REMOTE TECHNOLOGIES FOR HANDLING SPENT FUEL

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Abstract

The nuclear programme in India involves building and operating power and research reactors, production and use of isotopes, fabrication of reactor fuel, reprocessing of irradiated fuel, recovery of plutonium and uranium-233, fabrication of fuel containing plutonium-239, uranium-233, post-irradiation examination of fuel and hardware and handling solid and liquid radioactive wastes. Fuel that could be termed "spent" in thermal reactors is a source for second generation fuel (plutonium & uranium-233). Therefore, it is only logical to extend remote techniques beyond handling fuel from thermal reactors to fuel from fast reactors, post-irradiation examination etc. Fabrication of fuel containing plutonium and uranium-233 poses challenges in view of restriction on human exposure to radiation. Hence, automation will serve as a step towards remotisation. Automated systems, both rigid and flexible (using robots) need to be developed and implemented. Accounting of fissile material handled by robots in local area networks with appropriate access codes will be possible. While dealing with all these activities, it is essential to pay attention to maintenance and repair of the facilities. Remote techniques are essential here. There are a number of commonalities in these requirements and so development of modularized subsystems, and integration of different configurations should receive attention. On a long-term basis, activities like decontamination, decommissioning of facilities and handling of waste generated have to be addressed. While robotized remote systems have to be designed for existing facilities, future designs of facilities should take into account total operation with robotic remote systems.

1. INTRODUCTION

India's nuclear programme encompasses use of uranium (natural and enriched), reprocessing spent fuel and extraction of plutonium, fabricating fuel containing plutonium and uranium (mixed oxide or MOX and mixed carbide). The MOX fuel will be used in thermal reactors (pressurized heavy water reactors, PHWRs, and boiling water reactors, BWRs) and the mixed carbide fuel in the Fast Breeder Test Reactor (FBTR). Further, the programme includes irradiation of thorium, recovery of uranium-233 by reprocessing, fabrication of fuel with uranium-233 and use of uranium-233 fuel. Figure 1 gives an overview of the various fuel types developed and fabricated. Hence, the handling of spent fuel involves various activities including the fabrication of fuel containing plutonium-239 and uranium-233.

Handling spent fuel from research and power reactors is a continuous activity. The thermal research reactors (CIRUS and DHRUVA) use natural metallic uranium. Power reactors use oxides of enriched and natural uranium. Reprocessing of irradiated fuel is carried out in reprocessing plants, fabrication of plutonium bearing fuels is done in dedicated facilities. An important activity needing handling of irradiated fuel is post-irradiation examination of various types of fuel.

Effective closure of the "back-end" of the fuel cycle while highlighting reprocessing, will have to include handling waste generated. While dealing with waste (solid and liquid), a matter that could be kept in mind would be activities like decontamination and decommissioning of facilities.

In the above mentioned activities, it may be noted that there could be commonalities in technologies, and development of remote techniques will have impact on several areas of applications.

The two Research Reactors in Bhabha Atomic Research Centre (BARC), Trombay, Mumbai use metallic uranium as fuel. Fuel discharged from reactors is handled under water and underwater cutting of aluminum and components is carried out using special equipment designed for the purpose.

