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Lawrence Radiation Laboratory
UNIVERSITY OF CALIFORNIA
LIVERMORE

**A PLEA FOR CONSISTENT LUNG BURDEN CRITERIA
FOR INSOLUBLE ALPHA EMITTING ISOTOPES**

David S. Myers

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A PLEA FOR CONSISTENT LUNG BURDEN CRITERIA FOR INSOLUBLE ALPHA EMITTING ISOTOPES*

*Work performed under the auspices of the U.S. Atomic Energy Commission

University of California
Lawrence Livermore Laboratory

David S. Myers

INTRODUCTION

The maximum permissible annual dose to an individual's lungs as defined by existing radiation standards is 15 rem/year.¹ In the case of lung doses resulting from alpha emitting isotopes, the assumption is made that the alpha energy is deposited uniformly in the lung tissue and that the mass of the lungs is 1000 grams.² The amount of alpha activity in the lungs which will produce a dose rate of 15 rem/year is on the order of 10 to 20 nCi depending upon the effective half-life of the alpha emitting isotope.

For the purposes of this discussion and associated calculations, insoluble ²³⁹Pu with a maximum permissible lung burden of 16 nCi will be used as representative of long-lived alpha emitting isotopes. The MPCa for insoluble ²³⁹Pu for radiation workers is 4×10^{-11} uCi/cc.¹ This value is based on the "Original Lung Model"² which assumes that 12.5% of the inspired ²³⁹Pu is retained in the lower respiratory tract and is cleared from that region with an effective half-life of 120 days.

In 1966 a revised lung model was promulgated by the ICRP's "Task Group on Lung Dynamics."³ In addition to more clearly defining the deposition compartments in the respiratory system, the revised lung model considered (1) the effect of particle size on deposition, (2) the chemical form of the inhaled material, and (3) the specific clearance pathways from the various deposition compartments. It is of special interest in the case of insoluble isotopes that the revised lung model stipulates that 15% of the activity

deposited in the pulmonary region is eliminated to the pulmonary lymph nodes and that 90% of this activity is retained in these lymph nodes permanently. Based on this revised lung model, the dose received by the pulmonary lymph nodes is considerably greater than the dose received by the pulmonary region of the lungs for either acute or chronic inhalation of insoluble ^{239}Pu .

ACCUMULATED ACTIVITY AND INTEGRATED DOSE COMPARISONS

The two types of inhalation exposures considered are acute and chronic. For each of these two exposure categories the following information is computed:

1. Amount of activity remaining in the lungs after 50 years
2. Integrated dose to the lungs at 50 years
3. Amount of activity in the pulmonary lymph nodes after 50 years
4. Integrated dose to the pulmonary lymph nodes after 50 years

The parameters for each of the exposure categories and the corresponding computations are shown in the following paragraphs.

A. Acute Inhalation

For purposes of this discussion, the acute exposure will be defined as an inhalation incident which deposits 26.7 nCi of insoluble ^{239}Pu oxide in the pulmonary region of the lungs. According to the revised lung model, 60% (or 16 nCi) of this deposited activity will be retained with a 500-day half-life; the remaining 10.7 nCi being cleared to the G.I. tract with a 24-hour half-life.³

1. Amount of Activity Remaining in the Lungs after 50 Years:

The following familiar equation describes the elimination of the insoluble ^{239}Pu from the lungs:

$$Q_p = Q_{p0} e^{-\lambda_p t} \quad (1)$$

where

Q_p = the quantity of activity in nCi remaining in the pulmonary region of the lung at any time.

Q_{p0} = initial amount of activity in nCi deposited in pulmonary region of the lungs, 60% of which is eliminated with a 500-day half-life.

λ_p = effective decay constant of insoluble ^{239}Pu in the pulmonary region of the lung $\lambda_p = .51 \text{ yr}^{-1}$

t = time in years

If $Q_{p0} = 26.7 \text{ uCi}$, then the value of Q_p when t equals 50 years is essentially zero.

2. Integrated Dose to the Lungs at 50 Years:

Assuming a lung mass of 1000 grams² and an effective absorbed energy of 53 MeV/dis², the dose rate to the lungs from 16 nCi of ^{239}Pu is 15 rem/yr.

Then:

$$D_T = 1.5 \times 10^1 \int_0^t e^{-\lambda_p t} dt \quad (2)$$

where

D_T = the total integrated dose in rem to the pulmonary region of the lungs.

Integrating equation #2 and evaluating for $t = 50$ years yields a value of $D_T = 29.4 \text{ rem}$.

