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STUDY ON THE ACCIDENTAL RUPTURE OF HOT LEG OR SURGE LINE IN SBO ACCIDENT

Kun, Zhang*
Department of Nuclear Science and System Engineering, Shanghai Jiaotong University,
Huashan Road 1954, Shanghai, 200030, China
Phone & Fax: +86 (21) 62933916,
E-Mail: zhangkun@sjtu.edu.cn

Xuewu, Cao
Department of Nuclear Science and System Engineering, Shanghai Jiaotong University,
Huashan Road 1954, Shanghai, 200030, China
Phone & Fax: +86 (21) 62933916,
E-Mail: caoxuewu@sjtu.edu.cn

ABSTRACT

The postulated total station blackout accident (SBO) of PWR NPP with 600 MWe in China is analyzed as the base case using SCDAP/RELAP5 code. Then the hot leg or surge line are assumed to rupture before the lower head of Reactor Pressure Vessel (RPV) ruptures, and the progressions are analyzed in detail comparing with the base case. The results show that the accidental rupture of hot leg or surge line will greatly influence the progression of accident. The probability of hot leg or surge line rupture in intentional depressurization is also studied in this paper, which provides a suggestion to the development of Severe Accident Management Guidelines (SAMG).

INTRODUCTION

The core melt at high pressure in nuclear power plant may cause severe accident results, such as Direct Containment Heating (DCH) which challenges the integrity of containment. Therefore, intentional depressurization at primary and secondary sides is considered in the development of SAMG to reduce the high pressure in the progression of core melt. However, according to the research results of Idaho National Engineering Laboratory [1,2,3], the overheated steam and large pressure difference may cause the rupture of hot leg and surge line before the lower head of RPV ruptures in the SBO accident. The accidental rupture of hot leg or surge line will cause the RCS depressurization and prevent the core from melting at high pressure, but it will also change the progression of accident in an uncertain way. Therefore, it is necessary to study the accident progression considering the rupture of hot leg or surge line.

This paper includes four cases. The postulated SBO accident is choosen as the base case. Case 2 considers the rupture of hot leg or surge line in base case. Case 3 and case 4 consider both the rupture of hot leg or surge line and the intentional depressurization in base case. All the accident progressions are analyzed in detail using SCDAP/RELAP5 code.

DESCRIPTION OF PLANT

The plant is a PWR NPP with 600MWe in China, which contains two loops. The important data of the plant are shown in Table 1.

TABLE 1. Data of the Plant

Reactor Power	1930MW
Reactor Coolant System (RCS) Average Temperature	583.15K
Pressurizer Pressure	15.5Mpa
RCS Mass Flow Through One Loop	4997kg/s
Steam Generator (SG) Pressure	6.86Mpa
SG Level (Narrow Range)	13.3m
Turbine Inlet Steam Flow	541.9kg/s

CALCULATION MODEL

The calculating model is built using SCDAP/RELAP5 code (Fig.1). The primary side of the plant model mainly consists of the pressurizer (PRZ), SG, RPV, reactor coolant pump (RCP), and safety injection system. The secondary side model consists of main feedwater system (MFW), auxiliary feedwater system (AFW), main steam pipes, turbines, etc.

