IMPROVEMENT OF LIFETIME AVAILABILITY THROUGH DESIGN, INSPECTION, REPAIR AND REPLACEMENT OF COOLANT CHANNELS OF INDIAN PRESSURIZED HEAVY WATER REACTORS

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Abstract

This paper covers an overview of the work carried out for the life management of the coolant channels of Indian Pressurised Heavy Water Reactors.

In order to improve maintainability of the coolant channels and reduce down time needed for periodical creep adjustment, improved designs of channel hardware were developed. The modular insulation panel, designed as a substitute for the jig saw panels, reduces the time needed for accessing the space around the end-fitting significantly. A compact mechanical snubber has been developed to totally eliminate the need for periodic creep adjustment.

In addition, the paper also describes the technologies developed for performing some special inspection, repair and replacement tasks for the coolant channels. These include systems for garter spring repositioning by Mechanical Flexing Technique for fresh reactors and Integrated Garter Spring Repositioning System for operating reactors. A tooling system, developed for in-situ retrieval of sliver scrape samples from pressure tubes, is also described. These samples can be analysed in laboratories to yield valuable information on hydrogen concentration in pressure tube material. The current and planned activities towards development of technologies for improvement of the life time availability of the power plants are addressed.

1. INTRODUCTION

Current phase of the Indian nuclear power programme is based on 220 MWe and 500 MWe horizontal pressure tube type Pressurised Heavy Water Reactors (PHWRs). At present, seven 220 MWe PHWRs are under operation, one is under en-masse coolant channel replacement, four 220 MWe PHWRs are under construction and a programme of construction of additional reactors is under way. [1]

The schematic of a typical PHWR coolant channel is given in Fig. 1. The material of the pressure tubes of the seven Indian PHWRs is 20% cold worked Zircaloy-2, and in these reactors the garter spring spacers are loose fit around the pressure tubes. Subsequently the pressure tube material has been changed to 20% cold worked Zr-2.5%Nb alloy and the garter spring spacers are made tight-fit around the pressure tubes. Safe operation and life time availability of the reactor demand high assurance of structure integrity of the coolant channel, throughout the operating life of the reactor. In order to improve maintainability, inspectability and availability of the reactor, the development and implementation of the following approaches and technologies are necessary:

- Measures to extend the service life of the reactor
- Special devices for inspection of the coolant channels
- Design improvements to reduce downtime needed for periodical inspection
- Technologies to replace the coolant channels
- Analytical methodologies for assessment of safe operating life of the coolant channels

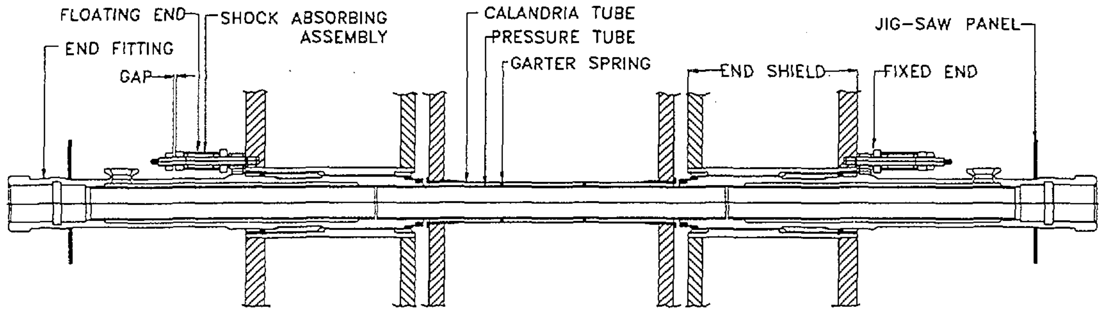

FIG. 1. Coolant Channel Assembly

2. MEASURES TO EXTEND THE SERVICE LIFE OF THE REACTOR

2.1. Life Extension of Coolant Channels by Garter Spring Spacer Repositioning

The annulus gap between pressure tube (PT) and calandria tube (CT) is maintained by annulus spacers called Garter Spring (GS) spacer. The loose-fit GS spacers, used in the first seven Indian PHWRs, have been found to be susceptible to displacement from their installed positions, mainly during the construction and commissioning stage of the reactor. This could result in occurrence of an early Pressure Tube-Calandria Tube (PT-CT) contact due to creep deformation of both tubes in that channel where such displacement of GS spacer is significantly large. The service life of a coolant channel may be reduced below its intended design life due to accelerated creep sag deformation of the PT followed by occurrence of PT-CT contact, when GS spacers are significantly shifted from their design locations.

