728046 R

REPOSITORY DOE-OHRE

COLLECTION PLUTONIUM INJECTION

BOX NO. 1

FOLDER Centers for Human Radiobiology (40-017)

8002003

PRIVACY ACT MATERIAL REMOVED

CENTER FOR HUMAN RADIOBIOLOGY

January 2, 1973

Bureau of Vital Records
State Department of Health
Albany, New York 12208

Gentlemen:

The Center for Human Radiobiology was established by the United States Atomic Energy Commission and given the responsibility of making a long-range study of persons who have been exposed to radioactive materials. We would like very much to have you search the official death records of New York for five names of persons who may have been exposed to such materials at sometime.

I have asked that a check be issued for advance payment of the search fee. Would you please send the results of your search to my personal attention at the address at the bottom of the page.

Many thanks for your cooperation with our long-range investigations.

Very truly yours,

Harvey A. Schultz
Curator of Records
Center for Human Radiobiology

dk

encl: List

Orig.: Purch. Dept.
cc: R. E. Rowland
A. F. Stehney

PRIVACY ACT MATERIAL REMOVED

8002005

CENTER FOR HUMAN RADIOBIOLOGY

January 2, 1973

New York Death Record Search

( )

Date of Birth: about
Date of Death: 27 October 1946
Last known address: Stafford, New York

( )

Date of Birth: about
Date of Death: April 1946
Last known address: , Genesee, N.Y.

Date of Birth: about
Date of Death: April 1946
(Autopsy at Strong Memorial Hospital of
the University of Rochester)

Date of Birth: about
Date of Death: 2 July 1947
Last known address: Gates, N.Y.

Date of Birth: about
Date of Death: 26 February 1946
(Autopsy at Strong Memorial Hospital of
the University of Rochester)

Requested by:
Harvey A. Schultz
Curator of Records
Center for Human Radiobiology

dk

40-017

ARGONNE
NATIONAL
LABORATORY

INTRA-LABORATORY MEMO

November 27, 1985

TO: E. Huberman

FROM: R. A. Schlenker RAS

SUBJECT: Freedom of Information Act Request

We have been unable to locate the memo from Rowland to Schultz dated December 21, 1972 which you requested about 5:15 p.m. yesterday following the receipt of a letter from D. T. Goldman to A. Schriesheim concerning this matter. As today is the last business day before the deadline, December 2, further search is not possible without missing the deadline. Locating this memo is complicated by the fact that Rowland retired about two years ago and Schultz is dead.

Other intra-laboratory memos on the 18 plutonium research subjects referred to in the Goldman letter, mention them by name and give personal information about them. The release of such documents would be a violation of the patients' privacy and the right-to-privacy is protected by law. It would also constitute a violation of normal ethical practice in the handling of patient medical records.

The subjects referred to have been studied by several organizations since the mid 1940s. Non-personal information can be found in the scientific literature. A good review and guide to the literature up to the time of its publication can be found in Patricia W. Durbin, "Plutonium in Man: A New Look at the Old Data," pp.469-530, Radiobiology of Plutonium, Edited by Betsy J. Stover and Webster S.S. Jee, Published by the J. W. Press, Department of Anatomy, University of Utah, Salt Lake City, 1972.

DEC 04 19[illegible]

lw

8002007

ARGONNE NATIONAL LABORATORY
U of C-AUA-USAEC

CENTER FOR HUMAN RADIOBIOLOGY

*Argonne National Laboratory • Massachusetts Institute of Technology • New Jersey Field Station • Southwest Field Station*

April 4, 1975

MEMO TO: Jan Lieben, M.D.

F R O M: Mary Margaret Shanahan

SUBJECT: Exhumation Cases

Enclosed are copies of the death certificates on four persons who received radium injections at the Mayo Clinic ( , and ) together with copies of various memos to file dated March 27, March 3, March 14, and March 7 respectively. The memos will give you the next-of-kin for these four Mayo Clinic cases.

received 50 μg of radium chloride in 1927 for arteriosclerosis. received 35 μg of radium chloride in 1925 for hypertension. received 25 μg of radium chloride in 1925 for Buerger's disease. received 25 μg of radium chloride in 1925 for carcinoma of the stomach.

I have just heard from Dr. Stehney that he is quite anxious to obtain exhumation permission for these cases, for , and for any plutonium cases on whom you have been given information previously (how about , and )?

s
encs.
xc: M.H.Chalfen
A.F.Stehney





SOUTHWEST FIELD STATION
5619 East Monterosa St., Phoenix, Arizona 85018 Tel. 602-949-5600

40-017

ARGONNE NATIONAL LABORATORY

PRIVACY ACT MATERIAL REMOVED

INTRA-LABORATORY MEMO



August 1, 1973

TO: CHR Records Room

FROM: Jan Lieben, M.D.

SUBJECT: Contacts

7-24-73: Received letter from Postmaster, Rochester. address is: Carmel, Cal. 93921.

7-25-73: Called Carmel information re: phone listing of not listed, but there is a there on Rd., phone . Will investigate this on trip to California.

Re: called 7-16 at YWCA where is said to have been employed. She wants to look through her files re address, etc., call me back on Friday.

Received exhumation permits from for sisters. This is the last signature for these 2 cases. Mailed forms to MMS.

Called re: . Don't know whether I'll be home, may go to our farm on Saturday, call me tomorrow. Called 7-27 5 times until 9 p.m., no answer.

7-27-73: Re: . Called re exhumation permit. Will see my daughter shortly, you ought to get it soon.

Made appointment with and re: .

7-28-73: Visited at her home at , Bath, Ohio, phone , explained purpose of visit. She will consult with "the good Lord" on whether she will give her permission. There is too much research being done. He - the good Lord - will let me know on what to do. (Don't know how I could influence Him). Am to call in a week, left forms.

7-27-73: Called re: , Rochester. I have looked but could not find anything about him. There is one more place, if I find anything there I'll call you - collect, I said.

dk

cc: A. M. Brues, M.D.
M. S. Littman, M.D.
M. M. Shanahan
A. F. Stehney

PRIVACY ACT MATERIAL REMOVED



8002009

NL-26 (11-68)

40-017

ARGONNE NATIONAL LABORATORY

MICROFILMED

INTRA-LABORATORY MEMO

RECEIVED

PRIVACY ACT MATERIAL REMOVED

CHR RECORDS

Received July 30, 1973

JUL 31 1973

JUL 31 1973

TO: CHR Records Room

FROM: Jan Lieben, M.D.

SUBJECT: Contacts

(1) Re: Sisters. 7-15-73.

Called , Orange, N.J., phone re exhumation of above. (This was at least the 12th call) found him finally home - "Send me the forms, I'll sign them".

(2) Wrote letter with exhumation forms to .

(3) Called in Rochester 3 times - not home.

7-21-73

(1) Re: - went to Apts. to look for , talked to superintendent," was funny, walked around naked in the halls so we had to throw him out, don't know where he is". Sat down in the lobby of the apt. building and asked residents whether they knew 4 didn't, the 5th said yes, "he moved to ."

(2) Drove to superintendent is away for the weekend. A said he moved away about 2 months ago. Superintendent's name is later looked for him in phone book - is not listed.

(3) Returned to 86 South Union, his number (the superintendent's) is He may be back on Sunday.

(4) Went to Post Office to check re my letter to Postmaster for forwarding address - closed on Saturday.

(5) Re: - Went to where he allegedly had worked. The only person who may know about him is not here today, call Monday, , ext. 15.

cc: A. M. Brues, M.D.
M. S. Littman, M.D.
M. M. Shanahan
A. F. Stehney

dk

PRIVACY ACT MATERIAL REMOVED

8002010

AEC-26 (11-68)

ARGONNE NATIONAL LABORATORY

PRIVACY ACT MATERIAL REMOVED

01-736
01-614
05-538

INTRA-LABORATORY MEMO

40-017

Received May 16, 1973

TO: CHR Records Room

FROM: J. Lieben, M.D.

SUBJECT: Phone Calls, 5-6-73, etc.

5-73 1. Re: Called Town Clerk's Office at 716-HO 7-8840 in Irondequoit re cemetery record. "Will check, call me back tomorrow." Called back 5-7-73. "No I can't find anything on this man -- not even that he is buried."

2. Called re cemetery request. Nobody home.

3. Called re Mary Margaret Shanahan's request to have further cemetery papers completed. He agreed to sign them.

4. Wrote letters and mailed above papers.

5. Called address: , phone re Cemetery requests. He'll go along. The are his mother's relatives and there is only one left - for whom works so there will be no trouble.

6. Wrote letters to with cemetery requests.

-73 7. Called , in East Whittier, California re exhumation permits for . "Yes, I'll put them in the mail."

8. Called re sisters - in Chatham, New Jersey. "My brother will be back from Mexico on the 16th."

9. Called for appointment re . lives Road, W. Caldwell, New Jersey, phone .

PRIVACY ACT MATERIAL REMOVED

JL/jt

cc: A. M. Brues
M. S. Littman
M. M. Shanahan
A. F. Stehney

46-017

ARGONNE NATIONAL LABORATORY

PRIVACY ACT MATERIAL REMOVED

INTRA-LABORATORY MEMO

May 10, 1973

TO: CHR Records Room

FROM: Jan Lieben, M.D.

SUBJECT: Rochester 5/4 and 5/5

Re: _____. Went to Cemetery to try to find relatives. Their records start at 1948, records prior to 48 are kept at town clerk's office. Phone Monday 717/HO 7 -8840.

Went to Cemetery re _____ and _____. Lady very uncooperative but finally learned that there are six in the grave. The last one, was buried in 1959. May be by Funeral director. Called funeral home, no records. But they think may have buried him.

Called no answer. Called all 8 listed in the phone book. Spoke to 4 of them, none is related to or .

Called funeral home again. Man there remembers that was a She is a vice president of Company - ). No residence listed. Owner of Restaurant. No listed in Rochester phone book.

Drove to Restaurant, yes, sold the restaurant. Now lives in Canandaigua. Called information at Canandaigua, his phone number is on .

Called above number, nobody home. Drove to Carl Street, where informant had lived. There is no such number, street is deteriorated. Policeman stated it could be Street. Drove to Street. Present owner did not know but had bought home from owner of .

Called Canandaigua again, spoke to , my wife is out, she will be back tomorrow. Called about 10 a.m., does not know

dk

cc: A. M. Brues, M.D.
M. S. Littman, M.D.
M. M. Shanahan
A. F. Stehney

PRIVACY ACT MATERIAL REMOVED

8002012

-26 (11-68)

ARGONNE NATIONAL LABORATORY

PRIVACY ACT MATERIAL REMOVED

40-017

INTRA-LABORATORY MEMO

Received: April 12, 1973

TO: CHR Records Room

FROM: Jan Lieben, M.D.

SUBJECT: Rochester Cases

4-7-73: On arrival at Rochester, checked phone book. Found listed on Street, phone . Made appointment to visit. She is in her seventies, has no children, no other relatives, but will not go along with exhumation. (Maybe court order after herdeath?)

Re: : No in phonebook, but many others listed. Visited Funeral Home, phone . No children listed only wife. Obituary states: He was a janitor at the and a Spanish War Veteran.

Spent 3 hours looking for Lake View Ave. in Lea Breeze and Trandequoit, (on death cert) none listed on city map at fire house. Visited 2 Lakeview Terraces but none has a number 99.

Re: : Went to Nanna Funeral Home. The don't know whether is still alive. There are two sons: . lives at Street near the funeral home (off Goodman). - other son - no address. Went to above address, nobody home. Called later, nobody home.

Re: : Went to undecipherable undertaker at 712 W. Main Street - - doors closed, for speedy service call - read notice on door. I did, "Am not in my office - call me Monday".

dk

cc: A. M. Brues, M.D.
M. S. Littman, M.D.
M. S. Shanahan
A. F. Stehney

PRIVACY ACT MATERIAL REMOVED

8002013

ARGONNE NATIONAL LABORATORY
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PRIVACY ACT MATERIAL REMOVED

CHR

CENTER FOR HUMAN RADIOBIOLOGY

*Argonne National Laboratory • Massachusetts Institute of Technology • New Jersey Field Station • Southwest Field Station*

TO: M. M. Shanahan MIT Radioactivity Center

FROM: A. F. Stehney RER Division

SUBJECT: Exhumation of CHR cases with prefix number 40.

Enclosed are folders containing copies of all CHR information on ten radioactivity patients in the "40" series. These are all the cases in this series for which we now have death certificates.

Please take the necessary steps to locate relatives and obtain permissions to exhume any or all of these ten persons. It should be noted that we want to examine the remains in order to determine the microscopic distribution of residual radioactivity from past medical treatment.

Date

A. F. Stehney, Deputy Director
Center for Human Radiobiology

Today, I received from A. F. Stehney copies of folders for the following ten CHR cases:

| | | | | |
|---|---|---|---|---|
| 40-001 | 40-005 | 40-008 | 40-011 | 40-015 |
| 40-004 | 40-007 | 40-010 | 40-013 | 40-017 |

Date

M. M. Shanahan, Deputy Director
MIT Radioactivity Center

dk

cc: R. D. Evans
R. E. Rowland
CHR Records Room

PRIVACY ACT MATERIAL REMOVED

8002014

CORRESPONDENCE/PICTURES

8002015

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

40-017

Telephone: 312-972-7678

February 27, 1986

Dr. Robert G. Thomas
ER-72
GTN
Mail Stop G236
U.S. Department of Energy
Washington, D. C. 20545

Bob
Dear Dr. Thomas:

With respect to your telephone inquiry relating to plutonium studies in the Environmental Health Section (previously Center for Human Radiobiology), I refer you back to the factsheet furnished Dr. Thiessen in 1984 (copy enclosed).

I had follow-up completed on cases Cal-III and HP-6. Case Cal-III died in 1984 of causes not reasonably relatable to plutonium. Case HP-6 is living as of several days ago. Both the interviewer who contacted the household, and a review of the case file, suggest that the functioning of this subject is such that direct contact is contraindicated. I hope this is of some assistance to you.

Best personal wishes.

Sincerely yours,

Jim Stebbings

James H. Stebbings, Sc. D.
Epidemiology Group Leader

JHS:llf

Enclosures

cc w/enc.: H. Drucker, BIM
E. Huberman, BIM
D. T. Goldman, DOE-CH



8002016

40-017

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

Telephone 312/972-4146

July 23, 1984



Dr. Jacob Thiessen
Mailstop E-201, Human Health Studies
Office of Health and Environmental Research
Office of the Environment
U.S. Department of Energy
Washington, D. C. 20545

SUBJECT: Congressional Investigation into Health and Safety Policies of the Department of Energy (DOE)

Dear Dr. Thiessen:

In response to Dr. C. W. Edington's memorandum of June 27, 1984, on the above subject, I have enclosed a factsheet on "Plutonium Studies at the Center for Human Radiobiology (CHR)." The factsheet is in the format requested by Dr. Edington.

Please let me know if you need more information or documentation.

Sincerely yours,

A. F. Stehney
Environmental Research Division

AFS:pat
Enclosures

cc: H. Drucker
H. J. Rauch
P. Failla
P. F. Gustafson
E. Huberman
J. Rundo



8002017

Project Name:
Plutonium Studies at the Center for Human Radiobiology (CHR)

Date Started: 2 January 1973
Date Terminated: Ongoing

Principal Investigators: R. E. Rowland, A. F. Stehney

Objectives of Test:

1. To determine the excretion rate of plutonium 27 years after injection.
2. To determine the retention and body distribution of plutonium.

Short Description:

In 1945-1947, 18 hospital patients of limited life expectancy were injected with plutonium in order to obtain information about the retention and organ distribution of plutonium. An important objective was to determine the relationship between the body content and the rate of excretion in order to provide data for estimating the body content of plutonium from measurements of plutonium in excreta (bioassay). The results of this study were described in Report LA-1151 (1950).[1]

The data in LA-1151 were reviewed in a manuscript prepared by P. W. Durbin for publication in the 1972 volume, Radiobiology of Plutonium.[2] Tissue and bone samples had been obtained at autopsy from six of the cases at times ranging from 5 days to 456 days after injection, and the longest collection time for excreta was about 5 years. In addition to preparing the manuscript, Durbin traced the later history of the cases and discovered that four were still living in 1972.

The Center's direct knowledge of the plutonium injection cases dates from December 13, 1972, when Dr. Durbin brought her records to CHR for possible further follow-up. The Center then undertook to determine excretion rates in study subjects who were still alive and to exhume deceased subjects in order to determine the amounts and body distribution of plutonium. During 1973, CHR obtained metabolism samples from three living patients, obtained permission to exhume from next of kin of three deceased patients, and disinterred and transferred to CHR the remains of one of these deceased. The metabolism samples (blood and excreta) were taken at Strong Memorial Hospital (SMH), Rochester, New York.

In 1974, the U.S. Atomic Energy Commission (AEC) reviewed the origins and subsequent follow-up of the plutonium studies. On December 31, 1974, the AEC authorized CHR to proceed with the program of study of the living patients who were injected with plutonium during 1945-1947 and of the bodies of deceased individuals from that group for whom legal consent for examination is obtained.

Follow-up Data:

Table 1 summarizes CHR follow-up activities and last known status (July 5, 1984) for each of the plutonium injection cases.

CHR personnel have published 10 reports on results obtained by study of these cases.[3-12] Copies of these reports are attached.

Table 1. Plutonium injection cases: Summary of CHR activities and last known status (July 5, 1984).

| Old Case Number | CHR Case Number | CHR Activities | Status |
|---|---|---|---|
| Cal-I | 40-001 | 10/16/75: Exhumed cremains<br>Aug 78: Returned | Died 1/9/66 |
| Cal-II | 40-002 | No contacts; said to have died in Australia | Died 1/6/47 |
| Cal-III | 40-003 | 6/11/73: Examined at CHR<br>6/23-26/77: Metabolism study at SMH | Living 10/19/83 |
| Chi-1 | 40-004 | 6/10/75: Exhumed<br>Apr 78: Returned | Died 10/3/45 |
| Chi-2 | 40-005 | No contacts; cremation ashes scattered | Died 1/13/46 |
| Chi-3 | 40-006 | No contacts; case unidentified | Lost to study, 1946 |
| HP-1 | 40-007 | 1973: Next of kin refused permission to exhume | Died 1/12/60 |
| HP-2 | 40-008 | 1973: Next of kin refused permission to exhume | Died 4/4/48 |
| HP-3 | 40-009 | 1/28-2/18/73: Metabolism study and radioactivity measurement at SMH<br>1/23-24/79: Metabolism study at SMH | Died after 6/5/81 |
| HP-4 | 40-010 | 9/24/73: Exhumed<br>Jul 75: Returned | Died 4/29/47 |
| HP-5 | 40-011 | 1973: Next of kin refused permission to exhume | Died 4/29/46 |
| HP-6 | 40-012 | 2/14/73: Metabolism study at SMH<br>6/21-7/1/73: Metabolism study at SMH | Living 12/30/74 |
| HP-7 | 40-013 | 1973 and 1977: Next of kin refused permission to exhume | Died 10/27/46 |
| HP-8 | 40-014 | No contacts | Died 11/22/75 |
| HP-9 | 40-015 | 5/18/78: Exhumed<br>Jul 81: Returned | Died 7/2/47 |
| HP-10 | 40-016 | No contacts | Died 6/2/57 |
| HP-11 | 40-017 | No contacts | Died 2/26/46 |
| HP-12 | 40-018 | No contacts | Died 4/13/53 |

References:


1. W.H. Langham, S.H. Bassett, P.S. Harris and R.E. Carter. Distribution and excretion of plutonium administered to man. Los Alamos Scientific Laboratory, LA-1151 (September 1950).

2. P.W. Durbin. Plutonium in man: a new look at the old data. In The Radiobiology of Plutonium, B.J. Stover and W.S.S. Jee (eds.), The J.W. Press, Salt Lake city, UT, pp. 469-537 (1972).

3. J. Rundo, P.M. Starzyk, J. Sedlet, R.P. Larsen, R.D. Oldham and J.J. Robinson. The excretion rate and retention of plutonium 10,000 days after acquisition. In Diagnosis and Treatment of Incorporated Radionuclides, Proc. Seminar, Vienna, 8-12 December 1975, IAEA, Vienna, pp. 15-22 (1976).

4. R.E. Rowland and P.W. Durbin. Survival, causes of death, and estimated tissue doses in a group of human beings injected with plutonium. In The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6-9 October 1975, W.S.S. Jee (Ed.), The J.W. Press, Salt Lake City, UT, pp. 329-342 (1976).

5. R.A. Schlenker, B.G. Oltman, and H.T. Cummins. Microscopic distribution of $^{239}Pu$ deposited in bone from a human injection case. In The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6-9 October 1975, W.S.S. Jee (Ed.), The J.W. Press, Salt Lake City, UT, pp. 437-450 (1976).

6. J. Rundo and F.H. Ilcewicz. Blood content and excretory plasma clearance of plutonium $10^4$ days after injection. Abstracts of Papers-22nd Ann. Mtg. Health Phys. Soc., Atlanta, 3-8 July 1977, Pergamon Press, NY, p.26 (1977); Health Phys. 33, 668 (1977).

