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The prediction of ^{41}Ar radionuclide releases to the neighboring environment during operation of TRIGA PUSPATI Reactor

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Abstract: This article discusses about prediction of the ^{41}Ar radionuclide as a Noble gas released from stack during operation of the PUSPATI TRIGA reactor in Bangi, Selangor of Malaysia.The ^{41}Ar radionuclide released from the stack to the neighboring areas was modelled for each month within one year period based on the average wind speeds with wind directions for each particular month.The maximum concentration of ^{41}Ar radionuclide measured from the reactor during operation was used as the source term and it was considered as the worse case scenario with the magnitude around 50×10^4 Bqm^{-3}.The results were able to demonstrate that there are some areas in neighboring zone could received only small amount of γ dose due to ^{41}Ar radionuclide with just less than 1 μSv in each month from the operation of PUSPATI TRIGA reactor. This dosage is extremely small and it is much lower than the minimum allowable limit to the member of public in Malaysia.

Keywords: Dispersion modelling, nuclear, PUSPATI TRIGA reactor, ^{41}Ar radionuclide, effluent.

1 Introduction

Nuclear reactor is equipped with the system that can detect and monitor any releases due to nuclear reaction in the reactor environment to the atmosphere. There are gases and particulates effluent release from the reactor building into the open environment and this is monitored continuously by stack system.This system is designed to detect and record and gives feedback about the concentration of particulate, noble gases and iodine in the effluents. Monitoring of effluents release from reactor is crucial to ensure the reactor safety always in place and the priority, the particulate detection is for monitoring radionuclide in the form of solid dust, especially radionuclide ^{137}Cs. Monitoring a noble gas is to probe the existence of Xenon-135, Krypton-85 and etc. The existence of iodine especially ^{131}I in the effluents is also monitored. These radionuclides amongst the indicators important in an ensuring the reactor is operated safely. The fuel condition and integrity should be checked properly if any of these radionuclides were detected by stack system.

Radionuclides in the form of light particulate or gases in the effluents are created by nuclear reaction particularly during the reactor operation. These fission products are remained inside the cladding of fuel element. The integrity of cladding determine the nuclear fuel healthy and reactor safety. The reactor core or nuclear fuel is said not in the healthy condition if ^{137}Cs, ^{131}I were detected in the effluents. The reactor should be stopped and operation is not allowed if these fission product detected in the effluents. It is because these radionuclides should be kept inside cladding of nuclear fuel at all time. Otherwise it will indicates some leaks on the cladding material where these radionuclides can diffuse from nuclear fuel into the environment. Instead, the particulate, some noble gas and iodine radionuclides released created from nuclear reaction inside nuclear fuel appears outside nuclear fuel. Typical nuclear reaction contributed to the release of effluent ^{41}Ar radionuclide is mainly as a result when neutron interacted with ^{40}Ar with the existence of hydrogen or oxygen atoms as water molecules. Air in the irradiation channel also contain ^{40}Ar, which finally contributed to the content of ^{41}Ar in the effluents

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released. Another large contribution to the content of effluents during the operation is from nuclear reaction of irradiated samples in neutron irradiation channel.

The release of effluent noble gas particularly ^{41}Ar radionuclide from stack of research reactor into the atmosphere environment were studied in the past including [1] and [2]. There have been reported that the total activity of ^{41}Ar radionuclide from Oregon State University reactor was 18.18 mCi in 1 hour operation at full power of 1 MW thermal [3]. Comparable to this report, there also has been reported that the released from Austrian TRIGA reactor in Vienna was 130 mCi at similar period with the rector power of 250 kW.The released from Austrian TRIGA reactor was about one order of magnitude higher than released from Oregon State University even though the power operated at three times lower. The release rate of this radionuclide was not compared because there were many differences in stack dimension and operating parameters [2]. There are many factors could affect the concentration of ^{41}Ar radionuclide from stack released, such as the type and amount of sample being irradiated or the cooling period of water in the reactor pool.

