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# ROLE OF ANIMATED HUMAN MACHINE INTERFACE IN NUCLEAR POWER PLANT SIMULATION

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**Abstract**
The recent advances in Computer Science and Technology have revolutionized the way graphical user interfaces are used towards Human Machine Interface (HMI). The graphical user interface is so powerful, that the knowledge of a process or system can be transferred to plant personnel accurately and effectively within a short period of time. The techniques of animation can enhance the illusion of direct manipulation that many human computer interfaces strive to represent. This paper describes the role of human machine interface using animated information in Full Scope Replica type training simulator of Prototype Fast Breeder Reactor (PFBR). This paper covers general description of PFBR, the Full Scope Replica Simulator, the concept of simulation of plant dynamics, development of the animated core temperature distribution diagram and process flow diagram followed by its features. Also it covers how animated core temperature distribution and dynamic process flow diagrams are advantageous for operator training.
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**Key Words:** Animation, Full Scope Replica Simulator, Human Machine Interface, Process Flow Diagram, Prototype Fast Breeder Reactor

## 1. INTRODUCTION

Full Scope Replica Simulator is used for real time dynamic simulation of nuclear power plant operations for training purposes. The increasing demand for well trained power plant operators has led to the realization that the simulator is the most effective tool for such training. An actual nuclear power plant cannot be used for extensive training such as, start up, shutdown, malfunctions, incidents etc for safety considerations and reactor availability reasons. Only after years of experience, the understanding and knowledge acquired about the plant reach high levels. Even then it is unlikely that an operator would observe the effect of important malfunctions and transients and be able to adopt the best corrective procedures. Such reasons have led to use of simulators for power plant operator training. Full Scope Replica Simulator consists of complex mathematical models which mimic the real nuclear power plant operations. Process Models of the nuclear power plant are modelled in the simulator so that it can simulate real time physical processes. There is a need for operators to construct a mental representation of the nuclear processes and its operations for full understanding of nuclear power plant. A static diagram might aid this. However, it has been proven many times that animations are superior to static diagrams, especially when learning concerns a series of events in dynamic systems [1]. An animation can be defined as a series of rapidly changing computer screen displays suggesting movement to the viewer [2].

Animation techniques not only depict objects, they also additionally provide information concerning object changes such as position, colour, shape or orientation over time. It aims at giving an exact presentation of a process or procedure to facilitate generating an adequate mental model [3]. They also quickly draw the attention of operator and depict the information more effectively.

## 2. BRIEF DESCRIPTION OF PFBR

The Prototype Fast Breeder Reactor (PFBR) under construction in India is a pool type, sodium cooled, plutonium-uranium oxide fuelled, reactor with a thermal power of 1250 MWt and an electrical power output of 500 MWe. The primary objective of the PFBR is to demonstrate techno-economic viability of fast breeder reactors on an industrial scale [5]. PFBR consists of three circuits namely Primary sodium, Secondary sodium and Steam - Water circuits. The primary sodium circuit with two pumps and four IHX (Intermediate Heat Exchanger) is contained within the reactor assembly and the secondary sodium circuit consists of 2 identical loops each with a sodium pump and four Steam Generators (SG). Primary sodium in the pool absorbs heat produced by nuclear fission. Heat is transferred from primary sodium to secondary sodium in Intermediate heat exchanger (IHX). Heat gained by secondary sodium is used to convert feed water in Steam Generators (SG) into super heated steam to drive Turbine-Generator to produce electricity. Variable speed sodium pumps are used to circulate primary sodium in the pool and secondary sodium in the IHX & SG.

The reactor core is made up of subassemblies, arranged in a hexagonal lattice as shown in Fig. 1. Of these, the active core is made up of 181 fuel subassemblies (FSA). There are two enrichment regions in the active core for power flattening. There are 2 rows of radial blanket subassemblies and 12 absorber rods, comprising 9 control and safety rods (CSR) and 3 diverse safety rods (DSR) arranged in two rings. Enriched boron carbide is used as the absorber material. The radial core shielding is provided by stainless steel and $B_4C$ subassemblies. They limit the secondary sodium activity and radiation damage and activation of the primary circuit components to acceptable levels. PFBR has been developed under the philosophy pursuing safety as the most important goal from commencement.

