JPPIPA 10(2) (2024)

Jurnal Penelitian Pendidikan IPA
Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Measurement and Risk Analysis of Ozone (O_3) Concentrations in the 9 MeV and 12 MeV Electron Mode LINAC

Nur Khasanah[1*], Raehanah[2], Bunawas[3], I Wayan Ari M[4], Rinarto Subroto[4], Lalu Sahrul H[5], Paramita Putri A[1], Dia Ulfariah[1]

[1] Physics Education Department, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Mataram, Mataram Indonesia.
[2] Chemistry Education Department, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Mataram, Mataram Indonesia.
[3] NuklindoLab-Koperasi JKRL, Tangerang Selatan, Indonesia
[4] Radiotherapy Installation, RSUD Provinsi NTB, Mataram, Indonesia
[5] Physics Department, Faculty of Mathematical and Science, University of Mataram, Mataram, Indonesia.

Received: September 17, 2023
Revised: November 24, 2023
Accepted: February 25, 2024
Published: February 29, 2024

Corresponding Author:
Nur Khasanah
nurkhasanah@uinmataram.ac.id

DOI: 10.29303/jppipa.v10i2.5347

Abstract: This study investigates potential non-radiation hazards, specifically Ozone (O3) production, during Linear Accelerator (LINAC) electron mode radiotherapy. The research uses experimental measurements to determine Ozone concentration in the LINAC patient waiting room and control room. Measurements are taken assuming a ±2-hour delay in one working day, using 9 MeV and 12 MeV energy, 400 MU dose rate, and illumination angles of 0o, 90o, and 270o. Maximum Ozone concentrations in the LINAC patient waiting room and control room are found to be 6.6 ppb (12 MeV) and 8.3 ppb (12 MeV), respectively. These concentrations fall below the chemical threshold limit and are deemed safe for human exposure. Notably, potentially detectable Ozone levels are observed in the LINAC banker. Overall, this research highlights the importance of monitoring Ozone levels to ensure the safety of both patients and personnel in LINAC facilities.

Keywords: Electron; LINAC; Ozon.

Introduction

Radiotherapy is the most common modality for treating cancer in humans (Rismawati et al., 2022). The goal of radiotherapy is to deliver the precise dose to cancerous tissues while preserving normal tissues or reducing the effects on them (Yunasfi et al., 2003). This objective can be achieved with current technological advancements, and one method is by using a Linear Accelerator (LINAC) machine (Mirnawati et al., 2019). LINAC can generate two radiation beams during its operation: a photon beam with energy ranging from 6-28 MeV for cancer therapy within body tissues Pupillo et al. (2023), and an electron beam with energy ranging from 4-22 MeV for treating skin surface cancers (Khabaz, 2018).

However, during normal LINAC operation, there are potential risks associated with both secondary radiation (Kurniasari et al., 2022) and non-radiation (Mihai et al., 2021) hazards that need to be considered for safety, such as the production of neutron (Banaee et al., 2021) and gamma radiation (Polaczek-Grelik et al., 2019), as well as ozone (Hara et al., 2022). High levels of ozone are also generated during LINAC electron mode operation (Arismunandar & Silakhuddin, 2002). Ozone is a toxic gas, and prolonged exposure to elevated ozone concentrations in the workplace can pose health risks (Gao et al., 2022). Research by Lia Wilda Izzati and colleagues indicates that LINAC electron mode operation can indeed produce ozone radiation (Izzati et

How to Cite:
Khasanah, N., Raehanah, Bunawas, M, I. W. A., Subroto, R., H, L. S., A, P. P., & Ulfariah, D. (2024). Measurement and Risk Analysis of Ozone (O3) Concentrations in the 9 MeV and 12 MeV Electron Mode LINAC. *Jurnal Penelitian Pendidikan IPA*, *10*(2), 757–763. https://doi.org/10.29303/jppipa.v10i2.5347

al., 2021), a fact not widely known among radiation workers.

