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Profile of Occupational Dose at TRIGA 2000 Nuclear Facility

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Abstract

Occupational dose is one of the safety parameters that must be verify to meet the safety objectives. Monitoring of occupational dose at TRIGA 2000 nuclear facility in 2015-2017 was performed using TLDs. The objectives of the monitoring were to evaluate and assess the occupational dose not to exceed the dose limit. In Technical and Health and Safety Division showed the maximum occupational dose for individual of 2.16 mSv and the highest collective dose of 0.029 man-Sv. The maximum occupational dose for individual in Reactor Division was of 1.48 mSv and the highest collective dose of 0.019 man-Sv. The maximum occupational dose for individual in Technophysic Division of 1.4 mSv and the highest collective dose of 0.017 man-Sv. In the Labeled Compound Division, the maximum occupational dose for individual of 2.59 mSv and the highest collective dose of 0.035 man-Sv . From the total of 82 radiation workers, the highest percentage of radiation workers received the occupational doses in the dose range of (1.01-1.50) mSv were: 50% (41 persons, in 2015), 85.36% (70 persons, in 2016) and 70.73% (58 persons, in 2017). 4 persons dose record were within of (2.01-2.50) mSv and 2 persons within of (2.51-3.00) mSv. No radiation worker received doses exceeded the annual dose limit of 20 mSv.

Keywords: Occupational dose, Equivalent dose, Dose limit, Radiation worker

1. Introduction

The Center for Applied Nuclear Science and Technology (CANST) is one of BATAN Center which has a TRIGA 2000 research nuclear reactor and radiation laboratories as well as radioactive waste facility. This research reactor is utilized for research in nuclear field, radioisotopes production and other studies in related fields. TRIGA 2000 is a nuclear research reactor with a tank type reactor of 2 MW power designed and today is operating at 1000 kW. Irradiation facilities which are available in TRIGA 2000 reactor are Central Thimble (CT), Pneumatic Transfer System, Rotary Specimen Rack (Lazy Suzan/ LS), Grid Position outer of D Ring, beam ports, Thermal Column and Thermalizing Column [1].

Main sources of radiation from a reactor at power are the core and the coolant. The radiation from the core includes fission neutrons, fission gamma rays, fission product decay gamma rays, neutron capture gamma rays and activation product decay gamma rays [2]. In TRIGA 2000 reactor the main sources of radiation are the fission products remained in the cladding of nuclear fuel in the reactor core, activation products in the water coolant, contaminated ion exchange resin in demineralizer system and used filters of ventilation system [3].

Labeled Compound and Radioisotope Laboratory as part of TRIGA 2000 nuclear facility used some radioisotopes such as iodium-131, brom-82, technicium-99m, phosphorus-32 and molybdenum- 99 and still many more of standard sources which were located in some laboratories of CANST for research and studies [1]. Radioactive wastes were also sources of the radiation since some of it exposure rate were significant. The X-Ray unit owned by CANST also become a potential radiation hazards upon operating. Radiation workers at the TRIGA 2000 reactor or its laboratories and facilities may be exposed to radiation from all of those sources of radiation externally or internally.

The radiation risks to people and the environment that may arise from the use of radiation and radioactive material must be assessed and must be controlled by means of the application of standards of safety. Radiation exposure may have an effect on health that includes stochastic and deterministic effects. Exposure of human tissues or organs to radiation can induce the death of cells on a scale that can be extensive enough to impair the function of the exposed tissue or organ. Effects of this type, which called 'deterministic effects', are clinically observable in an individual only if the radiation dose exceeds a certain threshold level. Above this threshold level of dose, a deterministic effect is more severe for a higher dose. Stochastic effects have characteristics: are random, have no threshold dose, the probability of occurrence depends on the dose, may occur in the exposed individual and the offspring; while the deterministic effect has characteristics: having a threshold dose, severity depending on the dose and only occurring in the exposed individual [4,5,6].

