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Doses in Radiation Accidents Investigated by Chromosomal Aberration Analysis XXV

Review of Cases Investigated, 2006–2015

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Doses in Radiation Accidents Investigated by Chromosomal Aberration Analysis XXV

Review of cases investigated, 2006–2015

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Abstract

During the period between the start of 2006 and the end of 2015, 73 people suspected of being overexposed to ionising radiation were referred to Public Health England (and one of its predecessor organisations, the Health Protection Agency) for biological dosimetry. Of these, 45 were related to industrial uses of radiation, 27 were associated with radiation used in institutions of research, education or health and 1 was from a major nuclear organisation. Although the vast majority of cases were suspected occupational overexposures, the most serious case concerned a 2-year-old boy (a non-EU citizen) who sustained radiation burns during CT scans performed outside the EU, which were incorrectly repeated numerous times, resulting in an estimated head and neck dose of approximately 8 Gy. The cases included in this summary bring the total number of individuals examined since the laboratory was established in 1968 to 1092.

In addition to carrying out biological dosimetry for routine and emergency exposure investigations, a number of new biological dosimetry techniques have been developed within the last 10 years. These include validation and integration of the high throughput γ-H2AX DNA damage response assay, increasing the laboratory's emergency response operating capacity to approximately 3000 individuals a week, and the novel Bayesian and classical statistical analysis methods to further aid interpretation and presentation of estimated doses. These developments, briefly summarised in this report, together represent a large improvement in the laboratory's ability both to perform accurate routine biological dose estimations and to provide rapid response triage dose estimates following a mass casualty event.

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Contents

1 Introduction

This report is the twenty-fifth in a series that summarises biological dosimetry investigations undertaken by Public Health England (and previously by the Health Protection Agency, HPA, 2005–2012, and before that by the National Radiological Protection Board, NRPB, 1970–2005). The PHE cytogenetics laboratory was established in 1968 in the Health and Safety Branch of the United Kingdom Atomic Energy Authority, UKAEA, that, together with the Radiation Protection Division of the Medical Research Council, MRC, were combined to create the NRPB in 1970. Since those very early days, the laboratory has been involved in the development and application of chromosomal aberration analysis as a biological dosemeter for investigating accidental ionising radiation exposure. Reports have been produced at regular intervals, detailing the accident cases investigated by the PHE biological dosimetry service.

In common with previous reports in this series, most of the cases are briefly described in an appendix, except for those discussed in detail in the main text. Biological dose estimates are expressed in gray (Gy) and are equivalent whole body doses unless otherwise stated. The dose estimates are chiefly derived from the frequency of dicentric chromosomal aberrations (DCA) observed in blood lymphocytes, by comparison with an appropriate in vitro dose-response calibration curve. Analysis is carried out in accordance with ISO Standard 19238:2014[1]. For suspected exposures dating back more than approximately 3 years from the date of the investigation, fluorescence in situ hybridisation (FISH) analysis has been used to identify levels of stable chromosomal translocations. Where available, physical estimates are also shown in the appendix expressed in sievert (Sv) and are obtained from personal dosemeters. Occasionally these are traditional film badges, but more frequently thermoluminescence based badges (TLD), optically stimulated luminescence (OSL) or personal electronic (PE) dosemeters.

In addition to carrying out biological dosimetry for routine and emergency exposure investigations, PHE cytogenetics laboratory members, collaborators and colleagues have been instrumental in establishing new techniques. During the period 2006–2015, there have been a number of new developments in the field of biological and retrospective dosimetry. For the traditional cytogenetics assays, these include automation of dicentric and cytokinesis-block micronucleus (CBMN) assays and the development of new calibration curves. In addition, the high throughput γ-H2AX DNA damage response assay has also been successfully validated and integrated into the biological dosimetry service, increasing the laboratory's emergency response operating capacity to approximately 3000 individuals a week. Finally, statistical advances have included the development of new methods for creating calibration curves and for estimating probabilities of exposure above, below or within a defined dose range. This work has aided the accuracy of dose estimates and interpretation of the results of the analysis for medical professionals, safety officers and other relevant professionals, as well as for the suspected exposed individuals themselves.

2 Summary of Cases Investigated

The numbering system for the investigations continues from the 2003–2005 report[2]. Except for those academically noteworthy cases discussed in the main text, brief details for each investigation are given in the appendix.

Table 1 summarises the cases in terms of four categories. Category A scenarios, comprising 43 (of the total of 73 people investigated during this reporting period), are situations where the first indication of a possible overexposure comes from an unexpectedly high reading on a personal physical dosemeter. It is then necessary to determine whether the badge dose truly reflects the dose received by the wearer. In total, 27 people were placed in category B, individuals for whom an overdose is suspected but no dosemeter was worn. This situation could arise because a radiation worker omitted wearing their dosemeter or because a non-radiation worker or a member of the public was involved in an accident. Category C covers cases serious enough to merit a full reconstruction of the event, using phantoms incorporating physical measuring devices, for which satisfactory estimates of the whole body dose can be made from physical measurements. No cases fell into this category during the 10-year period, 2006–2015. The final 3 cases were assigned to category D, individuals for whom internal exposure was suspected. However, in all 3 cases, internal exposures were not indicated by the biological dosimetry results.

Table 1: Distribution of investigations between the four categories

Category	Description	Previous reports	Present report	Total
A	Possible non-uniform exposure in which the relationship between dose to the physical dosemeter and to the body is uncertain	627	43 (59%)	670
B	Suspected overexposure of people not wearing a dosemeter	247	27 (37%)	274
C	Overexposure where satisfactory estimates of the whole body dose can be made from physical measurements	7	0	7
D	Chronic internal or external exposure	138	3 (4%)	141
Total		**1019**	**73**	**1092**

Table 2 illustrates the origins of the cases examined during the period 2006–2015. The trend is unchanged from previous years in that most cases arose from industrial uses of radiation, especially gamma radiography sources used for non-destructive testing of metal objects. Also for most people (65%) the analysis led to the conclusion that the individual had received a dose below the minimum detectable level of approximately 100 mGy for the dicentric assay. This detection limit arises due to a combination of the background level of approximately 1 dicentric in 1000 cells and the statistical uncertainty associated with the scoring of a sample number of cells from the total irradiated population.

