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INPUT DATA TO THE AEC HEALTH AND MORTALITY STUDY

RADIATION EXPOSURE  
EXPERIENCE OF EMPLOYEES  
1944 THROUGH 1974

Revised

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by

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## PERSONNEL RADIATION EXPOSURE EXPERIENCE OF EMPLOYEES AT HANFORD

### SUMMARY

Radiation exposure data are included in the AEC Health and Mortality Study for the following groups of employees at Hanford:

- (1) duPont employees for the period 1944 through September 1946 who subsequently transferred to the General Electric Company and remained at Hanford.
- (2) General Electric employees since September 1946.
- (3) Vitro employees beginning in 1963.
- (4) Battelle-Northwest Laboratories beginning January 04, 1965.
- (5) Atlantic Richfield Hanford Company (formerly Isochem) beginning January 01, 1966.
- (6) United Nuclear Industries (formerly Douglas United Nuclear Company) beginning November 01, 1965.
- (7) International Telephone and Telegraph/Federal Support Services (from March 01, 1966, to September 01, 1971).
- (8) Hanford Environmental Health Foundation beginning August 01, 1965.
- (9) Computer Sciences Corporation beginning July 01, 1965.
- (10) Hanford Engineering Development Laboratory (Westinghouse) beginning July 01, 1970.

Records for groups (4) through (10) are available since these groups took over when the General Electric Company was phased out beginning in 1965. All known occupational exposure is included for each of these employees. Exposure received by these employees as a result of prior employment by another contractor at some site other than Hanford is included when known. This is identified as "off-site" exposure.

The total radiation dose from external sources received by each person during his Hanford employment is summarized by year. From 1944 through 1972 these data were accumulated on data processing cards and listings prepared from these cards. Off-site exposure was summarized on a separate card for each employee for each known intake of bone seeking radionuclides. The formats used for these cards are described in the attached exhibits.

Since 1972, the external radiation exposure has been picked up yearly by interfacing with the Hanford External Exposure System. Exhibits #1, 1A describe the format.

## EXTERNAL RADIATION EXPOSURE DATA

### Historical Data

A record is included for each year an employee was monitored and exposure data were recorded. Since 1964, exposure records have been kept for all employees whether monitored or not. These records will include the following employee identification:

- Payroll number(s)
- Social Security number
- Name(s) (Last, First and Second [initials only])

These doses, including zeros for years monitored without any recorded doses, are recorded for each year in units of Rem, rounded off to the nearest 0.01 Rem. Details are shown in Exhibit #2.

Special computer programs were written to retrieve data from the exposure information that has been stored on magnetic tape at Hanford over a twenty-one period starting in 1944. These data, which include identification of the employee external exposure data (beta, gamma, X-ray, neutron, tritium, and extremity doses prior to 1972) have been entered on data processing cards. Exposure data, not available from any of the magnetic tapes, were obtained manually from other sources. The sources of the exposure data are described in detail in Exhibit #3.

### Beta-gamma Dosimetry

Exposure data are based primarily upon the results of dosimeters worn by employees at Hanford, currently in accordance with the following criteria: (Earlier criteria was at least as restrictive as the current criteria).

At Hanford a Thermoluminescent Dosimeter shall be worn by each person who enters either a Hanford manufacturing or laboratory facility wherein there are sources of ionizing radiation or in any Hanford radiation zone. Employees who are not expected to receive more than 1 rem/year as a result of their work are assigned a Basic TL Dosimeter. Those expected to receive 1 rem or more to the whole body in a year are assigned a Multipurpose TL Dosimeter.

### Beta-gamma Dosimetry (contd.)

The dosimeter worn by employees while in a zone where the measured neutron dose rate is known to exceed 1 mrem/hour shall include capabilities for measuring the neutron radiation. A Hanford Ring Dosimeter shall be worn, while in a Radiation Zone or while working with radioactive materials, by employees whose extremity exposure may be expected to exceed 3 rems per calendar quarter.

All exposure data indicated by personnel dosimeter results are considered to be valid measurements of exposure received by the individual unless they can be clearly demonstrated otherwise.

If a dosimeter result is lost or proven to be invalid, an estimate of the individual's exposure for the period involved is established. This estimate is included in the individual's exposure record.

Four types of dosimeters have, at various times, been utilized at Hanford to measure beta and gamma exposure. Detailed descriptions of these dosimeters are included in Exhibits #4 and #5.

### Neutron Dosimetry

The reported neutron exposures are either estimates based on field dose rate measurements and the duration of exposure or upon results of a neutron dosimeter worn by the individual. Four types of neutron dosimeters have, at various times, been worn to measure neutron exposure. Exhibit #6 contains a detailed description of these dosimeters. A quality factor of 10 is applied to convert the fast neutron dose from rads to rems and a quality factor of 3 is used for slow neutrons. The sum of the fast and slow neutrons, in rems, is reported on data processing cards.

### Tritium Dosimetry

Although tritium exposure is based upon results of urine samples collected it is considered as whole body penetrating exposure. Exposure from tritium is routinely calculated utilizing a data processing program. This program assumes a twelve-day effective half-life in the body in the absence of sufficient measurements to establish a better half-life and applies a quality factor of 1.7 to convert the dose to rem. This twelve-day half-life may slightly overestimate the exposure; however, persons having significant potential for exposure to tritium are sampled frequently enough so that any overestimate is minimized. The method utilized to evaluate exposure for tritium is described in Exhibit #7.

Extremity Dosimetry

The extremity exposure data are routinely based on measurements of finger ring dosimeters and occasionally on special evaluations based on other exposure information. Extremity dosimeters are worn only when significant hand exposure is anticipated and therefore may not represent a valid measure of the total extremity dose. A more conservative estimate of the total extremity dose would include a portion or all of the dose to the skin of the whole body. Extremity dosimeters used at Hanford are described in Exhibit #8.

Off-Site Exposure

Exposure received prior to employment at Hanford has been obtained and entered in the person's exposure record. Prior to 1962, this practice was followed only for cases involving known or suspected exposure. Beginning in 1962, all persons hiring-in at Hanford were instructed to complete a questionnaire describing prior employment history. For each case identified in this manner the prior exposure history was obtained. The site at which the exposure was received is identified along with the penetrating dose in Rem, rounded to the nearest 0.01 Rem, referenced to the last year of employment at that site. Thus the exposure will not necessarily be listed for the year in which it was received by the individual. Exhibit #9 shows details of the card layout.

Recommendations for Interpretation of External Radiation Exposure Data

Exposure is normally utilized at Hanford as whole body penetrating, whole body skin, or extremity exposure. However, for this study only the basic measurements have been reported; that is, each type of measured radiation is reported separately so that the exposure can be recombined in any method desired or in any of several ways as the occasion demands. The following procedure was used at Hanford prior to 1972 for combining the various types of exposure:

<u>Basic Units Reported in the HMS</u>	
<u>Prior to 1972</u>	<u>1972 to Date</u>
Gamma	Penetrating Photons
Beta	Non-Penetrating
X-ray	(Nothing Comparable Reported)
Fast Neutron	Fast Neutron
Slow Neutron	Slow Neutron
Tritium	Tritium
Rings	Rings

Recommendations for Interpretation of External Radiation Exposure Data (contd.)

Interpretation of Exposure Data

	<u>Prior to 1972</u>	<u>1972 to Date</u>
Whole Body Penetrating:	Gamma 35% X-rays Fast Neutrons Slow Neutrons Tritium	Pen. Photons ---- Fast Neutrons Slow Neutrons Tritium
Whole Body Skin (Derma):	All types reported except rings	All types reported except rings
Extremities:	All types reported	All types reported

INTERNAL RADIATION EXPOSURE DATA

Routine Surveillance Program

A routine surveillance program (described in Exhibit #10) is maintained at Hanford to detect and/or measure any internally deposited radionuclides. These examinations are conducted using bioassay plus in-vivo examination procedures.

Bioassay Data

Urine, feces, and blood samples are collected and analyzed as part of the routine and special internal dosimetry programs provided for Hanford employees. The raw data are provided as backup since it is conceivable that it may later prove desirable to re-evaluate the deposition data previously reported (systemic burdens), which was evaluated using the best currently available techniques. The technique employed often utilizes one model to determine the soluble burden and another model to determine the burden of initially insoluble material. These are then added to provide an estimate of the total systemic burden.

Sources of Bioassay Data

1944-1958 - These data were obtained from microfilmed records maintained for all Hanford employees included in the study to date and punched on data processing cards. (See Exhibit #11)

Sources of Bioassay Data (contd.)

1959 to Date - These data were obtained from records which had previously been placed on magnetic tapes.

Systemic Burden Evaluations

That portion of an intake that will eventually be solubilized, transferred to the blood, and finally be deposited in various organs of the body is determined utilizing various mathematical models. These models are described in Exhibits #12, #13, and #14. These evaluations are based on urine as described in Exhibit #15 and for each intake the following information is provided:

- Name (Last, First and Second [initials only])
- Payroll number
- Social Security number
- Date(s) of intake (month, day, year)
- Estimated quantities deposited in the body as a result of each intake in units of  $\mu\text{Ci}$ .

Evaluations are reviewed periodically and should additional data indicate the utilization of a different model would result in a better fit of the data, the estimate and/or probable date of intake may be revised at some subsequent date.

In-Vivo Data

In-vivo measurements have been made to determine the internal contamination status of Hanford workers since 1959.

Several sources have been used to assemble these data. Since 1970 the data have been routinely keypunched and placed on magnetic tape. Prior to that the data were retrieved from microfilmed records in the individual's radiation exposure record file. The card format used to provide these data is shown in Exhibit #16.

Several types of examinations are utilized for various purposes. These examinations and the equipment utilized are briefly summarized below:

Whole Body Count - In-vivo measurement of gamma emitting radionuclides with a photon energy of 200 keV or greater is done in the standard chair position using a 4-inch thick by 9-3/9 inch diameter sodium iodide crystal which is observed by four 3-inch diameter phototubes. The counting

Whole Body Count - equipment is located in an iron room with  
(contd.) 10-inch thick walls with 1/8-inch thick lead liner for background reduction. The measurement period is 10 minutes and the minimum detectable amount is from 0.5 to 1 nCi for  $^{60}\text{Co}$ ,  $^{65}\text{Zn}$ ,  $^{24}\text{Na}$ , and  $^{127}\text{Cs}$  in an average individual.

Lung Count,  $^{241}\text{Am}$  - In-vivo chest measurements for  $^{241}\text{Am}$  (60 keV) are made by placing two 3/8-inch thick by 5-inch diameter sodium iodide crystals coupled to 5-inch phototubes in front of the chest and two identical detectors in back of the chest region. The measurements are made in a 4-inch-thick lead room which is copper lined. The measurement period is 2000 seconds or 33-1/3 minutes with a minimum detectable amount of from 0.15 nCi to 0.6 nCi depending upon chest thickness which is related to the weight/height ratio of the subject.

Lung Count, U - In-vivo chest measurements for U are identical to that for  $^{241}\text{Am}$  except the photon energy includes the ~60 and ~90 keV from the thorium daughters of U. The  $^{235}\text{U}$  content is observed from the 185 keV photon. The minimum detectable amount for U is from 2 to 3.7 nCi, depending upon chest thickness and for  $^{235}\text{U}$  from 0.17 to 0.37 nCi.

Lung Count -  $^{90}\text{Sr}$ ,  $^{147}\text{Pm}$  - The equipment used and counting procedure is the same as for  $^{241}\text{Am}$  and U. The detectors measure the "Brehmstrahlung" from the beta particles emitted. The minimum detectable amount for  $^{90}\text{Sr}$  is from 25 to 40 nCi and  $^{147}\text{Pm}$  from 0.5 to 1.5  $\mu\text{Ci}$ .

Bone Count - This is an in-vivo measurement for bone deposited radionuclides present in the bone in the head. It is done with a 3/8-inch thick 5-inch diameter sodium iodide detector observed by a 5-inch phototube. The detector is positioned near the side of the head in the iron room and the measurement made at the same time as the whole body count. The thin beryllium window permits measurement of Brehmstrahlung for beta emitters such as  $^{90}\text{Sr}$ - $^{90}\text{Y}$ . The minimum detectable amount of  $^{90}\text{Sr}$  is ~50 nCi.

Wound Count - Contaminated  $^{239}\text{Pu}$ ,  $^{241}\text{Am}$ ,  $^{235}\text{Pu}$  injuries are measured in the lead room with a 1 mil thick 2-inch diameter sodium iodide detector observed by a 2-inch phototube. The detector has a thin beryllium window which permits measurement of low energy X-rays. The minimum detectable amount for  $^{239}\text{Pu}$  is ~0.1 nCi in a 10-minute counting period.

Thyroid Count - In-vivo examination for  $^{131}\text{I}$  is done by thyroid measurement through the side of a 3-inch thick, 3-inch diameter sodium iodide crystal observed by a 3-inch phototube. The detector is mounted on a movable arm that permits positioning of the detector near the thyroid of a subject seated in the standard chair in the iron room. The minimum detectable amount is 20 pCi for a 30-minute count. In general, actual numbers have been reported for all positive measurements. Examinations showing < detection limits are also reported. Questionable results have been included but are identified so that less credence may be placed on these suspect data.

#### Plutonium-241 Estimates

Estimates of the systemic burden of plutonium-241 as a result of involvement in a known or suspected radiation occurrence has been calculated based on the isotopic composition of the material involved in the incident. This technique is described in Exhibit #13 of the 1969 Hanford report. This assigned  $^{241}\text{Pu}$  deposition has been provided along with the date of intake.

#### Organ Dose Commitments

Dose commitments resulting from internally deposited plutonium have been calculated using recommendations provided by the Advisory Committee on Plutonium Dose that was appointed by the HMS staff. The annual dose commitment for 50 years following each intake and the 50-year dose commitment are listed for bone and liver. Additionally, the same data are provided for lung and lymph node when the intake occurs as a result of inhalation of contaminated atmosphere. The assumptions used for these calculations are shown in Exhibit #18 and the formats of the data reported are shown in Exhibits #17-A and #17-B.

NOTE: This phase of the program has been developed but is not currently included as part of the input to HMS.

**EXHIBIT #1**  
**CARD PUNCHING OR VERIFYING INSTRUCTIONS**

JOB NAME <b>Exposure Data Result Cards</b>	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS TENTHS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	12
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	3
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	4

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Pay No.	2	6		
2. P.E. date	9	14		
3. T/C		15		
4. N.C.	16	17		
5. Non-Pen Crems	46	49		
6. Pen Crems	50	53		
7. Finger Ring	54	58		
8. Off-Site Loc	60	61		
9. F/N Dose Crems	62	65		
10. S/N Dose Crems	66	69		
11.				
12.				
13.				
14.				
15.				
<b>TOTAL KEY STROKES PER CARD</b>				

EXHIBIT #1A

OFF-SITE LOCATION CODES

Argonne National Lab., IL	AR
Bettis, Pittsburgh, PA	BA
Berkeley, CA	BE
Brookhaven National Lab., NY	BR
A.E.C. Headquarters	HQ
Idaho Falls, ID	IF
K.A.P.L., NY	KA
Los Alamos, NM	LA
Livermore, CA	LR
Nuclear Test Site, NV	NT
Oak Ridge, TN	OR
Other Locations	OL
Rocky Flats, CO	RF
Savannah River, SC	SR
Universities	UN
U.S. Military	US
Department of the Interior	US
Civil Defense Disaster Council	US

EXHIBIT #2

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME Plant Results - Exposure Data Cards	JOB NO.	FREQUENCY				ESTIMATED VOLUME	ESTIMATED TIME		
		<input type="checkbox"/> DAILY	<input type="checkbox"/> WEEKLY	<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> SEMI-MONTHLY		<input type="checkbox"/> MONTHLY	<input type="checkbox"/> QUARTERLY	<input type="checkbox"/> ANNUAL

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Payroll No.	2	6		
2. Last Name	8	25		
3. Initials	26	28		
4. Social Security No.	29	37		
5. Beta	38	43		Rems rounded to nearest .01
6. Gamma	44	49		
7. X-ray	50	55		Total X-ray dose. Rems rounded
8. Neutron	56	61		Sum of the slow/fast. Rems rounded
9. Tritium	62	67		Rems rounded to nearest .01
10. Rings	68	73		Highest rings totaled. Rems rounded
11. Code		78		"11" punch in all cards. Plant results.
12. Year	79	80		
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #3

SOURCES OF EXPOSURE DATA

<u>Year</u>	<u>Beta-Gamma</u>	<u>X-Ray</u>	<u>Neutron</u>	<u>Tritium</u>	<u>Extremity</u>
1944	Tape				Photometry Records
1945	Tape				Photometry Records
1946	Tape				Photometry Records
1947	Tape				Photometry Records
1948	Tape				Photometry Records
1949	Tape			Bioassay Result Cards	
1950	Tape		Hist. File	Bioassay Result Cards	Photometry Records
1951	Tape		Hist. File	Bioassay Result Cards	Photometry Records
1952	Tape		Hist. File	Bioassay Result Cards	Photometry Records
1953	Tape		Hist. File	Bioassay Result Cards	Photometry Records
1954	Tape		Hist. File	Bioassay Result Cards	Photometry Records
1955	Tape		Hist. File		Photometry Records
1956	Tape		Hist. File		Photometry Records
1957	Tape	Tape	Hist. File		Photometry Records
1958	Tape	Tape	Hist. File		Photometry Records
1959	Tape	Tape	Tape		Photometry Records
1960	Tape	Tape	Tape		Photometry Records
1961	Tape	Tape	Tape	Front of 1962 Year-End Report	Photometry Records

Since 1961 all data was taken directly from tape.

