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# DEVELOPMENT OF DISASTER PREVENTION SYSTEM FOR ACCELERATOR TUNNEL*

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*Abstract*

In an enclosed space such as a particle accelerator tunnel, ensuring worker safety during a disaster is an issue of critical importance. It is necessary to have a system in which the manager can know from outside the tunnel whether there is any worker left behind and whether the worker is escaping in the right direction. Because a global positioning system (GPS) is not available in the tunnel, we are developing a disaster prevention system that uses Wi-Fi to transmit the positioning of workers, and two-way communication. The Wi-Fi access point (AP) installed in the tunnel should be radiation resistant. Additionally, the equipment carried by the worker is convenient and easy to carry. We tested the radiation hardness of commercial AP devices and developed a smartphone application to perform location information transmission and simultaneous character transmission. In 2019, we installed the system on the J-PARC Main Ring and started its operation. In this paper, the functions of the developed system and its prospects are described.

## INTRODUCTION

The Great East Japan Earthquake that occurred in 2011 marked the beginning of this research. One of the authors was affected in the J-PARC Main Ring (MR) tunnel. Unfortunately, it is difficult to say that appropriate evacuation guidance was provided at that time. The major issue is that it is not possible to know in real-time where the workers are and in which direction they are evacuating in a tunnel with a length of approximately 1.6 km.

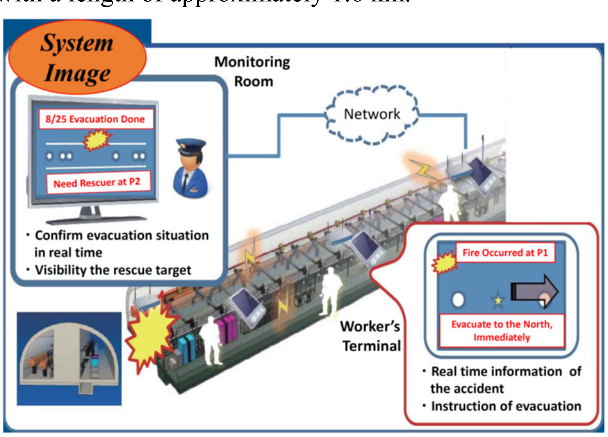


Figure 1: System image.

The current safety system in accelerator tunnels focuses on radiation exposure control and tunnel entry/exit control. Entry/exit control, known as the Personnel Protection System (PPS), ensures that no one is in the tunnel during beam operation. J-PARC also adopts PPS management [1], and it is obligatory to carry a key and an alarm dosimeter for each person entering the tunnel. The PPS key is used to unlock the double door to enter and permit beam operation. If all keys are not returned, the beam is not licensed. Because the number of keys is the number of people entering the tunnel, the manager on the ground can know the number of people, but not where they are.

Figure 1 shows the system to be developed. To suppress ground motion, an ILC tunnel with a total length of 20 km is planned to be built in a mountainous area. Evacuation buildings are built only every few kilometers. When a disaster occurs in a long tunnel, there is a need for a system that allows to observe the movements of all workers in real time. It is also desirable for outside managers and inside workers away from the disaster site to be able to know in detail what is happening in the tunnel. It is necessary to prepare a system that allows all members to share information, including photographs. By knowing the situation inside the tunnel in detail, the manager can provide appropriate evacuation guidance. Units for people in need of rescue can also be dispatched if necessary.

A similar safety system has already been used in many other locations where GPS is not available, such as tunnel construction sites. The authors have been developing an indoor positioning sensor network technology using mobile terminals [2]. We worked on the development of this disaster prevention system by utilizing previous research and applied its technique to J-PARC Main Ring.

## IRRADIATION TEST

Many access points (APs) must be set to build a Wi-Fi network in a large accelerator tunnel. Even in an electron accelerator, it is necessary to confirm the radiation resistance of AP. In 2015, we set up commercial and custom APs in the MR tunnel and performed operation tests in a radiation environment. The radiation monitor (RadMon) [3] developed at CERN near the collimator was used to estimate the radiation dose. APs were placed near the RadMon, and computers and APs were connected by wire so that the status of APs could be monitored even during beam operation. Immediately after the beam operation started, all APs broke. The radiation dose was estimated to be 1 Gy or less from the detection limit. J-PARC is a proton accelerator, and the ratio of neutron rays to gamma rays

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near the collimator was estimated to be approximately 1: 1 in the simulation.

A test was performed at a cobalt-60 irradiation facility to investigate the effect of gamma rays only. Six APs were irradiated for 1 h at doses of 1, 10, 100, and 1000 Gy/h from the far side of the radiation source. Three of the six APs were tested with the power off during irradiation, and the other three were tested with the power on. It was confirmed that all six APs worked without problems with irradiation up to 100 Gy, and three of them failed at 1000 Gy. From this result, it can be considered that the failure in the MR is caused by neutrons. We also found that turning off the power during irradiation extended the life of the AP by an order of magnitude.