Table 2: Origins of the cases and the number of 'zero' dose estimates

Case origin	Number of cases		Number of dose estimates < ~100 mGy
	Present report	All reports	
Industrial radiography	45	704 (64.5%)	459
Major nuclear organisations	1	154 (14.1%)	91
Research, education and health institutions	27	234 (21.4%)	155
Total	**73**	**1092**	**705**

Of the 73 cases investigated during the last 10 years, there was no evidence of radiation exposure (greater than the 100 mGy detection limit) for 43 people and a dose estimate of less than 200 mGy for 24 cases, of which 6 showed inconclusive results due to the statistical uncertainty. Positive exposure was confirmed in 6 cases, of which 5 were found to be partial body exposures, and 1 case involved exposure to the individual from an unknown source.

Noteworthy cases for research purpose are highlighted in the following paragraphs to illustrate the diversity of situations encountered.

In case B140, a man developed a series of eye problems commencing 1 week after having been exposed to radiation leaking through a defective door to a linear accelerator. After 6 weeks a cataract developed. He was concerned that this was radiation induced despite the absence of any accompanying facial skin effects and the advice that the time delay was far too short for cataract development. Biological dosimetry was requested to further explore the possibility of radiation exposure: 1000 cells were scored and no chromosomal aberration was detected. The best estimate of his averaged whole body dose was zero. However, zero carries statistical uncertainty – for high energy gamma radiation, there was a 2.5% chance that an averaged whole body dose of about 100 mGy could have been received with no chromosomal damage detected. Additionally, if only a small volume of the body had been exposed briefly from a narrow beam through a small aperture in the shielding, it was very unlikely that the damage would have been detected, due to the dilution of the few exposed blood cells into the whole blood pool. However, it was judged that a local dose sufficient to cause clinical concern or a cataract within 6 weeks, which would otherwise have resulted in localised erythema (skin reddening), was unlikely to have been received.

The most serious case investigated in the period covered by this report was number B142. A 2-year-old boy sustained radiation burns as a result of incorrectly repeated head and neck CT scans which occurred in a non-EU country. It was reported that the dose received by the child during the total exposure period of approximately 65 minutes could have been of the order of 11 Gy to the neck, as a result of receiving 150 scans in 3 mm cuts to sections of skin just below the hairline. Erythema was observed 3 hours after the procedure. A total of 585 lymphocyte metaphases were scored using the conventional unstable aberrations assay, which detected 3 dicentrics and 2 acentric fragments, all in separate cells. This frequency of dicentrics was in excess of what would be expected in a control infant. In addition, 3000 metaphases with highlighted chromosome pairs 2, 3 and 5 and all centromeres in the FISH assay revealed that the number of translocations (4.9/1000) was well above the reported baseline mean of 0.4/1000 for a comparable age range. Furthermore, despite the delay of

several months between exposure and blood sampling, there had not been much reduction of unstable damage due to lymphocyte turnover. It should be noted that only a very small proportion (less than 1%) of the blood lymphocytes would have been in the exposure field at any one time, accounting for the difference in the calculated dose and the frequencies of dicentrics and translocations. However, scattered radiation to the rest of the body might provide an explanation for the observed elevated levels of chromosomal aberrations. Owing to the uncertainties surrounding biological dose estimation in this case, the patient was referred to colleagues for electron paramagnetic resonance (EPR) analysis. EPR dosimetry was performed on a baby tooth that was exfoliated 5 years later and produced an estimated dose of 7.9 Gy with an uncertainty of ± 3 Gy without consideration of any 'background' signal.

CT scans, properly conducted, would involve doses far below the threshold for any detectable sickness or discomfort, nevertheless the laboratory has been referred patients (eg B147) who felt ill after scans and feared that their doses had been excessive. Early tissue reactions are by no means unique to radiation and in these cases biological dosimetry was able to show that there had been no excessive exposures. A literature search revealed reports of patients occasionally suffering adverse reactions, mimicking the early responses to high radiation doses, caused by the contrast medium used during CT scans[3]. Informing the medical advisers of these reports assisted them greatly in counselling their patients.

A particularly unusual case of overexposure to radiation during a prolonged diagnostic cardiac fluoroscopy procedure (involving X-rays) was examined as case B145. The patient had 1 hour of fluoroscopy in September 2007, another hour in January 2008 and 5 hours in April 2008. Fluoroscopy was taken primarily of the heart with two fluoroscopy machines on the exposure in April 2008, which caused severe local radiation injury to the left and right upper back. The surface area exposures on the back were rectangular and 4" x 5" (10 cm x 12 cm) on the right just lateral to the scapula (shoulder blade) and another over the left scapula. The left side lesion healed with scarring, whereas the right side lesion was worse with residual liquefaction necrosis and a surrounding area of fibrosis. A blood sample was analysed in January 2009. The dicentric analysis (76 dicentrics, 2 centric rings and 55 excess acentrics in 1564 cells) corrected for dose protraction gave an estimate of 0.7 ± 0.1 Gy whole body equivalent exposure. The whole genome translocation yield (44 translocations and 1 insertion in 1476 stable cells), with background corrected for age and gender, was equivalent to 79 in 1000 cells. Corrected for protraction over 5 hours with an assumed mean lifetime of breaks of 2 hours, this gave a dose estimate of 1.0 ± 0.1 Gy in the FISH analysis. The damage was significantly over-dispersed with a *U*-value (Papworth's extended *U*-test, quantifying deviation from the expected Poisson distribution) of 29.03 and a ratio of variance to mean of 2.03 ± 0.04. Using the contaminated Poisson method, it was estimated that 20% of the body was exposed to a dose of approximately 3.5 Gy. It was concluded that the averaged whole body dose estimate of 1 Gy, based on translocation levels, reflected the radiation dose to which this patient had been exposed during his lifetime. The observed dicentics levels confirmed that most, if not all, of this exposure occurred within the last few years, which was consistent with the reported fluoroscopy treatments. The biological dosimetry results were compared in a publication in the open literature[4].

