A HOSPITAL RADIUM ACCIDENT

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Abstract—Uncontrolled spread of radium from a damaged radium tube resulted in extensive building contamination. There was no serious contamination of personnel. Decontamination work and the measurement of internal contamination of personnel is described.

On the 24th of November 1964, damage was discovered to one of the tubes in the radium safe in the Radiumstation's operating theatre in Århus. The Radiophysical Laboratory established that there was a hole in one end of the tube and that the inner cell containing the radium sulphate powder had disappeared. Measurements showed contamination in the room containing the combined radium safe and radium bench, indicating that the missing cell was not intact.

The accident was assumed to have happened on 20th of November, 4 days before its discovery, since the type of tube concerned was last used on that day, though it cannot be completely excluded that it happened even earlier.

The damaged 10 mg radium tube was of the type RAC9, manufactured by the Radiochemical Centre, Amersham. This type is designed for calibration purposes and is not so strongly made as those normally used for clinical purposes.

The tube was sent to the Radiochemical Centre for examination and it appears from the metallurgical laboratory's report that the tube had no manufacturing faults and that the most probable cause of failure was that the tube had suffered mechanical damage such as a blow or by bending.

It has not been possible to explain satisfactorily how the damage could have happened, but the possibility cannot be entirely excluded that the tube was cut open in the radium safe as the drawer containing it was moved in or out.

EXTENT OF CONTAMINATION

Mapping of the contamination was done by personnel from the Radiophysical Laboratory, and from the Radiation Hygiene Laboratory. Measurements were made with a portable battery-powered α-monitor and a gamma scintillation monitor.

Measurable contamination was confined to the surgical department and to the hospital laundry, where it was probably carried in cloths used for wiping down the radium bench before the accident was discovered.

In the surgical department, the radium room was highly contaminated. The greatest activity was measured on the radium bench around the part of the safe where the leaky tube had been kept. The contamination level of the floor in the radium room which, like the rest of the department, is terrazzo-covered, was higher than 10^{-4} μCi/cm^2, the limit of permissible α-contamination (MPL) in an "active area" according to British recommendations (1957).

Floor contamination was measured over all the actual walking space in the department, but nowhere else was it more than 10^{-4} μCi/cm$_2$. Besides the floor, there was detectable contamination of porous surfaces, such as the joints between wall tiles. The rubber soles of the staff's wooden shoes were also found to be contaminated.

In the laundry, the waste ducts of the two laundering units were contaminated. The sides and bottoms of these ducts had a calcareous deposit (from the washing water) in which appreciable quantities of activity had been found (estimated quantity about 1.5 mg).

Among the finished articles on the laundry shelves there was a pile of hand towels with measurable but insignificant activity. A bag of unwashed articles from the surgical department was also weakly contaminated.

The staff of the surgical department and the laundry sorting departments were examined for surface contamination with an α-monitor the day after the discovery of the accident. Of the first group, all but one had contaminated fingers, but none exceeded the maximum permissible level for "parts of the body", i.e. 10^{-5} μCi/cm^2 according to the British recommendations (1957).[(1)] There was no sign of contamination among the laundry staff.

None of the clothes and personal effects of the surgical department and laundry staff were found contaminated.

A rough estimate of the amount of activity found by the contamination survey can be given as follows:

Table 1.

Place	Estimated amount of Ra (mg)
Laundry drainage ducts	1·5
Remainder in tube	1
Wall and floor in radium room	0·25
Radium safe and bench	0·2
Floor of rest of surgical dept.	0·05
Total found	3 mg

When evaluating the amount of radium on contaminated surfaces it was assumed that one half of the radon had escaped.

This corresponds to about 30% of the original activity. Most of the missing 70% presumably has gone out through the laundry sewer, as indicated by the large quantity found in the waste ducts. The radium cell, which was never found, may have been picked up in a cleaning cloth and carried to the laundry with much of its original contents. This would explain the comparatively small contamination of places apart from the radium room.

After the mapping out of the contamination, it was necessary to prevent its further spread and to check the surgical department staff for internal contamination. These operations were carried out by the Radiophysical Laboratory and the Radiation Hygiene Laboratory respectively.

DECONTAMINATION

Decontamination of the laundry drainage ducts was begun the day after the discovery. The ducts were filled with 0·1 N sodium hydroxide containing 1% EDTA-3 Na. The solution remained for 15 hr, after which the ducts were rinsed out. After this there was no detectable α-activity.

