CHAPTER I
INTRODUCTION

Nuclear energy supplies a significant part of the electrical energy produced in the world today. Canada presently has twenty two power reactors commonly referred to as CANDU reactors. One of the problems which has been identified for the long term operation of these reactors is the corrosion of the pipes which transfer the primary system coolant between the reactor pressure tubes and the boiler headers. This has been identified as "flow assisted corrosion". This thesis presents a model of this process based on the understanding of the corrosion phenomena which are achieved to have an effect in this type of corrosion at this time.

There are two types of nuclear reactions: fusion reactions and fission reactions. Both are exothermic reactions. Fusion reaction occurs by the combination of light nuclei into heavier ones. Fusion can be used as an energy source, but there must be sufficient energy to overcome the repulsion between nuclei. Fission occurs when a heavy nucleus absorbs a neutron and splits into two lighter nuclei with high velocity neutrons, as shown in Figure 1.1. The difference in mass causes energy which can be determined from Einstein's formula ($E=mc^2$). Fission is used as an energy source in the nuclear reactors where this chain reaction is initiated, maintained and controlled. The commercial nuclear plant was initiated in 1957.

Heat from a nuclear plant is used to produce steam for generating electrical power. Thus, there are three major systems: nuclear steam supply system, turbine generator system, and electrical power system. The diagram of a nuclear power plant is shown in Figure 1.2. The nuclear reactor supplies steam to the turbine generator system, which generates work. This work is conveyed to the generator and changed from mechanical work to electric work.

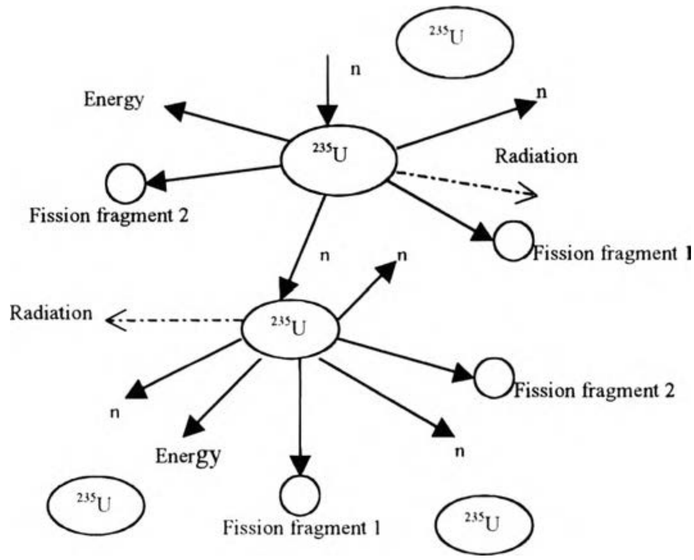

Figure 1.1 Schematic of ^{235}U fission (Foster and Wright, 1977).

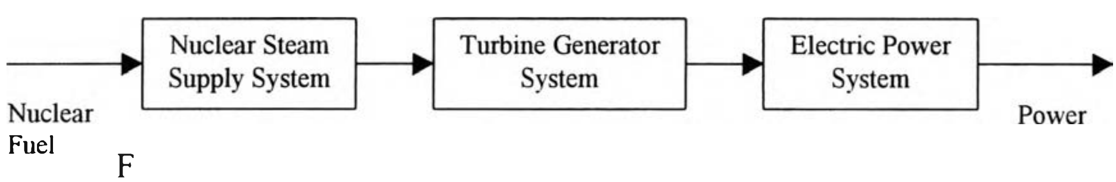

Figure 1.2 Diagram of nuclear power plant process.

There are many types of nuclear reactors such as Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR). CANDU, standing for CANada Deuterium Uranium, is a type of nuclear reactor which was initiated during 1950's with the decision to build pressure tube reactors (MacEwan, Notley, Wood and Gacesa, 1983). In 1971, the first unit of a commercial CANDU power reactor was built at the Pickering Generation Station in Canada with a capacity of 540 megawatts.

In the nuclear reactor, there are several components and materials which play different roles. The summary of the reactor components and materials is shown in Table 1.1.

Table 1.1 Reactor components and materials (Foster and Wright, 1977).

Component	Material	Function
Fuel	^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu	Fission reaction
Moderator	light water, heavy water, carbon, beryllium	To reduce energy of fast neutrons to thermal neutrons
Coolant	light water, heavy water, air, CO_2, He, sodium, bismuth, sodium potassium, organic	To remove heat
Reflector	same as moderator	To minimize neutron leakage
Shielding	concrete, water, steel, lead, polyethylene	To provide protection from radiation
Control rods	cadmium, boron, hafnium	To control neutron production rate
Structure	aluminum, steel, zirconium, stainless steel	To provide physical support of reactor structure and components, containment of fuel elements

Most fuels in nuclear reactors are radioactive materials which are suitable for fission such as ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu. These species split into smaller species and release energy and neutrons when they absorb a neutron. The neutrons released cause a chain reaction. The fast neutrons in the reactor are slowed by a moderator. A good moderator should be material with low mass number of atoms such as hydrogen.

A function of the coolant is to remove heat from the nuclear reactor. Thus, the coolant should have a high specific heat, high conductivity, good stability, good pumping characteristics, and low neutron absorption. It can be either a liquid or a gas.

The problem that can be found in a nuclear plant and the other industrial fields is corrosion. The CANDU reactor is presently facing such a problem. Corrosion is a general and significant problem in several industries. It is the major factor used in selecting the material of construction for each system.

There are many forms of corrosion: uniform corrosion, pitting corrosion, crevice corrosion, galvanic corrosion, erosion corrosion, etc. To predict which forms occur depends upon the system and the environment. Normally, uniform corrosion is observed. Uniform corrosion is a removal of metal from the surface. This form is preferred from a technical viewpoint because it is predictable and thus acceptable for design. For the CANDU system, it is found that not only uniform corrosion but also erosion corrosion occurs in the outlet feeder pipes of the reactor. Erosion corrosion is a result of combination of a corrosive fluid and high flow velocity of fluid relative to materials.

In order to predict this phenomenon, it is necessary to develop a model. The model is used to predict the thinning rates of various outlet feeder pipes of a CANDU reactor. Such a model can be used to interpret data from the laboratory and plant and predict life expectancy of the feeder pipes.

In this thesis, the mechanisms of thinning are explained by a semi-empirical model to understand better thinning phenomenon of the outlet feeder pipes of a CANDU reactor. There are many factors that influence this thinning phenomenon: material of pipes, mass transfer, electrochemical effects, oxide solubility, the corrosion reaction, erosion, entrance effects and surface roughness.

The operating conditions have an important effect on magnetite layer formed on the material surface. An increase in magnetite solubility with temperature at pH of 10(at room temperature) or above leads to undersaturation of the coolant at the reactor outlet. This causes magnetite dissolution into the bulk coolant. The velocity of the coolant in the pipes produces shear stress at the surface. Consequently, erosion of the magnetite can occur. The above factors that are included in the corrosion model for the reactor feeder pipes are presented in this thesis.