Jin-Kook Lee and colleagues conducted a study aiming to evaluate ozone concentrations after exposure to high radiation in the LINAC room. They measured background ozone concentrations and compared them with those inside the LINAC room. The average background ozone concentration was 17.4±7.9 ppb, which was 50% lower than the ozone concentration inside the LINAC room (36.8±22.3 ppb) ($p<0.05$). Ozone concentration doubled after exposure, and it took more than 10 minutes for the room's ozone concentration to decrease (Lee et al., 2016).

According to a study by Hara et al., ozone inside the room is undetectable before treatment begins. The maximum ozone concentration in a PVC tube was only 0.006 ppm when exposed to 2400 monitor units (MU)/minute. Depending on the X-ray dose rate used, the concentration increased to 0.010 ppm with oxygen flowing through the other end of the tube at 1.5 L/minute. Ozone concentrations in the PVC tube did not significantly differ between X-rays and electron beam irradiation (Hara et al., 2022).

Additionally, the toxic characteristics of ozone pose a significant respiratory health risk, especially for radiation workers and patients in LINAC electron mode radiotherapy. According to the National Council on Radiation Protection and Measurements (NCRP), indoor ozone produced by the Linear Accelerator (LINAC) in radiation treatment rooms is a safety risk for patients or radiation workers. Therefore, it is essential to calculate or measure the level of ozone radiation produced in the LINAC electron mode room to effectively minimize ozone exposure (Dubey et al., 2009).

Ozone is a nearly colorless gas with a distinct odor detectable by the sense of smell at concentrations as low as 0.01 ppm. The maximum ozone concentration in open spaces is around 0.10 ppm, and a concentration of 1.00 ppm is considered non-hazardous as long as it is not inhaled into the respiratory system for more than 10 minutes. According to the Regulation of the Minister of the Republic of Indonesia No. 70 of 2016 regarding Health Standards and Requirements in the industrial workplace, one of the standards is the chemical substance limit in the workplace, set at 0.1 ppm or 100 ppb. Ppm or mg/unit represents the average concentration of ozone by all workers without causing health disturbances or diseases in daily work for a minimum of 8 hours per day and 40 hours per week (Pieri et al., 2015).

In the future, it is hoped that this research can serve as a reference for the evaluation of radiation worker and patient protection. All radiotherapy installations in Indonesia using LINAC electron mode should evaluate the level of ozone concentration produced and enhance radiation protection and ozone concentration safety in the workplace to mitigate potential adverse effects.

Method

Ozone concentration measurements in the patient waiting room and LINAC control room were carried out using the Ozone Meter Air Quality Detector measuring instrument. This device can detect the minimum ozone concentration of 0.001 ppm, and measurements are accurate to 0.001 ppm. The LINAC tool used in this research is the CLINAC CX brand. The LINAC was used with a full-sized irradiation field (40 cm × 40 cm at a source axis distance of 100 cm). To evaluate the dependence of electron beam energy on ozone concentration, measurements were carried out by irradiating with electron beam energies at 9 MeV and 12 MeV with a dose rate of 400 MU/min.

Figure 1 presents a clear and concise guide for measuring ozone concentration in the LINAC patient waiting room and control room, ensuring patient safety and regulatory compliance. Measurements were carried out for two days with five measures each and a break between each step of ± 2 hours once in 1 working day or 8 hours. The LINAC illumination angles used are 0^{o}, 90^{o}, and 270^{o}. The measurement point was carried out in the LINAC patient waiting room, a distance of ±3 meters from the LINAC room and LINAC control room. This patient waiting room has a size of 5.67 m × 3.63 m × 2.48 m, and the size of the LINAC control room is 9.04 m × 2.42 m × 2.48 m. The ventilator speed in each room is 0.8 m/s. Data analysis was carried out by calculating the actual ozone concentration in the patient waiting room and LINAC control room with the equation:

$$Ozone\ (ppb) = \frac{Measurable\ value - Ozone\ background}{Calibration\ factor} \quad (1)$$

The calibration factor for the ozone meter is 0.6. The actual ozone concentration calculation results in ppm units converted into ppb units. where 1 ppm = 1000 ppb. Then, the ozone concentration calculation results are compared with the limit values for chemicals in the workplace based on the Regulation of the Minister of Health of the Republic of Indonesia No. 7 of 2016, namely 0.1 ppm or 100 ppb.