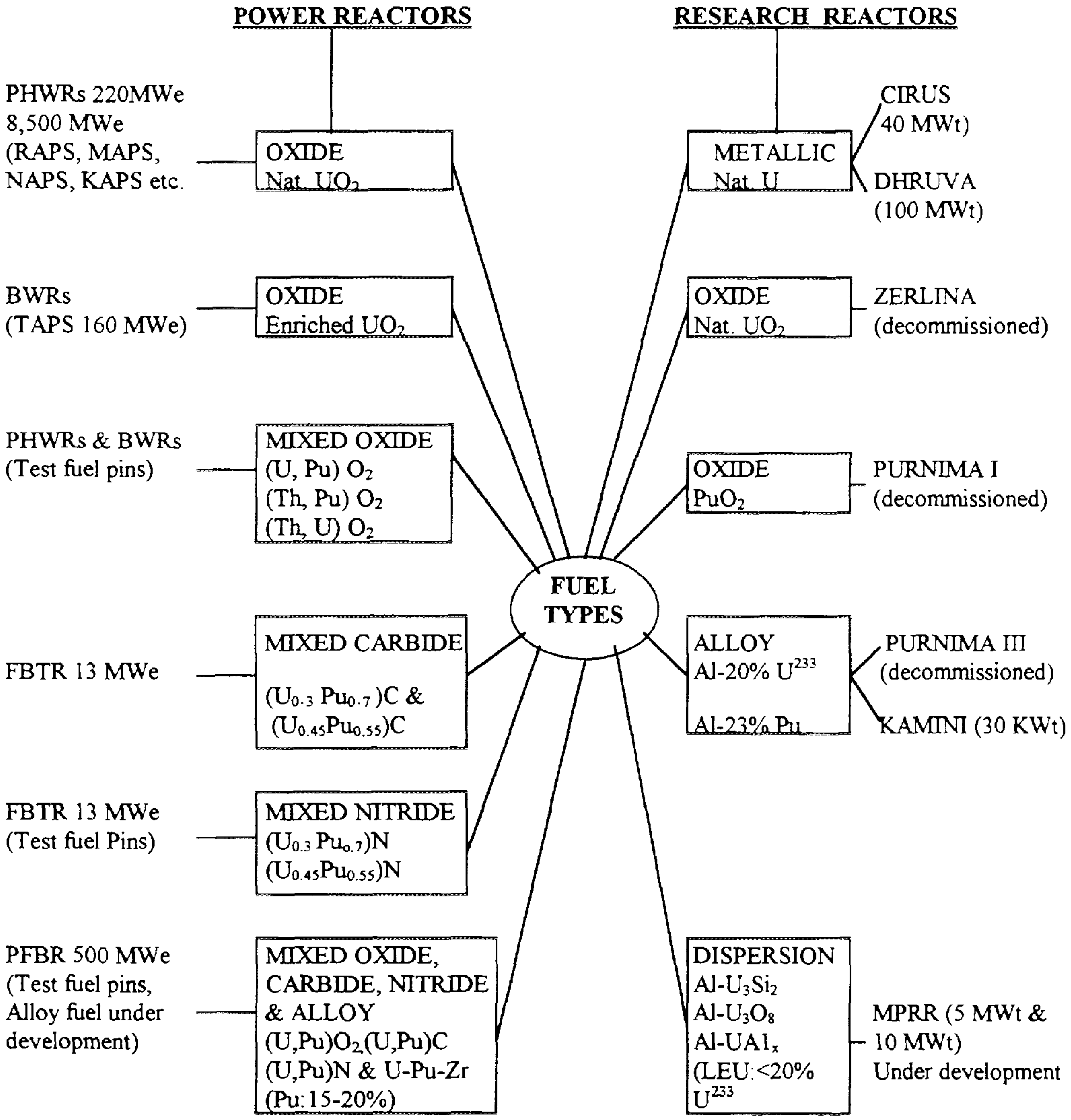

FIG. 1. Nuclear fuels developed and fabricated indigenously in India

The fuel assembly of the research reactor "Dhruva" is 9,256 mm long and weighs around 100 kg. The irradiated fuel assembly is brought vertically from the reactor building to the Spent Fuel Storage Bay and it is bisected into two pieces to get the fuel part separated from the main assembly. The fuel part is canned and loaded into the shipping cask which carries the fuel for reprocessing. A number of operations such as cutting, canning and loading into the shipping cask are carried out remotely in the bays under water 10 meters deep, with the help of a spent fuel handling and cutting system designed and built for this purpose (see Figures 2 and 3). A brief description of the operations and the machines used is given below.

■ DESCRIPTION OF OPERATION	■EQUIPMENT USED
➤ LIFT THE FUEL BUNDLE ASSEMBLY (F.B.A.) FROM THE BUGGY AND PLACE IT IN THE HINGED BRACKET & SWING THE SAME TO BE POSITIONED IN THE CUTTING MACHINE.	➤ SELF CLOSING GRAPPLER WITH EOT CRANE.
➤ CLAMP THE F.B.A. ON V-CLAMPS BY OPERATING HAND WHEELS.	➤ HAND WHEEL OF THE CUTTING MACHINE.
➤ CUT THE F.B.A. IN TWO PIECES.	➤ SLITTING CUTTER MOUNTED ON SUBMERSIBLE MOTOR OF THE CUTTING MACHINE.
➤ REMOVE SEAL/SHIELD PLUGS AND PLACE IT IN THE RACKS.	➤ GRAPPLER AND EOT CRANE
➤ RETRACT THE CUTTER & GRIP THE FUEL BUNDLE IN MANIPULATOR JAWS.RELEASE UPPER AND LOWER CLAMPS OF THE CUTTING MACHINE.	➤ CUTTING MACHINE AND UNDER WATER MANIPULATOR.
➤ PLACE THE CAN (WITH PLUG) IN THE CANNING UNIT AND LOCK IT IN VERTICAL POSITION.	➤ CANNING UNIT AND UNDERWATER MANIPULATOR.
➤ SLIDE THE FUEL BUNDLE IN THE CAN AND PLUG IT FROM THE TOP.	➤ UNDER WATER MANIPULATOR.
➤ REMOVE THE CANNED FUEL BUNDLE & PLACE IN TILTER.	➤ UNDER WATER MANIPULATOR.
➤ REMOVE THE LOCK & ALLOW THE FUEL BUNDLE TO COME TO DESIRED POSITION.	➤ TILTER.
➤ TAKE OUT THE CANNED FUEL BUNDLE & KEEP IT IN THE RACK.	➤ DOUBLE JAW GRAPPLER.

FIG. 2. Spent fuel handling and cutting system installed in the water filled bays of the reactor DHRUVA

