New Hot Cell Facility for Post Irradiation Examination

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Abstract

The New Hot-Cells Facility (NHF) of Post Irradiation Examination Division (PIED) at RLG, BARC is designed for the Post Irradiation Examination (PIE) of irradiated nuclear fuels and structural components from research and power reactors. The NHF consists of two hot cells made of heavy density concrete and a number of lead cells. The hot cells are designed to handle $\beta-\gamma$ radioactivity. The lead cells in the facility are equipped with testing machines for evaluation of mechanical properties of irradiated materials. In addition, the facility will be also used for failure analysis of nuclear reactor components. This article describes the salient features of the hot cells and the PIE capabilities of the NHF.

Introduction

Reliable performance of nuclear fuels and critical core components have a large bearing on the economics of nuclear power and radiation safety of the 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 suitable changes for improved performance of the fuel and components. Examination of the fuel bundles has to be carried out inside hot cells due to the high radioactivity associated with them. 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 cell facility of the Post Irradiation Examination Division of BARC. The new hot cell facility (NHF) has been designed, built and commissioned with additional features and capabilities, as an add-on facility to the old hot cells. A view of the operating area of the NHF is shown in Fig. 1. The hot cells at the NHF will cater to the PIE of a variety of irradiated fuels, core components and materials as given in Table 1. The facility will also be used for failure analysis of reactor components. An overview of the salient features and capabilities of the new hot cell facility at PIED is given in this article.

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

**Comparison of New and Old Hot Cells**

**Fuel transfer port size**

The old hot cells were designed for the PIE of fuel from CIRUS reactor. The cell has a 150 mm cylindrical port for introducing irradiated fuel/structural component into the hot cell. This poses a limitation on the size of the fuel/component that can be introduced into the old hot cell. The new hot cells have a transfer port with the maximum opening of 500 mm x 500 mm section which will facilitate loading of larger components like LWR fuel assembly, control blade assembly, etc. into the cells for PIE. Fig. 2 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 16.9 m as compared to 4.8 m in the old hot cell. This provides the advantage of examining longer components such as full length irradiated pressure tube, LWR fuel rods, etc. In the old hot cells, application of certain techniques such as seamless gamma scanning of long fuel elements like those of Dhruva was difficult.

Table 1: List of fuels and components which can be examined in NHF

| a. | NU fuel bundles and MOX fuel bundles from the PHWRs |
| b. | MOX fuel bundles and LEU bundles from the BWRs |
| c. | Experimental MOX fuels irradiated in research reactors |
| d. | MOX/LEU fuel bundles from future PWRs |
| e. | Fuels of research reactors & future reactors such as AHWR, CHTR, etc. |
| f. | Pressure tubes, Calandria tubes and End fittings of the PHWRs |
| g. | Control blades of BWRs and Control elements of the PHWRs |
| h. | Shut off rods of the PHWRs |
| i. | Other core internals which are to be assessed |
| j. | Surveillance specimens from BWRs |
| k. | Material irradiated for materials development programme |

**Fig. 2: (a) Cold side and (b) hot side of the transfer port in the new hot cell**
The NHF provides the facility of continuous scanning of longer fuel elements.

Shielding Capacity

The shielding capacity of the old hot cells is up to $10^5$ Ci of $^{60}$Co. The hot cells at the NHF are capable of handling higher activities up to $2.5 \times 10^5$ Ci of $^{60}$Co or $2.6 \times 10^6$ Ci of fission products.

Features of the New Hot Cells

The NHF consists of two hot cells, namely Cell-1 & Cell-2 and is designed to handle $\beta$-$\gamma$ 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 seven radiation shielding windows and seven 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 equipment and their removal. The rotating roof plug assemblies above the hot cells are shown in Fig. 3. 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.

Both cells have been provided with dedicated in-cell cranes of 2.0-ton capacity. 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.

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 for both Cell–1 and Cell–2; comprising of normal / standing blowers and High Efficiency Particulate Air (HEPA) filter banks. Radioactive
areas are also provided with separate lab exhaust and air supply system. 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 that the 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, pressure drop across HEPA filters etc. is monitored and logged in the central console located at operating area.

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. Fig. 4 gives the plan of the NHF showing the hot cells and associated areas.

The location of the operating area is shown in Fig. 4. Remote operations of equipment kept inside the hot cells are carried out from this area (see Fig. 1) using MSM and viewing windows. Control consoles of the in cell equipment and other measuring instruments are at kept in this area.

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

Fig. 4: Plan of the NHF showing the hot cells and the associated areas depicting appropriate health physics colour coding
is provided. Dollies running on rails are used to dock the cask to the transfer port of the hot cell (Fig. 5). Airlocks have also been provided for personnel entry into the warm work area.

**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. Fig. 6 shows the dismantling of a fuel bundle using the mechanical cutting machine inside the hot cell as seen through the cell window.

**Lead Cells and Low Active Laboratories**

The low active laboratory is primarily used for carrying out mechanical tests on irradiated test specimens. Towards this an instrumented drop tower, 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 200 mm thick steel cased lead bricks and the rear walls are made of 100 mm 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\textsuperscript{60} equivalent.

**PIE Capabilities**

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 in the following system to highlight the unit steps and capabilities of the hot cells.

**Visual examination**

Detailed visual examination of the fuel bundle and the pins is carried out inside the hot cells using a radiation resistant camera with pan tilt zoom (PTZ) facility. 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 can also be examined.

**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 Fig. 7 (a). In case of a fuel pin with a leak, the trapped liquid
nitrogen will bubble out, indicating the location of leak. Fig. 7 (b) shows bubbles emanating from a leak in one of the fuel pins.

**Alcohol tray**

**(b)**

![Liquid nitrogen-alcohol leak testing set-up inside the hot cell and (b) Bubbles emanating from the failure location in the fuel pin](image)

**Fig. 7: (a) Liquid nitrogen-alcohol leak testing set-up inside the hot cell and (b) Bubbles emanating from the failure location in the fuel pin**

**Profilometry**

A laser micrometer and a LVDT transducer based profilometer are used to determine the variation of the fuel pin diameter along its axis. Fig. 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 Fig. 10.

**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. Fig. 9 shows the ultrasonic scanner fitted with probes for detection of axial and circumferential defects in the cladding.

**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 the collimator in the operating area. Relative burnup distribution in the fuel pin is measured by

**Fig. 8: Laser profilometer inside the hot cell**

**Fig. 9: Ultrasonic testing set up installed in the hot cells**

**Fig. 10: Scanning stage for profilometry and gamma scanning inside the hot cells**
gamma scanning which uses Cs$^{137}$ as the monitoring isotope for gamma counting. Fig. 10 shows the fuel pin loaded on the scanning stage inside the hot cells for gamma scanning.

**Fission Gas Release measurement**

The released fission gas analysis set up is used for estimation of the quantity and composition of released fission gases inside the fuel pins. The setup essentially consists of a puncture chamber fixed inside the hot cell (Fig. 11), 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.

**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 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. Fig. 12 (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 grinder-polisher placed inside the hot cell, as shown in Fig. 12 (b).
Waste Management in NHF

The solid and liquid radioactive wastes generated from the PIE activities in the facility are collected and sent to the 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.

Summary

The new hot cell facility with the necessary equipments has been commissioned and activated for 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 as dimensional changes, fission gas release in the fuel pins, the burnup profile, fuel centre temperature etc. Evaluation of irradiated structural components and allied materials will provide the essential data for efficient life management of nuclear facilities.

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