

Development of Cosmic Radiation and Energetic Particle Analyzing System: CREPAS

Hiroshi YASUDA^{1,*}, Kazuaki YAJIMA¹, Masashi TAKADA¹,
Tatsuhiko SATO² and Takashi NAKAMURA^{1,3}

¹ National Institute of Radiological Sciences, 4-9-1, Anagawa, Inage, Chiba, 263-8555, Japan

² Japan Atomic Energy Agency, 2-4, Shirakata-Shirane, Tokai, Ibaraki 319-1195, Japan

³ Tohoku University, Aoba, Aramaki, Aoba-ku, Sendai 980-8578, Japan

Information on the accurate spectrum of energetic cosmic-ray particles, particularly neutrons and protons, are important for radiological protection of aircraft crew. However, verification of cosmic radiation doses in aircraft is still difficult because detector signals attributing to different radiation components are mixed and hardly separated by means of a conventional, transportable radiation instrument. We have thus developed a new monitoring system "CREPAS" composed of a phoswich-type scintillation detector coupled with a high-speed data acquisition unit which can measure the waveform of 0 to 5 V signals from -20 to 400ns with 2ns intervals; the waveform data of 12-bit dynamic range are transferred to a personal computer via USB2.0 interface. The signal waveforms are analyzed on site in real time for discrimination of different radiation components such as neutrons, protons, muons/electrons and gamma rays. In order to examine its feasibility, CREPAS was exposed to accelerator beams and then used for cosmic radiation measurements at the summit of a high mountain and in a chartered jet aircraft. It was verified that this system can successfully measure cosmic-ray energetic neutrons (>10MeV) separately from other components. Determination of the precise energy spectra of neutrons and other components calls for further investigation.

KEYWORDS: cosmic-ray, neutron, radiation dosimetry, aircraft, CREPAS

I. Introduction

Aircraft crew are exposed to elevated levels of cosmic radiation that are high-energy galactic or solar origin particles and their secondary radiation produced in atmosphere and the aircraft. The International Commission of Radiological Protection (ICRP) has thus recommended that exposures to cosmic radiation in the operation of a commercial jet aircraft be part of occupational exposure.^{1,2)}

Since cosmic radiation particles have high energies, the intensity of radiation in an aircraft is mostly uniform and doses received by crew are predictable by numerical simulations using particle transport models. However, verification of the numerically predicted values by measurements is no doubt necessary to secure the reliability of assessments.³⁾

The radiation field at aviation altitude is complex as it comprises various particle species such as protons, neutrons, electrons, photons, pions and muons. In this field, detector signals attributing to different radiation components are inseparably mixed. In addition, large radiation monitors are hardly employed due to the restricted operational conditions of aircraft. Cosmic radiation measurement is then still difficult with a conventional, transportable instrument.

Under these circumstances, neutron energy spectra have

been measured onboard aircrafts and also at high mountains several times.³⁻⁵⁾ These measurements were performed with the multi-moderator spectrometer, so-called Bonner ball detector which can detect neutrons with energies from thermal to about 10MeV. However, the energy resolution of the Bonner ball detector is not good and very low for the higher energies greater than 10MeV. Because the Bonner ball detector requires an assumed initial guess spectrum which must depend on model calculation. Another question is contribution of cosmic-ray protons that may make similar signals of those of high-energy neutrons.

Therefore, we have developed a new, transportable monitoring system for in-flight measurement of energetic cosmic radiation components, with particular attention to detect high-energy cosmic-ray neutrons (>10MeV) separately from protons, keeping in mind the limited resources of a civilian aircraft.

II. Monitoring System

The system consists of a detector probe, signal processing unit, high-voltage supplier and a data analyzing program which runs on Windows PC. The detector probe, which can flexibly change, is a phoswich-type scintillation detector composed of a short-decay-time liquid scintillator covered with a long-decay-time plastic scintillator. The cross section is shown in Fig.1.

The phoswich detector gives different pulse shapes for charged and non-charged particles, respectively. Fast

* Corresponding author, Tel. +81-43-206-3233, Fax. +81-43-206-3542, E-mail: h_yasuda@nirs.go.jp

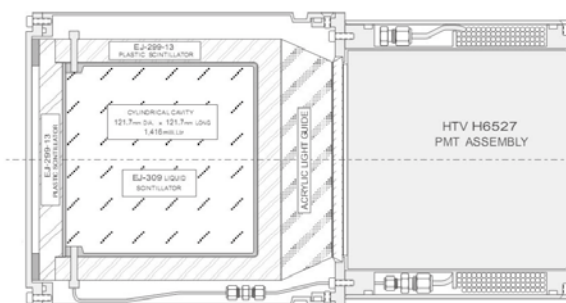


Fig.1 A cross section of the detector probe employed in the present study. The phoswich-type scintillation detector is composed of a 5-inch cylindrical liquid scintillator (EJ-309) covered with a 15mm-thick plastic scintillator (EJ-299).

neutrons make short signals from the inner liquid scintillator only, whereas energetic protons make longer signals coming from the outer plastic scintillator. Accordingly, we can discriminate different particle species by analyzing the pulse shapes.

