The London Polonium Poisoning: Events and Medical Implications

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Abstract

The poisoning of Alexander Litvinenko on 23 November 2006 was an unprecedented event. Po-210 is a highly toxic radioactive heavy metal with a physical half-life of 138 days. Dispersal of the material by the perpetrators and the victim resulted in widespread contamination that led to a trail across London and abroad. This resulted in a massive operation for health protection staff and the police service. The surreptitious nature of this act almost escaped detection. The fact that the nature of the poison was not known for a number of weeks after admission to hospital indicates the difficulty in detecting alpha radiation. In this article, the sequence of events, the nature and uses of this radioactive element and the medical consequences of ingestion are outlined. The illicit use of radioactive materials raises important health and security issues. Medical and scientific staff in nuclear medicine and hospital emergency departments should be aware of these issues.

Key words: Polonium-210, Litvinenko, alpha therapy, radiological security

World J Nucl Med 2007;6:102-106

Introduction

The death of Alexander Litvinenko in London on 23 November 2006 elevated the prospect of a deliberate radiation poisoning from a theoretical possibility to a reality. This was an unprecedented incident that has implications for health teams and security officials throughout the world. The revelation that radioactivity had been used as a lethal poison resulted in many hospital management teams throughout the world seeking advice from their local Nuclear Medicine and Medical Physics staff, most of whom would only previously be aware that Po-210 was a radioactive element in the U-238 decay chain and would not at the time have had any idea of the nature or characteristics of this now infamous radionuclide.

The London poisoning was well organized, sophisticated and carefully executed. The surreptitious nature of the Litvinenko murder almost escaped detection by the medical staff and UK authorities. It is believed that there may have been previous killings of this nature outside the UK, however they have not formally been confirmed or reported. There have certainly been other high profile poisonings in Europe, the most notable being the "immunotoxin umbrella" killing of George Markov, a Bulgarian dissident in London in 1978 and the poisoning of Viktor Yushchenko with dioxins in Ukraine in 2004.

As the events unfolded in London the medical, public health, security and political implications became evident. Although Alexander Litvenenko's symptoms of radiation sickness were apparent (Figure 1), the fact that the nature of the poison was not detected by the medical team until a few days before his death, a number of weeks following his admission to hospital, indicates the difficulty in detecting alpha radiation poisoning. At one point it was considered that he had been poisoned with thallium but that was ruled out prior to his death.

The manufacture of a lethal amount of alpha radiation that could be brought across international boundries without detection and administered in an unobtrusive manner would at first sight seem more like the fictional plot of a 007 thriller. In reality the incident has raised important issues for medical teams. These issues are particularly relevant for nuclear medicine and medical physics staff. This paper outlines the events and highlights the implications that should be considered by hospital staff.

The events

The sequence of events that took place in London in November and December 2006 are given in Table 1. The implications of the poisoning led to a great deal of media

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Figure 1. Photograph of Alexander Litvinenko released on 20 November 2006. His appearance is tytpical of toxic radiation poisoning with loss of hair and a jaundiced appearance due to impaired liver function.

attention both within the UK and abroad. The fact that this type of poisoning was previously unheard of before November 2006 meant that newspaper and television broadcasters were avidly seeking information relating to the incident. As a result numerous medical and scientific societies and academic institutions were contacted for information on the nature of the poison and its medical effects. Because of the widespread health implications and public concern many hospital managers sought advice from their local nuclear medicine and medical physics departments for further information on how a local incident could be handled and what reassurance could be given to the worried but well members of the general public.

The medical team caring for Alexander Litvinenko was initially confused as to the nature of the poison. Bedside monitoring failed to detect evidence of radiation since Po-210 only produces 1 gamma ray in every 100,000 decays. The final diagnosis was made by assay of 24 hour urine collection. This was carried out with the assistance of the UK Health Protection Agency (HPA), previously known as the National Radiological Protection Board.

