of spectral resonances thus found is used to specifically determine which resonance spike in which particular normal mode causes each rapid oscillation in the cavity's summed amplitude $|f^{pp}|$. Making bistatic (that is, away from the monostatic $\theta = \pi$ direction) determinations of $|f^{pp}(\theta)/a|$ from Eq. 1 at angles $\theta_{nm}$ chosen to be the zeroes of $P_n$ (cos $\theta$) for a given $n$, we can eliminate the contribution from that $n^{th}$ mode to the summed amplitude in Eq. 1. In this way bistatic measurements or calculations can be used to suppress and further disentangle the selected individual contribution of any given mode $n$ from the sum of all the others. The use of this theory to decipher the scattering code about material composition contained in the cavity's echo has applications to a variety of problems in geophysics, nondestructive material testing, oil prospecting, and also to scattering from bubbles in liquids or from certain fluidlike substances (namely, tumors) in animal tissue.

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## Metabolism of Americium-241 in Man: An Unusual Case of Internal Contamination of a Child and His Father

Abstract. *The metabolism of americium-241 has been studied during an 8-year period in an adult male and his son who, at the ages of 50 and 4 years, respectively, were accidentally and unknowingly contaminated within their home by means of inhalation. Chelation therapy with calcium trisodium pentetate was more effective in enhancing the removal of americium-241 from the child than from the father.*

During the past 8 years, sequential measurements have been made of the internal americium-241 burdens of an adult male and his son. Both are believed to have received significant exposures in their home beginning in 1964, when the adult was about 50 and his son about 4 years old. Their contamination was discovered at our laboratory in 1970, when the man and child were approximately 57 and 10 years old, respectively (*1*). Since then, the content and the distribution of $^{241}$Am in both subjects have been determined one or more times per year in a whole-body counting facility with a low background, using two or three thin NaI(Tl)-CsI(Tl) Laurer detectors (*2*). These detection systems are specifically designed to measure low-energy, photon-emitting nuclides while minimizing contributions from Compton scattering background radiations with pulse-shaping coincidence electronics.

Americium-241 (half-life, 433 years) is an alpha particle–emitting actinide that also emits a 59.6-keV gamma ray in 36 percent of all decays, permitting its determination in vivo by external counting. Since $^{241}$Am is a trivalent actinide which, on entering the body, is deposited primarily in the liver and on skeletal surfaces (*3*), detectors were positioned in configurations so that measurements could be made of $^{241}$Am in the whole body, the thorax (lung), the liver, and the head (skull). Results of these measurements, as determined from 1970 through 1977, are listed in Table 1. In 1970, values for the whole body content for the man and his son were 180 and 72.8 percent, respectively, of the maximum permissible occupational body burden of 50 nCi for an adult male (*4*).

Most of the exposure presumably occurred by inhalation, since (i) approximately 44 nCi of $^{241}$Am was measured on the basement air-conditioning filter in 1970; (ii) the gastrointestinal absorption factor for $^{241}$Am is reported to be less than $10^{-4}$ (*4*); (iii) the original source activity was reported to be approximately 50 mCi, most of which is still on the recovered source planchet (*5*); and (iv) early clearance of $^{241}$Am from the lung of the father was observed. Furthermore, it could be ascertained that the major part of the total exposure occurred sometime in 1964 by determining the $^{241}$Am content of the youngster's deciduous teeth and by estimating formation and shedding times of the various teeth types (*6*).

The estimated lung burdens for $^{241}$Am in the adult and his son in 1970 were 14.9 and 7.8 nCi, respectively; these values are approximately 93 and 49 percent of the occupational lung burden limit of ~ 16 nCi for an adult. Estimates for lung deposits were made from measurements with two detectors positioned over the anterior thorax. The contribution to this count rate from activity associated with the rib cage structure was determined from measurements of $^{241}$Am in skull bones and from the assumption of a similar concentration throughout the thoracic bone structure (*7*).