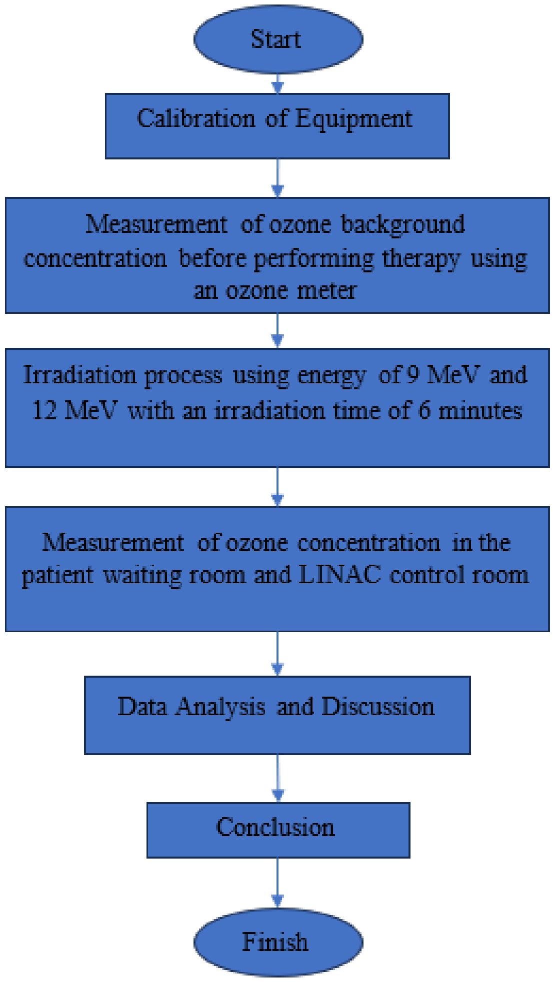

Figure 1. Ozone Measurement Procedure for LINAC Patient Waiting Room and Control Room

Result and Discussion

Results of Ozone Concentration Measurements in the LINAC Patient Waiting Room

Ozone concentration measurements in the LINAC patient waiting room were carried out on two working days. The following is the data from the analysis, which is presented in graphic form.

No ozone was detected the morning before LINAC therapy radiation began. Based on Figure 1 above, it can be seen that the ozone concentration level in the LINAC patient waiting room during the afternoon and evening is 5 ppb. This figure is 20 times smaller than the limit value for chemicals in the workplace based on Ministerial Regulation of the Republic of Indonesia No. 70 of 2016. This Ozone (O_3) concentration is still in the Good or Moderate category because it is still far from the Limit Value for Chemicals without causing respiratory health problems or other diseases.

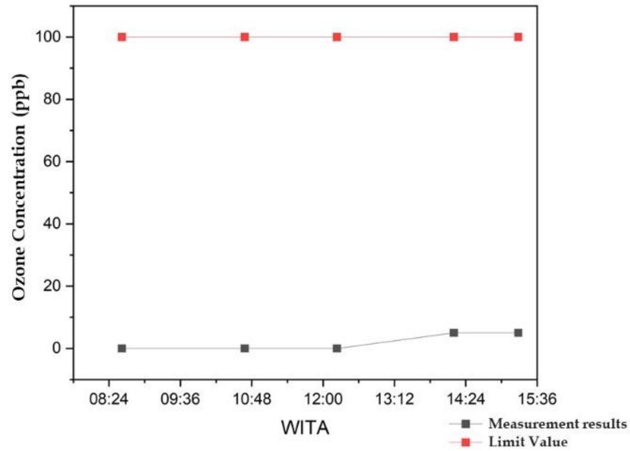

Figure 2. Graph of ozone concentration in the patient waiting room after electron mode LINAC irradiation with 9 MeV energy for 8 hours/1 working day compared to the Chemical Threshold Limit Value