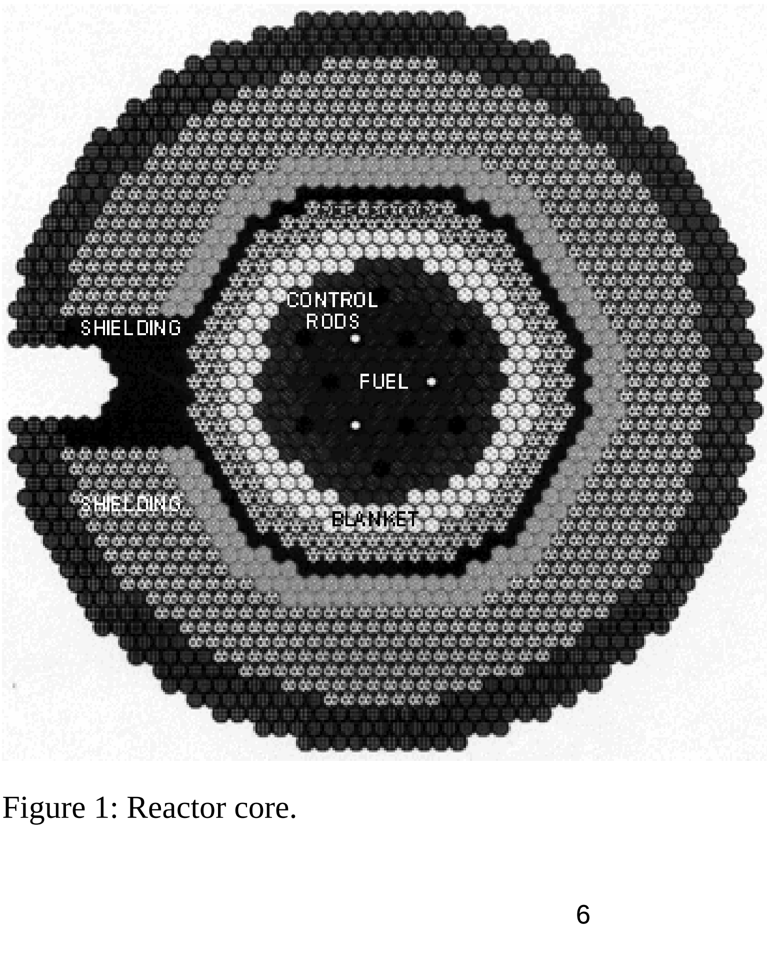


Figure 1: Reactor core.

## 3. FULL SCOPE REPLICA SIMULATOR

PFBR Operator Training Simulator is a Full Scope, Replica Type Simulator which provides comprehensive training to operators in the Prototype Fast Breeder Reactor plant operations. The simulator is essentially made up of mathematical models of PFBR subsystems running in a computer system in real time and actual sequence to replicate the operational characteristics of the plant. PFBR Training Simulator is designed to simulate the steady state and dynamic responses of the plant to operator actions in real-time [6]. The simulator is helpful in training the operators about the process dynamics, operations in normal and abnormal situations, various malfunctions & incidents, plant start-up etc. Full Scope Replica Simulator consists of Process models, Logic models and Panel models. Fig. 2 depicts the simplified block diagram of Full Scope Replica Simulator. There is also a provision to integrate the simulator models with external models such as other mathematical models written in C or FORTRAN codes through suitable library calls. All these models share a common database. The variable reference /memory bindings are organized in tables that deliver high performance updates.

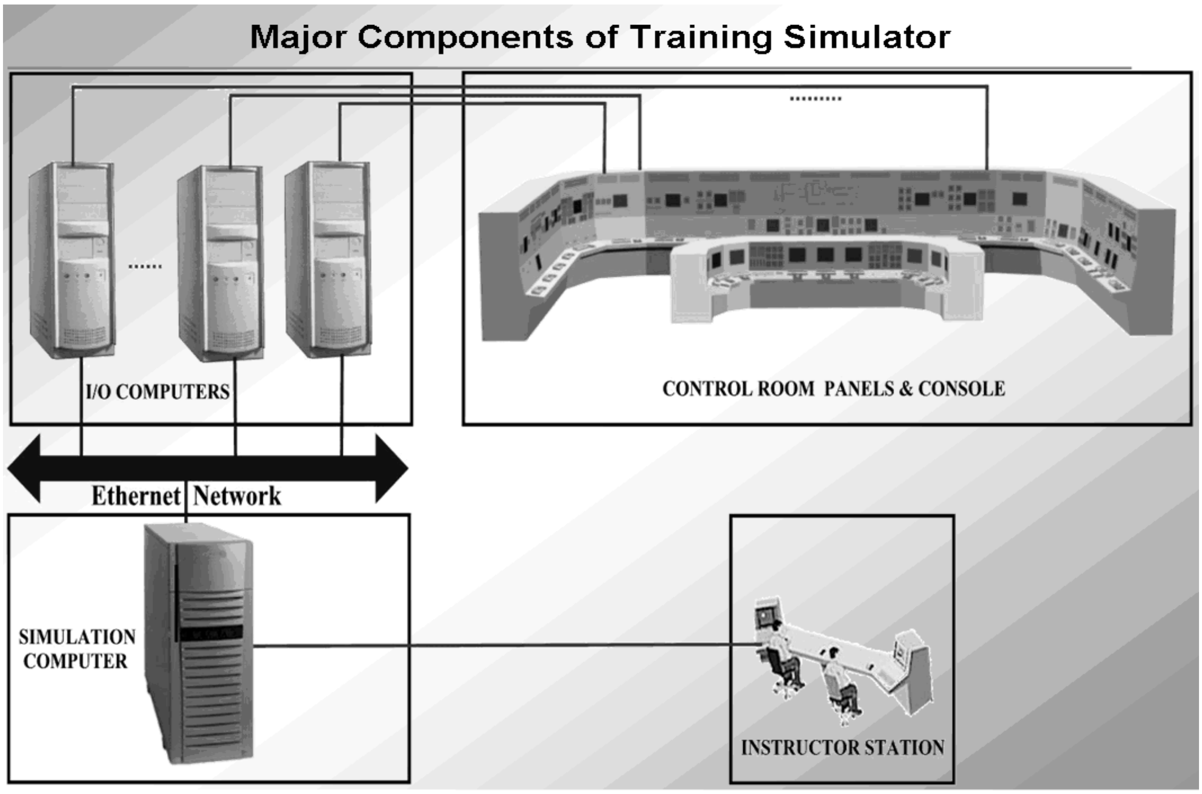


Figure 2: Block diagram of Full Scope Replica Simulator.

