Testing and Qualification of shielded flasks for handling sodium wetted large sized components of PFBR

P. Pooran kumar, P. Chandrasekaran, M. Gunasundari, B.K. Chennakeshava

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) Department of Atomic Energy, Kalpakkam 603 102, Tamil Nadu, India

Email contact of main author: pooran_bhavini@igcar.gov.in

Abstract.

BHAVINI is constructing Prototype Fast Breeder Reactor (PFBR), forerunner of FBRs, a 500 MWe sodium cooled, pool type, mixed oxide (MOX) fueled reactor at Kalpakkam. Presently PFBR is in the commissioning phase. The reactor has three main heat transport circuits' namely primary sodium, secondary sodium and steam-water system. The Primary sodium Pump and Intermediate Heat exchanger housed inside the Reactor vessel need to be handled for repairs / replacements during reactor life. Due to the radio activity of primary sodium, corrosion products or induced activity in these components and to avoid chemical reaction of Sodium with air and moisture, PI Flask (Pump and IHX Flask) is used for handling these components. PI Flask is a 35m tall and ID 2250mm leak tight structure to handle 60T load in a leak tight and shielded environment. The total weight of the PI flask along with Pump or IHX is weighing 200 MT which is handled with 280MT EOT crane installed in Reactor Containment Building (RCB). Constructional feature includes hoist mechanism to lift 60T load designed with single failure proof system, mechanical stoppers to support the load at 30m height, 12 leak tight shells with bolted construction meeting the verticality, horizontality and leak tightness requirements and disc valve drive mechanism integrated with Airlock to facilitate opening and closing of separable discs for the movement of Pump or IHX. All the materials used were tested to ensure that specification requirements are met and the fabricated joints were subjected to NDE and HLT. The shielded shells were subjected to radiometric testing to ensure shielding requirements. The mechanical stopper mechanism, hoist mechanism and disc valve drive mechanism were independently tested before final assembly and Performance tests under 'No' load, 'Full' load and 'Over' load conditions including verification of interlocks were conducted for the qualification of PI Flask using mobile Control Panel. This paper presents the various performance tests conducted under 'No of various in built mechanisms viz., Hoist, Disc Valve and Mechanical Stoppers using PLC of PI Flask load' and 'full load' conditions for the qualification of leak tight requirements, shielding adequacy and functionality checks

1. Introduction

BHAVINI is constructing Prototype Fast Breeder Reactor (PFBR), forerunner of FBRs, a 500 MWe sodium cooled, pool type, mixed oxide (MOX) fueled reactor at Kalpakkam (Ref Fig. 1 for PFBR Reactor Vessel Cross section). Presently PFBR is in the commissioning phase. The reactor assembly [1] consists of large dimensional vessels viz., Safety Vessel, Main Vessel and Inner Vessel. The top shield comprises of Roof Slab, Rotatable plugs viz., Large and Small plugs and Control Plug at the center. The entire core is placed over the Grid Plate which in turn is supported by Core Support Structure equipped with Core Catcher at the bottom. The control and shutdown mechanisms are housed inside the Control Plug with necessary provisions for core instrumentation. The vessel houses the primary heat transport circuit which consists of two Primary sodium pumps (PSP), four Primary Pipes and four Intermediate heat exchangers (IHX) for transferring the primary heat from the core [2] to intermittent secondary sodium circuit. The in-vessel and ex-vessel core subassembly handling is performed by Transfer Arm and Inclined Fuel Transfer machine. The decay heat is removed by passive systems consisting of Decay Heat Exchanger and associated components. The bulk of the primary sodium is contained in the main vessel. During full power operation of the reactor, sodium is drawn from the cold pool by PSPs working in parallel and is delivered to the grid plate through primary pipes. From there, it passes through the core and picks up the heat. Then the sodium flows into hot pool and enters the inlet windows of IHXs. The flow through IHX is due to difference in sodium levels between hot & cold pools, which is generated by operation of PSPs. The primary sodium passes through the shell side of the IHX and transfers heat to the secondary sodium which passes through the tube side. The primary sodium leaves the IHX through the outlet window and returns to the cold pool.

