Remote and automation technologies:

Review of Japan's experience in the nuclear field

by K. Uematsu

Nuclear energy's share of total power generation in Japan today has grown to over 20%, with 30 nuclear power plants in operation as of July 1985. Additionally, various kinds of nuclear fuel cycle facilities also have been built, including those for uranium enrichment, fuel fabrication, reprocessing, and high-level liquid waste treatment.

Should trouble occur at such plants, repairs would be time consuming and operator radiation exposure would significantly increase. Remote system technologies, therefore, have been developed for use in areas where radiation levels are so high that workers cannot enter. In nuclear power plants, the overall benefits of remote systems are that they reduce the time for regular inspections, minimize the number of inspection personnel required, and hence decrease radiation exposure for inspection and maintenance personnel.

This article introduces and briefly reviews some of the remote and automated technologies that have been or are being developed at the Tokai reprocessing plant, the associated high-level liquid waste (HLLW) vitrification plant, and Japanese nuclear power plants. The reprocessing plant is operated by the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan, which also designed the HLLW vitrification plant.

The Tokai reprocessing plant

PNC constructed the Tokai reprocessing plant, which has a processing capacity of 0.7 tonnes of light-water reactor fuel per day. Hot operation began in 1977, and by March 1985 the plant had processed 179 tonnes of the heavy metal, uranium.

Two types of remote systems are used at the plant. One remote handling system is used to unload fuel, and a remote maintenance system is used in the mechanical head-end process. Fuel handling is carried out remotely in a cooling water pool to protect against exposure. In this system, a telescopic tube and special tool for gripping the fuel basket are used.

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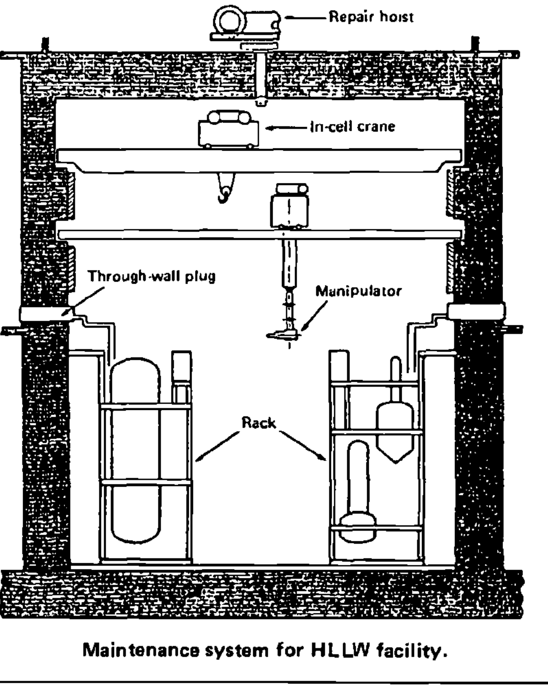
Maintenance of the mechanical equipment used in the head-end process is performed remotely by a power manipulator, an in-cell crane, and a master-slave manipulator; operations are viewed through shielding windows. The chemical process areas are maintained by contact maintenance after necessary decontamination.

Apart from the systems mentioned above, some remote techniques or systems have been developed to counteract equipment failure and to meet requirements for inspection of the nuclear facility. These are: remote repair devices for the dissolver; in-cell remote inspection equipment; and a decontamination robot.

Remote repair devices. After radioactive leaks occurred in 1982 and 1983 in two dissolvers, remotely operated devices were developed and manufactured to stop them. Successful repair work was done by grinding and welding aided by a periscope and a television camera; results were checked by dye-penetration and ultrasonic tests.

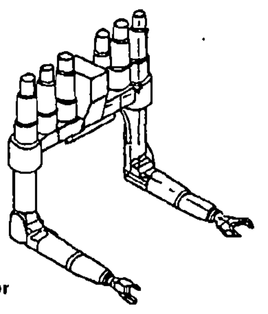


Maintenance system for HLLW facility.

Specifications for Prototype II manipulator

Number of arms:	2	
Shape of arm:	Elbow-down	
Degree of freedom: (DOF)	7	
Bilateral DOF:	7	
Operating speed:		
shoulder:	40°/sec	(pitch)
elbow:	60°/sec	(pitch)
	60°/sec	(roll)
wrist:	160°/sec	(pitch)
	160°/sec	(yaw)
	160°/sec	(roll)
tongs:	100 mm/sec	

Handling capacity:	15 kg	
Self-weight balance:	Electrical	
Control method:	Digital	
Range of motion:		
shoulder:	+135°	−45° (pitch)
elbow:	+45°	−60° (pitch)
	+35°	−215° (roll)
wrist:	±45°	(pitch)
	±45°	(yaw)
	±90°	(roll)
tongs:	0	90 mm



Prototype-II manipulator

In-cell remote inspection equipment. This system was developed for inspecting equipment and the cell drip-tray, where access is difficult due to high radiation levels. The remote inspection equipment is of two types: floor-rambling and multiple-armed. The first type has a specially developed vehicle that can move around on the drip-tray. The other type has a flexible arm that carries an Industrial TV (ITV) camera which has a wide field of view.

