Component Handling System: Prototype Fast Breeder Reactor (PFBR) and Beyond

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Abstract. Component handling system deals with the handling of fresh and spent subassemblies (fuel handling) and irradiated primary system components using special flasks (special handling). In Fast Breeder Reactors (FBR), design of fuel handling machines is very important considering the fact the coolant sodium used in FBRs is opaque and most of the handling operations are carried out remotely. Special features are provided in the design of hoisting system of fuel handling machines like single failure proof design features in order to avoid fall of subassembly during handling. Incidents on component handling system have a serious impact on plant availability and hence utmost care is taken in the design to avoid wrong operations of fuel handling machines.

PFBR in-vessel handling utilises two rotatable plugs and an offset arm type machine (Transfer Arm). For ex-vessel handling, an A-frame type machine called Inclined fuel transfer machine (IFTM) is used. Several other machines are used as part of the fresh and spent fuel handling chain. Water pool type storage is provided for ex-vessel storage before the subassemblies are transferred to the reprocessing plant. Critical primary fuel handling machines namely Transfer arm and IFTM were qualified by cyclic testing in air and in sodium in dedicated test facilities. The design of PFBR fuel handling system and the design validation of the critical fuel handling machines are described in this paper.

The experience gained in the design, manufacturing and testing of fuel handling machines for PFBR has given valuable feedback for future FBRs. Beyond PFBR, six more oxide fuelled FBRs are planned as twin units. Refuelling in fast reactors being done off-line, gives opportunity to evolve a fuel handling system shared between multiple units for improved economy. The design of fuel handling system for the twin unit 600 MWe future FBRs is described. The rationale behind the changes proposed with respect to PFBR is brought out. Most of the fuel handling equipment is shared between the twin units and a unique twin unit layout has been evolved which is also covered in this paper.

Key Words: component handling, innovative reactor designs, FBR 1&2, PFBR.

1. Introduction

India started fast breeder reactor programme by constructing a 40MWt/ 13.5MWe loop type fast breeder test reactor (FBTR) at Kalpakkam, which is in operation since 1985. This was followed by the design and development of a 500 MWe capacity Prototype Fast Breeder Reactor. The construction of PFBR was started in 2003 and is now in a very advanced stage. Beyond PFBR, it is planned to construct six 600 MWe reactors by adopting twin unit concept (three 2×600 MWe reactors). One twin unit (FBR 1&2) would be built at Kalpakkam, near PFBR. It is planned to commission these reactors by 2029 /2031. Many innovative design features are introduced to achieve improved safety and significant cost reduction. More details of FBR 1&2 design are covered in a companion paper [1].

2. Component Handling System

Component handling system deals with handling & storage of fresh & spent subassemblies (core SA handling) and handling & decontamination of sodium wetted primary system components like primary sodium pump, intermediate heat exchangers, decay heat exchangers etc (special handling). Fig. 1 shows the sequence of component handling. It accounts for ~ 5 % of the overnight capital cost of the reactor and is an important area from the point of view of achieving improved safety and economy. Component handling operations are carried out under reactor shutdown conditions and hence there is a need to minimize the time for component handling to improve the capacity factor. FBR 1 & 2 being twin units and considering the very low utilisation time of component handling equipment in a year due to short time for refuelling , there is a merit to study and implement sharing of component handling facilities to the extent possible without compromising safety between the twin units in order to achieve an economical design and for better utilisation of the equipment..