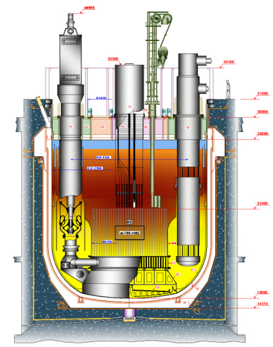

Fig 1: PFBR Reactor Vessel

There are many components working in Primary sodium and some of these components need to be handled for repairs or replacements during the life of the reactor. Due to the radio activity of primary sodium, corrosion products or induced activity in these components and to avoid chemical reaction of Sodium with air and moisture, leak tight shielded flasks with inert atmosphere are used for handling. PI Flask (Pump & IHX Flask) is used for handling primary sodium pump (PSP) and intermediate heat exchanger (IHX) [3]. PI Flask is 35m tall and with Inner Diameter 2250mm. This flask handles 60T load in a leak tight manner and under shielded environment. The total weight of the PI flask along with Pump or IHX is 200 MT which is handled with 280MT EOT crane installed in Reactor Containment Building. Constructional feature includes in built hoist mechanism at the top of the flask to lift 60T load designed with single failure proof system, mechanical stoppers to support the Pump or IHX at 30m height, 12 leak tight shells with bolted construction meeting the verticality, horizontality and leak tightness requirements and disc valve drive mechanism integrated with Airlock to facilitate opening and closing of separable discs for the movement of Pump or IHX. This paper presents the challenges faced during assembly and in meeting the verticality and horizontality requirements for individual shells and overall assembly. The various performance tests conducted under 'No load' and 'full load' conditions for the qualification of the flask are presented. Also, testing and qualification required to meet leak tightness, shielding adequacy and functionality checks of various in built mechanisms viz., Hoist, Disc Valve and Mechanical Stoppers using PLC of PI Flask is presented in this paper.

2. Description of PI Flask

The Flask consisting of the Flask body (~28m) is supported on the Airlock (~7m) at its storage location (Ref Fig. 2) and operated using control panel (mobile). The flask body and the control panel are moved separately between various work positions using EOT Crane of RCB. In order to maintain the leak tightness of the pits, there are two airlocks, one on the location from where the component is removed and the other on the pit where the component is to be discharged.

The flask body consists of Lower part with disc valve, intermediate part, upper part which includes mechanical stoppers and the hoisting mechanism and its enclosure. The lower part with disc valve consists of disc valve drive mechanism which allows passage of the handled component by operating the mobile disc. The flask body is closed at its lower part by the mobile disc ensuring leak tightness. During handling of the flask body, the active part of the components handled viz., PSP or IHX will remain in the intermediate part location which is provided with lead shielding. The upper part houses 3 mechanical stoppers and the hoisting mechanism is mounted on top of this part. It is a single failure proof hoisting mechanism mounted on top of the flask in a leak tight enclosure. The special features of the hoist are as follows:

1. Capacity of hoist : 60T
2. Hoisting speed (max) : 1 m/min
3. Total lift of hoist : 24.5 m
4. No. of wire ropes : 2
5. No. of brakes : Two mechanical holding brakes of diverse type
6. No. of drums : 1

The load block of the hoist is fixed with Shackles, which can be connected to the primary sodium pump or IHX through intermediate lifting piece. The load block is prevented from rotation by sliding type guide mechanism mounted at two places diametrically opposite on the inner surface of the flask throughout its travel. The load block, wire ropes and drum of the hoisting system are mounted inside the leak tight enclosure of the flask body. There are 3 mechanical stoppers located 120 degree apart and they are used to support the load block with the load attached, during transportation of the flask with load from one work position to other.

Airlock consists of a leak tight cylindrical shell with bottom flange suitable for fixing at the Primary sodium pump or IHX location in roof slab or at work location. The airlock disc has a male conical part at the center, which fits into the corresponding female part provided on the lower side of the flask disc valve. Coupling and uncoupling of these two discs is done by means of a linear actuator. Leak tightness of the independent airlock is achieved by clamping the airlock disc by the actuation of the locking ring. The clamping is done by rotating the circular ring by means of two linear actuators located diametrically opposite. The rotation of the ring causes the rollers to move on an inclined surface of the disc causing wedge effect and there by clamping the disc to achieve leak tightness. The lifting beam is the connecting link between EOT Crane hook and the PI Flaks during handling. The lifting beam is connected to PI Flask at top portion by means of two plate hooks located diametrically opposite and the lifting beam is connected to the EOT Crane hook (Ramshorn) through two D -shackles.