Decontamination robot. In the installation of a new dissolver, the cell was to be decontaminated to allow personnel to enter and set up associated parts. A remotely operated robot was manufactured for the decontamination work. This robot has a manipulation arm with a tong to grip a water jet or brushes to wash the floor and walls of the cell.

Remote systems for the HLLW

Construction of the HLLW vitrification facility for the Tokai reprocessing plant is scheduled to start in 1987. The detailed design, completed in 1984, incorporates a new concept of remote maintenance for process equipment so that plant availability is increased and personnel exposure decreased.

Process equipment is installed in racks which are ordered along both sides of the cell wall. Remote maintenance tasks will be carried out by 20-tonne in-cell cranes, a two-armed, advanced servo-manipulator, and an ITV viewing system. PNC is currently developing:

- A two-armed bilateral servo-manipulator system with transporter, an optical fibre signal transmission system, and a radiation-hardened, high-definition television system
- A module system, including a rack design
- Remote fluid and electric connectors
- A remote sampling system
- An in-service inspection system.

In 1983, PNC developed the first prototype for the two-armed bilateral servo-manipulator; development of a single-armed manipulator, Prototype II, began in 1984. Specifications for Prototype II, which is expected to be used at the HLLW plant, have been decided and are given in the accompanying table.

Remote and automation technologies for nuclear plants

The 30 nuclear power plants operating in Japan as of July 1985 comprise 29 light-water reactors (LWR) and one gas-cooled reactor (GCR). An advanced thermal reactor (ATR) is being developed.

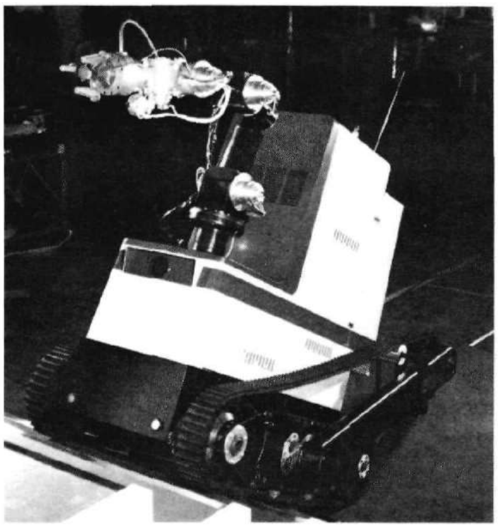
In the early days, remote technologies for nuclear power plants were mainly used for exchanges of fuel. Operators would get on the exchanging machine and run it while guiding the spent fuel through water.

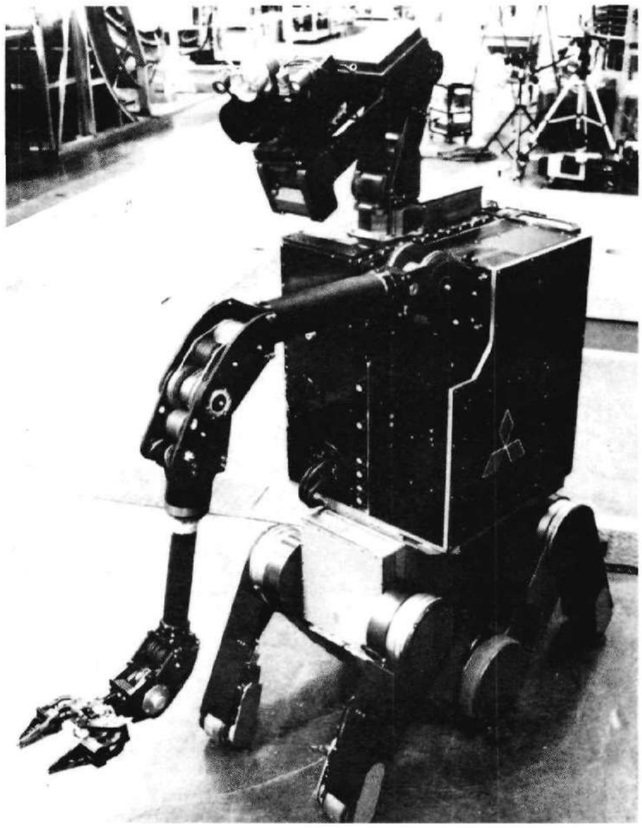
Through operations experience, various automatic machines and robotic systems have since been developed for inspection and other purposes. Expected benefits are the reduction of the time required for regular inspections, the decrease of operator radiation exposure, and the minimization of required inspection personnel.

Reducing inspection times: The Japanese Government has established a rule requiring yearly inspections of power plants. The inspections include equipment maintenance.

