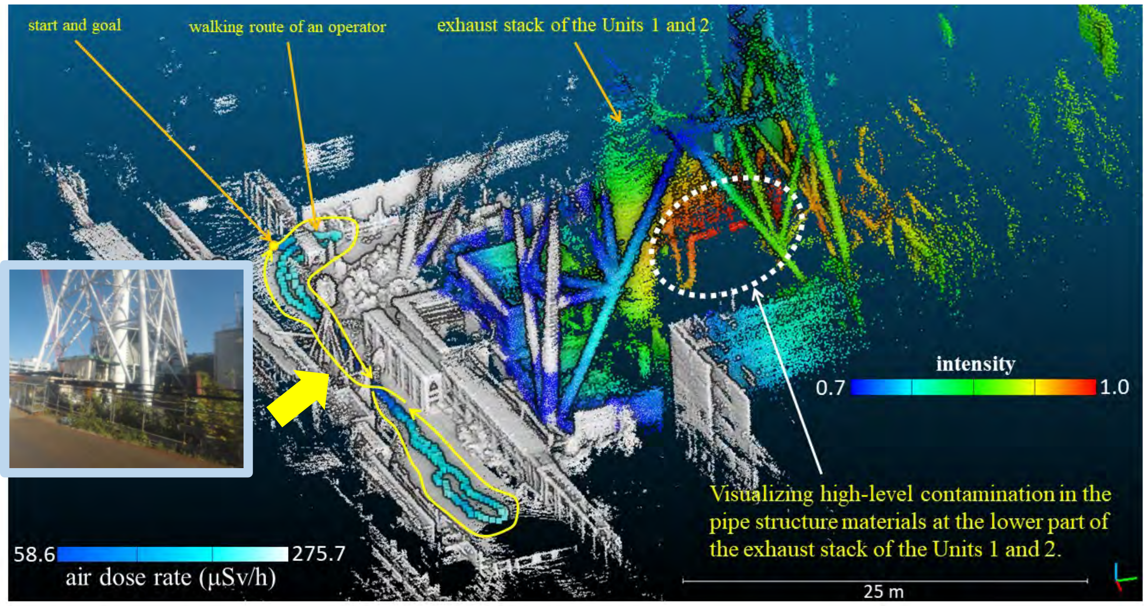


Fig.1 Three-dimensional map that visualizes air dose rates and high-level contaminated parts around the exhaust stacks of the Units 1 and 2, Fukushima Daiichi Nuclear Power Station.

"Visualizing" distribution of radioactive contamination at the decommissioning site by three-dimensional map

— By grasping invisible radioactive contamination in virtual space, radiation exposure of workers was reduced. —

Collaborative Laboratories for Advanced Decommissioning Science (CLADS), Sector of Fukushima Research and Development, Japan Atomic Energy Agency (JAEA) has developed an integrated Radiation Imaging System (hereafter referred to "iRIS"*1)), which combines three kinds of instruments, i.e., 1) a Compton camera*2) which visualizes radioactive substances, 2) a three-dimensional laser range scanner (Light Detection and Ranging, hereafter referred to "3D-LiDAR"*3)), and 3) survey meters which measure radiation dose rate. The iRIS is a system that draws three-dimensional maps of the decommissioning site in the Fukushima Daiichi Nuclear Power Station (hereafter referred to "1F"), Tokyo Electric Power Company Holdings, Inc (TEPCO), in a virtual space. Thereby, contaminated parts can be observed from arbitral direction.

◈ What is the iRIS system?

In the 1F site, contamination is three-dimensionally widespread, because radioactive substances are adsorbed on various objects such as many instruments, rubble, and building. Under such circumstance, radiation is flying around everywhere, so that it has been difficult to precisely know the distribution of radioactive contamination only by measuring radiation dose rate “in a point” using conventional survey meters. Furthermore, it took long time to measure radiation in many spots using survey meters. In addition, there has been a serious problem that the workers may be exposed to radiation.

In order to solve these problems, the following systems have been developed this time.

① Three-dimensional model for the decommissioning site was constructed by simultaneously conducting the self-position-estimation and the environment-map-making using 3D-LiDAR (SLAM[*4]: Simultaneous Localization and Mapping). Using this system, information on self-position of the moving system and its posture are recorded one by one.

② The above information is synchronized with the information on the flying direction of radiation obtained at each spot using a Compton camera. Thereby, three-dimensional visualization of contamination based on the data obtained while moving has become possible for the first time (Fig. 2).

