Remote Handling & Robotics

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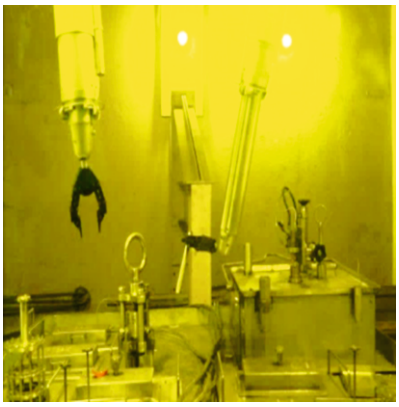
Advances in Remote Handling & Robotics in Backend of Nuclear Fuel Cycle

R. Tripathi[1], Jyoti Diwan[1], S. Panda[2], S. Wadhwa*[1], M. Padmanabhan[3] and S. Manohar[4]

[1]*Waste Management Division, Bhabha Atomic Research Centre, Mumbai 400085, INDIA*
[2]*Division of Remote Handling and Robotics, Bhabha Atomic Research Centre, Mumbai 400085, INDIA*
[3]*Security Electronics and Software Systems Division, Bhabha Atomic Research Centre, Mumbai 400085, INDIA*
[4]*Nuclear Recycle Group, Bhabha Atomic Research Centre, Mumbai 400085, INDIA*



Mechanical manipulator arm inside the cell

ABSTRACT

Nuclear energy plays a crucial role in expansion of the horizons of green technology. It provides access to clean, reliable and affordable energy, mitigating the negative impacts of climate change. A three-stage nuclear power programme, based on a closed nuclear fuel cycle due to modest uranium reserves, was then stated out by the founder father of the department of atomic energy and the program comprises of the design & commissioning of Natural uranium fuelled Pressurized Heavy Water Reactors (PHWRs), Fast Breeder Reactors (FBRs) utilizing plutonium based fuel and Advanced nuclear power systems for utilization of thorium. To sustain this Closed Fuel Cycle, reprocessing of spent fuel to extract useful Pu & U for its further utilization in second stage, and management of High-Level Waste (HLW) for waste minimization have been adopted. Radiochemical Processing of spent fuels necessitates handling of high radioactive material behind heavy shielding, where it also requires highly reliable and safe remote handling gadgets. A variety of remote handling gadgets have been deployed by BARC in Indian Back-end facilities as per different process treatment requirements. This article discusses existing remote handling systems and recent advances made in remote handling and robotics of Backend of Nuclear Fuel Cycle deployed for better reliability, productivity and safety.

KEYWORDS: *Robotics, Remote viewing, Advanced servo manipulator, Wireless camera, Gantry mounted Power manipulator*

Introduction

The used spent fuel undergoes a series of steps including temporary storage, reprocessing & recycle, waste management known as Back-end of Nuclear Fuel Cycle. In reprocessing, Uranium & Plutonium, constituting bulk of spent nuclear fuel are separated and subsequently recycled. Remaining portion constitutes High Level Radioactive Liquid Waste (HLRLW) containing most of the fission products & minor actinides etc. Radiochemical plants in back end of fuel cycle depends heavily on remote technology for operation and maintenance. These functions have been achieved by way of operating general type remote handling gadgets and special customized equipment. Design of various manipulators, special equipment for handling & viewing devices, specially designed cranes etc. developed indigenously adapting modern technologies are the key for increasing reliability & availability of these plants.

Remote handling of Back end fuel cycle

Major operations in Radiochemical Plants are carried out in heavily shielded thick structures known as hot cells, to reduce radiation exposure. 'Hot cell' term refers to cells or areas where radioactivity is very high with highly acidic or corrosive, hot and humid environment, and also with no manual access inside for Operation and Maintenance (O&M). Remote Technology for O&M of such plants is under development with several objectives where the technology ensures increased operation, safety against hazards of radiation exposure to operating personnel, availability of Radiochemical plants at Back-end for continued production, overall reduction in secondary waste generation and effect on operating cost/life of the plant. List of major operation activities of Nuclear back end cycle have been shown in the Fig.1.