Retrospective overexposure analysed using the FISH translocation technique confirmed three historic partial body exposure cases. In case B153, a patient experienced two partial body exposures to her head during CT scanning, 21 months prior to blood sampling. Overexposure was suspected and chromosomal analysis requested by her GP. The results

showed an excessive whole genome translocation yield (14 translocations in approximately 1004 whole genome equivalent cells). This, when corrected for background for age and gender, was equivalent to 6 in 1000 cells. By comparison with an appropriate calibration curve, this would be consistent with one whole body exposure of just over 100 mGy X-rays with lower and upper 95% confidence limits of 3 and 216 mGy, respectively. For a fractionation scenario with two exposures approximately 1 month apart, the dose estimate increases to approximately 200 mGy with lower and upper 95% confidence limits of 87 and 323 mGy, respectively. The results would be equally compatible with a non-uniform exposure in which a small fraction of the body received a larger dose. Among the FISH painted cells, 8 unstable cells that contained 7 dicentrics (1 un-painted, 1 painted and 5 bi-painted) and 3 excess acentrics (1 un-painted and 2 painted) and 2 one-way translocations were also observed. Of the 8 unstable cells, 2 contained a complex arrangement involving a dicentric, acentric fragment and translocation. However, no cells with multiple dicentrics were observed, so that reliable identification of a partial body exposure was impossible. The dose estimate for 7 dicentrics among 3008 cells was just over 40 mGy assuming two fractions, with lower and upper 95% confidence limits of 0 and 102 mGy, respectively. In parallel, 500 Giemsa-stained cells were also analysed and 1 dicentic and 2 excess acentrics were observed. This result would be consistent with a two-fraction exposure of less than approximately 120 mGy X-rays (upper 95% confidence limit). It was concluded that both translocation and dicentric levels were slightly higher than the spontaneous levels observed in non-exposed individuals and were consistent with a low dose whole body exposure of the order of 100–200 mGy X-rays, with large uncertainties as indicated by the stated confidence limits. However, the results were equally compatible with a large dose given to a small fraction of the body. In such a case, most of the heavily damaged cells containing multiple aberrations would have been more likely to be lost during the subsequent 21 months, obscuring the non-uniform nature of the exposure.

Case B155 is also notable. A 5-minute exposure was received by a technician who was testing an X-ray set in a cardiac catherisation room. He had accidently activated the set by stepping on the foot switch and had forgotten to wear his dosemeter. He developed an erythema a few hours later and his head and neck skin dose was estimated at 5–10 Gy. Biological dosimetry (1 dicentric and 4 acentric fragments in 500 cells), however, was able to provide reassurance that his averaged whole body dose was low. The likely X-ray energy was 30–40 keV, based on typical parameters for heart catheter X-ray sets. The depth-dose profile at this energy means that only around 25% of the dose would be deposited at 5 cm body depth, dropping to close to zero at the exit. A lead apron covering most of the torso and upper legs provided excellent shielding in this region, resulting in very low exposure to the lymphatic tissues which contain the vast majority of lymphocytes. Therefore, the total dose to lymphocytes would be small, despite the high surface doses to the head and neck. This case highlights one of the limitations of biological dosimetry, in dealing with soft X-rays.

In case A525, 10 industrial workers were suspected of overexposure from an unshielded ^{169}Yb radiography source. It was thought from the start that any exposures would have been below the detection limit for the chromosomal aberration assays; however, the incident was discovered very promptly and it was possible to take blood samples 8 hours later within the short time window to allow the γ-H2AX foci assay (described in Section 3.2) to be used. The samples were transported on ice to PHE. Repeat blood samples were taken at 28 hours for the dicentric assay and the γ-H2AX foci assay also was repeated. This scenario presented an opportunity for the first time to work under realistic triage conditions to give rapid reassurance of a low

dose exposure, by ruling out any high or significant whole body dose. This reassurance was aimed at reducing the stress and anxiety of the exposed individuals before further sampling and analysis using the more accurate, but time consuming, traditional cytogenetic assays.

For each sample 500 metaphase cells were randomly assessed and no dicentics and not more than 3 acentrics per sample were found. As the mean gamma energy of 93 keV for ^{169}Yb is much closer to the mean energy of around 90 keV for 250 kVp X-rays than to the 1.25 MeV for ^{60}Co, the X-ray calibration curve was used to calculate the upper dose limit. Assuming an acute exposure, ie the total exposure time being of the order of minutes, not hours, the 95% upper confidence limit for 500 cells was 0.1 Gy, the 95% lower confidence level in all cases was 0 Gy and the mean dose was also 0 Gy. Based on this result, the odds ratio for the dose being 0 Gy or 180 mGy is approximately 85 : 1. Importantly, the calculations above refer to whole body doses and cannot exclude the possibility that much higher peak doses might have been delivered locally, eg to the fingers of those who held the source. As hands contain only very few lymphocytes, the chance of scoring a cell which had been in the region of the body at the time of exposure was judged to be minimal. The γ-H2AX assay results reflected a recent low dose exposure to these workers; however, it was unlikely that anybody had received more than around 200 mGy.

This appears to be the first time that this assay has been used for a real irradiation incident and, in this case, was able to provide a result that very rapidly provided reassurance to all involved. If a higher level overexposure had been suspected, then a further blood sample would have been taken at a later time in order to determine each individual's background level and thus to refine the γ-H2AX dose estimates. However, in view of the low lesion levels in the first samples, further analysis was felt to be unjustified. The results of the analyses are shown in Table 3 and Figure 1.

Table 3: Whole body dose estimates based on the γ-H2AX and dicentric assays for case A525

	8 h samples		28 h samples				
Person	Mean γ-H2AX foci	Estimated whole body dose (Gy)	Mean γ-H2AX foci	Estimated whole body dose (Gy)	Dicentrics	Excess acentrics	Estimated whole body dose (Gy)
1	0.27	0.07	0.03	0.01	0	2	0
2	0.49	0.13	0.27	0.13	0	1	0
3	0.15	0.04	0.15	0.07	0	1	0
4	0.62	0.16	0.44	0.21	0	0	0
5	0.32	0.08	0.17	0.08	0	0	0
6	0.33	0.09	0.08	0.04	0	3	0
7	0.41	0.11	0.17	0.08	0	1	0
8	0.56	0.15	0.15	0.07	0	0	0
9	0.22	0.06	0.06	0.03	0	0	0
10	No sample	–	0.02	0.01	0	0	0

