MOVE THE WORLD FORWARD

MITSUBISHI HEAVY INDUSTRIES GROUP

MITSUBISHI ROBOT TECHNOLOGY

MITSUBISHI HEAVY INDUSTRIES

From plant fires to tunnel disasters and highly radioactive work sites, there are numerous extreme environments that are off-limits to humans. Mitsubishi Heavy Industries, Ltd. (MHI) leverages its technologies and experience in nuclear power in innovating robots that can overcome such extremes.

Delivering Unparalleled Robustness

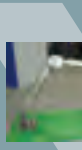
—MHI robotics for extreme environments

Historical Highlights

Developing robots for the nuclear power field

1980s

10-kg general-purpose arm 7-axis general-purpose robot arm



Nuclear reactor heat transfer tube inspection system

A-UT machine Underwater robot for nuclear reactor inspections

1990s

MARS-i remote visual inspection robot

Reactor vessel maintenance and inspection equipment

2000s

MEISTeR nuclear disaster response robot

Power Assist Suit (PAS) for heavy tasks

2010~ Present

Sakura No. 2 explosion-proof mobile robot

PA-2000 large hydraulic arm for debris removal

Robots that can operate in extreme environments

Water cannon robot for fighting large fires

Technological Innovations

- Explosion-proof function • Autonomous movement • Radiant heat-resistant structure • Hydraulic multi-axis arm precision control
- Crawler motion function • Stair climbing • Simultaneous super-multi-axis control
- Underwater specifications • Precision multi-axis arm control
- Radioresistance • Remote operation

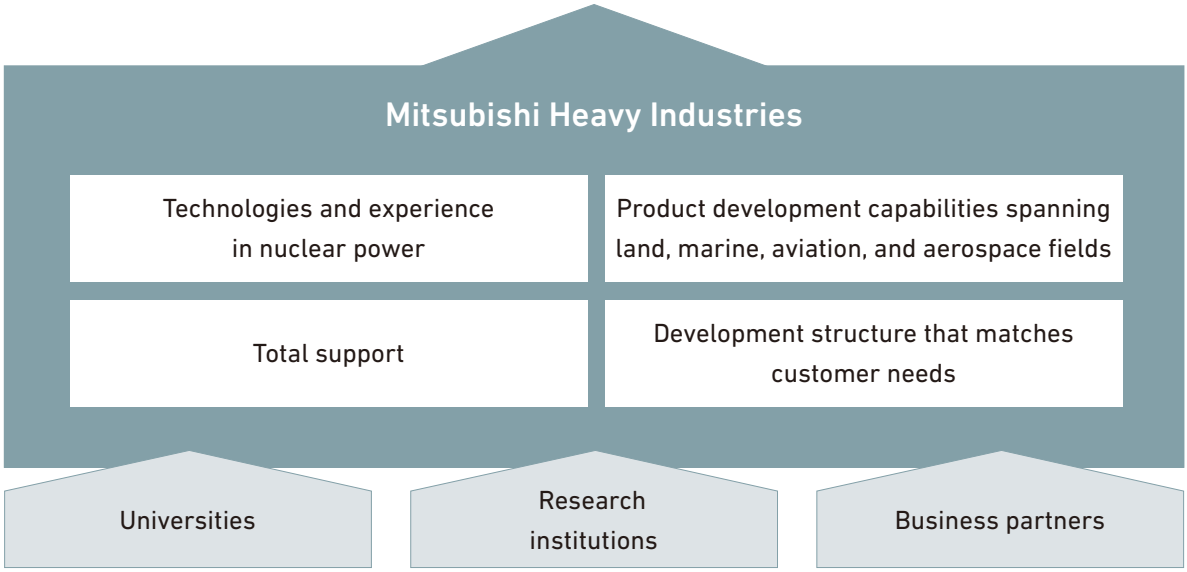
Nuclear Plant Component Designing Department, Nuclear Energy Systems Division, Power Systems

MHI entered the robotics business in the 1980s by developing inspection robots a decade after nuclear power plants started operating in Japan. Over the years, we have refined our technologies through in-house innovations targeting applications for underwater, radioactive, and other special environments, amassing a solid record in robot customization.

Today, we help tackle disasters as a social infrastructure provider. We develop robots that can operate in all sorts of extreme environments that are off-limits to humans, including petrochemicals complex fires, tunnel accidents, and disaster sites.

We will draw on our technologies and experience in nuclear power in our ongoing drive to safeguard society by creating robots that deliver unparalleled robustness.

