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THE HANFORD EMERGENCY DOSIMETRY SYSTEM

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THE HANFORD EMERGENCY DOSIMETRY SYSTEM

Although the atomic energy industry is reportedly one of the safest industries in the world, nearly all of the major atomic energy sites throughout the world have had at least one criticality accident or radiation incident of similar magnitude. Therefore, it has become mandatory for each site to prepare in advance for such an occurrence. Part of this preparation includes an emergency dosimetry system. The object of this paper is to describe the emergency dosimetry system currently in place at Hanford.

The Hanford system consists of instrumentation, procedures, and training that are intended to minimize the time of exposure, effect prompt identification and medical treatment for those exposed, and estimate the dose to personnel associated with the incident. Procedures for estimating dose are based upon whether or not personnel dosimeter data is available, types of radiation involved, magnitude of exposure, and areas and/or organs of the body irradiated.

COMMUNICATIONS AND MOBILIZATION

Probably the most important function in any emergency dosimetry system is good communications. These communications include proper warning devices, evacuation routes, and notification of emergency teams. Good communications not only reduce the time personnel are exposed, but also help assure safe re-entry and stabilization during recovery operations.

RADIATION ALARMS AND BUILDING EVACUATION

Radiation alarms are used at Hanford wherever there is a potential for high dose rates ($> 5R/hr$) from fluxes of ionizing radiation external to the body, or the air concentrations of radioisotopes could substantially exceed the maximum permissible concentrations recommended by the National Commission on Radiological Protection⁽¹⁾. These alarms must be audible to all personnel working in the facility, and must give off a warning that is easily distinguishable from other warnings, such as fire and civil defense. Care is taken to assure that the alarms used for detecting incidents, such as a criticality incident, respond properly at high dose rates. A flash X-ray⁽²⁾ unit is used for testing these alarms in dose rates up to $10^{11}R/hr$.

All personnel are adequately trained to be aware of the alarms that signal for immediate evacuation of the facility and the correct evacuation routes. Practice sessions are frequent and serve the double purpose of training personnel and assuring that alarms are functioning properly. This training cannot be over emphasized. Experience has shown⁽³⁾ that the response of the individuals most closely associated with an incident will be no better than the level of preparedness that has been sustained over the past several years.

PERSONNEL ACCOUNTING AND SEGREGATION

After building or area evacuation, personnel report to preassigned staging areas. Each small group has a preassigned warden and alternate who are responsible for accounting for all personnel in the group. Also, radiation monitoring teams report to these staging areas to direct radiation monitoring activities such as sorting exposed personnel, making contamination surveys, and monitoring re-entry personnel. Methods used in sorting

potentially exposed personnel are dependent upon the type of incident and radiation encountered, and the degree of contamination present.

NEUTRONS

The feasibility of detecting gamma radiation from neutron activated body sodium with conventional monitoring instruments available in field situations was investigated at Hanford.^(4,5) As a result, a sorting procedure was devised by which uncontaminated personnel exposed to fast neutrons can be quickly recognized by a direct survey of their bodies. This sorting procedure consists of holding a GM-type portable radiation survey instrument against the stomach and abdomen area of a potentially exposed person. In case of injury or hysteria, approximately the same results can be obtained by placing the probe under the arm pit. The GM reading obtained from either of the above geometries is roughly proportional to the dose received. A simple relationship was developed between dose, count rate, and body weight using Hanford calibrated GM-type portable radiation survey instruments, a thick beryllium target bombarded with 1.88 Mev neutrons ($E_{ave} = 2.1$ Mev), and a remab manikin.⁽⁶⁾ The relationship is

$$D = 2.5 R/W \quad (1)$$

where R is the count rate in counts per minute for a GM tube instrument calibrated to indicate 3,200 ~~counts/minute~~ counts/minute per mR/hr, W is the body weight in pounds, and D is the dose in rads.