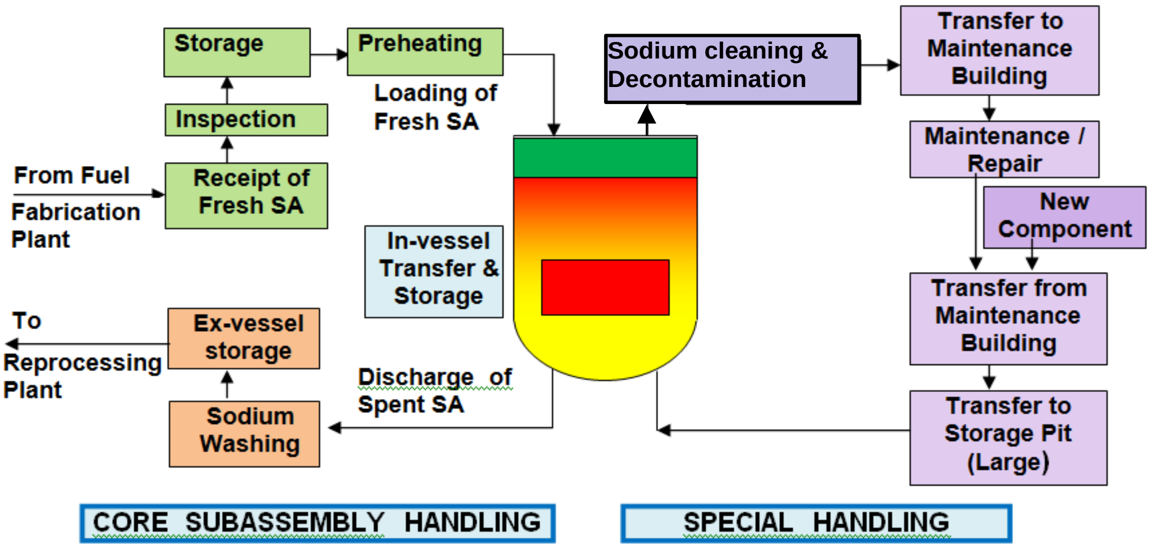


FIG.1. Sequence of Component Handling

3. PFBR Component Handling System

Fig. 2 shows the scheme of component handling in PFBR. From the co-located fast reactor fuel fabrication plant, six fresh subassemblies are transferred in a fuel transport cask. The subassemblies are inspected in fresh subassembly inspection facility before storage in fresh subassembly storage bay. Before loading into the reactor through nitrogen filled fuel transfer cell, the subassemblies are preheated to 323 K (150°C) in fresh subassembly preheating facility. The preheated subassembly is loaded into a sodium filled pot kept in the ex-vessel transfer post using the cell transfer machine. It is then transferred using the inclined fuel transfer machine to the in-vessel handling post located in the periphery of the core. The subassembly is loaded into the required core location using the combined action of two rotatable plugs and transfer arm, the in-vessel handling machine.

From safety considerations to avoid clad breach during handling, the irradiated spent fuel subassemblies are stored in in-vessel storage locations in the periphery of the core to reduce the decay heat. Using the combined action of transfer arm, rotatable plugs and inclined fuel transfer machine, the spent subassembly is transferred to the ex-vessel transfer post in fuel building in the same route as a fresh subassembly but in the reverse direction. The subassembly is then cleaned of sodium in the spent subassembly washing facility before