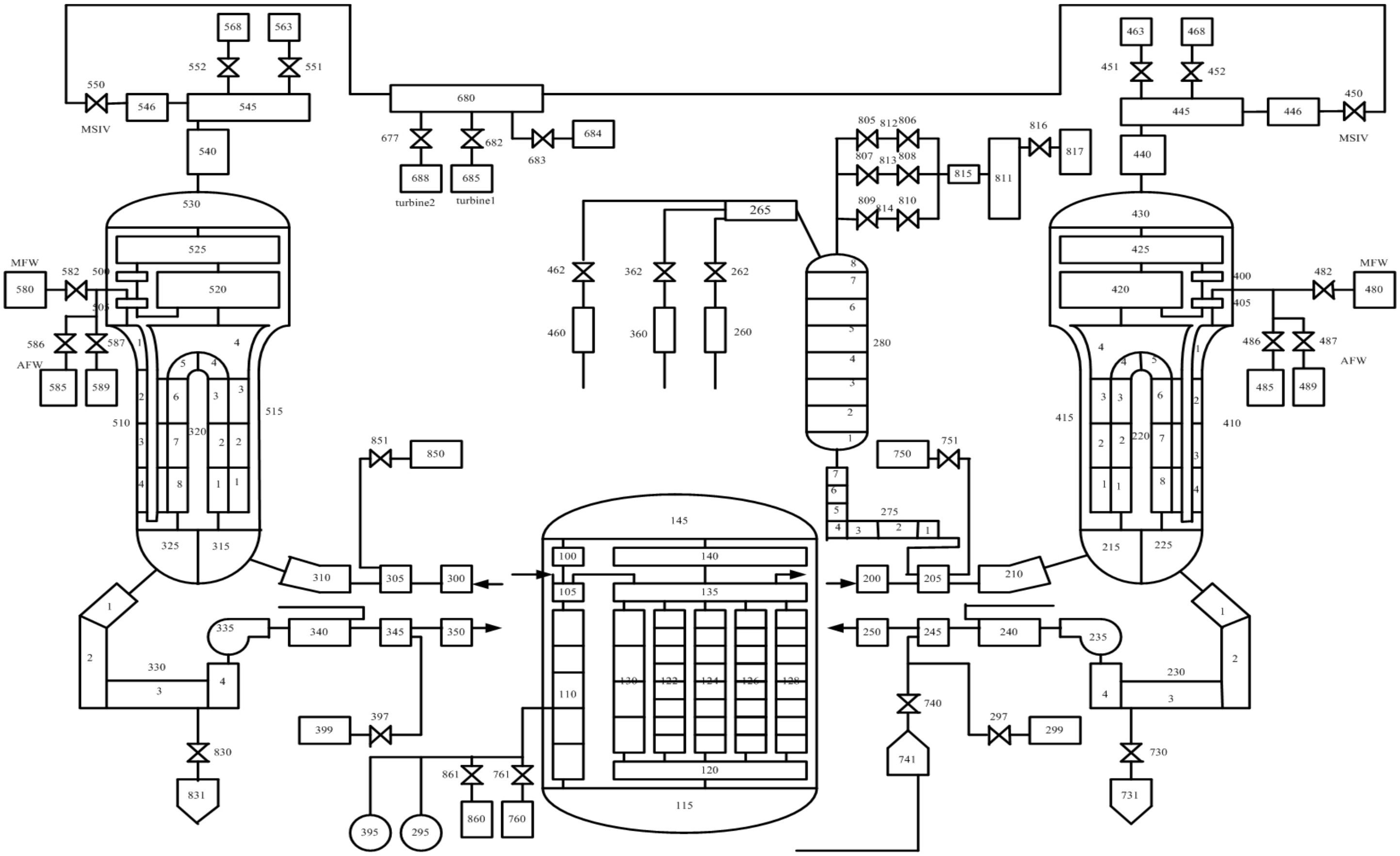

Fig.1 Plant model

DESCRIPTION OF BASE CASE

Accident Assumptions

This paper makes the following assumptions to the base accident: the plant loses all the power at 0s, HPIS (High Pressure Injection System) and AFW are unavailable. The calculation lasts 60000s.

Description of Accident Progressions

After the postulated SBO accident begins at 0s, the RCP trips, and the reactor trips soon by the drop of control rods. The primary pressure drops quickly due to the reactor trip. At about 3000s, the SGs are empty (Fig.2) due to the unavailability of AFW, and the primary heat cannot be removed by the secondary heat sink, so the primary pressure rises quickly which induces the opening of PRZ PORVs(Pressurizer Power Operated Relief Valves). The PORVs open and close frequently around the set point, which maintains the primary pressure at about 16.3MPa (Fig.3). The leakage of coolant through PRZ PORVs accelerates the decrease of water level in RPV, and the accumulators cannot be activated at the high pressure, so the uncovery of core is inevitable. The core begins to uncover at 5787s, and becomes completely uncovered at 7172s (Fig.4). Since the fuel bundles lack of cooling, the heat transfer gets worse extremely. The core temperature rises quickly to the melting point of the fuel and the core begins to melt down at 8393s (Fig.5). The penetration failure of RPV lower head occurs at about 16610s. The results indicate that the base case of SBO accident will cause the core melt and penetration failure of RPV lower head at high pressure (16.2582MPa).