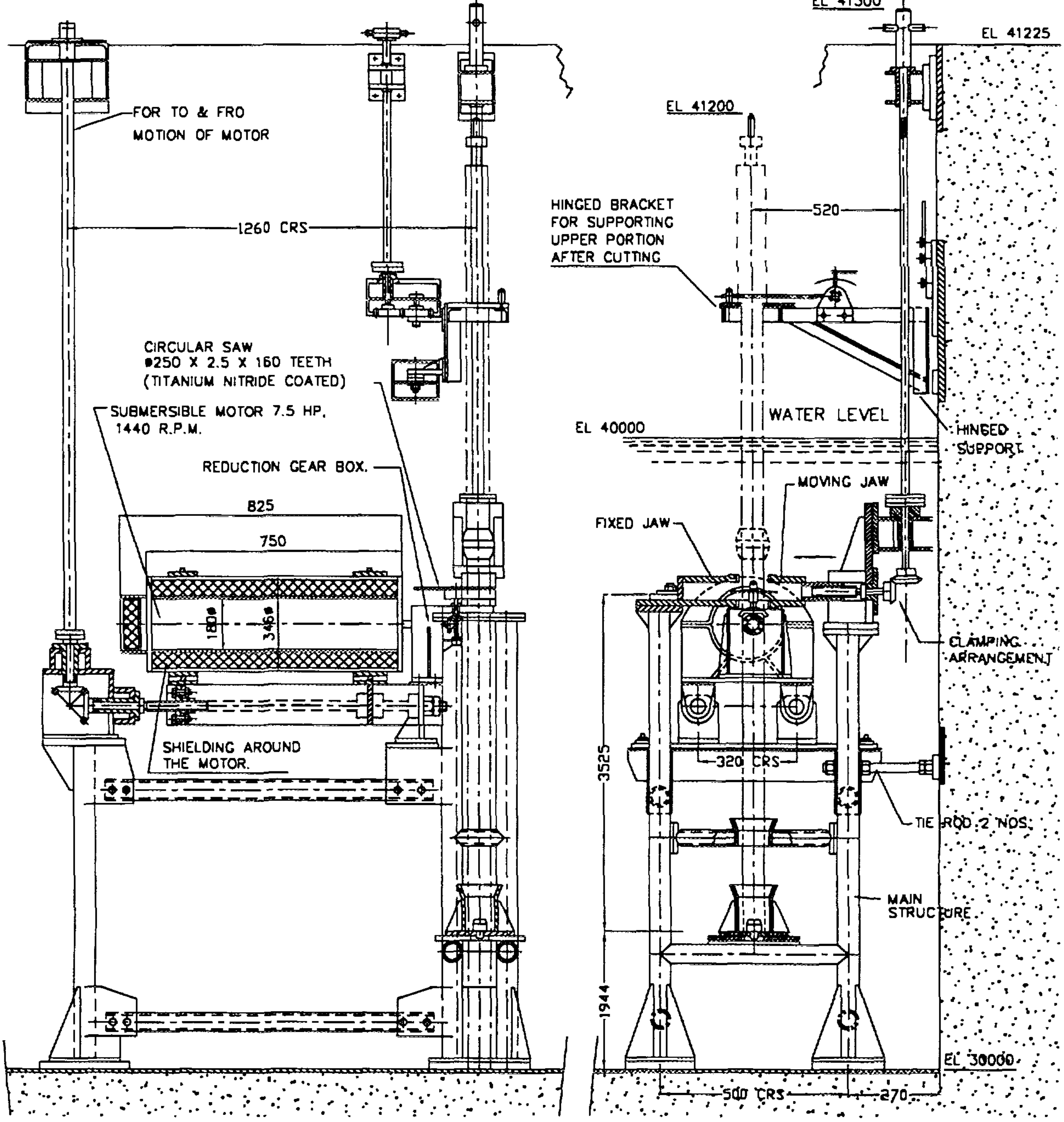

FIG. 3. General assembly of underwater cutting facility installed at DHRUVA, BARC

Operation of removal of fuel bundle from fuel buggy and placing it in the cutting machine is done, using a manually operated grappler and an Electrical Overhead Gantry crane. Bisection of fuel assembly is done with the help of a cutting machine. The machine consists of a main frame to support the fuel assembly vertically, a pair of V-clamps, a swinging bracket and a titanium carbide coated high speed steel circular saw, mounted on a shielded/canned submersible motor. Screw drives are provided for actuating the clamps and for feeding the saw forward. The drives are operated manually from the top of the pool through long shafts.

The upper part of the bisected fuel assembly containing the seal and shield plug is kept aside by swinging the bracket supporting the cut part. The lower part containing the irradiated fuel is held and transported to the canning station with the help of an under water manipulator. The canned fuel assembly is made horizontal or set into any angle with the help of a tilting machine and is loaded into the cask with the help of a grappler having two pairs of jaws.

Reprocessing is carried out in shielded facilities with Master Slave Mechanical Manipulators. Plans are being now made to use advanced remote systems that have been developed in the Division of Remote Handling and Robotics, BARC. Mention should be made of the telemanipulators developed and manufactured totally indigenously. These servo-telemanipulators use A/C induction motor servo systems developed in BARC (Figure 4). Accessibility of the parts of the plant will be greatly improved by using these systems. Other special systems developed for remote operation in reprocessing facilities are remote pipe cutters and welding systems. Currently, experiments are being planned to use servo telemanipulators not only for handling irradiated fuel and other components but also for carrying out repair and maintenance in facilities. Operations like cutting and welding will be carried out on a robotic mode by using telemanipulators as computer aided telemanipulation systems. Use of these manipulators is being expanded by mounting them as remote controlled mobile platforms for decontamination, decommissioning of facilities. Experiments using sensory interfaces between the task environments and the manipulators are being done to improve transparency of operation and telepresence with improved sensitivity. Water jet techniques for extensive repair, decontamination and decommissioning are being actively pursued with help from Indian Institute of Technology, Madras.

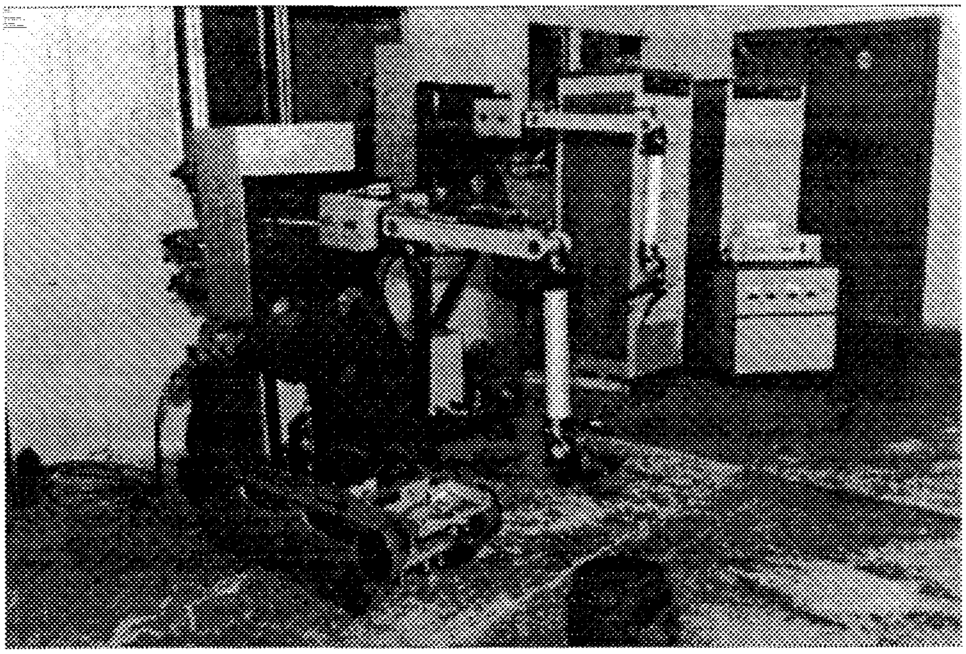

FIG. 4. Servo manipulator mounted on a tracked mobile platform

Trials have been performed on unirradiated Zirconium clad PHWR fuel bundles (containing natural uranium oxide fuel) with objectives of dismantling and decladding, by using Nd-YAG (yttrium aluminum garnet) laser systems. The results of the trials are encouraging. This approach will greatly help to reduce the presence of zircaloy in irradiated fuel being reprocessed. Plans are being made to implement this technology in operating reprocessing plants. This technique will be friendly for efficient remote operation. Manipulation of the laser beam can be done by a robot or a numerically controlled table. Alternatively, the fuel bundle or element can be manipulated by these devices against a steady laser beam (see Table I and Figures 5 to 7).

