Engineering aspects of hot cells and in-cell equipment

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Abstract

Reliable performance of nuclear fuels and critical core components has a large bearing on economics of nuclear power and radiation safety of plant operating personnel. In view of this, PIE is periodically carried out on fuels and components to generate feedback information which is used by the designers, fabricators and the reactor operators to bring about changes for improved performance of the fuel and components. Examination of the fuel bundles has to be carried out inside hot cells due to their high radioactivity. The new hot cell facility (NHF) has been designed, built and commissioned with additional features and capabilities. The NHF consists of two hot cells made of heavy density concrete and a number of lead cells. The new hot cells are designed to handle higher levels of β–γ radioactivity. NHF has fully automated ventilation system with improved safety systems. NHF has a charging port with adequate opening to accommodate India PHWR components. All material transfer system in the cell has electronic and mechanical interlocks which eliminate chance of accidental personal exposure. NHF is provided with in cell crane and cranes in all radioactive areas which facilitates handling of larger irradiated components and heavier shielding cask. Automated data acquisition and monitoring system is installed in NHF.

Various equipment are installed inside the hot-cells for the material property evaluation and performance assessment. The details regarding the engineering aspects of NHF and in-cell equipment will be discussed.

1. **Introduction**

Reliable performance of nuclear fuels and critical core components has a large bearing on economics of nuclear power and radiation safety of plant operating personnel. In view of this, PIE is periodically carried out on fuels and components to generate feedback information which is used by the designers, fabricators and the reactor operators to bring about changes for improved performance of the fuel and components. Examination of the fuel bundles has to be carried out inside hot cells due to their high radioactivity. In the last four decades, post irradiation examination of different types of experimental as well as power reactor fuels and structural components used in the core of the reactor has been carried out in the old hot cells facility of the Post Irradiation Examination Division of BARC. The new hot cell facility has been designed, built and commissioned with additional features and capabilities. A view of the operating area of the NHF is shown in Figure 1. An overview of the salient features and capabilities of the new hot cell facility (NHF) at PIED is presented in this paper.

Figure 1: Operating area of the hot cells in the NHF showing the viewing windows and master slave manipulators.

2. Engineering aspects of New Hot Cell Facility (NHF)

The new hot cell facility has two areas for handling radioactive materials. They are:

- Hot cells for handling highly radioactive irradiated fuels and structural materials
- Lead cells and low active laboratories for handling of specimens with a lower radiation field

The NHF consists of two hot cells, namely cell-1 & cell-2, and is designed to handle β–γ radiation. The front, rear and side walls of the cells are 1.5 m thick and are made of heavy density concrete (density=3.4 g/cc). The bigger cell (cell–1) is 16.9 m long, 2.1 m wide and 4.7 m high and the smaller cell (cell–2) is 5 m long, 2.1 m wide and 4.7 m high. All regions of cell–1 and cell–2 are provided with lead glass viewing windows, master slave manipulators (MSMs), ports for in-cell camera and service plugs, which are essential for carrying out PIE. Cell-1 is fitted with 7 radiation shielding windows and 7 pairs of rugged duty master slave manipulators. Cell-2 is fitted with two radiation shielding windows and two pairs of rugged duty master slave manipulators.

- Cell–1 is provided with three personnel entry doors and Cell–2 with one personnel entry door. The roof of the hot cells is made of steel with rotating roof plug assemblies for introduction of heavy equipments and for their removal. The rotating roof plugs assemblies above the hot cells are shown in Figure 2. The rotating roof plugs are eccentric to each other and have 250 mm diameter opening each, which can be positioned so as to gain access to any location within the cell. These openings can be used to deploy remotely operating tools to handle objects/ equipments kept in the cells, which cannot otherwise be handled using MSMs.

Typical rotating roof plug assembly

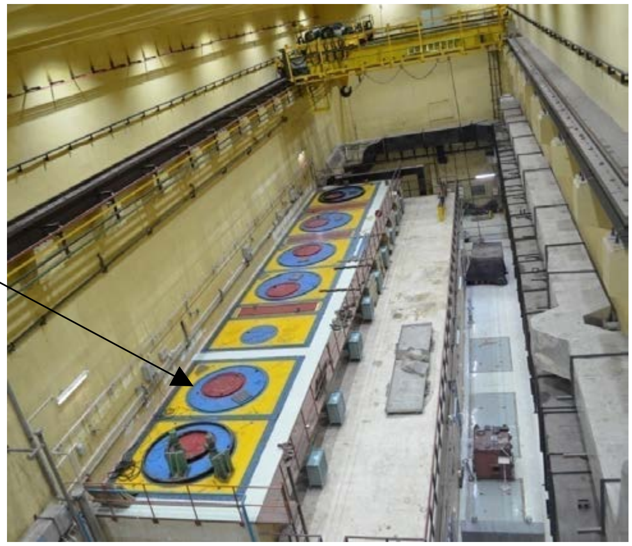


Figure 2: Hot cell roof with rotating roof plug assemblies.

