

Nuclear forensics

30th November 2019

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Nuclear forensics

involves the laboratory analysis of seized illicit nuclear materials or debris from a nuclear detonation to identify the origins of the material or weapons.

What is Nuclear Forensics?

- Extract information from evidence
 - Radioactive material
 - What? Where? When?
 - Isotopic composition
 - Place of origin
 - Trafficking route
 - Age

Nuclear forensic science—From cradle to maturity

K. Mayer, M. Wallenius, T. Fanghänel*

European Commission—Joint Research Centre, Institute for Transuranium Elements, 76125 Karlsruhe, Germany

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Abstract

Since the beginning of the 1990s, when the first seizures of nuclear material were reported, the IAEA recorded more than 800 cases of illicit trafficking of nuclear or other radioactive materials. Despite the decreasing frequency of seizures involving nuclear materials (i.e. uranium or plutonium), the issue continues to attract public attention and is a reason for concern due to the hazard associated with such materials. Once illicitly trafficked nuclear material has been intercepted, the questions of its intended use and origin are to be addressed. Especially the origin is of prime importance in order to close the gaps and improve the physical protection at the sites where the theft or diversion occurred. To answer the questions, a dedicated nuclear forensics methodology has been developed. In this paper, an overview is given on the methodologies used, the measurement techniques that are applied and on the characteristic parameters that help in the identification of the origin of the material. Some selected examples shall illustrate the challenges and the complexity associated with this work. In particular the past and on-going developments in this new area of science will be highlighted and special attention is attributed to the challenges ahead.

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Keyword: Nuclear forensics

Dissolution of USSR in 1990's

(Union of Soviet Socialist Republics, or USSR)



What is this?

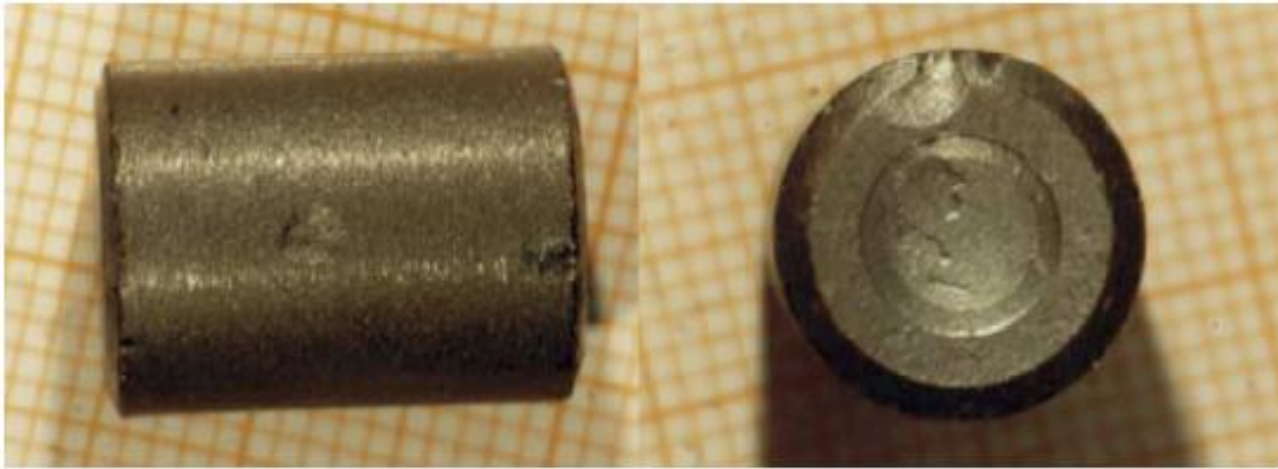


Fig. 1. Photo of a U pellet of "Find-1".

- In March 1992 seized **nuclear material** was analyzed.
- The seizure consists of 72 uranium pellets so called "Find 1."

Nuclear material refers to the metals uranium, plutonium, and thorium, in any form.

Analysis of “Find 1”

Table 1
Analytical results of “Find-1” (average of three pellets ± 1 s)

Parameter	Dimension	U-isotope (wt.%)	U-concentration (wt.%)
\emptyset (mm)	11.45 ± 0.01	U-232 ($8.27E-8 \pm 6.5E-9$)	87.98 ± 0.03
Height (mm)	14.42 ± 0.24	U-234 (0.034 ± 0.002)	
Weight (g)	15.454 ± 0.315	U-235 (2.507 ± 0.014)	
		U-236 (0.449 ± 0.051)	
		U-238 (97.011 ± 0.067)	

