RESIDUAL RADIATION MEASUREMENTS AT J-PARC MR USING THE ASTROCAM 7000HS NEWLY DEVELOPED RADIOACTIVE SUBSTANCE VISUALIZATION CAMERA

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Abstract

Mitsubishi heavy Industries, Ltd. (MHI) released the ASTROCAM 7000HS, a radioactive substance visualization camera. The ASTROCAM 7000HS incorporates the technologies for the gamma-ray detector used for the ASTRO-H satellite, which MHI has been developing under entrustment from and together with scientists at the Institute of Space and Astronautical Science (ISAS) at the Japan Aerospace Exploration Agency (JAXA), and the design was modified for use on land to commercialize the product [1]. MHI and Mitsubishi Heavy Industries Mechatronics Systems, Ltd. (MHI-MS) performed on-site residual radiation measurements at the 50 GeV Main Ring (MR) of the Japan Proton Accelerator Research Complex (J-PARC) under collaboration with the High Energy Accelerator Research Organization (KEK) and the Japan Atomic Energy Agency (JAEA) and succeeded visualization of radiation hot spots of the accelerator components. The outline of the ASTROCAM 7000HS, the measurement principle and the first measurement results at the J-PARC MR are described.

INTRODUCTION

MHI has been manufacturing X-ray and gamma-ray detectors on board ASTRO-H satellite by ISAS in JAXA. The detector, called "Si/CdTe Compton Camera", is based on silicon (Si) semiconductors and cadmium telluride (CdTe) semiconductors and has functions to image gamma-rays [2]. The technology of the camera has been developed in ISAS/JAXA for more than 10 years aiming at future astronomical satellites. By incorporating the technologies for space development in the device for use on land, MHI commercialized the ASTROCAM 7000HS, the first camera that can visualize radioactive substances.

ASTROCAM 7000HS was initially used for on-site gamma ray measurement in Fukushima Prefecture to visualize Cesium 134 and Cesium 137 (^{134}Cs, ^{137}Cs), release gamma rays featuring a high amount of energy ranging from approximately 600 to 800 keV. By using ASTROCAM 7000HS, we can measure every corner of the wide range of areas that may be contaminated and can avoid the risk that the individuals perform measurement could be exposed to radiation for a long time and some of the hot spots could be overlooked. These issues are same at the accelerator facilities those accelerate protons or heavy ions. Therefore MHI and MHI-MS performed on-site measurements by using ASTROCAM 7000HS at J-PARC MR and the first measurement results are described.

OUTLINE OF ASTROCAM 7000HS

Imaging Principle

ASTROCAM 7000HS (hereafter, ASTROCAM) incorporates Compton camera method. In this method, Compton scattering is utilized to image gamma rays. The camera has a pixel detector consisting of the scattering layer and the absorbing layer, as shown in Fig. 1. Gamma rays that enter the camera go through Compton scattering at the scattering layer, and the scattered gamma rays undergo photoelectric absorption at the absorption layer. The energy measured at the scattering layer is defined as (E1), the 3D coordinate position on the detector surface where Compton scattering occurred is defined as position vector (X1), the energy measured at the absorbing layer as (E2), and the position where photoelectric absorption occurred as (X2). The energy of gamma rays that enter is obtained by E1+E2. As for the direction of incoming gamma rays, it is estimated that they pass through one of the points along the ring of the cone shown in Fig. 1. The ring is obtained from the scattering angle (θ) calculated from the energy information and the central axis of the cone calculated from the position information.

If multiple gamma rays are detected from the same gamma ray source, the direction of incoming gamma rays can be obtained from the intersection point where the rings overlap. The intersection point of the rings is emphasized in red as the events of detected gamma rays increase and the images of gamma rays become clearer as shown in Fig. 2.

System Configuration

The overall system configuration and the basic specifications of the ASTROCAM are shown in Fig. 3 and Table 1 respectively.

In the camera unit there are 12 sensor layers in total, 8 layers of Si semiconductor for the scattering layer and 4 layers of CdTe semiconductor for absorbing layer. The sensitivity of the camera can be adjusted according to the application and the sensitivity can be increased to about

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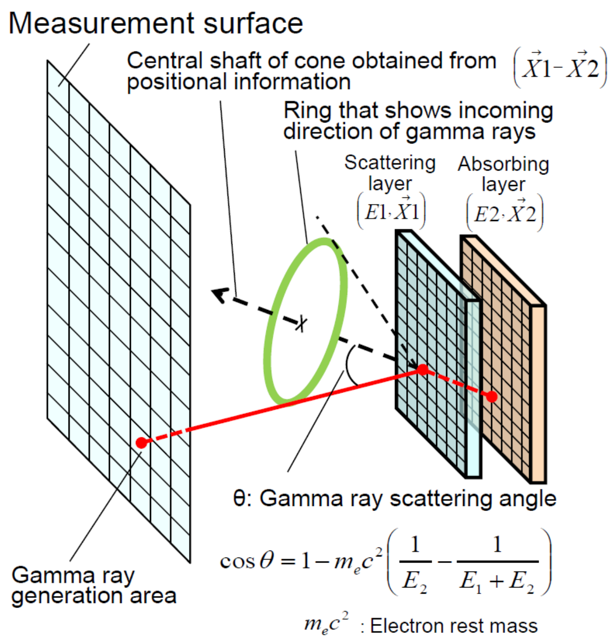

Figure 1: Imaging principle of Compton camera.

