CHAPTER I
INTRODUCTION

As energy demands increase constantly and global warming and climate change threaten the earth, nuclear technology is one of the solutions to an increase in electricity production and a decrease in harmful greenhouse gases because it does not release greenhouse gases such as CO_2, SO_2 and NO_x. There are many types of nuclear reactor such as Boiling Water Reactors (BWRs), Pressurized Water Reactors (PWRs), Pressurized Heavy Water Reactors (PHWRs), etc. PWRs are the most common type, and are widely used in power stations.

In a typical PWR, the main materials contacting the primary coolant are Zircaloy-4 (as fuel sheath), Ni-based alloy (as steam generator tubing) and stainless steel (as piping). Under primary coolant conditions, the high temperature water coolant containing dissolved boric acid can cause corrosion, developing roughly double-layered oxide films (corrosion products) on nickel alloy and stainless steel and single-layered oxide films on Zircaloy-4 (Lister, 2003). There are also corrosion products dissolving and circulating in the primary coolant loop. When the corrosion products (crud) deposit on the fuel cladding surface (Zircaloy sheath), especially in the boiling upper region of the high duty core, it can cause Crud Induced Power Shift (CIPS – also known as Axial Offset Anomaly, AOA). AOA is caused by a combination of crud level in the coolant, high boiling intensity in the core and the presence of boron. It has been a problem in PWRs because it shifts the neutron flux distribution. The bulk of deposits on the cladding consist of a compound with a nickel component such as nickel ferrite ($Ni_xFe_{3-x}O_4$) and NiO, which originate mainly in the Ni-based alloy steam generator (SG) tubing. Therefore, the SG tubing is the primary concern for corrosion product inventory that has led to the development of CIPS. An example SEM image of crud found on the cladding is shown in Figure 1.

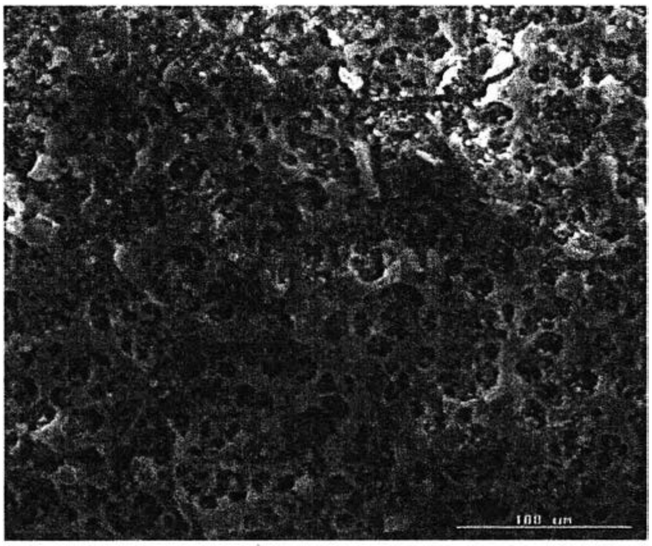

Figure 1 SEM image of Crud found on the cladding (Hawkes, 2004).

The Ni-based alloy SG tubes being used worldwide are Alloy 600, Alloy 690 and Alloy 800, which are processed with different heat treatments such as mill annealing (MA), thermal treatment (TT), cold drawing (CD) and shot peening (SP). The SG tubes used in the US are either Alloy 600 MA, Alloy 600 TT or Alloy 690 TT (US NRC, 2004). Bates *et al.* (2006) mentioned that in some PWRs, it is believed that the SG tubing is fully passivated and shutdown releases and CIPS cannot occur. Two most important factors affecting tube passivation are its composition and heat treatment.

The purpose of this work is to study the effect of SG alloy composition and alloy heat treatment, boron concentration and zinc addition on oxide film formation under PWR primary coolant conditions by analyzing oxides grown on alloys in high-temperature water in titanium or stainless steel autoclaves. In the experiment, a Zircaloy-sheathed heater, with a heat flux sufficient to provide sub-cooled boiling conditions, was installed in a titanium autoclave. Ni-based alloys (as cooling heat transfer surfaces), stainless steel and Zircaloy-4 samples were assembled inside the autoclave and operated under PWR primary coolant conditions with dissolved boric acid, lithium hydroxide and hydrogen. After exposures of several days, the samples were removed and weighed. The oxides on the samples were characterized with Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray spectroscopy

(EDX). The oxides on some samples were analysed with Secondary Ion Mass Spectrometry (SIMS) and X-ray Photoelectron Spectroscopy (XPS).