EXHIBIT #4

HANFORD BETA-GAMMA FILM DOSIMETERS

A. DOSIMETER USED 1944 UNTIL APRIL 1957

The first Hanford dosimeter was a large metal dosimeter which was used to measure only the beta and gamma radiation. The dosimeter utilized a 1 mm thick silver shield having a window cut in it to permit obtaining both "shielded" and "unshielded" measurements. The darkening on the film under the open window area of the dosimeter resulted from both gamma and beta. It was assumed that the gamma component was responsible for darkening equal to 1.5 times that measured behind the silver shield and that the balance of the darkening was due to beta radiation. The dosimeter contained both sensitive and relatively insensitive film.

B. DOSIMETER USED APRIL 1957 UNTIL SEPTEMBER 1962

1. Description of Dosimeter

A plastic film dosimeter was developed for use at Hanford in 1957. This dosimeter was composed of two main parts; the removable portion, referred to as the slide, and the housing or body of the dosimeter. To assemble, the slide was placed into the housing of the dosimeter where a magnetic locking device secured it.

The film packet was held between a series of three metal shields and an "open window" area. Matching shields were located on both the slide and the body of the dosimeter so that identical shielding existed on both sides of the film when it was in place. Lead tape positioned over

another area of the film was utilized for identifying the film. Figures identifying the employee's payroll number and general work location were perforated in the tape and that portion of the dosimeter was exposed to low energy x-rays (10KVP, 10 ma, 1-1/2 sec.) before the film was removed, thereby, permanently identifying the film. That portion of the film utilized for dosimeter purposes was well shielded to prevent darkening by these low energy x-rays. The three metal shields may be described as follows: (1) a 1 mm thick silver shield ( $1 \text{ gm/cm}^2$ ), (2) a 0.005in. silver shield ( $0.13 \text{ gm/cm}^2$ ), and (3) a 0.0191 in. aluminum shield ( $0.13 \text{ gm/cm}^2$ ). The thin silver and aluminum shields were equal in mass per unit area, thereby rendering them essentially beta equivalent. However, the gamma absorption properties were decidedly different. With this shield system it was possible to determine the dose to the film due to gamma radiations of various energies. This evaluation could be made to a certain limited extent even in the presence of beta radiation, however, this was not routinely accomplished.

Later, a security credential was placed in front of the badge, adding to the shielding in front of the film. This had no appreciable effect on the evaluation of gamma doses due to energies above 200 keV. A "thin window" was provided in the accompanying security credential over the area used for lower energy gamma dose evaluation.

## 2. Dose Interpretation

Interpretation of gamma dose was accomplished by measuring the film density behind the thick silver and comparing to a calibration curve. In addition to gamma dose evaluations, it was possible to determine the dose contribution from each of three energy groups, 17 keV, 58 keV, and  $>200 \text{ keV}$ . This procedure was necessary because of the spectral

response of the film. For energies of about 200 keV or greater, the ratio of true dose to dose calculated from the radium calibration curve was about one. As the gamma energy decreased, the ratio decreased reaching a minimum behind the thick silver shield at approximately 130 keV and at 45 keV for the open window area. These ratios for the open window were approximately 0.10 and 0.027 for the 17 and 58 keV energies, respectively. The true total dose was indeterminate when a mixture of these energies were present since only a single shield density measurement was available. Several assumptions were required in using these equations; first, the density for the high energy radiation was equal behind all shield areas. Error was introduced by this assumption particularly in the open window, however, on the conservative side. Since dose for high energy radiation was based on the density behind the thick silver shield, any excess appearing in the open window was included in the dose assigned to low energy radiations. Second, it was assumed the 17 keV group x-rays produced no density behind either silver shield and the 60 keV component produced no density behind the thick silver shield. Error in this assumption appeared only at the higher dose levels, 100 mR or more for the 60 keV component. Very few personnel exposures approach this dose for this energy component. Third, it was further assumed that no beta radiation was received by the dosimeters exposed to the lower energy radiations. Hanford's methods of operation tend to validate this third assumption.

After determination of dose for each energy group, summations for individual exposure records were made in the following manner: all dose contributed by the 60 keV group and higher energy radiations were considered as penetrating dose but only 35% of the 17 keV component was considered

as penetrating dose. The total of all radiations was assigned as skin dose. Assignment of only 35% of the 17 keV group as penetrating was based on absorption studies and the assumption that the gonads are at a depth of one centimeter and are the critical organ.

C. DOSIMETER USED SEPTEMBER 1962 TO 1972

In 1962, a new personnel film badge dosimeter was placed into service at Hanford. This dosimeter utilizes the latest advances in film filter systems for routine dose evaluations and provides high neutron dose, and high gamma dose evaluation capabilities following any serious radiation event.

The new dosimeter is similar in appearance, size (3-1/8 in. x 1-3/4 in. x 5/16 in.) and weight (34 grams) to the previously-used Hanford dosimeter. It is molded from "cycolac" plastic (styrene - butadiene - acrylonitrile). The dosimeter provides for the evaluation of radiation dose from beta, gamma and x-ray radiations present independently or concurrently. Activation foils provide neutron dosimetry in the event of a criticality or similar serious radiation event. Two small silver phosphate glass rod dosimeters are included to provide measurement of high gamma dose. Indium foil is provided for prompt sorting of directly-involved personnel following a criticality event.

The dosimeter was designed to take full advantage of mechanized processing. Each dosimeter contains a lead tape perforated with the employee's payroll number. Prior to the removal of the film packet, the payroll number is x-rayed onto a part of the film to provide positive and permanent identification. Film identification and film exchange are performed mechanically by a film dosimeter processing machine.

The dosimeter design provides for the use of the Hanford security credential in a neat integrated assembly. The security credential is removable from the dosimeter and can be readily removed by the wearer for dosimeter exchange.

Dosimetry

The new dosimeter contains a film packet and a film filter system for the interpretation of beta, gamma and x-ray radiation dose from normal Hanford operations. Components are provided to measure the gamma and neutron doses that might occur as the result of a criticality or other serious radiation event.

Routine Dosimetry

The new dosimeter utilizes four film filter areas to provide the interpretation of radiation dose to beta, gamma, or x-ray radiations. The filter areas provided are designated as open window, plastic, iron and tantalum. The physical characteristics of the filter system are shown in Table I.

TABLE I

Filter System - Physical Characteristics

<u>Filter</u>	<u>Size In Inches</u>	<u>Thickness In Mils</u>	<u>Total mg/cm<sup>2</sup> (Excluding Security Credential)</u>
Tantalum	1/2 x 1/2	20	915
Iron	3/8 x 1/2	1	148
Plastic	3/8 x 1/2	70	178
Open Window	3/8 x 1/2	--	---

Both the iron and tantalum filters are covered with 20-mil thick "Tenite II" plastic to improve the energy response characteristics of the system. The filter system provides

a linear density response, within  $\pm 10\%$ , for a given gamma radiation dose at any energy between 50 keV and 2 MeV.

To interpret the dose from a film dosimeter that was exposed to beta, gamma, and x-ray radiations, the density behind each of the four filter areas is measured. This density is measured and the identifying payroll number from the film is read with the Hanford automatic densitometer. An electronic data processing machine card containing this information is automatically provided for machine processing. The machine processing, utilizing appropriate calibration data, provides an evaluation of the radiation dose due to: (1) Electromagnetic radiation between 50 keV and 2 MeV; (2) electromagnetic radiation between about 15 keV and 50 keV; (3) beta radiation assuming a beta energy spectrum similar to the beta spectrum emitted by natural uranium. The dose interpretation is made as follows:

(1) Electromagnetic Radiation 50 keV to 2 MeV

The density behind the tantalum filter is due essentially to electromagnetic radiations with energies greater than 50 keV. This density can be directly related to the dose by use of an appropriate calibration curve.

(2) Electromagnetic Radiations From About 15 keV to 50 keV (x-rays)

The density behind the plastic filter and the iron filter areas results from electromagnetic radiation and beta radiation. The response characteristics of the filter system are chosen so that electromagnetic

radiation with energies greater than 50 keV and beta radiation produce equal densities behind each of these filters. For electromagnetic radiations with energies less than 50 keV, the iron filter has a significantly higher absorption coefficient than the plastic filter; consequently, the difference in density between the plastic and iron filters can be directly related to dose by use of a calibration curve constructed for electromagnetic radiation energies similar to those encountered by the dosimeter.

(3) Beta Radiation

The density behind the open window and the plastic filter areas results from electromagnetic radiation and beta radiation. Electromagnetic radiations with energies greater than 50 keV produce equal densities behind each of these filters. The difference in density between these two filters is a function of the low energy, less than 50 keV, electromagnetic radiation dose and the beta radiation dose. Since the low energy electromagnetic radiation dose has been determined independently from the plastic and the iron filter density difference, it is possible to correct the density difference observed between the open window and the plastic filter area for the low energy dose contributions by an appropriate calibration correction curve. After this correction is made, the remaining density difference between the open window and the plastic filter may be related to a beta calibration curve and the beta dose determined.

D. FILM USED IN PERSONNEL DOSIMETERS

Beta-Gamma Dosimetry

1944 to 1957: duPont, 502 film  
1957 to 1965: duPont, 508 film  
1965 to 1967: duPont, 519 film  
1967 to 1971: duPont 558 film  
1971 : Kodak, Type II film

E. DENSITOMETRY

Radiation dose determinations were made by comparison of densities produced on film by exposure to unknown amounts of radiation to densities produced by exposure to known amounts of radiation. These film densities were determined by measuring the light transmission through the film from a controlled light source.

Density measurements were made utilizing a Beckman V micro-microammeter connected directly to a type 922 phototube. The light source was a type 1321, 6 volt auto lamp beamed through a focusing lens and spotted on an opalized diffusion window. A regulated voltage was fed to the densitometer to adjust for possible instrument drift.

A metal jig was used as a film positioning guide to insure the film was correctly oriented in the light beam from the opalized diffusion window for each shield area measurement.

With the densitometer equipment in use during this time, it was possible to obtain optical readings from a minimum of 0.005 density units to about 3.0 density units. It was possible to estimate doses up to approximately 50 R using the 510 insensitive film and our processing procedures.

A statistical study of a large number of blank 502 film showed the standard error of density measurement to be approximately 0.002 density units.

Limitations in aperture dimensions were established by the smallest shield areas used in the film badge. The aperture used for routine dosimetry was 3.5 mm in diameter. A rectangular aperture of 1/8 in. x 3/8 in. was used for special dosimetry evaluations.

#### QUALITY ASSURANCE MEASURES - EXTERNAL DOSIMETRY

##### Film Shelf Life

Film packets used at Hanford have always been ordered in small lots. From 1945 to 1957 duPont film type 502 utilizing acetate base was used. In 1957 the type 502 film was replaced with type 508 film utilizing acetate base. This was used until 1965 when type 519 film utilizing Kroner base replaced the 508 film.

Specifications required that all film in one shipment be of the same emulsion lots. Refrigerated facilities were provided where the film was stored for a maximum of three months after its delivery.

##### Spot Check of Film Prior to Use

Each shipment of film was sampled prior to being placed in service by removing one packet from the top, middle and bottom of each box of 150 packets. These films were processed to determine the background density for that lot of film.

##### Film Identification

Each film worn by an individual in a regularly assigned dosimeter was x-ray coded prior to removal from the dosimeter (or manually

perforated as it was removed from the dosimeter for a few specific situations) to positively identify the individual wearing it and the period worn. A lead shield was used to shield that portion of the film under the open window and filters during the x-ray coding operation.

### Film Processing

Approximately 850 personnel film were processed in one batch. With each batch of personnel film a set of calibration film was also processed. The number of calibration film in each set varied but normally consisted of 13 or 14 pieces of film exposed to radium gamma at doses from 20 mR to 10 R, 13 to 14 pieces of film exposed to a slab of uranium beta at doses from 20 mrad to 5 rads, 7 pieces of film exposed to 17 keV x-rays at doses from 20 mR to 160 mR and 10 blank film.

Standard developing solutions were used and were carefully mixed according to the manufacturer's recommendations. This solution was replaced each month. Uniform agitation of the developing solution was accomplished by one-second bursts of nitrogen gas every fifteen seconds. Air was used in a similar manner for agitating the bath and fixing solutions. The film was then allowed to dry for a two-hour period. All film was sufficiently fixed and washed for archival storage.

The processing time was carefully controlled. Since 1962 the film was processed through the various stages of photographic development by a chain-driven, pneumatic lift system. This system utilized a built-in timing mechanism with microswitches providing precise control to within one second in each of the processing steps. The temperature was maintained automatically at 68°F. A signal was activated whenever the temperature deviated more than 2 in. from that desired.

After development, each film was stamped with a batch number to associate it with the calibration film which was processed at the same time.

#### Measurements of Film Darkening

Identification of the individual wearing the dosimeter and the darkening of the film was read on a densitometer. In 1964 the system was automated to where measurements of the optical density of the film behind each of the various filters in the form of electrical impulses were fed directly to a keypunch machine which recorded individual identification and densitometer readings in keypunch language.

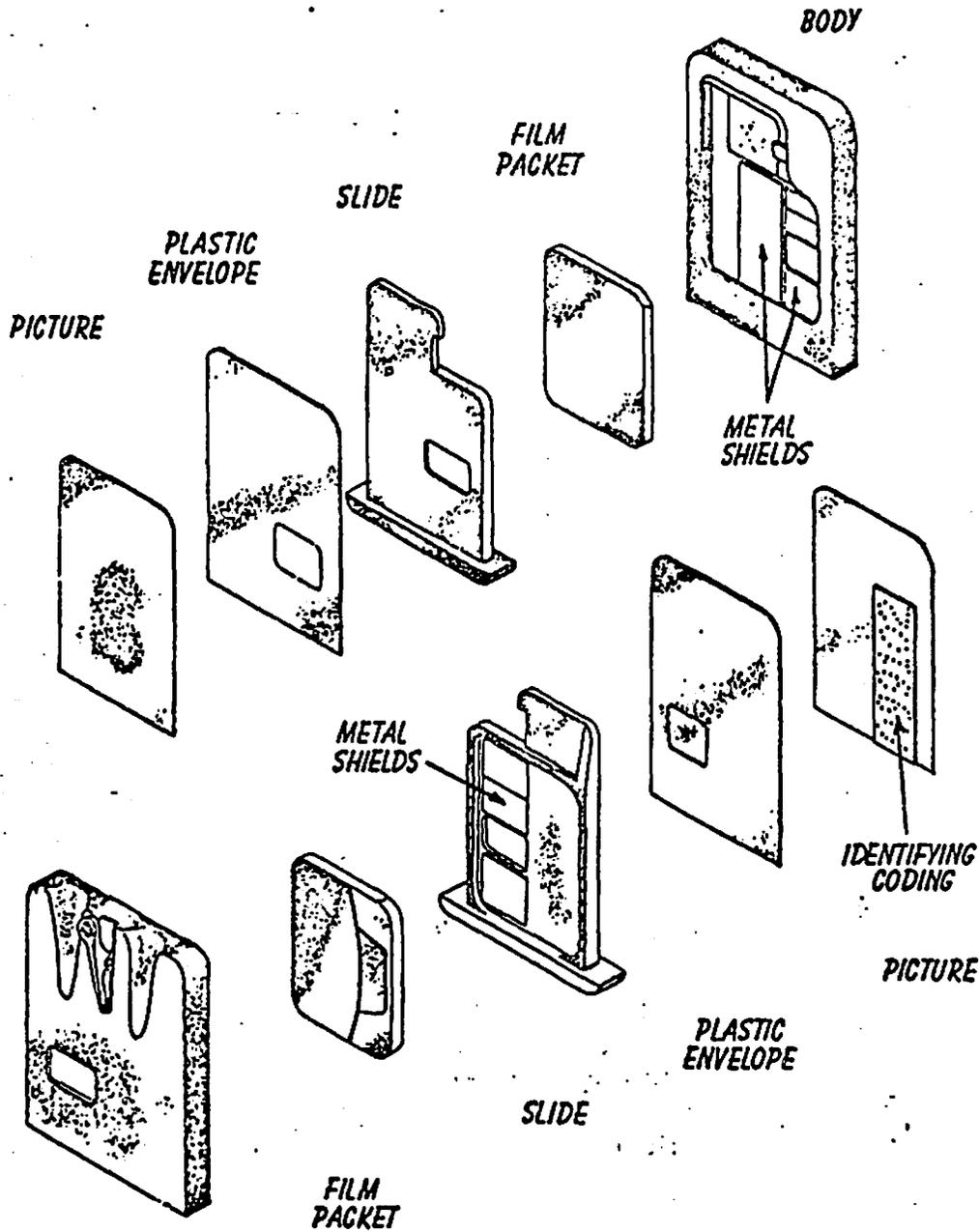
#### Calibrations

The radium gamma source used to expose calibration film was routinely calibrated utilizing a Victoreen R-meter which had been checked against a primary standard.