Robots for extreme environments that underpin social safety and progress



Firefighting Robot System

消防庁消防大学校
消防研究センター
National Research Institute of Fire and Disaster

This system provides rapid initial fire extinguishing capabilities at petrochemicals complexes and other sites that firefighters cannot approach in major conflagrations.

■ The world's first autonomously moving and controlled firefighting robots

Firefighting Procedure

1 A vehicle transports the firefighting robot to a safe distance from a fire.

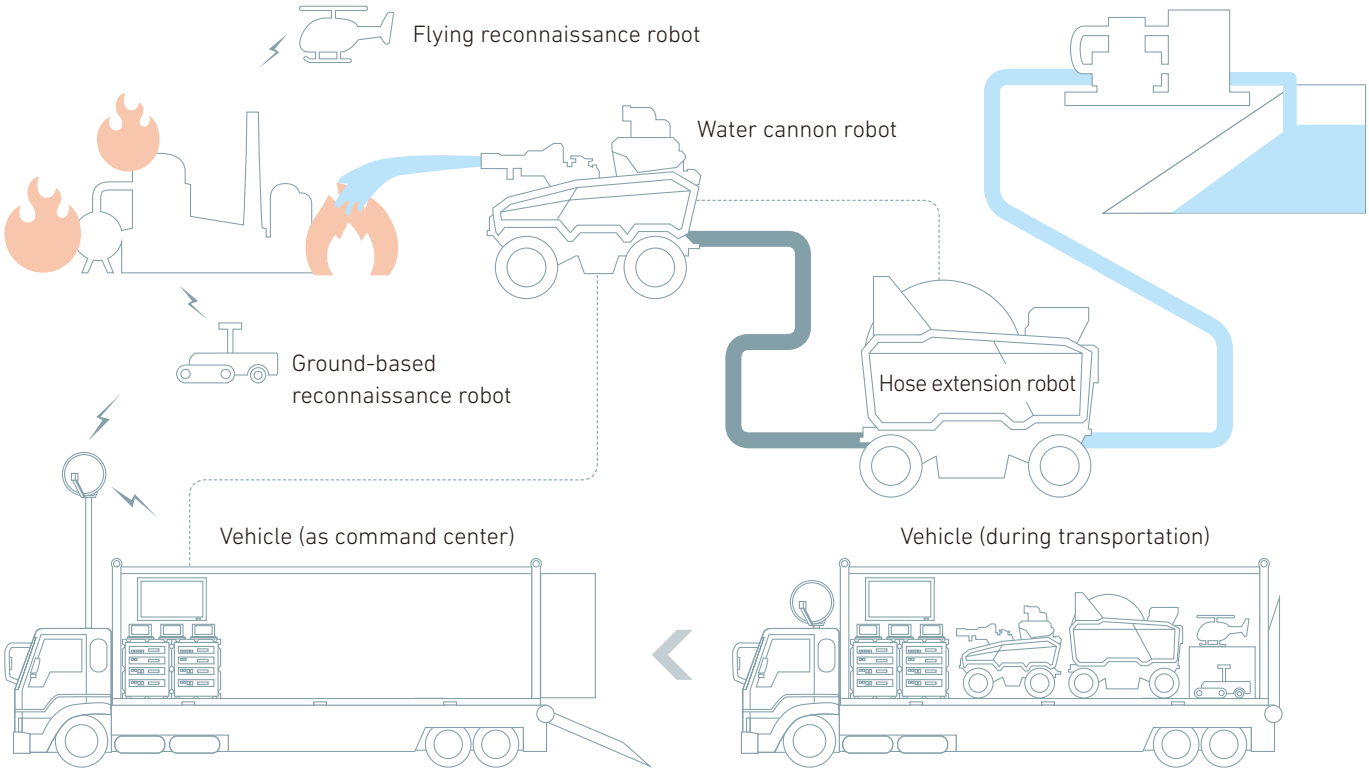
2 The robot is unloaded, with personnel connecting a cable and hose to prepare it for operations.

3 A reconnaissance robot is deployed.

4 Based on its findings, water cannon and hose extension robots are connected and travel autonomously toward a location near the source of the fire to discharge water.

5 The water cannon and hose extension robots automatically lay hoses out. After the hose and pump are connected the system starts discharging water.

Firefighting Robot System Activities



Practically Deployable Water Cannon and Hose Extension Robots (First models)

The National Research Institute of Fire and Disaster of Japan's Fire and Disaster Management Agency finished a five-year development project in spring 2019, thereby completing the first water cannon and hose extension robots.