Fig 2: Full View of PI Flask

3. Design of Single Failure Proof Hoisting System

One of the possible accident scenarios which could cause a safety problem is the drop of large component during lifting operation with PI flask. To rule out the possibility of fall of heavy loads, all the hoisting systems are required to satisfy single failure proof criteria. The hoisting systems are designed such that a single failure will not result in the loss of the capability of the system to safely retain the load. The single failure proof hoisting mechanism needs dual components so that in case of subsystem or component failure, the load will be held and retained in a stable or immobile position. This requires two separate load paths from the load attaching point to the hoist brakes, each path capable of supporting rated load and arranged such that the single failure of any component in the load paths will not result in an uncontrolled movement of the load. The following philosophy is considered while designing the components and systems in the load path depending on practicability of each system.

1. Duplicating the system so that if one fails, the second is able to sustain the load.
2. Increasing the factor of safety to reduce the probability of failure.
3. Adding special features to reduce the consequences of failure.

Handling of component with this flask over the reactor is required to be done only when the reactor is in shutdown condition. The Component is supported inside the flask after lifting to the top position. The path of handling the flasks in RCB is chosen such that there is no safety related equipment below the flask. The special features required for single-failure-proof criterion are limited to parts of hoisting mechanism and braking systems of PI flask.

4. Special features provided to meet it single failure proof criteria.

The load block is connected to the load at multipoint location. These load attaching points are designed for 300% of safe working load. The remaining components of load block and head blocks are designed for 200% percent of safe working load. The rope reeving system is designed to have two individual independent rope systems, each system providing the load balance separately from the head block to load block such that excessive drop or swing will not occur upon the failure of one rope. Sufficient factor of safety for wire rope is formulated at both the conditions when both ropes are intact and when single rope is in operation. A single rope drum was chosen for dual rope reeving system considering the synchronizing and operating difficulties, space requirement and load balancing during hoisting operation. The drum is provided with suitable supports which will prevent the drum gear and pinion from coming out of the mesh in case of failure of drum shaft or bearing. There are two sets of gears between brakes and drum. There are two mechanical holding brakes of diverse type. The holding brakes will be activated when power is off and automatically trip on over-speed if malfunction occurs in the electrical drive controls. Each holding brake is designed for not less than 125% of the full load hoisting torque at the point of application. The maximum hoisting speed considered is 1m/ minute. A continuous load indicating system is incorporated in both the two rope reeving systems.

5. Manufacture and Assembly of PI Flask

The material of construction is in accordance with ASME Section III Class 3 components and the principal material of construction is Carbon Steel. The Flask body consists of various shells with ID 2250 mm and the shells are connected by bolted arrangement with a provision to maintain leak - tightness between the flanges using O rings arrangement. Detailed manufacturing drawings were made and sequential manufacturing process plans were drafted before manufacture and stages of inspection were introduced to ensure meeting stringent quality requirements. The raw materials including plates, forgings, etc. were subjected to various tests to conform relevant specification requirements. The welding procedures and welder qualification were as per ASME Section IX and welding and fit up tolerances were as per ASME Section III Class 3 components. Non destruction examinations viz., radiographic examination, liquid penetrant examination, magnetic particle examination were carried out as per the requirements of Class 3 components of ASME Section III. Machining allowances were maintained at intermediate stages in order to meet the final dimensional requirements. The leak - tightness was checked using Helium leak testing and the local leaks as well as global leaks were within the specification requirements. The dimensional inspection was carried out to meet the relevant drawing requirements by qualified personnel at various stages of manufacture. The perpendicularity and parallelism requirements of individual shells were achieved considering the overall height verticality and horizontality requirements of 35m tall flask. After completion of individual shell manufacture, the overall flask assembly was carried out starting from the lower most part i.e. Airlock and followed by Lower part and various shell segments and finally the Hoist assembly. At each and every stage of assembly, the guide channel alignment was checked and also verified by lowering and raising the Load Block within the Guide channels provided at 90° and 270° orientation inside the shells (Ref Fig 3) thereby confirming the dimensional requirements and ensuring smooth travel of Load Block inside the PI Flask. This ensured that the overall assembly requirements of the PI Flask meet the specification criteria and the flask is ready for further performance testing.

