MISUSE OF A MEDICAL RADIOISOTOPE: $^{125}$I LABELED PLAYING CARDS IN GERMANY, A CASE STUDY

Emily Alice Kroeger, Alexander Rupp, and Joachim Gregor

Abstract—The security of medical radioactive sources, both open and sealed, is an important consideration for reducing the risk of an intentional or inadvertent additional radiation dose to the public, according to the principle of keeping any additional radiation dose as low as reasonably achievable. The detection and following radiological investigation of the misuse of iodine-125 ($^{125}$I), a medically used radionuclide, in Germany is described in detail with the aim of sharing experience and raising awareness. The misuse of $^{125}$I shows that the security of $^{125}$I is not guaranteed completely at the present time.


Key words: $^{125}$I; as low as reasonable achievable (ALARA); occupational safety; radiation protection

INTRODUCTION

The security of medical radioactive sources, both open and sealed, is an important consideration for reducing the risk of an intentional or inadvertent additional radiation dose to the public according to the ALARA (as low as reasonably achievable) principle (ICRP 1977; IAEA 2009, 2004). Radiactive marked playing cards and cigarette packets are a world-wide phenomenon, and incidents have been reported in the open literature since at least 2006, including in Germany (Bild Zeitung 2014). Detection takes place mainly at airports through the use of Radiation Portal Monitors (RPM). Some cases have also been reported to the Incident and Trafficking Database (ITDB) of the International Atomic Energy Agency (IAEA 2019). According to this reporting, there appears to be a link to the Vietnamese expat community worldwide.

Over the last 4 y, the German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) has gathered considerable experience in the location, identification and analysis of playing cards labeled with $^{125}$I, both at the scene and in the laboratory. This experience has been gained partly through the support the BfS has provided to the Brandenburg Criminal Police Office (LKA-Brandenburg) and the Berlin Criminal Police Office (LKA-Berlin) during their investigation of radioactively labeled playing cards found in Brandenburg and Berlin (Berlin Police 2017). The aim of the work of the BfS is to contribute to the radiological forensics of the cards, which is a subtopic of nuclear forensics for the investigation of nuclear security events (Mayer 2013).

Manipulating gambling via $^{125}$I marking

The most penetrating radiation following the electron-capture of $^{125}$I is low energy photons (35.5 keV gamma and two intense x-ray lines at 27.5 keV and 31.0 keV) with a half-value thickness for lead of roughly 25 μm. This means that it is easily shielded, making handling and transport straightforward. Iodine-125 has a half-life of 59.4 d (rounded to one decimal place; Nucleonica 2019a), so that the manipulated cards can be transported and then used, presumably over several weeks. Iodine-125 is produced by neutron capture on enriched (up to 99%) $^{124}$Xe in reactors and has many legal uses in medicine; for example, for brachytherapy (e.g., implantation seeds) and laboratory diagnostics. This means that the medical radionuclide is available in sealed and unsealed form, and there is a potential for misuse. In Germany, legal regulations require that any activity used in the nuclear medical department is tracked precisely. The inventory is overseen by the competent radiation protection authority in the federal state. For this reason, the potential for misuse is greatly reduced. However, a manipulation of the inventory by a hospital worker (insider threat) cannot be completely ruled out.
Iodine is an important constituent of human thyroid hormones. For this reason, after incorporation, a large fraction of the incorporated radioiodine is concentrated in the thyroid (although this is strongly dependent on the amount of stable iodine already present). The remaining radioiodine is excreted with urine. The distribution of radioiodine is not dependent on whether the incorporation occurred via inhalation or ingestion (Hormann and Fischer 2009).