- Both cells have been provided with dedicated in-cell cranes of 2.0-ton capacity as shown in the Figure 3. The inter cell wall between Cell–1 and Cell–2 is provided with a shielded inter cell transfer drawer that can be used for transfer of material between the two cells. The rear walls of the cells are provided with external transfer drawers (ETDs) that can be used for transfer of material in and out of the hot cells. Both cells have a port on the sidewall in the warm work area to introduce irradiated materials into the cells. Tables of about 900 mm height are laid in the cells to provide the working surface. Various pipe lines are available within the cells. These lines can be used for providing services like compressed air, gas, vacuum, etc. as per requirement. Three floor drains in Cell–1 and one in Cell–2 are provided to drain out the effluents to underground sump tanks located in the warm work area through a network of stainless steel pipe lines.

Figure3: Inside view of the cell with in-cell crane

Salient features:

- *Fuel transfer port size*

The new hot cells have transfer port which will facilitate loading of larger components like control blade assembly into the cells for PIE. Figure 4 shows the (a) cold side and (b) hot side of the fuel transfer port in the new hot cell.

- *Cell dimensions*

The length of the hot cell in the NHF is several meters. This provides the advantage of examining longer components such as full length irradiated pressure tube. The NHF provides the facility of continuous scanning of longer fuel elements.

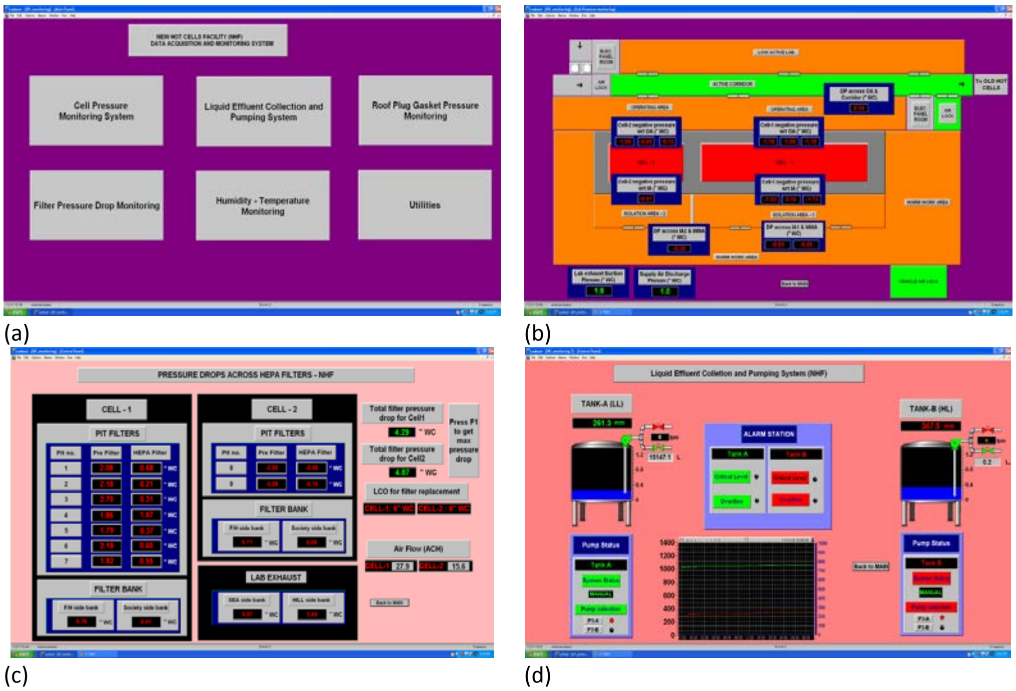
- *Shielding capacity*

The hot cells at the NHF are capable of handling higher activities up to 2.5 x10^5 Ci of Co^{60} or 2.6x 10^6 Ci of fission products.

Figure 4: (a) Cold side and (b) hot side of the transfer port in the new hot cell.

