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Hanford Whole Body Counting Manual

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June 1990

**Prepared for the U.S. Department of Energy
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**Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

This document describes the Hanford Whole Body Counting Program as it is administered by Pacific Northwest Laboratory (PNL) in support of the U.S. Department of Energy-Richland Operations Office (DOE-RL) and its Hanford contractors. Program services include providing in vivo measurements of internally deposited radioactivity in Hanford employees (or visitors). Specific chapters of this manual deal with the following subjects:

- program operational charter, authority, administration, and practices, including interpreting applicable DOE Orders, regulations, and guidance into criteria for in vivo measurement frequency, etc., for the plant-wide whole body counting services
- state-of-the-art facilities and equipment used to provide the best in vivo measurement results possible for the approximately 11,000 measurements made annually
- procedures for performing the various in vivo measurements at the Whole Body Counter (WBC) and related facilities (including whole body counts; in vivo lung, liver, bone, and thyroid measurements; in vivo measurements of transuranic radionuclides in wounds and axillary and tracheobronchial lymph nodes and for criticality accidents; use of a linear scan; and identification of unknown radionuclides)
- operation and maintenance of counting equipment
- quality assurance provisions of the program
- WBC data processing functions
- statistical aspects of in vivo measurements
- whole body counting records and associated guidance documents.

In addition Appendix A contains a copy of "The Hanford Whole Body Counting Center" brochure.

This document was originally developed as a controlled manual with distribution limited to those Hanford Site personnel who routinely use the program services. The uncontrolled version of the manual was prepared for distribution to those individuals who have an interest in the services offered by the program but who do not actually use the services. The

SUMMARY (contd)

manual should not be considered to be applicable to facilities or circumstances other than those at Hanford. This document reflects the operational practices only as they existed as of February 1990. There is no plan or intent to update the uncontrolled copies as changes are made in the Hanford program.

INTRODUCTION

CHARTER AND AUTHORITY

As part of its service responsibilities, the Health Physics Department of the Pacific Northwest Laboratory (PNL)(a) is charged with providing in vivo measurements of internally deposited radioactivity in the employees of the Hanford contractors. The authority and responsibility for providing this service are assigned through the Hanford Site Services Handbook (1983) issued by the U.S. Department of Energy's (DOE's) Richland Operations Office (RL).

Chapter XI of DOE Order 5480.11 (1989), requires that monitoring for internal radioactivity be carried out where the potential exists for an individual to receive a dose commitment in any quarter of a calendar year in excess of 10% of the quarterly standard. DOE contractor radiation protection personnel decide which employees in their organizations have the potential to exceed those dose standards. These decisions, as well as the frequency of in vivo bioassay (whole body counting), are based on the guidance provided in PNL's Hanford Internal Dosimetry Program guidelines and the Internal Dosimetry Program of the Hanford Dosimetry Support and Emergency Preparedness Section in the PNL Health Physics Department.

MANUAL CONTENT

The work described in this manual is performed by the Whole Body Counter (WBC) Group of Hanford Dosimetry Support and Emergency Preparedness Section within the Health Physics Department. The manual replaces the previous internal "Whole Body Counting Procedure Manual" issued in 1980. This manual is different because the detailed procedures and instructions on the operation of the electronic equipment such as the multichannel analyzers and the computers are not included. The extensive instructions for equipment operation are in separate manuals, which are referenced in the appropriate places in this manual.

The purposes of this manual are to:

- provide training for WBC personnel
- document the methods and procedures for identifying and quantifying radioactivity in radiation workers
- fulfill quality assurance requirements

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by the Battelle Memorial Institute.

MANUAL CONTENT (contd)

- provide references to documented calibration work from which calibration factors are derived
- provide information on the facility and its capability for the DOE and the Hanford Site contractor companies.

PURPOSE OF THE WHOLE BODY COUNTER

The WBC facilities provide in vivo measurements of internally deposited radioactivity in the employees of Hanford Site contractors. This service is needed to document the absence of radioactivity in most radiation workers and to determine the amount, distribution, and retention of radioactivity in those few employees who become internally contaminated. From the results of these and other types of measurements, the internal radiation dose can be calculated.

SCOPE OF SERVICES

Whole body counting services are available to employees of all Hanford Site contractors. Whole body counting services are also extended to local private nuclear energy-based companies and to selected research studies when time and facilities are available, and upon approval by the DOE.

FACILITIES AND LOCATION

Most of the WBC equipment is located in the 747A Building; other equipment for special purposes is maintained and operated in the Emergency Decontamination Facility (EDF) located adjacent to the Kadlec Hospital in the city of Richland, and in two mobile units.

FACILITIES AVAILABILITY

Regular services are available weekdays, from 8:00 a.m. to 4:30 p.m. Emergency services are available at any time.

RELATION TO OTHER RADIATION PROTECTION FUNCTIONS

Except for routine scheduling of contractor employees for chest or lung measurements, communication with other radiation protection personnel is almost entirely with the Internal Dosimetry Program of the Hanford Dosimetry Support and Emergency Preparedness Section in PNL's Health Physics Department.

DISPOSITION OF RESULTS

All in vivo bioassay results are communicated to the occupational radiation exposure (ORE) data base and the PNL Internal Dosimetry Group for evaluation and distribution to the Hanford Site contractors. A preliminary summary of results is given to each individual measured. Official measurement results are not given directly to the DOE contractors by WBC personnel. Questions from the DOE contractors about WBC results are communicated through the Internal Dosimetry Group. However, results of measurements made on employees of private companies and people involved in research studies are reported directly from the WBC.

RECOMMENDATION FOR
TYPE OF COUNT AND
RESULTS NEEDED

The Internal Dosimetry Group determines (based on information provided by the contractor representative) the appropriate measurements necessary to evaluate the deposition and clearance. The Internal Dosimetry Group will then advise the WBC staff of the type of measurement needed.

In the case of contamination incidents the Internal Dosimetry Group also contacts radiation monitoring for survey services. This monitoring is necessary to assure that the low back-ground facilities do not become contaminated from external radioactivity that may be on the worker or his clothes.

EVALUATION OF
DEPOSITION AND DOSE
COMMITMENT

The WBC staff provide the Internal Dosimetry Group with best determination of the burden at the time of the measurement. Based on this information, the Internal Dosimetry Group then evaluates the deposition and dose commitment.

FINANCIAL OPERATION

The WBC operates as a plant-wide service, funded by each DOE contractor through an annual assessment based on each company's usage of the WBC during the previous 9 months. Each year a budget request for the WBC operation (in the form of a work element plan) is prepared, reviewed with each contractor's radiation protection representative, and submitted to DOE-RL for approval. From the approved budget and an estimate of the number of measurements to be performed, charges for each contractor are established for the fiscal year.

Private companies for whom measurements are performed are billed once a month. Information on the type and number of measurements performed for each company is provided to PNL cost accounting near the end of each month. Cost accounting distributes the costs to the appropriate contractor's financial system or invoices the private company.

REFERENCES

U.S. Department of Energy-Richland Operations Office (DOE-RL). 1983. Hanford Site Services Handbook. RLPI 9-50.5, Richland, Washington.

U.S. Department of Energy (DOE). 1989. Radiation Protection for Occupational Workers. DOE 5480.11, Washington, D.C.

ACRONYMS

ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
BCS or BCSR	Boeing Computer Services Richland
BOMAB	bottle-manikin-absorption (phantom)
CRT	cathode ray tube
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy's Richland Operations Office
EDF	Emergency Decontamination Facility
FWHM	full width at half maximum
HEHF	Hanford Environmental Health Foundation
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
KEH	Kaiser Engineers Hanford
MCA	multichannel analyzer
MCS	multichannel scale (mode)
NBS	U.S. National Bureau of Standards
OPSC	offsite property control
ORE	occupational radiation exposure (data base)
PAC NU	Pacific Nuclear Services
PNL	Pacific Northwest Laboratory
REMAB	radiation-equivalent-manikin-absorption (phantom)
RORSR	routine onsite radioactive shipment record
SCA	single-channel analyzer
UST	United States Testing Company, Inc.
WBC	whole body counter (facility)
WHC	Westinghouse Hanford Company
WPPSS	Washington Public Power Supply System

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SECTION 1.0

ADMINISTRATION

1.0 ADMINISTRATION

This section describes the request, scheduling, authorization, preliminary procedures, and results reporting for in vivo measurements.

1.1 REQUESTS FOR WHOLE BODY COUNTS

The types of requests for the authorization of whole body counts are described in the following section. A routine measurement is classified as a Type I and maximum sensitivity measurement is classified as Type II. A maximum sensitivity measurement involves a longer period of measurement than a routine measurement. Because of the limited facilities it is not possible to perform Type II measurement for all routine measurements. Each measurement is assigned a "reason for measurement" code, as described in Table 1.1.

1.1.1 Routine Requests from DOE Contractors

Each contractor is responsible for determining the specific radionuclides an employee may work with. The contractor and the Internal Dosimetry Group then determine the type of count required. These measurements are typically scheduled when an employee is newly hired, terminated, beginning or ending a special project involving radioactivity, or upon the request for a periodic routine measurement.

No appointments are required for whole body counts, but an appointment must be made for a lung count. In vivo examinations normally take place on the same day of the annual physical examinations scheduled for all radiation workers.

1.1.2 Internal Dosimetry Group Requests for Special Counts

In some cases of internal contamination, the Internal Dosimetry Group needs more information to complete dosimetry calculations. This group will then request additional whole body counter (WBC) measurements.

These specialized measurements will be scheduled in advance to allow enough time to prepare for the requested measurements. When these requests conflict with the routine schedule, the routine measurements may be delayed or rescheduled.

TABLE 1.1. Reason Codes for In Vivo Bioassay Counting

<u>Reason for Measurement</u>	<u>Code</u>	<u>Description of Reason</u>
Routine	1	Measurement is performed on a predetermined, periodic schedule for routine surveillance.
New hire	2	Measurement is performed before worker begins employment or enters a radiation zone.
Termination	3	Measurement is performed when a worker terminates employment. No entry into radiation zones should occur after measurement is performed.
Unusual exposure (incident)	4	Measurement is requested after an incident of potential occupational internal exposure.
Evaluator exposure (EE) request	5	Measurement is requested by an EE for special purposes not covered by other reason codes.
Contractor request	6	Measurement is requested by Field Dosimetry for reasons other than an indication of potential occupational internal exposure.
Recount	7	Count is performed to verify an original measurements.
Follow-up	8	Measurement is performed 1) as a follow-up to any unexpected activity, or 2) for a long-term follow-up to an incident.
Beginning work	9	Measurement is performed before a worker begins a specific type of radiation zone work or before a trip offsite where potential internal exposure could occur.
Ending work	10	Measurement is performed after a worker completes a specific type of radiation zone work or after the worker returns from a trip where potential offsite internal exposure could have occurred.
Visitor	11	Measurement is performed on a visitor to Hanford.
Contract work	12	Measurement is performed by special contract work to the PNL WBC Facility.
Research project	13	Measurement is performed specifically for a research project.
Investigate high routine	16	Measurement is performed after the report of an unexpectedly high result.

1.1.3 Requests by DOE Contractors for Special Counts

A U.S. Department of Energy (DOE) contractor may request nonroutine measurements for a number of reasons including skin contamination, elevated air samples, or concern of the worker. Such requests are termed "contractor requests" and the probability of the worker having internal contamination is considered to be very low. All contractor requests are channeled through the Internal Dosimetry Group. The Internal Dosimetry Group determines which measurements should be performed and coordinates appointments with the WBC scheduler and the contractor.

1.1.4 Incident Requests

When a worker is involved in a contamination release where a high probability of internal deposition exists, the event is called an incident. Requests for WBC measurements for the worker are phoned immediately to the Internal Dosimetry Group.

1.1.5 Urine Sample Requested by Internal Dosimetry Group

The Internal Dosimetry Group may request a spot urine sample from selected individuals involved in potential exposures. Employee information obtained and attached to the sample bottle includes (Exhibit 1.1):

- initials and last name
- payroll or social security number
- contractor
- current date
- analysis request code.

United States
Testing Company, Inc.

Normally the United States Testing Company, Inc., (UST) will pick up any samples at the WBC on the same day they are given. Should additional sampling kits be required, a detailed map showing the location of the individual's home should be obtained and given to UST so that the kits can be delivered.

1.2 AUTHORIZATIONS FOR IN VIVO MEASUREMENTS

In vivo measurements are performed whenever a count authorization has been received. The three types of recognized and accepted authorizations are described in the following sections.

1.2.1 Computerized Authorization - Occupational Radiation Exposure Tracking System

The occupational radiation exposure (ORE) system allows any DOE contractor to input the initial request for a WBC measurement. All WBC requests for measurements for new hires, terminations, and employees beginning or ending a special project involving radioactivity, and routine measurements should be scheduled by this method. Any questions regarding ORE should be directed to:

Technical Specialist/Radiological Records
376-6549
Federal Building, Room 301-F
PNL 700

Computerized scheduling eliminates the need for an employee to transmit the written authorization for a WBC measurement. This method of automated-measurement request aids the scheduling by tallying the number of counts that are requested daily. The WBC staff is also alerted to the worker's previous WBC measurement history through the automated system.

The WBC staff updates the ORE tracking system file daily, by recording whether or not employees keep their scheduled appointments for measurements. Each contractor has access to this updated file to record any appointments that were not kept.

1.2.2 Written Authorizations

Written authorizations are normally hand carried by the employee and presented to the WBC technician upon arrival.

The request specifies the employee's name, payroll number, social security number, the reason for the count, and type of measurement required. Although these written requests are honored, the automated scheduling using the ORE data base should be used whenever possible.

1.2.3 Special Authorizations

This type of authorization is requested by the Internal Dosimetry Group. Additional measurements may be performed on individuals for any of the following reasons:

- unusual exposures
- field request
- evaluator requests
- follow-up measurements.

1.3 SCHEDULING

The procedures for scheduling the different in vivo measurements are described in this section.

1.3.1 Routine Whole Body Counts

For DOE contractors, no specific time is assigned for the routine whole body count and a measurement will be performed on a walk-in basis as long as proper authorization has been received.

1.3.2 Lung and Head Counts

All contractors should contact the WBC scheduler at 376-4785 in advance for an appointment for a routine lung or head count. The contractor then prepares a list containing the following information for each employee tentatively scheduled for an appointment

- initials of first and middle name and complete last name
- payroll number
- social security number
- count reason (new hire, routine, beginning or end of special project involving radioactivity, visitor, or termination)
- desired appointment time and date
- Type I or Type II measurement.

This list is forwarded to:

WBC Scheduler
747A/700
PNL

The scheduler confirms the appointment and notifies the contractor if any exam requires rescheduling. Appointments are scheduled at times that will not interrupt the in vivo examinations in progress. An answering machine is used to record requests during the times that technicians are busy. The DOE-contractor appointments are scheduled during the most convenient times of the work-day. Non-DOE contractors may have the remaining appointment openings.

-
- (a) The Internal Dosimetry Group may have contacted the contractor about performing special measurements in conjunction with the next routinely scheduled count. The WBC scheduler should be notified of this by the contractor when the routine lung count is scheduled.

1.3.3 Handling DOE-Contractor Employees Without Authorization Papers

Any contractor employee arriving at the WBC for a whole body count without prior authorization must fill out the preliminary record information (name, payroll number, and social security number). The WBC technician will then call the designated contractor representative from the company contacts list (see Table 1.2).

The representative will specify the type of count(s) required. If the representative requests a lung count in addition to the whole body count, both counts will be performed that day only if the current schedule could continue without interruption. If not, the WBC technician will schedule an appointment on another day.

1.3.4 Handling Non-DOE-Contractor Employees Without Authorization Papers

A non-DOE-contractor employee requesting WBC measurement without prior authorization should be asked to wait in the reception area. Before any count is performed, the contract and count type should be verified with the WBC manager or the senior WBC technician. Any telephone contact with these company representatives should be handled by the WBC supervisor.

1.3.5 Visitors Entering Radiation Areas

Visitors sometimes require measurements before and after entering radiation areas. Most visitors to DOE contractors will have a special payroll number issued to them by PNL's Radiological Records Group before arriving at the WBC. For the payroll number assignment, call Radiological Records at 376-1513.

Typically these visitors are employed under special programs (e.g., NORCUS). Issued payroll numbers usually begin with AG---, OG---, IG---, RG---, XG---, and LG---.

A release form (see Exhibit 1.2) must be signed at the WBC for all visitors issued an RG--- payroll number. The signed release form allows all radiological exposure information to be forwarded. All release forms are forwarded to:

Specialist/Radiological Records
376-6342
Federal Building 301-I
PNL 700

TABLE 1.2. List of Company Contacts for Whole Body Count Authorization

<u>Company Name/Code</u>	<u>Code</u>	<u>Payroll Numbers</u>	<u>Company Representative</u>	<u>Count Types</u>	<u>Telephone Number</u>
Boeing Computer Services (BCS)	E	4----	Iva Schrimsher	All	373-3477
		5----	"		
		6----	"		
		8----	"		
		9----	"		
U.S. Department of Energy (DOE)	9	G	Gerry Yesberger	All	376-7463
			Iva Schrimsher	All	373-3477
Westinghouse Hanford Company (WHC)	W	9----	Iva Schrimsher	All	373-3477
		8----	Iva Schrimsher	All	373-3477
		6----	Sylvia Garcia	All	373-3477
		5----	Vicki Llewellyn (alt.)	All others	373-3124
Hanford Environmental Health Foundation (HEHF)	M	BG---	Mary Ann Hensyel	All	376-3538
Kaiser Engineers Hanford (KEH)	R	Y or Z	Donna Janikowski	All	376-7113
		YA---	Carole Weaver	(Sub-cont)	376-6616
		K----	David Foust (alt.)	All	376-7113
Pacific Northwest Laboratory (PNL)	D	3----	Connie Cranna	Routine	376-3645
			Mary Ann Hensyel	All	376-3538
			Stacy Berg	NH/Sphy.	376-5770
Advanced Nuclear Fuels	X	XVX	Colleen Basha	All	375-8197
			Jim Pieper (alt.)	All	375-8638
U.S. Ecology	N	XVN--	Mike Nolan	All	377-2411
Allied Nuclear Company	Z	XVZ--	(a)		
Pacific Nuclear Systems	L	XVL--	(a)		
Teledyne Wah Chang, Albany	D	FG---	(a)		

(a) Contact WBC supervisor at 376-6281.

1.3.6 Visitors Who Come to the WBC for Special Measurements

In vivo measurements by special request shall have a special visitor payroll number FG---. This type of request usually would come for an individual who is not from the Hanford Site. The special measurement is requested by the WBC supervisor or DOE. Under this circumstance, the WBC technician will call PNL Radiological Records at 376-1513 for the payroll number assignment.

1.3.7 Foreign Visitors

Foreign nationals do not have social security numbers. Since data input requires information in this field, a special number is generated. The number for a foreign visitor would be 999-XX-XXXX. These special numbers have a 999 prefix and the individual's birthdate is entered (month/day/year) in place of the Xs to complete the number. A special payroll number is assigned to foreign visitors by Radiological Records.

1.3.8 Non-DOE-Contractor Requests

Whole Body Count	Whenever five or more employees from the same company are to be measured on one day, the WBC scheduler (376-4785) should be notified in advance. This advance notice will allow the WBC staff to schedule a specific time for the measurements that will not interfere with any DOE-contractor appointments. A written authorization should be hand carried by the employee and presented to the WBC technician upon arrival at the WBC.
Lung Count	This measurement requires an appointment by calling the WBC scheduler at 376-4785.
Emergency Counting	Notify the WBC supervisor at 376-6281.

1.4 PRELIMINARY PROCEDURES FOR IN VIVO MEASUREMENTS

Subjects arriving at the WBC will fall into one of three categories:

- the routine scheduled whole body count
- the routine scheduled lung or head count
- a nonroutine count resulting from a contamination incident or a field request or a follow-up count from an incident or field request.

A description of these counting procedures is given in Section 3.0.

1.4.1 In Vivo Count Request Form

When the routinely scheduled subjects arrive they will be listed on the computer scheduling sheet or have an In Vivo Count Request form generated by their employer's radiation protection operation. This request will be checked for accuracy and the subject will be asked to fill out the top part of an In Vivo Count Record (form A-1200-269[3-84] shown in Exhibit 1.3).

1.4.2 Assuring Measurement of Internally Deposited Radiation

To assure that only internally deposited radioactivity is measured and to limit the amount of naturally occurring radioactivity being transferred into the shielded enclosures, several precautions are taken.

For a routine whole body count the person removes only his shoes and puts on a pair of paper slippers. If the measurement shows a detectable amount of radioactivity, the person then showers, washes his hair and changes into a pair of cotton coveralls and is counted again to determine if the radioactivity was located on the skin, clothing, or if it is truly internally deposited.

1.4.3 Lung Count

For a routine lung count, the person showers, puts on a pair of cotton coveralls and paper slippers. If the lung measurement shows a detectable amount of radioactivity, the person showers again, washes his hair, and is recounted.

1.4.4 Potential Contamination in the Last 24 Hours

In cases where the person has potential internal contamination from an incident that happened in the last 24 hours, the person must first be monitored at the WBC for external contamination by a radiation protection technologist. After this monitoring, which is done in the change room, the person showers, washes his hair, and puts on a pair of coveralls before being counted.

Storage of Street Clothes and Personal Effects

When a change of clothing is necessary, the street clothing is placed in lockers in the change room. The person brings all valuable personal items with him to be placed nearby and in view while he is being counted. Valuable personal items can also be checked with the WBC technician.

1.4.5 Information and Safety Instructions for the Subject

The person being measured should be asked if he has had a previous whole body count. If the answer is yes, he can be placed in the WBC while briefly reviewing the safety aspects of the counting procedure. If the answer is no,

1.4.5 Information and Safety Instructions for the Subject (contd)

a brief description on the purpose, method, safety precautions, and noninvasiveness of the procedure should be given to him by the technician. A brochure on the whole body counting operation should also be offered to him at the completion of the measurement (see Appendix A). If the person has further questions, he should be referred to the WBC supervisor.