The following systems have been developed for extending the service life of the coolant channels, when the GS spacers are not at their design locations. The displaced GS spacers are relocated to optimum positions in new as well as in operating reactors.

2.1.1. Mechanical Flexing Technique

GS spacer repositioning was carried out in NAPS-1&2 and KAPS-1 reactors after their hot conditioning using Mechanical Flexing Technique (MFT). The schematic arrangement for repositioning operation is shown in Fig. 2. The MFT employs a specially developed hydraulically actuated Pressure Tube Flexing Tool. The PTFT causes gentle cyclic flexing of the pressure tube, which enables the displacement of GS spacer [2]. A computer code "SCAPCA" (Static and Creep Analysis of Pressure tube and Calandria tube Assembly) was developed to assess the creep contact time on the basis of locations of GS spacers. This code also identifies the strategy of relocating the GS spacers to improve the service life of the coolant channels, if required.

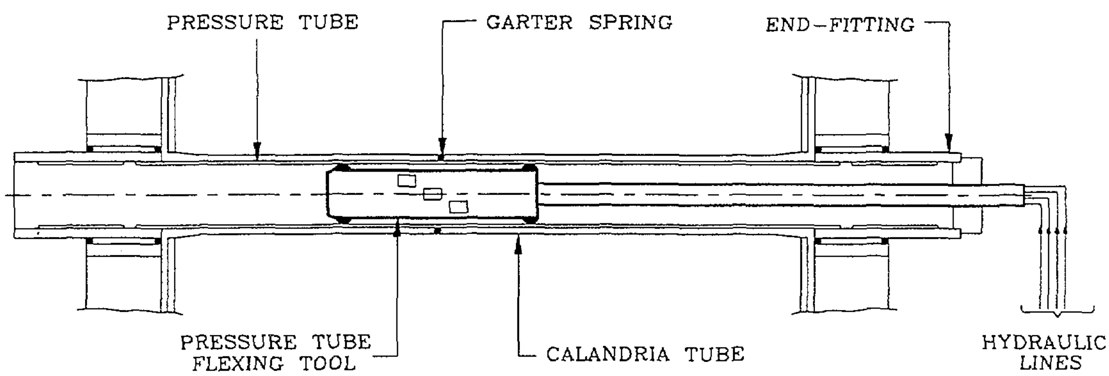

FIG. 2. Mechanical Flexing Technique

2.1.2. Integrated Garter Spring Repositioning System (INGRES-1S)

At time of construction of the first four reactors, RAPS and MAPS, displacement of GS spacers was not anticipated. For repositioning of the loose GS spacers in such operating reactors, a modular system called Integrated Garter Spring Repositioning System (INGRES-1S) for dry channels has been developed. The schematic arrangement of INGRES-1S is shown in Fig. 3. The major sub-systems of INGRES-1S are Pressure Tube Flexing Tool (PTFT), Electro-Magnetic Device (EMD), calibration set-up and feeding mechanism. The EMD consists of garter spring detection probe, concentricity detection probe, garter spring repositioning device and thermocouples. Operation of INGRES does not impose any unacceptable loads on coolant channels during its operation. The INGRES-1S has the following capabilities:

- Creation of restriction-free passage for the GS spacers
- Detection of location of the GS spacers
- Detection of the PT-CT concentricity
- Re-positioning of GS spacers as per identified strategies
- Accessibility up to centre of PT from one vault
- Measurement of temperature of GSRD

For operation of INGRES, the coolant channel should be defuelled and drained. An assembly of EMD is inserted through one end of the coolant channel, while the PTFT is inserted through the other end. After detection of locations of GS spacers and concentricity between PT and CT, the PTFT is operated to correct eccentricity between PT and CT at the location of GS spacer. This operation is done to provide a restriction free passage for the GS spacer. The GSRD causes GS spacer to move in the desired direction. This sequence is repeated after air cooling of GSRD, till the GS spacer is shifted to its desired position. The INGRES-1S was successfully used in nine coolant channels during first campaign in operating reactor at MAPS-2.