Occupational dose is one of the safety parameters that shall be verify to meet the safety objectives. As stated in the Fundamental Safety Principles, "The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation". This objective must be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks [7]. Therefore, the system of protection and safety aims to assess, manage and control exposure to radiation so that radiation risks, including risks of health effects and risks to the environment, are reduced to the extent reasonably achievable [4].

Monitoring of occupational dose at nuclear facility is an obligation of a licensee according to nuclear regulations, therefore BATAN is subject to routine inspection from the regulatory body for verified its safety parameters. Registrants, licensees and employers of workers who engaged in activities involving normal exposure or potential exposure shall be responsible for protection of workers from occupational exposure [8].

Occupational exposure is all exposures of workers incurred in the course of their works. Radiation Worker is define as any person who works at nuclear installations or Ionizing Radiation installations which are supposed to receive annual doses more than doses for the general public [9]. For safety purposes any worker working in nuclear power facilities shall obtain the monitoring of the radiation dose it receives. This is in accordance with the provisions of Law no. 10 of 1997 on nuclear power and is mentioned in Article 16 paragraph 1 [10].

The validity period of the TRIGA 2000 Reactor Operations permit expires in December 2016. In 2017 the TRIGA 2000 reactor began to operate routinely after the license for extension of operations was issued. In 2015 the TRIGA 2000 reactor was shutdown for the purpose of repairing and maintaining structures and systems, while in 2016 the reactor was operated for the purpose of power calibration and maintenance thus to be more ready to be operated securely and safely in the following year. The use of the TRIGA 2000 reactor by the researchers at CANST were to irradiated many target samples. Target samples that have just been released from irradiation facilities generally have very high radiation dose rates and potentially harm the workers. With the increase in reactor utilization and the number of operating hours of the reactor in 2016-2017 will have an impact on increasing the radiation doses to workers. Radiation doses to workers need to be controlled and the actual doses received need to be recorded and retained.

Considering that the TRIGA 2000 reactor and its supporting nuclear facilities will resume routine operation and the obligation for the permit holder to verify the safety of the operation of the TRIGA 2000 reactor, an evaluation of the occupational dose received by radiation workers for 3 years (2015-2017) was conducted to see the profile of occupational dose which is expected to not exceed the dose limit.

2. Materials and Methods

2.1. Radiation workers and radiological work situation

TRIGA 2000 nuclear facilities and its supporting laboratories are radiation areas that can be divided into controlled and supervision areas. The controlled area is a work area requiring protection measures and special safety requirements to control normal exposure or prevent the spread of contamination during normal working conditions and to prevent or limit the level potential exposure. While the supervisory / supervision area is a work area outside the control area that requires a review of occupational exposure and does not require any special protection or safety measure [9].

To ensure that the occupational exposure dose received by radiation workers does not exceed the dose limit value, radiation workers are monitored for occupational exposures using thermoluminescence dosimeters. In addition to measure the dose received by workers, the dose profile can provide information about the trends of these doses and about the conditions in places of work.

Total of 82 radiation workers from 4 work division at CANST were monitored their occupational dose using NG-7776 thermoluminescence dosimeter (TLD). 22 radiation workers worked in the Technical and Health and Safety (THS) Division with tasking group as Radiation Protection Officer (RPO), radioactive waste operator, environmental radioactivity monitoring officers, decontamination officers, reactor and facilities maintenance officers. RPOs were assigned to all controlled areas and supervision areas at the TRIGA 2000 nuclear facility in order to monitor radiation safety. Figure 1 shows RPO monitored the controlled area at TRIGA 2000 nuclear facilities.

There were 17 radiation workers worked in the Reactor Division with the tasking group as, Supervisors, Operators and maintenance officer of the reactor. Personnel team work including the RPO operates the reactor in an 8 hour shift schedule with operating duration was of 72 hours a week. When the reactor operates, RPO and radiation workers from the THS Division and the Reactor Division respectively worked in the reactor building where some certain area inside the reactor building have the potential dose rates for external radiation exposure of more than 10 μSv/hour. During shut down periods of the reactor, many non-routine tasks may undertake, such as maintenance works, fuel reshuffling or refueling. In year of 2015 and 2016 many maintenance works were done and in 2017 many samples were irradiated for isotope productions and research.

