A 5000-HR TEST OF A EUTECTIC LEAD-BISMUTH CIRCUIT
CONSTRUCTED IN STEEL AND NIOBium

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INTRODUCTION

The thermal neutron target of the recent Intense Neutron Generator (ING) project at Chalk River Nuclear Laboratories was to incorporate a lead-bismuth eutectic circuit passing through a moderator tank containing heavy water. The section of the circuit in the tank was to be made of a zirconium alloy, to minimize thermal neutron absorption. Various protective coatings insoluble in lead-bismuth eutectic were considered. The literature on bismuth and lead-bismuth suggested that a low chromium-molybdenum steel would be suitable for the external circuit, but possibly only if the lead-bismuth was thoroughly de-oxidised and treated with zirconium or titanium. [1,2]

A series of tests was planned to assess the candidate coatings operating with the lead-bismuth treated in various ways. In view of the complex interactions possible the best approach seemed to be to make each test an entity. A small pumped loop was evolved, which modelled the salient features of the proposed ING circuit. One such loop was built for each test and operated under predetermined and realistic conditions of chemical control.

This paper reports the operation and post-test examination of the first of the series. In this test wrought niobium (columbium) was the protective coating. Before filling the loop the charge was gettered with magnesium and had zirconium added: during the 5000 hours of operation at hot and cold leg
temperatures of 500°C and 375°C. Periodic additions of magnesium and zirconium were made in an attempt, only partially successful, to keep the concentrations above 10 ppm and 1 ppm respectively.

MODELLING CONSIDERATIONS

It was intended that the test loop should model the solution-erosion and -deposition processes which might occur in the parent proposed ING circuit, to the extent possible within bounds of size and operating time. The parent circuit was to comprise components of steel and niobium, of various flow sections, running variously at 450°C, 325°C or at the transition between these temperatures. For modelling purposes the circuit components were lumped in 4 categories, combinations of hot and cold, steel and niobium.

The solution-erosion and deposition processes to be modelled involve mass transfer and transport. It can readily be shown that for similarity of solute concentration distribution around the circuit the parameter

\[ N* = \frac{\alpha S L}{A V} \]  

(1)

and the temperature in each component category must be identical in model and parent circuits. The nomenclature is described in an appendix.

For turbulent flow of a given fluid at a given temperature in a circular pipe the modelling parameter is proportional to the size and fluid mass flow as follows:

\[ N* \propto L d^{-0.8} W^{-0.2} \]  

(2)

This is based on the usual mass transfer equation

\[ N_{Sh} = 0.023 \left( \frac{N_{Re}}{N_{Sc}} \right)^{0.8} \]  

(3)

If modelling parameter and temperature identity obtains, similar erosion and deposition depths should be observed in the model and parent circuits when the ratio of operating periods (model to parent) is

\[ R_T = \frac{\alpha_{\text{parent}}}{\alpha_{\text{model}}} = \left( \frac{W_{\text{parent}}}{W_{\text{model}}} \right)^{0.8} \left( \frac{d_{\text{model}}}{d_{\text{parent}}} \right)^{1.8} \]  

(4)