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Radiological safety assessment for safe transportation of Co-60 disused sealed radioactive sources of teletherapy machines

M. Shamsuzzaman [1,*], M. H. Rahman [1], B. C. Sutradhar [1], K. Assaduzzaman [1], M. M. H. Bhuiyan [1] S. M. Shome [1], M. M. Islam [2] and D. Paul [3]

[1] Health Physics and Radioactive Waste Management Unit, Institute of Nuclear Science and Technology, AERE
[2] Planning Division, Bangladesh Atomic Energy Commission, Dhaka-1207
[3] Atomic Energy Research Establishment (AERE), Savar, Dhaka-1349

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Abstract

The radiological circumstances of Co-60 teletherapy source heads were inspected to ensure their safe transportation from four medical college hospitals to CWPSF. In this perspective, shielding containers for four Co-60 source heads were manufactured, and inspected their radiological safety in terms of dose equivalent rates (DERs), as well as Transport Index (TI). In case of DMCH, CMCH, SMAGOMCH and RMCH, maximum DER on container surface were found to be 10.00 μSvh^{-1}, 13.30 μSvh^{-1}, 17.16 μSvh^{-1}, 25.70 μSvh^{-1} with observed TI 0.03, 0.05, 0.06, 0.08, respectively. Transport safety was verified by measuring DER on the vehicle surface, as observed in the maximum range of 0.11 - 3.13 μSvh^{-1} ; and 0.08 – 0.25 μSvh^{-1} at 2 m distance for RMCH, which is significantly less than the IAEA permissible limit [12]. Consequently, DER was further verified at driver's position, as observed 0.11 – 0.17 μSvh^{-1} for head, 0.14- 0.16 μSvh^{-1} for Chest, 0.11 - 0.13 μSvh^{-1} for gonad, and 0.09 – 0.11 for Leg, which are remarkably lesser than the IAEA and ICRP limit of 10 μSvh^{-1} and 0.5 μSvh^{-1} for occupational and public, respectively. Therefore, the investigated DERs indicated no significant radiological safety concern as per international dose limits [6, 7], and IAEA guidelines for safe transportation of radioactive materials [12].

Keywords: Radiological safety; Cobalt-60 teletherapy source; Gamma dose equivalent rate; Transport index; Ionizing radiation

1. Introduction

Cobalt-60 teletherapy machines are commonly applied for external beam radiotherapy procedure with high specific activity that emits high-energy gamma rays to kill cancer cells. Assurance of radiological safety for the safe transportation of disused sealed Co-60 teletherapy source is a crucial issue. Based on the International Atomic Energy Agency (IAEA) code of conduct on the Safety and Security of the radioactive Co-60 source, it is assigned to category 1, which corresponds to security level 'A' as per IAEA Nuclear Security Series [1]. In spite of radiological concern, radioactive cobalt-60 teletherapy machines still find a place in radiation therapy departments, in more populated and developing countries because of less maintenance costs, less infrastructure requirements, low power demands, and simple quality assurance of the beam parameters [2,3,4]. Generally, an activity about 444 TBq (12,000 Ci) is loaded initially in these cobalt machines and Co-60 source decays at a rate of about 1% per month. Thus, while Co-60 teletherapy is no longer functional, the unwanted teletherapy units should be dismantled and Co-60 sources need to be properly disposed to prevent radiological theft or accident [5]. In addition, cautious handling is required to mitigate any radiological safety concern as per international code of conduct [6,7] during transportation or accidental situation. The IAEA regulations are based on the philosophy that radioactive material being transported should be adequately

