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HISTORICAL REVIEW OF PERSONNEL DOSIMETRY DEVELOPMENT AND ITS USE IN RADIATION PROTECTION PROGRAMS AT HANFORD

1944 to the 1980s

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FOREWORD

This report documents the personnel dosimetry programs at Hanford from 1943 through 1985. It is the desire of the author not only to present a general history of these operations as they relate to practices at Hanford, but to provide a guide for future use if it is ever necessary to initiate an in-depth study of specific areas of personnel dosimetry.

ABSTRACT

This document is an account of the personnel dosimetry programs as they were developed and practiced at Hanford from their inception in 1943-44 to the 1980s. This history is divided into sections covering the general categories of external and internal measurement methods, in vivo counting, radiation exposure recordkeeping, and calibration of personnel dosimeters. The reasons and circumstances surrounding the inception of these programs at Hanford are discussed. Information about these programs was obtained from documents, letters, and memos that are available in our historical records; the personnel files of many people who participated in these programs; and from the recollections of many long-time, current, and past Hanford employees. For the most part, the history of these programs is presented chronologically to relate their development and use in routine Hanford operations.

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I would like to express my appreciation to the many past and current Hanford employees who kindly contributed their time and information to assist me in preparing this review of personnel dosimetry development and application in the Hanford radiation protection programs since their start in 1944.

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1.0 INTRODUCTION

In late December 1942, three weeks after the first successful nuclear chain reaction was achieved by Enrico Fermi in Chicago, the U. S. government signed a contract with the du Pont Company for the engineering, design, construction, and operation of the Hanford Engineer Works (HEW). The du Pont Company assigned this responsibility to the Explosives Department, and a new division was formed within the company, the Explosives Department--TNX. A site was selected for HEW in January 1943; two months later in March, construction began. By late September 1944 the first Hanford reactor began operation, and in February 1945 the first plutonium was delivered.

The rapid construction of HEW and the production of the plutonium that fueled the bomb dropped on Nagasaki in August 1945, were the events that formed the backdrop for the development of radiation protection programs that are discussed in this report.

1.1 ORIGIN OF RADIATION PROTECTION AT HANFORD

During the initial days of the Manhattan Project Dr. Arthur H. Compton asked Dr. Robert S. Stone, a radiologist from the University of California with a background and training in radiation, which included study at the Curie Institute in France,[a] to join the group at the University of Chicago Metallurgical Laboratory. In turn, Dr. Stone recruited Dr. S. T. Cantril, a radiation therapist, and H. M. Parker, a physicist from the Swedish Hospital in Seattle, because of their work with radiation at the hospital's tumor institute. These recruitments marked the beginning of the development of the large-scale radiation protection programs that evolved from the small group of scientists assembled in Chicago.

In February 1943, Dr. W. D. Norwood was transferred from the du Pont Kankakee Ordinance Plant to work at the Chicago and Clinton laboratories on radiation hazards control under the direction of Dr. S. T. Cantril and H. M. Parker. Dr. Norwood's transfer, along with the recruitment of other

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(a) R. H. Wilson, PNL, personal communication with Dr. P. A. Fuqua, August 26, 1986.

medical and technical personnel, laid the groundwork for the Hanford Medical Department.

In April 1943 Dr. P. A. Fuqua, also from the Kankakee Ordinance Plant, joined Dr. Norwood at the Chicago and Clinton laboratories (Parker 1944; Cantril 1944b).

In the spring of 1944, Dr. Norwood and Dr. Fuqua were transferred to Hanford. In July of the same year H. M. Parker was transferred to Hanford and became the chief supervisor of the Health Instrument (HI) Section in the Hanford Medical Department. Dr. Cantril came to work at Hanford as the assistant superintendent of the Hanford Medical Department in September 1944.

The original plans for Hanford included only a small "hazards engineer" group assigned to the Technical Department for radiation control. This group's functions were envisioned as being similar to conventional production plant safety engineers or inspectors. However, the experience of the du Pont staff and both Cantril and Parker at the Clinton and University of Chicago Laboratories indicated that a much larger, technically oriented group was required.

In May 1944 a proposal[(a)] was submitted to the du Pont headquarters in Wilmington, Delaware that requested a much larger Hanford organization (Table 1.1).

Parker, who headed the radiation control work at University of Chicago and Clinton laboratories at that time, approved of this proposal. Immediately afterwards Parker transferred to du Pont from the University of Chicago and came to work at Hanford as a member of the Medical Department. After reviewing the personnel needs, he proposed a staff of 138 for the HI Section for radiation control at HEW (Table 1.2).

At the time of the formation of the Medical Division at the Metallurgical Laboratory in August 1942 at the Chicago Laboratory, radiation protection on the scale that would develop had never been envisioned before. The development of a radiation protection program was later applied at the Clinton Laboratory,

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(a) J. N. Wilson. May 4, 1944. Letter to S. J. Bugbee, subject: H.E.W. Hazards Group. du Pont, Richland, Washington.

TABLE 1.1. Organization Proposed for the Hazard Engineer Group, May 4, 1944[a]

Position	Number of Employees
Hazards Engineer	1
Secretary	1
Assistant Hazards Engineer	1
Pocket Meter Supervisor	1
Assistant Pocket Meter Supervisor	1
Pocket Meter Foremen	24
Instrument Checkers	48
Film Laboratory Foremen	4
Operators	12
Film Marking Foremen	4
Helpers	4
Repair Man	1
Hazards Coordination Supervisors	4
Area Engineers	32
General Site Surveyors	8
Drivers	4
Chief File Clerk	1
File Clerks	8
Stenographers	2
Records Coordination Supervisor	1
Clerks	2
Laboratory Supervisor	1
Technicians	2
TOTAL	167

(a) J. N. Wilson. May 4, 1944. Letter to S. J. Bugbee, subject: H.E.W. Hazards Group. du Pont, Richland, Washington.

where this program grew to meet the demands because of the foresight of a few people who realized the future importance of radiation control (Cantril 1944a).

No precedent had been established for any aspects of reporting radiation exposure, training personnel, or orienting a large pool of workers who did not have any knowledge of the nature of radiation or the project on which they worked. No one knew what potential impact radiation might have on large numbers of people.

TABLE 1.2. H. M. Parker's Proposed Health Instruments Section Organization, July 19, 1944

Position	Number of Employees
Chief Supervisor	1
Assistant Chief Supervisor	1
Survey Area Supervisor	1
100 Area Senior Supervisor	1
Shift Supervisors	12
200 Area Senior Supervisor	1
200 E and 200 W Shift Supervisors	12
231 Shift Supervisor	1
Shift Surveyors	4
300 Area Senior Supervisor	1
Shift Surveyors	2
Site Senior Supervisor	1
Shift Surveyors	8
Calibration Supervisor	1
Operators	3
Personnel Meters Area Supervisor	1
Pocket Meter Senior Supervisor	1
Shift Supervisors	4
Laboratorians	48
Film Meter Senior Supervisor	1
Shift Supervisors	4
Operators	8
Laundry and Decontamination Senior Supervisor	1
Senior Laboratorians	6
Special Studies Senior Supervisor	1
Technician	1
Laboratorians	2
Records	10
TOTAL	138

The Hanford Medical Department's organization as of March 1, 1944 is listed in Table 1.3.

TABLE 1.3. Hanford Medical Department Organization, March 1, 1944

Superintendent - W. D. Norwood
Assistant Superintendent
Chief Supervisor, Hospital
Chief Supervisor, Industrial Medical
Senior Supervisor
Physicians
Physicians, Village Medical
Senior Supervisor, Pharmacist
Shift Supervisor, Nurses

Following his arrival at Hanford, H. M. Parker assumed the position created for him, Chief Supervisor of Health Instruments. The HI Section was divided into three groups: survey, personnel meters, and special studies. By August 1944 there were 27 members working in the section.

A small nucleus of technical personnel (with the exception of H. M. Parker and C. C. Gamertsfelder) was quickly trained at the Clinton laboratory. Twelve people were given general training in the principles and practices of health physics, two others were trained in personnel meters, and another person was trained as a counselor. By September 1944, 14 other people were given a quick orientation course and sent to Hanford. Two instructors from the Clinton laboratory were available for transfer to the personnel meters program.

Recruiting qualified technical personnel was difficult during World War II, but personnel were found and trained for this specialized work by the time production operations began at HEW. Table 1.4 shows the growth of the Medical Department and the HI Section.

TABLE 1.4. Growth of the Medical Department and the Health Instruments Section from March 1944 to June 1945

Medical Department		Health Instruments	
March 1944 -	8	August 1944 -	27
December 1944 -	278	December 1944 -	98
January 1945 -	311	January 1945 -	104
June 1945 -	382	June 1945 -	155

The responsibilities of HI were established soon after the arrival of Cantril and Parker. In November 1944, Dr. Cantril issued Responsibilities of Health Group for Radiation Safety (Cantril 1944b), a document that reported the agreements that had been established with the du Pont Operating Department and Maintenance Department resolving responsibilities for radiation control. The following is an excerpt of this document:

1. Responsibility for maintaining radiation within safe limits in the operating areas rests with the area superintendent or those delegated by him.
2. The Medical Department, through representatives in the HI group, has the responsibility to management to insure that over-exposure does not occur. To carry out this function, it will be necessary to:
   (a) Maintain an HI representative in each of the operating areas at all times.
   (b) It will be his duty to make sufficiently adequate surveys to detect hazardous conditions or those potentially hazardous.
   (c) We should have access to any information that bears upon the safety of operations and should be consulted by Operations any time when there is a question of a potential hazard or one known to exist or of any hazardous incident that has occurred.
   (d) Conditions may arise which call for alterations in routine operations and these are considered in Class A, B, and C.
      Class A This is defined as a emergency requiring immediate attention or possibly evacuation. The HI representative reports to the Acting Area Supervisor and in this case the advise of the HI representative must be considered final.
      Class B This is defined as an unsafe condition in which there is a sufficient period of time (a matter of hours) to discuss the condition with Operating Supervision or other members of the HI Group or the Medical Department. In this case the advice of the Medical Department or its HI representative is the discussion as to safe levels of exposure is to be followed. The method of rectifying the existing condition to insure safety will in most instances be defined by Operations. The HI Group will act in this regard wherever it can give assistance.
      Class C Conditions which do not need attention immediately or within a period of hours.
3. Channels of reporting unsafe conditions:
   (a) The HI representatives will not report to Operations unless an unsafe or potentially unsafe condition is found. Operations may request a survey or report from the HI representative in the area.

(b) In a Class A emergency the HI representative will report verbally to the Acting Area Supervisor, as stated in 2a above. When there is time and need for discussion with Operating Supervision and other members of the HI or Medical Department the report will go verbally from the HI or Medical to the Acting Area Supervisor. This is envisaged under Class B above. All other reports (Class C) will go in writing from the HI Group or Medical Department to the Area Supervisor. Maintenance reports will go to the Maintenance Superintendent with a copy to the Chief Supervisor concerned.

4. Integron Records:
   (a) Integrons used for monitoring of radiation safety will be calibrated by the HI Group at periodic intervals.
   (b) The Instrument Group will service the integrons and remove the records periodically, transmitting them to the HI Group. The HI Group will review and store these records in some location provided for them. It has been suggested that one of the metal vaults in the 300 Area could be made available.
   (c) It is suggested that notes made on the integron records concerning any unusual recording. It is proposed that notes could be written on the record by either Operations or an HI representative but that in an initial start-up period, we would request Operations to contact the HI representative and that the usual writing on the record be done by the HI Group. The reason proposed for this procedure was that it would give the HI Group a chance to further acquaint Operations with radiation hazards problems. Any note placed on the chart should be dated and signed with signature of the man making the notation.
5. The Medical Department and HI Group will feel free to make any investigations necessary concerning any incident of radiation hazard which may potentially exist or have occurred. This may at times be totally independent of any investigations conducted through the Central Safety Committee.

This statement of responsibilities was signed by both Dr. Norwood and Dr. Cantril. Those in charge of the work had the responsibility to inform their workers, within the limits of security, of the nature of the hazards they encountered. The Medical Department and HI disseminated this information. Frequent, informal meetings were held with operations personnel for training and a formal program of six lectures on radiation hazards and protective measures were developed with the Technical Department.

The policy for radiation safety was also established and stated in a memorandum[a] issued in August 1945 which stated in part:

> "...by agreement with management and the various departments, that the responsibility for radiation safety was in the last analysis the responsibility of the department concerned in the particular operation. It likewise was agreed it was the function of Plant Medical and Health Instruments to call to the attention of the department concerned unsafe practices which it observed or, of potentially unsafe conditions which might arise. This policy has been followed, and has proved a practical solution for the safe conduct of a potentially very hazardous undertaking."

On December 31, 1945 Dr. Cantril left Hanford to return to Swedish Hospital in Seattle; but he continued to serve as a consultant for Hanford. His position in the Medical Department was discontinued. The HI Section was separated from Plant Medical and reported directly to the Medical Department Superintendent. Not long following this reorganization, H. M. Parker was made an Assistant Superintendent in the Medical Department, a promotion which further upgraded the importance and emphasis on radiation protection functions.

1.2 OPERATIONAL PROCEDURES FOR RADIATION CONTROL

With the ability for large-scale irradiation of uranium metal and separation of radioisotopes, the need for large-scale radiation protection programs never before considered was thrust upon the people working at Hanford. The 3745 and 3746 Buildings in the 300 Area, shown in the lower right hand corner of Figure 1.1, were assigned to the HI Section. In addition, the upstairs space in the 3701 Gatehouse was used for film and pencil dosimeter processing.

1.2.1 Special Hazards Bulletins

In November 1944 a Special Hazards Committee was appointed as a subcommittee of the Hanford Central Safety Committee. The Hanford Central Safety Committee and Special Hazards Committee reviewed various phases of radiation hazards and issued five Special Hazards Bulletins (SHBs)in the early part of 1945.

(a) S. T. Cantril. August 27, 1945. Memorandum to the File, subject: Plant Medical Section - Activities to August 1, 1945. du Pont, Richland, Washington.

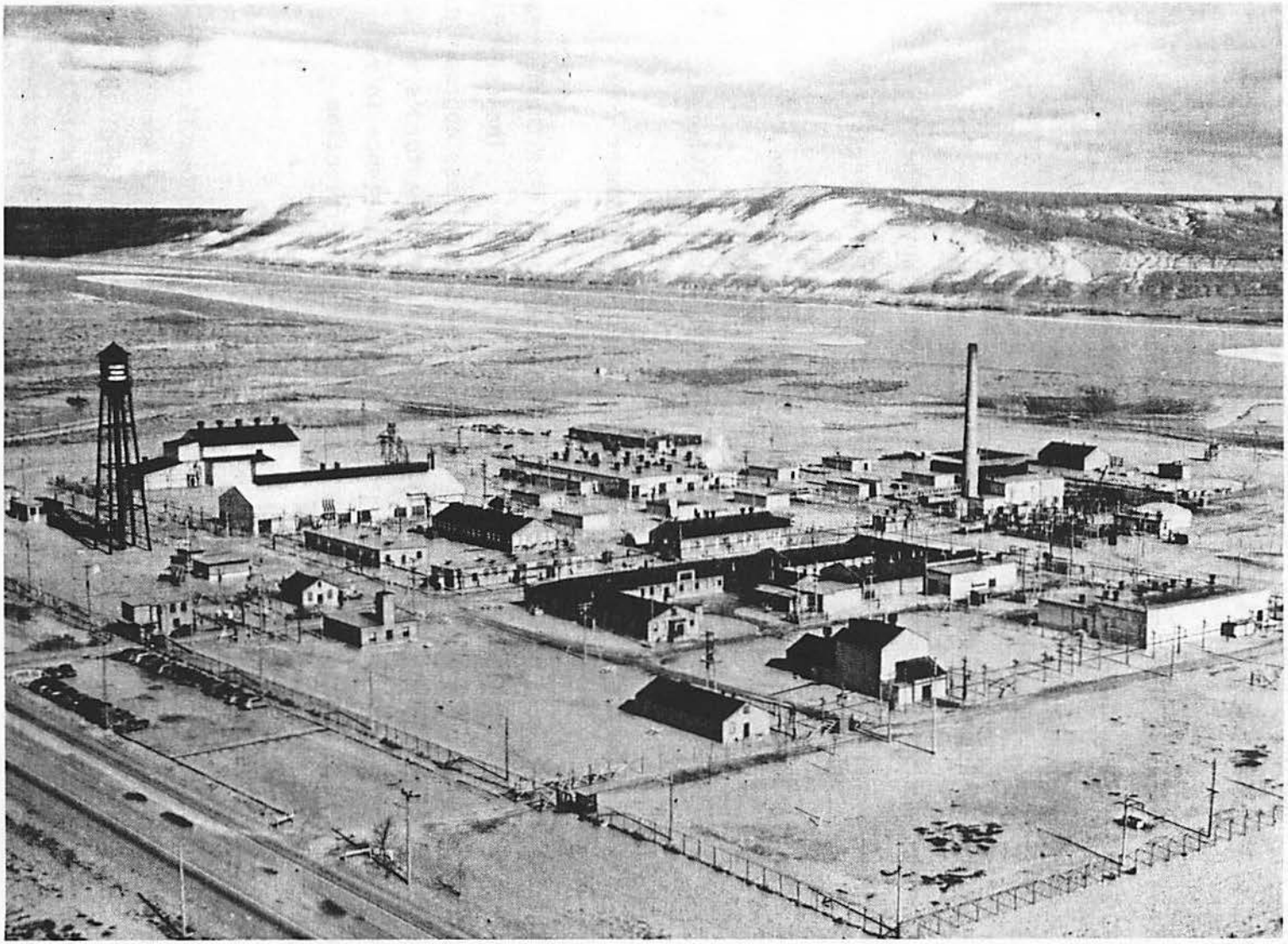

FIGURE 1.1. The 300 Area in 1945 (the 3745 and 3746 Buildings were assigned to the Health Instruments Section)

The SHBs had official sanction at Hanford. The first bulletins were published in 1945. Three other bulletins were subsequently published to provide guidance in handling situations that required control and special consideration because of radiological conditions. Table 1.5 lists the titles of the SHBs.

TABLE 1.5. List of the First Special Hazards Bulletins

No. 1	Procedures for Work in Danger Zones.
No. 2	Procedures on Suspected or Known Overexposures or Contamination
No. 3	Contaminated Waste Disposal
No. 4	Procedures for Injuries in a Product Work Zone
No. 5	Procedure for Interarea and Off-Plant Transfer of Special Process Materials
No. 6	Investigation and Reporting of Unsafe Practices or Incidents Arising from Special Hazards
No. 7	Procedure for Releasing Equipment from Areas Wherein Contamination is Possible
No. 8	Procedure for Fire Fighting in Radiation Danger Zones

The SHBs were periodically reviewed and revised to utilize the increasing experience and knowledge gained in the radiological sciences. The use of terms such as danger zones and special hazard zones became less appropriate. A need for a more detached and professional application of Hanford's radiation protection policies and practices arose with increased competence in radiation protection and with the National Council on Radiological Protection recommendations.

1.2.2 Special Work Permit

Soon after his arrival at Hanford, Parker introduced innovative operational controls for work with radiation; one of these was the Special Work Permit (SWP). This control form was completed prior to starting any radiation work in order to define the task, identify locations, and specify the type of special protective measures that would be required for the duration of the permit.

The SWP was used throughout Hanford for many years until it was phased out and replaced by more broad working procedures and control methods developed from operational experience. For many years the protective apparel and equipment used in the production and laboratory areas had the nickname of "SWPs."

1.2.3 Operational Standards

The concept of standards was initiated in 1951 when the SHBs were phased out and were gradually replaced by appropriate sections of the Manual Of Radiation Protection Standards, written by the staff of the Radiological Sciences Department. The first, partial manual was published in 1952; other sections were added as they were developed. The Manual of Radiation Protection Standards was implemented at its first publication on August 8, 1952, phasing out some of the old SHBs. The replacement of the SHBs by the manual was completed when the document was revised and expanded for its December 15, 1954 publication.

These standards as outlined in the manual, were further implemented by detailed work procedures and practices developed for use to meet the particular needs of each operating facility. One of the first formally published set of procedures was a Manual of Standard Procedures For 100, 200, and 300 Area Survey Work, December 1949. With the development of radiation protection standards, terms such as "Radiation Danger Zone" and "Special Hazards" were no longer used.

Table 1.6 presents a list of Special Hazards Bulletins, the standard that superseded them in the Manual of Radiation Protection Standards (1952), and the date of publication for that standard.

Essentially overnight, the large-scale operation at Hanford created the problem of controlling radiation exposure for the thousands of workers in facilities which handled the equivalent of billions of times the world's supply of radium. A whole new field of endeavor generally referred to as Health Physics was established to deal with this problem.

In order to cope with this enormous problem, Hanford operated under the recommendations of the 1934 National Committee on x-ray and Radium Protection (Taylor 1958) used by physicians treating patients with cancer. During the years 1944 to 1948, the Advisory Committee recommended a limit of 0.1 roentgen

TABLE 1.6. List of Special Hazards Bulletins and the Protection Standard That Replaced Them

SHB No.	Radiation Protection Standard Subject	Man. Sec. No.	Issue Date
1	Responsibility For Work In Radiation Zones	4.2	Aug. 1, 1952
2	Procedure At Time Of A Radiation Incident	6.1	Aug. 1, 1952
3	Radioactive Solid Waste Disposal	7.1	Dec. 15, 1954
4	Radiation Zone Injuries	6.2	Aug. 1, 1952
5	Shipment Of Radioactive Materials	4.9	Aug. 1, 1952
6	Radiation Incident Investigation	6.4	May 1, 1953
7	Release Of Equipment From Radiation Zone Status	4.5	Aug. 1, 1952
8	Emergency In A Radiation Zone	6.3	Aug. 1, 1952

(R) per day to control exposure of the individual worker to radiation. Hanford assumed a conservative control limit of 0.05 R per day as a working level.

The name of the Advisory Committee was changed to the National Committee on Radiation Protection (NCRP) in 1946 and enlarged its scope and membership to handle the problems and issues of the growing nuclear era. In 1948, the NCRP made basic changes in the concept of exposure limits by lowering the daily limit by a factor of 2 and expressing this limit in terms of 0.3 R per week to the blood-forming organs. Skin became a critical organ with a limit of 0.6 R per week. Extremities were allowed 1.5 R per week and relative biological effectiveness factors (RBE) were established.

No change was necessary in Hanford's basic operating rules as a result of the revised exposure limits because the previous conservative stand was in line with trends for more restrictive recommendations. However, around 1950 the concept of long-range control was introduced at Hanford. Attention was then given to the annual exposure of personnel. A permissible exposure limit

of 3 R per year was introduced and at the same time planned changes in controlling exposure were assumed to more fully utilize the allowable 3 R per year. This concept was in full use by 1952. By 1955, provisions were made to double the daily limit, or even allow an exposure level of 0.25 R in one day if necessary for efficient operation. Very strict controls and approvals were enforced to assure no exposure exceeded the weekly limit of 0.3 R.

Once again, the NCRP made basic changes in exposure control limits by extending the weekly limit to 3 rem per 13 weeks and a yearly exposure limit of 5 rem. Further changes, made in 1959, established exposure limits to a maximum permissible accumulated dose based on the concept of age. The accumulated dose at any age was not to exceed 5 rem multiplied by the number of years beyond the age of 18. Accumulation could not be faster than 3 rem in any 13 consecutive weeks. Administrative control at Hanford limited exposure to 1 rem per four weeks and 5 rem per year.

The historical trend has been toward decreasing national and international permissible limits applicable to radiation protection. These limits are now broadly similar to the limits that have been applied at Hanford for the past several years.

1.3 TRAINING FOR RADIATION PROTECTION CONTROL PERSONNEL

After World War II when Hanford's operations were no longer secret, the influence of H. M. Parker and many working with him in the emerging nuclear industry caused HEW to adopt a fundamental philosophy of maintaining the workers radiation exposure as low as practicable.[a] Very early in the history of Hanford, this philosophy led to the development and maintenance of a program to educate HEW employees about their radiological working conditions and to train them to perform their work in a safe manner.

Training courses were presented to those individuals working directly in the radiation protection organization in order to maintain the highest quality service to the Hanford workers. The reputation of this training grew rapidly

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(a) H. M. Parker. September 7, 1945. Memorandum to the File, subject: Health Instruments Section - Exposure Standards, Reports, and Records. du Pont, Richland, Washington.

and people came from other plants, laboratories, and from the military to attend these courses.

The instruction and training of personnel responsible for radiation protection activities throughout HEW was considered very important. Training for personnel began at the Clinton and Metallurgical Laboratories prior to assignment to the HEW. Very soon after the initial establishment of the HI Section formal training courses were developed to upgrade the abilities of staff.

One of the first intensive training courses involved mostly biological and medical information covered in ten lectures presented by the medical staff. The training course was called the "College Of H.I. Knowledge" and the agenda is listed in Table 1.7.

TABLE 1.7. College Of H. I. Knowledge Agenda, Medical 1 and 2

Lecture	Date	Subject	Instructor
1	Oct. 3, 1946	Anatomy - General	Dr. De Nicola
2	Oct. 10, 1946	Anatomy - General	Dr. De Nicol
3	Oct. 17, 1946	Anatomy - Skin & Bone	Dr. De Nicola
4	Oct. 24, 1946	The Thyroid Gland - Anatomy, Physiology & Biochemistry	Dr. Fuqua
5	Oct. 1, 1946	Respiration - Anatomy, Physiology & Biochemistry	Dr. Scudder
6	Nov. 7, 1946	Respiration - Anatomy, Physiology & Biochemistry	Dr. Scudder
7	Nov. 14, 1946	Digestion - Anatomy, Physiology & Biochemistry	Dr. Brockman
8	Nov. 21, 1946	Metabolism - Physiology & Biochemistry	Dr. Brockman
9	Dec. 5, 1946	The Excretory System - Anatomy, Physiology & Biochemistry	Dr. Brockman
10	Dec. 12, 1946	Blood & Lymph - Normal values, formation & regeneration	Dr. Fuqua

By 1948 a training course was developed to relate more directly to the problems of radiation protection and the methods used to solve those problems. This intensive course, the HI Engineers School, lasted several weeks and involved some testing to assure understanding of the material that was presented. Each section of the lecture series had a reading list to reinforce the material presented in the lectures. The following is an excerpt of the manual that was given to all the HI Engineers School participants, including a preface by H. M. Parker and an agenda for the material presented in the course:

> These lectures are part of the regular training course for men assigned to radiation protection duties. These were prepared by the several members of the H.I. Section supervision, with the exception of Lecture 10, for which we are indebted to Dr. P. A. Fuqua (Industrial Medical Section, Medical Department). They are aimed primarily at those who have technical degrees; for example, B.S.Ch.E., or the approximate equivalent. Much of the included physics is, therefore, of a review nature, pointing out the features which will be required for a proper understanding of the specialized radiation measurements to be made in the field.
>
> At the present time, the various lectures have not been edited to ensure uniformity of nomenclature and presentation. If the Series is found to have general interest, this may be attempted later. There will also be revisions in the subject matter as the knowledge of radiation effects and protection methods advances. Readers are invited to advise the writer of any factual errors detected, and to make suggestions for additions or improvements in the Series.
>
> Some interest has been expressed in the course by sources outside the Hanford Engineer Works. With this in mind, Lectures 16 through 20 have been published separately as Part II since these involve plant construction and processes which may not be available to such readers.
>
> H. M. Parker
> MEDICAL DEPARTMENT
> (H.I. Section)

INTRODUCTORY LECTURE SERIES IN HEALTH INSTRUMENTATION

Each lecture will cover about two and a half hours instruction, and the course will occupy alternate mornings of the first five weeks of the training course.

1. Scope of Health Instrumentation
2. Fundamental Concepts of Nuclear Physics
3. Properties of the Elementary Particles
4. Ionization in Gases
5. G. M. Counters and other Particle Detectors
6. Electrometers, Scalers, and Related Circuits
7. Health Instruments

8. Radioactivity
9. Fission and Fission Products
10. Effects of Radiation on the Body
11. Radiation Dosimetry
12. Tolerance Dose
13. Protection Methods
14. Special Hazard Bulletin #1
15. Other Special Hazards Bulletins #2,3,4,5,6

LECTURE SERIES PART II

16. Radio-chemistry of Fission Products and Plutonium
17. Description of the 100 Area Processes
18. 200 Areas Buildings
19. H. I. Training School Lecture, 231 Building
20. H. I. Survey Training -- 300 Area
21. Radioactive Waste Disposal

This lecture series was indeed continued and expanded, drawing people from other nuclear sites to take advantage of the excellent training. When the Savannah River and Rocky Flat plants were started up many of their radiation protection personnel attended the HI Engineering School. The U.S. Navy and U.S. Air Force also sent many of their personnel to Hanford for radiation protection training. During the early 1950s many specialized training courses, such as "Calculations Of Internal Emitters," were also developed.

1.4 REFERENCES

Cantril, S. T. 1944a. Procedures and or Room Rules Adopted by the Central Safety Committee on June 14, 1944. DuH-1702. du Pont, Richland, Washington.

Cantril, S. T. 1944b. Responsibilities of Health Group for Radiation Safety. HW-7-854. du Pont, Richland, Washington.

Manual of Radiation Protection Standards. 1952. HW-25457, General Electric, Richland, Washington.

Parker, H. M. 1944. Operating Standards #300-2. DuH-740. du Pont, Richland, Washington.

Taylor, L. S. 1958. "Brief History of the National Committee on Radiation Protection and Measurements (NCRP) Covering the Period 1929-1946." Health Physics 1:3-10.

2.0 EXTERNAL PERSONNEL DOSIMETRY

In the past, control of radiation hazards had been limited to the radium industry and to hospital work with radium and x-rays. Pocket ionization chambers (pencil dosimeters) and film had been developed for personnel monitoring by the small group of specialists in radiation therapy and were adopted almost entirely at the start of the Manhattan Project in Chicago, and subsequently at the Clinton Laboratory and at Hanford.

2.1 EARLY PERSONNEL DOSIMETERS

When the external personnel dosimetry program began at Hanford, both the Victoreen pocket ionization chamber (pencil) and the film badge were already being used at the Metallurgical and Clinton Laboratories. The projection minometer was considered satisfactory for bulk operations with pencils. The film badge was considered a satisfactory adjunct to the personnel meter (pencil) program. These devices were placed in service at Hanford more or less intact as soon as equipment and personnel could be obtained. Film badges (Figure 2.1) used during the first few months at Hanford were identical to those used

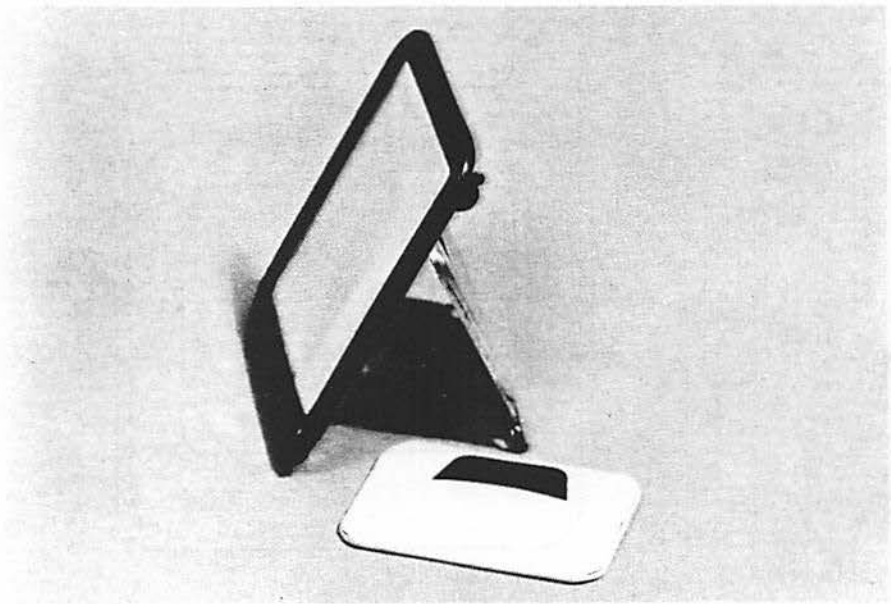


FIGURE 2.1. The Original Film Badge Worn by Hanford Workers

at the Metallurgical and Clinton laboratories but were soon modified to incorporate a security credential along with the film dosimeter (Figure 2.2). A few pencils with internal electroscopes were also available for making special measurements.

