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Disposal of Radioactive Waste Generated at the End of 18F- Fluorodeoxyglucose Production for Positron Emission Tomography - Computed Tomography (PET-CT) Scan at Armed Forces Institute of Radiology and Imaging, Rawalpindi

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ABSTRACT

Objective: To find out the optimal timeline for the safe disposal of radioactive wastes generated at the end of normal and anomalous productions of 18F-Fluorodeoxyglucose for positron emission tomography-computed tomography scans.
Study Design: Quasi-experimental study.
Place and Duration of Study: Armed Forces Institute of Radiology and Imaging, Rawalpindi Pakistan, from Aug to Dec 2020.
Methodology: Wastes generated at the end of 18F-Fluorodeoxyglucose production were tested for residual radioactivity at 2, 12 and 24 hours after synthesis to ascertain the optimal timeline for discarding. The radiation dose at 5 cm from the surface of the container was also assessed.
Results: Fifty productions were included in the study, of which 46(92%) were normal, and 4(8%) were anomalous productions. The mean activity at 2 and 24 hours after the end of synthesis was 4.102±0.831mCi and 0.0047±0.00116mCi, respectively, in normal productions and 45.125±2.332mCi and 0.005±0.00026mCi respectively in anomalous productions. The mean radiation dose at 5cm from the surface of the container at 2 and 24 hours after the end of synthesis was 8.2107±1.665mSv/h and 0.00000966±0.00000212mSv/h in normal productions and 90.32±4.66mSv/h and 0.00975±0.0005-mSv/h respectively in anomalous productions.
Conclusion: The residual radioactivity in wastes was negligible 24 hours after the end of synthesis in both normal and anomalous productions. Radioactive wastes from 18F-Fluorodeoxyglucose production should, therefore, be conserved for at least 24 hours before their disposal to the environment.

Keywords*:* Cyclotron, F18-fluorodeoxyglucose, Positron emission tomography, Radioactivity.

How to Cite This Article: *Bilal R, Mehdi SA, Slehria AR, Ullah H, Amin Z. Disposal of Radioactive Waste Generated at the End of 18F- Fluoro-deoxyglucose Production for Positron Emission Tomography-Computed Tomography (PET-CT) Scan at Armed Forces Institute of Radiology and Imaging, Rawalpindi. Pak Armed Forces Med J 2022; 72(5): 1734-1738. DOI: https://doi.org/10.51253/pafmj.v72i5.7132*

INTRODUCTION

In the present times, positron emission tomography (PET) has become a widely used molecular imaging technology for the diagnosis of cancer patients.[1] The facility of PET-computed tomography (CT) and Cyclotron has been recently provided at the Armed Forces Institute of Radiology and Imaging (AFIRI) for the diagnosis of cancer patients. The radioactive isotope of Fluorine 18F is used as the main component to serve this purpose. There is a possibility of radiation exposure during the management of production and administration of radioactive material, constituting an unwanted occupational hazard to the radiation workers.[2] Additionally, there is also a possibility of disposing of unwanted radionuclides in the environment as waste products from the synthesis procedure.[3]

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Received: 19 Jul 2021; revision received: 24 Jan 2022; accepted: 26 Jan 2022

Positron emission tomography utilizes 18F-Fluorodeoxyglucose (18F-FDG), which is synthesized from 18F fluoride ion and produced from 18O water, having the stable O-18 isotope through 18O (p,n) 18F reaction in a cyclotron. 18F is later transformed into 18F 2-fluoro-2-deoxyglucose or 18F-FDG with the help of a synthesizer serving the purpose.[4]

In our setup, FASTlab 2 synthesizer produces 18F-FDG with a synthesis time of about 22–25 minutes. The synthesizer uses a consumable FDG cassette that has to be inserted into the unit.[5] The cassette contains all necessary chemicals for synthesising bulk 18F-FDG. The synthesis is controlled and monitored with vendorsupplied custom software, which automates the process.[6,7] It also directs the residual waste material, including 18F, to the waste bottle of the synthesizer. In normal production, the activity of radioactive waste collected inside the waste bottle of the synthesizer is approximately 50mCi, but in anomalous conditions, this activity can rise to 500mCi. The faulty performance

of the cassette used for the synthesis procedure is the possible cause of this inefficient outcome. Most of the produced 18F is flushed into the waste bottle without tagging into Fluorodeoxyglucose. Particular attention needs to be paid to the amount of radioactivity present inside the waste bottle because the disposal of this waste can cause the release of radioactive contamination into the atmosphere. The radionuclides inside the bottle can potentially result in unjustified radiation exposure to individuals and the environment.[8,9] Quantification of the radiation levels in the waste is required to ensure the radiological safety of workers and the environment. In normal productions, disposal of activity is recommended after the completion of 10 half-lives for the safety of workers and the environment.[10]

