SAFETY ASSESSMENTS FOR SUPPORTING THE APPLICATION OF NUCLEAR TECHNOLOGY IN INDONESIA AND A COMPREHENSIVE STUDY ON HIGH NATURAL RADIOACTIVITY AREA

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ABSTRAK

PENGKAJIAN KESELAMATAN UNTUK MENDUKUNG APLIKASI TEKNOLOGI NUKLIR DI INDONESIA DAN STUDI KOMPREHENSIF DI DAERAH DENGAN RADIOAKTIVITAS ALAM TINGGI. Secara historis, BATAN didirikan untuk mengantisipasi dampak negatif akibat percobaan ledakan nuklir di wilayah Pasifik di masa lalu. Saat ini, satu Pusat dari lembaga pemerintah ini memiliki tugas untuk melakukan penelitian dan pengembangan serta layanan di bidang keselamatan dan metrologi radiasi. Tujuan dari makalah ini adalah membahas semua kegiatan yang dilakukan oleh Pusat ini yang mencakup banyak aspek dalam pengkajian keselamatan pekerja, masyarakat dan lingkungan. Untuk metrologi radiasi, sumber standar laboratorium dosimetri (SSDL) dalam layanan kalibrasi dibangun untuk mendukung keberhasilan dalam radioterapi, di mana pencapaian tertinggi adalah sebagai Lembaga yang Ditunjuk untuk Radiasi Pengion. Penelitian kesehatan mencakup pemanfaatan sinar gamma untuk mengembangkan bahan vaksin, diagnosis penyakit metabolik dengan teknik kedokteran nuklir dan mikrodosimetri dalam penilaian radiodiagnostik. Untuk radioekologi dan biologi radiasi, salah satu penelitian utama adalah penentuan dosis efektif dan studi epidemiologi di Mamuju sebagai daerah radiasi latar belakang tinggi (HBRA) yang memberikan kesempatan unik untuk mempelajari efek kesehatan dari paparan radiasi kronis tingkat rendah pada manusia. Melalui kerja sama dengan Universitas Hirosaki, penting untuk menilai kesehatan dan status fisik serta kerusakan asam sitogenetik dan deoksinukleotida (DNA) dalam limfosit populasi lokal yang dapat memberikan informasi yang berharga. Studi dosimetri dilakukan dengan pengukuran langsung di area lapangan, termasuk analisis paparan radiasi eksternal dari tingkat dosis gamma di dalam dan di luar ruangan. Penentuan radiasi internal dilakukan dengan mengambil sampel makanan, urin, air minum, dan air inhalasi (radon). Studi epidemiologis melalui respon sitogenetik dari tempat tinggal yang didukung oleh γ-H2AX, G_0 dan G_2 micronucleus, dan genotip TP53 dari daerah penelitian menunjukkan bahwa tidak ada perbedaan yang signifikan dalam efek radiasi alami dengan kontrol. Studi radiologi kelautan dan pemantauan radionuklida di seluruh kepulauan Indonesia juga tidak menunjukkan suatu dampak negatif. Praktik kedaruratan nuklir pun juga harus dilakukan secara rutin di Pusat ini untuk memperkuat budaya keselamatan dan keamanan.

Kata kunci : keselamatan, metrologi, radioaktivitas lingkungan, laju dosis gamma

ABSTRACT

SAFETY ASSESSMENTS FOR SUPPORTING THE APPLICATION OF NUCLEAR TECHNOLOGY IN INDONESIA AND A COMPREHENSIVE STUDY ON HIGH NATURAL RADIOACTIVITY AREA. *Historically BATAN was established to investigate the negative impacts of nuclear explosions previously conducted in the Pacific area. However, this governmental institute is presently tasked to carry out research and development as well as services in the field of radiation safety and metrology. Therefore, this study aim to determine the activities carried out by BATAN in assessing the safety of workers and the environment. For instance, a standard source of dosimetry laboratory (SSDL) is used in calibration services to successfully support radiotherapy, with the highest achievement in the Designated*