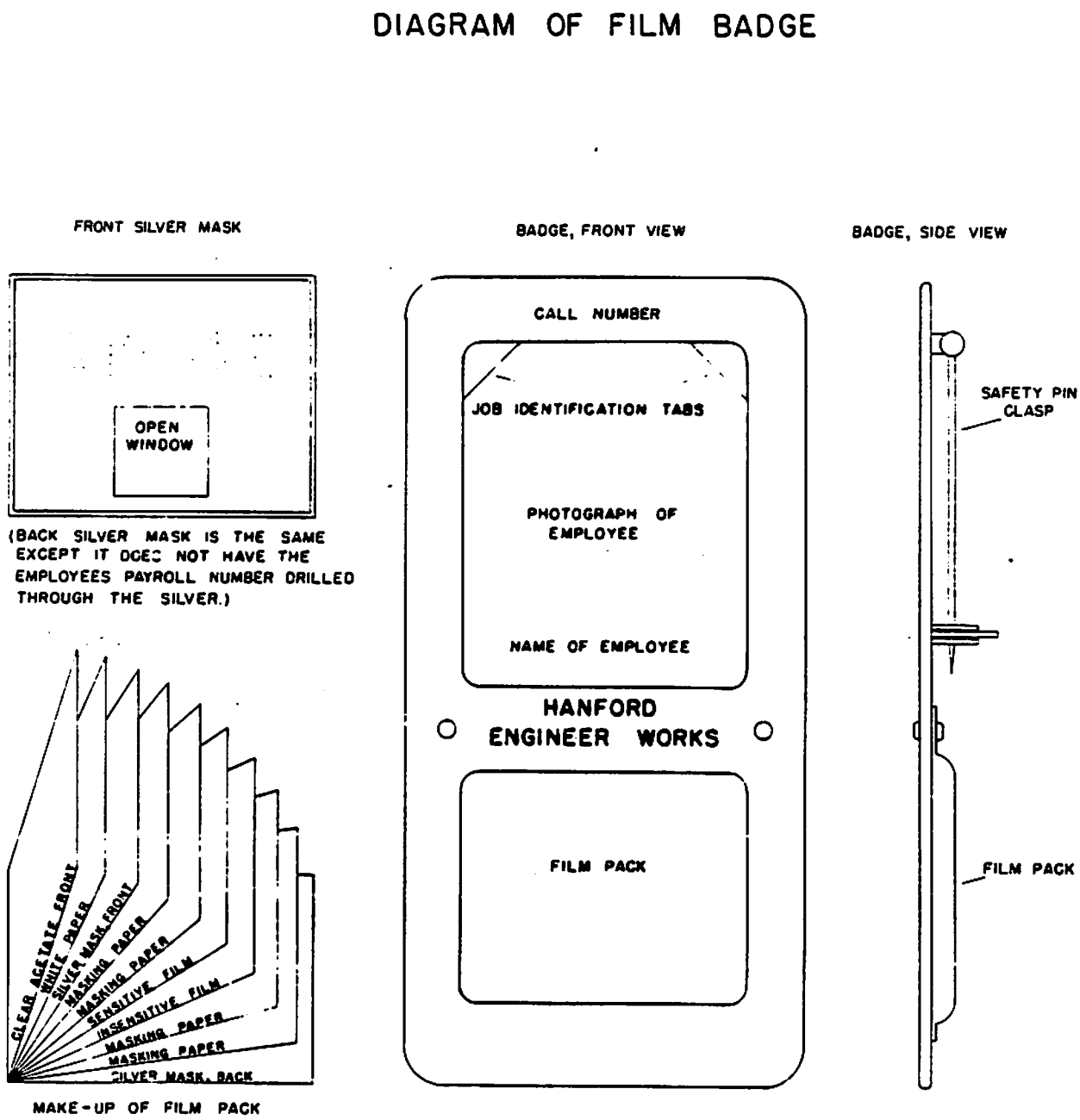


FIGURE 2.2. The Modified Film Badge in Combination with the Security Photo Credential.

2.2 FIRST USE OF DOSIMETERS AT HANFORD

The first pencil dosimeter program was started in January 1944 in the 100 Areas by the "P" Department and subsequently in the 300 Area. In July 1944, following formation of the HI Section, the 300 Area pencil dosimeter program was transferred to the HI Section, followed by the responsibility for plant-wide pencil dosimeter and film badge programs that were to be activated as equipment and personnel became available to administer these operations.

Pencil and film badge dosimeter coverage of selected personnel began in the plant operating areas on a regular basis on the following dates:

- 100-B Area: September 11, 1944 (pencils), Sept. 13, 1944 (film badges); B Reactor became reactive September 15, 1944.
- 200-W Area: November 7, 1944, T-Section of 200-W was accepted for use October 9, 1944 and the first tracer run of Clinton slugs was started December 6, 1944. All of 200-W was accepted for use on December 18, 1944.
- 300 Area: November 25, 1944. The 305 Test Pile became reactive February 23, 1944 and production line canning of slugs started May 11, 1944.
- 100-D: December 5, 1944 and D Reactor became reactive December 6, 1944.
- 100-F: February 13, 1945 and F Reactor became reactive February 15, 1945.
- 200-E: March 15, 1945. Area was accepted for use February 2, 1945.

The original design at Hanford located the laboratories for processing film badges and pencils in the gatehouse at the entrance of each operating area. However, when the personnel meter program actually started all film badges were processed and read in the 3701 Gatehouse. Pencil crews handled and serviced the pencil dosimeters in each area gatehouse for each shift. A traveling badge crew serviced the film badges weekly. The film packets, after being identified with a portable X-ray unit, were brought to the 3701 Gatehouse for processing and reading.

Film used at that time was the du Pont 552 packet, which contained a sensitive film and an insensitive film packaged together in a lightweight, light-tight wrapper. The packet was housed in a badge shielded by 1-mm-thick silver. This system was developed by E. O. Wollan (Pardue, Goldstein, and

Wollan 1944) at the Metallurgical Laboratory for balancing film energy dependence.

The film dosimeter was made an integral part of the security badge required to be worn in full view by all persons entering any of the Hanford operating areas. These badges were not allowed to be taken from the area in which they were used; so it was necessary to pick them up from the Security Patrol (Figure 2.3) upon entering an area and drop them off with a patrolman when leaving. Two pencil dosimeters were also given to each employee upon entering an operating area; they were turned in when leaving the area.

The film badge was introduced for the first time for regular use in the 100-B Area on September 13, 1944 and plans called for weekly processing. However, these film dosimeters were not processed for the first time until October 18, because equipment was not ready to handle them. Film badges were then processed at the end of November in the 300 Area, followed by processing 100-D and 200-W Area dosimeters in January 1945. By February a total of 20,300 film badges had been processed and because of the unriveting and riveting necessary for processing, the badges started showing wear and required more and more repair and replacement of dosimeter equipment.

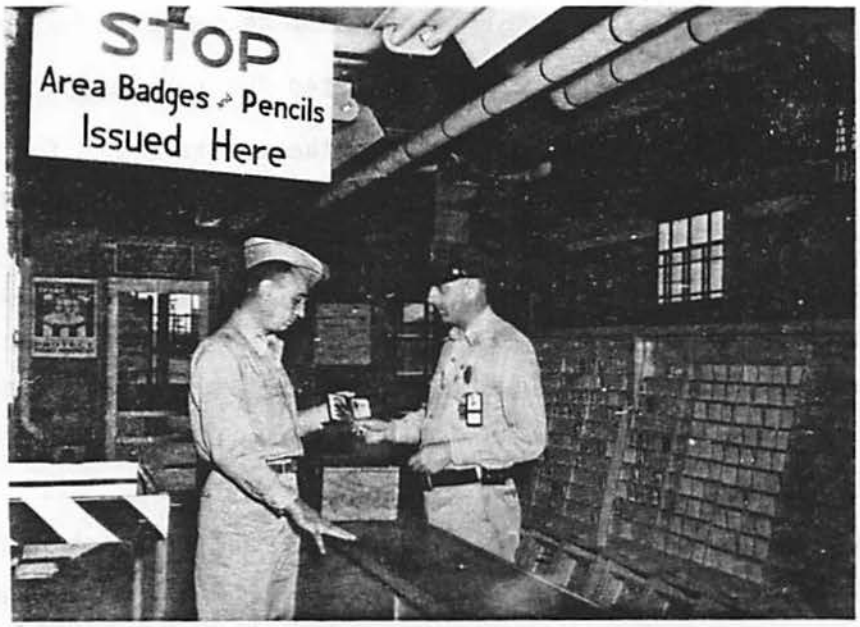


FIGURE 2.3. Hanford Worker Picking Up Badge at the Gatehouse

There are some indications that film was used in the latter part of July 1944, but it probably was used on a trial basis with dosimeters from the Metallurgical or Clinton Laboratories. In October 1944, the first film badges at Hanford to record radiation exposure were processed. During this early period, film reportedly was spread out on a white table top and only the film with visible darkening was read on a densitometer (Figure 2.4). No evidence of calibration has been found and it appears that values of exposure were assigned according to film density, ie., .03, .05, .06 represented 30 mR, 50 mR, and 60 mR.

The first calibration data used for reading personnel film apparently came in March 1945. At that time, radium gamma data for a 10-day period were averaged and a curve for the shielded and open window portions was established. A radiation dose was assigned for both open window and shield areas by reading directly from the calibration curve. This system was used through 1945 until a beta curve was established for the open window by exposure to a slab of uranium. All open window density was considered beta exposure during the first two years of operation.

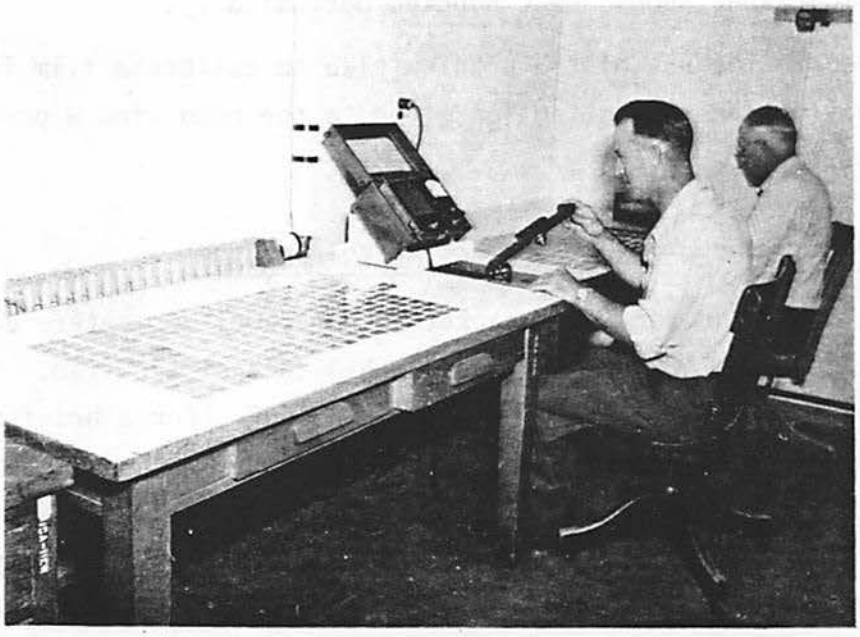


FIGURE 2.4. Reading Film from Badges Worn by Hanford Workers

Very early audits of the film badge records identified less than one error per 1000 entries even with all of the manual handling and recording of these results. Most of these errors occurred in what was called the "Rover" series; these were badges assigned to certain workers in as many as seven work locations at one time resulting in seven badges being processed each week for one person whether the badges were used or not.

A very early intercomparison study (Parker 1945) was conducted during 1945 involving the regular badge films that were exposed and photometered at the HEW, Clinton, and Metallurgical Laboratories. At that time all three laboratories used a radium source of known strength and at a known distance for calibration. This intercomparison study concluded that:

- Determination of gamma radiation exposure was satisfactory.
- There was a need for beta or low-voltage x-ray calibration.
- More frequent calibration at high exposures was needed.
- Attention should be given to photometer reproducibility.
- Neutron films were useful only in high neutron exposures that were not expected to occur normally at HEW.
- Intercomparisons should be conducted periodically.

This study led to the use of the uranium slab to calibrate film for exposure to beta radiation and more attention given to the open window portion of the badge in early 1946.

2.3 THE BETA-GAMMA PERSONNEL FILM DOSIMETER AND BADGE

Hanford used a du Pont film packet in personnel dosimeters designated as 552 which contained a 502-sensitive and a 510-insensitive film. This particular film packet was used exclusively from 1944 to 1957. For a brief period during 1957, a new du Pont film packet which contained an improved sensitive film designated as 508, as well as the 510 insensitive film, was used. The packet was coded as 222SX. This film improved the measurable sensitivity by lowering the detection limit to approximately 10 mR at the 95% confidence level as compared to 40 mR for the old 502-sensitive emulsion. By 1960, a new insensitive emulsion, 1290, was ready and was packaged with the 508-sensitive

emulsion. This packet designated as 558, was used until it was replaced by thermoluminescent dosimeters (TLDs).

Film packets were ordered in small lots and specifications required that all film be from the same emulsion lot. One order usually covered about a three-month operation using approximately 45,000 film packets. Each shipment of about 300 boxes was sampled; one packet from the top, middle, and bottom of every box was removed for immediate processing to determine background density. One carton contained 25 boxes of film packets and one box was used from each carton for calibration control purposes.

The badge which holds the film packet has a 1-mm silver shield and open window area around the film packet. This badge was adopted from the system originally developed for use at the Metallurgical and Clinton Laboratories and remained essentially unchanged until introduction of a new plastic film holder with multiple filters in April 1957. The shortcomings of dose interpretation (particularly in mixed radiation fields) were recognized very early, especially when large-scale processing of plutonium where mixtures of low-energy photons were present became routine. Interpretation of dose as measured by the film badge was studied (Larson and Roesch 1954; Larson, Myers, and Roesch 1955) extensively and methods of evaluating densities were determined to interpret dose contributions from low-energy photons. These detailed methods did not lend themselves to routine processing of literally thousands of dosimeters each week. If densities measured on the film indicated unusual and/or high exposure, a detailed analysis would be attempted for a better estimate of exposure. Figure 2.5 shows an early Hanford densitometer used to read film densities.

Design and development of a new dosimeter and new methods of dose interpretation were actively pursued starting in 1955. A new plastic film (Figure 2.6) holder with multiple filters was placed in service in April 1957 (Kocher 1957). It was constructed of Tenite II[a] plastic and consisted of two main parts: the housing or body and a removable portion called the slide. The design (Figure 2.7) allowed automatic unloading and loading of the film packet (Figure 2.8).

(a) Tenite II is a trademark of Eastman Chemical Products, Inc.

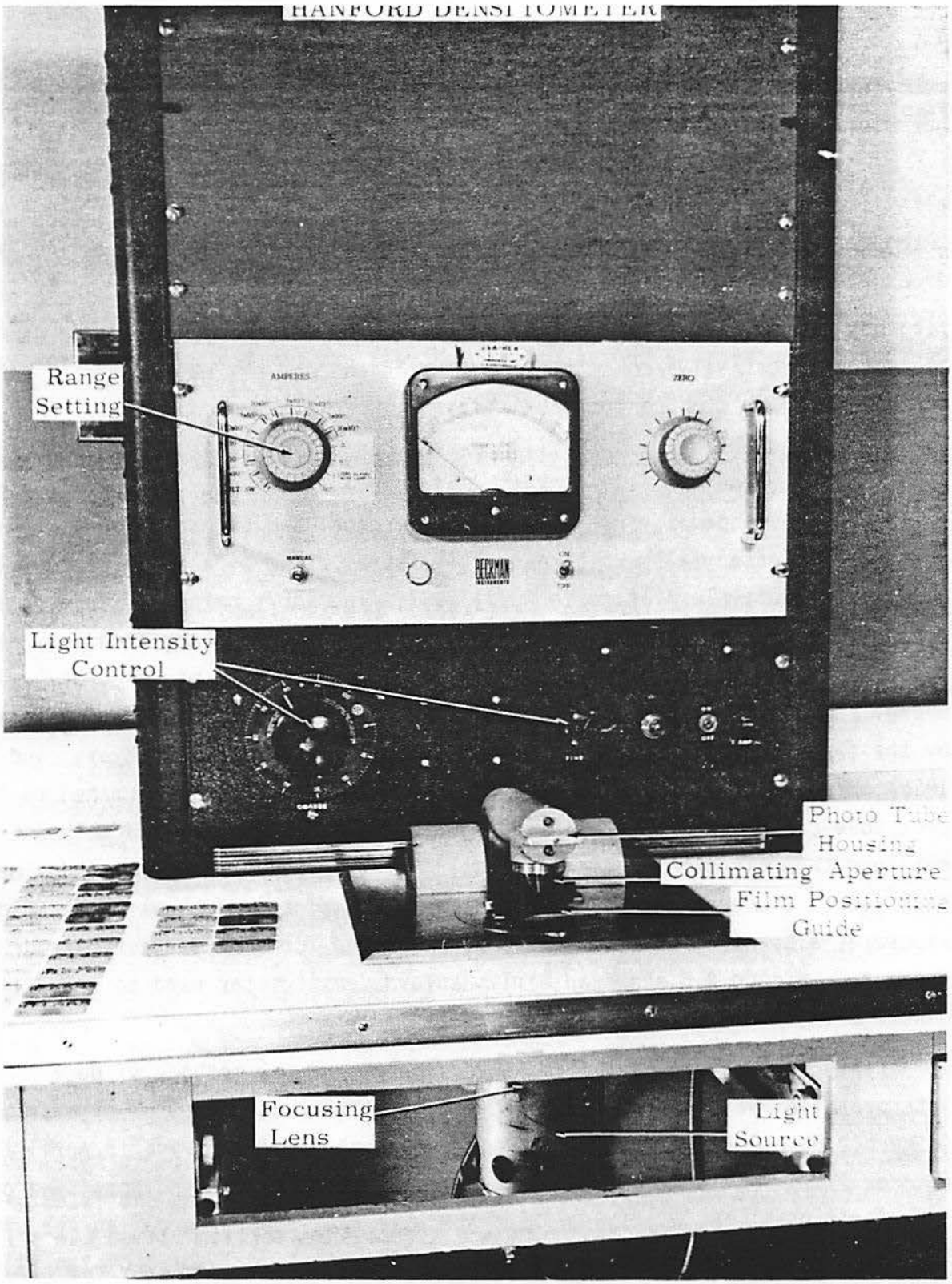


FIGURE 2.5. Densitometer Used to Read Film Densities

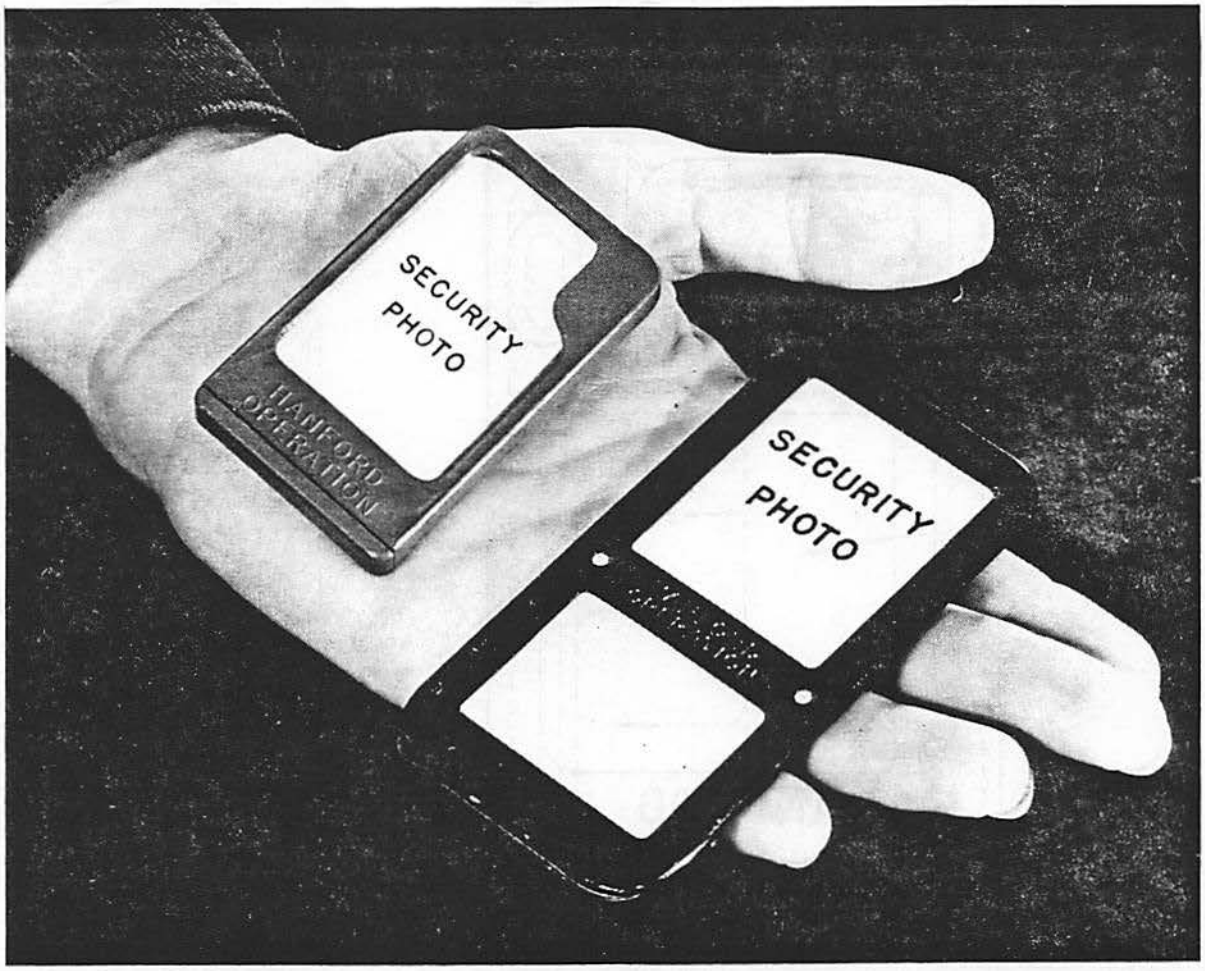
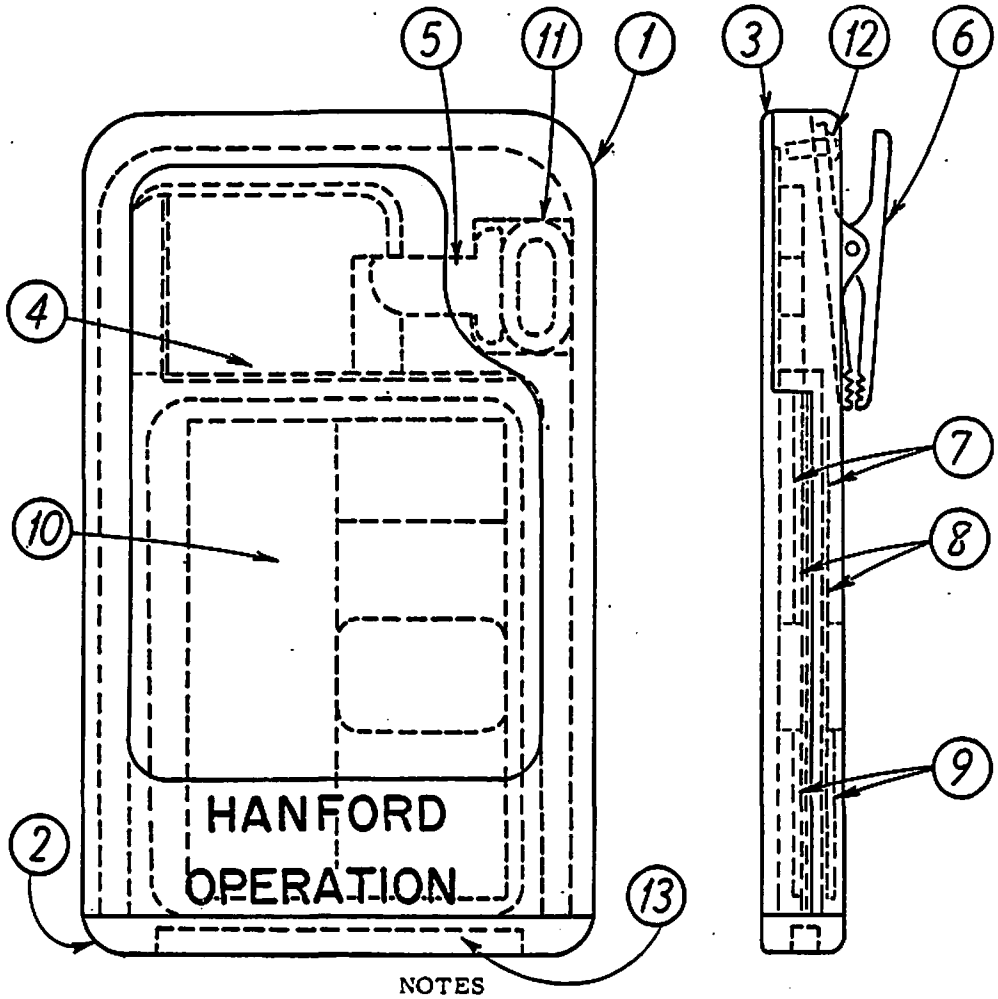


FIGURE 2.6. The Plastic Film Badge (left) and the Metal Film Badge

The new holder incorporated a three-filter system to more accurately interpret exposure from various energy ranges of gamma radiation. The three filters were made of 1) a 1-mm silver shield, 1 gm/cm^2, 2) a 0.005-inch silver shield, 0.13 gm/cm^2, and 3) a 0.019-inch Al shield, 0.13 gm/cm^2. The thin silver and aluminum shields were equal in mass per unit area for beta equivalency but decidedly different in absorption qualities for gamma radiation. The evaluation (Wilson et al. 1960) of gamma dose could be made to a limited extent even in the presence of beta radiation, and was a major step in improving dose interpretation in mixed radiation fields. A system of simultaneous equations was used to determine dose and with the recent utilization of the IBM 702 computer for dose evaluation and exposure recordkeeping, these calculations were easily integrated into routine processing.



NOTES

A. Cement Part 3 to Part 1 After Parts 5, 11, 7, 8, 9, 10 Are Assembled. Use Acetone
B. Cement Part 6 in Groove Using Duco. Press in Drive Screw.
C. For Shields use "3-M" Brand #EC847 Cement or Equal.

MATERIAL LIST

Qty.	Part No.	Description	Material	Item
1	1	Molded	Noted	Body
1	2	Molded	Noted	Slide
1	3	Molded	Noted	Cover
1	4	.010 x 2-9/16 x 3-1/4	Cellulose Acetate	Envelope
	5	.075 (14GA.) x 25/64 x 15/32	Soft Iron	Lock
1	6	Mueller #30 Mini-Gator	Cad Plate Steel	Clip
2	7	.0191 Th'k x 21/64 x 35/64	2s Aluminum	Shield
2	8	.005 Th'k x 21/64 x 35/64	Std Ster Silver	Shield
2	9	.03937 Th'k x 35/64 x 35/64	Std Ster Silver	Shield
1	10	.0065 Th'k x 1/2 x 13-9/64 3M Co. #420	Lead	Tape
1	11	.176I. D. X. 071 Th'k x .316 O. D.	Neoprene	"O" Ring
1	12	#00 (.058) x 1/8 Parker-Kalon Type U	Steel	Drive Scr.
1	13	.09 x 10 x 1-1/4	Soft Iron	

FIGURE 2.7. Design of the Plastic Film Badge (Kocher 1957)

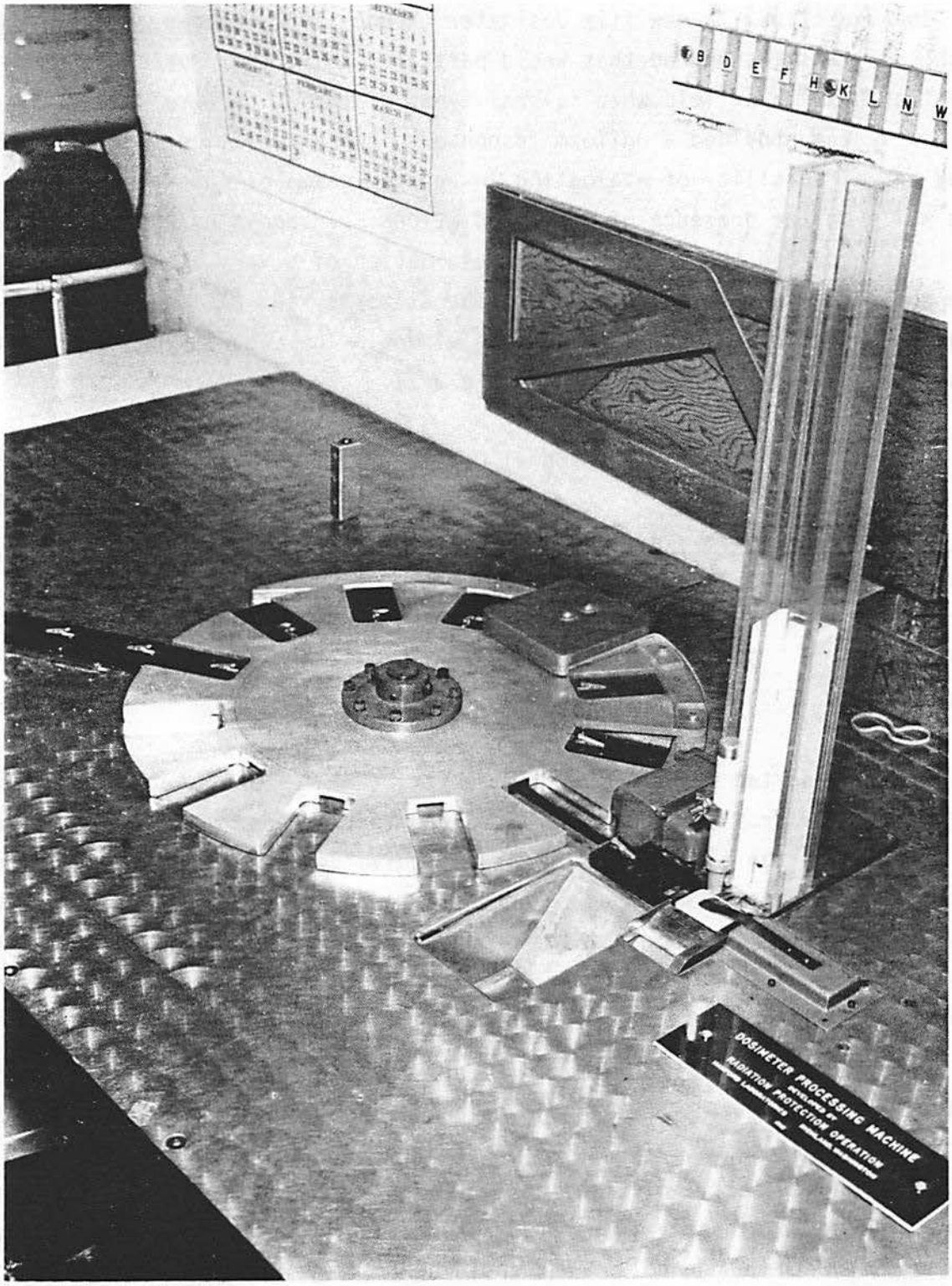


FIGURE 2.8. The Automatic Film Packet Unloading and Loading Machine

In August 1962, a new film dosimeter (Kocher 1962; Kocher, Bramson, and Unruh 1963) was introduced that would partially solve the problems of measuring radiation dose in a field when several types of radiation were present. The new system provided a uniform response to gamma radiation from <50 keV to 1 MeV and a capability of evaluating low-energy gamma of <50 keV and beta dose while in the presence of other radiations. In addition the new personnel dosimeter provided the capability for evaluation of a very high radiation dose from nuclear excursion, for example. The filter system utilized tantalum, iron, and plastic filters, plus an open window. The security photo of about 38 mg/cm^2 covered the open window (Table 2.1).