In Technophysics (TP) Division there were 16 radiation workers were utilized reactor facilities for experiments. Worker

(a) (b) (c)

Figure 1. Radiation Protection Officers surveyed the controlled area dose rates at the reactor TRIGA 2000 (a), work process in solid waste storage facility (b), radiation safety supervision in Labeled Compound and Isotope Production Process laboratory(c).

in TP Division were also worked using ionizing radiation generator (X-ray) unit. Mostly workers in TP Division spent more work hours in the supervised area than in the controlled area.

In the Labeled Compound (LC) Division, 27 radiation workers carried out research and radioisotope production by processing irradiated target samples. In the Radioisotope and Labeled Compound laboratory the radiation dose rate is quite high and so is the level of contamination because unsealed radiation sources were used. At some observation points there were work place with the dose rate of 20 μSv/hour.

2.2. Thermoluminescence Dosimeter

Dose equivalent is a quantity used by International Commission on Radiation Units and Measurements (ICRU) in defining the operational quantities ambient dose equivalent, directional dose equivalent and personal dose equivalent. The quantity dose equivalent has been supersede for radiation protection purposes by equivalent dose [5].

The equivalent dose ($H_{T,R}$) is defined as:

$$H_{T,R} = D_{T,R} \ w_R$$

Where $D_{T,R}$ is the absorbed dose delivered by radiation type R averaged over a tissue or organ T w_R is the radiation weighting factor for radiation type R. The equivalent dose is expressed in sievert (Sv) [2].

TLD measures the individual equivalent dose received by workers using the thermoluminescence principle. The equivalent dose is a dose quantity specially used in radiation protection to indicate the extent of damage to the tissues of the body due to the absorption of a certain amount of radiant energy by observing the radiation weighting factor affecting it [11].

Personnel monitoring is based on international recommendation of ICRP [6]. The primary objective of individual monitoring of external radiation is to assess, and thus limit, radiation doses to individual radiation workers [12].

Occupational exposure were measured in CANST and the dosimeters used were TLD for neutron and gamma monitoring type 7776 (TLD NG-7776). A TLD card consists of 3 TLD-700 dosimeter chips and one chip of TLD-600 dosimeter for neutron monitoring.

The occupational dose is expressed in individual equivalent dosage or Hp (d). The equivalent dose of a soft-tissue point in depth d (spherical ICRU model) corresponds to strong or weak radiation penetration, d depth in the case of strong penetrating radiation such as gamma rays and neutrons 10 mm, so that Hp (d) can be written as Hp (10), while the depth for weak translucent radiation such as X-rays or beta rays for the skin is 0.07 mm and for 3 mm eye lenses, therefore Hp (d) each written as Hp (0.07) and Hp (3) [11]. For radiation workers in CANST, monitoring of Hp radiation (10) was conducted.

The risk of radiation induced cancer in various body organs are under continuous review as new experimental data become available [6]. Regarding radiation risk, the dose in a population is introduced as a collective dose. Collective dose is an expression for the total radiation dose incurred by a population, defined as the product of the number of individual exposed to a source and their average radiation dose. The collective dose is expressed in man-sieverts (man-Sv) [4].

2.3. Dose monitoring and assessment processes

Total of 164 TLD cards and 164 TLD holders were used to monitor the occupational dose of 82 radiation workers at CANST during 2015-2017. The monitoring period is a quarterly, for each period worker were given cleaned TLD that has been annealed so that the TLD information is empty. Each TLD card is given a TLD code (TLD ID) and user identity (ID PR). Furthermore, TLD cards are packed into TLD holders of the appropriate type, put on the worker's name and monitoring period then TLD badge were ready. TLD badge is then distributed to radiation workers and after a monitoring period (quarterly) the TLDs were taken back and replacement of TLD badges for subsequent period monitoring were provided.