Alpha emitters are currently being developed in a small number of centers for targeted radionuclide therapy, but most hospital departments would not possess the necessary counting facilities for the assessment of the body burden of an alpha emitter. Data released from the HPA (1) was based on an accepted background level of Po-210 from natural sources being typically less than 20mBq/day. A reporting level of 30mBq/day was used as a basis for determining any significant increase in ingested activity. The total number of urine samples tested was 738 out of which 601 were below the reporting level. The number of people presumed in contact with Po-210 was 137.

Once the nature of the poison had been identified further monitoring revealed a trail of contamination across London at sites viited by Alaxander Litvinenko. Including the Itsu Sushi Bar at 167 Piccadilly, London, the Pine Bar at the Millenium Hotel in Mayfair, his London home and The Emirates Football Stadium. Radioactivity was also found on British Airways aircraft and subsequently at a London lap-dancing club.

Litvinenko's death became a major criminal investigation and as a result of the public concern following the Press release the National Health Service telephone enquiry offices received almost 4000 calls. In London management of the events resulted in an overall cost of $4 million. The City of Westminster spent $500,000 on environmental health staff to close and clear sites of contamination. The HPA checked 47 sites and more than 1,000 people. The London Metropolitan Police spent nearly $2 million on the investigation.

1 NOVEMBER 2006: *Mr Litvinenko meets 2 Russian men at The Millennium Hotel in London. He also meets the academic Mario Scaramella at a sushi bar where he said he received documents about the death of Russian journalist Anna Politkovskaya. Several hours after his meetings, Mr Litvinenko complains of feeling sick and spends the night vomiting.*
4 NOVEMBER: *After 3 days of sickness and stomach pains Mr Litvinenko is admitted to Barnet General Hospital, north London.*
17 NOVEMBER: *Mr Litvinenko is transferred to the University College Hospital (UCH), London, as his condition worsens. He is placed under armed police guard.*
19 NOVEMBER: *It was reported that Mr Litvinenko was poisoned with thallium.*
20 NOVEMBER: *Mr Litvinenko is moved to intensive care. Pictures were released showing his dramatic weight and hair loss (Figure 1). Scotland Yard's counter-terrorism unit takes over the police investigation.*
The police suspect "deliberate poisoning" but await toxicology test results.
21 NOVEMBER: *Confusion over what made Mr Litvinenko ill. Professor John Henry, a toxicologist at St Mary's Hospital London, says Mr Litvinenko may have been poisoned with "radioactive thallium".*
22 NOVEMBER: *Mr Litvinenko is described as "critically ill". Dr Geoff Bellingan, director of critical care at UCH rules out thallium as the cause of his sickness. The ex-agent has a heart attack overnight.*
23 NOVEMBER: *Mr Litvinenko dies in intensive care. Scotland Yard investigations concentrating on "an unexplained death".*
24 NOVEMBER: *A statement made by Mr Litvinenko before he died accuses Russian President Vladimir Putin of involvement in his death. Mr Litvinenko's father Walter tells reporters his son was killed by a "tiny little nuclear bomb". Health experts say they believe Mr Litvinenko was deliberately poisoned by radioactive matter, believed to be polonium-210.*
Police find traces of radioactivity at the Itsu sushi bar, the Millennium Hotel and at his north London home.
25 NOVEMBER: *Tests are carried out on people who may have come into contact with Mr Litvinenko, including clients and staff at the Itsu Sushi Bar and the Pine Bar at the Millennium Hotel.*
26 NOVEMBER: *Hundreds of people contact the NHS telephone hotline to seek advice about radiation poisoning.*
27 NOVEMBER: *An emergency statement was made in the House of Commons, by Home Secretary John Reid.*
Police confirmed that traces of radioactive Po-210 had been discovered at 2 more central London addresses. Three people linked to the venues Mr Litvinenko visited on 1 November are referred for radiological tests, after reporting possible radiation symptoms.

Table 1. Events leading to the death of Alexander Litvinenko in December 2006

Plonium-210

Po-210 is a highly toxic radioactive heavy metal with a physical half-life of 138 days. It decays to stable lead-206 giving off 5.3MeV alpha particles that have a range of 40-50 µm in tissue. It occurs naturally in the earth's crust and was the first element to be discovered by Marie and Pierre Curie as they worked to discover the nature of radioactivity in pitchblend ore in 1898.