TABLE 2.1. Personnel Dosimeter Filter System

Filters	Size, in.	Thickness, mils	Total mg/cm^2 Less Security Credential
Tantalum	1/2 by 1/2	20	915
Iron	3/8 by 1/2	1	148
Plastic	3/8 by 1/2	70	178
Open Window	3/8 by 1/2	--	---

Plastic was inserted between the film and the tantalum and iron filters to shield the film from secondary electrons and very low-energy gamma radiation and to surround the film by air or tissue-equivalent materials. A system of simultaneous equations was used to determine exposure in the various energy ranges resulting the from densities produced on the film behind each filter. For very high-level dosimetry, the dosimeter contained a sulfur rod, glass fluorods, indium and copper foils, and a cadmium-indium-cadmium sandwich.

The modified plastic dosimeter (Figure 2.9) was very similar in appearance to the one previously used. Its dimensions were 3-1/8 by 1-3/4 by 5/16 in. and it weighed 34 grams. It was molded from Cycolac[(a)] plastic (styrene-butadiene-acrylanitrile) and was designed for use with the Hanford security badge in a neatly integrated assembly. The dosimeter credential was removable from the badge holder and could be readily removed by the wearer

(a) Cycolac is a trademark of Trapco Paint, Inc.

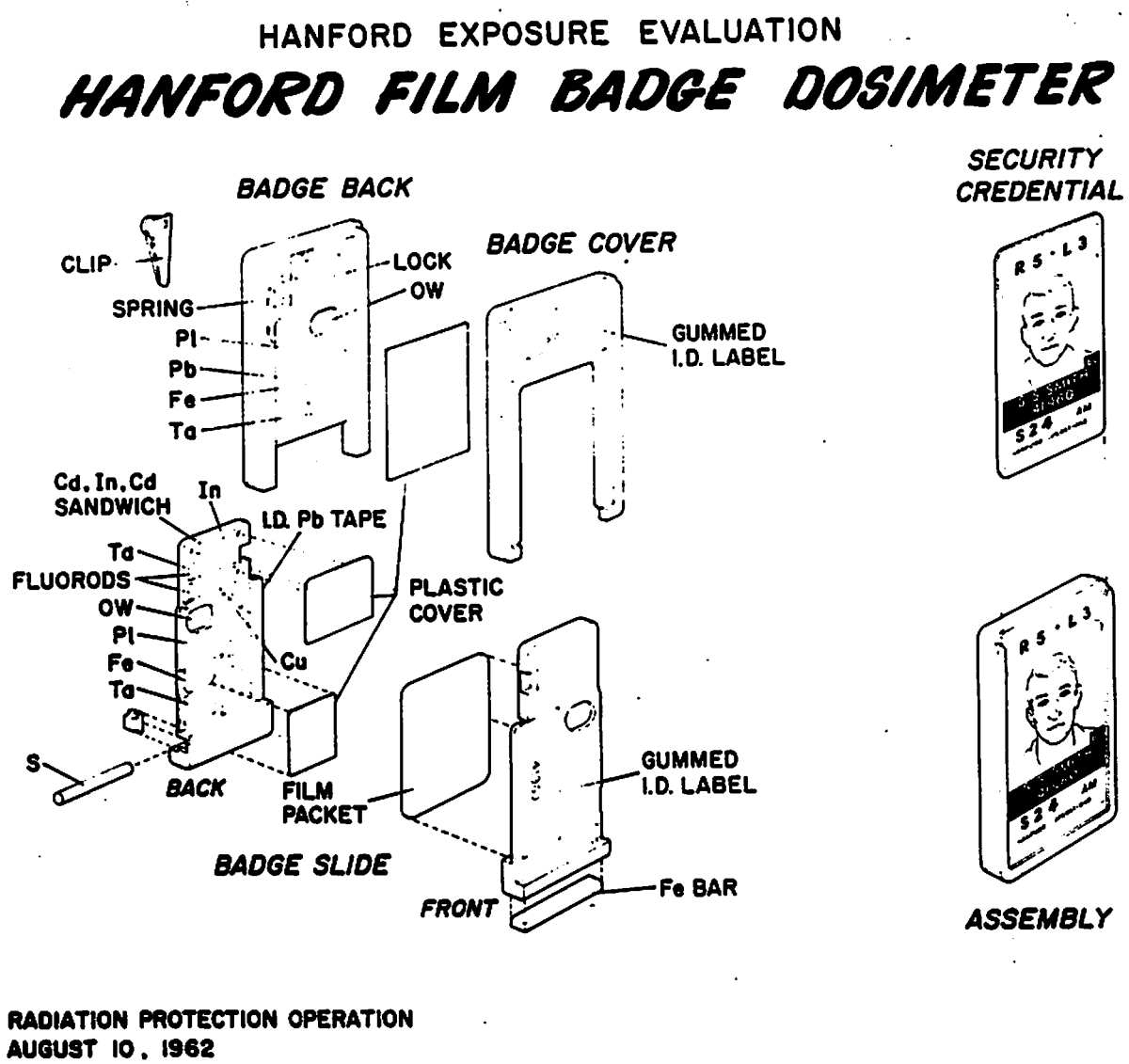


FIGURE 2.9. The Modified Plastic Film Badge and Filter System

for dosimeter exchange. The dosimeter was designed to take full advantage of mechanized processing. Each dosimeter contained a lead tape perforated with the employee's payroll number; prior to removal of the film packet, the payroll number was x-rayed onto part of the film to provide positive identification. Film identification and film pocket exchange were performed mechanically by the dosimeter processing machine.

Both the iron and the tantalum filters were covered with 20-mil thick "Tenite II" plastic to improve the energy response characteristics of the system. The filter system provided a linear density response ±10% for a given gamma radiation dose at any energy between 50 keV and 2 meV.

For dose interpretation of a film dosimeter exposed to beta, gamma, and x-ray radiation, the density behind each of the four filters was measured. The Hanford automatic densitometer (Figure 2.10) measured the density and read the payroll number, then provided an electronic data processing machine card which contained this information for machine processing. The machine processing utilized appropriate calibration data and made an evaluation of the radiation dose resulting from electromagnetic radiation between 50 keV and 2 MeV, electromagnetic radiation between 15 keV and 50 keV, and beta radiation assuming a beta energy spectrum similar to that emitted by natural uranium. The dose interpretation was made as follows:

- Electromagnetic radiation from 50 keV to 2 MeV - The density behind the tantalum filter was caused by electromagnetic radiations with energies greater than 50 keV. This density could be directly related to the dose by use of an appropriate calibration curve.
- Electromagnetic radiations from about 15 keV to 50 keV - The densities behind the plastic filter and the iron filter result from electromagnetic radiation and beta radiation. The response characteristics of the filter system were chosen so that electromagnetic radiation energies greater than 50 keV and beta radiation produced equal densities behind each of these filters. For electromagnetic radiations with energies less than 50 keV, the iron filter had a significantly higher absorption coefficient than the plastic filter; consequently, the difference in density between the plastic and iron filters could be directly related to dose by use of a calibration curve constructed for energies similar to those encountered by the dosimeter.
- Beta radiation - The densities behind the open-window and the plastic-filter areas resulted from electromagnetic radiation and beta radiation. Electromagnetic radiations with energies greater than 50 keV produced equal densities behind each of these filters. The difference in density

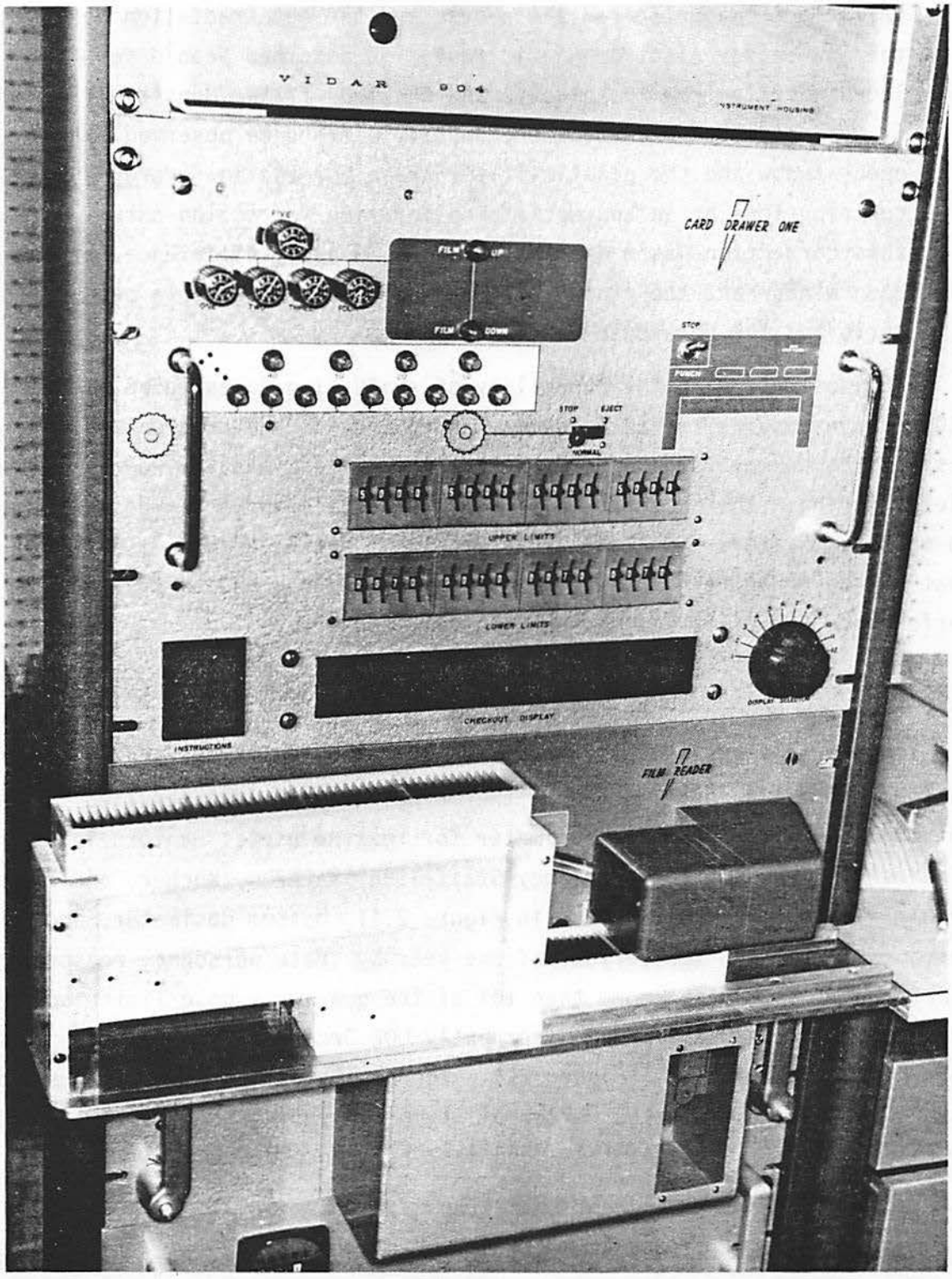


FIGURE 2.10. The Hanford Automatic Densitometer Used to Read Badge Film

between these two filters was a function of the low-energy (less than 50 keV) electromagnetic radiation dose and the beta radiation dose. Since the low-energy electromagnetic radiation dose had been determined independently from the plastic and the iron-filter density difference, it was possible to correct the density difference observed between the open-window and the plastic-filter areas for the low-energy dose contributions by an appropriate calibration correction curve. After this correction was made, the remaining density difference between the open window and the plastic filter could be related to a beta calibration curve and the beta dose determined.

The dosimeter had the capability of evaluating doses to an accuracy of ±10% from exposures to radium gamma, and plutonium and uranium metal radiations besides the normal range of dose evaluation. These results were obtained by field testing. The dosimeter also contained foils and other dosimeter materials to measure the very high level exposure from neutron and gamma radiations that may be encountered during a nuclear excursion. Table 2.2 shows the performance capability of the Hanford film badge.

2.4 THERMOLUMINESCENT DOSIMETRY

The great interest in the 1960s in the use of materials that could record and measure radiation exposure by thermoluminescence (TL) resulted in the introduction of a personnel dosimeter for routine use at Hanford in June 1971 (Endres 1968; Dosimetry Technology Staff 1966; Kathren, Kocher, and Endres 1970). This basic TLD is shown in Figure 2.11, bottom dosimeter, and is designed to be worn for periods of one year by those personnel reasonably expected not to receive more than 10% of the quarterly dose limits specified in the AEC Manual Chapter 0524 (currently DOE Order 5480.1 Ch. 11). In January 1972, a multipurpose TLD (Figure 2.11, top dosimeter) was placed in service for radiation workers with the capability of measuring beta, gamma and low-energy photons, as well as slow- and fast-neutron exposures.

2.4.1 Basic Thermoluminescent Dosimeter

The basic TLD consists of small block of ^{7}LiF 3.2-mm^2 square and 0.9 mm thick. It is embedded in a thin plastic card about the same size as the Hanford

TABLE 2.2. Summary of Hanford Film Badge Dosimeter Performance (Wilson et al. 1960)

DOSIMETER COMPONENT	TYPE OF RADIATION	RESPONSE ENERGY	DOSE RANGE	MEASUREMENT	CALIBRATION ENERGY
ROUTINE DOSIMETRY					
FILM	X-RAY, γ-RAY	0.01-0.050 Mev.	0.001 - 15 r	FILM DENSITY	0.017 Mev.
FILM	X-RAY, γ-RAY	0.05 Mev.-UP	0.015 - 1500 r	FILM DENSITY	0.05 - 2 Mev.
FILM	BETA RAD.	0.5 Mev.-UP	0.025-2000 rads	FILM DENSITY	URANIUM BETA RADIATION
SERIOUS RADIATION EVENT DOSIMETRY					
UNSHIELDED FLUOROD	X-RAY, γ-RAY	0.02-0.05 Mev.	5 - 1000 r	FLUORESCENCE	0.03 Mev.
TANTALUM SHIELDED FLUOROD	X-RAY, γ-RAY	0.05 Mev.-UP	10 - 10,000 r	FLUORESCENCE	0.05-2 Mev.
INDIUM	NEUTRON	0.025 - 0.3 ev	1 - > 2000 rads	In^{116} DECAY	0.025 ev
CADMIUM - INDIUM - CADMIUM	NEUTRON	0.3 - 2 ev	1 - > 2000 rads	In^{116} DECAY	0.3 - 2 ev
COPPER	NEUTRON	2 ev - 1 Mev.	1 - > 2000 rads	Cu^{64} DECAY	0.05 - 1 Mev.
CADMIUM - INDIUM - CADMIUM	NEUTRON	1 - 2.9 Mev.	1 - > 2000 rads	In^{115} DECAY	1 - 2.9 Mev.
SULFUR	NEUTRON	2.9 Mev.-UP	1 - > 2000 rads	P^{32} DECAY	3 - 14 Mev.

FIGURE 2.11. The Hanford Thermoluminescent Dosimeters (top, the multipurpose dosimeter, and bottom, the basic dosimeter)

security credential. A back-up dosimeter in the form of a ^{7}LiF-Teflon[a] disc about 8 mm in diameter is taped to the back of the plastic card to verify any unusually high reading obtained from the primary dosimeter block. An extensive evaluation and testing program that included structural and wear testing, as well as a radiological evaluation (Kathren 1970) was conducted before this dosimeter was placed in service. This dosimeter is still being used at Hanford, only the packaging of the TL chip has been changed. The TL chip is currently packaged in a Teflon sandwich arrangement, which ensures good light transmission.

2.4.2 Multipurpose Thermoluminescent Dosimeter

The multipurpose dosimeter (Kocher et al. 1971) is made up of five blocks of LiF with the same dimensions as used in the basic badge. One of the ^{7}LiF blocks is shielded to provide a measurement of the 1-cm tissue depth dose, a second unshielded block is used for interpretation of the derma dose, two ^{6}Li$_{F}$ blocks and a ^{7}LiF block are used to determine the fast- and thermal-neutron dose. Packaging of the dosimeter chips is similar to the basic dosimeter except five positions for the chips are used and the card holding the chips is placed in another plastic holder containing the necessary shielding to give the response for interpretation of beta, x-ray, and gamma (low- and high-energy) radiations, and slow and fast neutrons. The unique arrangement of dosimeter chips and shielding provides the ability to record these mixed exposures with one dosimeter unit and eliminates some of the effects of environmental conditions that affected the film dosimeter. Figure 2.12 shows the first TL reader used for routine processing of personnel dosimeters.

During the late 1970s, the fifth chip, located in the center of the dosimeter and used for neutron dose evaluation, was eliminated and plans were made to use a Harshaw commercial reader for the TLDs that only read four locations on the chip-card holder. Mechanical problems with the reader prevented its use, so the original reader built at Hanford was maintained in until replacement readers could be developed and constructed. In 1981 a concerted effort was made to procure additional TL chips to replace the fifth chip that had been removed, make new dosimeter cards, design a completely new

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(a) Teflon is a trademark of the E. I. du Pont de Nemours Company.

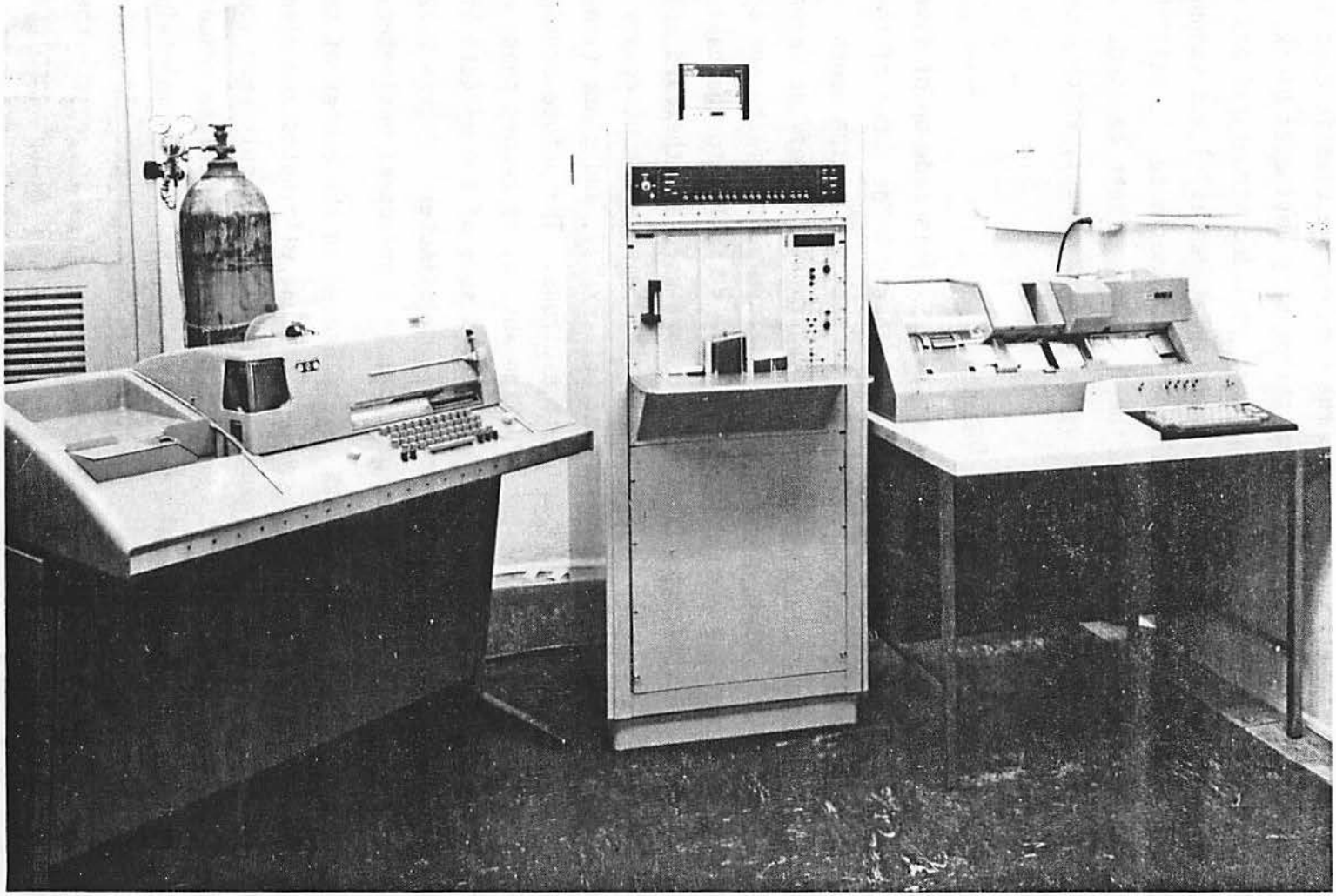

FIGURE 2.12. The First Hanford Thermoluminescent Dosimeter Reader

holder to accommodate a new type of security badge, and restore the use of the fifth chip in the radiation dose evaluation.

2.5 PERSONNEL NEUTRON DOSIMETRY

During the early years of the Hanford operation some attempts were made to measure neutron exposure with pocket ionization chambers that had liners of enriched boron-10 for slow neutron exposure evaluation. There were not many of these dosimeters available and they were used mostly for special cases. Some attempts were also made to use a fine-grain film on which tracks from recoil protons would record neutron exposure, but no known success resulted from these early attempts at neutron measurement.

A nuclear track film (NTA) that was capable of measuring fast neutrons of approximately 0.7 to 0.8 MeV or greater was developed by Eastman Kodak and placed in service in 1950. The recoil proton tracks etched in the emulsion were viewed microscopically at 970X magnification for 40 fields in a given area of the film and compared with tracks for 40 fields obtained from exposure to the fast neutron sources used for calibration and reduced to mrep equivalent dose. During this period polonium-boron (PoB) was the primary source for neutron film calibration until it was replaced by the positive ion accelerator in late 1955. In 1958, a plutonium fluoride source was obtained and used exclusively until replaced by californium-252. The NTA film was used in a regular beta-gamma film holder until 1957, at which time a separate cellulose acetate butyrate holder was placed in service. A double-pocket film badge holder (Figure 2.13) was developed and placed in service in July 1958. It held the Kodak NTA packet and a regular beta-gamma film packet for measurement of both fast and slow neutron exposure. Cadmium and tin shields were used to provide the density differential on the beta-gamma film for slow neutron measurement. This film holder was used by workers having potential exposure to neutrons until the introduction of the multipurpose TLD in 1972.

2.6 HIGH-LEVEL PERSONNEL DOSIMETRY - NUCLEAR EXCURSIONS

The personnel film dosimeter placed in service in August 1962 (Figure 2.9) also had the capability to measure very high-level radiation exposures. Gamma-dose interpretation was provided by the sensitive and insensitive films for

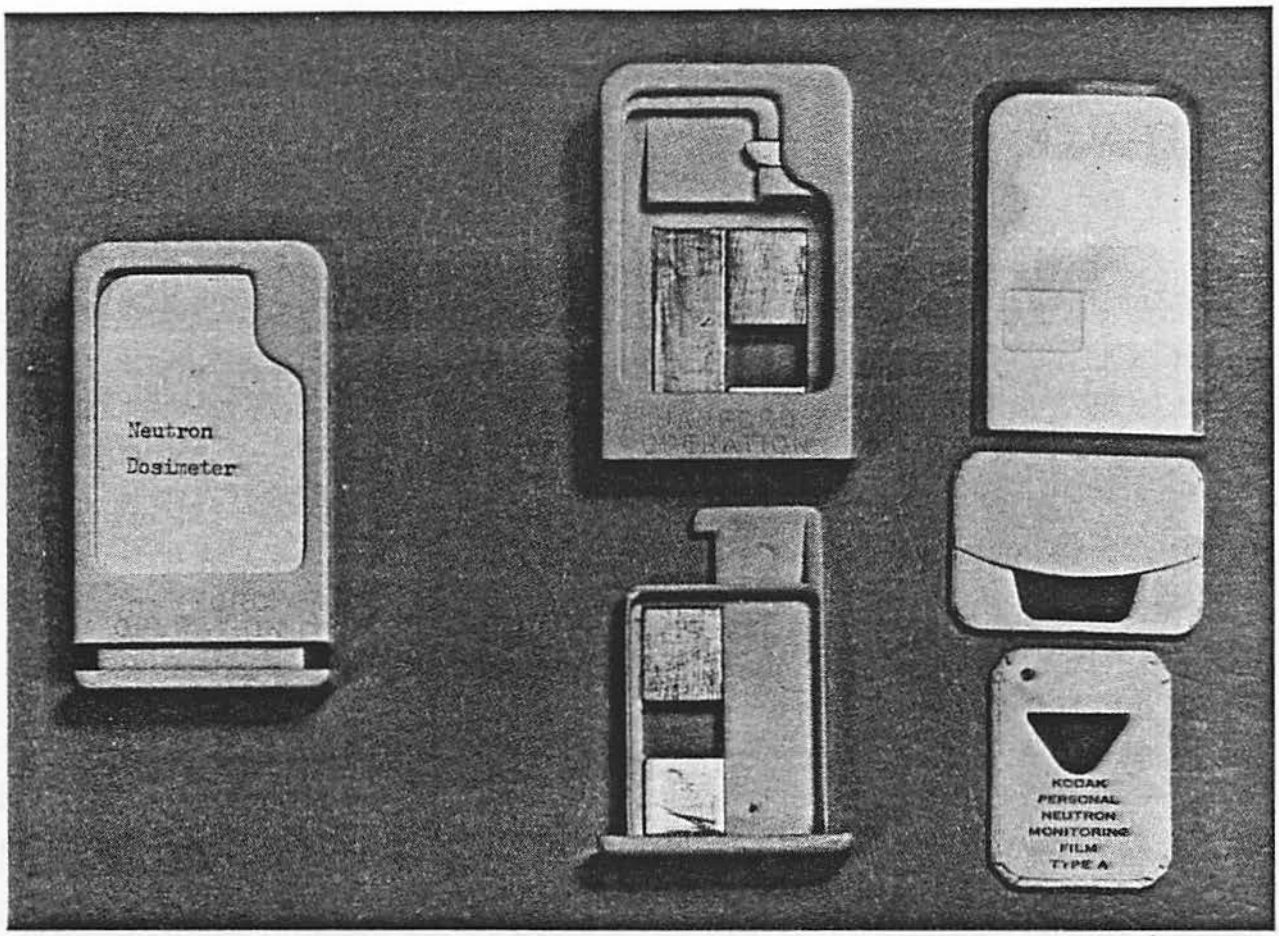

FIGURE 2.13. The Double Pocket Film Dosimeter Used for Neutron Measurement

exposures between 15 mrem and 1500 rem. With the glass fluorods the gamma dose range was extended to about 10,000 rem. An activation foil system consisting of indium, cadmium-covered indium, copper, and sulfur provided an estimation of neutron flux and spectra following a nuclear excursion or other serious radiation event for radiation dose in the range of 1 rad to >2000 rad. The evaluation was the same as that used for the Hanford criticality dosimeter (Bramson 1962.) The foil system was sensitive to a minimum of about 1 rad of fission spectrum neutrons as shown in Table 2.3.

The use of indium foil in the dosimeter also provided a rapid-sort capability to identify personnel who may be seriously exposed following a criticality event. A few rad dose of fission spectrum neutrons could be easily detected by surveying the dosimeter with a conventional Geiger Mueller-type meter.

TABLE 2.3. Personnel Dosimeter Foil System

Foil Material	Size, Inches	Neutron Energy Range
Indium	9/32 by 15/32 by 0.010	0.025 eV to 0.3 eV
Cadmium-Indium-Cadmium	9/32 by 15/32 by 0.010	0.3 eV to 2 eV
Copper	1/4 by 15/32 by 0.040	2.0 eV to 2.9 MeV
Sulfur cylinder	0.145 by 1.0 long	2.9 MeV and up

When the multipurpose TLD was placed in service in 1972, there was no need for special foils because this dosimeter can measure both gamma and neutron radiations over a very broad range of exposure levels.

2.7 PROCESSING PERIODS FOR PERSONNEL DOSIMETERS

The numerous work areas on the Hanford Reservation where personnel dosimeters are required have had many processing schedules. These schedules have changed over the years as operating experience increased and dosimeters and processing techniques improved. Table 2.4 lists the various changes in processing routine for the personal film badge dosimeters since 1944.

By the end of 1945 and early 1946 detailed procedures[(a)] were in place to provide direction for operation and handling equipment used in the processing of personnel meters (pencils, film badges) and in recording results. These procedures covered the various details for work in each of the operating areas, calibration and performance checks for equipment, repair of some dosimeters, detailed instructions for recording results for employees, and summaries for correlation and statistical studies. This information was routinely forwarded to the HI headquarters office in the 300 Area for review and storage.

Processing of film used in the dosimetry programs was handled manually until 1960, when an almost completely automatic system was placed in service. The automatic equipment (Figure 2.14) provided precise temperature and time control throughout processing, automatic agitation with nitrogen bursts supplied to the developing tank, and regulated temperature for drying. The strengths

(a) J. C. Hart. 1946. Personnel Meters Branch Procedures, Internal Manual, Hanford Engineering Works, Richland, Washington.

TABLE 2.4. Dosimeter Processing Schedules

Year	Processing Routine Changes
1944 & 1945	Dosimeters processed on a weekly basis for the 100-B, 100-D, 100-F, 200 North Areas, 200-E and 200-W, and the 300 Area.
1946	Riverland railroad yard added.
1947	241-BX added.
1948	105-DR, 231-TX, 241-BY added. In April of this year the processing interval was changed to every two weeks for each area.
1949	200-W RX, 100-H added. No change in processing interval.
1950	No new posts or change in processing interval.
1951	100-C, P-11, 101 Post, 224-U, Redox added. No change in processing interval.
1952	300-L added.
1953	No changes made.
1954	100-K added.
1955 to 1957	No changes made.
1958	Several posts in the 300, 700 and 1100 Areas were added. In June bi-weekly dosimeter processing was changed to monthly processing.
1959	No changes were made.
1960	In April all areas were processed in one exchange of dosimeters rather than on area basis. Specially designated plutonium workers in 234-5 and PRTR were left on a two-week processing interval until June 1960, then they were placed on a monthly processing schedule.
1963	In the latter part of 1963, a quarterly film badge exchange schedule was established for employees not classified as radiation workers.
1971	The basic TLD was placed in service in January 1971 and exchanged on an annual schedule for the "non-radiation worker." This exchange schedule has not changed to date.
1972	The multipurpose TLD was placed in service in January 1972 with a quarterly exchange as the primary schedule. Some selected workers remained on a monthly exchange schedule.
1985	An annual exchange schedule was established for some workers assigned a multipurpose TLD.

of processing chemical solutions were continuously monitored and the solutions changed on a strict schedule. Reading the density recorded on the film was

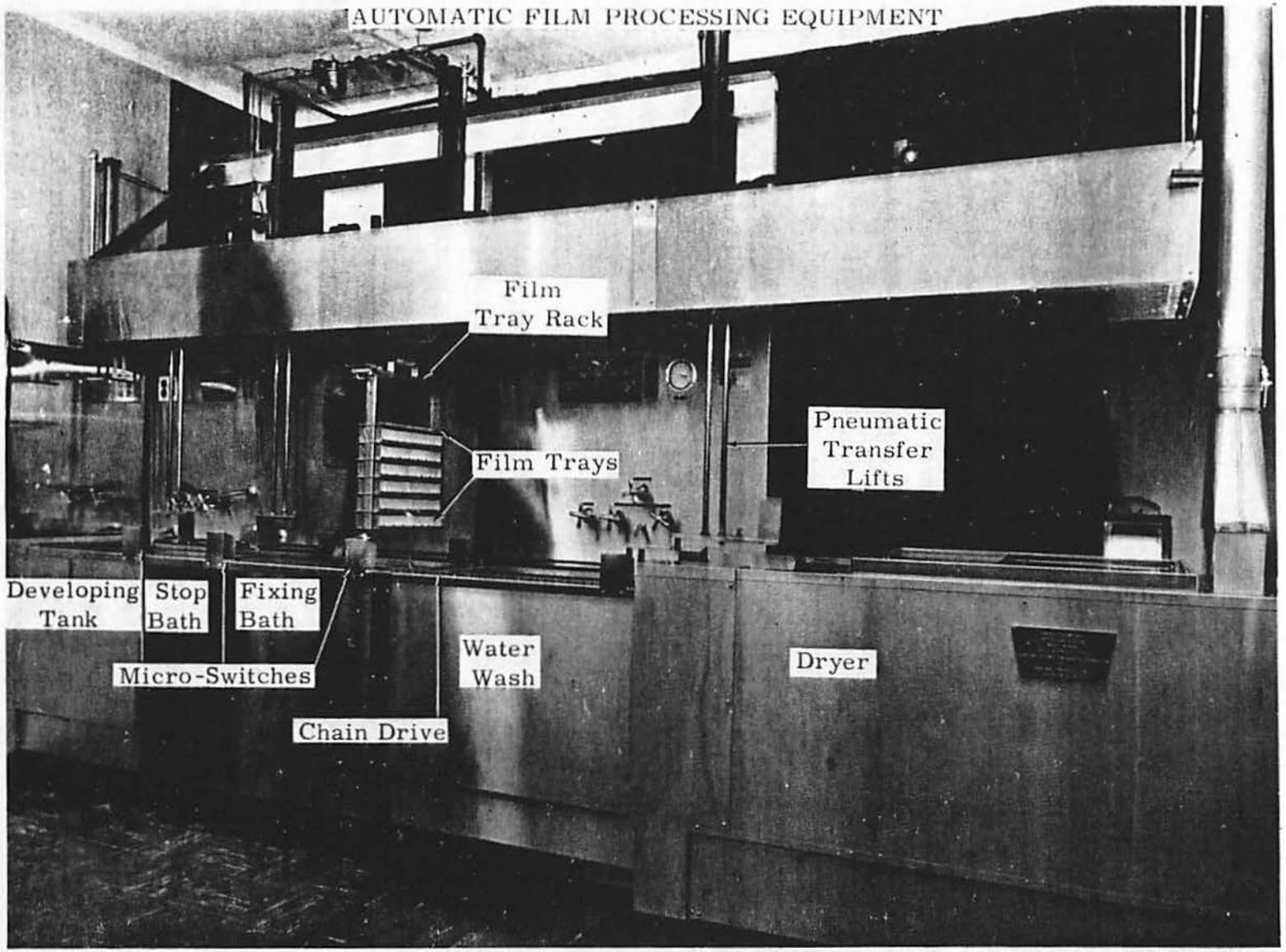

FIGURE 2.14. The Automatic Film Processing Equipment

also a manual operation requiring handling of each individual film until mechanized densitometers were developed and placed in service during the 1960s.