7. R.E. Rowland. The risk of bone sarcoma from plutonium-239. In Biological Implications of Radionuclides Released from Nuclear Industries, Proc. Symp., Vienna, 26-30 March 1979, Vol. II, IAEA, Vienna, pp. 211-224 (1979).

8. R.P. Larsen, R.D. Oldham, and R.E. Toohey. Macrodistribution of plutonium in the human skeleton. In Actinides in Man and Animals, Proc. Snowbird Actinide Workshop, 15-17 October 1979, M.E. Wrenn (Ed.), RD Press, Salt Lake City, UT, pp. 191-197 (1981).

9. J. Rundo. The late excretion of plutonium following acquisition of known amounts. In Actinides in Man and Animals, Proc. Snowbird Actinide Workshop, 15-17 October 1979, M.E. Wrenn (Ed.), RD Press, Salt Lake City, UT, pp. 253-260 (1981).

10. R.A. Schlenker and B.G. Oltman. Plutonium microdistribution in human bone. In Actinides in Man and Animals, Proc. Snowbird Actinide Workshop, 15-17 October 1979, M.E. Wrenn (Ed.), RD Press, Salt Lake City, UT, pp. 199-206 (1981).

11. R.A. Schlenker and B.G. Oltman. Uranium concentrations in human bone. In Actinides in Man and Animals, Proc. Snowbird Actinide Workshop, 15-17 October 1979, M.E. Wrenn (Ed.), RD Press, Salt Lake City, UT, pp. 473-476 (1981).

12. R.E. Toohey, C.G. Cacic, R.P. Larsen, and R.D. Oldham. The concentration of plutonium in hair following intravenous injection. Health Phys. 40, 881-886 (1981).

Attachments:
Reprints of references 3-12 are attached.

40-017

**Department of Energy**
Argonne Area Office
9800 South Cass Avenue
Argonne, Illinois 60439

NOV 21 1985



Dr. Alan Schriesheim, Director
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

Dear Dr. Schriesheim:

SUBJECT: FREEDOM OF INFORMATION ACT (FOIA) REQUEST DATED OCTOBER 30, 1985, DOCKET NO. 11048504D

The enclosed FOIA request is for a copy of a memo from R. E. Rowland to H. A. Schultz dated December 21, 1972, which discusses records of 18 plutonium research subjects. The requestor is also asking for any supporting documentation and any subsequent memos regarding the subject.

Due to statutory time limitations for responding to FOIA requests, we must have your response no later than December 2, 1985.

Sincerely,

Thomas J. Balcerski

for David T. Goldman
Area Manager

Enclosure:
As Stated

cc: A. Zilberstein, ANL, w/enclosure
R. E. Rowland, Princeton, KY, w/enclosure
[redacted] w/enclosure

502-365-2979

DEC 04 1985

8002022

40-017


# THE KNOXVILLE JOURNAL

A GANNETT NEWSPAPER
P.O. BOX 911
KNOXVILLE, TENNESSEE 37901


1985 NOV -4 PM 3:39

Oct. 30, 1985

Mr. Ronald Turner
MA-232.1
U.S. Department of Energy
Freedom of Information and Privacy Act Branch
1000 Independence Ave. S.W.
Washington, D.C. 20585

To the FOI Officer:

This request is made under the federal Freedom of Information Act, 5 U.S.C.'552.

Please send me copies of Memorandum, dated 12-21-72, from Dr. R.E. Rowland to H.A. Schultz, senior staff assistant, Records and Data Processing, Center for Human Radiobiology, Argonne National Lab. Memo discusses instructions from Rowland to Schultz on records of 18 plutonium research subjects. Records were transferred to Schultz for his disposition. Please include any supporting documentation and any subsequent memos regarding this subject.

As you know, the FOI Act provides that if portions of a document are exempt from release, the remainder must be segregated and disclosed. Therefore, I will expect you to send me all nonexempt portions of the records which I have requested, and ask that you justify any deletions by reference to specific exemptions of the FOI Act. I reserve the right to appeal your decision to withhold any materials.

I promise to pay reasonable search and duplication fees in connection with this request. However, if you estimate that the total fees will exeed $50, please notify me so that I may authorize expenditure of a greater amount.

I am prepared to pay reasonable search and duplication fees in connection with this request. However, the FOI Act provides for waiver or reduction of fees if disclosure could be considered as "primarily benefiting the general public." I am a journalist employed by The Knoxville Journal and intend to use the information I am requesting as the basis for a planned article. Therefore, I ask that you waive all search and duplication fees. If you deny this request, however, and the fees will exceed $50, please notify me of the charges before you fill my request so that I may decide whether to pay the fees or appeal your denial of my request for a waiver.

DEC 04 1985

As I am making this request as a journalist and this information is of timely value, I will appreciate your calling me by telephone, rather than by mail, if you have any questions. Thanks and I will look forward to your reply within 10 business days, as required by law.

8002023

Sincerely,

Randell B[illegible], reporter
(615) 522-4141, Ext. 423

40-017

DOE F 1325.8
(7-79)

U.S. DEPARTMENT OF ENERGY

# memorandum

DATE November 12, 1985

REPLY TO ATTN OF MA-232.1 -Joan Ogbazghi

SUBJECT Freedom of Information Request #1104850SD

TO Jane Monhart, CH Operations Office

Attn Bernie Russ

The attached Freedom of Information (FOI) request is being sent to you for action as the records requested appear to be principally within the purview of your organization. If our determination is incorrect, please inform me immediately to whom you are forwarding this request.

If other divisions, offices or field organizations also have records relevant to this request, you as the appropriate FOI Office are responsible for requesting their participation and for coordinating the response. It is important that an appropriate response be forwarded to the requester within 10 working days as failure to act can be deemed a denial.

On the reverse side of this memorandum, a "Reminder of Procedures for Handling FOI Requests" should assist your staff. If you have any questions, I can be reached on FTS 252-5955.

John H. Carter
Chief of FOI and Privacy Acts
Activities Branch
Division of Reference and
Information Management

Attachment

DEC 04 1985

8002024

40-017

November 14, 1985

Mr. Randall Beck
The Knoxville Journal
P.O. Box 911
Knoxville, TN 37901

Re: 1104830901
1104850701
1104850801
1104850220

Dear Mr. Beck:

Your October 30, 1985, Freedom of Information requests (copies enclosed) addressed to the U.S. Department of Energy were received on November 8, 1985, and have been sent to our Freedom of Information Officers at our Chicago, Oak Ridge, Richland and San Francisco Operations Offices. They will correspond directly with you about your requests.

In compliance with the Freedom of Information Act, the 10 day response period will begin when the offices designated above have received your requests. If you need further assistance, please contact Jane Hanbert, Chicago Operations Office, 9800 South Cass Avenue, Argonne, IL 60439, (312) 972-2076; Wayne Range, Oak Ridge Operations Office, P.O. Box E, Room 1012, Oak Ridge, TN 37831, (615) 576-0885; Gail H. Bohlan, Richland Operations Office, 825 Jadwin Avenue, P.O. Box 550, Richland, WA 99352, (509) 376-8274; Elsie Mutobo, San Francisco Operations Office, 1333 Broadway, Wells Fargo Building, Oakland, CA 94612, (415) 273-4358.

We have assigned the above referenced numbers to your requests and ask that you refer to them in any future correspondence.

Sincerely,

Original signed by John H. Carter

John H. Carter
Chief of FOI and Privacy Acts
Office of Administrative Services

cc: Official File Copy
Action Officer &
Official File (RF)
Doc. 2832
MA-232.1:JBO:ejb:26025:11/13/85

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SECRET



40-017

February 27, 1946

Dr. Wright Langham
% Dr. Louis Hempelmann
P. O. Box 1663
Sante Fe, New Mexico

Dear Dr. Langham:

I have your note of the 20th of February calling my attention to failure of adhesive to be placed on specimen bottles. I think the matter has now been corrected.

I hope this next part of the letter will not prove too much of a shock to you since we have run through an acute experiment. No collections of urine or feces were made in this instance. We are calling the experiment Hp11. The material was given on February 20th at about 4 PM. The subject died on February 26 at 4:50 AM. The complete post mortem was performed about 5½ hours later. I have tabulated below the weights of the principle organs and the size of the samples obtained from each. In the case of the kidneys, you have approximately half of both the right and left. All the specimens are preserved with 75% alcohol. We were somewhat pressed for time and perhaps did not obtain as much in the way of bone samples as we might have. The cause of death was cirrhosis of the liver and thrombosis of the portal vein. We do not have the body weight, but in health it was probably in the neighborhood of 70 kg.

The dose given was the same as that previously used in our work. Dr. Fink or Miss Silberstein will write you soon with regard to standardization.

Hp 6 has been discharged and we will probably discharge Hp 7 within a few days. I am planning to start Hp 8 sometime this week.

In addition to the samples listed in the tabulation below, we are sending two 15 ml. samples of blood and two 15 ml. samples of ascitic fluid.







Sincerely yours,

Samuel E. Bassett

SEB:rmh



8002026

Pool (1) Control
3/16/46 8:00 A.M. to 3/20/46 8:00 A.M.

| 24 Hr. Period | Volume |
|---|---|
| 3/10/46 to 3/17/46 | 900 ml |
| 3/17/46 to 3/18/46 | 1300 ml |
| 3/18/46 to 3/19/46 | 1200 |
| 3/19/46 to 3/20/46 | 1500 |
| | 4900 |

Pool mixed and 1700 ml forwarded.

Pool (2) Control
3/20/46 8:00 A.M. to 3/24/46 8:00 A.M.

| 24 Hr. Period | Volume |
|---|---|
| 3/20/46 to 3/21/46 | 1400 |
| 3/21/46 to 3/22/46 | 1400 |
| 3/22/46 to 3/23/46 | 1200 |
| 3/23/46 to 3/24/46 | 1800 |
| | 5800 |

Pool mixed and 1600 ml forwarded.

In preparing each days urine, sufficient distilled water has been added to bring the volume exactly to the 100 ml mark next above that of the actual urine volume. It is my intention to send on another urine sample from the four-day pool ending at 8:00 A.M., 3/28/46 .

The experimental period will begin as soon as possible thereafter and subsequent urines will be collected in accordance with our usual schedule.

Rpll — This case did turn out to be terminal, but at the time I started the experimental period, there was sufficient uncertainty regarding the outcome to make me feel that the dose should be within the range of tolerance. From the standpoint of allowing adequate time for mixing and deposition, I think it should have been a good experiment. Many of the physiological functions seemed reasonably intact.

The larger doses that you mention, particularly 50 micrograms, might be given if a suitable opportunity occurred and if you are very anxious that I should carry it through. I will see what can be done.



Sincerely yours,

Samuel H. Bassett, M.D.

SHB:rmh



1/27/46 mgw

February 27, 1946

## Total Gross Weight of Organs.

| | |
|---|---|
| Liver | 2325 grams |
| Heart | 370 grams |
| Spleen | 300 grams |
| Lung, right | 690 grams |
| Lung, left | 370 grams |
| Kidney, left | 130 grams |
| Kidney, right | 150 grams |

## Weights of Specimens

| | |
|---|---|
| Liver, left | 57.4 grams |
| Liver | 113.5 grams |
| Heart muscle | 21.3 grams |
| Spleen | 83.1 grams |
| Lung, left | 13.8 grams |
| Kidney, left | 61.9 grams |
| Kidney, right | 80.0 grams |
| Adrenal | 7.3 grams |
| Thyroid | 19.3 grams |
| Testicle & Epididymis | 46.5 grams |
| Intestine, small | 50.2 grams |
| Intestine, large | 40.0 grams |
| Skeletal muscle | 23.0 grams |
| Vertebral body | 26.3 grams |
| Sternum | 5.5 grams |
| Sternal marrow | 6.4 grams |
| Costal cartilage (1) | 8.5 grams |
| Costal cartilage (2) | 8.4 grams |
| Costal cartilage (3) | 6.8 grams |
| Rib | 21.5 grams |
| Bile | 8.8 grams |

This is a Joint Report from the Los Alamos Scientific Laboratory of the University of California and the Atomic Energy Project of the University of Rochester School of Medicine and Dentistry.

The Report covers a Cooperative Research Project initiated under the supervision of the Manhattan Engineer District and completed under Contract No. W-7401-Eng-49 and Contract No. 7405-Eng-36 for the Atomic Energy Commission.

September 20, 1950

LA - 1151

# DISTRIBUTION AND EXCRETION OF PLUTONIUM ADMINISTERED INTRAVENOUSLY TO MAN

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HEALTH AND BIOLOGY





## ACKNOWLEDGEMENT

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Dr. Stafford L. Warren was primarily responsible for the initiation of the program under the Manhattan Engineer District.

Drs. W. S. McCann, A. H. Dowdy, W. F. Bale, Harold Hodge and L. H. Hempelmann participated in the early planning of the work and frequently made general and specific decisions which contributed much to the success of the program.

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Drs. J. G. Hamilton, Jack Schubert, E. R. Russell, Austin Brues and H. M. Parker contributed some of the information used in this report and in some cases reviewed parts or all of the manuscript.

Drs. L. H. Hempelmann, T. N. White, Frederick Reines, E. C. Anderson, J. T. Brennan and G. W. Taylor reviewed the report and contributed many constructive criticisms.

Fig. 1 Nuclear Track Autoradiograph Showing Localization of Plutonium in the Bone of the Rat. (A. Williams, J. Wellnitz; Photomicrography by Los Alamos Photographic Laboratory).







D-57-57



# DISTRIBUTION AND EXCRETION OF PLUTONIUM ADMINISTERED INTRAVENOUSLY TO MAN

## I. INTRODUCTION

It is now a well established fact that the deposition of radioactive material (Ra, its isotopes and daughter products) in the skeletal system of radium dial painters was responsible for the bone necrosis, radiation osteitis, osteogenic sarcoma and other pathological changes in bone which characterize the condition commonly known as chronic radium poisoning.

Hamilton and co-workers (1) were the first to demonstrate that plutonium, like radium, concentrates in the skeletal system of the rat. Numerous reports have emphasized that bone is a major site of plutonium deposition regardless of the animal species, the valence state of the material or the route of administration (2), (3a, b, c). Autoradiographic studies of the mode of deposition of plutonium in bone (4), (5), (6), (7) showed that it was deposited in a pattern quite different from that of radium. The latter element tends to be incorporated into the bone salts exclusively and becomes buried in the calcified structure in the manner to be expected from a member of the calcium family in the periodic table. Plutonium, however, shows some deposition in soft tissues (especially in the liver) and a remarkable affinity for the non-calcified, non-cartilaginous areas of bone. The material is highly localized in the epiphyseal line, the periosteum and the endosteum so that localization is predominately in regions of trabecular bone (See Fig. 1, frontpiece). The general conclusion was that the mode of deposition of plutonium made it potentially more hazardous than radium. Although there is only limited proof that the above conclusion is justified, it must be considered when evaluating the potential chronic toxicity of the material.

Subsequent experiments with rodents by Brues, Lisco and Finkel (8) and others (9) have demonstrated that plutonium is quite effective in producing pathological changes in bone including osteogenic sarcoma (See Fig. 2).

Brues (10) compared the relative chronic toxicity of equivalent microcurie amounts of plutonium and radium by following 1000 rats, 600 mice throughout life and 37 rabbits for over 400 days. A comparison of survival time, radiographically determined bone damage, pathological fractures and bone tumors in these animals appeared to bear out a plutonium-radium chronic toxicity ratio of 12-15/1 on the basis of injected dose or about 4-5/1 on the basis of retained material.

The above observations and the experiences of the radium dial industry have emphasized the necessity of employing extremely rigid control over all plutonium operations. The major health problem associated with plutonium processing is, of course, the possibility that small amounts of plutonium accumulated in the skeletal systems of workers may, over a period of from ten to thirty years, cause bone changes similar to those observed in chronic radium poisoning. The possibility is serious enough to justify the adoption of a rigid maximum permissible body burden as is currently done with radium.

Only recently the subcommittee on internal radiation tolerances of the National Bureau of Standards established a tentative maximum permissible body content of 2.5 $\mu$g (0.032 $\mu$c) for plutonium. This value was adopted immediately by the Division of Biology and Medicine of the Atomic Energy Commission as the official maximum permissible tolerance for plant personnel (11).

Adequate information as to the fixation and excretion of plutonium by man is essential to the evaluation and interpretation of the maximum permissible body tolerance. More specifically such studies seem highly important for the following purposes:

1. To minimize the degree of uncertainty inherent in extrapolating the vast amount of animal experimental data to man.

2. To provide the best possible quantitative basis for the diagnosis of degree of exposure of personnel to plutonium.
3. To determine the degree of fixation of plutonium by man and establish criteria for the period of retirement from further exposure of workers having received a maximum permissible dose.
4. To provide more extensive and quantitative data on the deposition and excretion of plutonium by man as a basis for future consideration of maximum permissible body tolerance.

Need for the above information was recognized several years ago. It was also recognized that such information could be obtained only by administering small tracer amounts of plutonium to persons with a relatively short life expectancy. The first tracer study was initiated April 10, 1945 (12). Shortly thereafter, both the Chicago and Berkeley groups initiated similar studies (13), (14).

This report is the final presentation of the results of twelve plutonium tracer cases studied as a joint project of the Los Alamos Scientific Laboratory of the University of California and the Atomic Energy Project of the University of Rochester School of Medicine and Dentistry.

The results of the studies conducted by the Berkeley and Chicago groups are correlated with the present ones providing a collection of data from sixteen cases.

In addition to the twelve tracer cases mentioned above, the Los Alamos Scientific Laboratory has had approximately six years experience with exposure problems associated with the processing of large amounts of plutonium.

Wherever applicable, the Laboratory's experiences with the exposure of personnel are used to enlarge and supplement the data collected from the plutonium tracer studies presented in this report.

## II. METHODS

### A. Selection and Description of Subjects

The life expectancy of the individual was carefully considered as a basis of selection of subjects for study. As a rule, the subjects chosen were past forty-five years of age and suffering from chronic disorders such that survival for ten years was highly improbable. By adhering to these criteria, the possibility of late radiation effects developing would be avoided. Furthermore, an opportunity to obtain post-mortem material within a few months, or at most a few years, would be much greater.

Of twelve patients chosen, ten were past the age of forty-five. One was only eighteen years old, and has since died of Cushing's Syndrome. Up to the time of this report, and approximately five years since the initiation of the first study, five subjects are known to have died of their diagnosed illness. Autopsies and tissue samples were obtained from only three of the five terminated cases.

Brief summaries of the medical histories of the subjects of these studies are as follows:

Hp-1

This patient, a sixty-seven year old white male with a nine year history of peptic ulcer, was admitted to the hospital following a severe gastrointestinal hemorrhage. The presence of a duodenal ulcer was confirmed by x-ray examination and a traction diverticulum of the esophagus was noted. Clinical diagnoses included duodenal ulcer, gastrointestinal hemorrhage with secondary anemia, and esophageal diverticulum.





Hp-2

This patient, a forty-nine year old white male, was a known hemophiliac and entered the hospital on this occasion for the thirty-eighth time. Symptoms referable to hypertension had been present for three years. Clinical diagnoses on this admission included hemophilia, essential hypertension with hypertensive cardiovascular disease and coronary insufficiency, and chronic arthritis.

Hp-3

This patient, a forty-nine year old white female, was admitted to the hospital with complaints of pigmentation of the skin, pruritic dermatitis and dependent edema. Initial clinical studies were carried out in November and December 1945, at which time diagnoses of hepatitis of unknown etiology and hypoproteinemia were made. She was admitted for follow-up examination in October 1948, when she appeared in good health.

Hp-4

This patient, an eighteen year old white female, had a history of Cushing's Syndrome since 1941. Her admission in October 1947 was the fifth period of hospitalization. Chief complaints on this occasion were referable to hypertension and osteoporosis. The clinical diagnoses were basophile adenoma of the pituitary gland with hypertension, hypertensive heart disease, nephropathy with uremia, osteoporosis, and a staphylococcic infection of the urinary tract. The patient ran a down hill course until death in uremia occurred in April 1947. Diagnoses at autopsy included basophile adenoma of the pituitary gland, atrophy of the thyroid gland, hypertrophy of the adrenals, hypertrophy of the left ventricle, hypoplasia of the uterus and ovaries, osteoporosis of the spine and pelvis, and chronic nephritis.

Hp-5

This patient, a fifty-six year old white male, was admitted to the hospital in November 1945 with complaints of generalized weakness and difficulty in walking and swallowing of three years duration. The clinical diagnosis was amyotrophic lateral sclerosis. Death occurred in April 1946. The diagnoses at autopsy included amytrophic lateral sclerosis, bronchopneumonia, generalized arteriosclerosis, renal cysts and adenoma of the right kidney.

Hp-6

This patient, a forty-five year old white male with a history of Addison's disease since January 1945, was admitted to the hospital on December 14, 1945, for treatment of numerous infected lesions of the eyelids and toes. He responded to conservative treatment and studies began during convalescence. On readmission in June 1947, his condition was essentially unchanged.

Hp-7

This patient, a fifty-nine year old white female who had been previously treated for heart disease and hyperthyroidism, was hospitalized on January 21 1946, for cardiac decompensation. The clinical diagnoses were rheumatic heart disease with mitral insufficiency and auricular fibrillation, and toxic nodular goiter. She expired in October 1946. Permission for autopsy was withheld, but the probable cause of death was lobar pneumonia.

