Research Progress of Nuclear Emergency Response Robot

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Abstract. This paper introduces the research progress and application of nuclear emergency response robot since the Fukushima nuclear accident in detail, and briefly introduces the research process of nuclear emergency response robot in China. By summarizing the characteristics of emergency work after nuclear accident and the experience of using nuclear emergency response robot, the demand characteristics and development trend of nuclear emergency response robot are analyzed. The key technologies of radiation protection, communication and radiation detection for nuclear emergency response robots are summarized in detail. Finally, a nuclear emergency fire fighting robot developed by this project is introduced briefly.

1. Introduction
With the public attention on nuclear safety and the increasing safety requirements of nuclear facilities all over the world, it is very necessary to monitor the nuclear radiation situation and deal with emergency response work in nuclear facilities. Robotic technology, as an important technology that can replace workers to enter the special radiation environment for emergency response task, is widely concerned by domestic and foreign researchers [1-3].

The Three Mile Island nuclear accident [4], Chernobyl nuclear accident [5], JCO reactor accident [6] and Fukushima nuclear accident [7], indicate that the site condition needs to be confirmed as soon as possible after the nuclear accident to provide reference information for emergency disposal. Researchers have been studying robotic systems in strong radiation environments to meet the needs of nuclear emergency response task. This paper summarizes the research progress and application of nuclear emergency response robot at abroad after the Fukushima nuclear accident in detailed, introduces the research progress of nuclear emergency response robot in China, and analyzes the development trend and key technology of nuclear emergency response robots. Finally, the characteristics of nuclear emergency firefighting robot designed in this project are introduced.

2. Research and application progress of nuclear emergency response robot at home and abroad
2.1. Progress in research and application of foreign nuclear emergency response robot
In the development process of nuclear emergency response robot, the Fukushima nuclear accident in Japan has a very important impact. Before the Fukushima nuclear accident, the nuclear emergency response robot carried out corresponding emergency modification according to the characteristics of the nuclear accident. These robots focused on radiation tolerance, mostly large in size, lack of...
functional diversity, and with certain limitation in application. After the Fukushima nuclear accident, especially after the establishment of IRID (International Research Institute for Nuclear Decommissioning) by Tokyo Electric Power Co, Toshiba, Mitsubishi, Hitachi and other companies, the nuclear emergency response robot tends to be smaller and more intelligent, and can adapt to more complex nuclear accidents.

2.1.1. Research progress of nuclear emergency response robot before Fukushima nuclear accident.

Since the nuclear accidents at Three Mile Island in America in 1979, the American research institutions began to research robotic technology for high radiation environments, replacing the high radiation areas entered by personnel for radiation detection and related accident handling [8]. In this context, Odetics developed the first robot ‘ODEX-I’ made in American, which can be used in radioactive environment [9].

In 1986, a serious nuclear accident occurred at the Chernobyl nuclear power plant in Ukraine. The No. 4 reactor of the nuclear power plant exploded. After the explosion, a number of robots were sent into the accident site for emergency response task, but all of them were damaged by radiation [10]. Subsequently, American DOE (Department of Energy) and NASA (National Aeronautics and Space Administration) began to study nuclear accident emergency robot [11]. Red Zone Corporation sponsored by DOE and NASA developed the ‘Pioneer’ robot, which entered the Chernobyl accident site in 1998 for emergency monitoring [12].

The ODEX-1, Pioneer, and other contemporary nuclear emergency response robots were limited by the technical conditions at that time. These nuclear emergency response robots were large in size, weak in radiation resistance and simple in function. They could only detect simple information such as video and radiation. ODEX-1 was not even equipped with a manipulator which could be used for emergency disposal. Pioneer's manipulator can only carry out simple emergency disposal.

In 1999, a serious nuclear criticality accident occurred in JCO Company of Japan. After the accident, the serious radiation environment on the scene prevented the staff from entering the accident site in the first time. Affected by the accident, the Japanese government funded the NUSTEC (Nuclear Safety Technology Center) [13], JAERI (Now renamed as Japan Atomic Energy Agency, hereinafter referred to as JAEA) [14-15], and MSTC (Manufacturing and Science Technology Center) [16] to study nuclear emergency response robot. MSTC joined five companies, Hitachi [17], Mitsubishi Heavy Industry [18], Toshiba [19], Nisshow-Iwai and Cybernix [20] to study the project.