Immediately following the criticality accident⁽⁷⁾ that occurred at Hanford in April, 1962, this sorting procedure was used to segregate exposed personnel. The nuclear excursion took place in a waste processing tank

as the result of the presence in that tank of approximately 1400-1500 g of plutonium contained in about 40-50 liters of dilute nitric acid. The three individuals who received significant neutron exposure were promptly identified by this sorting procedure. Table I shows a comparison between the dose estimated by this sorting procedure and by whole body and blood counting techniques for the four personnel receiving the highest exposure. This experience has shown that even with some moderating material surrounding the source the GM survey is an effective method of sorting personnel exposed to sources of fast neutrons.

If personnel are contaminated, the above method of sorting personnel exposed to fast neutrons is invalid. An indium foil is mounted in the Hanford personnel dosimeter for use when contamination is present. Using this method, ~~max~~ neutron dose estimat~~ions~~ in the range of a few to 10^3 rads can be made assuming an unmoderated fission spectrum.

TABLE I

COMPARISON OF BODY SODIUM ACTIVATION MEASUREMENTS

HW-SA	Subject	Body Weight lb	Observed c/m	Dose (rads)		
				Sorting Procedure	Whole Body Counter	Blood Counter
	A	155	2,000	32	23	28
	B	216	600	7	9.2	14
	C	188	300	4	2.9	3.7
	D	160	bkg.	≤ 1	0.16	-

X AND GAMMA RAYS

A relatively rapid assessment of those personnel who have been exposed only to X and gamma radiation is made by evaluating the response of the two 1 mm diameter 6 mm long silver-activated phosphate glass dosimeters⁽⁸⁾ that are mounted in the Hanford personnel dosimeter as shown in Figure 1.⁽⁹⁾ The property of radiophotoluminescence of silver-activated phosphate glass has been discussed thoroughly in the literature,^(10, 11, 12, 13, 14) and will not be discussed here. It will suffice to say that radiophotoluminescence is the acquisition, after irradiation by X or gamma rays, of the property of luminescence when excited by light of a suitable wave length. Reliable commercial readers such as the Bausch and Lomb reader used at Hanford, are available for ~~very~~ rapidly measuring the luminescence.

Hurst and Ritchie have shown that gamma energy dependence of the glass ~~rod~~ rods can be minimized by shielding with 0.02 in. tantalum and 0.015 in. of teflon as also shown in Figure 2. One of the glass rods in the Hanford personnel dosimeter is shielded with 0.02 in. of tantalum. An unshielded glass rod is included in the dosimeter to provide an estimate of the dose from photons with energies less than about 100 Kev. When tantalum-shielded and unshielded glass rods are exposed to the same dose of photon radiation of about 1 Mev energy, the tantalum-shielded fluoro rod yields a 16% higher luminescence because of the tantalum shield. The assumption may be made, therefore, that the unshielded glass rod luminescence (L_u) should be equal to 0.84 times the tantalum-shielded glass rod luminescence ($0.84 L_s$) if no photon energies below 300 Kev are present. If the relation

$$L_u = 0.85 L_s \quad (2)$$

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does not hold, then the difference of the two quantities, L_u and $0.85 L_s$, is a measure of the photon radiation due to energies below 300 Kev. The relative sensitivity between the shielded and unshielded glass rods at 60 Kev (from Figure 2) is about 0.05. Therefore, a rough estimate of the luminescence, L , from photons with energies less than 100 Kev is given by

$$L = 0.05 (L_u - 0.85 L_s) \quad (3)$$

A cobalt-60 source is used to calibrate the reader. Typical calibration curves are shown in Figure 2 for both the shielded and the unshielded glass rods. Since the dose, (D) , is proportional to the glass rod dosimeter dial reading which in turn is proportional to the luminescence equation (3) becomes

$$D = 0.05 (D_u - 0.85 D_s) \quad (4)$$

Dose from photons with energies greater than 100 Kev is estimated from the shielded glass rod dosimeter curve, and dose from photons with energies less than 100 Kev is roughly estimated from both the curves and equation (4).