This study aimed to assess the radioactivity and the resultant radiation dose to the environment present inside the waste bottle of the synthesizer, irrespective of their content, that may be released in the normal and anomalous synthesis process of 18F-FDG. In addition, serial testing for radioactivity will help decide the timeline and protocols for the safe disposal of the waste produced during normal and anomalous production of 18F-FDG.

METHODOLOGY

This quasi-experimental study was carried out at Armed Forces Institute of Radiology and Imaging, Rawalpindi, Pakistan, after getting approval from the Institutional Ethical Review Board (No.0033, dated 1 January 2021).

Inclusion Criteria: All productions of 18F-FDG from August to December 2020 were included in the study.

Exclusion Criteria: None

Cyclotron, MINItrace Qilin, GE Healthcare GE MS PET Systems AB Box 15024, Husbyborg SE-750 15 Uppsala Sweden irradiated 18O enriched water, which worked as a consumable for the production of 18F. The 18F fluoride was then transferred into the synthesis unit (FASTlabTM 2 synthesizer, GE Healthcare GE MS PET Systems AB Box 15024, Husbyborg SE-750 15 Uppsala Sweden) for the production of injectable FDG. The 18F-FDG synthesis was carried out in a disposable fluid pathway called the FDG cassette (FDG Single Citrate Cassette, GE Healthcare GE MS PET Systems AB Box 15024, Husbyborg SE-750 15 Uppsala Sweden). To determine the yield in the most precise manner, the starting activity, as well as the activity in the waste bottle, was measured using a separate dose calibrator (CRC®-55t, Capintec, Inc. Sales and Marketing and Customer Support 6 Arrow Road Ramsey, NJ 07446 Phone (800) ASK-4CRC USA). The radiation dose at 5 cm from the surface of the container was checked using a Radiation Alert Ranger detector with an Internal Halogen Quenched Uncompensated GM tube 45 mm with a thin mica window. The whole production assembly, i.e., synthesizer and waste bottle, were placed inside a controlled environment (6-inch lead shielding) for the safety and protection of the radiation staff to operate and calibrate the instruments. 18F was received inside the synthesizer and then converted into 18F-FDG during the synthesis process. The production was regarded as normal if more than 70% of the raw 18F was converted into Fluorodeoxy-glucose and anomalous if less than 70% of 18F was converted into Fluorodeoxyglucose.

Irrespective of the content, the activity in the waste bottles was quantified at 2 and 24 hours after the end of the synthesis (EOS) by using a 3ml representative sample of the waste from the waste bottle. The radiation dose at 5 cm from the surface of the container for each production was also measured using a Radiation Alert Ranger detector at 2 and 24 hours after EOS.

Statistical Package for Social Sciences (SPSS) version 20.0 was used for data entry and analysis. Frequency and percentage were calculated for the type of production. Mean with the standard deviation of residual activity and radiation dose were calculated at 2 and 24 hours for both normal and anomalous productions. The independent sample t-test was used. The p-value of≤ 0.05 was considered significant.

RESULTS

A total of 50 productions of 18F-FDG were included in our study, out of which 46(92%) were normal, and 4(8%) were anomalous productions.

The mean activity in the waste bottle at 2 hours after EOS was 4.102±0.831 mCi with a range of 2.77mCi to 5.55mCi in normal productions and 45.125±2.332-mCi with a range of 42.14mCi to 47.5mCi in anomalous productions.

The mean activity in the waste bottle at 24 hours after EOS was 0.0047±0.00116mCi with a range of 0.0033mCi to 0.0065mCi in normal productions and 0.005±0.00026mCi with a range of 0.0047mCi to 0.0053mCi in anomalous productions (Table-I).