Hp-8

This patient, a forty-one year old white female, had a history of scleroderma since January 1945, and a duodenal ulcer first diagnosed in 1944. The clinical diagnoses on this admission were scleroderma and duodenal ulcer.

Hp-9

This patient, a sixty-six year old white male, was admitted to the hospital in March 1946 with a history of generalized dermatitis and weakness of eighteen months duration. A diagnosis of dermatomyositis was made. The patient expired in July 1947. Diagnoses at autopsy included generalized muscular atrophy, dermatitis, purulent bronchitis and bronchopneumonia, hypertrophy and dilatation of the heart, and chronic passive congestion of the liver and spleen.

Hp-10

This patient, a fifty-two year old negro male, was admitted to the hospital on March 24, 1946, in acute congestive heart failure. A history of heart disease since 1926 was obtained, and his history included both rheumatic fever and luetic infection. The clinical diagnoses on this admission included rheumatic heart disease, latent treated syphilis and ethmoidal and frontal sinusitis.

Hp-11

This patient, a sixty-eight year old white male with history of alcoholism and dietary inadequacies for many years, was admitted to the hospital on December 12, 1945, with complaints of dyspnea and abdominal swelling. He expired on February 26, 1946, and diagnoses at autopsy were cirrhosis of the liver, ascites, and thrombosis of the portal vein.

Hp-12

This patient, a fifty-three year old colored male, was hospitalized on March 25, 1945, following an automobile accident in which he sustained comminuted fractures of the left femur and right patella and a transverse fracture of the right radius and ulna. Physical findings of note included a left lenticular cataract and marked hypertrophic and atrophic arthritic changes in both knees, together with osteochondromatosis of the left knee.

B. Management of Subjects and Collection of Samples

Ten of the twelve patients were cared for in the special metabolic ward of Strong Memorial Hospital. The general management of the ward patients was as follows:

A control period of about ten days was utilized to instruct the patient in the quantitative collection of urine and fecal specimens. During this period all necessary adjustments to ward routine and all necessary modifications in diet were completed. After the patient had proven himself capable of cooperation, a series of control urine and fecal samples were collected for the purpose of "blank" determinations by the method of plutonium analysis. Preceding the injection of plutonium and again at termination, physical and laboratory examinations were conducted on each subject.

Blood samples were drawn into dry sodium citrate as an anticoagulant. Samples of 15 ml were taken before administration of plutonium and at four hours, one day, three days, six days, ten days, fifteen days, etc., post injection.

Urine samples were collected directly into half-gallon fruit jars and preserved with formaldehyde. The urine was usually collected in 24 hour periods except on the day the plutonium was given. During the first day it was collected in two 12 hour periods.

Fecal samples were collected in three-liter beakers. The patient was instructed to empty the bladder before defecation to avoid admixture of urine and feces. As a rule feces were pooled during intervals of four days, except immediately after the plutonium was given when the first two stools were collected separately. All samples were preserved by boiling for ten minutes with 6 N HCl.

Tissue samples of from 25 to 150 g were obtained at autopsy and preserved in 80 per cent alcohol.









C. Administration of Plutonium

The plutonium solution used in these studies was prepared by dissolving 5.0 mg of spectrographically pure plutonium metal in 1.0 ml. of 2 N $HNO_3$. The solution was assayed for plutonium by alpha counting. An appropriate aliquot of the plutonium solution was placed in a 10 ml volumetric flask and diluted to volume with sterile 0.41 per cent sodium citrate·$2H_2O$. The solution prepared in the above manner had a pH of approximately 5.5 and the plutonium was in the form of $Pu^{+4}$-complex.

The technique of injection and the method of assay of the injected dose were as follows: One syringe was filled with sterile saline and a 22-gauge needle attached. The other syringe was filled with 0.5 ml of the plutonium solution and the needle used for filling the syringe was discarded. The needle of the syringe containing sterile saline was introduced into a cubital vein and the saline slowly injected to insure unrestricted entry into the vein. The syringe was then carefully detached from the needle, which was still in the vein, and the syringe containing the plutonium injection solution was substituted. The plutonium solution was injected rapidly after which the syringe was rinsed once by drawing it full of the patient's blood and discharging the blood back into the vein.

The same syringe and needle used to inject the patient was used to measure 0.5 ml aliquots of the plutonium solution into each of four volumetric flasks. The washing of the syringe and the other essential steps of the injection technique were duplicated. The contents of each flask was diluted to volume with 2 N HCl and a suitable aliquot of each evaporated directly on platinum discs and assayed for alpha activity. The average of the four assays was taken as the amount of plutonium administered to the patient. The average standard deviation for each set of four results was 3.0 per cent. The amount of material received by each subject and the date of injection are presented in Table I.

TABLE I

AMOUNT OF PLUTONIUM ADMINISTERED TO SUBJECTS VIA INTRAVENOUS INJECTION* AND THE DATE OF ADMINISTRATION

| Designation of Subject | Date of Injection | μg Pu Injected** |
|---|---|---|
| Hp- 1 | October 16, 1945 | 4.6 |
| Hp- 2 | October 23, 1945 | 5.1 |
| Hp- 3 | November 27, 1945 | 4.9 |
| Hp- 4 | November 27, 1945 | 4.9 |
| Hp- 5 | November 30, 1945 | 5.1 |
| Hp- 6 | February 1, 1946 | 5.3 |
| Hp- 7 | February 8, 1946 | 6.3 |
| Hp- 8 | March 9, 1946 | 6.5 |
| Hp- 9 | April 3, 1946 | 6.3 |
| Hp-10 | July 16, 1946 | 6.1 |
| Hp-11 | February 20, 1946 | 6.5 |
| Hp-12 | April 10, 1945 | 4.7 |

* Pu was administered as $Pu^{+4}$-citrate in 0.5 ml of 0.41% solution sodium citrate·$2H_2O$.

** Average standard deviation of determination of dose was 3.0 per cent.

D. Analytical Procedures

All urine samples were analyzed for plutonium using the cupferron extraction procedure developed at the Los Alamos Scientific Laboratory for the determination of exposure of laboratory personnel (15).

Fecal samples were analyzed by a modification of the cupferron procedure published earlier (16).

Blood and other tissue samples were "ashed" either in a muffle furnace or with conc. $HNO_3$ and $H_2O_2$. The ash solution was analyzed for plutonium by the cupferron extraction procedure in exactly the same manner employed for the analysis of urine ash solutions.

## III. RESULTS

### A. Clinical Observations

Acute toxic effects from the small doses of plutonium administered in these studies were neither expected nor observed.

As seen from the summaries of case histories (Pages 10 - 14), the subjects used in this study were suffering from a variety of conditions. In most cases, however, kidney and liver function appeared to be essentially normal. There were two notable exceptions.

Hp-4 was suffering from Cushing's Syndrome and chronic nephritis. The highly abnormal condition of this subject was accompanied by higher plutonium content in blood and urine and apparently a slower rate of plutonium fixation in bone. In fact, several of the urine analyses were ruled non-representative on the basis of the Chauvenet criterion.

Hp-11 was moribund at the time plutonium was administered. Therefore, no plutonium excretion values were obtained. Anatomical diagnosis revealed cirrhosis of the liver with associated ascites, which indicated marked impairment of liver function.

The data in Table 2 summarize some of the clinical laboratory observations. These data show no consistent trends in hemoglobin, red blood cell count, white blood cell count and differential count as a result of the injection of approximately 5 μg of plutonium. The rise in hemoglobin and red blood cell count in Hp-12 probably was a result of therapeutic measures. The observations in Table 2 were quite in accord with those made by Russell and Nickson (13) who collected excellent clinical laboratory data from two cases following administration of plutonium. One individual received 6.5 μg of plutonium and was followed for 155 days. Another subject received 95 μg of plutonium and was followed for six days. No alterations attributable to plutonium were found in the constituents of the peripheral blood of either patient.

In the present series clinical evidence suggestive of liver damage did not appear. While specific tests of liver function were not as a rule listed in the protocols, the possibility that injury to this organ might appear was considered.

Admittedly the observations made during this study provide no evidence of what may happen in 10-30 years. It may be said, however, that these studies and those of other investigators indicate that the intravenous injection of a single dose of 5 to 100 μg of plutonium was without acute subjective or objective clinical effects.

### B. Deposition of Plutonium in the Body

Since the beginning of this study, four of the subjects (Hp-4, 5, 7 and 9) have died as a result of their diagnosed illness. Another subject, Hp-11, was in the terminal phase at the time of injection. Autopsy and tissue samples were obtained in only three of the five cases. Two bone specimens were obtained from Hp-12 during open reduction of fractures and a number of his teeth were obtained at a later date. Blood samples were obtained from all









TABLE 2

CLINICAL DATA ON SUBJECTS RECEIVING INTRAVENOUS INJECTION OF APPROXIMATELY 5 μg OF PLUTONIUM AS $Pu^{+4}$ CITRATE

| PATIENT CODE | SEX | AGE | WT kg | Pu ADMIN AMT μc | Pu ADMIN DATE | LABORATORY STUDIES* DATE | HGB | RBC | WBC | PMN | LYMPHS | EOS | BASO | MONO | UREA Cl | BUN | SPS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hp- 1 | M | 87 | 70.3 | 4.8 | 10 10 | 10 4<br>10 19 | 13.5<br>13.5 | 4.47<br>4.55 | 7.1<br>7.0 | 74 | 19<br>24 | 1 | 0<br>1 | 6 | 96 | 21 | |
| Hp- 2 | M | 49 | 69.0 | 5.1 | 10 22 | 10 6<br>11 7 | 15.0<br>14.5 | 4.7<br>4.3 | 5.05<br>7.85 | 57<br>68 | 28<br>22 | 8<br>8 | 0<br>0 | 2<br>2 | 96<br>48 | 25<br>23 | |
| Hp- 3 | F | 49 | 69.9 | 4.9 | 11 27 | 11 5<br>12 16 | 14.5 | 4.3<br>5.6 | 5.2<br>6.8 | 58<br>69 | 39<br>25 | 2<br>0 | 0<br>1 | 0<br>5 | 96 | | 34<br>31 |
| Hp- 4 | F | 18 | 55.5 | 4.9 | 11 27 | 11 30<br>12 21 | 15.0<br>16.0 | 5.3 | 10.0<br>6.9 | 77<br>76 | 20<br>22 | 0<br>0 | 1<br>0 | 2<br>4 | | | |
| Hp- 7 | F | 58 | 68.0 | 6.3 | 2 8 | 1 23<br>2 27 | 12.1 | 3.26 | 4.25<br>8.2 | 64<br>64 | 24<br>25 | 3<br>0 | 0<br>0 | 6<br>9 | 96 | | 26 |
| Hp- 8 | F | 61 | 54.4 | 6.3 | 3 9 | 2 22<br>3 27 | 13.1<br>14.5 | 4.2<br>4.05 | 9.5<br>11.9 | 71<br>86 | 22<br>12 | 0<br>0 | 0<br>0 | 13<br>0 | 85 | 10 | 30 |
| Hp- 9 | M | 66 | 63.0 | 6.3 | 4 3 | 3 13<br>3 29 | 12.3<br>12.3 | 3.9<br>4.1 | 6.25<br>7.4 | 70<br>61 | 17<br>9 | 0<br>12 | 0<br>1 | 13<br>17 | 72 | | |
| Hp-10 | M | 45 | 70.0 | 6.1 | 7 16 | 7 9<br>8 13 | 13.3 | 4.6 | 5.65 | 31<br>42 | 52<br>48 | 5<br>3 | 2<br>2 | 7<br>8 | 52<br>52 | 11 | 22 |
| Hp-12 | M | 53 | | 4.7 | 4 9 | 4 6<br>7 3 | 8.9<br>13.5 | 2.85<br>4.51 | 5.6<br>4.3 | 74<br>52 | 20<br>64 | | | 6<br>4 | | 57<br>17 | 44<br>55 |

*Explanation of Symbols: HGB Hemoglobin, RBC Red Blood Cell Count, WBC White Blood Cell Count, PMN Polymorphonuclear Cells, LYMPHS Lymphocytes, EOS Eosinophiles, BASO Basophiles, MONO Monocytes, PCN Blood Urea Nitrogen, SPS Sun Protein Sulfate, UREA Cl Urea Free Chloride, BUN Blood Urea Nitrogen

Note: Per Cent of Normal at One Hour

subjects before plutonium injection and at frequent intervals thereafter. All tissue samples were analyzed for plutonium by the cupferron extraction procedure subsequent to ashing.

The data in Table 3 show the results of analyses of the various samples for plutonium. The results obtained by Russell and Nickson (13) (referred to as Cal. I, II, III) and Hamilton et al (14) (referred to as Cal. 1) are presented also. Two important points must be kept in mind when considering these data: (1) The samples of human tissues were, for obvious reasons, rather unsatisfactory. In most cases they were too small, poorly representative and were usually what could be obtained under the circumstances rather than what were desired; (2) The subjects were chronically ill and/or elderly and the results may not represent exactly the distribution of plutonium in tissues of healthy persons of average working age. These data, however, are all that are available and, therefore, must provide the basis for our present concept of the distribution of plutonium in the organs and tissues of man. They must also provide a basis for comparison with the results obtained from the numerous studies of plutonium deposition in experimental animals.

#### 1. Deposition in the Skeleton

Animal experiments (1) (2) reveal that approximately 60 per cent of plutonium injected as $PuO_2^{++}$ and $Pu^{+4}$ - citrate is localized in bone. If the vertebra, sternum and whole ribs are taken as representative bones of the skeleton, and the average plutonium content [illegible]

TABLE 3

DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUES FOLLOWING INTRAVENOUS INJECTION OF PLUTONIUM SALTS

| Tissue[2] | Subject[1] and % of Injected Dose g of Tissue | | | | | | | | Rel. Pu Affinity[3] | Org. Wt., g[4] | Calc. % Organ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-5 | Hp-9 | Hp-11 | Chi. I | Chi. II | Hp-12 | Cal. I | Av. % g | | | |
| Bone Marrow | -- | -- | .0096 | .0153 | .0210 | -- | .0280 | .0187 | -- | 3,000 | (56.1)[6] |
| Radius (Prag. head) | -- | -- | -- | -- | -- | .0187 | -- | -- | -- | -- | -- |
| Liver | .0320 | .0144 | .0053 | .0139 | .0024 | -- | -- | .0136 | 8.7 | 1,700 | 23.1 |
| Rib (Cortex) | -- | -- | -- | .0015 | .0190 | - | .0170 | .0127 | 8.1 | -- | -- |
| Patella | -- | -- | -- | -- | -- | .0149 | -- | -- | -- | -- | -- |
| Vertebra | .0071 | .0060 | .0070 | -- | -- | -- | -- | .0073 | 5.2 | | -- |
| Sternum | .0070 | -- | .0100 | .0044 | -- | -- | -- | .0071 | 5.1 | 10,000 | = 65.7[5] |
| Rib (Whole) | .0050 | .0038 | .0068 | -- | -- | -- | -- | .0052 | 3.7 | | -- |
| Periosteum (R) | -- | -- | -- | .0043 | .0019 | -- | .0048 | .0037 | 2.6 | -- | -- |
| Spleen | .0007 | .0015 | .0048 | .0024 | .0016 | -- | .0019 | .0021 | 1.5 | 200 | 0.4 |
| Kidney | .0002 | .0002 | .0015 | .0004 | .0004 | -- | -- | .0015 | 1.0 | 300 | 0.4 |
| Thyroid | .0001 | -- | .0009 | -- | .0034 | -- | -- | .0014 | 1.0 | 30 | -- |
| Adrenal | .0004 | -- | .0042 | -- | -- | -- | -- | .0013 | 1.0 | 14 | -- |
| Lung | .0005 | -- | .0018 | .0008 | .0018 | -- | -- | .0011 | 0.8 | 950 | 1.0 |
| Pancreas | .0002 | .0002 | -- | -- | .0022 | -- | -- | .0009 | 0.6 | 65 | -- |
| Gonads | .0003 | -- | .0012 | .0034 | .0009 | -- | -- | .0007 | 0.5 | -- | -- |
| Lymph Node | -- | -- | -- | .0014 | .0001 | -- | -- | .0007 | 0.5 | 700 | 0.5 |
| Teeth (Av. of 7) | -- | -- | -- | -- | -- | .0003 | -- | -- | -- | -- | -- |
| Heart | .0330 | .0000 | -- | .0003 | .0011 | -- | -- | .0003 | 0.2 | 350 | 0.1 |
| Large Intestine | .0002 | - | .0004 | -- | .0001 | -- | - | .0002 | 0.1 | 2,300 | 0.5 |
| Small Intestine | .0001 | -- | .0005 | -- | .0001 | -- | -- | .0002 | 0.1 | -- | -- |
| Muscle and Skin | .0000 | -- | .0002 | .0002 | .0001 | -- | | .0001 | 0.1 | 38,500 | 3.9 |
| Blood | -- | -- | - | -- | -- | -- | -- | -- | -- | 5,400 | 0.2[8] |
| Balance | -- | -- | -- | -- | - | -- | -- | .0001[7] | -- | 9,600 | 0.9 |
| Total | -- | -- | -- | -- | - | - | -- | -- | -- | 70,000 | 96.7 |

(1) The various subjects received the following doses of plutonium: Hp-5 - 5 μg, Hp-9 - 8.3 μg, Hp-11 - 8.5 μg, Chi. I - 6.5 μg, Chi. II - 94.9 μg, Hp-12 - 4.7 μg, Cal. I - 103 μg

(2) Tissues were obtained at the following times after injection: Hp-5 151 days, Hp-9 456 days, Hp-11 5 days, Chi. I 155 days, Chi. II 16 days, Hp-12 5 days, Cal. I 4 days

(3) Calculated by dividing % g of tissue in % g of body weight if a unit dose of Pu was equally distr. in a 70 Kg. man.

(4) Hermann Lisco, Memorandum to AEC, July 21, 1947, Project Standard Man

(5) Assumption made that vertebra, sternum and whole rib represent average bone of skeletal system.

(6) Bone marrow not included in total recovery because bone samples were not freed of marrow before analysis

(7) Balance assumed to have same Pu content as muscle

(8) Value for blood taken at 30 day point, Fig. 3









multiplied by the skeletal weight of the "Standard Man" (17), then 65.7 per cent of the injected dose is the estimated amount of plutonium in the skeleton of a 70 kg man. Although the latter value was established rather arbitrarily, it is in good agreement with the value expected from animal experiments.

The data in Table 3 indicate a rather high plutonium content in bone marrow. The average of four determinations from three different laboratories was 0.0187 per cent of the injected dose per gram of marrow. On the basis of 3000 g of bone marrow, there would be 56 per cent of the injected dose concentrated in the marrow of a 70 kg man. Animal studies do not show appreciable concentrations of plutonium in the marrow. The major areas of plutonium concentration in rats and mice are the endosteum, periosteum and the epiphyseal line. It is quite possible that the samples of human marrow were too small to be representative, contained endosteum or spicules, or that the high deposition was an indication of an age factor related to the fact that the epiphyses of man unlike those of the rat unite at maturity.

2. Deposition in the Liver

The average plutonium deposition in the liver for the five cases was 0.0136 per cent of the injected dose per gram, which corresponds to 23.1 per cent of the dose in a 1700 gram liver (Standard Man). Table 4 presents the liver data in more detail, including the two cases reported by the Chicago investigators (13).

TABLE 4

LIVER DEPOSITION OF PLUTONIUM ADMINISTERED INTRAVENOUSLY TO MAN

| Subject | Days After Injection | Liver Wt. in Grams | % of Dose per Gram | % of Dose per Organ |
|---|---|---|---|---|
| Hp-5 | 151 | 1340 | .0320 | 42.8 |
| Hp-9 | 456 | 1600 | .0144 | 23.0 |
| Hp-11[1] | 5 | 2325 | .0053 | 12.3 |
| Chi. I[3] | 155 | 2050 | .0139 | 28.5 |
| Chi. II[2,3] | 16 | 1110 | .0024 | 2.7 |
| AVERAGE | 156 | 1641 | .0136 | 21.9 |

(1) Hp-11 was in terminal phase of illness; plutonium deposition probably low because of severe cirrhosis of the liver.

(2) Chi.-II was in terminal phase of adenocarcinoma; plutonium deposition probably low because of metastases to the liver.

(3) Russell, E.R. and Nickson, J.J. (13)

Two cases (Hp-11 and Chi.-II) were in the terminal phase of illness at the time plutonium was administered. Both showed advanced liver disease. The values for plutonium deposition in the liver of these cases is highly questionable. The results in the other three cases, however, were rather striking. As pointed out by Russell and Nickson (13), the content of

plutonium in the liver was much higher than was to be expected from results in experimental animals. Even though one of their cases survived 155 days after receiving plutonium in the +6 valence state (a form known to give low liver deposition in rats (1) (2) ), 28.5 per cent of the injected dose was found in the liver. Subject Hp-5 had 42.8 per cent of the plutonium injected as $Pu^{+4}$-citrate deposited in the liver after 151 days. The third case (Hp-9) survived 456 days and had 23.0 per cent of the injected material deposited in the liver. Considering the elapsed time after injection, the plutonium content of the liver in the two latter cases was even higher than that observed by Russell and Nickson (13). The apparent higher deposition in the latter cases might indicate the destruction of the $Pu^{+4}$-citrate complex by the human liver. The results compare favorably with those obtained when rats were injected with uncomplexed quadrivalent plutonium ion (1), (2), (3). The limited data presented in Table 4 indicated rather strongly that the retention of plutonium by the liver may be much greater for man than for rats and mice, and may be of the order of 20 - 40 per cent of the injected dose during the first year. A comparison of the survival times and the amounts of plutonium deposited in the livers of Hp-5 and Hp-9 seems to indicate a "plutonium retention half-time" in the liver of one year or greater for man as compared to 40 - 60 days for rats.