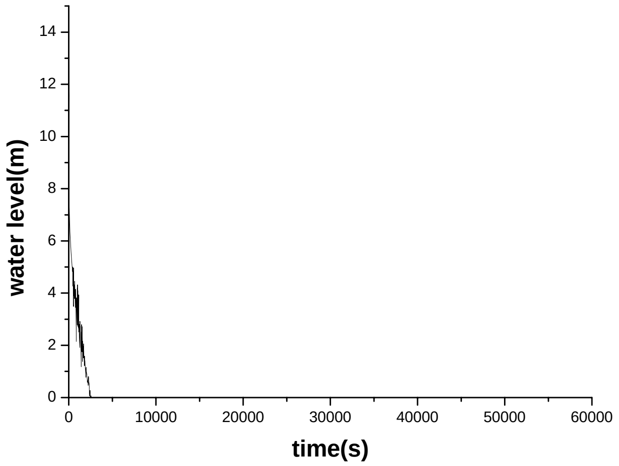

Fig.2 Water level in SG

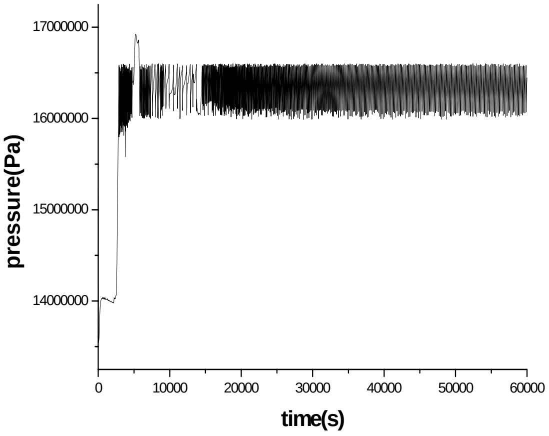

Fig.3 Primary pressure

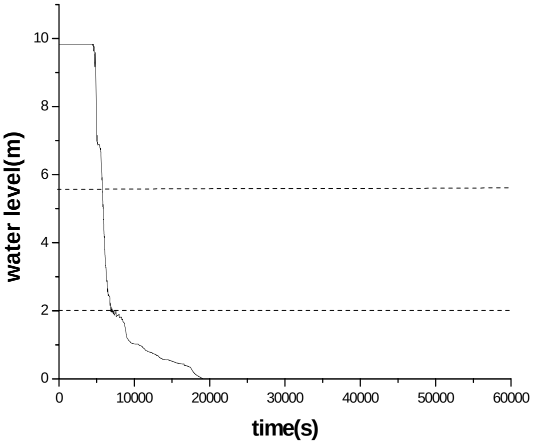

Fig.4 Water level in RPV(the two imaginal lines in Fig.4 mean the top and the bottom of the core, which have the same meanings in the following figures)

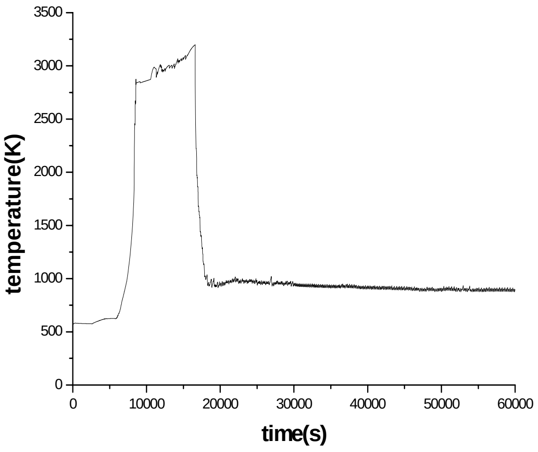

Fig.5 Highest surface temperature of fuel bundles

DESCRIPTION OF CASE 2

Accident Assumptions

The base case has not considered the rupture of hot leg or surge line. In fact, there is a large probability that the rupture will occur. SCDAP/RELAP5 code can effectively indicate the time of rupture. This case will analyze the influence of this accidental rupture to the base accident progression.