Institute (DI) for Ionizing Radiation. The health research covers the application of gamma rays to create malaria vaccine, diagnose metabolic diseases with nuclear medicine techniques, and microdosimetry through radiodiagnostic assessment. This study also determined the effective dose and epidemiological study of radioecology and radiation biology in Mamuju (HBRA), which provides a unique opportunity to examine the health effects of chronic low-level radiation exposure to humans. Furthermore, the authors collaborated with Hirosaki University to obtain valuable information on the essential need to assess the health and physical status as well as cytogenetic and deoxynucleotide acid (DNA) damages in the lymphocytes of local populations. Dosimetry study was conducted by direct measurement in the field area by analyzing external radiation exposure of indoor and outdoor gamma dose rate. The internal radiation assessment was conducted by taking urine and inhaled air (radon) from the residents. Studies through the cytogenetic response supported by γ-H2AX, G0, and G2 micronucleus assays and TP53 showed no impacts on the natural radiation with significant differences compared to the control. Marine radioecology studies and radionuclides monitoring throughout the Indonesian archipelago showed no negative impacts as well. Nuclear emergency practice needs to be routinely conducted in the Center for strengthening safety and security cultures.

Keywords: environmental radioactivity, gamma dose rate, HBRA, metrology, safety

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INTRODUCTION

Bioethanol is a renewable energy that can be produced from the fermentation process of sugar or it can also be produced by synthesizing ethylene in a chemical reaction using hot steam [1]. Currently, most of the bioethanol is produced from molasses, corn syrup, or other food raw materials that have a high value. However, the use of the main raw material competes with its more primary use, called as a food source. Bioethanol can also be produced from materials containing lignocellulose. This material is abundant and has a high cellulose content, for example, agricultural waste. Agricultural waste has many benefits, including the fact that it does not interfere with the availability of food, is inexpensive, and is widely distributed across Indonesia [2].

Shortly after World War II, the Pacific area was used for nuclear testing until 1995. These activities led to radioactive contamination and uninhabitable Islands (1). Therefore, in 1954, a State Committee to Investigate radioactivity was established to investigate and assess the negative impact of radioactive fall-out due to nuclear weapons testing on the atmosphere or underwater. This Committee was renamed Atomic Energy Institution (LTA) and was improved to become the National Nuclear Energy Agency of Indonesia, also known as BATAN. This institution was also established to enhance the quality of services for radiation safety in all sectors of this country and as the main duty of the Center for Technology of Radiation Safety and Metrology. On the other hand, regulating safety and security in radiation, either for people or the environment, is the main responsibility of the Regulatory Body (BAPETEN) (2).

Radioactivity is a natural phenomenon and source of radiation in the environment. However, radiation risks to the public and environment that arise from these radioactivity existences need to be assessed and controlled (3). To ensure the protection of humans and the environment from harmful effects of ionizing radiation, the International Atomic Energy Agency (IAEA) established fundamental safety principles, requirements, and measures to control radiation exposure. These principles were adopted by BATAN in its daily activities on research and services. In addition, regulations on protecting the environment from ionizing radiation are enforced through explicit requests to demonstrate the absence of risk or impact to all ecosystems through an environmental risk/impact assessment for radioactive substances (4,5).

The Fukushima Daiichi nuclear disaster, which led to the 2011 Tōhoku earthquake followed by a tsunami, was the most severe nuclear accident after the Chernobyl disaster in 1986. It led to radioactive contamination of the Pacific Ocean. Therefore, the concerns on the possibility of a large-scale release of radioactive elements such as cesium-137 led the Center to do monitoring this area.

This research analyzes all activities conducted by the Center, such as the study on high natural radioactivity, marine study on determining the impact of the recent nuclear disaster in Japan, safety assessment, and dosimetry for workers and patients.

