Simulation calculation of cosmic radiation dose at latitude 0°

R Safitri, L Miska and E Yusibani
Physics Department, Faculty of Mathematics and Natural Science, Universitas Syiah Kuala, 23111 Indonesia

Corresponding Author: rsafitri@unsyiah.ac.id

Abstract. Cosmic radiation is a type of natural radiation that comes from outer space. Above sea level, the dose rate of cosmic radiation is 0.03 µSv and will increase rapidly with increase altitude, even reach 2.38 µSv at 10 km altitude. Cosmic radiation makes the flight crew receive higher radiation than the general public. Simulation of the calculation of cosmic radiation dose rates based on altitude at latitude 0° have been done. This simulation using radiation energy data at several points above sea level. This data is then interpolated to obtain continuous radiation energy data from a height of 0 to 16 km with an increase of 0.1 km. The radiation dose rate calculation is carried out using a simple dosimetry equation. The results have been compared with several studies that have been conducted where the deviation value is below to 40% for a height of 9 to 16 km with a difference in the dose rate of $10^{-7}$. While at an altitude below 9 km the deviation value is still quite high so a correction factor is needed.

1. Introduction
The exposure of ionizing radiation is one phenomenon that is considered as one of the factors causing health problems for humans. Basically, every human being receives radiation exposure at any time. The exposure can come from artificial radiation or natural radiation. One source of natural ionizing radiation is cosmic radiation. Cosmic radiation is radiation that come from outer space, consisting of protons that travel through the galaxy and reach the earth at any time. Before reaching the earth's surface, the radiation is first deflected by the Earth's magnetosphere so that the energy level is much reduced. Every place on the earth's surface receives a different dose of cosmic radiation. On average, the dose rate of cosmic radiation above sea level is 0.03 µSv/hour [1].

There are several factors that influence the level of cosmic radiation exposure in an area, including the height and position of the region to latitude. The closer to the poles, the higher the exposure to cosmic radiation, as well as the height [2]. At altitude 2000 m above sea level, the dose rate of cosmic radiation can reach 0.1 µSv/hour. Calculation of the effective dose rate of cosmic radiation as a function of height has been carried out by Frederico on January 2008 using CARI-6 for the region of São José dos Campos, Brazil [3]. The results of the calculation show a very significant difference in the dose rate between the rate of the above sea level and some altitude. The dose rate increase is almost 200-fold, where the height above sea level is only 0.03 µSv/hour while at an altitude above 17.5 km the dose rate reaches 5.14 µSv/hour. Long before, in February 1998 calculations had been done using CARI-6 by Nicholas (2000) [4]. Calculations are performed at position 200 east longitude with varying latitude positions. The results show the greater the degree of latitude, the greater the dose of cosmic radiation. The height of the place also varied from 0, 20, 30 and 40 km. The dose rate increases more than 100 times between the minimum height and maximum height. The largest
increase was obtained at 800 north latitude with a dose rate reaching 9.1 µSv/h at an altitude of 40 km. Several studies have shown a significant difference in the value of cosmic radiation dose rates at various latitude positions. This is important considering the magnitude of the dose rate at a certain height and the high mobility at this height. As it is known that aircraft operate at altitudes above 10 km above sea level. This makes the crew and passengers of the aircraft vulnerable to the adverse effects of high exposure to cosmic radiation. Because cosmic radiation is classified as low-dose radiation, the effect can be stochastic. This effect occurs due to long-term exposure to low-dose radiation. The intended effect can be in the form of somatic cell disorders such as the emergence of cancer seeds, to disturbances in genetic cells in the form of defects in offspring to infertility. For example, research conducted by the American Medical Association shows that flight crews have twice the risk of developing malignant skin cancer compared to the general population. Therefore, for the general public is 1 mSv per year [5]. The ICRP recommends that flight crew be categorized as radiation workers even though the radiation exposure comes from nature. This led to the need to map the dose rate for each region at various heights.

2. Methodology
Calculation of cosmic radiation dose rates at latitude 0° is carried out using energy data of cosmic radiation from sources of gamma, neutrons, muons and electrons in region 4 with 100% magnetic moments or around the equator [6]. Because the cosmic radiation energy data is available only at some height points, interpolation is carried out with the aim of estimating the energy of cosmic radiation from gamma, neutron, muon and electron sources at all elevation points in the range of 0 to 16 km above sea level with an increase of 0.1 km. This interpolation was carried out using two methods, namely interpolation using Microsoft Excel and interpolation of Lagrange Polynomials [7]. After the cosmic radiation energy data is interpolated, then the calculation is done using a simple dosimetry equation so that the value of the dose rate at each height point is obtained.