Description of Accident Progressions

The early accident progressions are similar to those in base case until 8775s. The hot steam and gases exiting the core heat the hot leg structures as they flow towards the PRZ PORVs. At 8775s, the steam temperature at hot leg near surge line reaches more than 1600K which is high enough to cause creep rupture failure, and there is a large change of temperature at this time (Fig.6). Thus, the hot leg ruptures while the surge line remains its integrity (Fig.7). After that, the accident progressions are changed distinctly.

The primary pressure starts to drop quickly to the set point of accumulators after the hot leg ruptures (Fig.8). The activation of accumulators complements the coolant in the core, so the water level in RPV begins to increase at about 9350s (Fig.9). However, the inventory of accumulators is limited, and the accumulators are empty at 14670s, so the water level in RPV decreases again and the core is completely uncovered at 15575s. The core has begun to melt before the rupture of hot leg. Although the core melt is delayed by the activation of accumulators, the highest surface temperature of fuel bundles rises up later (Fig.10). The penetration failure of RPV lower head occurs at about 21125s. The results indicate that the base case of SBO accident with rupture of hot leg will cause the core melt and penetration failure of RPV lower head at low pressure (0.5998MPa).

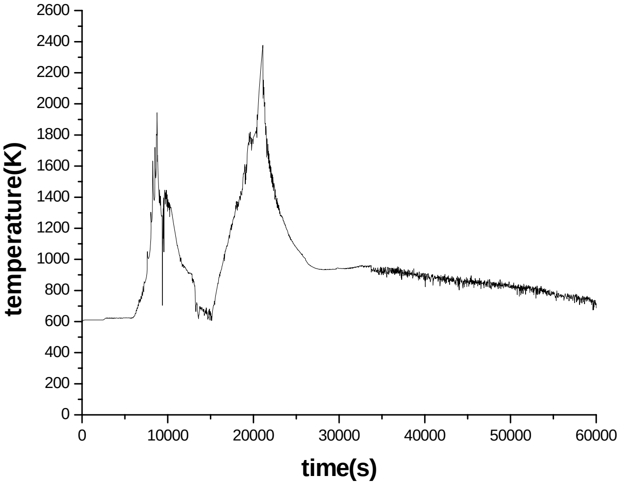

Fig.6 Steam temperature at hot leg

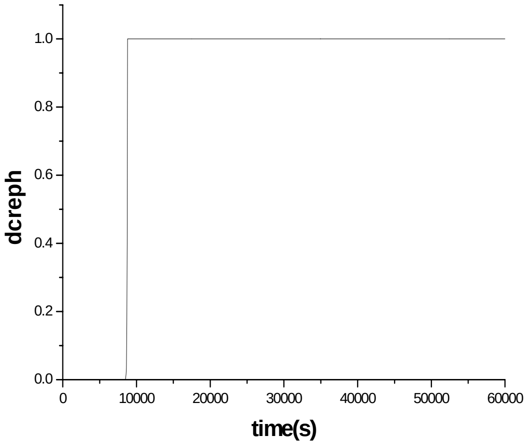

Fig.7 Fraction of life expended for hot leg

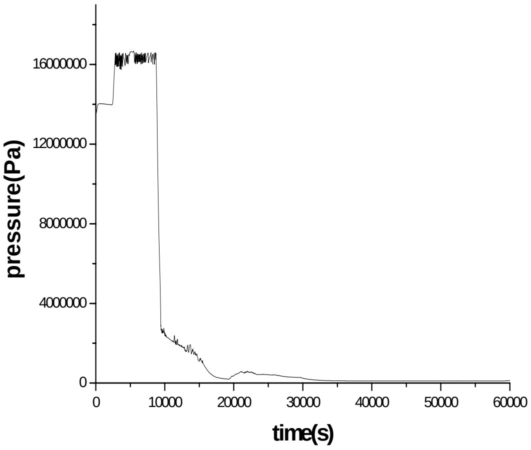

Fig.8 Primary pressure

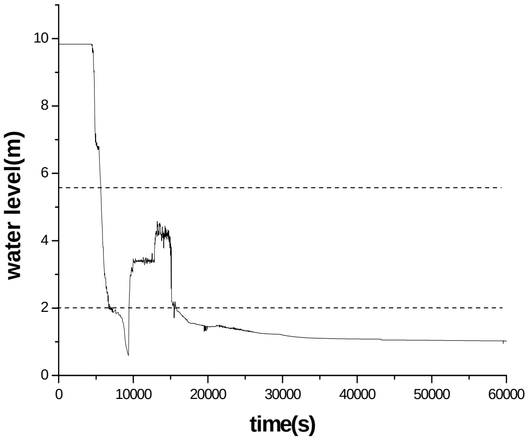

Fig.9 Water level in RPV

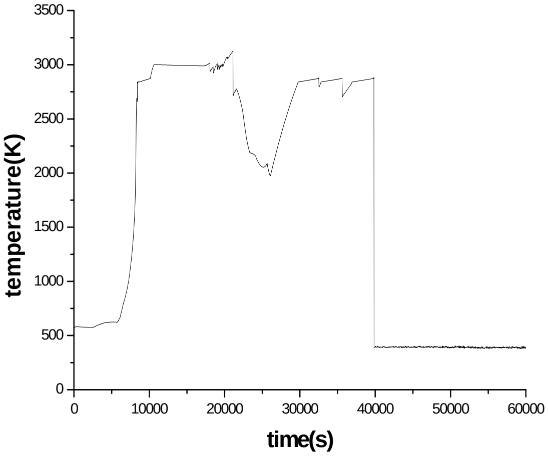

Fig.10 Highest surface temperature of fuel bundles

DESCRIPTION OF CASE 3

Accident Assumptions

The case 3 also considers the rupture of hot leg or surge line in base case of SBO accident. To be different from case 2, the intentional primary depressurization will also be studied in this case.