The TLD badge that has been used

were packed and sent to the Center for Safety Technology and Radiation Metrology (CSTRM) for reading using TLD Reader 6600. CSTRM is an accredited BATAN's center for evaluating personnel dose.

2.4. Dose Record

The results of TLD readings will be received by CANST from to the CSTRM, after 2 weeks working days. CANST will recapitulate the occupational dose data and put it into reports for each of 4 work division and individual dose cards. Regulatory body will received one copy of TLD data dose readings. The data will be kept for at least 30 years. If the unusual dose record were found then the data will be evaluated related to the work performed by related worker during the monitoring year. The average occupational dose of each work division were evaluated, as well as the maximum dose and collective dose were recorded.

3. Result

The results of occupational dose monitoring during year of 2015 to 2017 for the THS Division is shown in Figure 2. A total of 22 radiation workers were monitored for their occupational doses. The bar chart is made to show the annual accumulation dose of each radiation worker.

From the chart (Figure 2), the lowest occupational dose of 0.31 mSv and the highest of 2.16 mSv were observed. The highest occupational dose were referred to radiation worker who worked in the decontamination facility where the work place is close to the radioactive waste facility with high back ground radiation. The lowest dose was recorded for operator. Only 1 radiation worker received a dose below 0.5 mSv and 2 radiation workers received the dose above 2 mSv. Generally the monitoring results in 2015 were lower than monitoring results in 2016 and 2017. Nevertheless, in 2015 there were 5 radiation workers receiving more doses than in 2016. They were radiation workers with their respective activities as RPO (3 workers) radioactive wastes officer and a technical worker. In 2016 there were 5 radiation workers received doses greater than 1.5 mSv, and in 2017 there were 2 workers received doses greater than 2 mSv.

The results of occupational dose monitoring during 2015 - 2017 for 17 radiation workers in Reactor Division were shown in Figure 3. No radiation worker received the occupational dose more than 2 mSv.

For 3 years of monitoring, the lowest dose of 0.26 mSv and the highest 1.48 mSv were observed. In 2015 there was one radiation worker received the dose below 0.5 mSv, while in 2016 it can be seen from the graph all workers get doses more than 1 mSv. The results of occupational dose monitoring of 16 radiation workers during 2015 - 2017 in TP Division were shown in Figure 4.

During 3 years of monitoring (2015-2017) it had been observed the lowest and the highest dose of 0.26 mSv and 1.4 mSv respectively. In 2015, there were no radiation workers received doses below 0.5 mSv and 6 workers received doses above 1.0 mSv. In 2016 as many as 13 radiation workers received more than 1 mSv, as well as in 2017 there were 13 workers received doses greater than 1 mSv but less than 1.5 mSv.

The results of occupational dose

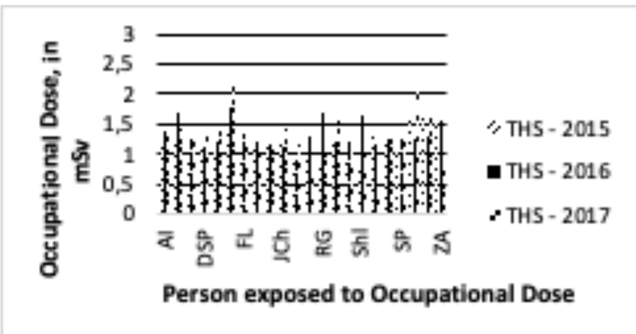

Figure 2. Occupational Dose at Technical and Health and Safety Division in the year 2015 – 2017