### 3. Concentration in Blood

The data in Table 5 show the concentration of plutonium in blood at various times after the intravenous injection of approximately 5 μg of plutonium as $Pu^{+4}$-citrate. The results are expressed in per cent of the injected dose in the total blood volume. The blood was assumed to be 7.7% per cent of the total body weight (17).

The individual observations varied widely, especially during the first four days. The mean values, however, fell on a smooth curve (shown in Fig. 3).

The drop in blood plutonium content was very rapid at first, and reflected the very rapid rate of fixation of the material in the body. The mean blood concentration 4 hours after injection was 35.7 per cent, at one day 15.7 per cent, at 10 days 1.2 per cent. Thirty days after injection the blood concentration of plutonium read from the curve in Fig. 3 was only 0.3 per cent of the injected dose in the total blood volume. The extremely small amount of plutonium in the circulating blood eliminates blood analysis by the usual counting procedures as a means of diagnosing the degree of exposure of personnel. The application of techniques employing the counting of alpha tracks registered by alpha sensitive nuclear track photographic emulsions may prove possible.

### 4. Deposition in Other Organs

The amounts of plutonium deposited in organs and tissues other than skeleton, liver and blood were rather small. When the per cent per organ was calculated, based on the organ weight of the "Standard Man", the results were in reasonable agreement with what was anticipated from animal experiments. The data showing the per cent of dose per gram of organ and per cent per organ are given in Table 3 (Page 18). The kidney and spleen each had an estimated average plutonium content of 0.4 per cent of the injected dose per organ.

The relative affinity of the various tissues for plutonium was calculated by dividing the per cent of the dose per gram of organ by the per cent of the dose per gram of body weight when the material was assumed to be equally distributed in a 70 kg man.

The bone, bone marrow and liver were the only tissues that showed a relative plutonium affinity appreciably greater than unity. The spleen was 1.5; all other tissues and samples were 1.0 or less. Obviously the skeletal system and liver are the tissues of major interest when considering the plutonium tolerance, as these two organs alone account for 90 per cent or more of the total plutonium in the entire body.









TABLE 5

PLUTONIUM CONTENT OF BLOOD SAMPLES* FOLLOWING INTRAVENOUS INJECTION OF APPROXIMATELY 5 μg OF PLUTONIUM AS $Pu^{+4}$ - CITRATE

| DAYS AFTER INJECTION | PATIENT CODE AND PER CENT OF INJECTED DOSE IN TOTAL BLOOD VOLUME* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-1 | Hp-2 | Hp-3 | Hp-4 | Hp-5 | Hp-6 | Hp-7 | Hp-8 | Hp-9 | Hp-10 | Hp-12 | AVERAGE |
| 1/6 | 46.02 | - | 26.32 | 83.31 | 31.51 | 36.70 | 42.57 | 37.64 | 40.83 | 51.57 | 5.31 | 35.7 |
| 1 | 21.83 | 19.35 | - | - | 6.23 | 10.97 | 16.40 | 14.51 | 12.39 | 24.86 | - | 15.7 |
| 2 | - | 8.38 | 11.56 | - | - | - | - | - | - | - | - | 9.97 |
| 3 | - | 10.03 | - | 16.64 | 1.16 | 2.94 | 6.97 | 4.94 | 6.22 | 20.06 | - | 8.62 |
| 4 | - | - | 4.22 | - | - | - | - | - | - | - | - | - |
| 5 | - | - | - | - | 0.66 | - | - | - | - | - | - | - |
| 6 | 3.30 | 4.25 | 2.17 | 6.14 | - | 1.66 | 2.06 | 2.67 | 2.91 | 5.91 | - | 3.4 |
| 8 | | 2.32 | 1.42 | - | - | - | - | - | - | - | - | 1.9 |
| 9 | - | - | - | 4.60 | - | - | - | - | - | - | - | |
| 10 | 1.42 | - | - | - | 0.39 | 0.38 | 1.13 | 1.37 | 2.21 | 1.72 | - | 1.2 |
| 13 | - | - | 0.61 | 2.34 | - | - | - | - | - | - | - | 1.5 |
| 15 | - | - | - | - | 0.11 | 1.26 | 0.66 | 0.71 | 1.42 | 1.02 | - | .73 |
| 17 | - | - | 0.51 | 1.45 | - | - | - | - | - | - | - | 1.0 |
| 22 | - | 0.29 | - | - | 0.16 | 0.25 | - | - | - | - | - | .34 |
| 23 | - | - | 0.25 | 0.72 | - | - | - | - | - | - | - | .48 |
| 29 | - | - | - | - | - | - | 0.37 | - | - | - | - | |
| 30 | - | - | - | - | - | - | - | - | - | 0.36 | - | |
| 31 | - | - | - | - | - | - | - | - | - | - | 0.51 | |
| 36 | - | - | - | - | - | - | - | - | 0.42 | - | - | |
| 42 | - | - | - | - | - | - | - | 0.11 | - | - | - | |
| 46 | - | - | - | - | - | - | - | - | - | - | 0.45 | |

*Total Weight of Blood Taken as 7.7% of Total Body Weight.

## C. Excretion of Plutonium

### 1. Urinary Excretion

The urinary excretion of plutonium was studied in eleven of the subjects following the intravenous injection of approximately 5 μg of plutonium as $Pu^{+4}$ in 0.4 per cent solution of sodium citrate $\cdot 2H_2O$. With the exception of the first day, urine from all subjects was collected in 24 hour samples through 22 days post injection. After 22 days the collection of 24 hour urine samples was continued as long as the patients were available for study. It was not possible to retain the subjects as long as was desired and the major weakness in these results is the short time interval over which the studies were continued. Two subjects were followed 22 days, one for 23 days, one for 27, and the remainder for 30 days or longer after injection. The Chicago cases (13) were followed for 16, 140, and 186 days and the California case (14) was followed for a period of 341 days. Because of the great importance of measurements at longer time intervals, the Chicago and California data have been incorporated with

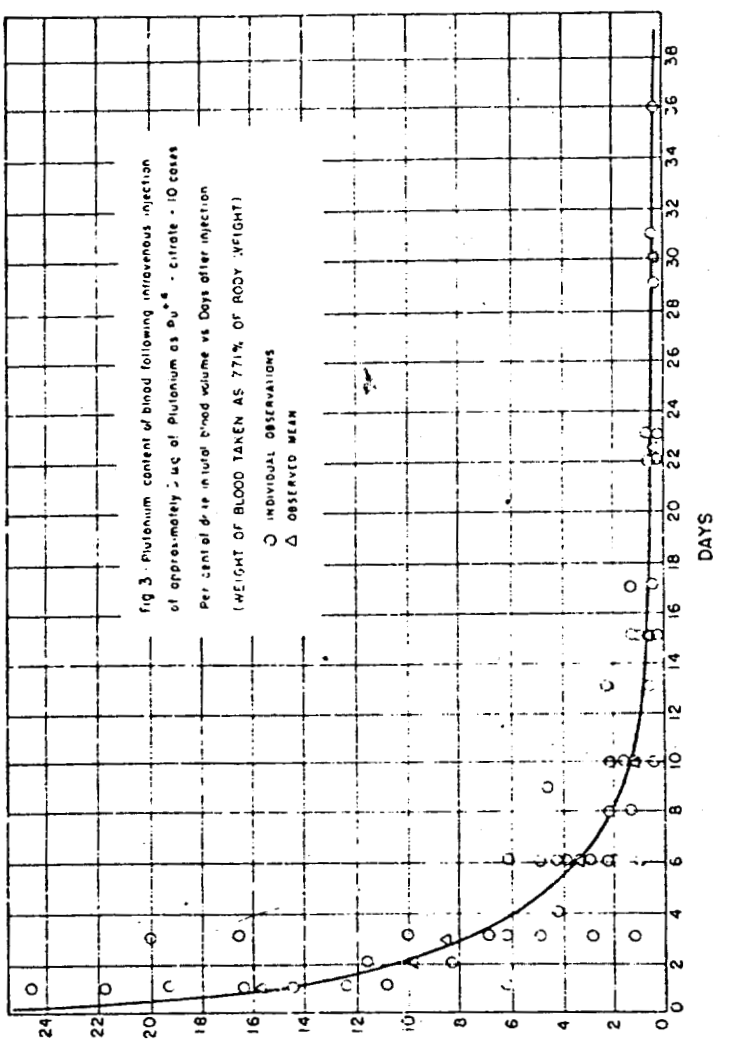


Fig 3. Plutonium content of blood following intravenous injection of approximately 1 μg of Plutonium as $Pu^{+4}$ - citrate - 10 cases
Per cent of dose in total blood volume vs Days after injection
(WEIGHT OF BLOOD TAKEN AS 7.7% OF BODY WEIGHT)
○ INDIVIDUAL OBSERVATIONS
△ OBSERVED MEAN
%
DAYS

the data from these studies. The results of all urine analyses through 138 days post-injection are given in Table 6. Results are expressed as per cent of injected dose excreted per day.

The means, revised standard deviations, and standard deviations for the daily urinary excretion of plutonium from 0 to 138 days post-injection are given in Table 7. The equation of best fit for the observed means is a logarithmic function:

$$Y = aX^{-b} \qquad [1]$$

where Y is the amount of plutonium (expressed as per cent of injected dose) excreted in a single day, X is the time of observation in days post-injection, and a and b are constants derived from the observed data by the method of least squares. Solution gives the following expression for the best curve of fit for the urinary excretion of plutonium utilizing all available data from 0 to 138 days post-injection:

$$Y_u = 6.23\ X^{-0.77} \qquad [2]$$

The agreement between observed mean values and the derived expression for the urinary excretion of plutonium through 138 days post-injection is illustrated graphically in Fig. 4. In this graph the circles represent the observed means and the solid line represents the derived expression. The agreement is fairly good. The overall standard error of estimate, $S_{YX}$, (determined by the usual methods of correlation analysis) was ± 32 per cent. The largest contributions to the standard error of estimate come from the 0 to 10 day portion of the curve and from the latter portion where there is an increased scatter of points because of the decrease in number of observations. Actually, attempts at curvilinear regression fine fitting, indicate that the function $Y = aX^{-1}$ is the best curve for the 0 to 10 day period rather than the logarithmic curve presented. We believe this difference in functional relationship may be due to the clearance of the injected plutonium from the blood during this early period after injection.

Extrapolation of the derived expression beyond 138 days introduces increasing uncertainty with increasing values of X. In order to interpret the excretion results in standard terms, i.e. "biological half-life", despite the fact that the data are not fitted by a single exponential curve, we have chosen to determine $T_{\frac{1}{2}}$ by assuming exponential excretion beyond the limits of observation and estimating $T_{\frac{1}{2}}$ from the last point on the excretion curve (a single value of the urinalysis). One may then assume the slope of the excretion curve to be zero at this point and calculate an absolute minimum value for the "biological half-time". For the above reasons it is important to supplement the urinary excretion data beyond 138 days to the greatest possible extent. Three additional groups of samples were obtained from two of the cases after the close of the experiment. One group of four consecutive daily urine samples was obtained from Hp-6 beginning on the 523rd day and another group beginning on the 1610th day after injection. The average daily urinary excretion of plutonium at 523 days was 0.002 per cent, and at 1610 days 0.001 per cent of the injected dose. Four daily samples collected from Sp-3 beginning at 1545 days after injection showed an average daily urinary excretion of 0.0008 per cent of the injected dose.

In addition to the three groups of samples mentioned above a number of urine plutonium assays were made on workers at the Los Alamos Laboratory. A few of these individuals accumulated measurable amounts of plutonium during wartime operations. They were removed from further exposure to plutonium and occasional urine assays were made over a period of the next several months. The urine assays on three members of the group are given in Table 8. Since these individuals received unknown exposure doses via the usual routes of entry over an indefinite time, the results are not analogous to a single intravenous injection of a known amount of plutonium. However, the inclusion of these individuals has been attempted in order to extend the excretion curve. An attempt has been made to interpret their

TABLE 6

INDIVIDUAL URINARY EXCRETION VALUES OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION[1] TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF DOSE EXCRETED PER DAY)

| DAYS POST INJECTION | PER CENT OF INJECTED DOSE EXCRETED PER DAY | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-1 | Hp-2 | Hp-3 | Hp-4 | Hp-5 | Hp-6 | Hp-7 | Hp-8 | Hp-9 | Hp-10 | Hp-12 | Cal.-I[2] | Cal.-II[2] | Cal.-III[2] | Cal.-IV[2] | Cal.-V[3] |
| 1 | .181 | .472 | .569 | .440 | .296 | - | .217 | .277 | .183 | .414 | .101 | .857 | 3.551* | .15 | | .480 |
| 2 | .176 | .294 | .389 | .238 | .166 | .218 | .212 | .232 | .085 | .330 | .163 | .182 | .153 | .[illegible] | | .198 |
| 3 | .114 | .174 | .112 | .231 | .077 | .127 | .127 | .128 | .069 | .215 | .088 | .063 | .184 | .09 | | .120 |
| 4 | .094 | .123 | .107 | .132 | .052 | .111 | .096 | .140 | .068 | .170 | .078 | .077 | .133 | .09* | | .11 |
| 5 | .069 | .116 | .078 | .116 | .030 | .078 | .089 | .083 | .047 | .068 | .068 | .038 | .033 | .04* | | .077 |
| 6 | .068 | .081 | .043 | .119* | .030 | .057 | .056 | .078 | .053 | .080 | .044 | .0256 | .028 | .043 | - | |
| 7 | .062 | .063 | .043 | .077 | .033 | .044 | .045 | .066 | .050 | .078 | .056 | .0234 | .034 | .036 | - | |
| 8 | .045 | .048 | .049 | .061 | .026 | .043 | .027 | .057 | .022 | .065 | .060 | .0227 | .023 | .025 | .038 | |
| 9 | .051 | .048 | .022 | .065* | .027 | .[illegible]32 | .045 | .047 | .032 | .051 | .043 | - | .027 | .018 | .068 | |
| 10 | .045 | .038 | .027 | .041* | .022 | .031 | .033 | .050 | .035 | .044 | .038 | .0062* | .034 | .030 | .028 | |
| 11 | .040 | .048 | .027 | .054* | .021 | - | .018 | .044 | .026 | .041 | .058 | .0097 | .047 | .018 | .036 | |
| 12 | .038 | .039 | .015 | .072* | .026 | .034 | .015 | .023 | .030 | .038 | .027 | .0095 | .047 | .014 | .029 | |
| 13 | .034 | .[illegible]4 | .020 | .067* | .023 | .023 | .019 | .037 | .027 | .029 | .030 | .0236 | .018 | .034 | - | |
| 14 | .035 | .026 | .020 | .058* | .018 | .020 | .013 | .03[illegible] | .020 | .029 | .039 | .007 | .034 | .009 | - | |
| 15 | .034 | .039 | .028 | .050 | .015 | .022 | .012 | .0[illegible] | .030 | .025 | .028 | .0052 | .026 | .016 | .013 | |
| 16 | .026 | .024 | .034 | .033 | .020 | .017 | .012 | .0[illegible] | .048* | .021 | .023 | .0100 | .012 | .004 | .015 | |
| 17 | .027 | .027 | .021 | .032 | .020 | .013 | .011 | .023 | .036 | .022 | .029 | - | .028 | - | .0056 | |
| 18 | .01[illegible] | .020 | .017 | .027 | .020 | .015 | .011 | .[illegible]29 | .027 | .021 | .026 | - | .026 | - | .010 | |
| 19 | .0[illegible] | .018 | .018 | .022 | .018 | .018 | .010 | .021 | .[illegible]25 | .017 | .029 | .0032 | .015 | - | .006 | |
| 20 | .017 | .021 | .[illegible]12 | .025 | .021 | .015 | .009 | .022 | .029 | .018 | .022 | .0063 | .028 | - | .0048 | |
| 21 | .017 | .017 | .015 | .029 | .020 | .[illegible]12 | .010 | .029 | .022 | .022 | .023 | .0078 | .022 | - | .0031 | |
| 22 | .018 | .015 | .014 | .023 | .018 | .012 | .013 | .021 | .022 | .016 | .025 | .0145 | .027 | - | .0050 | |
| 23 | .025 | .[illegible]15 | .014 | .016 | - | - | .008 | .021 | .022 | .018 | .020 | .0161 | .029 | - | .0061 | |
| 24 | .021 | .014 | - | - | - | - | .[illegible]08 | .[illegible]25 | .022 | .016 | .023 | .0138 | .020 | - | .0078 | |
| 25 | .013 | .014 | - | .011 | - | - | .006 | .023 | .020 | .016 | .021 | .0128 | .148* | - | .011 | |
| 26 | - | .017 | - | .011 | - | - | .007 | .022 | .022 | .018 | .023 | .0173 | .034 | - | .0022 | |
| 27 | - | .008 | - | .008 | - | - | .004 | .028 | .022 | .014 | .017 | .0151 | .043* | - | .[illegible].44 | |
| 28 | - | .009 | - | - | - | - | .004 | .023 | .024 | .013 | .024 | .0187 | .034 | - | .0076 | |
| 29 | - | .009 | - | - | - | - | .008 | .015 | .025 | .014 | .023 | .0138 | .[illegible]43 | - | .0043 | |
| 30 | - | .008 | - | - | - | - | .008 | .021 | .023 | .014 | .021 | .0151 | .024 | - | .0069 | |
| 31 | - | .007 | - | - | - | - | .005 | .017 | .025 | - | .021 | .010 | .027 | - | .0077 | |
| 32 | - | .007 | - | - | - | - | .007 | .016 | .024 | - | .012 | .010 | .020 | - | .0063 | |
| 33 | - | .008 | - | - | - | - | .006 | .015 | .022 | - | .031* | .017 | .011 | - | .0073 | |
| 34 | - | .008 | - | - | - | - | .006 | .015 | .020 | - | .020 | .0139 | .004 | - | .0064 | |
| 35 | - | - | - | - | - | - | .005 | - | .022 | - | .026 | .0127 | .009 | - | .0068 | |
| 36 | - | - | - | - | - | - | .006 | .015 | .022 | - | .018 | .0165 | .015 | - | .0079 | |
| 37 | - | - | - | - | - | - | .008 | .011 | - | - | .022* | .0111 | .011 | - | .0063 | |
| 38 | - | - | - | - | - | - | - | .016 | - | - | .018 | .0174 | .009 | - | .0068 | |
| 39 | - | - | - | - | - | - | - | .012 | - | - | .021 | .0112 | .008 | - | .0064 | |
| 40 | - | - | - | - | - | - | - | .017 | - | - | .019 | .0072 | .009 | - | .0072 | |
| 41 | - | - | - | - | - | - | - | .018 | - | - | .013 | .0092 | .011 | - | .0060 | |
| 42 | - | - | - | - | - | - | - | .014 | - | - | .012 | .0127 | - | - | .0061 | |
| 43 | - | - | - | - | - | - | - | .016 | - | - | .015 | .0095 | .017 | - | .0078 | |
| 44 | - | - | - | - | - | - | - | .014 | - | - | .015 | .0031 | - | - | .0055 | |
| 45 | - | - | - | - | - | - | - | .013 | - | - | .017 | .013 | .018 | - | .0063 | |
| 46 | - | - | - | - | - | - | - | .015 | - | - | - | .013 | - | - | .0073 | |
| 47 | - | - | - | - | - | - | - | .014 | - | - | .018 | - | .020 | - | .0058 | |
| 48 | - | - | - | - | - | - | - | .014 | - | - | .017 | .0064 | - | - | .0058 | |
| 49 | - | - | - | - | - | - | - | .018 | - | - | .011 | .0042 | - | - | .0063 | |
| 50 | - | - | - | - | - | - | - | .016 | - | - | - | .0034 | .016 | - | .0078 | |
| 51 | - | - | - | - | - | - | - | .015 | - | - | - | .007? | - | - | .0082 | |
| 52 | - | - | - | - | - | - | - | - | - | - | .025 | .0073 | - | - | .0098 | |
| 53 | - | - | - | - | - | - | - | .013 | - | - | .019 | .0023 | - | - | .0076 | |
| 54 | - | - | - | - | - | - | - | .013 | - | - | .043 | - | - | - | .0077 | |
| 55 | - | - | - | - | - | - | - | .015 | - | - | .[illegible]3* | .0073 | .014 | - | .0098 | |
| 56 | - | - | - | - | - | - | - | .013 | - | - | .036 | .003 | - | - | .[illegible]044 | |
| 57 | - | - | - | - | - | - | - | .013 | - | - | .016 | .0075 | - | - | .0040 | |
| 58 | - | - | - | - | - | - | - | .013 | - | - | .036 | .0094 | - | - | .0058 | |
| 59 | - | - | - | - | - | - | - | .013 | - | - | - | .011 | - | - | .0098 | |
| 60 | - | - | - | - | - | - | - | .011 | - | - | - | .0083 | .022 | - | .0067 | |
| 61 | - | - | - | - | - | - | - | .013 | - | - | - | .0068 | - | - | .0086 | |
| 62 | - | - | - | - | - | - | - | .010 | - | - | - | .0092 | - | - | .0058 | |
| 63 | - | - | - | - | - | - | - | .009 | - | - | - | .0064 | - | - | .0077 | |
| 64 | - | - | - | - | - | - | - | .012 | - | - | - | .0071 | - | - | .0043 | |
| 65 | - | - | - | - | - | - | - | .011 | - | - | - | .0079 | .034 | - | .0043 | |
| 66 | - | - | - | - | - | - | - | - | - | - | - | .014 | - | - | .0047 | |
| 67 | - | - | - | - | - | - | - | - | - | - | - | .014 | - | - | .0084 | |
| 68 | - | - | - | - | - | - | - | - | - | - | - | .011 | - | - | .0068 | |
| 69 | - | - | - | - | - | - | - | - | - | - | - | .011 | - | - | .0078 | |
| 70 | - | - | - | - | - | - | - | - | - | - | - | .014 | - | - | .0100 | |
| 71 | - | - | - | - | - | - | - | - | - | - | - | .0096 | - | - | .0073 | |
| 72 | - | - | - | - | - | - | - | - | - | - | - | .0068 | .014 | - | .0093 | |
| | | | | | | | | | | | | .0063 | - | - | .0089 | |