According to the previous study in the world, the intentional primary depressurization can be divided into two strategies: early depressurization strategies and late depressurization strategies. Early depressurization strategies mean initiating depressurization when the SGs boil dry. Late depressurization strategies initiate depressurization when the core exit temperature reaches 922K (650℃). The late depressurization will maximize the time available for the operator to recover ac power and auxiliary feedwater, so it is preferred to the early depressurization strategy [1,2].

The intentional depressurization may effect the heating and rupture of hot leg or surge line. Thus, this case assumes opening two of the three PRZ PORVs for intentional depressurization when the core exit temperature reaches 922K [4].

Description of Accident Progressions

The early accident progressions are similar to those in base case until 7887s. At about 7887s, the core exit temperature reaches 922K which is the set point of intentional depressurization (Fig.11). Thus, two of the three PRZ PORVs are latched open and the primary pressure begins to drop quickly to the set point of accumulators (Fig.12). At about 7900s, the accumulators are initiated to complement the coolant in the core, so the water level in RPV begins to increase (Fig.13). However, the inventory of accumulators is limited, and the accumulators are empty at 11880s, so the water level in RPV decreases again and the core is completely uncovered at 14237s. The highest surface temperature of fuel bundles rises up quickly and the core begins to melt at about 14400s (Fig.14). The penetration failure of RPV lower head occurs at about 19925s. The results indicate that the base case of SBO accident with two of the three PRZ PORVs latched open will cause the core melt and penetration failure of RPV lower head at low pressure (0.2952MPa).

It is necessary to mention that the hot leg or surge line has not ruptured during this accident progression (Fig.15). The integrity of surge line is partly influenced by the hot steam and gase flowing towards the PRZ PORVs, but it has not reached the point of rupture.