Advantages of the glass rod dosimeters are that they are essentially dose rate independent, directional independent, temperature independent, and have a very low background fluorescence. Also, the glass rod dosimeter's response covers a wide exposure range (10 to 10^4 R). One disadvantage of using glass rods is that they are about 1.4 times more sensitive to thermal neutrons than to 1 Mev photon radiation. In mixed X and gamma and slow and epithermal neutron exposures the above photon dose measurements must be corrected by subtracting the slow and epithermal neutron dose component.

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NOTIFICATION AND MOBILIZATION OF EMERGENCY RADIOLOGICAL TEAM

Emergency directors are appointed for each Hanford manufacturing and laboratory area, and each facility within these areas. In the event of a serious incident these directors, among other responsibilities, are assigned the task of notifying patrol who in turn activate the city crash alarm system. The latter system summons by telephone a radiological emergency staff who assemble at a predesignated emergency control center. The control center serves as a focal point to assemble technical support teams, arrange for processing of dosimeters and biological samples, and dispatch additional supplies and manpower to the event site as needed.

DOSIMETRY EVALUATIONS FOR PERSONNEL WEARING DOSIMETERS

All personnel working in Hanford manufacturing and laboratory areas where radioactive materials are handled are required to wear personnel dosimeters. This requirement increases the probability of having some data from dosimeters worn by other personnel in the vicinity of the incident, even if an exposed individual forgot to wear his dosimeter or his dosimeter was somehow destroyed. The Hanford personnel dosimeter is shown in Fig. 1. It contains, a film identification section, a section for interpreting chronic low level dose, a section for interpreting neutron spectra and high level dose and a security section.

Several precautionary measures are taken with personnel dosimeters that are suspected of having been acutely exposed to ionizing radiation. Contamination spread is prevented by surveying the dosimeters with freshly calibrated portable instrument before the dosimeters are brought into the building for processing. For routine chronic exposures, the

dosimeter contains a lead tape perforated with the employee's payroll number. Prior to the removal of the film packet, the payroll number is x-rayed onto a part of the film to provide positive and permanent identification. If the film was worn during an acute exposure, the latent image may be rendered totally developable and the x-ray coding technique would not identify the film with the wearer. A perforating machine is used to code the film whenever the film has been worn by personnel who are suspected of receiving an acute exposure. This machine perforates the film and packet with the identification number, and places tape over the perforated holes to prevent light leaks. In the case of power failure, the perforating machine can be hand operated.

ASSESSMENT OF WHOLE BODY DOSE

Whole body dose is estimated from personnel dosimeter and body sodium activation. The latter data is obtained from blood and whole body counting techniques.

X, GAMMA AND BETA RAYS AND ELECTRONS

The x and gamma ray exposure is estimated from both the glass rods and the dental film that is contained in the personnel dosimeter. Normally, the glass rod data would be used for quickly estimating whether or not the exposure was less or greater than 100 R. Initially, this is the exposure level that the attending physician is most interested in because the first signs of radiation injury such as nausea, vomiting, diarrhea, and loss of appetite are expected at this level. The film, which takes much longer to process, is used for a more accurate estimate of the exposure.

The dental film and associated filter system in the Hanford Personnel Dosimeter has been described in the literature,^[9] but for completeness

is included in the Appendix A. For our purposes, it will suffice to state that the dental film and associated filter system provides for the evaluation of radiation dose from X, gamma, and beta rays, and electrons present independently or concurrently. Table II lists the calibration energies and dose ranges of the glass rods and the dental film.