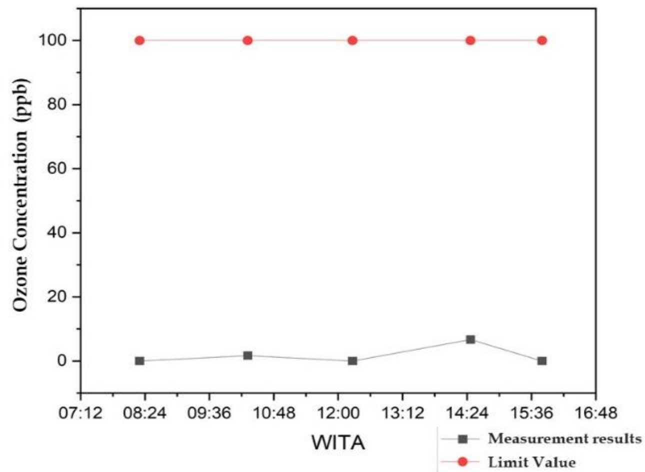

Figure 3. Graph of ozone concentration in the patient waiting room after irradiating the LINAC with 12 MeV energy for 8 hours/1 working day compared to the Chemical Threshold Limit Value

The same experiment was conducted in the patient waiting room using 12 MeV LINAC illumination. The results of measuring the ozone concentration after irradiating the LINAC with an energy of 12 MeV and an irradiation time of 6 minutes were less than 0.1 ppm or 100 ppb. The Ozone concentration was detected at 1.67 ppb after 2 hours of starting LINAC illumination in the morning. The ozone concentration detected during the day was 6.67 ppb. The highest ozone concentration occurs at noon, precisely at 14:28 WITA. The comparison between the ozone concentration level in the LINAC patient waiting room and the workplace chemical limit in the Minister of Health Regulation of 0.1 ppm can be seen in Figure 2. The highest ozone concentration in the LINAC patient waiting room is 6.67 ppb. This value means this figure is 14 times smaller than the Chemical

Limit based on the Regulation of the Minister of Health of the Republic of Indonesia No. 7 of 2016, 0.1 ppm or 100 ppb without causing respiratory health problems or other diseases.

Ozone Concentration Measurement Results in the LINAC Control Room

Ozone concentration data was collected for two days in the LINAC control room, using 9 MeV energy, shown in Figure 3, and 12 MeV energy in Figure 4.

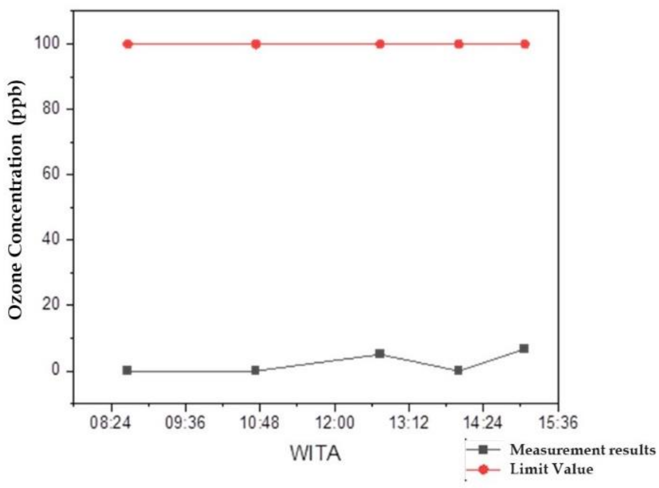

Figure 4. Graph of ozone concentration in the LINAC control room after irradiating the LINAC with 9 MeV energy for 8 hours/1 working day compared to the Chemical Threshold Limit Value