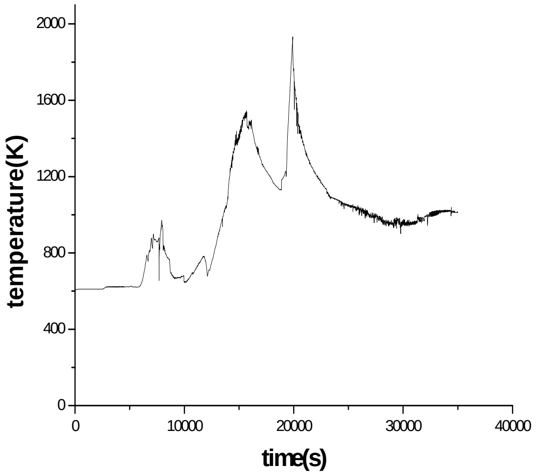

Fig.11 Core exit temperature

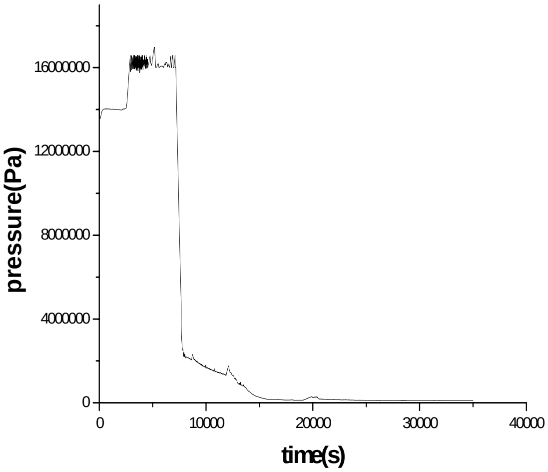

Fig.12 Primary pressure

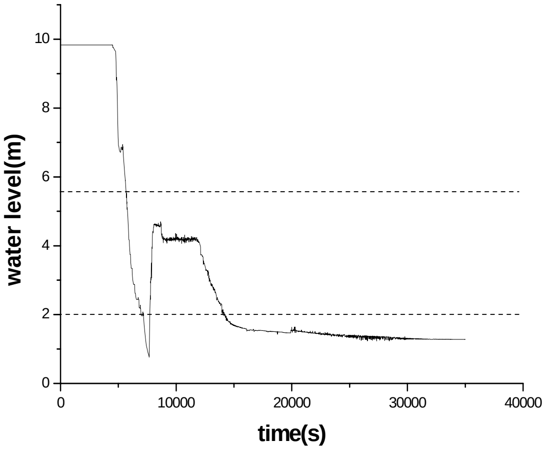

Fig.13 Water level in RPV

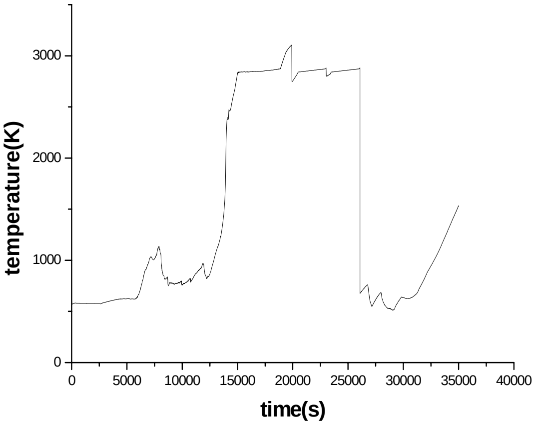

Fig.14 Highest surface temperature of fuel bundles

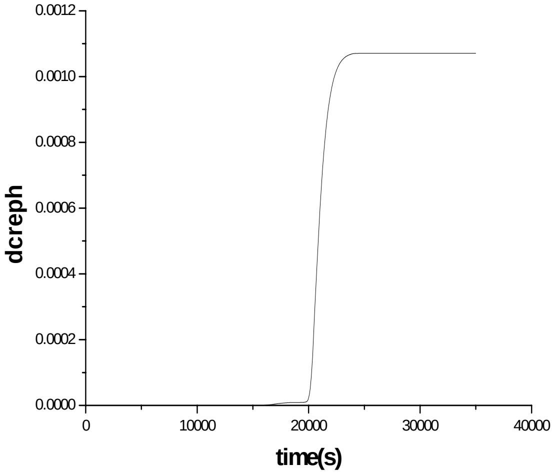

Fig.15 Fraction of life expended for surge line

DESCRIPTION OF CASE 4

Accident Assumptions

This case also considers the rupture of hot leg or surge line in base case of SBO accident. To be different from case 3, this case assumes opening one of the three PRZ PORVs for intentional depressurization when the core exit temperature reaches 922K.