A set of high level calibration films that have been exposed to gamma ray dose levels of 10, 25, 35, 50, 60, 70, 120, 150, 300, 450, 600, and 1200 R and regular X, gamma, and beta ray calibration films are kept in the dark room and processed with every set of dosimeter films worn by potentially acutely exposed personnel. These calibration films help to eliminate errors in dose evaluation due to such variables as development time, solution strength, solution temperature, etc. Each high level gamma calibration film is positively identified by perforating the dose level in the film with the perforating machine. This procedure not only positively identifies the calibration film for future dose estimates, but also allows the film to be read while still wet by simply raising the film tray out of the wash water and comparing the acutely exposed personnel film with the calibration film. Several hours of valuable evaluation time can be saved by the above procedure.

Recent tests with the flash x-ray unit have shown that the glass rods and dental film response is independent of dose rate up to 10^{11} R/hr, and that 30% of the latent image fades for both the film and glass rods during the first half hour after exposure. Because of this latter fact, films that have been worn by personnel who are suspected of having received an acute exposure should not be developed during the first half hour after exposure.

TABLE II

SUMMARY OF HANFORD PERSONNEL DOSIMETER PERFORMANCE

X, Gamma and Beta Rays

<u>Dosimeter Component</u>	<u>Type of Radiation Measures</u>	<u>Response Energy Mev</u>	<u>Dose Range</u>	<u>Calibration Energy Mev</u>
Film	Photon	0.01-0.05	0.001-15 R	0.017
Film	Photon	0.05-up	0.015-1500 R	0.05-2
Film	Beta	0.5-up	0.025-2000 rads	Uranium Beta
Glass Rod (unshielded)	Photon	0.02-0.05	5-1000 R	0.03
Glass Rod (shielded)	Photon	0.05-up	10-10000 R	0.05-2

NEUTRONS

The Hanford personnel dosimeter is fitted with an activation foil system for measuring neutron flux and spectra. The system shown in Fig. 1 and summarized in Table III consists of (1) bare and cadmium-shielded indium foils whose activation difference is a measure of the thermal neutron flux, (2) a cadmium-shielded indium foil which measures neutron flux between the cadmium cutoff (0.4 ev) and indium resonance (2 ev) and neutron flux above about 1 Mev by the indium-115 (n,n') indium-115^m neutron threshold reaction, (3) a copper foil which measures flux between indium resonance (2 ev) and the indium neutron threshold activation at 1 Mev, and (4) a sulphur pellet for measurement of neutron flux above 2.5 Mev. The neutron flux and spectra measurements can be converted to first collision dose by using the constants provided in the National Bureau of Standards Handbook 63.^[9] Flux, dose and spectra evaluation are discussed in Appendix B. Each foil used in the system is sensitive to a minimum neutron dose of about 1 rad of fission spectrum neutrons.

A complementary method of estimating fast neutron dose is by assessing the body sodium activation. When fast neutrons are incident upon the body approximately 10% pass through the body, about 50% escape at lower energies including 20% as thermal neutrons and the remaining 40% are captured in the body hydrogen, nitrogen, sodium, chlorine and other elements.^[10] The sodium activity at Hanford is measured by whole body and blood counter techniques modeled after those of the Oak Ridge National Laboratory.^[15,16] Ten ml blood samples are taken from the exposed individuals if their gamma dose exceeds 25 roentgens. These samples are taken as soon as possible after exposure because of the short half life

TABLE III

SUMMARY OF HANFORD PERSONNEL DOSIMETER PERFORMANCE

<u>Dosimeter Component</u>	<u>Response Energies</u>	<u>Neutrons</u>	
		<u>Dose Range rads</u>	<u>Activity Counted</u>
Indium	0.025 - 0.3 ev	1 - 2000	In ¹¹⁶ Decay
Dacmium-Indium- Cadmium	0.3 ev - 2 ev	1 - 2000	In ¹¹⁶ Decay
	2 ev - 1 Mev	1 - 2000	Cu ⁶⁴ Decay
Copper			
Cadmium-Indium- Cadmium	1 - 2.9 Mev	1 - 2000	In ¹¹⁵ Decay
Sulphur	2.9 Mev - up	1 - 2000	P ³² Decay

of Na-24, and before new sodium is given to the individual through food or medical treatments.