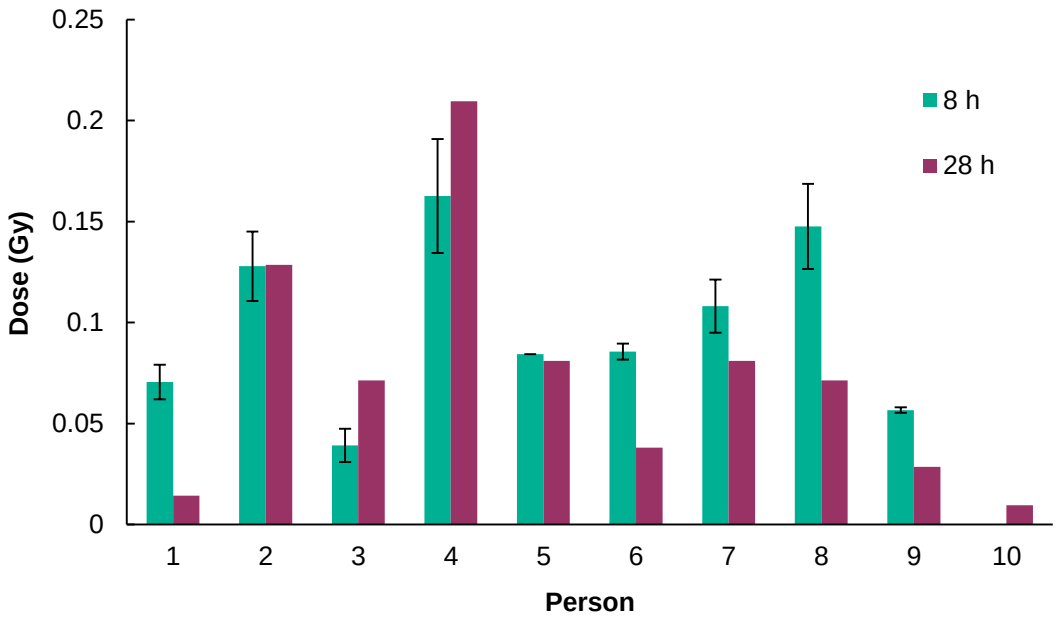

Figure 1: Maximum whole body doses based on the 8 and 28 h γ-H2AX samples for case A525

3 Methodological Advances

3.1 Cytogenetic techniques

In recent years, the retrospective dosimetry communities have been focusing on two key areas of scientific development: firstly, refinements including automation of techniques to increase throughput; and, secondly, networking to ensure emergency preparedness and resilience of biological dosimetry capabilities across the EU and worldwide.

Recent refinements to the traditional cytogenetic assays have chiefly concerned development of automated scoring techniques, ie using technology such as the Metasystems Metafer – a computer controlled microscope that can automatically scan a slide and use pattern recognition to identify and capture images of metaphase clusters of chromosomes – and the DCScore dicentric scoring package to significantly increase throughput by reducing the amount of time needed for identification of dicentrics[5]. Semi-automated dicentric scoring, whereby a human scorer checks the validity of dicentrics identified by the Metafer, is now available at PHE, although it has not yet been implemented in a biological dosimetry case. Telescoring – whereby captured images are shared for analysis remotely – has also been validated for use in a radiation emergency[6].

In addition to the traditional cytogenetic assays, a number of physical methods of retrospective dosimetry have been gaining popularity in recent years. Electron paramagnetic resonance (EPR) relies upon measurement of unpaired electrons induced by radiation in materials such as the teeth or nails of exposed individuals. Optically or thermally stimulated luminescence (OSL or TL) techniques use stimulation of recombination of trapped electron-hole pairs to release a luminescence signal proportional to the dose received. PHE has now implemented

the technique of using OSL on aluminium oxide on electronic components taken from mobile phones to give radiation dose estimates[7,8]. The technique is fully operational but has yet to be used in a real routine or emergency case.

The PHE cytogenetics laboratory has been involved in two major development and networking projects in the period covered by this report – namely the EU FP7 funded MULTIBIODOSE collaboration, which aimed to standardise and validate new and existing assays for triage dose estimation, and the FP7 RENEB collaboration to set up a formal network for biological and physical retrospective dosimetry within Europe. MULTIBIODOSE concluded in 2013, with the main outputs being a set of coordinated biological dosimetry tools and contacts for emergency triage categorisation[9] and software for carrying out triage dose estimation[10]. The RENEB project concluded at the end of 2015, with the key results being formal establishment of the RENEB network, creation of quality assurance standards and procedures, and formation of a sustainable training programme for biological dosimetry in Europe. PHE contributed heavily to this project through leading the γ-H2AX training, standardisation and validation task, statistical analysis of intercomparison data, and running an intercomparison to test new methods. Intercomparison exercises performed within and in parallel to these projects have continued to demonstrate that PHE is ready to assist the EU and retrospective dosimetry community if a large-scale radiation accident or incident should occur.

3.2 γ-H2AX foci analysis

γ-H2AX is the phosphorylated form of the histone H2AX which is modified in the chromatin region surrounding a DNA double strand break to form foci which can be visibly quantified with the use of a microscope following appropriate immunostaining. There is strong evidence that H2AX foci give excellent radiation dose responses[11] and a fraction of the foci persist for up to several days following exposure to doses of 0.5 Gy or more. Thus this method was proposed and has been gaining popularity as a radiation biomarker, both for detection of radiation exposure[12–14] and in medical exposure settings[15]. Most recently, the γ-H2AX assay has been standardised and validated in the EU funded collaborative research project MULTIBIODOSE and the RENEB networking project[16]. The assay has been shown to be particularly applicable for triage dose estimation for samples taken in the period 0–24 hours after irradiation.

At PHE, several calibration curves have been created to allow radiation dose estimation, including for X-rays and gamma rays at 4 and 24 hours. The assay has been used for one case to date – A525 described above – following immediate discovery of exposure. Blood samples were taken very quickly and laboratory members worked throughout the night to provide fast reassurance that the exposures were low. Introduction of this assay has increased the laboratory's emergency response operating capacity to approximately 3000 individuals a week.

3.3 Bayesian statistical analysis methods

An important benefit of biological dosimetry is the reassurance provided in suspected cases of exposure that result in only background levels of aberrations being identified. People involved in radiation incidents often fear the worst, especially if there is no reliable physical dosimetry (eg category B in Table 1). It is therefore important to be able to explain coherently the idea of

uncertainty associated with the dose estimations provided. Experience over many years has shown that recipients of biological dosimetry reports, both health professionals and report subjects, often have difficulty in comprehending confidence limits.

A number of methods have been developed to address this. A Poisson odds ratio based approach[17] has been used in several of the cases outlined in the appendix to illustrate the relative chance of observing, for instance, zero dose compared to the calculated dose, or the calculated dose compared to a recorded TLD badge dose. This approach is popular as it quantifies the likelihood of dose in a format more readily understood by the general population. Most recently, statistical analysis for biological dosimetry using Bayesian techniques has been developed and established at PHE in collaboration with the Mathematics Department at the Autonomous University of Barcelona. The Bayesian framework relies upon the assessment of probability rather than taking point estimates. The resulting dose estimation is presented as a probability distribution which therefore incorporates all the uncertainty information, giving a much more realistic picture of the likely exposure dose and the associated probability. It is possible to provide statements such as: “The suspected exposed individual had a 60% chance of receiving a dose greater than 20 mSv; an 80% chance of receiving a dose under 100 mSv; or a 90% chance of receiving a dose between 100 and 200 mSv”. The Bayesian approach is now fully validated[18–22] and has thus far been applied to one case, A538, to demonstrate a probability of approximately 60% that the received dose was below the recorded badge dose of 115 mSv.

