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Advanced operation strategy for feed-and-bleed operation in an OPR1000

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ABSTRACT

When the secondary side is unavailable in a pressurized water reactor (PWR), heat from the core will accumulate in the primary side causing core damage. In this situation a heat removal mechanism called feed-and-bleed operation (F&B operation) must be used, which is a process of directly cooling the primary reactor cooling system (RCS). However, conventional operation strategy in emergency operating procedures (EOPs) does not cover all possible conditions to initiate F&B operation. If the EOP informs on the urgency of F&B operation, operators will be able to more clearly make decisions regarding F&B operation initiation. In order to cover all possible scenarios for F&B operation and systematically inform its urgency, an advanced operating strategy using a decision tree is developed in this study. The plant condition can be classified according to failure of secondary side, RCS pressure condition, injectable inventory to RCS, and remaining core inventory. RCS pressure, core level, and RCS temperature are representative indicators which provide information regarding the initiation of F&B operation. Indicators can be selected based on their detectability and quantification, and a decision tree is developed according to combinations of indicators. To estimate the effects of the advanced operation strategy, human error probability (HEP) of F&B operation is re-estimated based on a thermohydraulic analysis. The available time for operators to initiate F&B operation is also re-estimated to obtain more realistic data. This study is expected to provide a systematic operation strategy to initiate F&B operation under various plant situations. An OPR1000 is used in this study as an example plant, with the resulting advanced operating strategy able to be applied to most PWRs which have F&B operation capability.

1. Introduction

One of the important lessons from the Three Mile Island accident is that the role of the operator is critical in nuclear power plants. After the Fukushima accident, it cannot be overemphasized how important the availability of safety systems and securing safety functions are for plant safety.

Safety functions are a group of conditions or actions to prevent core meltdown or minimize radiation releases to the general public. They are related to safety systems and operators' actions, and provide a hierarchy of practical plant protection measures that operators should use. The operators need a systematic approach to mitigate the consequences of an event (Corcoran et al., 1981).

After any reactor trip, decay heat generated in the core must be eliminated and is transferred through the primary cooling system to the secondary cooling system or to some other heat sink. Safety features that remove residual heat from the core and coolant are crucial to prevent core damage after accidents. When the secondary side fails, the heat from the core cannot be eliminated and will accumulate in the primary side, leading to core damage. To prevent this, operators can initiate another heat removal mechanism which directly cools the reactor cooling system (RCS), called feed-and-bleed operation (F&B operation) (Kim et al., 2014).

F&B operation cools down the core and the RCS using a safety depressurization system (SDS) and safety injection system (SIS) as shown in Fig. 1. The "feed" and "bleed" in F&B operation refer to the functions of the SIS and SDS, respectively. For F&B operation, operators must manually open the SDS valves, and a safety injection actuation signal (SIAS) should be generated to force the high-pressure safety injection (HPSI) pumps to inject coolant into the RCS (Kim et al., 2014).

Operators follow emergency operating procedures (EOPs) to initiate F&B operation as shown in Fig. 2 (Kim et al., 2005). EOPs are

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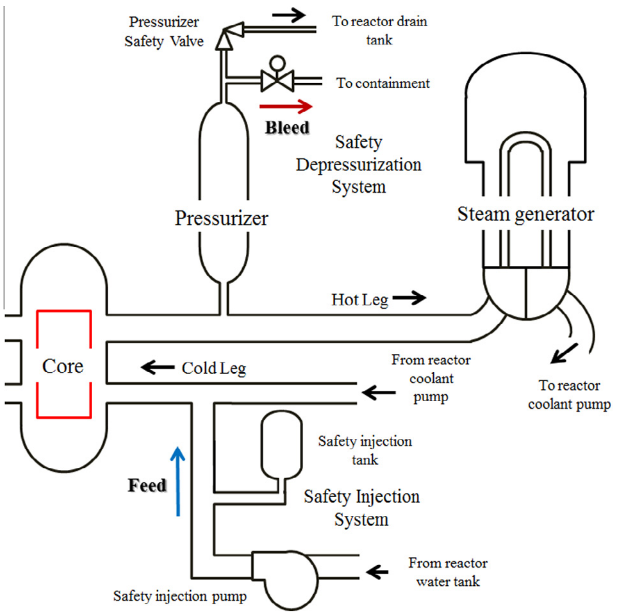

Fig. 1. Schematic diagram of feed-and-bleed operation in an OPR1000 (Kim et al., 2014).

plant-specific procedures containing instructions for operators to implement preventative measures for managing accidents. An EOP contains all of the steps needed to take the plant from a post reactor trip state to a safe and stable condition.