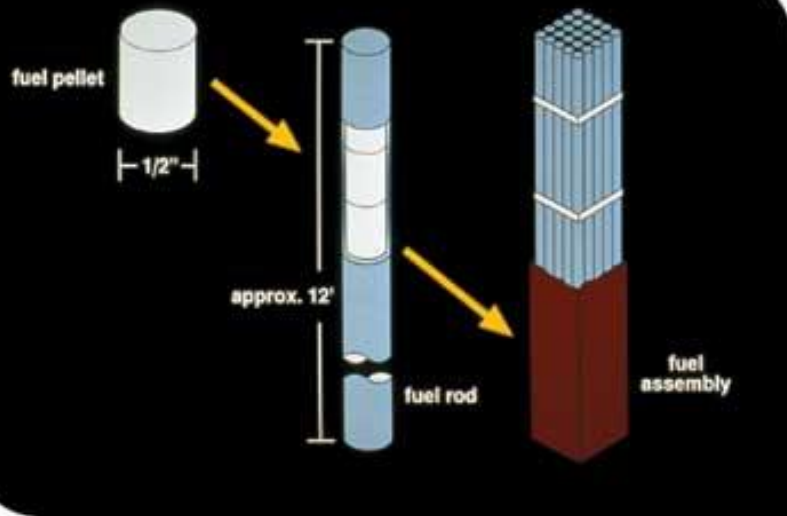
Preliminary results in terms of the physical dimensions and isotropic composition pointed out that the material was intended to be used as **fuel pellets for a nuclear reactor**.

Dimensions of the pellet



Fig. 4 Uranium oxide fuel pellet, intended for RBMK-1500 reactor, seized in Lithuania.

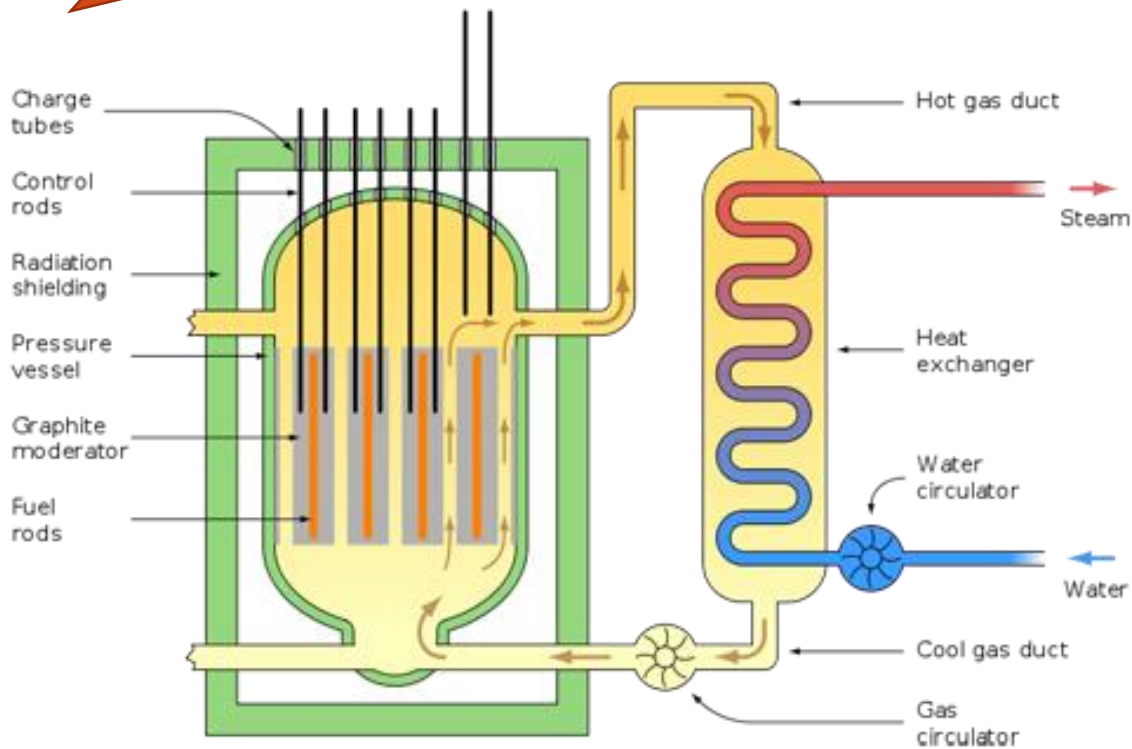
- Because the dimensions are characteristics for different reactor types, varying significantly from reactor type to another.
- The intended use of the pellet was for a Russian type graphite moderated reactor (RBMK).