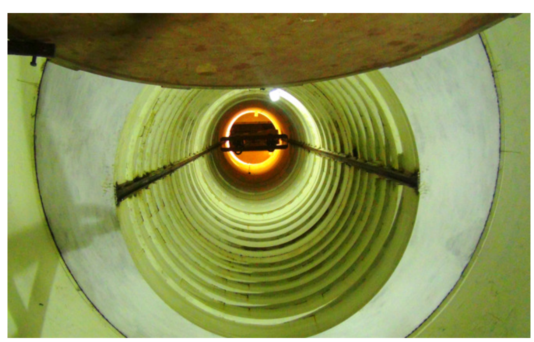

Fig 3: Internal View of PI Flask

6. Radiometry Testing and Qualification of Intermediate Shells for shielding requirements:

The intermediate part where the active part of the components handled viz., PSP or IHX will be accommodated is provided with lead shielding. Lead shots were filled in the annular space and radiometric testing was carried out to conform the effectiveness of shielding. Specification requirement demands that the maximum loss of shielding shall be within 6% and the packing density of lead shots shall not be less than 6.8 g/cc and shall not exceed 7 g/cc. The intermediate part consists of 4 shells for a height of 11m. Prequalification tests were conducted simulating the annular space of shells and filling density, subsequent radiometry testing results were satisfactory. The structure is cylindrical with lead shots poured and with steel lining on either side. A grid size of 5cm × 5cm marked on the outer surface of the structure and identified by column / row. Source guide was fabricated and aligned to the center of the shell. The gamma source attached with suitable arrangement was lowered in to the source guide and aligned with the grid by moving the mechanism and the observations were taken in all the rows and columns from outer surface. A source guide was erected exactly along the vertical axis of the shell to enable the source ^{60}Co to move vertically. The results indicated the absence of void / defects and the overall, the packing density was observed to be quite uniform. Radiometry testing carried out confirmed the absence of radiation streaming in the various shell joints. Variations observed in the dose rates were within estimated values for the given material, density and thickness.

7. Performance Testing and Qualification of the of PI FLASK

This testing of PI Flask includes checking the performance of the Disc Valve Drive Mechanism (including coupling and clamping operations) and the Hoist Mechanism (including Mechanical Stopper operation) under ‘No Load’ and ‘Full Load’ condition. Further, the smooth movement (upward and downward) of the Load Block throughout the guide channel length in the flask especially in the transition region were ensured. The lifting Beam was load tested (static) earlier with the dummy load of 220T and the integrity of all the load bearing points were examined and found satisfactory.

8. Testing work post

The PI flask was assembled over the Storage Pit for Large components. The 60T load simulating the dimensions of the actual IHX was placed inside the Storage Pit. Interconnecting Piece (ICP) was assembled with the dummy IHX. The Airlock was assembled around the ICP over the Storage vessel and over which, the entire Flask was assembled and Performance testing of the flask was conducted.

9. PI Flask control

The Operation of PI Flask was carried out from the Control Panel. Programmable Logic Controller is used for the control of PI Flask. Hard wired push button switches are provided for the forward and reverse direction of motion of the hoist, disc valve open / close and linear actuator movement. An emergency stop push button switch is provided to stop the ongoing operation at any point of time. Normal operating speed available for hoist operation was through VFD. Indications for position of the load block, open / close status of flask disc valve, couple / uncouple status, clamp / unclamp status of airlock valve are provided in the Control Panel.

10. Interlocks and Logic Checks during testing

To protect the components which are handled by the flask and also to protect the flask itself from incidents having serious repercussions, proper instrumentation, controls and safety interlocks are provided in PI Flask. Following interlocks and logic checks are provided considering the overall integrated functioning of various mechanism viz., Load Block movements, mechanical stopper actuations and disc valve mechanisms including clamping, coupling operations.