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Appendix

A Possible non-uniform exposure in which the relationship between dose to a personal dosemeter and to the body is uncertain

A508	
Cells scored	1000
Dicentrics	0
Centric rings	0
Other aberrations	2
Biological dose (Gy)	0
95% CL (Gy)	0–0.12
Badge dose (mSv)	Not provided

A scientist became anxious after neutron irradiating targets substantially larger than his routine procedures. His concern was that there may have been a much wider scattering of neutrons extending to his control position. This coincided with his feeling ill with flu-like symptoms. Dose reconstruction with neutron detecting instruments proved reassuring and the cytogenetics was undertaken to provide further reassurance

A509	
Cells scored	500
Dicentrics	0
Centric rings	0
Other aberrations	0
Biological dose (Gy)	0
95% CL (Gy)	0–0.19
Badge dose (mSv)	254

The most likely cause of the overexposure registered on an OSL badge was that it fell off, unnoticed, in an area where industrial radiography was carried out using a 3.52 TBq (95 Ci) ^{192}Ir source. It could have lain there while up to 30 exposures were carried out. The badge readings were inconclusive due to different exposure geometries. The chromosomal analysis favours zero dose with odds of 90 : 1

A510	(i)	(ii)	(iii)
Cells scored	1000	500	500
Dicentrics	4	1	0
Centric rings	0	0	0
Other aberrations	3	0	0
Biological dose (Gy)	0.14	0	0
95% CL (Gy)	0.01–0.26	0–0.23	0–0.10
Badge dose (mSv)	11	3	22

A 1.48 TBq (40 Ci) ^{192}Ir industrial radiography source was not properly retracted into its safety housing and this probably resulted in low doses to 3 workers. Man (i) was believed to have carried the source next to his leg for about 30 seconds but there were no skin reactions. All 3 doses registered on the badges are below the sensitivity level for biological dosimetry but for man (i) chromosomal damage was noted. A possible explanation was discovered that this individual had been involved in a previous radiation incident at work

A511		The TLD badge was worn by an operating theatre nurse who assisted several times in the implantation of cardiac pacemakers. No reason could be found for the recorded dose. None of the other people present wore a dosemeter that might have provided confirmation of whether the exposure to staff was genuine. The finding of no dicentrics favoured the possibility of zero dose with an odds ratio of 10,000 : 1 for acute exposure. The corresponding ratio for protracted exposure is 500 : 1
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.13 (acute exposure)	
	0–0.16 (protracted/fractionated exposure)	
Badge dose (mSv)	311	
A512		An industrial radiographer reported losing his film badge and it was discovered 3 weeks later in a vehicle used for radiography with an ^{192}Ir source. The two possibilities were that either the badge had been irradiated at this time while not worn or that he had indeed been exposed to the recorded dose. The biological dosimetry result favoured zero dose with an odds ratio of 5 : 1
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.16	
Badge dose (mSv)	110	
A513		An OSL badge was issued to a service engineer who worked on radiotherapy accelerators. He was certain that he had experienced no unusual events and suggested that he may have left the badge inside a treatment room. Cytogenetics was requested to support this explanation and the recorded dose of 430 mSv was firmly rejected
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.19	
Badge dose (mSv)	430	

A514		An industrial radiographer was engaged in recovery of detached ^{192}Ir sources. The low doses recorded on his TLD were considered to indicate real exposure but below the detection threshold for biological dosimetry. Nevertheless because of the unusual tasks he had performed, biological dosimetry was requested for further reassurance
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.16	
Badge dose (mSv)	1.2	
A515		The overexposure was recorded on a badge worn by a worker who operated an electron accelerator for various industrial processes such as sterilisation, polymerisation and colouring gem stones. He admitted to having made an improper entry a short distance into the entrance maze in order to clear a conveyor jam. Dose reconstruction, according to his account, indicated < 1 mGy; inconsistent with the 330 mSv recorded on the badge. The reason for the recorded dose remained unresolved. Biological dosimetry backed up the probability that he had not been excessively exposed with an odds ratio of 35,000 : 1 favouring zero dose rather than 330 mGy
Cells scored	1000	
Dicentrics	1	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.16	
Badge dose (mSv)	330	
A516		A nuclear medicine physician routinely recorded ~3 mSv a year mainly from administering ^{90}Y and ^{131}I to patients. This dose was considered to be consistent with his workload. Four successive monthly dosemeters recorded unexpectedly high values totalling 18 mSv. Investigators could find no explanation: working practices had not altered, no colleague had recorded similar unexpected doses and the doctor's workload had somewhat decreased during the period in question. The recorded doses are below the detection limit for biological dosimetry but it was requested because no explanation was forthcoming and so there was a need to exclude more serious exposure. Given the statistical limitations, the cytogenetics could advise that there was only a 2.5% chance that a dose of 100 mSv could have been received with no chromosomal damage found and the probability that he received no exposure at all was about 50%
Cells scored	1000	
Dicentrics	0	
Centric rings	0	
Other aberrations	2	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.10	
Badge dose (mSv)	20 (total accumulated over 6 months)	

A517		The proffered explanation for an overexposed and late-returned dosemeter was that it had been in a pocket of a jacket hung up inside a radiation area (with the exposure type unspecified). Biological dosimetry concluded that this was a false alarm with an odds ratio of 1000 : 1 favouring zero dose rather than the recorded 227 mSv
Cells scored	1000	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.10	
Badge dose (mSv)	227	
A518		Four successive monthly finger dosemeters recorded exceptionally higher doses than were usually shown on dosemeters issued to a hospital physicist who routinely prepared radiopharmaceuticals, notably ^{90}Y. His body-worn badges indicated no exposure during this period. Being aware that external beta radiation is insufficiently penetrating to be detected by lymphocyte cytogenetics, the method could neither confirm nor reject a surface dose calculated value of 50 mSv for a worst case scenario. The analysis was nevertheless undertaken to relieve anxiety
Cells scored	1000	
Dicentrics	1	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	Inconclusive	
95% CL (Gy)	0–0.15	
Badge dose (mSv)	50 (estimated dose in the worst case scenario)	
A519		An industrial radiographer entered an ^{192}Ir source enclosure without carrying the required portable radiation alarm. The source was probably exposed as its shielding was found to be dysfunctional. An approximate calculation suggested that he might have received up to 130 mGy. He said that he was wearing his TLD badge and that recorded no exposure. Given two possibilities, zero dose or 130 mGy, biological dosimetry result favoured zero dose with odds of 3700 : 1
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.19	
Badge dose (mSv)	30 (calculated dose)	