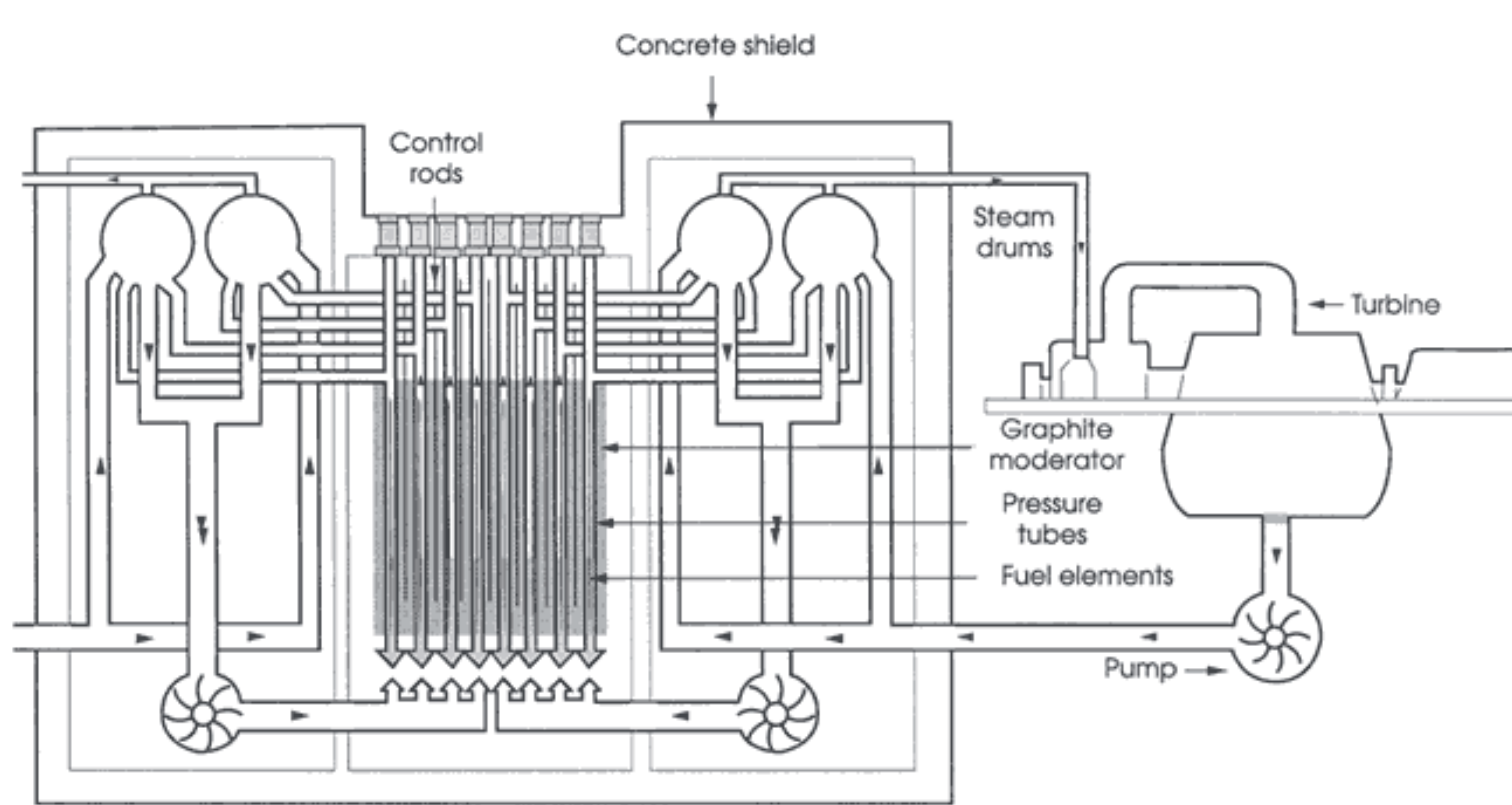
Fuel pellets are inserted into fuel rods, which are grouped together in a fuel assembly.

Fuel rods are placed into the reactor to start nuclear reaction.

<https://panthersgetnuclear5.wikispaces.com/Types+of+Nuclear+Reactors>



Nuclear power plant RBMK type in Russia



RBMK (reaktor bolshoy moshchnosti kanalniy means reactor (of) large power (of the) channel type)

Figure 30. Soviet-Designed Nuclear Power Plants



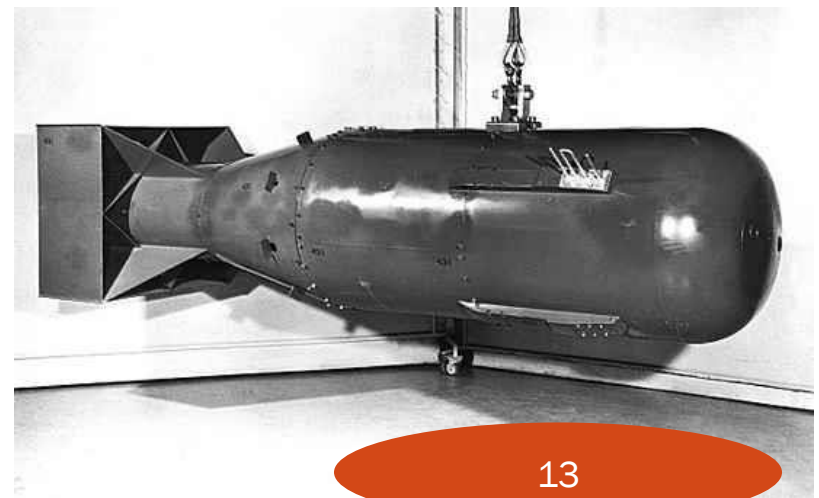
Techniques used for analyzing seized nuclear material