In the present study, we employed a naphthalene-base liquid scintillator (Eljen Technology EJ-309) contained in an acrylic cylindrical case with dimensions of $\phi 121.7$ mm x 121.7 mm covered with 15mm-thick plastic scintillator (Eljen Technology EJ-299). The scintillator part is coupled with a 5-inch photomultiplier tube (Hamamatsu Photonics K.K. H-6527). Total weight is about 10kg. An original design of this probe was given by Takada et al.⁶⁾

The dimensions of the signal processing unit are W150mm x D150mm x H50mm and the weight is 1kg. This unit has a flash ADC with the sampling rate of 500MHz. It converts an analog signal (0 to 5V, negative) from the detector probe via a BNC cable to the digital data with 12-bit dynamic range from -20 to 400ns from the trigger point with 2ns intervals. The maximum processing rate at present is about 400 events per second. Signal voltage levels integrated for 2 ns each is transferred to a personal computer via USB2.0 interface. Though this unit cannot store all the waveform data in a high-intensity radiation field, it can count up to 10 MHz trigger events and record event numbers.

The converted digital data are processed on PC with an originally developed program which displays in real time two-dimensional plots of signal integrals for optional ROI regions. The program can discriminate different particle species according to the protocol which can be flexibly given by a user. For neutrons, the energy spectra can be derived by using the FERDO-U unfolding code⁷⁾. Data acquisition status can be monitored on display in real time.

This monitoring system is named as “CREPAS”, as an abbreviation of “Cosmic Radiation and Energetic Particle Analyzing System”. It is expected that combination of CREPAS and a Bonner ball detector enables us to evaluate wide-range energy spectra of cosmic-ray neutrons

from thermal to several hundreds MeV.

The feasibility of CREPAS was examined using accelerator beams and also tested for cosmic radiation measurements at the summit of a high mountain and in a chartered jet aircraft.

III. Results and Discussion

1. Responses to accelerator beams

Data acquisition abilities of CREPAS were examined using quasi-monoenergetic neutron and monoenergetic proton beams supplied at selected accelerators in Japan: Facility of Radiation Standard (FRS) of Japan Atomic Energy Agency (JAEA)^{8,9)}; Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) of JAEA⁹⁾; Cyclotron and Radioisotope Center (CYRIC) of Tohoku University¹⁰⁾; Research Center for Nuclear Physics (RCNP) of Osaka University¹¹⁾; and Heavy Ion Medical Accelerator in Chiba (HIMAC) of National Institute of Radiological Sciences (NIRS)¹²⁾. The locations of these facilities and maximum beam energies are shown in **Fig.2**.

Figure 3 shows the results as two-dimensional plots of signal integrals obtained for selected quasi-monoenergetic neutrons and monoenergetic protons supplied at particle accelerators in Japan; they are (a) 14.8MeV neutrons at FRS; (b) 45MeV neutrons at TIARA; (c) 65MeV neutrons at CYRIC; (d) 392MeV neutrons at RCNP; and (e) ~ 230 MeV protons at HIMAC. The X values of the figures are fast signal components (-20 to 100ns from the trigger point) and Y values are slow components (150 to 400ns) that come from the plastic scintillator. The voltage of photomultiplier was -1,200V and the trigger level was -0.1V in all the cases.

We can see that most plots of neutrons with the energies greater than 15MeV appear within a specific area (lower part of the plot area). In comparison with the results of proton beams (**Fig.3e**), we can expect that energetic cosmic-ray neutrons can be well discriminated from protons using this system.

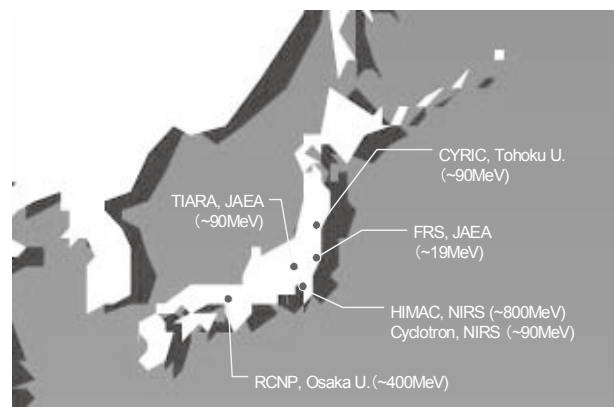


Fig.2 Particle accelerator facilities where responses of the new monitoring system (CREPAS) was examined using neutron or proton beams. The neutron energies range from 5 to 390 MeV.