The activity density of the samples is then measured in a conventional three-inch well crystal scintillation counter or on a total absorption gamma ray spectrometer.[17] For a criticality incident the activity density of the Na²⁴ in the whole blood is then converted to neutron first collision dose by multiplying the factor 1.65×10^5 rad-cm³/μc. This is the ratio of first collision dose to blood activity found in the Oak Ridge burro experiment.[18]

Whole body counting of Na²⁴ activity at Hanford is based on experimental work performed at Los Alamos and Oak Ridge on man phantoms[19] and live burros.[18] These burros and phantoms were exposed to a bare criticality assembly and the dose per unit specific activity calculated. The burro data yielded a value of 204 ml-k_g/μc and phantom data yielded a value of 226 ml-k_g/μc. An average value of 215 rad-k_g/μc is used at Hanford for Na²⁴ measurements. The Hanford whole body counter[19] iron room is shown in Fig. 3. For sodium-24 measurements the patient sits in a reclining chair so that his body forms an arc around the 4" x 11" sodium iodide crystal. To obtain the dose, the measured values of Na²⁴ activity, corrected for decay since the time of the accident, are divided by the patient's weight and the quotient multiplied by 215 rad-k_g/μc.

ASSESSMENT OF INTERNAL AND CRITICAL ORGAN DOSE

Dose to the eyes and gonads will be estimated from P³² in hair measurements and dose calculations. Where personnel are exposed to fast neutrons, the P³² in hair measurements will also be used in helping to determine the geometrical relationship of exposed personnel to the source. Internal

exposure will be estimated from exterior spectroscopy measurements such as whole body, thyroid, and wound counter measurements, and from human excreta and blood data.

X and Gamma Rays from Sources External and Internal to the Body

The Hanford whole body counters will be used to measure the internal deposition of gamma emitting fission and activation products. For incident dosimetry the extreme sensitivity of these counters is not needed. However, the routine use of these counters help to assure that they will be operating and properly calibrated. The stationary counter^[20] is a NaI (Tl) scintillation counter in an iron room modeled after the one at the Argonne National Laboratory, U. S. A.^[21] For analysis of whole body deposited gamma-emitting radionuclides, the patient sits in a reclining chair, shown in Fig. 3, and a 9-inch by 4-inch sodium iodide crystal is placed in a geometry such that the patient's body forms an arc around the crystal. The crystal assembly may also be placed on a track in such a geometry that the crystal can remotely scan a patient reclining on a litter. This counting geometry is used to determine the location of an isotope in the body. Fig. 4 shows a subject being examined for the presence of radioiodine in the thyroid. The detector system used is a 3-inch by 3-inch NaI crystal and photomultiplier tube mounted on the boom of a movable dolly. This arrangement allows the detector to be easily adjusted for any subject so that the crystal axis will be perpendicular to the subject's neck, just touching the clavicle.

The Hanford mobile whole body counter^[22] is also available for assistance during emergencies. This counter is housed in the semitrailer shown in Fig. 5. The mobility of this laboratory provides versatile capabilities for measuring internally deposited gamma-ray emitting radionuclides in

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human beings during emergencies. The mobile whole body counter shadow shield detector shown in Fig. 6 is based on the design by Roesch and Palmer and incorporates an 11-1/2 inch by 4-inch NaI crystal having seven, 3-inch photomultiplier tubes. The subject lies on a cushioned sled which is gear driven under the crystal by an electric motor. Microswitches at either end of the counter base automatically stop the sled when it has traversed the length of the counter. Shielding is provided by lead bricks. The shielding system has been optimized to achieve a maximum of shielding with a minimum of weight. An ambient gamma ray must penetrate a minimum of slightly more than two inches of lead to strike the crystal. The crystal with its shield rests on a 2-inch iron plate over the center of the counter and four inches of lead surround the crystal on top and sides. The combined weight of the shield is approximately 2200 pounds. The entire shadow shield weighs approximately six tons. The normal counting time is ten minutes per examination and may be changed by changing gears on the motor-drive mechanism.