Table 1 Techniques used for analysing seized nuclear material

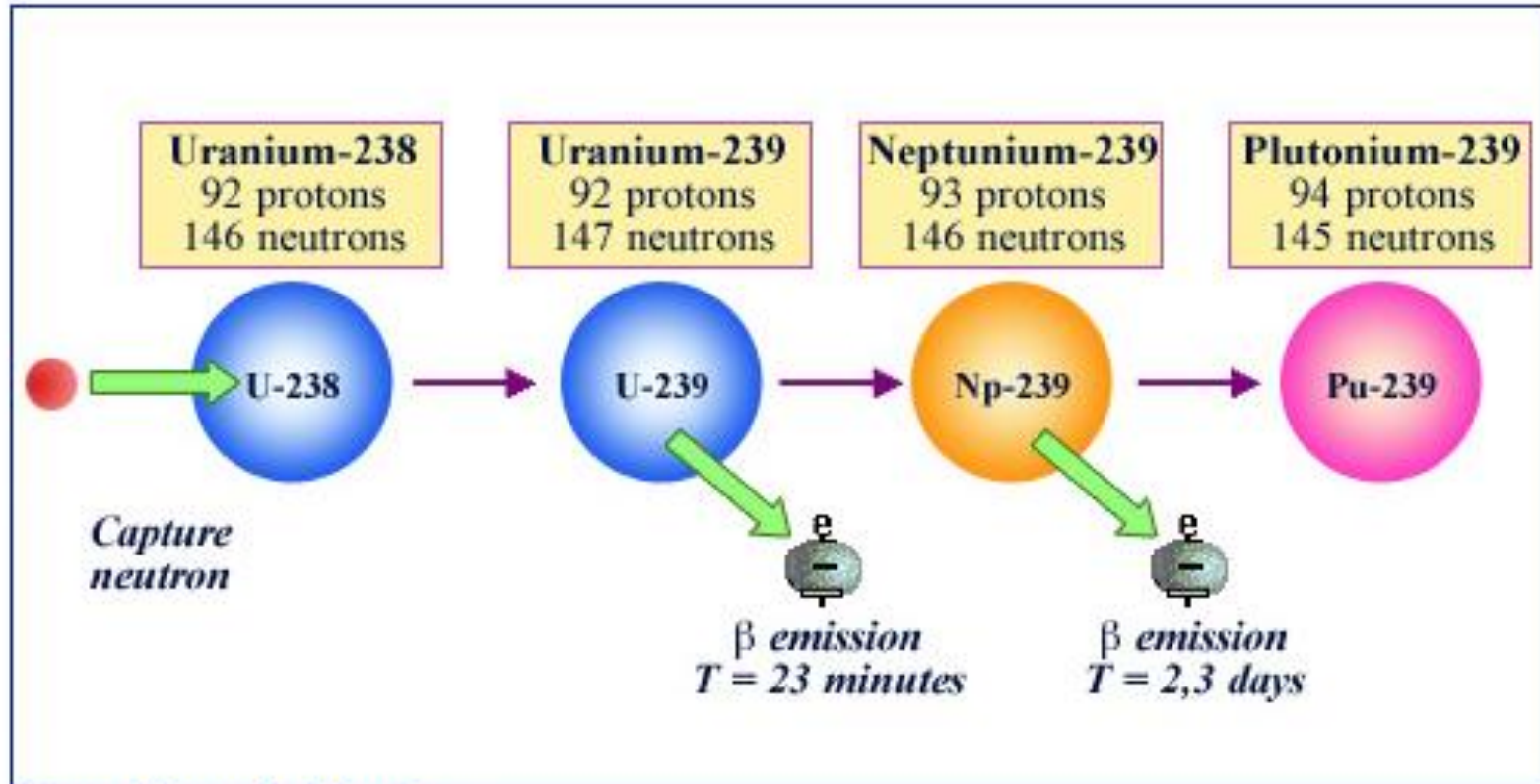
Techniques/methods	First analysis	Information	Detailed analysis	Information
Radiological	Estimated total activity Dose rate (α , γ , n) Surface contamination	Radiological hazard Precautions		
Physical characterization	Visual inspection Photography Size measurement Optical microscopy Radiography Weighing	Macroscopic dimensions Mass	SEM (EDX) XRD TEM	Microstructure and elemental composition Crystal structure Microstructure
Traditional forensic analysis Isotope analysis	Fingerprints, fibers γ -Spectroscopy	Isotopic composition	Mass spectrometry (SIMS, TIMS, MC-ICP-MS) Radiochemical separations α -spectrometry ICP-MS XRF Assay (titration, IDMS) GC-MS	Accurate isotopic composition
Elemental/Chemical analysis				Chemical impurities Chemical composition

Enriched Uranium Classes

- **Low Enriched Uranium (LEU)**
0.72-20% U 235
 - LEU is primary fuel for nuclear reactors
- **High Enriched Uranium (HEU)**
>20% U 235 .
 - HEU is used primarily in weapons.
 - Atomic weapons of WWII used HEU of about 93.5% U 235



Production of Pu-239 from U-238



Generation of plutonium

The capture of a neutron by a nucleus of uranium-238 leads to the formation within a few days of a nucleus of fissile plutonium-239. The nucleus of uranium-239 resulting from the capture of the neutron is radioactive beta-minus. By emitting an electron and an antineutrino, it becomes neptunium-239, which being itself unstable transforms in its turn the same way into plutonium-239.