Liver burden estimates were made in

Table 1. Estimation and sequential measurements of $^{241}$Am distribution in an adult male and an adolescent male.

| Months since April 1970* | Adult $^{241}$Am burden† (nCi) | | | | Adolescent $^{241}$Am burden† (nCi) | | | |
|---|---|---|---|---|---|---|---|---|
| | Lung | Liver | Skeleton‡ | Total body | Lung | Liver | Skeleton | Total body |
| 0 | 14.9 | 3.0 | (70.1) 72.1 | 90.0 | 7.8 | 10.0 | 17.9 | 36.4 |
| 12 | 15.5 | 2.6 | (75.9) 38.8 | 56.9 | 4.6 | 5.2 | 9.9 | 19.7 |
| 17 | 19.4 | 3.1 | (74.7) 33.6 | 56.1 | 4.0 | 5.2 | 13.9 | 23.1 |
| 29 | 12.7 | 4.9 | (70.1) 54.6 | 72.2 | 3.8 | 6.5 | 13.0 | 23.3 |
| 37 | 16.4 | 2.9 | 54.0 | 73.3 | 3.1 | 4.1 | 19.1 | 26.3 |
| 38 | 16.3 | 5.2 | 46.5 | 68.0 | 2.8 | 6.4 | 12.1 | 21.3 |
| 42 | 11.7 | 1.6 | 48.0 | 61.3 | 2.1 | 4.2 | 11.7 | 18.0 |
| 52 | 12.3 | 1.3 | (40.2) 42.4 | 56.0 | 0.3 | 3.8 | 14.7 | 18.8 |
| 57 | 10.4 | 0.7 | (34.5) 50.2 | 61.3 | N.D.§ | 2.6 | 15.9 | 18.5 |
| 58 | 11.5 | 1.5 | (40.2) 41.3 | 54.3 | 0.3 | 1.8 | 10.1 | 12.2 |
| 75 | 9.3 | 0.4 | (48.4) 49.9 | 59.6 | N.D. | 2.3 | 10.7 | 13.0 |
| 93 | 9.3 | 1.5 | (45.3) 44.3 | 55.6 | 0.1 | 1.7 | 10.5 | 12.3 |

*Decorporation therapy was administered during the periods between months 0 and 12, 37 and 38, and 57 and 58. †No error terms have been assigned to these values, since it was determined that unknown positioning consistency, body size variability, detector refabrication, and changing biological distribution of $^{241}$Am will all account for errors that may be larger than counting statistics alone. ‡Values in parentheses are determined by extrapolation of skull measurement. Other values are determined as skeleton = total body + lung + liver; values so obtained for 12 and 17 months may be in error because of detector refabrication and calibration change. §Not determined.


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vivo from measurements performed over both the liver area and an adjacent and identical region on the left side of the body. Appropriate corrections were then made for background, taking into account the liver activity data and the measurements made over the left side of the body. The values obtained in 1970 were 3.0 and 10.7 nCi for the man and the boy, respectively.

The skeletal burden was determined from measurements made with two, and subsequently three, detectors surrounding the head to determine the activity associated with the skull bones. Then, by assuming that the concentration of activity in all bones is the same as that measured in the skull (*7*, *8*), the skeletal $^{241}$Am content was determined in 1970 to be 72.1 nCi for the father and 17.9 nCi for his son (*9*). The percentages of the total body burden that these values represent were calculated from Table 1 to be 80 and 49 percent for the father and son, respectively.

Finally, the total body burden was measured with two detectors placed 1 m from the subjects, who were positioned in an arc position. These values were ~ 90 and ~ 36 nCi in 1970 for the father and son, respectively.

The only external indication of contamination in 1970 was on the soles of the man's feet—presumably the result of his walking barefoot on contaminated floors. The externality of this radioactivity could be inferred from the presence of the 18-keV x-ray which, because of its relatively large mass attenuation coefficient, is less easily measured when material is deposited internally.

The sequential measurements obtained at these sites during an 8-year period are not an indication of the normal metabolic retention of $^{241}$Am in humans, because each subject was administered three courses of chelation therapy with calcium trisodium pentetate, which significantly enhanced excretion. These treatments (as seen in Fig. 1, a–c) occurred approximately between 3 and 4, 37 and 38, and 57 and 58 months after the initial measurement in 1970. In addition, interpretation of the retention measurements is complicated by the likelihood that exposure to the original source continued to occur to various degrees between 1964 and 1970 and by the probability of additional exposure during cleanup operations in the home after discovery of the contamination.

As the result of normal excretion and excretion due to three courses of decorporation therapy, the most recent estimates in 1978 for activity present in the body of these individuals, as percentages of the 1970 values, are 62 percent (whole body), 66 percent (lung), 50 percent (liver), and 61 percent (skeleton) for the adult and 34 percent (whole body), 1 percent (lung), 16 percent (liver), and 59 percent (skeleton) for the adolescent. Approximate estimates of integrated alpha radiation doses (rads) to the lung, liver, and skeleton (from 1970 to 1977) associated with the changing magnitudes of these values are 9.5, 1.4, and 5.8 rads for the adult and 4.2, 4.2, and 2.6 rads for his son.