NATURAL AND MAN-MADE RADIOACTIVITY

Natural or environmental radiation is the major source of human exposure to ionizing radiation, originating from the terrestrial environment that varies tremendously worldwide. Some of the radiated elements include potassium, uranium, thorium, and radioactive decay products. Radiation and environmental radioactivity have been described in Indonesia as exposure to environmental gamma radiation and ^{226}Ra, ^{232}Th, and ^{40}K concentrations in surface soil and radon and thoron in many dwellings (6–8). The scope was divided into many sections or grids with the size of about 1 kilometer using the Global Positioning System (GPS). Furthermore, data on radon concentration in dwelling and GPS location were put into MapInfo Software v.10.5 to create a map. Measurement of radon– thoron was carried out using CR-39 detectors in several areas, such as Bali and Aceh (7–9). This passive radon–thoron dosimetry is an anti-static plastic material made from polycarbonate mixed with black carbon type FD-9054F. The data are useful in the regional extension and development plans and act as the basis for health policy analysis due to the existence of radon gas in Indonesia. These data were also introduced and used at the international level through the United Nations Scientific Committee on the Effects of Atomic Radiation, IAEA, and the World Health Organization (WHO). Furthermore, the data obtained are partially used to create a map of radon concentration in houses.

A high background radiation area (HBRA) is a complex region comprising cosmic radiation and natural radioactivity in soil, indoor and outdoor air, water, food, etc. This exposure leads to chronic situations from external and internal sources. For example, people living in HBRAs such as in Ramsar, Iran, and Kerala, India received 10.0 – 100.0 times more radiation d dose for a human being (2.4 mSv/y) compared to other parts of the world. In Indonesia, there is an area of Mamuju, located in West Sulawesi, which is also known for its high radiation dose rates due to the naturally occurring radioactive material (NORM), especially the natural uranium and thorium contents, as shown in Figure 1 (10). The survey on the radioactivity in 63 houses in Botteng Village showed that the average indoor and outdoor radioactivities for gamma rays were 568.88 nSv/h and 760.95 nSv/h with the range of 330 – 1500 and 420-2000, respectively.

Figure 1. Map of gamma radiation dose in the environment (10).

Table 1. Indoor and outdoor gamma dose rate (nSv/h) in several sub-villages of Takandeang Village, Mamuju, West Sulawesi (11)

Sub Village	Dose rate (nSv/h)			
	Indoor		Outdoor	
	Range	Average	Range	Average
Salumatti	300 – 650	462	500 – 800	655
Taloba	480 – 700	575	580 – 760	670
Limbeng	350 – 540	441	440 – 760	553
Salubiru	300 – 730	509	410 – 1340	658
Takandeang	320 – 500	398	340 – 560	450
Palada	500 – 1,360	719	600 – 2,300	965
Rantedunia	450 – 900	604	570 – 1,300	754
Tabanga-banga	310 – 430	373	360 – 550	412
Bettengkata	500 – 550	533	700 – 800	750

Table 1 shows the dose rate in several sub-villages of Takandeang Village, Mamuju, West Sulawesi. These results were obtained in 2016 by the Environmental survey team of the Center and indicated a high dose rate of 6-30 times higher than the normal level in that area (11).

The natural condition in Mamuju is an interesting subject that study's the health

effects of chronic low-level radiation exposure to humans (12). The authors poorly understood the health effects of chronic low-level radiation exposure in this area. The chromosomal aberration was used to determine the relationship between the individual radiosensitivity of several village inhabitants. Until now, the chromosomal aberration assay is commonly used to predict individual radiosensitivity. The lymphocytes are irradiated in vitro in the G0 phase and then stimulated to proceed and evaluate in the cell cycle. A more comprehensive study in this area was also carried out by covering cytogenetic evaluation and nucleic acid damage observation with comet assay and γ-H2AX using standard procedures (13). This study showed that the elevated level of natural background radiation in Botteng, Mamuju assessed by cytogenetics analysis to determine the DNA damage, has no significant effect on the blood lymphocytes of the population residing in this area. Furthermore, there are limited data on the effects of high-level natural radiation on some cytogenetic parameters in the habitants of HLNRA. Therefore, higher numbers of samples are needed to obtain comprehensive results (12).