2.8 EXTREMITY EXPOSURE

From early work in the Metallurgical and Clinton Laboratories researchers realized that hand exposure may be significantly higher than what is received by the body and measured by dosimeters worn on the body. Early attempts were made to develop a dosimeter that would monitor more closely the exposure received by the extremities (Healy 1944).

Aluminum rings with a thin silver shield covering part of the film were fashioned (Figure 2.15). The film discs were about 1/2 in. in diameter, cut from the 552-film packet using the 510 film. Later large sheets of the 510 film were obtained from which the ring film was cut. The film discs were packaged in various materials to provide a lightweight, light-tight cover and still be considered thin enough for most beta radiations. Some trial packages were even dipped in paraffin and taped directly to the worker's fingers. These early attempts were clumsy and tore the gloves occasionally but did provide some measurement of hand exposure. The metal ring was soon followed by a rubber ring in which the film disc and black plastic cover were held in place with a flange.

By mid-1967, a flexible rubber finger ring (Kathren, Kocher, and Endres 1970; Kathren, Kocher, and Endres 1971) utilizing a rectangle-shaped wafer of LiF in a Teflon matrix was available for routine hand dosimetry. The ring had a surface area of about 1.5 cm^2 that provided enough area for easy identification. The Teflon wafer and cover were easily inserted in the ring top to form a compact package that could be worn comfortably by workers. The wide range of response provided by the TL ring, <30 mR to $>1 \times 10^5$ R, gave more than adequate coverage for all work situations. At the low exposures, the standard deviation was about $\pm 50\%$ and with higher exposures, it was reduced to $\pm 10\%$. Another advantage was minimal energy dependence allowing use for essentially any photon energy greater than 10 keV. At the 17-keV energy most commonly associated with plutonium, the response per unit of exposure was virtually the same as for cobalt-60. Beta response was only about half in terms of light output per rad but the ring was not usually used in mixed photon

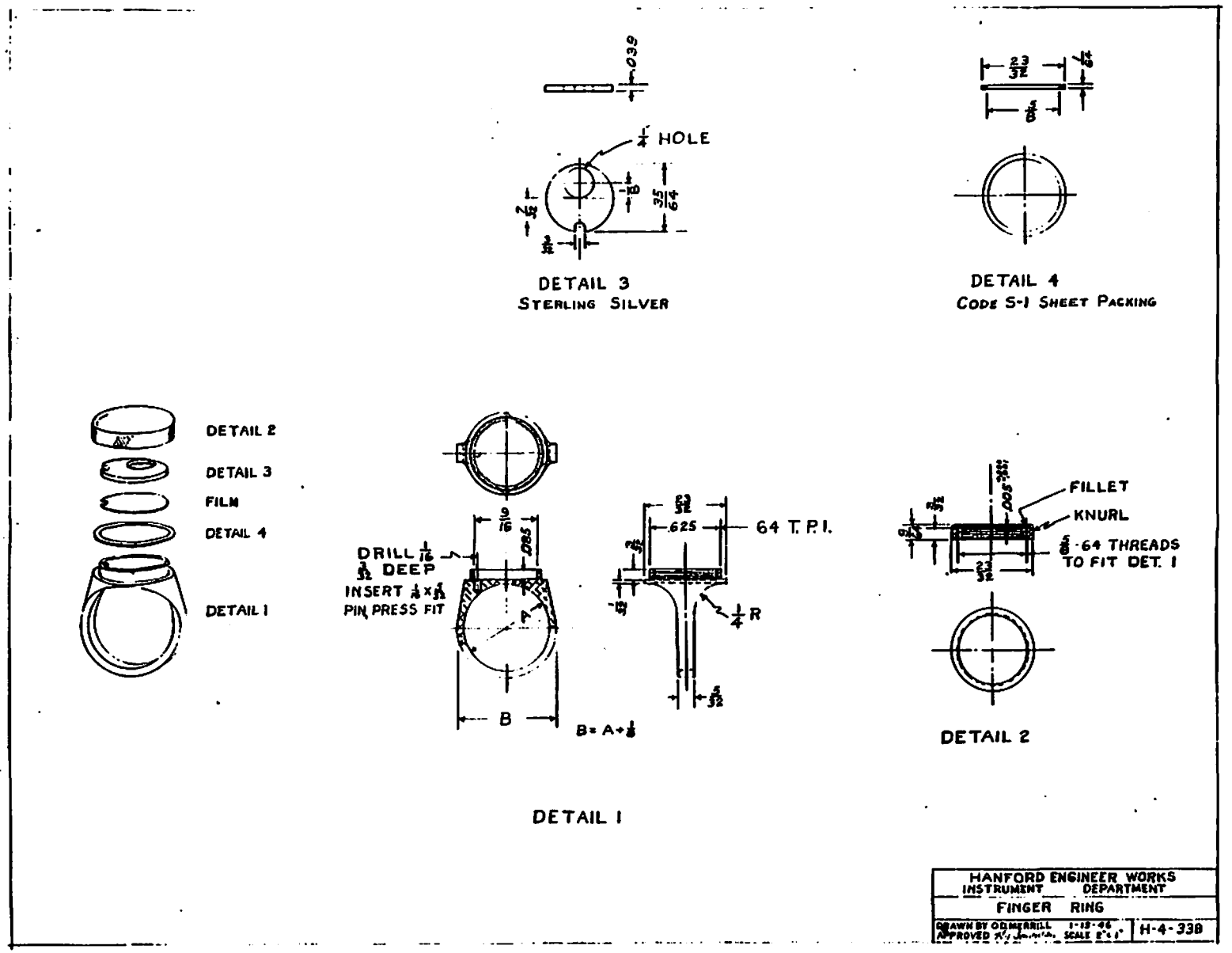

FIGURE 2.15. Drawings of the Hanford Aluminum Finger Ring Film Dosimeter

and beta fields. The ring has been used since January 1968 and has been well received by the workers. Blind audits indicate routine accuracy of ±25% at the 95% confidence level covering a range of 0.1 to 10 R, regardless of exposure conditions.

2.9 HAND COUNTS

By the end of April 1945, a systematized hand-monitoring capability was extended to all principal separations-process buildings and laboratories. These hand counts for beta and gamma contaminants (Figure 2.16) were recorded on cards assigned to personnel in each facility. The results were recorded by the individual on the cards each time a hand count was taken. The cards were exchanged weekly with the used card being taken to the radiation records group and placed with the individual's record of radiation exposure. Cards for recording hand counts were gradually phased out and replaced by forms on which workers could record all their hand-count results along with their name and payroll number. These tally sheets were also phased out and only positive hand counts were recorded when verified by the facility radiation monitoring organization. This procedure is still being used. The verified results, along with decontamination information, are forwarded to Personnel Dosimetry and placed in the individual's permanent radiation exposure history file.

2.10 PENCIL DOSIMETERS

At the outset, pencil dosimeters were considered the primary personnel monitoring device at the Clinton and Metallurgical Laboratories and the film badge was considered only a valuable adjunct. But as large-scale operations started with HEW in 1944 and 1945, this concept reversed and the pencil dosimeter (Figure 2.17) became a monitor for day-to-day control of radiation exposure, supplementing the exposure recorded by the film badge. The film badge was considered the official record of exposure to external radiations on a long-term permanent basis. The pencil dosimeters were issued to personnel along with their film badge each day as they entered an operating area. Pencil crews read all pencil dosimeters worn each day in each operating area and recorded the results for the employee's record. Results from pencil dosimeters were the signal for investigating a potential unusual exposure and requesting

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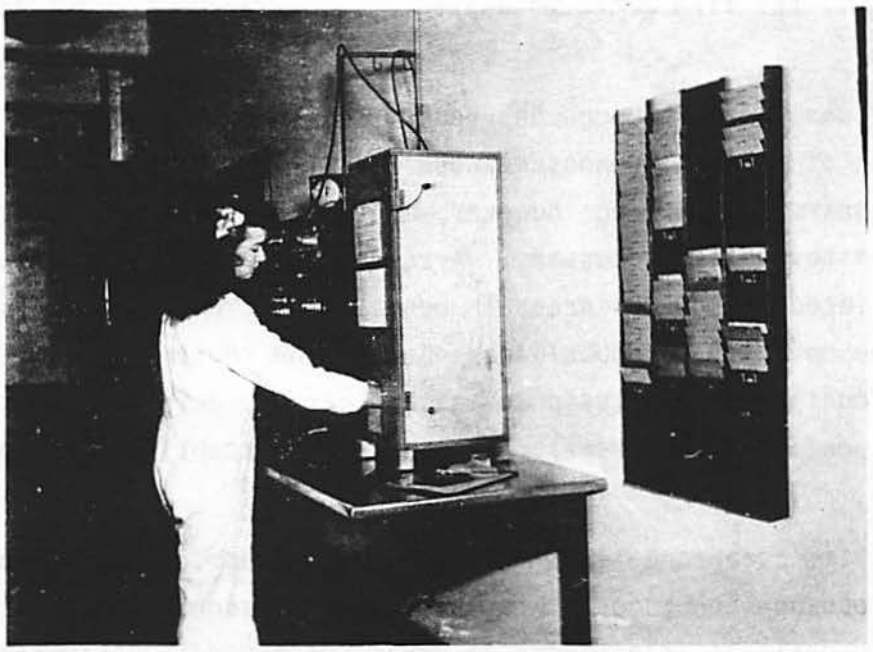

b)

FIGURE 2.16. Hand Counts, a) Hand Monitoring Instruments Used in Process Areas, b) Worker Using a Hand Counter

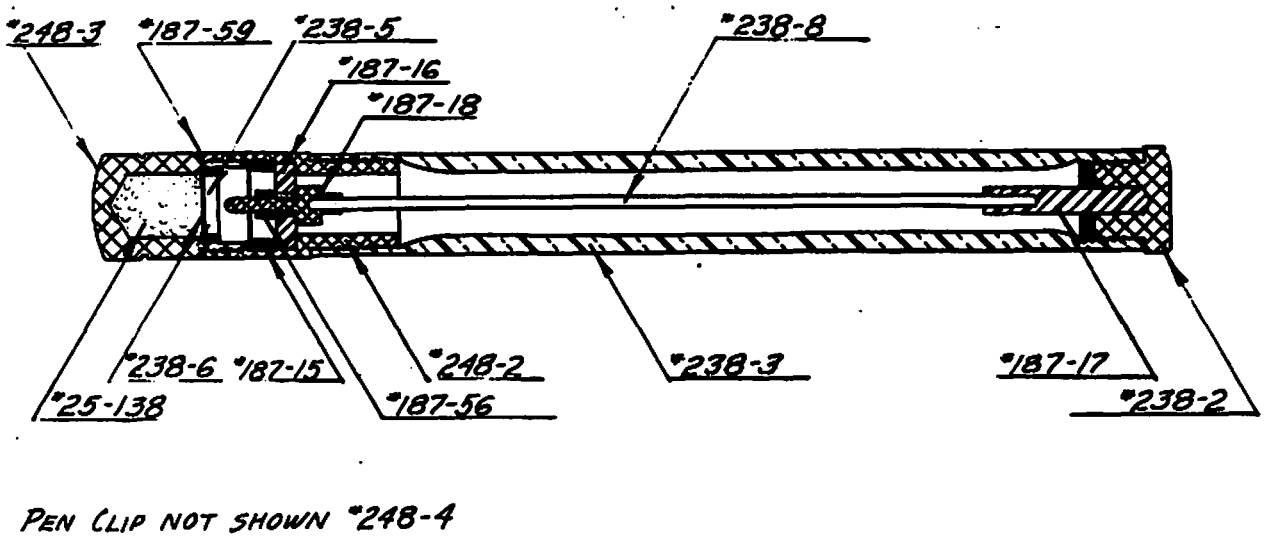

FIGURE 2.17. Drawing of the Hanford Pocket Ionization Dosimeter (Pencil) (Parker 1946)

special processing of the film badge to assist in determining the actual radiation exposure.

As experience was gained through the years from study of radiation exposure, locations of potential exposure were identified. People working in these locations required monitoring; however, many employees did not work in locations where monitoring was necessary. A reduction in pencil dosimeters use was first initiated in the 200 Areas in December 1951 when more and more administrative-type operations and buildings became the routine. Radiation work was strictly confined to exclusion areas and certain designated locations where wearing the pencil dosimeters was required. The exception was the 300 Area.

Prior to this time clearance level and building access were designated by colored tabs placed on the badge. This system was discontinued, but the red tab was used to designate clearances to areas where pencil dosimeters were required for entry (105, 108-B, 271-B and T, 224-U Riverland, 101, P-11, 200-E and 200-W construction sites and the 200-N areas). With issuance of the General

Electric Management Newsletter on October 26, 1956, the wearing of pocket dosimeters (pencils) was discontinued in some 300 Area work locations. Personnel film badges were flagged for those employees requiring pencil dosimeters because of their work location. Patrolmen would issue the pencil dosimeters at the gatehouse along with the film badge, as had been done in the past. Locations were established where the pencil dosimeter could be picked up by an employee if entry into an area where they were required was necessary. These pencil dosimeters were turned in at the end of the day along with the film badge. Pencil dosimeters were read and the results were recorded.

Development work[a] was continuous in the field of personnel dosimetry and by 1962 improvement in the pocket dosimeter pencil and its reader justified a major revision in dosimeter requirements. Statistical studies were done which supported the revision in use of the pocket dosimeter pencil. Again, with an announcement in the General Electric Management Newsletter of September 6, 1962 the practice of wearing only one pocket dosimeter pencil was initiated.

2.11 HIGH LEVEL DOSIMETRY - NUCLEAR EXCURSION

At Hanford, the need for quick detection and measurement of high-level radiation exposure received by personnel from an unforeseen nuclear event was recognized. In response to this need, efforts were concentrated on the development of a method to quickly identify the high-level exposures and immediately segregate in the field the personnel whose level of exposure would require immediate attention. In 1959, these efforts led to the development of the "quick sort" procedure (Wilson 1962; Gamertsfelder et al. 1963) which was immediately placed in effect throughout the Hanford facilities. This procedure utilized a Geiger Mueller-type (GM) survey meter being held against the abdomen or in the armpit to detect the sodium-24 in the body caused by neutron exposure. Fast neutron exposure of as low as 5 rads can be detected

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(a) H. V. Larson and C. M. Unruh. July 20, 1962. Letter to file, subject: Justification for a Single Pocket Dosimeter Program. General Electric, Richland, Washington.

in this manner. Investigation[a] (Wilson 1961; Baumgartner 1959) also revealed other methods where personnel film dosimeters could indicate the dose from high-level gamma exposure when processed and properly evaluated. Fixed dosimeter systems were also installed throughout the plant facilities for area monitoring where very high-level exposures were a possibility. The Hurst dosimeter (Bramson 1960; Hurst et al. 1956; Hurst and Ritchie 1959) was the first fixed system to be installed in 1960. It was replaced with a Hanford-designed dosimeter (Bramson 1962) in 1962. The Hurst system (Figure 2.18) contained some foils of fissionable material which were considered hazardous especially in case of fire. The Hanford dosimeter (Figure 2.19) contains no fissionable materials and some of the foils are well protected to withstand destruction from short-term fire or small explosions. These dosimeters are currently in use throughout the Hanford facilities where fissionable material is handled. The only alterations to these dosimeters since their inception have been a minor change in the design of the holder for the foils and the replacement of the glass rods with the TLD chips.

2.12 TRANSFER OF PROCESSING PERSONNEL DOSIMETERS TO U. S. TESTING COMPANY

In 1964, preparations began for the transfer of the personnel dosimeter processing operation to the U.S. Testing Company (UST). This transfer of responsibilities included some of the processing equipment and some selected personnel as part of the segmentation of the Hanford Plant. On December 31, 1964 the responsibility for processing personnel film badge and finger-ring dosimeters was transferred to UST.

Calibration services for personnel dosimeters as provided prior to transfer of processing to UST has continued to the current time. An extensive quality assurance program was established to ensure quality processing, including acceptance testing of each personnel dosimeter processing before assignment of radiation dose to an individual's radiation exposure history.

(a) R. H. Wilson 1961. High Level Radiation Dose Evaluation Methods and Procedures, Radiation Protection Operation. Internal Manual, General Electric, Richland, Washington.

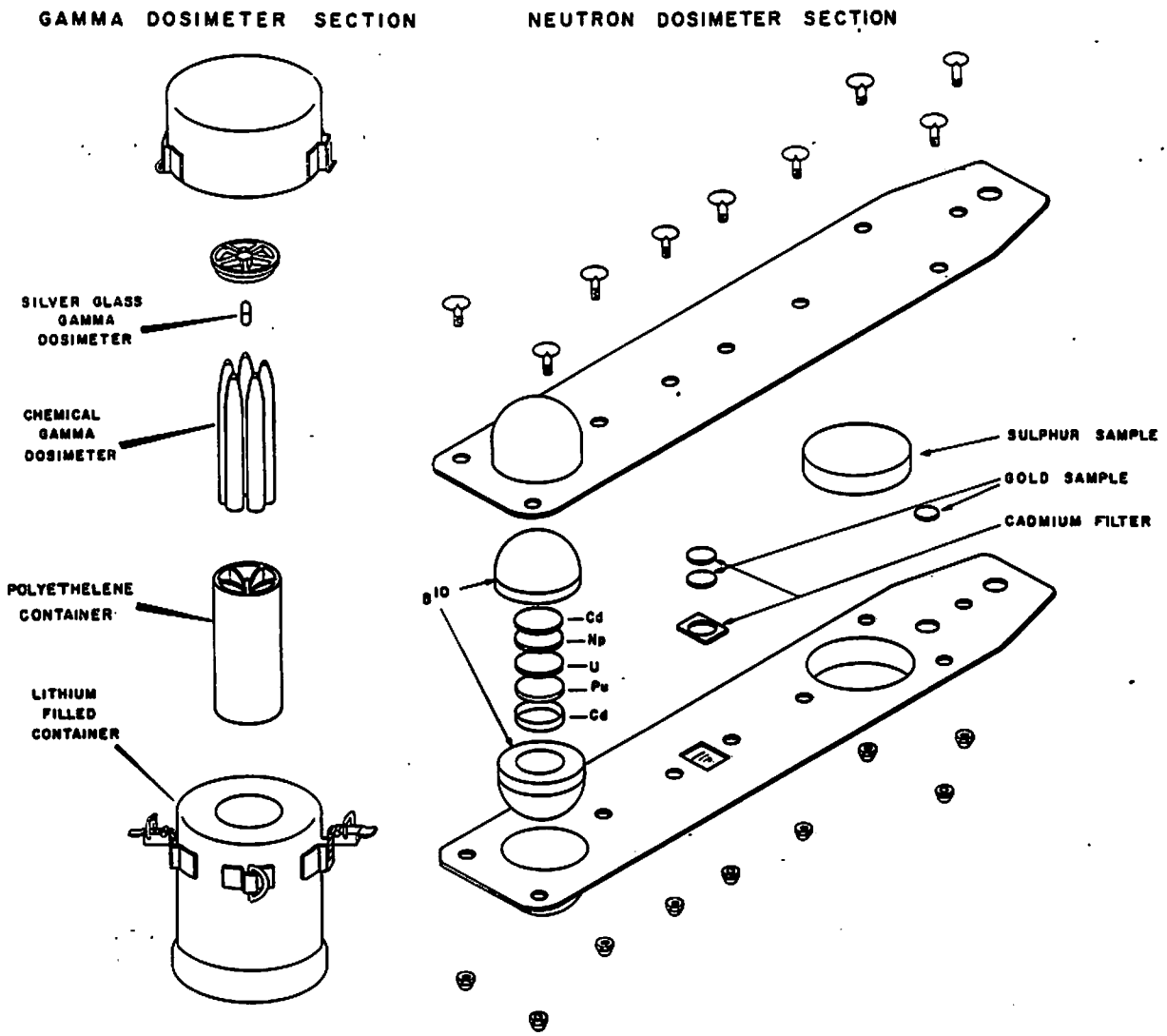

FIGURE 2.18. A Exploded View of the Hurst Dosimeter

FIGURE 2.19. Hanford Criticality Dosimeter

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3.0 INTERNAL PERSONNEL DOSIMETRY

The health physics group at the Chicago and Clinton Laboratories recognized the need to detect and measure radioisotopes deposited in the body. Because of the scale of work with radioactive materials at Hanford, developing the capability to measure exposure from internally deposited radioisotopes was important and required immediate attention.

3.1 BIOASSAY PROGRAM STARTUP

A special studies group was initiated soon after the formation of the HI Section in July 1944, and one of the priority problems was detection of "product" (plutonium) inside the body by some physical method (Parker 1944). Three pathways for intake existed: ingestion, inhalation, and absorption. Ingestion was considered to present little hazard because of the very small absorption of plutonium through the gastrointestinal (GI) tract.

The special studies group thought that inhalation could be controlled by restricting dust concentrations in the air and by air masks. Plutonium removal from the body for ingestion and inhalation was not feasible, but surgical removal of plutonium from subcutaneous tissue was possible and probably would be necessary in some cases. The special studies group needed a means of measuring the amount of plutonium to determine whether it was above or below a safe limit. At that time the limit was set at 0.5 μg plutonium. The first allowable limit for plutonium in the body was extrapolated from the radium limit. Following a few experiments the limit was lowered to 0.1 μg in November 1944 but was soon raised to the former level of 0.5 μg in May 1945.

One of the first means of measuring the level of plutonium thought possible was to produce fission products by exposing the plutonium to a slow neutron beam and then measuring the fission neutrons with a Chang and Eng detection system. The detection level believed possible at that time was about 3 μg; the level could be lowered considerably by a modified, fixed version of the Chang and Eng detection system. How far this investigation was actually carried is not clear because other methods, such as separation of product in urine with a resin column, were also forthcoming.

In 1945 a new method used by the Crocker Laboratory at the University of California at Berkeley for the analysis of plutonium in biological samples was developed. This method used a thiophenyl trifluoracetone (TTA) extraction process. By December 1945 the decision was made to develop the Berkeley plan for use in a bioassay analysis program at Hanford (Parker and Healy 1945).

Early in 1946 a bioassay group was organized at HEW and started establishing a plant-wide urinalysis program (Healy 1946). Plans went forward in training of laboratory staff and cleaning a 700 Area (Figure 3.1) laboratory formerly used for uranium analysis. A standard alpha counter was installed in the laboratory and another was available in the 300 Area. To improve the detection level, a low-background alpha counter was ordered from Chicago. Beginning sampling routines were established for three classes of employees:

Class I - Continuously >50% in product work--every 2-3 months
Class II - Occasionally <50% in product work--every 4-6 months
Class III - All other employees for control--every 12 months.

FIGURE 3.1. An Early Bioassay Laboratory

The proposed sampling method allowed urine sample collection at home with equipment delivered by the bioassay group. Originally, the sample consisted of two to five morning voidings. Notification of sampling schedules were to be given through the HEW hospital or through First Aid units. The analytical procedure used initially was the same as performed by the University of California and the critical reagent, TTA, was obtained directly from the university's chemistry department.

Alpha counting equipment available at that time had backgrounds of 0.2 to 0.3 counts per minute (cpm). The sensitivity of this equipment was considered good enough to detect about one-third of the provisional Hanford tolerance dose of 0.5 μg at about 160 days following intake. Early results were erratic, with poor yields and poor control of the process; however, with experience the yields became more consistent and were in the 80% to 90% range. Because of the delay in obtaining high quality counting results, starting the routine program was slower than expected. Many of the difficulties were solved and by August 1946, 500 urine samples had been assayed since opening the laboratory.

The bioassay group was concerned about delivering and picking up samples because many people giving samples did not know what the equipment was for and they developed an animosity towards the sample collection. During that early period virtually no publicity was given to the program. Information on sample collection was on a need-to-know basis; the reason for this policy was to minimize concern among plant employees about the possibility of having plutonium in their bodies.

Excretion rates were mostly guesses, based on a few experimental results where humans were injected with small amounts of plutonium. These rates varied from 1% per day immediately following injection to about 0.004% per day one year later. At that time all alpha activity was considered to be plutonium. Estimates of internally deposited plutonium at the beginning of the routine program were based on the assumption that intake occurred at least one year prior to sampling. On this basis, the "tolerance" concentration of plutonium in urine was about 2.8 disintegrations per minute (dpm) per day (Healy 1948).

During the early period of operation, attempts were made to collect urine samples from persons leaving HEW employment. This program was not successful

because of the inability to establish a system whereby the bioassay group was notified when an employee was terminated. The responsibility for employees who gave samples for the first time in the routine program shifted from the Medical Department to the employee's supervisor. About two-weeks notice was given prior to sampling. No further notification was given the employee for subsequent sampling. Sampling for day workers took place on the weekends, and over the long weekends for shift workers to minimize the contamination potential from external sources such as clothing worn to work.

In case of incidents, bioassay sampling to detect intake was attempted as soon after the potential exposure as possible. These samples were for the most part morning and night collections rather than the complete voidings for the period sampled. Simulation of a complete 24-hour voiding was considered the best method of sampling and to introduce this concept, about a dozen members of the staff underwent a urine measurement program for a short period of time. Each voiding was collected and the volume was measured. From these measurements it was determined that collection after waking in the morning and prior to retiring for the night gave a sample about equivalent to a 24-hour, total collection. This system was immediately instituted and has continued as the standard for routine urine collection in the bioassay program.

Controls had been set up to monitor the yields obtained in the routine program by running one spiked sample of 2.0 to 3.0 dpm per 2000 mL with every batch of six employee samples. If the yield for the spiked sample was less than the 99% confidence limit for a 90% yield, each sample in that batch was corrected if the result after correction fell outside of the 0.65-dpm limit.

In the early 1950s there was an attempt to improve the bioassay program and provide better coverage of plant worker. In a 1952 letter to J. L. Bird, U.S. Naval Radiological Defense Laboratory, W. A. McAdams of the General Electric Company in Richland, Washington outlined the bioassay program as it was established and noted expected improvements for the future. The expected improvements included urinalysis for all persons working inside the plant barricades to determine their exposure to plutonium and fission products. Sampling frequencies were to be based on the percent of time exposed to the potential of intake. These intervals were loosely described as: major part of work time, quarterly sampling; not routine exposure, semiannual sampling;

all others, annual sampling. During incidents where the potential for intake of radioactive materials was likely, a 24-hour sample was to be collected and the subject would be resampled until the activity level was less than 0.33 dpm of plutonium or less than 1×10^{-5} μCi of fission product. Langham's curve (Langham 1950) would be used to evaluate the internal deposition of plutonium. At this time the electrodeposition procedures were being developed and the detection level was expected to be about 0.12 dpm per sample, a significant reduction from previous analytical methods.

The need for greater sensitivity was realized soon after the bioassay program was established at HEW, and investigations (Schwendiman, Healy, and Reid 1951) led to the potential sensitivity that may be achieved by using nuclear-track emulsions, thus measurement of electrodeposited plutonium was possible. Emulsions were prepared by Kodak on 1-in. by 3-in. microslides, about 25 μm thick.

From statistical evaluations of data collected in 1953, the true detection limit with nuclear-track film was determined. These evaluations showed 0.05 dpm was achievable within reasonable confidence levels. Occasionally recovery, counting, etc., allowed detection levels to be as low as 0.028 dpm within reasonable confidence levels, and for a short period, a level of 0.027 dpm was reached and used as the detection level. This greater sensitivity for detection was due in part to the experience and dedication of the laboratory technicians. A new or inexperienced technician could not achieve the level of precision of the experienced worker.

Routine statistical analysis of spiked urine samples were performed monthly by the control services group to evaluate the detection level of the plutonium recovery and electrodeposition procedures placed in use. These detection levels varied from 0.05 to as low as 0.025 dpm[(a)] during the next several years and occasionally the low figure was used as the official detection level. This practice was discontinued and the more conservative 0.05 dpm was used routinely even though lower levels were possible part of the time. Periodically

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(a) H. T. Norton. 1955. Letter to R. L. Watters, subject: Electrodeposition Procedure Detection Limits. General Electric, Richland, Washington.

a detailed precision study[a] was made to evaluate the several stages of the bioassay plutonium deposition estimation procedure based on alpha track counting.

Carefully prepared and measured calibration sources[b] were made up for use with the new electrodeposition system for plutonium analysis; the sources were plutonium oxide electrodeposited on platinum discs.

3.2 DETECTION LEVEL FOR PLUTONIUM BIOASSAY PROGRAM

The detection levels developed for the bioassay program showing the sharp improvements brought about by the electrodeposition method are shown in Table 3.1.

TABLE 3.1. Detection Levels for Plutonium Bioassay Program

Prior to June 1949	0.66 dpm
June 1949 to December 1952	0.33 dpm
December 1952 to January 1953	0.18 dpm
January 1953 to March 1953	0.15 dpm
March 1953 to November 1953	0.05 dpm
November 1953 to December 1953	0.07 dpm
December 1953 to May 1955	0.05 dpm
May 1955 to September 1955	0.027 dpm
September 1955 to October 1955	0.04 dpm
October 1955 to September 1983	0.05 dpm
September 1983 to December 1983	0.035 dpm[a]
January 1984 to present	0.02 dpm[a]

(a) alpha spectroscopy analysis method with plutonium-242 tracer in each sample for yield factor

(a) R. L. Buschbom. 1959. Letter to G. D. Brown, subject: Precision Study of Bioassay Spike Sample Analyses. General Electric, Richland, Washington.
(b) L. C. Schwendiman. 1953. Letter to file, subject: Sources for NTA Film Calibration. General Electric, Richland, Washington.

3.3 BIOASSAY SAMPLING PROGRAM UPGRADE-1950s

In 1954 the bioassay program required a thorough review, and internal deposition of plant employees needed a more complete evaluation. The evaluation would include a review of the ongoing program for long-term analyses of deposition cases. In early 1955, a program was initiated to review all known cases of deposition, particularly plutonium, and reevaluate the estimate of deposition. Some adjustments of the early estimates were made, particularly those of long standing that required an upward adjustment in some cases (Wilson 1956; Healy 1957). The bioassay coverage was also audited to give a realistic view of the extent and frequency of sampling provided by the program. This audit revealed incomplete coverage, particularly among the minor construction workers. Changes were also made in the U Plant uranium bioassay program to improve coverage of uranium workers and to provide a follow-up when results indicated an intake of uranium.

