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RADIAC INSTRUMENTS AND FILM BADGES USED AT ATMOSPHERIC NUCLEAR TESTS

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JAYCOR
205 S. Whiting Street
Alexandria, VA 22304-3687

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This report is part of the Nuclear Test Personnel Review. It summarizes, for the period 1945-1962, those radiac instruments, pocket dosimeters, and film badges used by participants at atmospheric tests. It also includes the accuracy of each, where documentation can be found, or estimates of accuracy based on similar equipment and badges.

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PREFACE

This report summarizes the types of radiac instruments and film badges used at atmospheric nuclear tests (1945-1962) and discusses accuracies, variance, and performance criteria as applicable. The meanings assigned to accuracy by the authors of referenced documents cannot be explained in detail or corrected within the scope of this report or with documentation available at this time.

Because data will be used in answering a variety of inquiries, they are as exact and fully documented as possible. This explains why some instruments are listed under a variety of different names. Nevertheless, each is listed -- exactly -- as given in the reference. In some cases, different references list different accuracies for the same film badge, and both accuracies are listed. Such preciseness may somewhat confuse the reader, but ensures historical accuracy.

As will be seen, not all accuracies have been documented. However, rather than withhold the report, estimates are used in some instances. In such cases these are clearly indicated and the source of the estimate is given in the List of References.

It should be noted that this report only includes those radiac instruments, pocket dosimeters, and film badges which were used to measure ionizing radiation exposures and assign doses received by participants. It does not cover in detail those special types used for various experimental programs or projects.

More detailed data and additional information are solicited for succeeding revisions. These should be sent (with references or backup material as available) to the Defense Nuclear Agency (NTPR).

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SECTION 1

INTRODUCTION

While specifics concerning radiation detection instruments, pocket dosimeters, and film badges used during 1945-1962 are covered in Section 3, this introduction provides information on general accuracy considerations in this report. It is keyed to the level of the general reader who has had limited scientific experience or training. Basic information on alpha, beta, gamma, and x-radiations (especially regarding their detection and measurement) is given first to familiarize the reader with their characteristics.

CHARACTERISTICS OF ALPHA, BETA, GAMMA, AND X-RADIATIONS

Alpha, beta, and gamma radiations are emitted from the nuclei of atoms while x-rays originate outside the nucleus. X-rays result when negatively charged electrons release energy by being slowed down when they come near the positively charged nucleus or when electrons orbiting the nucleus release energy as they drop into lower energy orbits. X-rays are bundles of electromagnetic energy (like radio and TV signals or light) that are called photons. X-ray photons and gamma photons of the same energy are identical except for their origins.

Gamma photons originate in the nuclei of unstable nuclides (radionuclides). Gamma photons are emitted alone or with particles from these nuclei. Most radioactive fission products created during a nuclear detonation emit gamma photons with beta particles. Beta particles are high-speed electrons of nuclear origin.

The nuclei of all atoms consist of protons, which have positive charge, and neutrons, which are neutral as indicated by their name. In the nuclei of certain radionuclides, a neutron may spontaneously change into a proton, while emitting a negative beta particle and an anti-neutrino (a neutral and very light particle compared to the electron, with essentially no weight, i.e. mass). Beta particles are emitted with a range of energy up to a maximum depending on the particular radionuclide. Gamma photons (uncharged) also may be emitted from many fission product radionuclides.

Another type of radioactive decay involves the emission from the nucleus of a particle consisting of two protons and two neutrons. This emission, called an alpha particle, is identical to the nucleus of a helium atom. Alpha particles are very heavy compared to beta particles or photons.

One way photons (gamma and x-ray) ionize atoms is by stripping orbital electrons to create a free negative electron and the positively charged remainder of the formerly neutral atom. The negative electron and positively charged residual atom are called an ion pair. Beta particles create ion pairs by collisions with orbital electrons. Alpha particles, with two positively charged protons, also form ion pairs by removing electrons. Each ionizing event decreases energy of photon or particulate radiation until, eventually, the sum total of photon energy is insignificant, the beta particle joins the sea of electrons around us, or the alpha particle acquires and keeps two electrons to become a neutral helium atom.

Because alpha particles are so heavy, they are relatively slow, and also because they have two positive charges, they create many ion pairs along very short path lengths in air. For example, alpha particles emitted from plutonium-239 travel only 3.7 centimeters in air (about 1 1/2 inches), and most alpha particles can be stopped by a sheet of paper. Thus, alpha particle detection and measurement instruments must have very thin "windows" (like mylar or similar lightweight material) to permit alpha particles to pass into the detection chamber.

Beta particles are very light, are relatively fast, do not create as many ion pairs per unit of track length as alpha particles, and travel up to several tens of feet in air depending on their energy. Most beta particles are stopped by a quarter-inch of aluminum or a thin steel shield. Thus, beta particles enter a detection chamber through light material such as mica or plastic. If a metal shield is placed over this beta "window," then gamma radiation, which still passes through the metal shield, produces a measurement which can be subtracted from the beta plus gamma measurement to obtain a beta measurement.

Gamma photons only have mass because they are moving, are uncharged, travel at the speed of light, and produce zero to several ion pairs per centimeter of track length in air. Consequently, they theoretically have infinite range, but practically penetrate deeply in most materials before being absorbed to insignificant amounts. For example, one inch of lead will reduce average energy fission product gamma radiation to about one-tenth of its original intensity. Thus, gamma measuring instruments can have substantial thicknesses of metal or other materials around their detection chambers.

PORTABLE RADIATION DETECTION (RADIAC) INSTRUMENTS

Several different types of portable survey instruments were used to detect and measure ionizing radiation intensity and ionizing particles emitted from radionuclides. All of these instruments measure radiation indirectly by detecting and evaluating ionization events caused by the radiation in some medium. The types of instruments differ primarily in the medium in which an event takes place and in the method by which an event is detected and measured. Most portable survey instruments fall into two general categories: gas ionization detectors and scintillation detectors. The gas ionization detector takes advantage of the ionization produced when radiation passes through a gas (which may be air); the scintillation detectors depend on the property of certain materials to emit light (scintillate) when exposed to ionizing radiation.

Gas Ionization Detectors

As the name implies, this category of detectors uses a gas as the detection medium. The typical detector consists of a cylindrical, rectangular, or other shape chamber with a wire through the cylinder or some distance from a wall of the several other chamber shapes. This wire is insulated from the chamber wall and a voltage potential exists with the chamber wall negative and the wire positive. The chamber is filled with air or a gas, and this gas-filled space serves as the sensitive volume. Radiation entering the sensitive volume can ionize the fill gas. Ionization produces free electrons which, because they are negatively charged, are attracted to the positive wire (anode). The current or pulse of electrons is amplified and a calibrated meter indicates the radiation intensity.

The three basic types of gas ionization detectors are the ionization chamber, the proportional counter, and the Geiger-Mueller (GM) detector. The primary differences between these detector types are the amount of voltage potential applied between the anode and the chamber wall and the radiations detected.

The ionization chamber instrument operates at a voltage potential great enough to cause free electrons produced by ionization events taking place in the chamber and walls to move rapidly toward the anode with essentially no recombination of ions. The rapidly moving ions, however, do not have sufficient energy to cause secondary ionizations. Because no secondary electrons are produced, ion chamber instruments are relatively insensitive. Their primary use is measuring high-range gamma radiation.

By increasing the voltage potential, the free electrons produced by the original ionizing events can be accelerated to the point that they cause additional ionization events as they are attracted toward the anode. The secondary ionization electrons also may produce additional ionization, the subsequent electrons may produce ionization, and so forth. This avalanche of electrons may be as great as 10,000 times the number of initial negative ions formed, creating a large current pulse.

In this voltage region, individual alpha particles entering the chamber volume can be detected. The higher ionization of alpha particles causes larger pulses than beta particles and gamma photons. By setting an electrical gate to count only large pulses, the counter becomes a convenient alpha counter. Because the size of the pulse detected is proportional to the initial number of ionizations produced by particles entering the chamber, alpha detecting instruments operating in this voltage region are named proportional alpha counters (PAC).

If the voltage potential is greatly increased, ionization can be amplified to the point that nearly all of the gas in the chamber is ionized in an avalanche of electrons whenever a single ionizing event takes place, compared to an electron avalanche only in one part of the chamber in a proportional counter. Detectors operating at this voltage, thus in this greatly increased sensitivity region, are called Geiger-Mueller (GM) detectors. Such detectors are best suited for monitoring low-level radiation where high sensitivity is needed, while ionization chamber detectors generally are used as high-range instruments.

Gas ionization instruments can be used to detect all forms of ionizing radiation. Since the radiation must penetrate the chamber before it can be detected, the type of radiation to be measured must be considered in the chamber design. For example, a chamber wall of an alpha radiation detector must be constructed of ultra-thin, lightweight material that will allow entry of a majority of incident alpha particles. On the other hand, the chamber walls of a gamma detector can be fairly substantial because gamma rays are highly penetrating. The chamber walls of beta-gamma detectors normally have a thin window of mica or other light material that can be exposed or shielded depending on whether or not beta particles are to be detected. Thus, beta radiation readings are obtained by subtraction of closed-shield gamma readings from open-shield beta plus gamma readings.

Scintillation Detectors

Another kind of portable survey meter is the scintillation detector. This detector consists of a fluorescent material that emits light (scintillates) when irradiated, and a system to convert the light into electrical energy, amplify it, and measure the electrical output. Scintillation detectors can detect alpha and beta particles, and are especially efficient in measuring gamma radiation.

Measurement Accuracies

Accuracies of ion chamber, GM, and scintillation detectors generally are specified as plus or minus a percentage of full scale meter deflection or as a percentage of any meter position. These accuracies are the accuracies of the meter, and it is assumed that the instrument is not defective, is operating properly, and has been appropriately calibrated for the radiation to be measured. Instrument meter accuracies generally are those stated in this report. Where references were not available, instrument accuracies were estimated by using the least accurate of similar instruments referenced. Other factors may decrease stated accuracies of the instrument under field conditions: use of defective instruments, poor calibration procedure, measurement of radiation energies or types not calibrated for (particularly if instrument is energy dependent), gross changes in altitude of instrument use if detection chamber gas pressure changes, and damage to the instrument during use. Actual field errors of these types were minimal if technicians and monitors were well trained and followed correct procedures.

Some of the GM detectors used during the early testing years were subject to another source of error called "saturation." This problem occurred when the instrument was taken into a gamma field much higher than the maximum range of the instrument. For example, if an MX-5 GM detector were taken into a 1 roentgen per hour (R/h) field, the meter reading could decrease from its maximum of 0.02 R/h to a false reading of 0.015 or 0.01 R/h.

The three types of "quenching" (of the electron avalanche pulse - so another could occur) were with organic gas, halogen gas, and external electronic circuitry. Only the first type, a few percent of polyatomic or ethyl alcohol (a gas at low pressure) normally mixed with argon gas, suffered this problem. Because pulses were not being registered during quenching, the ionized organic gas molecules could not recombine fast enough in high radiation fields to maintain necessary quenching and, subsequently, an adequate number of pulses to register full-scale readings.

If organically quenched GM detectors were operated above scale limits long enough, or in very high gamma radiation intensities, permanent tube damage occurred. Normally, the organic gas in the tube would not decompose or "wear out" enough to affect instrument operation until after a long period of use. High gamma fields, however, could cause positive residual organic molecules to plate on the inside of the tube wall, or negative residual molecules to plate on the anode, reducing quenching capability enough to cause instruments to malfunction.

This problem apparently was observed in 1948 when the procedure was to carry a high range ionization chamber detector with the low range GM detector, and turn off the GM detector if intensities above its range were encountered. Almost all organically-quenched GM tubes were replaced with halogen-quenched tubes, which did not "saturate," before the total test ban began in 1958, and use of organically-quenched tubes was rare when nuclear testing resumed in 1961.

PERSONNEL DOSIMETER INSTRUMENTS

Pocket dosimeters generally are used to determine the wearer's external exposure to x- and gamma radiation. These devices are worn by personnel working in a radiation environment. Dosimeter is the name applied to a class of radiation detection equipment. Dosimeter means dose (radiation) meter (measurement). Self-reading pocket dosimeters were instruments which enabled wearers to observe information on their cumulative exposure while in a radiation area, but pocket chamber instruments were read with calibrated equipment after the wearing period. These dosimeters were used primarily to measure x- or gamma radiation.

Pocket Chambers

Pocket chambers are small dosimeters about the size and shape of a fountain pen. They are simplified ionization chambers with the cylindrical chamber wall insulated from the central anode which has a capacity for charge. A known amount of positive static charge is put on the anode with a charger contacting both the anode and the outer case (which extrude and are insulated from each other at one end of the pocket chamber). During use, electrons released by ionization events in the chamber are drawn to and neutralize the anode's positive charge. After use, the remaining charge is measured with a combination charger/reader and compared with calibration data to determine amount of gamma exposure.

Disadvantages of pocket chambers are a number of inaccuracies - almost all of them resulting in overestimates of exposure. The chamber wall cannot be too heavy or electrons from ionization events in the wall will be too numerous, and the capacity for charging must be too great to have a useful exposure range. Also, if the walls are too heavy, low energy gamma photons cannot penetrate the chamber. Calibration of the chamber to the energy spectrum to be encountered solves the problem of detecting low energy gamma. Maximum energies of many fission product beta particles, however, are sufficient for them to penetrate the walls. With greater ionization in air than gamma photons, a relatively small amount of high-energy beta radiation can cause a significant over-estimate of gamma exposure.

A small amount of moisture at the end of the chamber where the anode and wall contacts are insulated can result in leakage of charge and subsequent overestimates of exposure. A cracked or otherwise deficient insulator can cause the same problem.

