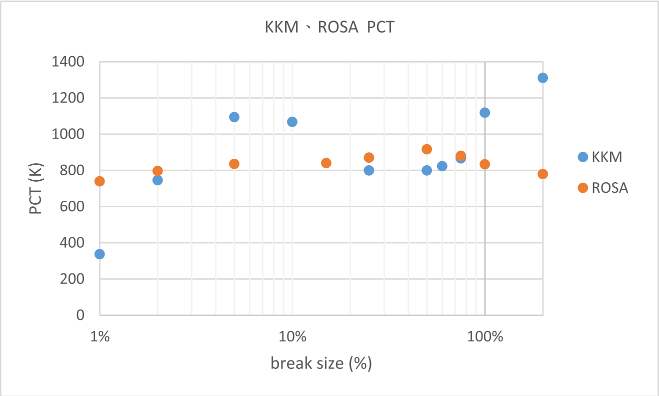

Fig. 7. Lists the PCT and fracture size data established by the ROSA III and K. Nikitin KKM simulation experiment.

1. The monitoring system provides temperature data at each recirculation water inlet without the need for additional sampling equipment.
2. Operators can assess the break size of the LOCA event at the loop by monitoring the temperature difference at the inlet within the window of time following the reactor scram.
3. Furthermore, the temperature difference between the inlet at the broken loop and the intact loop can determine the ruptured loop.
4. Although this scenario is specific to a nuclear reactor, the existing temperature difference between the ruptured and intact pipes in the coolant loop may be applicable to other types of piping systems.

By utilizing the temperature difference between each loop, it can not only determine the size of a fracture or break in a recirculation system but also indicate which loop has a rupture. Importantly, there is no need to install additional facilities, as the temperature at the recirculation loops can be transmitted to the main control room. Based on this, the operators can have a good idea of the break size of the break of the LOCA shortly after the reactor scram. In the future, if there are experimental equipment capable of providing more information about the temperature difference between break and intact loops, it should be possible to establish a more comprehensive relationship between temperature difference and the break size. And, if the temperature difference is less than 7 °C, the break size is considered small; if the temperature difference exceeds 36 °C, it indicates a large break size.

To summarize, the absolute value of the maximum temperature difference approach provides a practical tool to preliminarily determine the magnitude of a break in the recirculation loop, especially within 2∼300 s after the reactor scram, without the necessity for additional specialized instruments. Operators can monitor the maximum temperature differences at the inlet to preliminary estimate the break size during a short time after LOCA, although some LB-LOCA may miss estimating the size based on the mentioned fitting curve. The temperature difference between the inlet section can be an assistance parameter to the PCT in determining the break size.

Although, this study confirms the feasibility of establishing the relationship between break size and temperature differential through the method of using simulation programs. However, we will endeavor to further organize the data that meets the criteria from additional sources to identify a research that better aligns with actual data for further comparison, with the aim of further demonstrating its reliability.

CRediT authorship contribution statement

Sheng-Dih Hwang: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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