Description of Accident Progressions

The early accident progressions are similar to those in base case until 7040s. At about 7760s, the core exit temperature reaches 922K (Fig.16). Thus, one of the three PRZ PORVs is latched open and the primary pressure begins to drop quickly to the set point of accumulators (Fig.17). At about 7780s, the accumulators are initiated to complement the coolant in the core, so the water level in RPV begins to increase (Fig.18). The accumulators are empty at 18340s, so the water level in RPV decreases again and the core is completely uncovered at 20640s. The highest surface temperature of fuel bundles rises up quickly and the core begins to melt at about 20800s (Fig.19). The penetration failure of RPV lower head occurs at about 26680s. The results indicate that the base case of SBO accident with one of the three PRZ PORVs latched open will cause the core melt and penetration failure of RPV lower head at low pressure (0.4392MPa).

The hot leg or surge line has not ruptured during this accident progression.

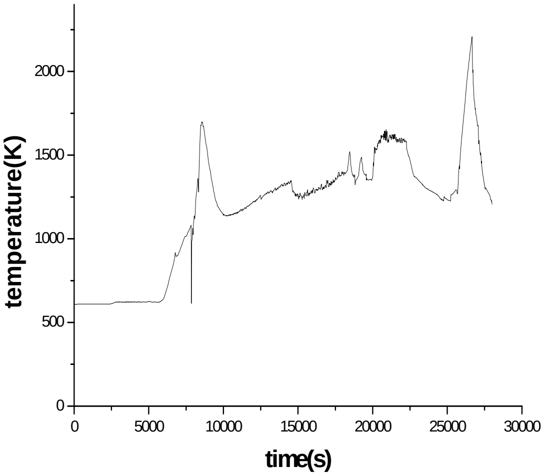

Fig.16 Core exit temperature

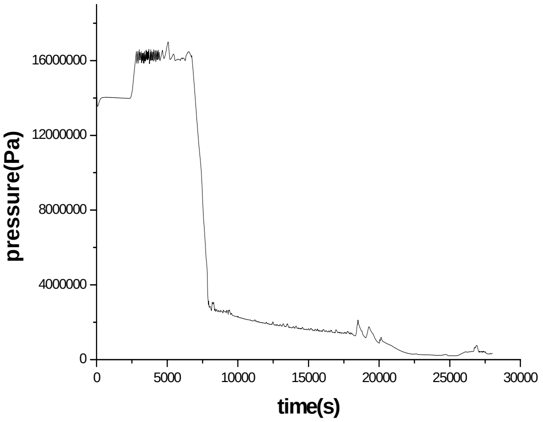

Fig.17 Primary pressure

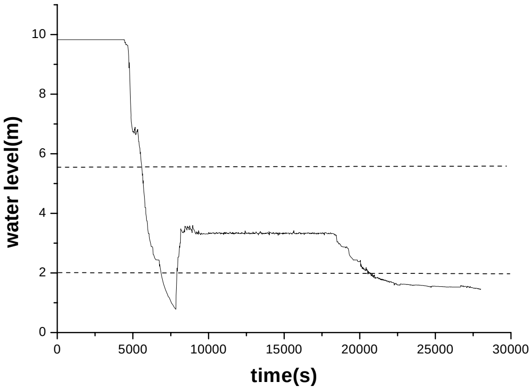

Fig.18 Water level in RPV

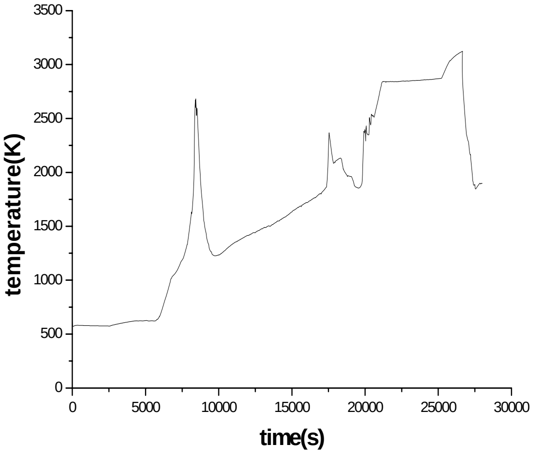

Fig.19 Highest surface temperature of fuel bundles

DISCUSSION

The calculation results of the cases in this paper are summarized in Table.2.

TABLE.2 Summary of Calculation Results

		Base case	Case 2	Case 3	Case 4
Progression (s)	Calculation begins	0.0	0.0	0.0	0.0
	RCP trip	0.0	0.0	0.0	0.0
	reactor trip	10.0	10.0	10.0	10.0
	SG empty	3000	3000	3000	3000
	PRZ PORVs latched open	/	/	7887	7760
	HPIS initiation	/	/	/	/
	AFW initiation	/	/	/	/
	Hot leg or surge line creep rupture	/	8775	/	/
	Accumulator initiation	/	9350	7900	7780
	Core completely uncovered	7172	15575	14237	20640
	Core melt starts	8393	8250	14400	20800
	RPV lower head melts through	16610	21125	19925	26680
Consequences of accidents		Core melt at high pressure (16.2582MPa)	Core melt at low pressure (0.5998MPa)	Core melt at low pressure (0.2952MPa)	Core melt at low pressure (0.4392MPa)

As shown in Table.2, in the postulated SBO accident, the core will melt at high pressure, which is the main reason of DCH. (base case)

In the actual condition, if no intentional depressurization strategy is implemented, the hot leg will rupture quite early before the lower head of RPV melts through. The creep rupture of hot leg delays the uncovery of core and penetration failure of RPV lower head effectively. The core melts down at very low pressure. (case 2)