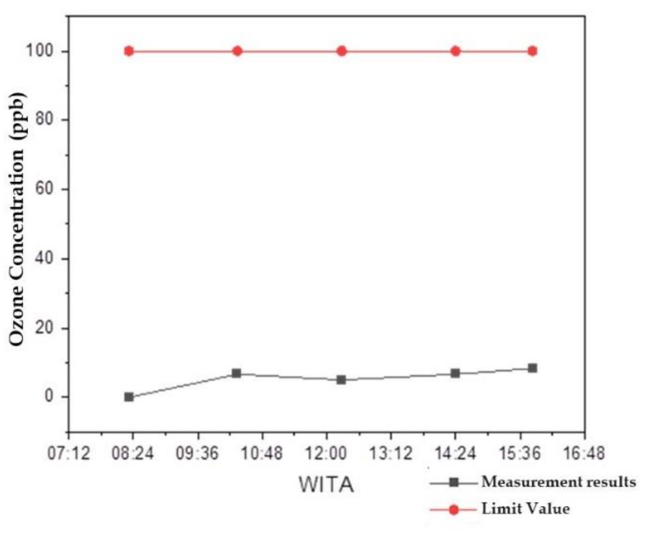

Figure 5. Graph of ozone concentration in the LINAC control room after irradiating the LINAC with 12 MeV energy for 8 hours/1 working day compared to the Chemical Threshold Limit Value

No ozone was detected in the LINAC control room the morning before the LINAC therapy irradiation began. Ozone began to be seen after 4 hours of linac therapy irradiation. Figure 3 shows that the highest ozone concentration level in the LINAC control room with 9 MeV illumination was in the last measurement at 15:50 at 6.67 ppb. This figure is 14 times smaller than the threshold limit set by Regulation of the Minister of Health of the Republic of Indonesia No. 70 of 2016 in the workplace, namely 0.1 ppm or 100 ppb.

The maximum ozone concentration in the LINAC control room with 12 MeV irradiation was 8.3 ppb in our study, significantly higher than the Ozone concentration in the LINAC patient waiting room. Based on Figure 4 above, it can be seen that the highest ozone concentration level was at the last measurement at 15:50, namely, 8.3 ppb. This figure is 12 times smaller than the threshold limit set by Regulation of the Minister of Health of the Republic of Indonesia No. 70 of 2016 in the workplace is 0.1 ppm or 100 ppb.

The ozone concentration depends on the amount of radiation from the electron beam; the higher the energy produced, the higher the ozone concentration detected by the ozone measuring instrument (Barshan et al., 2020; Cleland & Galloway, 2015; Mishra et al., 2018). The ozone concentration in the patient waiting room is also far from the workplace chemical limit based on the Regulation of the Minister of Health of the Republic of Indonesia, which is 0.1 ppm or 100 ppb. The maximum concentration occurred during 12 MeV LINAC operation at 8.3 ppb in the LINAC control room. This value means that this figure is still 12 times smaller than the limit for chemicals in the workplace based on Ministerial Regulation of the Republic of Indonesia No. 7 of 2016. The maximum concentration in the treatment room that the human senses can feel is 0.15 ppm or 150 ppb. These data show that ozone concentrations were not detectable before LINAC operation but increased substantially after treatment began. Indoor concentrations can vary significantly from hour to hour, day to day, season to season, room to room, and structure to structure (John P. Gibbons, 2020; Mittal, 2012).