To confirm the effect of neutrons if the AP power was off, we brought them again to the MR tunnel and performed a test. Nine APs were arranged in the MR tunnel to form a network, and one AP was installed near RadMon in a high-radiation collimator. The power line and wired LAN were connected in series, and nine power supplies were turned off during the beam operation. Confirmation of AP failure was performed once a week on a maintenance day by entering the tunnel. Figure 2 shows the radiation dose obtained using the RadMon. In the two years from the summer of 2016 to the summer of 2018, a total dose of 1000 Gy was applied. During this time, nine APs operated without any problems. Subsequently, tests in the MR tunnel and gamma-ray irradiation facility were continued, and it was confirmed that the APs used had a radiation resistance of approximately 2000 Gy regardless of the presence or absence of neutron rays when the power was turned off.

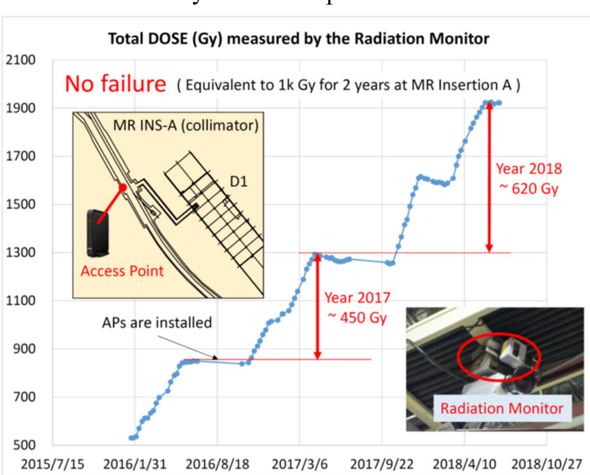


Figure 2: Radiation tests in J-PARC MR.

## PREVENTION DISASTER SYSTEM

Since it was established that a Wi-Fi network could be constructed in the tunnel, 30 APs were installed at 50 m intervals over the entire J-PARC MR tunnel. In 2019, we prepared a dedicated smartphone and wearable device, and introduced the developed application. From an administrative viewpoint, the application is not installed on a personal smartphone. Wearable devices were introduced with the assumption that workers will be able to easily notice an emergency notification during work, and simultaneously, they will also help to manage the physical condition of workers in the future. A smartphone and a wearable device were prepared as a set and connected by Bluetooth.

Figure 3 shows the screen of a smartphone, the WEB screen that can be viewed on each PC, and the state of the prepared smartphone cart. The position of the workers in the tunnel was defined as the location of the nearest AP. It is technically possible to determine a more precise position using the signal strength, but this has not been introduced at present. For information sharing, we developed an application similar to LINE. It is possible to attach photos taken with a smartphone, and stamps are also available. All the information was recorded and stored on a dedicated server in the network. The server used in J-PARC, including the OS (Linux), was used. We developed server and smartphone applications in that environment, and even installed and managed them.

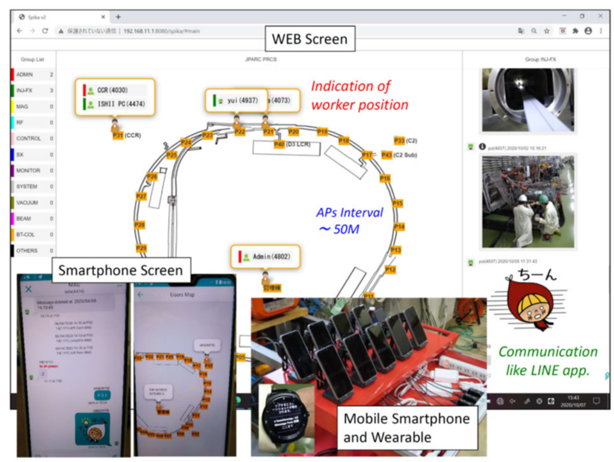


Figure 3: Our prevention disaster system.

If the system goes down due to a power outage, it will not be useful as a disaster prevention system. During the great earthquake, emergency power generation was activated, and the lamp in the tunnel was turned on. However, because emergency power generation is switched after a power outage occurs, a momentary power failure time is created, and the PCs and servers are stopped. Owing to the recent remarkable development of lithium batteries, we have built an independent power supply network through batteries. We used a large power capacity of 2 kWh and a general-purpose battery of 0.7 kWh and confirmed operation for 12 h or more in the test.