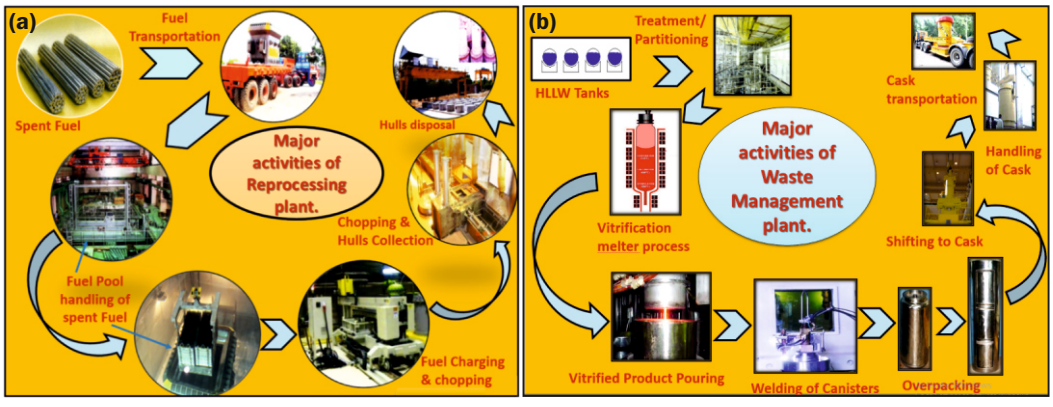


Fig.1: List of activities involved: (a) Reprocessing cycle (b) Waste management cycle.

*Author for Correspondence: S. Wadhwa
E-mail: swadhwa@barc.gov.in

Table 1: Major Terminology of Robotics.

Payload-	Maximum load, equipment can handle at end of arm in any configuration.
Degree of freedom(DOF)-	No. of independent parameters required to define configuration of a mechanism.
Kinematics-	Study of motion without regard to forces.
Dynamics	Study of motion with regard to forces
Actuator-	Provides force for motor/ joints motion.

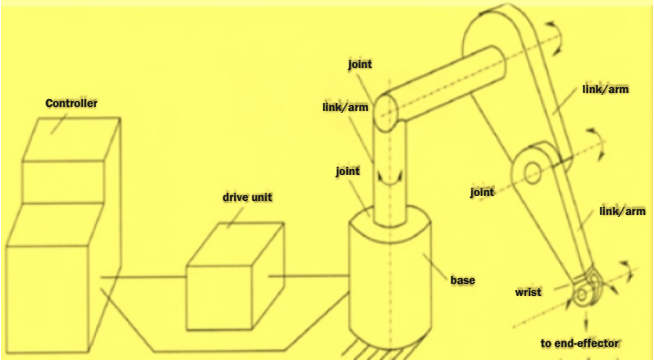


Fig.2: Robotics mechanism showing controller to end effector.

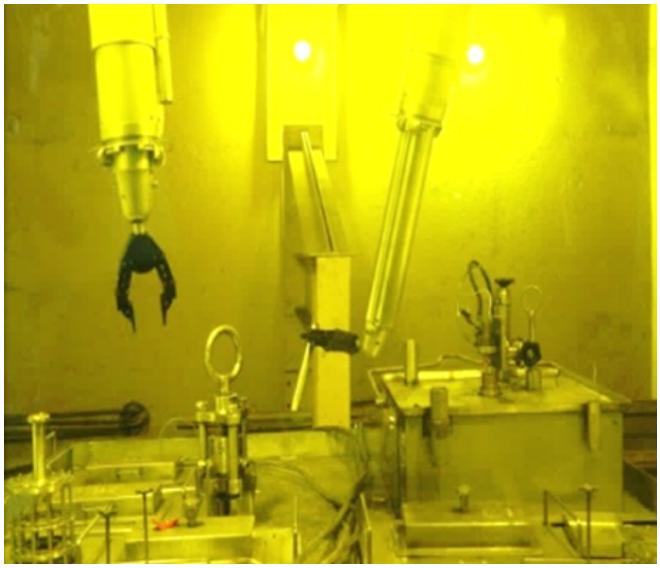


Fig.3: Mechanical manipulator arm inside the cell.

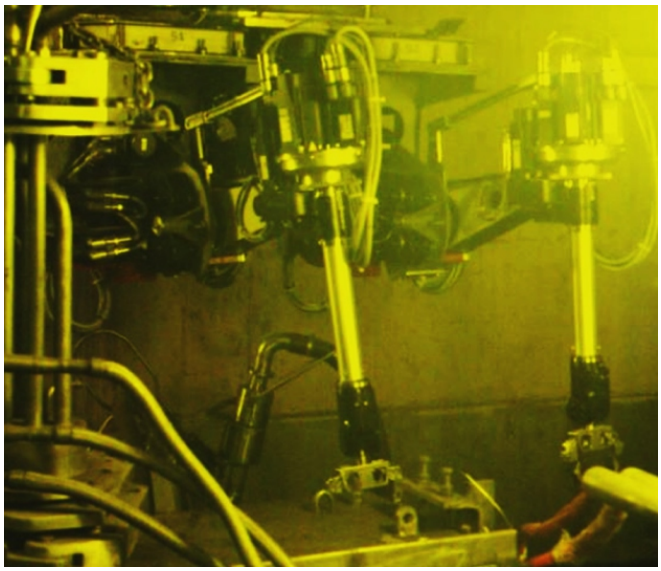


Fig.4: ASM arm inside the cell.

