Visual Inspection of Components in Very High Radiation Field Using Radiation Resistant CCTV Camera System

H. M. Bapat\textsuperscript{1,a}, M. Padmanabhan\textsuperscript{1,b}, Sunita Thomas\textsuperscript{1,c}, R. K. Puri\textsuperscript{1,d}, Manojit Bandyopadhyay\textsuperscript{1,e} and Manjit Singh\textsuperscript{1,f}

\textsuperscript{1}Bhabha Atomic Research Centre, DRHR Division, Mumbai-400085, India

\textsuperscript{a}hbapat@barc.gov.in, \textsuperscript{b}mpadmana@barc.gov.in, \textsuperscript{c}sunitatt@barc.gov.in, \textsuperscript{d}rkpuri@barc.gov.in, \textsuperscript{e}manojit@barc.gov.in, \textsuperscript{f}msingh@barc.gov.in

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**Abstract**

Visual examination is the first and most important stage in the examination of a component. It is one of the simplest methods used for the inspection of defects / discontinuities open to the surface. The flaws present on the surface are very detrimental, as surface is the part directly connected to environment. Hostile environment may introduce corrosion, erosion etc. Thus visual inspection plays a major role in assessing the condition of component. When it comes to visual inspection of components in very high radiation field, it becomes a big challenge as the area is mostly inaccessible due to high radiation and contamination. Remote inspection using commercially available camera is difficult because Charge Coupled Devices (CCD) have limited radiation life. Exposure to high radiation fields causes browning of optics and failure of camera electronics including the CCD sensors. Hence for visual inspection of components in high radiation environment we need specialized cameras. DRHR, BARC has developed Radiation Resistant Closed Circuit Tele Vision Camera (RR CCTV) System which can withstand cumulative radiation dose of 100MRads at the dose rate of 1MRads/hr. This camera system has been used for inspection of critical components in high radiation fields. This includes gamma source rack frame of radiation sterilization irradiator plant (ISOMED, Trombay), Calandria tubes of five different units of Indian PHWR’s during En-mass Coolant Channel Replacement (EMCCR) activity and cut pressure tube of Kakrapara Atomic Power Station, Unit-2 (KAPS-2) as a part of post irradiation examination at BARC. These visual inspections provided useful information for assessing the condition of these components. The paper briefly describes the RR CCTV camera system, major challenges involved in visual inspection and inspection results.

1. **Introduction**

Visual inspection is a non-destructive testing technique that provides a means of detecting and examining a variety of surface flaws, such as corrosion, contamination, surface finish, and surface discontinuities on joints (for example welds, seams, solder connections, and adhesive bonds). Visual inspection is also the most widely used method for detecting and examining surface cracks, which are particularly important because of their relationship to structural failure mechanisms. Many studies have revealed that small imperfection on the surface has served as nucleus for fatigue crack initiation and such cracks can lead to catastrophic failure [1]. Thus visual inspection plays a major role in assessing the condition of component.

Even when other nondestructive techniques are used to detect surface cracks, visual inspection often provides a useful supplement. For example, when the eddy current examination of process tubing is performed, visual inspection is often performed to verify and more closely examine the surface disturbance. Given the wide variety of surface flaws that may be detectable by visual examination, the use of visual inspection may encompass different techniques, depending on the product and the type of surface flaw being monitored.
Visual inspection of components in very high radiation field, is a big challenge, as the area is mostly inaccessible due to high radiation and contamination. Remote inspection using commercially available Charge Coupled Device (CCD) camera is also difficult because CCD’s have limited radiation life. Exposure to high radiation fields causes browning of optics and failure of camera electronics including the CCD sensors. Hence a specialized RRCCTV camera system has been developed. This camera system has been used for inspection of critical components in high radiation fields. The camera is capable of both axial and radial viewing with the help of easily interchangeable axial and radial attachments.