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Death by Polonium-210

By Robin B. McFee, DO,
MPH, FACPM, &
Jerrold B. Leikin, MD,
FACEP, FAACT, FACP,
FACOEM, FACMT

Lessons learned from the murder of
former Soviet spy Alexander Litvinenko



Alexander Litvinenko
in the ICU on Nov. 20, 2006.

PHOTO NATASJA WEITZIG/GETTY IMAGES

Case report

- On Nov. 1, 2006, a former KGB agent named Alexander Litvinenko presented to a North London hospital with acute, severe, progressive gastrointestinal symptoms.
- Litvinenko's health rapidly deteriorated : his hair fell out and developed **pancytopenia**.
- The symptoms were consistent with radiation **or thallium toxicity**.
- However, the patient's urine and blood samples were negatively tested.

POISON CHEMISTRY - THALLIUM SULFATE

Sometimes referred to as 'the poisoner's poison', thallium sulfate is colourless, odourless, and tasteless. It is slow-acting, and difficult to diagnose.

HISTORY



Thallium was discovered in 1861 by William Crookes, and its toxicity was quickly noted. It is especially toxic in its bivalent compounds, including thallium sulfate, acetate, and carbonate.



In the late 1800s, thallium sulfate was used to treat some medical conditions, including syphilis, gonorrhoea, & gout. The side effects meant that it was not widely used, however.



Thallium sulfate was often employed as a rodenticide and insecticide, making it easy for would-be poisoners to obtain. Its usage in rat poisons has been banned in many countries since the 1970s, however.

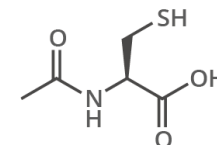


THALLIUM (I) SULFATE



MEDIAN LETHAL DOSE: 10-15mg/kg

TREATMENT



N-ACETYL-CYSTEINE

No substance can remove thallium which has already been absorbed, but Prussian blue and sodium iodide help remove unabsorbed thallium from the intestinal tract. As thallium binds to sulfhydryl groups, N-acetylcysteine has also been suggested as a treatment.

EFFECTS



CONSTIPATION



ABDOMINAL PAIN



VOMITING & NAUSEA



PAIN IN EXTREMITIES



'MEES' LINES' ON NAILS



HAIR LOSS



INCREASED HEART RATE



CONVULSIONS, COMA & DEATH

Initial symptoms indistinct. Large doses kill before some effects are apparent, but with lower doses, hair loss occurs 2-3 weeks after poisoning. Damage to nerves, causing pain, is also characteristic. Toxicity is due to the similarity between potassium & thallium ions.



DETECTION



URINE

0.4% BISMUTH NITRATE
IN 20% NITRIC ACID, THEN
10% SODIUM IODIDE IN
A SATURATED SODIUM
THIOSULFATE SOLUTION



RED PRECIPITATE OF
THALLIUM BISMUTH IODIDE

Qualitative testing for thallium in urine can be carried out as detailed above, though this method can produce false positive results. More common is the use of atomic absorption photospectrometry of a urine sample, which uses absorption of light to identify thallium.