A520			An external exposure to ^{90}Y caused a film badge to record 300 mSv. The wearer was not thought to have inhaled or ingested the ^{90}Y and so the poorly penetrating beta radiation would not have resulted in an internal dose. A small amount of bremsstrahlung would have penetrated but biological dosimetry indicated a normal background level of aberrations. It was reported that the body exposure was below the detection threshold of ~100 mGy, but the analysis could not reject the surface dose indicated by the badge
Cells scored	500		
Dicentrics	0		
Centric rings	0		
Other aberrations	2		
Biological dose (Gy)	0		
95% CL (Gy)	0–0.10		
Badge dose (mSv)	300		
A521	(i)	(ii)	A nuclear power reactor was shut down for routine maintenance and two workers were installing lamps in an enclosed space below the pressure vessel. Other workers engaged on a separate task withdrew a guide tube used for neutron flux monitors and this caused a sudden rise in the dose rate below the vessel to >1000 mSv/h. The two workers exited the area promptly but their dosemeters recorded exposures. Biological dosimetry was undertaken as an extra precaution to demonstrate that the exposures were not substantially higher than those indicated by the badges
Cells scored	1000	1000	
Dicentrics	1	1	
Centric rings	0	0	
Other aberrations	0	3	
Biological dose (Gy)	0	0	
95% CL (Gy)	0–0.18	0–0.18	
Badge dose (mSv)	37.8 (body)	25.4 (body)	
	38.8 (skin)	27.0 (skin)	
A522			The explanation proffered for a TLD recording a high dose was that it had been exposed, unworn, when accidentally left in an area where ^{192}Ir radiography of pipe work was frequently undertaken. The absence of chromosomal damage supported the explanation and the odds ratio favouring zero dose versus 1 Gy was an overwhelming 4×10^{18} : 1
Cells scored	512		
Dicentrics	0		
Centric rings	0		
Other aberrations	2		
Biological dose (Gy)	0		
95% CL (Gy)	0–0.10		
Badge dose (Sv)	1.04 (body)		
	0.94 (skin)		

A523		A hospital radiological assistant recorded an inexplicable exposure to gamma radiation on his dosemeter badge. The absence of chromosomal aberrations supported the conclusion that he had not been irradiated. The statistical uncertainty on a zero dose estimate is an upper 95% confidence limit of 300 mGy for protracted irradiation. The odds ratio favouring zero dose was 25 : 1
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.33	
Badge dose (mSv)	143	
A524		A dosemeter badge issued to a radiologist with only occasional exposure to gamma sources and a linear accelerator recorded an unexplained high dose. The absence of chromosomal aberrations gave a zero dose estimate with an upper 95% confidence limit of 110 mGy. The odds ratio favouring zero over the recorded 250 mSv is 2400 : 1
Cells scored	1000	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.11	
Badge dose (mSv)	249 (body)	
	278 (skin)	
A525		Refer to main text
A526		Investigators concluded that a dosemeter badge issued to a hospital worker had been irradiated when not worn. The clinic contained both ^{60}Co sources and a linear accelerator. The absence of dicentric aberrations and one acentric, consistent with normal background, supported the view that the person had not been irradiated. The odds ratio against the recorded dose is a convincing 10^{70} : 1
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.12	
Badge dose (mSv)	2000	

A527		No explanation could be found for an overexposed monthly TLD issued to an engineer who worked with several electron beam accelerators. A deliberate exposure of the badge was suspected. He had a recent history of X-ray diagnostic exposures that might explain the chromosomal aberrations found. Unfortunately the presence of these aberrations meant that a workplace exposure could not be ruled out. The aberrations seen would indicate a lower whole body dose than suggested by the badge, but because he was unaware of any specific exposure event, the aberrations could be consistent with a partial body exposure to a beam with the dosemeter in the field. The case remained unresolved
Cells scored	1000	
Dicentrics	3	
Centric rings	0	
Other aberrations	4	
Biological dose (Gy)	0.10	
95% CL (Gy)	0–0.15	
Badge dose (mSv)	328 (body)	
	2035 (skin)	
A528		A 2-minute duration exposure to 150 kV X-rays resulted in a negligible dose on an engineer's TLD badge. However, a detailed reconstruction was possible as he could describe his movements and this led to a calculation of 80 mSv. This is consistent with the biological dosimetry estimate of 50 mGy with 95% confidence limits of 3 and 150 mGy
Cells scored	1000	
Dicentrics	3	
Centric rings	0	
Other aberrations	2	
Biological dose (Gy)	0.05	
95% CL (Gy)	0.003–0.15	
Badge dose (mSv)	Negligible	
A529		A worker's badge recorded a dose of 179 mSv that could have been due to ^{169}Yb or ^{75}Se gamma rays or 160 kV X-rays. Although two dicentrics were observed in one single cell, the total observed chromosomal aberrations were consistent with an acute whole body X-ray or low energy gamma ray exposure of ~50 mGy, with lower and upper 95% confidence limits of 0 and 130 mGy. An odds ratio for zero dose versus the suspected dose was 45 : 1. It was concluded that, if an exposure had been acute and homogeneous, the dose received was substantially below that recorded on the badge
Cells scored	1004	
Dicentrics	3	
Centric rings	0	
Other aberrations	3	
Biological dose (Gy)	0.05	
95% CL (Gy)	0–0.13	
Badge dose (mSv)	179	

A530		A routine monthly TLD issued to a worker in an industrial linear accelerator facility recorded 274 mSv for which there was no explanation. Biological dosimetry found no dicentric aberrations and so the best estimate was zero dose. The upper 95% confidence limit on zero is 100 mGy, which does not encompass the badge dose. Expressed as an odds ratio, zero dose was favoured over 274 mSv by 5 : 1
Cells scored	1000	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.11	
Badge dose (mSv)	274	

A531		A TLD worn by a worker at an industrial sterilisation facility recorded a massive overexposure but he was fit and well. The biological dosimetry result was unremarkable, consistent with normal background. This supported his suggestion that during his absence the badge could have been moved by a colleague and left in a radiation area
Cells scored	500	
Dicentrics	1	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.23	
Badge dose (Sv)	>10	

A532		A service engineer who worked on X-ray and CT machines returned a quarterly TLD that had recorded 613 mSv for which he had no explanation. There had been no unusual events or non-routine tasks undertaken during the issue period. The biological dosimetry result was consistent with normal background and exposures above 130 mGy, the upper 95% confidence limit, could be discounted. The odds ratio approach gave a highly reassuring value of several billion : 1 in support of zero dose
Cells scored	500	
Dicentrics	1	
Centric rings	0	
Other aberrations	4	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.13	
Badge dose (mSv)	613	