The decontamination of the radium safe and room proceeded as follows: All radium appliances were cleaned with a mixture of nitric and sulphuric acids and taken to another safe. The safe and all walls and furniture were covered with a layer of plastic strip-coat. When dry, this was stripped off and removed 90% of the activity with it. The safe needed several applications and the drawers had to be removed for cleaning. Rubber gloves, face masks and special overalls were used in the beginning but precautions were relaxed as the contamination was reduced. A few parts of the safe could not be sufficiently cleaned in this way so the paint had to be dissolved and scraped off.

While the walls and safe were being cleaned the floor was covered with thick plastic sheeting. The cleaning of the floor was left to the end so as not to recontaminate it while the other parts of the room were being cleaned. From the experience with the walls, it had been hoped that the strip-coat would remove the activity from the floor, but it was soon apparent that the method would not work on terrazzo, so the surface had to be ground off, using wet grinding to avoid dust. Afterwards the room and safe were painted.

The lower contamination in the corridor outside the radium room was removed by similar methods.

During decontamination the activity was followed with an α-monitor. When all was finished in January 1965, the average surface contamination was 5% of the MPL.

The activity has decreased continuously throughout 1965, presumably because of daily cleaning. After 20 months only a few places with uneven surfaces showed activity approximately 2% of the MPL.

All waste was collected in bags and buried in a deep hole on the hospital grounds.

CONTROL OF INTERNAL CONTAMINATION OF PERSONNEL

Urine samples collected from the surgical department staff during the first week after the discovery showed definite signs of activity in 8 of 13 persons. More samples were taken 8 weeks later, this time also from the Radiophysical Laboratory, but no more cases were discovered. Urine measurements were chosen for sorting the exposed personnel because this was a simple and sufficiently sensitive method.

The two apparently most contaminated persons were further examined by whole-body, faeces and urine sample counting 2, 6, 12 and 19 months after the accident. At the time of the 12 months whole-body count, exhaled radon-222 was measured, with a view to determining accurately ^{226}Ra body burden.

Methods:

Urine Sample Measurements

12-hour urine samples were collected away from the premises in polythene bottles containing 10 ml of 10% nitric acid. A longer collection time might have been desirable and was in fact used for the three latest measurements, but would have entailed collection at the hospital, with possible contamination of the samples. A method given by Harley in a WHO-report[2] was used. Two independent analyses of each sample were made. 10 mg of barium-carrier were added and samples were counted in a windowless flow counter with a background of about 0·2 cpm. Counting efficiency was 82% as determined by a standard radium solution (IAEA, Vienna). Radium was identified by counting samples at different intervals after preparation and thereby noting the increase of daughter products.

Faeces Sample Measurements

About 30 g from a 24 hr faeces sample was ashed by a combination of wet combustion and incineration at 900°C. The ash was then treated with hydrofluoric acid and dissolved in concentrated sulphuric acid. 20 mg of barium-carrier were used.

Whole Body Measurements

Whole body measurements of the γ-emission from Ra-C (^{214}Bi) were used to determine that part of the body ^{226}Ra content, which is in equilibrium with the retained ^{222}Rn. The total body burden is obtained by adding that quantity of ^{226}Ra, which is in physical equilibrium with the exhaled ^{222}Rn.

Whole body measurements were made at Lund University with a 8 × 4 in. sodium iodide crystal in both scanning bed and chair arrangements.[3]

Determination of exhaled radon was made at Statens strålskyddsinstitutt Stockholm.[4]

RESULTS

The results of the urine measurements for the two persons (P. and M.) who were followed further are given in Table 2.

It should be emphasized that the figures refer only to amounts excreted in 24 hr and that the relevant metabolic periods can differ from 24 hr. The actual uncertainty is therefore greater than that given in the table, which only includes counting errors. Faeces results are given in Table 3.

None of the results indicated contamination during collection or preparation.

There are few reports on excretion of radium

Table 2. Urinary Excretion, pCi ^{226}Ra/24 hr

Time after accident, months	0·3	1	6	11	12	20
P.	9·5 ± 1·0	2·4 ± 0·3	1·4 ± 0·1	0·3 ± 0·1	0·4 ± 0·1	0·3 ± 0·1
M.	7·4 ± 0·5	1·2 ± 0·1	0·5 ± 0·1	<0·1	0·3 ± 0·1	0·4 ± 0·1

Table 3. *Faecal Excretion, pCi* ^{226}Ra/24 *hr*

Time after accident, months	11	12	20
P.	20 ± 2	3 ± 1	10 ± 2
M.	1 ± 1	3 ± 1	4 ± 1

in urine after intake of radium sulphate. Marinelli[5] has followed a few cases but gives little information specifically on urinary excretion. On the other hand, Norris *el al.*[6] have good information on radium chloride. Basing our calculations on this work, P. and M. should have body burdens 2 months after the accident of about 20 and 8 nCi respectively (MPBB = 100 nCi). This first estimate of internal contamination should, of course, be taken with all possible reservations.