2.1.3. Integrated Garter Spring Repositioning System (INGRES-2S)

On the basis of experience gained during MAPS-2 operation, INGRES-2S has been developed for enhancement of performance. INGRES-2S has the following additional capabilities as compared to INGRES-1S.

- Improvement of restriction-free passage for the GS spacers
- Reduction in time, required for operation
- Accessibility of full length pressure tube from one vault with the help of 2000 mm long extension tubes
- Improvement in operating parameters of EMD
- Integration of all modules including two bending modules (BM)

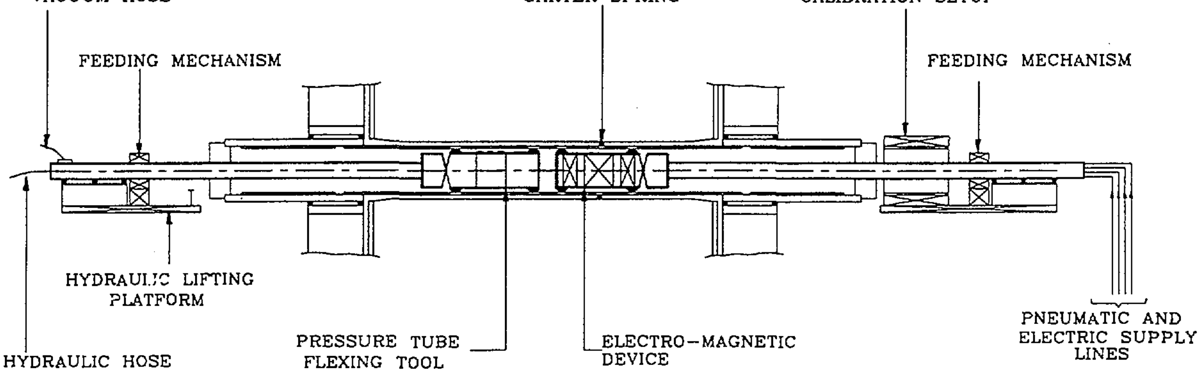

FIG. 3. Integrated Garter Spring Repositioning System (INGRES-1S)

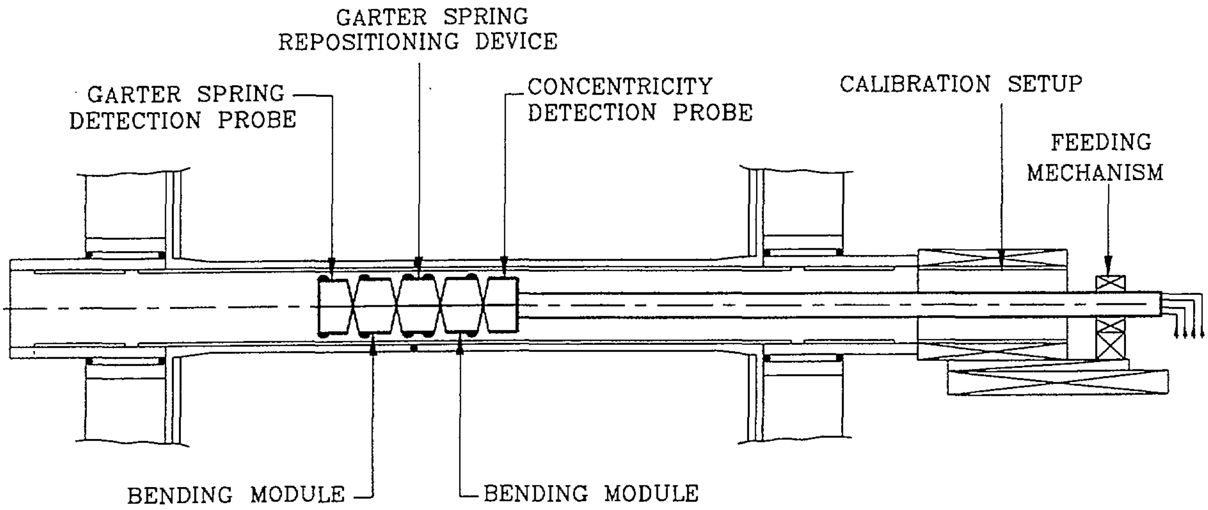

FIG. 4. Integrated Garter Spring Repositioning System (INGRES-2S)

INGRES-2S has been fully assembled at present. The testing of integral assembly of EMD and BM, called In-Channel Device (ICD), has been successfully completed. The qualification trials of INGRES-2S are being conducted. A schematic of the complete system of INGRES-2S is shown in Fig. 4.