The mean radiation dose at 5 cm from the surface of the container at 2 hours after EOS was 8.2107±1.665-mSv/h with a range of 5.54mSv/h to 11.11mSv/h in normal productions and 90.32±4.66mSv/h with a

range of 84.35 to 95.07 in anomalous productions. The mean radiation dose at 5 cm from the surface of the container at 24 hours after EOS was 0.00000966±0.0-0000212mSv/h with a range of 0.0000072mSv/h to 0.000013mSv/h in normal productions and 0.0097-5±0.0005mSv/h with a range of 0.009mSv/h to 0.01 mSv/h in anomalous productions (Table-II).

Table-I: Activity (mCi) In Waste Bottle In Normal And Anomalous Productions At 2 Hours And 24 Hours After EOS Showing A Marked Difference In Activity In Both Situations Along With A Sharp Decline With Time (n=50

Type of production	Frequency n (%)	2 Hours After EOS (mCi)	24 Hours After EOS (mCi)
		Mean±SD	Mean±SD
Normal (mCi)	46 (92)	4.102±0.831	0.0047±0.00116
Anomalous(mCi)	4 (8)	45.125±2.332	0.005±0.00026

Table-II : Radiation dose (mSv/h) at 5 cm From The Surface Of The Container In Normal And Anomalous Productions At 2 Hours And 24 Hours After EOS Showing A Marked Difference In Dose In Both Situations Along With A Sharp Decline With Time (n=50)

Type of Production	Frequency n (%)	2 Hours After EOS (mSv/h)	24 Hours After EOS (mSv/h)
		Mean±SD	Mean±SD
Normal (mSv/h)	46 (92)	8.2107±1.665	0.000966±0.000212
Anomalous (mSv/h)	4 (8)	90.32±4.66	0.00975±0.0005

DISCUSSION

This study was carried out at the newly installed PET/CT scan facility at AFIRI Rawalpindi, Pakistan, to analyze the radioactive wastes produced during 18F-FDG synthesis. The idea was to find out if it was safe to discard the wastes to the environment, especially in anomalous runs, when more than 70% of the radioactivity was disposed into the waste bottle rather than converted into 18F-FDG.

It was found that 8% of the productions at our setup went anomalous during the study period. This observation was relatable with a study conducted at a Joint Commission International (JCI) accredited tertiary care setup in Pakistan where the chemistry and quality control (QC) failure rate during the study period was 5.3% (29/545 runs), which was much frequent in the early phase after commissioning.[11]This frequency was much smaller than that reported by Awasthi et al. which was 13%.[12] Design modifications in the equipment may have been one of the reasons for lesser failure rate in our settings. Gaspar *et al*. reported a dispensing failure of 3% in 2286 productions over a 9-year period.[13] This implies that the frequency of anomalous runs reduces gradually over time as the working protocols of the departments mature.

The representative sample of 3 ml, irrespective of the nature of the content, was collected from waste bottles for both normal and anomalous productions. The average activity in the representative sample after 2 hours of the synthesis process was 45.1mCi and 4.1mCi for anomalous and normal productions, respectively. The average radiation dose at 5cm from the surface of the container was 90.3mSv/h and 8.21 mSv/h at 2 hours after the end of synthesis for anomalous and normal productions, respectively. In both situations, it exceeded the safe radiation exposure limit.[2] The disposal of radioactive waste to the environment at two hours was thus unsafe. The samples were conserved for 24 hours and tested again at 24 hours. It was found that the activity in the representative sample was nearly zero after 24 hours of the synthesis process for both anomalous and normal productions. The mean radiation dose at 5cm from the surface of the container was also negligible 24 hours after the end of synthesis for both anomalous and normal productions, and thus safe for disposal to the environment. Shaukat studied the disposal of radioactive wastes and recommended a safe timeline of 10 half-lives (1100 minutes or 18.3 hours) waiting period for 18F-FDG disposal to the environment.[14] This study, however, did not specifically address the anomalous productions and had given a general guideline regarding Fluorodeoxyglucose waste disposal. Ferguson did different research on cassettes and found out that "the minimum time the cassettes should be left in a decay store before the specific activity falls below 0.4Bq/g (1.081 mCi), the limit for disposal alongside Clinical Waste was found to be 24 months.[15]