Water cannon (left) and hose extension robots


Flow of 4,000 liters per minute


Laying hose

Water Cannon Robot

The robot has a radiant heat-resistant structure and autonomously moves to locations that humans cannot approach to extinguish and cool fires.

Main Specifications

External dimensions*	Length: 2,100 mm; Width: 1,400 mm; Height: 1,900 mm
Weight*	1,600 kg
Movement system	4-wheel drive and front-wheel steering system
Speed	7.2 km/h (2m/sec)
Onboard sensors	RTK-GPS, LRF, IMU, Odometry
Functionality	Designed to travel autonomously to a designated map position and operate in a radiant heat environment of 20 kW/m^2 Water and foam are discharged to extinguish and cool fires: 4,000 ℓ/min at 1 MPa pressure (water discharge angle, nozzle discharge, and wide-angle discharge can be switched remotely)

The main specifications are for the prototype. Figures for the completed model may differ.
* Reference value

Hose Extension Robot

This robot automatically lays fire hoses up to 300 meters long and supplies water to the water cannon robot.

Main Specifications

External dimensions*	Length: 2,400 mm; Width: 1,750 mm; Height: 2,150 mm
Weight*	2,800 kg
Movement system	4-wheel drive and front-wheel steering system
Speed	7.2 km/h (2m/sec)
Onboard sensors	RTK-GPS, LRF, IMU, Odometry
Functionality	150A hose extension laying 300 meters; designed to travel autonomously to a designated map position

The main specifications are for the prototype. Figures for the completed model may differ.
* Reference value

The designs of the water cannon and hose extension robots in this brochure are for prototypes (without radiant heat covers installed).

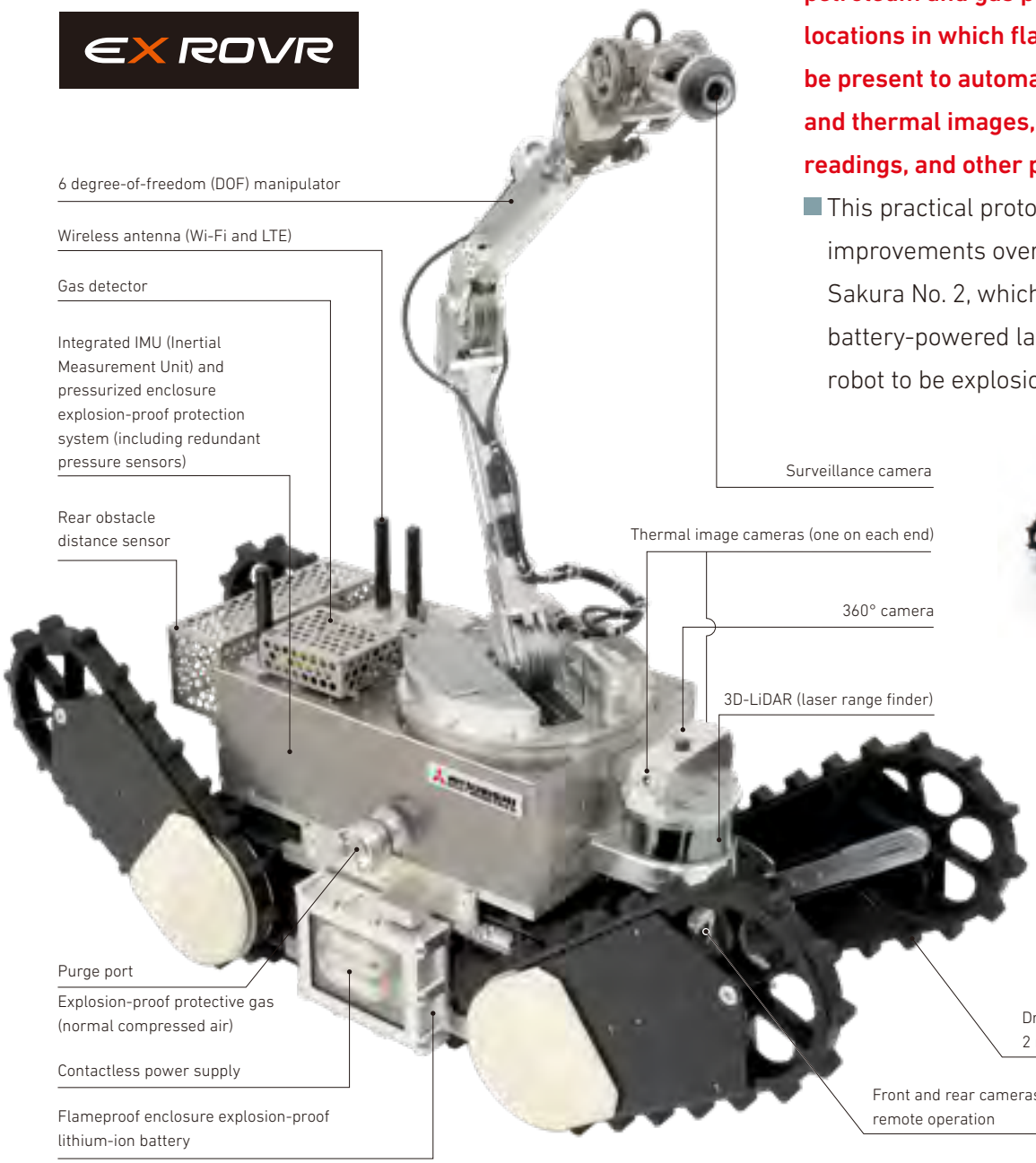
This robotics system is part of a project that the National Research Institute of Fire and Disaster of Japan's Fire and Disaster Management Agency initiated for R&D into firefighting robots to assist in energy facility and industrial infrastructure disasters. MHI was in charge of the water cannon and hose extension robots and overall systems engineering for this system.