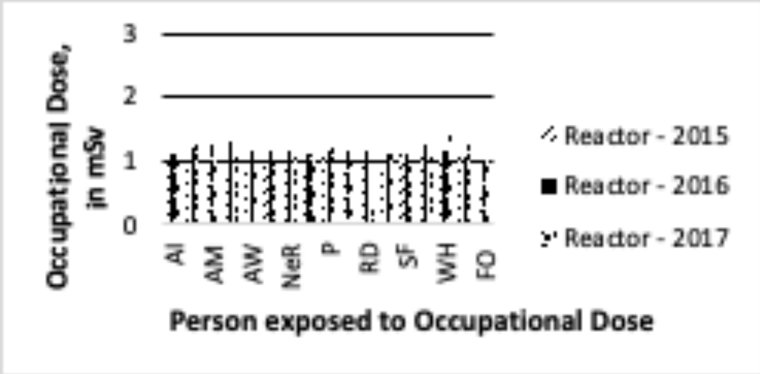

Figure 3. Occupational Dose of worker at Reactor Division in the year 2015 - 2017.

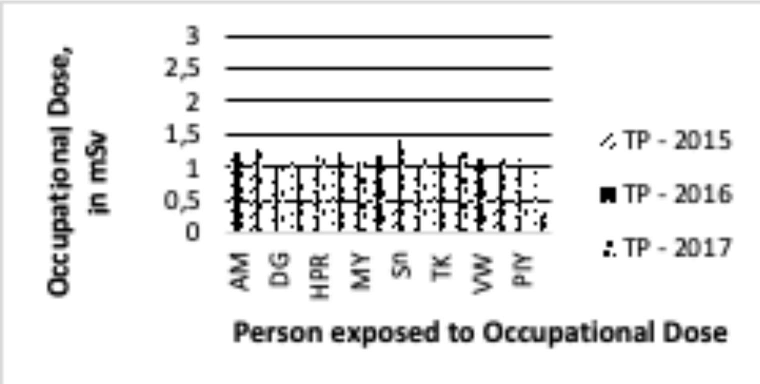

Figure 4. Occupational Dose of worker at Technophysics Division in the year 2015 – 2017

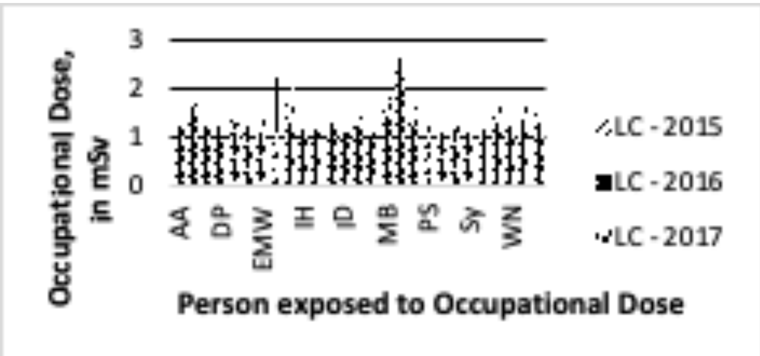

Figure 5. Occupational Dose of worker from Labeled Compound Division in the year 2015 – 2017

monitoring during 2015 - 2017 for 27 radiation workers in the LC Division were shown in Figure 5. The dose received for 3 years of monitoring has been observed to be the lowest dose were 0.28 mSv and the highest were 2.59 mSv. In 2015 none of radiation workers received doses below 0.5 mSv and one radiation workers received more than 2.5 mSv but less than 3 mSv. In 2016, 2 radiation workers were observed received occupational dose of more than 2 mSv. From the graph (Figure 5), in 2017 the highest dose received were 2.2 mSv.

4. Discussion

For any worker who usually works in a controlled area, or who occasionally works in a controlled area and may receive a significant dose from occupational exposure, individual monitoring shall be undertaken where appropriate, adequate and feasible [3]. From the 4 bar charts of monitoring results (Figures

Table 1. Profile of Minimum and maximum dose, average and collective dose of worker in 4 work division of TRIGA 2000 nuclear facility in year 2015 - 2017

