ORNL/TM--8294

DE82 014727

ORNL/TM-8294

Contract No. W-7405-eng-26

Industrial Safety and Applied Health Physics Division

CALIBRATION OF THE INDIUM FOIL USED FOR CRITICALITY ACCIDENT DOSIMETRY IN THE UCC-ND EMPLOYEE IDENTIFICATION BADGE

M. T. Ryan
H. M. Butler
E. D. Gupton
C. S. Sims*

*Health and Safety Research Division.

Date Published: May 1982

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U. S. Department of Energy

TABLE OF CONTENTS

LIST OF TABLES

CALIBRATION OF THE INDIUM FOIL USED FOR CRITICALITY ACCIDENT DOSIMETRY IN THE UCC-ND EMPLOYEE IDENTIFICATION BADGE

Abstract

The UCC-ND Employee Identification Badge contains an indium foil disc that is intended for use as a dosimetry screening device in the event of a criticality accident. While it is recognized that indium is not a precise mixed neutron-gamma dosimeter, its activation by neutrons provides adequate means for separating potentially exposed persons into three groups. These three groups are: (1) personnel exposed below annual dose limits, (2) personnel exposed above annual dose limits but below 25 rem, and (3) personnel exposed above 25 rem. This screening procedure is designed to facilitate dosimeter processing in order to meet regulatory reporting requirements. A quick method of interpreting induced activity measurements is presented and discussed.

1.0 Introduction

The UCC-ND Employee Identification Badge, shown in Figure 1, contains an indium foil disc (0.79 g) that is 0.015 in (0.38 mm) thick.[1] The indium foil is intended for use as a screening device for rapidly identifying personnel that may have been exposed to neutrons during a criticality accident. The measurement and interpretation of data from an employee's badge exposed during a criticality accident are given in the ORNL IS&AHP Emergency Manual.[2] The data presented in this report document the response of the indium foil to neutron irradiation by a critical assembly and how these readings may be interpreted. Also, the relationship between measurements of induced activity and various actions in the IS&AHP Emergency Procedure No. 3 is discussed.

2.0 Exposure of Test Badges

The Oak Ridge National Laboratory's Health Physics Research Reactor (HPRR) is a small, unmoderated, fast pulse reactor[3] which can be operated in the steady state or the pulse mode. The HPRR has been widely used in the development and testing of personnel neutron dosimeters[4] and nuclear accident dosimeters.[5] This wide use is the result of the