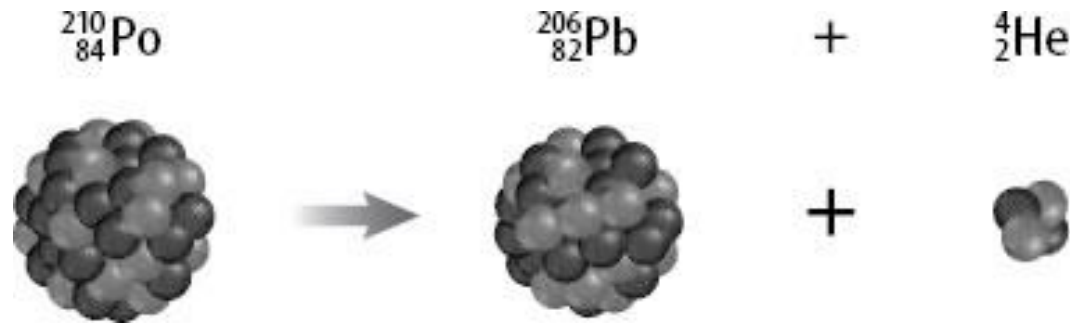


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Positive test for Po-210

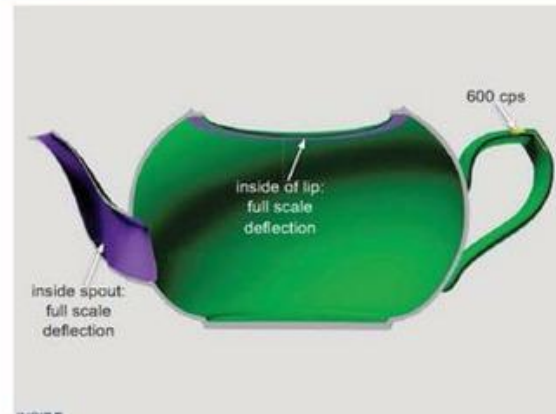
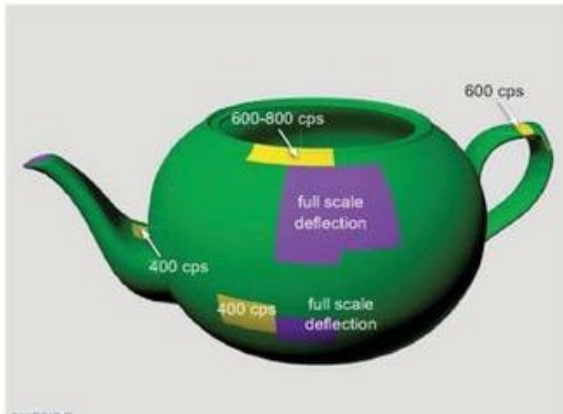
- Advanced tests by Britain's Atomic Weapons Establishment revealed significant amount of **alpha particle radiation**.



- This indicated the poisoning to the patient by Polonium-210 (${}^{210}\text{Po}$).
- Litvinenko died of internal contamination from the radioactive.
- Traces of polonium were found in several locations where Litvinenko had visited shortly before becoming ill.



KEY	
Green	1-300 cps
Yellow	301-3,000 cps
Red	3,001-10,000 cps
Purple	> 10,000 cps



- An image of the teapot used to poison Russian dissident Alexander Litvinenko have been released.
- Traces of polonium 210 were discovered in the teapot in the Pine Bar at the Millennium Hotel.

Understanding Polonium-210

- Polonium is a rare radioactive metalloid, and was discovered in uranium ores by Marie and Pierre Curie in 1897.
- Polonium may now be made in milligram amounts in nuclear reactors.
- Polonium is a solid but dissolves readily in dilute acids.

Polonium Characteristics

<http://en.wikipedia.org/wiki/Polonium>

Most stable isotopes					
Main article: Isotopes of polonium					
iso	NA	half-life	DM	DE (MeV)	DP
^{208}Po	syn	2.898 y	α	5.215	^{204}Pb
			β^+	1.401	^{208}Bi
^{209}Po	syn	103 y	α	4.979	^{205}Pb
			β^+	1.893	^{209}Bi
^{210}Po	trace	138.376 d	α	5.307	^{206}Pb

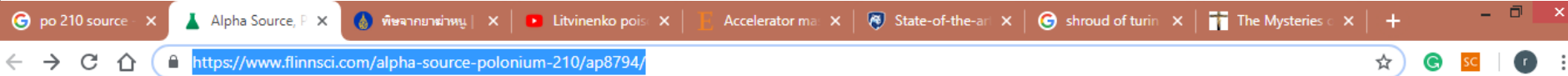


$t_{\text{Po210}} := 138.376\text{day}$ *Polonium-210 half life.*

$E_{\alpha} := 5.307\text{MeV}$ *Polonium-210 alpha decay energy*

<http://mathscinotes.com/2014/01/radiation-exposure-from-cigarette-smoking/>

Polonium 210 on sale from internet



Home > Chemistry > Student Laboratory Kits > Radioactive Sources > Alpha Source, Polonium-210

Alpha Source, Polonium-210

Item #: AP8794

Price: \$135.40

Ships directly from the manufacturer.

Use these radioactive sources to compare different types of radiation. The isotope name, type of radiation, activity in microcuries and half life is written on each sealed disc. See more product details

Options: Polonium-210

[view options as chart](#)

[Product Details](#)

[Specifications](#)

This item can only be shipped to schools, museums and science centers

Purchase Options

Quantity:

1

[Add to cart](#)

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Other Options



Quantifying Radioactive Decay

Measurement of **Activity** in disintegrations per second (dps);

- 1 **Becquerel (Bq)** = 1 dps;
- 1 **Curie (Ci)** = 3.7×10^{10} Bq (dps) ;
- **Specific activity of substances are expressed as activity per weight or volume (e.g., Bq/gm or Ci/l).**