- *Ventilation in NHF*

The ventilation in the NHF is of once-through type and ensures dynamic confinement of radioactive particulates within the radioactive zones of the facility. The ventilation system is based on radioactive area zoning principles and satisfies the regulatory guidelines. The hot cells are provided with dedicated cell exhaust system consisting of four blowers; one for each cell with a standby High Efficiency Particulate Air (HEPA) filter bank and a standby blower. Other radioactive areas are also provided with separate lab exhaust and supply system. The supply system air is provided with filtration, cooling and humidity control. The dust free cooled air is supplied in all radioactive area except hot cells. The hot cell is maintained at a negative pressure of 25 mm of water column (WC) with respect to operating area. There are 20 air changes per hour in the hot cells. The elaborate safety interlocks provided in the ventilation system ensure radiological safety of the plant personnel and public. Contaminated air passes through multiple HEPA filter banks before being released through the stack after monitoring to ensure release of radioactivity in the environment is within the approved regulatory limits. The ventilation system is provided with data acquisition and monitoring system. Real time data of safety related parameters of ventilation such as negative pressure in hot cells, air changes per hour, activity level etc. are available for monitoring and logging in the central console in operating area which are shown in the Figure 5.



(a) (b) (c) (d)

Figure. 5 (a) Centralised data acquisition and monitoring system, (b) Differential pressure monitoring of radioactive areas, (c) Pressure drop monitoring across the cell & lab exhaust filters, (d) Liquid effluent collection and pumping system monitoring console

- **Areas associated with the hot cells**

The facility is divided into four zones depending on the probability of radioactive contamination. The zones are coded white, green, amber and red, with green having the lowest and the red having the highest probability of contamination. The white areas have a very remote chance of contamination by radioactivity. Figure 4 gives the plan of the hot cells indicating various associated areas.

The location of the operating area is shown in the Figure 6. Remote operations of equipment kept inside the hot cells are carried out from this area (see Figure 1) using MSM and viewing windows. Control consoles of the in cell equipment and other measuring instruments are also kept in this area.

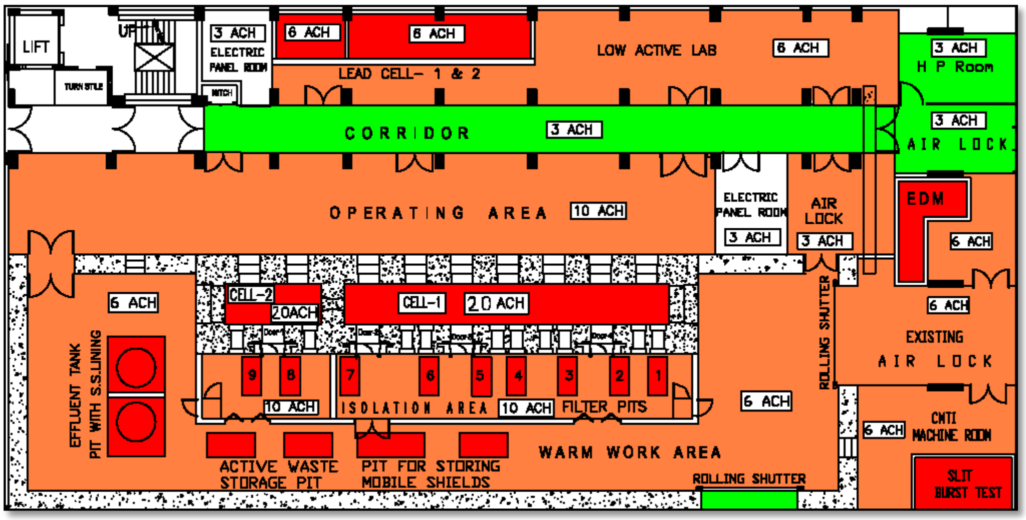


Figure 6: Plan of the NHF showing the hot cells and the associated areas depicting appropriate health physics colour coding.

The isolation area is on the rear of the hot cells and acts as a buffer between the cells and the high bay surrounding the cells. The isolation area is provided with a 2T hand operated overhead travel underslung crane. The cell exhaust filters are located in nine separate pits below the isolation area floor.

The high bay surrounding the cells and isolation area on three sides is called the warm work area and houses a 40T/5T EOT crane. This area is used for receiving shielded casks containing radioactive materials. An airlock capable of accommodating a 30T trailer truck is provided. Dollies running on rails are used to dock the cask to the transfer port of the hot cell (Figure 7). Airlocks have also been provided for personnel entry into the warm work area.