Explosion-Proof Mobile Robot

EX ROVR

This robot moves autonomously around petroleum and gas plants and other locations in which flammable gases may be present to automatically acquire visible and thermal images, gas concentration readings, and other plant information.

- This practical prototype model features improvements over the predecessor, Sakura No. 2, which was Japan's first battery-powered land-based mobile robot to be explosion-proof certified.



Sakura No. 2
(Explosion-proof model)
(Approval number:
TIIS (Japan) TC22032X)

This was Japan's first battery-powered land-based mobile robot to be explosion-proof certified. This high-performance remote-controlled model boasts high travel performance and can inspect areas as a first responder following tunnel accidents and other disasters without creating sparks or heat that could cause an explosion.

Main Specifications

External dimensions	Length: 700 mm to 1,284 mm (with sub-crawler extended); Width: 450 mm; Height: 539 mm (main unit, or 1,300 mm with manipulator included); Minimum turning diameter: 804 mm
Main unit weight	75 kg
Speed	1.2 km/h
Climbing angle	45° (can climb and descend)
Travel and climbing method	Joint use of 2 main-crawlers and 4 sub-crawlers with adjustable angle that can extend forward or backward
Continuous operational time	Around 2 hours (2 hours of contactless power from automated charging station)
Autonomous travel	3D laser SLAM (setup for multi-floor deployment, including to negotiate stairs)
Remote operation	Remote control through Wi-Fi or LTE connection is possible while watching video from front, rear, and manipulator bird's-eye view cameras
Environmental data collection system	360° camera, surveillance camera, thermal image camera, and gas detector, with cloud storage secured through an LTE-connected IoT system
Environmental resistance	IP47 (protection against objects 1 mm or larger in diameter and temporary water submersion)
Explosion-proof specification	Ex pxd II B + H2 T3 Gb Pressurized enclosure + flameproof enclosure explosion-proof method, may be used in inflammable gas, including hydrogen and zone 1* areas (with charging station compatibility planned)
Manipulator	6 DOF, with visible surveillance camera and variable illumination at end (1 DOF gripper under development)

* This second of three hazardous area classifications is where a hazardous atmosphere is likely during normal operations, and applies to most hazardous places other than inside oil tanks (zone 0).

CONCEPT MODEL

This system employs 3D-LiDAR to estimate its own position and automatically charges contactlessly. As well, it autonomously patrols preset routes at petroleum and steel plants and other sites in which flammable gases may be present in the air to acquire conventional images, thermal images, audio, and the presence of flammable gases. This model will also be able to undertake light tasks, notably to open and close valves and collect samples.

Other Operational Settings

- Nuclear accidents
- Tunnel disasters
- Plant inspections
- Firefighting
- Removing hazardous objects

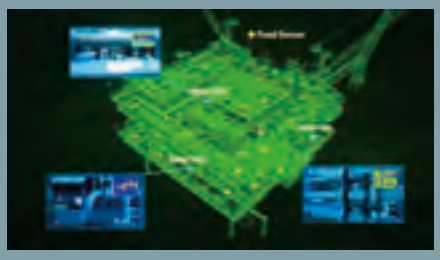
POTENTIAL APPLICATION

Deployment at Offshore Oil Rigs

These sites are hazardous to workers because of the constant presence of flammable gases, and are also prohibitively expensive. Robots could provide valuable services and reduce human risks by patrolling areas and checking instruments, detecting abnormalities, and operating equipment.