There is a practise where each sample has to be analysed by reactor physicist before irradiation. It is required to ensure the possible radionuclide created due to nuclear reaction in neutron irradiation does not affect the safety of reactor. It is known that there are several noble gases occur naturally, with ^{40}Ar is the dominant one in nature. So that ^{41}Ar radionuclide is very likely the result when ^{40}Ar is interacted with neutron in the reactor. Therefore, it is assumed to be the main component of noble gas released from the stack system of PUSPATI TRIGA reactor during the operation. Therefore, the most probable radionuclide content was ^{41}Ar.It is known that the ^{41}Ar radionuclide is an emitter of γ radiation during decay process with 1.827h half life at photon energy of 1293 keV [3]. In this study, the distribution of ^{41}Ar radionuclide released from the stack of PUSPATI TRIGA reactor during the operation and the dose within the neighboring areas are systematically studied within twelve month using HotSpot effluent dispersion code.

2 Methodology

Systematic collection of reactor operation data including reactor power as well as reading from stack system of PUSPATI TRIGA reactor have been analysed. The data from stack system comprises of concentration of radionuclide particulate, noble gases and iodine.The data of reactor power has been collected from power channel of reactor digital control console. The data of radionuclide which have passing through the stack system have been acquired in every 0.5 second and the average of 10 minutes period have been recorded. The data of reactor power and effluents from stack have been measured and recorded non-stop regardless reactor operation or shutdown.Both data have been recorded continuously either the reactor is operating or shutdown.

The concentration of each effluent components were taken from stack monitoring system and the value of reactor power was taken from data acquisition system of digital control console. It is assumed that the effluent of noble gas has a single component of ^{41}Ar radionuclide. Therefore, the concentration of ^{41}Ar radionuclide in Bq/m^3 was estimated as follows, firstly converted to activity in Ci for input into the HotSpot computer code.The absolute value of ^{41}Ar activity in Bq was obtained when the flow capacity of stack is 35.31 CFM (cubic foot perminute) is determined.This gives the flow rate of ^{41}Ar passing the stack opening at 3.3 m^3 for every second.Based on this flow rate, total activity of radionuclide ^{41}Ar during the operation is obtained when the operation time in one day is known. In average, the reactor has been operated in 5 hour a day in four days a week, then the total hour of reactor operation in one month is about 20 hours. Therefore, the total activity of ^{41}Ar radionuclide in each month has been determined based on these facts. The activity as a source term based on this calculation is used as an input into the HotSpot computer code [4].Similar code was used to estimate the radioactive dispersion for hypothetical nuclear power plant in Malaysia environment [5].

Disperion of ^{41}Ar radionuclide from RTP to its surrounding areas were modelled using built-in Gaussian distribution function governed in HotSpot dispersion code. The directions and speeds of ^{41}Ar radionuclide motion in the air are calculated based on the average wind speeds and wind directions data obtained from meteorology station in Morib, Hulu Selangor, Malaysia and also from the station in the Kuala Lumpur International Airport, Sepang. The average speeds and directions of wind used in the modelling are given in Table 1.

Table 1: Data for wind speed and wind direction used in the simulation of ^{41}Ar radionuclide dispersion in PUSPATI TRIGA reactor and surrounding neighboring areas.

Month	Wind Speed (ms^{1})	Wind Direction
JANUARY	2	45
FEBRUARY	3	67.5
MARCH	2	225
APRIL	2	225
MAY	2	180
JUNE	2	180
JULY	3	157.5
AUGUST	3	157.5
SEPTEMBER	2	180
OCTOBER	2	247.5
NOVEMBER	2	292.5
DECEMBER	2	360

The wind speed and direction used in this simulation are considered for the similar height with the stack outlet in the reactor building.Simulation have been performed for each month through out the year excepted for February, where it was not done because the annual reactor maintenance has been performed so that the reactor has been shutdown for the whole month.

The dispersion profile of ^{41}Ar radionuclide distribution predicted using HotSpot code have been merged into Google map, where the starting coordinate used in the simulation was the reactor building. This makes investigation the distribution of γ dose rate surrounding the zone within 10 km radius from the RTP a reality. The absorbed dose within these zones have been estimated quantitatively so that the result able to demonstrate the level of γ dose within the critical area of population for each month.