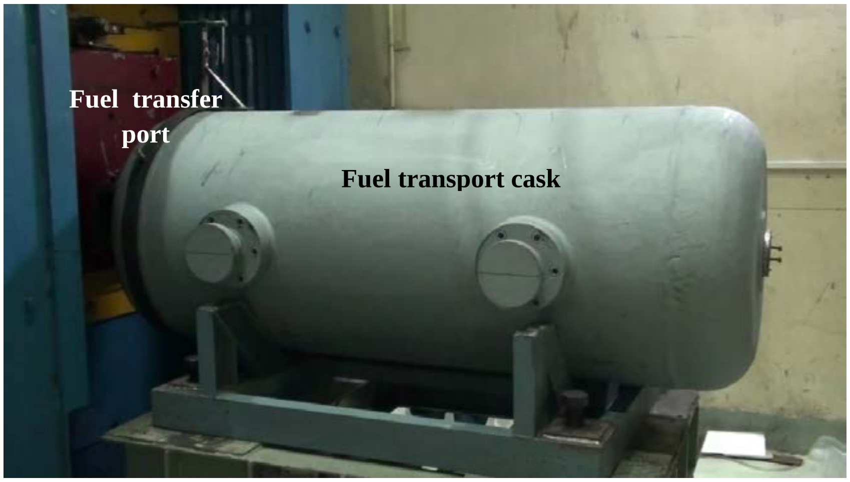


Figure 7: Docking of the fuel transport cask with the fuel transfer port of the hot cell.

The low active laboratory is primarily used for carrying out mechanical tests on irradiated test specimens. Towards this an instrumented drop tower, a servo hydraulic & screw driven universal testing machines, creep testing units and static load test setups have been installed in the low active laboratory. The front wall of the lead cells in this laboratory is made of 200mm thick steel cased lead bricks and the rear walls are made of 100mm thick lead bricks. The lead cells are fitted with articulated MSM, viewing windows, hatches/door for personnel entry, transfer ports, and other handling facilities. The radioactivity of the test specimens will be limited to a few mCi of Co^{60} equivalent.

3. Engineering aspects of the in-cell equipments:

The NHF has a comprehensive PIE facility in terms of material characterization and analytical capabilities required for PIE studies on nuclear fuels and materials. Various non destructive and destructive techniques are employed inside the hot cells for carrying out post irradiation examination on irradiated fuels. The PIE of irradiated PHWR fuel bundle is described below to highlight the unit steps and capabilities of the hot cells.

3.1. Dismantling of the fuel bundle

After preliminary survey of the fuel bundle for its overall integrity, the fuel bundle is dismantled to separate the fuel pins of the bundle for PIE investigations. Mechanical cutting machine using saw blade is installed in the hot-cells. Figure 8 shows the dismantling of a fuel bundle using the mechanical cutting machine inside the hot cell as seen through the cell window.

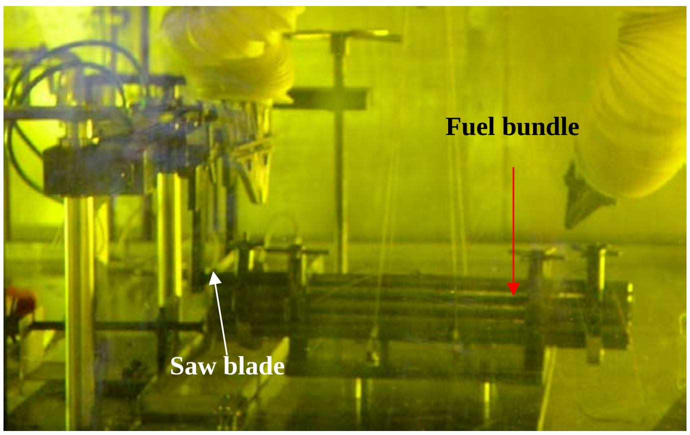


Figure 8: Saw blade based mechanical bundle dismantling machine installed inside the hot cells.

3.2. Visual examination

Detailed visual examination of the fuel bundle and the pins is carried out inside the hot cells using a high definition pan tilt zoom (PTZ) camera having optical zoom of 30X and 4MP resolution which is shown in the Figure 9. Surface conditions, such as abnormal distortion or deformation, defects, damage on the fuel pin can be examined on the visual display placed in the operating area. Condition of the bearing pads and other welded appendages of the pins are also examined.

Figure 9. High definition 4MP PTZ camera with 30X optical installed in hot cell.