1.5 REPORTING OF RESULTS

Results are communicated to the ORE data base and the Internal Dosimetry Group. It is the responsibility of the Internal Dosimetry Group to assure that contractors are aware of the results. Completed in vivo measurement results are transmitted by magnetic tape into the ORE data base on a weekly basis. An audit and reconciliation of the rejected records is performed by the PNL Radiological Records staff. After the records have been accepted, each contractor may access results for their employees. Letters to each individual are generated based upon predetermined reporting levels of radioactivity.

1.5.1 Routine Counts That Show No Radioactivity: DOE Contractors

Routine measurements during which no activity is detected, are reported to the Internal Dosimetry Group on a weekly basis.

1.5.2 Contractor Requests, Incidents, or Positive Counts

Results of the examination are immediately conveyed to the Internal Dosimetry Group. This group interprets the internal occupational dose for the contractor representative and involved employee. Additional follow-up measurements as well as bioassay sampling may be requested to complete the evaluation.

1.5.3 Handling Concerned Subjects' Questions About Results

Many individuals are unaware that naturally occurring radiation such as potassium-40 is contained in the human body. When potassium-40 is the only radionuclide detected, the WBC technician briefly explains to the count subject that the count was normal. A letter is also generated at the completion of the count with a brief explanation of the count.

1.5.3 Handling Concerned Subjects' Questions About Results (contd)

The brochure, The Hanford Whole Body Counting Center, is also available in the lobby for individuals wanting more information. A copy of the brochure is included in the Appendix A.

Subjects who have detectable activity are instructed to call their radiation protection officer for exam results. If the subject wants immediate information or seems worried, a staff member from the Internal Dosimetry Group will talk to the individual in person or by telephone.

Those individuals needing technical information are referred to the WBC supervisor.

1.5.4 Reporting Non-DOE-Contractor Results

All results are mailed biweekly to the company representative for radiation protection. Results are telephoned to the representative immediately when any subject is measured at the specified company's reporting level. Any questions regarding results are referred to the WBC supervisor at 376-6281.

EXHIBIT 1.1. Urine Sample Bottle Label Form

NAME: _____

SS OR PAYROLL #: _____

CONTRACTOR: _____

DATE: _____

ANALYSIS REQUEST CODE: _____

EXHIBIT 1.2. Release Form

Battelle

Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)
Telex 15-2874

I authorize release of my updated radiation exposure records to:

Company Name: _____

Company Address: _____

My payroll number is _____ and my Social Security Number is

(signature)

(date)

EXHIBIT 1.3. In Vivo Count Record Form

Battelle <small>Pacific Northwest Laboratories</small>		IN-VIVO COUNT RECORD	
PLEASE FILL IN THE INFORMATION IN THE BOX BELOW ONLY			
LAST NAME, INITIALS		SOCIAL SECURITY NUMBER	
PAYROLL NO.		EMPLOYED BY WHICH DOE CONTRACTOR?	
WORK LOCATION - BLDG / AREA	HEIGHT	WEIGHT (lbs)	AGE SEX TODAY'S DATE

FOR WHOLE BODY COUNTER USE ONLY

COUNT CODES	BODY	CODE	DETECTOR USED	CODE	DETECTOR USED	CODE
Routine ☐ 1	Whole Body	01	4" x 9" NaI single crystal	A	35% GeLi single crystal	L
New Hire ☐ 2	Head	02	3/8" x 5" NaI 4 crystal array	B	Intrinsic Germanium single array 10 cm ²	M
Termination ☐ 3	Chest	03	3/8" x 5" NaI single crystal	C	3/8" x 5" Phoswich single crystal	N
Unusual Exposure ☐ 4	Abdomen	04	1mm x 1" NaI single crystal	D	4" x 4" x 16" NaI single array	P
Evaluator Request ☐ 5	Knee	05	3" x 3" NaI single crystal	E	3/8" x 5" Phoswich single crystal	T
Field Request ☐ 6	Throat	06	3/8" x 5" NaI 4 crystal array	F	Specialized counting	Q
Recount ☐ 7	Hand	07	4" x 11" NaI single crystal	G	Intrinsic Germanium 3 crystal array 20 cm ²	R
Followup ☐ 8	Special	08	6" x 11" NaI single crystal	H	6" x 11" NaI & 2 GeLi's @ 32% & 35%	S
Beginning of Work ☐ 9	Thorax	09	32% & 35% GeLi	I	Intrinsic Germanium 5 crystal array 20 cm ²	T
End of Work ☐ 10			Planar GeLi - single crystal	J	4" x 9" Na. (A) & 6" x 11" NaI	U
Visitor ☐ 11			18% GeLi single crystal	K	Intrinsic Germanium 6 crystal array 20 cm ²	V
Contract Work ☐ 12						
Research Project ☐ 13						

Number Of Counts: _____ Measured Height _____ Weight _____

Body Location Code	Detector Code	Serial Number	Description
1			
2			
3			
4			
5			
6			

REQUIRED PROCEDURE(S)	COMPLETED	REQUIRED PROCEDURE(S)	COMPLETED
1. Sample	_____	7. Form Return	_____
2. Calc-WBC	_____	8. Plot(s)	_____
3. Calc-CHEST	_____	9. Phone Evaluator	_____
4. Calc-Special	_____	10. Add Comment	_____
5. Record-SPLOG	_____	11. Other	_____
6. Accountability	_____		

A-1200-269 (3-84)

SECTION 2.0

FACILITIES AND EQUIPMENT

2.0 FACILITIES AND EQUIPMENT

The Hanford WBC program maintains state-of-the-art facilities and equipment to provide the best results possible for the approximately 11,000 measurements that are made each year. Most of the measurements are made in the WBC facility with equipment located in the 747A Building. However, other equipment can be accessed in the Emergency Decontamination Facility (EDF), located adjacent to Kadlec Hospital in the city of Richland, and in a mobile unit that can be transported to any location when needed.

2.1 SHIELDED FACILITIES

Most of the procedures used in whole body counting require shielding to significantly reduce the natural background radiation associated with building materials, soil, air, and cosmic rays. Shielded facilities and equipment reduce the background radiation by a factor of 50 to 100, depending on the energy of the radiation.

2.1.1 Shielded Rooms

There are five shielded rooms in the 747A Building. They are described here in the order of their size in square feet of floor space.

The first room measures 8.3 ft x 12 ft x 8 ft with the walls, floor, and ceiling made of 12-in.-thick battleship armor plate, lined on the inside with a graded shield of lead, cadmium, and copper. This room was moved to Richland from the University of Utah in 1988 and put into service in June 1989. A 4-detector array of large-volume germanium detectors and a collimated 4-in.-x-4-in.-x-16-in.-long NaI(Tl) detector are installed in the room for whole body measurement of gamma ray energies above 100 keV. Refer to Section 3.1 for further details.

The second room measures 9.5 ft x 10 ft x 7.25 ft with steel walls that vary from 7.5 in. to 12 in. in thickness. It has common walls with two other shielded rooms. It has a graded shield of lead, tin, and stainless steel. An array of planar germanium detectors is installed in this room for measuring low-energy photon emitters in the lungs.

The third room measures 3 ft x 9.8 ft x 7.4 ft (the "lung counter" room shown in Figure 2.1) and has 10-in.-thick iron armor plate walls, ceiling, and floor. A lung counter is installed in this room to measure plutonium, americium, uranium, and other low-energy photon emitters.

FIGURE 2.1. Three Shielded Rooms

2.1.1 Shielded Rooms (contd)

A graded shield of lead, then cadmium, and then copper has been added to the inside of the room to further reduce the background radiation at low energies. For further details on this room refer to the report titled Hanford Whole Body Counter 1959 Activities by Roesch, McCall, and Palmer (1960), available in the WBC library.

The fourth room has 4-in.-thick lead walls, ceiling, and floor that are covered by a thin layer of copper. This room is used for special types of measurements associated with contamination incidents. The room is also used for calibration studies and the development of improved instrumentation and methods for in vivo measurement of radionuclides.

The fifth room (diagrammed in Figure 2.2) is also made of 4-in.-thick lead and is only large enough for a person to stand. This counter is called the preview counter (also known as the upright counter) because almost all people who come to the WBC are measured in this counter first to quickly determine if any significant gamma-ray-emitting radionuclide is present. If any radionuclide is detected, the person undergoes a whole body measurement using the 4-detector array of large-volume germanium detectors (in the "first" shielded room). For more details on this fifth room refer to the report titled Hanford Whole Body Counter 1983 Activities.^(a)

2.1.2 Shadow Shields

In shadow-shield-type counters a shield surrounds all but one side of the detector. The subject is in front of this open side. A shield behind the subject, the "shadow shield," is large enough and placed so that no photon traveling in a straight line from that side can enter the detector without passing through the shield. This shield "casts a shadow" over the opening in the detector shield.

The only rays that can reach the detector without attenuation by the shield are those that are emitted from the subject or the shielding material and those scattered from the subject or the shadow shield.

One shadow-shield counter is mounted in a mobile unit for use on location at the Hanford Site, emergency use, or research studies away from the Hanford Site. Two other shadow-shield-type counters are located in the EDF.

(a) Palmer, H. E., G. A. Rieksts and H. B. Spitz. 1984. Hanford Whole Body Counter 1983 Activities. Internal report of the Pacific Northwest Laboratory, Richland, Washington.

FIGURE 2.2. Preview Counter

Figures 2.3 shows an artist's rendition of the shadow-shield counter that is mounted in the mobile unit (which is depicted in Figure 2.4). Figure 2.5 shows the actual shadow-shield counter inside the mobile unit. The head, chest, and thyroid counter depicted in Figure 2.6 is also located in the mobile unit.

2.1.3 Mobile Facility

The mobile WBC briefly described in Section 2.1.2 is available for measuring high-energy gamma rays emitted from the body. The unit contains the standard Hanford shadow-shield counter with a 11.5-in.-diameter NaI(Tl) scintillation detector and a partially shielded area for measuring radioactivity in the skull, thyroid, or lungs.

FIGURE 2.3. Shadow-Shield Whole Body Counter Mounted in the Mobile Unit

2.1.3 Mobile Facility (contd)

The unit can be powered from existing 115- or 230-V commercial power or by a portable power generator unit. The background and sensitivity of the shadow-shield counter are very similar to that of the shielded rooms except at locations near nuclear facilities.

More detailed information on the shadow-shield unit is available in two reports that are available in the WBC library (Swanberg 1963; Eichner 1969). The original mobile counter van was replaced with a new larger van in 1989, but the shadow-shield counter is the same except that it was raised 12 in. off the floor to provide easier entry and exit to and from the counter.

FIGURE 2.4. Mobile Whole Body Counter

FIGURE 2.5. A View of the Shadow-Shield Counter Located in the Mobile Unit

FIGURE 2.6. Head, Chest, and Thyroid Counter

2.1.4 Equipment in the EDF

Occasionally in vivo measurements are done at the EDF when a worker becomes so extensively contaminated that he may contaminate the low-background WBC facilities in the 747 Building or when a contaminated injury has occurred. For these purposes, some equipment is maintained at the EDF.

This equipment includes a regular and a modified shadow-shield whole body counter in which the total body and lung, liver, or bone measurements can be made (shown in Figure 2.7) and a planar germanium detector and a multi-channel analyzer (MCA) for measuring plutonium-239 and americium-241 in wounds.

2.2 DETECTORS

The two main types of detectors used for whole body counting are scintillation and semiconductor detectors. Refer to the book by G. F. Knoll (1979) entitled Radiation Detection and Measurement, located in the WBC library for a detailed description of the following detectors.

2.2.1 Scintillation Detectors

The scintillation detectors are mostly NaI(Tl) crystals ranging in size from 1-mm thick and 1 in. in diameter to 6-in. thick and 11.5 in. in diameter.

2.2.2 Semiconductor Detectors

Three types of semiconductor detectors are used for whole body counting: coaxial germanium detectors used for higher-energy gamma-ray measurements; planar germanium detectors used for low-energy photons between 10 and 200 keV; and lithium-drifted silicon detectors used to measure and separate the 20.16- and 20.78-keV L-gamma peaks for determining the plutonium-239-to-americium-241 ratio in plutonium wounds.

2.2.3 Other Detector Types

Other detectors that are used occasionally are the CdTe probe for use on plutonium wounds and the Phoswich detectors.

FIGURE 2.7. Shadow-Shield Whole Body Counter Located in the Emergency Decontamination Facility

2.3 DATA ACQUISITION AND PROCESSING EQUIPMENT

The electronic pulses from the detectors are analyzed, stored, and displayed by several MCAs. These spectra are then transferred to a Hewlett Packard HP-9000 mini-computer.^(a) This computer has 2 megabytes of memory and has a hard disk capacity of 404 megabytes.

Spectra files are handled by a data base management system called IMAGE. The computer system has a built-in graphics capability for displaying spectra on a cathode ray tube (CRT), X-Y plotter, or graphics printer.

Once the spectra are in the computer, all calculations, storage, and reporting of data and results are handled by the main FORTRAN 77 program called EXEC. The computer is also interfaced to the ORE data base system on the UNIVAC 1100/44.

The routine counting operations are controlled by the computer, which provides instantaneous calculation of results and plots of unusual spectra.

For more detailed information, consult Section 6.0 of this manual, and the hardware, software, and maintenance manuals that are available in the WBC library.

(a) The HP-9000 minicomputer is a product of Hewlett Packard Company, Fort Collins, Colorado.

2.4 CALIBRATION METHODS

To determine the amount of radioactivity in the body, the detector response must be calibrated in terms of counts per photon emitted from the body. This is done by placing known amounts of radioactivity in an anthropomorphic phantom or an organ of the phantom and making a measurement of the activity in a standard reproducible position that will be used with people. All calibration factors that are developed are in units of nCi for the amount in the body or organ.

Details on calibration procedures, factors, and curves are given in Section 3.0 of this manual. Several types of phantoms are used and described in the following sections.

2.4.1 Bottle-Manikin-Absorption Phantom

The bottle-manikin absorption (BOMAB) phantom shown in Figure 2.8 consists of 10 polyethylene containers of sizes, which when appropriately assembled, are roughly equal to the size, weight, and shape of a Reference Man (ICRP 1975). Three BOMAB phantoms have been filled with solid tissue-equivalent plastic containing uniformly distributed radionuclides of a known content. One phantom contains cesium-137, a second one contains potassium-40, and a third phantom contains a mixed standard of antimony-125/technetium-125, europium-154, and europium-155. A fourth phantom is available that can be filled with radioactivity in solution. The liquid capacity of each part of the phantom is given in Table 2.1.

This phantom is used for the whole-body calibration of radionuclides uniformly distributed throughout the body. The phantom does not provide quite the same amount of absorption as an actual human body and the correction factor, which ranges from 10% to 25%, must be applied, depending on the gamma-ray energy. Details of this correction will be given in Section 3.0 on calibrations.

2.4.2 Radiation-Equivalent-Manikin-Absorption Phantom

The radiation-equivalent-manikin absorption (REMAB) phantom, shown in Figure 2.9, is constructed of radio-lucent plastic shells and contains a human skeleton. The entire body and organs can be filled with known quantities of radioactive solutions. The skeletons come from India and are typically smaller than the average U.S. male; therefore, this phantom is rarely used at Hanford for whole body calibration purposes.

FIGURE 2.8. BOMAB Phantom

TABLE 2.1. Weight and Liquid Capacity of the BOMAB Phantom

<u>Phantom Part</u>	<u>Volume, mL</u>	<u>Total Weight, g</u>
Head	3,690	4,200
Neck	920	1,135
Torso	17,090	18,500
Arms	8,190	9,988
Pelvis	10,350	11,690
Upper legs	13,125	14,982
Low legs	8,850	10,215
Total	62,215	70,710

FIGURE 2.9. REMAB Phantom

2.4.3 Tissue-Equivalent Torso Phantom

The tissue-equivalent torso phantom is shown in Figure 2.10. This phantom was specifically constructed for calibration of counting systems used to measure transuranic nuclides in the lung, liver, and pulmonary lymph nodes. However, it is also useful for measuring high-energy gamma-emitting radionuclides in the lung and liver.

FIGURE 2.10. Tissue-Equivalent Torso Phantom (a) Removal of the chest plate.
(b) Phantom without chest plate, organs visible

2.4.3 Tissue-Equivalent Torso Phantom (contd)

The phantom contains a rib cage of artificial bone-equivalent material, removable organs, and includes tissue-equivalent chest plates that can be placed over the torso to simulate the chests of people with a wide range of chest wall thicknesses. The radioactivity is homogeneously distributed in the lung, liver, and lymph nodes by mixing the activity into the liquid polyurethane before it cures in the mold to form a semi-hard plastic organ.

The basic phantom is made from muscle-equivalent material. There are three sets of chest plates: one set is made of 50% fat-to-50% muscle-equivalent plastic, a second set is made of 87% fat-to-13% muscle-equivalent plastic, and the third set is made from 100% muscle-equivalent plastic. Griffith, et al. (1978) discuss this phantom in greater detail.

Calibration curves corresponding to the chest wall thickness and the fat content are developed using these chest plates. The chest wall thickness of contaminated radiation workers is determined using medical ultrasound tissue thickness measurement equipment (see Section 3.10 for the details of the ultrasound procedure).

Separate lung sets containing plutonium-238 and -239, americium-241, natural uranium, enriched uranium, natural thorium, cobalt-60, cerium-144, europium-154, and cesium-137 have been purchased or constructed for use in the phantom. Radioactively tagged standard liver organs include plutonium-238 and -239, americium-241, and natural thorium.

The validity of this phantom as a good representation of absorption qualities of the human body for the L x-rays from plutonium has been proven by a study of 18 humans who inhaled known quantities of niobium-92m. This study (Gunston and Jeffries 1986; Newton et al. 1985) originated in England and was funded by the International Atomic Energy Agency (IAEA).

2.4.4 Skeletal Phantoms

Various phantoms are used to calibrate detectors for the amount of radioactivity in the skeleton. Head, torso, arm, and leg phantoms were made of skeleton from a total body donation to the Hanford Environmental Health Foundation (HEHF) and the U.S. Transuranium Registry.

2.4.4 Skeletal Phantoms (contd)

This body contained 118 nCi of americium-241 in the skeleton. The level of activity was determined by measuring the content in exactly half of the skeleton and reserving the other half so that skeletal parts containing known quantities of americium-241 naturally distributed in each bone are available.

The head phantom contains half of the skull from the donated body. The half skull has been matched with an opposite half of a noncontaminated skull. The cavities of the composite skull were filled with tissue-equivalent material that simulates the brain, the inner soft tissue, and the skin. This phantom is shown in Figure 2.11.

For calibration, the detectors must be placed symmetrically on both sides of the head phantom. The other skeletal parts have been placed in tissue-equivalent body parts and are shown in Figure 2.12.

2.4.5 Thyroid Phantom

A thyroid phantom is shown in Figure 2.13. The phantom is made of tissue-equivalent plastic and the thyroid lobes can be filled with radioactive solutions for calibration.

2.5 RADIOACTIVE SOURCES, RADIATION SAFETY PROCEDURES FOR HANDLING AND MAINTENANCE

Approximately 100 different sealed sources of radioactivity are kept at the WBC facilities for the purpose of calibrating radiation detectors used for measuring internally deposited radioactivity in Hanford Project Personnel. The content of the sealed sources ranges from a few nCi to 100 μ Ci. Most of these sources are dry and sealed in plastic materials that provide adequate containment of all the radioactivity. Several sources are sealed in metal containers and a few are liquids sealed in glass or polyethylene containers. Due to aging, use, mishandling, accidents, and in some cases radiation damage, the plastic, metal, or glass may rupture and allow small quantities of material to escape the source. A ruptured source can cause two serious problems: 1) some of the material may be inhaled or ingested by personnel handling the source, and 2) the expensive detectors and equipment used in the WBC may be contaminated and made useless. Careful adherence to the

FIGURE 2.11. Head Phantom for the Calibration of Radioactivity in the Skull

practices and procedures described below will eliminate or minimize these problems. (The instructions in this section are based on PNL's internal guidelines on radiation protection.)

FIGURE 2.12. Tissue-Equivalent Body Parts of an In Vivo Calibration Phantom

FIGURE 2.13. Thyroid Phantom

2.5.1 Definitions

Radioactive source - A radioactive source is one in which radioactive material is used exclusively for its emitted radiations and one that retains its physical form and configuration during use.

Sealed sources - Those radioactive sources in which the radioactive material is permanently encapsulated to prevent leakage.

Unsealed sources - Those radioactive sources containing radioactive material affixed to a surface by electroplating or chemical means embedded in a matrix of non-radioactive material, or by use of foil, MylarTM, or other coverings that allow penetration of alpha or beta-gamma radiations. Also included are sources prepared by evaporation of liquid on a backing material and which have no covering as part of the source.

2.5.2 Responsibilities

The responsibilities for handling and maintaining radioactive sources are split between the WBC technician, supervisor, and technical group leader as identified here.

Technician

- Understand and comply with the procedures and protocols described in this section (2.5) and other related training given by the WBC supervisor.
- Visually examine the sources each time they are used and report any suspicious appearances to the WBC supervisor.
- Conduct source inventories and source leak checks under the direction of the WBC supervisor. When repackaging of sources is necessary, this operation needs to be witnessed by the WBC supervisor.

Supervisor

- Provide training and guidance for technicians in handling and maintaining sealed sources. For new employees, this training shall be conducted prior to their handling of any radioactive sources. The training will be renewed annually for all WBC employees.
- Act as custodian and maintain adequate storage facilities and current inventory lists of all sources used for WBC operations.

TM Mylar is a registered trademark of E.I. duPont de Nemours, Co.,
Wilmington, Delaware.

2.5.2 Responsibilities (contd)

- Conduct a monthly inventory and semiannual leak check on all sources for which the Laboratory Safety and Safeguards Section has responsibility for monitoring the source control and accountability. This includes all alpha-emitting sources where the content exceeds 1 μCi . There are 10 of these sources as of August 1989.
- Conduct a semiannual inventory and leak check for all sources other than those monitored by the Laboratory Safety and Safeguards Section. There are approximately 80 of these sources as of August 1989.
- Perform all repackaging of sources when necessary and have this procedure witnessed by a technician or Radiation Protection Technologist (RPT). Perform all dilutions of radioactive liquid sources. Dispose of all unnecessary or leaking sources. Maintain current Radiation Work Procedures for all WBC operations.