3 Results

The creation of ^{41}Ar radionuclide during the operation of PUSPATI TRIGA reactor has been analyzed based on the concentration of noble gas data recorded using the stack system where its typical profile with the power of reactor is described in Fig. 1.

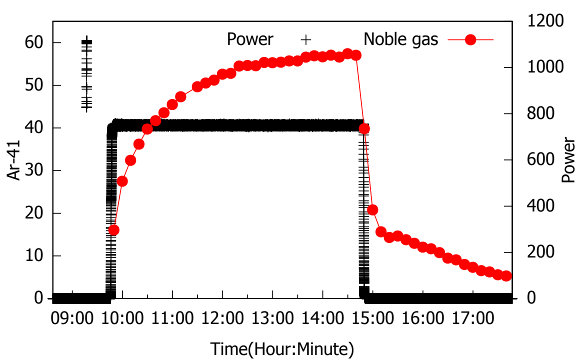

Fig. 1: The typical profile of concentration of noble gas in Bq/m^3 assuming majority effluent containing ^{41}Ar radionuclide in correllation with the power of PUSPATI TRIGA reactor in KW during five hour operation from 0950 to 1450.

The concentration of this radionuclide increases exponentially as the power of reactor maintained at 750 KW. This profile is typical example for the concentration of noble gas during the operation of PUSPATI TRIGA Reactor. The accumulated concentration of ^{41}Ar radionuclide was obtained from the profile gives the source term and therefore used as an input into HotSpot computer code to predict the γ dose in neighboring areas of the reactor. This is considered as the worth case scenario. In general,the total accumulated value of ^{41}Ar radionuclide concentration is 29.7 GBq for 5 hour operation, this value is equal to 0.8027 Ci. Fig. 1 shows that the concentration of ^{41}Ar radionuclide has dropped drastically upon the shutdown of reactor and further reduced after two hour shutdown. The profile of ^{41}Ar radionuclide shown in Fig. 1 is assumed representing a source term for a typical release of noble gas for PUSPATI TRIGA reactor used in this study.

The accumulated activity released from the stack was used as a source term in the simulation of atmospheric dispersion which carries the ^{41}Ar radionuclide into the surrounding areas. Distribution of ^{41}Ar radionuclide in critical neighboring zones from January to December, excepted February are given in the following figures.Fig. 2 shown the dispersion of ^{41}Ar radionuclide from PUSPATI TRIGA reactor in January, March, April, May and September and Fig. 3 shows the distribution of ^{41}Ar radionuclide in July, August, October, November and December.

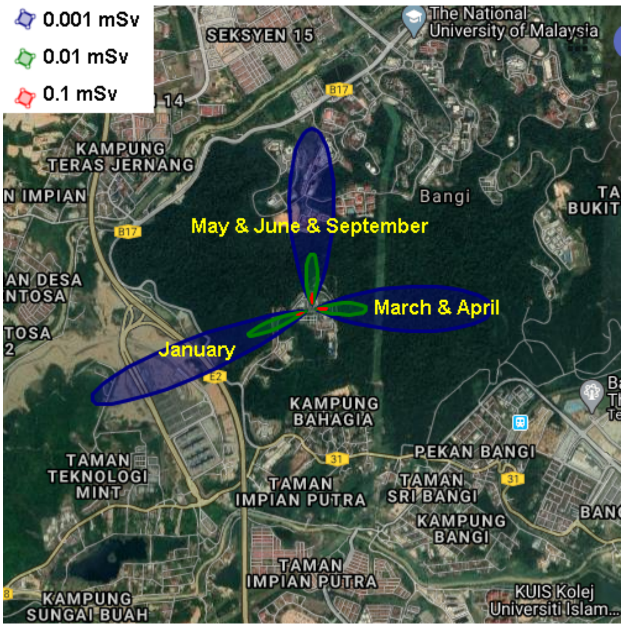

Fig. 2: Distribution of γ equivalent dose of ^{41}Ar radionuclide released from PUSPATI TRIGA reactor into the environment in January, March, April, May and September.