The pocket chamber was not convenient for use during atmospheric testing because it did not provide exposure information during exposure. This inconvenience plus the several sources of error caused the pocket chamber to have limited use.

Self-reading Pocket Dosimeters

These dosimeters are essentially the same shape as pocket chambers and the operating principles are similar. A major difference is inclusion of a miniature electroscope and scale. An electroscope has two hinged leaves or arms. When a charge is applied, the arms repel themselves, and when the charge is neutralized, the arms come together. In a self-reading dosimeter, one arm is fixed and the other is a metal-coated quartz fiber which moves along an exposure scale.

Positively charging the anode contact, which is the electroscope, moves the quartz fiber to zero on the scale. As ionization neutralizes the electroscope charge, the quartz fiber moves up scale toward the fixed arm and indicates accumulated exposure on the scale. The scale can be observed at any time by looking through the dosimeter toward daylight or an artificial light source. An optical system magnifies the scale and quartz fiber for viewing. Typical maximum ranges of self-reading pocket dosimeters are from 0.2 R to 10 R.

The same accuracy considerations apply as with pocket chambers. Thus, it was not uncommon under high humidity conditions (as in the Pacific) to leak charge and overestimate gamma exposure or to experience overestimates because high-energy beta radiation was present. In addition, dropping and jarring self-reading dosimeters can cause the quartz fiber to move up scale when no exposure has occurred. For these reasons, two dosimeters usually were worn together, and the lowest reading was taken as the exposure estimate. Figure 1 shows typical pocket dosimeters.

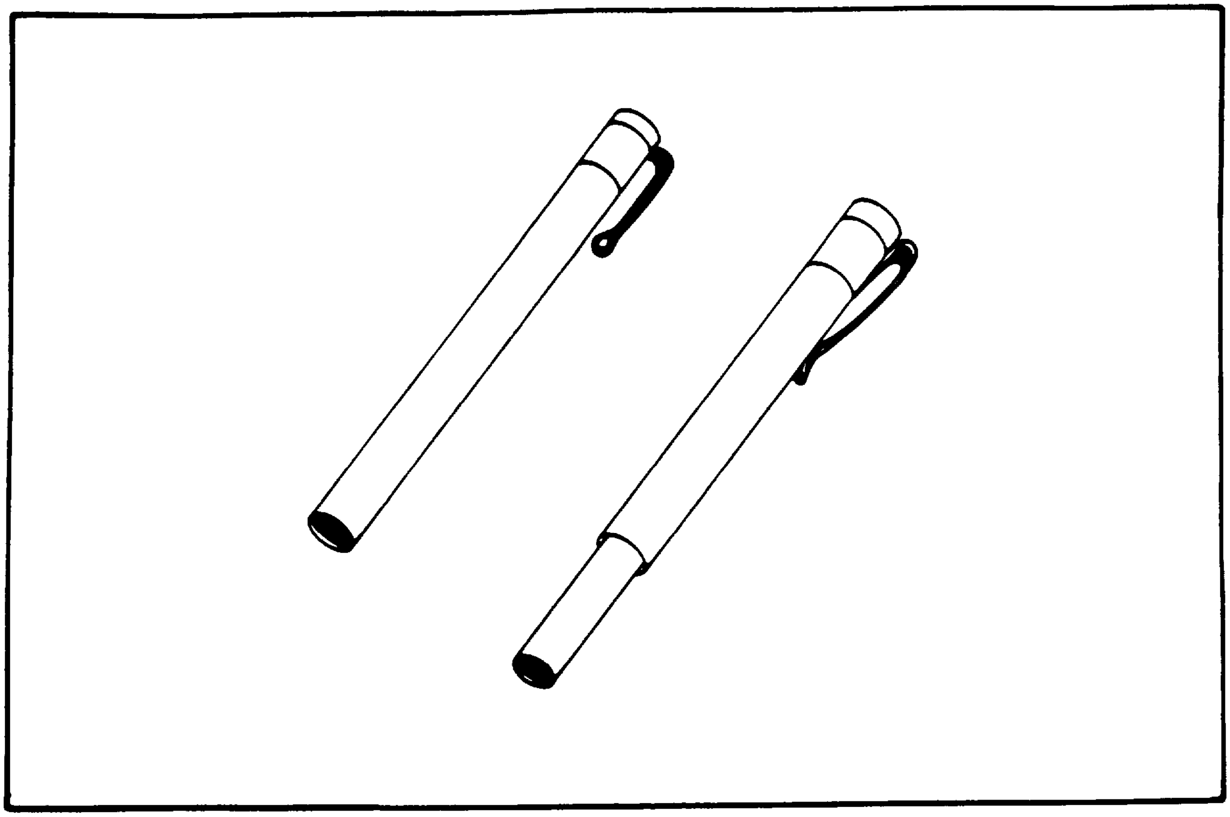

Figure 1. Pocket Dosimeters.

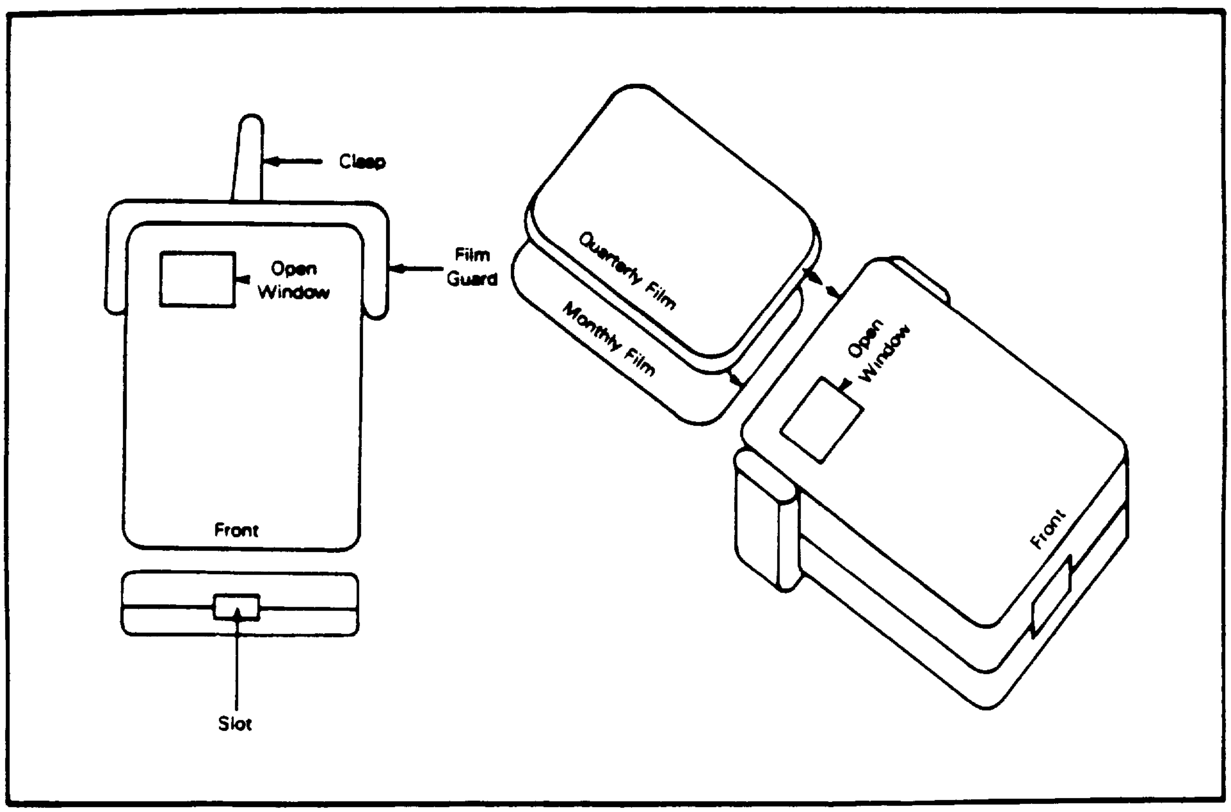

Figure 2. Film Badge Holder.

FILM BADGE DOSIMETERS

Photographic film is sensitive to ionizing radiation just as it is to light. Developed and processed film that has been exposed to radiation will exhibit a darkening or increased optical density that can be related to the degree of exposure. The net optical density (above background density) can be measured with a densitometer and compared with a calibrated standard to estimate the exposure. Using this technique, photographic film worn as a personnel dosimeter can be used to measure an individual's cumulative gamma radiation exposure.

Typically, the film is wrapped in a light-tight paper packet. Over the packet are areas filtered by metal or combinations of metal to accomplish two primary goals. First, the over-response of film emulsions to low energies of the same dose from photon radiation must be compensated for. Secondly, metallic filters amplify the ionization effects of gamma radiation on the film emulsion so that the initially low specific ionization of gamma photons becomes amplified in a filter and the resulting higher net optical density is more easily measured. Metallic filters sometimes were imbedded in a plastic film holder. A typical film badge holder used for occupational exposure dosimetry is shown in Figure 2.

Photographic film will respond to the ionizing effects of any radiation that reaches it. The paper wrapper stops alpha radiation and low energy beta radiation. The metallic filter absorbs most of the higher energy beta particles. Thus, net optical density of the processed dosimetry film under the metallic filter is a reasonable indication of the gamma dose received by the wearer.

Although neutron radiation does not cause sufficient ionization to affect the film directly, film can record ionization caused by secondary radiations produced from neutron interactions with certain metallic filters. Also, high energy neutrons cause tiny tracks by proton recoil in special film emulsions. Under magnification, these tracks can be counted and dose calculated. However, neutron film dosimetry was in its infancy at the time of early atmospheric nuclear tests, and such dosimetry was not widely used.

Film Badge Beta and Gamma Dosimetry

Darkening of developed film can be related to gamma exposure of the wearer because the same type of film packets and components have been exposed to known amounts of gamma radiation from sources of similar energies to the exposure energies.

Beta exposures cannot be so easily related. The primary reason is low-energy gamma photons that are partially attenuated by the metallic filters have a darkening effect on unfiltered areas of film emulsion that is much greater than the same exposure of high-energy gamma photons. Thus, the total darkening of film outside the metallic filter areas may result from a combination of low-energy gamma and beta exposure and cannot be used without additional information for quantitative determination of beta exposure.

Although attempts were made to monitor beta radiation exposure during early atmospheric testing operations, film dosimetry was mainly applicable only to gamma radiation exposure. In addition, accuracy of determining gamma exposure with film badges was dependent on a number of factors. For example, similarity of an exposure energy spectrum to the calibration spectrum determined whether laboratory calibrations and accuracies in laboratory processing applied to field exposure conditions. Also, most errors in film dosimetry were caused by environmental conditions and their effects on film emulsions during storage and use in the field. Light, heat, pressure, and age damage were among the causes of increased and extraneous optical densities. Only with the rare combination of maintained high humidity without water condensing on or in film packets did latent images fade and underestimation of doses possibly occur. Conversely and more likely, if packets became damp, increased density resulted, and exposure was overestimated. For this reason, film packets used in the Pacific during several test operations were waterproofed. Thus, almost all errors in film dosimetry from environmental effects resulted in assigning more exposure to an individual than actually occurred.

Film Badge Accuracies

Film dosimeter accuracies also are a function of dose. All low-exposure-range film component exhibit only a slight increase in developed film optical density with minimum gamma exposures. At higher levels of a few tenths of a roentgen exposure, the film dosimeter becomes more accurate. It is in these exposure ranges that most of the percentages of exposure accuracy in the body of this report are quoted.

Laboratory calibration accuracies for different film packets at still higher exposures generally vary from ± 5 to ± 20 percent of the determined exposure. At lower exposures (i.e. 0.05 R), accuracy decreases considerably. That is, at minimum film density levels, a slight error in density determination could result in a very large percentage error in exposure determination. For example, an actual exposure of 0.025 R could be overestimated by 100% as 0.05 R.

It is fortunate that these very large percentage errors occur only at very low exposures, where error in total exposure is small, or at very high exposures where a second, higher exposure range film component usually was included in the packet for density measurement and exposure evaluation. Most of the errors are positive and result in assigning more exposure than actually occurred. In Figure 3, the graph shows laboratory film badge variance at different amounts of gamma radiation exposure as determined during testing of 35 film badge processors by Battelle Northwest Laboratory in 1967 (Ref. 81, 82). Film badge accuracies during most atmospheric nuclear weapons testing series probably were similar. For TRINITY, 1945, and CROSSROADS, 1946, minimum detectable exposures were only 0.1 R and 0.04 R, respectively, and accuracies were somewhat less than in later operations. Thus, estimated accuracies for these test operations are indicated by the dashed curve on the graph. It is emphasized that essentially all of the errors resulted in assigning more dose than actually was received.

Film dosimeter exposure determinations usually were supported by other information. For example, if a film packet for a particular individual exhibited signs of damage and unusually high exposure, dosimetry results for a companion or recorded exposure rate measurements from the work area could be consulted to confirm or reassign a correct exposure amount. Further, if a damaged film could not be interpreted, such additional information could be used to assign a reasonably correct exposure.