These robots developed for the JCO nuclear accident focus on radiation resistance. As a result, most of the robots are large in size. At the same time, the Japanese government pays more attention to nuclear safety, nuclear emergency accidents have not occurred in many years. The nuclear emergency response robot developed after JCO nuclear accident has not really entered the nuclear accident scene. Most of the nuclear emergency response robots in the world have encountered similar problems. Because of the absence of nuclear accidents and the lack of application platforms, the nuclear emergency response robots were basically used for daily maintenance in nuclear facilities before Fukushima nuclear accident.

2.1.2. Research progress of nuclear emergency response robot since Fukushima nuclear accident.

In 2011, a serious accident occurred at the Fukushima Nuclear Power Station of Tokyo Electric Power Company, Japan. Several nuclear power plant reactors exploded in varying degrees, resulting in a large amount of radioactive material leakage. Subsequently, several countries, including the United States and Japan, have used many robots for emergency task. The research on nuclear emergency response robot has been greatly promoted by the demand for emergency task at Fukushima Nuclear Power Station in Japan. With the deepening of emergency work, especially the establishment of IRID in August 2013, IRID has fully analyzed the characteristics of emergency work at Fukushima Nuclear Accident, and developed various nuclear emergency response robots for the complex environment of the Fukushima nuclear accident site [21].
In 2011, the PackBOT and Warrior robots provided by iROBOT, and the TALON robots provided by QinetiQ, these robots were added extra shielding on the sensitive parts in order to quickly enter the nuclear accident scene [22]. The PackBOT robot is the first robot to get into the site of the Fukushima nuclear accident for onsite investigation. It has the characteristics of small size (minimum size 530 mm×700 mm×190 mm), low weight(30 kg), and strong motion ability (can climb 60 degree slope, the maximum speed of the road can reach 9.36 km/h), as show in Fig 1(a). PackBOT robot can maintain 8 hours of working time when using wireless communication control mode. The biggest characteristic of PackBOT robot is that its two crawler driving wheels are equipped with detachable front crawlers, which make it have strong ability to surmount obstacles and self-adjusting tilting function, and can adapt to the complex working conditions for Fukushima accident. PackBOT robot loading platform can be retrofit to install functional equipment such as gamma camera, as shown in Fig 1 (b).

The Warrior robot has a minimum size of 768 mm×889 mm×438 mm and weighs about 222 kg, the maximum speed of the flat road can reach 12.9 km/h. It can be loaded with various disposal equipments. Sampling pumps are used to absorb and clean radioactive dust from the site of the Fukushima nuclear accident, drills are used for solid sampling, and high pressure water guns are used for cleaning contaminated areas, as shown in Fig 1(c). TALON robot, which assembles a three-dimensional radiation dose distribution measurement system [23-24], mainly detects radiation field around the Fukushima nuclear accident site, and partially removes obstacles, as shown in Fig 1 (d).

In 2011, Chiba Institute of Technology in Japan developed a Quince-1 robot which is tested under radiation environment, and put it into the scene of the Fukushima nuclear accident for emergency rescue [25]. The Quince-1 robot lost communication during a surveillance mission, and then Chiba Institute of Technology designed the Quince-2 and Quince-3 robots that could use wireless relay communication [26-27], as shown in Fig 1(e), 1(f) and 1(g). The Quince series of robots can work normally for five hours at a dose of 40 Gy/h from a $^{60}$Co radiation source during the radiation tolerance test. Quince robots body structure using carbon fiber and aluminum alloy, can effectively reduce the local weight, the main crawler side with four independent auxiliary crawler drive, can effectively improve the stability of the body and the ability to overcome obstacles, it carries a 3D camera system for real-time mapping. The Quince robots can be fitted with a 2 degree of freedom manipulator for liquid sampling inside the reactor.

FRIGO-MA robot is developed by Mitsubishi Corporation in 2012, it is operated by cable while PackBOT is operated wirelessly by utilizing FRIGO-MA as a relay, FRIGO-MA with optimum functions such as a pan-tilt camera allowing to inspect in upward direction and image recording will be used for the inspection [28], as shown in Fig 1(h). High-Access Survey robot is developed by Honda Corporation in 2013, mainly used for monitoring the high position in the reactor factory building, the height is only 1800 mm when driving. When monitoring the high position, the maximum height can be extended to 7030 mm. With the 3D laser rangefinder, High-Access Survey robot can obtain the three-dimensional data of the high position [29], see Fig 1(i).