Direction of wind for twelve month cover almost all areas within PUSPATI TRIGA reactor circumferences. This indicates that the critical zone where there is high potential to receive ^{41}Ar radionuclide has changed in each month throughout the year. In fact, the inhabitant occupied within the circumferences zones especially within north zones are the most probable to be exposed as compared to other zone, but they are living at distance

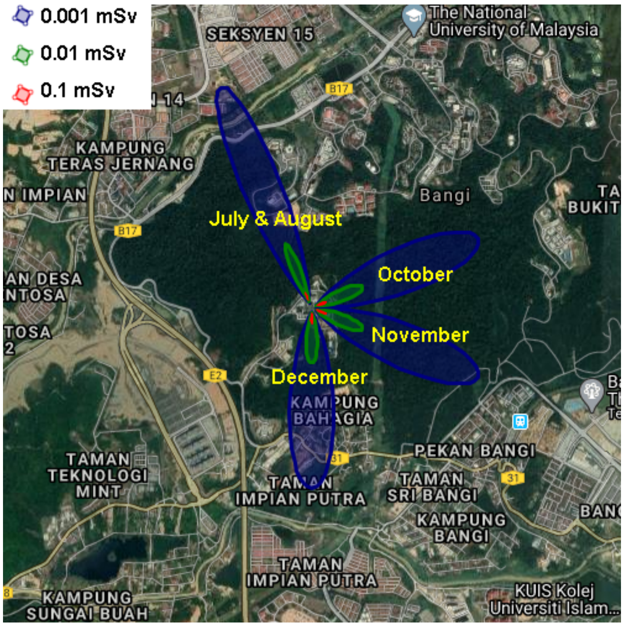

Fig. 3: Distribution of γ equivalent dose of ^{41}Ar radionuclide released from PUSPATI TRIGA reactor into the environment in July, August,September,October,November and December.

more that 1 km away from the release point where the radiation levels already 1 μSv, which is very low and safe for the member of public.

4 Discussion

The source term for ^{41}Ar radionuclide used as an input in HotSpot code was calculated based on the concentration of noble gas recorded from RTP operation data.Where, the activity of ^{41}Ar radionuclide from the calculation as source term was 0.8027 Ci. This value is based on five hour operation in each day. This is a typical operating period for PUSPATI TRIGA reactor. This value is obtained when it is assummed that the average concentration of ^{41}Ar radionuclide was 50 $\times$ 10^4 Bqm^{-3} at the flowrate of 3.3 m^{3}s^{-1}. The flowrate was calculated based on the as built design of stack system.With this parameters, the release of ^{41}Ar radionuclide in one hour is about 182.87 mCi, which is comparable with the one reported by [3] for the TRIGA reactor in Oregon State University operated at 1 MW and by [2] for Austrian TRIGA reactor operated at 250 kW.

The results obtained from modelling using HotSpot dispersion code shows that the neighboring areas within 1.4 km radius from PUSPATI TRIGA reactor have received very low dose, it was just about 10^{-6} mSv of γ radiation from ^{41}Ar radionuclide during operation when compared with the dose within the reactor building itself. The dose beyond 200 meter from the source is low and population within these zone and beyond this radius is safe since the level of dose from ^{41}Ar radionuclide is much lower than minimum limit for the member of public. In general,the people of public living in neighboring areas are not affected from the hazard of radiation during the operation of PUSPATI TRIGA reactor.

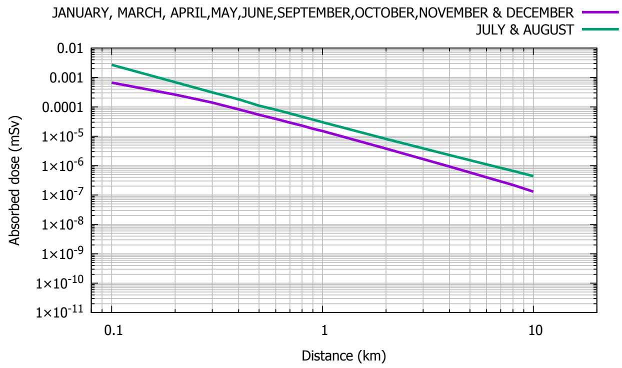

Fig. 4: The monthly absorbed dose of γ from released of ^{41}Ar radionuclide from PUSPATI TRIGA reactor into neighboring zone during operation as predicted by HotSpot code.