Artificial production normally requires a reactor for the bombardment of Bi-209 with neutrons. It is used industrially in static eliminators (the alpha particles ionise the air neutralising static electricity) for processes such as paper rolling, production of plastic sheeting, spinning synthetic fibres and spray-painting processes. Po-210 is also used in brushes to remove dust from photographic film and camera lenses. Substantial amounts of Po-210 generate much heat as the atoms decay. It has been used in thermoelectric power generators and heaters for a range of military and space applications, for example it was used in Russian lunar landers to warm the instruments at night. One early application was for use in automobile spark plugs as described in an early patent held by the Firestone Tyre and Rubber Company. The emission of alpha particles was considered to result in a more responsive and relaible spark for engine ignition, however this was never adopted commercially.

Polonium is usually electroplated onto other metals, making it difficult to separate into a form for use as poison. Po-210 is soluble in aqueous solution and forms simple salts (e.g. chloride) in dilute acids. Just how someone would get hold of polonium for criminal acts is uncertain. Around 100 grams a year of Po-210 are manufactured worldwide in nuclear reactors. At the time of writing there have been no reported thefts of materials, although there is some concern of lack of security in some eastern European countries.

It is thought that the London poisoning was carried out by the surreptitious addition of a small volume of radioactive liquid to a drink, probably a cup of tea taken in the Millennium Hotel. The subsequent dispersal of the radioactivity resulted in widespread contamination that was detected across London and on British Airways flights to the east. In the weeks following the event the main task of the UK Health Protection Agency was of contamination monitoring and reassurance of the general public.

Human data on the biological effects of Po-210 are limited (2,3). There are a few recorded events implicating the toxic nature of polonium poisoning starting with the death of Nobus Yamada in 1927 after working with polonium in Marie Curie's lab. Irene Curie died of leukaemia in 1956. During World War II Dr Robert Fink of the University of Rochester gave Po-210 water to a patient with myeloid leukaemia and 4 others as part of a medical experiment. The cancer patient died the other 5 individuals survived. In the years following the Second World War physicist Dror Sedah working with Po-210 on Israel's nuclear program