3. Amount of Activity in the Pulmonary Lymph Nodes at 50 Years:

The amount of plutonium in the pulmonary lymph nodes Q_L as a function of time is a composite of two components which are defined as follows:

Q_L^1 = the activity cleared from the pulmonary region to the pulmonary lymph nodes which remains there permanently $Q_L^1 = (90\%) (15\%) (Q_{po}) = .135 Q_{po}$

Q_L^{11} = the activity cleared from the pulmonary region to the pulmonary lymph nodes which is cleared from the lymph nodes with a half-life of 500 days. $Q_L^{11} = (10\%)(15\%) (Q_{po}) = .015 Q_{po}$.

At any time Q_L^1 and Q_L^{11} are described by the following equations:

$$\frac{dQ_L^1}{dt} = .135 \lambda_p Q_{po} e^{-\lambda_p t} \quad (3)$$

$$\frac{dQ_L^{11}}{dt} = .015 \lambda_p Q_{po} e^{-\lambda_p t} - \lambda_L Q_L^{11} \quad (4)$$

where

λ_L = effective decay constant of insoluble ^{239}Pu in the pulmonary lymph nodes for Q_L^{11} , $\lambda_L = .51 \text{ yr}^{-1}$

Integrating equations #3 and #4 and combining yields the following result:

$$Q_L = .135 Q_{po} (1 - e^{-\lambda_p t}) + .015 \lambda_p Q_{po} t e^{-\lambda_L t} \quad (5)$$

If $Q_{po} = 26.7 \text{ nCi}$ and solving for Q_L when $t = 50 \text{ years}$ yields a value of $Q_L = 3.60 \text{ nCi}$.

4. Integrated Dose to the Pulmonary Lymph Nodes at 50 Years:

Assuming a pulmonary lymph node mass of 15 grams^4 , the dose rate to the pulmonary lymph nodes is $6.59 \times 10^1 Q_L \text{ (nCi) rem/year}$. Thus, the total integrated dose in rem to the lymph nodes at any time (D_T) is:

$$D_T = 6.59 \times 10^1 \int_0^t Q_L \text{ (nCi) } dt \quad (6)$$

Substituting the value of Q_L from equation #5 in equation #6, integrating, and evaluating for $t = 50$ years yields a value of $D_T = 1.25 \times 10^4$ rem.

B. Chronic Inhalation:

In this discussion the chronic exposure will be defined as the inhalation of 1 MPCa of insoluble ^{239}Pu for the entire working lifetime (50 years) of an individual.

1. Amount of Activity in the Lungs after 50 Years:

Since the derivation of the MPCa for insoluble ^{239}Pu is based on the concentration which if breathed throughout the individual's working lifetime would result in a Maximum Permissible Lung Burden (MPLB), the amount accumulated in the lung at 50 years is simply 1 MPLB (or 16 nCi).

2. Integrated Dose to the Lungs after 50 Years:

The amount of activity in the pulmonary region of the lungs at any time is defined by the following equation:

$$\frac{dQ_p}{dt} = I - \lambda_p Q_p \quad (7)$$

where

I = intake of activity (nCi/yr) into the pulmonary region which assuming an inhalation rate of 10^7 cc/workday², 250 workdays/year², and a 1 μ particle size (15% retention in pulmonary region with a half-life of 500 days)³ is 7.5 nCi/yr.

Integrating equation 7 yields the following standard equation:

$$Q_p = \frac{I}{\lambda p} (1 - e^{-\lambda p t}) \quad (8)$$

The dose rate to the lungs for ^{239}Pu is $9.40 \times 10^{-1} Q_p$ (nCi) rem/year. Then the integrated dose to the lungs is defined by the following equation:

$$D_T = 9.40 \times 10^{-1} \int_0^t \frac{I}{\lambda p} (1 - e^{-\lambda p t}) dt \quad (9)$$

Integrating equation #9 and evaluating for $t = 50$ years yields a value of $D_T = 6.64 \times 10^2$ rem.

3. Amount of Activity in the Pulmonary Lymph Nodes after 50 Years:

As in the case of the acute inhalation exposure, the amount of ^{239}Pu in the pulmonary lymph nodes as a function of time is a composite of two components Q_L^1 and Q_L^{11} which were defined previously in this report.