INGRES-2S is being suitably modified for wet channel operation. The schematic arrangement of INGRES-2S delivery system for wet channel is shown in Fig. 5. Operation of INGRES-2S in wet coolant channel has the following additional capabilities as compared to operation of INGRES-2S in dry coolant channel:

- Special Closure Plug: To replace the normal channel closure plug (the replacement would be done using Fuelling Machine) before operation of INGRES and to retain pressure boundary of primary heat transport just before starting and just after completion of operation of INGRES.
- Closure Plug Actuating Mechanism: To operate the special closure plug to obtain a clear passage for ICD movement and to facilitate resealing of the coolant channel after completion of INGRES operation.
- Adaptor: To provide water seal for composite cables and to have junction box for electric, pneumatic and hydraulic connections to composite cables.

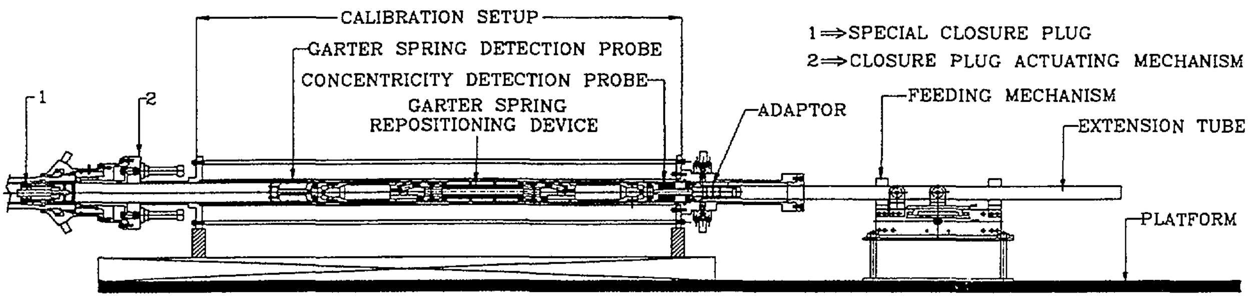

FIG. 5. INGRES-2S delivery system for wet channel operation

3. SPECIAL DEVICES FOR INSPECTION OF COOLANT CHANNELS

The regular In-Service Inspection (ISI) of the coolant channel of Indian PHWRs is performed under wet channel conditions, using a special system called BARC Inspection System (BARCIS). The regular ISI is sometimes required to be supplemented by additional visual inspection within the bore of the coolant channel components. For determination of equivalent hydrogen concentration in the pressure tube material, samples as slivers of 0.1 mm thickness and weighing about 50 mg are obtained. These special devices are discussed in the following paragraphs:

3.1. Dry Channel Visual Inspection System

The DRY channel Visual Inspection System (DRYVIS) is developed for carrying out visual inspection within PHWR coolant channels. Entire length of the bore of the coolant channel can be scanned with a good clarity, good resolution and reasonably accurate capability to size the indications found on the surface being scanned. The device can be remotely positioned anywhere within a given channel with low personnel radiation exposure. Once the device is placed in one of the ends of coolant channel manually, it can be propelled into the channel and withdrawn back to original location using remote control.

DRYVIS consists of a tool carrier system, CCTV system based on radiation resistance miniature camera, external lighting fixture, grating for sizing and axial position indicating system.

DRYVIS-1 & 2 are being used for visual inspection of the pressure tube and calandria tube respectively with basic design remaining same. The dimensions of tool carrier systems are suited to respective tubes. [3]

3.2. Sliver Sample Scraping Technique

For assessment of safe operating life of pressure tubes of PHWRs, it is necessary to estimate the hydrogen concentration in the pressure tube material, and to establish hydrogen or deuterium pick-up rate by the pressure tubes under service conditions. To carry out such assessment without removal of pressure tubes and to increase the availability of the reactor, it is necessary to obtain sliver samples of the pressure tube material without affecting integrity and residual service life of the pressure tube. [4]