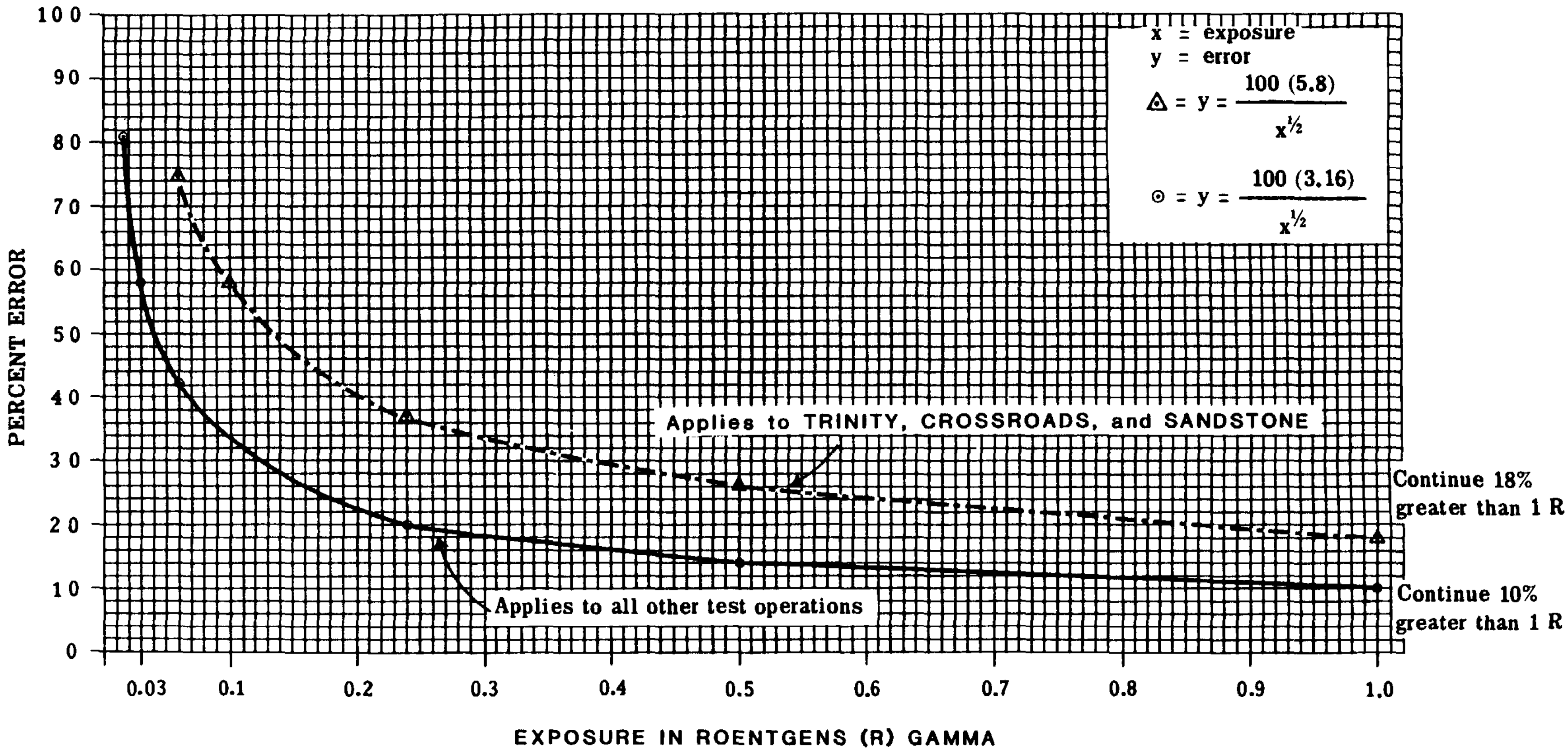

Figure 3. Estimated Film Badge Processor Error

SECTION 2

SPECIFICS OF MAJOR RADIAC INSTRUMENTS

This section contains, in alphabetical order, a brief summary description of the chief portable radiation detection instruments used during atmospheric nuclear testing. It is not all-inclusive nor is it developed in great detail. Readers desiring more information should consult the appropriate publications from the Reference List in this volume, especially those numbered 53, 77, 78, and 79.

Many instruments had several designations: a military JAN ("Joint Army-Navy") number, an AEC number, and the manufacturer's model number. Normally the JAN designation is given first in this section with other designations in the "remarks" portion. All designations or model numbers, when known, are cross-referenced in the Index.

AN/PDR-T-1

Name: Ionization chamber survey meter

Purpose: Detect high range gamma radiation

Manufacturer: Kelly-Koett

Range (mR/hr): 0-5; 0-50; 0-500; 0-5,000; 0-50,000

Shape: 10" x 6" x 7"

Weight: 10#

Remarks: First ionization chamber gamma survey meter built to military specifications; also called SIC-18A or K-350.

AN/PDR-T-2

Name: Geiger-Mueller counter for beta-gamma survey

Purpose: Detect low range beta-gamma radiation

Manufacturer: El Tronics

Range (mR/hr gamma): 0-0.5, 0-5, 0-50

Shape: 10" x 6" x 7"

Weight: 9# (approx)

Remarks: Replaced by AN/PDR-27 series. Also termed El Tronics Model PR-2.

AN/PDR-5

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: Victoreen

Range (mR/hr): 0-0.2, 0-2, 0-20

Shape: 12 1/4" x 3 1/4" x 8 1/2"

Weight: 13.4#

Remarks: Also called Model 263A, SGM-2B, and IM-1A/PD.

AN/PDR-7

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: Nuclear Instrument and Chemical Co.

Range (mR/hr): 0-0.2, 0-2, 0-20

Shape: 11" x 6" x 4"

Weight: 11.6#

Remarks: Also called Model 2610, SGM-4B, and IM-8/PD.

AN/PDR-8

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: Hoffman, RCA, Admiral

Range (mR/hr): 0-0.5, 0-5, 0-50, 0-500 (beta indication on first two scales)

Shape: Kidney-shaped, about 10" x 6 1/2" x 7"

Weight: 11.5-14#

AN/PDR-10A

Name: "Poppy"

Purpose: Portable alpha proportional counter

Manufacturer: General Electric

Range (full scale meter, counts/min): 1,000 and 10,000

Shape: 12 1/2" x 4 1/2" x 2 1/2" (approx)

Weight: 5#

Remarks: Required an extremely well-trained operator.

AN/PDR-15

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: —

Range (mR/hr): 0-0.5, 0-5, 0-50, 0-500 (beta indication on first two scales)

Shape: "flat iron" 11 1/4" x 4 3/8" x 3 1/2"

Weight: 11#

AN/PDR-18 type

Name: Photomultiplier survey meter

Purpose: Gamma scintillation counter

Manufacturer: —

Range (R/hr): 0.5, 5, 50, 500

Shape: 6" x 4" x 10" (approx)

Weight: 8 1/2# (max)

AN/PDR-26

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: El Tronics

Range (mR/hr): 0-0.2, 0-2, 0-20

Shape: 9 3/4" x 5" x 6"

Weight: 8 3/4#

Remarks: Also called SM-3 or SGM-18A.

AN/PDR-27 type

Name: Beta-gamma survey meter

Purpose: Detect low range beta-gamma radiation

Manufacturer: G.E., Admiral, Hoffman, Nems-Clarke, Chatham, Specialty Engineering, Watson Electronics, Industrial Electronics Hardware Corp., Northeastern Engineering

Range (mR/hr): 0-0.5, 0-5, 0-50, 0-500 (beta indication on first two scales)

Shape: 5 1/4" x 9" x 8"

Weight: 9# (approx)

Remarks: Employed halogen-filled GM tubes.

AN/PDR-39 type

Name: Ionization chamber survey meter

Purpose: Detect high range gamma radiation

Manufacturer: Tracerlab and Taffet

Range (mR/hr): 0-5; 0-50; 0-500; 0-5,000; 0-50,000

Shape: 10 1/2" x 6 1/4" x 8"

Weight: 11#

Remarks: Included internal check source. Navy version was SU-10 (in orange case vice olive green case). Also called AN/PDR-T1B.

AN/PDR-43

Name: Geiger-Mueller type, beta-gamma survey meter

Purpose: Detect high range beta-gamma radiation

Manufacturer: Electronic Products, Electro-Neutronics

Range (R/hr): 0-5, 0-50, and 0-500

Shape: 8" x 4" x 3 1/2"

Weight: 4 1/2#

Remarks: Miniature-pulsed, halogen-filled. Utilized scale changing meter.

AN/PDR-60

Name: Alpha scintillation counter

Purpose: Alpha detection

Manufacturer: Eberline

Range (counts/min): 0-2,000; 0-20,000; 0-200,000; 0-2,000,000

Shape: Rectangular

Weight: 6# 11 oz

Remarks: Eberline designation is PAC-1S.

CDV-700

Name: Low range survey meter (beta-gamma)

Purpose: Monitor personnel, food, water, and human habitation areas (for Civil Defense)

Manufacturer: Anton, Victoreen, Electro-Neutronics, Lionel, Chatham, Universal, Nuclear Measurements

Range (mR/hr): 0-0.5, 0-5, 0-50

IM-3/PD

Name: Ion chamber survey meter

Purpose: Detect gamma radiation

Manufacturer: Victoreen

Range (mR/hr): 0-2.5; 0-25; 0-250; 0-2,500

Shape: 10 1/2" x 5 1/2" x 13"

Weight: 12 7/8#

Remarks: Also termed Victoreen 247A and SIC-9B. The 247B version had scales (mR/hr) of 0-25; 0-250; 0-2,500; 0-25,000.

IM-4/PD

Name: "Zeuto"

Purpose: Detect alpha-beta-gamma radiation

Manufacturer: Victoreen

Range (mR/hr gamma): 4, 40

Shape: 9 1/2" x 6" x 5"

Weight: 6#

Remarks: Also called Victoreen 356 or SIC-2A.

IM-5/PD

Name: "Cutie Pie"

Purpose: Detect beta and gamma radiation

Manufacturer: Sylvania, Tracerlab and others

Range (mR/hr gamma): Sylvania: 50; 500; 5,000
Tracerlab: 25; 250; 2,500

Shape: 6 1/2" x 3" x 5"

Weight: 4-4 1/2#

Remarks: Had pistol grip and adjustable beta window; also called SIC-7, Sylvania RD-316, or Tracerlab SU-A1.

IM-108/PD

Name: Miniature ion chamber gamma meter

Purpose: Portable high range survey instrument

Manufacturer: Landsverk, Jordan

Range: 1-500 R/hr on logarithmic meter scale and 0.1-15 R/hr on decade scale

Shape: 6 1/2" x 4 1/8" x 4 1/4"

Weight: 2 1/2#

MX-2

Name: "Beckman meter" (ion chamber)

Purpose: Detect gamma and beta radiation

Manufacturer: Beckman, National Technical Labs

Range (mR/hr gamma): 20; 50; 200; 500; 2,000

Shape: 12 1/2" x 7 1/2" x 6 1/2"

Weight: 12 1/2#

Remarks: Also called SIC-11A.

MX-5

Name: Geiger-Mueller counter

Purpose: Detect beta-gamma radiation

Manufacturer: Beckman, National Technical Labs and others

Range (mR/hr): 0-0.2, 0-2, 0-20

Shape: 9 1/2" x 5" x 6"

Weight: 9.6#

Remarks: Also called IM-39/PD or SGM-15A.

MX-6

Name: Ionization chamber survey meter

Purpose: Detect gamma radiation

Manufacturer: National Technical Labs

Range (mR/hr): 0-5; 0-50; 0-500; 0-5,000

Shape: 9 1/2" x 5" x 6"

Weight: 7 3/4#

Remarks: Also called IM-40/PD or SIC-15A.

PAC-3G (AN/PDR-54)

Name: Gas flow proportional alpha counter

Purpose: Measure both low and high range alpha radiation

Manufacturer: Eberline

Range (counts/mins): 1,000; 10,000; 100,000

Shape: Rectangular

Weight: 8 1/2#

Remarks: Alternate standard was PAC-2GA.

Z-100

Name: "Zeus"

Purpose: Detect airborne alpha-beta-gamma radioactivity

Manufacturer: Rauland Manufacturing Co.

Range (mR/hr gamma): 25; 100; 500; 2,500

Shape: 13" x 10 3/8" x 5 3/8"

Weight: 10 1/3#

Remarks: Also called AN/PDR-20 (by General Electric).

2111

Name: "Pee Wee"

Purpose: Portable air proportional counter for alpha

Manufacturer: Nuclear Instrument and Chemical Corporation

Range (scale counts/min): 0-2,000; 0-20,000

Shape: 11 7/8" x 5 3/8" x 8"

Weight: 16#

Remarks: AEC number SPC-1C; also Model 41-A and 48-A; also termed "Pee Wee."

SECTION 3

SERIES SUMMARIES

In the following series summary section, radiac instruments, pocket dosimeters, and film badges used at each test series are itemized. References cited refer to those in the subsequent Reference List; numbers following the colon refer to page numbers of that reference.

Precise definition of the term "Accuracy" is not specified herein because the many different references do not agree on what their specific "accuracy" data encompasses. Consequently, while the reader probably will apply the standard dictionary definitions, these may be modified or amplified by definitions in the specific references.

In many cases, data given are generalizations. The reader is cautioned that data in Section 3 may be amplified or modified by the references cited.

SERIES: TRINITY (1945)

Radiac Instrument	Ref.	Accuracy	Ref.
Geiger counter	1:55 and 2:50	± 25% (est)	2A
Portable gamma meters	2:95	± 25% (est)	2A
Portable alpha meters	2:95	± 10% of full scale	14D:22;14B;14C
Easterline-Angus recording gamma meters	2:95	± 25%	2A

Pocket Dosimeter*	Ref.	Accuracy	Ref.
Landsverk-Wollan type	2:112	Lower than that expected from the Watts meter readings and time in the area	2:112

Film Badge	Ref.	Accuracy	Ref.
Eastman [Kodak] X-ray type K (0.1 R minimum)	2:113, 167	± 30% (est)**	76
DuPont 552 [packet]	2:113, 166	± 30% (est)**	76
Adlux [catastrophe badge]		±20% (est)	76

*Also termed "pocket electrometer" in early testing years and "self-reading pocket dosimeter" during later series (2:14; 2:52).

**Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.1 R), ± 30 percent in the range of 0.1-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: CROSSROADS (1946)

Radiac Instrument	Ref.	Accuracy	Ref.
Geiger counter, model X-263	4:49	± 20% (est)	76 from 11D:10
"Cutie Pie"	11B	± 10% of full scale	3:73
Ionization meter, model 247	4:49	± 25% (est)	2A
Victoreen Model 263	11H, 5	± 20%	11D:10
Victoreen Model X-263	11D	± 20%	11D:10
Alpha meter Model 356 ("Zeuto")	6	NA	30A
Watts meter (ion chamber)	11C	25% (est)	2A
Underwater probes:	7	Unknown	
Victoreen X-325	11G	Unknown	
NRL "special"	7	Unknown	

Pocket Dosimeter	Ref.	Accuracy	Ref.
Landsverk quartz fibre type	11D, 11E	± 3% (or) ± 10%	11F 11D

Film Badge	Ref.	Accuracy	Ref.
Personnel:			
Special dental film holder with lead cross shield. Film component Kodak type K (0.04-2 R)	83	30% (est)*	90, 76, 84

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.04 R), ± 30 percent in the range of 0.04-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: CROSSROADS (Continued)

Film Badge	Ref.	Accuracy	Ref.
Casualty:	4:49;10		
5301		12% under lead	9
		6% w/o lead	9
5302		8% under lead	9
		6% w/o lead	9

SERIES: SANDSTONE (1948)

Radiac Instrument	Ref.	Accuracy	Ref.
Instrument Development Lab Model 2610	12:7	± 10% (est)	76 from 47:63
National Technical Labs Model MX-5	12:7	± 10%	19C
Victoreen Instrument Co. Model 263A	12:7	± 20% (est)	76 from 11D:10
AN/PDR-1	12:7	± 10%	13: Appendix Nov. 16
AN/PDR-8	12:7	± 10%	12A:60 implies same as AN/PDR-1
National Technical Labs MX-2	12:7	± 25% (est)	2A, 13
National Technical Labs MX-6	12:7	± 25% (est)	2A, 13
Rauland Manufacturing Co. Z-100/100A ("Zeus")	12:7	± 25% (est)	2A
Victoreen 247A	12:10	± 25% (est)	2A
Victoreen 300	12:10	± 10%	47:95
Victoreen 356 ("Zeuto")	12:10	NA	30A
Los Alamos, AEC, SIC-7 ("Cutie Pie" type)	12:13	± 10% of full scale	14A
Los Alamos, AEC, SPC-1B ("Pee Wee")	12:13	± 10% of full scale	14D:22;14B;14C

Pocket Dosimeter	Ref.	Accuracy	Ref.
Beckman Mod MX-7 (0-0.2 R)	12A:60	All 8-20% higher than film badges	14

Pocket Dosimeter (con't)	Ref.	Accuracy	Ref.
Cambridge (AEC catalogue # PIC-9A) (0.02 R)	12A:60	All 8-20% higher than film badges	14
Kelley-Koett K-100 (0-0.2 R)	12:10	All 8-20% higher than film badges	14
Kelley-Koett K-150 (0-10 R)	12:10	All 8-20% higher than film badges	14
Kelley-Koett K-160 (0-50 R)	12:20	All 8-20% higher than film badges	14

Film Badge	Ref.	Accuracy	Ref.
Personnel:			
Special dental film holder with lead cross shield. Film component types Kodak A & K (0.05-3 R)	15:37 and 8:15	30% (est)*	76
Casualty:	16, 8:16		
5301	15:37 and 8:15	12% under lead 6% w/o lead	9
5302	15:37 and 8:15	8% under lead 6% w/o lead	9

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.05 R), ± 30 percent in the range of 0.05-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: RANGER (1951)

Radiac Instrument	Ref.	Accuracy	Ref.
T1B ion chamber (AN/PDR-39) (SU-10)	18:70	± 15%	19A:6
Victoreen 263A	18:70	± 20% (est)	76 from 11D:10
National Technical Lab MX-5	18:70	± 10%	19C
GM type 2610A	18:72	± 10% (est)	47:63
"Juno" type ion chambers	18:72	± 10% full scale gamma	3:73
Model 48-A ("Pee Wee")	18:84	± 20% of full scale	14D:22,14B,14C
Model 100 (ion chamber, 100 mR/hr-100 R/hr)	18:84	± 25%	2A, 13
Model 2680	18:84	Unknown	
Model MX-6	18:84	± 25% (est)	2A, 13
Model T (G-M)	18:84	± 25% (est)	2A, 80
Watts (ion chamber)	18:84	± 25% (est)	2A, 80

Pocket Dosimeter	Ref.	Accuracy	Ref.
2-R model	18.75 (app. D)	Unknown	
10-R model	18:75 (app. D)	Unknown	
Type unknown	18:71	"On the average pocket dosimeters read higher than the corresponding film badges"	18:71

SERIES: RANGER (Continued)

Film Badge	Ref.	Accuracy	Ref.
Eastman Kodak Type K	89	± 20% (est)*	89

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.05 R), ± 20 percent in the range of 0.05-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: GREENHOUSE (1951)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-5A	20:67	Unknown	
AN/PDR-8B	20:67	Unknown	
AN/PDR-27A (IM-57)	21B:30	± 20% above 10% of full scale	21F
AN/PDR-T1B (SU-10)	21B:30	± 15%	19B
El Tronics SGM-18A	20:67	± 10% (est)	76 from 47:61,63
Victoreen 247A	21B:30	± 20% (est)	76 from 19A
Victoreen 247E	20:67	± 25% (est)	2A
Victoreen 247H	20:67	± 20% (est)	76 from 19A
Victoreen 263B	20:67	± 25% (est)	76 from 11D:10
2610A	21B:30	± 10%	47:63
SU-1B ("Cutie Pie")	21B:30	± 10% of full scale	3:73
"Pee Wee" Model 41A	21:74	± 10% of full scale	14D:22;14B;14C
MX-5	21B:30	± 10%	21E
Victoreen 747A [probably 247A]	21:74	Unknown	

Pocket Dosimeter	Ref.	Accuracy	Ref.
Beckman Model 102 (0-0.2 R)	21:35	Unknown	
IM-50A/PD (0-0.2 R)	20:67	Unknown	
Kelley-Koett K-151 (0-10 R)	21:74	Unknown	
Kelley Koett K-161 (0-50 R)	21:74	Unknown	

Pocket Dosimeter	Ref.	Accuracy	Ref.
Kelly-Koett (0-0.2 R)	20:67	Unknown	
Victoreen Model 507 (0-100 R)	21:73	Unknown	
Victoreen Model E-507 (0-200 R)	21:73	Unknown	
DT-65/PD	21C:3	Complex, see p.5 and fig. 6 of Ref. 21C	
DT-64/PD	21C:3	"2/3 that of DT-65"	21C:5

ALSO SEE REFERENCE 21D

Film Badge	Ref.	Accuracy	Ref.
DuPont 553 film packet with film component types:	20:79		
502 (0.1-10 R)		± 10% above 0.4 R* ± 12% to 3 R*	21:29 8:16
606 (10-250 R)		1.0 to 20%	59B:2

ALSO SEE REFERENCES 19, 21A, AND 30

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.1 R), ± 25 percent in the range of 0.1-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: BUSTER-JANGLE (1951)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-27A	22:118	± 20 above 10% of full scale	21F
AN/PDR-T1B	23:113	± 15%	19B
MX-5	23:113	± 10%	21E
SU-10	24:18	± 15%	19B

Pocket Dosimeter	Ref.	Accuracy	Ref.
IM-20/PD (0-50 R)	23:113, 116	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 553 film packet with film component types:	23:110		
502 (0.02-10 R)	23:111 and 31:94	± 10% above 0.4 R* 1.0 to 1.2% of dose*	21:29 30
510 (5-50 R)	31:94	0.7 to 2.4% of dose*	30
606 (10-300 R)	31:94	2.3 to 16.0% of dose*	30

ALSO SEE REFERENCE 19

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 25 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: TUMBLER-SNAPPER (1952)

Radiac Instrument	Ref.	Accuracy	Ref.
MX-5	28:27	± 10	21E
AN/PDR-T1B	28:27	± 15%	19B
"B-21" gear	28:42-43	Unknown	
"Jasper" (IM-71/PD) (Modified T1B)	28:151	± 15% (est)	33:29;19B

Pocket Dosimeter	Ref.	Accuracy	Ref.
Quartz-fibre type (0-1 R) (0-5 R)	27:136 and 28:26	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 558 film packet with film component types:	27:136		
508 (0.015-6 R)	8:16	± 20%*	71C:2
1290 (20-3,000 R)	(F)	± 15% (est)	76

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.015 R), ± 20 percent in the range of 0.015-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: IVY (1952)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-T1B	31:91	± 15%	19B
IM-71/PD (XE-1) ("Jasper") (modified T1B)	31:91	± 15% (est)	33:29;19B
Beckman MX-5	31:91	± 10%	21E
AN/PDR-27C	31:91	± 20% of above 10% of full scale	34

Pocket Dosimeter	Ref.	Accuracy	Ref.
IM-91PD (0-200 mR)	31:92	Unknown	
IM-19PD (high range)	31:92	Unknown	
IM-20PD (high range)	31:92	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 558 film packet with film component types:	31:94		
508 (0.015-6 R)	31:94	± 20%*	71C:2
1290 (5-750 R)	31:94	± 15% (est)	76
DuPont 553 film packet with film component types:	31:94 see also note 32		

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.015 R), ± 20 percent in the range of 0.015-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: IVY (Continued)

Film Badge	Ref	Accuracy	Ref.
502 (0.1-10 R)	31:94 and	± 10% above 0.4 R	21:29
(0.03-15 R)	33:80	1.0 to 1.2%	30
510 (5-50 R)	31:94	0.7 to 2.4%	30
606 (10-300 R)	31:94	2.3 to 16.0%	30

ALSO SEE REFERENCE 19

SERIES: UPSHOT-KNOTHOLE (1953)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-T1B*	35:27	± 15%	19B
SU-10*	35:27	± 15%	19B
MX-5	35:27	± 10%	21E
AN/PDR-39*	35:27	± 15%	19A:6
Victoreen (Thyac) 389A	35:27	± 10%	26
AN/PDR-10A (air proportional alpha counter)	35:27	± 10% of full scale	14D:22;14B;14C; 66:130;53:70
"Pee Wee" 2111	35:27	± 10% of full scale	14D:22;14B,14C
IM-71/PD ("Jasper") (modified T1B)	36:56	± 15% (est)	33:29;19B

Pocket Dosimeter	Ref.	Accuracy	Ref.
Types unspecified with ranges:	37:163	± 10%	86:15
0-0.2 R	37:163	± 10%	86:15
0-1 R	37:163	± 10%	86:15
0-10 R	37:163	± 10%	86:15
0-50 R	37:163	± 10%	86:15

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with component types:			
502 (0.02-10 R)	86:15	± 10% above 0.4 R** 1.0 to 1.2% of dose	21:29 30
606 (10-300 R)	86:15	2.3 to 16.0% of dose	30

ALSO SEE REFERENCE 19

*Essentially the same instrument

**Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 25 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: CASTLE (1954)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-27F	39:100fn	± 20% above 10% of full scale	34
AN/PDR-18A	39:100fn	10% of full scale	42,3:76
Ion chamber with Easterline-Angus recorder	39:101	± 25% (est)	2A
Specialized aircraft instruments	40	—	—

Pocket Dosimeter	Ref.	Accuracy	Ref.
Victoreen (0-5 R)	39:101	"Consistently high by a factor of two"	39:101
Cambridge (0-1 R)	39:101		
Kelley-Koett (0-0.2 R)	39:101		

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:	41:62	Film badges averaged about 14% too high	41:62
502 (0.02-10 R)	39:101	± 10% above 0.4 R* ± 12% to 3 R* 1.4 to 28%	21:29 8:16 59B:2
606 (10-300 R)	39:101	1.0 to 20%	59B:2

ALSO SEE REFERENCES 19 AND 30

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: TEAPOT (1955)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-27A	43:156	± 20% above 10% of full scale	21F
AN/PDR-T1B*	43:156	± 15%	19B
Beckman MX-5	44:151	± 10%	21E
AN/PDR-39*	44:151	± 15%	19A:6
"Juno"	44:161	± 10% full scale gamma	3:73
Victoreen (Thyac) 389	44:161	± 10%	26
"Pee Wee" alpha survey meter	44:161	± 10% of full scale	14D:22;14B,14C
Model 2610	44:162	± 10% (est)	76 from 47:63

Pocket Dosimeter	Ref.	Accuracy	Ref.
0-1 R	46:4	Unknown	
0-5 R	46:4		

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:	44:15		
502 (0.02-10 R)	44:15	1.4 to 28%** ± 25%**	59B:2 45
606 (10-300 R)	44:15	1.0 to 20%	59B:2

ALSO SEE REFERENCES 19 AND 30

*Essentially the same instrument

**Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: WIGWAM (1955)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-27	49	± 20% above 10% of full scale	21F
AN/PDR-18	49:43	± 10% of full scale	42,3:76
AN/PDR-T1B	49:43	± 15%	19B
Model 2610	49:40	± 10% (est)	76 from 47:63
NRDL Model III, Mod I	49:40	Unknown	
Berkeley Mod 2750	49:40	Unknown	
"Pee Wee"	49:41	± 10% of full scale	14D:22;14B,14C
Logarithmic response meters	49:40, 43	Unknown	
El Tronics CP-3D ("Cutie Pie")	49:43	± 10%	14A

Pocket Dosimeter	Ref.	Accuracy	Ref.
Type unspecified (0-5 R)	49:72	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:	48:2-9		
502 (0.02-10 R)	49:36	1.4 to 28%* or ± 12% to 3 R*	59B:2 8:16
606 (10-600 R)	49:36	1.0 to 20%	59B:2