$$\frac{dQ_L^1}{dt} = .135 \lambda_p Q_p \quad (10)$$

but from equation #8, $Q_p = \frac{I}{\lambda p} (1 - e^{-\lambda p t})$ and substituting this value of Q_p in equation #10, we obtain

$$\frac{dQ_L^1}{dt} = .135 I (1 - e^{-\lambda p t}) \quad (11)$$

and integrating

$$Q_L^1 = .135 I \left(t - \frac{e^{-\lambda p t}}{\lambda p} \right) \quad (12)$$

in a similar manner from equation #4

$$\frac{dQ_L^{11}}{dt} = .015 \lambda p Q_p - \lambda_L Q_L^{11} \quad (13)$$

but from equation #8, $Q_p = \frac{I}{\lambda p} (1 - e^{-\lambda p t})$

$$\frac{dQ_L^{11}}{dt} = .015 I (1 - e^{-\lambda p t}) - \lambda_L Q_L^{11} \quad (14)$$

and integrating

$$Q_L^{11} = .015 I \left(\frac{1}{\lambda_L} - t e^{-\lambda_L t} - \frac{e^{-\lambda_L t}}{\lambda_L} \right) \quad (15)$$

Adding equations #12 and #15 yields the value of Q_L

$$Q_L = .135 I \left(\frac{t - e^{-\lambda p t}}{-\lambda p} \right) + .015 I \left(\frac{1}{\lambda_L} - t e^{-\lambda_L t} - \frac{e^{-\lambda_L t}}{\lambda_L} \right) \quad (16)$$

The evaluation of equation #16 for $t = 50$ years and an intake of 7.5 nCi/yr yields a value of $Q_L = 50.8$ nCi.

4. Integrated Dose to the Pulmonary Lymph Nodes after 50 Years:

From equation #6, the total integrated dose (D_T) in rem to the pulmonary lymph nodes is:

$$D_T = 6.59 \times 10^1 \int_0^t Q_L \text{ (nCi)} dt \quad (6)$$

Substituting the value of Q_L from equation #16 into equation #6, integrating, and solving for $t = 50$ years and $I = 7.5$ nCi/yr yields a value of $D_T = 8.30 \times 10^4$ rem.

In summary, the results of organ accumulations and integrated doses for the acute and chronic inhalation exposures are presented in Table I.

TABLE I
ACTIVITY ACCUMULATIONS AND DOSE COMPARISONS

<u>Inhalation Mode</u>	<u>Amount in Lungs at 50 Yrs (nCi)</u>	<u>Accumulated Dose to Lungs at 50 Yrs (rem)</u>	<u>Amount in Pulmonary Lymph Nodes at 50 Yr(nCi)</u>	<u>Accumulated Dose to Pulmonary Lymph Nodes at 50 Yr (rem)</u>
Acute*	0	2.9×10^1	3.6	1.3×10^4
Chronic**	16	6.6×10^2	5.1×10^1	8.3×10^4

- * The acute inhalation is defined as an incident which deposits 26.7 nCi of insoluble ^{239}Pu oxide in the pulmonary region of the lungs. Sixty per-cent (or 16 nCi) of this deposited activity will be retained with a 500-day half-life.
- ** The chronic inhalation is defined as the inhalation of 1 MPCa of insoluble ^{239}Pu for the entire working lifetime of the individual.

MAXIMUM PERMISSIBLE LUNG BURDEN

If the pulmonary lymph nodes are considered as the critical organ with a maximum permissible dose rate of 15 rem/yr, then the "maximum permissible lung burden" which would deposit sufficient activity into the pulmonary lymph nodes to deliver 15 rem/yr would depend on whether the inhalations were of an acute or chronic nature.

A. "Maximum Permissible Lung Burden" for Acute Inhalation:

As discussed previously in this report, the dose rate to the pulmonary lymph nodes is $6.59 \times 10^1 Q_L$ (nCi) rem/year for insoluble ^{239}Pu .

Thus, for a maximum permissible lymph node burden

$$Q_L = \frac{1.5 \times 10^1 \text{ rem/year}}{6.59 \times 10^1 \text{ rem/year/nCi}}$$

$$Q_L = .23 \text{ nCi}$$

Substituting the value of .23 nCi for Q_L in equation #5, setting $t = 50$ years, the value of Q_{po} obtained is 1.70 uCi. Since 60% of the deposited activity is retained with a half-life of 500 days, then (60%) (1.7 nCi) or 1.02 nCi is the "maximum permissible lung burden" which will produce a maximum permissible pulmonary lymph node burden of .23 nCi for the acute inhalation exposure. This is less than 1/10 of the currently accepted maximum permissible lung burden of 16 nCi.

B. "Maximum Permissible Lung Burden" for Chronic Inhalation

The annual intake of insoluble ^{239}Pu required to produce a maximum permissible lymph node burden after 50 years can be determined from equation #16. If $Q_L = .23$ nCi and $t = 50$ years, then solving for I yields .034 nCi/year. Then from equation #8, the lung burden after 50 years of inhalation of .034 nCi/year yields a value for Q_p of .067 nCi. Thus, the "maximum permissible lung burden" for chronic inhalation of ^{239}Pu which would produce a "maximum permissible pulmonary lymph node burden" of .23 nCi is .067 nCi. This value is less than .5% of the currently accepted maximum permissible lung burden.