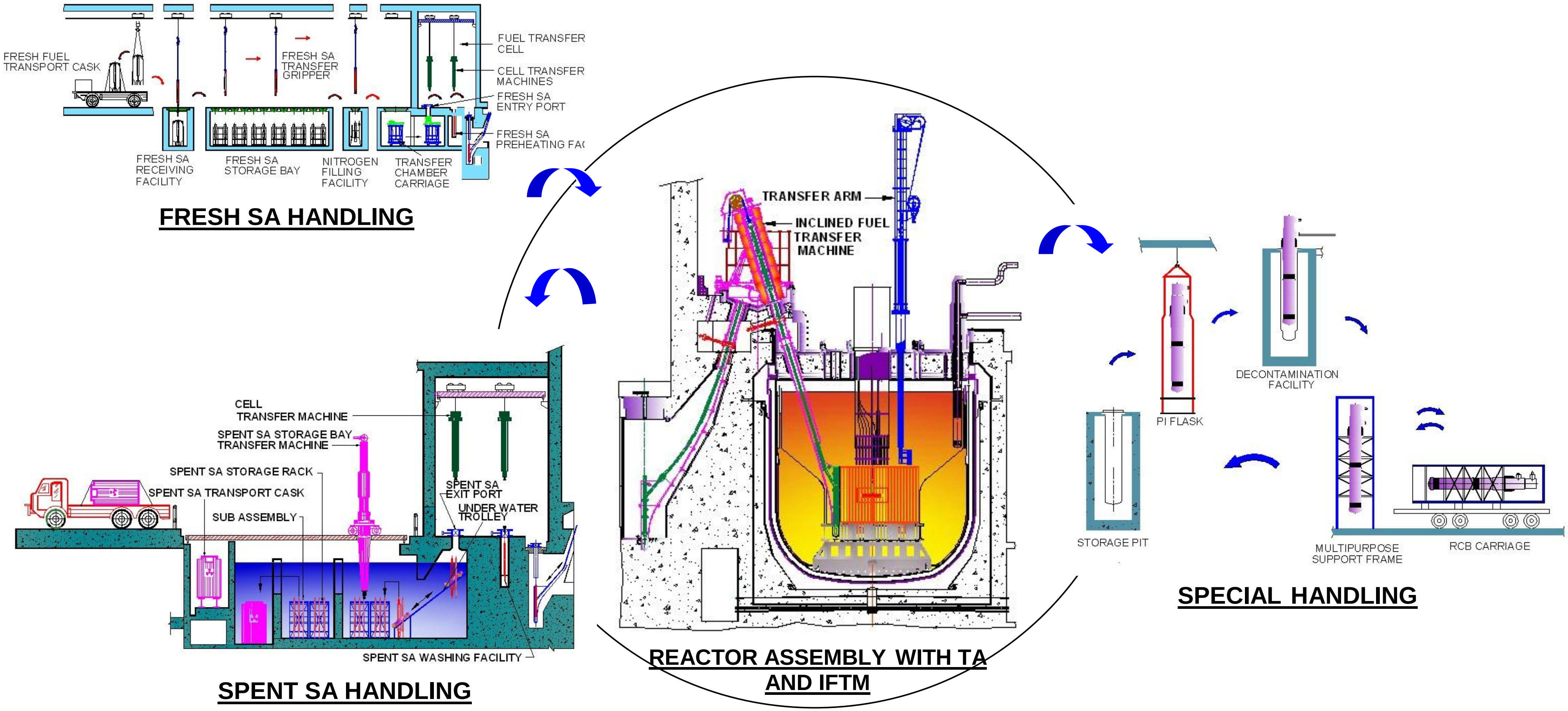


FIG. 2. Component Handling System in PFBR

transferring to the water filled spent subassembly storage bay. Three subassemblies are loaded into a spent subassembly transport cask before despatch to the reprocessing plant. Failed subassemblies are canned in leaktight water filled containers before storage in the storage bay. Absorber subassemblies being sodium wetted are stored in nitrogen filled containers and are not sodium cleaned.

Special handling operations are expected to be carried out rarely based on FBTR and other fast reactor operating experience. Leaktight flasks are used to handle the sodium wetted components and for transfer to the storage pits / decontamination facility. The components are sodium cleaned and decontaminated in the decontamination facility before doing active maintenance. A dismantling cell for cutting the irradiated absorber rod drive mechanisms to shorter lengths suitable for disposal as waste and a transfer arm examination facility for carrying out maintenance works on transfer arm after decontamination are additionally provided. Active maintenance works on Pump, IHX, DHX are carried out in a separate maintenance building after transport of the components from Reactor Containment Building (RCB) by trailer. The decontamination facility is located inside RCB to avoid transport of highly active sodium wetted components prior to decontamination.

4. Performance Qualification of Principal Fuel Handling Machines of PFBR

Both the principal fuel handling machines of PFBR namely Transfer Arm and Inclined fuel transfer machine were tested in reactor simulated conditions for ~10% of the total cycles experienced during service life. Testing was carried out in both air (~ 100 cycles) and in sodium (~600 cycles) in separate test rigs.

During Erection | During Air Testing

Fig.3. Transfer Arm

Transfer Arm (TA) is the in-vessel handling machine located in the Small Rotatable Plug, with an offset length of 572.5 mm (Fig. 3). The machine is 0.9 m wide, 1.5 m long, 23.4 m height and weighs 25t. It works at 200°C sodium during fuel handling, while a portion of it experiences 550°C during reactor operation. The machine was tested in air at room temperature, hot air, hot argon and in sodium at 200°C. Two high temperature dwell periods at 400°C/550°C to match reactor operating conditions were also simulated during sodium testing. A seven subassembly cluster was used to simulate the core and a full scale dummy transfer pot was also provided. Each cycle of testing involved gripping and lifting the subassembly from the centre of the simulated core, rotation to simulated transfer pot location, lowering & releasing the subassembly into the transfer pot and vice-versa. The performance of the machine was smooth and the torque/current required for the various drive mechanisms were within limits.

Inclined Fuel transfer Machine (IFTM) is the ex vessel fuel transfer machine used for transferring the subassemblies into and out of the main vessel. The machine is 5.5m in diameter, 16 m long, 23.5 m height and weighs 200t. The machine has two legs, the primary side (primary ramp (PR) & primary tilting mechanism (PTM)), located inside the reactor with 17° inclination and the secondary side (secondary ramp & secondary tilting mechanism), located outside the reactor with 17-23° inclination (Fig. 4). The subassembly to be transferred is loaded inside a sodium filled transfer pot, which moves on rails using multiple rollers.