Division	Monitoring Year	Worker (person)	Minimum Occupational Dose (mSv)	Maximum Occupational Dose (mSv)	Average Occupational Dose (mSv)	Collective Dose (man-Sv)
THS	2015	22	0.78	1.69	1.18	0,026
	2016	22	0.89	1.8	1.32	0.029
	2017	22	0.31	2.16	1.29	0.028
Reactor	2015	17	0.46	1.12	0.94	0.016
	2016	17	1.08	1.3	1.16	0.019
	2017	17	0.26	1.48	1.11	0.018
TP	2015	16	0.49	1.19	0.94	0.015
	2016	16	0.26	1.4	1.11	0.017
	2017	16	0.33	1.37	1.08	0.017
LC	2015	27	0.9	2.52	1.23	0.033
	2016	27	1.02	2.59	1.31	0.035
	2017	27	0.28	2.2	1.32	0.035

2-5), the following discussion is presented. The occupational dose value received by an individual is closely related to the radiologic situation in the work place. From Figure 2-5 data results, it can be listed in Table 1 the values of minimum and maximum dose, average and collective dose for each work division from 2015 to 2017.

Table 1. Profile of Minimum and maximum dose, average and collective dose of worker in 4 work division of TRIGA 2000 nuclear facility in year 2015 - 2017.

During 2015-2017 monitoring in the THS Division, the lowest dose observed were between 0.31-0.89 mSv and the highest dose were between 1.69-2.16 mSv, and the average dose was 1.18 - 1.29 mSv. The dose value of 1.69 mSv in 2015 was obtained by an officer of radioactive waste while in 2016 and 2017 the highest dose value was obtained by the decontamination officer. In 2015 there were 5 radiation workers receiving more doses than in 2016, they were 3 RPOs, a radioactive wastes officer and a technical worker. The radiological situation of the workplace greatly affected the amount of occupational dose received by radiation workers. RPOs did much work as a safety supervisor for operational activity, maintenance and repair activities with high dose rate in the workplace, so they still get a large enough dose even though the reactor has not been operated regularly in 2015. The occupational exposure in the processing and radioactive waste storage area was quite high [13]. With a longer duration of work and more processed wastes and decontaminated clothes, worker will receive high occupational dose. During 2015 - 2017 the highest collective dose for THS Division with 22 radiation workers was 0.029 man-Sv according to the average dose of 1.32 mSv.

From the Reactors Division (17 radiation workers) and TP Division (16 radiation workers) seemed to have a dose profile that is almost the same and it can be seen from the average dose obtained from 0.94-1.16 mSv and 0.94-1.11 mSv therefore the collective dose also has almost the same values, namely (0.016-0.019) and (0.15 -0.17) man-Sv. During reactor on operation, the operator will stay in the control room with low occupational exposure. On contrary, radiation worker from the THS and LC Division worked with sealed and unsealed radiation sources with short distances from the radiation sources, and it caused the radiation worker from these 2 Division will received more occupational dose than personnel from the Reactor and TP Division.

It is shown in Table 1, for the LC division, in 2015 - 2017 the highest personnel dose was obtained between 2.2 - 2.59 mSv. This occupational dose were received by a research assistant who had the task for routinely transfer the irradiated target samples from the reactor to the Radioisotope and Labeled Compound laboratory, cut samples and processed it in the glove box. With this radiological work situation where the irradiated target samples have high dose rate, and the more frequent work done and each task had longer duration caused the high occupational dose will obtained. One researcher in 2016 also received the high dose of 2.19 mSv (Figure 5) where this dose due to the high exposure from pneumatic facility works she involved. For LC Division the highest collective dose of 0.035 man-Sv in 2016 and 2017.

Generally, in 4 work division that were monitored there was a tendency to receive more dose than in the previous year, with the maintenance and power calibration activities in the reactor, there was a significant increase in occupational dose in 2016. The recorded maximum dose at LC Division from 2015-2017 tends to be almost the same, this is due to the research activity in 2015 and 2016 was continued before the reactor is fully operational since it still has a supply of irradiated target samples from GA Siwabessy reactor in Serpong for experiments. Usually irradiated samples were taken from a reactor in Serpong by radiation worker from LC Division accompanied by RPO from the THS Division, thus RPO also received occupational dose which is generally quite high.