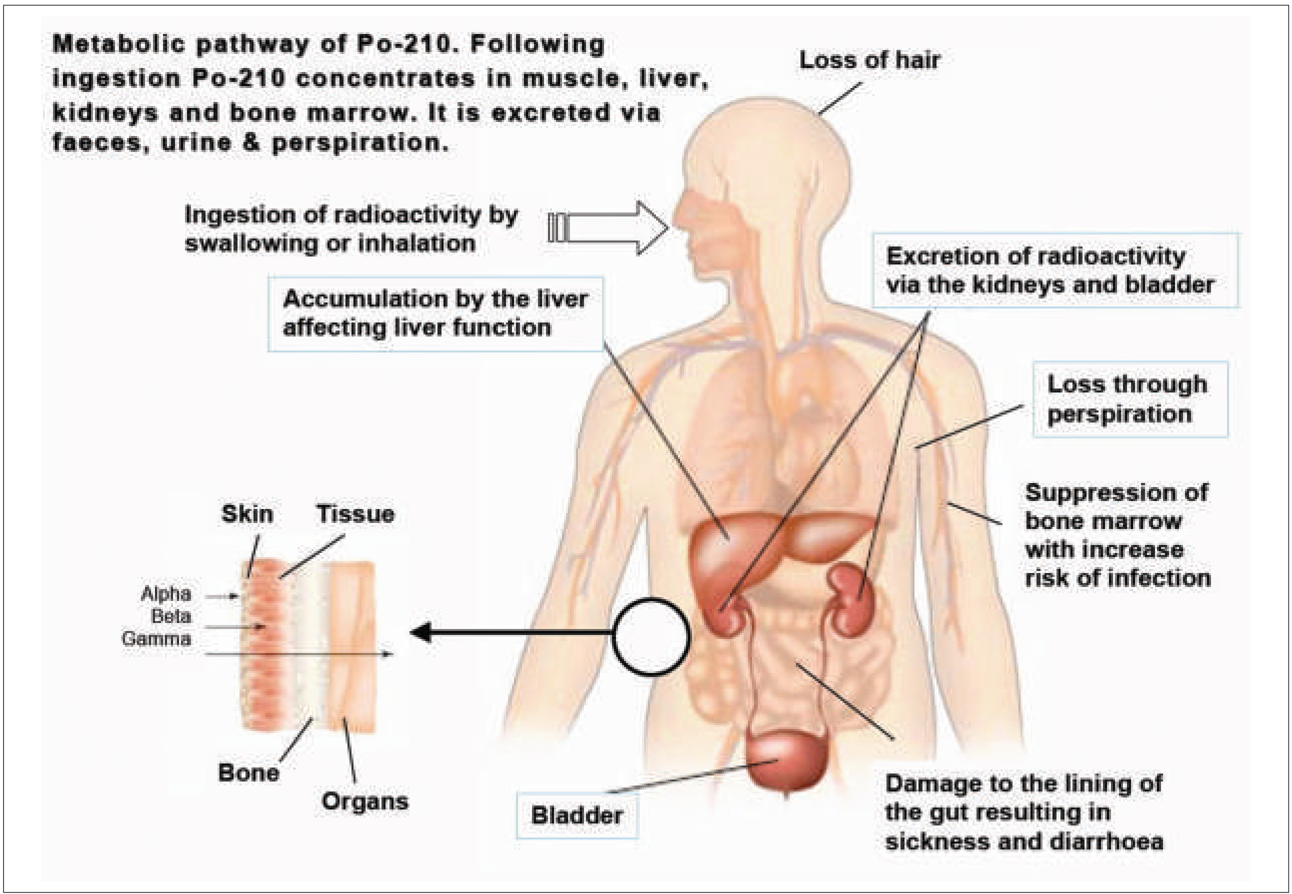

Figure 2. Diagram showing the metabolic pathway of Po-210 following ingestion.

reported widespread contamination on everything he touched in his lab and his home. One of his students subsequently died of leukaemia. There is one reported case of a Russian male worker who accidentally inhaled an aerosol estimated to contain approximately 530MBq of Po-210. The total retention was estimated as being approximately 100MBq, with 13.3MBq in the lungs, 4.5MBq in the kidneys and 21MBq in the liver. At the time of admission to hospital 2 to 3 days after ingestion the patient had a fever and severe vomiting, but no diarrhoea. He died after 13 days. Anyone receiving such doses would show symptoms of acute radiation sickness syndrome with bone marrow failure. About 5% of Po-210 reaching the blood will be deposited in the bones. Subsequent damage to the liver and kidneys will contribute to death from multiple organ failure. Remedial medical treatment strategies are considered to be unsuccessful within a few hours of ingestion, once significant amounts of Po-210 have entered the blood stream and deposited in tissues.

Weight for weight Po-210 is a million times more toxic than hydrogen cyanide. A microgram, (no larger than a speck of dust), would deliver a fatal dose of radiation. The maximum safe body burden of Po-210 is only seven picograms. Following ingestion Po-210 has a biological half-life of 50 days. Approximately 10% is absorbed from the gut into the blood. Once within the bloodstream it is rapidly deposited in major organs and tissues including the liver, kidneys and bone marrow as well as the skin and hair follicles (Figure 2). Approximately 5% is deposited in bone. The intense alpha radiation within these tissues results in massive destruction of cells, leading to a rapid decline in health. Animal studies have shown that 0.1-0.3GBq or greater of Po-210 absorbed into the blood of an adult male is likely to be fatal within 1 month (2). This corresponds to ingestion of 1-3GBq or greater assuming 10% gastrointestinal absorption to blood. Remedial medical treatments are considered unhelpful within a few hours following ingestion!