The ozone concentration will depend significantly on the amount of electron beam radiation energy produced; the more significant the electron beam energy, the greater the concentration detected by air quality monitors (Khan & Kumar, 2014; Xue et al., 2021). The maximum concentration occurred during 12 MeV LINAC operation at 8.3 ppb in the LINAC control room. A low ozone concentration in a room is due to ozone molecules decomposing naturally after the LINAC stops operating (Adler & Severnini, 2023; Ma et al., 2020; Niu et al., 2018). In contrast, a high ozone concentration indicates that the remaining ozone in the room has increased again due to the operation of the LINAC when the patient arrives and will continue to increase over time. Indicating that residual ozone generated from previous LINAC operations will accumulate with the ozone concentration in subsequent LINAC operations. In this case, the number of patients per day can influence the ozone concentration in the electron mode LINAC operating room (Izzati et al., 2021).

Under normal conditions, the half-life of ozone indoors ranges from 7 to 10 minutes and is determined by surface removal and air exchange (Weschler, 2000). Ozone in our air can harm health, and ozone concentrations can reach unhealthy levels (Nuvolone et al., 2018). Ozone, which enters the body through human skin or the respiratory tract, is a potent chemically active gas that easily forms chemical bonds with surrounding substances and decomposes so that it can be broken down into proteins, lipids, and carbohydrates, which interact with the constituent materials to produce free radical oxidation, resulting in permanent damage (Lee et al., 2016). People most at risk of ozone exposure include people living with asthma, children, adults who have health problems in the body's systems, in this case, cervical cancer, breast cancer, etc., and people who are active in the room (radiation workers) are at greater risk of exposure (Guan et al., 2022; Nazaroff & Weschler, 2022; Salonen et al., 2018). Ozone exposure. In this study, ozone concentrations in the patient waiting room and LINAC control room were undetectable before LINAC use began, but ozone concentrations increased significantly after irradiation began. Concentrations were much higher in the control room after 12 MeV LINAC irradiation than in the LINAC patient waiting room. Regardless, ozone concentrations in the patient waiting area and the LINAC control room were much lower than the upper safety limit of 0.1 ppm.

Conclusion

The maximum concentration occurred during 12 MeV LINAC operation at 8.3 ppb in the LINAC control room. The ozone concentration in the patient waiting room and the LINAC control room is much lower than the upper safety limit based on Ministerial Regulation of the Republic of Indonesia No. 7 of 2016 of 0.1 ppm. This Ozone concentration is too low for human perception. However, ozone concentrations reached potentially detectable levels in the LINAC chamber.

Acknowledgments
The researcher would like to thank the parties involved in this research until the publication of this article.

Author Contributions
Conceptualization, NK and B; formal analysis, LSH and R; investigation, IWA, RS, PP, and DU.

Funding
This research was funded by LPPM UIN Mataram

Conflicts of interest
The authors of this article declare no conflict of interest.

References

Adler, D., & Severnini, E. (2023). Timing matters: Intra-day shifts of economic activity and ambient ozone concentrations. *Journal of Public Economics*, *223*. https://doi.org/10.1016/j.jpubeco.2023.104905

Arismunandar, & Silakhuddin. (2002). Struktur dan segi-segi keselamatan linac medik. *Prosiding Seminar ke-7 Teknologi dan Keselamatan PLTN Serta Fasilitas Nuklik*, 378-388. Retrieved from https://www.osti.gov/etdeweb/servlets/purl/20788495

Banaee, N., Goodarzi, K., & Nedaie, H. A. (2021). Neutron contamination in radiotherapy processes: a review study. *Journal of Radiation Research*, *62*(6), 947-954. https://doi.org/10.1093/jrr/rrab076

Barshan, S., Pazirandeh, A., & Jahanfarnia, G. (2020). Measurement of ozone produced by 10 MeV electron accelerator Yazd in various currents. *Journal of Instrumentation*, *15*(1). https://doi.org/10.1088/1748-0221/15/01/P01004

Cleland, M. R., & Galloway, R. A. (2015). Ozone Generation in Air during Electron Beam Processing. *Physics Procedia*, *66*, 586–594. https://doi.org/10.1016/j.phpro.2015.05.078