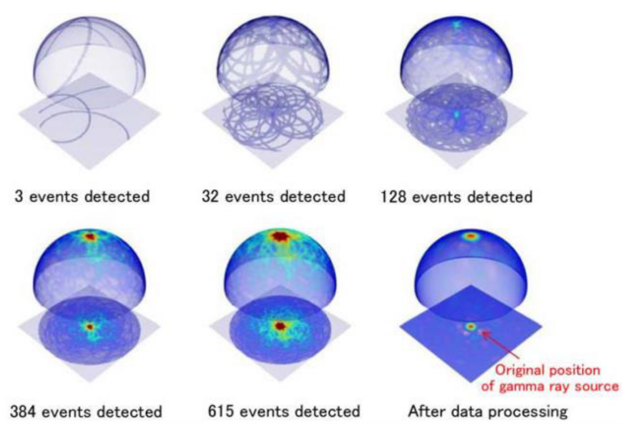

Figure 2: Changes of gamma image as increasing events.

16 times the current specification if the number of sensor layers is increased maximum. A fisheye visible camera is installed in front of the camera, and the direction of incoming radioactive rays is identified by superimposing the optical image of the fisheye camera over the gamma ray image.

The control unit houses a camera control circuit, a temperature control circuit, a high voltage control circuit, a power supply circuit, etc. The control unit features a safety design and constantly monitors temperature and humidity abnormalities and communication between the operation unit and the image processing unit. All measurements can be controlled on the user interface screen of a PC. Therefore, remote operation by PC is possible, reducing the exposure of measurers to radiation.

ON-SITE MEASUREMENTS AT J-PARC

During the accelerator shutdown period of J-PARC, on-site measurements were performed. The measurement was done just after the accelerator shutdown on December 2015. In this measurement the short half-life nuclides such as Cobalt 58 (^{58}Co) and especially Scandium 46 (^{46}Sc) are expected to detect. The nuclides expected to be measured are listed in Table 2. [3, 4]

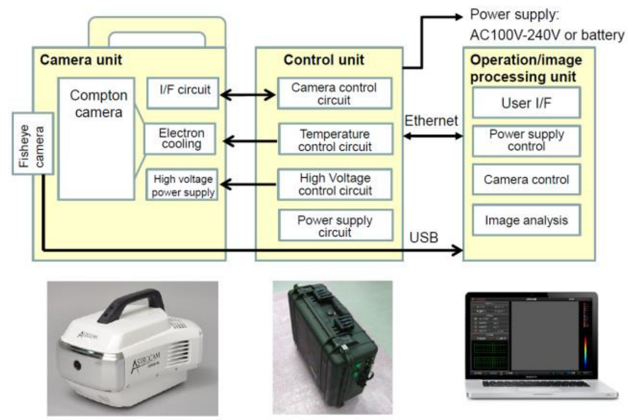

Figure 3: System configuration of ASTROCAM 7000HS.

Table 1: Basic Specifications of ASTROCAM 7000HS

Model No.	ASTROCAM 7000HS
Outer dimensions	L445 x W340 x H235 (mm) (Camera unit, excluding projections)
View angle	180 degrees (super wide) Detecting efficiency varies depending on the angle
Nuclide	12 types Can be selected by user
Energy resolution	2.2% (FWHM) at 662keV
Angle resolution	5.4° (FWHM) at 662keV ARM (Angular Resolution Measure) evaluation value
Weight	Approx. 8 to 13 kg (Camera unit) Depends on number of sensor layers inside the camera
Power supply	AC 100V to 240V / battery
Operating temperature	0 to +40℃
Storage temperature	0 to +50℃
Operating humidity	35 to 80% To be free from condensation
Accessories	Camera control box Notebook PC Measurement software

Table 2: Expected Nuclides to be Measured

Nuclide	Energy	Half-life
^{57}Co	0.122 MeV	272 days
Electron pair annihilation	0.511 MeV	--
^{58}Co	0.811 MeV	71 days
^{54}Mn	0.835 MeV	312 days
^{46}Sc	0.889 MeV	84 days
	1.121 MeV	84 days

Cobalt 57 (^{57}Co), Cobalt 58 (^{58}Co) and Manganese 54 (^{54}Mn) are estimated coming from iron used as radiation shields and support fixtures of accelerator components. Scandium 46 (^{46}Sc) is estimated coming from titanium used as vacuum beam pipes and flanges. ASTROCAM was placed inside the tunnel of J-PARC MR, near the iron absorber. There are stainless steel gate valve and titanium vacuum beam pipe and flanges downstream of the iron absorber. Distance between the iron absorber and ASTROCAM is 3 meter and its elevation is 0.8 meter from the tunnel floor. Measurement set-up is shown in Fig. 4. The radiation dose rate at the beam pipe surface was measured by a conventional radiation survey meter and its dose rate was around 250 μ Sv/h.