TABLE 6 (Contd)

INDIVIDUAL URINARY EXCRETION VALUES OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION[1] TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF DOSE EXCRETED PER DAY)

| DAYS POST INJECTION | PER CENT OF INJECTED DOSE EXCRETED PER DAY | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-1 | Hp-2 | Hp-3 | Hp-4 | Hp-5 | Hp-6 | Hp-7 | Hp-8 | Hp-9 | Hp-10 | Hp-12 | Cal.-I[2] | Cal.-II[2] | Cal.-III[2] | Cal.-IV[3] |
| 74 | - | - | - | - | - | - | - | - | - | - | - | .010 | - | - | .0078 |
| 73 | - | - | - | - | - | - | - | - | - | - | - | .013 | - | - | .0081 |
| 75 | - | - | - | - | - | - | - | - | - | - | - | .0061 | - | - | .0041 |
| 77 | - | - | - | - | - | - | - | - | - | - | - | .0043 | - | - | .0043 |
| 78 | - | - | - | - | - | - | - | - | - | - | - | .014 | - | - | .0[illegible]4 |
| 79 | - | - | - | - | - | - | - | - | - | - | - | .0052 | - | - | .0081 |
| 80 | - | - | - | - | - | - | - | - | - | - | - | .0046 | .034 | - | .0043 |
| 81 | - | - | - | - | - | - | - | - | - | - | - | .0044 | - | - | .0053 |
| 82 | - | - | - | - | - | - | - | - | - | - | - | .003 | .018 | - | .0040 |
| 83 | - | - | - | - | - | - | - | - | - | - | - | .0041 | - | - | .0061 |
| 84 | - | - | - | - | - | - | - | - | - | - | - | .0039 | - | - | .0033 |
| 85 | - | - | - | - | - | - | - | - | - | - | - | .007 | - | - | - |
| 86 | - | - | - | - | - | - | - | - | - | - | - | .0048 | - | - | .0100 |
| 87 | - | - | - | - | - | - | - | - | - | - | - | .0076 | - | - | .0058 |
| 88 | - | - | - | - | - | - | - | - | - | - | - | .0[illegible]9 | - | - | .0039 |
| 89 | - | - | - | - | - | - | - | - | - | - | - | .0049 | - | - | .007[illegible] |
| 90 | - | - | - | - | - | - | - | - | - | - | - | .0032 | .[illegible]17 | - | .0077 |
| 91 | - | - | - | - | - | - | - | - | - | - | - | .0078 | - | - | .0068 |
| 92 | - | - | - | - | - | - | - | - | - | - | - | .014 | - | - | .0071 |
| 93 | - | - | - | - | - | - | - | - | - | - | - | .008 | - | - | .0056 |
| 94 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | .0073 |
| 95 | - | - | - | - | - | - | - | - | - | - | - | .0093 | .017 | - | .0062 |
| 96 | - | - | - | - | - | - | - | - | - | - | - | .011 | .018 | - | .0043 |
| 97 | - | - | - | - | - | - | - | - | - | - | - | .0[illegible]7 | - | - | .0057 |
| 98 | - | - | - | - | - | - | - | - | - | - | - | .011 | .018 | - | .0052 |
| 99 | - | - | - | - | - | - | - | - | - | - | - | .009 | - | - | .0070 |
| 100 | - | - | - | - | - | - | - | - | - | - | - | .0094 | - | - | .[illegible]61 |
| 101 | - | - | - | - | - | - | - | - | - | - | - | .005 | - | - | .0058 |
| 102 | - | - | - | - | - | - | - | - | - | - | - | .005 | .00[illegible] | - | .0050 |
| 103 | - | - | - | - | - | - | - | - | - | - | - | .008 | - | - | .0070 |
| 104 | - | - | - | - | - | - | - | - | - | - | - | .0048 | - | - | .0061 |
| [illegible] | - | - | - | - | - | - | - | - | - | - | - | .019 | - | - | .0[illegible]6 |
| 106 | - | - | - | - | - | - | - | - | - | - | - | .0078 | - | - | .0048 |
| 107 | - | - | - | - | - | - | - | - | - | - | - | .0093 | - | - | .0[illegible]6 |
| 108 | - | - | - | - | - | - | - | - | - | - | - | .0053 | .008 | - | .0053 |
| 109 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | .0044 |
| 110 | - | - | - | - | - | - | - | - | - | - | - | .0056 | - | - | .0035 |
| 111 | - | - | - | - | - | - | - | - | - | - | - | .0078 | - | - | .0043 |
| 112 | - | - | - | - | - | - | - | - | - | - | - | .015 | - | - | .[illegible]51 |
| 113 | - | - | - | - | - | - | - | - | - | - | - | .0096 | .007 | - | .0034 |
| 114 | - | - | - | - | - | - | - | - | - | - | - | .011 | - | - | .0039 |
| 116 | - | - | - | - | - | - | - | - | - | - | - | .0118 | .008 | - | .0053 |
| 118 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | .0047 |
| 117 | - | - | - | - | - | - | - | - | - | - | - | .0089 | - | - | .[illegible]23 |
| 118 | - | - | - | - | - | - | - | - | - | - | - | .0035 | - | - | .0039 |
| 119 | - | - | - | - | - | - | - | - | - | - | - | .0068 | - | - | .0038 |
| 120 | - | - | - | - | - | - | - | - | - | - | - | .0051 | .007 | - | .0035 |
| 121 | - | - | - | - | - | - | - | - | - | - | - | .0041 | - | - | .0047 |
| 123 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | .0029 |
| 125 | - | - | - | - | - | - | - | - | - | - | - | .0118 | - | - | .0034 |
| 124 | - | - | - | - | - | - | - | - | - | - | - | .0088 | - | - | .0029 |
| 125 | - | - | - | - | - | - | - | - | - | - | - | .0108 | .009 | - | .0038 |
| 126 | - | - | - | - | - | - | - | - | - | - | - | .0077 | - | - | .0032 |
| 127 | - | - | - | - | - | - | - | - | - | - | - | .008 | .011 | - | .0040 |
| 128 | - | - | - | - | - | - | - | - | - | - | - | .0053 | - | - | .0018 |
| 129 | - | - | - | - | - | - | - | - | - | - | - | .0052 | - | - | .0024 |
| 130 | - | - | - | - | - | - | - | - | - | - | - | .0034 | - | - | .0014 |
| 131 | - | - | - | - | - | - | - | - | - | - | - | .0073 | - | - | .0031 |
| 132 | - | - | - | - | - | - | - | - | - | - | - | .0053 | .008 | - | .0038 |
| 133 | - | - | - | - | - | - | - | - | - | - | - | .0068 | - | - | .0037 |
| 134 | - | - | - | - | - | - | - | - | - | - | - | .0081 | - | - | .0027 |
| 135 | - | - | - | - | - | - | - | - | - | - | - | .011 | .007 | - | .0049 |
| 136 | - | - | - | - | - | - | - | - | - | - | - | .0054 | - | - | .0038 |
| 137 | - | - | - | - | - | - | - | - | - | - | - | .0071 | - | - | .0032 |
| 138 | - | - | - | - | - | - | - | - | - | - | - | .0073 | .009 | - | .0010 |

Values eliminated from revised mean on basis of the Chauvenet Criterion.

(1) All cases except Cal-I, II, V and Cal-I received $Pu^{+4}$ in .4 per cent $Na_2C_6H_5O_7 \cdot 2H_2O$ solution. The latter cases received $PuO_{2+x}$.

(2) Russell, E. R., Nickson, J. J., Argonne National Laboratory Report CH-3907 and unpublished data.

(3) Hamilton, J. G., et al, Report No. CH-3789.

TABLE 7

MEANS*, REVISED MEANS, AND STANDARD DEVIATIONS OF URINARY, FECAL, AND URINARY PLUS FECAL EXCRETION OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF INJECTED DOSE)

| DAYS POST INJECTION | URINARY EXCRETION | | | FECAL EXCRETION | | | URINARY & FECAL EXC. |
|---|---|---|---|---|---|---|---|
| | Mean %/Day | Revised Mean %/Day | Standard Deviation | Mean %/Day | Revised Mean %/Day | Standard Deviation | Mean %/Day |
| 1 | .5176 | .3628 | .614 | .1553 | .1988 | .1168 | .5616 |
| 2 | .1974 | - | .070 | .2458 | - | .1230 | .4252 |
| 3 | .1266 | - | .052 | .2275 | - | .0905 | .3541 |
| 4 | .0962 | - | .041 | .1842 | - | .1105 | .2804 |
| 5 | .0652 | - | .030 | .1582 | - | .0857 | .2234 |
| 6 | .0540 | .0490 | .026 | .1096 | - | .0440 | .1586 |
| 7 | .0501 | - | .022 | .0766 | - | .0401 | .1287 |
| 8 | .0440 | - | .022 | .0717 | - | .0412 | .1157 |
| 9 | .0424 | .0384 | .023 | .0647 | - | .0415 | .1031 |
| 10 | .0355 | .0341 | .018 | .0538 | - | .0385 | .0860 |
| 11 | .0350 | .0319 | .018 | .0566 | - | .0360 | .0885 |
| 12 | .0300 | .0270 | .016 | .0568 | - | .0351 | .0838 |
| 13 | .0307 | .0279 | .013 | .0512 | - | .0354 | .0791 |
| 14 | .0274 | .0250 | .014 | .0453 | .0386 | .0301 | .0636 |
| 15 | .0253 | - | .012 | .0438 | .0370 | .0286 | .0623 |
| 16 | .0219 | .0199 | .011 | .0617 | .0296 | .1090 | .0495 |
| 17 | .0236 | - | .0092 | .0402 | .0285 | .0411 | .0521 |
| 18 | .0219 | - | .0078 | .0377 | .0268 | .0394 | .0487 |
| 19 | .0190 | - | .0081 | .0278 | - | .0188 | .0466 |
| 20 | .0200 | - | .0101 | .0274 | - | .0169 | .0474 |
| 21 | .0195 | - | .0093 | .0263 | - | .0183 | .0458 |
| 22 | .0186 | - | .0083 | .0243 | - | .0182 | .0431 |
| 23 | .0203 | - | .0105 | .0224 | - | .0156 | .0427 |
| 24 | .0179 | - | .0077 | .0211 | .0167 | .0141 | .0346 |
| 25 | .0279 | .0159 | .0142 | .0199 | .0145 | .0160 | .0304 |
| 26 | .0172 | - | .0088 | .0211 | .0160 | .0156 | .0332 |
| 27 | .0178 | .0149 | .0126 | .0163 | .0119 | .0126 | .0268 |
| 28 | .0180 | - | .0092 | .0153 | .0122 | .0140 | .0302 |
| 29 | .0153 | - | .0074 | .0180 | - | .0146 | .0333 |
| 30 | .0154 | - | .0072 | .0179 | - | .069 | .0333 |
| 31 | .0150 | - | .0086 | .0191 | - | .0119 | .0341 |
| 32 | .0128 | - | .0067 | .0188 | - | .031 | .0316 |
| 33 | .0155 | .0125 | .0102 | .0192 | - | .011 | .0317 |
| 34 | .0125 | - | .0056 | .0192 | - | .011 | .0317 |
| 35 | .0138 | - | .0083 | .0201 | - | .012 | .0339 |
| 36 | .0143 | - | .0056 | .0151 | - | .0091 | .0294 |
| 37 | .0114 | .0091 | .0062 | .0183 | - | .0119 | .0274 |
| 38 | .0138 | - | .0043 | .0181 | - | .0121 | .0319 |
| 39 | .0119 | - | .0055 | .0079 | - | .0044 | .0198 |
| 40 | .0119 | - | .0058 | .0088 | - | .0031 | .0207 |
| 41 | .0120 | - | .0044 | .0087 | - | .0032 | .0207 |
| 42 | .0120 | - | .0027 | .0082 | - | .0040 | .0202 |
| 43 | .0130 | - | .0040 | .0079 | - | .0031 | .0209 |
| 44 | .0094 | - | .0059 | .0094 | - | .0015 | .0188 |
| 45 | .0135 | - | .0050 | .0087 | - | .0049 | .0222 |
| 46 | .0114 | - | .0041 | .0088 | - | .0053 | .0202 |
| 47 | .0137 | - | .0058 | .0064 | - | .0072 | .0221 |





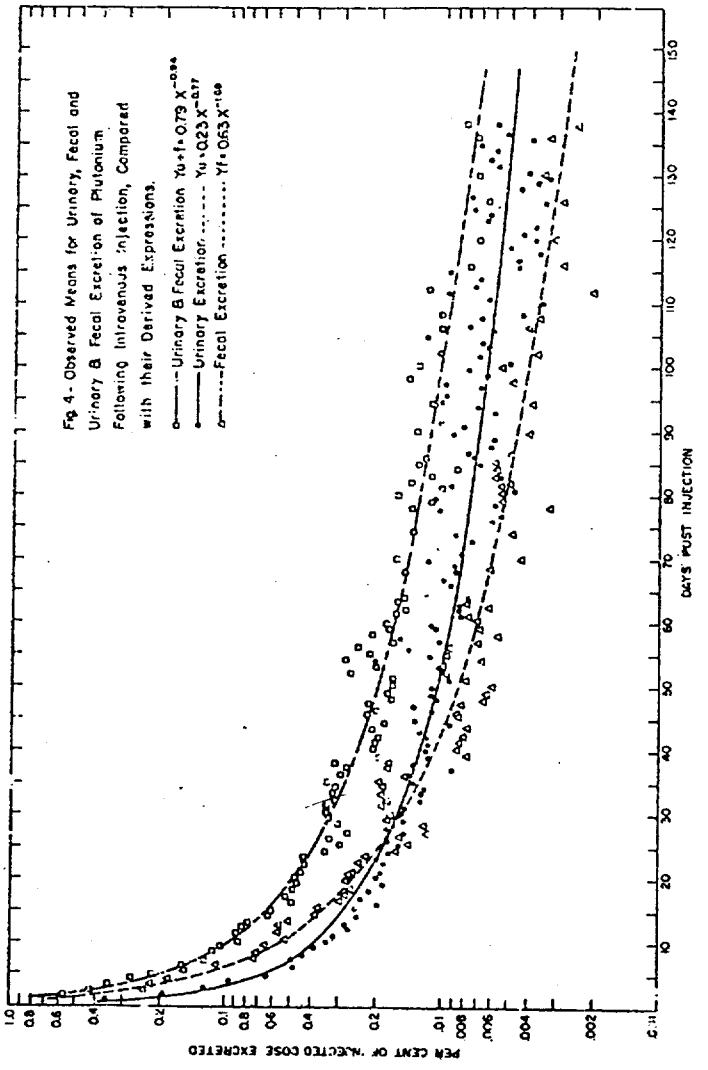


TABLE 7 (Contd)

MEANS*, REVISED MEANS, AND STANDARD DEVIATIONS OF URINARY, FECAL, AND URINARY PLUS FECAL EXCRETION OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF INJECTED DOSE)

| DAYS POST INJECTION | URINARY EXCRETION | | | FECAL EXCRETION | | | URINARY & FECAL EXC. |
|---|---|---|---|---|---|---|---|
| | Mean %/Day | Revised Mean %/Day | Standard Deviation | Mean %/Day | Revised Mean %/Day | Standard Deviation | Mean %/Day |
| 43 | .0108 | - | .0056 | .0067 | - | .0018 | .0175 |
| 49 | .0114 | - | .0062 | .0064 | - | .0028 | .0178 |
| 50 | .0113 | - | .0059 | .0060 | - | .0028 | .0173 |
| 51 | .0094 | - | .0032 | .008 | - | - | .0174 |
| 52 | .0173 | - | .0154 | .010 | - | - | .0273 |
| 53 | .0104 | - | .0074 | .010 | - | - | .0204 |
| 54 | .0212 | - | .0189 | .0069 | - | .0047 | .0281 |
| 55 | .0178 | .0115 | .0144 | .010 | - | - | .0215 |
| 56 | .0146 | - | .0149 | .010 | - | - | .0246 |
| 57 | .0106 | - | .0056 | .0070 | - | - | .0176 |
| 58 | .0101 | - | .0133 | .0057 | - | .0019 | .0217 |
| 59 | .0109 | - | .010 | .0070 | - | - | .0179 |
| 60 | .0115 | - | .0074 | .0070 | - | - | .0185 |
| 61 | .0085 | - | .0029 | .0080 | - | - | .0185 |
| 62 | .0083 | - | .0021 | .0064 | - | .0023 | .0147 |
| 63 | .0067 | - | .0007 | .008 | - | - | .0167 |
| 64 | .0078 | - | .0041 | .008 | - | - | .0158 |
| 68 | .0089 | - | .0028 | .0063 | - | - | .0152 |
| 70 | .0120 | - | .0028 | .0045 | - | - | .0165 |
| 74 | .0090 | - | .0022 | .0050 | - | - | .0140 |
| 78 | .0107 | - | .0050 | .0033 | - | - | .0140 |
| 79 | .0059 | - | .0022 | .0055 | - | .0007 | .0114 |
| 80 | .0111 | - | .0110 | .0055 | - | .0007 | .0166 |
| 81 | .0048 | - | .0010 | .0055 | - | .0007 | .0103 |
| 82 | .0093 | - | .0081 | .0051 | - | .0009 | .0144 |
| 83 | .0055 | - | .0022 | .0060 | - | - | .0115 |
| 84 | .0028 | - | .0010 | .0060 | - | - | .0086 |
| 85 | .0070 | - | - | .0060 | - | - | .0130 |
| 86 | .0073 | - | .0036 | .0050 | - | - | .0123 |
| 90 | .0093 | - | .0071 | .0042 | - | - | .0133 |
| 94 | .0071 | - | - | .0040 | - | - | .0111 |
| 98 | .0101 | - | .0044 | .0050 | - | - | .0151 |
| 100 | .0079 | - | .0028 | .0056 | - | - | .0135 |
| 102 | .0070 | - | .0028 | .0038 | - | - | .0108 |
| 106 | .0081 | - | .0022 | .0043 | - | - | .0104 |
| 108 | .0068 | - | .0021 | .0038 | - | - | .0106 |
| 112 | .0101 | - | .0071 | .0021 | - | - | .0122 |
| 116 | .0047 | - | - | .0029 | - | - | .0076 |
| 120 | .0039 | - | .0023 | .0032 | - | - | .0071 |
| 126 | .0035 | - | .0010 | .0030 | - | - | .0065 |
| 130 | .0034 | - | .0028 | .0037 | - | - | .0071 |
| 136 | .0041 | - | .0029 | .0034 | - | - | .0075 |
| 138 | .0058 | - | .0042 | .0025 | - | - | .0083 |

*Cases of Russell and Nickson and Hamilton, et al used in computing means where applicable.





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chronic variable exposure dose in terms of an effective single dose given at some effective time between the limits of exposure. This interpretation was accomplished by fitting the slopes of the urinary excretion curves of these individuals to the slope of the 138 day curve in the following manner: If $Y_u = 0.23\ X^{-0.77}$ gives the per cent ($Y_u$) of a single dose excreted on day X, then $0.0023\ DX^{-0.77}$ is the expression for the measured activity, i.e., counts per minute, excreted on day X when the single dose (D) is expressed in the same units. If the assumption is made that a chronic variable exposure dose may be represented by a single effective dose ($D_E$) then the activity ($Y_q$) in the sample excreted q effective days after this single dose is given by the expression

$$Y_q = 0.0023\ D_E\ q^{-0.77} \qquad [3]$$

The activity ($Y_{q+a}$) of the sample excreted on q+a days after the single dose (there being no exposure between q and q+a) is given by the expression

$$Y_{q+a} = 0.0023\ D_E\ (q+a)^{-0.77} \qquad [4]$$

Dividing 3 by 4 and solving for q gives

$$q = \frac{a}{\left(\frac{Y_q}{Y_{q+a}}\right)^{1.30} - 1} \qquad [5]$$

q then is the effective time of exposure and its substitution in [3] gives the effective dose $D_E$, as follows:

$$Y_q = 0.0023\ D_E \left[\frac{a}{\left(\frac{Y_q}{Y_{q+a}}\right)^{\frac{1}{0.77}} - 1}\right]^{-0.77}$$

$$D_E = 434.8\ Y_q \left[\frac{a}{\left(\frac{Y_q}{Y_{q+a}}\right)^{1.30} - 1}\right]^{0.77} \qquad [6]$$

This expression gives an approximation of the total body burden of a person chronically exposed to plutonium. The body burden is expressed in terms of a single effective dose as determined from two urinary excretion measurements ($Y_q$ and $Y_{q+a}$) taken sufficiently far apart (with no exposure between) so that the two measurements are significantly different.