If the late intentional depressurization measures are taken, the rupture of hot leg or surge line can be avoided in SBO accident. The uncovery of core and penetration failure of RPV lower head are also delayed effectively, which cause the core melt at much lower pressure. (case 3 and 4)

Although the rupture of hot leg can change the high pressure core melt into low pressure core melt and mitigate the consequences of accident, it is an uncertain method to depressurize the primary system. Uncertainties in the heat transfer characteristics of the core, the amount of heat transferred to the components in the flow path, and the heat transfer and structural characteristics of the pipes, could strongly affect the timing of hot leg or surge line failure [1]. Thus, the severe accident management should not depend on these accidental ruptures.

Late intentional depressurization can accomplish similar function as hot leg or surge line rupture. Comparatively, it can be controlled by the operators and avoid the occurrence of ex-vessel rupture. Therefore, the late intentional depressurization strategies have more advantages than the accidental ex-vessel rupture. Especially, opening one of the three PRZ PORVs can delay the core melt to much later time.

CONCLUSIONS

According to the calculation results, four main conclusions can be obtained:

(a). If no intentional depressurization is implemented in SBO accident, there is a great probability that the hot leg near surge line will rupture due to the hot steam and gase exiting the PRZ PORVs. This kind of ex-vessel rupture can convert the high primary pressure to low primary pressure when the RPV lower head melts through.

(b). In the condition of implementing late intentional depressurization, the rupture of hot leg or surge line can be avoided. The primary pressure will also be low enough to avoid High Pressure Melt Ejection (HPME).

(c). Considering the characteristics of the above phenomena, late intentional depressurization strategy is preferred to the ex-vessel rupture. This strategy should be emphasized in the development of Chinese SAMG.

(d). As for the certain plant mentioned in this paper, opening one of the three PRZ PORVs by operators is the best measure in intentional depressurization strategies to mitigate the consequences of SBO accident.

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