Dubey, P., Sawatkar, A. R., Sathe, A. P., Sarma, K. S. S., & Soundararajan, S. (2009). Generation of Ozone and Safety Aspects in an Accelerator Facility of BARC. *Indian Particle Accelerator Conference (InPAC), Fev,* 10-13. Retrieved from https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=46028312

Gao, Q., Zang, E., Bi, J., Dubrow, R., Lowe, S. R., Chen, H., Zeng, Y., Shi, L., & Chen, K. (2022). Long-term ozone exposure and cognitive impairment among Chinese older adults: A cohort study. *Environment International*, *160*. https://doi.org/10.1016/j.envint.2021.107072

Guan, Y., Xiao, Y., Chu, C., Zhang, N., & Yu, L. (2022). Trends and characteristics of ozone and nitrogen dioxide related health impacts in Chinese cities. *Ecotoxicology and Environmental Safety*, *241*. https://doi.org/10.1016/j.ecoenv.2022.113808

Hara, N., Oobuchi, J., Isobe, A., Sugimoto, S., Takatsu, J., & Sasai, K. (2022). Generation of ozone during irradiation using medical linear accelerators: an experimental study. *Radiation Oncology*, *17*(1). https://doi.org/10.1186/s13014-022-02005-6

Izzati, L. W., Agus Firmansyah, M., & Bunawas, D. (2021). Risk of ozone exposure in LINAC room electron mode and attempts to minimize It: A theoretical review. *Annual Nuclear Safety Seminar 2021*, 116–121. Retrieved from https://inis.iaea.org/collection/NCLCollectionStore/_Public/53/122/53122451.pdf?r=1

John P. Gibbons. (2020). *Khan's The Physics of Radiation Therapy - six edition*. Lippincott Williams & Wilkins.

Khabaz, R. (2018). Effect of each component of a LINAC therapy head on neutron and photon spectra. *Applied Radiation and Isotopes*, *139*, 40–45. https://doi.org/10.1016/j.apradiso.2018.04.022

Khan, A. G., & Kumar, P. (2014). Beam dump for 10 kW 10 Mev LINAC. *Applied Thermal Engineering*, *70*(1), 541–545. https://doi.org/10.1016/j.applthermaleng.2014.05.065

Kurniasari, S., Hentihu, F. K., Anto, A. K., & Prasetyo, H. (2022). The Measurement of Enviromental Radiation Exposure Around the Linac Radiotherapy Bunker. *Indonesian Physical Review*, *5*(1), 23. https://doi.org/10.29303/ip

Lee, J., Lee, H.-Y., Im, I.-C., & Yu, Y.-S. (2016). Variation of Indoor Average Ozone Concentration within the Radiation Therapy Room by High Energy Radiation. *Journal of the Korean Society of Radiology*, *10*(3), 171–180. https://doi.org/10.7742/jksr.2016.10.3.171

Ma, R., Ban, J., Wang, Q., & Li, T. (2020). Statistical spatial-temporal modeling of ambient ozone exposure for environmental epidemiology studies: A review. In *Science of the Total Environment*, 701, 134463. https://doi.org/10.1016/j.scitotenv.2019.134463

Mihai, A. M., Rock, L., & Milano, M. T. (2021). Technical challenges of linac-based stereotactic ablative body radiotherapy: Short review for non-radiation oncologists. In *Annals of Palliative Medicine*, *10*(5), 5931–5943. https://doi.org/10.21037/apm-20-950

Mirnawati, F., Jati, S. P., & Sugiarto, J. (2019). Evaluation Of Linear Accelerator Utilization for Ca Mammae Radiotherapy At A Private Hospital. *Indonesian Journal of Health Administration*, *7*(2), 132–138. https://doi.org/10.20473/jaki.v7i2.2019.132-138

