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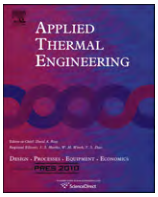

Numerical simulations of sodium mixing in a T-junction

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A B S T R A C T

Thermal fatigue is a major problem for liquid metal fast reactors due to the high temperature differences of the coolant in the circuits and because liquid metals efficiently transmit thermal fluctuations to walls. Detailed thermal hydraulic investigations have been carried out to quantify the amplitudes and frequencies of the temperature fluctuations in the secondary sodium circuit of the Phenix pool type fast reactor. Computational fluid dynamics calculations have been performed using either Reynolds Averaged Navier Stokes equations or Large Eddy Simulations. The characteristics of the mixing jet are well reproduced by the simulations and the high thermal fluctuation zones fit the thermal crack locations observed in the T-junction. Simulations with conjugate heat transfers, which allow inter- changing heat at the wall between fluid and solid, lead to noticeable heat transfers in the pipe wall and to high surface heat flux at fluid/solid interface.

1. Introduction

Sodium has some favorable properties for thermal power reactors such as a high capacity of heat transport and a large margin between its melting point (371 K) and boiling point (1155 K) at ambient pressure. Nevertheless, sodium is a flammable substance. Indeed, at the working temperature of sodium power plant systems, sodium burns when it comes in contact with oxygen in the air. Sodium burning produces a large amount of high-density, opaque, white smoke composed of sodium oxides (Na_2O and Na_2O_2) that react with the humidity in ambient air to produce caustic sodium hydroxide (NaOH) and then, interacting with carbon dioxide, into the carbonate (Na_2CO_3). Sodium spray fires may lead to great damage to the surrounding structures as it was observed in the Almeria solar plant in 1986 [1]. Several accidental sodium fires (pool and spray fires) occurred at various plants throughout the world. They generally started by sodium leaking from circuits or vessels. That is why it is crucial, from the safety standpoint, to avoid any leakage of sodium in power plants.

A survey of sodium leak events in reactors indicates leaks ranging from a few grams to about 2 tonnes [2]. One of the causes of sodium leak incidents is flow induced vibrations as experienced in the Monju reactor in December 1995 [3,4] and thermal fatigue failure as it was witnessed in the Superphenix reactor in April 1990 [5,6]. Thermal fatigue can be generated when two flow streams at different temperatures are mixed in a fluid domain, leading to an arbitrary change of temperature field of the fluid with respect to time. Because of the high heat transfer coefficient associated with liquid metal coolants such as sodium, the temperature fluctuations are transmitted to the adjoining structures with a fairly low attenuation. This eventually leads to high cycle fatigue and crack initiation in the structures. In liquid metal cooled fast reactors, thermal striping potential exists in the upper plenum as a result of the mixing of sodium jets from fuel subassemblies (SA), breeder SA and control SA [7–9] and in T-junctions in primary (for loop type reactors), secondary and auxiliary circuits. Note that thermal striping is also a safety issue for pressurized water reactors [10,11].

To minimize risks of sodium leaks induced by thermal fatigue or induced vibrations, detailed thermal–hydraulic analysis should be carried out for the steady state and the transient state [12,13]. Different methods are available for such CFD (Computational Fluid Dynamics) calculations. Some mixing flows in a T-junction were calculated using RANS (Reynolds Averaged Navier Stokes) [14,15], using LES (Large Eddy Simulations) [16–19], and using DNS (Direct Numerical Simulations) [20,21]. In this study, the commercial code Fluent is used to simulate the configuration of a mixing flow.

Defects were detected during a campaign of inspections on the secondary circuits of the Phenix reactor. In fact, through-wall cracks involving a main pipe of the secondary circuit were revealed. The cracks of about 100 mm in length were observed on a circumferential weld which was 160 mm behind the centerline of a branch pipe. Metallurgical observations clearly indicate that the defects

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