The method of interpretation given above was applied to the urinary plutonium excretion data from three Los Alamos personnel and their average total plutonium body content approximated in terms of an effective dose at some effective time (q). The effective doses for W. B. G., W. A. B. and D. L. W. were estimated at 1.3 μg, 1.2 μg, and 1.0 μg respectively at respective effective times of 37, 53, and 42 days before the first urine assay used in the calculation. Assuming the above doses, all urinary excretion data (Table 8) collected from these persons were used to adjust the experimental urinary excretion curve (2) extending it to 1750 days again using least squares analysis. The adjusted expression is

$$Y_{ua} = 0.20\ X^{-0.74} \qquad [7]$$

TABLE 8

PLUTONIUM URINE ASSAYS ON LOS ALAMOS PERSONNEL AFTER REMOVAL FROM FURTHER PLUTONIUM EXPOSURE

| W.B.G. | | | W.A.B. | | | D.L.W. | | |
|---|---|---|---|---|---|---|---|---|
| Days[1] | c/m/24-hr.[2] | P.Error[3] | Days[1] | c/m/24-hr.[2] | P.Error[3] | Days[1] | c/m/24-hr.[2] | P.Error[3] |
| 1 | 8.4 | 0.33 | 1 | 21.3 | 0.60 | 1 | 13.8 | 0.55 |
| 27 | 6.9 | 0.51 | 20 | 11.6 | 0.54 | 21 | 8.4 | 0.52 |
| 104 | 5.5 | 0.50 | 45 | 8.2 | 0.52 | 94 | 3.9 | 0.48 |
| 205 | 6.4 | 0.51 | 163 | 7.7 | 0.51 | 118 | 3.5 | 0.48 |
| 261 | 4.8 | 0.49 | 370 | 6.7 | 0.50 | 195 | 3.2 | 0.48 |
| 315 | 3.7 | 0.48 | 1480[4] | 1.2 | 0.17 | | | |
| 387 | 5.8 | 0.48 | | | | | | |
| 450 | 3.3 | 0.48 | | | | | | |
| 498 | 2.4 | 0.47 | | | | | | |
| 652 | 1.4 | 0.48 | | | | | | |
| 707 | 1.9 | 0.47 | | | | | | |
| 734 | 1.4 | 0.48 | | | | | | |
| 798 | 0.9 | 0.48 | | | | | | |
| 831 | 1.3 | 0.48 | | | | | | |
| 947 | 2.1 | 0.47 | | | | | | |
| 1022 | 0.9 | 0.48 | | | | | | |
| 1044 | 1.8 | 0.47 | | | | | | |
| 1162 | 1.3 | 0.48 | | | | | | |
| 1203 | 1.1 | 0.48 | | | | | | |
| 1294 | 1.3 | 0.47 | | | | | | |
| 1322 | 0.8 | 0.48 | | | | | | |
| 1348 | 0.8 | 0.48 | | | | | | |
| 1378 | 0.7 | 0.48 | | | | | | |
| 1448 | 0.7 | 0.48 | | | | | | |
| 1574 | 0.3 | 0.45 | | | | | | |
| 1636 | 0.6 | 0.48 | | | | | | |
| 1698 | 1.1 | 0.48 | | | | | | |

W.A.B. - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - $D_\Sigma$[5] = 1.2 μg
W.B.G. - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - $D_\Sigma$ = 1.3 μg
D.L.W. - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - $D_\Sigma$ = 1.0 μg

(1) Days after removal from further plutonium exposure.

(2) Alpha counts per minute per 24-hour urine sample at 50 per cent counting geometry.

(3) Probable error calculated from empirical formula derived specifically for the cupferron extraction procedure for determining plutonium in urine (15).

(4) Result due to H.M. Parker in private communication to N.E. Bradbury, July 7, 1948.

(5) Estimated by equation [8] Page 28.

Figure 5 shows the adjusted curve through 1750 days represented as a heavy broken line. The points representing the three sets of data collected from Hp-3 and Hp-6 beyond 138 days after injection are shown on the graph as triangles. Points originating from the urine assays of the three Los Alamos workers are shown as circles and the theoretical curve [2] through 138 days is given as a heavy solid line for comparison. The standard error of estimate for the adjusted expression is 42 per cent due largely to the poorer fit during the first few days and to the small number of observations during the later time period.

Integration of the expression $Y_{ua} = 0.20\ X^{-0.74}$ between the limits of $X = 1/2$ and $X = (n+1/2)$ gives the area ($A_{ua}$) under the urinary excretion curve which represents the total per cent of the injected dose of plutonium excreted in the urine up to and including the nth day after injection.









$$A_{ua} = 0.20 \int_{1/2}^{n+1/2} X^{-0.74}\, dX = \frac{0.20}{0.26}\left[(n+1/2)^{0.26} - (1/2)^{0.26}\right]$$

$$= 0.77\,(n+1/2)^{0.26} - 0.64 \qquad [8]$$

When n = 1750 days, $A_{ua}$ (the total amount of plutonium excreted in the urine through 1750 days) is only 6.3 per cent of the total injected dose.

2. Fecal Excretion

The same cases used for urinary excretion studies were used for the study of fecal elimination of plutonium following intravenous administration of Pu+4 - citrate. Fecal samples were collected daily for the first few days. Later stools were pooled at four day intervals because of the uncertainty of obtaining representative 24-hour samples. Plutonium analyses were made on aliquots of each specimen using methods described earlier. The results of analysis of individual fecal specimens are given in Table 9. Results are expressed as per cent of the administered dose excreted per day. Fecal excretion data could be obtained for only one of the cases (Chi.-1) reported by Russell and Nickson (13). The original data were no longer available and it was necessary to read individual values from the graph given in their report. The original fecal excretion data were not available for the one case studied

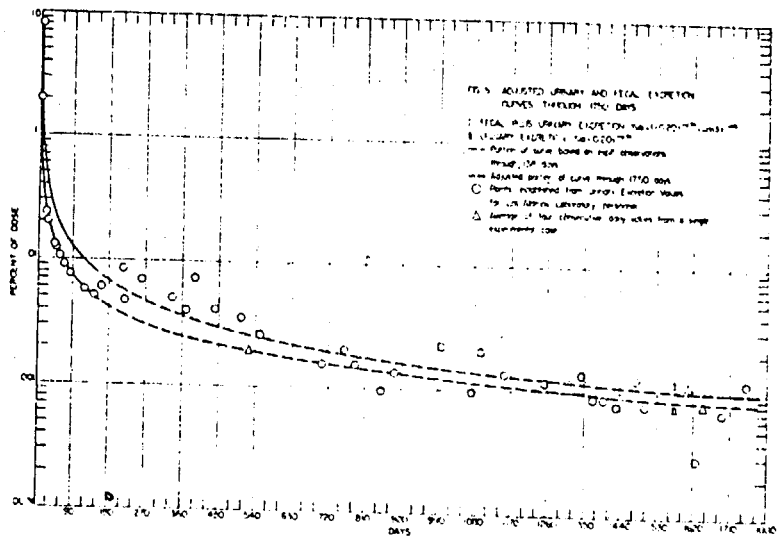

TABLE 9

INDIVIDUAL FECAL EXCRETION VALUES OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION[1] TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF DOSE EXCRETED PER DAY)

| DAYS POST INJECTION | PER CENT OF INJECTED DOSE EXCRETED PER DAY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-1 | Hp-2 | Hp-3 | Hp-4 | Hp-5 | Hp-6 | Hp-7 | Hp-8 | Hp-9 | Hp-10 | Hp-12 | Chi-1[2] |
| 1 | .052* | .204 | .018* | .134 | .004* | .085 | .147 | .178 | .333 | .087 | .370 | .250 |
| 2 | .321 | .204 | .157 | .274 | .311 | .085 | .120 | .266 | .389 | .087 | .370 | .468 |
| 3 | .241 | .204 | .157 | .274 | .311 | .170 | .087 | .210 | .389 | .087 | .297 | .294 |
| 4 | .050 | .317 | .095 | .308 | .185 | .179 | .080 | .080 | .131 | .110 | .297 | .380 |
| 5 | .105 | .317 | .099 | .306 | .110 | .179 | .055 | .080 | .131 | .110 | .188 | .223 |
| 6 | .048 | - | .070 | .126 | .110 | .179 | .055 | .080 | .131 | .110 | .163 | .116 |
| 7 | .021 | - | .070 | .126 | .110 | .037 | .055 | .080 | .131 | .110 | .020 | .083 |
| 8 | .021 | .120 | .070 | .126 | .064 | .037 | .055 | .070 | .131 | .034 | .020 | .112 |
| 9 | .021 | .120 | .070 | .128 | .051 | .037 | .032 | .070 | .131 | .034 | .020 | - |
| 10 | .021 | .084 | .027 | .117 | 051 | .037 | .032 | .070 | .131 | .034 | .020 | .021 |
| 11 | .048 | .084 | .027 | .117 | .052 | .023 | .032 | .070 | .118 | .034 | .020 | - |
| 12 | .048 | .084 | .027 | .117 | .052 | .023 | .032 | .045 | .118 | .034 | .020 | .083 |
| 13 | .048 | .084 | .027 | .117 | .032 | .023 | .023 | .045 | .118 | .034 | .020 | .045 |
| 14 | .048 | .062 | .023 | .085 | .032 | .023 | .023 | .045 | .118* | .022 | .020 | .044 |
| 15 | .035 | .062 | .023 | .085 | .032 | .015 | .023 | .045 | .118* | .022 | .023 | .042 |
| 16 | .035 | .062 | .023 | .040 | .017 | .015 | .023 | .032 | .414* | .022 | .023 | .034 |
| 17 | .035 | .062 | .023 | .040 | .017 | .015 | .016 | .032 | .157* | .022 | .023 | - |
| 18 | .035 | .055 | .018 | .040 | .017 | .015 | .016 | .025 | .157* | .022 | .023 | .031 |
| 19 | .015 | .055 | .018 | .028 | .017 | .015 | .016 | .025 | .055 | .012 | .053 | .027 |
| 20 | .015 | .055 | .018 | .028 | .020 | .015 | .016 | .025 | .055 | .012 | .053 | .019 |
| 21 | .015 | .055 | .018 | .028 | .020 | .010 | .008 | .025 | .055 | .012 | .053 | .019 |
| 22 | .015 | .022 | .006 | .028 | .020 | .010 | .008 | .045 | .055 | .012 | .053 | .018 |
| 23 | .017 | .022 | .006 | .026 | - | - | .008 | .045 | .052 | .012 | .026 | .010 |
| 24 | .017 | .022 | - | - | - | - | .008 | .009 | .052* | .012 | .026 | .023 |
| 25 | - | .022 | - | - | - | - | .011 | .009 | .052* | .006 | .026 | .012 |
| 26 | - | .021 | - | - | - | - | .011 | .009 | .052* | .006 | .026 | .023 |
| 27 | - | .021 | - | - | - | - | .011 | .009 | .043* | .006 | .016 | .0183 |
| 28 | - | - | - | - | - | - | .011 | .009 | .043* | .006 | .016 | .0189 |
| 29 | - | - | - | - | - | - | - | .009 | .043 | .006 | .016 | .0158 |
| 30 | - | - | - | - | - | - | - | .018 | .043 | .006 | .016 | .0063 |
| 31 | - | - | - | - | - | - | - | .018 | .035 | - | .016 | .0074 |
| 32 | - | - | - | - | - | - | - | .018 | .035 | - | .016 | .0062 |
| 33 | - | - | - | - | - | - | - | .018 | .035 | - | .016 | .0079 |
| 34 | - | - | - | - | - | - | - | .018 | 035 | - | .016 | .0079 |
| 35 | - | - | - | - | - | - | - | .018 | .035 | - | .022 | .0054 |
| 36 | - | - | - | - | - | - | - | .018 | - | - | .022 | .0054 |
| 37 | - | - | - | - | - | - | - | .028 | - | - | .022 | .0050 |
| 38 | - | - | - | - | - | - | - | .020 | - | - | .022 | .9042 |
| 39 | - | - | - | - | - | - | - | .011 | - | - | - | .0047 |
| 40 | - | - | - | - | - | - | - | .011 | - | - | - | .0066 |
| 41 | - | - | - | - | - | - | - | .011 | - | - | - | .0064 |
| 42 | - | - | - | - | - | - | - | .011 | - | - | - | .0053 |
| 43 | - | - | - | - | - | - | - | .011 | - | - | .008 | .0047 |
| 44 | - | - | - | - | - | - | - | .011 | - | - | .008 | .0062 |
| 45 | - | - | - | - | - | - | - | .014 | - | - | .008 | .0042 |
| 46 | - | - | - | - | - | - | - | .014 | - | - | .008 | .0033 |
| 47 | - | - | - | - | - | - | - | .014 | - | - | - | .0028 |





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TABLE 9 (Contd)

INDIVIDUAL FECAL EXCRETION VALUES OF PLUTONIUM FOLLOWING INTRAVENOUS ADMINISTRATION[1] TO HUMAN SUBJECTS (EXPRESSED AS PER CENT OF DOSE EXCRETED PER DAY)

| DAYS POST INJECTION | PER CENT OF INJECTED DOSE EXCRETED PER DAY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-1 | Hp-2 | Hp-3 | Hp-4 | Hp-5 | Hp-6 | Hp-7 | Hp-8 | Hp-9 | Hp-10 | Hp-12 | Chi-1[2] |
| 48 | - | - | - | - | - | - | - | .008 | - | - | - | .0054 |
| 49 | - | - | - | - | - | - | - | .008 | - | - | - | .0047 |
| 50 | - | - | - | - | - | - | - | .008 | - | - | - | .0040 |
| 51 | - | - | - | - | - | - | - | .008 | - | - | - | - |
| 52 | - | - | - | - | - | - | - | .010 | - | - | - | - |
| 53 | - | - | - | - | - | - | - | .010 | - | - | - | - |
| 54 | - | - | - | - | - | - | - | .010 | - | - | - | .0038 |
| 55 | - | - | - | - | - | - | - | .010 | - | - | - | - |
| 56 | - | - | - | - | - | - | - | .010 | - | - | - | - |
| 57 | - | - | - | - | - | - | - | .007 | - | - | - | - |
| 58 | - | - | - | - | - | - | - | .007 | - | - | - | .0043 |
| 59 | - | - | - | - | - | - | - | .007 | - | - | - | - |
| 60 | - | - | - | - | - | - | - | .007 | - | - | - | - |
| 61 | - | - | - | - | - | - | - | .008 | - | - | - | - |
| 62 | - | - | - | - | - | - | - | .008 | - | - | - | .0048 |
| 63 | - | - | - | - | - | - | - | .008 | - | - | - | - |
| 64 | - | - | - | - | - | - | - | .008 | - | - | - | - |
| 68 | - | - | - | - | - | - | - | - | - | - | - | .0063 |
| 70 | - | - | - | - | - | - | - | - | - | - | - | .0045 |
| 74 | - | - | - | - | - | - | - | - | - | - | - | .0050 |
| 78 | - | - | - | - | - | - | - | - | - | - | - | .0033 |
| 79 | - | - | - | .006 | - | - | .005 | - | - | - | - | - |
| 80 | - | - | - | .006 | - | - | .005 | - | - | - | - | - |
| 81 | - | - | - | .006 | - | - | .005 | - | - | - | - | - |
| 82 | - | - | - | .006 | - | - | .005 | - | - | - | - | .0042 |
| 83 | - | - | - | - | - | - | .008 | - | - | - | - | - |
| 84 | - | - | - | - | - | - | .008 | - | - | - | - | - |
| 85 | - | - | - | - | - | - | .006 | - | - | - | - | - |
| 88 | - | - | - | - | - | - | - | - | - | - | - | .0050 |
| 90 | - | - | - | - | - | - | - | - | - | - | - | .0042 |
| 94 | - | - | - | - | - | - | - | - | - | - | - | .0040 |
| 98 | - | - | - | - | - | - | - | - | - | - | - | .0050 |
| 100 | - | - | - | - | - | - | - | - | - | - | - | .0056 |
| 102 | - | - | - | - | - | - | - | - | - | - | - | .0038 |
| 106 | - | - | - | - | - | - | - | - | - | - | - | .0043 |
| 108 | - | - | - | - | - | - | - | - | - | - | - | .0038 |
| 112 | - | - | - | - | - | - | - | - | - | - | - | .0021 |
| 116 | - | - | - | - | - | - | - | - | - | - | - | .0028 |
| 120 | - | - | - | - | - | - | - | - | - | - | - | .0032 |
| 126 | - | - | - | - | - | - | - | - | - | - | - | .0030 |
| 130 | - | - | - | - | - | - | - | - | - | - | - | .0037 |
| 136 | - | - | - | - | - | - | - | - | - | - | - | .0034 |
| 138 | - | - | - | - | - | - | - | - | - | - | - | .0025 |

*Values eliminated from revised mean on basis of the Chauvenet Criterion.

[1]All cases except Chi-1 received $Pu^{+4}$ in 0.4 per cent $Na_3C_6H_5O_7 \cdot 2d_2O$ Solution.

[2]Russell, E.R., Nickson, J.J., Argonne National Laboratory Report CH-3607.





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by Hamilton and co-workers (14) and it was not feasible to include their results. The present report of the fecal elimination of plutonium is, therefore, confined to twelve cases.

The means, revised means, and standard deviations for the daily fecal excretion of plutonium from 0 to 138 days post injection are given in Table 7 (Page 26). The best curve of fit for the observed means was established by the method of least squares and was found to be:

$$Y_f = 0.63\ X^{-1.09} \qquad [9]$$

with a standard error of estimate of 28 per cent. In the above expression $Y_f$ is the amount of plutonium excreted in the feces on a specific day (expressed as per cent of the injected dose) and X is the day of measurement in days after injection. The agreement between the observed values and the derived expression is shown graphically in Fig. 4 (Page 28). In this figure the derived expression is represented by a heavy broken line and the observed points are represented as open triangles. The fecal excretion of plutonium in per cent of the injected dose excreted per day is plotted against time in days.

No representative fecal excretion data beyond 138 days were available from Los Alamos personnel because of small but significant contamination of feces from swallowed material removed from the lungs of the workers by ciliary action. One may ask why the small amount of lung contamination does not prevent the use of the urinary excretion results from these workers to adjust the 138 day urinary excretion curve to 1750 days. This material does not reach the absorbing area of the lung and is not absorbed appreciably from the gastrointestinal tract (probably less than 0.01 per cent). The small amount of material which has reached the alveoli is being absorbed into the blood at an infinitesimal rate. Of the amount absorbed only a fraction of a per cent contributes to the daily urinary excretion.

Studies of the excretion of plutonium by mice, rats, rabbits and dogs (1), (2), (18), (19) showed the urinary excretion of all species was quite uniform. The plutonium excretion in the urine thirty to fifty days after injection was 0.01 - 0.02 per cent of the administered dose per day. The urinary/fecal excretion ratio varied widely, however, for the various species. The ratio was 1/10 - 15 for the rat and only 1/2 - 3 for the dog.

Russell and Nickson (13) reported a plutonium urinary/fecal excretion ratio of 3/1 in man based on the observation of one case through 140 days. The California group (14) reported an excretion ratio of 3-4/1 by one subject followed for 341 days.

The adjusted urinary excretion curve for 0 to 1750 days and the fecal excretion curve for 0 to 138 days may be solved for the urinary to fecal excretion ratio:

$$\frac{Y_{ua}}{Y_f} = \frac{0.20\ X^{-0.74}}{0.63\ X^{-1.09}} = 0.32\ X^{0.35} \qquad [10]$$

The urinary/fecal ratio is 1.8/1 at 138 days post injection and 4.4/1 at 1750 days when calculated from the above expression. Unfortunately no applicable fecal excretion data are available from the Los Alamos personnel to permit adjustment of the expression for fecal excretion beyond 138 days. If the urinary/fecal ratios at 138 and 1750 days are calculated from the unadjusted expressions ($Y_u$ and $Y_f$) for both urinary and fecal excretion, the values are 1.7/1 and 3.9/1 respectively. Although extrapolation beyond 138 days is subject to increasing uncertainty with increasing values of X, the above values lead to the conclusion that the urinary/fecal plutonium excretion ratio is not constant, over the range (0-138 days) measured, but approaches 4/1 as a limit at some later time. The results obtained by Hamilton (14) on the case followed for 341 days seem to support the above conclusion.

