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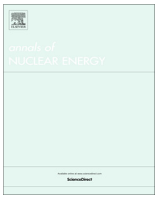

A comparative study of station blackout scenario dynamics initiated by internal and seismic event in boiling water reactor

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ABSTRACT

This paper studies one of the most challenging accident scenarios for nuclear power plants, the loss of power sources, referred to as a station blackout initiated by each different initiator. Recently, the station blackout accidents were highlighted by the Fukushima disaster in Japan on 2011. At Fukushima, tsunami hit the plant site and approximately one hour after the earthquake led to the loss of power, eventually leading to a significant core damage in multiple units. Unfortunately, the accident management against an overwhelming earthquake followed by a tsunami was not properly performed to avoid a fatal damage to plant site and environment. Current accident management in the station blackout scenario has no distinct differences by each different initiator, internal or external event. To find the differences in accident progression and a relevant management for both internal and seismic station blackout sequences, comparable sets are identified and analyzed from the Probabilistic Safety Analysis, accident management plan of the reference boiling water reactor. Findings from this study would contribute to improve a current understanding of the station blackout scenario dynamics and a proper operator responses of the boiling water reactor in each internal and seismic initiated sequence.

1. Introduction

The station blackout (SBO) is one of the most challenging accident scenarios to the plant and the operators. The SBO for boiling water reactor (BWR) is initiated by a loss of off-site power and failures of all diesel generators to activate (US NRC, 2002a). For this reason, the various active injection systems dependent on AC power are unavailable due to the loss of AC power. For example, at the Fukushima Daiichi unit 1 on March 2011, the earthquake brought the loss of off-site power and approximately one hour after the tsunami flooded the emergency diesel generators and hence all of AC power was lost. Furthermore, Isolation Condenser (IC) was removed from service and hence it could not bring back water injection into reactor pressure vessel. The only possible injection method was an alternative firewater injection following the reactor depressurization. The fire engine began injecting fresh water into the reactor pressure vessel after around 14 h from the loss of injection. During the period with no injection of water into the reactor vessel, the reactor pressure vessel has accumulated decay heat in itself and the accident sequence was escalated fast. Eventually, a hydrogen explosion occurred in the reactor building about 24 h after the earthquake (INPO, 2011). As happened at the Fukushima Daiichi Unit 1, the loss of water injection (also referred to as water make-up) eventually led to core damage. In order to prevent core damage in case of the SBO, the reactor depressurization and then immediate water make-up should be carried out before core uncover. Otherwise, there might be the fast decrease of the reactor water level in these accident sequences, and corresponding heat-up of the core makes the timely implementation of accident management difficult. For this reason, SBO accident could be considered as one of the most challenging accident scenarios to the plant and the operators. This paper examines some of the most probable SBO sequences from the PSA documents to

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Abbreviations: AC, Alternating Current; ADS, Automatic Depressurization System; AWI, Alternative Water Injection; BAF, Bottom of Active Fuel; BWR, Boiling Water Reactor; CCF, Common Cause Failure; CD, Core Damage; CDF, Core Damage Frequency; CST, Condensate Storage Tank; DC, Direct Current; DGs, Diesel Generators; EOPs, Emergency Operating Procedures; FWT, Feedwater Tank; HPCS, High Pressure Core Spray; IC, Isolation Condenser; LOCA, Loss of Coolant Accident; LPCI, Low Pressure Core Injection; LPCS, Low Pressure Core Spray; MCR, Main Control Room; PSA, Probabilistic Safety Analysis; RCIC, Reactor Core Isolation Condenser; RPV, Reactor Pressure Vessel; SBO, Station Blackout; SEHR, Special Emergency Heat Removal systems; SRVs, Safety Relief Valves; SSCs, Structures, Systems, and Components; TAF, Top of Active Fuel; TLOOP, Total Loss of Off-site Power.

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investigate the required plant systems and functions, the related operator actions, and the recommended accident management.

The scenarios and sequences identified and discussed in this paper are based on information, analyses, and study results from an actual power plant. However, the analyses and discussion in this work refer to a "reference plant" and are presented to demonstrate an analysis approach and some general tendencies in the contributors to and scenarios related to a SBO risk.