![Figure 1. Graph of comparison of gamma energy from interpolation of Lagrange polynomials (green line) and interpolation of MS-Excel polynomials (red line)](image)

3. Results and Discussion
Interpolation of radiation energy data for gamma, neutron, muon and electron using Microsoft Excel or Lagrange Polynomial is shown in the Figure 1 to 4. From the graph it can be seen that interpolation using the Lagrange polynomial gives more accurate results than interpolation using MS-Excel.
Interpolation of MS-Excel polynomials shows far different results compared to points without interpolation, this can occur because the existing energy data points form a very random pattern so that it is difficult to construct the right equations based on these points using polynomial equations. So it can be concluded that in general interpolation using Lagrange polynomials gives more accurate results than interpolation using MS-Excel polynomial equations, so in this study to calculate the effective dose of cosmic radiation in the range of 0 to 16 km above sea level with an increase of 0.1 km is done using the Lagrange polynomial interpolation (Figure 5). The radiation energy data are obtained from Ref [8,9,10,11].

Figure 2. Graph comparison of neutron energy results from interpolation of Lagrange polynomials (green line) and interpolation of MS-Excel polynomials (red line)
Figure 3. Chart comparison of muon energy from interpolation of Lagrange polynomials (Green Line), interpolation of polynomials (red line) and linear MS-Excel (blue line)

![Figure 3](image1.png)

Figure 4. Graph comparison of electron energy resulting from interpolation of Lagrange polynomials (green line) and interpolation of MS-Excel polynomials (red line)

![Figure 4](image2.png)

Figure 5. Graph of the effective dose rate calculated by the Lagrange polynomial interpolation

![Figure 5](image3.png)

To determine the level of correctness of the calculation results, the cosmic radiation dose rate calculated in this study is compared with several reference sources along with their deviation values as shown in the Figure 6.
The calculation results (blue line) show that the deviation value is within the range of 2-30% at an altitude of 10 to 16 km compared to the three studies that have been carried out. Calculating the effective dose of cosmic radiation only assumes the presence of a gamma radiation source (γ), neutrons, muons (µ) and electrons (β), not involving other cosmic particles such as alpha particles, protons, positrons. The measurement results show that at higher altitudes the deviation value is reduced compared to some studies that have been carried out at the same height. Correction factors need to be carried out for heights below 10 km because the deviation is still relatively high. Some factors become triggers, one of which is the number of cosmic particles that are reviewed and the differences in body weight used. The difference between the calculation results can be tolerated because the safe limit of radiation dose is 1 mSv while the cosmic radiation dose is received by the microSevert scale so that the error resulting from the calculation is still within the justified scope.

CONCLUSION
This calculation produces a dose rate value of cosmic radiation with a deviation below 40% at an altitude of 10 to 16 km with a difference between 0.25 to 0.45 µSv compared to some other studies. Further research can be done by reviewing more cosmic particles to obtain a lower deviation value.

REFERENCES
[1] Sofyan, H and Akhadi, M. 2014. Pemetaan Paparan Radiasi Kosmis pada Jalur Penerbangan Komersial. Alara3 April: 139-146
[2] WiryosiminS 1995 Mengenal Asas Proteksi Radiasi. ITB Bandung
[3] FedericoC A et al 2010 Estimates of Cosmic Radiation Dose Received by Aircrew of DCTA’s Flight Test Special Group J. Aerosp. Technol. Manag. 2 (2): 137-144.
[4] NicholasJS et al 2000 Gelatic Cosmic Radiation Exposure of Pregnant aircrew Members III U.S. Department of Transportation Final Report Nation Technical Information Service, Springfield, Virginia 22161.

[5] OECD 2011 Evolution of ICRP Recomendations 1977, 1990 and 2007 Nuclear Energy Agency. Radiological Protection, ISBN 978-92-64-99153-8.

[6] AtriD et al 2013 Galactic Cosmic Ray Induced Radiation Dose on Terrestrial Exoplanets Astrobiology. 13 (10): 910-919

[7] Chapra S G and Canale R P 2010 Numerical Methods for Engineers, 6th edition McGrawHill, New York.

[8] Bottollier-Depois J F et al 2012 Radiation Protection No 173: Comparison of Cosmic Radiation Exposure of Aircraft Crew due to Galactic Cosmic Radiation European Union, Luxembourg.

[9] Chen J S C and Pin M L 2006 Is It Safe to Fly During Pregnancy?. Journal of Chinese Clinical Medicine. 1 (6): 322-327

[10] Darling D 2004 The Universal Book of Astronomy Wiley, United States.

[11] Kojo K 2013 Occupational Cosmic Radiation Exposure and Cancer in Airline Cabin Crew. Dissertation University of Tampere, Helsinki.