PFBR simulation involves developing models for various subsystems. The PFBR subsystems identified for simulation are Neutronics System, Primary Sodium System, Secondary Sodium System, Decay Heat Removal System, Steam Water System, Electrical Systems, Instrumentation & Control systems, Core Temperature Monitoring System and Fuel Handling Operation. Fig. 3 gives various subsystems modelled in Full Scope PFBR (Prototype Fast Breeder Reactor) Operator Training Simulator. Further, in order to train the operator for eventualities such as malfunctions and incidents representing the unusual occurrences during the plant operation, a list of events has been identified. The list is quite exhaustive consisting of possible incidents, transients and malfunctions related to PFBR which have been included for modelling and simulation. Apart from normal system functions, all possible incidents, including less severe and more severe events connected to each process are simulated. The transients, incidents and malfunctions which are likely to happen in the system have been considered for simulation. They are classified as Category 1, 2, 3 & 4, based on the frequency of occurrence in the plant. Simulations can be used to observe a process in action, to examine the statistics that it generates as it runs, and to perform analysis on the simulation results.

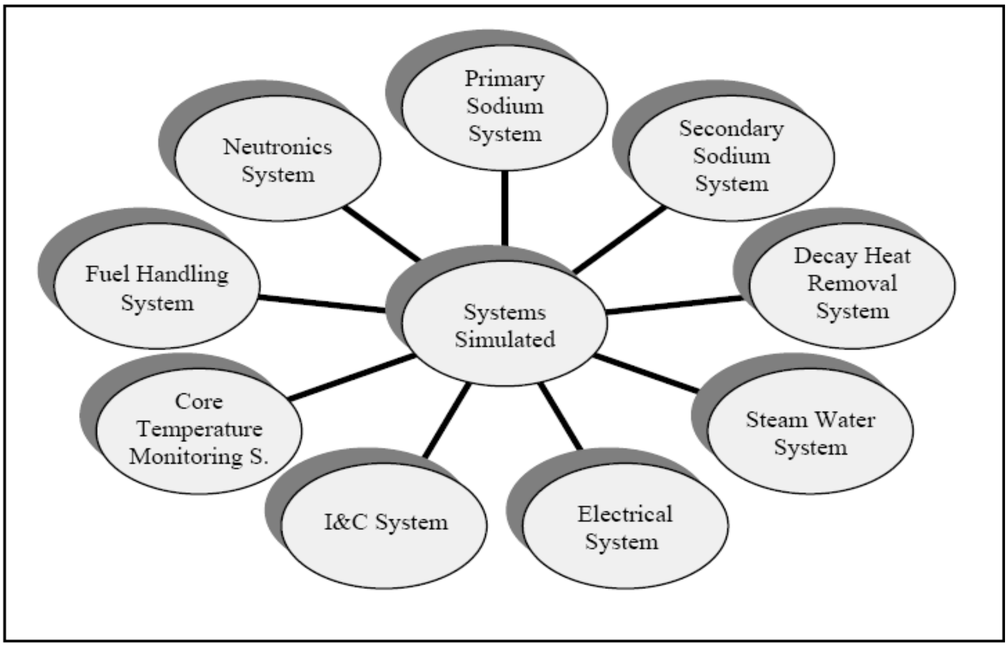


Figure 3: Reactor subsystems modelled.

The development of simulator models can be done using virtual panels. During the initial phase the process models are developed and tested using virtual panels. A virtual control panel is just a collection of controls which are graphically represented in 2D screen. They can be operated by button clicks using mouse [7]. Virtual Panel models mimic both plant control and console panels. Virtual panels consist of same layout as that of actual plant. Indicators, Digital recorders, Lamps, Control switches, Annunciation windows etc are replaced in virtual panels as shown in Fig. 4.