#### Quality Control Program

Beginning in 1965 a program was initiated wherein an outside group exposed film to known doses of gamma, beta, neutrons and x-rays which were sent in for processing as a blind audit utilizing fictitious payroll identifications. The results of these were required to fall to within  $\pm 25\%$  at the 95% confidence level.

# BADGE ASSEMBLY

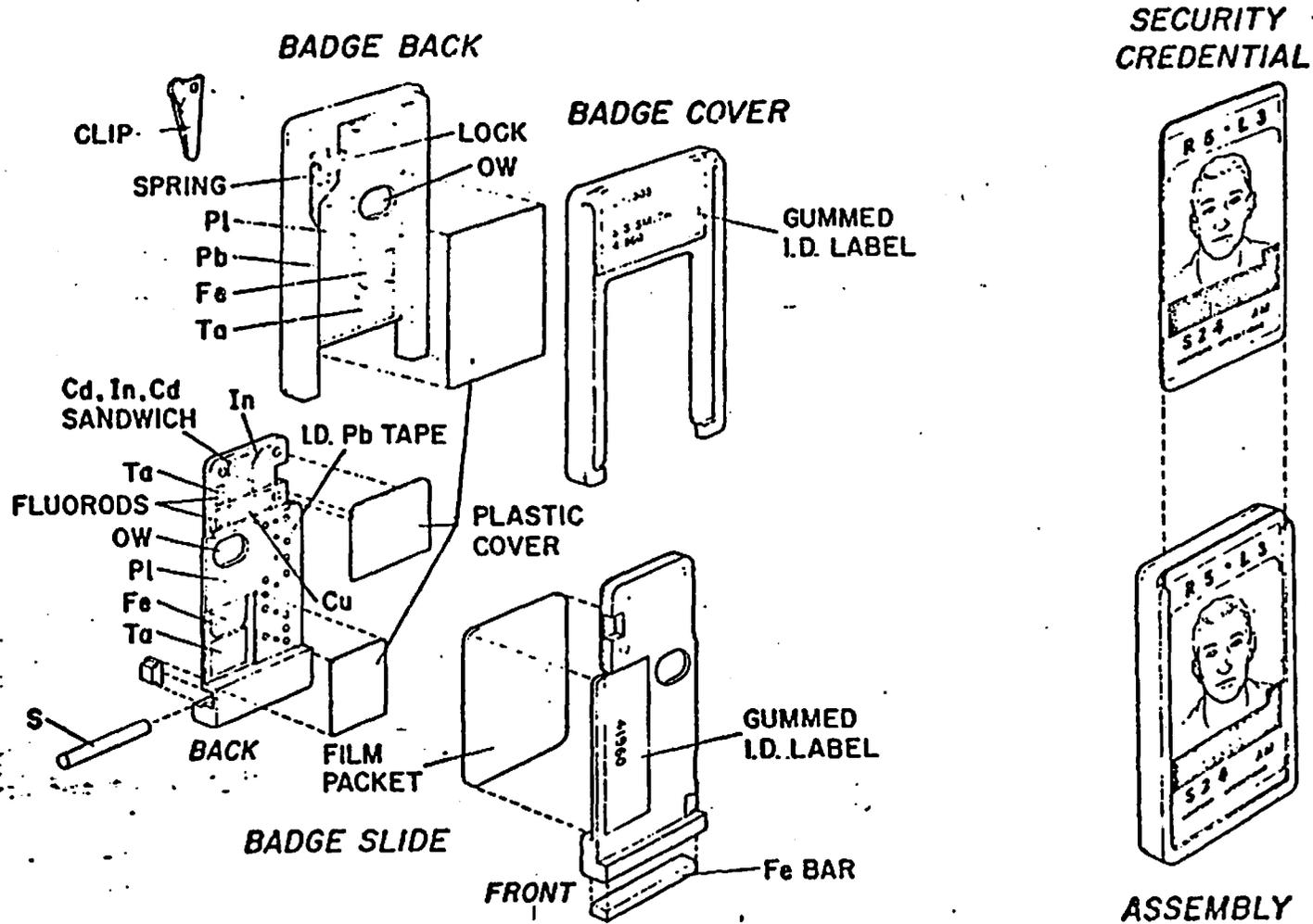


**BODY**

BETA-GAMMA DOSIMETER  
USED AT HANFORD  
1957 to 1962

# HANFORD EXPOSURE EVALUATION

## HANFORD FILM BADGE DOSIMETER



SECURITY CREDENTIAL

RADIATION PROTECTION OPERATION  
1962 to 1972

EXHIBIT #5

HANFORD THERMOLUMINESCENT DOSIMETERS

BASIC TL Dosimeter (June 1971 to date)

This dosimeter is worn by workers who receive little or no exposure as a result of their work assignment.

The dosimeter consists of a  $^7\text{LiF}$  block sealed in a modified phenylene oxide plastic card. An 8 mm diameter  $^7\text{LiF}$  disc provides backup but is normally not processed. Readout is accomplished without removal of the block from the card in a locally constructed reader. The block is heated to  $300^\circ\text{C}$  and the readout cycle is 20 seconds. Integral light output is measured rather than glow peak. To be conservative both penetrating and non-penetrating beta and photon radiation is measured and all interpreted as penetrating radiation.

The useful range of the dosimeter is 30 mR to  $10^5\text{R}$  for virtually any photon energy above 10 KeV.

MULTIPURPOSE TL DOSIMETER (January 1972 to date)

A dosimeter utilizing three  $^7\text{LiF}$  blocks and 2  $^6\text{LiF}$  blocks to measure beta, photon and neutron radiation was developed to replace both the Hanford beta gamma and neutron dosimeters. The card containing these LiF blocks measures 7.8 cm by 3.8 cm by 0.1 cm and weighs 3.6 grams. The LiF blocks are centered in 5 separate holes, each of which is 0.95 cm in diameter, using Teflon TFE skived tape.

The dosimeter holder is injection molded from styrene - butadieneacrybonitrile (cycolac). When the dosimeter card is inserted in the holder each block is centered between appropriate filter materials. See Table below:

Filter System - Physical Characteristics

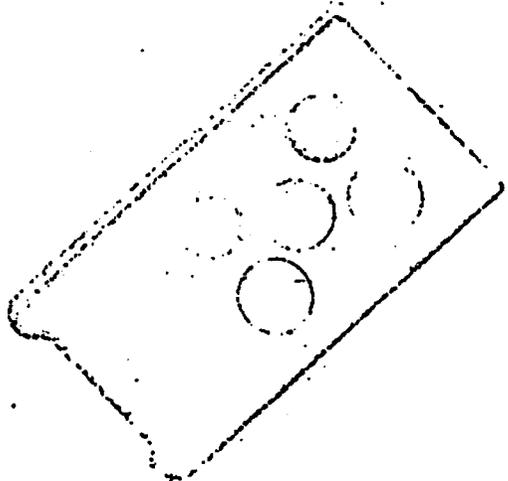
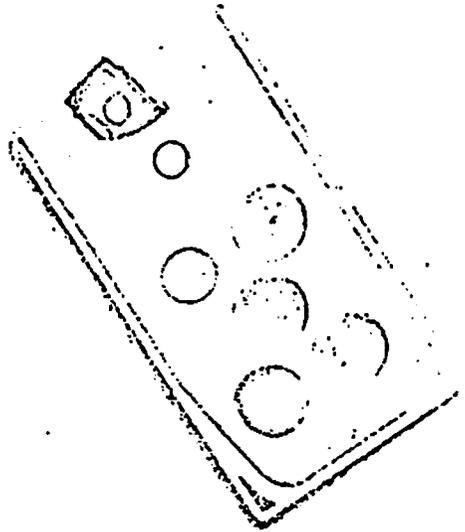
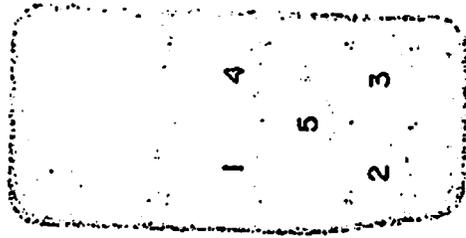
<u>TL Block #</u>	<u>Shield</u>	<u>Diameter in cm.</u>	<u>Thickness in cm.</u>	<u>Total mg/cm<sup>2</sup></u>
1	open window	0.95	0.0	0
	Teflon TFE tape	--	0.005	12
2	Cyclac	1.27	0.089	93
	Aluminum	--	0.064	173
	Mylar	--	0.007	7
	Teflon TFE tape	--	0.005	12
3	Cyclac	1.27	0.051	53
	Tin	--	0.102	750
	Mylar	--	0.007	7
	Teflon TFE tape	--	0.005	12
4	Cyclac	1.27	0.051	53
	Tin	--	0.051	375
	Cadmium	--	0.051	440
	Mylar	--	0.007	7
	Teflon TFE tape	--	0.005	12
5	Cyclac	1.27	0.051	53
	Tin	--	0.102	750
	Mylar	--	0.007	7
	Teflon TFE tape	--	0.005	12

The <sup>7</sup>LiF block #1 is used as a measure of the non-penetrating radiation.

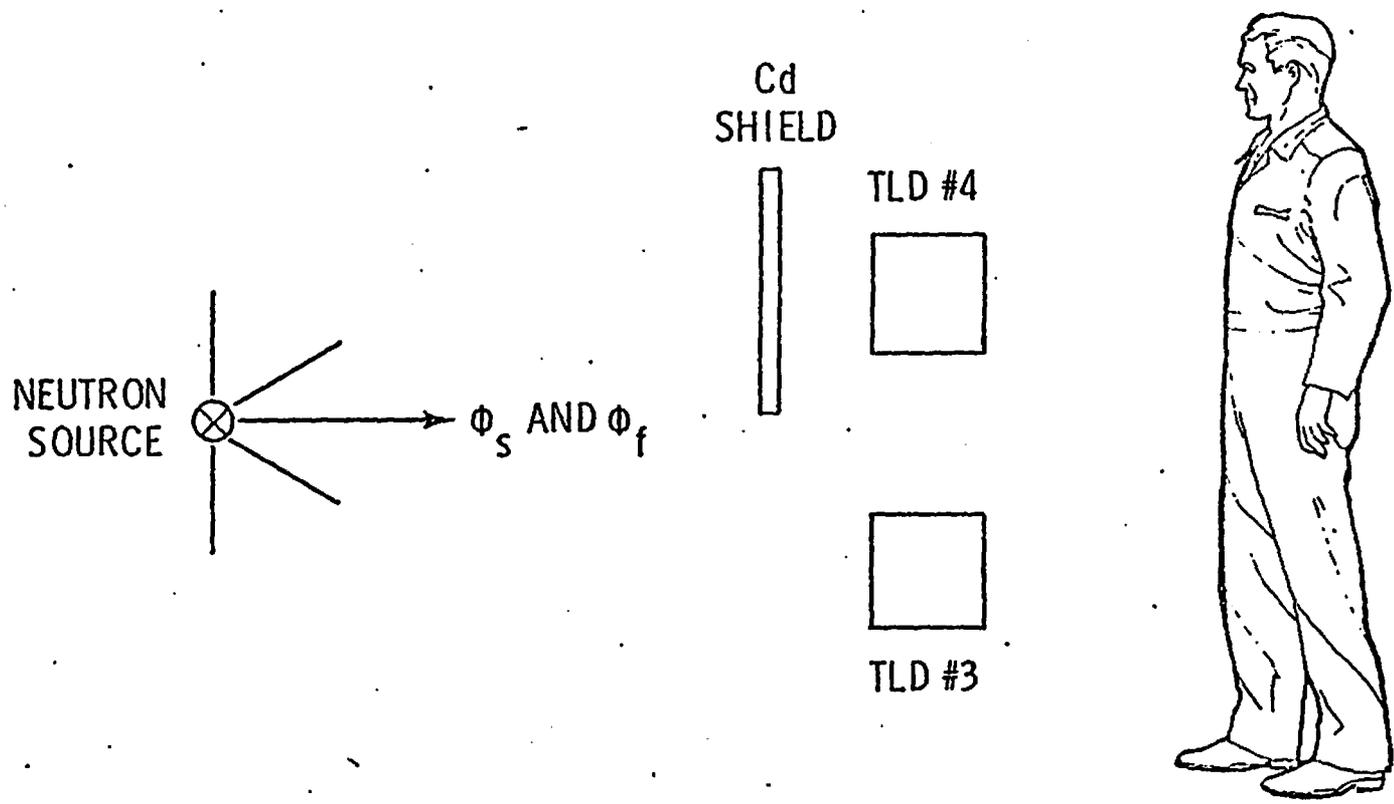
The <sup>7</sup>LiF block #2 is used to measure penetrating dose and its shield was designed to correspond to one centimeter of soft tissue for photon energies 10 KeV to 10 MeV.

Blocks #3, #4, and #5 are used to obtain a measure slow and fast neutron exposure. The  $^7\text{LiF}$  block is used to measure the penetrating radiation which is used to subtract this effect from the response of the two  $^6\text{LiF}$  blocks. The bare  $^6\text{LiF}$  block essentially measures both the incident slow neutrons and back-scattered neutrons from fast neutrons entering the body since the cadmium shields out the incident slow neutrons. Thus, utilizing data from blocks #3, #4, and #5 the fast and slow neutron doses can be determined.

The useful range of the dosimeter is 10 mrem to  $10^5$  rem for photon energies from 10 KeV to 10 MeV and for neutrons up to 10 MeV.



AN EXPLODED VIEW OF THE HANFORD MULTIPURPOSE DOSIMETER CARD.



SCHEMATIC REPRESENTATION OF NEUTRON EXPOSURE CONDITIONS

EXHIBIT #6

PERSONNEL FILM BADGE NEUTRON DOSIMETERS

INTRODUCTION

Hanford Atomic Products Operations initially relied on pocket ionization chambers with enriched Boron<sup>10</sup> liners for slow neutron exposure measurements. These chambers were supplemented by film badges containing Eastman nuclear track emulsions (Type A) for detection and measurement of fast neutron exposures.

1944 to 1950

Pocket ionization chambers were used exclusively.

1950 to 1957

Eastman NTA film was used in the regular beta-gamma dosimeter holder. The Eastman NTA film had limited capability to measure fast neutrons up to  $\sim 0.8$  MeV. The recoil proton tracks were viewed microscopically at 970X magnification for 40 fields and compared to 40 fields on calibration and control film.

April 1957 to July 1958

Eastman NTA film was used in a separate cellulose acetate butyrate holder. The method for interpretation of neutron dose was same as before.

July 1958 to January 1972

Design Characteristics

The badge was designed to meet the need for a reliable neutron dosimeter. Outwardly, it differs from the Hanford beta-gamma

badge by an increase of 0.10 inch in depth. This dimensional change was necessary to accommodate two packets of film and to reinforce the badge body.