A concerted effort was made to provide scheduling of bioassay on a basis of need that was determined by the job assignment and work location. In 1958, the sampling scheduling and the methods used to keep the individual's schedule correct for work location underwent a major revision.[a] This revision also introduced the concept of sampling once every five years for employees not working routinely in facilities where radioactive materials were present. The increasing use of electronic data processing provided the ability to quickly determine changes in work assignments and work locations so adjustments in sample schedules could be made when needed. Management also become more aware of the need to keep the sampling schedules current for workers in their organizations. The collection of new employee and termination samples was also increased greatly with the new sampling program.

3.4 URANIUM BIOASSAY PROGRAM

The early attempts to concentrate uranium in urine samples by either extraction and electroplating were erratic and not very successful. By 1948

(a) R. H. Wilson. 1958. Letter to H. A. Meloeny, subject: Details for Proposed Revision to Bioassay Sampling. General Electric, Richland, Washington.

the fluorometric method that fused uranium with sodium fluoride and then measured the fluorescence when the compound was exposed to ultraviolet light was refined so that much more reliable results, as well as consistent detection levels of less than 10 μg/L were obtained. Further refinement of this method soon reduced the detection level to about 3.8 μg/L.

Routine sampling of uranium workers was based on the "before" exposure and "after" exposure (Neuman 1945) that consisted of a voiding collection at the beginning of the work week and at the end of the work week. For workers with less frequent exposure to uranium the collections were done on a monthly basis. These samples were supplemented by additional "before and after" samplings whenever higher-than-normal contamination work was anticipated, or to pinpoint the time of a possible exposure. Frequency of sampling was reduced during the early 1960s until a semiannual schedule was in place.

Lung counting studies in 1967[(a)] indicated the usefulness of this sampling schedule method in detecting deposition of uranium. Workers were then scheduled for semiannual lung counts; one taken after a long period of no exposure, following a vacation, for example, and the other after at least two days of no exposure. Spot urine samples were collected at the time of the lung counts to give some measure of the soluble uranium still remaining in the worker. Lung measurements gave a positive evidence of the buildup of insoluble uranium or uranium oxide. The detection limit for uranium showing the improvement achieved is listed in Table 3.2.

(a) B. V. Andersen. March 7, 1968. Internal memo to H. V. Larson, subject: Program Uranium Internal Dosimetry. Pacific Northwest Laboratory, Richland, Washington.

TABLE 3.2. Detection Levels for Uranium Bioassay Program

Year	Level
1946 to 1948	>10 μg/L, indeterminate
Early 1948 to 1949	5 to 10 μg/L
1949 to 1975	3.8 to 4 μg/L
1975 to 1976	4 to 0.4 μg/L, determined for each sample
1976 to 1982	0.4 μg/L
January 1982 to 1983	0.2 μg/L
Early 1983 to present	0.5 μg/L, routine level for review (0.03 μg/L, a theoretically possible level)

3.5 FISSION PRODUCTS BIOASSAY PROGRAM

Soon after the bioassay group was formed, development of procedures to separate fission products from bioassay urine samples started with the primary objective of measuring plutonium excreted by plant workers. Originally a ferrous hydroxide precipitation from the supernatant solution of the lanthanum fluoride precipitation in the plutonium analysis was used. Results were erratic; later it was determined that much of the residual activity resulted from the presence of natural radioactive potassium.

When fission products became available for testing, a new procedure was developed with the realization that the rare earths and part of the strontium was precipitated with the lanthanum. During this period only three positive indications of fission product intake were obtained from plant workers but no additional samples were collected for confirmation. Later the positive indications were believed to the result of some carry over of naturally radioactive potassium with the oxalate. However, these three positive results were recorded as positive fission product intakes for 1948.

Analysis for gross fission products was carried on in conjunction with the plutonium program for plant workers until the 1960s when whole body counting techniques which provided a better measure of deposition than urinanalysis were developed. At that time, routine chemical analysis of urine for gross fission products was phased out except in special cases that involved radioisotopes such as strontium and promethium. Chemical analysis of urine

and feces are now performed only for special cases and for specifically designated employees.

Table 3.3 lists the fission product detection levels observed during the early years of HEW operation.

TABLE 3.3. Fission Product Detection Levels During Early Hanford Operation

Year	Level
1946 to 1948	100 dpm to 500 dpm, indeterminate
July 1948 to ?	approximately 30 dpm gross fission product
1950s	approximately 1.0×10^{-5} μCi/L
March 1956	approximately 3.1×10^{-5} μCi/L

3.6 WORK RESTRICTIONS RESULTING FROM INTERNAL DEPOSITION

Work restrictions were administered rather informally and with very little follow-up during the years prior to 1955 because of the uncertainty in bioassay results, high detection levels, and minimal control that was possible resulting from the pressures of work. A rule of thumb followed by the old Standards Unit of the Radiological Sciences Department beginning in the very early 1950s was approximately 20 percent of the maximum permissible limit (MPL) for restricting work with no consideration given to external exposure. Application and follow-up was erratic for restricting work of those with known depositions. When detection levels for plutonium improved significantly in 1953, dropping from 0.33 to 0.05 dpm, the potential for uncovering many more deposition cases was recognized. With the increased surveillance[(a)] of internal deposition in 1955, restriction of employees having high levels of deposition from further exposure to plutonium was inconsistent. Along with reevaluation of all known deposition cases, work began on development of procedures[(b)] to handle and control work restrictions.

(a) R. H. Wilson. 1955. General Electric Company Audit Report #70, Work Restrictions Because of Potentially Significant Internal Deposition of Radioactive Materials. Richland, Washington.

(b) R. H. Wilson 1956. Letter to H. A. Meloeny, subject: Work Restrictions Because of Internal Deposition. General Electric, Richland, Washington.

The first formal plant-wide policy was issued May 1, 1957 in the Radiation Protection Standards Manual stating, "Anytime a body burden is judged to exceed one-fifth of the applicable limit listed in Appendix A, further exposure to the offending or biologically similar isotope shall be prohibited." It was reissued March 1, 1960 stating, "Whenever the body burden from a radionuclide(s) exceeds one-half of the applicable limit listed in Appendix A, further planned exposure to the offending or biologically similar nuclide shall be prohibited."

During the 1960s work restrictions were modified to provide more individual review of each case involving deposition; it is as follows:

- Temporary Restriction - Long enough to ensure no new intake will occur and impact upon an assessment of internal deposition.
- Permanent Restriction - Cases of $\geq$50% of plutonium were individually reviewed and generally restricted from further exposure to plutonium or metabolically similar radionuclides, but not in every case. At 100% maximum permissible body burden (MPBB) level workers were restricted from most hands-on plutonium work but not necessarily from all plutonium work.

3.7 TRANSFER OF BIOASSAY SAMPLE PROCESSING TO U.S. TESTING COMPANY

In 1964 preparations were made to transfer the processing of bioassay samples to the UST as part of the operations diversification of the Hanford Plant. Some personnel and equipment were transferred to UST to maintain continuity in production and quality.

Transfer of responsibility to UST for processing biological samples collected in support of the internal dosimetry program at Hanford occurred December 31, 1964. The responsibility has continued in this manner to date. Technical support is provided by the Pacific Northwest Laboratory to ensure chemical recovery procedures and counting procedures yield the best possible results. Audit programs are also maintained on a continuous basis to monitor the accuracy and sensitivity achieved by UST.

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4.0 IN VIVO COUNTING

The ruthenium emissions that occurred at the Redox Plant in the early 1950s precipitated an investigation into methods of detecting and measuring lung burdens of people exposed to these emissions. In 1954 some rudimentary counting equipment was used to make the initial measurements of the ruthenium lung burden. The results of these studies, along with the development of highly sensitive instruments for whole body counting at Argonne and Los Alamos National Laboratories led to the decision that Hanford should also develop the capability of whole body counting.

4.1 DEVELOPMENT OF THE FIRST WHOLE BODY COUNTER AT HANFORD

In 1955 the Radiological Physics and the Radiation Protection groups embarked on the project to develop and construct a whole body counter. Radiological Physics was responsible for technical planning and overseeing construction, as well as the development of initial equipment and counting techniques.

The initial work involved finding suitable materials for shielding that contained little radioactive material in order to give the counter as little interference from background radiation as possible. All of the materials and equipment which were used in the whole body counter were measured for radioactivity as construction progressed. Many of these early measurements and the development of counting techniques were done in a temporary shielding of crushed rock found in the state of Washington (McCall 1960). This rock had a background radiation of only 1.6 to 2 times that of low-background lead and iron.

The design of the counter was similar to the one developed at Argonne; the counter consisted of a 9-3/8-in.-diameter by 4-in.-thick NaI(Tl) scintillation crystal and an iron room with 10-in.-thick walls (Figure 4.1). Hanford was fortunate in obtaining steel plate from the U.S. Navy that had been rolled prior to World War I. This material contained only very minute quantities of naturally occurring radioactive materials; therefore, the steel plate had a very low background, which made it suitable for the highly sensitive counting of small amounts of radiation emanating from the body. Following

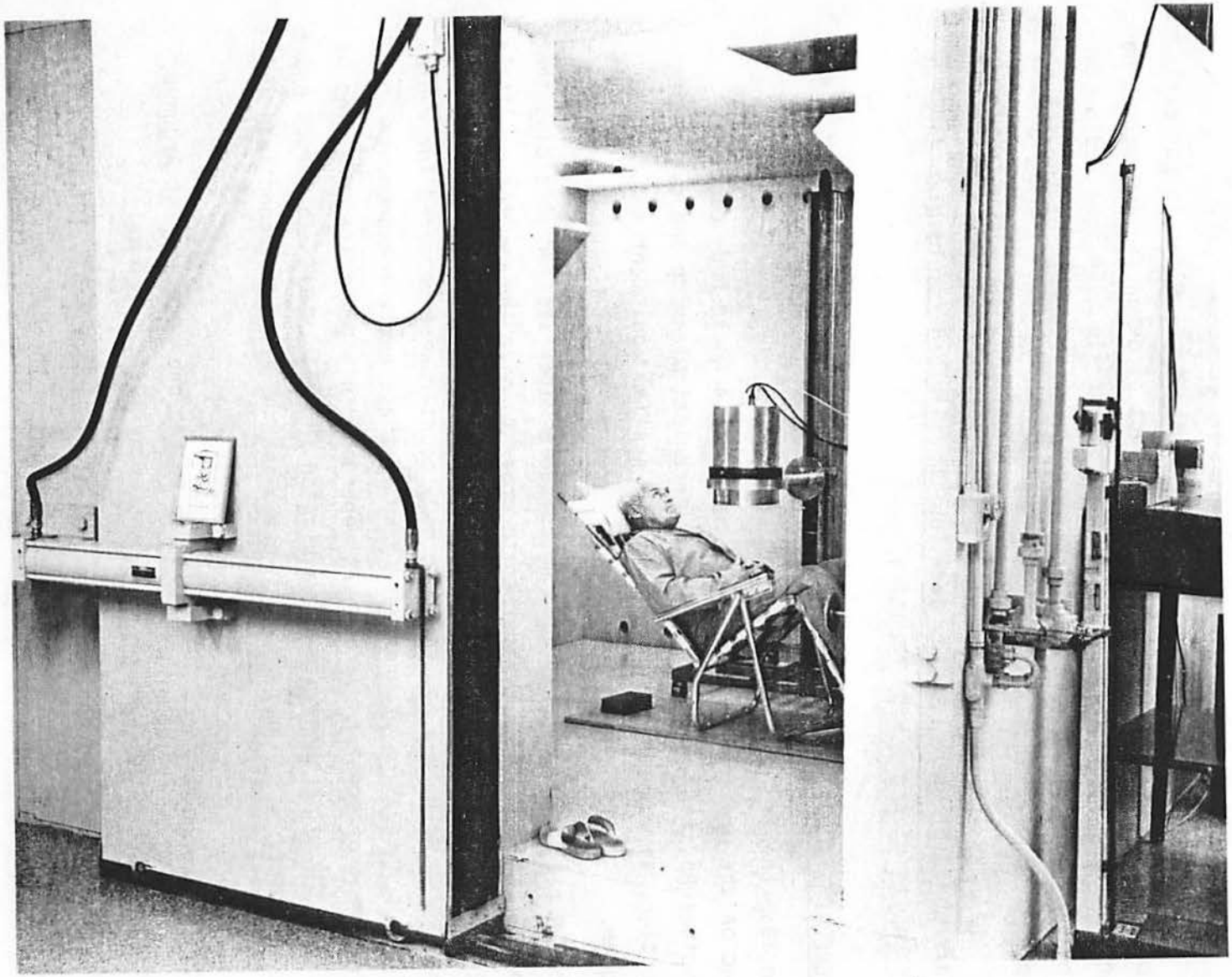

FIGURE 4.1. First Iron Room for Whole Body Counting

World War II, fallout from nuclear testing caused generally higher radiation backgrounds in many manufactured materials, and radioisotopes were also used extensively as tracers in the manufacture of steel.

The whole body counter was completed in early 1959. Following the development of counting techniques for use, semiroutine measurements of Hanford workers began by mid-1959.

One of the first discoveries after the counter was in use was the presence of zinc-65 in nearly everyone measured who lived and worked in the vicinity of Hanford. This radioisotope was found in human beings was a result of its presence in the water used to cool Hanford reactors. The cooling water was taken from and released back into the Columbia River. A study (Perkins et al. 1960) indicated that the principal routes of human intake of zinc-65 were from Columbia River drinking water, fish, and seafood. Oysters harvested at locations near the mouth of the Columbia River were good concentrators of zinc-65; these shellfish became the principal subjects for study. Whole body measurements also frequently detected sodium-24 in reactor-area workers who drank water originating from wells in these areas (Swanberg 1961).

By 1960 the operation of the whole body counter was turned over to the Radiation Protection Operation for routine measurements of Hanford personnel. The Radiological Physics group continued work on special cases. People exposed to neutrons during the Recuplex incident (Larson et al. 1963) were the subjects of one of their studies. This group also continued the development of the new counting equipment and techniques.

4.2 DEVELOPMENT OF THE SHADOW SHIELD COUNTER

The success of these early developments in whole body counting lead to the expansion of the measuring program to include a larger number of Hanford workers. As a result, the shadow shield counter (Figure 4.2) was developed.

The shadow shield counter could quickly screen Hanford workers to determine whether or not a more thorough examination should be carried out in the iron room. The shadow shield counter did not require an iron room; it could be placed in a small area. This counter determined the amount of radiation emitted from the body by moving the full length of the person (lying down) underneath

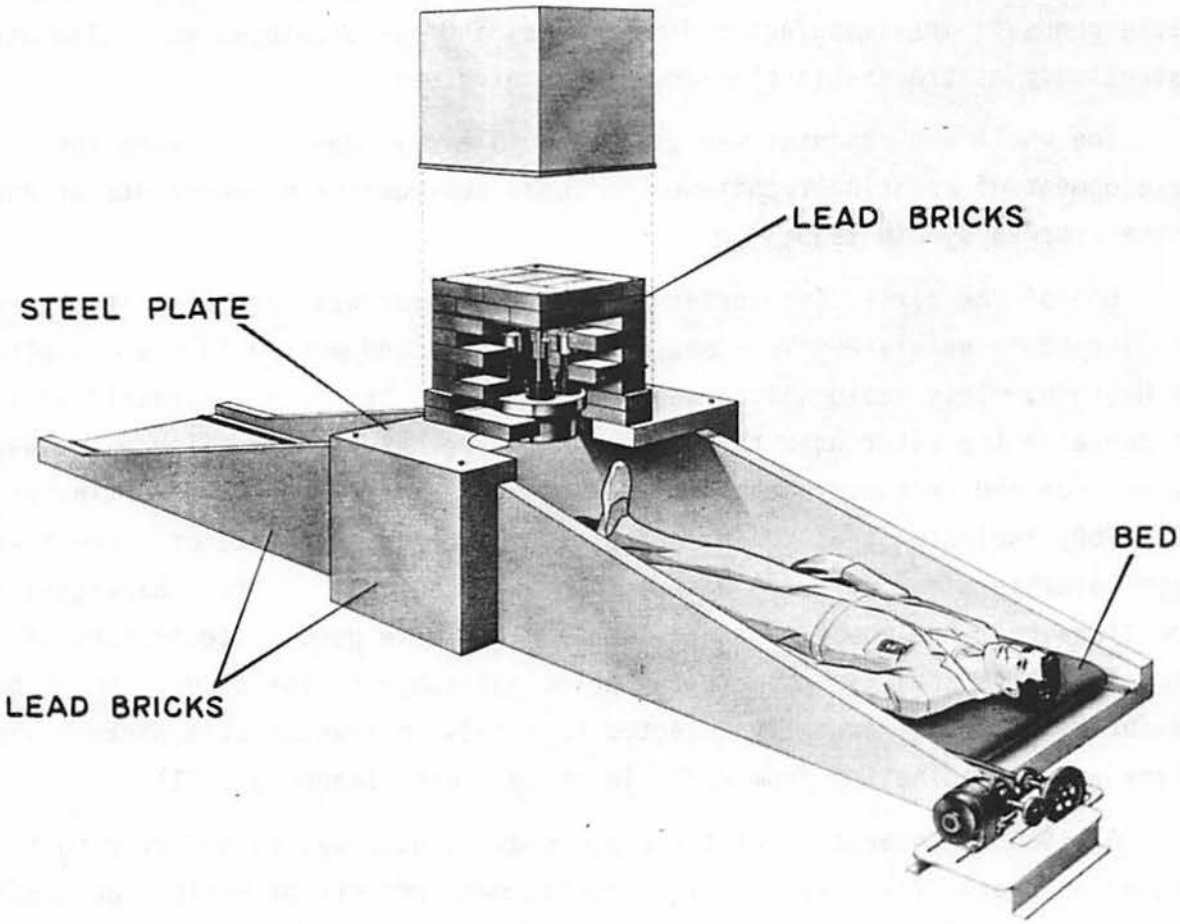

FIGURE 4.2. The Shadow Shield Whole Body Counter

the detector. The detector was shielded on all sides except the side that was facing the subject to be measured, and this side was in the "shadow" of the shield behind the subject, hence the name, "shadow shield" (Roesch and Palmer 1961).

The supine position of the subject passing under the detector provided a better measurement for zinc-65 (Palmer and Roesch 1961) than measurements obtained in the iron room because of the poor geometry of the seated subject in relation to the detector position.

Because of the success of the shadow shield counter, the sensitivity achieved, and its size, it was possible to house this counter in a trailer

and transport it to work locations facilitating the measurement of large numbers of people (Swanberg 1963). This mobility made whole body counting an important tool in the Hanford site radiation protection program and opened up the possibility of transporting the counter to remote areas of the world for study of deposition of radioactive materials in man and animals (Palmer, Hanson, and Griffin 1963).

Further upgrading of shadow shield counting was accomplished by controlling the speed of the drive to correspond to the analyzer live time so that the detector would spend proportionally more read-scanning time over an area of high deposition (Sveum and Bramson 1969). This upgrade resulted in the desired amount of "scanning live time" for which the counter calibrations apply.

4.3 DEVELOPMENTS IN THE 1960s

After the establishment of the Hanford whole body counter as a routine tool for measuring internal deposition, many improvements were made to increase its sensitivity and improve its mechanical operation. A 400-channel transistorized instrument, 2-channel and 4-channel auxiliary amplifiers, and 9-3/8- by 4-in. NaI(Tl) crystal was installed; this addition cut the counting time in half and maintained the same level of sensitivity.

4.3.1 Coincidence Counter

By 1965, specialized counting equipment that could accurately determine levels of phosphorous-32 was developed. During this period recreational fishing for whitefish in the Columbia River was very popular among people living in the Tri-Cities area. The principal nuclides found in fish and waterfowl feeding in the downstream of the Hanford reactors were phosphorous-32 and zinc-65 (Foster 1963; Foster 1964). These nuclides could be detected using the newly developed coincidence counter (Palmer 1966). The coincidence counter measured only the head (Figure 4.3), therefore the only shielding material required was around the head of the subject. The coincidence counter became part of the mobile counter facility because of the small amount of shielding material required.

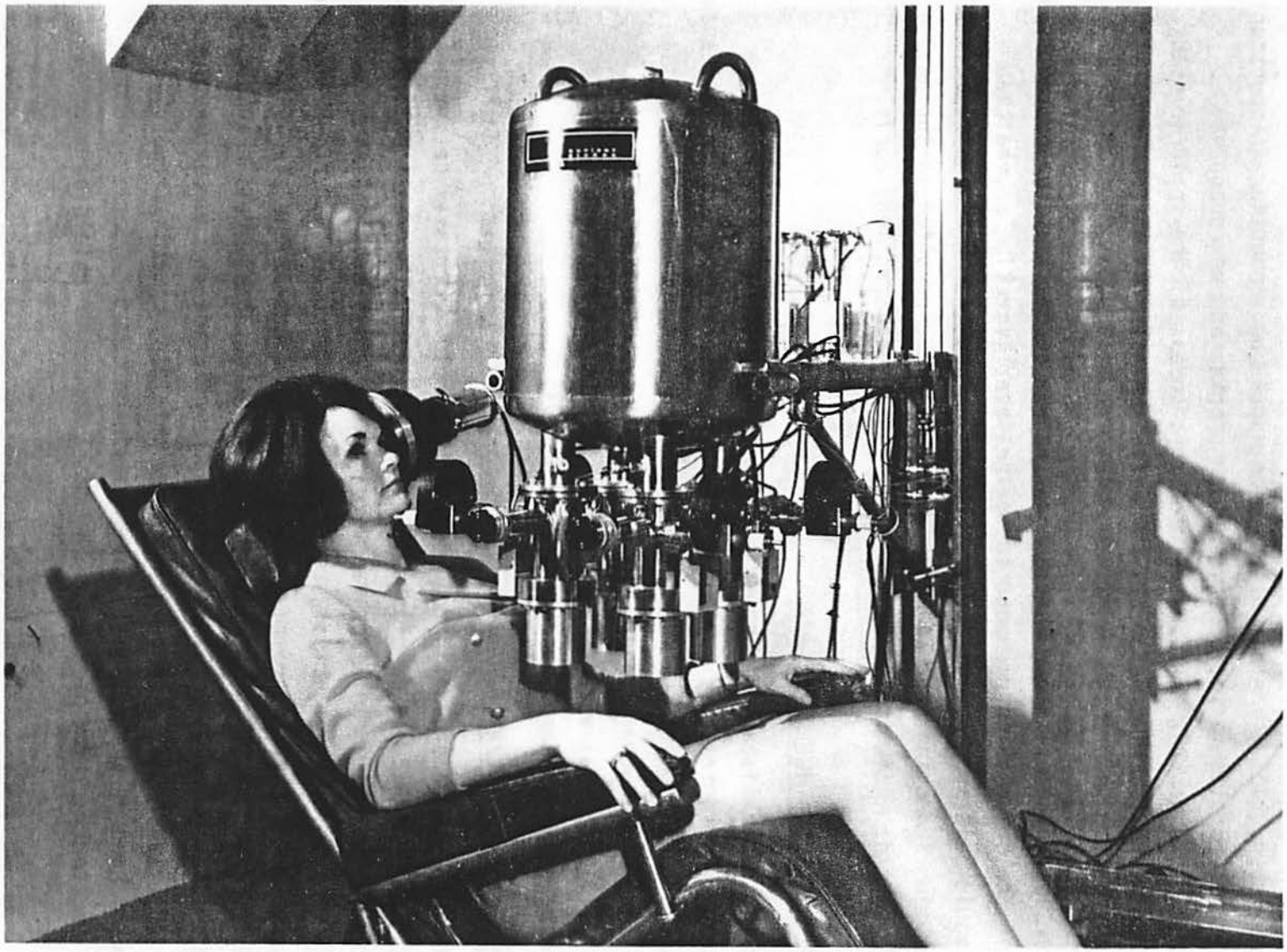

FIGURE 4.3. Coincidence Counter for Head Counting and Four GeLi Detectors Mounted in a "Chicken Feeder" Arrangement with a Liquid Nitrogen Dewar

4.3.2 Lead Room

In early 1968, another counting room was constructed using lead. The room's interior was lined with thin copper sheeting to reduce interference of the 74- and 85-keV lead x-rays. Routine counting for plutonium and americium in the lung was initiated after the lead room was constructed.

In vivo chest counts for americium-241 were made by placing two 3/8-in.-thick by 5-in. diameter NaI crystals coupled to 5-inch phototubes in front of the subject's chest and two identical detectors in back of the chest region. A measurement lasted 2000 seconds and the detectable amount, depending on chest thickness, was from 0.15 to 1.60 nCi.

Measurements for uranium were identical to those of americium-241 except that the photon energies included the 60- and 90-keV energies from the thorium daughters of uranium and the uranium-235 content contribution were observed from the 185-keV photon. The minimum amount of activity detectable, depending on chest thickness, was from 2.0 to 3.7 nCi. The same equipment was used to measure bremsstrahlung from beta particles emitted by strontium-90 and promethium-147. The minimum detectable amount (MDA) for strontium-90 was in the range of 25 to 40 nCi; for promethium-147 the MDA was 0.5 to 1.5 nCi.

4.3.3 Phantoms

Extreme differences in the body build of persons involved in plutonium inhalation incidents made it necessary to develop a chest phantom with variable chest wall thicknesses. A unique projection chest phantom (Waite, Andersen, and Bramson 1970) was constructed out of inexpensive materials which provided variability in chest thickness and incorporated bone structures of a bone-equivalent substance. This phantom was used for calibration of in vivo lung counters for measurement of 10- to 100-keV x-ray and gamma radiations.

Another system was developed to simulate the human GI tract to measure the dose rate contributed by the drinking water derived from the Columbia River near Hanford (Bramson 1970). The counter for drinking water was capable of determining the dose rate within a factor of 2 for at least 19 radionuclides, including the 7 radionuclides which contribute 90% of the potential GI tract dose.

4.3.4 Solid State Germanium Scintillators

When the solid state germanium scintillators became available, they were adapted for in vivo and wound counting. These scintillators provided an improvement in energy resolution for isotope identification and deposition evaluation (Andersen, Bramson, and Rising 1970; Andersen, Bramson, and Unruh 1971). The whole body counting system using 4 GeLi detectors mounted in separate cryostats, but mounted in a single 30-liter liquid nitrogen dewar of the "chicken feeder" design (Figure 4.3). This counter was used for whole body measurements in the standard chair geometry.

4.4 WHOLE BODY COUNTING ACTIVITIES DURING THE 1970s

In the early 1970s, the activity at the whole body counting facility was devoted primarily to the routine counting of Hanford employees. Many improvements and changes took place in the latter half of the 1970s. Research and development of new and improved counting systems were actively pursued.

4.4.1 Improvements and New Equipment

A permanent shadow shield counter was installed next to the iron room in the latter part of 1977 and essentially all gamma ray whole body measurements were taken with this counter rather than in the iron room. By 1978 the demand for chest measurements exceeded the capacity of the single lung counter, so a lead partition, which doubled the capacity for these measurements without any loss of sensitivity, was installed in the iron room.

In addition to increasing the lung-counting capacity, an ultrasound system was installed to improve the accuracy of corrections made for attenuation in the chest wall for low-energy x- and gamma rays emitted from the lung. Improvement in the calibration of the Hanford counters was made when a tissue-equivalent human torso phantom was obtained. This phantom included several sets of lung, liver, and pulmonary lymph node organs containing known quantities of plutonium-239, plutonium-238, americium-241, and natural uranium. A set of chest plates to simulate various wall thicknesses was also obtained with the phantom.

In 1979 many improvements were made to enhance the operating efficiency and appearance of the whole body counting facility. Additional offices, a

laboratory, and an instrument shop were installed next to the 747A Building. Construction on a second shadow shield counter which would contain two 35% Ge(Li) detectors and a 4-in. by 4-in. by 16-in. NaI(Tl) detector was started. With this counter the ability to quantify any number of radionuclides deposited in a worker would be greatly improved.

Improvements in the whole body counting facilities continued into the 1980s. The mobile whole body counting Unit #1 (Figure 4.4) that had been idle for several years was rebuilt to provide more efficient service in the field. This unit was also equipped with special radiation measuring instruments for emergency preparedness.

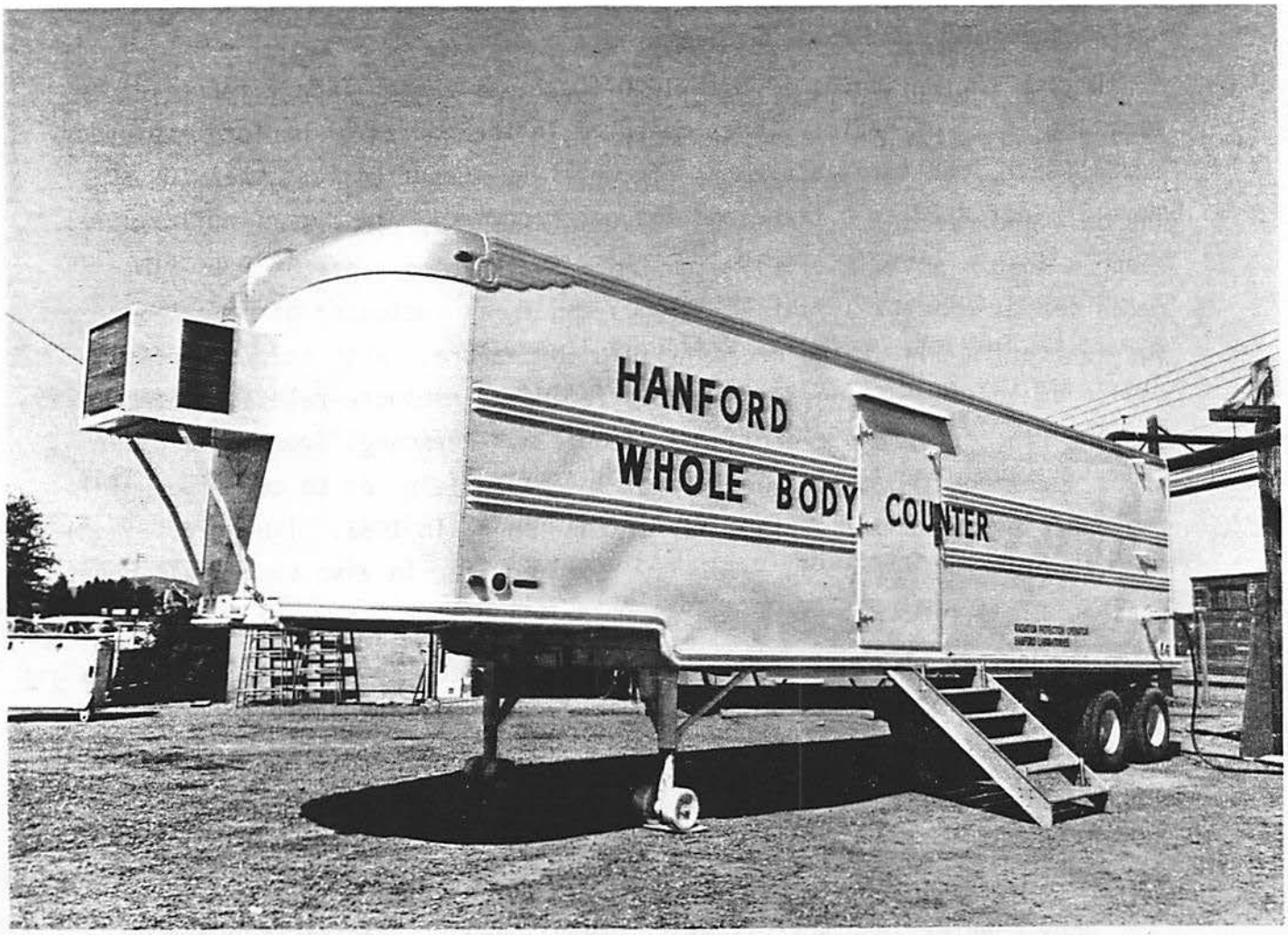

FIGURE 4.4. Mobile Whole Body Counter Unit #1

In the lead room, two special detector holders were installed in order to improve the ability to monitor any part of the body. They can also be used in conjunction with the third holder for positioning detectors around the head to measure the total skeletal content of radionuclides having photon energies high enough to penetrate bone. The two Ge(Li) detectors were calibrated and they provided the capability of identifying and quantifying mixtures of radionuclides. Because of their performance, the Ge(Li) detectors are replacing the NaI(Tl) detector as the primary detector for whole body counting.

