Radiological safety aspects in Californium-252 source transfer operation

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The methodology, radiological safety planning and technical experiences gained during the transfer of 1 mg of $^{252}\text{Cf}$ neutron source from transport container to exposure facility have been reported. Hot mockups with dummy sources and radiation safety planning in advance have been observed as the main contributing factor in personal dose reduction and to increase the confidence level in radioactive source transfer in open condition. The doses received by the personnel during this procedure are in the range 0.15-0.30 mSv, which are well within the planned dose limit during operation (5 mSv). No accidental or emergency situation had arisen during the course of this task. Before any new high strength source expected to arrive in any institution, a full-scale mockup should be performed to ensure all members of the work team to understand their parts in the operation. Minimum possible persons should be involved in source transfer. Too many minds at a time should not be applied in such a hazardous operation. There should be only one supervisor at the site and no one except the supervisor should be allowed to give instructions and suggestions during the source loading or transfer procedure. Only expert and experienced radiation safety personnel with high confidence level should undertake such operations. All technical aspects and challenges faced during the source transfer have been highlighted.

Keywords: Radiological safety, Source transfer, Californium-252 ($^{252}\text{Cf}$)

1 Introduction

The isotope $^{252}\text{Cf}$ is an intense neutron emitter and normally encapsulated in a compact cylindrical metal capsule. It decays by alpha emission (96.91%) and spontaneous fission (3.09%) with an overall half-life of 2.645 years; neutron emission rate of $2.314\times10^6$ s$^{-1}$ µg$^{-1}$; and specific activity 0.536 mCi/µg. The neutron energy spectrum of $^{252}\text{Cf}$ is similar to a fission reactor, with most probable neutron energy of 0.7 MeV and average neutron energy 2.1 MeV. The dose equivalent rates from 1 µg of $^{252}\text{Cf}$ at 1 m in air are 0.0221 mSv/h from fast neutrons and 0.0019 mSv/h from gamma rays. As a rule of thumb, the monthly decay of $^{252}\text{Cf}$ is slightly more than 2% of the initial activity. Portable $^{252}\text{Cf}$ neutron sources can provide an ideal non-reactor source of neutrons for lower-flux applications. Large masses of $^{252}\text{Cf}$ (>100mg) can approach reactor capabilities for applications such as neutron radiography with reduced design, regulatory requirements and staffing costs relative to a nuclear reactor. Defence Laboratory, Jodhpur has been engaged in research and development of neutron monitors and sensors, activation analysis and neutron radiography using $^{252}\text{Cf}$ source since last 25 years. The laboratory has acquired 1 mg of $^{252}\text{Cf}$ source in recent past for continuation of its research work. $^{252}\text{Cf}$ is a highly hazardous radioactive source and can be detected in the environment closer to nuclear reactors. The life time cancer mortality risk from $^{252}\text{Cf}$ source has been reported as $2.1\times10^{-6}$ (pCi$^{-1}$) and $4.1\times10^{-8}$ (pCi$^{-1}$) for inhalation and ingestion respectively$^1$. In view of the potential biological hazards associated with the source, its transfer from transport container to camera was a challenge to the personnel involved in this task. Close tubing, remote cable and magnet equipments are the main requirements for safe transfer of $^{252}\text{Cf}$ source between shipping cask and the facility$^2$. Radioactive source transfer operations are generally carried out in hot cell arrangement or with the remotely operated manipulators. Hot cells are required to protect radiation worker from exposure to high neutron emission from the sources. Use of hot cell facility allows personnel to remotely identify, monitor, store and process the highly radioactive sources with little or no radiation dose$^3$. However, the hot cell facility is a costly affair and not available with most of the institutions.

In the present paper, the approach, planning, mockup during transfer of $^{252}\text{Cf}$ source in open without remote operated automatic manipulators and shielding arrangements have been studied. The planned source transfer operation and deviation in the approach as per situational demand has also been discussed. After accomplishment of the source transfer, exhaustive radiation survey is conducted for the camera as well as for empty transport container.
The radiological safety planning and mockups are undertaken in the light of ALARA (As Low As Reasonably Achievable) concept of radiation practice. The main objective of this study is to communicate the planning approach and methodology adopted in safe transfer of the of $^{252}$Cf source from transport container to neutron exposure device with minimal exposure to involved radiation workers.

2 Radiological Safety Planning

Radiological safety planning for transfer of the $^{252}$Cf source was done well in advance; soon after the confirmation of supply of the isotope. As the transfer operation was to be undertaken in open with no remote operated instruments, expected equivalent dose rate at various distances were calculated. The removal and transfer was planned with the assistance of three remote tongs (40 cm, 1 m and 2 m long). The calculation of equivalent doses rate expected during the transfer of source in air is as follows. The total equivalent dose rate at 1 m from 1 $\mu$g of $^{252}$Cf source has been calculated as, 0.024 mSv/h. The equivalent dose rate at 1 m from 1 mg of $^{252}$Cf source would be 24 mSv/h. During radiological safety planning, it was decided that no personnel involved in source transfer be allowed to receive more than 5 mSv of equivalent dose. The planning and mockups were done using 40 cm, 1 m and 2 m remote tongs. The equivalent dose rate to the personnel working with 2 m, 1 m and 40 cm tongs were estimated as 6, 24 and 150 mSv/h, respectively. Accordingly, allowed working times were estimated as; 50, 12.5 and 2 min, respectively. Considering the concept of ALARA, the concerned personnel were strictly instructed to involve in the procedure for less than 2 and 10 min using 40 cm and 1 m/2m remote tongs, respectively. Large cylindrical plastic containers (2 nos) of capacity 1000 l each were filled with water and kept inside the facility room. A lead pot was kept in the bottom centre of one of the tanks and an aluminum source guide tube was vertically aligned in the container fitted with funnel arrangement, so that the source can be transferred in case of any incident or unusual circumstances. The second water filled container was kept inside the room as radiation shielding barrier for the personnel involved during emergency situation. Following radiation protection gadgets were allocated and deployed at the site for source transfer operation: Gamma survey meters (6 nos), neutron REM monitors (3 nos), Feldspec (1 no), TLD badges for all present, neutron badges for all present, pocket dosimeter (5 nos), remote tongs (3 m, 2 m, 1 m and 40 cm) (1 each), polythene sheet (5 m × 5 m$^{-1}$), source tray (1 no), funnel fitted in aluminium tube (3 nos), lead sheets (1 m×1 m) (2 nos).

