WITNESS STATEMENT

(CJ Act 1967, s.9; MC Act 1980, ss.5A(3) (a) and 5B; Criminal Procedure Rules 2005, Rule 27.1)

Statement of: HARRISON JOHN

Age if under 18: OVER 18 (if over 18 insert 'over 18') Occupation: RADIATION PROTECTION SCIENTIST

This statement (consisting of 6 page(s) each signed by me) is true to the best of my knowledge and belief and I make it knowing that, if it is tendered in evidence, I shall be liable to prosecution if I have wilfully stated anything in it, which I know to be false or do not believe to be true.

Signed: DR J D HARRISON Date: 26/04/2007

Tick if witness evidence is visually recorded ☐ *(supply witness details on rear)*

I am Dr John HARRISON of the Health Protection Agency, Radiation Protection Division (HPA-RPD), Chilton, Didcot, Oxon, OX110RQ . My qualifications are Bachelor of Science (B.Sc.) and Doctor of Philosophy (Ph.D.) degrees in Biochemistry. I have over 30 years experience of work on the behaviour of radioactive materials (radionuclides) in the body. I am a recognised expert in the field of radionuclide dosimetry and effects and I am a member of the committee on dosimetry of the International Commission on Radiological Protection.

I have compiled this statement at the request of Detective Superintendent Clive TIMMONS of the Counter Terrorism Command (SO15) of the Metropolitan Police Force. The purpose of this statement is to present the results of measurements of polonium-210 in samples of body organs from Mr LITVINENKO and to provide an interpretation of these measurements in terms of radiation doses and consequent organ damage. In addition, model predictions of levels of radioactivity in Mr LITVINENKO's urine, sweat and sloughed skin are presented. The questions addressed are:

1) What do the measurement results mean in terms of likely intake of polonium-210 by Mr LITVINENKO?

2) What were the estimated radiation doses to Mr LITVINENKO's body organs?

3) What do the estimated radiation doses mean in terms of organ damage and death?

4) What is the estimated concentration of polonium-210 in Mr LITVINENKO's urine and sweat from the assumed day of intake until death?

5) Could the loss of polonium-210 from Mr LITVINENKO in body fluids result in a life-threatening level of contamination of a second person?

Colleagues at HPA-RPD were responsible for making measurements of radioactivity, calculating the likely intake of radioactivity, calculating radiation doses and assisting with assessments of radiation doses required to cause lethal damage to body organs:

1) Measurements of polonium-210 in organ samples were made by Dr Michael YOUNGMAN, using gamma-ray spectrometry. Dr YOUNGMAN has over 25 years experience of gamma-ray spectrometry and has been responsible for the measurement facility at HPA Chilton since 1989. The laboratory has accreditation for measurement of gamma-emitting radionuclides in environmental and biological materials (UK Accreditation Service No. 1269).

2) Calculations of the estimated intake of polonium-210 by Mr LITVINENKO were done by Dr Alan BIRCHALL. Dr BIRCHALL has over 25 years experience of the interpretation of body organ and excretion measurements to estimate intakes and radiation doses. He has developed computer software for this purpose which is widely used around the world and implements reliable and well-known statistical methods of data fitting.

3) Calculations of radiation doses were done by Mr Alan PHIPPS. Mr PHIPPS has approaching 20 years experience of the application of internal dosimetry models in computer codes for the calculation of radiation doses. The computer code he used to calculate radiation doses from polonium-210 is that used to calculate doses for the International Commission on Radiological Protection, and European and U.K. legislative purposes.

4) Assessment of radiation doses estimated to cause lethal damage to body organs was assisted by Dr David LLOYD. Dr LLOYD has over 30 years experience of biological dosimetry and the assessment of the effects of radiation accidents involving high radiation doses.

Assistance was also provided by colleagues in the U.S.A.:

1) Dr Rich LEGGETT (Oak Ridge National Laboratory) provided advice on aspects of the use of a model that he has developed and published which describes the behaviour of polonium-210 in the body. This model was used to estimate intake and in the calculation of doses.

2) Dr Bobby SCOTT (Lovelace Respiratory Research Institute) provided advice on lethal radiation doses from alpha particle emitting radionuclides.

