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● *Note*

LUNG RETENTION AND CLEARANCE CLASSIFICATION OF A ^{14}C-CONTAINING AEROSOL PRODUCED DURING RE-TUBING OF A NUCLEAR REACTOR*

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INTRODUCTION

FOLLOWING the discovery of a ^{14}C-bearing aerosol during the re-tubing of a CANDU reactor, a procedure was developed to monitor workers for inhaled ^{14}C by measuring the amount of ^{14}C excreted in feces. This procedure requires that an appropriate lung model be used to give the relationship between the fecal excretion and ^{14}C in lung and possibly other tissues. Since preliminary studies on samples from air filters indicated that the ^{14}C aerosol was insoluble, it was decided to use the International Commission on Radiological Protection's (ICRP) lung model for insoluble material, commonly called Class Y (ICRP 1966; ICRP 1979). In order to ensure that the selection of the ICRP Class Y lung model was appropriate for this aerosol, an experiment was carried out to measure the rate that ^{14}C was cleared from the deep lung to the GI tract and then excreted in feces, and the rate that ^{14}C was solubilized and transferred to liver or excreted in urine in the rat. Liver and urinary excretion were chosen because it was assumed that any ^{14}C transferred to blood would be in an unknown organic form, and hence taken up the liver, or would be as HCO_3^-/CO_2. It is expected that both of these possibilities would result in ^{14}C in urea in the urine (Orten and Neuhaus 1986). Extrapolations to humans can be made by comparison of the ^{14}C results to those for a $^{141}CeO_2$ control exposure carried out at the same time. The CeO_2 was selected as the control exposure material as it was readily available and had been used by other laboratories (e.g., Lundgren et al. 1980). Its retention and excretion is consistent with that described by the ICRP Class Y model. Hence, if the ^{14}C aerosol had a retention and excretion pattern similar to CeO_2, its retention and excretion would also be reasonably described by the Class Y model. This note summarizes the results of this experiment.

MATERIALS AND METHODS

The ^{14}C material was obtained from glass fiber air filters. There was no evaluation of the physical or chemical form of this material or of the particle size of these particular samples, although other samples indicated that the aerosol was insoluble and in the range of 2–5 μm activity median aerodynamic diameter (AMAD). These filters were put into a saline solution and sonicated, the filters removed, and the suspension decanted after being allowed to settle for about 1 min. The $^{141}CeO_2$ was prepared by irradiating powdered BP-grade CeO_2 in the NRU reactor at the Chalk River Nuclear Laboratories (CRNL). After allowing the short-lived activation products to decay, the $^{141}CeO_2$ was sonicated in saline solution, and the suspension was decanted after being allowed to settle for approximately 1 min. The concentration of ^{14}C in the ^{14}C suspension was measured with a liquid scintillation counter and the ^{141}Ce concentration with a gamma spectrometer. Appropriate volumes of these suspensions were mixed to give about 900 Bq of ^{14}C and 10^4 Bq of ^{141}Ce 0.5 mL^{-1}. The volume 0.5 mL was the volume instilled into the rat lung, and the ^{14}C concentration was the upper limit on the concentration set by the amount of ^{14}C recovered from the filters. The amount of ^{141}Ce was selected so that this radionuclide would be easily measurable by gamma spectroscopy. This mixed suspension was sterilized with a dose of 10^4 Gy in a ^{60}Co irradiator.

A volume of 0.5 mL of the suspension was instilled into the lungs of young (100 d) male Sprague Dawley rats using the "average" technique described by Pritchard et al. (1985). On trials of this method at CRNL with a ^{198}Au colloid, an 80% success rate was obtained. That is, about 80% of rats retained more than 80% of the instilled material for times longer than 4 d. The others excreted

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most of the ^{198}Au in feces within the first few days, indicating that the colloid was not deposited in the deep, nonciliated region of the lung. The suspension was shaken vigorously immediately before drawing off each of the 0.5 mL for instillation in an attempt to ensure the same amounts of ^{14}C and ^{141}Ce were instilled into each rat.

The rats were maintained in metabolic cages, and all urine and feces were collected for the first 5 d post-instillation, and periodically thereafter. Rat No. 5 excreted a large fraction of the instilled ^{141}Ce (as measured by gamma spectroscopy) in feces in the first few days and was removed from the study at day 5. The remainder were sacrificed about day 60 and day 146 following the instillation, as shown in Table 1. These sacrifice times were chosen with the intent of getting the best estimate of long-term retention with the available ^{14}C material, at the expense of the details of the retention curve at earlier times.

All urine and feces samples for the first 2 wk post-instillation, and lung and liver at autopsy, were analyzed for ^{14}C. Feces were analyzed for ^{14}C throughout the experiment. Cerium-141 was analyzed using gamma spectroscopy and corrected for decay. Carbon-14 was analyzed using the methods described by Kramer and co-workers (Kramer and Bouchard 1987; Kramer et al. 1987).