X and gamma ray dose to the eyes and gonads from sources external to the body will be estimated from the personnel dosimeter data, the relative geometry between personnel and source, and the source geometry.

Neutrons

For neutron spectra that extend past the sulphur threshold at 2.5 Mev, an estimate of the dose to the eyes and gonads will be made from P^{32} in hair measurements. The methods of preparing and analyzing hair samples and estimating flux and dose are modeled after the techniques used at the Los Alamos Scientific Laboratory, U. S. A. [23]

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Alpha and Beta Emitters

Since the routine methods of radiochemical analyses of excreta and blood samples for alpha and beta emitters have been reviewed by a joint WHO/FHO Expert Committee[24] in September 1955, and the general methods of assessment of radioactive body burden in vivo have been the subject of a symposium[25] organized by the IAEA in May 1964, these topics will not be discussed in this paper. For our purposes it will suffice to say that standard liquid scintillation[26] and radiochemical analysis procedures[27, 28, 29] are used in determining the amounts of activity in excreta and blood. These activities are then related to internal deposition where models[30, 31, 32] exist.

DOSIMETRY EVALUATIONS FOR PERSONNEL NOT WEARING DOSIMETERS

There are several disadvantages in estimating dose for those who are not wearing dosimeters. First, there are no direct neutron spectrum measurements available for estimating first collision neutron dose. One has to assume that the neutrons impinging on the person have the same spectrum as measured by either a nearby fixed dosimeter or another personnel dosimeter. Second, gamma dose estimates must be made from a knowledge of the locations during the incident of other personnel or from fixed dosimeter measurements, or must be estimated from the neutron dose by assuming a ratio of gamma to neutron dose.

STATIONARY DOSIMETERS

DePangher[33] investigated the response of a BF_3 tube with respect to paraffin moderator thickness and initial neutron energy. He found that a paraffin thickness of 4-1/2 inches resulted in the optimum condition in which BF_3 counts per unit dose was fairly constant for neutron energies

from 150 Kev to about 6 Mev, (Figure 2). Proceeding on the basis of DePangher's study, a 9-1/8 inch long by 9-1/8 inch diameter paraffin moderator with 4-inch thick walls was constructed, (Figure 7), and equipped with a 1-inch diameter polyethylene and aluminum foil holder insert rather than a BF_3 tube. Two foils, a 1 cm by 1 cm by 0.005 inch gold foil and a 1/2 inch by 5/8 inch by 0.010 inch indium foil, were mounted on one end of the polyethylene rod insert. When in place in the dosimeter, the foils are positioned at the geometrical center of the moderator. A 2 Mev positive ion Van de Graaf accelerator, employing various beam particles and target materials, was used to study the neutron response of the dosimeter over the energy range of 55 Kev to 6 Mev. Neutron dose rates were generally below 10 rads per hour.

Distinct advantages of the Hanford Criticality Dosimeter over other presently available neutron dosimeters are: (1) absence of predose radioactivity in dosimeter components, (2) absence of toxic dosimeter components, and, (3) simple and rapid dose evaluation techniques. Unit cost of the completely-installed dosimeter is less than fifty dollars.

Neutron Flux, Dose and Spectra

Elementary indium is composed of two isotopes 4.23 per cent In^{113} and 95.77 per cent In^{115} (by weight). The primary activation of indium by neutrons is due to the In^{115} thermal neutron absorption cross-section of 145 barns and an In^{115} resonance absorption cross-section of 28,000 barns at 1.4 ev. In^{116} , the product of neutron absorption in In^{115} , decays with a 54-minute half life to Sn^{116} by emission of both beta and gamma

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radiation. The decay of In^{114} , formed due to the 56 barn In^{113} thermal absorption cross-section, is of no consequence during the decay of In^{116} due to its long, 49 day, half life. A plot of the relative indium foil activity per unit tissue dose as a function of neutron energy is shown in Fig. 8, and is seen to compare favorably with Dr. DePangher's double moderator BF_3 response. The normal value corresponds to about 3.7×10^3 d/m/gm per mrad.