In 2013, IRID and other units started to develop the nuclear emergency response robots for Fukushima nuclear accident. The nuclear emergency monitoring robots included Rosemary, Sakura, Smartphone, B1, Scorpion, PMORPH, Survey Runner, Surface boat, SC-ROV, Gengo, Trydiver, Teleesooopic, Lake Fisher and Underwater ROV, as shown in Fig 1(j) to Fig 1(w). The nuclear emergency clearance robot included ASTACO-SoRa, Raccoon, Arounder, Kanicrane, MEISTeR and DRV, as shown in Fig 2(a) to Fig 2(f).

Rosemary and Sakura robots are often used together to monitor the 2 and 3 layers of the accident reactor buildings. Both robots can use wireless communication when they are used independently. When the two robots were used together, the wired communication is used for Sakura and the wireless communication for Rosemary via Sakura. The design standard for radiation resistance of the two robots is referred to Quince series robots [30]. Smartphone robot is created with a 3D printer, equipped with a smart phone to capture images and sent the data to a PC outside by a wireless connection, it can turn back and forth by 180 degrees to take images of the ceiling and floor, go over a 5 cm bump [31]. B1, Scorpion and PMORPH robots are all deformable robots. They are designed to enter the
containment through the conduit of the containment for monitoring. When driving in a straight line, the 3 robots use a straight bar structure. After entering the containment, B1 and PMORPH change into concave-shaped structure for traveling monitoring, and Scorpion change into scorpion shape for traveling monitoring. B1's camera is designed for working in 10 Gy/h radiation field, with a total dose of 1000 Gy, but it eventually worked well in 70 Gy/h [32]. Scorpion and PMORPH robots are designed to work in 100 Gy/h radiation field [33-34].

Survey Runner carries an irradiation resistant camera for monitoring. The four independently driven crawler tracks can protect the robot from falling when it goes up and down stairs or crosses obstacles [35]. Surface boat robot carries three surveillance cameras, two underwater cameras and a dosimeter to monitor the surface of the water inside the containment shell [36]. SC-ROV is designed to monitor the site between the containment and the exterior pipeline. The whole structure is waterproof, and the platform can carry a video monitor which can work in the water [37]. Gengo and Trydiver are two robots that work in the water for monitoring. Gengo is neutral buoyancy in the water, Gengo can move forward, backward, left, right, up and down in the water. It only carry two underwater radiation-resistant cameras at the front and back for video monitoring. Trydiver weighs about 1.5 kg (in the water) and can crawl in the water, it carries two underwater cameras, and one ultrasonic sonar for positioning and measurement [38]. Telesoopic and Lake Fisher are two robots that monitor the lower side of the containment. They carry dosimeter, thermometer, hygrometer and video cameras [39]. Underwater ROV is developed in June 2017, mainly used to monitor the water in the lower part of the containment [40].

ASTACO-SoRa Robot is a heavy-duty robot with two robotic arms. It is mainly used to collect and pick up radioactive solid pollution in the reactor plant and put them into special recycling containers. According to the report, the radiation dose around the recycling container for radioactive pollution can reach 1 Gy/h [41]. Raccoon robot is a small cleaning robot that can flush the ground inside the reactor plant with clean water or dry ice [41]. Arounder robot can flush the floor or walls with clear water or dry ice [41]. Kanicrane robot is used to absorb dust from wall [41]. MEISTeR robot can replace different robotic arms, use drills to sample the ground, the total dose of the MEISTeR robot is more than 1000 Gy under 100 Gy/h radiation dose [42]. DRV robot is designed to clean the conduit that enter the containment and use nozzles to spray high pressure (7.5 MPa) water into the conduit. The contaminants accumulated in the conduit are pushed away by the metal structure of the robot, so that the follow up monitoring robot can enter the containment for monitoring. The DRV robot can operate at a radiation dose of 70 Gy/h for about 2 hours in a single continuous operation.

Partial performance parameters of the Fukushima nuclear accident emergency response robots are shown in Table 1.
Figure 1. Nuclear emergency monitoring robots
Figure 2. Nuclear emergency disposal robots