Preliminary studies have been conducted on cell proliferation as a potential biomarker closely associated with assessing general cytotoxicity of chemical and physical agents. However, the utilization of these biomarkers in response to environmental stimuli such as natural radiation has not been adequately explored. Therefore, this study aims to assess mitotic index (MI) in lymphocytes as biomarkers for predicting the health risks of residents living in high natural radiation areas (HNRA) in the Salletto and Ahu villages of Mamuju. As a control group, people living in other areas of Topoyo village were also studied. The observations of the parameter were carried out according to the standard protocol described by IAEA. The result showed that the MI percentage of lymphocytes obtained from the study area was higher than those in control (26.66 vs. 22.46) without significant differences. The MI's for all respondents and their matched control are shown in Figure 2. This finding is similar to the previous studies carried out in the adjacent area. The study also showed that MI for women is lower than men, with a decreasing trend in mitotic index and an increase in age. Therefore, it was concluded that natural radiation exposure did not affect the proliferation of cells for the local people, indicating a low risk of radiation exposure related to inflammation (14).

MOU-based collaborated with the Department of Radiation Science, Graduate School of Health Sciences, Hirosaki University, Japan, to assess local populations' health and physical status and determine valuable information on the impacts of chronic exposure to the local residents.

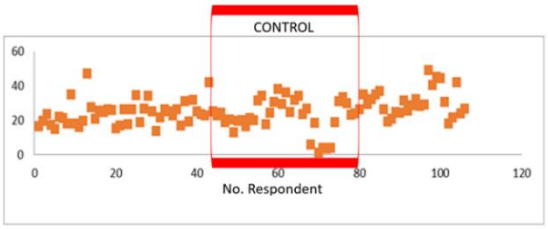

Figure 2. Mitotic index (MI in percent) for all respondents living in Mamuju and their matched control (red rectangle).

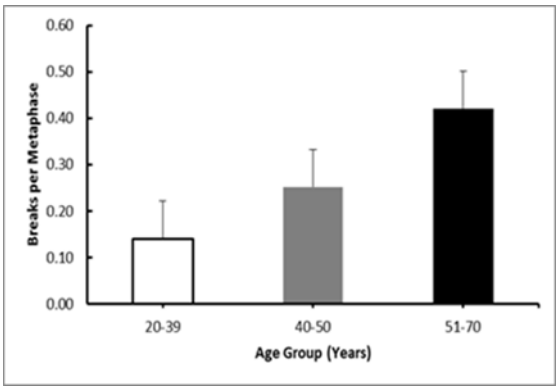

Figure 3. Individual Chromosomal Radiosensitivity increase by age in Mamuju inhabitants after in vitro irradiation at 1.5 Gy (15).

A study on age-dependent of chromosomal aberrations in lymphocytes exposed to ionizing radiation showed that the highest incidence of chromosome aberrations, especially dicentric, is unstable biomarker after 2 Gy irradiation was found in the oldest group (>50 years old), as shown in figure 3 (15). Other assessments such as proteomic with mass spectrometry were conducted to determine the research on γ-h2ax, g0, and g2 micronucleus assays. This is in addition to tp53 arg72pro genotyping, nuclear division, mitotic indexes, etc (16)

Based on all parameters or biomarkers evaluation and assessment, the natural radiation exposure in MAMUJU failed significantly to affect the health condition of the population under study. Furthermore, there is no significant difference between the study group and its control, which suggests a low risk of natural radiation-exposed related to the induction of any negative impacts (13–16). Therefore, a research to protect the affected inhabitants of such areas with improved methodologies is important and urgently needed. Meanwhile, safety assessments are useful tools for implementing nuclear technology for daily life, which need to be supported by management with tight and comprehensive regulations.

Conversely, to anticipate the possible entry of radionuclide contaminants from nuclear disasters in Indonesian waters such as fukushima in 2011, the national radioactive marine monitoring program using 137cs was used to determine several marine biota species. This includes deep-sea monitoring off the west coast of the Sumatra-Indian ocean (17,18).

SAFETY ASSESSMENTS AND DOSIMETER

An increase in public concern on radiation safety has generated a strong demand for reliable and accurate dose measurements. Similar to other countries, nuclear techniques applications for daily needs in Indonesia are widely used for diagnosis or therapy in medicine, agriculture, and industry (12). On the other hand, the nuclear technology utility in energy production is still in the planning stage, partly due to the negative perception of the community. Therefore, these activities require a reliable radiation protection service for workers and a facility for the calibration and checking of dosimeters. Such facilities need to have properly calibrated radiation sources and reference dosimeters. Furthermore, it must be linked to the world's dosimetry system to ensure proper calibration of the measurements against primary radiation standards (19). Problems of this kind have led to the establishment of the iaea/who network of Secondary Standard Dosimetry Laboratories (SSDLS) in many developing countries. Currently, the center is gaining a high achievement in calibration laboratory as the designated institute (di) for ionizing radiation for certain national standards and associated services. Figure 4 illustrates the numerous facilities available for calibration services.