A new Nova 4 Data General Computer that allowed greater storage capacity of data and made information such as previous measurement records readily available when needed, was installed.

4.4.2 Reduction in Reporting Levels

During the period of 1978 to 1980 there was a significant reduction in reporting level of radionuclides measured in the bodies of Hanford employees. For instance, routine measurement of cobalt-60 measuring less than 100 nCi was only indicated as a trace and was not reported. The reporting level was reduced to 2.6 nCi when studies[a] indicated that most of the long-term retention of cobalt-60 is in the lungs and is an indicator of other nuclides such as cerium-144, which are difficult to measure. With this reduction, closer evaluation of spectra and interferences from work-related contamination on the skin, hair, and clothing was required. Personnel from certain work areas were required to change into clean coveralls prior to counting. This procedure was placed in effect for all personnel in 1981. Tables 4.1 and 4.2 show the current detection levels and accuracy for in vivo counting currently reached for several of the more common radionuclides.

Progress is continuing on development of detector equipment such as a gas scintillation proportional counter, which should provide improved resolution for measurement over large areas of the body. Intercomparison studies are in progress for comparison of measurements made on subjects from England who

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(a) H. E. Palmer, G. A. Rieksts and H. B. Spitz. 1981. "Hanford Whole Body Counter 1980 Activities," Internal Report, Pacific Northwest Laboratory, Richland, Washington.

TABLE 4.1. Current Detection Levels (from an internal report by H. E. Palmer, G. A. Rieksts, and H. B. Spitz, 1981, "Hanford Whole Body Counter 1980 Activities," Pacific Northwest Laboratory, Richland, Washington)

Radionuclide	Gamma Ray Energy, MeV	Counting Time, seconds	Organ(a)	MDA (99% Confidence) Statistical Error, nCi	Precision, %	Estimate of Body Shape and Size Error, % (b)
^{144}Ce-^{144}Pr	2.18 MeV(c)	200	WB	100	5	+20
			L	20	5	∓15
^{137}Cs-^{137}Ba	.662 MeV	200	WB	2	5	+10
			L	.4	5	∓10
^{51}Cr	.32 MeV	200	WB	15	5	+15
			L	3	5	∓15
^{60}Co	1.17 and 1.33 MeV	200	WB	2	5	+10
			L	.4	5	∓10
^{131}I	.36 MeV	200	WB	4	5	+15
			L	.8	5	∓20
^{59}Fe	1.10 and 1.29 MeV	200	WB	4	5	+10
			L	.8	5	∓10
^{54}Mn	.84 MeV	200	WB	2	5	+10
			L	.4	5	∓10
^{106}Ru-^{106}Rh	.51 MeV	200	WB	12	5	+10
			L	1.4	5	∓10
^{40}K	1.46 MeV	200	WB	10	5	±10
^{110}Ag	.658 MeV	200	WB	2	5	+10
			L	.4	5	∓10
^{22}Na	1.28 MeV	200	WB	1	5	±10
^{24}Na	1.37 and 2.75 MeV	200	WB	.5	5	±10
^{232}Th	Using ^{208}Tl 2.61 MeV	200	WB			
			L			
^{65}Zn	1.12 MeV	200	WB	1	5	±10
			L	.2	5	±10
^{95}Zr-^{95}Nb	.724 and .756	200	WB	3	5	±10
			L	.6	5	±10
^{125}Sb	176 keV	200	WB	2	5	±10
			L	.4	5	±10
				3	5	±10
				.8	5	±10

(a) WB = Whole Body; L = Lung.
(b) Activity in the gastrointestinal tract can give counting rates which vary ≤50% depending on the location within the tract.
(c) See Low Energy Photon Emitter listing for 133-keV measurement on Table 4.2.

TABLE 4.2. Accuracy and Sensitivity for in Vivo Measurements of Common Radionuclides

Radionuclide	Photon Energy	Counting Time, sec	Organ	Detector System	99% Confidence MDA Statistical Error, nCi	Precision, %	Estimate of Body Shape and Size Error, %
^{239}Pu	59.5 keV ^{241}Am tag with 15:1, ^{239}Pu:^{241}Am ratio	2000	lung	6 IG[a]	1.8	10	20
			liver	3 IG	1.4	7	20
			bone	3 IG	3.6	10	20
^{239}Pu	59.5 keV ^{241}Am tag with 5:1, ^{239}Pu:^{241}Am ratio	2000	lung	6 IG	0.6	10	20
			liver	3 IG	.5	7	20
			bone	3 IG	1.2	10	20
^{239}Pu	17.0 and 20.4 keV x-rays from pure ^{239}Pu, 3 cm CWT[b]	2000	lung	6 IG	50	20	40
			liver	3 IG	100	20	40
			bone	3 IG	50	10	30
^{238}Pu	17.0 and 20.4 keV x-rays from ^{238}Pu 3 cm CWT	2000	lung	6 IG	20	20	40
			liver	3 IG	40	20	40
			bone	3 IG	20	10	30
^{241}Am	59.5 keV	2000	lung	6 IG	.12	10	20
			liver	3 IG	.09	7	20
			bone	3 IG	.24	10	15
^{238}U	93 kev from ^{234}Th	2000	lung	6 IG	1.2 nCi (3.6 mg)	10	20
^{235}U	183.7 keV	2000	lung	6 IG	.08 nCi (.037 mg)	10	20
^{232}Th	239 keV from ^{212}PB	2000	lung	6 IG	.38	8	15
^{144}Ce	134 keV	2000	lung	6 IG	.40	8	15
^{154}Eu	123	2000	lung	6 IG	.05	8	15
			bone	3 IG	.15	7	15
^{155}Eu	86.5	2000	lung	6 IG	.12	10	20
			bone	3 IG	.25	7	20
^{210}Pb	46.5	2000	bone	3 IG	2.0	8	15
^{125}I	27	2000	thyroid	2 IG	.003	10	15

(a) IG = intrinsic germanium
(b) CWT = chest wall thickness

have inhaled materials emitting low-energy photons for confirmation of accuracy of a tissue-equivalent torso phantom. When confirmation is complete the torso phantom will become an international calibration standard. Certification of the tissue-equivalent torso phantom as an international standard for lung calibration of adult human males was completed in 1982, but work is continuing for the adult human female.

4.5 MOBILE WHOLE BODY COUNTER

When the "shadow shield" concept was originated the design was such that a relatively light-weight whole body counter could be constructed that was easily transportable in a truck or trailer (Figure 4.4). Early models of the shadow shield counter were temporary assemblies of lead brick until a suitable shield geometry was obtained. Then it was possible to approach the measurement capabilities of the larger, conventional whole body counters using massive iron rooms. Sensitivity did decrease somewhat in the lower-energy regions (below 300 keV) because of increased contribution to background from scattered radiation.

4.5.1 Detectors

The primary detector installed in the mobile counter was an NaI(Tl) crystal, 11-1/2 in. in diameter and 4 in. thick. The detector was fitted with an assembly of seven matched photomultiplier tubes which gave an 8.6% resolution of the 0.667-MeV cesium-137 gamma radiation. There were other detectors available in the mobile counter for measuring the quantity of plutonium in a superficial wound and a detector for measurement of iodine-131 in the thyroid.

The plutonium wound counter was made up of a 1-mm by 1-3/4-in. NaI(Tl) crystal mounted on a 2-in. photomultiplier tube which was enclosed in a cylindrical 1/2-in. lead shield open at the top. The minimum detection level was 0.1 nCi for a 10-minute counting time assuming the plutonium was within 5 mm of the skin surface.

The iodine-131 detector consisted of a 3- by 3-in. NaI crystal fitted to a 3-in. photomultiplier. The minimum detection level was 20 pCi for a 30-minute count when properly positioned at the subject's thyroid.

All of the necessary electronic gear and high-voltage power supply were included in the mobile unit. The counting laboratory was installed in a 18,000-lb semi-trailer, 36 ft long, and air conditioned to maintain a comfortable temperature (Swanberg 1963).

Calibration of the detector equipment was done by comparison with measurements made in the large Hanford whole body counter (Table 4.3). People with known quantities of iodine-131, cesium-137, zinc-65, potassium-40, and sodium-24, spanning the energy range from 0.36 to 2.70 MeV were measured in both counters.

TABLE 4.3. Comparison of Counting Parameters Between the Hanford Whole Body Counters[a]

Parameter	Mobile Whole Body Counter	Iron Room
Crystal volume	6808 cm^3	4610 cm^3
Crystal number	1	1
Phototubes	7 (Dumont 6363)	4 (Dumont 6363)
Crystal can	stainless steel	stainless steel
Elevation	110 m	110 m
Internal shielding	10 cm lead	25.4 cm iron
Shield grading	none	3 mm lead
Background index[b]	0.530 cpm/cm^3	0.291 cpm/cm^3
Geometry	single crystal scanning	single crystal chair
Spectrometric resolution	7.5%	8%
Energy band: lower limit	1.36 MeV	1.36 MeV
width	0.20 MeV	0.20 MeV
Background	173 cpm	85 cpm
Sensitivity[c]	0.78 cpm/g K	0.72 cpm/g K
Spectrometric resolution	10%	9%
Energy band: lower limit	0.60 MeV	0.60 MeV
width	0.12 MeV	0.12 MeV
Background	196 cpm	104 cpm
Sensitivity[c]	8.3 E+3 cpm/uCi	9.0 E+3 cpm/uCi
K-40 contribution	0.145 cpm/g	0.132 cpm/g

(a) From D. N. Brady and F. N. Swanberg, Jr. 1964. The Hanford Whole Body Counter, an internal report, General Electric, Richland, Washington.
(b) Integral background in 0.1 to 2.0 MeV energy band/crystal volume.
(c) Net counting rate/unit mass or activity of radionuclides with selected channel width.

4.5.2 Educational Program

The mobile laboratory was put into operation during the latter part of 1963 in the Hanford production reactor areas. During this period special programs were also introduced to use the mobile counter in the community. Figure 4.5 shows one of the early forms people were asked to complete when receiving a whole body count. The form was designed to get information about dietary habits of the participants in the programs.

One of the most popular programs was an extensive measurement of school children at many of the elementary schools in the area. Children participated on a voluntary basis and the results of their measurements were made available to them and their parents. Through this educational program, the public learned about naturally occurring radioactive materials. Figure 4.6 is a poster used to depict the various food pathways for the intake of radionuclides.

4.5.3 Mobile Unit B

The construction of another mobile whole body counter, designed to support the study of environmental pathways taken by Hanford plant effluents to man, was begun in 1966 (Eichner 1969). The mobile unit B (Figure 4.7) was ready for operational use by April 1967. The unit was built into an 18- by 8- by 8-ft truck body, and had carpeting, air conditioning, radio music, and mahogany finishing to provide a pleasant atmosphere for the subject while the whole body measurement was being performed.

4.5.4 Study of the Radionuclides Present in the Local Population

Comprehensive studies were undertaken (Honstead 1967; Endres et al. 1972b) to count members of the local population and school children to determine which radionuclides were present and what their relationship was to diet. The unit was taken to the Washington and Oregon coast where the local population was counted to determine the transport of radionuclides down the Columbia River and the radionuclide concentration in aquatic foods eaten by the people in that area (Endres et al. 1972a). Small amounts of radionuclides associated with Hanford reactor operations were found in fish such as salmon, but the greatest amounts were found in shellfish near the mouth of the Columbia River. Two of the nuclides that were found in the seafood are biologically active (zinc-65 and phosphorous-32). The initial study determined the seafood

BATTELLE-NORTHWEST
RICHLAND, WASHINGTON

THE INFLUENCE OF DIET ON RADIOACTIVITY IN PEOPLE

THIS QUESTIONNAIRE IS TO OBTAIN DIET INFORMATION TO SUPPLEMENT YOUR WHOLE-BODY COUNTING RESULTS. THE DATA ARE OF REAL SCIENTIFIC VALUE TO HELP US UNDERSTAND THE WAY PEOPLE TAKE UP RADIOACTIVITY FROM THEIR FOOD, AND HOW LONG IT IS RETAINED IN THEIR BODIES. WE CAN DO THIS BY RELATING THE MINUTE AMOUNTS OF RADIOACTIVITY MEASURED BY THE WHOLE-BODY COUNTER TO INDIVIDUAL DIETS. WHEN A LARGE NUMBER OF THESE RELATIONSHIPS ARE OBTAINED WE CAN DETERMINE SIGNIFICANT AVERAGES. EVEN THOUGH IT IS NOT POSSIBLE TO PROVIDE PRECISE ANSWERS, WE APPRECIATE YOUR GIVING THE BEST ESTIMATES YOU CAN TO THE FOLLOWING QUESTIONS. TRY TO AVERAGE YOUR DIET THROUGHOUT THE YEAR WITHOUT BEING UNDULY INFLUENCED BY RECENT SEASONAL FACTORS. IT MAY HELP YOU TO UNDERSTAND THE QUESTIONS IF YOU REMEMBER THAT WE SIMPLY WANT TO FIND OUT YOUR AVERAGE CONSUMPTION RATE OF CERTAIN FOODSTUFFS AND WHERE THESE FOODS WERE PRODUCED.

NAME | SOC. SEC. NO. | DATE

HOME ADDRESS | PAYROLL NO. | OCCUPATION

AGE | HEIGHT | WEIGHT | SEX ☐M ☐F | EMPLOYED BY | BLDG. | AREA

1 RESIDENCE HISTORY

I HAVE LIVED IN MY PRESENT COMMUNITY FOR _____ YEARS.

BEFORE THAT I LIVED IN _____ CITY

FOR _____ YEARS.

2 DRINKING WATER

WHAT IS THE SOURCE OF DRINKING WATER IN YOUR HOME?
☐WELL ☐MUNICIPAL SYSTEM

HOW MANY GLASSES OF WATER DO YOU DRINK PER DAY?
_____ GLASSES

ON A WORK DAY HOW MUCH OF THIS WATER DO YOU DRINK WHILE AT WORK?
☐LITTLE ☐SOME ☐MOST OF IT

3 OTHER LIQUIDS

HOW MANY CUPS OF BEVERAGE MADE FROM TAP WATER (COFFEE, TEA, SOUP, KOOL-AID, ETC.) DO YOU DRINK PER DAY?
_____ CUPS

HOW MUCH OTHER LIQUID DO YOU DRINK (BOTTLED SOFT DRINKS, JUICE, BEER, ETC.)?
_____ GLASSES

4 MILK

HOW MANY GLASSES OF FRESH MILK DO YOU DRINK PER DAY?
_____ GLASSES

WHAT IS THE SOURCE OF YOUR FRESH MILK?
☐COMMERCIAL ☐LOCAL FARMS

WHICH BRAND OF COMMERCIAL MILK DO YOU USUALLY DRINK?
_____
(DO NOT INCLUDE CANNED OR POWDERED MILK)

5 MEAT

FOR HOW MANY MEALS A WEEK DO YOU EAT FRESH MEAT (OTHER THAN CANNED OR CURED)?
(DO NOT INCLUDE PREPARED MEATS SUCH AS WEINERS, LUNCH MEAT, AND TV DINNERS)
_____ MEALS

HOW MUCH OF THIS FRESH MEAT IS BEEF? ☐NONE ☐LITTLE ☐MOST ☐ALL OF IT

WHERE DO YOU OBTAIN YOUR FRESH BEEF? ☐MEAT MARKET ☐LOCAL FARMS

6 FRESH VEGETABLES

FOR HOW MANY MEALS A WEEK DO YOU EAT FRESH VEGETABLES (OTHER THAN CANNED OR COMMERCIALLY FROZEN? _____ MEALS

FRESH FRUIT? _____ TIMES

WHERE DO YOU OBTAIN MOST OF YOUR FRESH VEGETABLES?
☐GROCERY ☐LOCAL FARMS

WHERE DO YOU OBTAIN MOST OF YOUR FRESH FRUIT?
☐GROCERY ☐LOCAL FARMS

7 SEAFOOD

ABOUT HOW MANY TIMES A YEAR DO YOU EAT THE FOLLOWING SEAFOODS?

FRESH OYSTERS _____ TIMES

FRESH CRAB _____ TIMES

FRESH CLAMS _____ TIMES

(DO NOT INCLUDE FISH OR CANNED OR COMMERCIALLY FROZEN SEAFOOD. INCLUDE ONLY THAT FROM NEARBY PACIFIC SOURCES.)

8 GAME BIRDS

HOW MANY TIMES A YEAR DO YOU EAT THE FOLLOWING GAME BIRDS?

DUCK _____ TIMES

GOOSE _____ TIMES

PHEASANT _____ TIMES

QUAIL _____ TIMES

CHUKKAR OR GROUSE _____ TIMES

9 COLUMBIA RIVER FISH

HOW MANY TIMES A YEAR DO YOU EAT FISH CAUGHT IN THE COLUMBIA RIVER BELOW HANFORD (OTHER THAN COMMERCIAL FISH?)

ABOUT _____ TIMES

WHAT KINDS OF FISH WERE THEY?

	MOST	SOME	NONE		MOST	SOME	NONE
SALMON				STEELHEAD			
STURGEON				WHITEFISH			
BASS				CRAPPIE			
TROUT				PERCH			
CATFISH				OTHER			

FOR SECTION USE ONLY

IDENTIFICATION CODE _____

A B C D E F G H

NA-24 _____

ZN-65 _____

CS-137 _____

K-40 _____

_____

_____

10 OTHER QUESTIONS

WHEN WAS THE LAST TIME YOU ATE SEAFOOD (OTHER THAN FISH) AS THE PRINCIPAL PART OF A MEAL? _____

WHICH SEAFOOD WAS IT? _____

WHEN WAS THE LAST TIME YOU ATE FISH FROM THE COLUMBIA RIVER?
_____

WHEN YOU OBTAIN SEA FOOD OR LOCAL FISH DO YOU USUALLY PRESERVE IT BY FREEZING? ☐YES ☐NO SMOKING? ☐YES ☐NO CANNING? ☐YES ☐NO

BB-1200-100 (10-65) [illegible]

FIGURE 4.5. Record of Dietary Habits

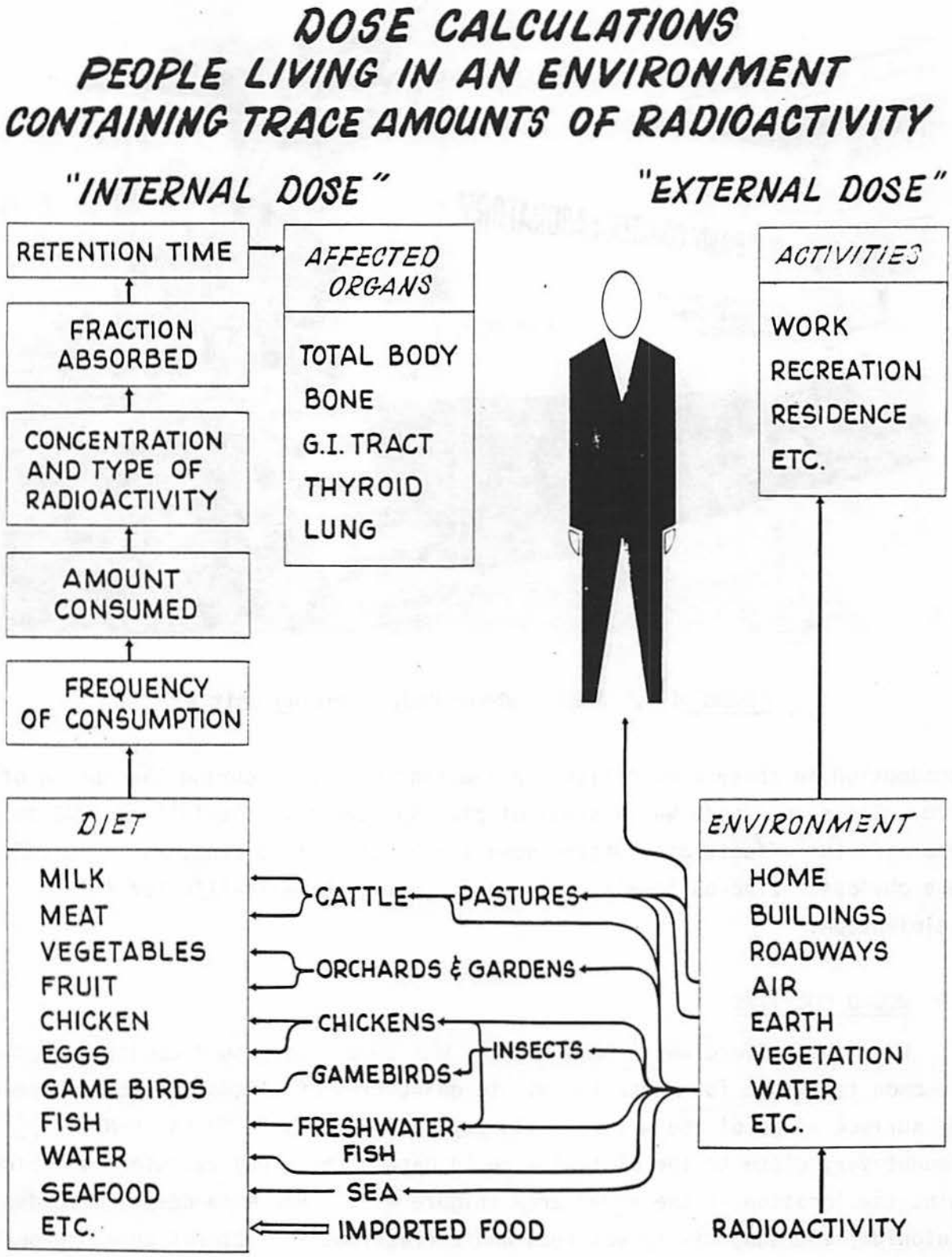

FIGURE 4.6. Food Pathways for Intake of Radionuclides

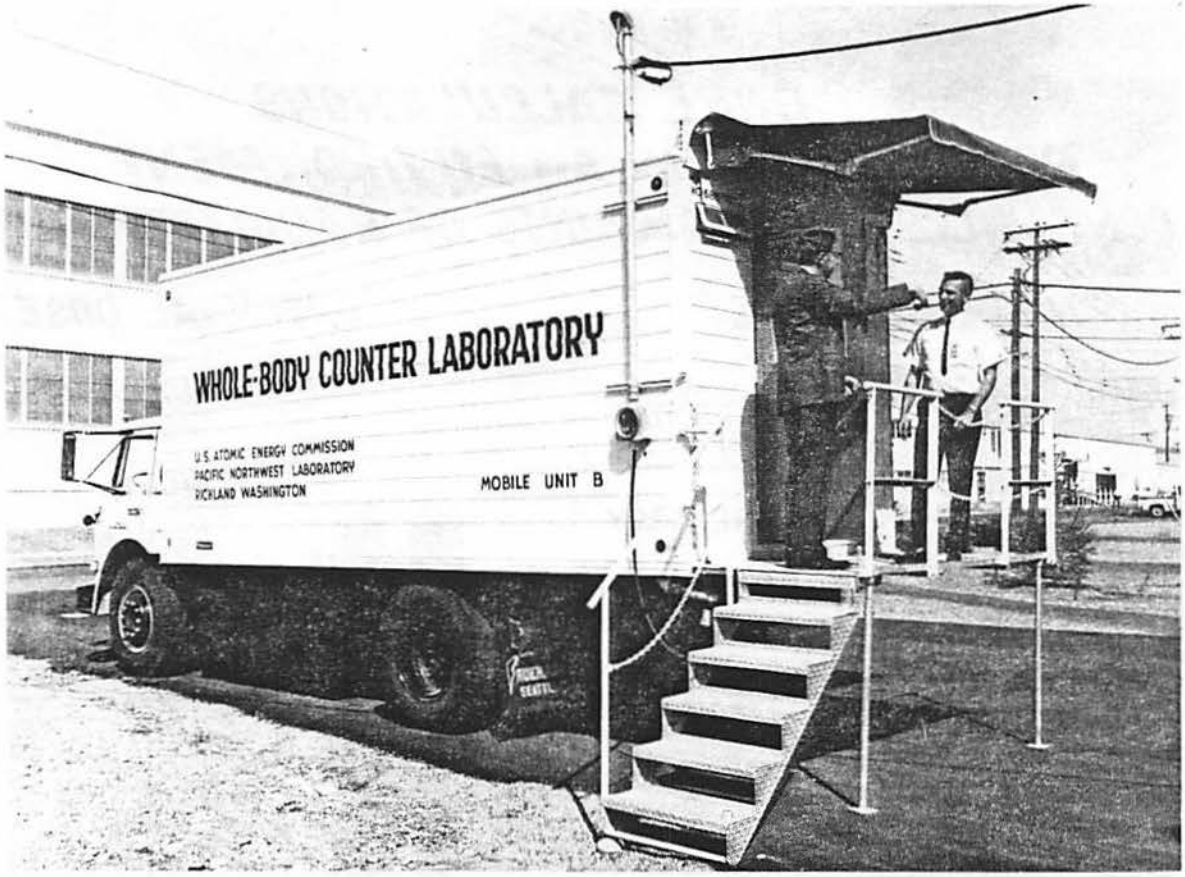

FIGURE 4.7. Mobile Whole Body Counting Unit B

consumption in these communities and the zinc-65 burden during the spring of 1970. The second part was a study of zinc-65 levels in the fall of 1971 to determine the effects of shutting down the older Hanford reactors. The effects were obvious: zinc-65 levels declined following the half-life for this radioisotope.

4.6 WOUND COUNTING

When the Hanford Whole Body Counter was completed, wound counting became a common technique for measuring minute quantities of plutonium imbedded near the surface areas of the wound. Thin crystal counters [1 mm-thick-NaI(Tl)] brought very close to the plutonium could detect the x-ray emissions and pin-point the location in the wound area (Figure 4.8). For more deeply imbedded plutonium, the sensitivity was less and corrections for absorption and geometry were determined (Roesch, McCall, and Palmer 1960; Roesch 1962).

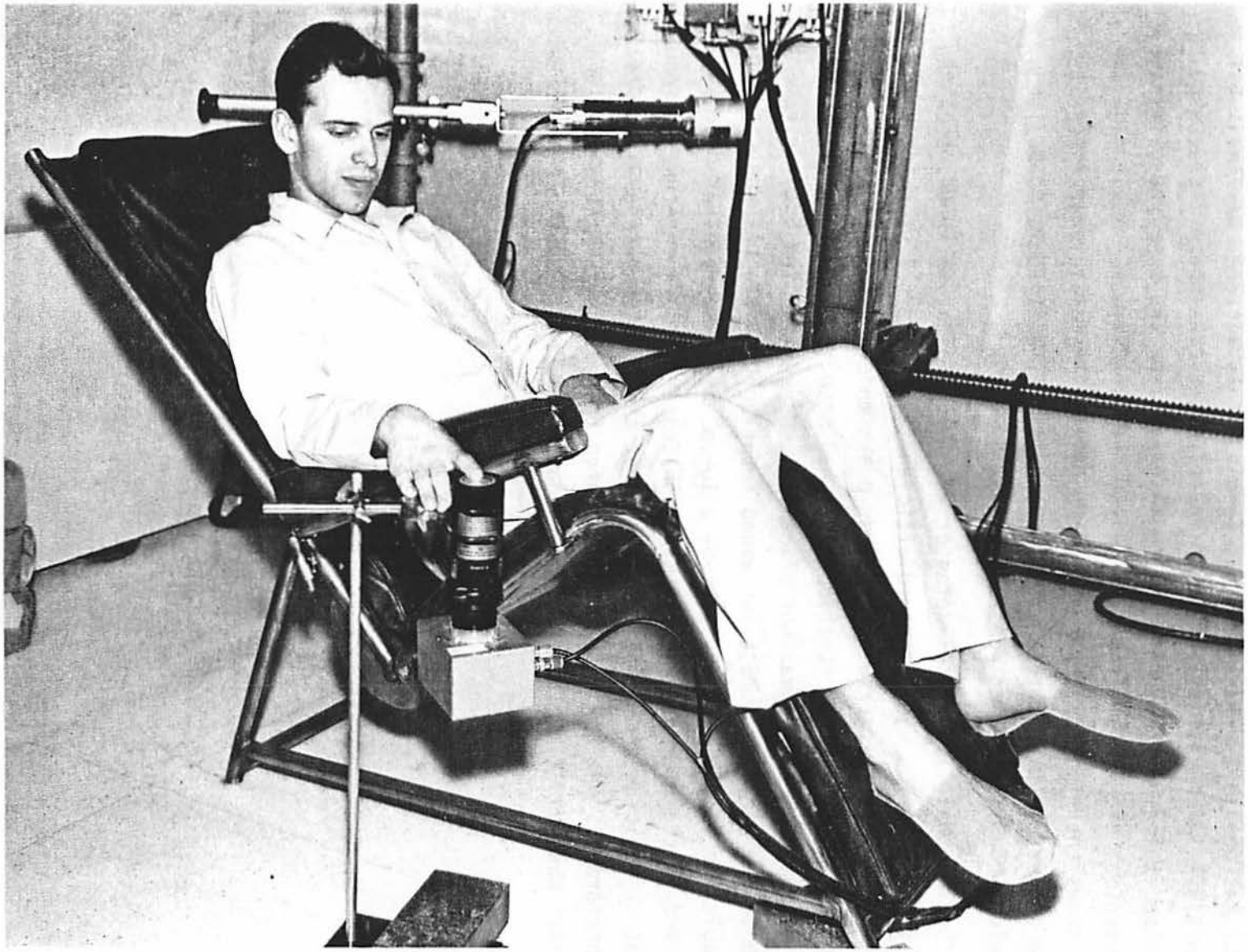

FIGURE 4.8. Wound Counting

Plutonium contamination in wounds was located by using a shielding screen with a small aperture and moving over the suspected wound area until the maximum count rate was obtained. With the thin crystal a detection limit of about 0.1 nCi was possible with a 10-minute count. This detector was invaluable to the physician and health physicist in defining the area where tissue should be excised to remove the contaminating material from the body and eliminate the potential of excessive absorption into the bloodstream. Table 4.4 (Brady 1964) shows the results of wound counting during the early years after it became a possibility and the reduction obtained by excision of deposited plutonium in a significant number of cases.

The thin NaI(Tl) crystal detector was the mainstay for wound counting until the late 1970s when improved efficiencies of the GeLi detector along with its capability of resolving energy peaks made it a practical instrument for wound counting. The detection level had been improved to the level below which excision of tissue was not practical. During 1980 the GeLi detector became the primary instrument for wound counting; however, both detectors are available for use if needed. In 1984 a 10-cm^2 by 13-mm Ge planar detector was moved to the Emergency Decontamination Center (EDC) and set up for counting so that it would be immediately available at the location where most excisions were performed. The new location eliminated the necessity of transporting personnel back and forth between the EDC and whole body counter facilities.