Technical Group Leader

- Ensure that the responsibilities assigned to the supervisor are met.

2.5.3 Personnel Practices

The surface dose of all sources is low enough that they can be handled with bare fingers when being transferred from source storage to the source holder in the various calibration assemblies. Nevertheless, transfer should be done as quickly as possible to minimize radiation dose to the hands to as low as reasonably achievable (ALARA). Sources should not be carried from one building to another in contact with the hand. Always use a carrier that decreases the dose either by distance or absorption. Never transport a source in your pocket or in other personal items.

Watch for deterioration, cracks, or holes in the encapsulation material. If these conditions are observed, or if a source is dropped, stepped on, crushed, or undergoes any physical damage, notify the WBC supervisor, and have an RPT check the integrity of the source before further use.

If a source develops a detectable leak or smearable activity, notify the RPT supervisor immediately.

2.5.4 Storage of Sources

Sources are to be kept in locked storage when not in use. The storage cabinet may remain unlocked during regular working hours, but must be securely locked when employees are not in the building. The one exception to this is that occasionally there is a need to measure a source overnight to test equipment. This may be done inside a closed shielded room with the WBC supervisor approval. The approved storage locations are the 747A Building, the EDF, and the mobile counter.

Sources may be used in the 747A Trailer during working hours, but must be returned to storage in the 747A Building at the end of the workday.

2.5.5 Source Accountability

A logbook will be maintained for all sources including temporary radionuclide calibration solutions obtained for the purposes of making sealed sources for long-term use and for making calibration phantoms. Information on all sources will be entered into this book at the time the source is received and at the time of the disposal. Any change in solution volume, activity, and consumption will be noted in the logbook for traceability purposes. This log book will be part of the inventory record and if a source remains in possession for more than 30 days it must also be entered onto the main inventory list.

Two additional files will be kept for information regarding sealed sources. One file will be the Onsite and Offsite Radioactive Shipment forms that accompany new sources.

These forms will be kept for 1 year. The other file will be the certifications of the amount of activity in each source. These certifications will be kept until the sources are disposed.

A program for auditable inventory and leak testing for containment integrity of all sealed sources will be maintained. The record system for this program will include the following:

1. Unique source identification number
2. Material type (isotope, material form)
3. Activity (in nCi, Bq, or D/M) at time of assay
4. Date of assay
5. Custodian
6. Normal storage location

2.5.5 Source Accountability (contd)

A formal audit of the inventory and an integrity check on each source will be conducted semiannually by a WBC technician and a RPT. At the completion of the audit, the audit form will be signed by the technician, the RPT, and the WBC supervisor, and it will be placed in the source inventory file.

Any source that is found to be missing will be reported to the manager of the Hanford Dosimetry Support and Emergency Preparedness Section. Any source found to be leaking will be disposed of in the radioactive waste containers at the EDF and so noted in the source inventory form and logbook.

2.5.6 Receiving, Shipping, Packaging, Repackaging, and Disposing of Sources

Receiving New Sources - When a new source arrives at the WBC facilities, a RPT must be called in to monitor the opening of the box containing the source. This procedure is followed regardless of the origin of the source. The source should be checked for leakage and the activity of the source should be measured to approximately confirm its stated value. Enter the source information in the logbook and inventory list if it is to be kept for more than 30 days.

Packaging Sources for Calibration Purposes - Solid sources obtained from commercial vendors usually do not need packaging for protection of the source, but because of their usually small size they shall be made more visible by either incorporating them into a holder that is at least 2 in. square, or by firmly attaching a small brightly colored streamer of at least 4 in. long to the source. In addition, a yellow and purple radioactivity label shall be attached in a conspicuous place on all sources. The nuclide(s) and activity of the source shall be clearly marked.

For sources where the package absorption needs to be kept at minimum, at least two layers of Mylar or polyethylene must be used to enclose the source. Where possible, mount the source within a hole that is centered in a thin piece of cardboard or plastic that is at least 2 in. square. If this is not possible attach a 4 in. long colored streamer to the edge of the source, place a small radiation label on it, and make sure that the nuclide and activity of the source and the unique source identification number are clearly visible.

2.5.6 Receiving, Shipping, Packaging, Repackaging, and Disposing of Sources (contd)

Make sealed sources from radioactive standard solutions in a hood that has been approved for use with radioactive materials. The hood in the laboratory at the EDF is ideal for this purpose and is usually available. An RPT must be present during this work and since it is done infrequently it should be done by the WBC supervisor or other exempt personnel who have had experience in transferring and diluting radioactive solutions.

2.5.7 Multiple Source Packages

Some energy calibration standards require that two or more sealed sources be placed together into one package. In these cases a label must be attached to the package, identifying the number of sources, the isotope, and the activity of each source. A radiation sticker must also be affixed to the outside of the package.

When these multiple source packages are repackaged or opened up for any reason, the WBC supervisor shall witness the action to assure that all the sources are in the new package, that each one is identified and that the old outer package is surveyed for possible radioactivity as a result of a source sticking to the old package material or leakage of one of the sources.

2.5.8 Disposal of Sealed Sources

Sources that are no longer needed or have developed leaks shall be disposed of in the radioactive waste receptacles at the EDF. Liquid samples can be poured down the sink in the hood, which drains into a tank for radioactive liquids, and solid samples can be placed in the clearly marked waste can in the northwest corner of the laboratory. A record of the disposal of each source shall be kept in the radioactive source logbook.

2.5.9 Transport of Sources Between Work Locations

Requirements for transporting check sources between the 747A Building and work locations:

- There are no special requirements for taking sources to the 747A trailer or to any facility, such as the mobile WBC, located in the parking lot of the 747A Building.
- A valid Routine Onsite Radioactive Shipment Record (RORSR) document listing the names of the authorized transporter personnel must accompany the source(s).

2.5.9 Transport of Sources Between Work Locations (contd)

- For shipment the sources must be placed in a container according to the RORSR. A box meeting the requirements of the RORSR is normally located in the source storage cabinet. This box also must contain a copy of a valid RORSR, be marked "RADIOACTIVE," and be labeled with the statement listed in the special instructions of the RORSR.
- Transportation will be done in a government vehicle.

2.5.10 Shipping of Material to Other Laboratories

1. Fill out an Offsite Property Control (OSPC) form. Obtain an OSPC serial number from property accounting (by phone).
2. Arrange for an RPT to monitor source and sign off on the OSPC form.
3. If activity is below 2 nCi/g:
 - a. An Offsite Radioactive Shipment Record is not required.
 - b. Obtain a Conditional Release of Low-Level Radioactive Material form.
 - c. Have it signed by the shipment originator and the supervisor or the Radiation Protection section.
 - d. Take the material to be shipped and the OSPC and the Conditional Release of Low-Level Material forms to WHC shipping in the 1100 Area using a governmental vehicle.
5. If activity is above 2 nCi/g:
 - a. An Offsite Radioactive Shipment Record needs to be filled out and signed by an RPT and a radioactive shipment representative.
 - b. Take the material to be shipped and the OSPC and the Offsite Radioactive Shipment Record forms to WHC shipping in the 1100 Area using a government vehicle.

2.6 REFERENCES

Eichner, F. N. 1969. Whole Body Counter Laboratory Mobile Unit B Description and Operation. BNWL-1154. Pacific Northwest Laboratory, Richland, Washington.

Griffith, R. V., P. N. Dean, A. L. Anderson, and J. C. Fisher. 1978. "Fabrication of a Tissue-Equivalent Torso Phantom for Intercalibration of In-Vivo Transuranic-Nuclide Counting Facilities." Paper presented at the Symposium on Advances in Radiation Protection Monitoring, June 26-30, 1978, Stockholm, Sweden.

Gunston, K. J., and S. J. Jeffries. 1986. Calibration of X-Ray Counters for Assessment of Internal Lung Contamination, with Low Energy X-Ray Emitters, in Women, Part I Measurements Made at AWRE. Final Report to the International Atomic Energy Agency, Technical Contract 3362/TC., Vienna, Austria.

International Commission on Radiological Protection (ICRP). 1975. Report of the Task Group on Reference Man. ICRP Publication 23, Pergamon Press, Oxford.

Knoll, G. F. 1979. Radiation Detection and Measurement. John Wiley and Sons, New York.

Newton, D., A. C. Wells, S. Mizushita, R. E. Toohey, J. Y. Sha, R. Jones, S. J. Jeffries, H. E. Palmer, G. A. Rieksis, A. L. Anderson, and G. W. Campbell. 1985. "The Livermore Phantom as a Calibration Standard in Assessment of Plutonium in Lungs." In Proceedings of an International Symposium on Assessment of Radioactive Contamination in Man, pp. 183-199. IAEA-SM-276/01, International Atomic Energy Agency, Vienna.

Palmer, H. E., and W. C. Roesch. 1965. "A Shadow-Shield Whole Body Counter." Health Physics 11(11):1213-1219.

Roesch, W. C., R. C. McCall, and H. E. Palmer. 1960. Hanford Whole Body Counter 1959 Activities. HW-67045, Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

Swanberg, Jr., F. 1963. Hanford Mobile Whole Body Counter. HW-80216. Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

SECTION 3.0

IN VIVO MEASUREMENTS

3.0 IN VIVO MEASUREMENTS

This section describes the procedures for performing the various in vivo measurements at the WBC and related facilities. Before any in vivo measurement is made, the technician should ensure that the subject understands the measurement procedure. This can be accomplished either by affirming that the subject has been through the procedure before or by describing the procedure to the subject before the count is started.

The technician should describe the room evacuation procedures and the video and audio communication equipment that is being used. This includes the intercom system that is voice-activated, the audible signal that the subject activates by pressing a button, if needed, and the closed-circuit television that allows the technician to observe the subject in the counting position.

The purposes of in vivo measurements as previously described in the Introduction Section are 1) to identify and quantify occupationally derived internally deposited radioactivity, or 2) to document that any internally deposited radioactivity is below the detectable level.

It is important to note that all results of radioactivity measurements in the body are stated in units of nanocuries. The information given in Section 7.0 is helpful in interpreting the results.

3.1 WHOLE BODY IN VIVO MEASUREMENTS

Three different devices are used to take whole body in vivo measurements: the preview counter, array of large-volume coaxial germanium detectors, and shadow-shield counter. An initial, preliminary whole body count is done using the preview counter. If any radionuclide other than ^{40}K is detected in the body, the person is then measured with the coaxial germanium detector array. From this measurement the amount of radioactivity is calculated and sent to the ORE data base. The preview counter is used only as a rapid screening counter to determine if any internal radioactivity is present (see Section 3.1.2). The coaxial germanium detector array system is used to quantify all gamma-emitting radionuclides above 0.1 MeV that are generally distributed over the length of the body, and above 0.2 MeV if the activity is in the lungs. The shadow-shield counter is used to sensitively and accurately measure radionuclides

3.1 WHOLE BODY IN VIVO MEASUREMENTS (contd)

that emit gamma rays with energies higher than 200 keV in the body (see Section 3.1.3). Because the germanium detector array provides the specific dose measurement of record, it is discussed first in this section.

3.1.1 Whole Body Measurements Using the Coaxial Germanium Detector Array

The germanium array is normally operated with four coaxial large-volume detectors (see Section 2.1.1 and Figures 3.1 and 3.2). However, if one detector malfunctions, it can be operated with three detectors, while the fourth one is being repaired. For a whole body count, the detector array travels at constant speed over the length of the body. For a lung or other organ count, the detectors are in a fixed position centered under the particular organ being counted.

Procedure for Daily Whole Body Counter Energy Calibration, Background Determination, and Efficiency Check

	• Obtain the combination americium-241 and cobalt-60 sources used for germanium array energy calibrations.
Energy Calibration	• Calibrate all 4 detectors of the germanium array using a multichannel analyzer (MCA) so that each channel represents 1.5 keV (refer to Section 4.0 and see Figure 3.3).
Background Determination	• Remove sources from the room and take a 1000-second background count with the detectors located at the approximate center of travel.• Enter this background spectra into the computer.
Efficiency Check	• Place the large cylinder standard potassium-40 source in its standard position and count for 200 seconds.• Save the spectra on the computer.

Procedure for Subject Measurement

- Have the subject lie on his back with the top of his head even with the mark at the south end of the bed.
- Make sure the body is centered between the sides of the bed.
- Instruct the subject to remain in position until he is instructed to move, which will be in about 20 minutes.

FIGURE 3.1. Coaxial Germanium Array Whole Body Counter

FIGURE 3.2. 4-Detector Coaxial Array

Data Sheet for the 4-Detectors Coaxial Germanium
Whole Body Counter

keV per channel	1.5
# of detectors	4
Detector code	14
Body location code	01
# of channels	2048
Routine count length, sec	200
Background length, sec	1000
Source used for calibration	$^{137}\text{Cs} + ^{40}\text{K}$
Source count used length	$^{40}\text{K} - 200 \text{ sec}$

FIGURE 3.3. The 4-Detector Coaxial Germanium Detector Array Counter
Schematic and Data Sheet

Procedure for Subject Measurement (contd)

- Count the subject for 1200 seconds.
- At the end of the count, remind the subject to watch his step while exiting.
- Save the spectra.
- Analyze the results.

Procedure for daily Whole Body Counter Energy Calibration, Background Determination, and Efficiency Check (contd)

Background Correction

The background is subtracted using the 12-channel continuum above the photopeak or the 11-point smoothing method (Spitz et al. 1984).

Calculations for Total Body Activity

Computer analysis is provided automatically for the radionuclides listed in Table 3.1. The computer calculation is the same as that for the manual calculation.

For manual calculation of the total body count, the following equation is used:

$$\text{nCi in the body} = \frac{\text{net counts per minute in the photopeak of interest}}{\text{counts per min per nCi}} \quad (3.1)$$

The count per minute per nCi (counts/min-nCi) factor is listed in the fifth column of Table 3.1.

For radionuclides not listed in Table 3.1, use the counts per gamma rays for the appropriate energy listed in Table 3.2 using the following equation:

$$\text{nCi in the body} = \frac{A}{B \times C \times D} \quad (3.2)$$

where

A = net counts per minute in photopeak of interest

B = 2.22×10^3 dpm/nCi

C = photon yield per disintegration(a)

D = count per gamma ray from second column of Table 3.2.

NOTE: For detailed calibration data see Volume WB-1 in the WBC library.

TABLE 3.1 Counting Efficiency for Common Radionuclides Using the Coaxial Germanium Array of Four Detectors

Radio-nuclide	Gamma Ray Energy, MeV	Channels Used for Photopeak	Channels Used for Background and Continuum Correction	Counts/min-nCi in the Total Body(a)	Counts Per Gamma Emitted from the Body
40K	1.460	971 to 976	978 to 995	0.16	0.00068
60Co	1.173	780 to 785	787 to 804	1.65	0.00074
137Cs	0.662	439 to 444	446 to 463	0.75	0.00092
54Mn	0.835	554 to 559	561 to 572	1.88	0.00084
154Eu	1.274	847 to 852	854 to 871	0.57	0.00072
22Na	1.274	847 to 852	854 to 871	1.60	0.00072
59Fe	1.099	730 to 735	737 to 754	0.96	0.00076
95Zr	0.757	502 to 507	509 to 526	1.08	0.00088
65Zn	1.115	741 to 746	748 to 765	0.86	0.00076
106Rh	0.622	412 to 417	419 to 436	0.21	0.00094
131I	0.364	241 to 246	248 to 265	2.09	0.00115
140La	1.596	1062 to 1067	1069 to 1086	1.41	0.00066
28Tl	2.615	1741 to 1746	1748 to 1765	1.22	0.00055
144Ce	0.133	87 to 92	94 to 111	0.33	0.00138
51Cr	0.320	211 to 216	218 to 235	0.27	0.00121
24Na	2.754	1834 to 1839	1841 to 1858	1.20	0.00054
110Ag	0.658	436 to 408	433 to 427	1.94	0.00092
214Bi	0.609	403 to 441	410 to 460	0.98	0.00095
58Co	0.811	538 to 543	545 to 550	1.89	0.00085
134Cs	0.796	529 to 534	537 to 554	1.64	0.00086

(a) These calibration factors were developed from measurements on the BOMAB phantom containing various radionuclides uniformly distributed throughout the phantom. A known "phantom-to-people" correction has also been applied.

3.1.2 Whole Body In Vivo Measurements Using the Preview Counter

Whole body in vivo measurements are done in the preview whole body counter. This counter consists of a column of five sodium iodide (NaI) detectors, mounted in a lead-shielded booth (see Figure 3.4). These detectors are

**TABLE 3.2. Counting Efficiency at Various Energies
in the Coaxial Germanium Array Counter
(counts per gamma ray emitted from the body)**

Coaxial Germanium Array Counter Efficiency Factors (using all counts in the photopeaks)	
Energy for Total Body, keV	WBC Factor, counts per gamma ray
100	0.00124
200	0.00146
300	0.00125
400	0.00112
500	0.00103
600	0.00096
700	0.00091
800	0.00086
900	0.00082
1000	0.00079
1100	0.00076
1200	0.00074
1300	0.00072
1400	0.00070
1500	0.00068
1600	0.00066
1700	0.00065
1800	0.00063
1900	0.00062
2000	0.00061
2100	0.00060
2200	0.00059
2300	0.00058
2400	0.00057
2500	0.00056
2600	0.00055
2700	0.00054
2800	0.00054
2900	0.00053
3000	0.00052

3.1.2 Whole Body In Vivo Measurements Using the Preview Counter (contd)

used to determine whether detectable quantities of high-energy gamma-emitting radionuclides (such as cesium-137, cobalt-60, and manganese-54) are present anywhere in the body.

Data from the five detectors are recorded as a sum of the counts of from all five detectors, as well as an individual count from each of the upper three detectors and a combined count from the two lower detectors. The relative counts from each detector output provide a measure of the distribution of activity in the body.

Virtually all people who come to the WBC will be measured in the preview counter first. If any significant activity is detected, the subject will then be measured with the 4-detector germanium counter.

Procedure for Daily Whole Body Counter Energy Calibration, Background Determination, and Efficiency Check

Energy Calibration

Background Determination

Efficiency Check

- Obtain the combination cesium-137 and potassium-40 sources used for large NaI(Tl) energy calibrations.
- Calibrate all 5 detectors of the preview counter using an MCA so that each channel represents 20 keV (refer to Section 4.0 and see Figure 3.5).
- Vertically stack each of the 4 containers filled with plastic beads against the detectors to simulate the presence of a nonradioactive subject.
- Rotate the adjusting wheel on the outside of the counter until the detectors are at the lowest position.
- Take a 1000-second background count.
- Enter this background spectra into the computer.
- Remove the containers from the preview counter.
- Place the 9-container standard potassium-40 source in its standard position and count for 200 seconds.
- Save the spectra on the computer.

WHOLE BODY EXAM

FIGURE 3.4. The Preview Whole Body Counter

Data Sheet for NaI Preview Whole Body Counter

keV per channel	<u>20</u>
# of detectors	<u>5</u>
Detector code	<u>U2</u>
Body location code	<u>01</u>
# of channels	<u>1024</u>
Routine count length, sec	<u>200</u>
Background length, sec	<u>1000</u>
Source used for calibration	<u>$^{137}\text{Cs} + ^{40}\text{K}$</u>
Source count used length	<u>$^{40}\text{K} - 200 \text{ sec}$</u>

FIGURE 3.5. The Preview Whole Body Counter Schematic and Data Sheet

3.1.2 Whole Body In Vivo Measurements Using the Preview Counter (contd)

Procedure for Subject Measurement

- Instruct the subject to carefully step into the counting booth: standing, backside leaning against plexiglass covering the detectors.
- Adjust the height of the detectors so the largest diameter detector is centered over the lungs.

Procedure for Subject Measurement (contd)

- Instruct the subject to remain in position for approximately 3 minutes until the "Finished" light goes on.
- Remind the subject to watch his step while exiting the counting booth when the count is finished.
- Count the subject for 200 seconds.
- Save the spectra.
- Analyze the results.

Background Correction

The procedure to obtain the daily count of the room background radiation is described previously in this section. This background activity is subtracted from the subject's whole body count spectra before quantifying any radionuclides.

Calculations for Total Body Activity

Computer analysis is provided automatically for the radionuclides listed in Table 3.3. The computer calculation is the same as that for the manual calculation.

For manual calculation of the total body count, the following equation is used:

$$\text{nCi in the body} = \frac{\text{net counts per minute in the photopeak of interest}}{\text{counts per min per nCi}} \quad (3.3)$$

The count per minute per nCi (counts/min-nCi) factor is listed in the fourth column of Table 3.3.

For radionuclides not listed in Table 3.3, use the counts per gammas for the appropriate energy listed in Table 3.4 using the following equation:

$$\text{nCi in the body} = \frac{A}{B \times C \times D} \quad (3.4)$$

TABLE 3.3. Counting Efficiency for Common Radionuclides in the Preview Counter

Radionuclide	Gamma Ray Energy, MeV	Energy Channels Used	Counts/min-nCi in the Total Body(a)	Counts/min-nCi in the Lung(b)
40K	1.460	68 to 78	6.9	9.1
60Co	1.173	52 to 62	65.0	84.4
137Cs	0.662	30 to 36	56.7	76.2
54Mn	0.840	38 to 44	66.3	87.5
154Eu	1.274	57 to 68	23.2	38.0
22Na	1.274	57 to 68	65.4	86.3
59Fe	1.099	48 to 59	27.2	35.9
95Zr	0.724	34 to 42	65.9	87.0
	0.756			
65Zn	1.115	52 to 60	33.3	43.0
106Ru	0.512	22 to 28	13.8	18.2
131I	0.364	15 to 19	54.6	72.1
140La	1.596	76 to 84	61.9	81.7
232Th	2.612	125 to 135	23.6	31.1
226Ra	1.764	83 to 97	12.2	16.1
144Ce	2.18	100 to 120	0.5	0.7
51Cr	0.320	13 to 17	6.0	7.9
110Ag	0.658	29 to 35	63.1	83.3
24Na	2.75	131 to 147	62.7	82.7

- (a) These calibration factors were developed from measurements on the BOMAB phantom containing various radionuclides uniformly distributed throughout the phantom. A known "phantom-to-people" correction has also been applied.
- (b) These calibration factors were developed from measurements on the tissue-equivalent torso phantom with the 11 1/2-in.-diameter detector located over the lungs with various radionuclides uniformly distributed in the lungs.