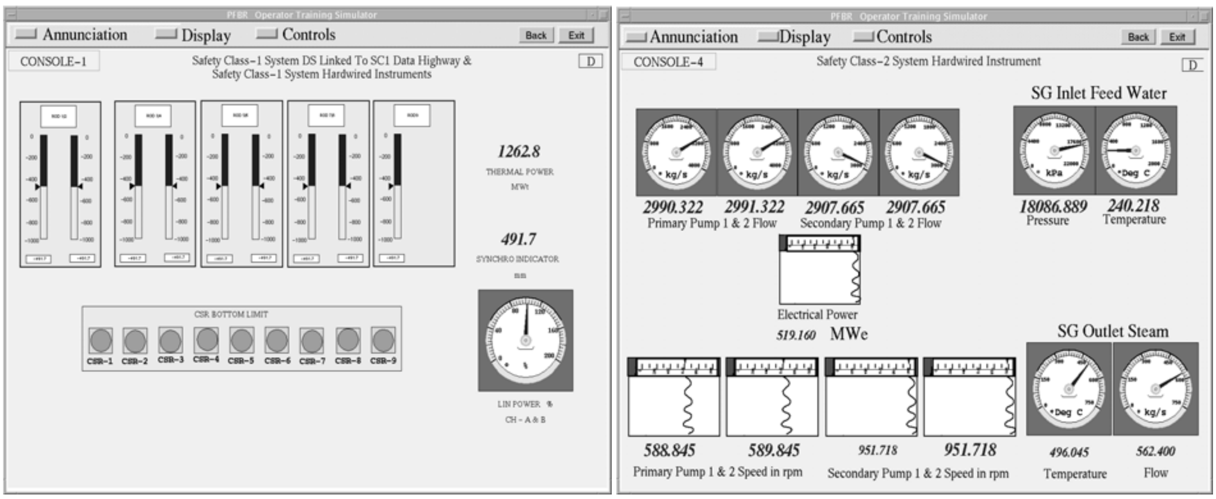


Figure 4: Virtual Panel containing LED lamps, bars, analogue meters and recorders.

A model in a graphic screen of a virtual panel is a collection of graphic objects. Models consist of objects, their parts, their location and their dynamics. Each object can be given a name using the graphical editor so that they can be accessed via the C code. Models may also contain other models within them; in such a case the models used are called sub models. These models are created using graphic objects such as lines, poly lines, rectangles, polygons, splines, circles etc. Each object contains a set of attributes which can be manipulated in the graphical editor or through the application code. Some of the basic object attributes are Fill, Text, Rotation, Scale, Move etc. For example in core temperature monitoring system, Fill attribute is used to fill colour dynamically at run time depending on the temperature change.

## 4. HUMAN MACHINE INTERFACE

Human Machine Interface (HMI) is a simple interface existing between humans and machines. The interface could be implemented in software as done in soft buttons or virtual panels, or in hardware as done in real control panels consisting of buttons, recorders etc. The HMI shall display information in such a way that one easily gets a visual image of what is going on in the plant. This information may be pressure, temperature, flow signals, valve/pump positions, alarms etc. The information could also be derived from processes, such as bar charts, trend graphs etc. HMI may or may not be connected to input devices such as buttons or mouse. It is a widely acknowledged fact that well designed HMI greatly improves operator performance and thus the safety of any nuclear plant. The role of HMI should not only aid an operator quickly in understanding the steady state operations/behaviour of the nuclear plant but should also guide the operator's decision during a transient or abnormal progression of plant. In almost all nuclear organizations HMI is taken very seriously and detailed study is conducted on its effective usability. Designing HMI for Nuclear Power Plant requires special attention towards procedural tasks. For an operator, procedural tasks are composed of monitoring, decision-making, and control. The main activities of monitoring are perception and judgment. This monitoring can be classified into two categories as follows. Simple monitoring is a simple observation of parameter values or equipment/component status by the human sensory systems. Cognitive monitoring is an observation that needs complex inference, such as the interpretation of the time trends of operating variables or the prediction of their future trends [4]. Animated information has been found many a times useful and hence while designing HMI special care has been taken to incorporate them along with the regular design. In subsequent pages they will be elaborated in detail. This paper discusses in detail about core temperature monitoring system and animated flow sheet in detail. It is planned in future to take up other subsystems of the reactor for animated HMI.

### 4.1 Development of dynamic core monitoring system

External code for core monitoring system has been developed in house using flow zoning technique. Further power factor and flow factors have been used in calculations to obtain various zone wise temperature distributions in 181 subassemblies. This code has been written in FORTRAN by design experts. External code developed has been later integrated with the simulator environment. This has been made possible by using C- based templates available in Full Scope Replica Simulator. The compiled code is used for publishing its outputs to simulator environment. Also the code subscribed inputs from the process models (internal models) of the simulator for producing the necessary outputs. For example in order to calculate each subassembly temperature it has to get inputs such as state of the reactor (full power or part power etc). All the published and subscribed variables are stored in a common database which in turn is shared by all the reactor processes (both internal and external). A pictorial representation of the above process is shown below. Fig. 5 depicts integration of Simulator tool with external model.

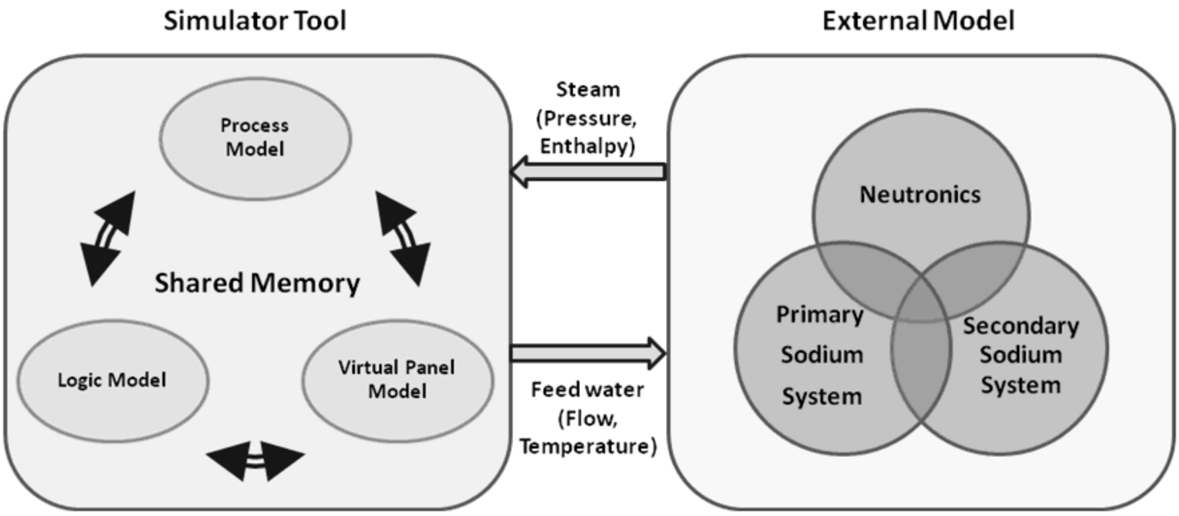


Figure 5: Integration of Simulator Tool with External Models.