Secondary Side Rotatable Shield Leg & Hoist Primary Side

Fig.4. Inclined Fuel Transfer Machine

Leaktightness of both primary and secondary sides is achieved using large sized vacuum tight gate valves. Shield plug provided on the primary side provides radiation protection for the gamma radiation incident from the sodium pool. The primary and secondary sides are linked at the top by the rotatable shield leg (RSL).

The primary side of IFTM was tested and qualified in air hot argon and in 200^{o}C sodium. A dummy subassembly was loaded inside the transfer pot and each cycle of testing involved raising the tranfer pot on the primary side from the PTM to the RSL and back. The sodium testing also involved two dwell periods at 550^{o}C to simulate reactor operating conditions. The performance of the machine was verified to be smooth and all machine parameters like hoisting torque and current were within limits. Subsequently, integral testing of IFTM was carried out in air and hot air at the manufacturer's shop itself. Temperature conditions corresponding to fuel handling condition were simulated using electrical heaters / gas heating. Testing was carried out in air for 65 cycles and in hot air for 535 cycles. Similar to the primary side testing, the machine performance was verified to be smooth and all machine parameters like hoisting torque and current were within limits. More details are covered in a companion paper [2].

5. **FBR 1&2 Component Handling System**

Fig. 5 shows the scheme of component handling in FBR 1&2.

5.1 In-vessel handling scheme

Different options were studied and a handling scheme utilizing two rotatable plugs and one offset arm type machine located in small rotatable plug (SRP) is arrived at (refer Table 1)

TABLE 1 : IN-VESSEL HANDLING SCHEME – OPTIONS

Sl. No	**Option**	**Flange diameter (mm)**	
		SRP	**LRP**
1	2 RP + 1 TA with IVTP within core at 2430 mm from core center (PFBR)	4685	6930
2	2 RP + 2 TA (one in LRP & one in SRP) with IVTP within core at 3132.5 mm from core centre (option 1)	5555	8040
3	2 RP + 1 TA in SRP with IVTP within core at 3132.5 mm from core centre (option 2)	5555	8040
3	1 RP + 1 Pantograph (option 3)	---	5600