TABLE 3.4. Counting Efficiency at Various Energies
in the Preview Counter (count per gamma
ray emitted from the body)

Preview Counter Efficiency Factors (using all counts in the photopeaks)		
Energy for Total Body, keV	WBC Factor, counts per gamma ray	Lung Factor, counts per gamma ray
100	$3.06 \times 10E-2$	$4.08 \times 10E-2$
200	$3.05 \times 10E-2$	$4.03 \times 10E-2$
300	$3.04 \times 10E-2$	$3.97 \times 10E-2$
400	$3.03 \times 10E-2$	$3.92 \times 10E-2$
500	$3.02 \times 10E-2$	$3.86 \times 10E-2$
600	$3.01 \times 10E-2$	$3.81 \times 10E-2$
700	$3.00 \times 10E-2$	$3.76 \times 10E-2$
800	$2.99 \times 10E-2$	$3.71 \times 10E-2$
900	$2.98 \times 10E-2$	$3.65 \times 10E-2$
1000	$2.97 \times 10E-2$	$3.60 \times 10E-2$
1100	$2.96 \times 10E-2$	$3.55 \times 10E-2$
1200	$2.96 \times 10E-2$	$3.50 \times 10E-2$
1300	$2.95 \times 10E-2$	$3.46 \times 10E-2$
1400	$2.94 \times 10E-2$	$3.41 \times 10E-2$
1500	$2.93 \times 10E-2$	$3.36 \times 10E-2$
1600	$2.92 \times 10E-2$	$3.32 \times 10E-2$
1700	$2.91 \times 10E-2$	$3.27 \times 10E-2$
1800	$2.90 \times 10E-2$	$3.22 \times 10E-2$
1900	$2.89 \times 10E-2$	$3.18 \times 10E-2$
2000	$2.88 \times 10E-2$	$3.14 \times 10E-2$
2100	$2.87 \times 10E-2$	$3.09 \times 10E-2$
2200	$2.87 \times 10E-2$	$3.05 \times 10E-2$
2300	$2.86 \times 10E-2$	$3.01 \times 10E-2$
2400	$2.85 \times 10E-2$	$2.97 \times 10E-2$
2500	$2.84 \times 10E-2$	$2.93 \times 10E-2$
2600	$2.83 \times 10E-2$	$2.89 \times 10E-2$
2700	$2.82 \times 10E-2$	$2.85 \times 10E-2$
2800	$2.81 \times 10E-2$	$2.81 \times 10E-2$
2900	$2.80 \times 10E-2$	$2.77 \times 10E-2$
3000	$2.80 \times 10E-2$	$2.73 \times 10E-2$

Calculations for Total Body Activity (contd)

where

A = net counts per minute in photopeak of interest

B = 2.22×10^3 dpm/nCi

C = photon yield per disintegration(a)

D = count per gamma ray from second column of Table 3.4.

NOTE: For detailed calibration data see Volume WB-1 in the WBC library.

Calculations for Lung Activity

Computer analysis is provided automatically for radio-nuclides listed in Table 3.3. For manual calculation of the lung content the following equation is used:

$$\text{nCi in the body} = \frac{\text{net counts per minute in the photopeak of interest}}{\text{count per minute per nCi}} \quad (3.5)$$

The count per minute per nCi (counts/min-nCi) factor is listed in the fifth column of Table 3.3. For radio-nuclides not listed in Table 3.3, use the counts per gamma for the appropriate energy listed in the third column of Table 3.2 using the following equation:

$$\text{nCi in the lung} = \frac{A}{B \times C \times D} \quad (3.6)$$

where

A = net counts per minute in photopeak of interest

B = 2.22×10^3 dpm/nCi

C = photon yield per disintegration(a)

D = count per gamma ray from third column of Table 3.4.

NOTE: For detailed calibration data see Volume WB-1 in the WBC library.

Procedure for Handling Positive Whole Body Counts

When radioactivity other than potassium-40 is detected, follow the whole body counting procedure outlined in the flow chart of Figure 3.6.

(a) The photon yield per disintegrations for radionuclides can be found in Radioactive Decay Data Tables by D. C. Kocher located in the WBC library.

FIGURE 3.6. Flow Diagram for Whole Body Counting In Vivo Examination

Distribution of Activity in the Body

As mentioned in the introduction to Section 3.1.2, data from the preview counter are collected and recorded as a sum of the five detectors and as an individual count from each of the upper three detectors and a combined count from the lower two detectors. These four individual counts provide a measure of the distribution of radio-nuclide activity in the body. The four body regions (Rs) covered by the five detectors are listed below.

Distribution of Activity in the Body (contd)

- R.1. Head area measured by a 4- x 9 3/8-in. NaI(Tl) detector
- R.2. Lung area measured by a 4- x 11 1/2-in. NaI(Tl) detector
- R.3. Abdomen area measured by a 4- x 9 3/8-in. NaI(Tl) detector
- R.4. Leg area measured by two 4- x 9 3/8-in. NaI(Tl) detectors.

The computer reads four sections of memory from the MCA. Each section includes 256 channels and represents one of the four general body regions. The computer determines the net counts of each nuclide from each of the four body regions. The distribution of activity over the length of the body is calculated by dividing the activity of any one region by the sum of the activity from the four body regions.

The computer plots the activity spectra from the four body regions on one page (an overlay plot). By referring to this overlay plot (an example is provided in Figure 3.7) the WBC technician can determine where the activity is distributed in the body. (The overlay plot of the four spectra should be referred to to assist in interpretation. Interpretation must consider statistical significance of the net counts in each region.)

If the distribution looks valid and the lung area has more than 50% of the activity, the net counts from the lung detector alone can be used to calculate the deposition in the lung by the factors of Table 3.3.

A computer estimate of the percentage of the total radioactivity in each body region is given for each radionuclide. An example is given in Table 3.5. The WBC technicians need to verify the estimates by studying the four spectra that are all plotted on one page (in the overlay mode) by the computer. The example of an overlay plot (Figure 3.7) indicates that the lung, abdomen, and leg regions contain most of the potassium-40 activity. A much lower amount of potassium-40 is contained in the head region; the highest amount is contained in the leg region, which is to be expected.

These distribution numbers, upon which the spectra are based, are only approximate. If a more accurate measure of distribution in the body is needed the method of linear scanning described in Section 3.9 should be used.

FIGURE 3.7. An Example Overlay Plot of the Activity Spectra for the Four Body Regions

TABLE 3.5. Computer Determination of the Percentage Activity in Each Body Region

Radio-nuclide	Percentage			
	R1	R2	R3	R4
⁴⁰ K	10.	30.	28.	32.
⁶⁰ Co	13.	27.	13.	48.
¹³⁷ Cs	27.	59.	1.	13.
⁵⁴ Mn	16.	14.	16.	54.
¹⁵⁴ Eu	1.	28.	12.	60.
²² Na	1.	28.	12.	60.
⁵⁹ Fe	16.	28.	16.	40.
⁹⁵ Zr	21.	15.	1.	63.
⁶⁵ Zn	47.	14.	33.	5.
¹⁰⁶ Ru	83.	6.	6.	6.
¹³¹ I	30.	9.	50.	11.
¹⁴⁰ La	21.	36.	21.	21.
²³² Th	27.	6.	27.	40.
²²⁶ Ra	54.	1.	1.	44.
¹⁴⁴ Ce	2.	2.	95.	2.
⁵¹ Cr	22.	1.	41.	37.
²⁴ Na	1.	50.	1.	48.
¹¹⁰ Ag	10.	53.	15.	21.

3.1.3 Whole Body In Vivo Measurements Using the Shadow-Shield Counter

Shadow-shield whole body counters (see Figure 3.8) provide sensitive and accurate measurements of radionuclides that emit gamma rays with energies higher than 200 keV in the body (Palmer and Roesch 1965). Three shadow-shield counters are used in the whole body counter operations. The three shadow-shield counters are identical except that one uses a 9 3/8-in.-diameter detector, the other two use 11 1/2-in.-diameter detectors. Two of the counters are located at the EDF near Kadlec Hospital, and the third is located in a mobile van unit. The counters in the EDF are used whenever worker contamination is very high and may contaminate the WBC at the 747A Building. The mobile counter is used wherever it is needed for both practical and emergency purposes.

Data Sheet for NaI(Tl) Shadow Shield Counter

keV/channel	<u>20</u>
# of detectors	<u>1</u>
Detector code	62 for 4 x 11-1/2 in. detector, 63 for 4 x 9-3/8 in. detector
Body location code	01
# of channels	1024
Routine count length, sec	600
Background length, sec	600
Source used for energy calibration	$^{137}\text{Cs} + ^{40}\text{K}$
Source and time used for efficiency check	^{40}K - 600 sec

FIGURE 3.8. The Shadow-Shield Whole Body Counter Schematic and Data Sheet

Procedure for Daily Shadow-Shield Whole Body Counter Energy Calibration, Background Determination, and Efficiency Check

- Obtain the combination cesium-137 and potassium-40 sources used for large NaI(Tl) energy calibrations.
- Energy Calibration**
 - Calibrate the NaI(Tl) detector using an MCA so that each channel represents 20 keV (refer to Section 4.0 and see Figure 3.8).
- Background Determination**
 - Place 15 10-lb sugar sacks on the counter bed.
 - Take a 600-second background count as the bed and sugar sacks travel through the counter.
 - Enter the background spectrum into the computer.
 - Remove the sugar sacks from the counter.
- Efficiency Check**
 - Place the standard potassium-40 source in the standard position and count for 600 seconds.
 - Save the spectra on the computer.

Procedure for Subject Measurement

- Instruct the subject to sit on the bed with his feet on the floor, then swing his feet up onto the bed and lay on his back with his head at the top of the bed. The subject's body should be centered on the width of the bed.
- Instruct the subject not to raise any part of his body until the count is finished. For all three of the shadow-shield counters the subject lies on a bed that travels beneath the detector; the subject begins the count at one end and finishes the count at the opposite end of the counter.
- Count the subject for 600 seconds as the bed travels beneath the detector and automatically stops at the end of the count.
- Save the spectra.
- Analyze the results.

Background Correction

The procedure to obtain the daily count of the background radiation is described previously in a subsection of Section 3.1.2. This background activity is subtracted from the subject's whole body count spectra before quantifying any radionuclides.

Calculations for Total Body Activity

Computer analysis is provided automatically for the radionuclides listed in Table 3.6. The computer calculation is the same as that for the manual calculation.

For manual calculation of the total body count, the following equation is used:

$$\text{nCi in the body} = \frac{\text{net counts per minute in the photopeak of interest}}{\text{counts per min per nCi}} \quad (3.7)$$

The count per minute per nCi (counts/min-nCi) factor is listed in the fourth and fifth columns of Table 3.6 for the 9 3/8-in. x 4-in. and the 11 1/2-in. x 4-in. NaI(Tl) detectors respectively that are used in the counters.

For radionuclides not listed in Table 3.6, use the counts per gamma rays for the appropriate energy listed in Table 3.7 using the following equation:

$$\text{nCi in the body} = \frac{A}{B \times C \times D} \quad (3.8)$$

where

A = net counts per minute in photopeak of interest

B = 2.22×10^3 dpm/nCi

C = photon yield per disintegration(a)

D = count per gamma ray from second column of Table 3.6.

3.2 IN VIVO LUNG MEASUREMENTS OF LOW-ENERGY PHOTONS (<200 keV)

In vivo lung measurements focus on activity deposited in the respiratory system. The low-energy photons of radiation emitted from the lung are measured by an array of 6 germanium planar detectors. These detectors are placed over the subject in a semireclining position; a semireclining position affords the highest counting efficiency for women and overweight men. Two lung counters are available for use (see Section 2.0).

The activity detected in the lung is affected by the chest wall thickness of the subject and any activity that might be emitted from the ribs. To obtain an accurate measurement of activity that has been initially detected by the lung counter, a chest wall thickness measurement is made (see Section 3.10).

TABLE 3.6. Counting Efficiency for Common Radionuclides in the Shadow-Shield Counter

Radionuclide	Gamma Ray Energy, MeV	Energy Channels Used	9 3/8-in. x 4-in. NaI(Tl) Detector Counts/min-nCi in the Total Body(a)	11 1/2-in. x 4-in. NaI(Tl) Detector Counts/min-nCi in the Total Body(a)
40K	1.460	68 to 78	0.609	0.765
60Co	1.173	52 to 62	6.191	7.583
137Cs	0.662	30 to 36	6.269	7.333
54Mn	0.840	38 to 44	6.950	8.261
154Eu	1.274	57 to 68	2.149	2.657
22Na	1.274	57 to 68	6.049	7.476
59Fe	1.099	48 to 59	3.618	4.402
95Zr	0.724 0.756	34 to 42	7.148	8.408
65Zn	1.115	52 to 60	3.230	3.936
106Ru	0.512	22 to 28	1.592	1.837
131I	0.364	15 to 19	6.579	7.492
140La	1.596	76 to 84	5.216	6.637
232Th	2.612	125 to 135	1.417	1.975
226Ra(b) (208Tl)	1.764	83 to 97	0.968(b)	1.250(b)
144Ce	2.18	100 to 120	0.035	0.047
51Cr	0.320	13 to 17	0.808	0.916
110Ag	0.658	29 to 35	6.963	8.142
24Na	2.75	131 to 147	3.770	5.322

- (a) These calibration factors were developed from measurements on the BOMAB phantom containing various radionuclides uniformly distributed throughout the phantom. A known "phantom-to-people" correction has also been applied.
- (b) The counting efficiency listed is for 208Tl measured in the body. Since 70% of the 222Rn escapes the body in the radioactive decay from 226Ra to 208Tl, the 208Tl content is multiplied by 3.33 to obtain the 226Ra in the skeleton.

TABLE 3.7. Counting Efficiency at Various Energies in the Shadow-Shield Counters (counts per gamma ray emitted from the body)

Shadow-Shield Counter Efficiency Factors (using all counts in the photopeaks)		
Energy for Total Body, keV	WBC Factor, 4 x 9-3/8-in. Detector, counts per gamma ray	WBC Factor, 4 x 11-1/2-in. Detector, counts per gamma ray
200	$3.846 \times 10E-3$	$4.316 \times 10E-3$
300	$3.725 \times 10E-3$	$4.218 \times 10E-3$
400	$3.607 \times 10E-3$	$4.122 \times 10E-3$
500	$3.494 \times 10E-3$	$4.028 \times 10E-3$
600	$3.384 \times 10E-3$	$3.936 \times 10E-3$
700	$3.277 \times 10E-3$	$3.847 \times 10E-3$
800	$3.174 \times 10E-3$	$3.759 \times 10E-3$
900	$3.074 \times 10E-3$	$3.674 \times 10E-3$
1000	$2.977 \times 10E-3$	$3.590 \times 10E-3$
1100	$2.884 \times 10E-3$	$3.509 \times 10E-3$
1200	$2.793 \times 10E-3$	$3.429 \times 10E-3$
1300	$2.705 \times 10E-3$	$3.351 \times 10E-3$
1400	$2.620 \times 10E-3$	$3.275 \times 10E-3$
1500	$2.537 \times 10E-3$	$3.200 \times 10E-3$
1600	$2.457 \times 10E-3$	$3.128 \times 10E-3$
1700	$2.380 \times 10E-3$	$3.056 \times 10E-3$
1800	$2.305 \times 10E-3$	$2.987 \times 10E-3$
1900	$2.232 \times 10E-3$	$2.919 \times 10E-3$
2000	$2.162 \times 10E-3$	$2.853 \times 10E-3$
2100	$2.094 \times 10E-3$	$2.788 \times 10E-3$
2200	$2.028 \times 10E-3$	$2.724 \times 10E-3$
2300	$1.964 \times 10E-3$	$2.662 \times 10E-3$
2400	$1.902 \times 10E-3$	$2.602 \times 10E-3$
2500	$1.842 \times 10E-3$	$2.543 \times 10E-3$
2600	$1.784 \times 10E-3$	$2.485 \times 10E-3$
2700	$1.728 \times 10E-3$	$2.428 \times 10E-3$
2800	$1.674 \times 10E-3$	$2.373 \times 10E-3$
2900	$1.621 \times 10E-3$	$2.319 \times 10E-3$

3.2 IN VIVO LUNG MEASUREMENTS OF LOW-ENERGY PHOTONS (<200 keV) (contd)

To determine the activity, if any, emitted from the ribs (bone), a head count is taken to measure skeletal activity. From this value measured chest activity can be corrected to obtain the lung content.

Because of intermittent electronic and microphonic noise in the detector in the region of 10 to 21 keV, false positive results can occur for direct measurements of plutonium-238 and plutonium-237, using the 19- and 21-keV energy regions. Therefore, lung counts are not yet considered to be a valid routine method for surveillance of plutonium-238 and plutonium-239 in Hanford employees, even though MDAs are listed for these two radionuclide in Table 7.1. The americium-241 in vivo measurements and excretion bioassay must be used for this purpose.

3.2.1 Procedure for Energy Calibration and Efficiency Check of Germanium Planar Detectors for Lung Counts

Energy Calibration

- Review system data sheet in Figure 3.9, which contains a diagram of the lung counting equipment in place on a subject during an in vivo lung exam (see also Figure 3.10).
- Obtain the americium-241 and uranium-235 sources.
- Calibrate and balance each planar germanium detector using an MCA so that each channel represents 0.500 keV. (Refer to Section 4.0)
- Remove calibration sources.
- Close iron room door.
- Preset time for 1000 seconds.
- Count background.
- Save and enter background spectra in the computer.
- Open the iron room.

Efficiency Check

- Position the plexiglass jig containing the americium-241 source and adjust all detectors as close as possible to the jig (see Figure 3.11).

FIGURE 3.9. In Vivo Lung Counting Equipment and Data Sheet

FIGURE 3.10. Second Lung Counter

FIGURE 3.11. Calibration of Detectors for In Vivo Lung Count

3.2.1 Procedure for Energy Calibration and Efficiency Check of Germanium Planar Detectors for Lung Counts (contd)

Efficiency Check (contd)

- Close the door.
- Preset the time for 300 seconds and acquire a source count.
- Save the spectra on the computer.

3.2.2 Procedure for Subject Measurement

Preparing the subject for the count

- Have the subject shower and change into paper slippers and cotton coveralls.
- Measure and record the subject's height and weight on the In Vivo Count Record.

Positioning the detectors

- USE EXTREME CAUTION WHEN POSITIONING THE DETECTORS OVER THE SUBJECT. The detectors are evacuated underneath the 20-mil-thick beryllium windows. The windows are brittle and could possible implode.
- Pull chair from underneath the detectors.
- Holding the chair in place, instruct the subject to sit down.
- Instruct the subject to carefully swing his legs on the chair without bumping the detectors and then recline on the chair.
- Move the chair horizontally until the subject's lung area is beneath the detectors.
- Tilt the back of the chair until the level bubble is centered. In this position the vertebral column is at an angle that is 45° from horizontal.
- Position the detectors by slowly raising the chair height and adjusting the tilt of the detectors by rotating the handle. The edge of the detector closest to the head should be just below the clavicle. Refer to Figure 3.12.
- The detectors should be placed as close as possible to the surface of the subject's lung area without restricting breathing.

FIGURE 3.12. Position of Detectors for a Lung Count

3.2.2 Procedure for Subject Measurement (contd)

Giving Instructions
to subject prior to
count

- When the subject and detectors are properly positioned, lock the carriage in place.
- Make sure the subject is as comfortable as possible.
- Explain the use of the emergency button and self-exit procedure.
- Instruct the subject not to move from underneath the detectors and to lie still for the duration of the count.

Taking the count

- Inform the subject of the length of the count.
- Close shielded room door.
- Start count.
- Count for preset time (usually 2000 or 3000 seconds).
- Save count on the computer.

3.2.2 Procedure for Subject Measurement (contd)

Taking the count (contd)

- When the count is completed, open the shielded room door.

Giving directions after the count

- Instruct the subject not to move until asked to do so.
- Slowly lower the chair.
- Release the locking mechanism.
- Slide the chair from underneath the detectors.
- Hold on to the chair and instruct the subject to carefully swing his legs to the side of the chair, stand, and watch his step while standing up and exiting the room.

3.2.3 Background Correction

The photopeak region is corrected for background contribution by subtracting one-third of a continuum region above the photopeak that is three times as many channels as are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used.

3.2.4 Calculation for Activity in the Lung

The computer is programmed to provide calculations using the estimated or actual chest wall thickness for the radionuclides listed in Table 3.8.

To manually calculate the lung activity, determine the chest wall thickness using the Equation (3.5). Using this chest wall thickness, refer to Table 3.9 and obtain the calibration factor corresponding to the determined chest wall thickness. This calibration factor used in Equation (3.6) provides the lung content.

$$\text{chest wall thickness in cm} = 0.68 + 0.974 \times \frac{\text{weight (lb)}}{\text{height (in.)}} \quad (3.9)$$

$$\text{nCi activity in lung} = \frac{\text{net counts per minute in lung}}{\text{counts/min/nCi}} \quad (3.10)$$

NOTE: For detailed calibration data see Volume LG-1 in the WBC library.

TABLE 3.8. Calibration Data for Lung Counts

<u>Radionuclide</u>	<u>Photon Energy, keV</u>	<u>Channel Group</u>
241Am	59.5	234 to 242
235U	185	739 to 747
234Th	63	249 to 257
144Ce	133	265 to 268
155Eu	86	530 to 538
154Eu	123	351 to 377
232Th	238	488 to 496

3.2.5 Correction of the Lung Count for Activity in the Bone and Liver

When activity such as americium-241 exists in the lung, liver, and bone, the lung count must be corrected for the contribution from the other organs. The bone contribution to the lung count is 0.46 times the net counts measured in the head when using the same number and size of detectors for both measurements (see the method for measuring bone content in Section 3.4).