Table 2. Changes in subject height, weight, and age across measurement dates.

| Measurement date (month)* | Height (cm) | | Weight (kg) | | Age (years) | |
|---|---|---|---|---|---|---|
| | Father | Son | Father | Son | Father | Son |
| 0 | 170 | 146 | 86.7 | 33.6 | 57.2 | 10.5 |
| 12 | 170 | 150 | 84.0 | 35.4 | 58.2 | 11.5 |
| 17 | 170 | | | | 58.6 | 11.9 |
| 29 | 170 | 158 | 82.7 | 38.6 | 59.6 | 12.9 |
| 37 | 168 | 159 | 84.3 | 41.1 | 60.3 | 13.6 |
| 38 | | | | | 60.4 | 13.7 |
| 42 | 170 | 162 | 85.9 | 39.8 | 60.7 | 14.0 |
| 52 | 169 | 170 | 82.6 | 45.9 | 61.5 | 14.8 |
| 57 | 169 | 173 | 85.9 | 48.0 | 61.9 | 15.2 |
| 58 | 169 | 174 | 86.4 | 48.2 | 62.0 | 15.3 |
| 75 | | 180 | | 53.0 | 63.4 | 16.7 |
| 93 | 169 | 182 | 88.6 | 55.5 | 64.9 | 18.2 |

*Measurement dates began in April 1970 and were not always identical for father and son; they are expressed to the nearest whole-month value.

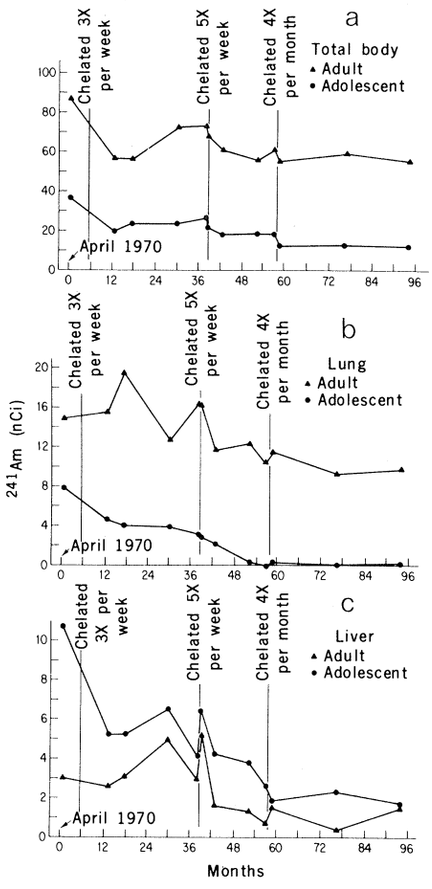


Fig. 1. Americium-241 as a function of time and chelation therapy in (a) total body, (b) lung, and (c) liver.

The incident described in this report is unique and extremely important for a variety of reasons. The most intriguing aspect of this case is the fact that, apparently for the first time, a child was exposed to $^{241}$Am and that the biological behavior of this man-made nuclide was followed over a long period, not only in the child but in an adult similarly exposed. By considering the measurement data collected concurrently for each subject (with appropriate corrections made for changes in calibration as a function of subject size), a comparison of retention parameters and the efficacy of chelation therapy as a function of age-related metabolic differences can be made (see Table 2).

Continued in vivo measurements of these individuals are in progress, as is the assay and interpretation of the $^{241}$Am content of excreta samples.


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9. For the adolescent, the skull extrapolation technique did not agree with a balance sheet method (that is, total body = liver + lungs + skeleton). Since maximum confidence was placed in the whole-body measurement, and since bone growth was rapid in the youth, the latter method of calculation was used to obtain his skeletal estimates.
10. This research is part of center programs supported by National Institute of Environmental Health Sciences grant ES00260, National Cancer Institute grant CA13343, and DOE contract EY-76-S-02. The skillful technical assistance of Lynn Ayres is gratefully acknowledged.