2. **RCCCTV Camera system description**

The Radiation resistant Camera system consists of a camera head, Camera control unit, Control cable, monitoring device (CCTV Monitor) and recording device (VCR/DVR). Fig. 1 shows the block diagram of system. The Camera is specially designed as a two part camera, with only minimum electronic components (Pick-up tube & pre-amplifier) working in high radiation environment. All other electronic components needed for camera operation are built in the Camera Control Unit, which is located outside radiation environment. The optical and electronic components of the Camera have been specially developed and qualified for use in radiation field of $10^6$ Rads/hr for an integrated dose of $10^8$ Rads. RRCCTV Camera system specifications are given in Table 1.

Camera head: Camera head is the part that directly handles the radiation environment and captures the image using the pick-up tube, which is amplified in the pre-amplifier and transmitted to the camera control unit for the formation of standard video signal. There are two type of attachments which can be mounted to the camera head namely axial viewing attachment and radial viewing attachment. Axial viewing attachment is used for visual inspection of components located axially like source rack frame, hot cells etc. Whereas radial viewing attachment is used for visual inspection of radially located components like pressure tube internal surface. Radial viewing attachment contains a mirror at an angle of 45 degrees which transmits the radial image to camera sensor and thus visual inspection of tubular component becomes possible.

Camera Control Unit: Camera control unit houses all the electronic cards and it act as interface between camera head, control cable, external power supply for illuminating lamps of camera, monitor and VCR/DVR.

Control Cable: The camera control unit and the camera head are connected through a 50- 100 meters long multi-core composite cable. This cable carries video signal and other electronic signals. It is a combination of different types of specialized cables such as coaxial cables, high voltage carrying cables, low voltage carrying cables and illumination current carrying cables bundled in a single spool with appropriate calculations keeping the application environment in mind and to make the inspection operation an easy task rather than carrying a number of different cable sets.

The camera control unit gives two video outputs. One for connecting it to monitor for display of images captured by camera and other output is used for recording. Any standard Video Cassette Recorder (VCR) or Digital Video Recorder (DVR) can be used for recording.
3) Visual Inspections carried out using RRCCTV Camera system

i ) In-Service Inspection of calandria tubes of Indian Pressurized heavy water reactors during En-mass coolant channel replacement (EMCCR)

Some early units of Indian Pressurized heavy water reactors (PHWR’s) were fitted with loose garter springs which tend to shift from the designed location leading to reduction in operating life of pressure tubes. These tubes were replaced during en-mass coolant channel inspection. After removal of old pressure tubes, visual inspection of calandria tubes which are concentric to pressure tubes has to be carried out to assess their healthiness. Visual inspection of Unit 1 & 2 of Narora Atomic Power Station (NAPS), Madras Atomic Power Station (MAPS) and Unit 1 of Kakrapara Atomic Power Station (KAPS) were carried out using radiation resistant CCTV Camera system during en-mass coolant channel replacement activity [2]. Camera with radial viewing attachment was deployed for visual inspection of inner surface of calandria tubes. For calibration images, wires of different thickness were placed on the surface of calandria tubes and recorded for sizing. During inspection marks of garter spring as shown in Fig 2 and few rubbing marks as shown in Fig. 3 were

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Table 1: RRCCTV Camera System Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Radiation tolerance</td>
<td>100 M Rad @ 1 M Rad per hour</td>
</tr>
<tr>
<td>Pickup element</td>
<td>2/3” non-browning vidicon tube</td>
</tr>
<tr>
<td>Resolution</td>
<td>Better than 600 lines at the centre</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>10 lux on face plate</td>
</tr>
<tr>
<td>illumination</td>
<td>3 Halogen bulb, (each 6 V, 20 W)</td>
</tr>
<tr>
<td>Controls</td>
<td>Macro focus control</td>
</tr>
<tr>
<td></td>
<td>Illumination control</td>
</tr>
<tr>
<td></td>
<td>Mirror rotation control</td>
</tr>
<tr>
<td>Environment (underwater)</td>
<td>Rated at 10 Kg/Sq cm; Working pressure 5 Kg/Sq cm</td>
</tr>
<tr>
<td>Cable</td>
<td>Radiation resistant cable length 100 metres</td>
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observed in few tubes. In the end portions of few tubes debris as shown in Fig. 4 were observed. In one calandria tube pieces of broken garter spring were observed whose image is shown in Fig. 5. Visual inspection helped in marking of scanning area for eddy current inspection of calandria tubes. Based on the feedback of visual inspection cleaning of calandria tubes is carried out before installation of fresh pressure tubes.