3.3 IN VIVO MEASUREMENT OF RADIOACTIVITY IN THE LIVER

Some radionuclides such as the transuranics and the rare earth elements have a preferential uptake in the liver after they are absorbed into the bloodstream of the body. Liver measurements are made using an array of three germanium planar detectors for low-energy photon emitters.

3.3.1 Procedure for Energy Calibration and Efficiency Check of the Germanium Planar Detectors

- Review data sheet in Figure 3.13.
- Energy Calibration
- Calibrate the MCA so that each channel is equivalent to 0.500 keV for the germanium planar detector (see Section 4.0).
- Efficiency Check
- See Section 3.2.1 for daily efficiency check of these detectors.

TABLE 3.9. Calibration Factor Versus Chest Wall Thickness for Lung Counter
Using the 6-Germanium-Detector Array (counts per minute per nCi)

Chest Wall Thickness, cm	Calibration Factor for Nuclides								
	²⁴¹ Am	²³⁵ U	²³⁴ Th	¹⁴⁴ Ce	²³⁹ Pu	²³⁸ Pu	¹⁵⁵ Eu	¹⁵⁴ Eu	²³² Th
1.8	13.89	12.51	1.36	3.35	0.0308	0.0888	7.12	9.37	2.09
1.9	13.46	12.18	1.32	3.26	0.0284	0.0832	6.92	9.11	2.02
2.0	13.05	11.85	1.28	3.17	0.0263	0.0779	6.72	8.85	1.96
2.1	12.65	11.54	1.25	3.08	0.0243	0.0730	6.52	8.60	1.89
2.2	12.27	11.23	1.21	3.00	0.0224	0.0684	6.34	8.38	1.83
2.3	11.89	10.93	1.17	2.92	0.0207	0.0641	6.15	8.13	1.77
2.4	11.53	10.64	1.14	2.84	0.0191	0.0600	5.97	7.90	1.71
2.5	11.18	10.36	1.10	2.77	0.0177	0.0562	5.80	7.68	1.66
2.6	10.84	10.08	1.07	2.69	0.0163	0.0527	5.63	7.47	1.61
2.7	10.50	9.81	1.04	2.62	0.0151	0.0494	5.47	7.26	1.55
2.8	10.18	9.55	1.01	2.55	0.0139	0.0462	5.31	7.06	1.50
2.9	9.87	9.30	0.98	2.48	0.0129	0.0433	5.16	6.86	1.45
3.0	9.57	9.05	0.95	2.41	0.0119	0.0406	5.01	6.67	1.41
3.1	9.28	8.81	0.92	2.35	0.0110	0.0380	4.87	6.48	1.36
3.2	9.00	8.57	0.89	2.29	0.0102	0.0356	4.73	6.30	1.32
3.3	8.72	8.34	0.87	2.23	0.0094	0.0334	4.59	6.13	1.28
3.4	8.46	8.12	0.84	2.17	0.0087	0.0313	4.46	5.96	1.23
3.5	8.20	7.91	0.82	2.11	0.0080	0.0293	4.33	5.79	1.19
3.6	7.95	7.70	0.79	2.05	0.0074	0.0274	4.20	5.63	1.16
3.7	7.70	7.49	0.77	2.00	0.0068	0.0257	4.08	5.47	1.12
3.8	7.47	7.29	0.75	1.94	0.0063	0.0241	3.96	5.32	1.08
3.9	7.24	7.10	0.72	1.89	0.0058	0.0228	3.85	5.17	1.05
4.0	7.02	6.91	0.70	1.84	0.0054	0.0211	3.74	5.03	1.01
4.1	6.81	6.72	0.68	1.79	0.0050	0.0198	3.63	4.89	0.98
4.2	6.60	6.54	0.66	1.74	0.0048	0.0186	3.53	4.75	0.95
4.3	6.40	6.37	0.64	1.70	0.0042	0.0174	3.42	4.62	0.92
4.4	6.20	6.20	0.62	1.65	0.0039	0.0163	3.33	4.49	0.89
ROI(a)	117 to 120	370 to 373	125 to 128	265 to 268	33 to 48	33 to 48	171 to 174	244 to 244	474 to 477
CCR(b)	122 to 133	375 to 386	130 to 141	270 to 281	44 to 55	44 to 55	176 to 187	249 to 260	484 to 495

(a) ROI = region of interest for a given nuclide by channel.

(b) CCR = region for background continuum correction by channel (not keV) spectra at 0.5 keV/channel.

3.3.2 Procedure for Subject Measurement

- Have the subject lie on his back underneath the array of 3 germanium planar detectors.
- Place the detectors over the liver in contact with the body.
- Place two of the detectors on the rib cage just above the lower edge and one detector on the edge of the rib cage as shown in Figure 3.13.
- Instruct the subject not to move and to keep in light contact with the detectors.
- Describe the use of the emergency button and the self-exit procedure.
- Close the shielded room door.
- Start the count.
- Count for the preset time (usually 2000 seconds).

3.3.3 Background Correction

The photopeak region is corrected for background contribution by subtracting one-third of a continuum region above the photopeak that is three times as many channels are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used.

3.3.4 Calculations for Liver Activity

Computer analysis is provided automatically for the radionuclides shown in Table 3.10 when the 3-germanium planar detector array is used.

The formula for manual calculation of activity in the liver is given below:

$$nCi \text{ in liver} = \frac{\text{net counts/min}}{\text{counts/min/nCi}} \quad (3.11)$$

The counts per minute per nCi factors are obtained from Table 3.10. This value is for an average tissue thickness of 3.2 cm overlaying the liver. Calibration factors for different thickness overlays have not been derived. If the overlay thickness is significantly different than 3.2 cm, a calibration factor can quickly be obtained by measuring a standard liver organ with the appropriate

Position of Detectors for Liver Count

Data Sheet for Liver Count

keV per channel	<u>0.25</u>
# of detectors	<u>3</u>
Detector code	<u>R3</u>
Body location code	<u>08</u>
# of channels	<u>2048</u>
Routine count length, sec	<u>2000</u>
Background length, sec	<u>NA</u>
Source used for calibration	<u>^{241}Am + enriched U</u>
Source count used length	<u>^{241}Am plexiglass jig from 6-Germanium.</u>

Planar Detector Lung Count

FIGURE 3.13. Data Sheet and Position of Detectors for Liver Count

TABLE 3.10. Calibration Data for Liver Counts

<u>Radionuclide</u>	<u>Energy, keV</u>	<u>Channel Group</u>	<u>Counts per Minute per nCi for 3.2-cm Chest Wall Thickness</u>
241Am	59.5	234 to 232	8.17
144Ce	134	Calibration pending	
154Eu	123	Calibration pending	
155Eu	86	Calibration pending	
232Th	239	Calibration pending	

3.3.4 Calculations for Liver Activity (contd)

overlay shell on the phantom. The thickness of tissue over the liver of a subject is determined by an ultrasound method as derived in Section 3.2 for lung counting.

If activity is also present in the skeleton, the liver count must be corrected for contribution from the bone that is viewed by the detectors. For americium- 241, the bone contribution to the liver count rate is 0.28 times the head count rate when using the same number of germanium planar detectors for both the head and the liver.

NOTE: For detailed calibration data see Volume LV-1 in the WBC library.

3.4 IN VIVO MEASUREMENT OF RADIOACTIVITY IN THE BONE

Radioactivity in the bone can usually be identified by noting that relatively high levels (determined by the whole body counter and compared to other parts of the body) exist in the head or in the bone joints. For radionuclides emitting high-energy gamma rays above 100 keV, a normal whole body count gives a good measurement of the content when activity does not exist in soft tissues. Most bone measurements presently made are for low-energy x-rays or gamma rays below 100 keV.

A count is made by measuring the activity content in the skull with germanium planar detectors (usually two detectors are used). The head is the preferred place for a measurement because of the high sensitivity and the low level of interference from other parts of the body.

3.4 IN VIVO MEASUREMENT OF RADIOACTIVITY IN THE BONE (contd)

However, other parts of the body such as the knee or ankle may be used for a bone measurement if the head has extensive contamination (Palmer, Rieksts, and Icyan 1983).

3.4.1 Procedure for Energy Calibration and Efficiency Check of Germanium Planar Detectors

- Review the system data sheet in Figure 3.14.
- Energy Calibration
 - Calibrate the MCA with the americium-241 and uranium-235 sources so that each channel is equivalent to 0.500 keV (see Section 4.0).
- Efficiency Check
 - Place the two detectors on the marked standard positions of the americium-241-labeled head phantom.
 - Count for 2000 seconds.
 - Compare the results with the original calibration results. The two sets of results should be the same.

3.4.2 Procedure for Subject Measurement

- Have the subject shower and wash hair to remove dust and attached radon daughter activity.
- The subject's hair should not be dried because dry hair attracts radon daughter activity from the air.
- Have the subject put on cotton coveralls for the measurement.
- Escort the subject into the shielded room and have him lie on his back on the bed that is supported by a hydraulic lifter.
- Place the detectors lightly against the subject's forehead by raising the bed up until the head comes into contact with the detectors. The detectors should be positioned so their front surfaces are tangent to the head surface (Figure 3.15).
- USE EXTREME CAUTION when bringing the subject's head into contact with the detectors. The detectors are evacuated underneath the 20-mil-thick beryllium windows. The windows are brittle and could possibly implode.

FIGURE 3.14. Head Counter Schematic and Data Sheet

FIGURE 3.15. Position of Detectors for a Head Count

3.4.2 Procedure for Subject Measurement (contd)

- NEVER PUT THE DETECTORS OVER THE EYES.
- Place a lead shield around the neck and over the chest of the subject to absorb radiation from the other parts of the body.
- Instruct the subject not to move his head and to keep it in contact with the detectors.
- Describe the use of the emergency button and the self-exit button.
- Close the shielded room door.
- Count for the preset time (usually 3000 seconds).
- When the count is over carefully remove the lead shield first and then remove the subject from beneath the counter and remind him to watch his step when he exits.

3.4.3 Background Correction

The photopeak region is corrected for background contribution by subtracting one-third of a continuum region above the photopeak that is three times as many channels as are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used.

3.4.4 Calculation for Bone Activity

The computer is programmed to provide calculations for the skull and the total skeletal content of radionuclides using the calibrated factors listed in Table 3.11.

TABLE 3.11. Calibration Data for Head Counts(a)

Radionuclide	Photon Energy, keV	Channel Group	Counts/min/nCi in Skull from 2 Detectors	Counts/min/nCi in Total Skeleton from 2 Detectors
²⁴¹ Am	59.5	234 to 232	8.9	1.13
²¹⁰ Pb	46.5	183 to 188	0.87	0.13

(a) For detailed calibration data see Volume SK-1 in the WBC library.

3.4.4 Calculation for Bone Activity (contd)

The calculation procedure determines the net count per minute in the region of interest and the net count is divided by the calibration factor given above to obtain the content in the skull. The skull content is multiplied by 6.67 to obtain the total skeleton content.

3.5 IN VIVO MEASUREMENT OF TRANSURANIC RADIONUCLIDES IN WOUNDS

Small injuries to the hands and arms in plutonium processing facilities sometimes result in plutonium-239 and associated americium-241 being injected into the skin and underlying tissue. This activity can be easily detected and quantified. The determination of the 239-plutonium content in the wound usually requires a correction for the amount of americium-241 present. The exact location and depth of the activity must also be determined in some wound areas.

3.5.1 Procedure for Energy and Efficiency Calibration of the Planar Germanium Detectors in the Shielded Room or at the EDF

- Review the system data sheet in Figure 3.16.
- Energy Calibration
- Locate the radioactive sources: americium-241, 116.5 nCi, #40; plutonium-239, 125.5 nCi, #42.
 - Calibrate one planar germanium detector using an MCA so that each channel represents 0.250 keV. Therefore, the 59.5-keV peak from americium-241 will be stored in channel 119 and the 185.5-keV peak from uranium-235 will be stored in channel 371.
- Efficiency Calibration
- Position the americium-241 source on the planar germanium detector so that the activity side of the source is closest to the detector and count for 60 seconds.
 - When the count is finished, save the americium-241 spectrum in the computer and print a hard copy.
 - Remove the americium-241 source.
 - Position the plutonium-239 source on the coaxial germanium detector so that the activity side of the source is closest to the detector and count for 100 seconds.
 - When the count is finished, save the plutonium-239 spectrum in the computer and print a hard copy.
 - Remove the plutonium-239 source.

FIGURE 3.16. Wound Counter Schematic and System Data Sheet

3.5.2 Procedure for Subject Measurement

Count an Uncontaminated Subject

- Take a count of an uncontaminated subject whenever possible.
- Position the uncontaminated subject's hand, finger, or body part corresponding to the body part of the contaminated subject in contact with the detector to simulate the same positioning when the actual subject's wound is counted.
- Set the count time for 600 seconds.

3.5.2 Procedure for Subject Measurement (contd)

Prior to Contaminated Subject's Count

- Take the count.
- Save the spectrum in the computer and print a hard copy.
- Subject is normally not required to shower.
- If the radiation protection technologist has detected external contamination in the wound area and is unable to remove the activity, cover the detector with a thin plastic bag before counting the wound.
- Position the subject comfortably with the wound centered and in contact with the detector.
- Use only light pressure against the beryllium window to avoid imploding.
- Instruct the subject to keep the wound area in contact with the detector during the count.
- Describe the use of the emergency button and the self-exit procedure.
- Close the shielded room door.

Taking the Contaminated Subject's Count

- Count for 600 seconds.
- Save the spectrum and print a hard copy.

When the Count is Finished

- Have the subject carefully leave the counter.
- Remind the subject to watch his step.

3.5.3 Background Correction

For americium-241, the background contribution in the photopeak is subtracted using one-third of the continuum region above the photopeak that is three times as many channels as are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used. The background from the uncontaminated subject is used when calculating the plutonium-239 activity.

3.5.4 Calculations for Shallow Wound Activity

The computer is programmed to provide the quantified activity using the calibration factors in Table 3.12 for measurements made using a 20-cm² detector at the 747A Building.

TABLE 3.12. Calibration Data for Wound Counts

Radionuclide	Photon Energy, keV	Channel Group	Counts/min/nCi
²⁴¹ Am	59.5	234 to 242	278.32
²³⁹ Pu	13.6 and 17	51 to 73	25.7

3.5.4 Calculations for Shallow Wound Activity (contd)

The basic method of calculation by hand is:

$$\text{activity in wound in nCi} = \frac{A - B}{C - B} \times D \quad (3.8)$$

where A = counts/min in wound
 B = background counts/min
 C = counts/min in source
 D = source strength in nCi

The detection level calculation is:

$$\text{MDA} = \frac{A}{B - C} \times D \quad (3.9)$$

where A = $3 \sqrt{\frac{\text{background}}{\text{min}}}$
 B = counts/min in source
 C = background counts/min
 D = source strength in nCi

The calculation of plutonium-239 with the correction for americium-241 is:

$$\text{nCi } ^{239}\text{Pu in wound} = \frac{A - B \left(\frac{C}{E} \right)}{D} \times F \quad (3.10)$$

where A = net counts/min in channels 26 to 37 for wound
 B = counts/min in channels 117 to 121 for wound
 C = counts/min in channels 26 to 37 for ²⁴¹Am source
 D = counts/min in channels 26 to 37 for ²³⁹Pu source
 E = counts/min in channels 117 to 121 for ²⁴¹Am source
 F = nCi in ²³⁹Pu source

3.5.4 Calculations for Shallow Wound Activity (contd)

The location of the activity is usually obvious from observation of the wound, but it always needs to be confirmed by placing a small (1/8-in.-diameter) lead disk over the suspected location to determine if all the activity is absorbed by the disk. If the wound is a long cut, a small lead slot collimator is useful in determining where the major portion of the activity is located.

NOTE: For detailed calibration data see Volume WD-1 in the WBC library.

3.5.5 Measurement of Plutonium-239 to Americium-241 Rates in Deep Wounds

For deep wounds, where the activity is more than 2 mm below the surface of the skin, a more accurate method for measuring the plutonium-239 and americium-241 ratio is to measure the americium-241 content and then determine the ratio of plutonium-239 to americium-241 using a Si(Li) detector as described by Palmer and Roesch (1989; a copy of this paper is available in the WBC library).

3.5.6 In Vivo Measurement of Fission and Activation Products in Wounds

Injuries to the body in work areas contaminated with fission or activated product materials sometimes result in radioactivity being injected into the skin and underlying tissue. These wounds are measured with a large coaxial germanium detector placed directly on the wound, but separated by a thin layer of polyethylene plastic to protect the detector from contamination. After the count on the wound, a standard source containing the same radionuclide or a radionuclide with a similar energy is counted in the same geometry as the wound count. Any activity in the wound is quantified by direct comparison with the activity in the standard source.

3.6 IN VIVO MEASUREMENT OF RADIOACTIVITY IN THE THYROID

For a person with normal thyroid function, about 20% of any radioiodine incorporated into the body will be taken up by the 20- to 25-gram adult thyroid gland. Because of this relatively high concentration compared to other body tissues, the amount of iodine-131 in the thyroid is of the most interest. A single 3-in. X 3-in. NaI(Tl) detector or the large coaxial germanium detector is effective for measuring iodine-131 and two germanium planar detectors are the most effective for measuring iodine-125. Using these detectors, the minimum

3.6 IN VIVO MEASUREMENT OF RADIOACTIVITY IN THE THYROID (contd)

detectable amount in the thyroid is 20 pCi for iodine-131 in a 30-minute count and 3 pCi for iodine-125 in a 30-minute count.

3.6.1 Procedure for Energy Calibration of the Detectors for Thyroid Measurements

Calibrate the MCA so that each channel is equivalent to 10 keV for the iodine-131 measurement or 0.250 keV for the iodine-125 measurement. (See Section 4.0).

Because of the short half-lives of iodine isotopes an efficiency check using iodine-125 and iodine-131 is not possible. The detectors used for this procedure have undergone efficiency checks for other radionuclides during other whole body counting procedures.

3.6.2 Procedure for Subject Measurement

Safety Precautions

- Have the subject lie on his back and place the detector(s) over the thyroid gland.
- When using the germanium planar detectors be sure that the liquid nitrogen in the detectors does not spill on the subject.
- Use care when placing the germanium planar detectors on the body, so that the thin beryllium windows are not broken. Breaking the beryllium windows could result in a minor implosion.

For an Iodine-131 Measurement

- Place the 3-in. x 3-in. NaI(Tl) detector on its side against the neck and centered between the clavicle bones (located at the base of the neck) and the thyroid cartilage, also known as the "Adams apple" (see Figure 3.17).

For an Iodine-125 Measurement

- Center the two germanium planar detectors close together on both sides of the verticle center line of the neck and in between the clavicle bones and the thyroid cartilage (see Figure 3.18).
- Angle the germanium planar detectors so that the end surface is parallel to the surface of the neck.

Continuing Procedure for Both the Iodine-131 and -125 Measurements

- Instruct the subject not to move and to keep his throat in contact with the detectors.
- Describe the use of the emergency button and the self-exit procedures.
- Close the shielded room door.

FIGURE 3.17. Placement of Detector for an Iodine-131 Measurement of the Thyroid

FIGURE 3.18. Placement of Detectors for an Iodine-125 Measurement of the Thyroid

3.6.2 Procedure for Subject Measurement (contd)

Taking the Thyroid Count

- Start the count.
- Count for preset time (usually 2000 seconds).
- Assist the subject from the counter.

When the Count is Finished

- Remind the subject to watch his step upon exiting the shielded room.

3.6.3 Background Correction

The background of an uncontaminated person is subtracted from the subject counts for the iodine-131 measurement. (a) For the iodine-125 measurement, the photopeak region is corrected for background contribution by subtracting one-third of a continuum region above the photopeak that is three times as many channels as are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used.

3.6.4 Calculations for Thyroid Activity

For Iodine-131

The computer is programmed to provide calculations for iodine-131 in the thyroid using the calibration factors listed below for a 3-in. x 3-in. NaI(Tl) detector.

Channel Group Used	Counts/min-nCi
33 to 39	130

The equation for the calculation is:

$$nCi \text{ of iodine-131} = \frac{\text{net counts/min}}{\text{counts/min-nCi}} \quad (3.11)$$

(a) The net count for the iodine-131 measurement can be determined without a background count using the following equation:

$$\text{net count/min} = \frac{A - B}{C}$$

where A = counts/min in channels 33 to 39

$$B = 3.5 \left(\frac{\text{counts in channels 31}}{2} + \frac{32 \text{ counts in channels 41} + 42 + 43}{3} \right)$$

C = counting time in minutes

3.6.4 Calculations for Thyroid Activity (contd)

For Iodine-131 (contd) If other interfering radionuclides are present in the body a 35% Ge(Li) detector may be used in the same way as the 3-in. x 3-in. NaI(Tl) detector. The side of the detector is placed on the neck with the centerline of the throat at 2- 1/4 in. from the end of the detector endcap. The calibration factor for the 35% Ge(Li) detector is 33.4 counts/min/nCi of iodine-131 in the thyroid.

For Iodine-125 The computer is programmed to provide calculations for the iodine-125 content in the thyroid using the calibration factor below.

Channel Group Used	Counts/min/nCi
107 to 112	159

The equation for the calculation is:

$$\text{nCi of iodine-125} = \frac{\text{net counts/min}}{\text{counts/min/nCi}} \quad (3.12)$$

NOTE: For detailed calibration data see Volume TH-1 in the WBC library.

3.7 IN VIVO MEASUREMENT OF TRANSURANIC NUCLIDES IN AXILLARY LYMPH NODES

Small insoluble particles of transuranic n contamination that enter the lymphatic system through contaminated wounds can become filtered out in the axillary lymph nodes located in the area of the armpit. This activity can remain in the lymph node area for long periods of time.

A single germanium planar detector placed in the region of the armpit over the location of the axillary lymph nodes is used to measure this activity. Determining the location and depth of the nodes is difficult.