* Corresponding author: M. Shamsuzzaman

packaged to provide protection against the hazards of the material under all conditions of transport [8]. In a developing country like Bangladesh, Co-60 teletherapy machines have been a suitable modality considering the cost and maintenance issues. Nevertheless, in the case of Co-60 teletherapy machine, after certain half-life(s) being elapsed, the source strength becomes significantly low as well as due to aging effect, desired treatment becomes inappropriate. In such a situation, the unusable Co-60 teletherapy machines of radiotherapy department at Dhaka Medical College Hospital (DMCH), Chattogram Medical College Hospital (CMCH), Sylhet MAG Osmani Medical College Hospital (SMAGOMCH), and Rajshahi Medical College Hospital (RMCH) were declared abandoned, and hence dismantled afterward. In these teletherapy machines, each Co-60 source is contained inside a welded cylindrical stainless-steel capsule, where the capsule is kept in a shielded container termed as "source head". This source head was removed from the gantry head of the Co-60 teletherapy machine after its dismantling. Then, the source head was kept at the existing machine room on temporary basis for further actions of radiological inspection to ensure safe transportation as well as long term interim storage at the Central Radioactive Waste Processing and Management Facility (CWPSF). The receipt and transfer of radioactive sources are crucial for radiation protection point of view as well as subject to government organization's supervision with mandatory reporting. In this perspective, according to the Regulations 1997 (NSRC Regulations) of Bangladesh [9] and Bangladesh Atomic Energy Regulatory Act, 2012 (Act No. 19 of 2012) [10] as well as other international bodies (IAEA, ICRP, etc.), the licensee of a nuclear /radiological facility or practices involving radiation sources must ensure the safety of the occupational workers, public and the environment. This paper sets out the considerations of technical arrangements that outlines the actions implemented for the safe transportation of four Co-60 radioactive sources in line with the verified radiological safety. The aim of the conducted activities is to prevent abnormal consequences that might undermine the radiological safety and physical integrity of relatively high active Co-60 radioactive sources as well as compromise public safety and the environment. The safe transportation of four Co-60 teletherapy heads to the CWPSF were performed according the existing national recommendations [9] for the transport of radioactive material and the recommendations of radiological protection based on the IAEA GSR Part 3(2011*),* ICRP-60 (1990) and IAEA SSR-6 (2012).

2. Materials and Method

2.1. Safety and Security Requirement of Co-60 Sources

To protect people and the environment from harmful effects of ionizing radiation, it is prerequisite to apply safety and security approach to achieve the ultimate goal of radiation protection. Hence, to accomplish this, safety is focused on achieving proper operating conditions, preventing accidents, mitigating unenvied circumstances and providing protection from exposure to ionizing radiation. Likewise, nuclear security is oriented to prevent and detect malicious acts, including theft, sabotage and other criminal or intentional unauthorized acts that might lead to unacceptable radiological consequences or other adverse situations. In this perspective, the safety and nuclear security measures implemented at radiation facilities help to ensure that adequate protection is achieved. Therefore, a properly managed interface between safety and security principle was implemented in the transportation activities of Co-60 sources for ensuring the protection of people and the environment from security related threats and radiological hazards potentially associated to the transferable Co-60 radiation sources [11].

2.2. Physical Security Consideration for Co-60 Source Transportation

To design an adequate transport security system, defence-in-depth principle was considered using multi-measures, multi-layers approach to ensure and maintain safety and security perspective. Consequently, a graded approach [11] was applied to achieve the objective of preventing the material from being susceptible to malicious acts in view of the potential vulnerability of radioactive material in transport. The transport security system has been designed taking into account of: the quantity and the physical form of the Co-60 source; the mode of transport; and the package type. To ensure transport security, possible malicious acts involving with consignment was presumed while transport route was selected. In the same vein, to mitigate potential incidental risk from transport to storage, the concerned law enforcement authority all through the transport route was informed to act as a fast responder to enable recovery efforts without any delay; The consignment was escorted by firefighters as well as police personnel, as shown in Figure 4(a) and 4(b) to mitigate fire incidence including rapid response to any attempts directed towards unauthorized access to Co-60 containers, or to intervene into other malicious acts involving consignment in the course of transport to the storage. This initiative permitted to adopt a better option for the envisaged control during the transportation of the Co-60 containers/ packages, as shown in Figure 2(a) and 2(b). In addition, the consignment was accompanied by radiation control officer (RCO) as a prerequisite step for monitoring radiological safety related to any minor damage, as well as minimizing and mitigating the radiological consequences due to any malicious act with a view to assure safe transfer of Co-60 containers by maintaining recommended regulatory framework. The transport processes of the Co-60 packages were accomplished as per the indications of the transport authorization by considering that the vehicles shall follow the specified route as decided in declared plan. Consequently, the escorting vehicle was planned to be equipped with emergency equipment such as fire extinguishers, lead shield, and radiation warning emblem/barrier tape. Furthermore, the transportations of all the disused Co-60 packages were performed in accordance with the national and internationally transport regulations, which are based on the IAEA's guidelines and recommendations for the safe transport of radioactive materials.