TABLE 4.4. Plutonium in Wounds, 1961-1963 (Brady 1964)

TABLE XV

PLUTONIUM IN WOUNDS, 1961

Serial No.	Original Amount Counted in Wound, ncuries	Postexcision, ncuries	In Excised Tissue, ncuries
1605	900	0.54	
1635	0.87	No excision	
1654	0.4	No excision	
1674	3.6	0.1	
1678	0.25	No excision	
1684	0.1	No excision	
1694	231	1.1	
1704	0.1	No excision	
1705	<0.1	No excision	
1751	0.23	No excision	
1824	<0.1	No excision	
1868	0.37	No excision	
1871	0.1	No excision	
1941	0.1	No excision	
1944	1.7	No excision	
1967	8.4	3.0	7.8
2101	23.8	2.3	
2131	<0.1	No excision	
2188	1.6	0.34	0.92
2280	0.58	No excision	
2315	<0.1	No excision	
2366	<0.1	No excision	
2374	3.75	1.77	1.54
2402	<0.1	No excision	
2495	0.2	No excision	

TABLE XVI

PLUTONIUM IN WOUNDS, 1962

Serial No.	Original Amount Counted in Wound, ncuries	Postexcision, ncuries	In Excised Tissue, ncuries
2568	5.7	<0.1	5.8
2575	0.73	<0.1	
2692	1.25	No excision	
2767	<0.1	No excision	
3274	0.24	No excision	
3278	2.9	No excision	
3293	0.55	No excision	
3294	<0.1	No excision	
3304	0.82	No excision	
3323	40	1	33
3324	10	1	10.8
3078	<0.1	No excision	
2801	No count	1.9	782
2933	0.98	No excision	
2935	<0.1	No excision	
2874	<0.1	No excision	
2880	No count	2.6	

TABLE XVII

PLUTONIUM IN WOUNDS, 1963

Serial No.	Original Amount Counted in Wound, ncuries	Postexcision, ncuries	In Excised Tissue, ncuries
3106	0.75	<0.1	
3109	7.09	<0.1	14.5
3110	1080	0.6	930
3137	3.4	<0.1	
3174	0.40	No excision	
3388	14.0	<0.1	14.0
3501	0.16	No excision	
3504	31.4	<0.1	40.8
3574	0.57	0.13	
3589	44.0	0.13	41
4166	1.45	0.2	0.77
4064	<0.1	No excision	
4076	134	0.12	152
4190	<0.1	No excision	
4217	43	0.69	39
4237	42	<0.1	36
4245	2.8	0.62	1.3
4246	<0.1	No excision	
4358	<0.1	No excision	
4362	0.21	No excision	
4413	5.88	0.12	5.38
4414	0 94	<0.1	0.88
4550	1.7	0.12	1.8
4574	<0.1	No excision	
4734	<0.1	No excision	
4735	<0.1	No excision	
4778	<0.1	No excision	

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5.0 RADIATION EXPOSURE RECORDS

Since formation of a Medical Division at the Chicago Metallurgical Laboratory in August 1942, a radiation protection program large enough to serve the Hanford operation had not been envisaged. No precedent for reporting and recording radiation exposure existed. However, the importance of such records for large numbers of Hanford workers that would soon be involved with radiation was immediately realized and development of a records system was started. Parker and Cantril were the prime influences in establishing a system of radiation control including recording of radiation exposure. In one of his early reports Parker stated "In a well-established system, many of the recorded incidents would have been considered too trivial or local for inclusion in the permanent record. However, the reader of these reports can be certain that no exposure or potential exposure which came to the attention of the HI Section has been omitted from the record."[a]

5.1 ORIGINAL RECORDS

The radiation exposure records for Hanford workers during the first several months of operation were recorded on temporary forms that were designed from the forms used at the Metallurgical and Clinton Laboratories. This system was used until March 1945[b] when Hanford-designed records and forms were initiated to permanently document the Hanford personnel radiation exposure history records.[a]

Pencil dosimeter results were recorded daily and the lower value of the weekly cumulation was compared with film badge results from the open window and shielded areas of both sensitive and insensitive films. These records were later transcribed to a master individual Kardex file at HI headquarters (Hart 1947).

(a) H. M. Parker. September 7, 1945. Memorandum for the file, "Health Instruments Section-Exposure Standards, Reports, and Records." Hanford Engineering Works, Richland, Washington.
(b) H. M. Parker. 1945. Memorandum for the file, "Health Instruments Section-Personnel Meters Experience to August 1945." Hanford Engineering Works, Richland, Washington.

The initial densitometer readings from early film badges were recorded on a special form. Badge crews converted area call numbers to payroll numbers and the four densitometer readings were then listed by payroll number and converted to dose. Readings of >100 mrep were listed on a weekly badge report, and those reading >300 mrep were placed on a master file in the same manner as high pencil dosimeter results. After reading and recording results, all film was sent to the 303-F metal storage hutment building. During this early period, radiation records were stored in available locations such as the 3746 Building (Figure 5.1), 3701 Gatehouse and 303-F Hutment. Pencil crews, badge crews, and clerical staff had to maintain the records in these separated locations, which caused some difficulty in consolidating an employee's complete radiation exposure history. The concept of a centralized records and personnel dosimeter processing facility finally became a reality in 1949 when construction started on a building to house this facility.

Radiation survey results obtained in the area production and laboratory facilities were entered in classified logbooks. Laboratory and calibration

FIGURE 5.1. Early Storage of Radiation Exposure Records

data were also entered in logbooks. The location of these early logbooks is not known, but many were probably taken away from Hanford with the rest of the du Pont records in September 1946 when du Pont turned operations of HEW over to General Electric and left Hanford. Many records were probably sent to government records storage. Radiation survey records were and continue to be kept at the respective facilities and then are sent to the government records storage center. Only copies of field surveys that are directly concerned with an employee's potential exposure to radiation such as skin contamination, personal effects contamination, potential exposure that may not have been recorded by personnel dosimeters, etc., are forwarded to the personnel radiation exposure records center for inclusion in an individual's file.

5.2 CONSOLIDATED RADIATION RECORDS CENTER

In 1949 the concrete, windowless 3705 Building was constructed as a centralized records center serving as the focal point for the radiation histories of all Hanford employees and visitors. In addition to the radiation records maintenance and storage, all of the processing of personnel dosimeter film and pencil dosimeters and the evaluating of results from these dosimeters were performed in this building. By early 1950, the building was completed and a concerted effort was made to consolidate all radiation exposure histories for each employee into one record that included all known involvement in unusual incidents where radiation or contamination may have been possible. This consolidation was a massive effort involving the manual transcription of information from the work sheets used by the badge crews and pencil crews to the individual employee's record. Microfilming the annual contents of the individual record folders started on a routine basis to preserve information in the event the hard-copy records were destroyed. Film from all personnel dosimeters worn by employees was processed for archival storage and kept so it could be recovered and reevaluated if necessary.[a] A detailed study (Wilson 1957) of the early film from personnel dosimeters was conducted to determine the reproducibility of densities assigned to each film, the condition of the film, and the accuracy of the early dose interpretations made for an individual.

(a) Badge Supervisors' Manual. Internal manual of the Radiological Sciences Department, 1945-55. General Electric, Richland, Washington.

Results of the study indicated that preservation of film was very good for that period of time and that the interpretation of dose was very accurate. In the late 1960s, the AEC decided that film no longer needed to be kept as part of the primary record of radiation exposure for an individual.

5.3 ELECTRONIC DATA PROCESSING OF EXPOSURE RECORDS

All radiation exposure records were accumulated and recorded manually until 1957. At that time exposure records were being maintained for about 14,000 individuals annually. Data for preparing reports had to be extracted manually, which limited versatility in analyzing the exposure record. At the beginning of 1957, the conversion to electronic data processing (EDP) began using an IBM 702 computer (Nelson 1958). With this improvement in record-keeping, data required for analyses and interpretation became much more accessible. Converting to electronic data processing also opened up many possibilities to study exposure trends and produce reports useful in the operating areas for exposure control. Other services that became available with the use of the EDP were the production of sampling labels and analytical sheets for the bioassay program, and the printing of the gamma pencil Kardex cards for recording each employee's pencil dosimeter readings. Besides increasing the scope of available radiation exposure information, there were further advantages of efficiency and cost savings resulting from electronic handling and storage of vast amounts of data.

In 1959 a more powerful computer, the IBM 709, was installed. In 1961 the 7090 computer became available, and improved the efficiency of record-keeping and expanded the ability to study the radiation exposure of Hanford workers. A UNIVAC 1108 was also placed in service in 1965. The UNIVAC was scheduled to be replaced with a Cyber computer in 1973. Because of the difficulty in converting the record systems from the 7090 to the Cyber, the UNIVAC 1108 began replacing the Cyber in 1974. Since then, the UNIVAC computer has been used for records storage. These records also contain peripheral information such as radiation training and protective mask fit data for every employee.

The computerized radiation record data base has always been a manual entry processing system, which limited immediate access to records until information

was entered on a monthly or longer input schedule. External and internal exposure data for individuals were processed by batch computer systems with the original data coming from the UST and the Whole Body Counter. Retrieval of information for a particular individual required a manual search through file cabinets for microfilm records, and report output from the batch systems. The batch computer systems were used until a data base management system (occupational radiation exposure, or ORE) was implemented in 1982. The ORE system allows continuous input of data to employees' radiation exposure history files as received by the Radiation Records group. The following is a list of the batch computer systems that were used previously:[a]

- External Exposure System (EXP). Input is received in the form of many different paper documents from the contractors, magnetic tape of dosimetry results from U.S. Testing, cards from the HEHF [Hanford Environmental Health Foundation] Mask Fit system and magnetic tape from the contractor payroll systems. PNL [Pacific Northwest Laboratory] edits this data and puts together batch input that is in card form to the EXP Univac [UNIVAC] system. Output consists of 15 monthly reports and 11 annual reports some of which are distributed to the DOE contractors. [Development was initiated in 1957 with the first computer and the system was fully implemented in 1974 with conversion to the UNIVAC.]
- Visitor Exposure System (VIS). Input is received in paper form from all contractors along with a magnetic tape of results from U.S. Testing. PNL edits all data and puts together batch input to the Univac [UNIVAC]. Output is in the form of seven monthly reports and five annual reports for use internally and for distribution to the DOE contractors. [Development was initiated in 1957 with the first computer and the system was fully implemented in 1974 with conversion to the UNIVAC.]
- Subcontractor Exposure System (EXS). This system works in the same way as the VIS does, except EXS supports the necessary requirements for maintaining occupational exposure for subcontractor employees. [This system was developed in 1975 for use on the UNIVAC.]

(a) J. R. Lewis. June 1980. "Personnel Dosimetry Summary of Information Processing." Internal report, Pacific Northwest Laboratory, Richland, Washington.

- Bioassay System (BIO). This system maintains the analytical results of samples of urine, feces, blood, and sputum. Input is received and includes documents from the contractors and cards from U.S. Testing reporting the results of the analysis. PNL edits the data and puts together batch input to the computer programs. The output includes four monthly and six yearly reports which are used in the support of the internal dosimetry program and distributed to other DOE contractors. [This system was initiated in 1976 for use on the UNIVAC.)
- In Vivo [or IVR System]. This system is used to maintain the analytical data from whole body counts, head counts, wound counts, and lung counts. Input is received on magnetic tape from the Whole Body Counter and the EXP system. Output includes five different monthly reports and four yearly reports which are used to support the Internal Dosimetry Program and for distribution to other DOE contractors. [This system was initiated in 1974 for use on the UNIVAC. The IVR and BIO systems were combined in 1981 to form a system called BIVR and placed on the PNL computer for processing. It was converted to the ORE data base management system in 1983.]
- HRO [Hanford Occupational Radiation Exposure Record System]. This is an HEHF file of external radiation exposure that PNL edits and updates yearly after the EXP annual processing. [The HRO system was developed in 1965 as a result of the Mancuso study (Mancuso, Sanders, and Brodsky 1965) of Hanford external radiation exposure and served as a history of this past exposure. The system was transferred from HEHF to PNL in 1979 and then converted to the ORE data base management system in 1983.]

Summary reports were generated annually from the batch systems and placed in the individual's occupational radiation exposure file. These records were then microfilmed, cut into strips, and placed in the individual's packet for storage in order of payroll number. Back-up microfilm of these records are stored at the National Archival Records Center in Seattle, Washington.

Two other small systems used in the radiation exposure records program were:

- Mask Fit (MAK). This system was initiated in 1978 and contained employee information about protective mask fit and training. It was the first system to be converted to the ORE data base.
- Hanford Internal Exposure (HIE). This system was initiated in 1974 as a history file of employee internal radiation exposure. Problems were encountered during its conversion to the UNIVAC computer in 1978 and part of the data was lost. The data are currently being recovered and placed in the ORE system.

Punched EDP card decks were produced to enter all personnel dosimetry information into the computer and for storage on magnetic tape. The transfer of this data to the computer for processing has always been done in a batch mode which caused some delay in making the information available for use.

The concept of a centralized database management system (Hunt 1983) that was visualized several years ago and ORE was finally developed for routine use in 1982. With this new system, information may be entered into an individual's record on a daily basis and then be immediately available to authorized users via on-line data communication links.

5.4 FILM IDENTIFICATION MARKINGS

Since the beginning of film dosimeter use, a concerted effort was made to identify and preserve the film after its removal from the holder for processing. During 1944 and 1945, film was identified with a payroll number perforated in the film packet and hand-stamped with ink to indicate date of processing. By 1946, an x-ray unit was obtained to permanently mark the film with a number, (1 through 52) to indicate the week, and a series of dot formations to indicate the area where the dosimeter was assigned. In 1947, another series of dot formations was introduced to mark the film with the year in which it was used, and these were arranged for an 8-year cycle (Hart 1947). This identification pattern was used until the plastic film dosimeter holder was introduced in 1957.

During the early years of Hanford operations, 300 Area Instrument and Electrical Maintenance provided the repair services on the film badge holders: drilling new payroll numbers in the shield plate, filling old holes with solder,

repairing broken pins, etc. This repair function was transferred to the Exposure Records Unit in August of 1955, where it remained until introduction of the new plastic film holder in 1957. The plastic badge was designed with a 0.0065-in.-thick adhesive-backed lead tape in which holes were punched using a binary code system for the payroll number and a designation for work area where the badge was issued. When x-rayed through the lead tape the identification was permanently recorded on the film. This system was used until replaced by the TLD.

5.5 THERMOLUMINESCENT DOSIMETER IDENTIFICATION

The early plastic cards holding the TLD chip had the identifying payroll number punched through the card. The punched payroll number could be read by the badge reader. This information was then transferred to a card punch that produced a data processing card with identification and light output readings for radiation dose interpretation. The perforation of the thin plastic card caused an easy point for breakage. To solve the breakage problem, a bar code reader was developed for use with the badge processing equipment which allowed use of a gummed label with a bar code for identification. This system is still in use to identify the personnel dosimeter and transfer the information to the individual's radiation exposure history file.

5.6 RECORD OF HANFORD CONTRACTORS

Many contractors have been responsible for the operation of Hanford since its inception during World War II when the U.S. Government and the du Pont Company came to an agreement to construct and operate the plant. The reorganization of some du Pont departments and the appointment of staff members started by December 14, 1942 and assumption of duties commenced by December 16. The first plant staff for plant operation started assembling in Richland by early spring of 1944. Intensive construction activities started in early 1943. A well-known former Hanford employee, T. W. Hauff, was the first person assigned to assist the Construction Division in the interpretation of technical and engineering field problems connected to process requirements. He reported to the Hanford Site on August 23, 1943.

When World War II ended, du Pont insisted that HEW had been built and operated only in the interest of national defense, and plant operations should be transferred to an organization interested in production of atomic energy. In June 1946, the government announced that General Electric had been selected to assume responsibility for Hanford operations on September 1, 1946.

Operation of HEW remained primarily under General Electric guidance until another company, Vitro, assumed the design-engineering function in May 1963. This change was followed by the push for segmentation of plant operations that started with Battelle Memorial Institute taking over the laboratory functions and certain service activities on January 4, 1965 including the evaluation of all plant employees' radiation exposure and maintenance of employees' radiation exposure history records. The U.S. Testing Company took over processing of personnel dosimeters, bioassay samples, and environmental samples.

The other Hanford contractors and the date they assumed responsibilities for various site functions are listed in Table 5.1. Segmentation was viewed as a way to stimulate the business climate with activities not related to Hanford operations when shutdowns were reducing plant operations and related employment.

TABLE 5.1. List of Hanford Contractors

Company	Dates at Hanford	Function	Acceptance of Previous Contractor's Record of Radiation Exposure
du Pont	12-21-42 to 08-31-46	Total Plant Operation	Start-up Contractor
General Electric	09-13-46 to 12-31-66	Total Plant Operation	No
Battelle Pacific Northwest Laboratory (Battelle-Northwest)	01-04-65 to present	Hanford Laboratory Functions	Yes
Computer Sciences Corporation	07-01-65 to 11-20-75	Plant Computer Operations	Yes
Boeing Computer Services, Richland	10-20-75 to present	Plant Computer Operations	Yes
Isochem	01-01-66 to 09-01-67	Chemical Processing and Waste Management	Yes
Atlantic Richfield Hanford Company	09-01-67 to 06-30-77	Chemical Processing and Waste Management	Yes
Rockwell Hanford Operations	07-01-77 to present	Chemical Processing and Waste Management	Yes
ITT Federal Support Services	03-01-66 to 09-01-71	Plant Services	Yes
Douglas United Nuclear	11-01-65 to 09-01-67	Reactor Operations and Fuels Preparation	Yes
United Nuclear Industries	09-01-67 to 04-19-73	Reactor Operations and Fuels Preparation	Yes
UNC Nuclear Industries, Inc.	04-19-73 to present	Reactor Operations and Fuels Preparation	Yes
Westinghouse Hanford Company (FFTF, WADCO, HEDL)	07-01-70 to present	Reactor Development	Yes
AII-Vitro Engineering Division	05-01-63 to 09-30-81	Design-Engineering Functions	Yes
Braun Hanford Company	10-01-81 to 03-31-82	Design-Engineering Functions	Yes
Kaiser Engineers Hanford	03-01-82 to present	Design-Engineering Functions	Yes
Hanford Environmental Health Foundation	08-01-65 to present	Plant Health Services	Yes
JA Jones Construction Services Company	01-01-53 to present	Plant Construction Services	Yes

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Mancuso, T. F., B. S. Sanders and A. Brodsky. 1965. Feasibility Study of the Correlation of Lifetime Health and Mortality of AEC and AEC Contractor Employees with Occupational Radiation Exposure. NYO-3394-2. Department of Occupational Health, Graduate School of Public Health, University of Pittsburgh. Pittsburgh, Pennsylvania.

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6.0 CALIBRATION OF PERSONNEL DOSIMETERS

With the formation of the HI Section when H. M. Parker arrived at HEW, immediate consideration was given to the calibration of the instrumentation that was available.

6.1 ORIGIN OF CALIBRATIONS

Beginning in July 1944, the first attempts to calibrate instruments were made using the 305 Test Pile. During August to October 1944, portable instruments were calibrated and distributed to the operating areas. Stationary monitoring instruments in 100-B Area were also calibrated at this time. The type of instrumentation available during these first days at Hanford were Victoreen integrons, Lauritsen electroscopes, Victoreen condenser-R chambers, Victoreen pocket ionization chambers and Victoreen Geiger-Mueller survey meters (GMs). A radium source certified by the National Bureau of Standards (NBS) was initially used as a reference source for these calibrations.

In October 1944, the calibration headquarters moved to the 3745 Standards Building (Figure 6.1) which was designed for radium and x-ray calibrations in October 1944. In March 1945 the 3745 Building was transferred to the HI Section from the Technical Department along with responsibility for all radium at Hanford.

During November 1944, the portable instruments used in 100-B, 100-D and the 300 Areas were calibrated along with fixed "health monitors" in 100-D and 200-W Areas. An attempt to calibrate film badge dosimeters and detachable ionization chambers (pencil dosimeters) was also made during this period. How successful this venture was is not known, and calibration of dosimeters probably was not done routinely until some time in 1945. By December 1944, routine weekly calibrations were initiated for instruments used in 100-B, 100-D, 200-W, and 200-N Areas. Instruments installed around the Hanford perimeter at Riverland, Hanford, Richland, and Pasco were also calibrated by January 1945.

During 1945, a system was started whereby all portable survey instruments were brought to the 3745 Standards Building for routine calibration. The

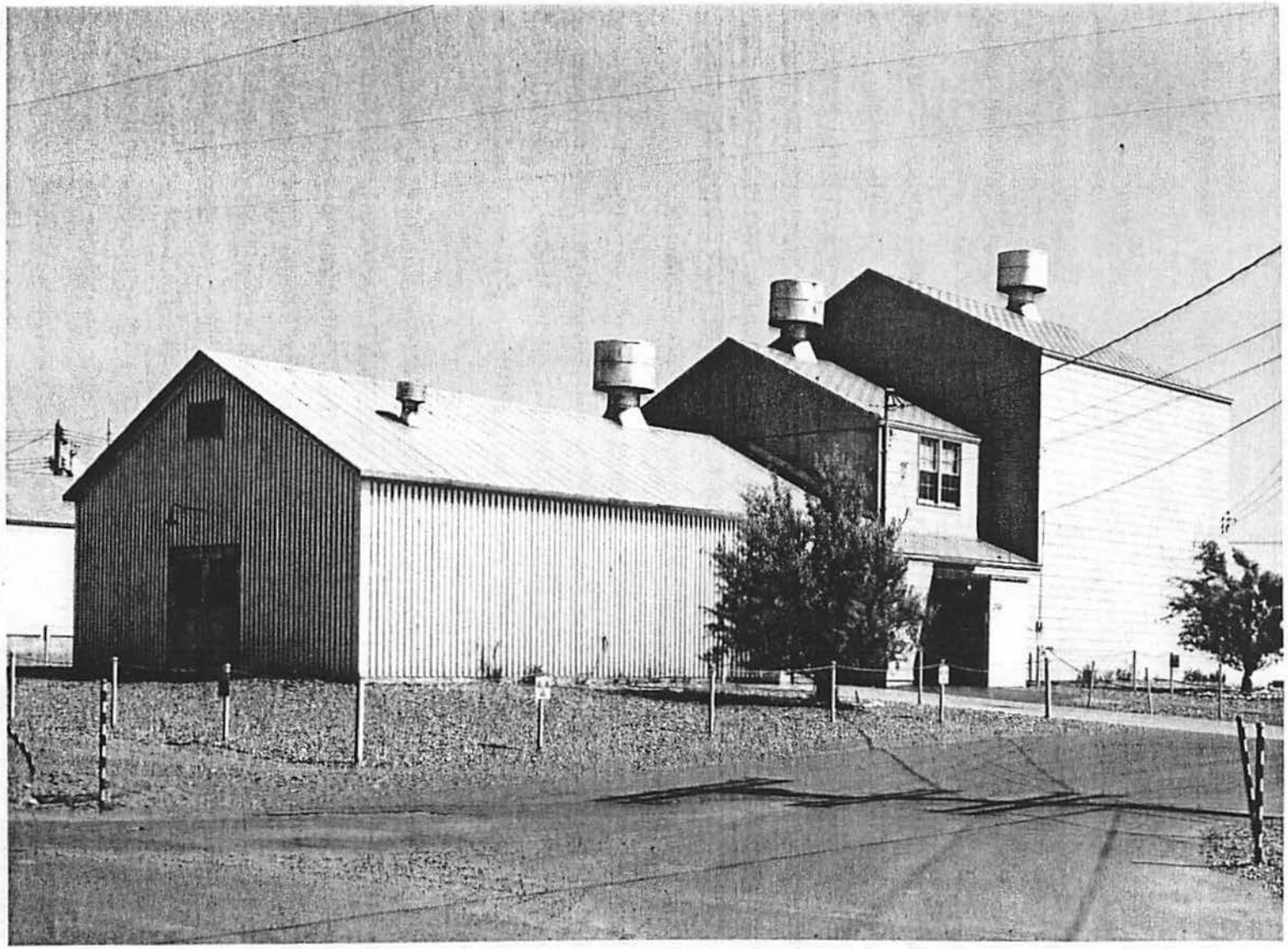

FIGURE 6.1. 3745 Building, 300 Area, Calibration Headquarters Since 1945

exception was an alpha survey instrument called the "Sandy" which was calibrated at the 231 Isolation Building in 200-W Area. By the middle of 1945, x-ray calibration procedures were established for routine calibration of portable survey instruments and pencil dosimeters as well as working with some fission product sources in an attempt to calibrate for the intermediate energies that would become prevalent in the operation of the separations facilities. Slow neutron monitors received a special calibration in the standard graphite column of the 305 Reactor and fast neutron calibrations were started using a RaBe source.

By July 1945, a total of 2835 portable survey instruments and 3324 fixed monitoring instruments had been calibrated. Later in that year a problem of contamination on the instruments returned for calibration was detected. This problem was handled successfully by establishing a special work area for checking all incoming instruments and doing the necessary decontamination prior to recalibrating. Because of the large amount of daily instrument calibration, other problems appeared: the radium sources leaked, and calibration involved heavy use of x-ray equipment. To reduce these problems, the radium source was checked routinely for leakage and lead shield was added to the 3745 Building.

As a result of an intercomparison study of film badge response, calibration, and photometer readings at the Clinton and Metallurgical Laboratories and at Hanford, Parker (1945) realized that beta radiation calibration was necessary. By the end of 1945, as a result of the intercomparison study, extensive beta calibrations were under way using uranium metal. Until this time the open-window portion of the film badge was not considered of much value. Studies were initiated to determine the ratios of densities in the open-window and shielded areas to improve calibration and interpretation of exposure. Until this time, very little attention had been directed to the insensitive emulsion, thus a program was started to include high level exposure in the routine calibration schedule. Table 6.1 indicates the volume of work, the beginning of routine film badge calibrations, and the increase in work because beta calibrations began in December 1945.

Neutron film with a special fine-grain emulsion was being used to monitor workers with a potential for neutron exposure but the response of the film and

the ability to calibrate and read proton tracks for this level of exposure was not successful. The neutron monitoring procedures at Hanford had not been established yet, but it was assumed that tests implied workers were adequately protected against fast neutron exposure.[a]

TABLE 6.1. Instruments Calibrated During the Period July through December 1945

Month	Portable Instruments	Fixed Instruments	Pencils	Film Badges
July	562	578	15,234	-
August	418	506	13,152	264
September	451	373	12,461	150
October	362	332	11,162	315
November	397	632	12,399	364
December	373	584	11,826	1096

Pencil dosimeters were calibrated with a radium "bug" placed in a holder in the center of a large plywood circle, or "Ouija Board" (Figure 6.2). The pencil dosimeters were placed in holes drilled in concentric circles at precise distances around the center.

6.2 BETA-GAMMA FILM BADGE CALIBRATION

Since the beginning of HEW, radium has been used to calibrate the film badge and pencil dosimeters used to measure gamma exposure. Film badge calibration was conducted on a "Ouija" board similar to pencil dosimeters and other wooden jigs that positioned the film badge at various distances from a source (Figure 6.3). The distances were carefully measured to provide the various levels of exposure to produce a calibration set.

In 1959, a calibration jig was placed in use to improve the accuracy of dose delivered to the film during calibration (Kocher 1959). During this period the first mechanization of source movement was also placed in service.

(a) H. M. Parker. December 7, 1945. Memorandum for the file, "7-3090, Comparison of Badge Film Readings at the Metallurgical Laboratories, Clinton Laboratories, and the Hanford Engineer Works."

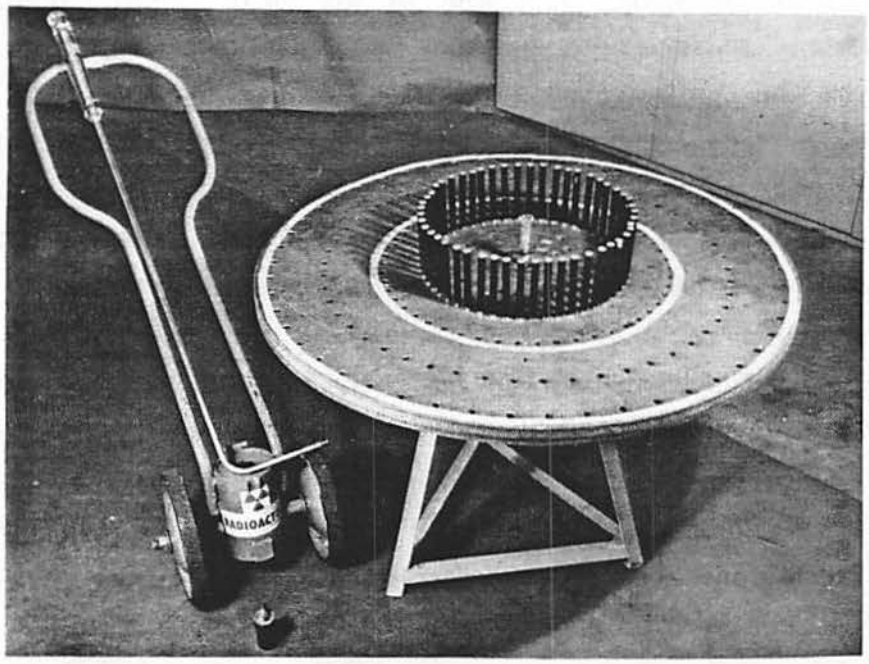

FIGURE 6.2. Pencil Calibrations on the "Ouija Board"

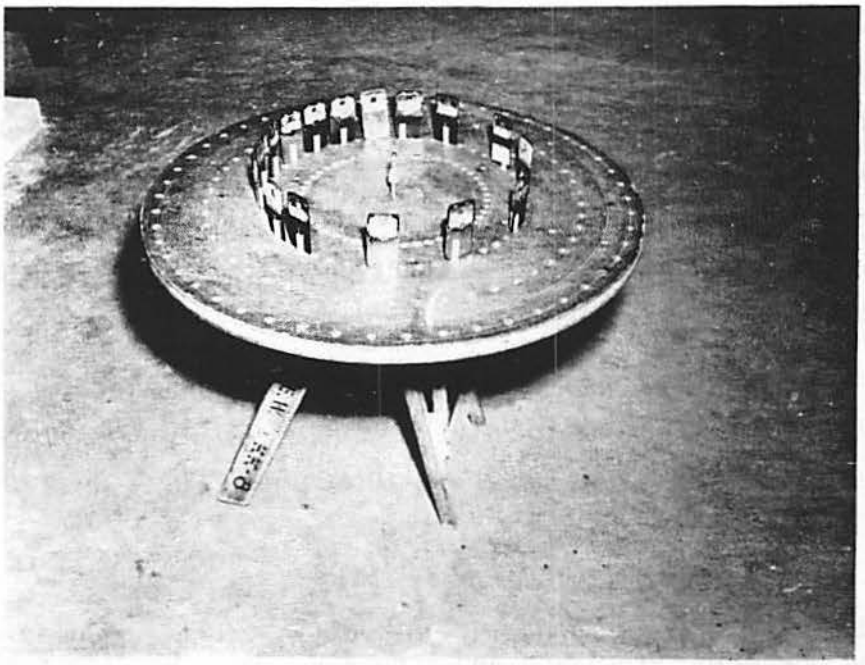

FIGURE 6.3. Film Calibration on the "Ouija Board"

The source used for calibrating was a 0.5-g radium capsule prepared in 1947. Periodic checks of the source were made by the Radiological Physics group using calorimetric measurements and they found it to be 1.4% less than that calculated from the certified weight of the capsule. A dose rate of 8.25 R/h at 1 cm from 1 mg radium-226 encapsulated in 0.5 mm platinum was considered the standard. The jig (Figure 6.4) held the film 4 feet above the concrete floor in a large open room to minimize scatter and an automatic source positioning mechanism was used to position the source and control the time of exposure. The system utilizes a vacuum pump to lower pressure in the tube attached to the storage cask causing the source to rise into correct exposure position. Timing was regulated by controlling the operating time of the vacuum pump with an accuracy of ±3 sec/h, and during exposure the source rotated in the tube which nullified any nonisotropic emission effects. Measurements on the Hanford source indicated that it possessed a nonisotropic effect of about 5% at 10 cm and decreased to about 1% at 100 cm.[a]

For routine gamma calibration a "set" of film was composed of 13 film packets, each of the packets was exposed to a different dose. The thirteen exposures were 30, 60, 90, 120, 180, 240, 300, 500, 750, 1000, 2000, 5000, and 10,000 mR. The film packets were arranged on the jig so that a complete calibrated set could be obtained by a single 20-minute exposure. Design of the holders allowed two films to be exposed at each calibration level. The angular dependence of film response (Little 1960; Nees 1969) was also studied extensively to determine what effect there might be on evaluation of personnel exposure. With large angles perpendicular to the film plane it was found that the degree of overresponse was a function of the photon energies, except at the 16- and 23-keV levels.

In the middle of 1965, new calibration procedures called for film calibration sets at 14 exposure levels; they were 15, 30, 60, 90, 120, 180, 240, 300, 500, 750, 1000, 2000, 5000, and 10,000 mR. These were prepared

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(a) C. G. Hough, G. A. Little and W. L. Nicholson. 1959. Radiation Protection Operation Precision and Accuracy Study; Non-Isotropic Effect in Radium Gamma Source. Internal report, General Electric, Richland, Washington.