3.7.1 Procedure for Energy Calibration of the Germanium Planar Detector

Calibrate an MCA connected to a germanium planar detector so that each channel is equivalent to 0.500 keV. Refer to Section 4.0, Operation of Counting Equipment and the data sheet in Figure 3.19.

3.7.2 Procedure for Subject Measurement and Efficiency Calibration

- Have the subject lie on his back with the arm having the suspected contaminated lymph nodes raised up so the hand rests above his head (see Figure 3.19).

Data Sheet for Lymph Count

keV per channel	<u>0.25</u>
# of detectors	<u>1</u>
Detector code	<u>J2</u>
Body location code	<u>08</u>
# of channels	<u>1024</u>
Routine count length, sec	<u>2000</u>
Background length, sec	<u>NA</u>
Source used for calibration	<u>241 Am + enriched U</u>
Source count used /length	<u>241 Am Plexiglass jig,</u> <u>300 sec.</u>

FIGURE 3.19. Sample Data Sheet for Lymph Count

3.7.2 Procedure for Subject Measurement and Efficiency Calibration (contd)

- If the wound is still contaminated, shield it with a lead sheet to absorb the radioactivity.
- Place the detector in contact with skin at the location shown in Figure 3.20.
- Make several measurements at locations near the original location to determine the location giving the highest count rate.

Efficiency Calibration

- Determine the depth of the lymph nodes using the ratio of the various photopeaks if there is sufficient activity. If the depth cannot be determined, assume a depth of 2 centimeters.
- Obtain a standard source of the activity that is present in the lymph node (usually americium-241 or plutonium-239).
- Place the source under a thickness of tissue-equivalent CaCO₃-loaded polyurethane that is the same as the estimated or assumed depth of the lymph node.
- With the detector in contact with the polyurethane plastic, measure the source activity for the same length of time as the lymph node count on the subject.

FIGURE 3.20. Proper Position of Detector for a Measurement of Radioactivity in the Axillary Lymph Node

3.7.3 Background Correction

The photopeak region is corrected for background contribution by subtracting one-third of a continuum region above the photopeak that is three times as many channels as are used for determining the counts in the photopeak. The smoothed median method (Spitz et al. 1984) can also be used.

3.7.4 Calculation of Axillary Lymph Node Activity

The activity in the axillary lymph nodes can be calculated manually using the following equation:

3.7.4 Calculation of Axillary Lymph Node Activity (contd)

$$nCi \text{ of radionuclide} = \frac{A}{B} \times C \quad (3.13)$$

where A = net counts/min from the lymph node
B = net counts/min from the standard source
C = nCi in source

NOTE: For detailed calibration data see Volume LY-1 in the WBC library.

3.8 IN VIVO MEASUREMENT OF TRANSURANIC NUCLIDES IN TRACHEOBRONCHIAL LYMPH NODES

Radioactivity in the tracheobronchial lymph nodes is difficult to detect and quantify because it is not easily distinguishable from lung-deposited activity. However, if a significant measurable fraction does exist in these lymph nodes, it can be detected and roughly quantified by making lateral scans of a cross section of both lung and tracheobronchial lymph nodes. This in vivo measurement method is still under development.

This measurement is done by using a collimated set of 2 germanium planar detectors shown in Figure 3.21. The slot collimator shown in Figure 3.22 extends 2 in. below the face of the detectors.

Figure 3.23 shows the response of such a scan with different fractions of americium-241 in the lymph nodes and lungs. Figure 3.23 also depicts the scan of a Hanford Site employee with americium-241 only in the lung.

NOTE: For detailed calibration data see Volume LY-1 in the WBC library and Northcutt, Binney, and Palmer (1988).

3.9 IN VIVO MEASUREMENT OF RADIOACTIVITY USING A LINEAR SCAN

When the activity is not evenly distributed within the body, knowing the location of the activity can be of help to the Internal Dosimetry Group. Rough estimates of the locations of activity can be made by a rapid measurement in the preview whole body counter. For more precise location information the linear scan system must be used.

A collimated 4-in. x 4-in. x 16-in. NaI detector scanning from below the body is used to determine the location of the activity using a longitudinal scan of the body. The linear scanner is shown in Figures 3.2 and 3.24. The system uses a single-channel analyzer (SCA) to select a

FIGURE 3.21. Two Germanium Planar Detectors Used to Measure the Tracheobronchial Lymph Nodes

FIGURE 3.22. A Slot Collimator that Extends Two Inches Below the Face of the Two Detectors Used to Measure the Tracheobronchial Lymph Nodes

FIGURE 3.23. Posterior Lateral Scan of Activity in the Lungs and the Tracheobronchial Lymph Nodes (LN)

3.9 IN VIVO MEASUREMENT OF RADIOACTIVITY USING A LINEAR SCAN (contd)

portion of the energy spectrum to better discriminate against background or even separate the location of one n from another providing the ns have sufficiently separate characteristic energy peaks.

3.9.1 Procedure for Calibration of the Linear Scan Detector

- If possible set up the system using a source of the same n as that observed in the subject. If such a source is not available, use the activity in the person.

FIGURE 3.24. Subject Being Measured with the Linear Scan System
(the detector scans from below the subject's body)

3.9.1 Procedure for Calibration of the Linear Scan Detector (contd)

- First the analyzer is set in the multichannel analyze mode; the SCA's output controls a linear gate that selects only a specific energy region output of the main amplifier. The resulting spectra on the MCA show exactly what energy region has been selected by the SCA as input to the multichannel scale mode.
- Observe the spectra on the MCA.
- Keep the calibration source on the detector and set the threshold and window settings of the SCA to select the major characteristic peak of the n of interest.
- If more than one n is present more sensitivity can be gained by using both peaks or all of the major peaks of interest.
- Switch the analyzer to the multichannel scale mode (MCS) to count the subject.
- Only the mode switch needs to be changed to the MCS mode since the analyzer has separate input ports for MCA and MCS functions.
- Now the same pulse that triggered the linear gate is fed to the analyzer in the MCS mode. This pulse is the output of the SCA and produces a square (mono-energetic) pulse for each pulse from the detector that meets the energy range restrictions specified by the SCA.

3.9.2 Procedure for Subject Measurement

- Position the subject on the bed centered and about 6 in. from the top of the bed. This position should place the collimator slit at about the top of the head for starting position.
- Position the collimator carriage to the top of the bed position. The carriage has only one speed and is powered only in a head-to-toe direction sweep.
- To move the carriage lift the handle that holds the gear and motor assembly until the gear is disengaged from the rack (geared teeth) bolted to the floor.

3.9.2 Procedure for Subject Measurement (contd)

- Push the following three switches at about the same time to start the analyzer counting and the detector moving at the same time: 1) the acquire button on analyzer, 2) the MCS start button, and 3) the collimator carriage drive start switch.
- Keep calibration source handy but out of the room except when the collimator slit is at the top of the head.
- When the collimator slit is at the top of the head and the count has begun, touch the calibration source to the detector end momentarily, then remove the source from the room.
- Touch the source on the detector end again when the scan is nearly complete and the bottom of the feet are even with the collimator. Other positions of interest such as liver or bone joints may be marked during the count by momentarily touching the source or the detector.
- Stop the carriage by pushing the red carriage stop switch, or let the carriage stop microswitch activate automatically when it reaches the far end.
- Print out the spectrum and label it.
- Plot the spectrum or study the analyzer display and refer to the following section for interpretation.

3.9.3 Calculations for Location of Activity Detected with the Linear Scan

The spectrum should clearly show a peak at each end. The peak on the left of the spectrum represents the head position when the collimator slit was above the head and the source was touched to the detector. The peak at the right of the spectrum represents the foot position when the collimator slit was at the end of the feet and the source was touched to the detector.

By calculating the number of channels between the peaks and dividing the subject's height in centimeters by the number of channels between the calibration peaks and entering this number as the keV per channel value as input data to plot the spectrum, a means of referencing activity to distance from the top of the head in centimeters is obtained.

3.9.4 Alternate Modes of Use

This system can be operated in two different modes depending on the time allowed and the precision desired. The normal longitudinal count is about 15 minutes; the movement of the collimated detector is motorized and the analyzer is operated in the MCS mode.

Resolution and sensitivity can be increased by varying the slit width of the collimator, by manually moving the detector carriage to increase the dwell per position, and by leaving the carriage stationary during each counting period. In this mode each position merits having the whole spectrum saved for each location counted.

Although the manual scan method is more versatile in the types of information to be gained, it also takes more time during analysis than continuous movement of the MCS mode. The MCS mode produces a histogram of relative activity versus location and can be stored or plotted by normal spectrum handling routines.

3.10 DETERMINING CHEST WALL THICKNESS BY ULTRASOUND

The chest wall thickness among adult males varies between 2 and 4 cm. The variation among women is even greater. Since the half thickness (half value layer) for 17-keV x-rays in muscle and fat tissue is about 7 mm, it is essential that the chest wall thickness be measured. In addition, a thicker chest wall causes the detectors to be located at a greater distance from the lungs which also results in a reduced count rate. The chest wall thickness can be measured within 1 mm using ultrasound equipment designed for this purpose.

3.10.1 Procedure for Determining Chest Wall Thickness

Required Supplies

- 2 bottles aquasonic transmission gel
- 3 packages Polaroid Film Type 107
- 3 bath towels
- template for 6 intrinsic germanium detector configuration (Figure 3.25)
- washable felt tip marker
- ultrasound thickness calibration phantom (Figure 3.26)

FIGURE 3.25. Template Configuration

FIGURE 3.26. Ultrasound Calibration Phantom

3.10.1 Procedure for Determining Chest Wall Thickness (contd)

Prior to Ultrasound Measurement

Preliminary adjustments for optimum clearness and machine calibration should be performed before an ultrasound measurement is taken. Refer to the routine settings listed on the machine and allow a 5-minute warmup.

Measuring the Ultrasound Calibration Phantom

- Place the ultrasound transducer on the surface of the ultrasound standard phantom shown in Figure 3.26.
- Measure the distance from the phantom surface to the three wires that are at distances of 1, 3, and 5 cm.

3.10.1 Procedure for Determining Chest Wall Thickness (contd)

- Position the transducer so that the distance marks are close to the 1-cm calibration markers on the side of the phantom.
- Take a Polaroid photograph of the marks.
- Date the photograph and put it into a record book as a quality assurance record.

Subject Preparation

- Place towel on recliner where subject will lie.
- Take special precautions to ensure the subject's privacy during this measurement.
- Instruct the subject to remove all clothing above the waist.
- Place one bath towel from the lower breast area down to the waist.
- Inform the subject that removable ink marks will be drawn on the chest to simulate the actual detector placement of the 6 intrinsic germanium detectors used for the in vivo lung exam.
- Position the edge of the template that has cut outs simulating the actual placement of the detectors in line with the subject's clavicle.
- Insert marker into the cut-out slots of the template and lightly draw all 12 vertical lines while holding the template in place (Figure 3.27).
- Remove the template.
- Inform the subject that the ultrasound transmission gel will be slightly cool when applied to the skin.
- Slowly squeeze gel and apply approximately 1/8-in.-thick to all drawn vertical lines. Apply the gel slowly to eliminate excessive air bubbles in the gel and for even application.

Taking the Measurement

- On the ultrasound keyboard, key in the current date, 2 spaces, subject's payroll number, 2 spaces, and the position number you wish to ultrasound first.
- Slowly apply approximately 1/8 in. of gel to the ultrasound probe.
- Lightly place the probe in contact with the gel on the subject's chest.

FIGURE 3.27. Using the Template to Draw the Lines that Indicate Ultrasound Probe Placement

3.10.1 Procedure for Determining Chest Wall Thickness (contd)

- Carefully adjust the controls on the ultrasound unit until a well defined interface is displayed on the screen. The probe may need to be rocked slightly back and forth to obtain a good interface (Figure 3.28).
- Make sure the probe is in the proper position before taking a Polaroid picture.
- Remove the photograph and set it aside for at least one minute for development.
- Erase the old position number on the screen by using the red clear (CL) key.
- Enter the next ultrasound position on the screen.
- Apply more gel to the probe, carefully position the probe and photograph the next interface.
- Separate the photograph from the developer after 60 seconds.
- Repeat the process until all 12 positions have been recorded on photographs.
- Examine developed photos closely to determine if any positions require retakes.
- Use the third towel to remove the excess gel from the subject's chest.
- Subject may return to the main lobby of the WBC.
- Using calipers, determine and record the actual chest wall thickness for each position on the Ultrasound Measurement forms (Exhibit 3.1).
- Add all 12 positions and divide the total by 12 for an average thickness in centimeters.

After Ultrasound
Measurements Have
Been Taken

3.11 IN VIVO COUNTING FOR CRITICALITY ACCIDENTS

The exposure of workers to neutrons will result in induced radioactivity in the body from the activation of the major elements of body composition such as calcium, nitrogen, sodium, chlorine, etc.

FIGURE 3.28. Positioning the Ultrasound Probe to Obtain a Good Interface with the Subject's Chest

3.11 IN VIVO COUNTING FOR CRITICALITY ACCIDENTS (contd)

A neutron dose of 20 mrad of fission spectra neutrons will produce approximately 10 nCi of sodium-24 in the body. Immediately after exposure calcium-49, sodium-24, chlorine-38, aluminum-28 and nitrogen-13 are easily measured, but because of the short half-lives, only sodium-24 is measurable by the time the worker is transported to the whole body counter. The assessment of sodium-24 in workers exposed to neutrons from a criticality accident provides a means of estimating the neutron dose.

After all the gamma ray emitters have decayed away in an exposed person, measurements of bremsstrahlung radiation from phosphorous-32 in the bone may give information on which portions of the body received the highest dose. Details of the bremsstrahlung measurements are not given in this procedure.

3.11.1 Procedure for Energy and Efficiency Calibration

- Use a cesium-137 and a potassium-40 source for an energy calibration of the MCA.
- Adjust the MCA until each channel is equivalent to 20 keV.
- Use the standard potassium-40 source and geometry to confirm that the counting efficiency is unchanged.
- Calibration details for determining the sodium-24 content are located in the Whole Body Counter Laboratory Notebook #1, (11/11/59) HWN-2454, pages 131-137, assigned to the WBC supervisor, available in the WBC library.

3.11.2 Procedure for Measuring Activity Resulting from Criticality Accidents

Since the level of sodium in the body of the worker exposed to a criticality event may be relatively high, the procedure used to evaluate the amount will depend on the quantity present.

Low levels can be quickly assessed by the preview whole body counter (measurement procedure described in Section 3.1), which will automatically calculate the results. For a more precise assessment, or for levels that exceed the preview counter's capacity, follow the procedure below.

3.11.2 Procedure for Measuring Activity Resulting from Criticality Accidents (contd)

- Take the measurement in the lead room using the tilted chair geometry with the 4-in. x 9 3/8-in. NaI(Tl) detector in the normal position.
- See Figure 3.29 for chair and detector positioning.
- Determine the amount with the detector in the normal position at the distance shown in Figure 3.29.
- Close the lead room door

Taking the Count

- Start the count with preset time at 5 or 10 minutes.
- Observe the MCA display to determine whether the count will overscale.

If Body Burden is Greater than 5 μCi

- If analyzer indications suggest that it will overscale before the count is finished, stop the count.
- Raise the detectors up to the distances shown in Figure 3.30 and begin counting again.
- Count for 1 to 10 minutes, depending on the level of activity.

3.11.3 Background Correction

The background is subtracted using a previously determined background or appropriate fraction of a long background count done with an uncontaminated person

FIGURE 3.39. Detector in Normal Position

3.11.3 Background Correction (contd)

sitting in the chair. If the alternate position was used (detector raised), a background count with the detector in the same position should be used for the precise calculation of the background.

By the time the exposed person arrives at the WBC, all interfering radionuclides will usually have decayed away.

3.11.4 Calculations of Activity

Calculating the Sodium-24 body burden

The calibration factor for determining the body burden of sodium-24 using a 4-in. x 9 3/8-in. NaI(Tl) detector in the normal chair position (shown in Figure 3.29) is 6522 counts per minute per μCi . The counts per minute are determined from the 2.75-MeV peak using channels 128 to 143 inclusive. Equation (3.14) determines the total body content of sodium-24.

$$\mu\text{Ci of } ^{24}\text{Na in the body} = \frac{\text{net counts/min}}{6522} \quad (3.14)$$

The calibration factor for the detector in the normal position (see Figure 3.29) can be found on pages 131-137 in the Laboratory Notebook #1 HWN-2454, assigned to the WBC supervisor, available in the WBC library. The calibration factor for the detector in the raised position (see Figure 3.30) is ____ (factor to be determined).

Calculating the Neutron Dose

The average total-body fast neutron dose calculated from total-body sodium-24 measurements is shown (Hanford Laboratories 1963; Harris 1961):

$$\text{dose in rads} = \frac{^{24}\text{Na activity in } \mu\text{Ci}}{\text{weight of subject in kg}} \times 226 \quad (3.15)$$

3.12 IDENTIFICATION OF UNKNOWN RADIONUCLIDES

Most of the radioactivity found in the Hanford employees is easily identified because it has been observed many times before. Occasionally a radionuclide is observed which is not immediately identified. This usually occurs as a result of a radiopharmaceutical that has been given to the person as part of a diagnostic nuclear medical procedure at a hospital or a new process or procedure being used at Hanford.

FIGURE 3.30. Detector in Raised Position

3.12.1 Procedure to Identify Unknown Radionuclides

- Use the germanium planar detectors at the WBC to determine the exact energy of unknown radionuclides.
- Determine the exact energy of all the unknown photopeaks in the spectrum. Remember that more than one radionuclide may be present.
- Observe the relative heights of the various photopeaks.
- Refer to Slater (1962), and note radionuclides with gamma-ray energies corresponding to those in the spectrum from the contaminated subject.
- Keep in mind that the radionuclides with a half-life of 1 day or less are not usually present unless they are a daughter of a long-lived parent.
- Select one or two possible radionuclides.
- Go to the spectra catalogues in the library and compare the spectrum from the body with that in the catalogue, taking in consideration that absorption occurs in the body at lower energies. The photopeak

3.12.1 Procedure to Identify Unknown Radionuclides (contd)

energy in conjunction with radionuclide gamma ray energy tables and gamma ray spectra catalogues usually provide all the information needed to identify any unusual radionuclides.

- If the presence of a radiopharmaceutical is detected, notify the Internal Dosimetry Group of this nonoccupational exposure.

3.13 REFERENCES

Hanford Laboratories, General Electric Company. 1963. "Dosimetry Investigation of the Recuplex Criticality Accident." Health Physics 9(7):757-768.

Harris, P. S. 1961. "Special Supplement on Acute Radiation Death Resulting from an Accidental Nuclear Critical Excursion." Journal of Occupational Medicine 3(3):179-180 (available in the WBC Library).

Kocher, D. C. 1981. Radioactive Decay Data Tables. DOE/TIC-11026, National Technical Information Service, Springfield, Virginia.

Northcutt, A. R., S. E. Binney, and H. E. Palmer. 1988. "In-Vivo Counting of ^{241}Am in Human Lungs and Tracheobronchial Lymph Nodes." Health Physics 54(1):73-81.

Palmer, H. E., and W. C. Roesch. 1965. "A Shadow-Shield Whole Body Counter." Health Physics 11(11):1213-1219.

Palmer, H. E., and W. C. Roesch. 1989. "Determining the Ratio of ^{239}Pu to ^{241}Am in Wounds by Measuring the L_{γ} X-Rays With a Si(Li) Detector." Health Physics 56:249-252.

Palmer, H. E., G. A. Rieksts, and E. E. Icyan. 1983. "1976 Hanford Americium Exposure Incident: In Vivo Measurements." Health Physics 45(4): 893-910.

Palmer, H. E., H. B. Spitz, and G. A. Rieksts. 1985. "Part III: Gamma-Ray Measurements." Health Physics 49(4):577-586.

Slater, D. N. 1962. Gamma-Rays of Radionuclides in Order of Increasing Energy. Butterworths, Washington D.C.

Spitz, H. B., R. L. Buschbom, G. A. Rieksts, and H. E. Palmer. 1984. "A New Method for Analyzing High-Resolution Spectra From Whole-Body Counter In Vivo Measurements." Health Physics 49(6):1085-1096.

EXHIBIT 3.1. Ultrasound Measurement Form

ULTRASOUND MEASUREMENT

Name: _____ Date: _____

Payroll No: _____ Height: _____ Weight: _____

Comments: _____

ULTRASOUND POSITIONS

Position 1: _____ Position 2: _____ Position 3: _____

Position 4: _____ Position 5: _____ Position 6: _____

Position 7: _____ Position 8: _____ Position 9: _____

Position 10: _____ Position 11: _____ Position 12: _____

Total of all 12 Positions = _____

Divided by 12 = _____

Chest Wall Thickness in centimeters

NOTE: Configuration is for six intrinsic germanium detectors

3-19-84

EXHIBIT 1.1. Unrecorded Measurement Form

UNITED STATES DEPARTMENT OF AGRICULTURE

Name _____
Page No. _____
Comments _____

UNITED STATES DEPARTMENT OF AGRICULTURE

Position 1: _____
Position 2: _____
Position 3: _____
Position 4: _____
Position 5: _____
Position 6: _____

Total of 12 positions: _____
Divided by 12: _____

SECTION 4.0

OPERATION OF COUNTING EQUIPMENT

4.0 OPERATION OF COUNTING EQUIPMENT

This section describes the operation and maintenance of the WBC counting equipment, which consists of detectors, preamplifiers, amplifiers, and MCAs.

4.1 DETECTORS

In Section 2.0 the detectors were briefly described. In this section, the operation, construction, maintenance, and repair of the detectors will be discussed.

4.1.1 Detector Types

The two types of detectors used in the WBC are the scintillation and semiconductors. Both types of detectors require very little maintenance but require close observation to detect any malfunction.

High Voltage Required

High voltage is required for the operation of both types of detectors. The scintillation detectors require positive high voltage, typically 800 to 1200 V; the semiconductor detectors require 2000 to 5000 V of positive or negative voltage, depending on the type of semiconductor detector.

