Biological dose estimation in a radiation accident involving low-dose exposure

S. JANSEN, G. J. VAN HUYSSTEEN

Summary

Blood specimens were collected from 8 people 18 days after they had been accidentally exposed to a 947,2 GBq iridium-192 source during industrial application. The equivalent whole-body dose received at day 0 was estimated using a model based on quantitative and *qualitative chromosome* aberration analysis in lymphocytes. According to physical dose estimations, all 8 people were exposed to whole-body *doses varyng from* 12 mGy to 61 mGy. Substantiated evidence to this effect was found in at least 3 cases using biological dosimetric criteria, proving the sensitivity of this cytogenetic model even at low doses.

S Afr Med J 1990; **78**: 280-282.

Chromosome aberration analysis in peripheral lymphocytes is an established method for dose assessment of radiation exposure. The method finds application where there is reason to believe that people not wearing dosimeters have been accidentally exposed to radiation. A supposed discrepancy between dosimeter reading and actual exposure can thus be resolved.

The biological estimates, expressed in grays (Gy), are equivalent whole-body doses based on chromosomal damage present in first-generation (M1) lymphocytes and obtained from *in vitro* dose-response curves.[1] In 1985, this laboratory was approached by the Atomic Energy Commission to render a service in this regard, details of which have been published.[2] Dose estimations in 48 people have since been completed. Unintentional exposure during industrial radiography constitutes the majority of referrals.

One such incident involving 8 people at a synthetic fuel plant is reported here.

Division of Human Genetics, Department of Neurology and Department of Oncotherapy, University of the Orange Free State, Bloemfontein, OFS
S. JANSEN, PH.D.
G. J. VAN HUYSSTEEN, M.SC.

Reprint requests to: Dr S. Jansen, Human Genetics (G11), University of the Orange Free State, PO Box 339, Bloemfontein 9300, RSA.

Subjects and methods

Eight people were unintentionally in positions where they were possibly exposed to an unshielded 947,2 GBq iridium-192 source for 1 minute. The incident occurred during radiographic examination of a welded joint. A diagram of the synthetic fuel plant indicates the relative position of each subject from the radiation source (Fig. 1).

Blood specimens were drawn from each subject 18 days after the accident and lymphocyte cultures[1] were set up on day 19. Chromosomal aberration analysis was performed to determine the extent of exposure in terms of absorbed whole-body dose. The classification system described by Savage[3] was used to determine the different types of aberrations. First generation metaphase spreads were identified according to the method of Perry and Wolff.[4] The aberration yield at time of investigation was taken as representative of the whole-body dose received at day 0, because less than 4 weeks had passed between the incident and sampling of the blood.[5] The linear-quadratic relationship ($y = 9{,}46 + 46{,}36\ D + 32{,}432\ D^2$) between chromatid equivalent aberrations (y) and radiation dose (D) for low linear-energy-transfer (LET) radiation established in a previous study[1] was utilised.

At the same time a separate and independent investigation was carried out by a physicist of the Department of National

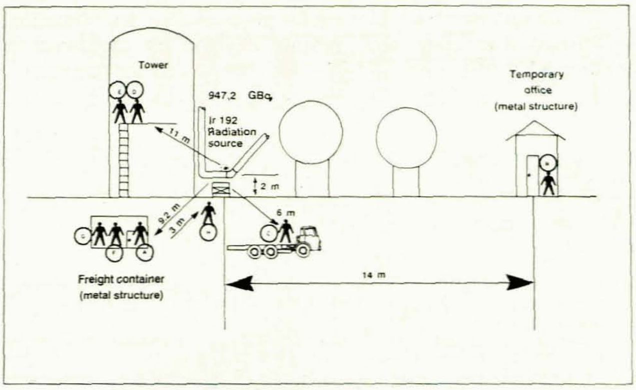

Fig. 1. Diagram of the synthetic fuel plant. The relative position of each subject from the radiation source is indicated.

Health and Population Development using physical criteria for dose estimation. Only after submission of the two independent reports to the requesting firm were the results of both investigations made known. Finally, clinical examinations were carried out on all subjects at days 0 and 18 after the accidental exposure.

Results

The calculated distance of each subject from the radiation source, types and amount of chromosomal aberrations, and estimated equivalent whole-body doses by biological and physical measures are shown in Table I.

According to physical dose determinations, all 8 subjects were exposed to radiation with doses ranging from 11 mGy to 61 mGy. These findings were substantiated by biological dosimetry in subjects C (quantitative chromosomal damage), G and H (qualitative damage present as dicentric chromosomes).