2.3. Radiological Safety Consideration for Co-60 Transportation

The radiological safety program was designed and performed by the assigned team of Health Physics and Radioactive Waste Management Unit of CWPSF at AERE. In all these performed activities, the principles of optimization and dose limits, as well as, As Low As Reasonably Achievable (ALARA) principle were considered to ensure radiological safety. To assure radiological adequacy with a view to reduce unnecessary risk for the involved personnel, a strategic plan was taken into considerations. The key steps of this strategic plan consist of: Accomplishment of administrative procedures; Coordination and perusal of logistical support; preparation of the work place; Elaborative assessment of necessary technical procedures for radiological safety assurance based on the sequential operations to be conducted for removing the Co-60 teletherapy heads; Preparation to apply materials and equipment; Preparation of work sheets and forms as a complementary documentation; Performance of comprehensive radiological assessment as a key part of technical procedures of radiological safety for the safe transport of the Co-60 packages, which are Type B equivalent.

3. Results and Discussion

3.1. Technical Assessment of Radiological Safety

Physical and radiological inspection of the disused sealed radioactive Co-60 source is a prerequisite prior to perform the source transportation. To fulfill this requirement the radiological inspection was conducted to ensure safe transportation of four Co-60 source heads. The working dates of physical and radiological inspections and the transportation dates of the Co-60 sources of four hospitals, namely DMCH, CMCH, SMAGOMCH and RMCH are presented in Table 1. In the course of inspections, radiological aspects and container integrity were verified, and taken into consideration to decide on the transport plan of the disused Co-60 sources from the aforesaid hospitals to CWPSF. The radiological inspections were performed as the first step of the transportation process in accordance with the schedule presented in Table1.

Table 1 Particulars of radioactive Co-60 sources with dates of inspection and transportation

Name of hospital	**Description of radioactive Co-60 sources**	**Date of Inspection**	**Date of Transportation**
DMCH	Name of isotope: Cobalt-60 (Co-60) Initial Activity: 285.40 TBq (~7714 Ci) (20/05/2004) Activity: 42.43 TBq (~1146.76 Ci) on 14/11/2018 Number of Capsule: Double Half Life: 5.27 years Capsule shape: Φ23 × 33mm Manufacturer: CHENGDU GAOTONG ISOTOPE CORPOTATION (China Nuclear Group)	24 June 2018	18 November 2018
CMCH	Name of isotope: Cobalt-60 (Co-60) Initial Activity: 285.40 TBq (~7714 Ci) on 20/05/2004. Activity: 45.00 TBq (~1216 Ci) on 10/06/2018. Number of Capsule: Double Half Life: 5.27 years Capsule shape: Φ23 × 33mm Manufacturer: SHANGHAI HUAXIAN NUCLEAR INSTRUMENTS CO. LTD.	06 June 2018	24 December 2018