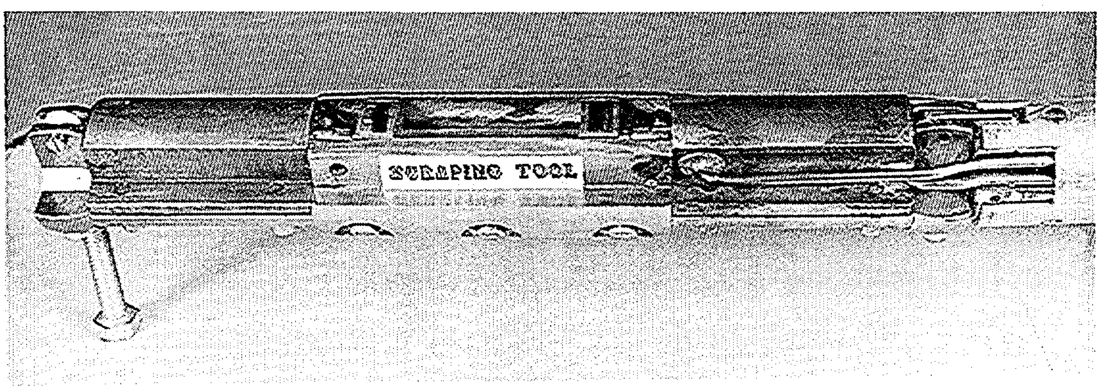

FIG. 6. Scraping Tool

A Sliver Sample Scraping Technique (SSST) has been developed to obtain samples from specified location within the bore of sagged (35 mm maximum) pressure tubes of PHWRs for determination of residual service life. During qualification trials, about 100 sliver samples have been obtained successfully from the irradiated pressure tubes, removed from RAPS & MAPS reactors for determination of operating parameters, evaluation of scraped region of pressure tubes and evaluation of material samples. In order to minimise personnel radiation exposures, a remotised driving system has also been developed for axial positioning of scraping tool in the pressure tube of a coolant channel at reactor site. A scraping tool is shown in Fig. 6.

4. DESIGN IMPROVEMENTS TO REDUCE DOWNTIME NEEDED FOR PERIODICAL INSPECTION

Components have been developed to increase the availability of the reactor and to reduce personnel radiation exposure as follows:

- Compact Mechanical Snubber: To eliminate periodic adjustment of gap for creep by incorporating a special device using as a shock absorbing assembly.

- Modular Insulation Panel: To reduce time required for overall creep adjustment and repair & maintenance works to be done on coolant channel by facilitating quick assembly and disassembly of panels.

4.1. Compact Mechanical Snubber

Axial restraint for the coolant channel, following postulated guillotine rupture of the pressure tube, is provided by a shock absorbing assembly (SAS). These assemblies are located on the both end-fittings of the coolant channel, as shown in Fig. 1. The functions of SAS are as follows:

- To absorb the shock or impact load in case of pressure tube rupture
- To permit axial elongation of coolant channel in a controlled manner

In present design, it is necessary to monitor the elongation of individual coolant channel and to carry out an adjustment of the gaps periodically to avoid the imposition of unacceptably high forces on the pressure tube and end-shields. Creep adjustment requires considerable personnel radiation exposure and also longer outage. In view of this, a device, called Compact Mechanical Snubber (CMS), has been developed to take care of above mentioned functions automatically.