3 Mockup Exercise with Dummy Source

Repeated mockups exercise were conducted with deliberate source drop in the transit, source drop on the camera top, source loss, source stuck in funnel transfer arrangement and source stuck in guide tube. The movements of the source from transport container to camera were optimized by attempting the source transfer by various ways keeping in mind the minimum time of exposure, easy movement, avoidance of collision with the personnel and building walls. At first stage of mockups, the dummy source was deliberately dropped on the rough sandy ground while removing from transport container to tray. The source then traced and remedial measured noted and method optimized. At second stage of mockups, the dummy source was dropped during its transit from transport container to camera; the best possible method to trace the source judged. At third stage, the dummy source was made stuck in the funnel arrangement on the top of the camera and tapped to put back in the tube. At final stage of mockups, the source made stuck in the source tube of the camera; the source tube removed and transferred to the safety water tank. All these stages of the mockup procedures were repeated three times at every step for refinement in the procedure. After mockup, the practice was optimized and decided that not more than three personnel will be involved in conducting the source transfer operation.

4 Source Transfer Operation

Three trained and experiences radiation workers had been assigned to undertake this source transfer operation. The first person had been given the responsibility of opening the crew and bolt of source container and shifting the source cylinder assembly to the designed platform and inside the tray. His allowed working time was 2 min. The second person had to use 2 m long tong and unscrew the source housing. The source had to be removed from the charging plug and transfer to transport beaker with maximum working time 10 min. The third person had to hold the source beaker with 1 m remote tong, carry up to the camera and transfer the source in the funnel arrangement attached with the source tube of the neutron exposure device in maximum of 10 min time.
The source container was taken out from the transport package by means of heavy duty crane. The container was facilitated with two cylindrical plugs namely, charging and shielding. As per packing note, the source was to be kept in charging plug, however there was no identification on the top of the container marked charging or shielding plug. The dimensions of both the plugs were looking approximately identical. By mistake, the shielding plug was removed first and immediately observed that there was no increase in the radiation level outside, however the radiation level at opening of the shielding plug was found extremely high; this suggested that the source was still inside. This way the source was confirmed to be in another plug. The first plug (shielding) was then inserted inside its position and decided to take out the other plug (charging), which had some coded sleeve. The sleeve was moved till the lifting of the plug became easier; however this was not indicated in instruction manual with the consignment. Actually, this was the position of the sleeve from where the plug could be lifted. One person took out the charging plug through top of the container manually by hand, as there was no other alternative; kept in the designed tray and escaped from the site. The first person’s job was over by then. The second person inspected the source resting position inside the charging plug and observed that outer casing of the source housing did not came out with the plug and the source was absolutely lying bared in its position and could be seen visually. The source was in one side sealed plastic transparent pouch. The pouch was gently tapped to remove the source capsule from pouch so that it can be transferred to the beaker. The source could not come out even after successive attempts of tapping. Incidentally, the plastic pouch was observed to be buckled and due to that such a small and light source was not coming out even after tapping. The pouch was then decided to be torn out with the help of two remote tongs or make it straight to remove the source but it could not helped even after repeated attempts. Then the plastic pouch was cut in two pieces in two successive attempts by sharp knife. Thereafter the pouch was again gently tapped and source then taken out of the pouch. The source was put in a transparent glass beaker and shifted to the camera room with the help of 2 m remote tong and finally transferred to the camera. The whole procedures took around 5-6 min.

5 Radiation Survey

After successful transfer of the source from transport container to camera, radiation survey was conducted using neutron monitors and gamma survey meters to confirm the source transfer and emptiness of the source transport container. All side and top of the camera were thoroughly scanned by the radiation meters in source shield position, whereas the survey of the building was conducted in source out condition. The former survey confirmed the shielding adequacy of the camera housing, whereas, the later case confirmed the radiation safety status of the facility. The details of the radiation doses reported by Personnel Monitoring Section, RP&AD, BARC, Mumbai using TLD badges and CR-39 (FNM) badges are given Table 1. It can be seen from the table that, the doses received by the personnel involved in this task were well within the limit to which the source transfer was planned. The source transfer operation was a great success.

6 Conclusions

The source was successfully transferred to its final destination in open condition with no shielding arrangement (hot cell) and no automatic remote operation such as robotics. The simple concept of time and distance with the knowledge of the type and nature of radioactive source helped many fold in planning this task. Using concept of ALARA and basic techniques of radiological safety, interdisci-
plinary planning and training resulted in workers being received lesser doses at every step of the process. Then a hot mockup helped a lot in successive improvement and refinement in the source transfer procedure. Before any new high strength source expected to arrive in any institution, a full-scale mockup must be performed to ensure all members of the work team understood their parts of the operation. This study may serve as guidelines for planning radioactive source transfer operation.

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References