Table 1. Partial performance parameters of response robots for Fukushima Daiichi accident

| Robot model     | Birthday | Institute | Size (W×L×H /mm) | Weight (kg) | Dose  | Communication         |
|-----------------|----------|-----------|------------------|-------------|-------|-----------------------|
| FRIGO-MA        | 2012     | Mitsubishi| 490×650×750       | 38          | 10 Gy/h | Wired/Wireless         |
| Survey Runner   | 2012     | Topy      | 510×505×830       | 45          | 1000 Gy | Wired                 |
| Surface boat    | 2013     | Hitachi   | 330×900×293       | 27          | --     | Wired                 |
| SC-ROV          | 2013     | IRID      | 280×305×140       | 10          | 0.5 Gy/h | Wired                 |
| Rosemary        | 2013     | IRID      | 500(W)×700(H)     | 65          | --     | Wireless              |
| Raccoon         | 2013     | ATOX      | 403×632×302       | 35          | 10 Gy/h | Wired                 |
| Arounder         | 2013     | IRID      | 740×1200×1700     | 550         | 10 Gy/h | Wired                 |
| Kanicrane       | 2014     | Hitachi   | 700×2360×1430     | 1250        | 10 Gy/h | Wired                 |
| Gengo           | 2014     | IRID      | 420×480×375       | 22          | 200 Gy  | Wired                 |
| Trydiver        | 2014     | IRID      | 480×628×378       | 40          | 200 Gy  | Wired                 |
| Telesoopic      | 2014     | IRID      | 509×440×826       | 70          | 1000 Gy | Wired/Wireless         |
| Lake Fisher     | 2014     | IRID      | 658×1038×1016     | 180         | 1000 Gy | Wired/Wireless         |
| Sakura          | 2014     | IRID      | 390(W)×500(H)     | 35          | --     | Wired/Wireless         |
| MEISTeR         | 2014     | IRID      | 700×1250×1300     | 550         | 100 Gy/h| Wired                 |
| Smartphone      | 2015     | TEPCO     | 77×319×105        | 0.787       | 1.3 Gy/h| Wireless              |
| B1              | 2015     | IRID      | 70×600×95         | --          | 10 Gy/h | Wired                 |
| Scorpion        | 2017     | IRID      | 90×550×90         | --          | 100 Gy/h| Wired                 |
| PMORPH          | 2017     | IRID      | 70×700×95         | --          | 100 Gy/h| Wired                 |
| DRV             | 2017     | IRID      | 90×300×90         | --          | 70 Gy/h | Wired                 |
| ROV             | 2017     | IRID      | 130(D)×300        | 2           | 200 Gy  | Wired                 |
2.2. Development status of nuclear emergency response robot in China

The research on nuclear emergency response robot in China started in the late 1980s. With the support of the 863 intelligent robot projects, the related research on nuclear emergency response robot technology was carried out. In 1994, Shenyang Institute of Automation Chinese Academy of Sciences, and Shanghai Jiao Tong University joined forces with several domestic institutes to develop the ‘Warrior’ robot [44], as shown in Fig 3. The robot is the first nuclear emergency response robot developed independently in China, which can monitor, inspect and deal with simple accidents on the background of practical application in nuclear industry. Warrior’s size is 710 mm(W)×500 mm(L)×1600 mm(H), weight 420kg. It supports both wired and wireless communication mode, the wireless communication control distance can reach 100 meters. It can climb 40 degrees stairs and cross 25 cm height obstacles. Limited by the domestic nuclear radiation hardening technology at that time, the radiation tolerance of Warrior robots is not strong.

In June 2009, a serious accident occurred in an irradiation plant in Qi County, Henan Province. After the accident, the response robot developed by Southwest University of Science and Technology entered the accident site, successfully solved the problem, and dragged out the robot which had been damaged by radiation. In November of the same year, a similar accident occurred in Fanyu District of Guangzhou City. The response robot developed by Southwest University of Science and Technology successfully completed many emergency tasks such as cutting, handling, clearing and assembling on the scene of the accident. Figure 4 is the accident scene.
Many institutes in China, such as Southeast University, Beihang University and China General Nuclear Power Corporation (CGN), have also carried out research on nuclear emergency response robots. The robot developed by Southeast University is mainly for nuclear detection and disposal [46], the robot developed by Beihang University is mainly for radiation detection and radioactive contamination sampling in highly radioactive areas [47], and the robots developed by China General Nuclear Power Corporation are mainly for maintenance and emergency disposal in nuclear power plants [48-49]. The robot developed by China Institute for Radiation Protection (CIRP) is mainly aimed at emergency monitoring in highly radioactive environment [50]. These robots are shown in Fig 5.

![Robot Images](image1.png)

**Figure 5.** Domestic robots

### 3. Requirements and development trend for nuclear emergency response robot

#### 3.1. Requirements for nuclear emergency response robot

Historically, emergency rescue personnel will use nuclear emergency robots to enter the accident scene after nuclear accident. However, several nuclear emergency rescue processes show that the use of nuclear emergency response robots is not ideal. The main reason is because of the complex situation after the nuclear accident.