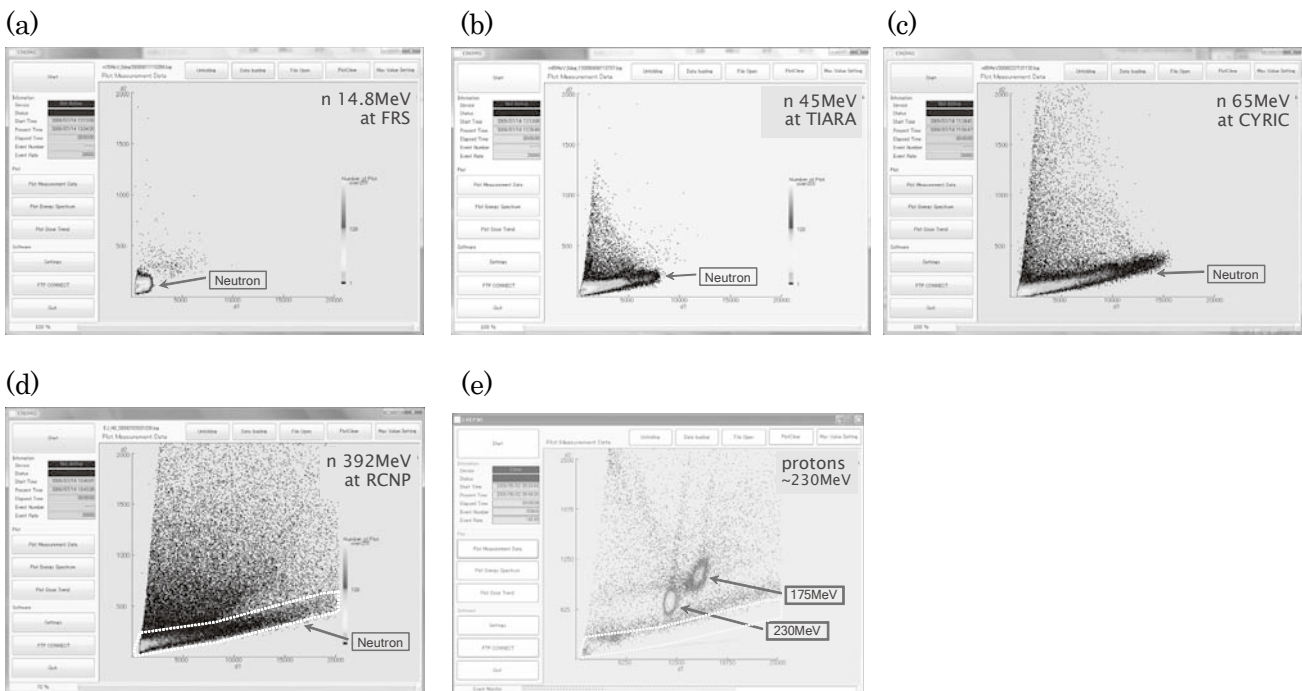


Fig.3 Two-dimensional plots on the CREPAS program of fast vs. slow signal components obtained for quasi-monoenergetic neutrons and monoenergetic protons supplied at particle accelerators in Japan: (a) 14.8MeV neutrons at FRS; (b) 45MeV neutrons at TIARA; (c) 65MeV neutrons at CYRIC; (d) 392MeV neutrons at RCNP; and (e) ~ 230 MeV protons at HIMAC.

2. Measurement at the summit of Mt.Fuji

The CREPAS was shipped to the Mt.Fuji weather station located at the summit of Mt. Fuji (3,776m in altitude), the highest mountain in Japan, and placed in a room at the second floor of the station for continuous cosmic radiation measurement during the summer season (July to August) in 2008 and 2009.

Two-dimensional plots of the CREPAS data obtained at the end of July, 2009 are shown in **Fig.4**. The count rate remarkably increased in comparison with that at the ground level, as expected from the model calculation.¹³⁾

According to this figure, we can expect that cosmic-ray neutrons with the energies (>50 MeV) can be well discriminated from other components such as protons. However, some area corresponding to lower energy neutrons overlap those of muons and/or electrons. Thus, more sophisticated protocols for particle separation are now under investigation.

3. Measurement in a jet aircraft

The CREPAS was flown in the sky to measure cosmic radiation at aviation altitude near Honshu Island, Japan using a chartered business jet aircraft (Mitsubishi MU-300) which is managed for scientific experiments or industrial use by Diamond Air Service, Inc.