SMAGOMCH	Name of isotope: Cobalt-60 (Co-60) Initial Activity: 305 TBq (~8243 Ci) on 19/05/2004. Activity: 46.71 TBq (~1262 Ci) on 27/08/2018 Number of Capsule: Double Half Life: 5.27 years Capsule shape: Φ23 × 33mm Manufacturer: SHANGHAI HUAXIAN NUCLEAR INSTRUMENTS CO. LTD.	14 August 2018	25 October 2018
RMCH	Name of isotope: Cobalt-60 (Co-60) Initial Activity: 285.40 TBq (~7714 Ci) on 20/05/2004. Activity: 44.52 TBq (~1203 Ci) on 08/07/2018 Number of Capsule: Double Half Life: 5.27 years Capsule shape: Φ23 × 33mm Manufacturer: SHANGHAI HUAXIAN NUCLEAR INSTRUMENTS CO. LTD.	27 June 2018	12 December 2018

As a part of radiological inspection, radiation dose equivalent rates and surface beta activity at different strategic positions were measured on the surface of the Co-60 source heads, as shown in Figure 1 (a) and (b).

Figure 1 (a) Typical photograph of gamma radiation dose equivalent rate measurement on the Co-60 source head surface

Figure 1(b) Typical photograph of β-surface activity measurement at a strategic location on the Co-60 source head surface

The measured data on radiological inspections of the Co-60 source heads are presented in Table 2. The observed gamma radiation dose equivalent rates indicated no significant concern for the radiological safety aspects as per the guideline of maximum permitted dose rate of 500 μSvh^{-1} on the external surface of a package [12]. Furthermore, it is evident from Table 2 that the dose equivalent rates at one meter distance are significantly low for occupational workers as well as within public tolerance level in comparison to the dose limit of the IAEA [6].

Table 2 Radiation dose rate and beta activity on the surface of Co-60 source heads

Hospitals	Strategic Survey Location	Max. gamma radiation dose equivalent rate (μSvh^{-1})	Max. surface beta activity ($Bqcm^{-2}$)	Dose equivalent rate at 1m distance from the shielding surface (μSvh^{-1})
DMCH	Top Surface	3.43 - 23.90	3.88 - 22.03	0.70 - 1.20
	Front Surface	0.58 - 12.00	1.13 - 9.90	0.23 - 1.21

	Right Surface	2.65 - 140.00	7.41 - 219.00	0.52 - 2.75
	Left Surface	0.38 - 9.44	0.78 - 5.62	0.62 - 0.84
	Rear Surface	0.86 - 98.40	1.88 - 77.74	0.66 - 1.04
CMCH	Top Surface	3.15 - 12.50	4.45 - 8.20	-
	Front Surface	0.19 - 53.00	53.00 - 86.00	0.86 - 0.95
	Right Surface	12.00 - 239.00	4.16 - 126.00	0.82- 1.99
	Left Surface	0.30-10.00	0.58 - 7.42	-
	Rear Surface	0.87 - 99.80	0.78 - 47.00	-
MAGOMCH	Top Surface	3.45 - 13.70	5.85 - 9.35	0.92 - 0.98
	Front Surface	0.29- 55.10	54.50 - 87.78	0.78 - 0.89
	Right Surface	13.50 - 241.16	5.27 - 128.50	0.74 - 2.12
	Left Surface	0.50-12.29	0.69 - 8.84	0.46 - 68
	Rear Surface	3.55 -14.60	5.56 - 9.35	-
RMCH	Top Surface	2.38 - 11.11	4.74 - 32.32	-
	Front Surface	0.28- 33.30	3.36 -11.30	
	Right Surface	1.65 - 260.00	1.35-188.00	0.18 – 7.32
	Left Surface	0.17-13.90	0.58 - 8.42	0.15
	Rear Surface	0.40 - 35.47	0.96 - 6.55	0.43

N.B.: Background radiation level (BRL) of 4 hospitals: 0.10 - 0.16 μSvh^{-1}, 0.18 – 0.26 Bqcm^{-2}.