There are two types of EOPs: optimal recovery procedures (ORPs) and functional recovery procedures (FRPs). ORPs are designed to mitigate accidents when the operators can diagnose the specific event. FRPs are designed for plant-specific functional recovery EOPs which the operators would use to verify the satisfactory control or restoration of all critical safety functions (Kim et al., 2008). When an event occurs and the reactor trips, operators check the critical safety functions and follow diagnosis procedures to clarify the event. When a total loss of feedwater (TLOFW) accident occurs and the secondary side fails, operators first follow the loss of all feedwater (LOAF) procedure, and then the procedure for RCS and core heat removal. The procedure for RCS and core heat removal can be divided into three sections: HR-1 (RCS and core heat removal via steam generator with SIS not in operation), HR-2 (RCS and core heat removal via steam generator with SIS in operation), and HR-3 (RCS and core heat removal via F&B operation). HR-1 is used when the RCS heat can be sufficiently transferred to steam generators. HR-2 is used when a combination of steam generator heat removal as well as heat removal by venting energy out of an RCS opening such as a break is necessary. HR-3

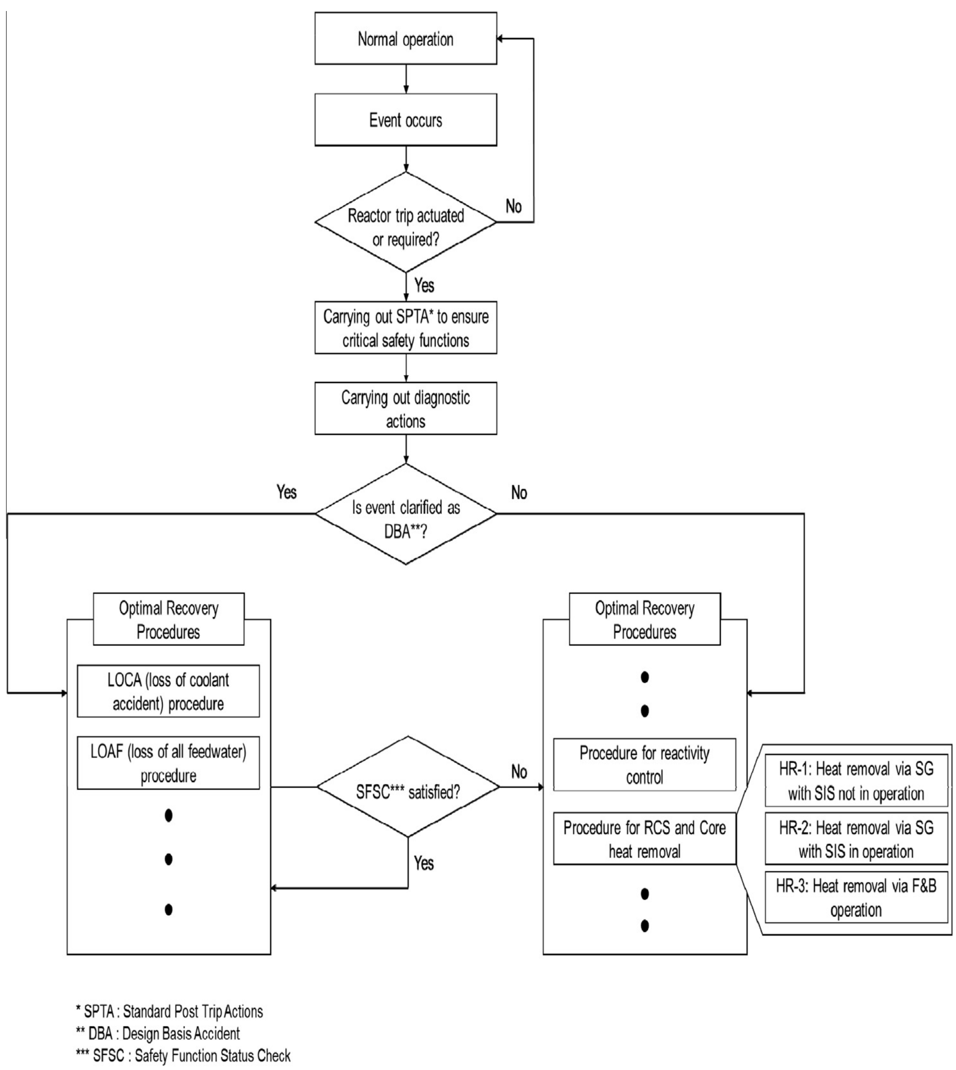

Fig. 2. The overall structure of an OPR1000's EOP (Kim et al., 2005).