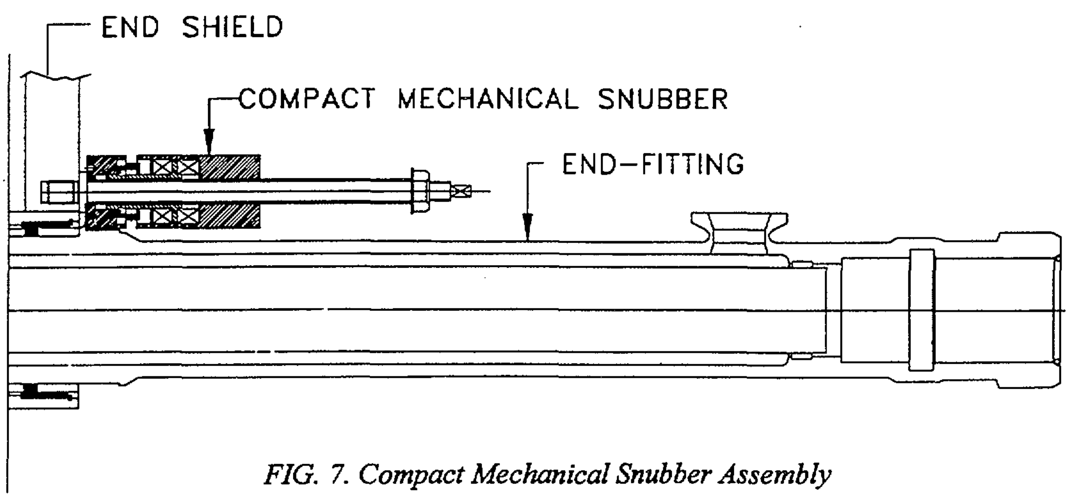

FIG. 7. Compact Mechanical Snubber Assembly

The CMS consists of major components, such as spring loaded sub-assemblies, non-rotating thrust-block, rotating nut and stud. An axial elongation of the coolant channel would be transmitted to the thrust block causing a resisting inertia force, proportional to the acceleration of coolant channel, being developed on CMS. Under the action of this force, the spring loaded sub-assembly would change its length. As long as the acceleration remains within the activation level of the snubber, it will permit the axial movement of the thrust block without any significant resisting force. However once the acceleration exceeds the activation level the non rotating thrust block gets locked up with the rotating nut, causing complete seizure of the snubber on the stud. The value of the activation level can be easily adjusted by altering a spring member. The schematic arrangement of the CMS, developed for RAPS and MAPS, is shown in Fig. 7.

4.2. Modular Insulation Panel

The construction of insulation cabinet at end fitting penetration is called Jig-Saw panel. These panels are required to prevent leakage of hot air into the fuelling machine vaults These panels fill the inter-space area among end-fittings. These panels form part of insulation cabinet in fuelling machine vaults. The present design requires considerable personnel radiation exposure for assembly or disassembly at the time of creep adjustment or any other repair or maintenance works to be done on coolant channels. In view of this new design called Modular Insulation Panel (MIP) is being developed as shown in Fig.8. This new design would minimise personnel radiation exposure and reduce plant down time considerably. A large number of MIPs has been fabricated and they are under qualification trials at operating reactor site. [5]

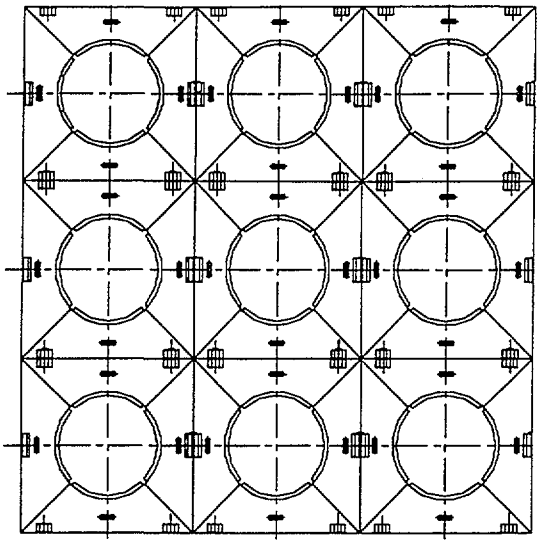

FIG. 8. Modular Insulation Panels

5. TECHNOLOGY TO REPLACE THE COOLANT CHANNELS

In-reactor service life of the Zircaloy-2 pressure tube is expected to be around 8 to 10 effective full power years. In order to enhance the life of a reactor using these pressure tubes, it is necessary to replace all the pressure tubes before their safe service life is over. Going by the experience of manual removal of pressure tubes in Indian PHWRs, it is expected that it would consume very high personnel radiation exposure for replacement of all coolant channels of one reactor. This would involve a long down time of a reactor and arranging a large trained man-power will be difficult.

Keeping this in view, a semi-automatic and remote operable Coolant Channel Replacement Machine (CCRM), as shown in Fig. 9, has been developed. CCRM mainly consists of a self elevating work table, cross travel system, co-ordinate table, remote operable overhead crane, alignment system and servo manipulator. A large number of tooling to perform various tasks for replacement and refurbishment has also been developed.