3.3. Leak testing

Leak testing of individual fuel pins is carried out using liquid nitrogen- alcohol leak test method. Fuel pin is first dipped inside a bath containing liquid nitrogen for a few minutes and then transferred to a bath containing alcohol, which is shown in Figure 10 (a). In case of a fuel pin with a leak, the trapped liquid nitrogen will bubble out, indicating the location of leak. Figure 10 (b) shows bubbles emanating from a leak in one of the fuel pins.

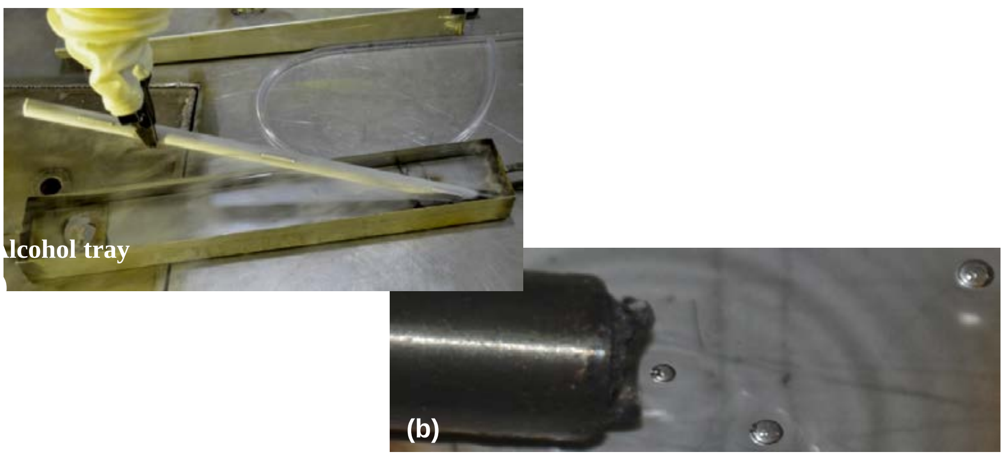


Figure 9: (a) Liquid nitrogen- alcohol leak testing set-up inside the hot cell and
(b) bubbles emanating from the failure location in the fuel pin.

3.4. Profilometry

A laser micrometer and a LVDT transducer based profilometer are used to determine the variation of the fuel pin diameter along its axis. Figure 8 shows diametral profile measurement of a fuel pin using laser profilometer. The scanning stage used for movement of the fuel pin during LVDT transducer based profilometry is shown in Figure 11.

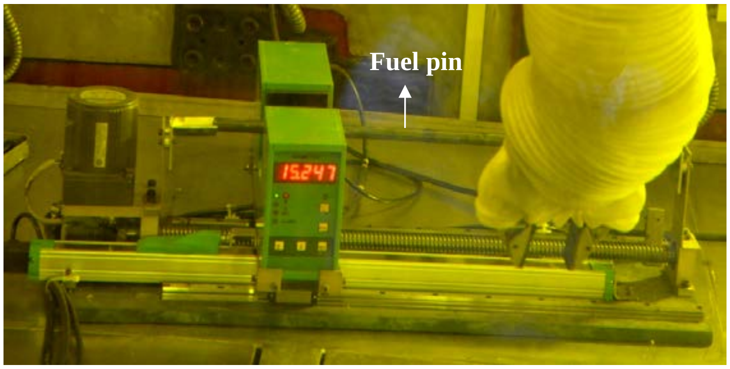


Figure 11: Laser profilometer inside the hot cell.

3.5. Ultrasonic testing

Ultrasonic testing of fuel pins immersed in water in horizontal tank is carried out to detect the presence of incipient flaws in its cladding. The end plug welds are also inspected to detect deterioration of the weld and the heat affected zone. Figure 12 shows the ultrasonic scanner fitted with probes for detection of axial and circumferential defects in the cladding.

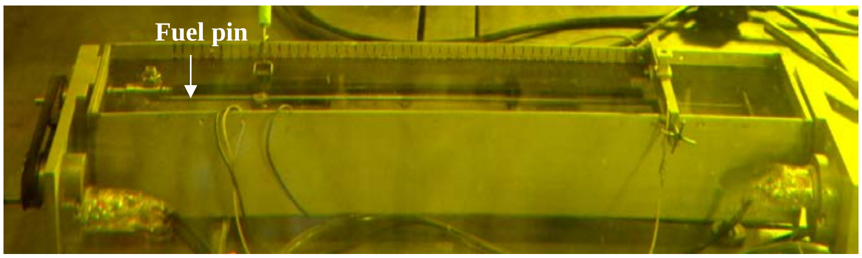


Figure 12: Ultrasonic testing set up installed in the hot cells.