Present Robotics & Remote handling equipment

Mechanical and electrical Master Slave Manipulators (MSM), special cranes & trolleys & transfer systems, remote viewing systems, specially designed grapplers etc., are the major remote handling tools and systems utilized in the present facilities. Methodology behind design of any remote handling equipment or robotics is to replicate operator as detailed in next section.

Linkage between Robotics and Human

Robotics refer to the field of machines that can be substituted for human and replicate human actions. Hence, to replicate a human being, 3Hs of Human being have been translated into Robotics. Hand which refers to arm, Head which controls & guide all motion refers to brain of a Robot (Controller) and Heart which pumps blood, refers to drives for power transmission which can be mechanical, electrical or pneumatic etc. Robotic sensors same as Human ear, eyes, nose etc. are used to estimate the robot's condition and environment. Sensors in the manipulators collect information from the environment, and send this information to the controller. The drives work, based on this feedback. Manipulator refers to a robot with fixed base and are composed of an assembly of links & joints. Links are rigid members between joints and these joints provide mobility or degrees of freedom in the system as shown in Fig.2. Two major types of manipulators are being used in Back end cycle: - Mechanical such as three piece manipulator (as shown in Fig.3), articulated manipulators etc. and Electrical manipulators such as servo manipulators, power manipulator etc. In mechanical manipulator, motion generated by operator's hand is mechanically transmitted to end effector of slave, through linkages of master arm, through tubes & slave arm and whereas electrical actuators such as different motors are being used for transmission of motion in electrical manipulators.

Recent Advances in Remote Handling Systems

Several developments have been carried out recently with advanced mechatronics, by utilizing multiple operation feedbacks and as they are discussed in next sections.

Advanced Servo Manipulator

Advanced Servo Manipulator (ASM) as shown in Fig.4 is an Electro-mechanical bridge mounted type of manipulator. It is a dual arm & kinematically similar arm, bilateral, force reflecting system using digital control system and servo feedback system as shown in Fig.5.

There is no direct mechanical links connecting the master arm and the slave arm. Slave arm has been installed inside the Hot Cell & the master arm in the workstation. Slave arm is basically used in precision remote handling, such as handling of thermocouples, airline connectors or alignment of impact wrench inside the hot cell.

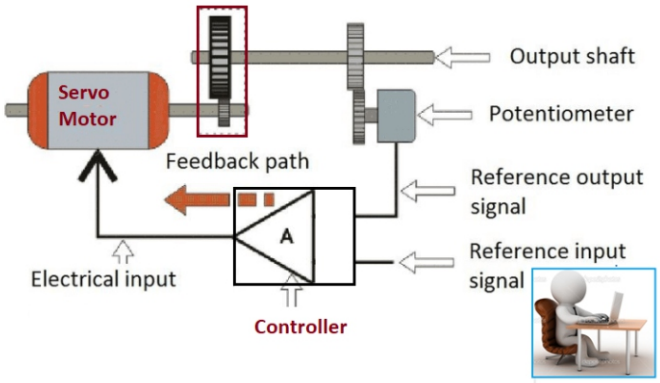


Fig.5: Servo motor working principle.

Table 2: GMPM Technical specification.