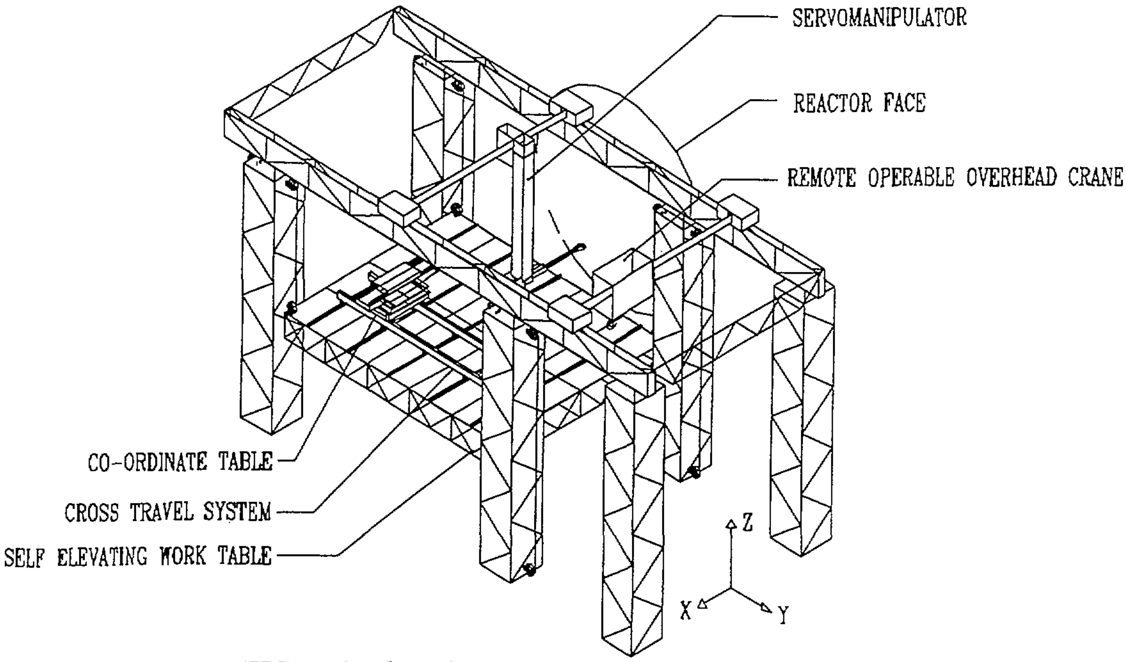

FIG. 9. Coolant Channel Replacement Machine

TABLE I. COMPUTER CODES

Computer code	Objective
(SCAPCA): Static and Creep Analysis of Pressure tube and Calandria tube Assembly	• To predict creep contact time • To determine the gap closing rate
(HYCON-95): HYdrogen CONcentration estimation	• To estimate the oxide thickness • To estimate Hydrogen concentration at any axial position along the length of the pressure tube • To estimate Hydrogen and Deuterium pick-up rate
(BLIST1D) & (BLIST2D): BLISTer estimation codes	• To study the relationship between time and depth of blister • To study the phenomenon of Hydrogen and Deuterium migration
(CEAL): A Code for Estimation of Assurance of Leak before break	• To estimate the critical crack length from fracture toughness • To estimate the leak rates through axial cracks in pressure tube • To assess required operator response time

6. ANALYTICAL METHODOLOGIES FOR ASSESSMENT OF SAFE OPERATING LIFE OF THE COOLANT CHANNELS

Methodologies have been developed in India to model and analyse the major life limiting mechanisms for pressure tubes. [6] Computer codes have been developed for determination of creep and growth related dimensional changes of coolant channels, deuterium pick-up rates in Zircaloy-2 pressure tubes, blister growth following occurrence of pressure tube-calandria tube contact, and operating domain to achieve Leak Before Break (LLB) of pressure tubes. These codes have been validated with reference to the data of In Service Inspection (ISI) and Post Irradiation Examination (PIE), available for the coolant channels of Indian PHWRs. The Computer codes, along with their objectives are listed in Table I.

7. CONCLUDING REMARKS

Technologies and facilities to carry out the required in-service inspection, life extension, and replacement for improving availability and reliability of the coolant channels of Indian PHWRs are either already available or in advanced stage of development. Capability to assess safe operating life of pressure tubes under the various degrading mechanisms has been developed in India in the form of computer codes. A large scale programme for carrying out en-masse replacement of coolant channels in the lead reactor, RAPS-2 is already under way. Future work will involve the augmentation of the current technologies for wet channel operation and automation to improve availability of current and future PHWRs. The computer codes would be tuned finely on the basis of data obtained from additional In Service Inspection and Post Irradiation Examination, performed on a large number of pressure tubes of Indian PHWRs.

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