Taking the use experience of the nuclear emergency response robot after the Fukushima nuclear accident as an example, the most obvious accident site characteristic after the nuclear accident is high radioactivity. A large amount of alpha, beta, gamma and neutron radiation will be produced by the radioactive material. Emergency workers are affected by radioactivity and often do emergency work at a distance. At meanwhile, it may encounter explosion, fire, flood and other situations, which make it difficult for emergency personnel or machinery to enter the accident site to carry out emergency work. What is more, the thick reinforced concrete sealing structure is often used in the nuclear facilities, the electromagnetic shielding effect inside and outside the building is obvious. After the accident, the wireless signal is difficult to send from the inside of the facilities to the outside world.

Combining with the characteristics of the nuclear accident scene and the experience of using the nuclear emergency response robot, the demand characteristics of the nuclear emergency response robot can be summarized as follows:

1. Strong radiation tolerance;
2. Strong athletic ability;
3. Adaptability to complex environment such as high temperature, high humidity and flooding;
4. Monitoring and emergency response;
5. Wired and wireless communication.

#### 3.2. Development trend of nuclear emergency response robot

Since the Fukushima nuclear accident, the development trend of nuclear emergency response robot in the world is becoming more and more small, modular, intelligent and universal.
3.2.1. Miniaturization and modularization. During the emergency work of Fukushima, JAEA found that the early design of the nuclear emergency response robot is bulky, which is neither convenient for transportation nor actual use. Subsequently, the original JAEA-3 robot is modified, each functional unit module of the robot is split and miniaturized [51], as shown in Figure 6. Unit 0 is motion module equipped with camera and radiation detection instrument, Unit 1 are three-dimensional camera and detection module, Unit 2 is remote control unit, Unit 3 are cable and winding equipment, Unit 4 is battery module. The weight of each function module is strictly controlled less than 35kg, so that it can be carried by one people. At least two functional modules make up a robot, the total weight of the robot does not exceed 70 kg, and it can be carried by two people. At the same time, each module is very easy to install and disassemble.

![Figure 6. Modularization for robot units](image)

3.2.2. Intellectualization. According to the working characteristics of emergency response robot, the intelligence of robot (operation, movement, task handling, etc.) has always been the development trend of emergency response robot. As early as 1998, Pioneer robot in the United States used 3D virtual reality technology, trying to use the minimum number of cameras to achieve the scene of three-dimensional mapping, and according to the three-dimensional mapping to provide robot trajectory planning and navigation. At present, many optimal trajectory planning algorithms, including predictive control algorithm, unpredictable control algorithm and bee algorithm, have been used to calculate the optimal trajectory automatically [52]. At the same time, the technologies of simulation, virtual reality operation platform and artificial Bionics are also widely used in nuclear emergency response robot [53].

3.2.3. Generalization. One of the characteristics of nuclear accidents is the low frequency. Several particularly serious nuclear accidents in history are several years apart, and most of the past nuclear emergency response robot did not use general components. The PackBOT and Quince robots, which were widely used in the early days of the Fukushima nuclear accident emergency work, were transformed by general components. Since 2013, IRID has widely used the general technologies of industrial robots, different types of nuclear emergency response robot also have many general components use each other. Generalization technology not only reduces the technical difficulty of development, but also improves the practicability of the robot.

4. Analysis of the key technologies of nuclear emergency response robot

4.1. Radiation resistance technology
The biggest difference between nuclear accidents and other accidents is that there are a lot of radioactive materials and radioactive rays around the site of nuclear accidents. The radiation resistant
technology is one of the key technologies of nuclear emergency response robot. There are mainly three ways to improve the radiation tolerance.

1. Selection and screening of radiation resistant components;
2. Radiation hardened circuit design;
3. Shielding materials.

4.1.1. Selection and screening of radiation resistant components. The internal transistors of integrated circuits in semiconductor electronic components mainly include bipolar transistors, junction transistors and MOS transistors. Among them, bipolar and junction transistors have better gamma rays radiation resistance than MOS transistors [54]. However, MOS transistor integrated circuits are most widely used in commerce. With the development of MOS radiation resistance technology, many MOS integrated circuits have high radiation resistance, such as aerospace grade components. In addition, sensitive components such as cameras, batteries and so on, which are commonly used in nuclear emergency response robot, also need to be screened for products with strong irradiation resistance.