TABLE I. PIE FACILITIES FOR IRRADIATED FUEL IN INDIA

	Hot cells BARC	Hot cells IGCAR
Type of cells	βγ	αβγ
Atmosphere	air	nitrogen
Ventilation	once through	recirculation
Type of fuel	thermal reactor fuel	fast reactor fuel
	Al clad metallic U	
	Zr-2 clad UO_2	SS clad mixed carbide
	Zr clad MOX $(U+4\%Pu)O_2$	$(U+55\%\ Pu)C$
Burnup range	20-25,000MWd/t	2,000-25,000 MWd/t
Remote handling	master slave manipulators (MSMs)	MSMs power manipulator
Dismantling	bundle dismantling machine	CNC cutting machine
Pin section	low speed cut off machine	low speed cut off machine
Viewing	shielded glass windows	shielded glass windows
	oil filled	all solid
	scanning wall periscope	scanning wall periscope
Testing equipment in hot cells	profilometry eddy current ultrasonic gamma scanning neutron radiography (APSARA) αβγ autoradiography remote microscopy clad ring tensile test	eddy current ultrasonic x-ray radiography neutron radiography neutron tomography replication facility remote microscopy

BARC - Bhabha Atomic Research Centre
IGCAR - Indira Gandhi Centre for Atomic Research