Determination of absorbed dose rate in water for therapeutic and protection levels is also carried out in calibration facility and completed with x-ray source and detector for electron and photon.

Figure 4. water phantom for calibration (left) and co-60 source for calibration of therapy level.

Besides that, this laboratory also provides standard sources, such as points, electrode-position, and liquid for hospital and industry application purposes. Medical uses of ionizing radiation are among the longest established applications of ionizing radiation, with a continuous increase in the number of procedures over the years ago. These medical uses bring considerable public health benefits. However, ionizing radiation causes harm therefore, a systematic approach needs to be applied to ensure a balance between utilizing the benefits from medical uses of ionizing radiation and minimizing the risk on patients, workers, and the public (20).

Approximately 5 to 10 years ago, the health research in the Center covered the application of gamma rays. Therefore, to control the infectious diseases, such as malaria vaccine (21,22) were developed with 150 Gy of gamma rays effective to attenuate malaria parasite. Furthermore, studies on the diagnoses of metabolic diseases with nuclear medicine technique (23) and Microdosimetry in Radiodiagnostic assessment have also been conducted (24). Diagnose of metabolic disease such as diabetes type 2 in the hearth with tc-99m-sestamibi (Myocardial Perfusion Imaging (MPI) and Multiple Gated Acquisition (MUGA) Methods) have been carried out and revealed as a method that plays a pivotal role in the evaluation of coronary artery disease.

This process identifies patients with coronary artery disease and also provides overall prognostic information or risk of adverse cardiac events, as shown in figure 5.

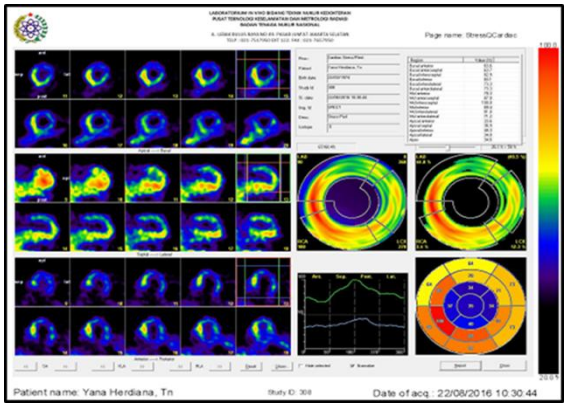

Figure 5. Result of nuclear medicine for Myocard Perfusion Imaging (MPI) of a disease (23).

This nuclear medicine is a medical specialty involving the application of radioactive substances in the diagnosis and treatment of disease. A nuclear medicine study of the whole-body bone scan was also conducted.

Hiswara et al. (24) carried out a research to determine the microdosimetry in radiodiagnostic assessment, and stated that interventional cardiology procedures represent the third largest contribution to the collective dose incurred by a population after computed tomography and nuclear medicine. The results showed that the PCI procedure was the most performed during this study, with the highest radiation doses given to the staff.

SUMMARY

In conclusion, this research enhanced the quality of services for radiation safety and metrology in Indonesia. These services have significantly increased in volume and quality in recent decades with significant contributions to nuclear science and technology in health, agriculture, energy and the environment. The center has specifically helped countries to take full advantage of nuclear science and technology to improve the lives of the people and care for the environment. Even though this technology is being used in diverse fields, it is still far from reaching its highest target of developing a nuclear power construction for clean energy, in line with technology trends such as industry 4.0. Future epidemiological studies have been planned for five to ten years to evaluate the health effects of exposure to elevated natural background radiation in MAMUJU, mainly the risk of cancer, either globally or on specific sites. Unavailable well-documented health statistics are the main weakness of studies in HBRA.

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