1. Conditions for raising the load block from bottom position
2. Conditions for lowering the load block from top position
3. Conditions for raising the load block from rest position:
4. Conditions for engaging mechanical stoppers
5. Conditions for retracting mechanical stoppers
6. Conditions for coupling flask disc valve with airlock disc valve
7. Conditions for de-coupling flask disc valve with airlock disc valve
8. Conditions for opening flask disc valve
9. Conditions for closing flask disc valve
10. Conditions for clamping airlock disc valve
11. Conditions for unclamping airlock disc valve

11. Performance test at "No load" conditions

After completion of manufacture, inspection, assembly and testing of individual mechanisms viz., Mechanical stopper, disc valve drive mechanism and Hoist Mechanism independently, the PI Flask along with Airlock was checked for all the following functions without attaching the load in vertical condition

1. Hoist operation
2. Load Block movement
3. Limits of the Hoist viz., top and rest position
4. Wire rope load indication through load cell
5. Mechanical stoppers operation and their limits
6. Disc Valve Operation and its limits
7. Coupling and de-coupling of the flask disc and airlock disc
8. Clamping and unclamping of airlock disc

Initially, the Load Block was supported on the 3 Mechanical Stoppers and Limit switches for mechanical stoppers at retracted position were not actuated. The Disc Valve was in the closed position and the flask was engaged under 280 T EOT Crane hook. Pre-operational checks of clamping and unclamping of the Airlock Disc, coupling and uncoupling of Flask Disc with Airlock Disc in the Disc Valve Drive Mechanism, respective limit switch operations etc. were checked and after coupling both the discs, the disc motor was operated and both the discs were opened. The Load Block was raised from the rest position to the Top position and the Hoist Motor parameters were monitored continuously. The Hoist Mechanism Drive Train operation was checked and smooth and jerk free operation was ensured. The Top limit switch actuation was ensured and the Encoder reading was monitored between rest and top position. The mechanical stoppers were retracted and ensured that the limit switch in the retracted condition was actuated**.** The Load Block was lowered and the hoist speed was recorded and the hoist motor parameters was monitored. The motor was operated to reach the lower most position with intermediate stoppings after every 3 m travel. The Load Cell indication was checked for satisfactory functioning. The Braking operation in the Hoist mechanism was checked. During this process, one of the brakes was disengaged and the other brake was checked for its satisfactory functioning. The process was repeated for qualifying both the brakes. The electrical parameters was recorded. The Guide Bar movement within the Guide Channel was smooth and was viewed from the manhole provided in the Lower Part**.** The Load block movement in the lower part was monitored visually through the man hole and the engaging of the Guide Bar in the Guide Channel provided in Airlock was ensured. The speed during lowering at the last phase of 500mm was reduced and controlled. The load Block was lowered in line with the lifting lug orientation of the Interconnecting Piece for IHX and insertion of the Pins connecting the Load Block with ICP was performed through the hand gloves provided in the Airlock. Lighting arrangement was checked for proper illumination and the encoder reading was monitored at this lower most position of the Load Block. The load block was disconnected from the interconnecting Piece and lifted to its top position. The actuation of top limit switches was verified. The three mechanical stoppers were engaged and actuation of the mechanical stopper was verified in engaged condition. The load block was lowered to rest position over the mechanical stoppers and low tension was sensed. The disc valve was closed using disc motor and the disc was uncoupled and airlock disc was clamped over the Airlock top flange. The operation for various functions was repeated 5 times for checking the repeatability.

12. Performance test at "Full Load" conditions

On completion of 'No Load' test, Full Load test was performed. The Load Block was initially supported on the 3 Mechanical Stoppers and Limit switch for mechanical stoppers at retracted position was not actuated. The Disc Valve was in the Open position and the flask was engaged under 280 T EOT Crane hook. The operation of lowering the Load Block was repeated as performed for "No Load" test and all the checks performed earlier were repeated. Once the Load block reaches the lower most position and aligns with the lifting lug in Interconnecting Piece, the Pins were inserted through the hand gloves provided in the Airlock thereby connecting the Load Block with ICP. The load block along with the Dead Load (60T) was lifted very slowly by operating the Hoist Motor and the electrical parameters of the motor were checked and recorded. The hoist speed was less than 1m/min and intermediate stopping (~ interval of 3m) was performed during lifting. During initial 10mm lift, there was no unusual increase in load cell reading and motor current readings were monitored continuously. The Load Cell reading was checked for 60T load and confirmed. The Braking operation in the Hoist mechanism was checked during lifting after just lifting the load ~10mm from the base. During this process, one of the brakes was disengaged and the other brake was checked for its satisfactory functioning. The process was repeated for qualifying both the brakes. The electrical parameters were monitored at full load condition. The engagement of the Guide Bar while entering the ITK Guide Channels was checked and ensured for further lifting of the Load Block with Dead Load. The raising operation of the Load Block was continued till the top position was reached and the encoder reading was continuously monitored. The motor current and load cell reading was monitored and recorded over the entire travel. At this juncture, the retracted mechanical stoppers was engaged to take the load of 60T. The limit switches of respective locations of Mechanical stoppers were checked for confirmation. The load Block was lowered over the 3 mechanical stopper (i.e. rest position) and the load was slowly transferred to the Mechanical stoppers. The Load Cell readings was continuously monitored till the entire load was transferred from the wire rope to the mechanical stopper. The Discs (Flask disc and Airlock Disc were in coupled condition) from Open position was actuated by Disc motor and the disc was closed over the Airlock. Uncoupling of the discs was performed and respective limit switches were checked for confirmation and the clamping operation was performed and the Airlock Disc was clamped with the Airlock. Dimensional inspection was carried out to ensure that there is no permanent deformation on the components of the flask. The Gears and Pinion in the Drive Mechanisms viz., Hoist and Disc Valve were inspected for smooth operation and the flask was disconnected from the Airlock and the same was lifted by 200mm and then lowered it back over airlock. Before and after load test, the leak tightness of flask and airlock space was checked after closure of the flask disc valve and recorded. After full load test and lifting of flask, the connection points and the lifting beam were checked visually for any changes and there was no recordable observations in any of the components.