Models in virtual panel consist of 2D top view of subassemblies. The internal C code communicates with external code of Core temperature monitoring and process models of the simulator. Internal C code has a timer function which helps in updating values. The dynamic temperatures are captured and displayed in the mimic through different colours. Fixed colours have been given to CSR, DSR and Blankets. A button click event is connected to subassemblies so that by clicking on a subassembly position, the respective temperature at that particular time is displayed along with the subassembly number. The database for all these operations is implemented through shared memory. An exit button is connected in order to quit the program. Plugging detection for 10 % flow blockage has also been calculated and associated alarms are indicated in virtual panel. The core temperature distribution panel is shown in Fig. 6.

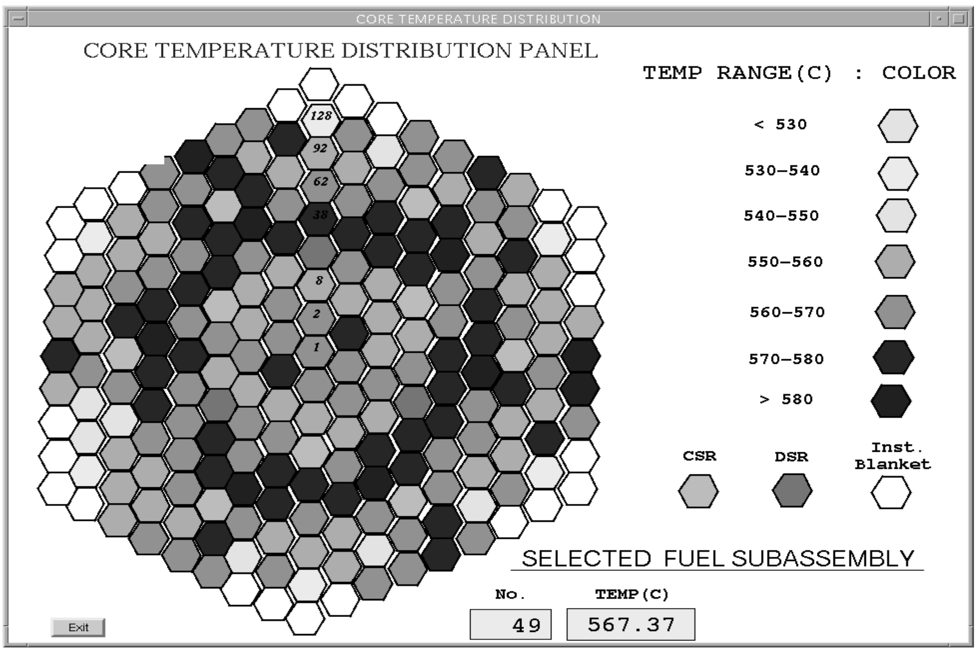


Figure 6: Core temperature distribution panel.

### 4.2 Development of dynamic flow sheet

The PFBR Process Flow diagram has been developed using simulator graphic tool provided in virtual panel model of Full Scope Replica Simulator. The flow sheet consists of core profile, primary sodium circuit, secondary sodium circuit, and finally, steam water system and electrical system. The interconnection such as valves, pipes and pumps have been drawn using the graphic tool. Each unit is considered as a separate object and dynamic properties are attached to it. Dynamic properties are attributes of objects along with other graphical attributes. At runtime, whenever specified data variable changes, the graphic tools automatically make the correct sequence of library function calls to make specified changes on the screen. The dynamic behaviour of objects has been interactively specified and exercised by external data sources. Fig. 7 indicates the development process of the flow sheet.