The dose range categories were made for mapping the number of radiation workers who received the occupational dose within a range of 0.00 - 3.00 mSv. The need to classify the dose range category is to evaluate the occupational dose received by radiation workers so as not to exceed the reference dose limit, ie the quarterly dose limit (5 mSv) and the annual dose limit (20 mSv) [9].

In 2017, even though the reactor has been operating regularly, the occupational dose recorded were not reach more than 2 mSv, because a reactor operator in Reactor Division had their routine work when reactor on operation were in the control room with a dose rate lower than 10 μSv/hr. During reactor maintenance the external radiation hazard were much more compare to reactor in operation. Although the reactor was shut down for maintenance in 2015-2016, researcher at LC Division still received higher occupational dose than other work division because radiation worker at LC Division also worked with radiation sources which was come not from reactor TRIGA 2000 alone

Compared with the percentage in 2016, in 2017 less worker (14.63%) received occupational dose in this dose range (1.01 - 1.50) mSv, but some radiation workers's dose record were distributed in higher dose range categories.

In 2017 the TRIGA 2000 reactor was ready for regular operation, in many routine operation activities of the reactor operators were in the control room the reactor with the maximum Operational Limit and Conditions allowed in the control room was 10 μSv / hour. In practice, during normal operation the dose rate in the control room does not reach the OLC of 10 μSv / hour [1]. Operational Limit and Conditions is a set of rules setting forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the reglatory body for safe operation of an authorized facility [14]. With the increasing frequency of operation of the TRIGA 2000 reactor, and many samples were irradiated, which means more processed activities therefore more exposed radiation workers.

5. Conclusion

Monitoring of occupational exposure at TRIGA 2000 nuclear facility had been done. There are 82 radiation workers from Technical and Health and Safety Division (22 workers), Reactor Division (17 workers), Technophysics Division (16 workers) and the Labeled Compound Division (27 workers) had been monitored their occupational dose during 2015-2017. Monitoring were carried out as one of the fulfillment of the obligations of the Licensee of the TRIGA 2000 nuclear facility in order to verify safety. Occupational dose monitoring were done using the NG-7776 TLDs. The monitoring results showed that there was a tendency to increase the maximum dose received by radiation workers from 2015 to 2017. The occupational dose received by the individual were related to the type of work and also affected by the radiological situation in the workplace.

Radiological situations in the workplace for radiation workers of the THS and LC Division were high exposure due to the utilization of unsealed sources, such as irradiated target samples for isotopes research and production. While the reactor operator conducts its activities routinely with a 72 hour period of operation and were followed by maintenance work. Upon operating the reactor, the operator will be in the control room with a fairly low exposure rate, while the exposure rate can change to higher during the maintenance period. Researchers from the Technophysics Division, utilized reactors with a shorter duration when the reactor is on operation and spent longer time in supervised area which was low exposure for their research works.

The objectives of the monitoring were to evaluate and asses the occupational dose not to exceed the dose limit. During 2015 – 2017, in Technical and Health and Safety Division showed the maximum occupational dose for individual of 2.16 mSv and the highest collective dose of 0.029 man-Sv. The maximum occupational dose for individual in Reactor Division was of 1.48 mSv and the highest collective dose of 0.019 man-Sv. The maximum occupational dose for individual in Technophysic Division of 1.4 mSv and the highest collective dose of 0.017 man-Sv. In the Labeled Compound Division, the maximum occupational dose for individual of 2.59 mSv and the highest collective dose of 0.035 man-Sv. From the total of 82 radiation workers, the highest percentage of radiation workers received the occupational doses in the dose range of (1.01-1.50) mSv were: 50% (41 persons, in 2015), 85.36% (70 persons, in 2016) and 70.73% (58 persons, in 2017). 4 persons dose record were within of (2.01-2.50) mSv and 2 persons within of (2.51-3.00) mSv. No radiation worker received dose exceeded the annual dose limit of 20 mSv. The occupational dose profile obtained can then be used as a basis for optimizing radiation protection in controlling of occupational exposure.

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