Radioactivity

Activity = decay constant \times number of radioactive nuclei

$$A = \lambda N$$

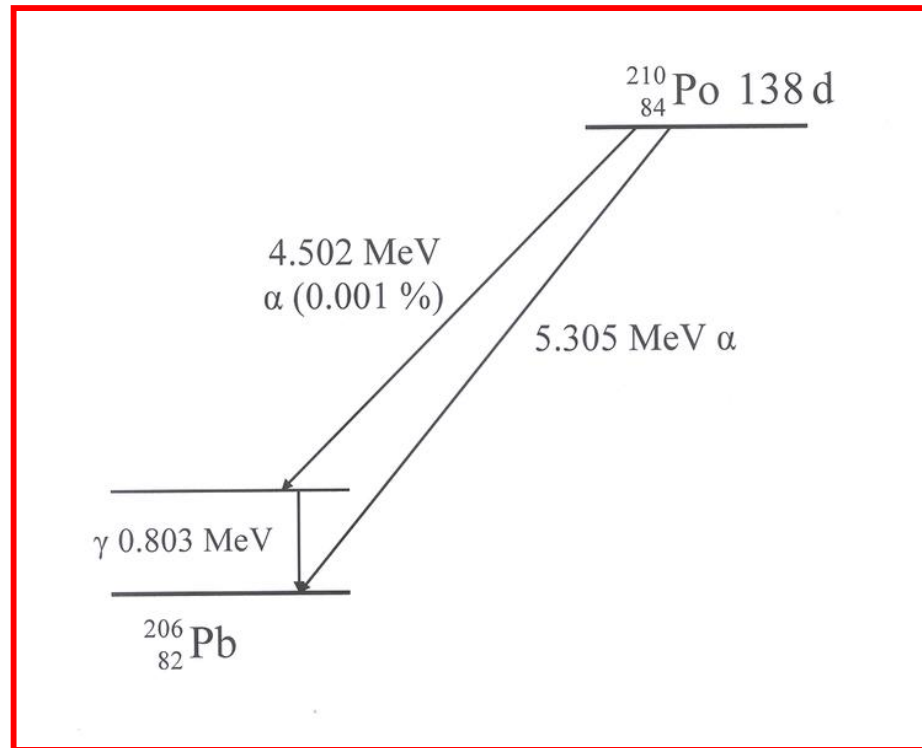
$$= \frac{\ln 2}{\text{half-life}} N$$

- According to experts' estimation, about 1 μg of the Po-210 could have been responsible for Mr Litvinenko's death.
- What should be the activity of this amount of the Po-210?

Calculation

Alpha emitter

- A single gram of ^{210}Po generates energy at the rate of 150 watts.
- Since nearly all alpha radiation can be easily stopped by ordinary containers and upon hitting its surface releases its energy.
- ^{210}Po has been used as a lightweight heat source for artificial satellites.

