CHAPTER - 6
CONCLUSIONS

For a safe and reliable operation of sodium cooled fast reactors, on-line monitoring of core cooling and sodium levels in various systems are very essential. Further for safe fuel handling operation in opaque sodium at elevated temperature, ultrasonic under sodium viewing for protrusion detection is very essential. All these formed the focus of the research. Detailed experimental and theoretical studies have been carried out in these three domains. Major findings of the thesis work are summarized below.

6.1 IN-SITU TIME CONSTANT ESTIMATION OF CORE THERMOCOUPLES

Response time of thermocouple probe forms an important input for reactor safety analysis of fast reactors and hence frequent time constant estimation is essential. Towards this, a new time constant measurement method has been devised with minimal interference using ramp signal generated during operation of nuclear reactor. As part of this study, the following conclusions are derived

- The thermocouple in thermowell has been modeled and the characteristic graph between contact resistance Vs time constant has been established. The ramp rate in the reactor is estimated from fast response thermocouple which is used as reference. The response time of bare thermocouple is determined by matching the response curve.
- Process time constant for different flow zones are estimated by mathematical model and are subtracted from the predicted response time.
- This procedure has been applied to 36 thermocouple probes and the results are found within the expected limits.
- Validation and repeatability of the proposed method have been established by comparing reactor data set for two different instants.
6.1.1 Future Directions

Degradation in response time due to creep, loss of spring pressure etc can be minimized (Carroll, 1982) by fitting the thermowell with suitable alloy. With suitable material selection, and after studying the fabricability, galloy filled thermocouple can be tried out.

6.2 ULTRASONIC TECHNIQUE FOR PROTRUSION DETECTION

Reactor core and mechanical components which make up the primary circuit coolant are totally immersed in sodium with the core being up to several meters below the sodium surface. Visual examination of the internal structure is impossible because of the opacity of sodium and lowering of liquid level is impractical once a reactor is operational. Under sodium ultrasonic method has been developed for detection and imaging of objects protruding above core top. The possible geometric shapes of the FBR objects /structures are not favorable for ultrasonic beam and imaging and detection of these structures with minimum axial gap is main challenge of the research. Full scale experiments have been performed in water properly simulating the beam spread half angle equivalent to that of sodium.

- Various absorber rod drive mechanism profiles have been simulated and different case studies have been carried out for different orientations. These experimental findings have been implemented in Indian FBR.

- It is found that the protrusion of absorber rods and their drive mechanisms can be detected and located except the extreme conical portion using direct imaging technique.

- All the reactor sectors have been simulated in both clockwise and anti-clockwise directions with and without retros for detecting protruded fuel subassembly or
conical shape of absorber rod drive mechanism which is not favorably oriented to the beam using an indirect imaging technique.

- Initially without any protrusion, the core is scanned and the C-scan image is constructed which served as the reference data. The gating is set based on reference data targeting blocking subassembly.

- Using a summation algorithm with angle specific gating, it is established that a differential growth of 45 mm protrusion of fuel subassembly is detectable up to a distance of 3 m.

- The conical shapes of absorber rod drive mechanism of 20 mm projection from core cover plate are detectable using indirect imaging technique.

- The inclination effect of peripheral blocking subassembly is also studied and found that 0.44 deg. inclination is tolerable to ultrasonic beam.

- A single channel ultrasonic scanning system has been developed in house along with an offline analysis program for plotting the images with summation algorithm.

### 6.2.1 Future Directions

Currently a rigid scanner is used in the reactor, during fuel handling operation which demands a long shut down time to scan the reactor core. Future development can be towards a flexible system, capable of examining all the core from one loading position and able to remain permanently installed if ultrasonic imaging is a regular feature of FBR operation. The requirement is therefore for the development of transducers or ultrasonic waveguide capable of operating at 650°C and a flexible transducer manipulator.

The image presented is constructed from raw data which undergoes degradation due to beam spread and scanning pattern. Various algorithms can be experimented to remove beam divergence effect and filling of missing points. Current scanner has only 2 degrees of freedom. Three dimensional imaging is possible using mechanical and synthetic scanning...
using 2 dimensional arrays. New methods for beam steering and focusing ultrasonic reflections arising from a specific spatial point on a target can be developed.

6.3 SODIUM LEVEL MEASUREMENT SYSTEM

The under sodium scanner works only if the components are adequately immersed in sodium, which is ensured using sodium level measurement system. Long length online level measurement system has been developed and experimented in sodium for large power reactor applications. As the temperature gradient along the level probe is large an improved dynamic temperature compensation technique with simple electronics has been developed. The following results are obtained

- A Prototype longer level probe of 6000mm has been fabricated and tested in sodium to assess the sensitivity.
- Using the proposed method of temperature compensation, the temperature effect on level probe is reduced from 10.59 % to 1.5 % over a temperature range of 200°C to 550°C without change in sensitivity of the probe.
- The optimum frequency of excitation and the external resistance to be connected across the secondary coil have been arrived at simultaneously.
- The sensitivity of the level probe is determined to be 20 % at the operating frequency with an accuracy of 1.5 %. The linearity of the probe was found to be 0.7 % over the operating temperature range.
- This technique not only improves the accuracy but also simplifies the electronic circuitry by eliminating the temperature compensation circuit.
- Experimental studies have been carried out to improve the sensitivity of the probe by varying the coil diameter.
- A prototype MI type discrete level probe with 5 levels has been fabricated with 32mm diameter bobbin and tested for its performance in sodium at different temperatures.
• The discontinuous level detection accuracy is about +/- 6 mm around the centre of the bobbin. The same former can carry up to 5 sensors in one discrete level probe.

• After successful development of prototype MI type continuous and discrete level probes, 29 numbers of continuous and discrete level probes of each are fabricated for deployment in PFBR. The active length of the continuous level probe varies from 660 mm to 9300 mm.

6.3.1 Future Directions

All the level probes require sodium calibration to arrive at optimum frequency, secondary millivolt levels and external temperature compensation resistor. Further studies can be carried out to dispense sodium calibration by choosing materials having same conductivity and permeability equivalent to that of stainless steel and sodium at 200 and 550°C. Improving the sensitivity of the sensor by changing the electrical windings of the primary and secondary coil can be studied. Further ultrasonic waveguide technique can be experimented for sodium level measurement.