Travel length	2350mm to 5100mm
Gripper payload	30Kg
Gripper opening	80mm
First roll/swivel	+/- 180^{o}
First pitch	0 to -120^{o}
Second pitch	+/- 90^{o}
Wrist pitch	+/- 90^{o}
Wrist roll	+/- 180^{o}

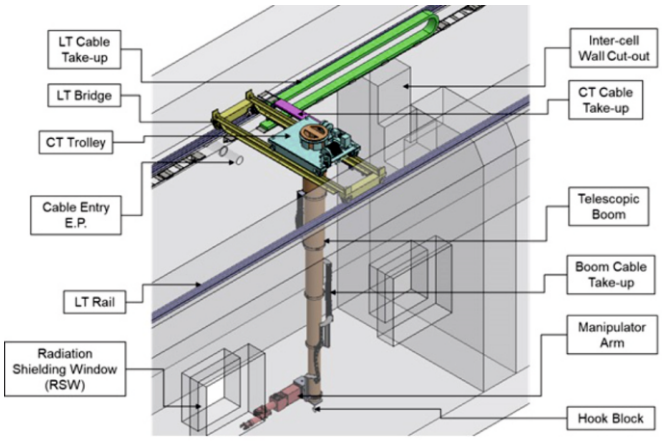


Fig.6: General Layout of the GMPM in Hot-Cell.

Fig.7: Remote handling Workstation.

Slave arm assembly is mounted on transporter inside the hot cell, providing large effective area of hot cell. All ASM operation are CCTV assisted and operated through master control station from outside hot cell (i.e. work station). Payload of the installed ASM is 25kg and it has an adjustable type gripping force control with feedback provision. All joints are operated using Servo motors.

Gantry Mounted Power Manipulator for Hot-cell

Gantry mounted power manipulator (GMPM) is an electrically actuated system utilized for remote handling operations of materials and maintenance activities inside hot-cell. GMPM consists of a gantry with long travel (LT), cross travel (CT), a telescopic boom, a hook for lifting loads and 6-axis articulated manipulator arm fitted to the boom assembly for object handling. Major technical specifications of GMPM are listed in Table 2. GMPM will be operated through pendant from multiple locations outside the cell/bay, by viewing it through the radiation shielded glass windows and remote viewing system. GMPM can also be controlled from a control station through a Human Machine Interface (HMI) interface. Fig.6 shows a general arrangement of the GMPM in the hot-cell.

Limiting design parameters of telescopic boom and articulated arm of GMPM are: Collapsed length which is restricted by inter-cell wall opening of the hot cells and the extended length to reach the cell floor during operation. Designing the gantry for GMPM was also constrained by the in-cell crane installed on the same LT rails in the work space. It is designed for remote maintenance, replacement of components/sub-assemblies. Five telescope tubes have been utilized for telescopic movement. Manual override is also being provided for gantry operation during emergency. The control system is designed for long lead operation with cable length of 100 m.

Remote viewing system

Remote viewing system in conjunction with radiation shielding windows are the key for efficient and safe remote handling inside hot cell. Reliable remote viewing system allows to optimum utilization of hot cells for design of equipment layout. In general, CCTV based remote viewing system as shown in Fig.7, has been used due to its cheaper cost and availability. CCTV based system consists of camera (lens & sensor) with cabling, Digital Video Recorder (DVR)/Network Video Recorder (NVR) & Video Monitor etc. Three types of CCTV camera system - Analog, Digital & IP network are in use. Image sensors used in these are either Charge Coupled Device (CCD) or Complementary Metal Oxide Semi-Conductor (CMOS).

These types of cameras in hot cell have limited life if used in direct exposure to radiation, resulting in frequent failure and downtime. In order to enhance the life of cameras, different customized mechanisms have been designed and developed for handling of cameras, to bring it into shielded environment in the hot cell during inoperative condition. These are Retractable Type (motorized and pneumatic), telescope type & wireless Cameras.

Retractable camera system

Special customized retractable camera systems have been designed, developed and tested for mounting on