CAUTION

High voltage can be very dangerous. The detectors must be turned off and disconnected whenever they are being moved or repaired.

4.1.2 Detector Hookup Design

The scintillation detectors are connected to the high voltage supply and signal processing instrumentation as shown in Figure 4.1.

The semiconductor detectors are connected to the high voltage and signal processing instrumentation as shown in Figure 4.2.

4.1.3 Detector Maintenance and Repair

Semiconductor Detectors

The only maintenance required for the semiconductor detectors is keeping them cooled with liquid nitrogen. All repairs on these detectors must be done by the manufacturer.

FIGURE 4.1. Schematic of a Scintillation Detector

FIGURE 4.2. Schematic of a Semiconductor Detector

4.1.3 Detector Maintenance and Repair (contd)

Scintillation Detectors

The NaI(Tl) scintillation detectors operate at room temperature and require only minimal maintenance. This maintenance includes balancing the photomultiplier tubes every 6 months and replacing the optical coupling compound between the photomultiplier tubes and the detector windows every 2 or 3 years as needed. Deterioration of the detector resolution would result from the imbalance of photomultiplier tubes and hardened coupling compound.

The replacement of the optical coupling can be performed by the instrument technician assigned to WBC. The balancing of the photomultiplier tubes is done by the WBC technicians.

4.1.3 Detector Maintenance and Repair (contd)

The procedure for balancing the photomultiplier tubes in the scintillation detector is:

- Center a cesium-137 source at least 12 inches from the face of the detector.
- Disconnect all high voltage leads from the photomultiplier tubes.
- Number the tubes 1 through the total number used on the detector.
- Connect high voltage lead to tube #1, accumulate spectra for 1 minute and note peak channel number.
- Repeat the previous step for all other photomultiplier tubes with high voltage connected to only one tube at a time.
- High voltage power supply must be turned off while connecting or disconnecting the high voltage lead.
- Determine which photomultiplier has the lowest gain by noting which one gives a photopeak in the lowest channel.
- Turn the gain potentiometer to the right to determine if the gain can be increased.
- If possible, adjust the gain so that the peak falls in about the same channel as the majority of the other tubes.
- If the adjustment is already at the maximum position, reduce the gain on all the other tubes until they all produce the peak in the same channel as the low gain tube.
- Connect high voltage to all the tubes and the balancing is complete.
- Check resolution.

CAUTION

4.1.4 Determination of Detector Resolution

A scintillation detector's performance is typically stated as a value of pulse height resolution, full width at half maximum (FWHM), for a particular gamma-ray peak.

4.1.4 Determination of Detector Resolution (contd)

Although any gamma line may be used, the most usual specified value is for the 662-keV gamma ray from cesium-137. With the source at least 12 inches away from the center face of the detector, accumulate counts until there are at least 5000 counts in the peak channel. Avoid high counting rates that will result in a "dead time" which exceeds 25% on the MCA.

From the resulting spectrum, calculate the resolution by dividing the peak channel into the number of channels comprising the upper half of the peak (see Equation [4.1] and Figure 4.3). Resolution values for the large NaI(Tl) detectors should be in the range of 8% to 9% for the 662-keV gamma ray.

$$\text{resolution} = \frac{\text{channel C} - \text{channel A} \times 100}{\text{channel B}} \quad (4.1)$$

FIGURE 4.3. Calculation of Detector Resolution

4.1.5 Diagnosing Detector Problems

Noise in a spectrum is generally defined as the extraneous events counted near the zero energy end of the spectrum. In scintillation detectors it is nearly always

4.1.5 Diagnosing Detector Problems (contd)

a result of spontaneous emission from the photocathode of the photomultiplier tube and the tube may need to be removed.

It is acceptable for noise to occur in channels corresponding to 0 to 20 keV for the large detectors with multiple tubes. For the thin crystal detectors used for plutonium-239 counting, the acceptable noise level is 0 to 10 keV.

Noise can also appear as discrete peaks at high energies. If unidentified peaks appear in a spectrum that has a peak width narrower than a gamma peak of equal energy, it is certain to be the result of a malfunction of the electronic system. If the peak is the same width as a gamma ray line, look for unshielded sources near the detector.

4.2 PREAMPLIFIERS AND AMPLIFIERS

The section describes the operation of the preamplifiers and amplifiers.

4.2.1 Preamplifiers

The output from a detector is a small charge pulse. It is necessary to precondition the output so that it can be utilized in a linear amplifier system. The linear amplifier system in turn provides the necessary pulse shaping and amplification required for use with the measuring unit. A preamplifier is generally inserted immediately after the detector to provide integration of the charge output of the scintillation/photomultiplier detector or semiconductor detector.

The output of the preamplifier is connected to pulse-shaping main amplifiers. Impedance matching between the detector output and the pulse-shaping and amplifier stage that follow are provided by the preamplifier. Connecting the preamplifier as close to the detector as possible increases the signal-to-noise ratio.

For further details on the operating instruction, refer to the manuals for the specific preamplifiers that are located in the WBC library.

4.2.2 Amplifiers

Main Amplifier

The main amplifier further increases the signal from the preamplifier so that it can be used within the dynamic operating range of the system.

4.2.2 Amplifiers (contd)

Linear Amplifier

Linear amplifiers are required to ensure that the relationship between the input and output signal is maintained.

To measure individual signals, independent of previous ones, the signal decay time must be reasonably short compared with the input repetition rate in order to reduce pulse pile-up distortion. In addition, to be proportional to the amplitude of the signal from the preamplifier (and therefore the charge from the detector) the duration of the output signals from the amplifier must be longer than the rise time of the input pulse. For further details on the operating instructions, refer to instruction manuals for the specific amplifiers, which are located in the WBC library.

4.3 SPECTROSCOPY EQUIPMENT: THE MULTICHANNEL ANALYZER

The MCA is the basic spectroscopy counting instrument used in the WBC. Because of the MCA's versatility and the facility of operation, it is often used in applications where a scaler or rate meter in combination with a SCA might suffice.

MCA Operation

The MCA converts the pulse received from the amplifier into an equivalent digital number that is stored in memory location which most closely corresponds to the pulse amplitude. The processing time for each pulse is typically 100 M!msec.

Types of MCAs

There are ten different MCAs used at the WBC facilities representing five different models. These range from manually controlled devices to programmable microcomputer-controlled instruments capable of highly automated sequences.

Operation of MCAs

There are five basic steps that are necessary to properly set up and operate the MCAs. These steps are:

- Erase the selected memory.
- Start analyzer acquiring.
- Stop analyzer and be able to recognize that it has timed out.
- Display a portion of the spectrum in sufficient detail to be able to ascertain what channel represents the peak energy.

4.3 SPECTROSCOPY EQUIPMENT: THE MULTICHANNEL ANALYZER (contd)

- Output the spectrum on some permanent medium such as paper tape or a printed page to be able to identify the channel number and the contents of that channel relatively easily.

These steps must be practiced by the WBC technicians until they can be done well. Improper execution of these functions will result in wasted time, unrealistic results, and may destroy valuable acquired data.

4.3.1 MCA Calibration

Before the MCA can be used for either quantitative or qualitative analysis, it must be calibrated to a standard energy scale of pulse height distribution. In other words, it must be adjusted so that each channel represents a predetermined energy range and that a plot of pulse heights versus channel number has a zero intercept.

There are two MCA parameters that can be changed which will allow the MCA to be calibrated for any range of radiation energy desired. The two parameters are gain (either amplifier- or MCA-conversion gain) and the zero-level offset adjustment.

Gain

When the gain is changed, the energy peaks shift to a channel position proportional to the change in gain. If two photopeaks were initially falling in channels 60 and 100, and the gain is doubled, the peaks would then fall in channels 120 and 200. Initially the peaks were separated by 40 channels but after the gain change the peak separation is 80 channels (see Figure 4.4).

FIGURE 4.4. Change in Peak Location with Conversion Gain

4.3.1 MCA Calibration (contd)

Zero Level

In the case of the zero level offset adjustment, the two peaks would shift the same number of channels (see Figure 4.5), and the number of channels between the peaks remain the same. With these two adjustments, the MCA can be calibrated for any energy region or range desired.

Example

As an example for calibration, assume that a setup for an MCA to measure low-energy photons ranging from 0 to 256 keV at 0.5 keV per channel with a zero intercept is desired. This can be done by using an americium-241 source that emits a 59.5-keV gamma ray and a uranium-235 source that emits a 185.5-keV gamma ray. To calibrate the MCA at 0.5 keV per channel, the 59.5-keV peak needs to center in channel 119 and the 185.5-keV peak needs to center in channel 371.

FIGURE 4.5. Change in Peak Location with Zero Level Offset Adjustment

4.3.2 Example of Adjustment

What change should be made if the 59.5-keV peak falls in channel 126 and the 183.5-keV peak falls in channel 384?

When properly calibrated, the number of channels between the peaks should be 371 minus 119, or 252. In the above situation there are 384 minus 126, or 258 channels. Since there are 6 channels too many between the peaks the first step would be to reduce the gain until 252 channels exist between the peaks. We can reduce the gain until the 185.5-keV peak is in channel 375 and the 59.9-keV peak is in channel 123.

4.3.2 Example of Adjustment (contd)

At this point there are 252 channels between the peaks, which is the number desired, but both peaks are 4 channels higher than what is needed. The next step is to change the zero level offset so that the spectrum shifts down by 4 channels and the energy calibration is then complete when the peaks fall in channels 119 and 371.

Some final, very small adjustment in gain or lower level offset may be necessary so that the 2 peaks are precisely centered in the appropriate channel.

SECTION 5.0

QUALITY ASSURANCE

5.0 QUALITY ASSURANCE

Whole body counting results are a very important part of an employee's documented work history. The WBC operations must conduct all work with the highest standard of quality commensurate with the requirements of internal dosimetry; cost; employees' time, safety, and comfort; and availability of equipment.

The quality assurance procedures are included in each of the measurement procedures described in Section 3.0; a summary of the overall quality assurance program as it relates to quality results is presented in this section. All WBC measurements are performed according to PNL's internal quality assurance guidelines; the American National Standard Institute (ANSI) Standards Internal Dosimetry for Mixed Fission Products and Activation Products (ANSI 1978) and Practice for Occupational and Radiation Exposure Records Systems (ANSI 1972).

5.1 EQUIPMENT CALIBRATION

Two types of basic calibrations--an energy calibration and an efficiency calibration--are made every time the equipment is used, or at least once a day for equipment in daily use.

5.1.1 Energy Calibration

Since all of the measurements are derived from energy spectra, the instrumentation and detectors must be calibrated for energy response so that a unit of energy of the output is exactly proportional to the energy of the radiation detected. At least two points on the energy spectrum, widely separated in energy, are needed for an energy calibration.

For example, the NaI(Tl) detector WBC is usually calibrated at 20 keV of gamma ray energy per channel of data output, whereas the lung counter is usually calibrated at 0.25 keV per channel.

5.1.2 Efficiency Calibration

After the detectors and instrumentation are calibrated for energy response, they are then calibrated for the primary efficiency response by measuring a National Bureau of Standards (NBS)-traceable, known quantity of a radionuclide in a phantom or organ as described in Section 3.0.

5.1.2 Efficiency Calibration (contd)

Daily Calibration Checks

The daily check of the efficiency is done with secondary reference sources that have long half-lives and that were measured for standard length of time in a reproducible geometry with respect to the detector at the time of the efficiency calibration. These secondary sources are contained in a matrix which does not change with aging so the geometry or the self-absorption of the source does not change.

A daily measurement of the background is also made. The daily efficiency count and the daily background are stored as retrievable computer data that are dated and accompany the employee measurement spectra data for that day.

If either of the daily efficiency check or background measurement do not fall within the expected limits of variance, the cause must be determined and eliminated before whole body counts are done. If the cause is a malfunctioning detector which must be replaced, a primary efficiency calibration with a phantom may be necessary.

The individual components of the measuring system such as detectors, amplifiers, high voltage supplies, and MCAs are not checked individually for sensitivity or linearity performance unless the total system fails to produce the proper count rate when measuring the standard reference source. If the count rate does not fall within acceptable limits of variability, the failing component is traced and replaced or repaired. Table 5.1 lists the quality assurance checks performed on each counting system.

Quarterly Calibration Checks

At quarterly intervals, the daily background and source efficiency counts are listed, the standard deviations calculated, and the listing reviewed for any trends that indicate changes in detector or instrumentation response that need attention. All measurements, whether absolute or relative, are referenced to an NBS-traceable radioactive source measured in a fixed reproducible position.

Frequency of Primary Efficiency Calibrations

Primary efficiency calibrations are only done every 5 or 10 years. However, if the secondary reference source counts indicate a change in the counting efficiency, or if the detector size or resolution changes, or a different geometry is used, then the system must be recalibrated with a NBS-traceable radioactive source in a standard phantom.

TABLE 5.1. Summary of Quality Assurance Checks for Counting Systems

<u>Counting System</u>	<u>Frequency of QA Check</u>	<u>Balance Multiple Detectors</u>	<u>Energy Calibration</u>	<u>Secondary Efficiency Calibration</u>	<u>Background-Interval</u>
Preview counter	Daily	Yes	Yes	Yes	Yes-1000 sec
Germanium array lung counters	Daily	Yes	Yes	Yes	Yes-1000 sec
Large-volume germanium array WBC	Daily	Yes	Yes	Yes	Yes-20 min
Shadow-shield counter (mobile counter and those in the EDF)	Each use	Yes	Yes	Yes	Yes-10 min
Wound counter	Each use	NA(a)	Yes	Yes	Yes-600 sec
Head and liver counter	Each use	Yes	Yes	Yes	NA(a)

(a) NA = not applicable

5.2 WHOLE BODY COUNTER RECORDS QUALITY ASSURANCE

All WBC measurements must be documented and stored for one year at the WBC. The documentation must be prepared with sufficient detail so that someone skilled in the work can reconstruct the calculation and confirm that energy and efficiency calibrations were performed and maintained on that day.

Fortunately, the natural potassium-40 existing in the body of every person acts as an internal standard of identification of any shifts in energy calibration and also gives a rough indication that the counting efficiency was satisfactory. Only the WBC final results are sent to Radiological Records for permanent record storage.

Records from the balancing of multiple detectors and energy calibration are not kept. The data from the efficiency calibration checks and the background are observed each day to note compliance with established good performance and then stored in the computer each day of its use.

5.2 WHOLE BODY COUNTER RECORDS QUALITY ASSURANCE (contd)

Each quarter these data are listed on hard copy output that is placed in a notebook. These notebooks are located in the library. The data are studied for any trends that might indicate instrumentation or detector problems.

The resolution of detectors is not checked on a daily basis. Any significant change in resolution will result in a loss of counting efficiency and therefore will be discovered during the source count. Periodic checks of resolution and balancing of photomultiplier tubes on detectors with multiple photomultiplier tubes will be done every 6 months for each detector used for in vivo counting. These checks provide valuable information on degradation trends in the detectors.

5.3 REFERENCES

American National Standards Institute (ANSI). 1972. Practice for Occupational and Radiation Exposure Records Systems. ANSI N13.6, New York, New York.

American National Standards Institute (ANSI). 1978. Internal Dosimetry for Mixed Fission Products and Activation Products. ANSI N343, New York, New York.

SECTION 6.0

WHOLE BODY COUNTER DATA PROCESSING

6.0 WHOLE BODY COUNTER DATA PROCESSING

The WBC facility utilizes a computer for most data processing functions. The following is a list of the eight general functions of the WBC computer:

- reduction of spectra from different sources into a standard format
- combination of descriptive alphanumeric information with the spectra into an easily retrievable record on a data base
- rapid calculation of results and storage of the results on the data base record
- comparison of the alphanumeric record with previously stored records to verify the accuracy of the alphanumeric record
- quick retrieval of records for recalculation
- plotting, printing, or summing of the regions of interest and tabulating results for additional analysis of single or grouped data
- transmission of data to a larger computer for reporting results to the field and permanent storage by records facilities or groups
- derivation of count information for cost accounting: number of counts, count type, and company statistics.

A detailed description of the data processing programs is included in two reports located in the WBC Library:

"Whole Body Counter Computer Programming Notes HP 9000/550 Executive Program,"(a) and "Whole Body Counter Computer Systems Programmers Guide."(b)

6.1 DATA SOURCES AND FORMAT

Each measurement or "count" done at the WBC represents a spectrum or histogram of the number of events versus the energy as detected by a given detector in a given geometry.

-
- (a) Pacific Northwest Laboratory internal report by D. M. Nieuwsma prepared for the Whole Body Counter facility, December 6, 1985.
 - (b) Pacific Northwest Laboratory internal report by K. K. Johnson prepared for the Whole Body Counter facility, May 28, 1986.

6.1 DATA SOURCES AND FORMAT (contd)

The MCAs that collect this information are from various manufacturers; therefore, the MCA information output can vary greatly in terms of the headers, the number of bits per word, parity, and other parameters. Spectra can also be entered manually, from magnetic tape, or through links to other computers. Input programs convert data to a uniform format so that all the data, whatever the source, may be handled by the same series of programs.

6.2 RECORD STORAGE

All spectra are assigned a unique serial number and if available, combined with descriptive alphanumeric information. The combination of a spectrum, alphanumeric descriptors, and the calculated results becomes a record that is stored in the computer's data base.

This data base can now be accessed by many different programs to plot, print, calculate, or do any number of statistical analyses. The descriptive information can be verified against previous entries in master files to assure the accuracy of social security numbers, payroll numbers, names, and initials. These data are essential for making results available to authorized parties.

Presently, the results from completed records are sent on the ORE data base in a batch mode on about a weekly cycle.

6.3 SUPPORTING PROCESSING FUNCTIONS

Calibration spectra are analyzed to develop factors used by the calculational programs. Daily background and source count spectra are organized and analyzed for quality assurance purposes. Curve-fitting and statistical programs reduce data to equations for easier use in computation or to indicate trends such as gradual loss of sensitivity or increases in background levels.

6.4 WEEKLY PROCESSING OF IN VIVO RESULTS

On a weekly basis, in vivo results are rigorously checked by the senior WBC technician to ensure that data are in the correct format, and that there are no duplicate records. The data are then transmitted by computer on the local area network to the UNIVAC computer for input to the ORE data base.

6.4 WEEKLY PROCESSING OF IN VIVO RESULTS (contd)

Two hard copies of the data are generated. One copy is retained by the WBC for future reference in the short term. The second copy is sent to Internal Dosimetry.

Non-DOE contractor measurements are stored on the computer at the WBC for 12 months. A hard copy of these measurements is also stored for 12 months. Within a week of any measurements, a form letter summarizing the results is typed, approved, and mailed to the individual non-DOE contractors.

6.5 CHECKING RESULTS

After the results have been written to the ORE file for submission to the ORE data base, visual record verification is performed. Results and other pertinent information are quickly scanned to assure that the proper calculation methods were used. Values calculated without computer automation are rechecked for accuracy.

Whenever errors are discovered, the weekly file is corrected before submission to the ORE data base. If any errors are detected after the tape is submitted, a letter of correction is sent to the Internal Dosimetry Group requesting that the record be revised and stating the reason for the required change. This letter should be addressed to Internal Dosimetry Specialist, and should contain the following information:

- Measurement identification (name, serial no., date, type, etc.)
- Correct result and data of correction
- Original result
- Reason for change
- Signature

6.6 WHOLE BODY COUNTER ANNUAL REPORT PREPARATION

The WBC supervisor prepares an annual report summarizing the activities of the routine counting program, research development, special studies, and improvements. The routine counting data for this report come from a log that is updated weekly. The number and types of counts performed for each contractor are required for the annual report.

6.7 SUBMISSION OF CHARGES

Charges for WBC services are distributed to the Hanford contractors on the basis of service provided the previous year. Charges for WBC services to non-DOE contractor are directed to work packages.

Automatic summing of count types is performed by computer for a designated time period for whole body, lung, head, abdomen, knee, throat, hand, special, and other counts.

SECTION 7.0

MINIMUM DETECTABLE AMOUNT, ACCURACY, AND PRECISION OF IN VIVO MEASUREMENTS

7.0 MINIMUM DETECTABLE AMOUNT, ACCURACY, AND PRECISION OF IN VIVO MEASUREMENTS

The statistical aspects of in vivo measurements, which are not as precise and as easily determined as those for measuring radioactive sources, are discussed in this section.

7.1 MINIMUM DETECTABLE AMOUNT

The value of the minimum detectable amount (MDA) indicates the ability of the WBC equipment to discern between the count rate from an internally deposited radionuclide and the count rate from the person if he were not internally contaminated.

Because of the variation in body size and shape in the general population, and the variable distribution of radioactivity within the body or organ, the MDA values are given for a uniform distribution in the body or organ for a "Reference Man" (ICRP 1975). The measurement sensitivity values will be less for thinner, smaller people and more for larger people because of differences in self-absorption.

Until the publication of this manual, the MDA values at the WBC were calculated as the equivalent to a count rate that is three times the standard deviation of the estimated background. This method did not give the same MDA that is recommended by Brodsky (1986) or the draft ANSI Standard N13.30 (1989), which uses 4.65 times the standard deviation of the background. This ANSI N13.30 method yields MDAs that are 55% higher than the values determined from 3 standard deviations.

For the measurements made with the germanium planar detectors, low-energy gamma, and x-rays above 25 keV, the photopeak can be visually observed on a plot of the spectrum when an amount equal to 3 standard deviations is present. The use of 4.65 standard deviation is considered to be too conservative for these measurements and MDAs using 3 standard deviations are used.

For measurements of x-rays below 25 keV with the germanium detectors and for high-energy gamma rays with the NaI(Tl) detectors, the MDA calculated by 4.65σ is probably more appropriate. The MDA values for various radionuclides in the body or organs measured at the WBC facilities are given in Tables 7.1, 7.2, 7.3, and 7.4.