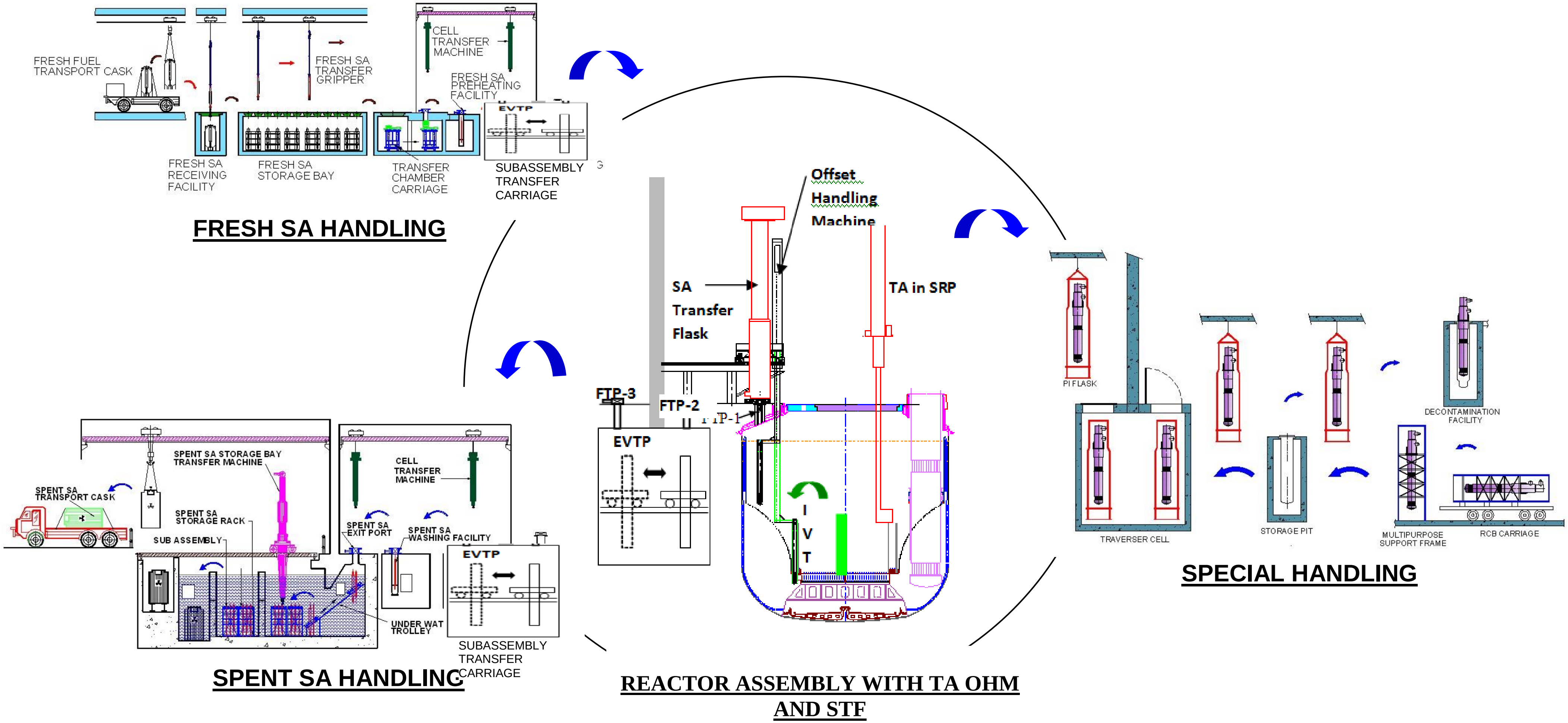


FIG. 5. Component Handling System in FBR 1&2

The in-vessel transfer post is located in inner vessel at a distance of 3132.5 mm from the core centre from considerations of location of corresponding discharge port in roof slab and ensuring adequate submergence of SA during in-vessel transfer to ensure removal of decay heat. Minimum diameter of LRP flange is achieved in case a pantograph type machine is used along with a slit in control plug (option 3). However, use of pantograph type machine is not foreseen in the near future and hence this option is not considered. Fig. 6 shows the details of the handling scheme.

In option 1, both the Transfer Arms have the same offset length of 572.5 mm as in PFBR. However, the fuel handling time is higher due to multiple handling of subassemblies by both the machines. In option 2, even though the offset arm length of TA in SRP is 791.5 mm (~ 1.4 times that of PFBR), the design is identical to the present TA. With the use of advanced ferritic clad & wrapper materials, the influence of bowing on extraction force will be minimum and hence the higher offset length will be acceptable.