To extend the life of the APs against radiation, it is necessary to turn off the power during beam operation. We decided to install a dedicated AC line that supplies power to the 30 APs into the tunnel and turn that line on and off from outside the tunnel. We also developed and introduced a PLC-based device that automatically switches the AC line ON/OFF in synchronization with the MR area integration. Beam operation cannot be performed unless the MR area is integrated, and tunnel entry cannot be performed unless the MR area is detached. This made it possible to use the disaster prevention system even for weekly maintenance and short-term emergency entry.

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## ADDITIONAL FUNCTIONS

The system would be useful in an emergency only if the user is accustomed to daily use. A good example is author's own experience during the great earthquake evacuating from the entrance 400 m away, even though he knew there was an emergency exit nearby. We add various functions so that this disaster prevention system can be used during daily work in the tunnel.

Figure 4 shows how the newly introduced video call function is used to remotely support work in the tunnel. Communication is one-to-one, but multiple lines can be connected to enable advanced work support. There are places in the tunnel where the amount of residual radiation is high, and we expect that the remote working will have an effect suppressing radiation exposure. It also enables a 360-degree camera connection. This can be used for unmanned monitoring of equipment in tunnels.

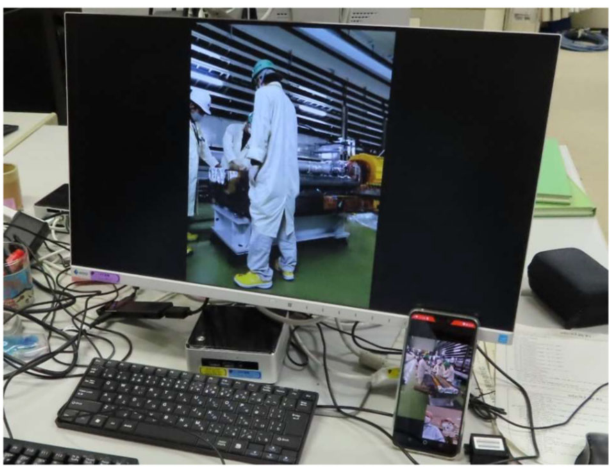

Figure 4: Video call function that provides work support remotely.

We also added a function to connect a radiation counter to a smartphone and automatically recorded the measured value and location inside the tunnel. The radiation counter used was Hamamatsu's C12137 (30 keV – 20 MeV, 0.01 – 100 µSv/h) capable of a USB output. Figure 5 shows the results going around the MR tunnel. High radiation doses are recorded in the collimator section and slow extraction section, which are high-dose areas. Because data can be obtained in real time, the manager can proceed with the radiation work while checking the exposure dose of the worker.

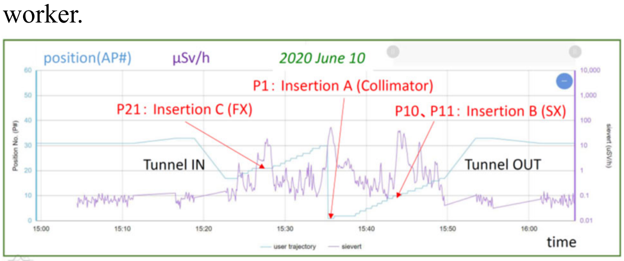


Figure 5: A demonstration of going around the MR tunnel with the smartphone connecting the radiation counter.

## FUTURE PROSPECTS

Any worker in the tunnel can use a smartphone for disaster prevention. However, mobile phones with disaster prevention applications have not yet become mandatory for tunnel entry. To make them mandatory, it is essential to link smartphones and workers. Furthermore, it is necessary to have a system that cannot be entered if it is not carried out. Technically, it is thought that it can be realized by introducing features such as face recognition, which is currently under consideration.

The current major issue is that the number of users is not increasing. For this reason, we are working to enhance various functions to improve daily convenience. Additionally, automatic acquisition of earthquake information, physical condition management of workers, and duplication of systems have not been implemented. Some of these features involve security issues; therefore it is necessary to proceed cautiously with their development.

Finally, integration with existing PPS systems has been discussed. It is difficult to verify that the integrated system ensures security because it is not permissible to have a security gap. More than 15 years have passed since J-PARC was built, and it is like performing safety checks that have been accumulated. In the current situation, the hurdles are high, and it can be said that it is difficult to realize. However, by accumulating achievements at J-PARC, we think it will not be difficult to incorporate it as a safety system from the beginning of the construction of a new accelerator facility such as the ILC.

## SUMMARY

We developed a disaster prevention application that enables two-way communication and shows the worker's position in the tunnel. We chose Wi-Fi technology, and the application can be used in a closed space such as an accelerator tunnel. A commercial access point (AP) was tested in neutron and gamma rays radiation environment, installed in a J-PARC MR tunnel, and put into operation in 2019. All equipment in the system, including the server, is powered through a lithium battery, and measures are taken in the event of power outages. In addition, video communication and radiation measurement with position data were also implemented. To increase the number of users, we will continue to improve the convenience of daily use to prevent disasters.

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