Using a suitable (hidden) detector, for instance a radiation detector hidden up the sleeve of the gambler, playing cards marked with $^{125}$I can be distinguished from those that are not marked during gambling. A thin layer of lead inside the card allows the distinction between face-up and face-down, which in turn allows the manipulation of gambling games such as the Vietnamese betting game “chơi xóc đĩa.” In the preparation of this game, four circular playing card chips are stamped or cut out of an unused playing card. The diameter of the chips is around 1.5–2 cm. The chips are placed between a rice bowl and a plate and then shaken. Bets are taken on how the chips have landed, before the rice bowl is removed. If all four chips have landed face-up, or if all four chips have landed face-down, or if two chips have landed face-up and two face-down, then this is known as a “Chẩn”-state (even-state). In all the other cases, it is a “Lẻ”-state (uneven-state) (see Fig. 1).

If a player uses chips manipulated with $^{125}$I together with a suitable (hidden) radiation detector, then this player gains more information about the state of the chips under the rice bowl. Over the course of the game, this player will be able to win more bets and therefore win more money. Both European-style poker cards and Asian-style playing cards are known to have been manipulated in this fashion, presumably for use in the game chơi xóc đĩa. There have also been reports of manipulated dice games (US DOT 2015), and it can be assumed that further gambling games have been manipulated also.

**METHOD**

The first case in Germany was a detection at an incineration plant in the state of Brandenburg equipped with a radioactive portal monitor (RPM) in 2014. A further such case in 2016 led to a property search in Berlin (Berlin Police 2017). The marked playing cards and playing card chips found at the incineration plant had already been used for manipulated gambling and were part of household waste, as shown in Fig. 2. In 2016, evidence was collected by BfS at the incineration plant and transported to the BfS as an exempted package of the type UN2910 [radioactive materials, with a limited quantity of material according to class 7 of the “Accord européen relatif au transport international des marchandises Dangereuses par Route” (ADR)] for further analysis, as shown in Fig. 3. Primary contamination was found on the cards and playing card chips that had been deliberately marked, but secondary contamination was found also, in particular on food

---

**Fig. 1.** Playing equipment for “chơi xóc đĩa” (reconstruction by BfS).

**Fig. 2.** Searching for playing cards marked with $^{125}$I in household waste using a contamination monitor.

**Fig. 3.** An example of a circular playing card chip marked with $^{125}$I.
waste and cigarette ends. Due to restrictions on working with evidence contaminated with radioactive material, the items collected could not be analyzed in a normal police laboratory. For this reason, the police investigators and radiation protection personnel worked together at the BfS site. The police experts investigated, documented, and photographed the samples while BfS experts handled the samples, took measurements, and carried out radiation protection measures.

The determination of the nuclide vector and the activity of the playing card chips was carried out using high purity germanium detectors manufactured by Mirion (Canberra 2019). For this purpose, measuring geometries for the gamma spectra with a correspondingly low detector dead-time were chosen. Two methods were used at the BfS to determine the spatial distribution of the activity on the back (reverse, patterned side) of the playing card chips. Using an improvised brass collimator comprising two fixed plates, which was improved upon during the period 2014–2017, selected samples were measured with a step size of 1 mm, later 0.5 mm, using a contamination monitor (Nuvia 2019). Two scan directions perpendicular to each other were selected. Further investigations to determine the spatial distribution of $^{125}$I on the playing card chips were conducted via the contact exposure of film badges from conventional film dosimeters. The films were developed after varying contact exposure times (the shortest exposure time was 3 s). Further investigation of the low-energy gamma spectra (including the x-ray emission) from the playing card chips was carried out using a planar high purity germanium detector manufactured by Mirion. X-ray pictures of the playing card chips were taken using a portable x-ray machine.

**RESULTS**

The results of the radiological forensic analysis at BfS showed that the activity per manipulated circular playing card chip was between 3 and 7 MBq $^{125}$I at the time of discovery. The maximum ambient dose rate was 12.6 $\mu$Sv h$^{-1}$ at a distance of 10 cm from the back (deck side) of a playing card chip at the time of measurement, using a dose rate meter sensitive to low energy photons (Automess 2019). During the find in 2016 at the incineration plant, a total of 46 contaminated items were identified with a total activity of 28 MBq. The four playing card chips purposely labeled with $^{125}$I had a total activity of 24.4 MBq. The other items (household waste including food waste and cigarette ends) were contaminated, but not purposely marked (secondary contamination), with a total activity of approximately 3.6 MBq $^{125}$I. The manipulated playing card chips exceeded the exemption limit for $^{125}$I pursuant to the German Radiation Protection Ordinance in terms of both the activity (1 MBq) and the specific activity (1 kBq g$^{-1}$) (GRPO 2018).