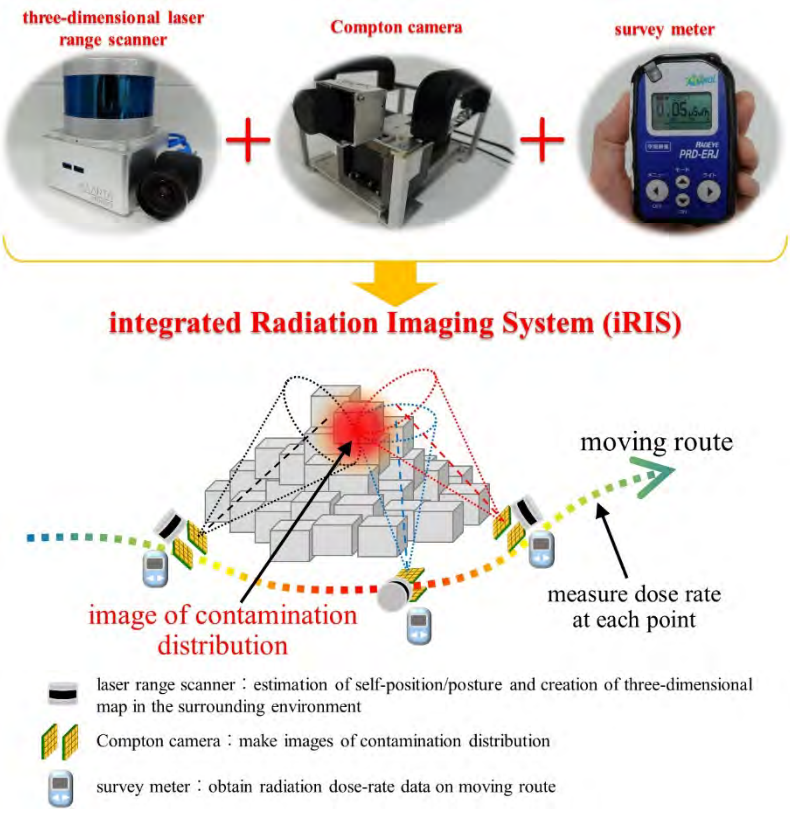


Fig.2 Construction of “iRIS” that combines three instruments.

③ Radiation dose rates on walking routes are recorded one by one using survey meters.

④ Special software (COMRIS) has newly been developed, where three-dimensional contamination map can be drawn by just a few clicks using multiple sensor information like ①～③ as input files.

Based on these developments, it has become possible to display radiation dose rates and highly contaminated spots in a virtual space on a computer as a color contour diagram[*5)].

◈ Results of demonstration tests using the “iRIS”

The demonstration test using the “iRIS” was conducted in November 2020 near the exhaust stack of the Units 1 and 2 at the 1F site, in cooperation with the TEPCO. Since the radiation dose rates in the lower parts of the exhaust stack were high, it was difficult for workers to enter there. In conventional spot-measurements using a Compton camera, we had to measure the objects from many spots, so it was necessary to repeat setting/moving the Compton camera and measurements.

On the other hand, using the “iRIS”, the measurements were completed only within 5 min by moving on a low radiation-level route without entering the lower parts of the exhaust stack. From the data obtained by these measurements, we succeeded in drawing three-dimensional maps that visualize the highly contaminated spots.

Figure 1 in the top page shows a three-dimensional contamination map, where the distribution image of radioactive cesium that is the main origin of the contamination is projected in red color to the three-dimensional model under the exhaust stack. This is the first result in which the distribution of contamination was visualized by continuous measurements while moving without approaching the high-level contaminated site in the 1F. On the map, air dose rates on the walking route of the operator are also displayed.

This three-dimensional map can be seen from arbitral direction using a PC or a tablet terminal. Therefore, we can observe the 1F decommissioning site with hotspots from 360-degree direction like a bird’s-eye view. Furthermore, using commercial goggles for virtual reality (VR), we can experience the decommissioning environment reproduced in the virtual space together with the distribution of contamination, thereby it can be used for the pre-training for workers.

In the future, by loading the “iRIS” on robots, it will become possible to easily obtain three-dimensional contamination maps inside high radiation dose area like nuclear reactor buildings in which workers are difficult to enter. These maps are expected to contribute to the reduction of radiation exposure for workers and formulation of the decommissioning plans.

◈ Evolving “iRIS”

In the future, JAEA will proceed to search the contamination spots in further deep regions inside the 1F reactor buildings by loading the “iRIS” on robots. By using “iRIS”, we need not to stop a robot at each measurement, so it will become possible to obtain data on contamination distribution and dose rate in a wide area in a short time. In addition, further developments of the “iRIS” are expected. For example, by reproducing in a virtual space the 1F working site and distribution of contamination, the method for setting radiation shields, and the effects of decontamination on the reduction of air dose rates will be simulated in advance. Through this system, in order to contribute to the effective elimination of contamination and lowering of radiation dose rates, we aim for presenting workers three-dimensional maps with which contaminated region and dose-rate distribution in buildings can be intuitively looked over. We will continue these research and development in cooperation with TEPCO.