The primary functional change in the Hanford beta-gamma badge permitting its use as a neutron dosimeter was the substitution of suitable shield materials. The selection of cadmium and tin in lieu of other metals was based upon their thermal neutron cross-sections and x-ray and gamma ray mass absorption coefficients. Cadmium has a high thermal neutron cross-section, and tin is relatively transparent with respect to neutrons. The prompt gamma coincident with a neutron capture in the cadmium is recorded as darkening of the film behind the cadmium shield. Since gamma rays experience nearly equal attenuation in either cadmium or tin, the difference in darkening behind the cadmium and tin shields was interpreted as a direct measure of the slow neutron exposure. In addition, the gamma ray attenuation of these two elements compare well with silver, which was the shield material selected for the beta-gamma film badge, making for excellent correlation of gamma dose between the tin shield of the neutron badge and the silver shield of the beta-gamma badge.

The film are identified with the user by x-raying his payroll number on the film.

#### Calibration of Nuclear Track Emulsions

The neutron badge incorporates Eastman NTA film as a means of assessing the exposure to neutrons of energies greater than 0.8 MeV. Calibration is accomplished using a  $\text{PuF}_4$  neutron source with average energy of the order of 1.4 MeV. The calibration films are exposed to a dose of 1.075 rem computed from first collision theory. The average film response yields  $71.24 \pm 13.51$  tracks per forty fields of view. This is equivalent to 1075 mrem exposure with a 95 per cent confidence interval.

Interpretation of NTA film after processing is accomplished by counting microscopically the tracks produced in the emulsion by recoil protons. A field of view of 1/129 square centimeter is viewed under 970 magnifications with oil immersion. Each of three observers count the tracks occurring in forty fields of view (a total of 120 fields). Films which indicate a significant increase in number of tracks relative to background are viewed for a total of 400 fields. A 90 per cent confidence interval of the tracks per forty fields is constructed. The upper limit of the count is compared with the lower limit of the similar interval for tracks per forty fields per 300 millirem on the calibration films. The ratio of the limits times 300 mrem is entered into the exposure record.

The dosimeter also had capabilities for measuring slow neutrons having energies from 0.025 to 0.5 MeV.

#### Cadmium Clad Tin Shields

For most purposes the use of pure cadmium and pure tin as shield material produces an excellent slow neutron dosimeter. In cases where the neutron exposure is accompanied by very soft x-rays, the small difference in mass absorption coefficients between the two materials becomes a limiting factor for the measurement of slow neutron exposure.

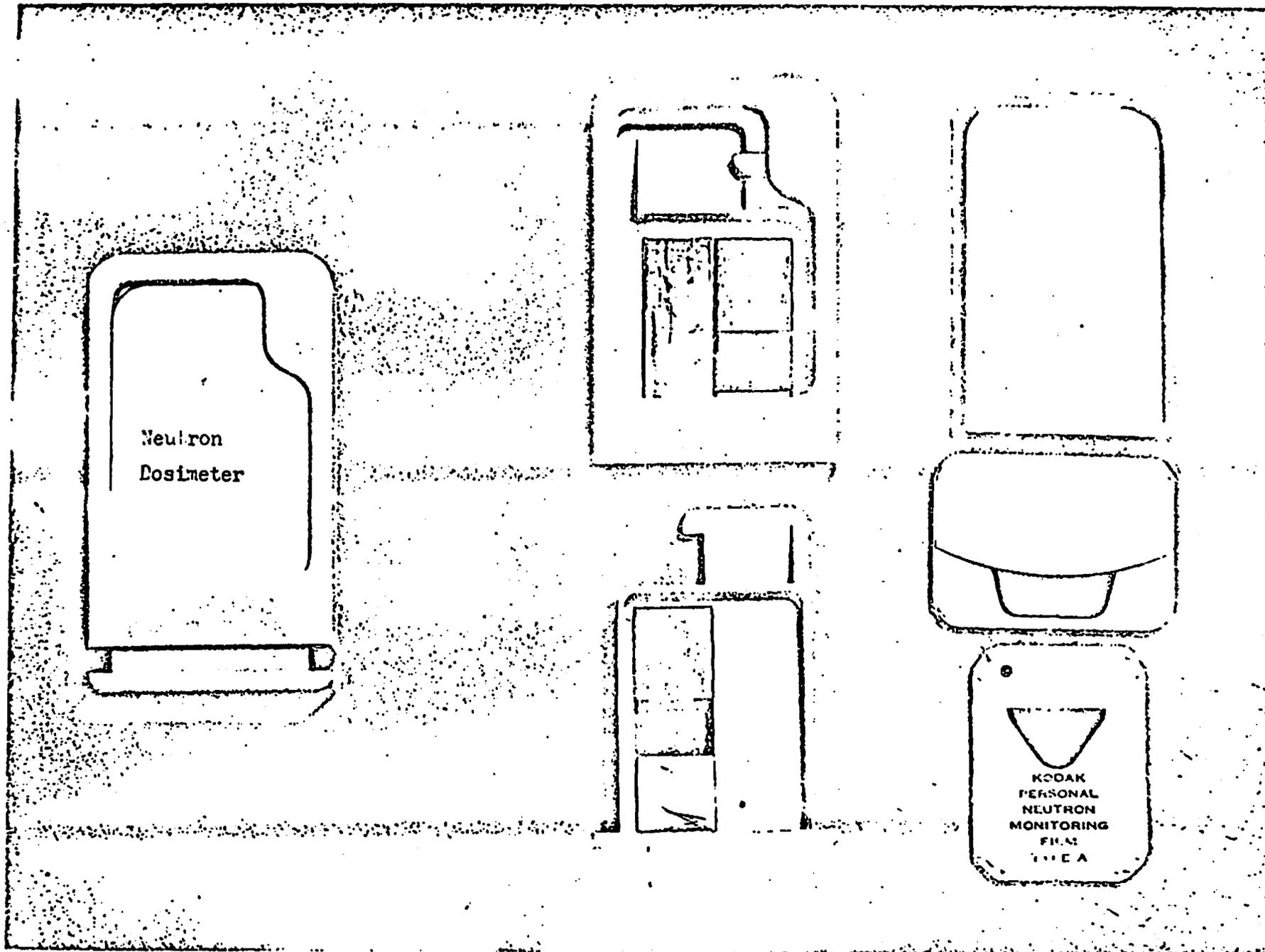
To make the two shields more similar with respect to x-ray attenuation, a number of tin shields were rolled to 0.036 inch and plated with cadmium until the original 0.040 inch thickness was attained.

#### Quality Factors

A quality factor of 10 is applied to convert the fast neutron dose from rads to rems and a quality factor of 3 is used for slow neutrons.

January 1972 to date

Personnel exposures to both fast and slow neutrons were measured using the Hanford Multipurpose Dosimeter described in Exhibit #5.



Neutron  
Dosimeter

KODAK  
PERSONAL  
NEUTRON  
MONITORING  
FILM  
TYPE A

EXHIBIT #7

THE EVALUATION OF WHOLE BODY DOSE FROM TRITIUM BY URINALYSIS DATA

The calculation of the dose rate from tritium oxide distributed in the body requires certain assumptions. It is assumed that: (1) the isotope is uniformly distributed in the organ of reference, and (2) that time over which the deposition occurred is small compared to the elimination time. Since the beta particles of a given isotope are emitted in a spectrum, the average beta particle energy per disintegration is used in the calculation of the radiation dose and is approximately 1/3 the maximum energy. The dose rate is computed in terms of the energy absorbed per gram per unit time. The unit of absorbed dose is the rad, which represents the absorption of 100 ergs per gram of material irradiated. Since total body water is used as the critical organ in calculating the internal exposure from tritium oxide, the material irradiated is assumed to be water.

Under the conditions outlined, and since the range of the tritium beta particle is small compared to the dimensions of the body, the beta particle energy absorbed per gram is equal to the beta particle energy emitted per gram. The expression for the dose rate then becomes:

$$D(\text{rads/day}) = \frac{(3.7 \times 10^4) (C_0) (1.6 \times 10^{-6}) (\bar{E}_\beta) (10^{-2})}{(8.64 \times 10^4)} \quad (1)$$

where:  $3.7 \times 10^4$  are the disintegrations per second per microcurie,  $C_0$  is the bioassay result in  $\mu\text{Ci}$  tritium/gram of  $\text{H}_2\text{O}$ ,  $1.6 \times 10^{-6} \bar{E}_\beta$  is the average beta particle energy expressed in ergs,  $10^{-2}$  is the number of rads/erg/gram,  $8.64 \times 10^4$  is the time conversion from seconds to days.

Therefore:

$$D = (51.2) \bar{E}_\beta (C_0) \text{ rads/day.} \quad (2)$$

The total dose received for a finite period of time can be expressed as:

$$D = (51.2) (\bar{E}_\beta) \int_0^t C_0 dt \text{ rads/day} \quad (3)$$

where the limits of integration range from the time of uptake ( $t=0$ ) to the time of interest ( $t-t$ ) in days.

Since tritium is eliminated exponentially from the body, the concentration at any time ( $C_t$ ) can be expressed as:

$$C(t) = C_0 e^{-\lambda_B t} \quad (4)$$

where:  $C_0$  = initial concentration in  $\mu\text{Ci}/\text{gram}$

$\lambda_B$  = elimination constant  $\frac{(0.693)}{T_B}$

$t$  = time in days

Substitution of the expression for  $C(t)$  from equation (4) into equation (3) gives:

$$D = (51.2) (\bar{E}_\beta) (C_0) \int_0^t e^{-\lambda_B t} dt \quad (5)$$

Integration of this expression gives:

$$D = (73.9) (\bar{E}_\beta) (C_0) (T_B) \frac{1 - e^{(-0.693)t}}{T_B} \text{ rads} \quad (6)$$

The derivation up to this point has been quite general and would apply to any beta particle emitting nuclide which conformed to the initial assumptions. Bioassay result can be expressed in terms of  $\mu\text{Ci}$  tritium/liter of urine assuming that 1 gram of urine is approximately equal to 1 milliliter of urine and that the tritium is homogeneously distributed in the body water. Specifically then for tritium,  $\bar{E}_\beta = 5.7 \times 10^{-3}$  MeV and if concentration is expressed in terms of  $\mu\text{Ci}/\text{liter}$  of urine, equation (6) becomes:

$$D = (4.2 \times 10^{-4}) (C_0) (T_B) \frac{1 - e^{(-0.693)t}}{T_B} \text{ rads} \quad (7)$$

The Quality Factor for beta particles of maximum energy  $\leq 0.03$  MeV is 1.7 and therefore equation (7) expressed in mrem becomes:

$$D = (0.72) (C_0) (T_B) \frac{1 - e^{(-0.693)t}}{T_B} \text{ mrem} \quad (8)$$

For approximate calculations of radiation dose, a 12-day biological half-life for tritium elimination is recommended (7). Substitution of this value into equation (8), the total dose expression reduced to:

$$D = (8.6) (C_0) (1 - 3^{-0.058t}) \text{ mrem} \quad (9)$$

EXHIBIT #8

FINGER RING DOSIMETERS

A. Film Dosimeters (1944 to 1968)

Two types of finger ring film dosimeters have been used at Hanford to measure exposure to extremities. One is aluminum and the other a heavy rubber. Both type dosimeters utilized duPont 510 film. The photometer had a lower optical density limit of 0.01 which corresponded to a dose of 250 mR.

These ring dosimeter film were calibrated by using a radium gamma source. Thus it was necessary to correct exposures based on ring dosimeter results when working with low energy gamma and x-ray emitters. A special study was conducted which resulted in using a correction factor of 1/10 for extremity exposures resulting from work with plutonium or promethium..

B. TLD Rings (April 1968 to date)

The TLD extremity dosimeter utilizes a  ${}^7\text{LiF}$  teflon wafer imbedded in a rubber ring. It has a surface area of nominally  $1.5 \text{ cm}^2$ . The wafer is covered by a sheet of polyethylene,  $40 \text{ mg/cm}^2$  thick. The useful range of the dosimeter is 30 mR to  $10^5 \text{ R}$  for virtually any photon energy above 10 KeV.

EXHIBIT #9  
CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME Off-Site Results - Exposure Data Cards	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS TENTHS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	12
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	3
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	4

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Payroll No.	2	6		
2. Last Name	8	25		
3. Initials	26	28		
4. Social Security No.	29	37		
5. Beta	38	43		Rems rounded to nearest .01
6. Gamma	44	49		Rems rounded to nearest .01
7. X-ray	50	55		Total X-ray dose. Rems rounded
8. Neutron	56	61		Sum of the slow/fast. Rems rounded
9. Tritium	62	67		Rems rounded to nearest .01
10. Rings	68	73		Highest rings totaled. Rems rounded
11. Off-Site Mnemonic Code	76	77		
12. Code		78		"12" punch all cards. Off-site results
13. Year	79	80		
14.				
15.				
TOTAL KEY STROKES PER CARD				

DATE \_\_\_\_\_ SECTION \_\_\_\_\_ PAGE \_\_\_\_\_

EXHIBIT #10

ROUTINE SURVEILLANCE PROGRAM FOR INTERNALLY DEPOSITED RADIONUCLIDES

Employees working in radiation zones at Hanford are currently examined for internally deposited radionuclides in accordance with the following schedule:

A. Gamma Emitters

Each employee working with gamma emitting radionuclides shall be examined annually using whole body counting techniques.

B. Plutonium and Other High Radiotoxicity Materials

1. Employees who spend more than 25% of their time working with quantities of plutonium exceeding 1 gram shall be sampled quarterly.
2. Employees who spend more than 10% but less than 25% of their time working with quantities of plutonium exceeding 1 gram shall be sampled annually.
3. Employees who work up to 10% of their time with quantities of plutonium less than one gram and/or those who do not work with plutonium but whose work locations are in facilities where quantities of plutonium exceeding one kilogram are present shall be sampled once every five years.
4. Employees working with biologically equivalent quantities of other high toxicity materials shall be sampled according to the same schedule as listed for plutonium.

Prior to the adoption of the above schedule utilizing WBC techniques, bioassay samples were routinely analyzed for both plutonium and fission products.