For the determination of the presence of further radio-nuclides, for example $^{126}$I, $^{134}$Cs, or $^{137}$Cs that could be a byproduct of the production method, a gamma spectrometric measurement of one circular playing card chip was carried out over 60 h (220,000 s) using a broad energy high purity germanium detector, in order to detect abnormalities in the energy range of 600 keV to 800 keV. No further nuclides were detected. The detection limit for the measurement method is on the order of a few mBq. Further measurements of all circular playing card chips with a planar and a broad energy high purity germanium detector showed no further nuclides in the gamma spectra. These measurements show that the $^{125}$I was extremely pure, strongly suggesting that the $^{125}$I was produced originally for medical use.

The low-energy gamma spectroscopic analysis from the planar high purity germanium detector indicated the presence of a layer of stable lead within the structure of the manipulated circular playing card chips, as the x-ray lines of lead (at 10.5 keV and 12.6 keV) were observed. This x-ray fluorescence occurs due to the excitation of the lead by the photons (x-ray and gamma) emitted by $^{125}$I and can be measured in a standard low energy gamma spectrum. The inbuilt layer of lead shields the radiation emitted in the direction of the face of the card, as shown schematically in Fig. 4. This is confirmed by the dose rate measurements: The dose rate from the back (deck side) of the playing card chips is a factor of approximately 2.4 that from the card face (front side). The presence of a metallic layer inside the manipulated playing card chips (but not the non-manipulated ones) was confirmed by an x-ray imaging investigation of the playing card chips, as shown in Fig. 5.

An investigation of the spatial distribution of the $^{125}$I on the playing card chips was carried out using an improvised brass collimator in combination with a contamination monitor. It was determined that 75% of the total activity was in an area of 1 mm$^2$ and that 95% of all activity was in an area of approximately 2 $\times$ 2 mm$^2$. The extent of the contaminated spatial area was confirmed by the direct contact exposure of film taken from dose meters on the playing card chips. The fact that secondary contamination of other household waste was discovered at the incineration plant indicates that the $^{125}$I was in a water-soluble compound. This was confirmed at the BfS laboratory by cross-contamination of humid samples and leaching tests. Further tests at the BfS showed that the volume of a liquid drop that spreads to an area of approximately 1 mm$^2$ was between about 0.3 $\mu$L.

![Fig. 4. Schematic representation of the cross-section of a manipulated circular playing card chip (not to scale). In reality the I-125 is attached to the lead layer, which is located in the exact center of the cross section.](www.health-physics.com)
to 1 μL. Taking into consideration the total activity on the manipulated playing card chips, the concentration of the $^{125}$I solution used for the production of the marked playing cards was consequently estimated to be in the range of 7 GBq mL$^{-1}$ to 20 GBq mL$^{-1}$.

**DISCUSSION**

Through the radiological forensic investigation, the BfS has gained experience in working with this type of manipulated playing card. The experience is shared here in the interest of international best practice in radiation protection. The first point is that the $^{125}$I from the cards can spread quickly to cause secondary contamination, as the $^{125}$I is present as a water-soluble compound. For this reason, it is best to wear double gloves (as indicated in international standard operating procedures) and overshoes when investigating a discovery of the misuse of $^{125}$I, so that the contamination is not accidentally spread further. To prevent potential incorporation, a filtering face mask and safety glasses should be considered. Regular contamination control measurements are important (especially on hands and feet). If a large activity of $^{125}$I is present, or if $^{125}$I has been in use over an extended time period (e.g., if the location where the playing cards are being manipulated is discovered), then the radiation protection authority may have to check for an incorporation dose of unwitting persons. Such a check for incorporation could include an external measurement of the thyroid with a gamma detector sensitive to low energy gamma radiation and the measurement of urine samples. In order to detect a deterministic dose (over 100 mSv), biological dosimetry should be considered. The second point is that the low-energy gamma of $^{125}$I is difficult to measure. For this reason, the use of a contamination monitor to search for hot spots and contamination is recommended. It is important to ensure that a suitable dose rate meter for measuring gamma and x-ray photons under 40 keV is used. The final point is that the use of a planar high purity germanium detector and the x-ray imaging investigation of the playing card chips were found to be very informative. The use of the planar high purity germanium detector allows the investigation of the stable x-ray lines of lead and can indicate an additional shielding layer inside the manipulated playing card chip: This layer can be confirmed using x-ray imaging.