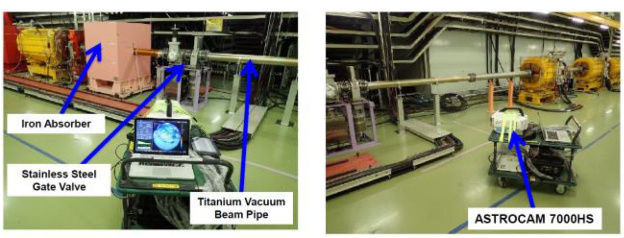

Figure 4: Measurement set-up inside J-PARC MR tunnel.

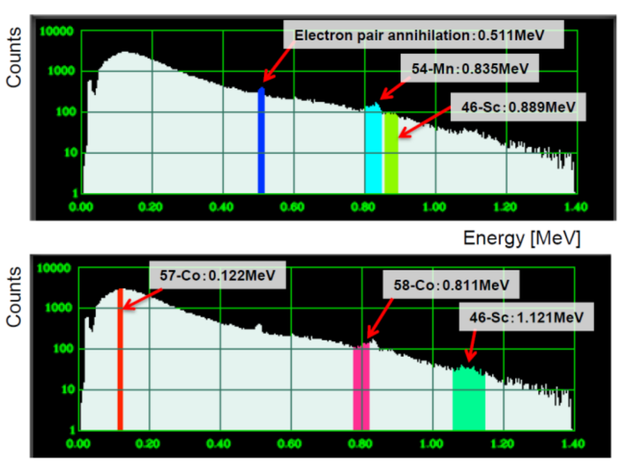

Figure 5: Measured time integrated energy spectra.

Measured time integrated energy spectra are shown in Fig. 5. Total measurement time is 30 minutes. In the energy spectra, targeted energy ranges listed in Table 2 are indicated by colour bars. Spectrum peaks of gamma rays from electron pair annihilation (0.511 MeV), ^{54}Mn (0.835 MeV) and ^{46}Sc (0.889 MeV) are observed.

Time integrated radiation images of each energy range are shown in Fig. 6 and 7. Radiation hot spots are indicated by colour contours. In the imaging software, a noise reduction scheme assuming an offset profile of the detector signal was applied. From Fig. 6 and 7, electron pair annihilation (0.511 MeV), ^{58}Co (0.811 MeV) and ^{54}Mn (0.835 MeV) images are observed coming from the iron used components such as the absorber and the gate valve. On the other hand, ^{46}Sc (0.889 MeV) image has some background noises but is observed obviously coming from the titanium beam pipe.

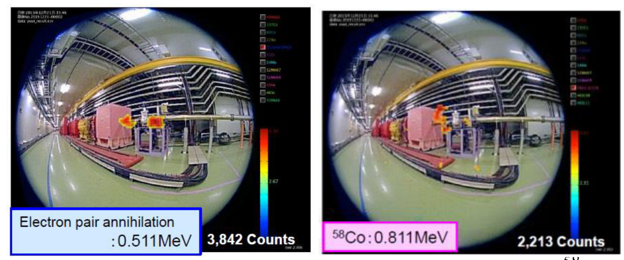

Figure 6: Images for electron pair annihilation and ^{58}Co.

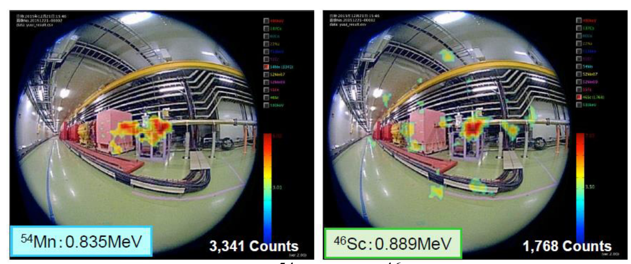

Figure 7: Images for ^{54}Mn and ^{46}Sc (0.889 MeV).

CONCLUSION

The first measurements using ASTROACM 7000HS at the J-PARC MR were performed and residual radiation visualization was demonstrated. In this measurements ASTROCAM succeeded to observe radiation images of electron pair annihilation, ^{58}Co and ^{54}Mn coming from the iron used components (the absorber and the gate valve) and that of ^{46}Sc (0.889 MeV) coming from the titanium beam pipe.

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