The expression $Y_f = 0.63\ X^{-1.09}$ gives the amount of plutonium (expressed as per cent of injected dose) excreted in the feces on a particular day (X) after injection. Integration of the expression between the limits of X = 1/2 and X = n+1/2 gives the total per cent ($A_f$)









of the injected dose excreted through day n:

$$A_f = .63 \int_{1/2}^{n+1/2} X^{-1.09}\,dX = -7.00\left[(n+1/2)^{-0.09} - (1/2)^{-0.09}\right]$$
$$= -7.00\,(n+1/2)^{-0.09} + 7.45 \qquad [11]$$

From the above expression $A_f$ = 2.88 per cent through the first 138 days.

3. Total Excretion (Urine plus Feces)

From the practical point of view the total urinary plus fecal excretion rate of plutonium is extremely important. The summed elimination rate determines how long a worker should avoid further exposure to plutonium after having reached an accepted maximum permissible body level.

The observed mean urinary plus fecal plutonium excretion values are given in Table 7 (Page 26). Results are expressed as per cent of injected dose excreted per day. The means were obtained from the individual urinary excretion data from fifteen cases and the individual fecal excretion data from eleven. The results reported by the Chicago and California groups were used when available and applicable.

Application of the method of least squares gives the expression

$$Y_{u+f} = 0.79\ X^{-0.94} \qquad [12]$$

as the best curve of fit for the urinary plus fecal excretion data for 0 to 138 days. The standard error of estimate of the computation is 17 per cent. $Y_{u+f}$ is the total plutonium excreted in feces plus urine on a particular day (expressed as per cent of injected dose) and X is the time after injection in days.

The observed means and derived expressions are compared graphically in Fig. 4 (Page 28). Observed values are represented by squares and the derived expression by the heavy broken line designated $Y_{u+f}$.

The expression $Y_{u+f} = 0.79\ X^{-0.94}$ represents the total excretion of plutonium only through the 138th day. Adjustment can be made, however, for urinary excretion measurements through 1750 days by summing the expression for fecal elimination [9] and the adjusted expression for urinary excretion [7].

$$Y_{ua+f} = Y_{ua} + Y_f = 0.20\ X^{-0.74} + 0.63\ X^{-1.09} \qquad [13]$$

This equation is adjusted to include all urinary excretion results from Los Alamos Laboratory personnel through 1750 days, and gives the total per cent of an injected dose of plutonium which may be excreted on a given day (X) after the time of injection.

The adjusted expression for total elimination rate ($Y_{ua+f}$) through approximately five years and the observed means are presented graphically in Fig. 5 (Page 31) for comparison with the adjusted urinary excretion rate ($Y_{ua}$) for the same time interval.

Integration of the adjusted expression for total elimination rate between X = 1/2 and X = n+1/2 days, gives the total amount of plutonium expected to be excreted up to and including day n

$$A_{ua+f} = 0.20 \int_{1/2}^{n+1/2} X^{-0.74}\,dX + .63 \int_{1/2}^{n+1/2} X^{-1.09}\,dX$$
$$= 0.77\,(n+1/2)^{0.26} - 7.00\,(n+1/2)^{-0.09} + 6.81 \qquad [14]$$

Table 10 compares the observed and calculated values of total plutonium excretion for various time intervals using the integrated expression [14] .

These results emphasize the relatively slow rate of elimination of systemically deposited plutonium by man. According to these data only 8.7 per cent of a single injected dose is excreted in 1750 days (approximately 5 years).

TABLE 10

OBSERVED AND DERIVED TOTAL URINARY PLUS FECAL PLUTONIUM EXCRETION VALUES FOR VARIOUS TIMES AFTER ADMINISTRATION OF A SINGLE DOSE OF PLUTONIUM TO MAN

| TIME AFTER INJECTION | PER CENT OF INJECTED DOSE | |
|---|---|---|
| | Observed | Calculated * |
| 10 days | 3.43 | 2.56 |
| 20 days | 3.06 | 3.17 |
| 30 days | 3.41 | 3.53 |
| 40 days | 3.70 | 3.81 |
| 50 days | 3.90 | 4.03 |
| 60 days | 4.11 | 4.21 |
| 70 days | 4.27 | 4.36 |
| 80 days | 4.42 | 4.50 |
| 90 days | 4.54 | 4.62 |
| 100 days | 4.67 | 4.74 |
| 120 days | 4.87 | 4.93 |
| 140 days | 5.01 | 5.10 |
| 1 year | | 6.26 |
| 2 years | | 7.22 |
| 3 years | | 7.83 |
| 4 years | | 8.30 |
| 5 years | | 8.68 |
| 10 years | | 9.96 |
| 20 years | | 12.17 |

* Calculated from the integrated expression for adjusted urinary plus fecal excretion [14] . The calculated values appear higher than the observed values by a constant amount because of the decision to accept a poor curve fit during the first ten days (See Page 23).

## IV. DISCUSSION

### A. Distribution of Plutonium in Tissues and Organs of Man

Table 3 (Page 18) contains all available data (up to the time of this report) on the distribution of plutonium in the tissues and organs of man. These data were the results of analysis of a miscellaneous group of samples collected from seven human subjects. The subjects were elderly persons or persons suffering from an incurable chronic disease. The samples were often small and poorly representative and not obtained from the seven cases at comparable times after injection of the plutonium. These unavoidable difficulties must be recognized and accepted when considering the results. Despite the above difficulties, the data are extremely valuable as a supplement to a much greater and more reliable mass of data











concerning the distribution of plutonium in the tissues and organs of laboratory animals. The data on man are in good agreement with results of similar studies in rats, mice, rabbits, and dogs. The good agreement permits the conclusion that there are no major differences in the quantitative distribution of plutonium in the tissues and organs of man and those of common laboratory animals with perhaps one exception - the liver. The results indicate that the retention of plutonium in the liver following its intravenous injection as $Pu^{+4}$-citrate complex and as plutonyl ion may be 20 - 40 per cent for man as compared to 10 per cent or less for rats. The "biological half-time" of plutonium in the liver of man is probably much greater than that for rats.

The average amount of plutonium found in vertebra, sternum and rib was 0.0063 per cent of the injected dose per gram of whole bone. Assuming vertebra, sternum and rib as representative of the entire skeleton, 66 per cent of the injected dose would be deposited in a 10 kg skeletal system (7 kg of bone, 3 kg of marrow) of a 70 kg man.

The observed concentration of plutonium in bone may be used to estimate the radiation dose received per gram of skeletal system when a "standard man" has accumulated the official maximum permissible plutonium body content of 0.5 $\mu$g (0.032 $\mu$c). Using the dosage rate formula: rep/day = 54 CE (where C = concentration of radioisotope in $\mu$c/g, E = energy of the radiation in Mev, and the rep = 93 ergs/g), the radiation dosage received per gram of skeleton from 0.032 $\mu$c of plutonium is as follows:

$$\text{rep/day} = 54 \times 6.6 \times 10^{-5} \times 0.032\ \mu\text{c} \times 5.15\ \text{Mev} = .00057$$

A similar calculation for the official maximum permissible radium content of 0.1 $\mu$c may be made for comparison. If 50 per cent of the radon from radium decay is retained in the body, then approximately 15 Mev of energy will be released in the body by the alpha particles per decay. If 100 per cent of the radium is deposited in a 10 kg skeletal system, then the radiation dosage in rep per day is given as follows:

$$\text{rep/day} = 54 \times 1 \times 10^{-5} \times 15 = 0.0081$$

According to the above calculation, the radiation dosage per gram of skeleton delivered by 0.1 $\mu$g of radium would be 14 times that delivered by the maximum permissible dose of plutonium if the two materials were distributed in a comparable manner in the skeleton. Autoradiographic studies show conclusively, however, that radium and plutonium do not distribute in a comparable manner. Plutonium is more localized and concentrates in the endosteal and periosteal surfaces. The choice of a more conservative body tolerance dose for plutonium was made to allow for its more specific localization in the skeletal system. It should be noted, however, that radium does not distribute uniformly throughout bone and Evans (20) has reported that analyses of bone samples from radium cases showed the radium to be unevenly distributed by as much as a factor of 10. It may be necessary, therefore, for plutonium to be concentrated by a factor of 140 over radium in order that 0.5 $\mu$g will give radiation intensities comparable to that which may occur with 0.1 $\mu$g of radium. Evans (21) has also pointed out that the presence of mesothorium in the radium responsible for the early radium poisoning cases may account for an additional safety factor of 5 in the 0.1 $\mu$g radium tolerance.

The above discussion supports the possibility that the 0.5 $\mu$g maximum permissible tolerance dose for plutonium is extremely conservative.

### B. "Biological Half-Time" of Plutonium in Man

The "biological half-time" of plutonium in man can be estimated from the excretion data presented in this report. Although the adjusted urinary plus fecal excretion curve is (empirically at least) logarithmic in nature, it appears that the curve approaches an exponential for longer times. Such an exponential curve would be in keeping with the assumption that

metabolic processes are primarily first order reactions. Whatever the true process is, from the data and curves given in this report, it is possible to calculate the absolute minimum half-time of plutonium in the body. It is assumed (not unreasonably) that the excretion of the plutonium measured in terms of the amount in the body at a given time does not increase at some time. If one takes the last point on the combined urinary plus fecal excretion curve (a single value of the ordinate in Fig. 5) and assumes exponential excretion thereafter, an absolute minimum value is obtained for the biological half-time. On this figure, which is a plot of $\Delta C/C_0$ versus $\Delta t$ exponential excretion would be represented by a straight line with zero slope. Examination of the adjusted curve shows that $0.001 \pm .00035$ per cent per day is excreted at 1750 days (approximately 5 years) after exposure. Up to five years 8.7 per cent of the total has been excreted. The time required to excrete an additional 41.3 per cent (assuming exponential excretion beyond 1750 days) is

$$\frac{41.3}{0.001 \pm 0.00035} = 41{,}300 \text{ days} = 113 \text{ years with limits of 84 and 175 years.}$$

Thus, the mean minimal biological half-time estimate is 118 years. From the above, one may conclude that the excretion coefficient is too small to be of any practical significance in elevating the maximum permissible dose of plutonium or in permitting the return to work of an individual who has reached the maximum permissible body burden. Once a worker is retired from work with plutonium because of a maximum tolerance exposure, it must be assumed that he is retired from such work for the balance of his lifetime.

C. Determination of Plutonium Body Burden from Urinary Excretion

In the determination of exposure doses by the use of excretion data, one is primarily concerned with three different situations. First is the case of a single acute exposure dose occurring at a known time. Second is the case of a variable chronic or subacute dose with only the total exposure time being known. Third is the case of a chronic invariant (usually low level) exposure dose with the time limits known.

The evaluation of the single acute exposure dose occurring at a known time is the basis of this paper. A urinary excretion curve through 138 days after a single acute exposure is given in Fig. 4 (Page 28). This curve has been extended beyond the observation limit to 1750 days (Fig. 5) by applying data collected on exposed personnel from the Los Alamos Laboratory. The method used to apply these data was explained earlier (Pages 23 and 29). It is worth noting that the difference between the adjusted curve and the extrapolated 138-day curve at 1750 days is less than the standard error of estimate of the former. This finding allows more confidence in further extrapolation beyond 1750 days post exposure. The calculation of the body burden from a single acute exposure is simple.

Since

$$Y_{ua}(\%) = 0.20\,X^{-0.74}$$

$$Y(c/m) = 0.0020\,D_E\,X^{-0.74}$$

Then

$$D_E = 100\,Y(c/m)\,X^{0.74} \qquad [15]$$

Thus, a single urine count, Y, made X days after an unknown single acute exposure, $D_E$, determines $D_E$ in counts per minute. The exposure dose in $\mu c$ or $\mu g$ is easily determined if the counting geometry, etc., is known.

In the Los Alamos exposures, we have an illustration of the variable chronic exposure case with known time of exposure. Only under conditions of stress when safety factors of design may be exceeded will this type of exposure be seen. There are three methods of







estimating the total exposure dose under such conditions. Past practice at the Los Alamos Laboratory was to assume that an individual contracted his total exposure dose on the last day of the exposure period. His total body burden was then determined by substitution in the urinary excretion formula as shown above. In this case, zero time is the last day of exposure. Obviously this method gives too low a value for the exposure dose as the estimated dose is directly proportional to time. A second method which has been used is exactly the same as the previous one except that zero time is taken as the first day of exposure which assumes that all of the dose was accumulated on exposure day one. It is evident that this estimate of total exposure is too high. The third method, which was used in this paper to determine the adjusted urinary excretion curve, is believed to more closely approximate the true situation. In this method it has been assumed that the total exposure dose may be represented by a single effective dose occurring at some effective time intermediate to the limits of exposure. The equations and steps to be followed with this method are shown on Pages 23 and 29. Ordinarily the first urine count is used to determine whether an individual should or should not be withdrawn from exposure. It is not used as one of the two significantly different dose determining counts. This is due to the fact that the initial withdrawal count may reflect the high urinary excretion resulting from the previous ten days exposure, and to the relatively high per cent excretion during the first 10 days post-exposure period. The high rate of elimination resulting therefrom may relatively obscure any exposure doses accumulated previous to that time.

The case of chronic invariant exposure is probably of primary interest. This is the type of exposure (within limits) that occurs in processing procedures in the plutonium industry in which air concentrations, etc., are rigidly controlled and the work is routine. An analysis of the general case is presented as follows:

If m = time of exposure in days, and

n = days from the beginning of an exposure to the time a urine analysis is made with n > m (preferably by more than 10 days)

then the counts per minute in the urine excreted on day n is:

$$Y_n = 0.0020\left[D_1 n^{-0.74} + D_2(n-1)^{-0.74} + D_3(n-2)^{-0.74} + \ldots\ldots + D_m\left[n-(m-1)\right]^{-0.74}\right]$$

where $D_1$ is the exposure dose in counts per minute on exposure day 1,

$D_2$ is the exposure dose in counts per minute on exposure day 2,

.

.

.

$D_m$ is the exposure dose in counts per minute on exposure day m.

Considering the case in which we are interested, namely, $D_1 = D_2 \ldots\ldots = D_m = D_j$ (the constant daily exposure dose), then

$$Y_n = 0.002 D_j\left[n^{-0.74} + (n-1)^{-0.74} + \ldots\ldots + \left[n-(m-2)\right]^{-0.74} + \left[n-(m-1)\right]^{-0.74}\right]$$

Thus

$$D_j = \frac{Y_n}{0.0020\left[n^{-0.74} + (n-1)^{-0.74} + \ldots\ldots + \left[n-(m-2)\right]^{-0.74} + \left[n-(m-1)\right]^{-0.74}\right]}$$

Considering the bracketed term in the denominator:

$$n^{-0.74} + (n-1)^{-0.74} + \ldots\ldots + \left[n-(m-1)\right]^{-0.74} =$$

$$(n-m+1)^{-0.74} + (n-m+2)^{-0.74} + \ldots\ldots + n^{-0.74}$$

This term is similar to the infinite series $r^t$ where r has the limiting values (n - m + 1) and (n) and t = -0.74. The sum of the series $r^{-0.74}$ may be written:

$$\sum_{r=1}^{r=R} \frac{1}{r^{-0.74}} = \frac{1}{1^{0.74}} + \frac{1}{2^{0.74}} + \frac{1}{3^{0.74}} + \ldots\ldots + \frac{1}{R^{0.74}}$$

Thus we may write:

$$(n-m+1)^{-0.74} + (n-m+2)^{-0.74} + \ldots\ldots + n^{-0.74} = \sum_{r=(n-m+1)}^{r=n} \frac{1}{r^{0.74}}$$

$$= \sum_{r=1}^{r=n} \frac{1}{r^{0.74}} - \sum_{r=1}^{r=(n-m)} \frac{1}{r^{0.74}} = \sigma(n) - \sigma(n-m)$$

and on substitution

$$D_j = \frac{Y_n}{0.002\left[\sigma(n) - \sigma(n-m)\right]}$$

The following empirical formula* is good to 2 parts in 50 for r = 1 and to better than 1 part in 1000 for r > 5:

$$\sigma(r) = 3.8462\,(r+1/2)^{0.26} - 3.2880 \qquad [16]$$

Thus, on substitution we have:

$$D_j = \frac{Y_n}{0.002\left[3.8462(n+1/2)^{0.26} - 3.8462(n-m+1/2)^{0.26}\right]}$$

or

$$D_j = \frac{130\,Y_n}{\left[(n+1/2)^{0.26} - (n-m+1/2)^{0.26}\right]}$$

Since the total exposure dose = $mD_j = T_{D_m}$

$$T_{D_m} = \frac{130\,mY_n}{\left[(n+1/2)^{0.26} - (n-m+1/2)^{0.26}\right]} \qquad [17]$$

In addition to the empirical formula for $\sigma(r)$ a plot of the real values of $\sigma(r)$ versus (r) for values of r up to 90 days has been included (Fig. 6) from which the values of the sums may be read directly.

In the equation for $T_{D_m}$ seven exposure days per week are assumed. The formula for $T_{D_m}$ may be adjusted for six exposure days per week as follows:
We assume that exposure begins on the first working day of a week for simplicity.

Obviously the only days not contributing to exposure are those on which $D_j = 0$. In the six day week, therefore, $D_7 = D_{14} = D_{21} = \ldots\ldots D_{7a} = 0$ where a = number of weeks worked by the subject. Thus, the terms corresponding to $D_7$, $D_{14}$, $D_{21}$ ..... etc., must be subtracted from the dose equation.

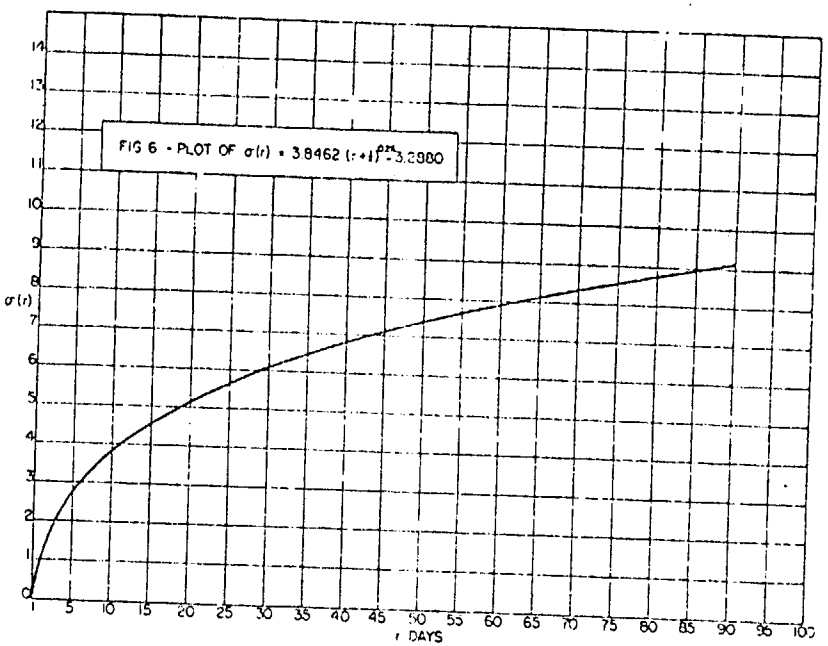
*Determined by Bengt Carlson of the Los Alamos Theoretical Division.












Hence:

$$D_j = \frac{Y_n}{0.002\left\{\left[\sigma(n) - \sigma(n-m)\right] - \left[(n-6)^{-0.74} + (n-13)^{-0.74} + (n-20)^{-0.74} + \ldots\ldots + (n-7a+1)^{-0.74}\right]\right\}}$$

And designating the total exposure dose for the six day week as $T_{D_{m_6}}$ then

$$T_{D_{m_6}} = \frac{500\,mY_n}{3.8462\left[(n+1/2)^{0.26} - (n-m+1/2)^{0.26}\right] - \left[(n-6)^{-0.74} + (n-13)^{-0.74} + (n-20)^{-0.74} + \ldots\ldots + (n-7a+1)^{-0.74}\right]} \qquad [18]$$

Similarly for 5 exposure days per week

$$D_6 = D_7 = D_{13} = D_{14} = D_{20} = D_{21} = \ldots\ldots D_{7a-1} = D_{7a} = 0$$

the total exposure dose $T_{D_{m_5}}$ =

$$\frac{500\ mY_n}{3.8462\left[(n+1/2)^{0.26}-(n-m+1/2)^{0.26}\right]-\left[(n-5)^{-0.74}+(n-6)^{-0.74}+(n-12)^{-0.74}+(n-13)^{-0.74}+\ldots\right.}$$

$$\left.\ldots+(n-7a+2)^{-0.74}+(n-7a+1)^{-0.74}\right]$$

In the preceding formulae exposure conditions were assumed to consist of an equal and constant daily exposure dose $D_i$ equivalent to a single injected dose. Also, the constants 0.0020 and -0.74 were empirically established on the basis of data available at the time of this report. These values may change as more data become available.

A specific example of the application of the above dosage calculation is given below, using the expression for seven exposure days per week. In fact, the seven day exposure formula may be valid for either the five or six day week. Such would be the case if one considers that absorption from the lung is the primary source of contamination and that the equilibrium between the alveolar and blood plutonium concentration is not radically altered by the one or two day period of no exposure each week.