A quantitative estimation of the received radiation dose to the persons using the playing cards was not carried out. If one evening of gambling with the manipulated playing card chips is considered, then the dose from a point source of 7 MBq $^{125}$I at a distance of 50 cm over 6 h would be of the order of 6 μSv (Nucleonica 2019b). For this reason, the external dose exposure can be considered negligible. Contaminated food waste and cigarette ends were found at the incineration plant. It is unclear when this cross-contamination occurred. In principle, secondary contamination from the manipulated playing cards could occur during play and cause an additional radiation dose due to incorporation (e.g., through ingestion and inhalation when eating and smoking). If 1% of the total activity of one chip (70 kBq of a total of 7 MBq) were to be incorporated, then a 50 y committed effective dose of the order of 1 mSv for ingestion or inhalation of fumes could be expected for persons over 17 y of age (Bundesanzeiger 2001). Of particular concern is the location where the manipulation of the cards is carried out. At this (unknown) location it must be assumed that larger activities of $^{125}$I are being handled. The radioactive material is out of regulatory control, and it must be assumed that working practices do not adhere to radiation safety standards and that a radiation exposure of persons in excess of 1 mSv total dose cannot be ruled out.

**CONCLUSION**

The misuse of an unsealed medical isotope in Germany has been confirmed. The $^{125}$I was most likely produced originally for medical use; however, the source of the material and the chemical compound have not been identified yet. The activity concentration of the $^{125}$I solution used for the production of the marked playing cards was estimated to be in the range of 7 GBq mL$^{-1}$ to 20 GBq mL$^{-1}$. That is a typical starting concentration after the industrial production of $^{125}$I solutions and indicates that $^{125}$I from production, without dilution, was used to manipulate the playing cards. Since the handling of such activities requires an official handling license, it can be assumed that an amount of $^{125}$I was taken illegally to produce marked playing cards, probably from a licensed institution such as a hospital, university hospital, or a producer of $^{125}$I seeds. The location of this
activity is unknown and could be outside the EU. On account of the short physical half-life of $^{125}$I, the misuse must be carried out on a regular basis.

Further international finds of playing cards marked with $^{125}$I in the open literature and reported to the IAEA show that the phenomenon remains an important and pressing topic for customs, police, and radiation protection authorities. In addition, it is important for hospitals to be aware that the misuse of $^{125}$I is a current issue. Unfortunately, the security of $^{125}$I from misuse is not guaranteed worldwide at the present time.

Acknowledgments—The authors would like to thank the following institutions and their colleagues for their support during the work detailed in this paper: Federal Office for Radiation Protection, Criminal Police Office Brandenburg, Criminal Police Office Berlin, Radiation Protection Brandenburg, Landesamt für Arbeitsschutz Brandenburg (LAVG), LPS Berlin, and JRC Karlsruhe.

REFERENCES


Dosiskoeffizienten zur Berechnung der Strahlenexposition, Beilage 160 a und b zum Bundesanzeiger [online]. 2001 (in German).


Hormann V, Fischer H. Materialsammlung zur internen Radiodekontamination von Personen, Ressortforschungsberichte zur kerntechnischen Sicherheit und zum Strahlenschutz, Nr. 0046/07/BMS, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; 2007 (in German).