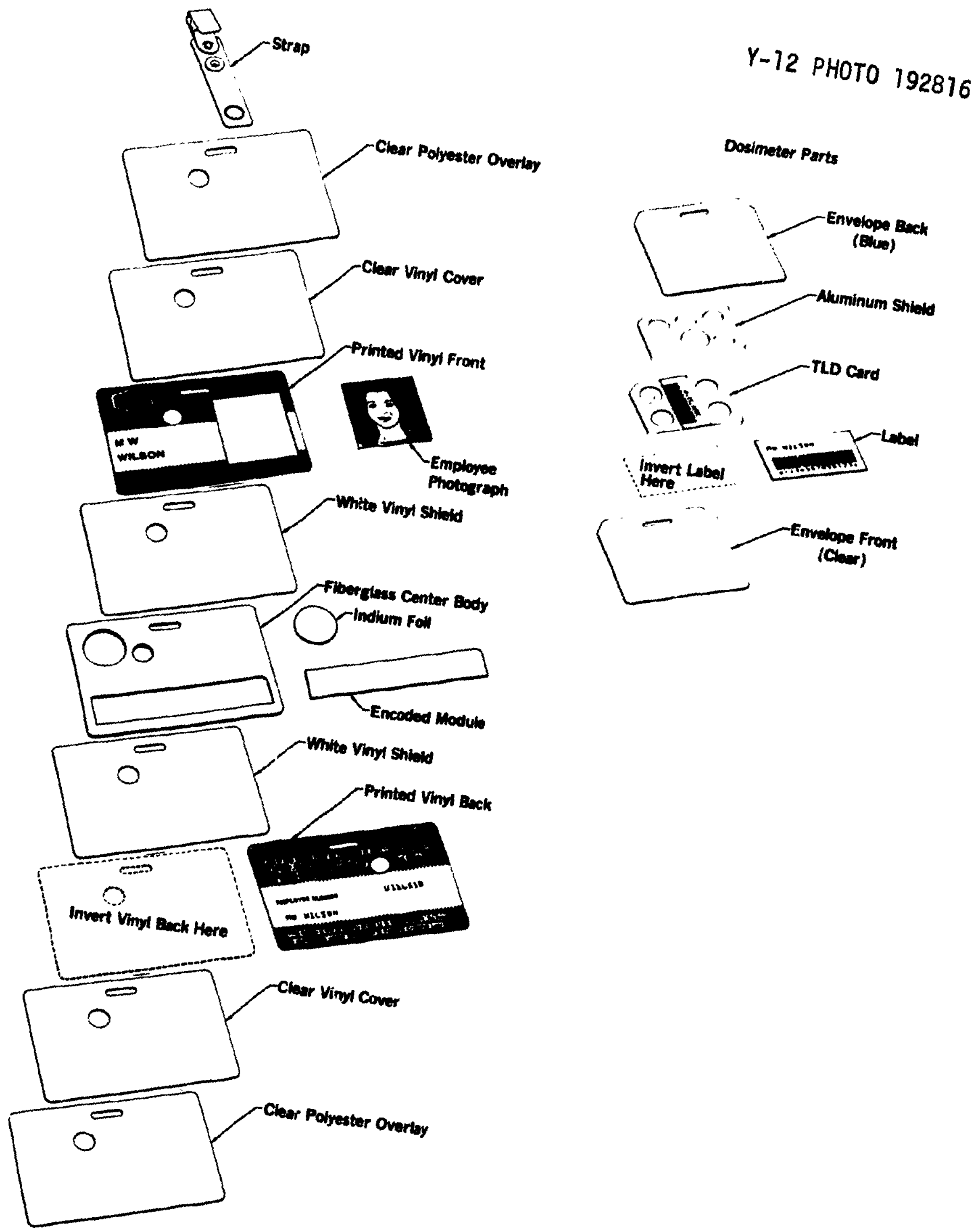

Figure 1: The UCC-ND Employee Identification Badge.

HPRR's availability, simplicity of operation, variety of well known shielded and unshielded spectra, and accuracy of the delivered neutron dose. Details concerning reference neutron dosimetry at the HPRR have been well documented.[6,7]

On November 10, 1981, the test badges containing indium foils mounted on trunk sections of tap-water-filled BOMAB[8] phantoms* at various distances from the reactor were exposed to a pulse of radiation from the HPRR. The pulse occurred at 09:59 a.m., and the pulse width was approximately 10 ms (full width at half maximum). The yield of the pulse was determined by standard HPRR sulfur pellet analysis to be 1.28×10^{15} fissions.

The neutron dose data at the distances of interest from the HPRR were determined from the number of fissions as explained in Reference 6 (see pages 27 and 68) and are presented in Table 1. The neutron dose reported is element 57 dose (i.e., absorbed dose in volume element 57 of the cylindrical Auxier phantom).[6] The neutron-to-gamma dose ratio is reported for completeness. The values of the ratios are available from Reference 5 and in dosimetry logs at the HPRR.

3.0 Measurement of Induced Activity in the Indium Foil

Two ORNL portable survey instruments, a Geiger-Müeller Survey Meter (GMSM) and a Cutie Pie Ionization Detector (CPID), were used to measure the radiation from the induced activity in the indium foils irradiated during the test. These instruments were used in order to test their efficacy in measuring radiation from indium foils under "field" conditions, as they are the instruments that would be used by survey personnel for screening potentially exposed individuals following a criticality accident. The count rate and the dose rate from each badge were measured at various times post-exposure using the GMSM and CPID, as

---

*The BOMAB trunk sections are 40 cm high and have 20 cm by 30 cm elliptical cross sections.

Table 1. Reference Neutron Absorbed Dose† to Test Badges

Badge No.	Badge Distance From HPRR, m	Neutron Absorbed Dose (rad)	Neutron Dose / Gamma Dose
X-133 front* X-234 back	1.00	45.3	7.6
X-233 front X-134 back	1.23	30.7	7.4
X-131 front X-147 front	1.72	16.4	7.0
X-113 front X-128 front	5.36	2.0	5.4
X-118 front X-129 front	9.00	0.8	4.7

*Indicates orientation on BOMAB phantom section relative to HPRR.

†1 rad = 0.01 gray.

they are the instruments that would be used by survey personnel for screening potentially exposed individuals following a criticality accident. The count rate and the dose rate from each badge were measured at various times post-exposure using the GMSM and CPID, respectively. The badge-survey meter placements for the GMSM and CPID, shown in Figure 2 and Figure 3, respectively, were repeated for each measurement. The data obtained from the GMSM (open-window) measurements are presented in Table 2 (background subtracted) and the data from the CPID measurements are presented in Table 3.