Although the above mentioned radiological safety aspects of the Co-60 teletherapy heads were found technically acceptable, however to comply with the ALARA principle [13] as well as to reduce the surface beta activity (Bqcm^{-2}) as observed in Table 2, it was decided to provide guidelines to the stakeholders to prepare containers (over-packs) prior to arrange a safe transportation of the Co-60 source heads from four hospitals to CWPSF. These guidelines focused on: (i) The collimator outlet of the source head needs to be protected with stainless steel cover (0.6 cm thickness) by bolting or welding, (ii) Four containers (over-packs) of dimension 120 cm×80 cm×80 cm need to be prepared with at least 0.6 cm thick non-rustic metallic element or carbon steel sheet. (iii) The stakeholders are suggested to inform the police stations all through the transport route to tackle any unexpected accidental situation or malicious act. The stakeholders fulfilled these guidelines accordingly. Hence, after receiving the manufactured containers (over-pack), its physical strength was verified. Then, the physical integrity of the stainless steel cover (0.6 cm thickness) on the collimator outlet protection of the respective Co-60 source head was re-checked to verify radiological condition. Consequently, Co-60 source heads were put into these containers and containers physical condition was cross verified. Afterwards, the removable cover of the container was attached by hinge & locks with having four lifting hooks for the convenience of handling. The fixing of the cover shielding was made by a flat carbon steel sheet, as well as four lifting hooks were fixed by welding at the top-lateral edges of the containers. The internal and external views of the container are shown in Figure 2(a) and Figure 2(b).

Figure 2(b) Internal view of the container with strategic radiation survey on the Co-60 source head encapsulated in the shielding container

Figure 2(a) External view of the container used for the transportation of the Co-60 source head

In this wide-ranging radiological inspection, various types of Gamma and Beta survey meters were used, which are listed in Table 3.

Table 3 Survey Meters used for radiation measurement

Name of Survey Meters	Model	S/N	Manufacturing country	Calibration Factor
Gamma Dose Rate Meter	Graetz X5 DE	53097	Germany	1.001
Gamma Dose Rate Meter	RadEye PRD	03232	Germany	0.759
Beta Monitor	DKS-96	028, 2003Г	Russia	1.086
Personal Pocket Dosimeter	POLIMASTER	111160	Europe UAB	0.978
		111270		0.950

3.2. Transportation of the Co-60 Source Containers

As a first step of Co-60 source transfer arrangement, the authorized personnel of the concerned hospitals handed over the Co-60 source containers to the authorized personnel of the assigned team from Health Physics and Radioactive Waste Management Unit who was engaged in this radiological inspection work. Then, radiation dose equivalent rates on the container surfaces were measured as presented in Table 4.

Table 4 Radiation dose equivalent rates on the containers (over-packs) surface

Hospitals	No. of Container	Dose equivalent rate (μSv/h) on the surface of the container					Transport Index
		Top	Front	Rear	Left Lateral	Right lateral	
DMCH	01	1.84	3.00	2.63	10.00	0.55	0.03
CMCH	01	11.20	9.76	12.50	0.20	13.30	0.05
MAGOMCH	01	17.16	6.85	15.74	16.10	0.36	0.06
RMCH	01	25.70	7.83	22.20	0.79	22.60	0.08

The maximum gamma dose equivalent rates on the container surfaces were found in the range of 0.79 - 25.70 μSvh^{-1} for RMCH, which were significantly lower in comparison to the maximum radiation dose rates on the Co-60 source heads, as presented in Table 2. Hence, the radiological safety concern is significantly minimized by applying the manufactured containers. Afterwards, Co-60 source heads were loaded onto the transport vehicle and fastened with rope to fix its position as shown in Figure 3(a) and Figure 3(b).