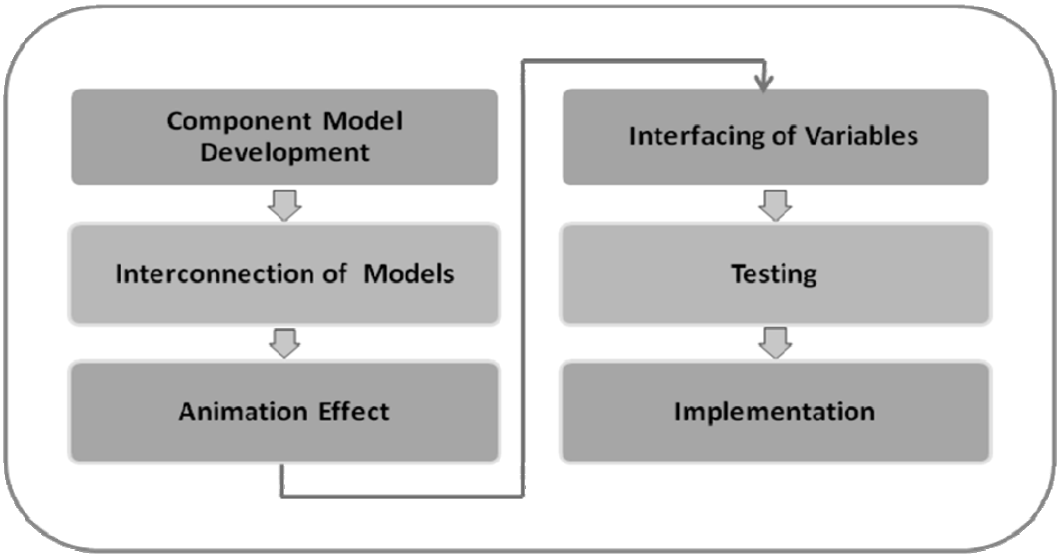


Figure 7: Development process.

The PFBR flow sheet consists of one top model and one sub model. The features like GISMO (Graphical Interactive Screen Management Object) which are Sub models having input dynamics are used in developing the PFBR flow sheet. Some of the GISMO commands include SCREEN, DATASCREEN, RETURN and QUIT GISMO. Here SCREEN GISMO displays a new screen and DATASCREEN GISMO displays a new screen and activates the screen's data file for dynamics. QUIT GISMO exits the application program. RETURN GISMO returns to the previous screen [8].

### 4.3 Integration and testing of plant parameters

Once the process models of the nuclear system and graphical interface are configured in Full Scope Replica Simulator, they are linked together through database. The process model variables are linked to the corresponding input/output of the graphical interface models using database. The Full Scope Replica Simulator graphical tool uses a data linkage technique that can be interfaced to any data acquisition system. Variable references in dynamic properties are bound within memory locations. Whenever there is a change in the value at the specified memory location, the graphic objects associated with that value are updated automatically. Simulator graphical tool has the updating rate of 200 ms. For the ease and convenience of the operators the frame update rate has been made to perceive easily for eyes.

The Process Models are tested independently and then integrated with the HMI and tested thoroughly. Here the process networks are linked using stub connections available which allows the input / output / feedback signal to flow between the networks. The input and output process parameters are then checked and compared with the actual process parameters. The deviation in simulator output parameters from the actual process parameter are narrowed down by tuning the network components. After process models are successfully integrated, normal operation or transient loading or malfunction initiation from instructor station is carried out and it is tested for the reflection in the animated HMI with their corresponding behaviour verification.

## 5. CORE TEMPERATURE MONITORING SYSTEM CAPABILITIES

Virtual panel model of Full Scope Simulator contains a 2D graphics software development tool that creates animated interface screens for the display and management of dynamic data. Dynamic graphical screens are used in applications to manage real time nuclear processes and events. The 2D graphical tools strive to establish one to one correspondence between events on the screen and events in the real time environment of the nuclear process being visualized. Dynamic behaviour is accomplished through actions which specify changes to be applied on the objects. For example, if a revolve action is specified in response to a change in a variable named Torque, the object is literally rotated in the screen, that is, the rotating effect is applied on the object which is visible to the human eye. Some of dynamic actions of core temperature monitoring system are explained below.

### 5.1 Temperature changes

Whenever there is a change in subassembly temperature, this is indicated by colour change of that subassembly. There are in total seven colours indicating temperature ranges. When reactor is in operation, each subassembly in the core profile will have a particular colour depending on its thermal power, hence lower and higher thermal powers will be indicated by different colour schemes of the core temperature profile.

### 5.2 Value display

On clicking a particular subassembly, the subassembly number and its temperature value will be displayed. The increase or decrease in subassembly temperature values can be seen by watching the values in the text box.

## 6. ANIMATED FLOW SHEET CAPABILITIES

Screenshot of animated PFBR flow sheet is shown in Fig. 8. Some of the dynamic actions used in PFBR Flow diagrams are explained below.

### 6.1 Flow

The sodium coolant is shown flowing in pipes through core, SGDHR (Safety Grade Decay Heat Removal), Intermediate Heat Exchanger and Steam Generator. The Steam flow and Water flow through corresponding pipes are also indicated. SGDHR system consists of four independent loops of each 8 MWt heat removal capacity. Each loop consists of the following: Sodium-Sodium Heat Exchanger that is Decay Heat Exchanger (DHX) which is dipped inside the hot pool, Expansion tank, Storage tank, Sodium Air Heat Exchanger (AHX) with associated piping, valves, air dampers and a stack. A simplified diagram of SGDHR (single loop) was animated for easy understanding of the system. Fig. 9 shows the flow dynamics through SGDHR loop.