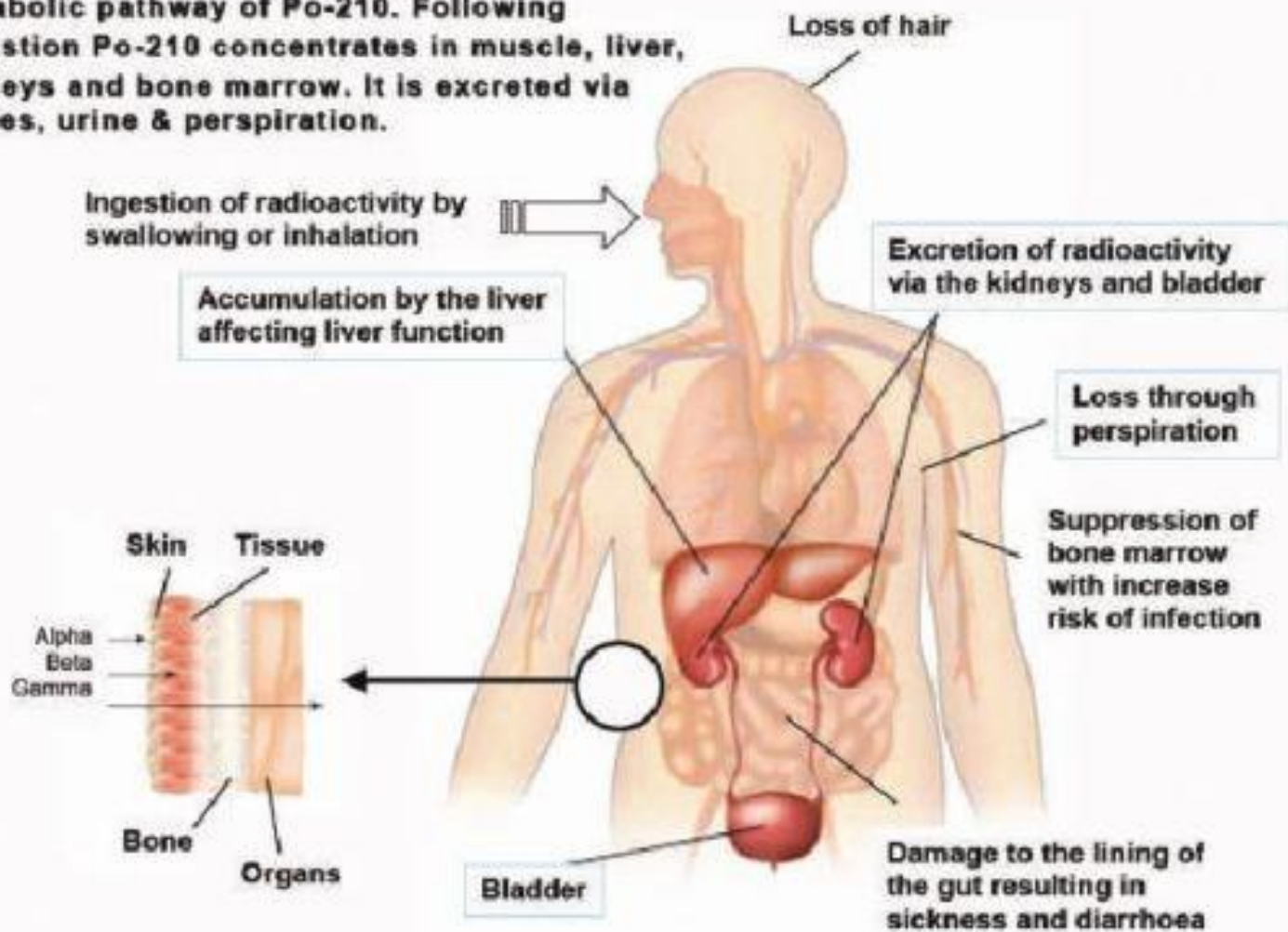


^{210}Po used as a poison

- Weight for weight Po-210 is a million times more toxic than hydrogen cyanide.
- **The maximum allowable body burden for ingested polonium is only seven picograms which gives a maximum allowable body burden for ingested polonium of 1100 Bq.**
- The amount of material required to produce a lethal dose would only be 0.12 micrograms.
- The alpha radiation has enough energy to tear apart the DNA killing or causing them to mutate into tumour-producing forms although **the radiation penetrate about 60 μm through biological tissue- equivalent to the wall cell thickness.**

The effect of Polonium poisoning

Metabolic pathway of Po-210. Following ingestion Po-210 concentrates in muscle, liver, kidneys and bone marrow. It is excreted via faeces, urine & perspiration.



Detection of Po-210

- Polonium-210 inside someone's body is not detectable with standard radiation survey instruments used outside that person's body.
- Testing the individual's urine or feces for alpha radiation would be the method of detection.
- The radioactive substance sometimes called the "**Perfect Poison.**"

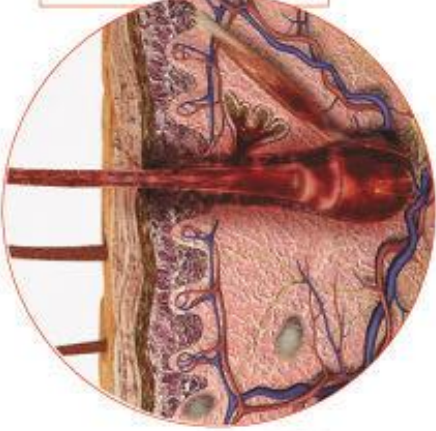
Summary

Po-210 : the perfect poison

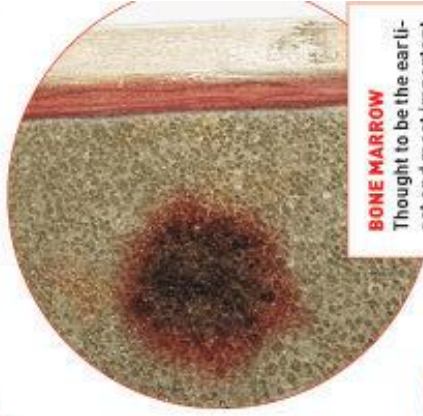
- Polonium is an immensely powerful poison. Its presence in the body is also very hard for doctors to identify unless they are looking specifically for it.
- Part of the difficulty in detecting polonium poisoning is that its outward symptoms resemble poisoning with much less powerful substances. **Among the earliest symptoms are hair loss, which is also a standard symptom of poisoning by thallium, an element in rat poison.**
- This ability of polonium to conceal its presence by appearing to be another, simpler, poison enables it to fool investigators into looking for other culprits than the real assassin.

HOW POLONIUM-210 KILLED LITVINENKO

The ex-spy's final days were an agonizing process of cellular damage throughout the body



HAIR AND SKIN Once the ingested polonium-210 entered Litvinenko's bloodstream, it first affected rapidly dividing cells, like those in skin, by bombarding them with alpha particles. Hair follicles in particular tend to absorb the radiation extremely readily. Litvinenko suffered hair loss, itching and painful breakdown of the epidermis.

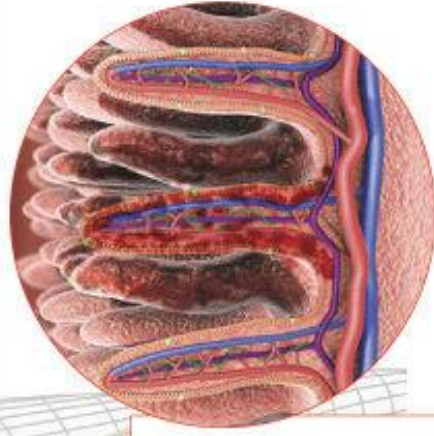


BONE MARROW Thought to be the earliest and most important contributing factor in a radiation victim's death, irradiated bone-marrow failure is compounded by organ failure elsewhere in the body. Damaged stem cells die off, driving down blood-cell counts and leading to infection and hemorrhaging.

KIDNEY By simultaneously passing polonium-210 to the bloodstream and the bladder, the kidneys distributed radiation before failing themselves.



LIVER The irradiated liver also helped spread deadly particles. In bile, it passed them on to the intestines.



INTESTINES The mucosal lining of the intestines is made up of protruding villi, which absorb nutrients. Some villi are sloughed off during normal digestion, and these cells are replaced. Radiation damages the villi's regenerative abilities, and digestion begins to painfully wear away the intestinal wall.