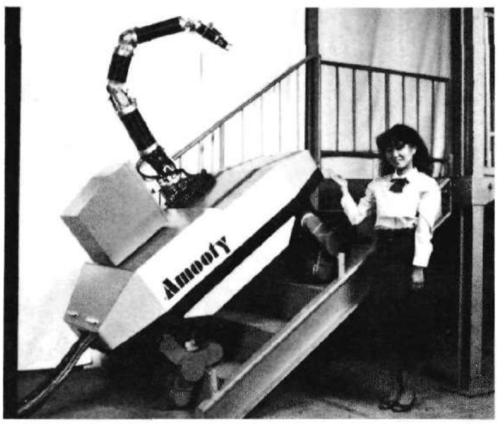
During the latter part of the 1970s, nuclear power plant availability was low because of shutdowns stemming both from problems at plants and increasing inspection requirements and the time needed to meet them. To raise plant availability, both problems and inspection times must be minimized; various robotic systems have been developed toward these ends. Reduction in the time required for regular inspections has been achieved using various robotics; operator radiation exposure has also been decreased.

Radiation exposures: Various robotic systems have helped reduce radiation exposures of inspecting personnel. As the accompanying graph shows, operator radiation exposure has decreased at the Fukushima nuclear power





These general-purpose robots were developed by Japanese companies for inspection and maintenance at nuclear power plants. "Amooty" was developed by Toshiba; the crawler by Hitachi; and the one-armed robot by Mitsubishi. (Credit: PNC)



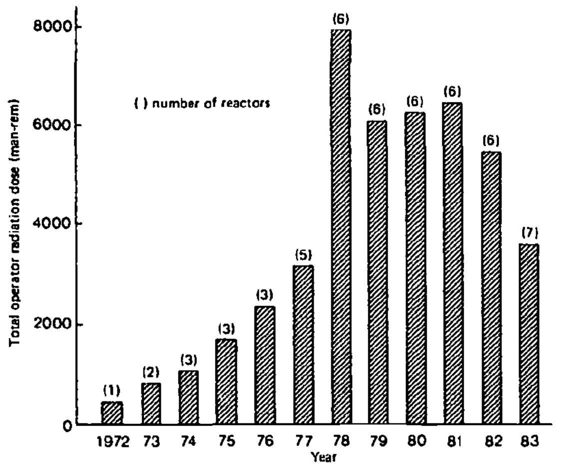
General-purpose robots developed in Japan

	Mitsubishi Heavy Industries Ltd.	Toshiba Ltd.	Hitachi Ltd.
Moving method	4 legs or wheels	4 wheel systems (wheel system has 3 wheels)	Crawler whose shape is variable
Arm			
Degree of freedom	6 + 1 (grip)	8 + 1 (grip)	6 + 1 (grip)
Driving method	Actuators are concentrated Wire drive	Actuators are dispersed	Actuators are dispersed
Handling capacity	10 kg force	10 kg force	3 kg force
Operation	Master arm with force reflection		Teaching play-back
Visual information	BW stereo TV	3-Dimension TV	Industrial TV
Total weight	420 kg	360 kg	300 kg

Special robots developed in Japan

Type of LWR	Kind of robotic system	Purpose* A	B	C
BWR	Automatic fuel exchanger	•		•
BWR	Remotely automatic exchanger control rod drive (CRD)	•	•	•
BWR	Exchanger of neutron detector	•	•	
BWR	Main steamline plug	•	•	
BWR	Fuel shipping machine	•		•
BWR	Automatic ultrasonic inspection machine for in-service inspection (ISI)		•	•
BWR	Decontamination machine for well		•	•
BWR	Decontamination machine for inside wall of reactor vessel (RV)		•	•
BWR	Automatic washing machine for cask		•	•
PWR	Automatic fuel exchanger	•		•
PWR	Fuel shipping machine	•		•
PWR	Decontamination manipulator in steam generator (SG) water room		•	•
PWR	Handling manipulator in SG water room	•	•	•
PWR	Eddy current test robot for SG	•	•	•
PWR	SG man-hole handling machine		•	•
PWR	CRD exchanger	•	•	•
PWR	Ultra-sonic testing machine for piping		•	•

* A: Reduce time for regular inspection
B: Decrease operator radiation exposure
C: Minimize number of operators required



Operator radiation exposure at Fukushima nuclear plants.

plants since various robotic systems came into use in 1978. During the 1972–78 period, exposures were rising.

Minimizing personnel requirements: It is very difficult to secure enough skilled operators for regular inspections, and it is becoming even more so as the number of nuclear power plants increases. Consequently, it is very important to perform regular inspections with fewer operators and more robotics. The tables on page 41 show robotic systems that have been developed so far, including those that were developed for specialized tasks in the early days of development.

The current trend in Japanese robotics development is to aim at general-purpose robots that can perform various kinds of tasks in a power plant. For valve maintenance, for instance, a general robot that has human-like legs, flexible hands, and high reliability is needed. As shown on page 41, various general-purpose robots have been developed in Japan.