EXHIBIT #11

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  Bioassay Data	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME	
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		HOURS	TENTHS
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY			
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL			
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER			

PROGRAM

1	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	12
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	3
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	4

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. File No.	1	5		Alpha numeric
2. Analysis Code	6			1 for <sup>239</sup> Pu, 2 for Nat U, 3 for any other isotope
3. Type of Analysis	7	11		Examples: <sup>239</sup> Pu, Nat U, <sup>147</sup> Pm, <sup>241</sup> Am, <sup>210</sup> Po, <sup>90</sup> Sr, Tr
4. Computer Code	12			6 except leave blank for tritium
5. Sample date	13	18		Mo, da, yr
6. Sample type (urine or feces)	19			U or F
7. Organization Code	20	22		Alpha numeric
8. Job Code	23	27		Alpha numeric
9. First two initials	28	29		
10. Last name	30	41		
11. Street address	42	55		
12. Town	56	59		Examples: Rich, WRic, Pasc, Pros, Sunn
13. Shift schedule	60			Example: A,B,C,D, or X,Y,Z (use only for 24 hr. samples)
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #11 (contd.)  
CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  Bioassay Data (contd.)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Collection period code	61			0=routine or field request 1=sim 12 hr used for termination
2.				2=sim 24 hr urine 3=total 24 hr urine or feces
3.				4=total 8 hr urine 5=single void (also used for 100 ml aliquot for emergency processing)
4.				
5. Sampling frequency code	62			1=annual 2=semi-annual 3=quarterly 7=every 5 years
6. Month sample requested	63	64		
7. Sample code	65			H=new hire I=incident T=termination
8.				B=beginning work E=ending work
9.				1-9=1st thru 9th sample to investigate high routines
10.				X=volume and result extrapolated from basic data
11. No result code	66			I=insufficient volume N=no sample L=lost sample
12.				
13. Sample volume X.XX liters or weight in kg.	67	69		
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #11 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME Bioassay Data (contd.)	JOB NO.	FREQUENCY				ESTIMATED VOLUME	ESTIMATED TIME	
		<input type="checkbox"/> DAILY	<input type="checkbox"/> WEEKLY	<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> SEMI-MONTHLY		<input type="checkbox"/> MONTHLY	<input type="checkbox"/> QUARTERLY

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Analysis date	70	73		Date UST analyzed Mo-da
2. Analysis result	74	78		X.XX + X <u>                    </u> UNITS <sup>239</sup> Pu µCi/sample
3.				Tr µCi/liter
4.				Nat U µg/liter
				All others µCi/liter
5. Blank	79			
6. Pu routine - "No Sample" count	80			
7.				
8.				Leave columns 66 through 80
9.				blank when requesting prepara-
				tion of result card
10.				
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

DATE \_\_\_\_\_ SECTION \_\_\_\_\_ PAGE \_\_\_\_\_

EXHIBIT #11 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME Bioassay Results Used Since 1972	JOB NO.	FREQUENCY				ESTIMATED VOLUME	ESTIMATE		
		<input type="checkbox"/> DAILY	<input type="checkbox"/> WEEKLY	<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> SEMI-MONTHLY		<input type="checkbox"/> MONTHLY	<input type="checkbox"/> QUARTERLY	<input type="checkbox"/> ANNUAL

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Social Security No.	1	9	N	
2. Constant	10	11	N	"30"
3. Sample date	12	17	N	XX XX XX Yr Mo Da
4. Payroll No.	18	22	N	
5. Initials	23	25	A	1st, 2nd, & 1st of last name
6. Sample volume	27	31	N	Weight in kilograms Sample volume in mls. X.XXXX
7. Sample type		32	A	S, U, F, or B
8. Sample code		33	A/N	b=routine B=beginning work H=new hire E=ending work
9.				T=termination I=incident 1-9 special investigation
10. Collection period		34	N	1-sim 12 hr 3-total 24 hr 2-sim 24 hr 4-total 8 hr
11.				5-100 ml aliquot
12. Result value	35	37	N	X.XX Do not print decimal-- for alignment only
13. Exponent		38	A/N	Sign + or -
14. Power exponent	39	40	N	Power of 10
15. Result flag		41	N	(1) Result less than 2.25x10 <sup>-8</sup> (0) if greater
TOTAL KEY STROKES PER CARD				

EXHIBIT #11 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME Bioassay Results Used Since 1972 (contd.)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME	
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		HOURS	TENTHS
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY			
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL			
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER			

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Analysis code		42	N	1= <sup>239</sup> Pu, 2=Nat U, 3=Other Isotope
2. Analysis type	43	47	A/N	
3. Employee's last name	48	65		
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #12

EVALUATION OF AMOUNTS OF INTERNALLY DEPOSITED SOLUBLE PLUTONIUM  
FROM URINALYSIS DATA

I. "SOLUBLE" PLUTONIUM

The evaluation of the amount of soluble plutonium internally deposited in a person is accomplished by quantitatively analyzing urine samples for plutonium content and fitting the plutonium urinary excretion data thus obtained to mathematical models derived to express the relationships between the amount of soluble plutonium deposited and the resulting plutonium urinary excretion rates to be expected at various lengths of time after deposition. After determining which mathematical model best fits the plutonium urinary excretion data and what values to assign to the parameters in the model, one can then calculate the amount of deposited soluble plutonium which the mathematical model indicates would result in the exhibited excretion rates.

The term "soluble" plutonium refers to that internally deposited plutonium which, at some time during the period of deposition, becomes soluble in the body fluids. For evaluation purposes, it is assumed that essentially all of the solubilized plutonium is subsequently deposited in the bone structure, with a small percentage being excreted at a very slow rate. No mathematical models and no detection or measurement techniques are available to permit the evaluation of that plutonium which might be internally deposited in insoluble form and remain permanently insoluble to the body fluids.

For evaluation purposes, the "soluble" plutonium deposited is considered to consist of "initially soluble" plutonium and/or "initially insoluble" (less readily-soluble) plutonium. "Initially soluble" plutonium is defined as that plutonium

which becomes solubilized by the body fluids within a few hours or days after being taken into the body, and hence is present in urine samples collected within a few days following intake. "Initially insoluble" plutonium is defined as that plutonium which is not solubilized by the body fluids during the first few days following intake, but does begin gradually to be solubilized after several weeks or months have elapsed. In determining whether the soluble plutonium was deposited in initially soluble form, initially insoluble form, or in both forms, the evaluator fits the plutonium urinary excretion data obtained following the deposition to mathematical models describing excretion rates to be expected from depositions of initially soluble and initially insoluble plutonium. The model(s) best fitting the data is then used to calculate an estimate of the amount of soluble plutonium deposited.

## II. LANGHAM'S MODEL FOR INITIALLY SOLUBLE PLUTONIUM

### A. Theory

The model used to evaluate the amount of initially soluble plutonium deposited was derived by W. H. Langham.<sup>(1)</sup> Langham derived the following equation to describe the rate of urinary excretion of initially soluble plutonium entering the bloodstream following an acute exposure, regardless of the mechanism by which internal deposition occurs:

$$X = 0.002 Q_0 t^{-0.74} \quad (1)$$

In this equation, "t" is the number of days elapsed between deposition and sample collection, while "X" is the predicted urinary excretion rate of initially soluble plutonium after "t" days, expressed as a fraction of the initial deposition of initially soluble plutonium,  $Q_0$ . Solving equation for  $Q_0$  yields:

$$Q_o = \frac{x}{0.002t^{-0.74}}$$

### B. Application

Equation (1) indicates that the plutonium urinary excretion rate decreases logarithmically as the number of days between deposition and sample collection increases. For a given value of  $Q_o$ , measured in d/m, equation (1) can be expressed graphically as a straight line with slope of -0.74 when varied values of  $t$  and  $X$  are plotted logarithmically (with "d/m excreted per day" as the ordinate and "number of days elapsed" as the abscissa). Hence, if one plots analytical plutonium urinary excretion data (from a person who received an internal deposition of initially soluble plutonium on a known date) logarithmically versus the number of days between deposition and sample collection, a straight line with slope of -0.74 can be fitted to the plotted data. Furthermore, substituting the  $X$  and  $t$  coordinates of any point on the "fitted" line for  $X$  and  $t$  in equation (1) will yield the estimate of  $Q_o$  provided by the application of equation (1). In practice, values of  $t = 1$  day and the corresponding value of  $X$  are substituted into equation (1) since with  $t = 1$  day the equation reduces to the simple form

$$Q_o = \frac{X}{0.002}$$

### III. HEALY'S MODEL FOR INITIALLY INSOLUBLE PLUTONIUM

#### A. Theory

The model used to evaluate the amount of initially insoluble plutonium deposited was derived by J. W. Healy.<sup>(2)</sup> Healy derived the following equation to describe the rate of urinary excretion of initially insoluble in the lung or other metabolic pool"....isolated from the normal metabolism of the body but

continually injecting plutonium into the bloodstream at a rate dependent upon the character of the deposited material and relevant physiological processes.":

$$E_{\mu} = 0.002 \lambda_s Q_0 \int_0^R e^{-\lambda t} (R-t)^{-0.74} dt \quad (2)$$

In this equation,  $E_{\mu}$  = the daily urinary excretion rate of initially insoluble plutonium expressed as a fraction of the initial deposition of initially insoluble plutonium;

$\lambda_s$  = the rate of solubilization and transfer to the bloodstream of initially insoluble plutonium;

$Q_0$  = the quantity of initially insoluble plutonium deposited in the body (and retained in the body following the initial clearance from the lung by ciliary action, in the case of deposition by inhalation);

$\lambda = \lambda_s + \lambda_c$  = the total rate of transfer of initially insoluble plutonium from the lung or other metabolic pool, due to solubilization and transfer to the bloodstream (and ciliary action following initial ciliary clearance in the case of deposition by inhalation);

$R$  = the number of days required for initially insoluble plutonium to be transferred from the lung or other metabolic pool to the bloodstream.

Although equation (2) is not integrable, the integral has been solved for several values of  $\lambda$ ,  $R$ , and  $t$  by expansion of the exponential term. The " $\lambda$  curves" thus obtained are used in solving equation (2) for the quantity of initially insoluble plutonium,  $Q_0$ , deposited in the body. Healy demonstrated that

$\lambda_c$ , the rate of transfer of initially insoluble plutonium from the lung via ciliary action (not including initial ciliary clearance), is on the order of ten percent of  $\lambda$ . Thus,  $\lambda_s$  can be assumed equivalent to  $\lambda$  for all practical purposes. Of course in cases where the metabolic pool is not the lung but some other site, such as a puncture wound,  $\lambda_c$  is inapplicable and  $\lambda_s$  is thus exactly equivalent to  $\lambda$ . Substituting  $\lambda$  for  $\lambda_s$  and solving equation (2) for  $Q_0$  yields:

$$Q_0 = \frac{E_\mu}{0.002\lambda \int_0^R e^{-\lambda t} (R-t)^{-0.74} dt} \quad (2)'$$

B. Application

Several " $\lambda$  curves" have been prepared to permit one to solve equation (2)' for  $Q_0$ . For each  $\lambda$  curve,  $\lambda$  was arbitrarily assigned some given value. Then, values of the integral were determined corresponding to the value assigned to  $\lambda$  and the several values assigned to  $R$ , the number of days elapsed between deposition in the metabolic pool and subsequent excretion in the urine. The values of the integral have no units, but express the relative excretion rates predicted by the integral at various times after deposition, for the value of  $\lambda$  assumed. Thus, plotting logarithmically the values of the integral versus the corresponding values of  $R$  yields a  $\lambda$  curve, for the value of  $\lambda$  assumed, which represents the shape of the excretion curve predicted by equation (2)' regardless of the magnitude of  $Q_0$ . The appropriate value of  $\lambda$  to use in evaluating the amount of initially insoluble plutonium urinary excretion data logarithmically ("d/m Pu per urine sample" as the ordinate versus "number of days between deposition and sample collection" as the abscissa") and experimentally determining which  $\lambda$  curve best fits the plotted data.

Equation (2)' can then be solved for  $Q_0$  by substituting for  $E_\mu$  and the integral a pair of values corresponding to any given number of days post intake. In practice it is convenient to choose the maximum value of the integral and the corresponding maximum value of  $E_\mu$ , the maximum excretion rate (expressed in units of d/m per sample) as determined by the  $\lambda$  curve fitted to the plotted analytical data.

#### IV. MISCELLANEOUS CONSIDERATIONS

Comments on several points are warranted to assist one in understanding the techniques, procedures and assumptions utilized in evaluating the amount of soluble plutonium deposited in a person.

##### A. Detection Levels

The analytical detection level for plutonium urinalysis has changed over the years as improved analytical and counting procedures were developed. The following table indicates these changes. In order for an analytical result to be considered "positive" it must be equal to or greater than the detection level in effect at the time of analysis.

<u>Time Period</u>	<u>Detection Limit (d/m Pu Per Sample)</u>
Prior to June 1949	0.66
June 1949 to December 1952	0.33
December 1952 to January 28, 1953	0.18
1/28/53 to 3/27/53	0.15
3/27/53 to 11/7/53	0.05
11/7/53 to 12/4/53	0.07
12/4/53 to present	0.05

B. Interpreting Plutonium Urinalysis Data

Currently, a person is not confirmed as a plutonium deposition case unless valid positive plutonium urinalysis results have been obtained from at least two samples collected from the person. Preferably a minimum of five samples are obtained, with the evaluator using his discretion during evaluation should both positive and negative results be obtained. For this study only a positive deposition evaluated as  $\bar{>}$  0.0001  $\mu$ Ci Pu is included.

C. Sample Collection Period

The models for evaluation of initially soluble and initially insoluble plutonium both involve the daily urinary excretion rate of plutonium; that is, the amounts of plutonium excreted in the urine during 24-hour periods. Hence, the urine samples analyzed must be representative of such plutonium excretion. In some cases persons to be sampled are instructed to collect all urine voided during a 24-hour period. However, in most cases the person is requested to collect a "simulated 24-hour urine sample" (sometimes referred to as a "48-hour urine sample"). Such a sample is to consist of all urine voided one-half hour before retiring and one-half hour after rising on two consecutive days. Such a sample is assumed to be equivalent in plutonium content to a 24-hour total urine sample collected on the date spanned by this sampling period.

D. Discrepancies in Recorded Sample Dates

At one time the date that sampling equipment was delivered to a person's home was recorded as the sample date on the analytical cards and various other records. (There are also a few instances where it is obvious that the "sample date" recorded was actually the date the sample was picked up from the person's home.) Effective with sample dates listed as 9-28-62 or later,

the listed sample dates are correct; that is, the listed sample date is the day following the equipment delivery date. In cases where evaluation of a person's plutonium deposition involves the use of data from samples obtained prior to 9-28-62, current practice is to list the "Sample date" as previously recorded (to preserve agreement between records) but to treat data obtained prior to 9-28-62 as though the sample dates were one day later when calculating the "number of days post intake" and when plotting the data. (Actually the only effect these one-day discrepancies have is one of nuisance value, since shifting the data by one day has little or no effect on the estimate of the amount of soluble plutonium deposited.)

E. Maximizing Estimates

Current policy is to perform evaluations so that the estimate of the amount of internally deposited soluble plutonium is the maximum estimate which can reasonably be obtained, in cases where the data leave doubt as to which mathematical model or which  $\lambda$  curve best describes the data. Such doubt can exist due to (1) variability in the data, (2) complications resulting from the person's having received previous internal depositions of plutonium, (3) lack of sufficient time lapse to permit collection of enough samples to adequately define the best fitting  $\lambda$  curve, etc. In the case of a deposition detected by receipt of positive results from routine surveillance samples, the date of deposition is an additional unknown. To obtain the maximum reasonable estimate in these cases it is usually necessary to assume that the deposition occurred on the day following the collection of the routine sample preceding the first positive routine sample.

F. Correction for Previous Depositions

In many cases the person being evaluated for a potential internal deposition from a current incident has received an internal deposition from a previous incident. In such cases currently collected urine samples may contain significant amounts of plutonium as the result of the previous deposition, causing the current plutonium urinalysis results to be larger than they would be had the person not previously received an internal deposition. To avoid an obvious overestimation of the added deposition, if any, received in a current incident, it is necessary to "correct" or "adjust" the current data to take the previous deposition into consideration. This is accomplished by subtracting from each of the current data the amount of plutonium present in the sample as the result of the previous deposition, as indicated by the current excretion rate predicted by the excretion curve which has been fitted to previous data in evaluating the previous deposition. The same situation applies in the case where the data indicate that a person received depositions of both initially soluble and initially insoluble plutonium from the same incident; that is, the data must be corrected for the influence of the initially soluble plutonium before one evaluates the amount of initially insoluble plutonium deposited.

G. Meaning of Estimate of Initially Insoluble Deposition

It should be emphasized that an estimate of the amount of initially insoluble plutonium deposited is not an estimate of initially insoluble plutonium which has been solubilized and transferred from the metabolic pool. Rather, in accordance with the theory underlying Healy's model, it is an estimate of the total amount of initially insoluble plutonium deposited which eventually will be solubilized and transferred from the metabolic pool, whether that pool be the lung or a localized deposition at a puncture wound site.

H. Reporting Units

The examples presented demonstrate the mechanics of obtaining an estimate of the amount of soluble plutonium deposited, expressed in units of d/m Pu since the analytical results are calculated and plotted in units of d/m Pu per sample. In practice, the estimate of the amount of soluble plutonium deposited is converted to units of microcuries ( $\mu\text{Ci}$ ) of plutonium deposited by dividing d/m plutonium by the conversion factor of  $2.22 \times 10^6$  d/m per  $\mu\text{Ci}$ . This estimate is then expressed as a percent of the maximum permissible body burden (MPBB) of 0.04  $\mu\text{Ci}$  soluble plutonium listed for occupational exposure in the National Bureau of Standards handbook 69,<sup>(3)</sup> considering bone to be the critical organ of reference.

REFERENCES

1. Langham, W. T., "Determination of Internally Deposited Radioactive Isotopes from Excretion Analysis," American Industrial Hygiene Association Quarterly, 17:3, 305-318 (September 1956).
2. Healy, J. W., "Estimation of Plutonium Lung Burden by Urine Analysis," American Industrial Hygiene Association Quarterly, 18:3, 261-266 (September 1957).
3. HBS Handbook 69, "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure," U.S. Department of Commerce, National Bureau of Standards (June 5, 1959).

EXHIBIT #13

EVALUATION OF AMOUNTS OF INTERNALLY DEPOSITED Pu-241

General

The body burden of plutonium-241 deposited within a person as the result of involvement in a known or assumed radiation occurrence is calculated based on the ratio of plutonium-241 activity to the plutonium-239\* activity in the material involved in a radiation occurrence. This method assumes that the fate of plutonium-241 in the human body is the same as for plutonium-239. The long-range program is to develop a practical method of directly measuring the plutonium-241 quantity in bioassay samples.