This statement provides a summary of the relevant information. Supporting information is provided in an extended and referenced analysis in a report, provided separately, entitled: "Mr LITVINENKO: estimated radiation doses and expected health effects following intake of polonium-210" by JD HARRISON, AW PHIPPS, DC LLOYD, RN GENT, A BIRCHALL and MJ YOUNGMAN. I produce this document as exhibit JDH/1. The scientific judgements made in this report are also contained in a paper that has been published in the peer-reviewed open literature, entitled "Polonium-210 as a poison" by JD HARRISON, RW LEGGETT, DC LLOYD, AW PHIPPS and BR SCOTT (Journal of Radiological Protection 27, 17-40; 2007). I produce this document as exhibit JDH/2.

1) Measurements of polonium-210 and estimates of intake

Table 1 shows the results of measurements of the polonium-210 content of post-mortem specimens obtained from Mr LITVINENKO's body. Measurements on samples of lung, spleen, kidneys and liver were made at HPA RPD using gamma-ray spectrometry. Thus, although polonium-210 decays to stable lead-206 with the emission of one alpha particle for each atom decaying, there is also a characteristic release of gamma rays. The measurement on a urine sample from Mr LIVINENKO was reported to HPA RPD by the Atomic Weapons Establishment, Aldermaston.

One becquerel (Bq) of polonium-210 releases, on average, one alpha particle per second. One gigabecquerel (GBq) of polonium-210 releases 1000 million alpha particles per second.

Table 1. Measurements of polonium-210 in post-mortem tissue samples and urine and estimation of intake by ingestion

Sample	Evidence Ref No	Activity, Bq per g of tissue	Estimated intake by ingestion on 1.11.06, GBq
Lung	NRBC/11	3,500	-
Spleen	NRBC/12	9,900	1.8
Kidney	NRBC/13	49,000	4.0
Liver	NRBC/15	30,000	3.7
Urine	Measurement by AWE[a]	825 (Bq per ml)	5.7

[a]The urine sample was taken on 22.11.06. Mr LITVINENKO died on 23.11.06.

Measurements of polonium-210 in tissue specimens and urine were used to estimate intake and radiation doses using the best available models of the behaviour of polonium-210 in the human body after either ingestion or inhalation.

The low concentration of polonium-210 in lung tissue was consistent with inhalation being a minor route of intake, estimated as < 5(PER CENT) of total intake. The possibility of greater intake by inhalation cannot be ruled out but the measurements are consistent with intake largely by ingestion. Assessed doses to organs other than the lungs are insensitive to the assumptions made on the relative contribution of intake by ingestion and inhalation. The possibility of a small intake by inhalation was ignored and intake was assumed to be wholly by ingestion, with absorption to blood being assumed to be 10 (PER CENT) of intake.

Table 1 also shows estimates of intake by ingestion based separately on individual measurements of the polonium-210 content of tissues and urine. We (Rich LEGGETT and I) consider that the model is less reliable in predicting retention in the spleen and hence in estimating intake from a measurement on spleen tissue. Therefore, a best estimate of intake was obtained using the measurements for kidney, liver and urine. The best estimate is 4.4 GBq (4,400 million Bq), assuming intake by ingestion on 1.11.06 and 10 (PER CENT) absorption to blood. More precisely, the estimated absorption to blood is 0.44 GBq (440 million Bq), with the calculation of intake being dependent on the assumed absorption to blood. If, for example, absorption was 20 (PER CENT) instead of 10 (PER CENT), intake would have been estimated as 2.2 GBq. The estimates of intake based separately on the kidney, liver and urine measurements were within 30 (PER CENT) or less of the best estimate, giving confidence that modelling assumptions had remained valid despite the gross tissue damage and loss of function implied by these activities.

Answer 1: The low concentration of polonium-210 in lung tissue is consistent with inhalation being a minor route of intake. Assuming intake solely by ingestion on 1.11.06 and 10 (PER CENT) absorption to blood, the best estimate of intake is 4.4 GBq.

2) Assessment of radiation doses

Table shows estimates of radiation doses to body organs of a reference 70 kg adult male over 22 days following the ingestion of 4.4 GBq of polonium-210, assuming 10 (PER CENT) absorption to blood.

Table 2. Cumulative doses to organs / tissues of a reference adult male after ingestion of 4.4 GBq of polonigm-210, assuming 10 (PER CENT) absorption to blood

Time after	Cumulative dose, Gy						
intake, d	R.B.M.	Gut	Liver	Kidneys	Spleen	Skin	Testes
1	0.8	0.2	5.0	8.1	2.9	0.6	0.8
2	1.8	0.4	11	18	6.4	1.3	1.9
3	2.7	0.6	17	27	9.9	2.0	2.9
4	3.6	0.8	22	36	13	2.8	4.1
5	4.5	1.1	28	44	16	3.6	5.2
10	8.7	2.0	51	80	31	7.9	12
15	12	2.8	70	110	44	13	19
20	16	3.5	86	130	55	18	26
22	17	3.7	92	140	59	20	29

RBM = Red bone marrow

The measure of radiation dose is the gray (Gy). One Gy is one joule per kg; that is, it represents the deposition of one joule of energy per kilogram of tissue.