Opening and closing valves

Contactless automatic charging



Assessing work conditions from remote monitoring center

Power Assist Suit (PAS)

This suit helps workers undertaking heavy tasks, and employs customizable upper body components.

■ Enables workers to enhance efficiency by assisting up to 40 kg

Multiple Tasks

A module mechanism combines various upper body components for each task with a common lower body robot.

Assistance with Heavy Tasks

The suit incorporates a powerful actuator, with which the wearer manipulates mounted robots for heavy tasks.

Harmonizing Humans and Robots

Controls remain stable, without the effects of perspiration, with force, acceleration, and other sensors doing exactly what the wearer wants and moving in sync without impeding movement.

Workability

With fewer parts to set up, the suit can be quickly removed. It can also go through passages just 700-mm wide.

Main Specifications

External dimensions	Length: 400 mm; Width: 620 mm; Height: 1,500 mm
Weight	39 kg
Power assist	Equivalent to 40 kg (excluding suit weight)
Power source	Lithium-ion battery that can operate continuously for up to two hours
Walking speed	4.5 km/h without load and 3.9 km/h with maximum load

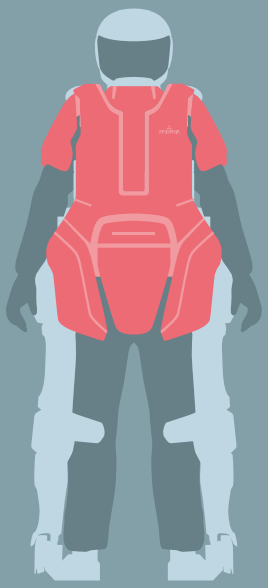
Jointly developed with The Japan Atomic Power Company.
Some development expenses are subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

CONCEPT MODEL

Smartly redesign the image of heavy work with design integrating advanced, functional, and safety technologies to handle heavy tasks

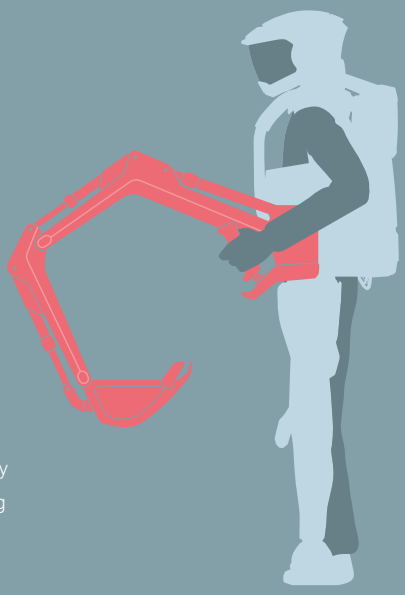
POTENTIAL APPLICATION

PAS Applications



Nuclear Power

Reducing the loads of heavy radiation shield jackets and improving work efficiency and radiation protection



Construction

Helping to reduce loads in materials handling and assembly and other heavy tasks at building sites, shortening construction times and cutting costs

Emergencies

Enabling safe and sure relief efforts at disaster sites where it is difficult to bring in equipment

Manipulator Arm Series

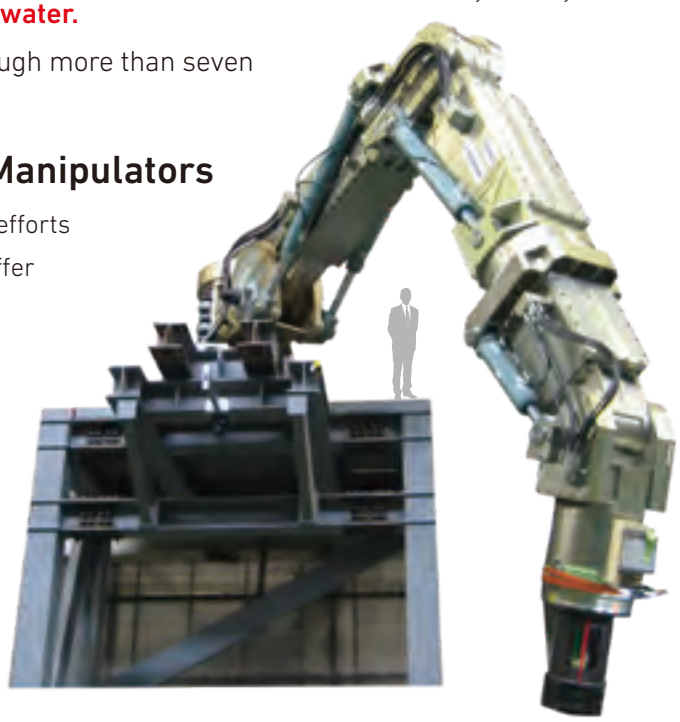
Our robotics technology is vital for high-precision work in environments that humans cannot approach, high-radiation sites, and underwater.

