CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Nickel Ferrite Deposition

- Substantial amounts of deposit were observed on the heated surfaces where the boiling occurred. The deposit morphology indicated "chimneys", typical of wick boiling. On the other hand, when there was no boiling, only clumps of deposit were found on the heated surfaces. In the low pH condition ($pH_{300°C}$ = 6.8), deposit thickness on the boiling surface was estimated to be 10 μm. Particle trapping at the liquid-vapour interface of bubbles is believed to be a key factor in the deposition of nickel ferrite particle deposition under subcooled boiling conditions.
- The characterization showed that the deposits were mainly composed of injected nickel ferrite particles. However, a decrease in the iron content of the deposits on the non-boiling sections of the heated surfaces was observed. This is ascribed to the fact that the solubilities of iron and nickel from nickel ferrite are lower at higher temperature, and that the solubility of iron is higher than that of nickel. Boron was not seen in the deposit analyses.
- Boron hideout-return results showed slight changes in boron concentration. It is likely that hideout return attributed to these changes; not because of water evaporation during the sampling.
- There were more deposits on the heated surfaces at lower pH. The pH affects the surface charges of both nickel ferrite particles and zirconium oxide. The interaction between the surfaces is less repulsive as pH decreases.
- Zinc addition had a significant effect on the deposition of nickel ferrite onto heated Zircaloy-4 surfaces, almost doubling the amount of deposits. Since nickel ferrite is more stable than zinc ferrite, it does not readily incorporate zinc into its crystal lattice. It should be noted, however, that the concentration of nickel ferrite particles in the coolant in this work was high; zinc addition at a

concentration of 10 ppb might not have to same effect as in a plant, where ferrite concentrations are of the order of 1 ppb.

5.1.2 Boron Measurement with Neutron-Based Techniques

- The investigation of PGAA methods and neutron slowing-down followed by absorption shows that after optimization both are able to distinguish the presence of a concentrated source of boron in the middle of the autoclave with a weak ^{252}Cf source (361 kBq). However, the sensitivity of the detection is insufficient to detect changes in boron concentration in the range of 100 ppm (the target concentration difference based on the boron hideout return results) in the high-temperature, high-pressure autoclave. The reason is that the experimented environment does not favor the detection; the autoclave is metal and contains a relatively large amount of water compared with the amount of boron. It should be noted that increasing the counting period and using the stronger source can improve the sensitivity of the measurement.

5.2 Recommendations

- The kinetics of deposition were not investigated in these experiments. It would be interesting to apply a radiotracing technique to study the kinetics of crud deposition under subcooled boiling conditions in a high-pressure, high-temperature loop. A kinetic model could then be developed.
- Two different pHs and one nickel ferrite composition were studied in this work. To see the complete effects of pH and the composition on the nickel ferrite composition on deposition, various pHs in the system and various composition of nickel ferrite should be investigated.
- Deposition under subcooled boiling was investigated in this work; it is believed that the mechanism is associated with the bubble nucleation. Thus, it is necessary to characterize the fluid mechanics inside the autoclave, in particular for deposition modeling. Furthermore, several studies have reported that the local chemistry of the coolant on the fuel cladding might be significantly different from

that in the bulk, especially once crud is formed on the heated surface. It would be interesting to study the relationship between these factors.

- The maximum heat flux that one can obtain from the present heater is about 18 kW/cm^2, which is about 10 times less than that of fuel elements. Valuable information would be obtained by extending the capacity of the heater.