For purposes of presenting a specific example we may assume the following conditions:

Duration of exposure (m) = 330 days
Duration of time from beginning of exposure until urine sample taken (n) = 360 days
Counts per minute of urine sample ($Y_n$) = 2 c/m
The total body dose $T_{D_m}$ may be calculated from the formula:

$$T_{D_m} = \frac{130 \times m \times Y_n}{\left[(n-1/2)^{0.26}-(n-m-1/2)^{0.26}\right]}$$

On substitution:

$$T_{D_m} = \frac{130 \times 330 \times 2}{\left[(360.5)^{0.26}-(30.5)^{0.26}\right]} = \frac{8.58 \times 10^4}{2.19} = 3.9 \times 10^4\ c/m$$

Assuming a 50 per cent counting geometry was used (1 $\mu g$ = $7 \times 10^4$ c/m)

$$T_{D_m} = 0.56\ \mu g$$

## V. SUMMARY

The distribution and excretion of plutonium administered intravenously to man has been studied. The data from twelve subjects have been correlated with similar data collected by other investigators, making a total of sixteen cases considered. The data have been supplemented further with observations made on three Los Alamos Laboratory personnel who absorbed measurable amounts of plutonium in the course of their work. The results of these studies may be summarized as follows:

1. Clinical observations and clinical data collected on the various subjects indicate that the intravenous injection of a single dose of 5 to 100 $\mu g$ of plutonium is without acute subjective or objective clinical effects.
2. The analysis of tissues following the intravenous injection of plutonium showed that there was little difference in the mode of deposition of plutonium in man











and in the common laboratory animals. As in the case of rats and other laboratory animals the skeletal system was the major site of plutonium deposition. Retention of plutonium by the liver of man seemed to be higher and the "biological half-time" in liver longer than for the more common laboratory animals.

3. Concentration of plutonium in the blood following intravenous injection drops very rapidly; only 0.3 per cent of the total injected dose was fixed in the total blood volume thirty days after injection.
4. The urinary excretion of intravenously administered plutonium was not exponential. Curvilinear regression line fitting showed that the urinary excretion through 138 days was best expressed by the fractional logarithmic function

$$Y_u = 0.23\ X^{-0.77}$$

In this expression $Y_u$ is the per cent of the injected dose excreted in a single day and X is the time of observation in days post-injection. The standard error of estimate is 32%.

5. The above expression for the urinary excretion through 138 days was adjusted by including data collected on Los Alamos Laboratory personnel. This adjustment permitted the development of an expression for the urinary excretion of plutonium through 1750 days. The adjusted expression is:

$$Y_{ua} = 0.20\ X^{-0.74}$$

The standard error of estimate of the adjusted expression is 42 per cent.

6. The excretion of plutonium in the feces likewise was not exponential. Application of the method of least squares showed the best curve of fit for the fecal excretion of plutonium through 138 days was:

$$Y_f = 0.63\ X^{-1.09}$$

In this expression $Y_f$ is the per cent of the injected dose excreted on a specific day and X is the time of measurement in days post-injection. The standard error of estimate of the above expression is 28 per cent.

7. The urinary to fecal plutonium excretion ratio obtained by solution of the above expressions for urinary and fecal excretion showed the urinary to fecal ratio was not constant. It was essentially 1:1 at 30 days and approached 4:1 at approximately five years.
8. The total (urine and fecal excretion) through 138 days was best expressed by the equation:

$$Y_{u+f} = 0.79\ X^{-0.84}$$

9. The total urine plus fecal excretion through 1750 days could be approximated by adding the expression for the fecal excretion through 138 days and the adjusted expression for the urinary excretion through 1750 days. The expression for the combined excretion is:

$$Y_{ua+f} = 0.20\,X^{-0.74} + 0.63\,X^{-1.09}$$

in which $Y_{ua+f}$ represents the per cent of the injected dose excreted in the urine plus feces on a specific day, and X designates the time of observation in days post-injection.

10. Integration of the above expression between the limits of 1/2 and n+1/2 days post-injection gives the following expression:

$$A_{ua+f} = 0.77\,(n+1/2)^{0.26} - 7.00\,(n+1/2)^{0.09} + 6.81$$

which represents the integrated amount of plutonium in per cent of the injected dose ($A_{ua+f}$) excreted up to and including the nth day after injection. Substitution in this expression showed that only 8.7 per cent of a single injected dose was excreted in approximately five years.

11. Application of the data of this report to the calculation of the "biological half-time" of plutonium in man gives a mean minimal "biological half-time" estimate of 118 years, with a variation of from 84 to 175 years.

12. The urinary excretion data of this report were applied to the diagnosis of exposure of personnel to plutonium. Three sets of exposure conditions were considered:

    (a) The application of plutonium urine analysis to estimate the total body dose following a single acute exposure occurring at a known time,

    (b) The application of plutonium urine analysis to estimate the total body burden of plutonium following variable chronic or sub-acute exposure with only the total exposure time being known and,

    (c) The application of urine analysis to estimate the total body burden following chronic invariant exposure (such as may occur in a carefully controlled routine plant process) with time of exposure known.

    Expressions for the calculation of body dose under the conditions set forth in (a), (b) and (c) are included in this report.









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## TABLE 3

## DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUES FOLLOWING INTRAVENOUS INJECTION OF PLUTONIUM SALTS

| Tissue[2] | Subject and % of Injected Dose/g of Tissue | | | | | | | | Rel. Pu Affinity[3] | Org. Wt./g[4] | Calc. %/Organ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hp-5 | Hp-9 | Hp-11 | Chi. I | Chi. II | Hp-12 | Cal. I | Av. %/g | | | |
| Bone Marrow | -- | -- | .0096 | .0153 | .0210 | -- | .0290 | .0187 | 13.3 | 3,000 | (56.1)[6] |
| Radius (Frag. head) | -- | -- | -- | -- | -- | .0187 | -- | -- | -- | -- | -- |
| Liver | .0320 | .0144 | .0353 | .0139 | .0324 | -- | -- | .0136 | 9.7 | 1,700 | 23.1 |
| Rib (Cortex) | -- | -- | -- | .0015 | .0196 | -- | .0170 | .0127 | 9.1 | -- | -- |
| Patella | -- | -- | -- | -- | -- | .0109 | -- | -- | -- | -- | -- |
| Vertebra | .0071 | .0080 | .0070 | -- | -- | -- | -- | .0073 | 5.2 | SKELETON | -- |
| Sternum | .0070 | -- | .0100 | .0044 | -- | -- | -- | .0071 | 5.1 | 10,000 | 65.7[5] |
| Rib (Whole) | .0050 | .0038 | .0068 | -- | -- | -- | -- | .0052 | 3.7 | | -- |
| Periosteum (Rib) | -- | -- | -- | .0043 | .0019 | -- | .0048 | .0037 | 2.6 | -- | -- |
| Spleen | .0007 | .0015 | .0048 | .0024 | .0014 | -- | .0019 | .0021 | 1.5 | 200 | 0.4 |
| Kidney | .0002 | .0002 | .0015 | .0004 | .0054 | -- | -- | .0015 | 1.0 | 300 | 0.4 |
| Thyroid | .0001 | -- | .0009 | -- | .0034 | -- | -- | .0014 | 1.0 | 30 | -- |
| Adrenal | .0004 | -- | .0022 | -- | -- | -- | -- | .0013 | 1.0 | 14 | -- |
| Lung | .0005 | -- | .0016 | .0006 | .0016 | -- | -- | .0011 | 0.8 | 950 | 1.0 |
| Pancreas | .0002 | .0002 | -- | -- | .0022 | -- | -- | .0009 | 0.6 | 65 | -- |
| Gonads | .0003 | -- | .0012 | .0005 | .0009 | -- | -- | .0007 | 0.5 | -- | -- |
| Lymph Node | -- | -- | -- | .0014 | .0001 | -- | -- | .0007 | 0.5 | 700 | 0.5 |
| Teeth (Av. of 7) | -- | -- | -- | -- | -- | .0003 | -- | -- | -- | -- | -- |
| Heart | .0000 | .0000 | -- | .0003 | .0011 | -- | -- | .0003 | 0.2 | 350 | 0.1 |
| Large Intestine | .0002 | -- | .0004 | -- | .0001 | -- | -- | .0002 | 0.1 | 2,300 | 0.5 |
| Small Intestine | .0001 | -- | .0005 | -- | .0001 | -- | -- | .0002 | 0.1 | -- | -- |
| Muscle and Skin | .0000 | -- | .0002 | .0002 | .0001 | -- | -- | .0001 | 0.1 | 38,500 | 3.9 |
| Blood | -- | -- | -- | -- | -- | -- | -- | -- | -- | 5,400 | 0.2[8] |
| Balance | -- | -- | -- | -- | -- | -- | -- | .0001[7] | -- | 9,600 | 0.9 |
| Total | -- | -- | -- | -- | -- | -- | -- | -- | -- | 70,000 | 96.7 |

(1) The various subjects received the following doses of plutonium: Hp-5 = 5 μg; Hp-9 = 6.3 μg; Hp-11 = 6.5 μg; Chi. I = 6.5 μg; Chi. II = 94.9 μg; Hp-12 = 4.7 μg; Cal. I = 103 μg.

(2) Tissues were obtained at the following times after injection: Hp-5 151 days; Hp-9 456 days; Hp-11 5 days; Chi. I 155 days; Chi. II 16 days; Hp-12 5 days; Cal. I 4 days.

(3) Calculated by dividing %/g of tissue by %/g of body weight if a unit dose of Pu was equally distr. in a 70 Kg. man.

(4) Hermann Lisco, Memorandum to AEC, July 21, 1947, Project Standard Man.

(5) Assumption made that vertebra, sternum and whole rib represent average bone of skeletal system.

(6) Bone marrow not included in total recovery because bone samples were not freed of marrow before analysis.

(7) Balance assumed to have same Pu content as muscle.

(8) Value for blood taken at 30 day point, Fig. 3.



LA-1151

Table 1. (Part 1)

Material balances of soft tissues and excreta. Six persons injected i.v. with Pu(IV) citrate, Pu(VI) nitrate, or Pu(VI) citrate

| | Pu(IV) Citrate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | HP-5, 151 days p.i. Male, 56 yr. | | | HP-9; 456 days p.i. Male, 66 yr. | | | HP-11; 5 days p.i. Male, 68 yr. | | |
| | % Pu/g | 70.8 kg[a] wt (g) | Calc. (%) dose | % Pu/g | 63 kg wt (g) | Calc. (%) dose | % Pu/g | 70.8 kg[a] wt (g) | Calc. (%) dose |
| Liver | 0.032 | 1,340[b] | 42.8 | 0.0144 | 1,600[b] | 23.0 | 0.0053 | 2325 | 12.3 |
| Spleen | 0.0007 | 184 | 0.13 | 0.0015 | 162 | 0.24 | 0.0048 | 184 | 0.89 |
| Kidney | 0.0002 | 312 | 0.062 | 0.0002 | 277 | 0.055 | 0.0015 | 312 | 0.47 |
| Lung | 0.0005 | 1,000 | 0.50 | | | | 0.0016 | 1,000 | 1.60 |
| Pancreas | 0.0002 | 100 | 0.02 | 0.0002 | 90 | 0.018 | | | |
| Intestines | 0.00015 | 1,020 | 0.15 | | | | 0.00045 | 1,020 | 0.46 |
| Testes | 0.0003 | 64 | 0.018 | | | | 0.0012 | 64 | 0.077 |
| Thyroid | 0.0001 | 16 | 0.0016 | | | | 0.0009 | 16 | 0.014 |
| Adrenals | 0.0004 | 14 | 0.0056 | | | | 0.0022 | 14 | 0.031 |
| Muscle | 0.0002[c] | 28,400 | 5.67 | 0.0002[c] | 25,200 | 5.92 | 0.0002 | 28,400 | 5.68 |
| Skin | | 4,950 | | | 4,410 | | 0.0002 | 4,950 | 0.99 |
| Residual soft tissue | 0.0001[d] | 23,080 | 2.31 | 0.0001[d] | 22,280 | 2.23 | 0.0001[d] | 22,200 | 2.22 |
| Excreted[e] | | | 5.20 | | | 16.5 | | | 2.00 |
| Total (accounted for) | | | 57.9 | | | 48.0 | | | 34.7 |
| Skeleton (calc.) | | 10,300 | 42.1 | | 9,166 | 52.0 | | 10,300 | 65.3 |

Footnotes to Table I.

[a] Body weight estimated to be the mean weight of six male cases whose body weights were recorded.

[b] Measured tissue weight.

[c] Pu concentrations in muscle and skin (when not measured) were estimated to be the average of other measured soft tissues such as heart, pancreas, etc.

[d] Pu concentration of residual soft tissue was estimated to be one-half the concentration in skin and muscle.

[e] Measured totals are used when available. Excretion between the cessation of collections and deaths of HP-5 and HP-9 was estimated from extrapolation of the last available measurements and the slopes of the U and F curves of persons followed for longer times. Excreta from HP-11 were estimated to be the mean for all the other Pu(IV) citrate-injected cases.

[f] Includes 7.95%, the average Pu content of blood of the two sickest persons (HP-4 and HP-10), from whom blood samples were obtained at this time.

[g] %/g of Pu recalculated from original data.

[h] Includes 3.25% estimated from the tissues of Chi-2, and HP-11.

[i] Chi-2 was emaciated; her skeleton was assumed to be the average reported by Mechanik[66] for slightly built females. Cal-1 had lost 15 lb during his illness; his skeletal weight was calculated from his body weight in good health, 64.8 kg.

PRIVACY ACT MATERIAL REMOVED

Name

Hospital No String Num. 242006 Autopsy # 9693

Date of birth

Date of injection - Feb 20, 1946 6.5 μg $^{239}Pu$ (IV) citrate

Age at injection

Date of death Feb 26, 1946

Age at death Time after injection - 6 days

Death certificate No

Hp-11

This patient, a sixty-eight year old white male with history of alcoholism and dietary inadequacies for many years, was admitted to the hospital on December 12, 1945, with complaints of dyspnea and abdominal swelling. He expired on February 26, 1946, and diagnoses at autopsy were cirrhosis of the liver, ascites, and thrombosis of the portal vein.

LA 1151

PRIVACY ACT MATERIAL REMOVED

8002059

PRIVACY ACT MATERIAL REMOVED

Dist. No. 2701 — To be inserted by registrar

# New York State Department of Health
DIVISION OF VITAL STATISTICS
## CERTIFICATE OF DEATH

10243
Registered No. 647

1 PLACE OF DEATH: STATE OF NEW YORK
County Monroe
Town
Village
City Rochester Ward
No. Strong Memorial Hospital St.
(If a hospital or institution give its NAME instead of street and number)
Length of stay:
In hospital or institution yrs. 2 mos. 4 days
In town, village or city yrs. 2 mos. 4 days

2 USUAL RESIDENCE OF DECEASED: (If an institution, give place of residence prior to admission.)
State New York
County Monroe
Town Irondequoit
Village or City
No. 99 Lake Front Ave. (Del Barge) St.
Is residence within limits of city or incorporated village? No
2a Citizen of foreign country (alien)? No (Yes or no)
If yes, name country

3 Full Name (Print)

4 (a) Social Security No.
4 (b) If Veteran, Name War Spanish Amer.

5 Sex: Male
6 COLOR OR RACE: White
7 Single, Married, Widowed, or Divorced (Write the word): Married

8 IF MARRIED, WIDOWED OR DIVORCED, Name of Husband (or) Wife: Louise Dunn — Age if alive — years

9 DATE OF BIRTH (month, day, year)

10 AGE: Years 69 | Months 0 | Days 7 | IF LESS than 1 day, hrs. or min.

11 Usual occupation Maintenance Man - Janitor

12 Industry or business

13 BIRTHPLACE (City or Town) (State or Country): Waterloo New York

FATHER
14 NAME
15 BIRTHPLACE (City or Town) (State or Country): Waterloo New York

MOTHER
16 MAIDEN NAME
17 BIRTHPLACE (City or Town) (State or Country): Wyoming New York State

18 THE ABOVE IS TRUE TO THE BEST OF MY KNOWLEDGE
Informant's own signature

19 PLACE OF BURIAL, CREMATION OR REMOVAL: Irondequoit Cem.
DATE OF BURIAL: Mar. 1, 1946

20 UNDERTAKER OR PERSON IN CHARGE (Signature)
ADDRESS 1611 Main St E
UNDERTAKER'S License No. 5267

21 Date received 2-27, 1946
Signature of Registrar or Subregistrar

Burial or Transit Permit issued by Arthur Fiedelund Date of issue 2-27-46

## MEDICAL CERTIFICATION

23 DATE OF DEATH (Month, Day and Year): February 25, 1946

24 I HEREBY CERTIFY, That I attended deceased from December 21, 1945, to February 26, 1946
I last saw h im alive on February 26, 1946
To the best of my knowledge, death occurred on the date stated above, at 4:50AM m.
Immediate cause of death: Bronchopneumonia

| Duration of Condition: Yrs. | Mos. | Hrs. |
|---|---|---|
| | | X |
| | | |
| | | |
| X | | |
| | | X |
| X | | |
| | | |
| | | |
| | | |

Other Conditions: Cirrhosis of liver, concretion of viscera
Due to: Uriosclerosis
Other conditions (Include pregnancy within 3 months of death)
Major findings of operation: No operation
Date of autopsy: as above
What laboratory test was made? Bl. Chem

PHYSICIAN: Underline the cause to which death should be charged.

If death was due to external causes, fill in the following:
(a) Accident, suicide, or homicide (specify)
(b) Date of occurrence
(c) Where did injury occur? (City or town) (County) (State)
(d) Did injury occur in or about home, on farm, in industrial place, in public place? While at work? (Specify type of place)
(e) Means of injury

25 Signature Robert H. Ivy M. D.
Address Strong Memorial Hospital Date 2/26/46

PRIVACY ACT MATERIAL REMOVED

8002060

ARGONNE NATIONAL LABORATORY — CENTER FOR HUM RADIOBIOLOGY

PRIVACY ACT MATERIAL REMOVED

| PROPOSAL FOR EXHUMATION | Proposed by AFS (JEF) | Date 4/1/73 |
|---|---|---|

PROSPECTIVE CASE DATA

| Name | | Case No. | Date of birth |
|---|---|---|---|
| SP-11 | | 40--017 | |
| **Date of death** | **Place of death** | **Autopsy?** | **Remains** |
| 2/26/46 | Strong Mem. Hosp. Rochester | — Yes — No | X Normal — Cremains |

RADIOACTIVITY DATA

| | | | | |
|---|---|---|---|---|
| EXPOSURE: | Company, Hospital, M.D., etc. (18) Strong Mem. Hosp. Rochester | | | Type Pu 46 |
| INTAKE: | Radionuclide, Amount (if known) $^{239}$Pu (IV) citrate 0.4 μCi | | Dates From Feb 20 1946 | To |
| RESIDUAL: | Nuclide Amt. Date Lab | | Nuclide Amt. Date Lab | |

REASONS FOR POST-MORTEM STUDIES

— Unknown body burden X Priority group — Known intake — Medical

— Calibration comparison — Ra-228/Ra-226 X Distribution — Other

EXPLANATION Pu

PROPOSED ANALYSES alpha auto, distribution - % ID ret., x-ray and micros for pathology, Radiochem.

REVIEW AND AUTHORIZATION

| Number of known relatives | Estimated number of consents needed | Court action anticipated |
|---|---|---|
| 1 | | — Yes X No |
| **Cemetery** | **Address** | **Cooperative?** |
| Cem | N.Y. | — Yes — No X Never used |
| **Funeral Home** | **Address** | |
| 6 | | — Yes — No X Never used |

Prognosis of suitable remains: — Good X Fair — Poor

Reason: Expect some erosion

By JEF

Date 4/3/75

Comments:

PRIVACY ACT MATERIAL REMOVED

RECOMMENDATION: — Yes — No — Cannot say

Scientific Reviewer — Date

Comments: Authorized for exhumation in AFS memo to MMS 3/24/73.

Assignment of responsibility for permits

APPROVAL? — Yes — No — Defer

Director of CHR — Date

8002063

filename = SNOP
file type = PDS

PRIVACY ACT MATERIAL REMOVED

Name _____



| Description | Case # | @M, | @A,T, | M, | E, | F, | D, |
|---|---|---|---|---|---|---|---|
| bronchopneumonia | 15-017 | oc | 2300 | 4001 | 0000 | 0000 | 4602C |
| cirrhosis of liver | | | 5600 | 4850 | | | |
| congestion of viscera | | | Y500 | 9810 | | | |
| arteriosclerosis: | | | 4100 | 5200 | | | |
| alcoholism | | | 0000 | 0000 | | 8805 | -50J |
| dyspnea | | | 2000 | 6000 | | 7101 | 4554 |
| abdominal swelling | | | Y410 | 3848 | | 0000 | 4650J |
| cirrhosis - liver | | | 5600 | 4850 | | | 4650F |
| ascites | | | Y410 | 3330 | | | |
| thrombosis - portal vein | | | 4881 | 3700 | | | |
| Pulmonary injection | | | 0001 | 1908 | 0000 | 0000 | 4650J |
| | | | | | | | |
| | | | | | | | |
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| | | | | | | | |
| PRIVACY ACT MATERIAL REMOVED | | | | | | | |

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