Fig. 2: Garter spring impression marks observed on L-01 calandria tube of MAPS-1

Fig. 3: Rubbing marks observed on calandria tubes of MAPS-1

Fig. 4: Debris near the south bell mouth region at 6 O’clock orientation

Fig. 5: Broken Garter Spring pieces
ii) Visual Inspection carried out in ISOMED Plant

ISOMED is a gamma radiation sterilization plant. It is mostly used for sterilization of medical products using gamma radiation. The plant is incorporated with product conveyor system that carries the product to be treated and the source rack which carries the source pins. Five passes of product at predefined speed through radiation area ensures a total dose of 25kilo gray. Since the plant is very old there was regulatory requirement for visual inspection of radiation source rack frame. The major challenge in this visual inspection was that camera has to directly face the radiation source. The dose rate at the time of inspection was around 1MRads/hr. After the required setup visual inspection of source rack frame was carried out by moving the source rack frame up and down. Camera control cable is routed up to control room located outside the radiation area through the carriage labyrinth. Fig. 6 shows the camera control setup in control room. During inspection it was observed that there were slight rubbing marks in middle portion of lower rows of tubes of source rack frame. There was thinning of wall in this region. The images captured during this inspection are shown in Fig. 7 & 8. Another major observation during inspection was that lower part of shielding plug also got some damage and there was thinning in this region. Total time for which the camera has seen full dose was 1hr and 36 minutes.

Fig. 6: Setup of RR CCTV Camera system for inspection of Source rack frame at ISOMED, Mumbai

Fig. 7: Rubbing marks on lower tubes of source rack frame of ISOMED plant

Fig. 8: Rubbing marks on middle portion of tubes of Source rack frame
iii) Visual Inspection of S-07 Pressure tube of KAPS-2 at PIED, BARC

KAPS-2 is a 220 MWe PHWR that uses Zr-2.5% Nb alloy pressure tubes. One coolant channel (S-07) of this reactor was cut and brought to BARC for analyzing and characterizing the service induced defects. Sliver sampling was carried out on this channel during in-service inspection of this channel. During sliver sampling a small portion of pressure tube was scrapped using scrapping tool. This scrapping process leaves mark on the surface of pressure tube. It was decided to carry out visual inspection of this channel to locate these scrapping marks and also to find out any changes which occurred in pressure tube during its service life. So visual examination of inner surface was performed using the radiation resistant camera as a part of post irradiation examination at BARC [3]. The camera was inserted in the pressure tube using a 7 m long scaled pusher rod holding the cable. All the features were video recorded and distance of each feature was measured on the scaled pusher rod. During inspection scrapping marks on inner surface were clearly visible. The images of scrap marks observed during inspection are shown in Fig. 9 and Fig. 10. Fig. 11 and Fig. 12 shows multiple scratch marks of different length, observed throughout the length of pressure tube.

![Fig. 9: Scrapping mark observed on pressure tube ID](image1)

![Fig. 10: Scrapping mark observed on pressure tube ID](image2)

![Fig. 11: Scratch marks observed on pressure tube ID](image3)

![Fig. 12: Scratch marks observed on pressure tube ID](image4)
4) Conclusion

The radiation resistant CCTV camera system developed by DRHR, BARC has been used for visual inspection of components located in very high radiation area. These visual inspections were impossible before development of this camera. These inspections provided useful information to users and helped them in assessing the condition of components. Development is going on to deploy this camera system for visual inspection of nuclear components placed underwater.

5) Acknowledgement

The authors are thankful to personals of ISOMED plant, Post Irradiation Examination Division (PIED) of BARC and KAPS, NAPS and MAPS NPCIL plant sites for their cooperation and support in carrying out visual inspection in these sites using RRCCTV camera system.

6) References

[1] IAEA –TECDOC-1037 Assessment and management of major nuclear power plant components important to safety : CANDU pressure tubes.

