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Original Article

Investigation of a Hydrogen Mitigation System During Large Break Loss-of-coolant Accident for a Two-loop Pressurized Water Reactor

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ABSTRACT

Hydrogen release during severe accidents poses a serious threat to containment integrity. Mitigating procedures are necessary to prevent global or local explosions, especially in large steel shell containments. The management of hydrogen safety and prevention of over-pressurization could be implemented through a hydrogen reduction system and spray system. During the course of the hypothetical large break loss-of-coolant accident in a nuclear power plant, hydrogen is generated by a reaction between steam and the fuel-cladding inside the reactor pressure vessel and also core concrete interaction after ejection of melt into the cavity. The MELCOR 1.8.6 was used to assess core degradation and containment behavior during the large break loss-of-coolant accident without the actuation of the safety injection system except for accumulators in Beznau nuclear power plant. Also, hydrogen distribution in containment and performance of hydrogen reduction system were investigated.

1. Introduction

Hydrogen safety is one of the biggest priorities for Nuclear Power Plants (NPP). During accident progression, large amounts of hydrogen can be released into the containment atmosphere to form flammable mixtures. If ignited, the integrity of the containment can be threatened.

To provide NPP hydrogen safety, special engineering features for accident management need to be developed. Hydrogen mitigation seems to be a possible way of solving the given problem [1].

The systems that use the devices of the hydrogen passive recombination are considered to be the most perspective technical solutions.

An analysis of hydrogen distribution during a beyond design basis accident, was done using the MELCOR computer code. The main results are presented below.

This analysis should include the following parts: (1) containment model; (2) accident sequences; (3) hydrogen and

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steam sources; (4) hydrogen mitigation and control measures; (5) determination of the ignition event; (6) possible flame regimes; and (7) the containment loadings.

The analysis was carried out based on the design characteristics of hydrogen removal systems in the modernized designs for Beznau.

In a loss-of-coolant accident (LOCA) event in a pressurized water reactor (PWR), coolant mass and energy are first released from the reactor coolant system to the containment through the break.

If the accident is not successfully mitigated by the action of safety systems, core meltdown, relocation, and release of radioactive material and hydrogen into the containment through the break will eventually occur, followed by reactor vessel failure and debris ejection.

The analysis is focused on the influence of hydrogen removal systems on hydrogen distribution in the atmosphere of the containment.

2. Materials and methods

2.1. *Description of MELCOR computer code*

MELCOR is a state-of-the-art computer code which can simulate the progression of severe accidents postulated for light water reactors. Several versions of the MELCOR code [2] have been developed by Sandia National Laboratories for plant risk assessment and source term analysis since 1982. In this study, MELCOR version 1.8.6 is utilized for the fulfillment of the addressed objectives. This code is used to treat the entire spectrum of severe accident phenomena, including thermal-hydraulic response in a reactor coolant system and containment, core heat-up, degradation and relocation, and fission product release and transport, in a unified framework for both PWR and boiling water reactor [2].

2.2. *Description of hydrogen reduction system*

The hydrogen reduction system (HRS) consists of 55 passive autocatalytic recombiners (PARs) installed in various parts of the containment. The models of PARs used have been developed by AREVA and are currently used in some European operating plants [3].

Each PAR consists of a metal housing designed to promote natural convection with a gas inlet at the bottom and a lateral gas outlet at the top. The horizontal cover of the housing at the top of the recombiner protects the catalyst against direct water spray and aerosol deposition.

Numerous parallel plates with a catalytically active coating are arranged vertically in the bottom of the housing. Accessibility to the catalytic plates is provided by the use of a removable inspection drawer. A rendering of a PAR is provided in Fig. 1.

Hydrogen and oxygen in containment gas mixtures are recombined upon contact with the catalyst in the lower part of the housing. The heat from this reaction in the lower part of the recombiner causes a reduction in gas density in this area, promoting natural circulation through the PAR and ensuring a high efficiency of recombination.

2.3. *Description of PWR plant model*

The reference power plant for this analysis is Unit 1 of Beznau NPP [4]. It is a PWR in Switzerland which produces 1,130 MW thermal power and generates 360 MW electrical power.

The core consists of 121 fuel assemblies with lattices of 14×14 and an active fuel height of 3.048 m [4]. There are two primary coolant loops (Fig. 2). Each loop contains a U-tube steam generator (SG), a reactor coolant pump, and associated piping. A single pressurizer is attached to the hot leg piping in one of the two loops. Two accumulators are attached to each cold leg. The Beznau emergency core cooling system employs four safety injection pumps as the active portion of a safety injection, and four safety injection tanks as its passive portion.

2.4. *Description of the input model*

The MELCOR input for the Beznau plant is modeled with 43 control volumes (29 in primary and secondary systems, 14 in containment), 71 flow paths (41 in primary and secondary

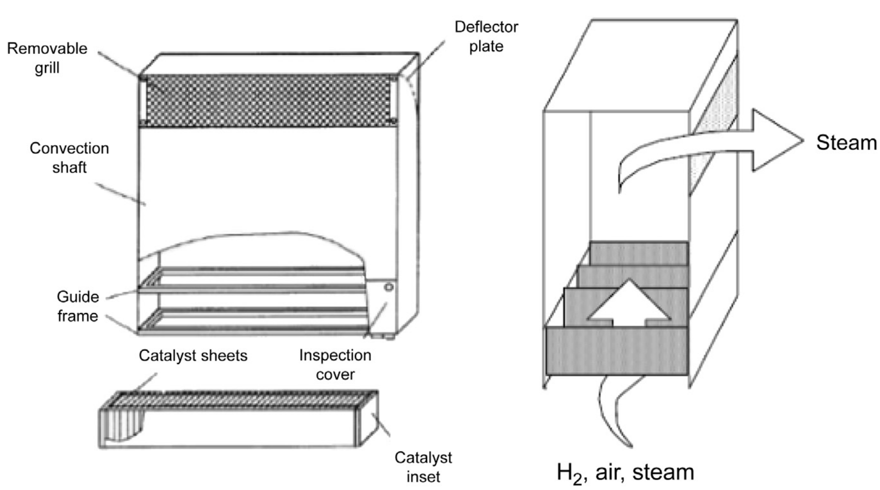

Fig. 1 – Passive autocatalytic recombiner.

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