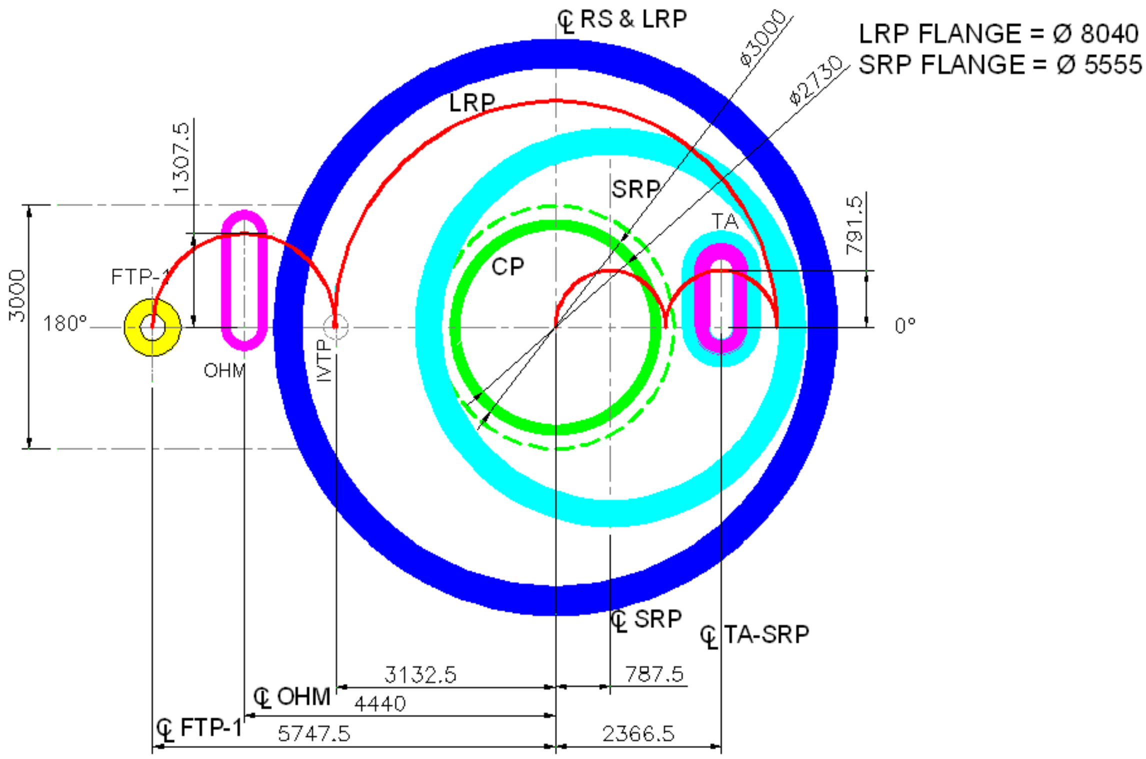


FIG. 6. In-Vessel Handling Scheme for FBR 1&2

5.2 Ex-vessel handling scheme

PFBR construction experience has shown that the Inclined Fuel Transfer Machine (IFTM) is costly and time consuming to manufacture and erect. Manufacture of Colmonoy coated long slender rails is a time-consuming process resulting in long manufacturing time. It is replaced with a combination of offset handling machine within main vessel and a simple shielded Subassembly Transfer flask located outside main vessel, moving on a carriage and similar to that used in FBTR. The offset handling machine is supported on roof slab and does the simple function of receiving the SA in a sodium filled transfer pot at IVTP and after rotation by 180o coupled with hoisting, delivers it at a higher elevation for further handling by subassembly transfer flask. The flask transfers subassemblies discharged through the discharge port in roof slab to the subassembly transfer carriage, which in turn transfers it to the fuel transfer cell in fuel building (Fig. 3). Flask transfer also enhances the capability to handle SA with higher decay power (adoption of sodium filled pot / possibility of providing forced cooling during transfer).

Provision of offset handling machine helps in meeting the approach of the SA transfer flask over roof slab and in reducing the overall height of flask. It has an offset arm at the end of which the sodium filled transfer pot is located (Fig. 5). An additional mechanism is provided for holding the pot during loading of SA into the pot and for releasing the pot for handling by the flask gripper.

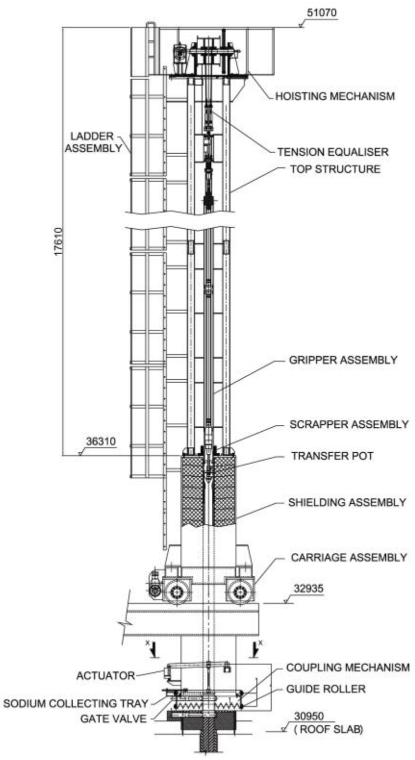


FIG. 7. Subassembly Transfer Flask

Fig. 7 shows the details of the subassembly transfer flask. The flask is provided with a vacuum tight (VAT) valve at the bottom. Over the roof slab discharge port, a similar VAT valve is provided. A separate flask is provided for each reactor unit and the concept of a fuel transfer cell with cell transfer machines is retained. The fuel transfer cell is made common to both the units to achieve an economic design.

5.3 Sharing of Component Handling Equipment

The utilization of component handling equipment in terms of their operating time is very less (~1month in a year). Most of the equipment are used only during fuel handling. Very few operations like spent fuel discharge to the reprocessing plant and transport of fresh fuel from the fuel fabrication plant are carried out during normal reactor operation and hence only few equipment associated with these are used during reactor operation. Special handling equipment are normally never used and are required only when the need arises. Hence, there is a merit in making a design such that component handling equipment are shared between the twin units. The need for simultaneous use in both reactors will not arise normally. Equipment, which is a permanent part of reactor assembly like the Transfer arm, cannot be shared and are provided separately, one each for each unit. The layout and design