RESULTS AND CONCLUSIONS

No measurable ^{14}C above background levels ($\sim$0.25 Bq g^{-1} C) was measured in urine or liver. Trace amounts of ^{141}Ce were measured in liver, carcass, and in urine. The liver and carcass burdens were both less than 10^{-4} of the lung burden at sacrifice. The urine excretion indicated that about 10^{-4} to 10^{-5} of the ^{141}Ce lung burden could have been excreted in urine per day, but another explanation is that the ^{141}Ce in urine resulted from a small cross-contamination between feces and urine in the metabolic cages. The initial fast clearance via fecal excretion was complete 5 d after the instillation, and after this time there was no further significant decrease in the fecal excretion rate for ^{14}C, although there was significant variation from sample to sample for any animal.

All of the instilled activity could be accounted for in lung or in feces, although the uncertainties were such that small amounts of ^{14}C could be in tissues that were not analyzed. The results for lung and feces are summarized in Table 1. The normalized ratio of the lung burdens at sacrifice indicate that the ^{14}C had the same (within experimental uncertainty) retention in the lung as did the ^{141}Ce, concluding that this ^{14}C aerosol was as insoluble *in vivo* as CeO_2. The mean ^{14}C fecal excretion rates in Table 1 are the means of the analyses of samples excreted after day 5 post-instillation. By this time, the fast clearance from the lung is complete. The ratio of the lung burdens to these mean fecal excretion rates give a crude estimate of the lung retention times. That is, if only one significant excretion pathway exists, and if first-order kinetics are assumed, then

$$\lambda = \frac{dB(t)}{dt} \Big/ B(t),$$

where λ is the rate constant (inverse of the mean residence time), $B(t)$ is the lung burden, and $dB(t)/dt$ is the ex-

Table 1. Summary of results. The lung burdens are the percent of the instilled activity remaining at sacrifice, and the fecal excretion rates are the percent of the instilled activity excreted per day. The uncertainties in the lung burdens are 1-σ estimates, and the uncertainties in the fecal excretion rates are the standard error in the mean of all rates for a given animal. The high measured lung burden for rat No. 4 may have resulted from an inhomogeneity in the ^{14}C particles in suspension, or alternatively, it may be a statistical "outlier."

Rat No.	Time of Sacrifice (Days Post Instillation)	^{14}C Lung Burden (%)	Mean ^{14}C Fecal Excretion (% day^{-1})	^{141}Ce Lung Burden (%)	Ratio of Lung Burdens (^{14}C to ^{141}Ce)
1	146	72 ± 6	0.188 ± 0.083	68 ± 2	1.06 ± 0.09
2	146	75 ± 6	0.094 ± 0.050	82 ± 3	0.92 ± 0.08
3	146	116 ± 10	0.111 ± 0.046	93 ± 3	1.25 ± 0.11
4	60	78 ± 7	0.110 ± 0.057	71 ± 2	1.10 ± 0.11
5	5	16 ± 5	-	19 ± 1	0.82 ± 0.27
6	146	-	0.054 ± 0.017	69 ± 2	-
7	146	99 ± 9	0.134 ± 0.077	95 ± 3	1.04 ± 0.10
8	146	79 ± 7	0.074 ± 0.019	87 ± 3	0.91 ± 0.09
9	58	88 ± 8	-	96 ± 3	0.92 ± 0.09
10	58	88 ± 8	-	90 ± 3	0.98 ± 0.09

cretion rate. The mean and standard deviation of λ calculated for the six animals in Table 1 for which data is available is 0.0014 ± 0.002. This average value of λ converts to a half-life of 490 d, which is in good agreement with the mean half-life (excluding rat No. 5) calculated from the measured ^{141}Ce lung burden.

However, this half-life is longer than would be expected in the rat from studies of inhaled insoluble compounds (e.g., Metivier 1984; Snipes et al. 1984). A possible explanation is that instilled material is deposited deeper in the rat lung from inhalation exposures. The observation by Ferin and Feldstein (1978) that the lymph node content is higher for rats exposed by instillation than by inhalation may also explain some of this longer retention.

This study has led to the conclusion that the only dose of concern when workers are exposed to this ^{14}C aerosol is the dose to the lung. Doses to any other tissues from the small fraction of ^{14}C that might be transported from the lung to these tissues will be trivial by comparison. Hence, exposures that result in lung doses of the order of 1 mSv y^{-1} can be evaluated by *in vivo* counting of the thorax (Johnson et al. 1988). In addition, fecal analyses appear to be a viable bioassay method for dose assessment when used with the ICRP Class Y lung model, particularly for low-level exposures where *in vivo* monitoring (Johnson et al. 1988) is not sufficiently sensitive to measure ^{14}C in the lung.

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