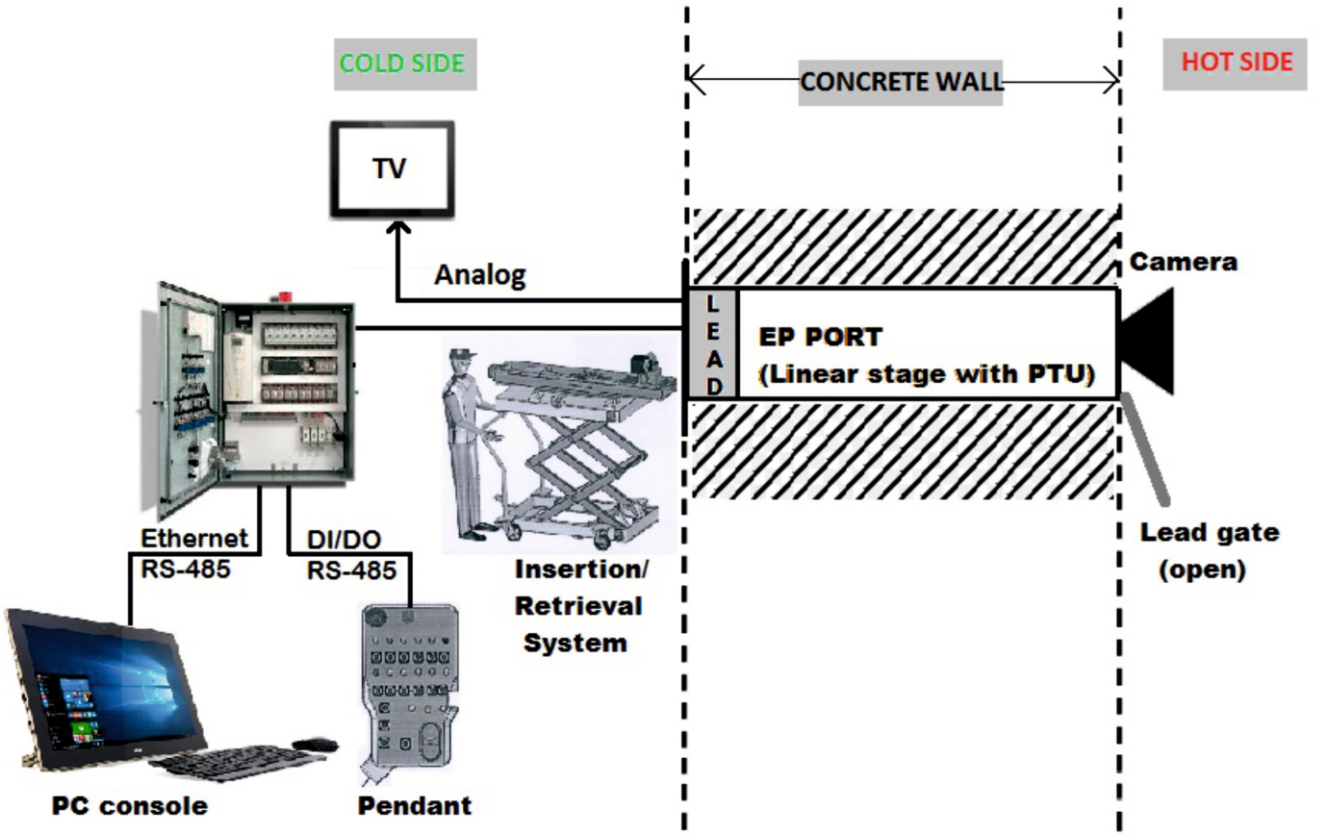


Fig.8: System Architecture.

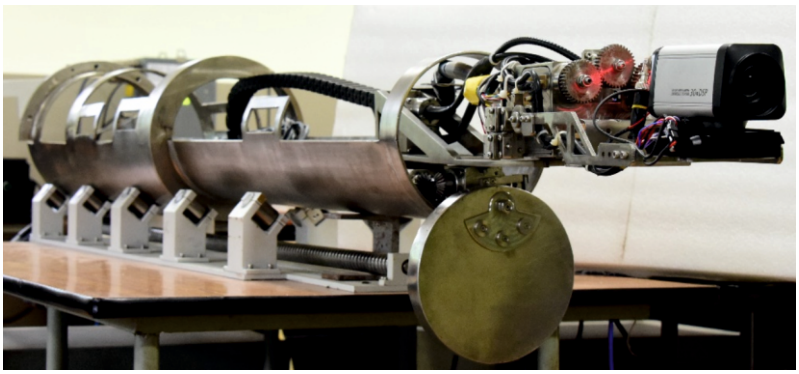


Fig.9: Motorized CCTV camera system.

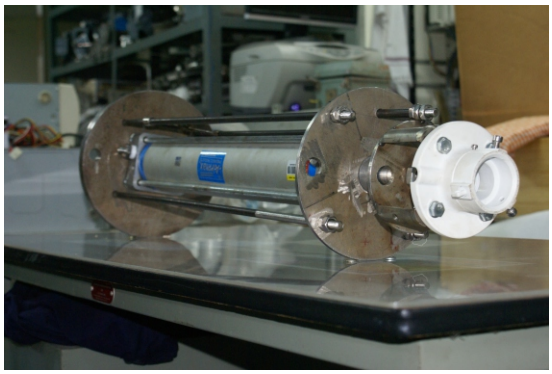


Fig.10: EP Camera pneumatic actuator mechanism.