Estimated radiation doses to the kidneys and liver are very high, about 9 Gy per day to kidneys and 5 Gy per day to the liver over the first few days after intake, reaching estimated values of 140 Gy for kidneys and 92 Gy for the liver after 22 days. Doses to the red bone marrow were estimated as about 6 Gy after one week after intake, 12 Gy by 2 weeks and 17 Gy after 22 days.

Answer 2: Doses to body organs increased from the time of intake to estimated values of 140 Gy to kidneys, 92 Gy to liver and 17 Gy to red bone marrow. Other organs, including skin, also received high radiation doses.

3) Consequent organ damage and death

Ionizing radiations, including gamma rays and alpha particles can kill cells by damaging biological molecules within them, including DNA. Alpha particles are particularly effective at killing cells because, although they travel only short distances (a few cell widths), they deposit a lot of energy along their paths. They can be thought of as atomic bullets, capable of killing at a cellular level. Enough alpha particles will kill enough cells to cause gross tissue damage, organ failure and death.

Doses required to cause lethal damage to body organs are often quantified in terms of the Lethal Dose estimated to kill 50 (PER CENT) of people so exposed, referred to as LD_{50} values. Thresholds above which lethal effects may be observed are referred to as LD0 values and doses at which all people are expected to die are referred to as LD_{100} values. Most available information applies to single high dose exposures to gamma rays from outside the body. For this analysis, account has been taken of the effect of delivery of dose over a prolonged period of time (which reduces effectiveness per Gy) and internal exposure to alpha particles (alpha particles are more damaging than gamma rays per Gy). LD_{50} values estimated to apply to irradiation by alpha particles at the levels and over the time-course considered to apply to Mr LITVINENKO are 2-3 Gy for bone marrow, 6 Gy for kidneys and 8 Gy for liver. Comparison with Table shows that following intake by ingestion of 4.4 GBq of polonium-210, these values are estimated to have been exceeded by 4 days after intake for the bone marrow, after 1 day for kidneys and 2 days for liver. Doses estimated to have been received by the bone marrow, kidneys and liver of Mr LITVINENKO by the time of death are substantially in excess of doses that could be survived by any person. Other organs also received high doses and death can be attributed to multiple organ failure.

The bone marrow is recognised to be particularly sensitive to radiation damage and its destruction rapidly depletes the levels of white blood cells and platelets in circulating blood, leading to vulnerability to infection and internal bleeding. Table 3 reproduces results made available to Dr RN GENT (HPA) on measurements of white blood cells and platelets in blood samples from Mr LITVINENKO from 3.11.06 to 17.11.06. These results are also included in the statement provided by Dr GENT. The results are consistent with complete destruction of the red bone marrow. An initial increase in neutrophil (also referred to as granulocytes) numbers above normal levels was observed on 3.11.06 and 5.11.06, characteristic of high dose radiation injury. Bearing in mind the protracted delivery of dose from polonium-210, this is consistent with intake on or around 1.11.06.

Table 3. Blood counts for Mr LITVINENKO at Barnet (and) Chase Farm Hospital; cells x 10^9 per litre.

Date	WBC	Neutrophils	Lymphocytes	Platelets
3/11	21.7	19.8	1.0	178
4/11	--	--	--	--

Signed: DR J D HARRISON Signature Witnessed by: DC I STEWART
2006/07(1)

5/11	17.2	16.1	0.6	105
6/11	--	--	--	--
7/11	7.1	6.8	0.1	92
8/11	--	--	--	--
9/11	1.3	1.1	0.0	63
10/11	--	--	--	--
11/11	0.3	0.3	0.0	35
12/11	0.2	0.1	0.0	21
13/11	0.1	0.0	0.0	9
14/11	0.0	0.0	0.0	2 (asterisk)
15/11	0.0	0.0	0.0	17
16/11	0.0	0.0	0.0	21
17/11	0.0	0.0	0.0	13
Normal	4 - 11	2.0 - 7.5	1.0 - 4.0	150-400

WBC, white blood cells.