Whole body measurements were made on P. and M. at Lund University after 2, 6, 12 and 19 months. A third person from the staff with a small radium excretion in urine compared with P and M. was also measured on the first occasion. The values found are given in Table 4.

The values for 1 month and 6 months were obtained from measurements using chair geometry which is more sensitive to an inhomogenous distribution of ^{214}Bi in the body than the more accurate scanning-bed geometry used in the two last measurements.

Exhaled Radon

Determination of radon exhaled by P. and M. was made after 12 months. The calculated amount of ^{226}Ra in physical equilibrium with the observed rate of exhaled ^{222}Rn, was for P. $4 \cdot 3 \pm 1 \cdot 1$ nCi and for M. $2 \cdot 7 \pm 1 \cdot 1$ nCi.

Total Body Burden

From the whole body measurements 12 months after the accident and exhaled radon measurements, the total body burdens of ^{226}Ra of P. and M. can be determined as:

1 year after the accident

P.: $8 \cdot 4 + 4 \cdot 3 = 12 \cdot 7 \sim 13$ nCi ($\pm$ 2 nCi)
M.: $2 \cdot 1 + 2 \cdot 7 = 4 \cdot 8 \sim 5$ nCi ($\pm$ 2 nCi)

From these figures the retention of ^{222}Rn can be calculated to be P.: 66 + 13% and M.: 44 + 27%.

DISCUSSION

The retention values found for ^{222}Rn are relatively high compared with the figure of 30% normally used. This might be due to external contamination contributing to the whole body measurement, but Marinelli[5] has also found comparable values in some cases of $RaSO_4$ inhalation.

Figure 1 shows results from case P. Total body burden is calculated from a Rn retention value of 66%. The function described by Norris *et al.*[6] is given for comparison and a rather good agreement is found.

The urinary excretion rate is also given in the figure. We found a slower urinary excretion rate than Norris. This may easily be explained by $RaSO_4$ being a very insoluble compound.

Table 4. *Body Content, nCi* ^{214}Bi

Time after accident, months	1	6	12	19
P.	18	10·6	8·4 ± 1·0	4·4 ± 1·0
M.	4·6	3·4	2·1 ± 1·0	1·1 ± 1·0
R.	3		(not measured)	

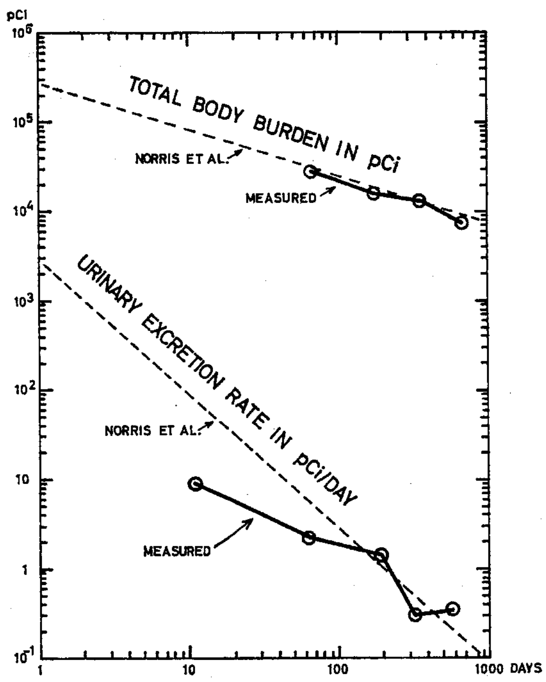

FIG. 1. ^{226}Ra body burden and urinary excretion rate (case P).

Unfortunately faeces samples were not obtained until the last three measurements, so no conclusion could be drawn about what percentage of the total excretion was represented by the urine measurements.

CONCLUSION

1. From the available measurements it can safely be concluded that none of the 20 persons investigated after the accident has acquired a lasting ^{226}Ra body burden of more than one-tenth of the maximum permissible according to the ICRP, i.e. 0·1 μCi.

2. The accident shows how important it is for a radium clinic to have some system of control that can detect leaky radium appliances in time. A simple and inexpensive solution is the daily use of a reliable handy α-monitor with low β- and γ-sensitivity.

In Denmark, as a direct result of the accident just described, the Radiation Hygiene Laboratory has now ordered all users of radium to make such a daily check.

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