In case the In^{115} activity could not be counted within a few hours, an alternate method using a gold foil is also provided in the dosimeter. Elementary gold is 100% Au^{197} which has a 98 barn thermal neutron absorption cross-section and a 15,000 barn resonance absorption at 4.9 ev. Calibration of the moderated gold foil over the 55 Kev to 6 Mev neutron energy range yields the average value of 21 d/m/gm per mrad. The gold, therefore, has a total activity of about 1/200 the activity of indium immediately after irradiation. The neutron energy response of the dosimeter using the gold foil was found to be satisfactory as is also shown in Fig. 8.

One advantage of using both indium and gold foil in the moderator is that the time of the incident can be established from a knowledge of the activities of the foils. Fig. 9 is a plot of the activity ratios versus elapsed time.

Neutron flux and spectra are measured with the same foils as used in the personnel dosimeter. The end of the polyethylene foil holder insert, which extends out of the dosimeter about 4 inches, is fitted with an aluminum foil holder as shown in Fig. 7. The same flux and dose equations as given for the personnel dosimeter in Appendix B apply to these foils.

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It must be remembered that neutron doses calculated by either the moderated foil method or the activated foil method are the doses at the stationary dosimeter location. Hurst, et al [34] have shown that the first collision neutron dose, D_n , received by personnel can be related to the blood sodium-24 activity measurement, A , and the neutron flux, D , by

$$D_{np} = 9.5 \times 10^8 A \int_0^\infty D_0(E) \phi(E) dE / \int_0^\infty (E) \phi(E) dE (5)$$

where (E) is fraction of neutrons of energy E that is captured in the body and A is in d/cm^3 . (E) is given as a function of energy in Fig. 10. Using the neutron dose D_n at the dosimeter location as calculated from the indium and gold activities or equation

$$D_{np} = 9.5 \times 10^8 A D_n / (0.18 (t_h + t_{ep}) + 0.5)$$

Gamma Dose

Two glass rod dosimeters, one shielded and one unshielded, are included in the stationary dosimeter. Evaluation of dose is the same as the evaluation given above for the glass rods in the Hanford Personnel Dosimeter. An estimate of the gamma dose to personnel can be made multiplying the neutron dose equation by the neutron to gamma dose ratio as determined from the stationary dosimeter.

Placement Criteria

To assure the collection of adequate dosimetry information following a serious radiation event, careful consideration should be given to the placement of these dosimeters. The intent of the placement criteria is to provide enough stationary dosimeters to result in the best practical interpretation of personnel exposure following an accident.

FIGURE 10

THERMAL NEUTRON CAPTURE PROBABILITY

General Placement Criteria

General Placement criteria are as follows:

1. The positioning of the dosimeters and the number of dosimeters required is:
 - a. Independent of the number of people working at the location.
 - b. Independent of the time spent by people working at the location.
 - c. Independent of the probability of an occurrence at any particular location.
2. Dosimeters are required to monitor any location where a criticality event or serious radiation event of a similar magnitude is at all conceivable.
3. Dosimeters are required in all locations which can be or are even occasionally occupied by personnel.
4. Dosimeters are to be placed where prompt retrieval is most likely; for example, placement of the dosimeters in the hallway to monitor adjacent rooms is recommended if the shielding provided between the hallway and the room being monitored is nominal.
5. In general the dosimeter should be placed with a minimum of shielding between the dosimeter and the radiation source.
6. In addition to technical placement considerations, the practicality of placing dosimeters in any particular location with respect to the interference of normal work practices is to be duly considered.