Figure 3(a) A representative photograph of Co-60 source container loaded on the transport vehicle

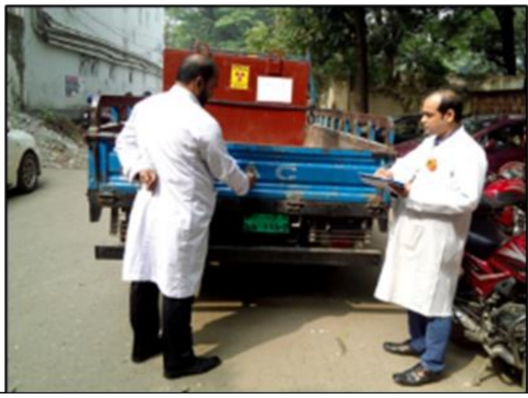

Figure 3(b) Measurement of gamma radiation dose equivalent rates at different strategic points on the vehicle surface

To ensure the radiological safety of the public including accompanying persons during transportation of the Co-60 sources, the radiation dose equivalent rates around the transport vehicle was measured, as presented in Table 5.

Table 5 Radiation dose equivalent rates around the vehicle

Hospitals	**Survey Locations**	**Maximum dose rate (µSv/h)**			**Permissible dose limit at 2 m distance from the external surface (µSv/h) [12]**
		On the surface	**At 1m distance**	**At 2 m distance**	
DMCH	Front side of the vehicle	0.10	0.09	0.07	100
	Rear side of the vehicle	0.25	0.20	0.11	
	Left side of the vehicle	0.11	0.10	0.08	
	Right side of the vehicle	0.82	0.23	0.14	
CMCH	Front side of the vehicle	0.20	0.09	0.08	
	Rear side of the vehicle	0.09	0.08	0.08	
	Left side of the vehicle	1.34	0.37	0.14	
	Right side of the vehicle	1.53	0.40	0.22	
MAGOMCH	Front side of the vehicle	0.08	0.07	0.07	
	Rear side of the vehicle	0.32	0.22	0.15	
	Left side of the vehicle	0.13	0.10	0.09	
	Right side of the vehicle	0.65	0.26	0.17	

RMCH	Front side of the vehicle	0.11	0.08	0.08	
	Rear side of the vehicle	2.22	0.52	0.18	
	Left side of the vehicle	0.18	0.14	0.10	
	Right side of the vehicle	3.13	0.62	0.25	

Consequently, radiation dose equivalent rates at the driver's seating position were measured to ensure radiological safety. The detailed technical observations of radiation dose levels at driver's seating position are presented in Table 6.

Table 6 Radiation dose level at driver's seating position

Hospitals	**Dose equivalent rate (μSv/h) at the driver's seat**			
DMCH	**Head**	**Chest**	**Gonad**	**Leg**
	0.17	0.14	0.12	0.10
CMCH	0.11	0.14	0.13	0.11
MAGOMCH	0.14	0.15	0.11	0.09
RMCH	0.15	0.16	0.12	0.11

N.B.: Background Radiation Level (BRL): (0.03 - 0.05) $\mu Sv h^{-1}$

At the same time, radiation emblem was posted on the container and on the vehicle surface *to warn about hazardous or dangerous materials of this consignment*. Finally, a pocket dosimeter was provided to the driver to record the effective dose during transportation. Finally, based on the observed radiological safety features in terms of radiation levels, it was decided to transfer the disused Co-60 sources from concerned four hospitals to CWPSF.

In the transportation activities from DMCH, CMCH, SMAGOMCH and RMCH, the received effective dose of the employed drivers were 0.53 μSv (about 2.5 hours), 184 μSv (about 9 hours), 1.6 μSv (about 9 hours), 1.8 μSv (about 8 hours), respectively. Thus, the corresponding dose equivalent rate per hour at the driving seat was less than the allowable annual dose limit of the respective radiation workers as per the IAEA recommendation.

In addition to radiological safety, safe transportation was ensured as per security code of conduct, hence the vehicles were scored by the vehicles of fire service and civil defense team and a police personnel team, as presented in in Figure 4(a) and Figure 4(b). Further, to ensure the security of Co-60 source during transportation from the concerned hospitals to CWPSF, all the highway police stations were notified about the time schedule of Co-60 source transportation.