Nuclear Medicine scenarios

With many researchers now investigating the use of tumor targeted alpha therapy (4) this incident has highlighted the importance of possible effects from the uptake of alpha emitters into sensitive normal tissues. Alpha particles have a mass 7000 times greater and energy typically 30 times greater than that of beta particles. The effective range of particles in tissue is approx 5 cell diameters compared with hundreds/thousands for particles. As a result the LET for alpha particles is of the order of 100 times greater delivering around 0.25Gy in 10μm cell diameter. These characteristics have made alpha emitters such as At-211, Bi-213 and Ra-223 attractive candidates for targeted radionuclide therapy. If delivered appropriately the short range and short physical half-life of therapeutic alpha conjugates can result in minimal effects on normal tissues and minimal residual accumulation of radiation in the body, resulting in greater overall therapeutic benefit. However if appropriate tumor targeting is not achieved the detrimental biological effects can be severe.

Nuclear medicine departments should be aware of the potential difficulties encountered by patients if they work at border control points, such as airports or intend to undertake international travel. It is possible that patients may trigger radiation alarms 3 days after receiving Tc-99m, 30 days after Tl-201 and up to 95 days for I-131 (5). In such cases departments should consider issuing a yellow travel card similar to the one routinely given to patients receiving therapeutic radioiodine. This should contain telephone contact details for validation of the record by immigration authorities.

The Litvinenko poisoning has also raised important issues for health emergency teams who may receive casualties contaminated with radioactivity. It is important to be aware of the range of potential radiological scenarios involving the use of nuclear materials (6). Illicit use of radioactivity may involve one or a combination of theft, smuggling, poisoning, attack or placement of materials. The main types of criminal/terrorist nuclear threat could include:

- Radiation poisoning
- Radioactive contamination of food or water
- "Dirty bomb" or Radiological Dispersal Device (RDD)
- Radiological Emplaced Device (RED)
- Attack on a nuclear reactor
- Construction of an improvised nuclear device (IND)

The criminal use of radioactive materials raises important security issues. Most countries have high security control over radionuclide production sites and transportation. In the UK security has been increased in hospital radiotherapy and nuclear medicine departments in view of the potential terrorist use of radioactivity for construction of a "dirty bomb". It is therefore important that departments handling large amounts of diagnostic or therapeutic radiopharmaceuticals have effective security measures in place. If Po-210 was, as suspected carried in to the UK from abroad, it might be anticipated that it would have been picked up by radiation detectors at ports of immigration, however these detectors would not detect pure alpha emitters. It is interesting to note that nuclear medicine patients have been subjected to prolonged questioning and strip-searches at airports some days following administration of radiopharmaceuticals (5). Illicit trafficking of nuclear material across national borders was first detected in the early 1990s. In 1995 the International Atomic Energy Agency (IAEA) set up a database to monitor unauthorised possession, use and transport of nuclear and radioactive material. A technical security report published by them in 2006 states that by the end of 2005 there have been 823 cases of nuclear smuggling most with a criminal dimension (7). This requires nuclear forensic investigations to characterise intercepted illicit sources in order to gain evidence on their identification and production history. The process of nuclear attribution involves the characterisation of nuclear and radioactive materials and determining their time and point of origin. These have become important tools in the fight against illicit nuclear shipping.

Conclusions

The London poisoning has alerted medical teams to the reality of lethal poisoning with an alpha emitting radionuclide. The toxic effects are now appreciated together with the problems of detection and diagnosis. In the hospital environment it is important to make staff aware of the potential risks associated with the receipt, storage and use of radioactive materials such as teletherapy sources, radionuclide generators and therapy doses. However even with the rigorous training of medical teams it is difficult to envisage the consequences of all possible events. A criminal act involving the theft of nuclear material at a production site would require some degree of skill and knowledge, however the theft of sources held in hospital, academic or commercial premises would be a great deal easier. As highlighted in this communication range of illicit uses of radioactive materials is broad and whilst recent attention has been on preparing for the consequences of potential terrorist activities it is clear that other actions such as extortion, assassination and suicide are real possibilities. Any such event will have political and socioeconomic consequences and will inevitably attract a plethora of media attention. It is important that medical practitioners and researchers involved with therapeutic radionuclides and emergency room staff should be aware of these issues.

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