Background Radiation Placement Criteria

The Hanford criticality dosimeters are dose integrating devices for both neutron and gamma radiation. They possess a high sensitivity to gamma and neutron radiation, hence, accumulation to excessive background radiation prior to an event could significantly distort the dose interpretation. The following criteria with respect to background radiation levels should be used in positioning the dosimeters.

1. The background gamma radiation dose rate at the location of dosimeters should be as low as possible and should not exceed 25 r/year.

Rationale - Glass rod dosimeters are used in the Hanford criticality dosimeters to provide a measure of the gamma radiation dose. In order to be useful the glass rod dosimeters should measure 100 r to $\pm 25\%$. If the integrated dose is greater than 25 r before the event, then the gamma radiation dose will not be estimated within the desired accuracy.

2. Dosimeters should be positioned in locations where a measurement of the neutron dose and spectra is required regardless of the possibility of measuring the gamma dose.

Rationale - Glass rod dosimeters will be included in the new Hanford personnel film badge dosimeters. Therefore, the glass rod dosimeters that are included in the Hanford criticality dosimeters are of secondary importance.

3. The background neutron dose rate at the location of the dosimeters should be as low as possible, generally not exceeding 20 mrem/hr. To monitor in locations where the neutron dose rates exceed 20 mrem/hr the Hanford criticality dosimeters should be positioned at a distance sufficient to reduce the chronic dose rates to the prescribed dose rate levels.

Rationale - In order to measure 100 rem to ± 10 rems the background neutron dose rates should be less than 20 mrem/hr (based on sulphur pellet activation).

Facilities Requiring Hanford Criticality Dosimeters

The following criteria determines those facilities requiring Hanford criticality dosimeters:

1. Dosimeters are required at any accessible location where personnel have occasion to enter and where criticality event could conceivably occur (wherever a critical mass of material is in inventory).
2. Dosimeters are required at any accessible location where personnel have occasion to enter and where radiation dose rates of 200 rem/hr or greater could conceivably occur as a result of radiation accident.

Number of Dosimeters Required

The number of dosimeters required to monitor a given location is a function of the type of operation performed. For isolated hoods where criticality events are conceivable, dosimeter requirements are different than for processing lines where a criticality event could occur at any location along the line.

1. For criticality or other serious radiation events in locations such as single hoods, storage vaults, hot cells, reactors, etc., the

Hanford criticality dosimeters should be placed as close to the fissionable material or other radioactive material as fully practical considering the criteria previously presented. In general, dosimeters positioned at distances of 5 feet, 50 feet, at the maximum available distance within the room, and near the exit from the room containing the fissionable material are required.

2. For processing lines or other "large sources" with maximum dimensions greater than about 25 feet, the criticality dosimeters should be located so that each point on the processing line or source is within 25 feet of a dosimeter. Dosimeters should also be positioned on approximate 50-foot centers with each dosimeter within 5 feet of the source material wherever practical.

Rationale - After a serious radiation event, the dose that is interpreted from the Hanford criticality dosimeters (corrected for any intervening shielding material) will be plotted as a function of the inverse square of the distance between the dosimeter and the radiation source. These corrected dose-distance plots will then be used to estimate the dose to exposed individuals by estimating the distance between the source and the individual and determining the dose (corrected for any intervening shielding material) to the individual from the dose-distance plots. In addition to the accuracy of the above dose interpretation depends on two independent requirements:

- a. The inverse square law is valid for distances that are large compared with the dimensions of the detector and the source.

- b. The Hanford criticality dosimeter dose-distance curve should be plotted using distances that encompass the distance from the radiation source to the individual. The distances were chosen to satisfy both requirements in a practical sense.

The closest distance, 5 feet, between the source and the dosimeter was chosen because the Hanford criticality dosimeter is a point dosimeter at approximately 5 feet. A fifty foot or maximum dimension of the room distance was chosen to attain a second dose point at a distance greater than that at which individuals may receive injurious exposures.