Calculations

Let A = the amount of normal plutonium\*\* (in  $\mu\text{g}$ ) that results in one body burden of plutonium-239, inferred from measurement of alpha activity in the urine specimen. Then:

$$(0.935 A \mu\text{g Pu}^{239}) (6.14 \times 10^{-2} \frac{\mu\text{Ci}}{\mu\text{g Pu}^{239}}) + 0.060 A \mu\text{g Pu}^{240}$$

$$(2.21 \times 10^{-1} \frac{\mu\text{Ci}}{\text{g Pu}^{240}}) = 0.04 \mu\text{Ci}$$

$$\text{and } A = 0.566 \mu\text{g Pu}$$

Therefore in a measured body burden of plutonium there is:

$$0.0324 \mu\text{Ci Pu}^{239} \text{ or } 81\% \text{ of the Pu}^{239} \text{ MPBB}$$
$$\text{and } 0.0075 \mu\text{Ci Pu}^{240} \text{ or } 19\% \text{ of the Pu}^{240} \text{ MPBB}$$

If there is 0.566  $\mu\text{g Pu}$ , based on measurement of alpha activity there is:

$$(0.566 \mu\text{g Pu}) (0.005) = 2.83 \times 10^{-3} \mu\text{g Pu}^{241}$$

This is equal to:

$$(2.83 \times 10^{-3} \text{ } \mu\text{g Pu}^{241}) (1.13 \times 10^2 \frac{\text{ } \mu\text{Ci}}{\text{ } \mu\text{g Pu}^{241}}) = 0.320 \text{ } \mu\text{Ci Pu}^{241}$$

or 35% Pu<sup>241</sup> MPBB of 0.9  $\mu\text{Ci}$

Therefore: for every measured body burden of Pu there is 35% MPBB of Pu<sup>241</sup>.

---

\*The plutonium-239 activity referred to is actually the combined Pu<sup>239</sup> and Pu<sup>240</sup> activity, since the analysis includes the total plutonium alpha activity.

\*\*Normal plutonium refers to a mixture of plutonium containing, by weight, 93.5% Pu<sup>239</sup>, 6.0% Pu<sup>240</sup>, and 0.5% Pu<sup>241</sup>.

EXHIBIT #14

EVALUATION OF AMOUNTS OF INTERNALLY DEPOSITED STRONTIUM-90  
FROM URINALYSIS DATA

I. Strontium Deposition

The evaluation of Sr-90 internally deposited in a person is accomplished by quantitatively analyzing urine samples for strontium content and fitting the urinary excretion data thus obtained to mathematical models derived to express the relationship between the amount deposited and the urinary excretion rate to be expected at various lengths of time after deposition. The model used is derived from data involving intravenous intakes of strontium chloride. Because this one model is used for evaluations of all internal strontium depositions regardless of the chemical form or mode of intake, there is a certain amount of uncertainty regarding these evaluations.

II. Evaluation Model

Dolphin, et.al., took the data of Bishop, et.al., and that of Cohn, et.al., and developed an expression in round numbers for the retention of strontium-90 following a single intravenous intake of strontium chloride as follows:

$$R(t) = 50 \exp \frac{-0.693t}{(2.5)} + 50 t^{-0.2} \quad t \geq 1 \quad (1)$$

where R is the percent of initial intake retained at time t. The authors claim that 0.8 of the total excretion is eliminated via the urine and since  $E_u = 0.8 \frac{dR}{dt}$ , then  $E_u = 12 \exp \frac{-0.693t}{(2.4)}$

$$+ 8t^{-1.2} \quad t \geq 1 \quad (2)$$

where  $E_u$  is the percent of the initial burden excreted in urine on day t.

### III. Application

It is assumed that the strontium-90 excreted in the urine on day 20 post-intake equals 0.2% of the initial intake. The lack of data reported by Bishop and Cohn past one year, coupled with an apparent very slowly changing elimination rate suggests that the amount retained at one year (~15% of the initial intake) be considered as the amount permanently retained. The total amount of strontium excreted in the urine collected during the first three days post-intake is assumed to be ~30% of the initial intake. If a significant amount of strontium is measured in the urine excreted in the first three days post-intake, additional bioassay sampling is scheduled. The evaluation of the amount of strontium initially deposited in the body is normally based on the average of the strontium activity excreted in the urine on days 19, 20, and 21; however, an estimate can be calculated based on bioassay data collected at any date using equation (2). The amount of strontium permanently deposited in the body is then taken to be 15% of the initial intake.

### IV. Conclusions

The total plutonium body burden resulting from normal plutonium material taken into the body is assumed to be 1.35 times the measured body burden based on plutonium alpha activity in the urine.

If the Pu<sup>241</sup> content exceeds 0.5% by weight of the plutonium mixture, it will be necessary to make special determinations of the total plutonium body burden.

EXHIBIT #15

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  Deposition Cases	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS    TENTHS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Payroll No.	1	5		
2. Last name	7	22		
3. Initials	24	25		
4. Social Security No.	27	35		
5. Intake date	37	40		Month and year
6. Flag	41			P=positive but less than MDA
7. Amount	42	46		Amount in $\mu\text{Ci} \times 10^{-4}$ X.XXXX--decimal for alignment on l.
8. Flag	48			A=assumed    K=known date of intake
9. Offsite	50			*=offsite    Blank=Hanford
10. Organ	52	55		Organ of interest
11. Mode of intake	57			I=inhalation    W=wound
12. Flag	74			T=terminated    D=deceased, blank
13. Radionuclide	76	80		
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #15 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  Internal Deposition (Used since 1972)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS    MINUTES
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Social Security No.	1	9	N	
2. Constant	10	11	N	"20" insert "21 replace
3. Incident date	12	17	N	Yr Mo Da XX XX XX
4. Payroll No.	18	22	N	
5. Initials	23	25	A	1st, 2nd, & 1st of last name
6. Last name	26	43	A	
7. Organ	44	47	A	Syst
8. Element code	48	49	A	
9. Element number	50	52	N	
10. Result value	53	57	N	in µCi X.XXXX Do not print decimal--for alignment only
11. Flag		58		Positive flag indicator (P or blank)
12. Flag		59		(A or K) Assumed or known
13. Flag		60		(I or W) Inhalation or wound
14. Flag		61		(T or D) Terminated/deceased
15. Offsite	62	63		See attachment to Exhibit #3A
TOTAL KEY STROKES PER CARD				

**EXHIBIT #15 (contd.)  
CARD PUNCHING OR VERIFYING INSTRUCTIONS**

JOB NAME Internal Deposition (Used since 1972) (contd.)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME	
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		HOURS	TENTHS
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY			
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL			
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER			

**PROGRAM**

2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	12
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	3
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	4

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Healy Lambda	64	67		XX-X [Example: $\lambda = .001 \rightarrow 10^{-2}$ ]
2. PU/AM ratio	68	70		do not print decimal-- XX.X it is assumed
3. Date of death	71	74		XX XX Yr Mo
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

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EXHIBIT #16

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  In-Vivo Examination Type 2	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Record Type	1	2		02 = In-Vivo Examination result
2. System Identification	3	5		In-vivo examination
3. Payroll Number	6	10		
4. Date of Count	11	16		mo., da., yr.
5. Count time	17	20		24 hr. - blank if not indicated
6. Organ counted	21	24		Wbdy, Head, Wund, Thyd, Lung, Hand, Other
7. Count type	27	32		Purpose of examination - N Hire, TERM, Routin, UP Exp, Other
8. Counter type	34	35		Codes assigned: 01=Whole Body Counter, 02=Lung, 03=Head,
9.				04=Wound, 05=Thyroid, 07=Mobil WBC
10. Na	37	42		X.X-XX express in whole number rounded to tenths with exponents
11. K	44	49		Same as above
12. Zn	51	56		Same as above
13. Cs	58	63		Same as above
14. Other $\mu$ Ci	65	70		Same as above
15. Other element name	71	74		Right justify
TOTAL KEY STROKES PER CARD				

EXHIBIT #16 (contd.)  
CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  In-Vivo Examination Type 2 (Cont.)	JOB NO.	FREQUENCY				ESTIMATED VOLUME	ESTIMATED TIME
		<input type="checkbox"/> DAILY	<input type="checkbox"/> WEEKLY	<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> SEMI-MONTHLY		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Other element number	75	77		
2. Action Code	78			I=insert, D=delete, R=replace
3.				
4. Note - If <MDA insert *				
5. If Trace insert **				
6. If Questionable insert ***				
7. (always justify left and leave blank)				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

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EXHIBIT #16 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME In-Vivo Examination Type 3	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Record type	1	2		03=Continuation of "02" card
2.				Record type which has identical
3.				date, time, and organ counted
4. System Identification	3	5		In-vivo examination
5. Payroll number	6	10		
6. Count date	10	16		mo., da., yr
7. Count time	17	20		24 hr-blank if not indicated
8. Organ counted	21	24		Wbdy, Head, Wund, Thyd, Lung,
9.				Hand, other
10. 1st Other element $\mu$ Ci	26	31		X.X-XX
11. 1st Other element name	32	35		Justify to right
12. 1st Other element #	36	38		Justify to left
13. 2nd other element $\mu$ Ci	40	45		Same as 1st element
14. 2nd other element name	46	49		Same as 1st element
15. 2nd Other element #	50	52		Same as 1st element
TOTAL KEY STROKES PER CARD				

-68-  
EXHIBIT #16 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME  In-Vivo Examination Type 3 (Cont.)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS    MIN.
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82	12
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82	3
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82	4

CARD	FIELD	COLUMNS		FUNCTION*	REMARKS
		FROM	TO		
1.	3rd Other element $\mu$ Ci	54	59		Same as 1st element
2.	3rd Other element name	60	63		Same as 1st element
3.	3rd Other element #	64	66		Same as 1st element
4.	4th Other element $\mu$ Ci	68	73		Same as 1st element
5.	4th Other element name	74	77		Same as 1st element
6.	4th Other element #	78	80		Same as 1st element
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
TOTAL KEY STROKES PER CARD					

EXHIBIT #16 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME In-Vivo Results Card 1 (Used since 1972)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. Social Security No.	1	9	N	
2. Constant	10	11	N	"40"
3. Count date	12	17	N	Year, month, day sequence
4. Organ	18	21	A	Head, whole body, lung
5. Card No. (1)		22	N	
6. Count time	23	26	N	
7. Payroll number	27	31	N	
8. Counter type	32	33		01=whole body 02=lung 03=head 04=wound 05=thyroid 06=hand 07=mobile
9.				
10. 1st count value	34	36		do not print decimal--for X.XX alignment only
11. Exponent sign		37		+ or -
12. Exponent	38	39		
13. Flag		40		(0)=positive (1)=<detection level (2)=trace (3) questionable
14. 2nd count	41	47		Same as 34-40
15. 3rd count	48	54		Same as 34-40
TOTAL KEY STROKES PER CARD				

EXHIBIT #16 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME In-Vivo Results Card 1 (contd.) (Used since 1972)	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATED TIME HOURS
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1. 4th count	55	61		Same as 34-40
2. 5th count value	62	68		Same as 34-40
3. 5th count description	69	75		
4. Count type	76	80		(1) N Hire, (2) Other, (3) Term, (4) Routin, (5) UP EX
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT #16 (contd.)

CARD PUNCHING OR VERIFYING INSTRUCTIONS

JOB NAME In-Vivo Result Card "2" or "3"	JOB NO.	FREQUENCY		ESTIMATED VOLUME	ESTIMATE TIME HOURS    MINUTES
		<input type="checkbox"/> DAILY	<input type="checkbox"/> MONTHLY		
		<input type="checkbox"/> WEEKLY	<input type="checkbox"/> QUARTERLY		
		<input type="checkbox"/> BI-WEEKLY	<input type="checkbox"/> ANNUAL		
		<input type="checkbox"/> SEMI-MONTHLY	<input type="checkbox"/> OTHER		

PROGRAM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			
4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80																			

CARD FIELD	COLUMNS		FUNCTION*	REMARKS
	FROM	TO		
1.	1	22		Same as Card 1. Card 2 for other counts 1-4. Card 3 for other counts 5-8.
2.				
3. Counts value	23	25		X.XX do not print decimal-- (1 or 5) for alignment only
4. Exponent		26		Sign + or -
5. Exponent no.	27	28		(Value exponent power of 10)
6. Exponent flag		29		(0) positive, (1) < d.l., (2) trace, (3) questionable
7. Description	30	36		
8.	37	50		Repeat 23-36
9.	51	64		Repeat 23-36
10.	65	78		Repeat 23-36
11.				
12.				
13.				
14.				
15.				
TOTAL KEY STROKES PER CARD				

EXHIBIT NO. 17-A

HANFORD INTERNAL EXPOSURE

SSN 021 14 9129 NAME John Q. Doe

PAYROLL NUMBERS 60500 05963

DEPOSITION RECORDS

INCIDENT DATE	NUCLIDE	SYSTEMIC BURDEN	POSITIVE RESULT FLAG	ASSUMED/ KNOWN FLAG	INHALATION/ WOUND FLAG	TERMINATED/ DECEASED FLAG	OFFSITE CODE	HEALY LAMBDA
600601	PU239	.0010		K	W			-0.
600601	PU241	.0079		K	W			-0.
610101	PU239	.0001	P	K	W			-0.
510101	PU241	.0001		K	W			-0.
621101	PL239	.0028		K	W			-0.
621101	PU241	.0221		K	W			-0.
661001	PU239	.0031		K	I			-0.
661001	PU241	.0245		K	I			-0.