3.6. Gamma spectroscopy and scanning

Gamma spectroscopy and gamma scanning using high resolution HPGe detector and multi channel analyser (MCA) are carried out on the irradiated fuel pins inside the hot cell. Co^{60}

and Cs^{137} sources are used for energy calibration. The fuel pin is fixed on the scanning stage and gamma counting at various axial locations is carried out, with the detector placed in front of collimator in the operating area. Relative burnup distribution in the fuel pin is measured by gamma scanning which uses Cs^{137} as the monitoring isotope for gamma counting. Figure 13 shows the fuel pin loaded on the scanning stage inside the hot cells for gamma scanning.

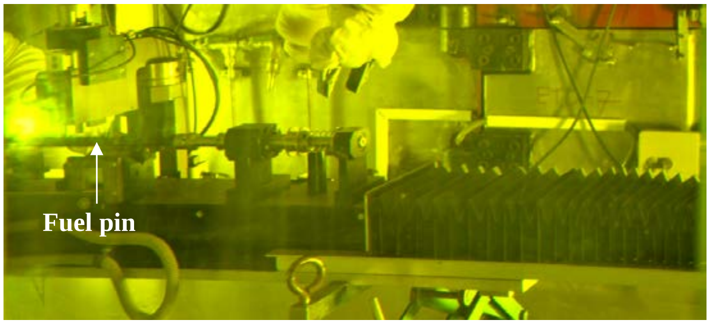


Figure 13: Scanning stage for profilometry and gamma scanning inside the hot cells.

3.7. Fission gas release measurement

The released fission gas analysis set up is used for the estimation of the quantity and composition of the released fission gases inside the fuel pins. The setup essentially consists of a puncture chamber fixed inside the hot cell (Figure 14), which is connected to the gas collection and measuring part located in the operating area, by means of stainless steel tubes. The estimation of parameters such as, void volume of the fuel pin and the pressure and volume of the released gases is carried out by connecting calibration flasks to the system and by applying standard gas laws.

Chemical composition of the released gases is determined using a dual column gas chromatograph, with argon as the carrier gas. Thermal conductivity detector is used for the detection of the individual gases. A quadrupole mass spectrometer is used for measuring the isotopic ratios of Xe and Kr isotopes.

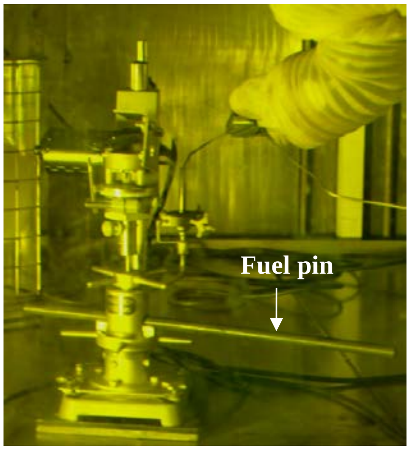


Figure 14: Puncturing set up in the hot cell for measurement of the fission gas release.

3.8. Bow measurement setup:

Bowing of fuel bundles result in differential flow of coolant which may lead to localized heating and failure of the fuel elements. During PIE, bow of individual fuel pins are measured in hot cell using movable dial gauge mounted over a leveled flat platform. The dial gauge is moved over the fuel pin and relative distance from the baseline of the dial gauge is measured at fixed intervals. The pin is rotated and the bow is measured at different orientations of the pin. The bow measurement set-up is shown in the Figure 15.