4.1.2. Radiation hardened circuit design. Radiation hardened circuit design mainly uses the methods of reduction design, tolerance design and redundancy design in the process of circuit design to improve the reliability of the circuit in the irradiation environment.

Redundant design can improve the radiation tolerance of the circuit. For the hardware and software system, when the radiation leads to performance degradation, the circuit system with excessive performance can still work normally [55].

4.1.3. Shielding materials. Radiation shielding materials are the most commonly used anti-nuclear reinforcement methods for radiation protection of sensitive circuits and devices. Gamma rays protection is commonly shielded by heavy metals such as lead, tungsten and tantalum. However, the shielding effect of the same material on different energy rays is different. For example, when the intensity of gamma rays is reduced by one order of magnitude, 4 cm thick lead is needed for 60Co sources, and 2 cm thick lead is needed for 137Cs sources [56]. Boron-containing materials are often used to shield neutron rays because of their wide neutron capture spectrum and good neutron absorption capacity.

4.2. Communication technology
Most of the nuclear facilities are complicated in structure, and nuclear accidents are complicated at the site. Therefore, reliable communication technology is one of the key technologies of emergency response robot. With the development of wireless communication technology in nuclear environment [57], remote control technology combining wired communication with wireless communication is often used in nuclear emergency response robot.

In wired communication, wired cable is the medium to provide energy and communication. The design of small flexible winding unit and efficient DC-AC power module can effectively improve the carrying capacity of cables [58]. In wireless communication, relay communication combines WDM (wavelength division multiplexing) and LTE (long Term Evolution) wireless communication technology, one relay can communicate with multiple robots wireless, and increase the use of relay, up to 50 km long-distance communication can be achieved [59].

4.3. Radiation detection technology
Combining radiation detection technology, such as gamma radiation field detection technology, with 3D virtual reality technology, it can provide all-round radiation distribution in nuclear accident scene, and provide information to support emergency work. The GM tube can only detect the dose rate of gamma radiation, however, if the autonomous learning algorithm is added to data analysis, combined with the trajectory analysis technology of the robot and the video virtual reality technology, the GM
tube can be used to rapidly measure the gamma radiation distribution in the nuclear accident scene [60].

4.4. Thermal protection technology
The high temperature environment that may occur in the nuclear accident site has a serious impact on sensitive parts such as circuit parts and motor components. Effective thermal protection technology is one of the key technologies of nuclear emergency response robot.

Thermal protection technology can be divided into active cooling and passive cooling according to different cooling modes. Active cooling technology has high heat dissipation efficiency. Additional refrigeration devices need to be used as cold source [61], which can easily increase the volume and weight of the robot system. Passive cooling technology, such as the use of phase change materials [62], has better radiation resistance, higher chemical stability, and does not require additional energy supply.

5. Nuclear emergency fire fighting robot
The project team has designed a nuclear emergency fire fighting robot, which is used to extinguish the fired material in nuclear environment. The main structure is shown in Fig 7. The robot's locomotion mechanism is made up of retractable tracks or wheels and can be selected according to the road conditions at the accident scene. The detection unit includes gamma radiation detection, temperature and humidity detection, infrared imaging detection, video monitoring and range finder. The seven axis manipulator can take fire extinguishing agent and cover the fire source with fire extinguishing agent. In order to improve the radiation resistance of the nuclear emergency fire fighting robot, the electronic components of the whole robot are integrated in a small printed circuit board shielded by special material, and installed on the back side of the loading platform of the robot. Robot communication using wired and wireless way, the cable is 100 meters long, wireless communication distance up to 200 meters.

![Figure 7. Three-dimensional structure of nuclear emergency fire fighting robot](image)

6. Conclusion
This paper reviews the research and application of nuclear emergency response robot after major nuclear accidents in history. According to the application of nuclear emergency response robot, the demand characteristics of radiation resistant, motion performance and environmental adaptability are summarized, and the development trend of miniaturization, modularization, intelligence and generalization is summarized. Based on the research situation at home and abroad, the key technologies of nuclear emergency response robot which are different from the general robot have been summarized, including radiation-resistant technology, communication technology, radiation
detection technology and thermal protection technology. Finally, a nuclear emergency fire fighting robot designed by this project team is introduced briefly.

Since the Fukushima nuclear accident, the managers and staff of nuclear facilities in various countries are increasingly accepting nuclear emergency response robot. Chinese institutes should keep up with the development trend of nuclear emergency response robot, master the key technologies, and study the nuclear emergency response robot with independent intellectual property rights to prevent trouble before it happens.

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