ALSO SEE REFERENCES 19, 30, AND 50

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: REDWING (1956)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-39	51:96	± 15%	19A:6
AN/PDR-T1B	51:96	± 15%	19B
AN/PDR-27F	51:97	± 20% of above 10% of full scale	34
AN/PDR-18A	51:97	± 10% of full scale	42,3:76
AN/PDR-27C	51:98	± 20% of above 10% of full scale	34
Berkeley side-window	51:98	± 25% (est)	2A
"Cutie Pie"	51:98	± 10%	3:73

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix 611 (0-5)	52:38	Unknown	
DT-60	51:98	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:	51:96		
502 (0.02-10 R)	51:96	1.4 to 28%* or ± 12% to 3 R*	59B:2 8:16
606 (10-300 R)	51:96	1.0 to 20%	59B:2

ALSO SEE REFERENCES 19 AND 30

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: PLUMBBOB (1957)

Radiac Instrument	Ref.	Accuracy	Ref.
Beckman MX-5	54:17	± 10%	21E
AN/PDR-34 (modified T1B with alpha, beta windows)	54:17	± 15% (est)	19B
Eberline PAC-1A	54:17	± 10% of full scale	14D:22;59
Nuclear Chicago Model 2111 ("Pee Wee")	54:17	± 10% of full scale	14D:22;14B,14C
AN/PDR-39	58:82	± 15%	19A:6
AN/PDR-43	58:82	± 20% of above 10% of full scale	59A:1-2

Pocket Dosimeter	Ref.	Accuracy	Ref.
(types unknown)	57	Unknown	

Film Badge	Ref.	Accuracy	Ref.
For NTS: DuPont 559 film packet with film component types:	54 and 55:79		
502 (0.02-10 R)	59B:1	1.4 to 28%*	59B:2
606 (10-300 R)	59B:1	1.0 to 20%	59B:2

ALSO SEE REFERENCES 19, 30, AND 56

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: HARDTACK I (1958)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-39	60:90	± 15%	19A:6
AN/PDR-39 modified to 500 R range	60:90	± 15%	19A:6
AN/PDR-27C	60:90	± 20% above 10% of full scale	34
AN/PDR-18	60:90	± 10% of full scale	42,3:76
CD-V-700 [sic]	60:90	within ± 25%	60A:7
Thyac (389)	60:90	± 10%	26
Beckman MX-5	60:90	± 10%	21E
Eberline PAC-3G	60:90	± 10% of full scale	14D:22;62:8

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix Model 611	61:47	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:	60:79		
502 (0.02-10 R)	60:79	1.4 to 28%* or ± 12% to 3 R*	59B:2 8:16
834 (5-800 R)	60:79	1.4 to 4.5%	19,71C

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: ARGUS (1958)

Radiac Instrument	Ref.	Accuracy	Ref.
"Alpha-detection equipment"	63:45	Unknown	

Pocket Dosimeter	Ref.	Accuracy	Ref.
Type unknown	63:52	Unknown	

Film Badge	Ref.	Accuracy	Ref.
Type unknown (from Army Lexington Signal Depot)	63:51	Unknown	

SERIES: HARDTACK II (1958)

Radiac Instrument	Ref.	Accuracy	Ref.
Eberline Model PAC-3G	64:7	± 10% of full scale	14D:22;62:8
Beckman MX-5	64:7	± 10%	21E
Tracerlab SU-10	64:11	± 15%	19B
AN/PDR-39	64:11	± 15%	19A:6
Thyac (389)	64:11	± 10%	26
"Juno" H-4 602	64:11	± 10% of full scale gamma	3:73

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix Model 611	61:47	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 559 film packet with film component types:			
502 (0.02-10 R)	65:66 64:8 and 59B:1	1.4 to 28%* or ± 12% to 3 R*	59B:2 8:16
834 (5-800 R)	65:66 and 64:8	1.2 to 4.5%	19,71C

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.02 R), ± 28 percent in the range of 0.02-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: DOMINIC I (1962)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-39 (T1B)	67:74	± 15%	19A:6
AN/PDR-39 (T1B) modified to read up to 500 R	67:74	± 15%	19A:6
IM-108	67:74	± 30%	66:138
AN/PDR-27J	67:74	± 20% above 10% of full scale	34
MX-5	67:74	± 10%	21:E
PAC-3G (AN/PDR-54)	67:74	± 10% of full scale	14D:22;62:8
Eberline:			
E-500B	67:74	± 8% to 20 mR/h ± 15% to 200 ± 10% to 2000	70:1
Gadora-2	67:74	± 8% of full scale	70A:1
E-112B	67:74	± 15% (est)	76 from 70
FM-3G (alpha floor monitor)	67:74	± 10% of full scale	14D:22;62:8

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix Model 611 (0-5 R)	68:28	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont 556 film packet with film component types:	68:28		
508 (0.03-5 R)	71C:3	1.0 to 20%*	71C:2;38
834 (5-800 R)	65:36 and 64:8	1.2 to 4.5%	19,71C:2;38

ALSO SEE REFERENCE 69

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.03 R), ± 20 percent in the range of 0.03-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: DOMINIC II (1962)

Radiac Instrument	Ref.	Accuracy	Ref.
AN/PDR-39A	72:20	± 15%	19A:6
AN/PDR-27J	72:20	± 20% of above 10% of full scale	34
Beckman MX-5	71:9	± 10%	21E
Eberline E-112B-1	71:9	± 15% (est)	76 from 70
Tracerlab AN/PDR-T1B	71:9	± 15%	19B
Victoreen AGB-500-B-SR	71:9	± 15%	3:73
Eberline E-500 B	71:9	± 8% to 20 mR/h ± 15% to 200 ± 10% to 2000	70:1
Jordan AGB-10K-SR	71:9	± 15%	71A:10-33
"Juno" HRJ-7, SRJ-6	71:9	± 10% of full scale for gamma	3:73

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix Model 611	68:28	Unknown	

ALSO SEE REFERENCE 73

Film Badge	Ref.	Accuracy	Ref.
DuPont type 301-4 film packet (also called 556) with film components:	71B:6 and 68:28		
508 (0.03-5 R)	71C:3	1.0 to 20%*	71C:2;38
834 (5-800 R)	71C:3	1.2 to 4.5%	71C:2;38

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.03 R), ± 20 percent in the range of 0.03-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

SERIES: PLOWSHARE (1961-62)

Radiac Instrument	Ref.	Accuracy	Ref.
Precision Model 111	74:10	± 10% of full scale	3:76
Beckman MX-5	74:10	± 10%	21E
Tracerlab SU-10	74:10	± 15%	19B
"Juno" Model 6	74:10	± 10% of full scale gamma	3:73
Jordan AGB-10-KG-SR	74:10	± 15%	71A:10-33
Jordan AGB-500-B-SR	74:10	± 15%	3:73

Pocket Dosimeter	Ref.	Accuracy	Ref.
Bendix Model 611	68:28	Unknown	

Self-reading pencil dosimeter			
0-200 mR	74:7	Unknown	
0-1 R	74:7	Unknown	
0-5 R	74:7	Unknown	

Film Badge	Ref.	Accuracy	Ref.
DuPont type 301-4 film packet (also called 556) with film components:	71B:6 75:7 68:28	--	--
508 (0.03-5 R)	71C:3	1.0 to 20%*	71C:2;38
834 (5-800 R)	71C:3	1.2 to 4.5%	71C:2;38

*Accuracy is a function of exposure. Generally, the sensitive film component accuracies could vary up to a maximum of ± 100 percent at minimum detection levels (0.01-0.03 R), ± 20 percent in the range of 0.03-1.0 R and ± 10-15 percent in the range above 1.0 R until the film density no longer increases with exposure; then another higher range film component normally is used.

REFERENCES

The following list of references represents documents consulted during preparation of the report. All specifics concerning radiac instruments, dosimeters, and film badges are backed up in the text by cited references.

AVAILABILITY INFORMATION

The following addresses are provided for those readers who wish to read or obtain copies of source documents.

Source documents, bearing an availability statement of DOE CIC, may be reviewed at:

Department of Energy
Health Physics Division
Coordination and Information Center
(Operated by Reynolds Electrical & Engineering Co., Inc.)
2753 S. Highland
P.O. Box 14100 — Phone: (702) 295-3194
Las Vegas, Nevada 89114 — FTS: 598-3194

Source documents, bearing an availability statement of NTIS, may be purchased from the National Technical Information Service. When ordering by mail or phone please include both the price code and the NTIS number.

National Technical Information Service
5285 Port Royal Road — Phone: (703) 487-4650
Springfield, Virginia 22161 — (Sales Office)

Additional ordering information or assistance may be obtained by writing to the NTIS, Attention: Customer Service or calling (703) 487-4660.

References herein bearing an asterisk availability indicator show the document is:

- * available at NTIS (above)
- ** available at REECo CIC (above)

1. Los Alamos Scientific Laboratory. Los Alamos 1943 - 1945; The Beginning of an Era. LASL Public Affairs Office, undated.

2. Aebersold, Paul. July 16th Nuclear Explosion - Safety and Monitoring of Personnel. Los Alamos, NM: Los Alamos Scientific Laboratory, 9 January 1947. Report LA-616.

2A. The Geiger-Mueller portable radiation detection instrument with the least accuracy listed in this report is the CDV-700 with an accuracy of ± 25% in Reference 60A. This accuracy is used for other GM instruments when their accuracies are unknown, and for other unknown types of instruments with unknown accuracies because only one instrument listed in this text is less accurate (IM 108, ± 30%, reference 66:138).

3. General Dynamics. Health Physics Handbook. Fort Worth Division: Fort Worth, TX, April 1963. Report OSP-379. **

4. Gladeck, F.R. et al. Operation Crossroads 1946. Washington, DC: Defense Nuclear Agency. DNA report 6032F. * NTIS number ADA146562.

5. Reference 4, page 6-14, mentions this as being used in the post-CROSSROADS survey of Bikini in 1947 "for all field and personnel monitoring operations."

6. Reference 4, page 6-14, mentions this also as being in the 1947 Bikini resurvey, but adds that "..it proved to be of no value in general terrain monitoring and of only limited value in the monitoring of underwater samples..."

7. Reference 4, page 6-15, mentions two specially-designed underwater probes used for special analyses. However, these were used only for deep diving operations in the post-CROSSROADS survey of Bikini in 1947.

8. Perkins, W.W. History of Pacific Proving Ground Dosimetry. San Diego, CA: Naval Oceans Systems Center, 1 April 1981. Technical report 725.

9. Geiszinger, Bruce. Letter dated 12 July 1946 to COL Stafford L. Warren, USA. Subj: Calibration results on films 5301 and 5302. Reynolds Electrical & Engineering Company, Inc.: CROSSROADS records, Tape 1, Box 2. ** Data therein applies to gamma only.

10. Scoville, Herbert ("for COL S.L. Warren, MC, AUS") Joint Task Force One internal memo dated 11 April 1946. ** The casualty badges read from 50-2,500 R and were placed aboard target ships and drone aircraft; few of the 5,000 procured were used on personnel (who also wore the standard film badge).

11. The following references are from the Stafford Warren collected papers, University of California at Los Angeles archives:

    11A. U.S. Engineer Office, Santa Fe, NM, ltr dtd 20 Mar 46 (Box 2, folder 4). **

11B. Letter by Wm G. Myers, MD, to COL Warren dtd 26 Aug 46 (Box 5, folder 3). **

11C. Memo from Wright H. Langham to Raemer Schreiber dtd 15 June 46 (Box 2, folder 7). **

11D. Collins, D.L. "Operations [sic] Crossroads: Report to Rad Safe Instrument Division" (Box 5, folder 7). **

11E. Landsverk, O.G. "Report on Maintenance and Repair of Quartz-Fibre [sic] Instruments" (Box 5, folder 7). **

11F. "Suggestions for the Operations and Care of the Pocket Dosimeter" dtd 13 July 1946 (Box 3, folder 9). **

11G. Faul, Henry. "Report on the Radiological Instruments Used at Crossroads" (Box 5, folder 7). **

11H. Handwritten notes, apparently by COL Warren (Box 2, folder 4). **

12. Andrews, CDR Howard L., USPHS and Campbell, LCDR Donald C., USN. Evaluation of Radiological Survey Instruments Used for Health Protection during Operation Sandstone. Task Group 7.6 Project Report, 1 April 1949. **

12A. Berkhouse, L. et al. Operation Sandstone: 1948. Washington, DC: Defense Nuclear Agency, 19 December 1983. DNA report 6033F. * NTIS number ADA139151.

13. Reference 12, pages 21-56, contains detailed analyses of the sensitivities and probable accuracies of these instruments. The data are much too elaborate to be summarized here.

14. Reference 12, pages 56-58, contains appreciable detail on probable dosimeter accuracies.

14A. Reference 3, pages 73, 74, and 77, lists Cutie Pie instruments from four different manufacturers and all have accuracies of ± 10% of full scale.

14B. Reference 62, page 8, states that a later proportional alpha counter, PAC-3G (gas flow) is electronically calibrated so that the meter is 100 percent efficient for counting alpha particles while the probe is only 30 percent efficient in detecting them.

14C. Dummer, Jerome E., Jr. Los Alamos Handbook of Radiation Monitoring. Los Alamos, NM: November 1958. Statement similar to reference 14B. Also, many sources of positive detection errors. **

14D. Davis, D.M. and Gupton, E.D. Health Physics Instrument Manual. Oak Ridge National Laboratory, 16 May 1963, ORNL-332 (third edition). **

15. Atomic Weapons Tests. Operation Sandstone: 1948. Report to the Joint Chiefs of Staff. Part 2 of Annex 1 to Volume 1, Section IX (Radsafe). Joint Task Force 7, 1948. **

16. These casualty badges apparently were intended to be worn together with the regular film badges by those participants who might be exposed to high levels of radiation. However, there is no evidence that they were worn.