The averaged half-lives for the normal and anomalous productions were 110.93min and 110.45min, respectively, after 10min measurement from the dose calibrator by setting the standard operating procedure of the dose calibrator to 20 seconds intervals. The measured half-lives appeared to be in the acceptable range for 18F (95-105min) therefore, it was concluded that the major radioactive material inside the waste bottle was 18F. However, further studies should be conducted to analyze the chemical nature of waste in disposal bottles. Ferguson *et al*. studied the impurities that gather in the cassette during Fluorodeoxyglucose production and found that eleven radionuclides, 51-Cr, 52-Mn, 55-Fe, 56-Co, 57-Co, 58-Co, 95m-Tc, 96-Tc, 109-Cd, 182-Re and 183-Re. He utilized a gamma-ray

spectrometry system consisting of an ORTECs GMX Series High-Purity Germanium (HPGe) Coaxial Photon Detector operated by GammaVision-32 v6.08 software. He found that the greatest contribution to the total activity over time was from 109-Cd, which determined the length of time the cassettes need to be stored before disposal.[15] Literature search shows that chemistry and quality control failure as being one of the possible reasons for such anomalous productions.[11]

The study showed that the radioactive waste disposal practice currently being followed at our centre was adequately safe because the detected activity in radioactive waste for all productions was down to background level and considered safe for disposal as per recommendations of the International Atomic Energy Agency (IAEA).[16] Thus the standard procedure of waste disposal at the end of 24 hours of production should continue for normal as well as anomalous productions. Furthermore, it should be applied as a standard protocol in other centres where 18F-FDG is generated at source for PET/CT scans, and potential anomalous productions occur, as seen in 8% of the productions in our study.

Occupational radiation exposure of the radiation workers during the preparation and administration of radionuclides for the PET-CT scanning of the patient was expected.[17] The doses of radiation workers were within acceptable limits. Shielding of cyclotron and radiopharmacy facility, daily area monitoring during cyclotron run and radiosynthesis, and close collaboration with the patients whose scans were to be carried out before the cyclotron run were ensured to avoid over production of 18F-FDG to reduce the exposure and radiation dose.

It is recommended that the activity doses to the staff injecting 18F- Fluorodeoxyglucose to the patients should be closely monitored as they have close exposure to the radiation source.[18] Additional monitoring should be considered before disposal of waste materials to the environment.

LIMITATIONS OF STUYD

A limitation of this study was that our setup lacked the equipment to analyze the chemical nature of the wastes generated during the 18F-FDG production. To overcome this problem, an indirect parameter was used to assess the nature of radioactivity in the waste bottle representative samples by considering the half-life of 18F (110 minutes). Another limitation of our study is that it did not assess the reasons for the anomalous productions as it was mainly aimed at finding an optimal timeline for radioactive waste disposal. A separate study may be conducted to find the reasons for anomalous productions.

CONCLUSION

It was found that the radioactive wastes produced at the end of normal and anomalous 18F-FDG productions were potentially hazardous to the safety of the environment. The radioactive content of the waste and the average radiation dose was much higher after anomalous productions than normal productions. Serial testing of the wastes showed no residual activity after 24 hours of both normal and anomalous 18F-FDG productions, thus suggesting an optimal timeline for which the radioactive wastes from 18F-FDG productions should be conserved before their safe disposal to the environment. The current practice of disposing of radioactive waste 24 hours after the end of synthesis was found to be adequately safe for both normal and anomalous productions.

Conflict of Intrest: None.

Author's Contribution

Following authors have made substantial contributions to the manuscript as under:

RB: Conception, data acquisition, drafting the manuscript, approval of the final version to be published.

SAM: Drafting the manuscript, data interpretation, critical review, approval of the final version to be published.

ARS & HU: Study design, data analysis, critical review, drafting the manuscript, critical review, approval of the final version to be published.

ZA & AJ: Critical review, drafting the manuscript, approval of the final version to be published.

Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

REFERENCES

1. Keshavarzi M, Darijani M, Momeni F, Moradi P, Ebrahimnejad H, Masoudifar A, et al. Molecular imaging and oral cancer diagnosis and therapy. J Cell Biochem 2017; 118(10): 3055-3060. doi: 10.1002/jcb.26042.
2. Rehman SU, Ahmed S, Mehdi SA, Fatima S, Faheem M. Measurement of extremities doses to occupational workers by using ring dosimeters. Pak J Radiol 2018; 28(2): 145-149.
3. Rahman S, Mehdi S, Jahanzeb Q, Rafique M, Tareen A, Iqbal J. Gamma rays measurements of naturally occurring radionuclides and resulting dose estimation in soil samples collected from district Chakwal. Pakistan J Rad Nucl 2018; 3(1): 23-31. doi:10.18576/jrna/03010.
4. Ródenas J, Jabaloyas E. Analysis of radionuclide production in cyclotrons for application in positron emission tomography (PET). J Radioanal Nucl Chem 2019; 322(3): 1691-1695. doi:10.1007/s10967-019-06903-0
5. Chiu C-H, Huang Y-Y, Tsai C-L, Chou T-K.. Performance analysis and operational experience of [18 F] FDG production with cassette-type modules in four hospitals of Taiwan. J Radioanal Nucl Chem 2020; 326(1): 25-32. doi:10.1007/ s10967-020-07348-6