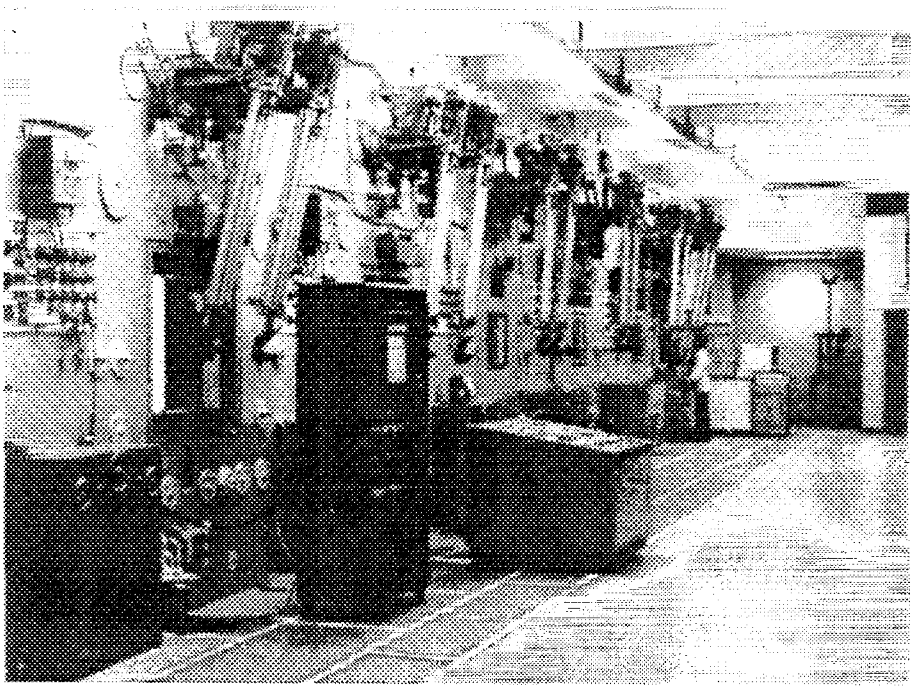

FIG. 5. Hot cell facilities for post irradiation examination in BARC

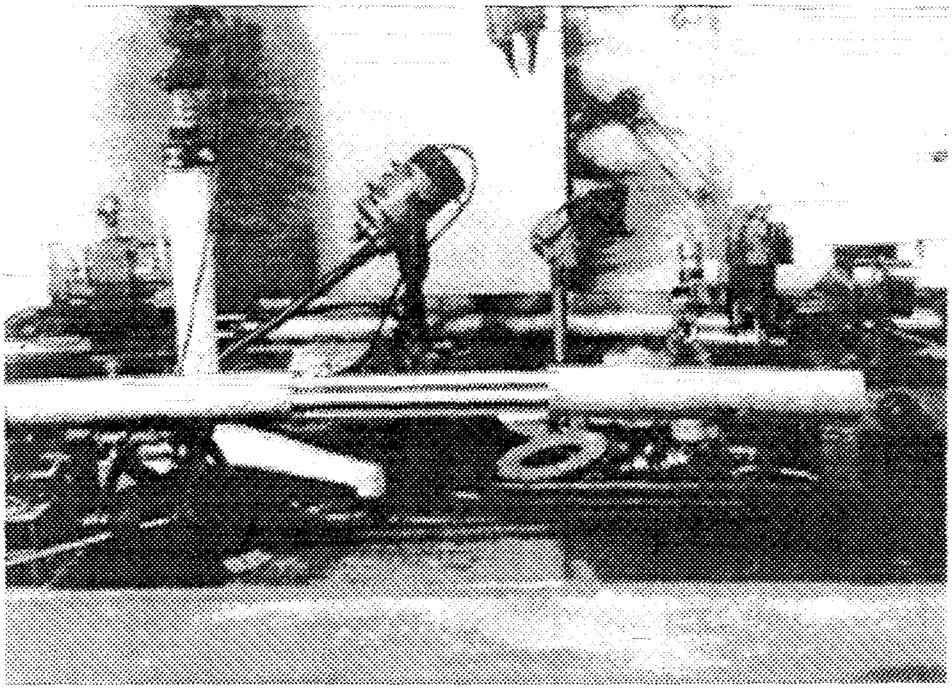

FIG. 6. Post irradiation examination equipment in BARC hot cells

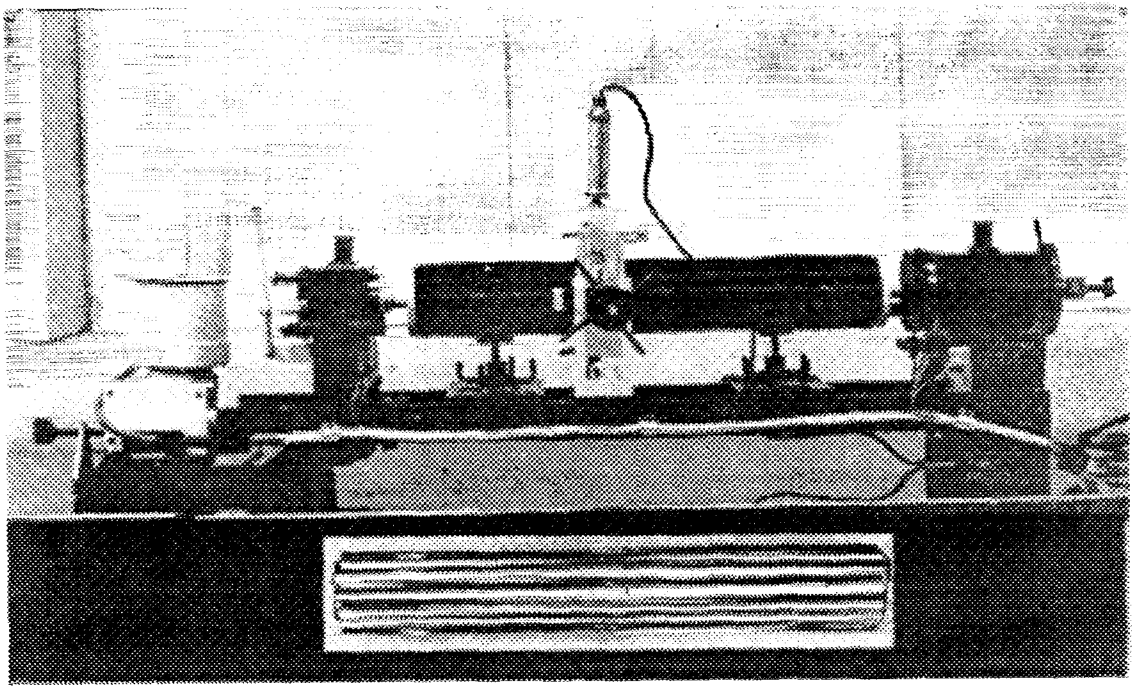

FIG. 7. Post irradiation examination equipment in BARC hot cells

The Fast Breeder Test Reactor (FBTR) at Indira Gandhi Centre for Atomic Research at Kalpakkam, Madras is a reactor fueled by mixed carbides of plutonium and uranium (70% plutonium-carbide and 30% uranium-carbide) with sodium primary cooling. The cladding is stainless steel and fuel elements are in bundles. Each bundle contains 61 pins and is encased in a hexagonal sheath (see Figure 8). Irradiated fuel bundles of FBTR are brought to a hot cell for dismantling, post-irradiation examination and reprocessing (Table I). Machining operations are required during dismantling and are carried out with the help of a special purpose machine built and installed in the hot cell. Handling of fuel assembly or its components and operating the special purpose machine are done remotely with the help of various types of remote handling equipment installed in the cell. These are a pair of master slave manipulators (MSMs), a power manipulator and an incell crane. Viewing is done through the lead glass shielding window. The special purpose machine has been designed to perform linear motions in X,Y,Z direction and a rotation motion of the spindle. These motions are essential for positioning and feeding the cutting tool. Provision is made to hold the fuel assembly in chucks and rotate it around a vertical axis.