17. Maag, Carl et al. Operation Ranger Shots Able, Baker, Easy, Baker-2, Fox, 25 January - 6 February 1951. Washington, DC: Defense Nuclear Agency, 26 February 1982. DNA report 6022F. * NTIS number ADA118684.

18. Shipman, T.L. Report of the Rad-Safe Group, Operation Ranger Program Reports. Operational Volume 5. Los Alamos: Los Alamos Scientific Laboratory, July 1952. **

19. Reynolds Electrical & Engineering Company, Inc. "Photographic Dosimetry, Third Supplemental Evaluation." Mercury, NV: REECo, Inc., 17 October 1957. ** This is a detailed analysis of the films listed below and is summarized as follows:

Densitometer Accuracy (Per Cent of Dose)

Exposure (r)	0.050	0.100	0.200	0.500	1.0	5.0	10.0	15.0	20.0	50.0
502 film	50.0	25.0	10.0	4.4	2.3	1.2	1.2	1.2	-	-
555 film	20.0	8.0	4.0	1.8	1.0	1.0	-	-	-	-
606 film	-	-	-	-	-	-	23.0	23.0	4.0	1.8
834 film	-	-	-	-	-	7.0	3.5	3.5	2.0	1.0

Film Accuracy (Standard Deviation in Per Cent Dose)

Exposure (r)	0.050	0.100	0.200	0.500	1.0	5.0	10.0	20.0	50.0
502 film	1.0	1.0	1.0	2.6	1.5	1.1	2.8	3.1	-
555 film	1.0	1.0	1.0	3.2	2.1	4.6	-	-	-
606 film	-	-	-	-	-	-	11.5	1.0	1.6
834 film	-	-	-	-	-	3.2	1.0	4.0	1.6

19A. Department of the Army. Radiac Set AN/PDR-39. Washington, DC: 13 July 1956. Technical Manual No. 11-5514A. **

19B. Reference 19A, page 6, lists accuracy of the AN/PDR-39 radiac instrument which is essentially the same instrument as the AN/PDR-T1B, AN/PDR-39/T1B, and SU-10 (Navy version).

19C. Reference 21E lists accuracy of the Beckman MX-5, which should have the same specified accuracy as an MX-5 made by another manufacturer.

20. Berkhouse, L. et al. Operation Greenhouse-1951. Washington, DC: Defense Nuclear Agency, 15 June 1983. DNA report 6034F. * NTIS number ADA134735.

REFERENCES (Continued)

21. Cooney, James P., Brig Gen, MC, USA. Radiological Safety, TU 3.1.5. Washington, DC: July 1951. Report WT-89. **

21A. Reference 8, page 15 (footnote), states that DuPont 554 film packets with film badge types 510 and 606 were used. But reference 21B, page 18, states "DuPont film packets containing No. 510 and 605 emulsions were used." The same reference, pages 20-21, gives the accuracy of these as ± 20%. However, it is believed that these film badges were used in conjunction with the various experiments and tests but not for personnel badging.

21B. Tochilin, E. and Howard, P. Scientific Director's Report, Annex 6.5: Interpretation of Survey Meter Data. San Francisco, CA: Naval Radiological Defense Laboratory, August 1951. Report WT-26. **

21C. Haselkorn, H. and Cohen, A.E. Scientific Director's Report, Annex 5.1: Polaroid Dosimeters. Evans Signal Laboratory, April 1952. Report WT-62. Pages 6-7 imply these were recently developed and being tested, but not used for personnel. **

21D. Leroy, G.V. Scientific Director's Report, Annex 2.10: Miscellaneous Studies of Dosimeters. Chicago, IL: University of Chicago, November 1951. Report WT-13. This mentions many types of proposed dosimeters ranging from corn to glass, but none were used for personnel. **

21E. Beckman Instruments, Inc. Instructions for Beckman Model MX-5 Radiation Meter. South Pasadena, CA: September 1950. Bulletin 192-B. **

21F. Reference 34, pages 1-5, lists accuracy of the AN/PDR-27T radiac instrument. Other AN/PDR-27 models should have the same accuracy except models 27, 27A, and 27B did not have lead shields over geiger tubes to reduce energy dependence. Thus, these models were less accurate at some photon energies.

22. Ponton, Jean et al. Operation Buster-Jangle, 1951. Washington, DC: Defense Nuclear Agency, 21 June 1982. DNA report 6023F. * NTIS number ADA123441.

23. Headquarters, III Corps. Exercise Desert Rock I. Sixth U.S. Army Fort MacArthur, CA: HQS III Corps, 26 June 1952. **

24. Shipman, Thomas, M.D. Radiological Safety, Operation Buster-Jangle. Los Alamos, NM: Los Alamos Scientific Laboratory, October 1979. Report WT-425-EX. **

25. From Reference 23, page 110. This is not in agreement with reference 22, page 117, which states that "...film badges were DuPont #533 with a range of 0.1 to 50 roentgens."

26. The Radiac Company. General letter with attached radiation instrument advertising: 489 Fifth Avenue, New York, NY; February 1951. ** Page 12 is the Victoreen Thyac advertisement giving instrument specifications. Accuracy stated is under field conditions.

27. Ponton, Jean et al. Operation Tumbler-Snapper 1952. Washington, DC: Defense Nuclear Agency, 14 June 1982. DNA report 6019F. * NTIS number ADA122242.

28. Gwynn, Philip S., Lt. Colonel, USAF. Radiological Safety, Operation Tumbler-Snapper. Washington, DC: Armed Forces Special Weapons Project, December 1952. Report WT-558. **

29. Merian, Richard F. Evaluation of Portable Alpha Survey Instruments. Kirtland AFB, NM: Air Force Special Weapons Center, December 1957. Report AFSWC TR-57-40. **

30. Reynolds Electrical & Engineering Company, Inc. "Supplemental Information for Photographic Dosimetry." Mercury, NV: REECo, Inc., nd. ** This was found attached to reference 59B and was probably produced in 1957. This is an analysis of DuPont type 553 film packs; data is summarized below:

Densitometer Accuracy (Per Cent of Dose)

Exposure (r)	5	10	30
Component 502	1.2	1.0	-
Component 510	2.4	1.1	0.7
Component 606	16.0	10.0	2.3

Standard Deviation (Per Cent of Dose)

Exposure (r)	5	10	30
Component 502	6.6	3.2	-
Component 510	3.4	2.3	5.1
Component 606	1.0	4.5	2.3

30A. The Victoreen 356 "Zeuto" alpha detector meter indicated counts per minute (c/m). To convert c/m to alpha disintegrations per minute (d/m), common practice was to calibrate weekly with a standard alpha source and affix a calibration curve relating c/m and d/m to the side of the instrument as discussed in reference 47, pages 14 and 15.

31. Gladeck, F.R. et al. Operation Ivy: 1952. Washington, DC: Defense Nuclear Agency, 1 December 1982. DNA report 6036F. * NTIS number ADA128082.

32. Reference 31, page 94, states that sampler pilots wore the DuPont 553 in addition to the standard DuPont 558.

33. Maynard, R.H., Captain, U.S. Navy, and Servis, J.D., Major, U.S. Army. Radiological Safety [IVY]. Los Alamos: LASL, January 1953. Report WT-614. This states (p. 80) that the 502 film emulsion range was .03-15R. **

34. Nuclear Research Corporation. Technical Manual, Operation Instructions, Maintenance Instructions, Overall Instructions with Parts Breakdown, Radiac Set AN/PDR-27T. Warrington, PA: Published under authority of the Secretary of the Air Force, 1 October 1982. **

REFERENCES (Continued)

35. Collison, Tom D., Lieutenant Colonel, U.S. Army. Radiological Safety Operation [UPSHOT-KNOTHOLE]. Albuquerque, NM: Field Command, Armed Forces Special Weapons Project, June 1953. Report WT-817. **

36. Massie, Jeannie et al. Shot Simon, a Test of the Upshot-Knothole Series 25 April 1953. Washington, DC: Defense Nuclear Agency, 13 January 1982. DNA report 6016F. * NTIS number ADA121667.

37. Ponton, Jean et al. Operation Upshot-Knothole, 1953. Washington, DC: Defense Nucler Agency, 11 January 1982. DNA report 6014F. * NTIS number ADA121624.

38. These are laboratory accuracies; field accuracies would be somewhat less.

39. Martin, Edwin J. Castle Series, 1954. Washington, DC: Defense Nuclear Agency, 1 April 1982. DNA report 6035F. * NTIS number ADA117574.

40. Variants of B-50, B-36, and F-84 aircraft were equipped with many different types of specialized radiac equipment for cloud sampling work. These are described in Reference 39, pp. 132-139.

41. Servis, John D., Major, Chemical Corps [USA]. Radiological Safety [CASTLE]. Los Alamos: LASL, August 1954. **

42. The AN/PDR-18 was a scintillation detector for high range gamma with four ranges: 0-0.5, 0-5, 0-50, and 0-500 R/hr. The Precision Model 111, although a low range gamma detector, was also a scintillation detector with three ranges. Because the accuracy of the AN/PDR-18 should have been the same or better, the accuracy of the Precision Model 111 from reference 3 was used.

43. Ponton, Jean et al. Operation Teapot 1955. Washington, DC: Defense Nuclear Agency, 23 November 1981. DNA report 6009F. * NTIS number ADA113537.

44. Collison, T.D., LTC, USA. Radiological Safety [at TEAPOT]. Albuquerque, NM: Field Command, AFSWP; May 1955. AFSWP report WT-1166. **

45. Reference 44, page 13, gives the accuracies as follows:

Table 1.1—FILM BADGE DATA

No. of films	Span of film Nos.	Dosage, r	Average density	Standard	Density deviation Standard, %	Single film maximum	Average, %
166	06650-41450	1.00	0.660	0.027	4.09	15.15	3.03
68	27350-41350	20.00	0.343	0.029	8.40	19.50	6.10
93	06550-26150	47.43	0.733	0.034	4.70	13.30	3.80

Evaluation shows that at	1 r	20 r	47 r
99% of film badges are accurate to	±12%	±25%	±14%
95% of film badges are accurate to	±8%	±17%	±9%
68% of film badges are accurate to	±4%	±8%	±5%

46. Test Division Test Managers Operation Order, Operation Teapot, Part III. Santa Fe, NM: Operations Office, AEC; February 1955. **

47. Davis, D.M., Gupton, E.D., and Hart, J.C. Applied Health Physics Radiation Survey Instrumentation. Oak Ridge, TN: Oak Ridge National Laboratory, 1 January 1954. Report ONRL-332 (1st Rev.). **

48. Weary, S.E. et al. Operation Wigwam (Series Volume). Washington, DC: Defense Nuclear Agency, 1 September 1981. DNA report 6000F. * NTIS number ADA105685.

49. Baietti, A.L. and Smith, A.L. Radiological Safety for Operation Wigwam. San Francisco, CA: U.S. Naval Radiological Defense Laboratory, January 1957. Report WT-1001. **

50. Hawkins, W.B. et al. Determination of Radiological Hazard to Personnel [WIGWAM]. San Francisco; CA: U.S. Naval Radiological Defense Laboratory, May 1955. Report WT-1012. ** This states on page 55 that DuPont dosimetry film packets, types 552 and 558, were used. However, to judge from the context of that report, these were only used as experimental badges (e.g. on YAG-39 and YAG-40) but not for personnel.

51. Bruce-Henderson, S. et al. Operation Redwing: 1956. Washington, DC: Defense Nuclear Agency, 1 August 1982. DNA report 6037F. * NTIS number ADA134795.

52. Jacks, Gordon L. Radiological Safety [REDWING]. Los Alamos, NM: LASL, May 1957. **

53. Campbell, D.C., LCDR, USN. Radiological Defense, Vol IV: An Introduction to Radiological Instruments for Military Use. Washington, DC: Armed Forces Special Weapons Project, January 1950. **

54. Reynolds Electrical & Engineering Company, Inc., Radiological Safety Division. Operation Plumbbob On-Site Radiological Safety Report. Mercury, NV: Nevada Test Site, undated. REECo report OTO-57-2. **

55. Harris, P.S. et al. Plumbbob Series, 1957. Washington, DC: Defense Nuclear Agency, 15 September 1981. DNA report 6005F. * NTIS number ADA107317.

56. Reference 54, page 239 reported that the following additional film pack components were evaluated at PLUMBBOB: DuPont types 510, 555, 824, 825, 834 and Eastman type 2. However, all personal dosimetry appears to have been done with the DuPont film pack type 559 with 502 and 606 components.

57. Reference 54, page 234, reports that 15,000 pocket dosimeters were issued and read. However, no information has yet been found on specific types and accuracies.

58. Field Command, Defense Atomic Support Agency. Operation Plumbbob Operational Summary. Albuquerque, NM: Field Command, DASA; 23 February 1960. Report WT-1444. **

59. Reference 14C, pages 53, 68, and 69 describe the PAC 1-A (proportional alpha counter, model number 1, air flow) as a transistorized version of the Model 2111 Pee Wee with essentially the same operation and use.