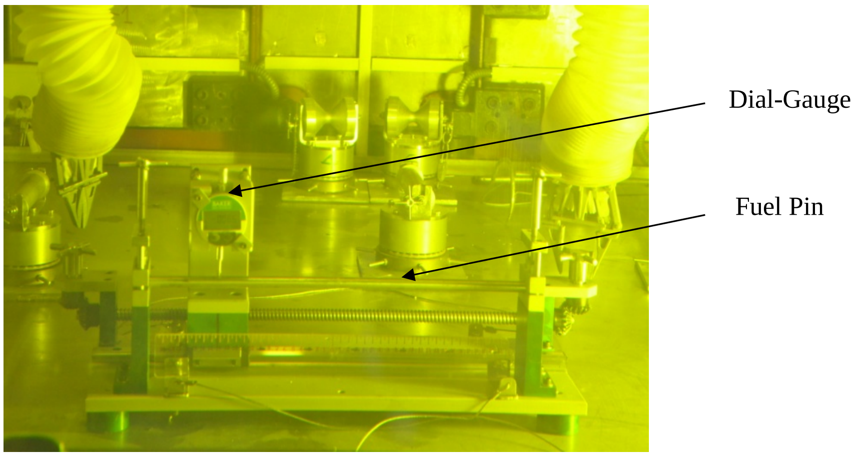


Figure 15. Bow measurement set-up

3.9. Set-up for preparation of fracture toughness specimens:

Trepanning of the specimens of ~30 mm diameter and full thickness samples are done from the full length pressure tube inside the cell. The full length pressure tube is clamped in the machine and disc compact specimens are trepanned by a cutter at the desired locations as shown in the Figure 16.

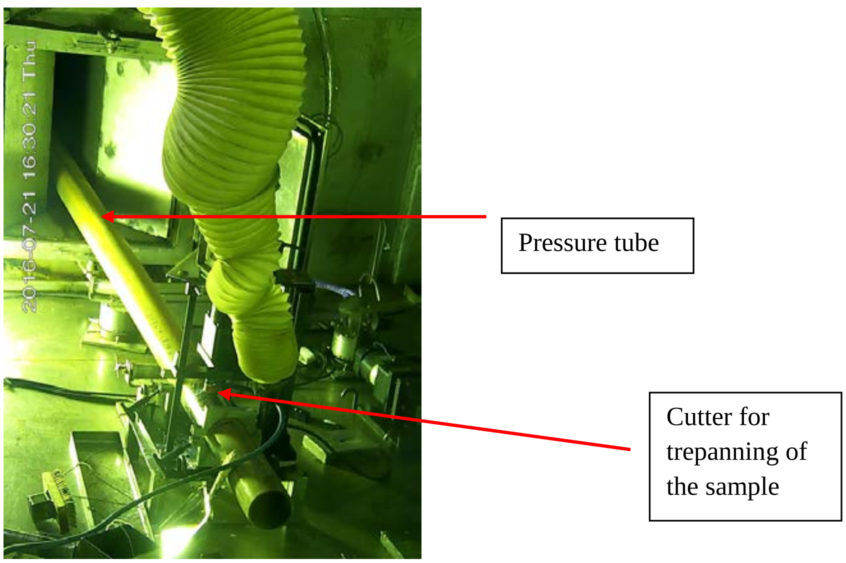


Figure 16. Trepanning of the disc compact specimens from the full length pressure tube

After trepanning the specimen is tightly placed in the holder for drilling of the specimen and notching at the centre as shown in the Figure 17. The cutter for trepanning, drill bit and the notching wheel all can be remotely changed.

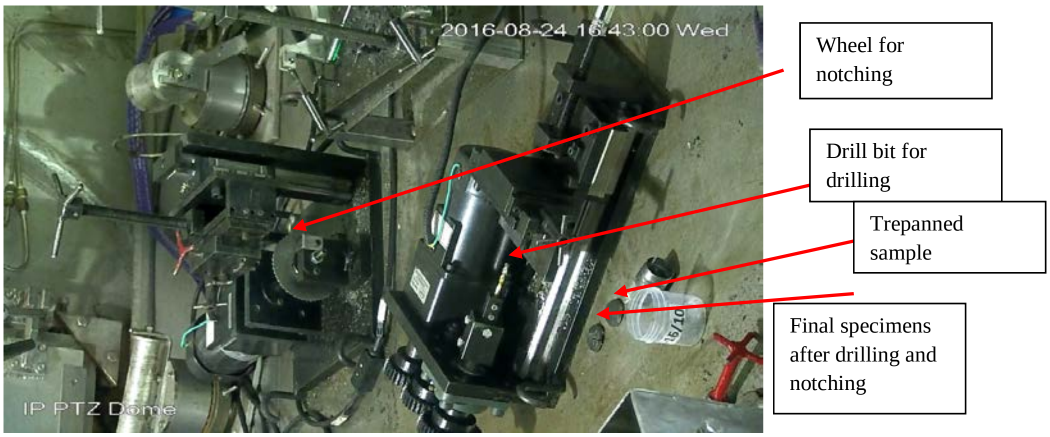


Figure 17: Drilling and notching set-up inside the cell

3.10. Preparation of samples for microstructural studies

The changes in fuel microstructure during irradiation are studied by performing ceramography of the fuel sections. Cutting of fuel pins to get samples for metallography/ceramography may lead to falling off of fuel pieces due to the cracks developed during their irradiation. Hence, the cut lengths of the fuel pins are impregnated with liquid Araldite using vacuum impregnation technique to keep the further fuel sections intact.