The application of “iRIS” is not limited to decommissioning sites. Up to now, drone system equipped with a Compton camera has been developed in cooperation with Chiyoda Technol Co. for the purpose of visualizing decontamination in the difficult-to-return zones, Fukushima Prefecture. We succeeded in visualizing hotspots deposited in the difficult-to-return zones (Press release on May 9, 2019). Now, this system is commercialized by the Chiyoda Technol Co. Further, the development of vehicles equipped with a large Compton camera “iRIS-V” (Press release on March 27, 2020) is being continued, and the performances of the vehicles are now being improved. In addition, these technologies to visualize radioactive substances are expected to be applied to the security use such as surveillance of terrorism using nuclear materials at large events.

The development of “iRIS” is a project which is being promoted mainly by young researchers. Each researcher is making effort to collaborate with researchers in the other fields beyond the specialty. Thereby, JAEA aims to establish unprecedent new technology for radiation imaging.

【Terminology】

***1) iRIS (integrated Radiation Imaging System)**

iRIS is a radiation imaging system that combines multiple sensing functions. Specifically, it consists of a combination of Compton camera, survey meter, and SLAM device to visualize the distribution of radioactive substances in three dimensions. In addition, the system can be mounted on a drone or crawler robot to enable remote measurements, and VR goggles can be used to experience a three-dimensional reproduction of the work site. The iRIS is designed to create a "mirror world" in which the real work environment is reproduced in a virtual space for various verifications (Y. Sato, “A concept of mirror world for radioactive working environment by interactive fusion of radiation measurement in real space and radiation visualization in virtual space”, Physics Open, 7, 100070, 2021).

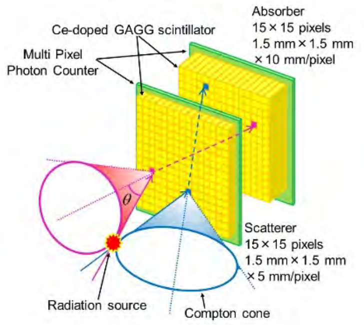
***2) Compton camera**

Gamma camera that is an instrument to visualize radioactive substances is roughly classified into “pinhole camera” and “Compton camera”. Although a pinhole camera is convenient, it is so large and heavy that it is not suitable for the measurements in narrow place. In Compton camera, the direction of a flying gamma-ray is determined by two parameters. One is the position where the incident gamma-ray (a kind of radiation) is interacted in each scatterer and absorber, and the other is the energy which these sensor materials receive. Since a Compton camera adopts a method where the position of radiation source is analytically determined, heavy radiation shield is in principle not necessary. Thereby, the camera can be made smaller and lighter. However, its development has been technologically difficult. Based on the Compton cameras developed by Hamamatsu Photonics K.K. and Waseda University, JAEA has newly made small and light Compton cameras that can be loaded on small robots and drones. The demonstration tests of the Compton camera were conducted at the 1F site.

(Explanation of right figure)

*Scintillator

Fluorescent material that emits light (scintillation light) by radiation. By converting scintillation light to electric signal, the number of radiation and its energy are measured.



*GAGG scintillator

One of the scintillator crystals. It is composed of gadolinium, aluminum, gallium, and garnet. Compared to conventional scintillator crystals such as sodium iodide (NaI) and cesium iodide (CsI), GAGG has high density, so highly sensitive measurements of radiation are possible even by a small crystal. In addition, since there is no anxious about humidity in air because it is not deliquescent, it can be used stably for a long time.

*Compton scattering and energy transfer in scatterer/absorber

A Compton scattering is a process where a photon (gamma-ray) interacts with an electron bound in an atom and loses a part of its energy. At that time, the lost energy is given to the electron. When this electron travels in a scatterer or an absorber, its energy is transferred to these materials.

***3) 3D-LiDAR (3D Light Detection and Ranging)**

One of the types of sensors to measure distance. By scanning pulse laser on an object, the distance is measured by the time until the reflected light returns. In the demonstration tests, the three-dimensional model in working environment was obtained by this sensor.

***4) SLAM (Simultaneous Localization and Mapping)**

A technology to simultaneously conduct self-position-estimation and the environment-map-making. Using cameras and laser scanners, self-position of the system and the surrounding information such as obstacles are simultaneously recognized. This technology is being applied to cleaning robots and self-driving.

***5) Contour diagram**

On a drawing, a line which connects points having the same value. When lines with the same value are drawn at a constant interval, the drawing is called isoline map. In an isoline map, the attribute and the distribution situation are contrived to be intuitively understandable. In order to make an isoline map easier to see, bands between lines are often colored step by step (color contour diagram).

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