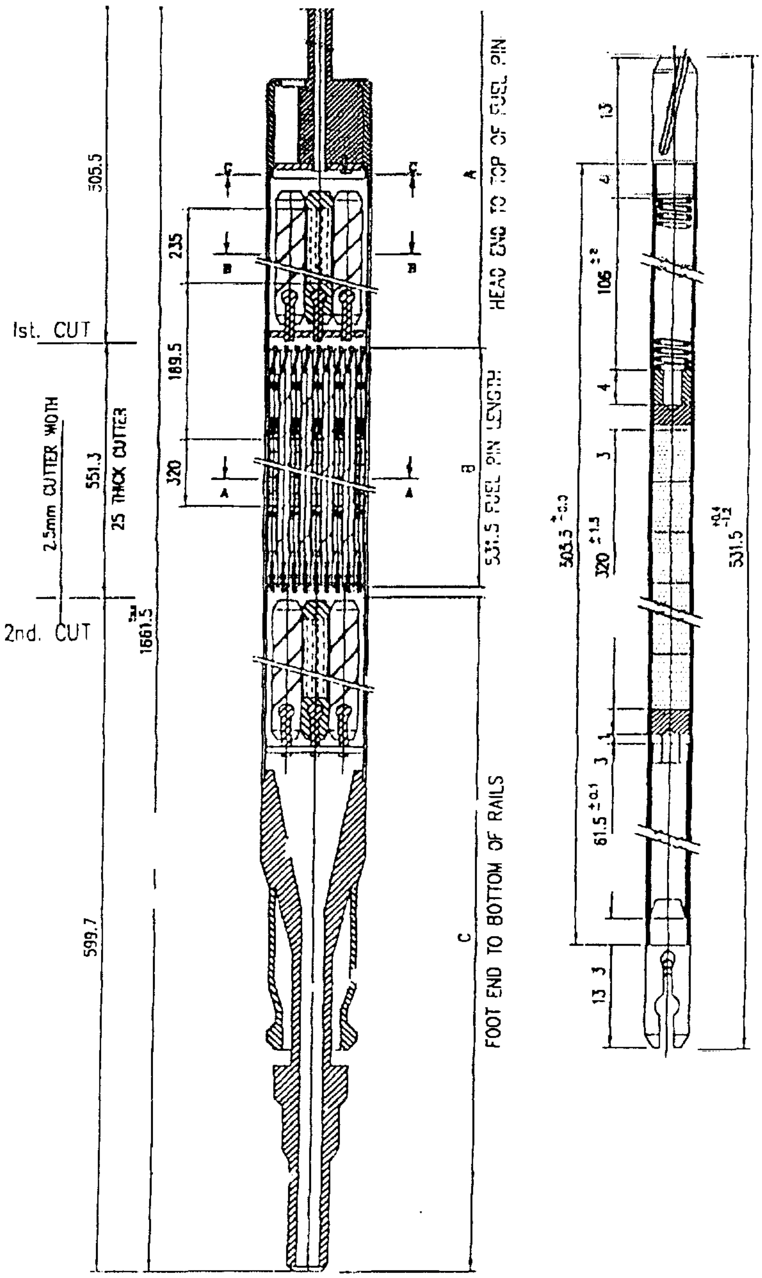

FIG. 8. FBTR fuel subassembly and fuel pin

The fuel bundle can be swung to enable loading and unloading from the machine. The fuel bundle to be dismantled is loaded vertically from top to go through the bores of the spindles carrying the pair of chucks. The X, Y & Z motions of the machine are 350 mm, 1,220 mm and 260 mm respectively. Though all motions are screw driven and are operated by geared electric motors, with push button control, provision has been made with additional design features to de-link all the motions from push button controls and perform motions including the tool changing operation manually but remotely with the help of manipulators (Figure 9).

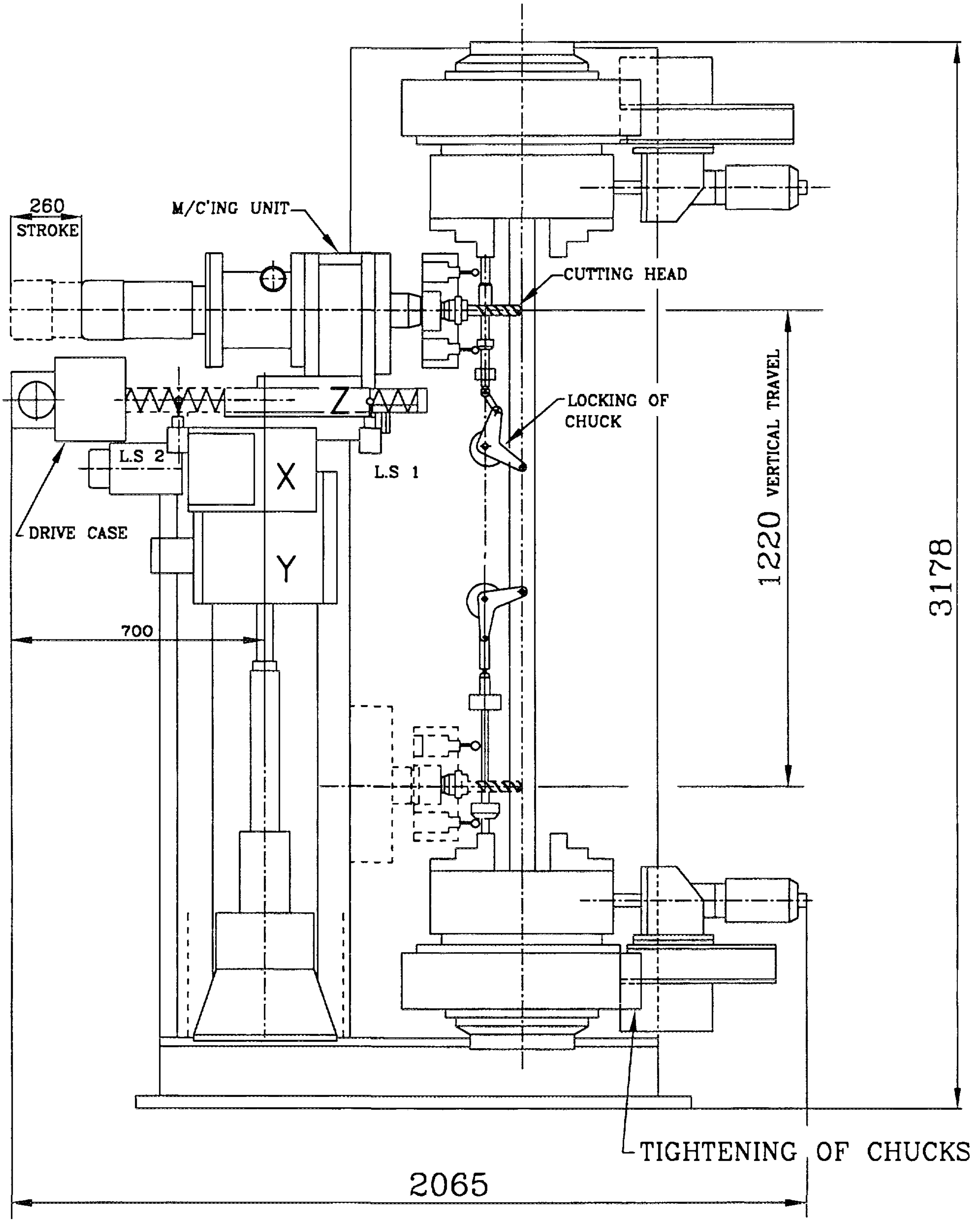

FIG. 9. Fuel dismantling machine for FBTR

Post-irradiation examinations have been carried out on a subassembly in hot cells at Indira Gandhi Centre for Atomic Research (IGCAR)`. Burn-up achieved was 25,000 MWd/t. The hot cells have been designed and constructed to handle plutonium based fuel. carbides of plutonium and uranium are highly pyrophoric and hence the hot cells are clad in stainless steel and operate under inert atmosphere of nitrogen under recirculation. A numerically controlled machine specially designed for the purpose is located in the hot cell and performs operations of dimensional inspection and dismantling of assemblies. Viewing is done through the lead glass shielding window. Other installed equipment like Master Slave Manipulators and Power Manipulators aid in handling fuel inside the hot cells. The entire operation of cleaning the assembly (of sodium), handling, inspection, dismantling and post-irradiation examination was carried out successfully. This has given the group great confidence to tackle problems connected with handling irradiated fuel in large numbers. Possibilities of reconstitution of fuel also are being considered.

Tomography offers possibilities of examination of assemblies without dismantling. With the KAMINI reactor going critical at IGCAR, work on neutron tomography of irradiated fast reactor fuel assemblies will be taken up. A 5-axis robot to handle and manipulate assemblies, in front of the neutron beam from KAMINI, has been developed. Extensive trials using this robot on fuel bundles with metallic uranium fuel have been carried out. The robot is driven by stepping motors, has three linear degrees of freedom for positioning assemblies, and two more degrees of freedom for orientation. While the initial trials were carried out using a gamma-beam, work is in progress to interface the system with a neutron beam from KAMINI (Figure 10).