TABLE 7.1. Accuracy and Sensitivity for In Vivo Measurements of Common Radionuclides Using Various Numbers of Germanium Planar Detectors

LOW-ENERGY PHOTON EMITTERS

$$MDA^{(a)} = \frac{3\sigma}{KT}$$

Radionuclide	Photon Energy	Time, sec	Organ	Number of Detectors	99% Confidence MDA or Statistical Error, nCi	1 σ Precision, (b) %	1 σ Estimate of Body Shape and Size Error, %
239Pu	59.5-keV 241Am tag with 15:1, 239Pu: 241Am ratio(c)	2000	Lung	8	1.8	10	20
		2000	Liver	3	1.4	7	20
		3000	Bone	2	3.5	10	20
239Pu	59.5-keV 241Am tag with 5:1, 239Pu: 241Am ratio	2000	Lung	8	0.8	10	20
		2000	Liver	3	0.6	7	20
		3000	Bone	2	1.2	10	20
239Pu(d)	17.0- and 20.4-keV x-rays from pure 239Pu, 3 cm CWT(e)	2000	Lung	8	50	20	40
		2000	Liver	3	100	20	40
		3000	Bone	2	50	10	30
		800	Wound	1	0.08	10	20
238Pu(d)	17.0- and 20.4-keV X-rays from 238Pu 3 cm CWT	2000	Lung	8	20	20	40
		2000	Liver	3	40	20	40
		3000	Bone	2	20	10	20
241Am	59.5 keV	2000	Lung	8	0.12	10	20
		2000	Liver	3	0.10	7	20
		3000	Bone	2	0.38	10	15
		800	Wound	1	0.10	10	15
238U(f)	93 keV from 234Th	2000	Lung	8	1.2 (3.5 mg)	10	20
235U	183.7 keV	2000	Lung	8	0.08 (0.036 mg)	10	20
232Th(g)	239 keV from 212Pb using 1:1 ratio	2000	Lung	8	0.38	8	15
144Ce	134 keV	2000	Lung	8	0.40	8	15
154Eu	123 keV	2000	Lung	8	0.06	8	15
		3000	Bone	2	0.14	7	15
156Eu	88.5 keV	2000	Lung	8	0.12	10	20
		3000	Bone	2	0.24	7	20
210Pb	48.5 keV	2000	Bone	3	2.0	8	15
125I	27 keV	2000	Thyroid	2	0.0025	10	15

- (a) See Equation 7.2.
 (b) Precision values are for cases where the count rate is high enough that the counting rate error is insignificant compared with the precision error.
 (c) This assumed ratio does not mean that this is a commonly found ratio, nor does it mean that the ratio of 239Pu to 241Am remains constant as it transfers from lung or wound to liver and bone.
 (d) Not valid routine procedures; see Section 3.0.
 (e) CWT = chest wall thickness.
 (f) 238U is determined by measuring the 234Th daughter. Calibration factors and MDAs are developed assuming that the activity ratio of 232Th and 212Pb is 1:1. The actual ratio must be applied to the MDA listed to obtain the actual MDA for each application.
 (g) 233Th is determined by measuring the 212Pb daughter. Calibration factors and MDAs are developed assuming that the activity ratio of 232Th and 212Pb is 1:1. The actual ratio must be applied to the MDA listed to obtain the actual MDA for each application.

TABLE 7.2. Accuracy and Sensitivity for Whole Body Counts in the Preview Counter

$$MDA^{(a)} = \frac{4.65 \sigma}{KT} + \frac{3}{KT}$$

Radionuclide	Gamma Ray Energy, MeV	Counting Time, sec	Organ(b)	95% Confidence MDA Statistical Error, nCi	1 σ Precision, (c) %	1 σ Estimate of Body Shape and Size Error, % (d)
137Cs-137Ba	0.662 MeV	200	WB L	3 2.4	5 5	± 10 ± 10
51Cr	0.32 MeV	200	WB L	22 18	5 5	± 15 ± 15
60Co	1.17 and 1.33 MeV	200	WB L	3 2.4	5 5	± 10 ± 10
131I	0.36 MeV	200	WB L	6 4.5(e)	5 5	± 15 ± 20
59Fe	1.10 and 1.29 MeV	200	WB L	6 4.5	5 5	± 10 ± 10
54Mn	0.84 MeV	200	WB L	3 2.4	5 5	± 10 ± 10
106Ru-106Rh	0.51 MeV	200	WB L	12 9	5 5	± 10 ± 10
40K	1.46 MeV	200	WB	15	5	± 10
110Ag	0.658 MeV	200	WB L	3 2.4	5 5	± 10 ± 10
22Na	1.28 MeV	200	WB	1.5	5	± 10
24Na	1.37 and 2.75 MeV	200	WB	0.7	5	± 10
232Th	Using 208Tl 2.61 MeV	200	WB L	2 1.5	5 5	± 10 ± 10
65Zn	1.12 MeV	200	WB L	4.5 3.4	5 5	± 10 ± 10
95Zr-95Nb	0.724 and 0.756	200	WB L	3 2.4	5 5	± 10 ± 10
125Sb	176 KeV	200	WB L	6 4.5	5 5	
154Eu	1.274	200	WB L	4.5(f) 3.4	5 5	± 10 ± 10
144Ce-144Pr	2.18	200	WB L	100(f) 75	5 5	± 10 ± 10
140La	1.596	200	WB L	2 1.5	5 5	± 10 ± 10

(a) See Equation (7.1).

(b) WB = whole body; L = lung.

(c) Precision values are for cases where the count rate is high enough that the count rate error is insignificant compared to the precision error.

(d) Activity in the gastrointestinal tract can give counting rates which vary 50%, depending on the location within the tract.

(e) Lower MDA can be obtained by other methods (see Table 7.3).

(f) Much lower MDA is obtained using 6 germanium planar detector systems (see Table 7.1).

TABLE 7.3. Sensitivity for In Vivo Measurement of Common Radionuclides Using a 4 Large-Volume Coaxial Detector Array for a 20-Minute Scan Count

Radionuclide	Gamma Ray Energy, MeV	MDA, μCi (calculated using $3\sigma/\text{KT}$)
^{40}K	1.46	4.7
^{60}Co	1.17, 1.33	0.83
^{137}Cs - ^{137}Ba	0.662	0.88
^{54}Mn	0.84	0.76
^{154}Eu	1.27	2.00
^{22}Na	1.28	0.71
^{59}Fe	1.10, 1.29	1.46
^{95}Zr - ^{95}Nb	0.72-0.76	1.44
^{65}Zn	1.12	1.50
^{106}Ru - ^{106}Rh	0.51	7.97
^{131}I	0.36	1.11
^{140}La - ^{140}Ba	1.60	0.45
^{208}Tl	2.61	0.33
^{149}Ce	2.18	13.06
^{51}Cr	0.32	11.75
^{24}Na	1.37, 2.75	0.37
^{110}Ag	0.66	0.80
^{214}Bi	0.61	1.69
^{58}Co	0.81	0.67
^{134}Cs	0.80	0.81
^{232}Th	2.61 using daughter ^{208}Tl	1.04

TABLE 7.4. Accuracy and Sensitivity for Selected In Vivo Measurements

Radionuclide	Photon Energy, MeV	Organ	Detector System	99% Confidence MDA Statistical Error, nCi	Precision	Estimate of Body Size and Shape Error
131I	0.36	Thyroid	3-in. x 3-in. NaI(Tl) 35% GeLi	0.030 0.020	±10% ±10%	±20% ±20%
Fission products in wounds	137Cs as an example	Wound	4-in. x 11 1/2-in. NaI(Tl) 35% GeLi	0.03 0.016	±5%	±5%
60Co	1.33	Whole body	Two 35% GeLi	5.0	±5%	±5%
241Am	0.595 lymph node	Axillary planar	20-cm ² germanium	0.01	±10%	±20%

7.1 MINIMUM DETECTABLE AMOUNT (contd)

The MDA formula recommended by ANSI N13.30 (1989) is:

$$MDA = \frac{4.65 \sigma}{KT} + \frac{3}{KT} \quad (7.1)$$

where σ = the standard deviation in the count of an uncontaminated person

K = the calibration factor in appropriate units as counts per unit of time per nCi in the body or organ.

T = the counting time interest used in consistent time units.

The MDA formula used for the germanium planar measurement is:

$$MDA = \frac{3\sigma}{KT} \quad (7.2)$$

7.2 ACCURACY AND PRECISION

The in vivo determination of radioactivity in the body or in an organ is not a highly accurate measurement because of the variable body size, shape, and distribution of radioactivity. Despite these shortcomings, the determinations are as accurate or more accurate than the radiation dose calculations which use the in vivo measurement results. For measurements of radionuclides that are rather uniformly distributed in the body such as potassium-40, cesium-137, and sodium-24, the precision and accuracy is relatively good but varies according to the amount in the body and the counting time. The accuracy and precision values have been estimated from human data such as those described in a study of niobium-92m in the lungs of 9 males and 11 females (Newton et al. 1985; Gunston and Jefferies 1986) and are given in Tables 7.1, 7.2, and 7.3.

Radioactivity that is not uniformly distributed in the body or which changes distribution with time is measured with less precision and accuracy. However, the measurement equipment has been designed to minimize the effects of nonuniform and changing distribution. The estimated values of precision and accuracy are given in Tables 7.1, 7.2, and 7.3.

7.3 REFERENCES

American National Standards Institute (ANSI). 1985. Performance Criteria for Radiobioassay. Draft ANSI N13.30, New York, New York.

Brodsky, A. 1986. Accuracy and Detection Limits for Bioassay Measurements in Radiation Protection - Statistical Considerations. NUREG-1156 (Draft), U.S. Nuclear Regulatory Commission, Washington, D.C.

Gunston, K. J., and S. J. Jeffries. 1986. Calibration of X-Ray Counters for Assessment of Internal Lung Contamination, with Low Energy X-Ray Emitters, in Women, Part I Measurements Made at AWRE. Final Report to THE International Atomic Energy Agency, Technical Contract 3362/TC, Vienna, Austria.

International Commission on Radiological Protection (ICRP). 1975. Report of Task Group on Reference Man. ICRP Publication 23, Pergamon Press, New York.

Newton, D., A. C. Wells, S. Mizushita, R. E. Toohey, J. Y. Sha, R. Jones, S. J. Jeffries, H. E. Palmer, G. A. Rieksts, A. L. Anderson, and G. W. Campbell. "The Livermore Phantom as a Calibration Standard in Assessment of Plutonium in Lungs." In Proceedings of IAEA Symposium on the Assessment of Radioactive Contamination in Man, pp. 189-199. IAEA-SM-276/01, International Atomic Energy Agency, Vienna, Austria.

SECTION 8.0

WHOLE BODY COUNTING RECORDS

8.0 WHOLE BODY COUNTING RECORDS

Internal dosimetry records are generated and maintained in accordance with DOE, ANSI, and PNL guidelines.

8.1 RECORD-KEEPING GUIDANCE DOCUMENTS

Requirements for the generation and maintenance of internal dosimetry records are contained in DOE 5480.11 (1989), as well as in several other guidance documents.

DOE 5480.11 states that individual occupational internal and external dose records and records of programs used to assess individual doses shall be generated and maintained sufficiently to provide appropriate reports to the employee, management, and those required by DOE 5480.11 and to support or re-calculate doses at a later date.

The DOE order references ANSI N13.6 (1972), Practice for Occupational Radiation Exposure Records Systems, for additional guidance. ANSI N13.6 provides detailed guidance for the generation of records for bioassay monitoring and dose assessments. Additional guidance is expected to be applicable in the future with the finalization of the "Performance Standard for the performance Testing of Internal Dosimetry Programs." (a) Upon its completion, it will become the basis for evaluation compliance with recording requirements in DOE 5480.11. Further guidance is given in draft ANSI N13.30, Performance Standard for Bioassay Laboratories (1989).

In addition to the requirements in the DOE-related guidance document requirements, the whole body counting function must meet the recording/documentation requirements set forth in PNL's internal quality assurance guidelines, because it has been defined as a QA Impact Level III function.

It is the intent that the records associated with the WBC results be in complete compliance with all the guidance documents listed above. The record compliance requirements and a list of the specific WBC records that fulfill each requirement are provided in the following two tables. Table 8.1 lists the requirements with a reference number for each item for the WBC record (listed in Table 8.2) that fulfills the specific requirement.

(a) Draft 8 of this performance standard was issued in November 1989. The draft standard was drafted by the DOE Expert Group on Internal Dosimetry, Chairman, R. M. Hall, Westinghouse Savannah River, Aiken, North Carolina.

TABLE 8.1. Record-Keeping Requirements for Whole Body Counting

<u>Requirement</u>	<u>Compliance Reference (See Table 8.2)</u>
Analysis Identification	
Measurement date and time	A-1
Reason for measurement	A-1
Type of measurement	A-1
Counting time	D-1
Identify responsible technician	D-1
Subject Identification	
Social Security Number	A-1
Measurement Process	
Procedure used	A-1
Date of measurement	A-1
Description of non-standard procedure	G-1
Approval signatures for non-standard procedure	G-1
Measurement system used	A-1
Energy range and energy/channel	D-1, A-1
Acquired Data	
Digital count results by channel	D-1, D-2
Factors for body size, chest wall thickness, etc.	A-1, F-11
Data Analysis Procedure	
Spectra data analysis procedure	A-1, C-3
Computer code and version	A-1, B-1 through B-7, E-1
Computer algorithm	A-1, B-1 through B-7, E-1
Departures from standard procedure and approval signature	F-10
Input data for calculations	D-1
Assumptions used in calculations, equations	B-1 through B-7, E-1
Analytical Result	
Body content of radionuclides	A-1
Units of body content	A-1
Uncertainty of measurement result	A-1
Location in the body	A-1
Minimum detectable amount	A-1
Quality Verification	
Calibration procedures	C-3
Equipment performance checking procedures	C-3
Description of phantoms and sources used for calibration	C-1, F-7, G-1
Calibration records	B-1 through B-11, E-1
Equipment performance checking results	D-1, B-8, E-1
QA test results and conclusions	D-1, B-8, E-1
QA/QC audit reports	D-1, B-8, E-1
Computer code documentation including software that runs hardware	F-6
Technician training and experience records	F-10

TABLE 8.2. Whole Body Counting Records That Fulfill Record-Keeping Requirements (see WBC Records Inventory and Disposition Schedule for location)

- A. Occupational Radiation Exposure (ORE) Data Base
 - 1. In vivo measurement results
- B. Calibration Notebooks
 - 1. Whole body measurements WB-1, Volumes 1,2 and 3
 - 2. Lung measurements LG-1, Volumes 1,2 and 3
 - 3. Liver measurements LG-1, Volume 1
 - 4. Lymph nodes, pulmonary and axillary LY-1, Volume 1
 - 5. Skeletal measurements SK-1, Volume 1
 - 6. Wound measurements WD-1, Volume 1
 - 7. Thyroid measurements TH-1, Volume 1
 - 8. Analysis of source and background counts SB-Stats. Volume 1
 - 9. Non-routine calculation documentation log NRC Log, Volume 1
 - 10. Realistic phantom data and instructions Phantom Data
- C. Whole Body Counter Manual, PNL-MA-574
 - 1. Policies
 - 2. Equipment description
 - 3. Procedures
- D. Magnetic Tapes (stored and rewritten every 5 years for 75 years)
 - 1. Spectra tapes from 1977 through 1989 (32 tapes)
 - 2. Spectra log tapes from 1977 through 1989 (10 tapes)
- E. Microfilm or Microfiche
 - 1. Calibration notebooks
- F. Hard Copy-Paper Files
 - 1. Software documentation
 - 2. Software design notes
 - 3. Software notes
 - 4. Program lists
 - 5. Quality assurance records
 - 6. Quality assurance audits
 - 7. Radiation source inventory
 - 8. Standard radioactive source inventory
 - 9. Standard radioactive source traceability records
 - 10. Job training records
 - 11. Chest wall thickness data
- G. Hard-Copy/Paper Files held by Radiological Records
 - 1. Hand calculations of in vivo results
- H. Laboratory Notebooks
 - 1. Production data for calibration phantoms and organs

8.2 REFERENCES

American National Standards Institute (ANSI). Practice for Occupational Radiation Exposure Records Systems. ANSI N13.6, New York, New York.

U.S. Department of Energy (DOE). 1989. Radiation Protection for Occupational Workers. DOE 5480.11, Washington, D.C.

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APPENDIX A

BROCHURE:

"THE HANFORD WHOLE BODY COUNTING CENTER"

The Hanford Whole Body Counting Center

Welcome to the Hanford Whole Body Counting Center. Hanford workers who are assigned to areas where radioactive materials are processed or stored may be scheduled for exams at the Whole Body Counting Center. Your examination provides another measure of assurance that the work place is safe and that the controls established to prevent and limit internal radiation exposure are adequate.

What Does the Whole Body Counter Do?

Your examination at the Whole Body Counting Center can detect the presence of very small quantities of gamma-emitting, radioactive materials that may be deposited in your body. For example, detectors at the Whole Body Counting Center can detect smaller quantities of gamma-emitting radioactive materials than the portable survey instruments and portal monitors at your workplace.

When are Exams Scheduled?

If you are a new employee and have formerly worked with or expect to work with radioactive substances, you will probably have an examination at the Whole Body Counting Center before you enter a radiation zone. You may also have an exam whenever a change in your job task or working condition involves a different type or form of radioactive substance. Most people who work in radiation zones at Hanford are examined on an annual basis; these exams establish a normal or "background" value against which future results can be compared. You also would be examined in the unlikely event you accidentally became exposed at work.

Results of most whole body exams are normal, meaning no radioactive substances from the site were detected in the body. However, if an intake is confirmed, additional exams are scheduled to observe the clearance of the material from your body.

What Kinds of Exams are Performed?

Two types of examinations, the whole body count and the lung count, are performed routinely at the Hanford Whole Body Counting Center. The whole body count measures the entire body from head to foot to determine whether any detectable quantity of radioactivity is present. The lung count focuses on the respiratory system. It is designed to detect gamma radiation from americium, plutonium, and uranium, the radionuclides associated with processing nuclear fuels at Hanford.

Your radiation protection group establishes a monitoring schedule for you based on the radiation protection requirements of your specific job. Everyone scheduled for an exam has a whole body count, which takes only three minutes. If you work in the fuels fabrication or separation areas, then you will probably receive a lung count as well as a whole body count.

Many other types of examinations can be performed at the Whole Body Counting Center, but they are reserved for special circumstances.

Preparing for the Exam

Because exam results are an important part of your permanent radiation records, the technician first requests that you put your name, payroll number and other identifying information on a form. About five minutes after you return the form, the technician calls you for your exam.

If you are having a lung count, the technician will ask you to shower and change into coveralls provided in the change rooms. These coveralls are required for the lung count because your personal clothing may have attracted small quantities of naturally occurring radioactivity from the air outdoors. Showers are also necessary prior to all lung counts because surface dust and naturally occurring radioactive particles from radon or thoron are attracted to the hair and skin and

may interfere with the measurement. These interferences may cause a result to be invalid. Since the objective of the exam is to measure radioactive substances deposited within the body, these interferences must be washed off prior to the exam.

The Whole Body Count

For a whole body count, five large stationary detectors have been installed in a lead-shielded booth. Lead shielding is necessary to reduce interference from natural sources of radiation in the environment.

When you step into the whole body counter booth, you are asked to stand upright against the detectors. The technician adjusts the detectors so that your chest is next to the one with the largest diameter. You need to lean against the detectors for about three minutes while electronic instruments and computers process the information they receive from the detectors.

No radiation is given off by these detectors. Instead, the detectors measure gamma rays emitted by radioactive substances deposited in the body. A computer analyzes the detector measurement to ensure that the results of your exam are accurate and reliable.

The final result of your whole body count may not be available immediately because processing takes time. In most cases, the lack of an immediate finding indicates that the result is normal. Your supervisor is informed of the findings and will pass the results to you. These results are maintained in your official permanent records.

The Lung Count

The lung count determines whether any detectable plutonium, americium, or uranium is deposited in your respiratory system. Before the lung count starts, you will lie on a bed and a technician will arrange a set of six individual detectors on your chest. (The position of the detectors is important for the measurement to be accurate.) The exam takes about fifteen minutes.

Because the detectors are very sensitive, the lung count must be performed in a room shielded with thick steel walls. This shielding reduces interference from natural sources of radiation in the environment.

Lung counts take more time for evaluation than whole body counts. In most cases you will know whether your exam was normal before you leave the laboratory, but detailed findings may not be available during your visit. Your supervisor will inform you of the findings and the results will also be in your official permanent records.

Sometimes Exams are Repeated

Occasionally, an exam has to be repeated. For example, a small amount of radioactive material on the skin or clothing can cause a higher than normal reading. This material may be due to naturally occurring radioactive dust particles from radon or thoron that attach to the hair or skin. If you are asked to have a repeat whole body count, the technician will request that you shower, scrub your chest and wash your hair. If the result of the repeat whole body count is normal, the source of activity found in the initial exam is attributed to external contamination.

Although it is unlikely, sometimes an internal deposition of radioactive material is confirmed. Additional examinations may be performed to identify the location of the deposit and the type and quantity of material present.

Follow-up exams may also be scheduled to determine the rate of elimination from the body. Results of these exams and the radiation dose estimates become part of your personal Hanford radiation records and also are made available to your supervisor.

Natural Radioactivity in the Body

Everyone has some internal body radioactivity. Most of it comes from potassium-40, the naturally occurring radioactive isotope of potassium. All plants and animals need potassium to live. An average person contains about 140 grams of potassium of which less than 0.01% is potassium-40.

Sources of Other Radioactive Materials in the Body

Other radioactive materials measured in humans, such as cesium-137 and strontium-90, are not naturally occurring, but are due to fallout from atmospheric weapons testing. Occasionally, small quantities of reactor fission products and radioactive cobalt, manganese and iron are found in workers who have been accidentally exposed while working on reactor piping. The cobalt, manganese and iron make up the stainless steel that very slowly becomes corroded as the reactor operates. Also, if your personal physician has recently prescribed a diagnostic or therapeutic radio-pharmaceutical, it may be detected during your whole body or lung count.

Questions?

If you have any questions regarding the systems used to perform exams or the methods employed to calculate results, please ask one of the technicians to direct you to a member of our professional staff. Our phone number is 376-6102. We will be glad to answer your questions.

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