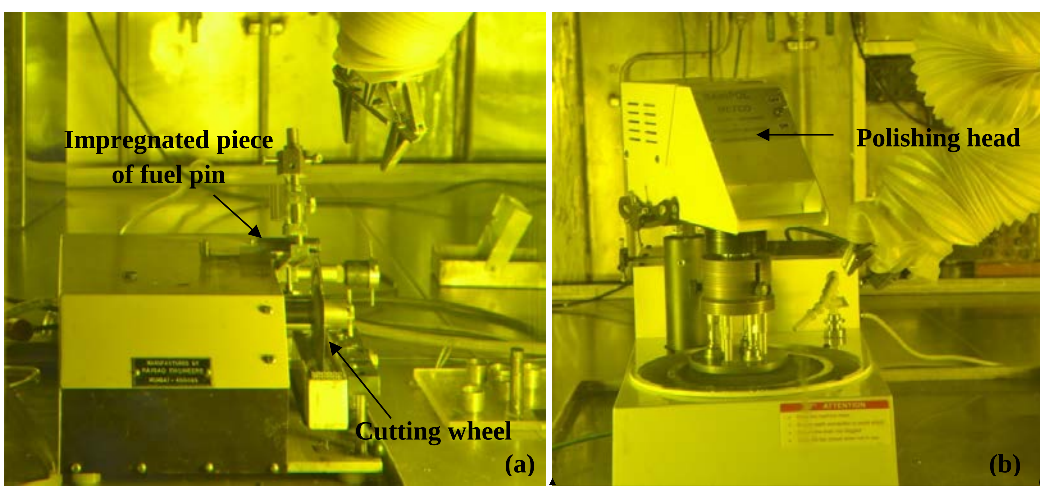


Figure 18: (a) slow speed cut off machine for cutting of metallographic samples (b) remotely operated grinder polisher inside the hot cells.

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Figure 18 (a) shows the slow speed cut off machine placed inside the hot cell used for sectioning of the impregnated fuel pin. The slices cut from the impregnated piece of the fuel pin are mounted in SS rings. The mounted samples are then sequentially ground and polished on a remotely operated grinder-polisher as shown in Figure 18 (b).

4. Waste management in NHF

The solid and liquid radioactive wastes generated from the PIE activities in the facility are collected and handed over to Waste Management Division for necessary treatment and disposal. The gaseous waste is discharged after two stages of filtration to the atmosphere through the 75m high stack of Radiological laboratories (RLG). The irradiated fuels and cut portions of fuel after completion of PIE will be packed in cans and sent for reprocessing. After PIE operation, the fuel pins shall be shifted to the storage pool for further processing or storage. Aluminum (Al) cans of dimension equivalent to 220 MWe PHWR fuel bundle will be used for transfer of irradiated intact fuel pins from PIED hot cell to spent fuel storage pool. The loose intact fuel pins will be packed in the Al cans and transferred to storage pool using double bundle transportation cask. The crimping press assembly will be used for crimping the threaded end cap of Al can as shown in the Fig.19.

Fig.19. Crimping press assembly for the crimping the threaded end of the Aluminium cans

5. Summary

The new hot cell facility with the necessary equipments has been commissioned and activated for the Post Irradiation Examination of irradiated nuclear fuels and structural components from research and power reactors. The results of PIE will provide valuable data on fuel performance such the dimensional changes, fission gas release in the fuel pins, the burnup profile, fuel centre temperature, etc. Evaluation of irradiated structural components and allied materials shall provide the essential data for efficient life management of nuclear facilities. Efforts have been put to use the technology which is readily available in industries to enhance the quality of output with reduced need of man power and also to reduce exposure to occupational worker as well as general public.

6. Acknowledgement

The valuable contributions made by Shri S. Anantharaman, Shri N.K. Mondal, Shri D.N. Sah and Shri K.C. Sahoo during different stages of the design, construction and commissioning of this facility is gratefully acknowledged. We also thank Shri Arun Kumar for the support and guidance given during the crucial stages of commissioning of this facility. We are also thankful to all the staff members of PIED for carrying out various activities during the project and commissioning stage.