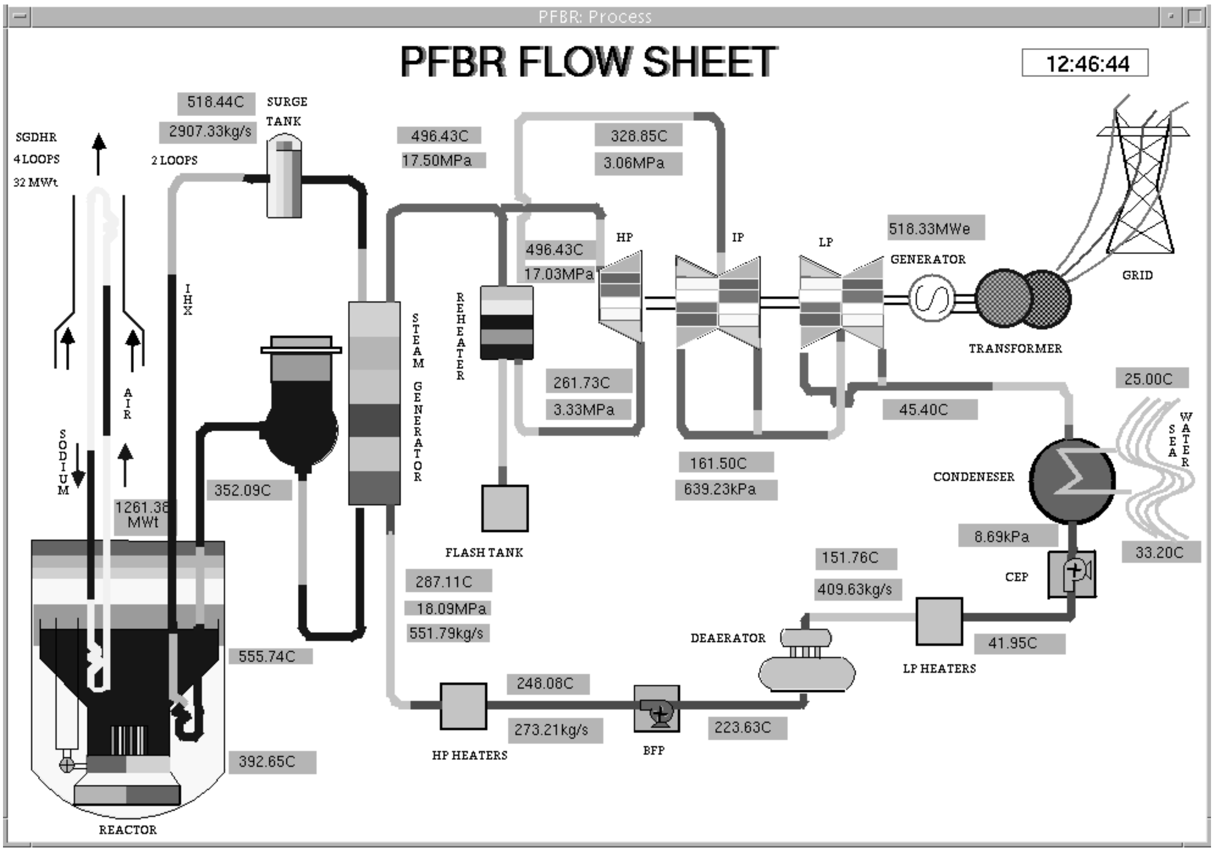


Figure 8: Animated PFBR flow sheet.

In secondary sodium system, the sodium coolant flows through four IHX (Intermediate Heat Exchangers). One of the IHX was shown in the PFBR flow sheet. Heat is exchanged between the hot and cold sodium through IHX. In Steam -Water system, the water flows through the steam generator picking up heat of secondary sodium and gets converted into steam which in turn is used to drive the turbines for generating power. The flow of water and steam through corresponding pipes is shown in a simplified form in a single loop.

### 6.2 Visibility

When the reactor turbine trips, then the steam produced from the steam generator is directed through Pressure Reducing De Superheating (PRDS) circuit and then dumped into the condenser. Hence during normal operation of the reactor, the PRDS circuit is in visibility OFF condition and whenever there is a turbine trip, the turbine bypass system is shown by turning visibility ON, that is, the PRDS circuit becomes visible in the PFBR flow sheet.

### 6.3 Rotation

Rolling of turbine during power generation is indicated by rotate dynamics. Also the pumps such as sodium pump, boiler feed pump, condensate extraction pump etc are shown rotating. On loading a transient such as Boiler Feed pump trip, the corresponding BFP rotate dynamics is stopped.

### 6.4 Text change

Through data sharing from process models key values of power level, temperature, pressure, flow variables are fetched from the database and are displayed in text format. For example core operating power level is displayed near the core, the inlet and outlet sodium temperatures are displayed at core inner vessel etc. The dynamic updates occur at 200 ms rate. Keeping the operators viewpoint the dynamic change of the text data in PFBR flow sheet is kept around 1 second interval.

### 6.5 Colour

Whenever there is a change in reactor power, it is indicated by colour change in the flow of sodium coolant and steam – water system. Also whenever there is any abnormal value in the text data displayed (such as in an event of transient loading), this is indicated by change in colour of the text displayed.

### 6.6 Cycle

For turbine, roll cycle dynamics was used. This was achieved by giving a colour change dynamic property for each step change in clockwise direction. Fig. 9 shows cycle dynamics. Whenever there is a turbine trip this cycle dynamics is made OFF indicating a stop in the rolling of the turbines.

