Detection and Quantitative Assessment of Corrosion Products Release Rate in Liquid LBE

1. Introduction

A world first accelerator driven research reactor, MYRRHA, will be constructed at SCK·CEN. The unique research facility will use liquid lead-bismuth eutectic as a primary coolant and a spallation target. The removal of solid particles and dissolved impurities from the liquid is primary important for the stable long term operation of MYRRHA. Among various sources, corrosion products dissolved from fuel cladding and structural steels are expected to be major source of those solid and dissolved impurities.

In order to design optimal coolant purification systems, to predict the detrimental effect of the corrosion products on the operation of MYRRHA and to develop mitigation methods, accurate prediction of corrosion products release rate in the primary circuit of MYRRHA is needed.

2. State of the art

In the corrosion R&D programme in support of MYRRHA, long-term experiments have been carried out in which candidate steels for MYRRHA have been exposed to LBE at various controlled temperature, dissolved oxygen concentration and flow velocity. By post-exposure microscopic analysis, correlations for the maximal corrosion depth have been established resulting in initial criteria for the operating conditions of MYRRHA mainly from the perspective of material integrity.

However, the corrosion process is not yet sufficiently well assessed to quantify phenomena such as the release rate of corrosion products other than the maximal corrosion depth. This is mainly due to the fact that the corrosion damage is localized rather than uniform. In addition to that, conventional weight loss measurement is hardly applicable to corroded specimens in LBE due to the difficulty of complete removal of residual LBE in corroded specimens.

3. Research hypothesis

Main corrosion products of MYRRHA candidate steels (SS316L, 15-15 Ti) are Fe, Ni and Cr. Cr will be present as an oxide, Fe will be present partly as an oxide and partly as a dissolved phase and Ni will be present as a dissolved phase. If one can measure the change of the dissolved corrosion products in LBE during corrosion test, the corrosion products release rate could be assessed accurately. Such a sensor has however not been developed yet.

One alternative methods is to measure oxygen consumption rate due to the oxidation of corrosion products. Experiments in which dissolved oxygen is simultaneously monitored using the oxygen sensor and pump technology developed at SCK·CEN, and thermochemical analysis of the results using the Gibbs Energy Minimization technique, would allow quantitative assessment of corrosion products release rate.

4. Objectives

The main objective of this work is accurate prediction of corrosion products release rate in the primary circuit of MYRRHA.

5. Methods (Tasks)

- Establishing and evaluation of experimental method with electrochemical oxygen pumping

Dedicated corrosion tests will be conducted in autoclaves with controlled LBE and cover gas chemistry in which steel specimens can be rotated with various speeds. The dissolved oxygen concentration in LBE will be controlled by electrochemical oxygen pumping methods coupled with oxygen sensor.

By using the measured oxygen pumping current, the global oxidation kinetics (which includes not only oxidation of released corrosion products but also oxide growth on steel surface) can be calculated precisely. The change of released corrosion products, especially Fe will be measured as well by fully reducing Fe oxide and re-oxidation by the controlled addition of oxygen using the oxygen pump before and after the corrosion tests. Furthermore, the information of the area of corroded region, chemical composition of the region and oxide layer will be obtained by post-exposure microscopic analysis of tested specimen.

By combining those results and thermochemical analysis, each (Fe, Ni, Cr) of corrosion products release rate will be estimated.

- Measurement of corrosion products release rate under various conditions

Corrosion products release rate in LBE under various dissolved oxygen concentration at various temperature (normal operating condition and transient condition of MYRRHA) will be conducted to establish a correlation of corrosion products release rate. Corrosion specimens with internal heater and cold finger will be implemented as well in order to see the effect of mass transfer by temperature gradient.

- Prediction of corrosion products release rate in the primary circuit of MYRRHA

Corrosion products release rate in the primary circuit of MYRRHA under normal operation and transient condition will be predicted using thermochemical model of MYRRHA which has been developed at SCK·CEN. The experimental results obtained in this work will be used as an input.

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