13. Qualification of PI FLASK

Before placement of the PI Flask for qualification over the reactor, the second airlock along with necessary pump interconnecting piece were placed over the PSP. The entire flask of 140T was lifted from the test work post, traversed over the roof slab and placed over the airlock. The flask was shifted by lifting beam with laminated hooks arrangement using 280T EOT Crane. The actual qualification of PI Flask by lifting the Primary sodium pump from the reactor vessel was successfully demonstrated with results in absolute conformance with the earlier performance tests thus proving its reliable usage for further component handling requirements in the plant.

14. Results:

The flask was thoroughly inspected after the PSP was lifted to top position of the flask, rested over the mechanical stoppers and the brought back to the reactor vessel. Visual Inspection was carried out from Manhole of Lower part for any deformation and rubbing of Guide bar with guide rail and weld joints of pad plates. There was no recordable observations in any of the components. Visual Inspection was carried out from the openings in the Mechanical stopper assembly location, Drive system (Hoist and Disc) and coupling of Disc mechanism and all the mechanisms were observed to be functioning meeting the specification requirements.

15. Summary:

The tremendous efforts taken by the manufacturing team for PI Flask have yielded best results. The assembly and testing requirements were met flawlessly and achieved the testing stipulations. All the electrical parameters monitored during the entire period of testing met the specified requirements. The various mechanisms viz., Hoist, Disc Valve Drive and Mechanical stoppers were integrated properly and performed their functions under ‘No Load’ and ‘Full Load’ perfectly. This indigenously designed, manufactured and tested PI flask confirmed its higher reliable operation during the entire reactor life. The methodology adopted for the manufacture of PI Flask, respecting quality aspects at every stage of manufacture, assembly and testing resulted in meeting the required performance criteria. The crucial performance testing of the sodium wetted large component handling PI Flask was successfully completed without any recordable deviation and meeting all the testing requirements stipulated from the design considerations. All these show the testing of shielded flask for handling large components of PFBR is successful and the PI Flask is well suited for handling such large sodium wetted components for future FBRs.

16. Acknowledgment:

The authors are thankful to the Erection team, M/s Titagarh Wagons Limited, Kolkatta, Task Force team for Component Handling and NPCIL QS for their valuable contribution towards inspection and testing during the manufacture of components at the contractors works and successful completion of performance testing of PI Flask.

17. References

[1] P. CHELLAPANDI, et al "Design concepts for reactor assembly components of 500 MWe future SFRs", Nuclear Engineering and Design, Vol 240, no. 10, pp. 2948–2956, 2010.

[2] S.C. CHETAL, et al "The design of the Prototype Fast Breeder Reactor", Nuclear Engineering and Design, Vol 236, no. 7–8, pp. 852–860, 2006.

[3] P. CHELLAPANDI, et al "Evaluation of Speed Lowering of Primary Sodium Pump into Sodium Pool for 500 MWe PFBR Based on Creep Damage" Procedia Engineering, Volume 55, 2013, Pages 451-456