59A. Electronic Products Company. Technical Manual for Radiac Set AN/PDR-43. Mount Vernon, NY: 15 January 1959. Published for Department of the Navy, Bureau of Ships. **

59B. Reynolds Electrical & Engineering Company, Inc. Photographic Dosimetry. Mercury, NV: REECo, Inc., 17 January 1957. ** This is a detailed analysis of the film badge listed below and is summarized as follows:

Densitometer Accuracy (Per Cent of Dose)

Exposure (r)	0.05	0.1	0.5	1.0	5.0	10.0	50.0	100.0
DuPont Type 555	20.0	10.0	2.4	1.5	1.2	1.2	1.2	1.2
DuPont Type 559 Emulsion #502	28.0	16.0	4.0	2.5	1.4	1.4	-	-
Dupont Type 559 Emulsion #606	-	-	-	-	20.0	6.0	1.0	1

Standard Deviation (Per Cent of Dose)

Exposure (r)	0.05	0.1	0.5	1	5	8	9	10	11	30	50	80	100
DuPont Type 555	-	-	-	1.8	3.8	-	-	6.6	-	7.8	-	-	4.1
DuPont Type 559/502	-	-	1	2.1	3.0	6.8	4.3	1.8	4.4	-	-	-	-
DuPont Type 559/606	-	-	-	-	-	6.0	7.8	8.0	5.1	4.3	2.7	1.3	-

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69. Perkins, W.W. and Hammond, R.R. Navy Film Badge Review: Dominic. San Diego, CA: Naval Oceans System Center, 28 May 1980. Technical report 583. This concluded (page i) "... that there is a high probability that doses over 400mR include a substantial contribution to the dose that is a result of moisture damage to the film badge."

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71B. Reynolds Electrical & Engineering Company, Inc. Radiological Safety Division Standard Operating Procedures. Health, Medicine and Safety Department. Mercury, NV: January 1961. **

71C. Horn, William. "Photographic Dosimetry, Fourth Supplemental Evaluation." Mercury, NV: Reynolds Electrical & Engineering Company, Inc., (Radiological Safety Division), 1 November 1960. ** This is a detailed analysis of the films listed below and is summarized as follows:

Densitometer Accuracy (Per Cent of Dose)

Exposure (r)	0.050	0.100	0.200	0.500	1.0	5.0	10.0	20.0	50.0	100.0
508 film	20.0	10.0	4.0	2.0	1.4	1.0	1.0	-	-	-
834 film	-	-	-	-	-	4.5	2.5	1.5	1.2	1.2

Standard Deviation (Per Cent of Dose)

Exposure (r)	0.050	0.100	0.200	0.5	1.0	5.0	10.0	20.0	50.0	100.0
508 film	6.0	4.0	6.0	1.1	3.5	4.2	11.0	-	-	-
834 film	-	-	-	-	-	5.2	2.0	2.6	2.4	5.0

72. Field Command, Defense Atomic Support Agency. Quick-Look Report, Shot Johnie Boy (U). Albuquerque, NM: FC, DASA; October 1962. Report FC/10620332.

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74. Reynolds Electrical & Engineering Co., Inc. On-Site Radiological Safety Report, Final Report, Project Gnome. Washington, DC: [Atomic Energy Commission] Office of Technical Services, May 1962. Report PNE-133F. **

75. Reynolds Electrical & Engineering Co., Inc. On-Site Radiological Safety Report, the Sedan Event. Washington, DC: [Atomic Energy Commission] Office of Technical Services, 1962. Report PNE-203F. **

76. A general discussion of estimated accuracies was given in the Introduction; this particular estimate was provided by William J. Brady, Technical Advisor, Environmental Sciences Department of Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV. Mr. Brady has been associated with the testing program for 32 years and has been in the Nevada Test Site health physics program for 28 years. While directing the radsafe laboratory at Mercury, NV, he designed analysis equipment as well as the combination personnel dosimeter/security credential holder in use at NTS for the past 18 years. References which read "76 from ..." mean that the instrument accuracy is estimated by Mr. Brady based on a closely-related instrument given in the second reference.

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81. Unruh, C. M. et al. The Establishment and Utilization of Film Dosimeter Performance Criteria. Richland, WA: Battelle Northwest Laboratory; September 1967. Report BNWL-542. **

82. Brady, William J. "Statement for NRC Meeting Regarding 10 CFR 20 on Personnel Dosimeter Performance Testing." Washington, DC: Reynolds Electrical & Engineering Company, Inc.; November 30, 1976. **

83. "Personnel Dosimetry, Operation CROSSROADS." Reynolds Electrical & Engineering Company, Inc., collection of microfilm records, Box 2: "Pacific 1946, CROSSROADS." **

84. The CROSSROADS Eastman Type K film packet had a 20-mil-thick lead filter shaped like a 90-degree cross on one side of the packet which was attached by bending the tips of the cross around the edges of the packet. This information and an illustration of the packet are in Roll 1 of the Reynolds Electrical & Engineering Company, Inc., microfilms of dosimetry source documents. Film packets worn during later Pacific and continent nuclear testing series used a 28-mil-thick lead filter bent around the packet and covering an area about one inch long by one-half inch wide on each side. William J. Brady (see reference 76) has estimated response of the Type K film packet under the thin 20-mil-thick filter by comparison with work done by Dr. Margarete Ehrlich of the National Bureau of Standards. Estimates are shown in the following table:

ENERGY SENSITIVITY (RELATIVE TO ^{60}Co) OF
DUPONT 502, DUPONT 606, AND (ESTIMATED) EASTMAN TYPE K

Photon Energy (keV)	Dupont 502 Sensitivity* 23 Mils Lead	Dupont 502 Sensitivity* 28 Mils Lead	Dupont 606 Sensitivity* 23 Mils Lead	Dupont 606 Sensitivity* 28 Mils Lead	Estimated Type K Sensitivity** 20 Mils Lead
40	0	0	0	0	0
70	1.83	1.22	1.68	1.23	2.30
120	1.30	0.99	1.18	0.89	1.55
170	1.17	1.02	1.14	0.98	1.28
210	1.00	0.94	1.03	1.07	1.05
1250 (^{60}Co)	1.00	1.00	1.00	1.00	1.00

*Work by Dr. Margarete Ehrlich in 1952, letter to W. Klaus AEC/DBM, personal communication.
**From DuPont 502 assuming an exponential relationship between 28, 23, and 20 mils of lead filter.

The over-response of more than 100 percent at 70 keV indicates that all positive CROSSROADS exposures determined from film badges were overestimated to some extent. The amount of overestimated exposure depended upon how much of the exposure energy spectrum was in the over-response energy region. For example, if 20 percent of a 1 R actual exposure were overestimated by 100 percent, this would be 0.4 R added to the remaining 0.8 R which would result in an apparent exposure of 1.2 R.

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ATTN: Dir of Libraries, Regional

Glassboro State College
ATTN: Librarian

DIRECTORY OF OTHER (Continued)

Gleeson Library
ATTN: Librarian

Government Publications Library
ATTN: Dir of Libraries, Regional

Graceland College
ATTN: Librarian

Grand Forks Public City-County Library
ATTN: Librarian

Grand Rapids Public Library
ATTN: Dir of Libraries

Greenville County Library
ATTN: Librarian

Guam RFK Memorial University Library
ATTN: Fed Depository Collection

University of Guam
ATTN: Librarian

Gustavus Adolphus College
ATTN: Library

Hardin-Simmons University Library
ATTN: Librarian

Hartford Public Library
ATTN: Librarian

Harvard College Library
ATTN: Dir of Libraries

University of Hawaii Library
ATTN: Govt Docs Collection

Hawaii State Library
ATTN: Fed Docs Unit

University of Hawaii at Monoa
ATTN: Dir of Libraries, Regional

University of Hawaii
ATTN: Librarian

Haydon Burns Library
ATTN: Librarian

Henry Ford Comm College Library
ATTN: Librarian

Herbert H. Lehman College
ATTN: Lib Docs Div

Hofstra University Library
ATTN: Docs Dept

Hollins College
ATTN: Librarian

Hoover Institution
ATTN: J. Bingham

Hopkinsville Comm College
ATTN: Librarian

University of Houston Libraries
ATTN: Docs Div

Houston Public Library
ATTN: Librarian

Hoyt Public Library
ATTN: Librarian

Humboldt State College Library
ATTN: Docs Dept

Huntington Park Library
ATTN: Librarian

Hutchinson Public Library
ATTN: XXXXX

Idaho Public Library & Info Ctr
ATTN: Librarian

Idaho State Library
ATTN: Librarian

Idaho State University Library
ATTN: Docs Dept

University of Idaho
ATTN: Dir of Libraries, Regional
ATTN: Docs Section

University of Illinois Library
ATTN: Docs Section

Illinois State Library, Regional
ATTN: Govt Docs Br

Illinois University at Urbana Champaign
ATTN: P. Watson, Docs Library

Illinois Valley Comm College
ATTN: Library

Indiana State Library, Regional
ATTN: Serial Section

Indiana State University
ATTN: Docs Libraries

Indiana University Library
ATTN: Docs Dept

Indianapolis Marian Cyt Public Library
ATTN: Social Science Div

Iowa State University Library
ATTN: Govt Docs Dept

Iowa University Library
ATTN: Govt Docs Dept

Irwin Library, Butler University
ATTN: Librarian

Isaac Delchdo College
ATTN: Librarian

James Madison University
ATTN: Librarian

DIRECTORY OF OTHER (Continued)

Jefferson County Public Library
ATTN: Librarian

Jersey City State College
ATTN: Librarian

Johns Hopkins University
ATTN: Docs Library

John J. Wright Library
ATTN: Librarian

Johnson Free Public Library
ATTN: Librarian

Kahului Library
ATTN: Librarian

Kalamazoo Public Library
ATTN: Librarian

Kansas City Public Library
ATTN: Docs Div

Kansas State Library
ATTN: Librarian

Kansas State University Library
ATTN: Docs Dept

University of Kansas
ATTN: Dir of Libraries, Regional

Kent State University Library
ATTN: Docs Div

Kentucky Dept of Library & Archives
ATTN: Docs Section

University of Kentucky
ATTN: Dir of Libraries, Regional
ATTN: Govts Publication Dept

Kenyon College Library
ATTN: Librarian

Lake Forest College
ATTN: Librarian

Lake Sumter Comm College Library
ATTN: Librarian

Lakeland Public Library
ATTN: Librarian

Lancaster Regional Library
ATTN: Librarian

Lawrence University
ATTN: Docs Dept

Lee Library
ATTN: Docs & Map Section

Library & Statutory Distribution & Svc
2 cys ATTN: Library

Little Rock Public Library
ATTN: Librarian

DIRECTORY OF OTHER (Continued)

Long Beach Public Library
ATTN: Librarian

Los Angeles Public Library
ATTN: Serials Div, US Do

Louisiana State University
ATTN: Dir of Libraries, Regional
ATTN: Govt Doc Dept

Louisville Free Public Library
ATTN: Librarian

Louisville University Library
ATTN: Librarian

Lyndon B. Johnson School of Public Affairs Library
ATTN: Librarian

Maine Maritime Academy
ATTN: Librarian

Maine University at Oreno
ATTN: XXXXX

University of Maine
ATTN: XXXXX

Manchester City Library
ATTN: Librarian

Mankato State College
ATTN: Govt Publications

Mantor Library
ATTN: Dir of Libraries

Marathon County Public Library
ATTN: Librarian

Marshall Brooks Library
ATTN: Librarian

University of Maryland
ATTN: McKeldin, Librarian, Docs Div

University of Massachusetts
ATTN: Govt Docs College

McNeese State University
ATTN: Librarian

Memphis Shelby County Public Library & Info Ctr
ATTN: Librarian

Memphis State University
ATTN: Librarian

Mercer University
ATTN: Librarian

Mesa County Public Library
ATTN: XXXXX

University of Miami Library
ATTN: Govt Publications

Miami Public Library
ATTN: Docs Div

DIRECTORY OF OTHER (Continued)

Miami University Library
ATTN: Docs Dept

Michel Orradre Library
ATTN: Docs Div

Michigan State Library
ATTN: Librarian

Michigan State University Library
ATTN: Librarian

Mich[illegible] Tech University
[illegible]TN: Library Docs Dept

Unive[illegible]sity of Michigan
ATTN: Acq Sec Docs Unit

Middlebury College Library
ATTN: Librarian

Millersville State College
ATTN: Librarian

Milne Library, University of New York State
ATTN: Docs Librarian

Milwaukee Public Library
ATTN: Librarian

Minneapolis Public Library
ATTN: Govt Documents

Minnesota Div of Emergency Svcs
ATTN: Librarian

Minot State College
ATTN: Librarian

Mississippi State University
ATTN: Librarian

University of Mississippi
ATTN: Dir of Libraries

Missouri University at Kansas City Gen
ATTN: Librarian

University of Missouri Library
ATTN: Govt Docs

MIT Libraries
ATTN: Librarian

Mobile Public Library
ATTN: Govt Info Div

Moffett Library, Midwestern University
ATTN: Librarian

Montana State Library
ATTN: Librarian

Montana State University Library
ATTN: Librarian

University of Montana
ATTN: Docs Div, Regional

University of Maryland
ATTN: Librarian

Moorhead State College
ATTN: Library

Mt Prospect Public Library
ATTN: Librarian

Murray State University Library
ATTN: Library

Nassau Library System
ATTN: Librarian

Natrona County Public Library
ATTN: Librarian

Nebraska Library Comm
ATTN: Librarian

University of Nebraska Omaha
ATTN: Librarian

Nebraska University Lib
ATTN: Acquisitions Dept

Nebraska Western College Library
ATTN: Librarian

University of Nebraska
ATTN: Dir of Libraries, Regional

University of Nevada Library
ATTN: Govt Public Dept

University of Nevada at Las Vegas
ATTN: Dir of Libraries

New Hampsire University Library
ATTN: Librarian

New Hanover County Public Library
ATTN: Librarian

New Mexico State Library
ATTN: Librarian

New Mexico State University
ATTN: Library Docs Div

University of New Mexico
ATTN: Dir of Libraries, Regional

New Orleans Library University
ATTN: Govt Docs Div

New Orleans Public Lib
ATTN: Librarian

New York Public Library
ATTN: Librarian

New York State Library
ATTN: Docs Control Cultural Ed Ctr

New York State University at Stony Brook
ATTN: Main Library Docs Section

New York State University Col at Cortland
ATTN: Librarian

DIRECTORY OF OTHER (Continued)