Mishra, A. S., Verma, V. P., Choudhary, R. S., Goswami, S. G., Petwal, V. C., & Dwivedi, J. (2018). Ozone concentration study using 10 MeV electron beam accelerator. In *Proceedings of the twenty first national symposium on radiation physics: book of abstracts cum souvenir 48.* Retrieved from https://inis.iaea.org/search/search.aspx?orig_q=RN:49082934

Mittal, K. C. (2012). High power electron accelerators for radiation processing and its safety aspects. In *Indian Journal of Pure & Applied Physics*, *50,* 772-775. Retrieved from https://nopr.niscpr.res.in/handle/123456789/14899

Nazaroff, W. W., & Weschler, C. J. (2022). Indoor ozone: Concentrations and influencing factors. In *Indoor Air*, *32*(1). https://doi.org/10.1111/ina.12942

Niu, Y., Cai, J., Xia, Y., Yu, H., Chen, R., Lin, Z., Liu, C., Chen, C., Wang, W., Peng, L., Xia, X., Fu, Q., & Kan, H. (2018). Estimation of personal ozone exposure using ambient concentrations and influencing factors. *Environment International*, *117*, 237–242. https://doi.org/10.1016/j.envint.2018.05.017

Nuvolone, D., Petri, D., & Voller, F. (2018). The effects of ozone on human health. *Environmental Science and Pollution Research*, *25*(9), 8074–8088. https://doi.org/10.1007/s11356-017-9239-3

Pieri, L., Vignudelli, M., Bartolucci, F., Salvatorelli, F., Di Michele, C., Tavano, N., Rossi, P., & Dinelli, G. (2015). Integrated environmental quality monitoring around an underground methane storage station. *Chemosphere*, *131*, 130–138. https://doi.org/10.1016/j.chemosphere.2015.03.009

Polaczek-Grelik, K., Kawa-Iwanicka, A., Rygielski, M., & Michalecki, Ł. (2019). Gamma Radiation in the Vicinity of the Entrance to Linac Radiotherapy Room. In *Use of Gamma Radiation Techniques in Peaceful Applications,* 157. https://doi.org/10.5772/intechopen.82726

Pupillo, F., Piliero, M. A., Casiraghi, M., Bellesi, L., & Presilla, S. (2023). RapidPlan models for prostate radiotherapy treatment planning with 10-MV photon beams. *Journal of Radiotherapy in Practice*, *22*(187). https://doi.org/10.1017/S1460396922000267

Rismawati, S. N., Noor, J. A. E., Yueniwati, Y., & Hentihu, F. K. (2022). Impact of In-House Bolus Thickness on The Percentage of Surface Dose for 10 and 12 MeV Electron Beams. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2833–2839. https://doi.org/10.29303/jppipa.v8i6.2344

Salonen, H., Salthammer, T., & Morawska, L. (2018). Human exposure to ozone in school and office indoor environments. In *Environment International 119*, 503–514. https://doi.org/10.1016/j.envint.2018.07.012

Weschler, C. J. (2000). Ozone in Indoor Environments: Concentration and Chemistry. *Indoor Air*, *10*, 269–288. Retrieved from https://www.aivc.org/sites/default/files/airbase_13439.pdf

Xue, X. M., Ru, S. M., Gu, X. N., Wu, Z., Yang, X., & Zhan, J. M. (2021). Gamma Radiation Source and Accelerator Room Radiation Shielding and Its Ozone Concentration Calculation Software Design. *Hedianzixue Yu Tance Jishu/Nuclear Electronics and Detection Technology*, *41*(4), 620–624.

Yunasfi, Mudjiono, Irwanti Dwi, & Hanifa. (2003). Penggunaan Akselerator untuk terapi di Indonesia. *Proseding Seminar Pengembangan Teknologi Dan Perekayasaan Instrumentasi Nuklir,* 97-100. Retrieved from https://inis.iaea.org/collection/NCLCollectionStore/_Public/37/092/37092470.pdf