The instruments were firmly fixed on to a rack placed at the cabin deck of MU-300. The aircraft departed from the Nagoya airport (35.3°N, 136.9°E) and flew north or south near the Chubu area in Japan.¹⁴⁾ Four flights in total were carried out for measurements with CREPAS from October

2007 to March 2008.

The results obtained in one north-route flight performed on 13th February 2008 are shown in **Fig.5**; the plot data were collected at 11km (36,000ft) in altitude for 20min over the Japan Sea near the Kanazawa prefecture.

As observed at the summit of Mt.Fuji (**Fig.4**), separation of high-energy neutrons from protons was good, though some overlapping for lower energy neutrons with muons or energetic electrons is found. Improvement of particle separation ability is required beforehand to derive the energy spectra of neutrons and cosmic-ray particles.

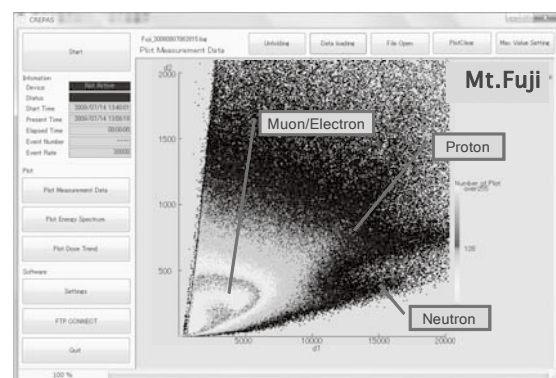


Fig.4 Plots of the signal integrals obtained with CREPAS placed at the Mt.Fuji weather station (about 3,778m in altitude). The data shown here were taken for about 4 days from 28 July to 1 August 2009.

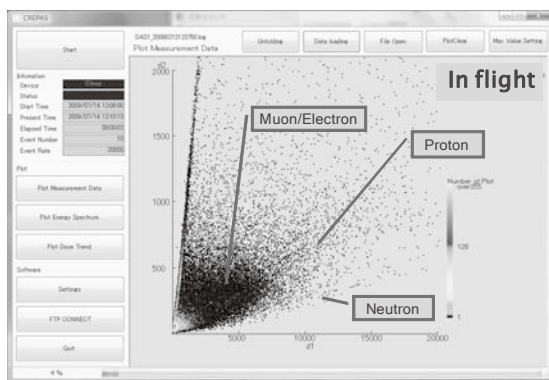


Fig.5 Plots of the signal integrals obtained with CREPAS in a business jet aircraft on February 13, 2008. The data shown here were taken at 11km in altitude for 20min over the Japan Sea near the Kanazawa prefecture.

IV. Conclusions

We have newly developed a transportable cosmic radiation monitoring system named as “CREPAS” for verification of cosmic radiation doses in aviation that are generally evaluated by numerical model calculations. According to the results of feasibility tests at the summit of Mt.Fuji and onboard a chartered jet aircraft, it was proved that this system can successfully measure high-energy cosmic-ray neutrons separately from protons by on-site pulse shape analyses.

Some difficulty still remains, however, in separating cosmic-ray particles, e.g. muons and lower energy neutrons. We try to solve these problems to derive the energy spectra of neutrons and hopefully those of other particle species, keeping in mind the restricted operational conditions; instruments employed should be safe, small, light weight, simple-handling and energy conservative for use in aircraft.

Acknowledgments

This study was supported in part by "Ground-based Research Program for Space Utilization" promoted by Japan Space Forum (JSF). Special thanks are given to Mr. Toru Fujishima (JSF) for his great support and patience. Measurements at the summit of Mt. Fuji were performed during the period in which the NPO “Valid Utilization of Mt. Fuji Weather Station” maintained the facilities, with support of the Watanabe Memorial Foundation for the Advancement of Technology. The exposures of proton beams were carried out as part of the Research Project using Heavy Ions at NIRS-HIMAC. The authors thank Dr. Shunji Takagi (MRI), Nobuyuki Sasaki (MRA), Kazuyoshi Nagasaka (MRA) and Dr. Yukio Sakamoto (JAEA) for their help in developing the data processing program; Prof. Mamoru Baba (CYRIC, Tohoku Univ.), Prof. Mitsuhiro Fukuda (RCNP, Osaka Univ.), Dr. Akira Endo (JAEA), Dr. Yoshiaki Shikaze (JAEA), Dr. Yoshihiko Tanimura (JAEA),

Dr. Masahiro Tsutsumi (JAEA) and Dr. Michio Yoshizawa (JAEA) for their kind, excellent cooperation in neutron exposures at the accelerator facilities: CYRIC, RCNP, TIARA and FRS.

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