TABLE 2 : MATERIAL CONSUMPTION IN FBR 1&2

Sl. No	**Item**	**Relative Material Consumption**		
		PFBR	**FBR 1&2**	**% Saving**
1	Fresh SA Handling	1	0.57	43
2	Spent SA handling	1	0.51	49
3	Items common to Fresh and Spent SA Handling	1	0.68	32
4	Special handling	1	0.39	61
	Net	1	0.54	46

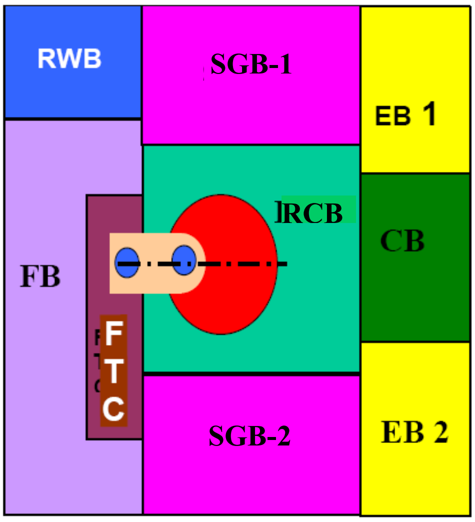
features of containment isolation are such that refuelling in one reactor does not influence or affect the operating status of the other unit.

Significant economic benefits are achieved by sharing of the component handling equipment between the twin units. Table 2 summarises the comparison of material consumption for component handling equipment for FBR 1&2 with PFBR considering sharing of equipment and also the possible increase in numbers, sizes and weights required in certain selected cases to meet the requirements of both the units. It is seen that the overall material saving expected is ~46 %.

5.4 Layout of fuel and decontamination buildings

The comparative layout of nuclear island connected buildings is shown in Fig. 8. In PFBR, the fuel building housing the major fresh and spent SA handling equipment is located north of the reactor containment building. The transfer arm and the inclined fuel transfer machine are located in the reactor containment building. The ex-vessel transfer post serves as the common link for fresh / spent SA loading/unloading point. All the special handling equipment & facilities are located inside the reactor containment building.

For the twin units, considering the requirement of sharing of component handling equipment, a common fuel building housing fresh & spent fuel handling equipment with the fuel transfer cell linking both the RCBs is provided north of the RCBs. A separate but common decontamination building, housing all special handling equipment is provided in between the two RCBs.



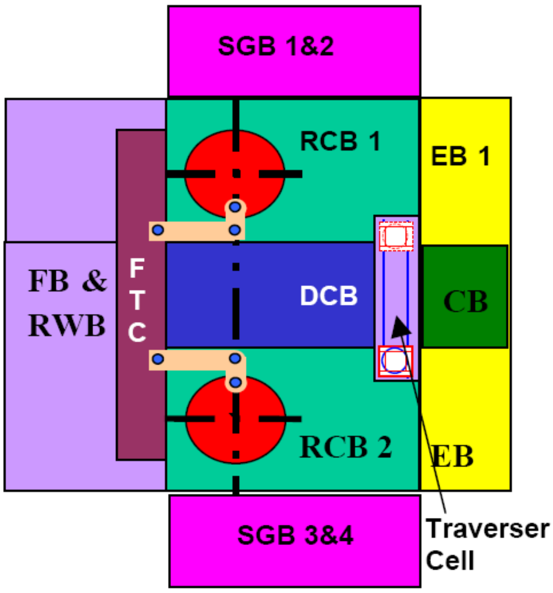


FIG. 8. Comparison of Layout

5.5 Spent Fuel Storage

For the spent subassembly storage bay, the storage capacity of the bay is sized to meet the normal storage requirements of both the units plus one full core emergency unloading of the entire core of one reactor unit. This meets the regulatory requirements also, which permits sharing the component of emergency core unloading storage between the twin units. A total of 1016 storage locations is provided for FBR 1&2, which as compared to 711 for PFBR.