In the reference plant, the Core Damage Frequency (CDF) from internal events core damage scenarios is approximately 12% of the total CDF. The remaining 88% is due to external events such as a seismic event, fires, winds, and so on. Among these external events, the contribution of the seismic event to CDF of the reference plant is highest, making up more than 50% of the CDF from external events core damage scenarios. This paper select two different initiators which are internal and seismic initiator to see their consequences on the accident sequences. It is expected that the internal and seismic initiators for a SBO event may result in a clear distinction between the corresponding sequences because of their quite different symptoms. Also, there would be several required operator actions to prevent core damage and assure a long-term cooling in the reference plant. These required operator actions would be same or different for both internally initiated and seismically initiated SBO scenarios. In order to support the Severe Accident Management Guidance (SAMG) developers for various SBO scenarios, it would be better to suggest them the common required operator actions and their operator performance conditions. For this reason, a comparable set of sequences from both internally and seismically initiated is necessary to identify the common required operator actions. A detailed process of this study is illustrated in Fig. 1.

As shown in Fig. 1, both internally and seismically SBO scenarios are investigated. As previously mentioned, the scenario dynamics would be varied by the accident initiator. For this reason, the available safety systems of the reference plant in SBO condition are firstly investigated in Section 2, and the differences in both internal and seismic initiating SBO scenarios are identified in Section 3. In addition, the comparable SBO sequences for both events are analyzed in Section 4, and sensitivity parameters that affect the performance condition (e.g. time constraints) of common required operator actions are identified in each comparable set. The insights gained from the investigation of comparable sets and a possible accident management strategy are discussed in Section 5. Finally, the main conclusion of the paper is given in Section 6.

2. Available safety systems of the reference plant

The analyses of SBO scenarios performed in this paper address a reference BWR plant. The reference BWR design is a BWR/6, the third generation of the first series of BWRs. In the SBO scenarios, it is required to bring the total loss of AC powers in the reference plant by both failures of off-site and on-site AC power sources. The diesel generators are on-site AC power source in the reference

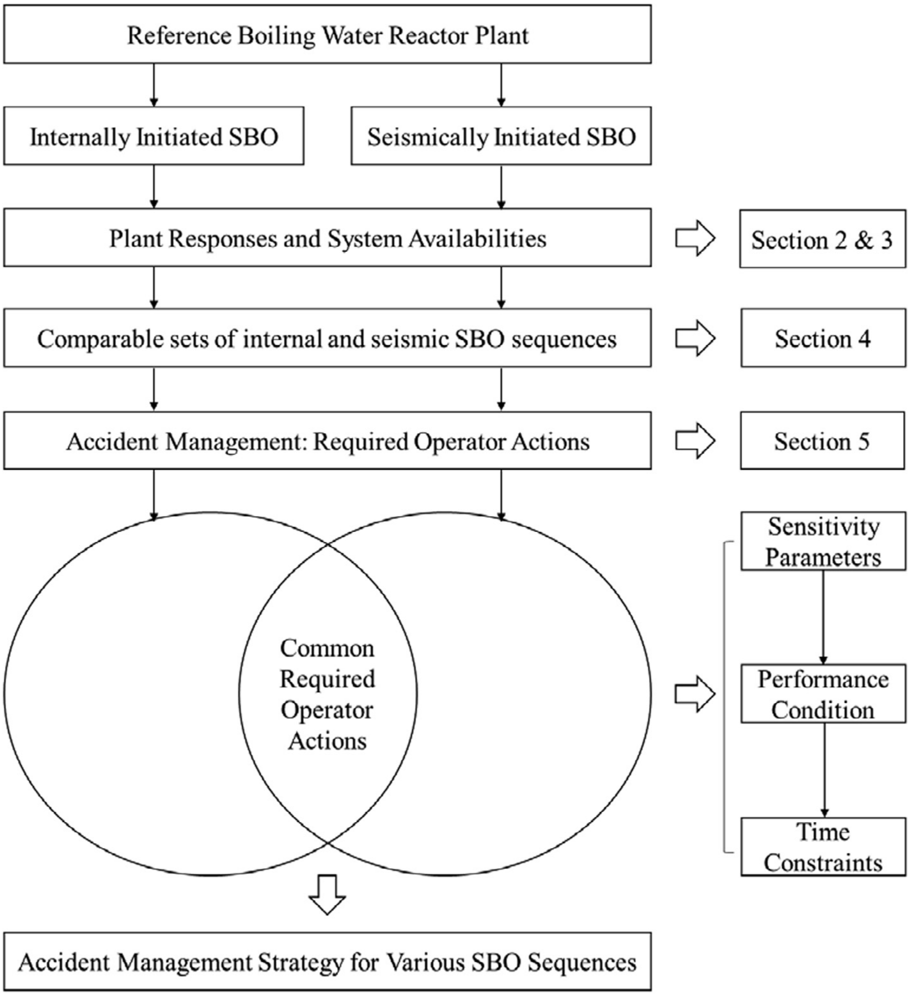

Fig. 1. Structure of present study.