IN VIVO CHEST EXAMS

DATE	RESULTS
700909	7.90E-04
720127	9.60E-04
730412	1.00E-03

EXHIBIT NO. 17-B

ANNUAL DOSE COMMITMENTS IN REM FROM INCIDENT # 4

INHALATION

DATE: 10 1 65

YEAR	PU 219				PU 241				TOTAL			
	LUNG DOSE	LYMPH DOSE	BONE DOSE	LIVER DOSE	LUNG DOSE	LYMPH DOSE	BONE DOSE	LIVER DOSE	LUNG DOSE	LYMPH DOSE	BONE DOSE	LIVER DOSE
1966	2.420	1.795	.005	.003	.037	.005	.700	.000	2.427	1.801	.005	.003
1967	7.764	31.225	.127	.070	.077	.290	.001	.001	7.861	34.115	.128	.071
1968	5.423	56.325	.329	.181	.117	.891	.005	.003	5.540	57.220	.335	.184
1969	3.778	62.155	.535	.293	.126	1.414	.013	.007	3.904	63.483	.548	.300
1970	2.632	59.145	.723	.393	.119	1.716	.023	.013	2.751	60.861	.746	.406
1971	1.834	52.284	.884	.478	.104	1.799	.035	.019	1.938	54.083	.919	.497
1972	1.278	44.144	1.015	.546	.087	1.721	.048	.026	1.364	45.865	1.064	.572
1973	.390	34.132	1.120	.599	.070	1.545	.062	.033	.960	37.677	1.182	.632
1974	.620	28.919	1.201	.638	.055	1.324	.076	.040	.675	30.243	1.277	.677
1975	.432	22.757	1.262	.665	.043	1.097	.089	.046	.475	23.854	1.351	.711
1976	.301	17.673	1.307	.683	.033	.884	.102	.052	.334	18.557	1.408	.736
1977	.210	13.529	1.339	.694	.025	.698	.113	.058	.234	14.277	1.452	.752
1978	.146	10.343	1.360	.700	.018	.542	.124	.063	.164	10.880	1.485	.763
1979	.102	7.821	1.374	.731	.014	.415	.135	.067	.115	8.235	1.509	.768
1980	.071	5.677	1.382	.699	.010	.314	.144	.071	.081	6.191	1.526	.770
1981	.049	4.393	1.385	.694	.007	.236	.153	.075	.057	4.620	1.538	.769
1982	.034	3.261	1.385	.687	.005	.176	.160	.078	.040	3.444	1.545	.765
1983	.024	2.422	1.382	.680	.004	.130	.168	.080	.028	2.552	1.550	.760
1984	.017	1.788	1.378	.671	.003	.096	.174	.083	.019	1.884	1.552	.754
1985	.012	1.316	1.372	.662	.002	.070	.180	.084	.014	1.362	1.551	.746
1986	.008	.966	1.364	.652	.001	.051	.185	.086	.010	1.027	1.550	.738
1987	.006	.707	1.357	.642	.001	.037	.190	.087	.007	.745	1.547	.729
1988	.004	.516	1.348	.632	.001	.027	.194	.088	.005	.544	1.543	.720
1989	.003	.376	1.340	.621	.001	.020	.198	.089	.003	.396	1.538	.710
1990	.002	.274	1.331	.611	.000	.014	.202	.090	.002	.288	1.533	.701
1991	.001	.199	1.322	.601	.000	.010	.205	.090	.002	.209	1.527	.691
1992	.001	.144	1.313	.591	.000	.007	.207	.090	.001	.151	1.520	.681
1993	.001	.104	1.304	.581	.000	.005	.210	.090	.001	.110	1.513	.671
1994	.000	.075	1.294	.571	.000	.004	.212	.090	.001	.079	1.506	.661
1995	.000	.054	1.285	.561	.000	.003	.214	.090	.000	.057	1.499	.651
1996	.000	.039	1.276	.552	.000	.002	.215	.089	.000	.041	1.491	.641
1997	.000	.028	1.267	.542	.000	.001	.217	.089	.000	.030	1.483	.631
1998	.000	.020	1.258	.533	.000	.001	.218	.089	.000	.021	1.475	.622
1999	.000	.015	1.249	.524	.000	.001	.219	.088	.000	.015	1.467	.612
2000	.000	.010	1.240	.515	.000	.001	.219	.087	.000	.011	1.459	.602
2001	.000	.008	1.231	.506	.000	.000	.220	.086	.000	.008	1.451	.593
2002	.000	.005	1.222	.497	.000	.000	.220	.086	.000	.006	1.442	.583
2003	.000	.004	1.213	.489	.000	.000	.220	.085	.000	.004	1.433	.574
2004	.000	.003	1.204	.481	.000	.000	.220	.084	.000	.003	1.425	.564
2005	.000	.002	1.196	.472	.000	.000	.220	.083	.000	.002	1.416	.555
2006	.000	.001	1.187	.464	.000	.000	.220	.082	.000	.001	1.407	.546
2007	.000	.001	1.178	.456	.000	.000	.220	.081	.000	.001	1.398	.537
2008	.000	.001	1.170	.448	.000	.000	.219	.080	.000	.001	1.389	.528
2009	.000	.001	1.161	.441	.000	.000	.219	.079	.000	.001	1.380	.520
2010	.000	.000	1.153	.433	.000	.000	.219	.078	.000	.000	1.371	.511
2011	.000	.000	1.145	.426	.000	.000	.218	.077	.000	.000	1.362	.502
2012	.000	.000	1.136	.418	.000	.000	.217	.076	.000	.000	1.353	.494
2013	.000	.000	1.128	.411	.000	.000	.216	.075	.000	.000	1.344	.486
2014	.000	.000	1.120	.404	.000	.000	.215	.073	.000	.000	1.335	.478
2015	.000	.000	1.112	.397	.000	.000	.214	.072	.000	.000	1.326	.470
TOTAL	28.083	466.434	56.857	25.914	.933	15.550	7.972	3.454	29.011	481.087	61.222	30.100

August 1973

-74-

EXHIBIT #18

Report of the Advisory Committee on Dose  
from Plutonium and Other Transuranics Recorded on Hanford Tapes

The Advisory Committee has been requested to recommend to the staff of the AEC-HMS those procedures which it could use to obtain the dose equivalent due to exposure to plutonium and other transuranic nuclides recorded on the radiation exposure record as part of the Hanford data available to the HMS. The staff of the AEC-HMS will realize that there are many uncertainties in our knowledge of the transport and retention of transuranic elements in the body and also in the dosimetry which might be the best measure of the hazard associated with exposure to these radio-nuclides. In offering this report at this time, the Advisory Committee realizes this general area of activity is changing rapidly, and it may be hoped that significant developments in the next few years may make this report obsolete. For example, the decision of the ICRP to use dose to endosteal cells near bone surfaces instead of an average dose to bone for radiation protection is not followed in the recommendations offered below, and, indeed, the ICRP is not at this time implementing the decision because of the lack of needed biological data on alpha emitters, particularly the so-called surface seekers. It is to be expected that in the near future something better will emerge than the present practice of averaging dose over bone and using a modifying factor to represent in some measure the hazard due to the inhomogeneity of the dose distribution and the absorbed dose received by endosteal cells. The Advisory Committee is recommending use of the presently recommended procedure for assessment of dose to bone rather than try to guess at data on intensity of the surface deposition and its rate of overlay by new bone, data which are hardly available even for experimental animals.

Likewise, the dose received by respiratory lymph nodes associated with the lungs is of quite uncertain hazard, and the ICRP presently has not recommended a dose limit for these organs. Nevertheless, there are some animal, as well as some human, data available for estimation of dose,<sup>(1-4)</sup> and these are used to arrive at a dose to this tissue. Here there is more uncertainty concerning the significance of the dose than there is concerning the level, and it is precisely on questions of this kind that the HMS might offer some guidance in the future. Thus the Advisory Committee is recommending a procedure for estimation of dose to these lymph nodes, believing it to be important to note whether the human data parallel the animal data in respect to the relative sensitivity to radiation of lungs vs. thoracic lymph nodes and the degree of translocation of the inhaled material to the thoracic lymph nodes.

It will be evident to the reader that these are only two examples of the pragmatic course followed by the Committee. It has tried to provide a fairly realistic assessment of dose using presently available data which seemed applicable for the majority of the cases it was asked to consider--namely, the Hanford employee exposure cases. It has tried not to invent or use models with little or no background of biological data, being content to offer dosimetric procedures which are largely those of health physics practices at Hanford.

It must be realized that the Committee has used, for the most part, data presently on the computer tapes of the HMS, and it may be that these procedures would not be acceptable for other installations. Moreover, the Committee is concerned that the models recommended here for dosimetry should not be regarded as final; rather they represent the best compromise the Committee could arrive at, taking into account the many gaps in the early data and the rapid changes in the available information on dosimetry of these nuclides. In the Committee's view, it would be most unfortunate

if the dosimetric model proposed below were regarded as more than an ad interim model and were to be enforced rigidly on the HMS or AEC contractors in the future.

#### Known Exposures--Inhalation

These exposures will be distinguished on the exposure record by a considerable amount of excretion data and/or by the presence of data on chest counts. These chest counts, when available, will provide an elimination half-time  $\lambda$  for long-term clearance from the lung. If only bioassay data are available and if a Healy-type analysis has been used, there will be available an estimate of  $\lambda$ , the long-term-clearance constant. Actually, the Hanford exposure records for plutonium used by the HMS show only the estimates based on the Healy-type analysis as well as the primary bioassay data. The discussion brought out that the clearance half-times were most often of the order of 700 days, and it was agreed this was sufficiently in accord with the lung model under consideration by the ICRP to make it unnecessary to seek a new lung retention model. This model was originally developed by an ICRP Task Group on Lung Dynamics<sup>(4)</sup> but has been revised by Morrow and his colleagues. The basic ideas and structure of the model remain the same, but there have been considerable changes in the values of some of the parameters. This is particularly true for material depositing in the respiratory lymph nodes and in the nasopharyngeal region where the present values reflect particularly the newer data.<sup>(5,6)</sup> A schematic diagram of the model and tables of the associated values for the parameters and determination of clearance classification are appended as Fig. 1 and Table 1 of this report. After discussion, it was agreed that the 700-day half-time was what one might expect from the Class Y clearance half-time of 500 days followed by a further component of clearance half-time of some 500-1000 days for activity reaching lymph nodes. Although long-term studies at much higher exposure

levels in large laboratory animals suggest nearly permanent retention of up to 70% of their accumulated burden, at lower levels of exposure a considerable fraction of the accumulated burden might clear to the blood. This fraction is subject to revision depending on results of much lower level plutonium exposures currently under way. It was decided to adopt one and the same clearance half-time recorded on the exposure record for pathways e, h, and i which are the only long-term pathways which transport material directly to blood. This disregards the fact that the lung model allows for 10% of the activity deposited in the lymph nodes remaining there subject only to radioactive decay. The data supporting this are all at very high levels of exposure where atrophy of the lymph nodes may be expected to be present. It was further decided to ignore contributions to dose by way of absorption from gut since they are insignificant.

In summary:

- (1) The estimated long-term deposit in the pulmonary region given on the tables represents the deposition clearing to blood by pathways e and h (see clearance model). This is not the entire intake but is taken to be equal to  $ID_5(f_e + f_h)$  and is denoted below by  $I'$ .
- (2) These deposits are assumed to clear with an elimination constant  $\lambda$  estimated on the basis of bioassay data. No estimate of deposits with a short-term clearance half-time in the lung seems possible at this time. This would require data on particle size distribution which simply is not available in most cases and would not markedly affect the estimates of dose to the lung. It may have more influence on dose to bone or liver, but this would only be true for the more soluble forms of Pu and does not seem to apply to most of the Hanford data. In a few cases of exposure to Am, there may be clearance rates available on the basis of chest counts. (See final section.)

- (3) In estimating dose to lungs, the material clearing by pathway  $f_g$  also must be considered. However, its contribution to the estimate of intake to blood is negligible as mentioned above.

The partitioning of this activity between bone, liver, and "other soft tissues" was next considered. Although some evidence points to as much as 25% of the activity reaching blood being deposited in "other soft tissues," this hypothesis was finally rejected because of the rather meager data on these tissues and the large extrapolations that were made on the basis of rather meager sampling of tissues. This autopsy data, even if valid, would provide a dose of about an order of magnitude or more less than that to lungs, or liver, or bone, and it was decided to ignore it for the present. However, further data on experimental animals or on autopsy cases may require a change in the model in this respect.

After further discussion and a review of some of the data indicating wide variations in the fractions of activity in bone and liver and the often meager data on the chemical form that might correlate with this partition, the Committee decided to recommend a 45-45% partition of the activity reaching blood to liver and to bone. This would allow for 10% being excreted or present in "other soft tissues." Clearly, this is at best a compromise with the uncertain status of most exposure situations. Hopefully, the deposition would not fluctuate by more than  $\pm 50\%$  from these values.

The Committee accepted a very long half-time for clearance of plutonium from bone--say, 200 years--although the precise value assumed makes little difference in the dose if it is of this order.

Data on clearance from liver was reviewed briefly and led to the Committee recommending a clearance half-time of 20 years which is well beyond the half-time observed for beagles ( $\sim 2000$  days) but of the same order of magnitude. (7)

The further point was discussed that the lung model shows some shift in the fractions going through the lymph to blood as one changes from clearance pathway Y to W. Discussion brought out that most of the Hanford cases have indicated half-times of 300 days or more although in a few cases, the activity appears to belong to clearance class W. It was decided to always use the value of  $\lambda$  estimated on the basis of the data but to use the class Y partition ( $f_e = 5\%$ ,  $f_h = 15\%$ ) if  $\lambda < 0.693/250 \text{ days}^{-1}$  and to use the partitioning for class W ( $f_e = 15\%$ ,  $f_h = 5\%$ ) if  $\lambda > 0.693/250 \text{ days}^{-1}$ .

In summary:

- (1) These exposures are represented on the record by an estimate  $I'$  of long-term deposition in the pulmonary region clearing via pathways e and h, that is,  $I' = D_5(f_e + f_h)I$ . The long-term deposition clearing via pathways e and h must be carefully distinguished from the total intake to the lung by inhalation,  $I$ , and from the total long-term deposition in the pulmonary region. If the total intake breathed is  $I$  and a fraction  $D_5$  deposits in the pulmonary region, then  $ID_5(f_e + f_g + f_h)$  represents this total deposition in the pulmonary region which clears slowly. This equals  $3I' = 3ID_5(f_e + f_h)$ . However, if estimates of long-term deposition are based on chest counting in the future, the above distinction should be borne in mind as a measurement of lung burden would correspond to an initial pulmonary deposition of activity which clears slowly of  $ID_5(f_e + f_g + f_h)$ . It is understood no such data are present on the Hanford tapes at this time. Also, a time of occurrence ( $t_0$ ) and a clearance rate ( $\lambda$ ) are given.
- (2) This deposition  $I'$  will be partitioned to pathways e and h with

$$\frac{I' f_h}{(f_e + f_h)} = 0.75 I' \text{ and } \frac{I' f_e}{(f_e + f_h)} = 0.25 I' \text{ if } \lambda < \frac{0.693}{250} \text{ days}^{-1} \text{ and}$$

$$\frac{I' f_h}{(f_e + f_h)} = 0.25 I' \text{ and } \frac{I' f_e}{(f_e + f_h)} = 0.75 I' \text{ if } \lambda > \frac{0.693}{250} \text{ days}^{-1}.$$

- (3) Assuming  $t_0 = 0$ , dose equivalent accumulated in the pulmonary region of lung is estimated to be:

$$\begin{aligned} H_{\text{lung}} &= \frac{51.1 \times 3 I' (1 - e^{-\lambda t}) \Sigma EQ}{\lambda M} \\ &= \frac{153.3 I'}{\lambda} (1 - e^{-\lambda t}) 53.3 \cdot 10^{-3} \text{ rem} \end{aligned} \quad (1)$$

in the time interval 0 to time  $t$  days. The factor of 3 represents the long-term activity in the pulmonary region, i. e.,  $f_e + f_g + f_h = 3(f_e + f_h)$ . In (1) the quantity  $3 I' (1 - e^{-\lambda t}) / \lambda$  represents the  $\mu\text{Ci-days}$  accumulated in the pulmonary region of the lung due to the long-term deposits. Thus the dose formula is essentially the familiar one  $H = 51 \text{ UEQ/M}$  with  $U = \mu\text{Ci-days}$ ,  $E = \text{energy absorbed (Mev/disint)} \approx 5.15 \text{ Mev}$  for the alpha and with a recoil energy of  $0.0377 \text{ Mev}$ . The quality factor  $Q$  is 10 for the alpha particle and 20 for the recoil energy, making a total of  $\sim 53.3$  effective Mev, and  $M$  is the mass of the lungs. It was decided to ignore the short-term deposition which would only change the estimates by a few percent at most. The question of whether the mass of the lung should be scaled in some way was considered, but it was decided not to recommend this because of the rather poor correlation reported by several members in use of such data.

- (4) As mentioned above, it is important to have an estimate of dose to thoracic lymph nodes so that data on these organs can be meaningfully interpreted in terms of radiosensitivity.

$$H_{\text{lymph nodes}} = \frac{51.1 I' f_h e^{-\lambda t} (e^{\lambda t} - 1 - \lambda t) 53.3}{(f_e + f_h) \lambda 15} \text{ rem} \quad (2)$$

where  $f_h/(f_e + f_h)$  is the fraction of  $I'$  eliminating via pathway h and

$$\frac{I' f_h}{f_e + f_h} \int_0^t d\tau \int_0^\tau ds \lambda e^{-\lambda s} e^{-\lambda(\tau-s)} = \frac{I' f_h}{f_e + f_h} \int_0^t d\tau \lambda \tau e^{-\lambda \tau}$$

$$= I' f_h e^{-\lambda t} (e^{\lambda t} - 1 - \lambda t) / \lambda (f_e + f_h) \text{ } \mu\text{Ci-days}$$

represents the  $\mu\text{Ci-days}$  accumulated in the thoracic lymph nodes during the passage of activity through them to blood, and 53.3 is the energy (Mev) absorbed in the mass of 15 g of respiratory lymph nodes weighted by the proper quality factors. The quantity  $I' f_h \lambda \tau e^{-\lambda \tau} / (f_e + f_h)$  represents the activity in the lymph nodes at time  $\tau$ . Formulas (1) and (2) represent the dose equivalent accumulated in liver or in bone over a period postintake of  $t$  days. In practice,  $t$  would be replaced by  $t = t_1 - t_0$  where  $t_0$  is the time of the intake and  $t_1$  is the time at which the accumulated dose is desired, i. e., time of death or time of analysis of data, whichever is smaller.