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## Neonatal Rat Surgery: Avoiding Maternal Cannibalism

Abstract. *A simple program of handling and care of pregnant rats before delivery makes it possible to carry out surgical procedures on newborn pups without resultant cannibalism or rejection of the operated animals by their mothers.*

Newborn rats subjected to surgical procedures and returned to their mothers are often killed and eaten by the mothers. Frequently, merely handling pups, as in the carrying out of simple injection procedures, produces similar results, or the young animals may be ignored and left to die. Here we describe methods for manipulating mother and young so as to obviate these undesirable occurrences. These methods have enabled us to carry out surgical procedures with considerable tissue removal and blood loss upon rat pups born only several hours before surgery. Maternal cannibalism and abandonment have been extremely rare, even when all pups in a litter have undergone surgery. Moreover, the operated animals gained weight and developed normally. These methods may be applicable to many other small mammals and may thereby greatly extend the utility of these organisms in studies in which surgery in early life is required.

*Preparation of the mother.* Whatever the source of the pregnant rats, they must be placed in breeding cages by the 13th day of gestation. We house commercially obtained gravid females in separate stainless steel cages approximately 30 by 25 by 61 cm. The cage must be large enough to accommodate the parent, the litter, food pellets, a thick layer of wood shavings, and the excreta that accumulate between confinement and weaning some 30 days later, because during that period the cage may not be cleaned. The cages are placed in dimly lit areas of the laboratory and covered from above with a cloth towel to further reduce the light level within. Often the maternal parent will draw a corner of the towel through the cage-top louvers and shred it for use as nest material. Each towel and water bottle should be assigned to an individual cage.

Starting on the day after the gravid females are installed in individual cages, and each day thereafter until the pups are delivered, the surgeon must follow a procedure that we have termed "hand gentling." This consists of removing the covering towel and cage top and placing one's hand in the cage near but not touching the female. In response to this incursion, and generally in a single motion, the rat will move its head so as to inspect the hand with its vibrissae and nose. After this has occurred the surgeon touches and, if possible, strokes the rat. It is helpful to repeatedly present the hand for nasal inspection during this ritual. With each successive day before birth, the surgeon extends the length of the gentling process, so that by day 20 of gestation there are 3 to 5 minutes of such contact. Simultaneously, the complexity of the encounter is increased, incorporating those maneuvers which later will be used to remove and handle the pups.

On day 17 of gestation several paper towels are placed inside the cage to assure the availability of nest-building materials. At this time the nursery area is darkened further so that little light reaches the cage floors. On day 20 of gestation noise in the immediate and the surrounding areas is reduced, and on the following day entry of humans other than the surgeon is restricted.

Employing these precautions we have been able to accommodate as many as 12 litters simultaneously in a 4.2 by 3 m room while still using its entire bench-top area for daily activities. Although predation and maternal rejection were rarely noted after surgery, it is advisable to breed several reserve litters in order that wet nurses be available should the mother die or fail to produce an adequate quantity of milk.

*Presurgical and surgical care of pups.* Generally, to effect adequate analgesia, we have employed hypothermic exposure by placing pups in a cold room. In our experience barbiturate or ether administration has somewhat unpredictable effects upon such young rats. When pups are placed in an environment of 7°C they become torpid within 30 to 45 minutes and also display reduced blood loss during surgery. The hands of the surgeon, however, warm the pup, and the torpor is dissipated within 5 to 7 minutes. This timing may be advantageous, permitting completion of relatively brief surgical procedures and return of the pup to the nest as it awakens. The awakened pup will often crawl to the teat and commence suckling immediately.

*Maternal response to repeated intrusion.* We have frequently employed rat pups 1 to 5 days old in studies of limb regeneration after above-elbow amputation of a forelimb. After surgery each pup was immediately returned to the nest area, was accepted by its parent, and commenced nursing forthwith. When a cage top is opened repeatedly as one pup after another is removed and then replaced, the mother may take a pup in its mouth and move some distance away from the nest and then extend its neck so that jaws and pup are thrust upward. Frequently this is accompanied by exaggerated running, purposeless changes of direction or digging maneuvers, and sometimes by return of the pup to the nest and replacement with another. We view these actions to reflect considerable distress of the mother and immediately discontinue our work with the pups. Often further hand gentling calms the mother and then manipulation of the pups may be safely continued. At other times it is useful to cover the head of the mother with a cage-top towel or to fold it so that it can be used as a cage divider separating the mother from the pups while at the same time blocking the nest from its line of sight. This last maneuver is particularly useful when members of the litter are to receive injections and the absence of the mother from the nest for several minutes is desired.

It is essential to ascertain that the pups are being fed by the mother. It does not suffice that they are suckling. During the first week of life, the pups should be lifted from the mother daily and their bellies inspected. Well-fed pups display distended abdomens. The whitish milk-filled stomach can be seen beneath the liver through the thickness of the abdominal wall.

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**Notes**

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