Fig. 4 shows the profile of γ absorbed dose in mSv from PUSPATI TRIGA reactor into surrounding neighboring area in each month within twelve month period.The γ dose from ^{41}Ar radionuclide at 1 meter height from the release point was about 0.005 mSv for July and August, while only around 0.001 mSv for other months. The dose was slightly smaller in July and August because the blowing speed was 2 ms^{-1} compared with other months where the speed was 3 ms^{-1}. The dose already reduced and its down to 0.0001 mSv at 0.5 km radius away from the release point.Based on this dose value, the possible dose reaches the personnel working within these zones is much smaller than the allowable limit for radiation worker. For total working period to all personnel when working in these zones for twelve month is about 2000 hours, therefore, the potential dose received by each personnel is about 0.04 mSv only. This magnitude is extremely small and it is just 0.2% compared with the maximum dose limit allowed for the radiation worker.

Results from prediction using HotSpot simulation has been compared with the measurement using Thermoluminescent Dosimetry (TLD) material for selected places surrounding neighboring areas from PUSPATI TRIGA Reactor. The measurement locations have been selected within the circumference of PUSPATI TRIGA Reactor. The measurement of dose has been done every month and the total accumulated dose for one year has been recorded. The accumulated dose from TLD measurement for each locations included in the RTP Annual Report to the regulatory body, Atomic Energy Licensing Board [6] has been compared with the simulation. Assuming the γ radiation measured was from ^{41}Ar radionuclide. Therefore, the total accumulated γ dose distribution obtained by measurement in comparison with the data predicted by HotSpot code simulation considering the possible exposure about 5 hour a day in 4 day a week for each month through out the year is given in Fig 5.

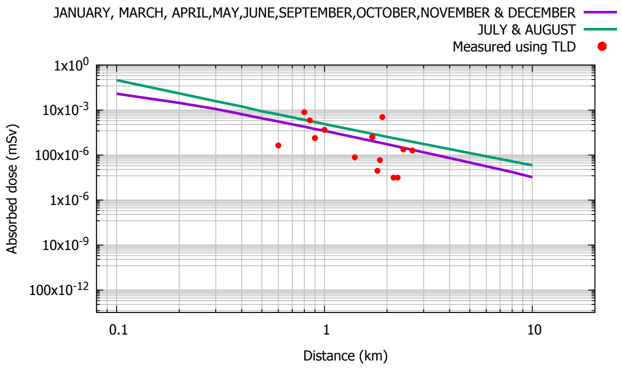

Fig. 5: The annual absorbed dose of γ radiation from released of ^{41}Ar radionuclide from PUSPATI TRIGA reactor stack into neighboring zone during operation predicted using HotSpot code compared with the measured annual dose using TLD materials.

This figure shows that the measured TLD data have well agreed with the predicted data using HotSpot code for each distance from the reactor. In overall, dose of gamma radiation is less than 0.01 mSv for all measurement points where there are many inhabitant live around that areas.Dose rate already less than 0.01 mSv at 0.8 km away the reactor and reduced again with the increment of distance from the reactor.Gamma dose rate of 0.01 mSv as predicted and measured within the living zone is 99.0% lower than maximum allowable limit for clean area [7]. This result indicate that the member of public within 1.0 km away from the reactor has no risk to the danger from this γ radiation.

5 Conclusions

This article successfully demonstrated the dispersion of ^{41}Ar radionuclide from stack release of PUSPATI TRIGA reactor effluent into the neighboring areas during reactor operation using HotSpot dispersion code. The critical area where the population that high potential to be exposed to the released are determined and the dose of γ radiation contributed to the population also estimated. This is found that the population will expose to the dose of γ radiation from ^{41}Ar radionuclide with only less than 1 μSv, therefore the consequences is low and most likely not harmful to their daily life. The prediction of the annual dose of γ radiation contributed by ^{41}Ar radionuclide using HotSpot code is well agreed with the measured value of environmental TLD materials.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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