Zirconium based alloys are the workhorse materials for nuclear industry due to their excellent performance in reactor environment viz. low neutron absorption cross section, low neutron activation cross-section for induced activity, along with excellent corrosion resistance and superior dimensional stability. Current scenario demands nuclear power plants to operate under rigorous safety criteria. However, to be economically viable, it should operate at a higher temperature with modified environments such as the coolant with partial boiling to achieve high burn up and/or longer residence time of fuel. This has necessitated the development of advanced materials for fuel tube as well as pressure tube for third generation advanced nuclear reactors. The development of material for advanced nuclear reactor involves either optimizing the existing compositions or modifying the fabrication route leading to improved microstructure for final products or addition of new alloying elements.

To improve the mechanistic understanding of microstructural evolution in Zr base alloy and to predict the microstructure during diffusional phase transformation at various temperatures, phase field model has been developed for Zr-Nb series alloys during the course of this study using Gibbs free energy functional and diffusional mobility.

In multi-component Zr-Sn-Fe-Cr system, effect of size, distribution and micro-chemistry of second phase precipitates as well as the addition of Sn in Zr-Sn-Fe-Cr alloy and Fe in Zr-Nb-Fe system, on oxidation and hydrogen-pick up behaviour of the alloys have been studied. The oxidation experiments were carried out in steam at 415° C and 10 MPa pressure. The base metal microstructures were characterized systematically using scanning electron microscope (SEM), transmission electron microscope - energy dispersive spectrometry (TEM-EDS), small angle neutron scattering (SANS) after accelerated autoclaving. Oxide formed in each case at 415° C as well as in a few samples at 500° C autoclaving were examined through SEM, X-ray photo electron spectroscopy (XPS) and grazing angle incidence X-ray diffraction (GIXRD) technique. On few selected samples cross sectional TEM was carried out for detailed investigations. To assess the feasibility of simulation of in-reactor damage of oxide by ion irradiation, the behaviour of the oxide in Zr- 2.5Nb-Fe and Zr-Sn-Fe-Cr alloys was studied using the GIXRD technique, after irradiation by heavy ions and protons. The results were compared with the in-pile oxide formed in fuel tube material during exposure in the temperature range of 260 - 263° C.
for 13 months in PHWR up to 7670 MWd/t burn up. GIXRD which is a nondestructive technique provides immense help in studying the distribution of phases in the oxide along the thickness direction without altering the stress pattern.

The detailed experimental and modeling studies of Zr base alloys performed during this period provide a comprehensive understanding of the evolution of microstructure specially Widmanstatten and allotriomorphic $\alpha$ during diffusional phase transformation in Zr-Nb base alloys. This thesis further discusses the effects of microstructure mainly second phase or precipitates size and distribution and the effects of alloying elements (Sn in Zr-Sn-Fe-Cr alloy, Fe in Zr-2.5Nb alloy) on oxidation and hydrogen pick up behaviour of the alloys. Finally the study improves in-depth understanding of irradiation induced phase transformation in oxide and distribution of phases in the oxide through thickness direction formed in the actual fuel tube during exposure in pressurized heavy water reactor (PHWR) and assesses the feasibility of simulation of the in reactor damage of oxide by ion irradiation.