A533		The dose recorded by an OSL badge was unexplained. It was worn by an engineer installing and servicing diagnostic X-ray sets. Biological dosimetry could rule out exposure greater than 100 mGy, the upper 95% confidence limit, but as this is close to the recorded dose a small real exposure could not be categorically excluded. The odds ratio favouring zero dose versus the OSL dose was 55 : 1
Cells scored	1000	
Dicentrics	1	
Centric rings	0	
Other aberrations	3	
Biological dose (Gy)	<0.10	
95% CL (Gy)	0–0.10	
Badge dose (mSv)	120	
A534		A massive dose recorded on a TLD issued to an industrial radiographer was clearly incompatible with him being fit and well. Biological dosimetry could report zero dose with the statistical uncertainty of 190 mGy upper 95% confidence limit
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	2	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.19	
Badge dose (Sv)	81	
A535		A worker confessed to having deliberately irradiated his badge for a few minutes in an 80 kV cabinet X-ray set. In view of this malpractice, biological dosimetry was requested to determine whether there was evidence of him having been genuinely overexposed. It could be reported that there was no indication of exposure
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.11	
Badge dose (mSv)	700	

A536		
Cells scored	500	Investigators concluded that an overexposed badge issued to a medical physics technician had been X-irradiated while not worn. Biological dosimetry was requested to support the investigation and the absence of chromosomal aberrations was reassuringly helpful
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.12	
Badge dose (mSv)	267	

A537		
Cells scored	500	A radiologist regularly performing angiographies had an unexplained dose recorded on a badge. Investigators were sceptical that it represented a genuine exposure because paradoxically the badge had been worn beneath his lead apron. By contrast, a similar badge worn outside the apron and an additional finger dosemeter both registered much lower dose. Biological dosimetry was requested and reassuringly it could be reported that the odds ratio favouring zero dose versus the 255 mSv on the badge was 1000 : 1
Dicentrics	0	
Centric rings	0	
Other aberrations	3	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.11	
Badge dose (mSv)	255 (body)	
	8.61 (head)	
	11.81 (finger)	

A538		
Cells scored	1000	An industrial radiographer who worked with ^{192}Ir sources returned an exposed dosemeter badge recording 115 mSv. The dicentric assay indicated 75 mGy with a lower 95% confidence limit of zero but an upper limit of 190 mGy, therefore encompassing the badge value. The overall conclusion was therefore that he had received a small exposure, most likely below 100 mGy, and a calculation based on Bayesian statistics gave a probability of about 60% that it was below the 115 mSv value
Dicentrics	2	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0.075	
95% CL (Gy)	0–0.19	
Badge dose (mSv)	115	

B Suspected overexposure of people not wearing a dosemeter

B136	(i)	(ii)	(iii)	(iv)	These men were exposed to a poorly shielded 37 GBq (1 Ci) ^{60}Co source used to detect illegal drugs or weapons in transit. They wore no dosemeters but based on their accounts they were thought to be at risk, although calculation of their dose was <10 mSv. However, because their exposure was intermittent over 2 months the calculations were imprecise. The lower confidence limit of the chromosomal analysis was zero, so the reconstructed dose was not rejected
Cells scored	1000	500	500	500	
Dicentrics	3	1	0	1	
Centric rings	0	0	0	0	
Other aberrations	1	3	0	2	
Biological dose (Gy)	0.08	0.05	0	0.05	
95% CL (Gy)	0–0.23	0–0.28	0–0.19	0–0.28	

B137		A 42-year-old man was suffering a number of skeletal problems associated with a marked reduction in bone density. He was concerned that it might be due to bone-seeking radionuclides. About 10 years previously he had received threats that his coffee would be 'spiked' by a person with ready access to a wide range of radionuclides including bone-seekers. A whole body dicentrics count detected nothing in excess of normal background. However, electron spin resonance measurements on tooth enamel indicated about 1 Gy. The dicentrics analysis suggested no significant recent exposure but the FISH translocation yield, more appropriate for historic exposure, was about double the expected generic control value for a 42-year-old male. The EPR and FISH therefore led to the conclusion that he had been unknowingly irradiated. The translocations were distributed singly in the cells and so qualitatively tend to rule out high LET radiation. In view of the unknown source the biological dosimetry result was given as ~0.35 Gy of gamma-equivalent protracted dose with an upper confidence limit of 0.85 Gy
Cells scored	3000 (FISH)	
	500 (DCA)	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
FISH translocations (#2,3,5)	11	
Age (year)	42	
Assumed translocation background	5.6	
Biological dose (Gy)	0 (DCA)	
	0.35 (FISH)	
	3 ± 1.5 (EPR)	
95% CL (Gy)	0.04–0.85 (FISH)	

B138		This man had been in close proximity to an unshielded 74 GBq (2 Ci) ^{137}Cs source for up to 4 hours. The dose rate at 50 cm was ~30 mGy/h but he could only provide a vague account of his movements and timings. Biological dosimetry was requested because he wore no dosemeter and there was the potential for a substantial exposure, which reassuringly could be discounted
Cells scored	1000	
Dicentrics	2	
Centric rings	0	
Other aberrations	6	
Biological dose (Gy)	0.1	
95% CL (Gy)	0–0.22	

B139		A patient presented with a history of symptoms that might, among several other possibilities, be attributed to high dose irradiation. He suggested deliberate 'radiation poisoning' during recent foreign travel. Biological dosimetry was undertaken and it served to discount radiation as a cause for his illness. This was backed up by whole body counting that detected only normal background
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	Not calculated due to uncertainty regarding potential source	
B140		Refer to main text
B141		A man suffering from a thyroid disorder believed that it was caused by his exposure during the past year to radiation from industrial non-destructive testing. He was not a classified radiation worker; indeed his main direct workplace hazard was exposure to benzene but from time to time he worked at the periphery of site radiography
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	3	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.19 (recent)	
	0–0.25 (20 months)	
B142		Refer to main text
B143		A young man consulted his family doctor concerning sickness that he suggested could have been due to irradiation while working in a factory abroad. There had been a 'radiation incident' but information was scant. Biological dosimetry was able to discount an exposure. Later enquiries eventually revealed that the 'incident' had been trivial; a barrier had been placed around a piece of metal on to which some NORM had been plated out
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.19	