MPCa FOR CHRONIC INHALATION EXPOSURE

If we assume as shown in the previous section that the "maximum permissible lung burden" for chronic inhalation of insoluble ^{239}Pu is .067 nCi, and that the annual intake which would produce this lung burden is .034 nCi/yr, then the corresponding MPCa is derived as follows:

$$X \text{ nCi/cc} \times 10^7 \text{ cc/day} \times 250 \text{ days/yr} = 3.40 \times 10^{-5} \text{ uCi/yr}$$

$$X = 1.36 \times 10^{-14} \text{ uCi/cc}$$

however, for 1 μ particles only 15% of the inhaled activity is retained in the pulmonary region of the lungs with a long half-life:

$$\text{MPCa} = \frac{1.36 \times 10^{-14}}{.15} = 9.1 \times 10^{-14} \text{ uCi/cc}$$

This value corresponds to the present MPCa of 4×10^{-11} uCi/cc.

SUMMARY

The ICRP's revised lung model includes provisions for determining the dose to pulmonary lymph nodes from insoluble alpha emitting isotopes. As shown in the previous sections, the integrated doses delivered to the pulmonary lymph nodes are more than 100 times greater than the doses delivered to the lungs for either chronic or acute inhalation exposures. Correspondingly, if the pulmonary lymph nodes are assumed to be the critical organ, the "maximum permissible lung burden" should be reduced to about 1 nCi for acute inhalation exposures and .07 nCi for chronic inhalation exposures. The "maximum permissible lung burden" used in this context is the amount of activity in the pulmonary region of the lungs which would correspond to a maximum permissible lymph node burden of .23 nCi based on the revised lung model. Furthermore, the MPCa for insoluble ^{239}Pu should be reduced by a factor of 4.4×10^2 if the pulmonary lymph nodes are considered the critical organ.

The adoption of the pulmonary lymph nodes as the critical organ for inhalation exposures to insoluble ^{239}Pu with the corresponding reductions in maximum permissible airborne concentration and internal deposition would introduce severe problems into (1) the determination of internal dose assessments for exposed personnel, and (2) the measurement of the MPCa for insoluble ^{239}Pu .

Presently the most sophisticated whole-body counting systems are capable of detecting in the range of 1/2 to 1 maximum permissible lung burden (8 nCi to 16 nCi) of ^{239}Pu in the lungs. A factor of approximately 50 in the increase

in the sensitivity in whole-body counting technology would be required to monitor the maximum permissible internal deposition if the pulmonary lymph nodes were considered the critical organ instead of the lung.

Fecal sampling is the most sensitive method of monitoring for internal depositions of ^{239}Pu , but fecal samples are of value only during the first few days following an inhalation exposure and thus an extremely large number of samples (perhaps 50-100/yr per individual) would be required for any routine monitoring program.

Present solid state alpha air monitoring instrumentation is capable of detecting an MPCa of insoluble ^{239}Pu (4×10^{-11} uCi/cc) in approximately 15 minutes at a sampling rate of 1.5 cfm. If the MPCa for insoluble ^{239}Pu were reduced by a factor of 4.4×10^2 based on the pulmonary lymph nodes as the critical organ, the sampling time to detect 1 MPCa would be increased correspondingly. That is, approximately 100 hours of sampling time would be required to detect the reduced MPCa of 9.1×10^{-14} uCi/cc.

Regardless of the serious problems which would be presented in estimating internal doses and monitoring MPCa concentrations, it appears based on the revised lung model that the pulmonary lymph nodes should be considered the critical organ for insoluble ^{239}Pu and that its MPCa as well as those of other long-lived insoluble alpha emitting isotopes should be reduced accordingly. This step would be particularly appropriate, considering the fact that it may be several years before data is available regarding the relative radiosensitivity of the pulmonary lymph nodes.

Recently the ICRP's Task Group on Spatial Distribution of Radiation Dose indicated that they were aware of the high doses which could be received by the pulmonary lymph nodes in the case of inhalation of insoluble alpha emitting

isotopes, but lacking any definitive experimental data they felt that the reduction of the maximum permissible lung burden was not warranted at this time.⁵ This seems somewhat inconsistent with past philosophy used by standards setting bodies that conservative assumptions be applied in establishing radiation exposure guidelines when specific experimental data is lacking, so that an adequate margin of safety will be provided.

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