(5) The activity reaching blood in a time interval  $d\tau$  is given by

$$\frac{I' f_h \lambda^2 \tau e^{-\lambda \tau} d\tau + I' f_e \lambda e^{-\lambda \tau} d\tau}{f_e + f_h} \text{ } \mu\text{Ci,}$$

of which 45% is assumed to deposit in bone and 45% in liver according to the model. Thus the activity in bone or in liver at any time  $t$  post-intake is given by

$$\frac{0.45 I'}{f_e + f_h} \int_0^t d\tau \left[ f_h \lambda^2 \tau e^{-\lambda \tau} + f_e \lambda e^{-\lambda \tau} \right] e^{-\lambda(t-\tau)} =$$

$$\frac{0.45 I' e^{-\lambda t}}{(f_e + f_h)(\lambda - \lambda)^2} \left\{ f_h \lambda^2 t (\lambda - \lambda) + f_e \lambda (\lambda - \lambda) e^{(\lambda - \lambda)t} - f_h \lambda^2 e^{(\lambda - \lambda)t} + f_h \lambda^2 - f_e \lambda (\lambda - \lambda) \right\} =$$

$$\frac{2.25 I'}{(\lambda - \lambda)^2} \left\{ f_h \lambda^2 \left[ t (\lambda - \lambda) - 1 \right] e^{-\lambda t} + f_h \lambda^2 e^{-\lambda t} + f_e \lambda (\lambda - \lambda) (e^{-\lambda t} - e^{-\lambda t}) \right\} \text{ } \mu\text{Ci,} \quad (3)$$

$\Lambda$  being the rate of elimination from bone or liver. The  $\mu\text{Ci-days}$  accumulated in bone or liver in the interval 0 to  $t$  days postintake is given by

$$\frac{2.25 I'}{(\Lambda - \lambda)^2} \left\{ f_h (\Lambda - \lambda) (1 - e^{-\lambda t}) + f_h \lambda^2 \left( \frac{1 - e^{-\Lambda t}}{\Lambda} \right) - f_h \lambda (1 - e^{-\lambda t}) \right. \\ \left. + f_e \lambda (\Lambda - \lambda) \left( \frac{1 - e^{-\lambda t}}{\lambda} - \frac{1 - e^{-\Lambda t}}{\Lambda} \right) \right\} = U, \quad (4)$$

and the dose to liver or to bone in the interval  $t_0$  to  $t$  days is given by

$$H = 51.1 U \frac{\Sigma EQN}{M} \quad (\text{rem}) \quad (5)$$

where for liver  $M = 1800$  g,  $Q = 10$ ,  $N = 1$  and the other values are as before, but for bone  $M = 5000$  g,  $Q = 10$ , and  $N = 5$ . The value of 5000 g as mass of bone neglects the weight of cartilage and periarticular tissue which would not contain much Pu. It is the value used in ICRP Publication 20.<sup>(8)</sup> The value of  $\Sigma EQN$  for liver is the same as for lung, namely, 53.3 Mev/disintegration; but the value for bone is higher since  $N$  is taken as 5, namely, 267 Mev/disintegration. The values  $\Lambda = 0.693 / (40 \times 365) \text{ days}^{-1}$  for liver and  $\Lambda = 0.693 / (100 \times 365) \text{ days}^{-1}$  for bone are taken from ICRP Publication 19.<sup>(11)</sup>

#### Known Exposures--Wounds

The Committee assumed that every known wound will be indicated on the exposure record. There will be an estimate of the early intake to blood with an indication of the time of intake. Later intakes will have to be picked up by analysis of the bioassay data and may not be relatable to a particular wound case. The data seem to indicate that the activity reaching blood shortly after the event is the major intake to blood, later amounts transferred to blood being rather small by comparison. It has been found in large experimental animals that plutonium from contaminated wound sites builds up rapidly, with apparently long retention times, in lymph nodes draining such sites.<sup>(9)</sup>

The uncertainties involved in the times of these intakes, as well as whether they can be related to a wound or to an inhalation exposure, constitute an ambiguity in the data in that, for cases where both exposure by wounds and by inhalation occur, one cannot be sure of the exact fraction of activity reaching blood from each source nor the precise time of entry. Because the evidence indicates most of the activity leaving a wound site appears to leave early and because of the relatively few cases involved in mixed exposures, this problem is probably not a severe one.

Having an estimate of intake to blood (say,  $I^*$ ) on day  $t_0$ , one can proceed to calculate dose to liver and to bone as before. The Committee decided to recommend the same partitioning of the activity between bone and liver as before--namely, 45% to each with an allowance of 10% deposited in other soft tissues or excreted. One can then compute dose by

$$\begin{aligned}
 H_{\text{liver}} &= \frac{0.45 I^* \int_{t_0}^t d\tau e^{-\lambda(\tau-t_0)} \Sigma EQN}{M} \\
 &= \frac{0.45 I^* (1 - e^{-\lambda(t-t_0)}) \Sigma EQN}{M} \text{ rem}
 \end{aligned}
 \tag{6}$$

with the same conventions as before, namely,  $\lambda = 0.693/(40 \times 365) \text{ days}^{-1}$ ,  $M = 1800 \text{ g}$ ,  $Q = 10$ , and  $N = 1$  for liver. For bone, one only requires  $M = 5000 \text{ g}$ ,  $N = 5$ , and  $\lambda = 0.693/(100 \times 365) \text{ days}^{-1}$ . Formula (6) represents the dose equivalent to these organs in the time interval  $t_0$  to  $t$  days.

It was decided to make no attempt at this time to compute a dose over any volume of tissue at or near the wound site. However, the AEC-HMS staff should consider an additional category of cases which might be analyzed for effects at the site. These cases will be signaled as wound cases and can be analyzed as a separate

category of cases. However, no quantitative estimate of dose at the site is attempted here. As mentioned above, data submitted by Stewart indicate that lymph nodes draining the site may accumulate a significant fraction of the activity leaving the wound site.

#### Known Cases--Mixed Exposures

These exposure records are relatively few in number, and in most instances the intakes by inhalation and those by a wound are fairly clear on the record. There are a few cases where this is not true. It was decided to assume the inhalation route applied when the record was not clear. Although this may somewhat overestimate dose to lungs and lymph nodes, these cases are not many. The formulas used above (Eqs. 1-5) would apply for these cases. The intakes to blood clearly indicated as from wounds will be signaled on the record, and for these instances, formula (6) would apply.

#### Unknown Exposures

There remain a certain number of cases where there is no known exposure time and, hence, no indication of the route of exposure. Thus there is no record of any wounds, and the Committee agreed it was reasonable to assume that inhalation was the likely route of exposure. Nevertheless, the record will contain only a series of intakes to blood with a time assigned for each such intake to blood. In practice, the exposure by inhalation is assumed to have occurred one day following the last negative bioassay result.

Selecting one such intake to blood,  $I^*$   $\mu\text{Ci}$ , at a time  $t_0$ , one may compute dose to liver and to bone by formula (6). If one assumes this intake to blood results from the transfer of activity  $I^* = ID_S(f_e + f_h)\lambda\Delta t$  to blood resulting from an actual

inhalation during time interval  $\Delta t$ , then one should postulate a long-term intake of  $3I^* = 1D_5(f_e + f_g + f_h)\lambda\Delta t = I''\Delta t$  to lung. Of course, one should not attribute an actual intake to this particular time interval. All one is certain of is that  $I^*$   $\mu\text{Ci}$  of activity entered blood in time interval  $\Delta t$ . The time when this activity entered the lung is not known. It happens that the relationship of  $(f_e + f_g + f_h)/(f_e + f_h) = 3$  is independent of time, and hence each bit of activity, such as  $I^*$ , entering blood is matched by 3 times that activity which should have been present in the long-term-clearance pathways of the lung. Since all this clearance is at the same rate, one has  $3I^*$  present in the lung for each activity  $I^*$  reaching blood. Dose to lung and to lymph nodes can then be computed using formulas (1-5) if one only knows the time of the inhalation. The only systematic inaccuracy in all this is the absence of a half-time for retention and a knowledge of the time of intake.

The Committee agreed to use 700 days for the elimination half-time in these cases of unknown date of intake, which is the value most frequently observed in known cases of exposure, and to enter the intake dose commitment (= dose accumulated over a period of 50 years) to lungs and lymph nodes. With a half-life of 700 days, as most often occurs, this merely anticipates some small fraction of the dose but would be most in error during the several years immediately following inhalation. There is some telescoping of the time when dose is received. This has the effect of putting some of the estimated dose equivalent earlier than it was received. It will be important only in those cases where an individual dies a few years after such an intake, as, otherwise, substantially all this dose is received. Since there seems to be no real remedy for this lack of information concerning time of intake, the Committee

felt it was a reasonable compromise in these cases to give the total dose to lungs and to lymph nodes to these organs prior to their appearance on the record of an intake to blood. It will be noted that this estimate of dose commitment does not apply to the liver or to bone which are the organs with the longest clearance half-times.

An allowance for dose received from  $^{241}\text{Pu}$  should be made in many of these cases. The amount of this correction will be coded for the tapes for each such case.

#### Other Transuranic Elements

Americium seems to be the only transuranic element present on the exposure records. After extended discussion, it was agreed that the same lung model should be used as for plutonium. This seems to fly in the face of much evidence indicating earlier removal of americium, but the selection of a quantitative allowance for this seemed a difficult task with little data available as a basis for the choice. The Committee believes that in those known cases where a half-time for removal from lung can be measured--and this includes most of these cases--the observed half-time for elimination is the best guide available for estimation of dose to lungs. When the estimate is based on chest counting, the factor of 3 in formula (1) and subsequent formulae for dose to lungs should be deleted. This is because the lung burden as measured by chest counting already includes the activity following pathway g. For estimation of dose to liver and to bone, there is little guidance available from animal experiments, and there are practically no human data on either deposition or retention in these organs. Therefore, the use of the same equations as for plutonium is recommended.

Some members of the Advisory Committee have approved the above procedures with extreme reluctance. They feel that the calculation of systemic body burden from excretion data is fraught with gross inaccuracies when applied to any given individual. Furthermore, they contend that the extension of this calculation by partitioning to specific organs and by proceeding to calculate dose equivalent, assuming uniform distribution in those organs, produces numerical results which have little or no bearing on the radiation damage to those organs. These committeemen point out that the ICRU and ICRP agree upon a definition of dose equivalent, specifically, "limited to radiation protection application."<sup>(10)</sup> They feel that the use of dose equivalent for retroactive risk evaluation via epidemiological studies is an inappropriate application of the concept. These committee members would advise against combining external radiation-dose measurements and internal-dose calculations for the Health and Mortality Study. They would advise the HMS to perform multiple correlations of observed damage (or lack of damage) with (1) dose from external radiation, (2) assessment of lung burdens (not lung-dose equivalent), (3) estimates of systemic body burden (not dose equivalent) from excreta analyses, and (4) the time since the dose was received under (1) or the time since the accumulation of the organ burdens under (2) and (3).

The Committee endorses the view that it is desirable that the data be analyzed with respect to these four factors. The Committee as a whole differs only in regarding it as appropriate to analyze the data on effects (or lack of effects) in terms of estimates of dose equivalent received by the various tissues of the body, this being the stated basis of the recommendations now in use for radiation workers. Although this report provides formulas by which dose equivalent can be estimated according to the best

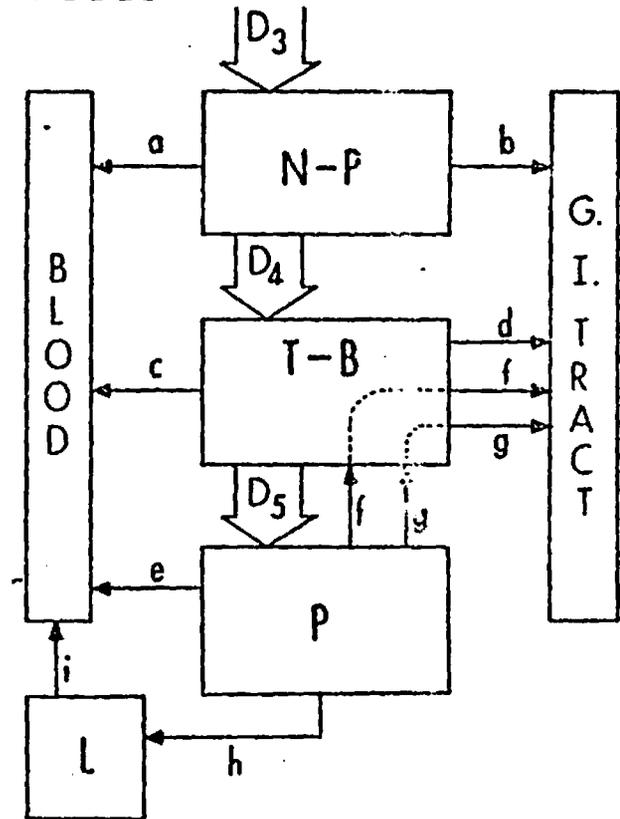
information now available, nothing in this report should be interpreted to suggest that other measures of exposure should not be tried or that the formulae given in this report should not be changed when better information is available.

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Fig. 1. CLEARANCE MODEL

COMPARTMENT		CLASS					
		D		W		Y	
		T	f	T	f	T	f
N-P ( $D_3 = 0.30$ )	a	0.01	0.5	0.01	0.1	0.01	0.01
	b	0.01	0.5	0.40	0.9	0.40	0.99
T-B ( $D_4 = 0.08$ )	c	0.01	0.95	0.01	0.5	0.01	0.01
	d	0.2	0.05	0.2	0.5	0.2	0.99
P ( $D_5 = 0.25$ )	e	0.5	0.8	50	0.15	500	0.05
	f	n.a.	n.a.	1.0	0.4	1.0	0.4
	g	n.a.	n.a.	50	0.4	500	0.4
	h	0.5	0.2	50	0.05	500	0.15
L	i	0.5	1.0	50	1.0	1000	0.9



The values for the removal half-times,  $T_{a-i}$ , and regional fractions,  $f_{a-i}$ , are given in the tabular portion of the figure for each of the three classes of retained materials. The values given for  $D_3$ ,  $D_4$ , and  $D_5$  are the regional depositions based on an aerosol with an AMAD of  $1 \mu\text{m}$ . The schematic drawing identifies the various clearance pathways in the model, a-i, in relation to the initial depositions  $D_{3,4,5}$  and the three respiratory regions, N-P, T-B and P.

Table 1. Pulmonary Clearance Classification of Inorganic Compounds

- Class Y—Avid retention: cleared slowly (years)**  
 Carbides—lanthanides, actinides, Zr, Y, Al  
 Sulfides—none  
 Sulfates—none  
 Carbonates—none  
 Phosphates—none  
 Oxides and hydroxide.—lanthanides, 4+ actinides; groups 8 (V and VI), and Co, Ni; 2b (IV and V); 3b; 4b (V and VI); 5b; 6b; and 7b (V and VI)  
 Halides—lanthanide fluorides  
 Nitrates—none
- Class W—Moderate retention: intermediate clearance rates (weeks)**  
 Carbides—Cations of all Class W hydroxides except those listed as Class Y carbides.  
 Sulfides—Groups 2a (V + VI), 4a (IV-VI), 5a (IV-VI), 1b, 2b and 6b (V + VI).  
 Sulfates—Groups 2a (IV-VII), and 5a (IV-VI)  
 Carbonates—lanthanides, Bi<sup>3+</sup> and Group 2a (IV-VII)  
 Phosphates—Zn<sup>2+</sup>, Sn<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>2+</sup>, Bi<sup>3+</sup> and lanthanides  
 Oxides and hydroxides—Groups 2a (II-VII), 3a (III-VI), 4a (III-VI), 5a (IV-VI), 6a (IV-VI), 1b (IV,VI); 2b (VI); 4b (IV); 7b (IV); Fe, and 3+ actinides.  
 Halides—lanthanides (except fluorides), Groups 2a, 3a (III-VI), 4a (IV-VI), 5a (IV-VI), 6a (IV-VI), 8, 1b, 2b, 3b (IV-V), 4b, 5b, 6b, 7b and actinides  
 Nitrates—all cations whose hydroxides are Class Y and W
- Class D—Minimal retention: rapid clearance (days)**  
 Carbides—see hydroxides  
 Sulfides—all except Class W  
 Sulfates—all except Class W  
 Carbonates—all except Class W  
 Phosphates—all except Class W  
 Oxides and Hydroxides—Groups 1a, 3a (II), 4a (II), 5a (II, III), 6a (III)  
 Halides—Groups 1a and 7a  
 Nitrates—all except Class W

Note: Where reference is made from one chemical form to another, it implies that an *in vivo* conversion occurs, e.g. hydrolysis reaction.  
 The following periodic table of the elements is used with the foregoing classification.

Period	Group																	
	1a	2a	3b	4b	5b	6b	7b	8		1b	2b	3a	4a	5a	6a	7a	0	
I	H																	He
II	Li	Be										B	C	N	O	F		Ne
III	Na	Mg										Al	Si	P	S	Cl		Ar
IV	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
V	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
VI	Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
VII	Fr	Ra	Act†															

* Lanthanides	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
† Actinides	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lw