B144	(i)	(ii)	(iii)	Three unclassified workers were concerned when they learned that they had been in the vicinity of gamma radiographic testing of pipes. Information was eventually obtained that the source was ^{192}Ir and from their time and positions in the area an inverse square law calculation gave a free in air dose of ~0.2 mSv. In reality, their doses were lower due to shielding from two courses of brickwork
Cells scored	500	500	500	
Dicentrics	0	0	0	
Centric rings	0	0	0	
Other aberrations	0	2	0	
Biological dose (Gy)	0	0	0	
95% CL (Gy)	0–0.19	0–0.19	0–0.19	
B145				Refer to main text
B146				Following shortly after a CT scan for examining her elbow a patient reported a wide range of symptoms, including some that are associated with acute radiation syndrome. She believed that her illness was due to the irradiation. She was not a sufferer from the rare, inherited radiosensitive conditions. The scan had proceeded normally; no problems had been encountered and it should have delivered at most 10 mGy to the elbow and a lower dose to the whole body. The biological dosimetry result confirmed that any exposure was well below the threshold for causing clinical reactions
Cells scored	500			
Dicentrics	1			
Centric rings	0			
Other aberrations	0			
Biological dose (Gy)	0			
95% CL (Gy)	0–0.12			
B147	(i)	(ii)		A malfunctioning X-ray set might have overexposed a dentist and an assistant to a single exposure lasting 15 minutes. Unfortunately they did not wear dosemeter badges. Biological dosimetry was able to show that any exposure would have been below the detection threshold of ~100 mGy
Cells scored	500	500		
Dicentrics	0	1		
Centric rings	0	0		
Other aberrations	0	1		
Biological dose (Gy)	0	0		
95% CL (Gy)	0–0.10	0–0.12		
B148				A man was testing the beam of an electron welding apparatus unaware that the protective lead glass window had been replaced with normal glass. X-rays were produced as a byproduct of the process and he was exposed over 4 days but, intermittently, probably for a total of only 10 minutes. A maximum whole body dose of 1 mSv was calculated but biological dosimetry was requested for reassurance that a substantially higher exposure had not occurred
Cells scored	500			
Dicentrics	0			
Centric rings	0			
Other aberrations	1			
Biological dose (Gy)	0			
95% CL (Gy)	0–0.10			

B149		
Cells scored	3000 (stable)	A 67-year-old woman suffering from numerous medical problems claimed that they were due to irradiation. 38 years previously she had undergone upper GI tract X-ray fluoroscopy and there had been machine malfunctions causing excessive exposure. No skin reactions had been reported at the time. FISH analysis found 15 translocations in 1000 metaphases, which was consistent with the generic background expectation of 13/1000 for a 67-year-old female. The detection limit by FISH for a person of this age is a whole body dose of 0.5 Gy. In view of the irradiation having been partial body, a localised dose of 2–3 Gy could not be ruled out, but such an exposure would be expected to have caused a skin reaction
Dicentrics	1	
Centric rings	1	
Other aberrations	5	
FISH translocations (#2,3,5)	15	
Age (year)	67	
Assumed translocation background	13	
Biological dose (Gy)	<0.50	

B150		
Cells scored	500	Several CT scans and an angiographic examination spanning 5 months culminated, about 9 months later, in a patient reporting a burning sensation in her upper torso and some skin reddening. She was fearful that it had been due to her exposures to radiation despite reassurances that the time course for such reactions was inconsistent with radiation aetiology. This was supported by the cytogenetics where the upper 95% confidence limit on zero dose is 100 mGy, well below the threshold for tissue reactions
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.10	

B151		
Cells scored	581	A worker received a calculated hand dose of 500 mGy of gamma radiation when she touched a source while diving at a nuclear power station. Exposure confined to an extremity is not detectable by lymphocyte cytogenetics but reassurance could be given that the averaged whole body dose was low
Dicentrics	1	
Centric rings	0	
Other aberrations	2	
Biological dose (Gy)	0.013	
95% CL (Gy)	0–0.27	

B152	(i)	(ii)	Following a fire aboard a ship two marine accident investigators made an initial assessment before allowing the vessel to proceed. Later, a more thorough investigation found that the fire had damaged and displaced the housing of a ^{60}Co source. Wipe tests showed no leakage but a dose rate of 3.6 mSv/h at 1 m was measured. A worst case dose reconstruction was 0.2 mSv whole body and 2 mSv to the face and hands. This is consistent with the results of biological dosimetry requested for added reassurance
Cells scored	500	500	
Dicentrics	0	0	
Centric rings	0	0	
Other aberrations	0	1	
Biological dose (Gy)	0	0	
95% CL (Gy)	0–0.19	0–0.19	

B153	Refer to main text

B154		Shortly after a full torso CT scan a patient complained of symptoms that she feared were due to excessive irradiation. The diagnostic procedure had been unremarkable and the apparatus was shown to be functioning properly. Reassurance was requested from biological dosimetry which showed only a normal background aberration frequency, thereby confirming that the dose from the CT scan was, as it should be, below the detection threshold for the dicentric assay. She accepted that her fears for radiation causation were groundless
Cells scored	500	
Dicentrics	1	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.12	
B155		Refer to main text

D Chronic internal or external dose

D92		This man was associated with some of the principal characters of the ^{210}Po event in London in 2006. A urine analysis indicated that he was seriously internally contaminated. However, the biological dosimetry and a repeated urine analysis both indicated that the earlier measurement was erroneous
Cells scored	500	
Dicentrics	0	
Centric rings	0	
Other aberrations	0	
Biological dose (Gy)	0	
95% CL (Gy)	Not calculated due to uncertainty regarding potential exposure conditions	
D93		A healthy young female traveller set off an airport radiation alarm. Having established that she was not a nuclear medicine patient, authorities told her that she had 'therapy-like' levels of radioactivity in her. They gave no further details of what or how much. Understandably concerned, she was referred for further examination, fearing that she might recently have eaten some contaminated fish in west Africa. Radioactivity measurements in urine, whole body monitoring and biological dosimetry all indicated nothing untoward
Cells scored	1000	
Dicentrics	0	
Centric rings	0	
Other aberrations	1	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.10	
D94		A member of the public presented with a number of symptoms, some of which could have been attributable to a high acute radiation exposure. He was convinced that he had ingested a radioactive substance, although he could not explain how. His work and lifestyle did not bring him into contact with any unsealed (or sealed) sources. Biological dosimetry was requested in the hope that it could resolve his belief. The aberration frequency was consistent with normal background. The upper 95% confidence limit on the zero dose estimate was 230 mGy assuming gamma radiation, well below the threshold for radiation-induced acute health effects. The analysis proved helpful to the medical adviser in counselling the patient
Cells scored	510	
Dicentrics	1	
Centric rings	0	
Other aberrations	6	
Biological dose (Gy)	0	
95% CL (Gy)	0–0.23	