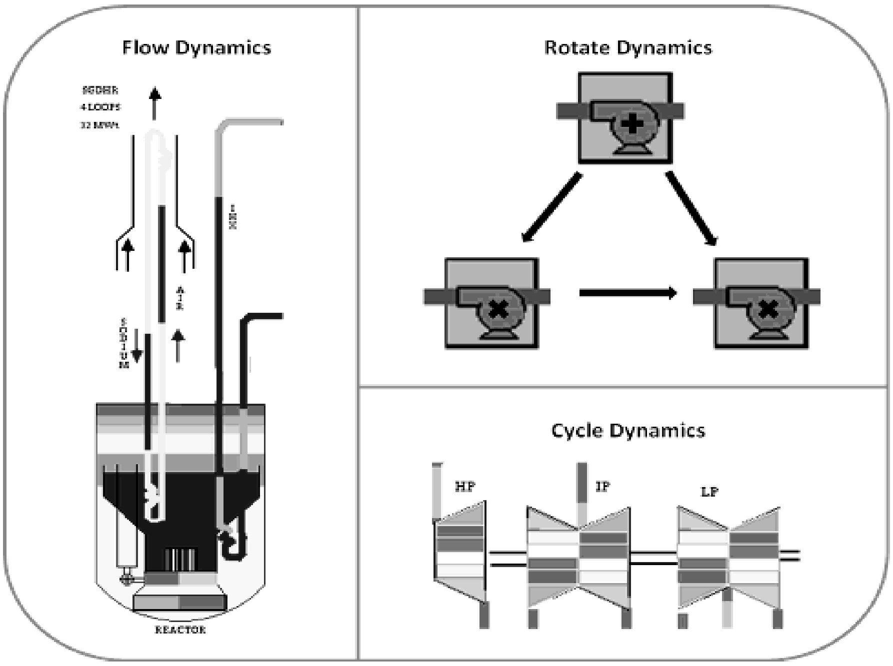


Figure 9: Sodium flow in SGDHR (Flow Dynamics), Boiler Feed Pump (Rotate Dynamics) and Turbine (Cycle Dynamics).

## 7. IMPROVEMENT OF OPERATOR PERFORMANCE

Proper design of human machine interface with animated information has become essential in any Nuclear Power Plant. Animation is a powerful tool for operator training in the sense that it can combine vast amounts of process data into a compact package, which can be presented simplistically in a pictorial form. Animation further captures the attention of the operator more effectively. They are greatly benefited by utilizing the animated HMI. In static pictures often abstract clues such as arrow marks have to be interpreted with pictorial information. This, many times, can lead to misinterpretation and deficient model. However animations can graphically simplify complicated concepts and convey complex inter-relationships which are difficult to visualize [9]. Human Machine Interface using animated information further aids the operator to have a smooth change over to the actual plant after completion of training. The advantages of animated HMI are listed below.

### 7.1 Better than conventional alarm system

In any conventional alarm system, an operator will be aware of alarm condition only after the alarm threshold is crossed which is indicated by blinking indications in alarm panels followed by hooter sound. In case of animated HMI, the flow of coolant inside a pipe is indicated by different colours depending on the temperature. Normal sodium flow is indicated by grey colour, when the sodium temperature increases the grey colour will change to yellow followed by to orange. Once it reaches alarm threshold it will change into a deep red colour. Hence the operator becomes aware well in advance that there is a probability of alarm by keeping a watch on coolant colour changes.

### 7.2 Captures attention

Flow of coolant or pump/motor running in traditional systems are indicated by change in numerical digital display of values. In case of an animated HMI, along with the change in digital display of values, an operator becomes more aware of speed change or flow change when he can practically see it, as this is what is happening in animated HMI. Flow of coolant is indicated by speed of movement of colour pellets inside the tube, when the flow rate is normal the speed is kept as 1 (normal).When the flow rate increases this is indicated by faster movement of pellets and lowering of speed is indicated by reduction of movement of pellets. Rotation of pumps is indicated by circular movement of shaft. Once the pump trips the movement stops indicating trip of pump. Simulation and display of core temperature monitoring system with dynamic display of individual sub assembly temperatures through colour changes makes the operator aware of which subassembly is the hottest. These simple animations draws operator attention and hence operator gets benefited by them.

### 7.3 Increases operator awareness

In animated HMI, flow of coolant is indicated by continuous movement of colour pellets which could be slower or faster depending on the system dynamics. Animated HMI increases operator awareness of the system. For example, when primary sodium pump trips, an operator expects flow of the coolant to stop. However, the flow does not drop to zero due to natural convective flow in the circuit. This increases the awareness and knowledge of the operator. In SGDHR system where the flow is by natural convection, this becomes important as it can also be seen in animated HMI by comparatively slower movement of pellets in SGDHR system alone.

## 8. CONCLUSION

The role of Process Simulator is quite significant in the present set-up of training Nuclear Power Plant Operators. Training of operator not only improves availability and efficiency in nuclear plant operation, but also safety in the nuclear industry. Because of this, training is organized, regulated, approved and monitored by government regulatory commission [10]. Animations help in mentally visualizing a process or a procedure with ease. It improves operator performance, as it is better than conventional alarm systems, captures operator attention and increase operator awareness as mentioned above in section 7.

It is planned to take up other subsystems of PFBR for animated HMI in future. Fuel Handling subsystem is one such subsystem where the operator will be greatly benefited by HMI, and hence it is planned to take up this subsystem first. The animated HMI of fuel handling includes display of 3D models like, Large Rotatable Plug, Small Rotatable Plug, with their rotating angle indications, Transfer arm translation motions, their sequence of operation etc.

## 9. ACKNOWLEDGMENT

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