6. Mark S. Jacobson HRD, Douglas W. Mahoney. Radiolysis of 2-[18F] fluoro-2-deoxy-d-glucose ([18F]FDG) and the role of ethanol and radioactive concentration. Appl Radiat Isot 2009; 67(6): 990-995. doi: 10.1016/j.apradiso.2009.01.005.
7. James Z. Long MSJ, Joseph C. Hung. Comparison of FASTlab 18F-FDG production using Phosphate and Citrate Buffer Cassettes. J Nucl Med Technol 2013; 41(1): 32-34. doi: 10.2967/jnmt.112.112649.
8. Marengo M, Lodi F, Magi S, Cicoria G, Pancaldi D, Boschi S. Assessment of radionuclidic impurities in 2-[18F] fluoro-2-deoxy-D-glucose ([18F] FDG) routine production. Appl Radiat Isot 2008; 66(3): 295-302. doi:10.1016/j.apradiso.2007.08.015.
9. Chung W-K, Yang N-H, Dong K-R, Choi J. Proposed dose constraints in the duties of radiation workers at the department of nuclear medicine. Radiat Prot Dosimetry 2019; 187(4): 535-539. doi: 10.1093/rpd/ncz249.
10. Mehdi A, Khan K, Abdul Jabbar, Abdul Rashid. Measurement of Gamma Emitting Radionuclides in Environmental Samples of Talagang Tehsil-District Chakwal. Nucl Sci 2017; 2(2): 54-58. doi:10.11648/J.NS.20170202.14
11. Fatima N, Sami M, Kh K, Khan G. Personalized 18FDG dose synthesis using BG-75 generator: 1st year experience at JCI accredited tertiary care hospital in Pakistan. J Biomed Phys Eng 2019; 9(4): 409-416. doi: 10.31661/jbpe.v0i0.792.
12. Awasthi V, Watson J, Gali H, Matlock G, McFarland A, Bailey J, et al. A "dose on demand" Biomarker Generator for automated production of [18F] F− and [18F] FDG. Appl Radiat Isot 2014; 89: 167-175.
13. Gaspar L, Reich M, Kassai Z, Macasek F, Rodrigo L.. Long-term quality assurance of [18F]-fluorodeoxyglucose (FDG) manufacturing. Am J Nucl Med Mol Imaging 2016; 6(3): 154-165.
14. Khan S, Syed A, Ahmad R, Rather TA, Ajaz M, Jan F. Radioactive waste management in a hospital. Int J Health Sci (Qassim) 2010; 4(1): 39–46.
15. Ferguson D, Orr P, Gillanders J, Corrigan G, Marshall C. Measurement of long lived radioactive impurities retained in the disposable cassettes on the Tracerlab MX system during the production of [18F] FDG. Appl Radiat Isot 2011; 69(10): 1479-1485. doi: 10.1016/j.apradiso.2011.05.028.
16. Agency IAE. Management of radioactive waste from the use of radionuclides in medicine: International Atomic Energy Agency; 2000, [Internet] available at: https://www-pub.iaea.org/MTCD/publications/PDF/te_1183_prn.pdf
17. Zargan S, Ghafarian P, Monfared AS, Sharafi A, Bakhshayeshkaram M, Ay M. Evaluation of radiation exposure to staff and environment dose from [18F]-FDG in PET/CT and cyclotron center using thermoluminescent dosimetry. J Biomed Phys Eng 2017; 7(1): 1-5.
18. Fathy M, Khalil MM, Elshemey WM, Mohamed HS. Occupational radiation dose to nuclear medicine staff due to Tc99m, F18-FDG PET and therapeutic I-131 based examinations. Radiat Prot Dosimetry 2019; 186(4): 443-451. doi: 10.1093/rpd/ncz046.

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