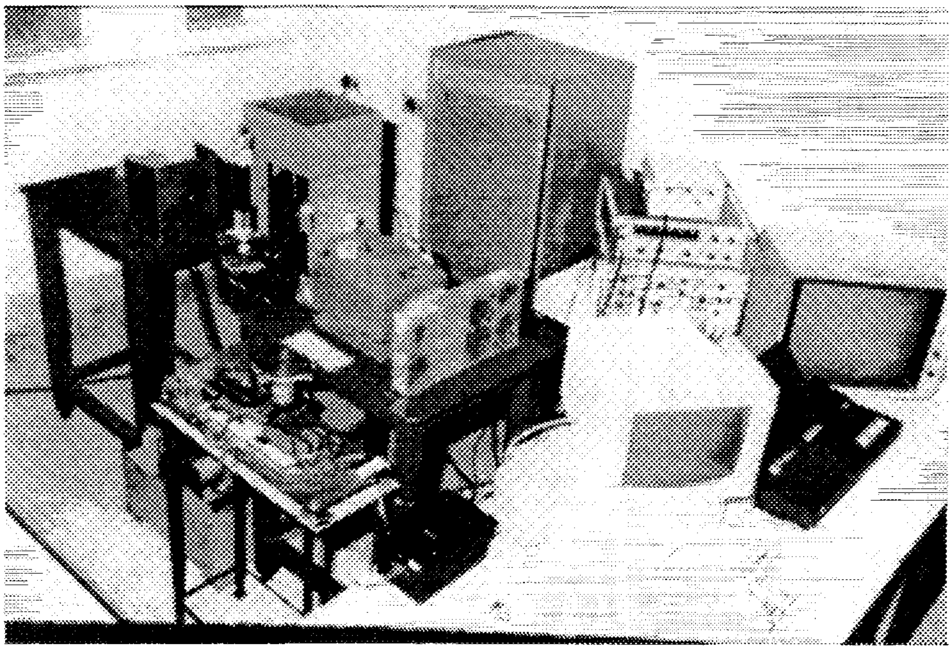

FIG. 10. Robotic system for neutron tomography of irradiated fuel

Automation is a way of achieving objectives of remote operation. This can reduce human operator exposure drastically. As mentioned before, our programmes include the use of plutonium and uranium-233 in our reactors.

Carbides of plutonium and uranium constituting FBTR fuel are highly pyrophoric. Therefore, the fuel fabricating train has to be enclosed in glove boxes under inert atmosphere with adequate shielding to eliminate radioactive exposure to operators. Handling of plutonium for fuel fabrication needs both rigid and flexible automation. A special automated inspection system for inspection of carbide fuel pellets has been developed. This system has been in successful operation for more than 10 years. The sintered pellets of mixed carbides are 4 mm wide and 8 mm long. The system measures diameter, length and weight. The linear density is calculated by a computer. The measured diameter and density are compared with acceptance parameters after which the pellet is accepted or rejected. Accepted pellets are automatically stacked in columns of pre-determined length. All the data, including the position of pellets in the column, are recorded and can be accessed when needed (Figure 11).

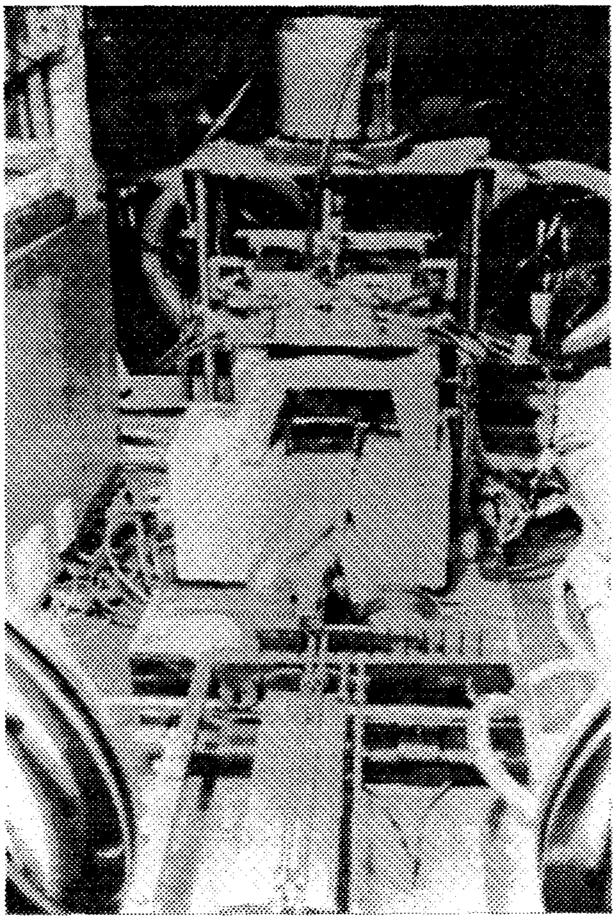

FIG. 11. Computerized automated inspection system for mixed carbide fuel pellets (for FBTR)

Mixed oxides (MOX) of plutonium and uranium are now being used in our thermal reactors also. One interesting area of automation is the fuel fabricating train which deals with handling of compacted green mixed oxide pellets. A special system has been developed to unload green compacts from a hydraulic press and convey them down on a special inclined conveyor. There are sensors that count four pellets at a time when the conveyer is stopped. A 5-axis articulated robot picks the pellets and stacks them in a molybdenum tray for the next step, i.e. sintering. The pellets are handled gently to avoid damage. The number of rows, arrays and layers of stacking can be programmed. The manufacturing cell consisting of the press, conveyer and robot is controlled by a personal computer which will be a part of a local area network. The entire system has been so developed that it can be dismantled and installed in active glove boxes housing the fuel fabricating train. Subsequent maintenance of the robot is ensured as the system is a standardized configuration with modular subsystems that can be inserted through transfer ports of glove boxes (Figure 12).