5.6 Traverser for special handling

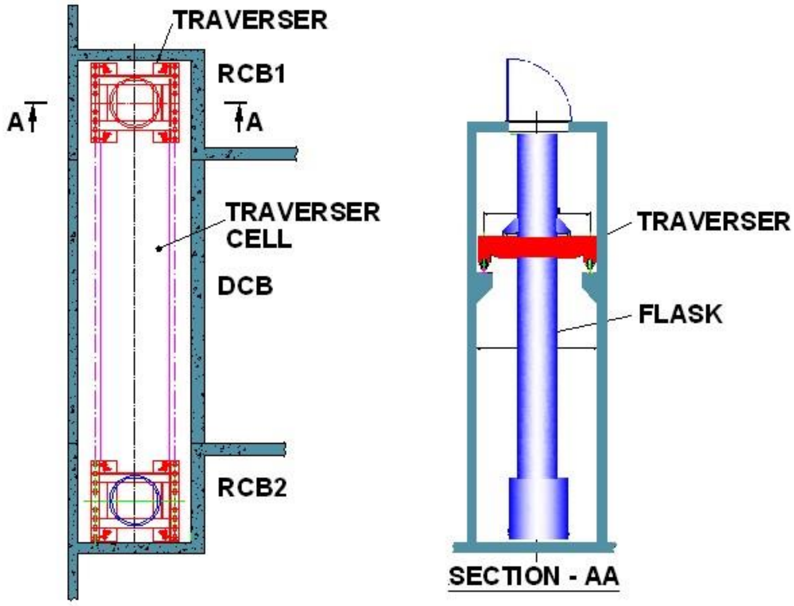


FIG. 9. Traverser for Special Handling

A traverser is provided linking the reactor containment buildings of the twin units with the common decontamination building. The traverser is like a crane and the special handling flasks are loaded and supported on the traverser for transfer of the flask between reactor containment building and decontamination building. Fig. 9 shows the details of the traverser. On the floor of RCB of each unit, a leaktight hatch opening is provided to lower the special handling flask housing the component. The flask is supported on the traverser at nearly its centre of gravity. A similar opening is provided on the floor of DCB through which the flask is lifted and moved to the storage pit / decontamination vessel.

Provision of traverser enables sharing of special handling equipment between the twin units resulting in improved economy. The shifting of decontamination facilities outside the reactor containment building improves safety due to reduction in use of water inside RCB. Also, the liquid effluent tanks for decontamination system is housed close to the decontamination vessels within the DCB itself, thus eliminating the need for long length effluent piping resulting in improved safety.

5.7 Economical benefits of the proposed design measures

The saving in cost is accrued due to sharing of component handling equipment located in fuel and decontamination buildings between the twin units, which results in reduction in the number of equipment provided. The shared equipment account for ~ 75% of the total number of component handling equipment. In addition, a few have been provided separately for each unit, while capacity of certain shared equipment has also been augmented from functional requirements. Considering the effect due to addition/deletion/augmentation of the component handling equipment, the net saving in cost is expected to be ~ 44% of the component handling system cost (which is equivalent to ~2% of the overnight capital cost). The comparison of overall fuel handling time indicates that it will be about 31 d for FBR1&2 as compared to 20 days for PFBR. The increase is due to higher number of subassemblies to be handled per campaign as well as due to addition of fuel handling machines. But the refuelling interval is expected to be 9 months as compared to 8 months for PFBR and hence the overall capacity factor is expected to be slightly improved. The cost figures as well as time estimates are initial estimates and will be refined in the detailed design phase.

6. Comparison of Component Handling System Features with other Reactor Designs

The concepts chosen for component handling system equipment for PFBR/ FBR 1 & 2 are well proven and have been adopted in other reactor designs [3-6]. This includes offset arm type machine for in-vessel handling, flask or inclined fuel transfer machine for ex-vessel handling, ex-vessel water pool storage and straight pull type handling machines. The Fast Breeder Test Reactor in operation at Kalpakkam, India also uses a flask with straight pull gripper for ex-vessel handling. The critical fuel handling machines of FBR1&2 will be qualified by full scale testing in air and sodium as in PFBR.

7. Summary

The design of component handling system for Prototype fast breeder reactor is explained in this paper. In-vessel handling is done using two rotatable plugs and one offset type Transfer Arm. Ex-vessel discharge from the main vessel is done using the A-frame type Inclined fuel transfer machine. The feedback gained from the design / construction experience of PFBR has also been utilized to arrive at the design of component handling equipment for FRBR 1&2. The in-vessel handling scheme is similar to that of PFBR, while an offset handling machine and subassembly transfer flask combination is used in place of the inclined fuel transfer machine. Spent fuel storage in both PFBR and FBR 1&2 is done in a water pool.

Being a twin unit, the major saving in cost of component handling system in FBR 1&2 is achieved by sharing of component handling equipment between the units. The proposed design measures are expected to give a savings in material consumption of 46% and a reduction in overall cost of ~ 2% of the overnight cost. The R&D efforts required for realising the above economical benefits have also been identified. The above efforts are expected to further significantly improve the economics and safety of future SFRs

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