Comparison of biological and physical dose calculations showed good correlation at dose levels below the accepted lower limit for biological dosimetry (50 mGy for X-rays and 100 mGy for gamma rays).[6] Clinical examination revealed no symptoms that could be linked to radiation exposure.

Discussion

Chromosome aberration analysis in peripheral lymphocytes is at present the most accurate biological indicator of absorbed whole body exposure of X- and gamma rays. The number of cases (48) referred to this laboratory through the Department

TABLE I. DISTANCE FROM RADIATION SOURCE, DETAILS OF CYTOGENETIC ANALYSIS AND BIOLOGICAL AND PHYSICAL DOSE ESTIMATIONS

		Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
	Distance from radiation source (m)	**9,2**	**14**	**6**	**11**	**11**	**9,2**	**9,2**	**3**
BIOLOGICAL DOSE ESTIMATION	**Cytogenetic investigation**								
	Cells analysed	**220**	**220**	**400**	**250**	**338**	**250**	**269**	**322**
	Metaphase spreads with damage	**8**	**4**	**19**	**3**	**12**	**7**	**6**	**9**
	Tetraradial rearrangements		**1**						
	Dicentrics							**1**	**1**
	Acentric fragments	**2**		**6**	**1**	**3**	**1**	**3**	**2**
	Chromatid breaks	**6**	**4**	**12**	**2**	**8**	**6**	**3**	**5**
	All aberrations expressed as % of chromatid aberrations in M1	**4,68**	**2,22**	**10,76**	**2,08**	**6,36**	**3,56**	**4,59**	**5,69**
	Equivalent whole-body X-ray dose (mGy) (lower limit of sensitivity = 20 mGy)	< 20	< 20	70	< 20	< 20	< 20	< 20	< 20
	Physical dose estimation (mGy)	**26,09**	**11,32**	**61,48**	**18,24**	**18,24**	**26,09**	**26,09**	**14,75**

of National Health and Population Development by various institutions in the last 5 years illustrates the importance of biological radiation dosimetry in the RSA. This model, however, determines an average whole-body radiation dose and cannot provide an indication of dose distribution after partial body exposures. There are the further complications of absence of data regarding the original aberration frequency and exposures involving mixed LET values. Nevertheless its most important contribution, as shown in this case study, is to reassure the victims of a radiation accident that they were not exposed to a 'dangerous' dose ($\geqslant$ 250 mGy whole-body dose).[6,7]

The lower dose limit of sensitivity of cytogenetic models is a controversial issue but increasing in importance as more accurate and detailed data become available regarding low-dose exposures and the probability of serious late effects. The subjects under consideration in this report were not radiation workers, non-occupational limits in man-made sources were therefore applicable. This implies a maximum annual effective dose equivalent limit of 5 mSv as recommended for infrequent exposures.[8] The independent physical dose determinations placed all 8 subjects above this limit with biological dosimetry confirming these results in 3 subjects and placing the other 5 at $<$ 20 mGy. It appears that the biological model used is sensitive enough to be of value even at radiation doses approaching non-occupational exposure levels.

The authors thank Mr L. Smit for physical dose determination, and Elana Swanepoel and Tommy Pearson for assistance in preparing the MS.

REFERENCES

1. Jansen S. 'n Sitogenetiese model as biologiese dosismeter vir geabsorbeerde Röntgenstrale. Ph.D. thesis, 1984; University of the Orange Free State, Bloemfontein.
2. Jansen S, Van Huyssteen GJ. Stralingsongelukke — 'n protokol vir optrede. *S Afr Med J* 1988; **73:** 61-62.
3. Savage JRK. Classification and relationship of induced chromosomal structural changes. *J Med Genet* 1975; **12:** 103-122.
4. Perry P, Wolff S. New Giemsa method for the differential staining of sister chromatids. *Nature* 1974; **251:** 156-158.
5. Preston RJ, Brewen JG, Gengozian N. Persistence of radiation-induced chromosome aberrations in marmoset and man. *Radiation Res* 1974; **60:** 516-524.
6. Lloyd DC, Edwards AA, Prosser JS *et al.* Doses in radiation accidents investigated by chromosome aberration analysis: XVII. A review of cases investigated, 1986. (NRPB - R207). Chilton, Didcot, Oxfordshire: National Radiological Protection Board, March 1987.
7. Steinfeld AD. Environmental radiation hazards. *Am Fam Physician* 1980; **22:** 95-99.
8. National Council on radiation Protection and Measurements. *Recommendations on Limits for Exposure to Ionizing Radiation.* (Report No. 91). Bethesda, Md: NCRP, 1987.