Embedded Plugs (EPs) of hot cells. The system comprises of 1.5-meter SS tube housing which dwells inside the wall port and has a provision of rotating the shielding inside the hot cell to prevent radiation streaming on camera sensors.

The overall architecture of the system's final design is shown in Fig.8. The system comprises of tube housing having a motorized linear trolley as shown in Fig.9, to facilitate extension and retraction of camera mounted on a pan-tilt pedestal for viewing of the hot cell view. This system can be operated directly using a control pendant or PLC based system which incorporates safety interlocks using hardwired relay circuitry. The system has a provision for manual retrieving from hot cell in case of any motorized movement of components which fails inside hot cell. Similar type of remotely operated pneumatic mechanism has been developed using standard IP based camera system for hot cells. The system comprises of a pneumatic actuator which provides forward and retrieval motion inside the 1.5-meter-long EP of the Hot Cell wall as shown in Fig.10.

This system has no other moving parts and hence it does not need high maintenance. Shielding blocks have also been designed to avoid any radiation streaming towards cold side (operating gallery). It has been commissioned inside the hot cell and has provided maintenance free operation for long time.

Remotely replaceable IP based Wireless Camera System

A remotely replaceable IP based wireless camera system is one of the recent developments for the existing in-cell crane mounted camera inside the hot cells of Waste Management Plant of BARC. The development has resulted in the negligible man-rem exposure, as well as reduced system downtime due to its remote replaceability and auto latching connector design features.

Conclusions and Future Challenges

Remote handling mechanisms play a vital role in the Back-end of Fuel Cycle. Several campaigns have been

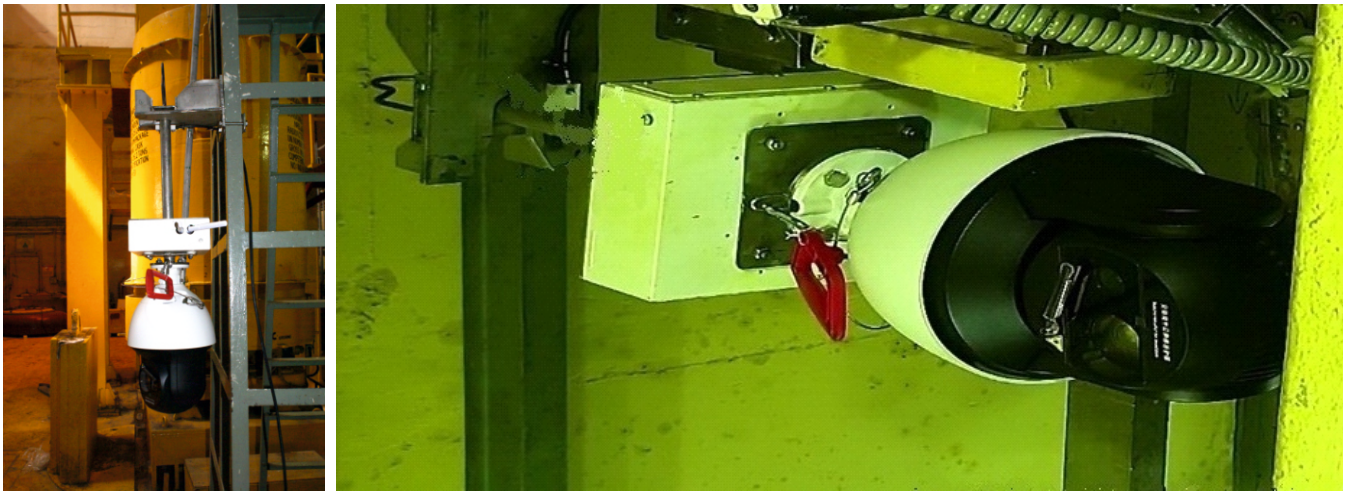


Fig.11: Wireless camera assembly during testing and inside view during commissioning.

performed by utilizing indigenously developed remote handling equipment. This matured indigenous remote handling equipments have reduced man-rem exposure, decreased down time by reducing the maintenance frequencies, and also reducing disposal quantities of malfunctioned gadgets/ equipment, thus decreasing radioactive waste.

To summarize, major future challenges are ahead in the designing of robotics for cell manipulation, decommissioning, dismantling of facilities, indigenous & reliable remote handling equipment with advanced automation for reducing downtime with increasing availability & operability at rated capacity. In this era of modern technologies, virtual reality modelling for better understanding during hot cell planning and designing of plant for higher level of remote operability & maintainability etc. will be adopted.

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