(asterisk)Platelet and plasma transfusions started.

Information on human exposures to radiation from external sources and on animal exposures to polonium-210 allow comment on time to death. Human data are consistent with bone marrow failure being an important component of the contributory causes of death occurring within a few weeks of delivery of alpha doses to red bone marrow of about 6 Gy per week. Results for a number of mammalian species (cats, dogs, rabbits, rats and mice) show that death occurred within 20 days following intake by ingestion corresponding to 1 - 3 GBq or more by a 70 kg man, assuming 10 (PER CENT) absorption to blood.

Answer 3: Death is the inevitable outcome of the radiation doses estimated to have been received by Mr LITVINENKO's red bone marrow, kidneys and liver. Bone marrow failure is likely to be an important contributory cause of death occurring within a few weeks of intake, as a component of multiple organ failure. An initial rise in levels of circulating neutrophils (white blood cells) on 3.11.06 and 5.11.06 is consistent with intake of polonium-210 on or around 1.11.06.

4) Polonium-210 in urine and sweat

Following ingestion of 4.4 GBq of polonium-210 and 10 (PER CENT) absorption to blood, model predictions of urinary excretion are about 3 MBq (3 million Bq) per day on the first two days after intake, falling to about 1 MBq per day after 22 days. Assuming a standard daily output of urine of 1600 ml, these values correspond to concentrations of about 2 kBq (2000 Bq) per ml on the first two days, falling to about 0.6 kBq (600 Bq) per ml after 22 days. These model predictions are consistent with the single measurement of polonium-210 in urine on 22.11.06, reported by AWE as about 0.8 kBq per ml. In rounded figures, concentrations of polonium-210 in Mr LITVINENKO's urine can be assumed to have been about 1 - 2 kBq per ml (1000 - 2000 Bq per ml) throughout the period from intake to death.

Losses in sweat cannot be predicted with any certainty and sweat volumes are very variable. Model predictions are of total loss from skin in sweat, hair and sloughed skin of around 0.2 MBq per day (200,000 Bq per day) for most of the period from intake to death (initially lower over the first 3 days as uptake of polonium-210 into skin takes place). Assuming that about half this activity might be present in readily transferable sweat and sloughed skin, this corresponds to around 0.1 MBq per day. For a normal adult engaged in light indoor activity, sweat loss is estimated as 650 ml per day, but if we take this volume to be 0.5-1 litre per day, concentration of polonium-210 in sweat ((plus) particles of sloughed skin) may be estimated as around 100 - 200 Bq per ml, around a factor of 10 lower than concentrations in urine.

Answer 4: The concentration of polonium-210 in Mr LITVINENKO's urine may be assumed to have been about 1-2 kBq per ml (1000 - 2000 Bq per ml) throughout the period from intake to death. Concentrations in sweat are estimated to be lower, roughly by a factor of ten.

5) Secondary contamination from Mr LITVINENKO

A judgement on the lowest level of intake of poloniurn-210 that might prove fatal as a result of cell killing and organ damage can be made by reference to results for the effects of polonium-210 in animals and estimated Lethal Dose values for humans. Results for the effect of polonium-210 in rats and dogs show that death may occur at 6-18 months after an intake corresponding to around 3 (PER CENT) of the assessed intake by Mr LITVINENKO, around 0.1 GBq. In these cases, the primary cause of death was considered to be kidney damage. For an intake by ingestion of 0.1 GBq, assuming 10 (PER CENT) absorption to blood, the total cumulative dose to the kidneys would be about 6.4 Gy, compared with the LD_{50} values referred to above of 6 Gy and an LD0 value of 4.5 Gy.

Results for dogs indicate that even lower intakes and doses (by a factor of 2-3) may prove fatal after a number of years. Thus, it appears reasonably cautious to assume that an intake of 0.04 GBq (40 MBq) might prove fatal; that is, 1 (PER CENT) of the intake estimated for Mr LITVINENKO. An intake of 40 MBq corresponds to 20-40 litres of Mr LITVENENKO's urine and larger volumes of sweat.

This analysis does not comment on increased risk of cancer in later life at lower levels of intake.

Answer 5: The levels of poloniurn-210 in Mr LITVINENKO's urine and sweat could not have resulted in a life-threatening intake of polonium-210 by another person.

Radioactivity conversions:

1 GBq	1000 million Bq
1 MBq =	1 million Bq
1 kBq =	1000 Bq
1 Bq =	1 decay per second