The robot mentioned above has been made into a standard configuration which can be applied in other operations too. After sintering, pellets have to be unloaded from the molybdenum trays. This will be done by a robot, equipped with tactile sensors, which will search and pick up the pellets and stack them on a stand for the next operation, which is centreless grinding. Owing to the configuration of the trays and poor color contrast between pellets and trays, vision systems will not be effective.

With tactile sensors on the end effector, the robot 'blindly' searches for the pellets and picks them up. The programmes for the robot control are such that the end effector of the robot can move on to the pellet whether in a cluster, standing alone or in a row. Extensive cold trails have been carried out and the system is now being readied for actual use in the MOX fuel plant at Tarapur, near Mumbai (Figure 13).

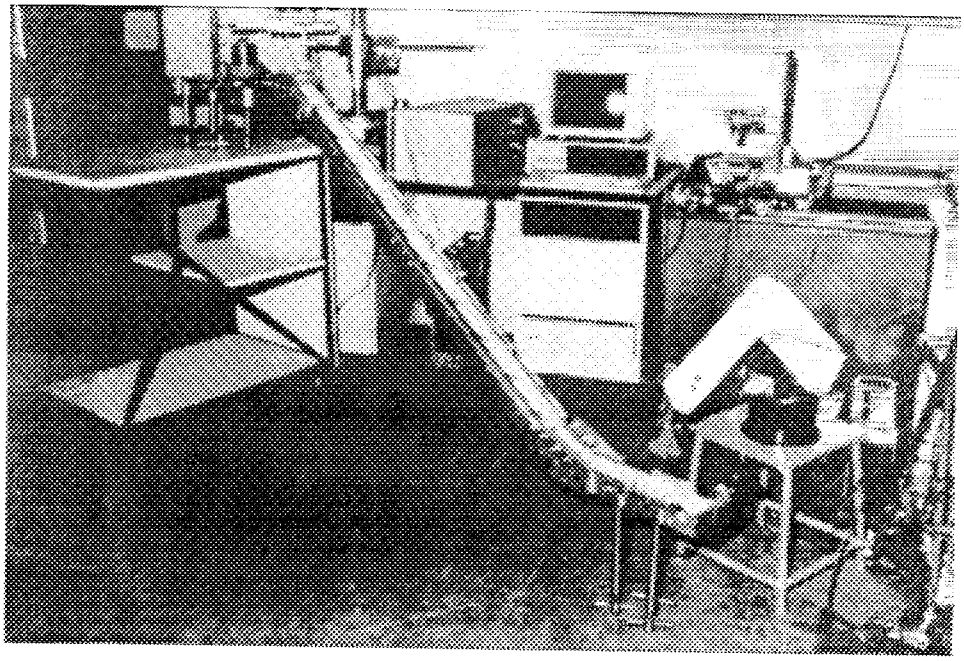

FIG. 12. Robotized manufacturing cell for handling compact green mixed oxide fuel pellets

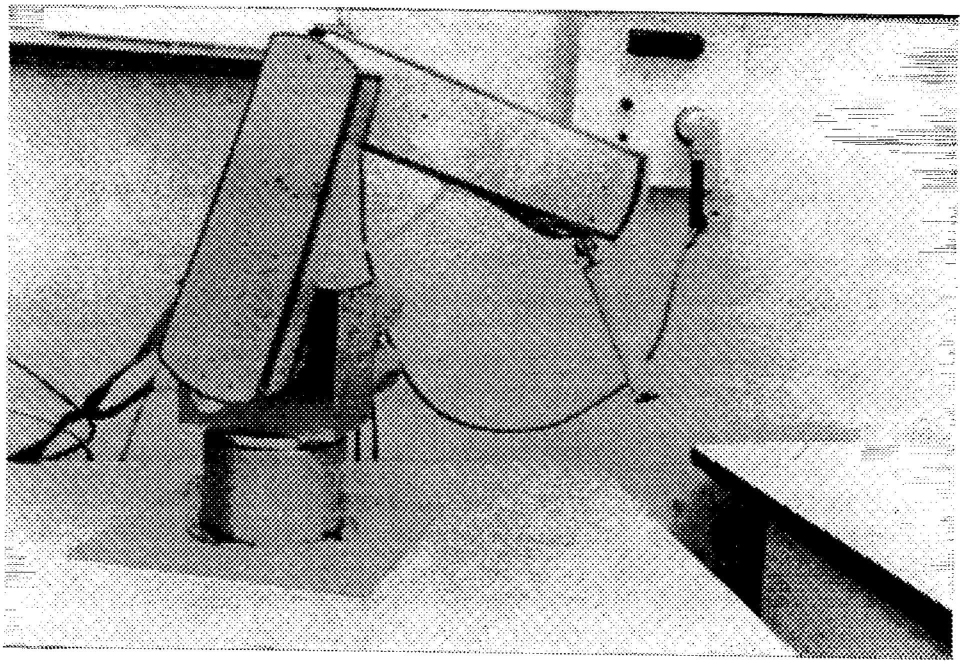

FIG. 13. Articulated robot with tactile sensors for searching, picking up and stacking MOX fuel pellets.

Many other experiments like intelligent stacking of pellets into column lengths, inspection of diameter and surface morphology etc. have been done to develop system resulting in flexible automation eliminating operator exposure in fabrication of fuel containing plutonium.

With a programme to build power reactors using natural uranium and thorium reserves in the country we have to plan for three generations of reactors. While FBTR represents the plutonium fueled second generation, KAMINI with uranium-233 belongs to the third generation. A 500 MW fast reactor, namely Prototype Fast Breeder Reactor, is in an advanced stage of design and planning. Fuel fabrication, reprocessing of irradiated fuel, fabrication of fuel with plutonium-239 & uranium-233 and waste management will become large scale activities. Remote technologies, automation and robotics which will be the main support for the whole programme, are being given strong emphasis. The emphasis of handling large quantities of irradiated fuel will have to be at an international level. If designs of reactors, fuels, fuel assemblies take into account activities connected with fuel fabrication, remote inspection (of reactors, fuel assemblies etc.) facility operation and spent fuel handling which need robotic remote devices, all the systems can be made safe and transparent for remote operation and management.