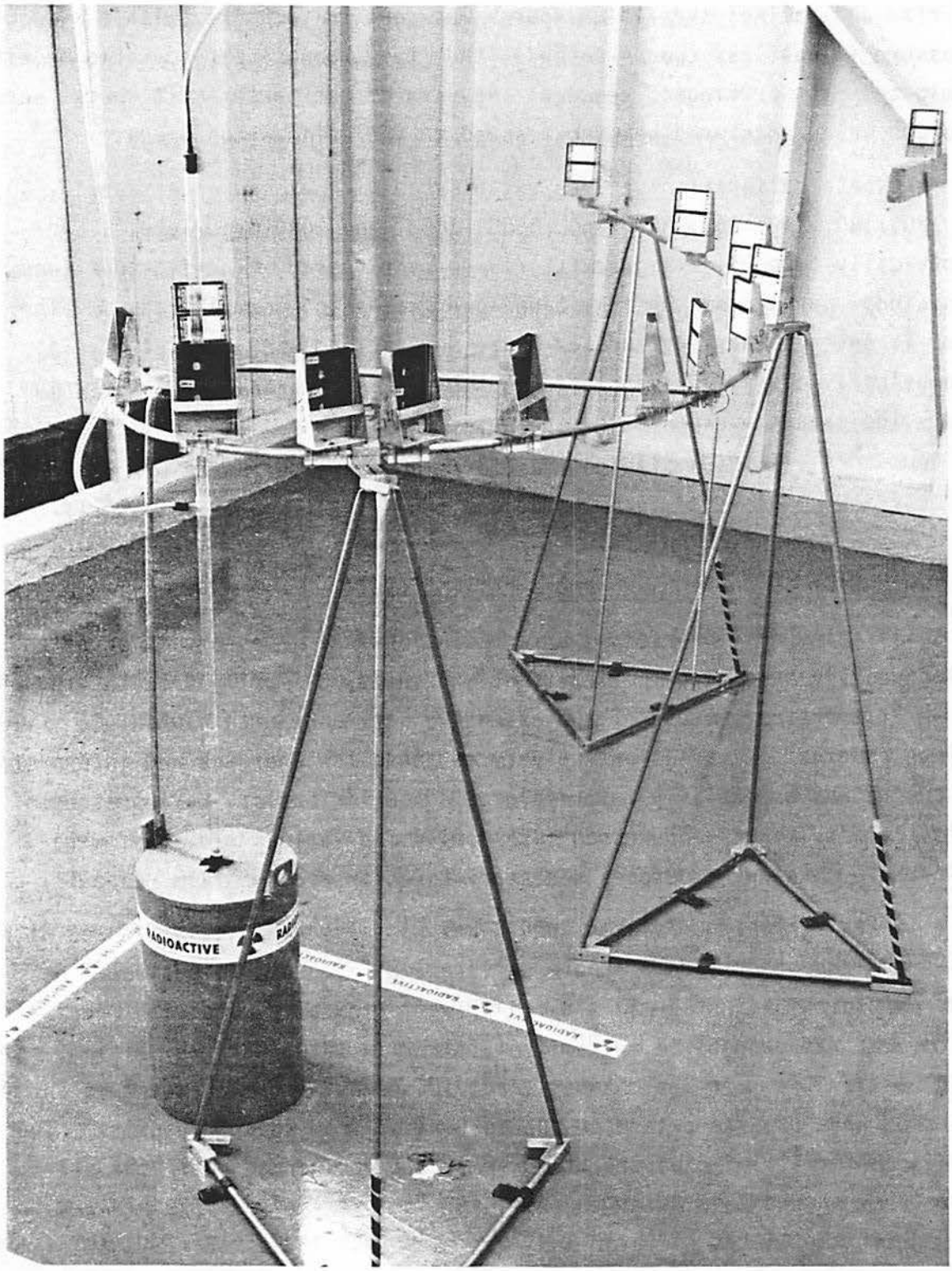

FIGURE 6.4. Improved Film Calibration Jig with Rotating Source

using the same jig as previously used for calibrations with periodic checks being made at each exposure position with a certified Victoreen R-Meter chamber. The rise and fall of the radium source was routinely checked with a stop watch to assure it was less than 4 seconds, thus the exposure period would be within 20 minutes plus or minus 5 seconds. Results of the these audit checks were recorded in a registered notebook issued to the Calibration group.

The beta calibration set was established with exposures at the 15, 30, 60, 90, 120, 180, 240, 300, 500, 750, 1000, 1800, and 5000 mrad levels. An electrically timed jig (Figure 6.5) is currently used. The jig positions the open window portion of the film badge over wafers of normal uranium. The timer is set for the length of exposure desired and when complete the jig automatically opens. Extrapolation chamber measurements over the uranium wafers indicate the exposure at the position of the film is about 225 mrads per hour. Prior to this time beta calibrations were performed by placing the dosimeters on a slab of uranium metal and manually timing the exposure.

6.3 LOW ENERGY GAMMA, PHOTON, AND X-RAY CALIBRATION

Calibrating for low-energy gamma radiations was necessary in order to more accurately determine the resultant exposures, primarily from the 16-keV and 59-keV energies because of the extensive work done with plutonium. Film response (darkening) varied extensively at these low energies and interpretation of exposure was essentially impossible on a routine basis. K-fluorescence x-rays (Larson, Myers, and Roesch 1955) utilizing various radiators were developed to obtain the energies necessary to calibrate the film response.

A 16-keV zirconium radiator and 59-keV tantalum radiator were used with a 220-Kvp x-ray generator to expose calibration film used to evaluate the dose from plutonium. A 16-mil tin filter was originally used with the tantalum radiator but was changed to a 32-mil Al filter in 1970 (Kathren, Rising, and Larson 1971). Free air ion chambers and Victoreen thimble chambers calibrated by the NBS were used to determine the dose rates from these radiators. To maintain uniformity of exposure, the x-ray unit was warmed until the oil temperature reached 75°F prior to each use. A dose rate of 4.79 R/h was measured for the 16-keV radiator and 70.2 mR/h for the 59-keV radiator. Another

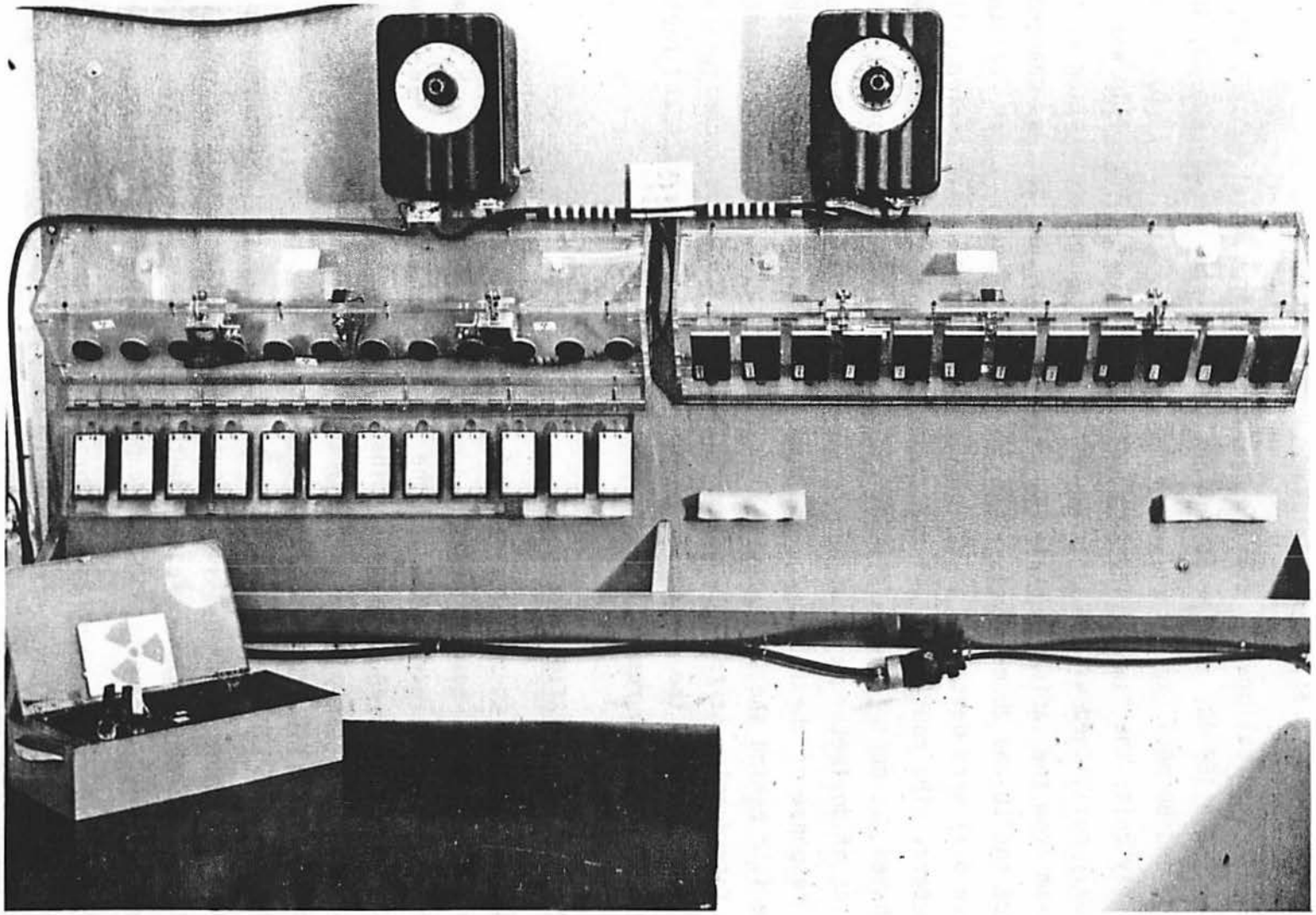

FIGURE 6.5. Uranium Calibration Jig

change in 16- and 59-keV radiators was made in mid-1984 when those radiators recommended in ISO No. 4037 (ISO 1979) were placed in service. For 16 kev, a zirconium radiator with $SrCO_3$ filtration is used and for 59 keV, a tungsten radiator with Yb_2O_3 filtration is used.

A standard calibration set for the 16-keV energy level was 40, 60, 80, 100, 120, 140, and 160 mR; for the 59-keV energy level the set was 20, 30, 40, 50, 60, 70, and 80 mR. Exposure times were controlled to within 1% by a timer on the x-ray unit; the time varied for each exposure level. The film was precisely positioned with a jig (Figure 6.6) at a specific location within the beam from the radiator. Later the standard exposure set was changed to include the 10 and 20 mR levels at 16.1 keV. Subsequently other radiators (Figure 6.7) were developed to give a broader range of energies for calibrating dosimeters. The routine use of radiators for personnel dosimeter calibration was phased out during the late 1960s and they were used only for occasional checking of dosimeter response and for special irradiations. The characteristic response of the film badge dosimeter to the radium source and darkening of the film behind the various shield areas was used for photon calibrations. After introduction of the TLD systems, the same calibration techniques were used. During 1977, the radium source was phased out of service and replaced with a cesium-137 source for routine photon calibrations.

6.4 NTA FILM CALIBRATION PROCEDURE

Early attempts to calibrate film for fast neutron exposure was done primarily with RaBe; however, others experimented with sources such as PoBe and PuBe. With the introduction of the Kodak NTA film in 1950, PoB became the source of choice and was used exclusively until replaced by the positive ion accelerator in late 1955. In July 1958, a plutonium fluoride source for calibration was obtained from the chemical processing organization at Z Plant. This source more closely approximated the neutron exposure received by plutonium workers. This source was placed in routine calibration service at about the same time as a new double-pocket dosimeter holder was developed for use by employees working in locations where exposure to neutron radiation was possible.

The procedure developed for calibration using the plutonium source included the following steps: 1) the film badge holder was placed 50 cm from the source

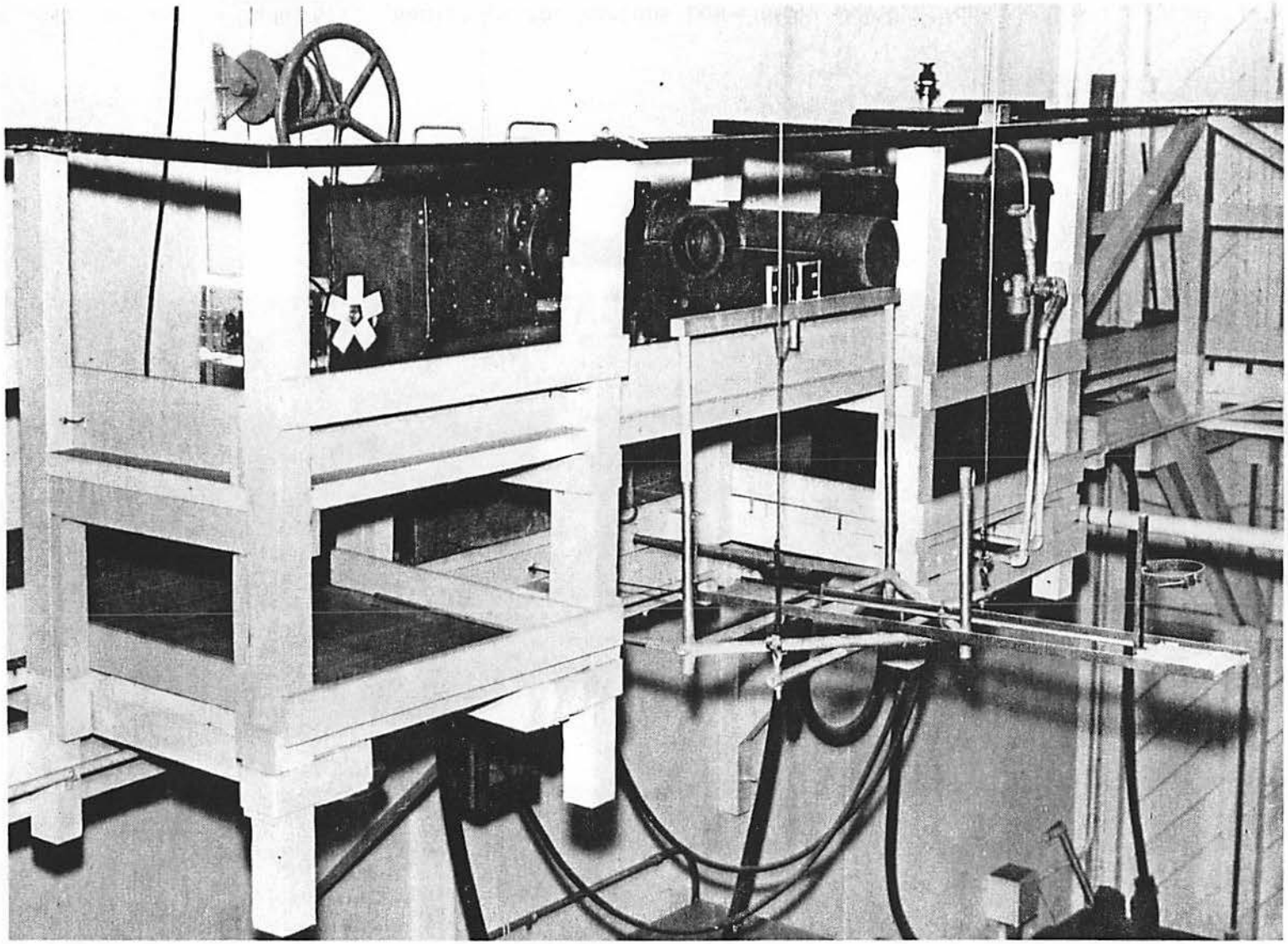

FIGURE 6.6. Jig for X-Ray (K-Sources) Calibration

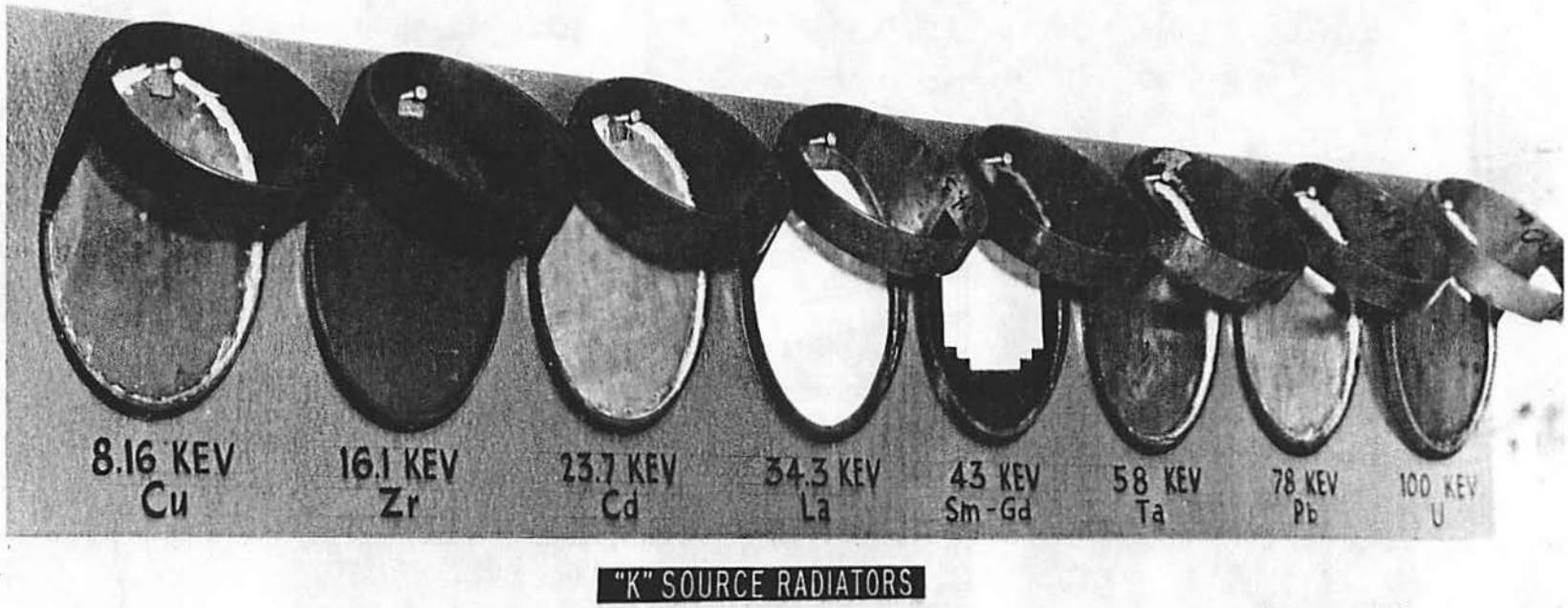

FIGURE 6.7. Radiators for Various Low-Energy Calibrations

and exposed for 64 hours to yield an integrated dose of 1050 mrem; 2) the calibrated film was aged for two weeks to simulate the use period of personnel film; and 3) a fast neutron dose was calculated per neutron track from the calibrated film. The plutonium source was considered to have a strength of 6.00×10^6 n/sec and an average energy of 1.4 Mev. Precision long counter measurements were used to determine the flux at this distance and then were converted to dose rate by first collision dose calculations. Calibration film was allowed to age because of the significantly fewer tracks that could be observed following the aging period. This track fading was thought to be caused by humidity. Thermal neutron calibration was done in the Sigma pile (Figure 6.8) which had graphite stringers for positioning the neutron source and stringers for positioning the dosimeters for calibration. Gold foils were used to calibrate the positions for dosimeter placement.

Starting in January 1965 calibration of NTA film was done with the film badge being placed on a phantom simulating the human body. This arrangement more closely measured the backscatter that affected the film and radiation dose received. When the TLD was introduced, it was calibrated in the same manner. In 1981, a californium-252 source replaced plutonium fluoride for routine neutron calibration. This change eliminated the potential problems of handling and storing a large plutonium source.

6.5 CALIBRATION BLANKS

In 1962, a system was introduced to assist in the detection of whether calibration film was exposed to any extraneous radiation during its storage and exposure to the various sources in the 3745 Building. Film packets called "calibration blanks" were used to measure the radiation background and extraneous exposure to calibration sources. These film packets were selected from the same emulsion lot, and preferably from the same film carton that the film used for the calibration sets were taken. The "blanks" were kept with the film sets at all times except during the exposures to a source. The blank was placed outside of the lead storage pig during radium gamma calibration, on the uranium film jig table, and on the table next to the x-ray console during these calibrations. Processing these blanks along with the calibration sets indicated whether or not the film had received any measurable stray radiation

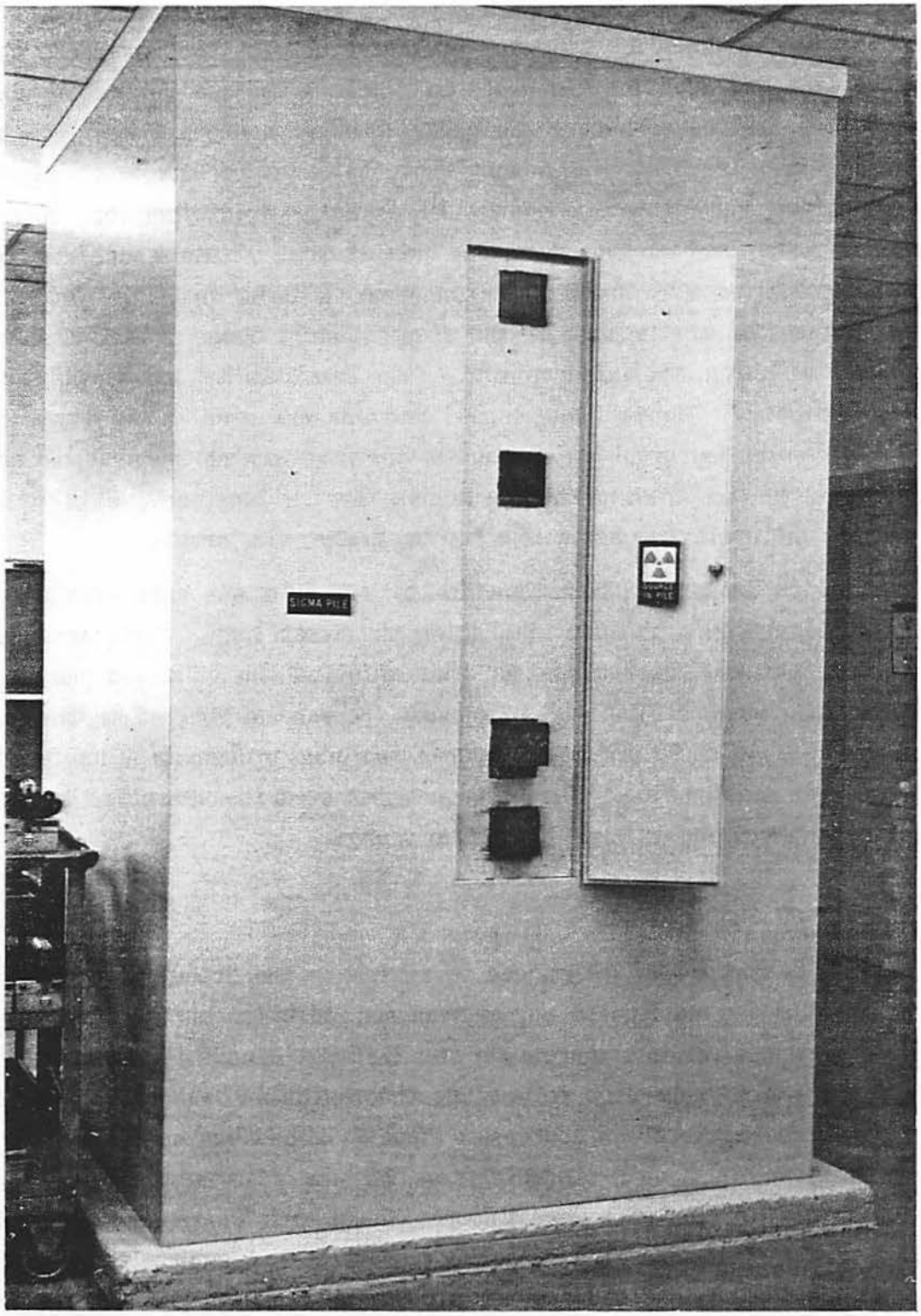

FIGURE 6.8. Sigma Pile

exposure. This control was temporarily dropped during the transition to TL dosimetry but was reinstated shortly thereafter to check for any stray radiation affects.

6.6 CRITICALITY CONTROL FILM

Film was routinely exposed to high-level radiation doses on a monthly basis. These exposed films served as standards for suspected high dosages between about 10 R and 2000 R. An aluminum jig was used to position the film badge holders at 12 different distances from a cobalt-60 source. Monthly corrections were made for the source strength prior to the monthly calibration exposures because of the 5.2-year half-life of the source. The distances from the source-holder center to each film-badge holder on the jig were measured to ensure proper doses would be delivered to each film. These calibration sets were handled, stored, and accompanied with a blank just as the other calibration sets were treated. A large cesium-137 source, obtained in the early 1970s, replaced the cobalt-60 source in order to reduce exposure times.

6.7 CALIBRATIONS FOR THE U.S. TESTING COMPANY

Following transfer of processing responsibilities for personnel dosimeters to UST, these dosimeters were calibrated in essentially the same manner as before the transfer. The calibration sets were exposed at the calibrations facility and delivered to UST for each processing. Results obtained for the calibration sets were examined during each processing to ensure the film densities and resultant dose assignment fell within the tolerances established for each type exposure, i.e., beta, gamma, x-ray, neutrons, etc., before assigning the dose recorded by personnel dosimeters. The TLDs are checked in the same manner to ensure correct dose assignment to personnel. Whenever anomalies occur in the calibration set results, they are resolved to the satisfaction of Personnel Dosimetry before the results are entered in the employee's radiation exposure record, or additional calibration sets are processed until satisfactory results are obtained.

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APPENDIX

ADDITIONAL INFORMATION ON THE EARLY YEARS OF THE HANFORD ENGINEERING WORKS

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ADDITIONAL INFORMATION ON THE EARLY YEARS OF THE HANFORD ENGINEERING WORKS

Several significant first happenings at Hanford had a direct or indirect effect on the level of radiation protection programs that were required onsite. These radiation protection programs were in their infancy when Hanford was first established because large-scale work with radiation had not even been considered until development of nuclear power became a possible reality.

Du Pont's Explosive or TNX Department remained in existence until June 1945 when the Technical Department was dissolved and TNX activities were subsequently curtailed. The TNX organization was placed on a divisional basis and remained in this form until September 1, 1946, the date General Electric assumed responsibility for operation of the HEW.

Some of the significant firsts at Hanford that led to full operation of the plant are listed in Table A.1. Table A.2 indicates the size and organization of the Health Instruments Section at HEW by July 1, 1945. Table A.3 shows the Medical Department's organization following the takeover of Hanford Plant operations by the General Electric Company in September 1946.

TABLE A.1. Significant Early Events at Hanford

July 30, 1943	First Village (Richland) house was occupied
February 1, 1944	Operation of Village passed from Construction Division of the Engineering Department to the Operating Group.
February 23, 1944	Test Pile 305 became reactive (300) Area.
March 20, 1944	First "slug" canned, development line.
May 11, 1944	First "slug" canned, production line in the 313 Building, 300 Area.
September 15, 1944	100-B Pile became reactive.
October 9, 1944	T-Section of 200 West Area was accepted.
November 24, 1944	First tube discharge, one tube from the B reactor.
November, 1944	North Storage Basin used for the first time to store metal.
December 6, 1944	T-Plant tracer run started, Clinton slugs.
December 14, 1944	T-Plant tracer run started, Hanford slugs.
December 18, 1944	All of 200-West Area was accepted.
December 26, 1944	First production separations run started.
January 16, 1945	231 Isolation Building, first run started.
February 2, 1945	200-East Area was accepted.
February 2, 1945	First "product" was delivered.
February 15, 1945	100-F reactor became reactive.

TABLE A.2. Size and Organization of the Health Instrument Section as of July 1, 1945

- Chief Supervisor - H. M. Parker
  - Survey Branch - Senior Supervisor
    - Survey Alternates (6)
    - Senior Supervisor - 100 Areas
      - 100-B H.I. Supervisor
        - Engineers (3)
      - 100-D H.I. Supervisor
        - Engineers (3)
      - 100-F H.I. Supervisor
        - Engineers (2)
    - Senior Supervisor - 200 Areas
      - 200-T & U Plants H.I. Supervisor
        - Engineers (5)
          - Inspectors (5)
          - Helper (1)
      - 200-B & N Plants H.I. Supervisor
        - Engineers (3)
          - Inspectors (3)
          - Helper (1)
      - 231 Bldg. Senior Supervisor
        - Engineers (4)
          - Helpers (4)
      - Site Survey Senior Supervisor
        - Engineers (4)
        - Inspectors (4)
    - 300 Area Group Supervisor
        - Engineer
          - Inspectors (2)
      - Calibration Shift Supervisors (2)
        - Engineer
          - Inspectors (6)
          - Helpers (3)
    - Laundry & Decontamination Supervisor
      - Helpers (4)
  - Personnel Meters Branch Supervisor
    - Senior Supervisor
      - Pencil Shift Supervisors (4)
        - Inspectors
        - Laboratorians (45)
      - Badge Supervisors (2)
        - Inspectors (12)
        - Helpers (2)
  - Special Studies Branch Supervisor
    - Senior Supervisor
      - Helpers (2)

TABLE A.3. Organization of the Medical Department

Superintendent - W. D. Norwood, M.D.
- Asst. Medical Supt. - -Village Medical
- Chief Supervisor - H. H. Pitluck, D.D.S. Dentist
- Chief Supervisor - P. A. Fuqua, M.D., Industrial Medicine
- Asst. Superintendent - H. M. Parker, Health Instruments
  - Chief Supervisor-Operational - C. M. Patterson
    - Assist. Chief Supr.-Survey - L. L. German
      - Senior Supr.-Survey Alternates - L. J. Cherubin
        - Engineers - P. C. Jerman J. D. Duncan
          L. C. Roos J. D. Myers
      - Area Supervisor - 100 Areas & 300 A - M. L. Mickelson
        - Senior Supr. - J. M.Smith (100-D) - W. A. McAdams (100-F)
          - Engineers - B. Anderson R. G. Clough P. Griffiths
            W. C. Reinig M. T. Lewis L. P. Rolph
            G. W. Pomeroy
        - Senior Supr. - 300-A - R. B. Bixler
          - Engineers - Records Section - F. J. Zelley
      - Area Supervisor - F. P. Seymour
        - Senior Supr. - 200-T - P. R. Nelson
          - Engineers - L. V. Barker L. V. Zuerner J. D. Ryan
            R. W. Harvey G. B. Foster S. R. Smith
        - Senior Supr. - 200-B & N - C. R. E. Merkle
          - Engineers - G. M. Rolph R. A. Hultgren A. R. Keene
            W. C. Armstrong R. T. Woolsey
        - Senior Supr. - 231 & 2723 Bldgs. - H. A. Moulthrop
          - Engineers - ------ ------ ------ ------
          - Shift Supr. - 2723 Bldg. - A. I. Moore
      - Area Supr. - Personnel Meters - F. G. Tabb, Sr. Supr. act.
        - Shift Supr. -Pencils - J. C. Ledbetter N. W. Hope
        - Engineer - J. L. Gabriel
        - Senior Supr. - Badges - H. C. Money
          - Shift Supr. - K. F. Baldridge C. L. Wheadon
    - Chief Supervisor - Development - C. C. Gamertsfelder
      - Assist. Chief Supr. - Methods - J. W. Healy
        - Senior Suprvisor - P. L. Eisenacher
          - Engineers - K. E. Herde W. Singlevich ------
          - Shift Supr. - Bioassay Lab - J. R.Hobaugh
        - Senior Supervisor - Site Survey - L. D. Turner
          - Engineers - H. J. Paas
      - Area Supervisor - Instruments - ------
        - Engineers - F. L. Vencill H. G. Ruppert ------
        - Engineer - Calibrations - R. J. Gandy
      - Assist. Chief Supr. - Radiobiology - ------
        - Senior Supervisor - Fish Lab - R. F. Foster

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