University of New York State
ATTN: Library Documents Section

University of New York State
ATTN: Librarian

New York State University
ATTN: Docs Center

University of New York State
ATTN: Docs Dept

New York University Library
ATTN: Docs Dept

Newark Free Library
ATTN: Librarian

Newark Public Library
ATTN: Librarian

Niagra Falls Public Library
ATTN: Librarian

Nicholls State University Library
ATTN: Docs Div

Nieves M. Flores Memorial Library
ATTN: Librarian

Norfolk Public Library
ATTN: R. Parker

North Carolina Agri & Tech State University
ATTN: Librarian

University of North Carolina at Charlotte
ATTN: Atkins Library Docs Dept

North Carolina University Library at Greensboro
ATTN: Librarian

North Carolina Central University
ATTN: Librarian

North Carolina State University
ATTN: Librarian

North Carolina University at Wilmington
ATTN: Librarian

University of North Carolina
ATTN: BA SS Div Docs

North Dakota State University Library
ATTN: Docs Librarian

University of North Dakota
ATTN: Librarian

North Georgia College
ATTN: Librarian

North Texas State University Library
ATTN: Librarian

Northeast MO State University
ATTN: Librarian

DIRECTORY OF OTHER (Continued)

Northeastern Illinois University
ATTN: Library

Northeastern Oklahoma State University
ATTN: Librarian

Northeastern University
ATTN: Dodge Library

Northern Arizona University Library
ATTN: Govt Docs Dept

Northern Illinois University
ATTN: Librarian

Northern Iowa University
ATTN: Library

Northern Michigan University
ATTN: Documents

Northern Montana College Library
ATTN: Librarian

Northwestern Michigan College
ATTN: Librarian

Northwestern State University
ATTN: Librarian

Northwestern State University Library
ATTN: Librarian

Northwestern University Library
ATTN: Govt Publications Dept

Norwalk Public Library
ATTN: Librarian

University of Notre Dame
ATTN: Doc Ctr

Oakland Comm College
ATTN: Librarian

Oakland Public Library
ATTN: Librarian

Oberlin College Library
ATTN: Librarian

Ocean County College
ATTN: Librarian

Ohio State University
ATTN: Libraries Docs Div

Ohio University Library
ATTN: Docs Dept

Oklahoma City University Library
ATTN: Librarian

Oklahoma City University Library
ATTN: Librarian

Oklahoma Dept of Libraries
ATTN: US Govt Docs

DIRECTORY OF OTHER (Continued)

Oklahoma University Library
ATTN: Govt Doc Collection

Old Dominion University
ATTN: Doc Dept University Library

Olivet College Library
ATTN: Librarian

Omaha Public Library, Clark Branch
ATTN: Librarian

Oregon State Library
ATTN: Librarian

University of Oregon
ATTN: Docs Section

Ouachita Baptist University
ATTN: Librarian

Pan American University Library
ATTN: Librarian

Passaic Public Library
ATTN: Librarian

Paul Klapper Library
ATTN: Docs Dept

Pennsylvania State Library
ATTN: Govt Publications Section

Pennsylvania State University
ATTN: Library Doc Section

University of Pennsylvania
ATTN: Dir of Libraries

Penrose Library, University of Denver
ATTN: Penrose Library

Peoria Public Library
ATTN: Business, Science & Tech Dept

Philadelphia Free Library of Logan Square
ATTN: Govt Publications Dept

Philipsburg Free Public Library
ATTN: Library

Phoenix Public Library
ATTN: XXXXX

University of Pittsburg
ATTN: Docs Office G 8

Plainfield Public Library
ATTN: XXXXX

Popular Creek Public Lib District
ATTN: XXXXX

Portland Library Assoc of Social Sci & Sci Dept
ATTN: XXXXX

Portland Public Library
ATTN: XXXXX

Portland State University Library
ATTN: XXXXX

Prescott Memorial Library, Louisiana Tech University
ATTN: XXXXX

Princeton University Library
ATTN: Docs Div

Providence College
ATTN: Physics Dept

Providence Public Library
ATTN: XXXXX

Public Library Cincinnati & Hamilton County
ATTN: XXXXX

Public Library of Nashville
ATTN: XXXXX

University of Puerto Rico
ATTN: Doc & Maps Room

Purdue University Library
ATTN: XXXXX

Quinebaug Valley Community College
ATTN: XXXXX

Ralph Brown Draughon Lib
ATTN: Microforms & Docs Dept

Rapid City Public Library
ATTN: XXXXX

Reading Public Library
ATTN: XXXXX

Reed College Library
ATTN: XXXXX

Reese Library, Augusta College
ATTN: XXXXX

University of Rhode Island Library
ATTN: Govt Publications Office

University of Rhode Island
ATTN: Dir of Libraries

Rice University
ATTN: Dir of Libraries

Richard W. Norton Memorial Library, Louisiana College
ATTN: XXXXX

Richland County Public Library
ATTN: XXXXX

University of Richmond
ATTN: Library

Riverside Public Library
ATTN: XXXXX

University of Rochester Library
ATTN: Documents Section

DIRECTORY OF OTHER (Continued)

University of Rutgers, Camden Library
ATTN: XXXXX

The State University of Rutgers
ATTN: XXXXX

Library of Science & Medicine, Rutgers University
ATTN: Govt Docs Dept

Rutgers University Law Library
ATTN: Fed Docs Dept

Salem College Library
ATTN: XXXXX

Samford University
ATTN: XXXXX

San Antonio Public Library
ATTN: Bus Science & Tech Dept

San Diego County Library
ATTN: C. Jones, Acquisitions

San Diego Public Library
ATTN: XXXXX

San Diego State University Library
ATTN: Govt Pubs Dept

San Francisco Public Library
ATTN: Govt Docs Dept

San Francisco State College
ATTN: Govt Publications Collection

San Jose State College Library
ATTN: Docs Dept

San Luis Obispo City-County Library
ATTN: XXXXX

Savannah Public & Effingham Liberty Regional Library
ATTN: XXXXX

Scottsbluff Public Library
ATTN: XXXXX

Scranton Public Library
ATTN: XXXXX

Seattle Public Library
ATTN: Ref Docs Asst

Selby Public Library
ATTN: XXXXX

Shawnee Library System
ATTN: XXXXX

Shreve Memorial Library
ATTN: XXXXX

Silas Bronson Public Library
ATTN: XXXXX

Simon Schwob Memorial Library, Columbus College
ATTN: XXXXX

Sioux City Public Library
ATTN: XXXXX

Skidmore College
ATTN: XXXXX

Slippery Rock State College Library
ATTN: XXXXX

South Carolina State Library
ATTN: XXXXX

University of South Carolina
ATTN: XXXXX

University of South Carolina
ATTN: Govts Docs

South Dakota School of Mines & Tech Library
ATTN: XXXXX

South Dakota State Library
ATTN: Federal Docs Dept

University of South Dakota
ATTN: Docs Librarian

South Florida University Library
ATTN: XXXXX

Southdale-Hennepin Area Library
ATTN: Govt Docs

Southeast Missouri State University
ATTN: XXXXX

Southeastern Massachusetts University Library
ATTN: Docs Section

University of Southern Alabama
ATTN: XXXXX

Southern California University Library
ATTN: Docs Dept

Southern Connecticut State College
ATTN: Library

Southern Illinois University
ATTN: XXXXX

Southern Illinois University
ATTN: Docs Ctr

Southern Methodist University
ATTN: XXXXX

University of Southern Mississippi
ATTN: Library

Southern Oregon College
ATTN: Library

Southern University in New Orleans Library
ATTN: XXXXX

Southern Utah State College Library
ATTN: Docs Dept

DIRECTORY OF OTHER (Continued)

Southwest Missouri State College
ATTN: Library

University of Southwestern Louisiana Libraries
ATTN: XXXXX

Southwestern University
ATTN: XXXXX

Spokane Public Library
ATTN: Reference Dept

Springfield City Library
ATTN: Documents Section

St Bonaventure University
ATTN: XXXXX

St Joseph Public Library
ATTN: XXXXX

St Lawrence University
ATTN: XXXXX

St Louis Public Library
ATTN: XXXXX

St Paul Public Library
ATTN: XXXXX

Stanford University Library
ATTN: Govt Documents Dept

State Historical Soc Library
ATTN: Docs Serials Section

State Library of Massachusetts
ATTN: XXXXX

State Library of Ohio
ATTN: Librarian

State University of New York
ATTN: XXXXX

Stetson University
ATTN: XXXXX

University of Steubenville
ATTN: XXXXX

Stockton & San Joaquin Public Library
ATTN: XXXXX

Stockton State College Library
ATTN: XXXXX

Superior Public Library
ATTN: XXXXX

Swarthmore College Library
ATTN: Reference Dept

Syracuse University Library
ATTN: Docs Div

Tacoma Public Library
ATTN: XXXXX

DIRECTORY OF OTHER (Continued)

Tampa, Hillsborough County Public Library
ATTN: XXXXX

Temple University
ATTN: XXXXX

Tennessee Technological University
ATTN: XXXXX

University of Tennessee
ATTN: Dir of Libraries

Terteling Library, College of Idaho
ATTN: XXXXX

Texas A&M University Library
ATTN: XXXXX

University of Texas at Arlington
ATTN: Library Documents

University of Texas at San Antonio
ATTN: Library

Texas Christian University
ATTN: XXXXX

Texas State Library
ATTN: US Docs Section

Texas Tech University Library
ATTN: Govt Docs Dept

Texas University at Austin
ATTN: Docs Coll

Texas University at El Paso
ATTN: Docs & Maps Library

University of Toledo Library
ATTN: XXXXX

Toledo Public Library
ATTN: Social Science Dept

Torrance Civic Center Library
ATTN: XXXXX

Traverse City Public Library
ATTN: XXXXX

Trenton Free Public Library
ATTN: XXXXX

Trinity College Library
ATTN: XXXXX

Trinity University Library
ATTN: Docs Collection

Tufts University Library
ATTN: Docs Dept

Tulane University
ATTN: Docs Dept

University of Tulsa
ATTN: XXXXX

DIRECTORY OF OTHER (Continued)

UCLA Research Library
ATTN: Public Affairs Service, US Docs

Uniformed Svcs University of the Health Sciences
ATTN: LRC Library

University Libraries
ATTN: Dir of Libraries

Upper Iowa College
ATTN: Docs Collection

Utah State University
ATTN: XXXXX

University of Utah
ATTN: Special Collections

University of Utah
ATTN: Dept of Pharmacology
ATTN: Dir of Libraries

Valencia Library
ATTN: XXXXX

Vanderbilt University Library
ATTN: Govt Docs Section

University of Vermont
ATTN: Dir of Libraries

Virginia Commonwealth University
ATTN: XXXXX

Virginia Military Institute
ATTN: XXXXX

Virginia Polytechnic Inst Library
ATTN: Docs Dept

Virginia State Library
ATTN: Serials Section

University of Virginia
ATTN: Public Documents

Volusia County Public Libraries
ATTN: XXXXX

Wagner College
ATTN: Librarian

Washington State Library
ATTN: Docs Section

Washington State University
ATTN: Library Docs Section

Washington University Libraries, FM-25
ATTN: Dir of Libraries

University of Washington
ATTN: Docs Div

Wayne State University Library
ATTN: XXXXX

Wayne State University Law Library
ATTN: Docs Dept

DIRECTORY OF OTHER (Continued)

Weber State College Library
ATTN: XXXXX

Wesleyan University
ATTN: Docs Librarian

West Chester State Coll
ATTN: Docs Dept

West Covina Library
ATTN: XXXXX

University of West Florida
ATTN: XXXXX

West Hills Community Coll
ATTN: Library

West Texas State University
ATTN: Library

West Virginia Coll of Grad Studies Library
ATTN: XXXXX

University of West Virginia
ATTN: Dir of Libraries, Regional

Westerly Public Library
ATTN: XXXXX

Western Carolina University
ATTN: XXXXX

Western Illinois University Library
ATTN: XXXXX

Western Washington University
ATTN: XXXXX

Western Wyoming Community College Library
ATTN: XXXXX

Westmoreland City Comm Coll
ATTN: Learning Resource Ctr

Whitman College
ATTN: XXXXX

Wichita State University Library
ATTN: XXXXX

William & Mary College
ATTN: Docs Dept

DIRECTORY OF OTHER (Continued)

William Allen White Library
ATTN: Govt Documents Div

William College Library
ATTN: XXXXX

Willimantic Public Library
ATTN: XXXXX

Winthrop College
ATTN: Docs Dept

University of Wisconsin at Whitewater
ATTN: Govts Docs Library

Wisconsin Milwaukee University
ATTN: XXXXX

Wisconsin Oshkosh University
ATTN: XXXXX

Wisconsin Platteville University
ATTN: XXXXX

Wisconsin University at Stevens Point
ATTN: Docs Section

University of Wisconsin
ATTN: Govt Pubs Dept

University of Wisconsin
ATTN: Acquisitions Dept

Worcester Public Library
ATTN: XXXXX

Wright State University Library
ATTN: Govts Docs Dept

Wyoming State Library
ATTN: XXXXX

University of Wyoming
ATTN: Docs Div

Yale University
ATTN: Dir of Libraries

Yeshiva University
ATTN: XXXXX

Yuma City County Library
ATTN: XXXXX