- Handling singular points and preventing interference through more than seven rotational axes

PA Series of General-Purpose Multi-Axis Manipulators

We developed these manipulators to serve in disaster response efforts (maintenance and inspections) for nuclear reactor vessels. We offer a range of arms to match customer needs including ultra-high-precision electromotive models and powerful hydraulic ones offering exceptional portability.

PA-2000
(Hydraulic cylinder)



Main Specifications (Hydraulic)

Arm length	7,100 mm
Maximum arm tip load	2,000 kg
Drive system	Hydraulic cylinder and swing motor
Number of axes	6
Repetitive positioning accuracy	± 5 mm or less

MHI undertook part of the development of this robot using subsidies from the International Research Institute for Nuclear Decommissioning (IRID) for a project of Japan's Agency for Natural Resources and Energy.

MHI-MEISTeR II

This robot was developed to help recovery efforts at the Fukushima Daiichi Nuclear Power Plant. It can climb stairs and negotiate other environments.

Main Specifications

Movement system	4-crawler drive
Travel	Can climb stairs with angles up to 40° and steps of 200 mm and can also negotiate rough terrain and narrow areas
Arm	Double 8-axis manipulators with arm-loading capacity of 25 kg
Remote operability	Wireless and wired communication, battery-driven for up to four hours

MHI undertook part of the development of this robot using subsidies from IRID for a project of Japan's Agency for Natural Resources and Energy.

SUPER-Giraffe

This was developed for accident response work at the Fukushima Daiichi Nuclear Power Plant. It can open and close valves and handle other tasks at locations up to eight meters high.

Main Specifications (Electromotive)

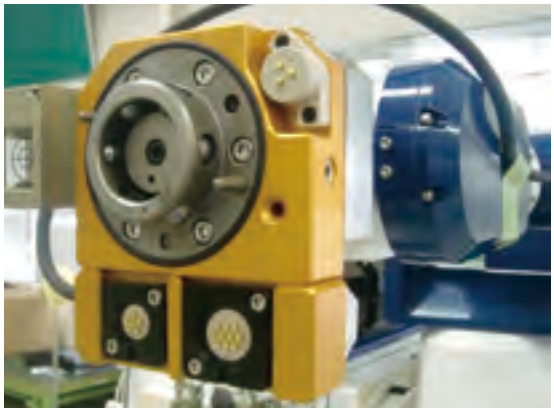
Movement system	4-wheel drive and 4-wheel steering system
Travel	Up 15° slopes and 50-mm steps
Arm	9-axis manipulators with arm-loading capacity of 25 kg
Remote operability	Wireless and wired communication, battery-driven for up to five hours

This robot was developed for the Unmanned Disaster Response System Research and Development Project of NEDO.

Main Specifications (Electromotive)

Arm length	1,350 mm (for load capacity of 25 kg)
Load weights	10 kg, 25 kg, and 60 kg
Structure	Dustproof and drip-proof (IP54) (IP67 also possible)
Drive system	AC servomotor
Number of axes	7 (expandable to base)
Power source	Three-phase AC 200 V (3 kVA)
Operating temperature range	0 to 50°C
Repetitive positioning accuracy	± 0.1 mm or less

PA-25
(Electromotive)



Tool Changer

Replaces tip tools and handles various tasks. The use of a common tool changer platform makes it possible to share tip tools for each arm.

Work Examples

Core boring

Pipe cutting

Opening and closing valves

A-UT Machine

This machine was developed to inspect for flaws underwater and under high-radiation environments for nuclear reactor vessels.

Main Specifications

Movement system	Swims via propeller, with wheels for self-propulsion on wall surfaces
Inspection method	Ultrasonic inspection
Arm	7-axis manipulators with arm-loading capacity of 10 kg
Remote operability	Wired communication and wired power supply

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