Figure 4(a) Fire service and civil defence team

Figure 4(b) Police personnel for transport security

The transport vehicles of DMCH, CMCH, SMAGOMCH and RMCH were travelled 2.5 hours, 9 hours, 9 hours, and 8 hours, respectively to reach at the CWPSF, AERE. After their arrival at CWPSF, the shielding containers (over-packs) of the Co-60 sources were unloaded from the transport vehicles by using a fork lift, as shown in Figure 5(a). Subsequently, the Co-60 source containers were safely kept at the sealed source room of CWPSF for interim storage, as shown in Figure 5(b).

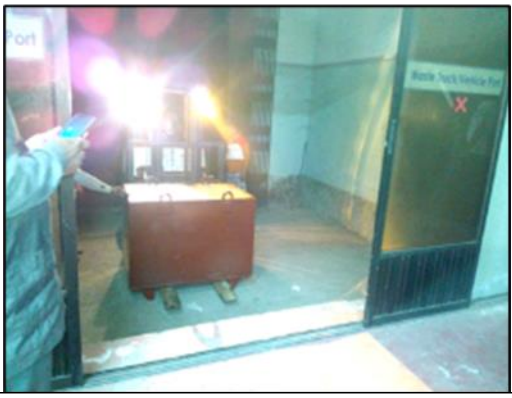

Figure 5(a) Representative photograph of Co-60 source transfer activity at CWPSF

Figure 5(b) Storage of the Co-60 container at the interim sealed source room of CWPSF

4. Conclusion

The physical and ~~the~~ radiological conditions of the disused sealed radioactive Co-60 source heads were inspected, and radiological safety was verified to ensure Co-60 source heads' safe transportation. In this inspection of Co-60 source heads, it was observed that on the surface of Co-60 source heads among four hospitals, maximum gamma dose equivalent rate and surface beta activity was found to be in the range of 1.65 - 260.00 µSvh^{-1} and 7.41 - 219.00 Bqcm^{-2}, respectively. Consequently, maximum gamma dose equivalent rate at 1m distance from the source head surface was found to be in the range of 0.18 - 7.32 µSvh^{-1}. The observed gamma radiation dose equivalent rates of Co-60 source heads were found technically acceptable as per the permitted dose rate of 500 µSvh^{-1} on the external surface of a package [12]. In line with this aspect, to comply with the ALARA principle [13] as well as to reduce the surface beta activity (Bqcm^{-2}) significantly, four containers (over-packs) were prepared by the stakeholders as per provided guidelines. The Co-60 source heads were put into the manufactured containers, and the maximum gamma dose equivalent rate on the containers (over-packs) surface was reduced to 25.70 µSvh^{-1} and transport index was found 0.08, which indicated less radiological concern for the safe transportation of the Co-60 source containers. Consequently, the Co-60 source containers were placed on the vehicle and measured level of maximum gamma dose rate on the vehicle surface was found 3.13 µSvh^{-1}. Correspondingly, the maximum gamma dose equivalent rate at 1m from the vehicle surface was found to be 0.62 µSvh^{-1} which is much less than the permissible dose limit of 100 µSvh^{-1} at 2 m distance from the external vehicle surface [12]. Moreover, the observed radiation dose equivalent rates at driver's seating position indicated no significant radiological safety concern as per the IAEA dose limit [6] as well as ICRP-96 (1990) [7]. Thus, in accordance with the observed radiological aspects, a safe transportation of the Co-60 source containers were performed from concerned hospitals to CWPSF. The transport vehicles were arrived safely at CWPSF, then the shielding containers of the Co-60 sources were unloaded from the transport vehicle and kept at the sealed source room of CWPSF for interim storage. In the course of this transportation activities, the guidelines briefed in NSRC Rule 1997 [9] and IAEA SSR-6 (2012) [12] were strictly followed; hence no incidental or accidental situation was occurred during loading, transportation, and unloading of the Co-60 source containers.

Compliance with ethical standards

Disclosure of conflict of interest

The author declares no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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