4.0 Calculation of Survey Meter Response

In order to check the precision of survey meter readings the half-life associated with the decay of the indium foils was individually determined by a least squares fit to the equation

$$C(t) = C_o e^{-\lambda t} \tag{1}$$

where

C_o = count rate at t=0 (cpm) ,
λ = decay constant (min^{-1}) ,
$C(t)$ = count rate at time t (cpm).

The half-life was calculated from each decay constant using:

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

The mean of the half-life calculations was 54.1 min ± 6% which is in excellent agreement with the published value of 54.2 min.[9] The statistical data are given in Table 4. In order to determine the response function of the GMSM, fits were made to the plot of count rate

ORNL PHOTO 8626-81

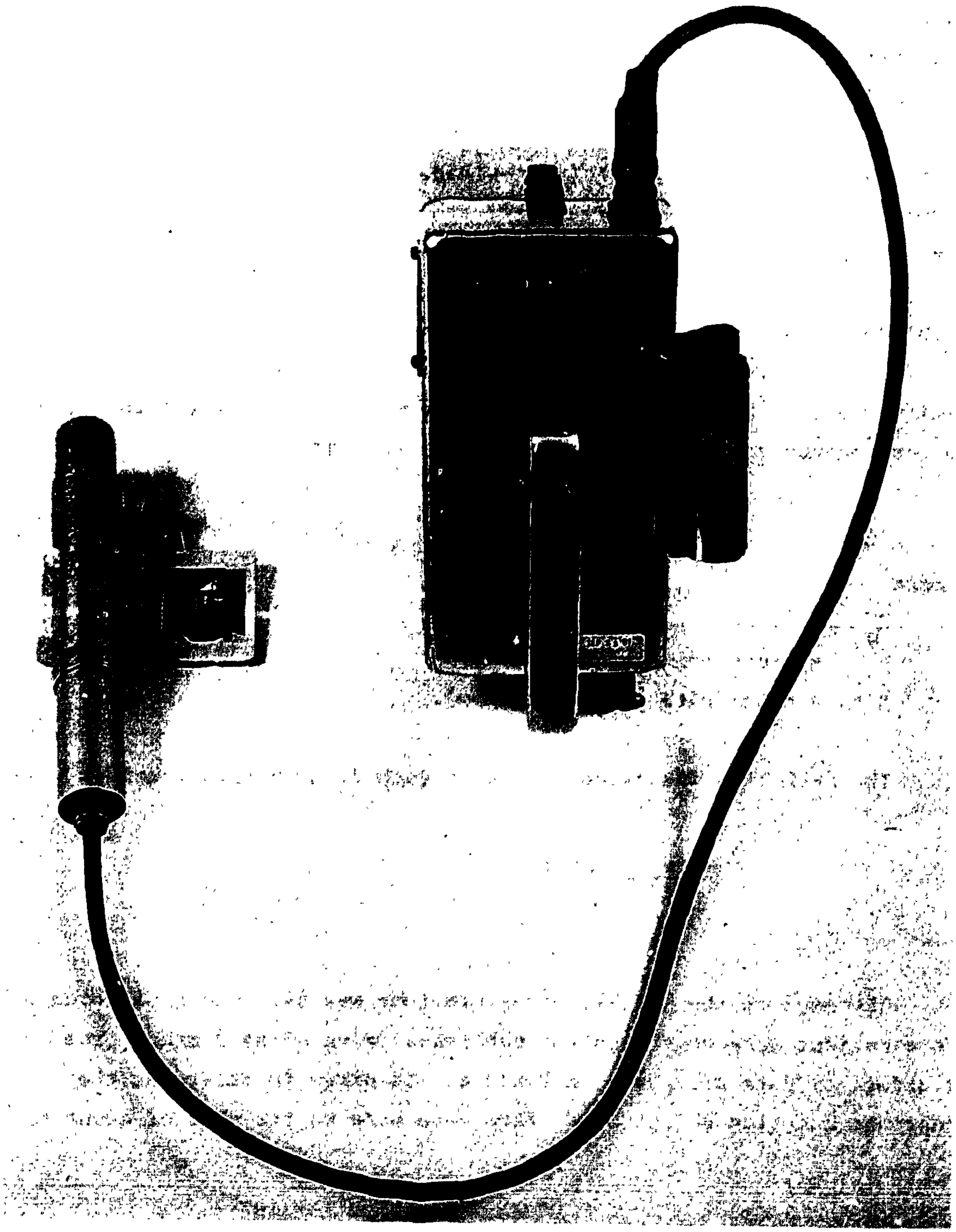

Figure 2: GMSM Placement for Direct Reading of Indium Disc

ORNL PHOTO 8627-81

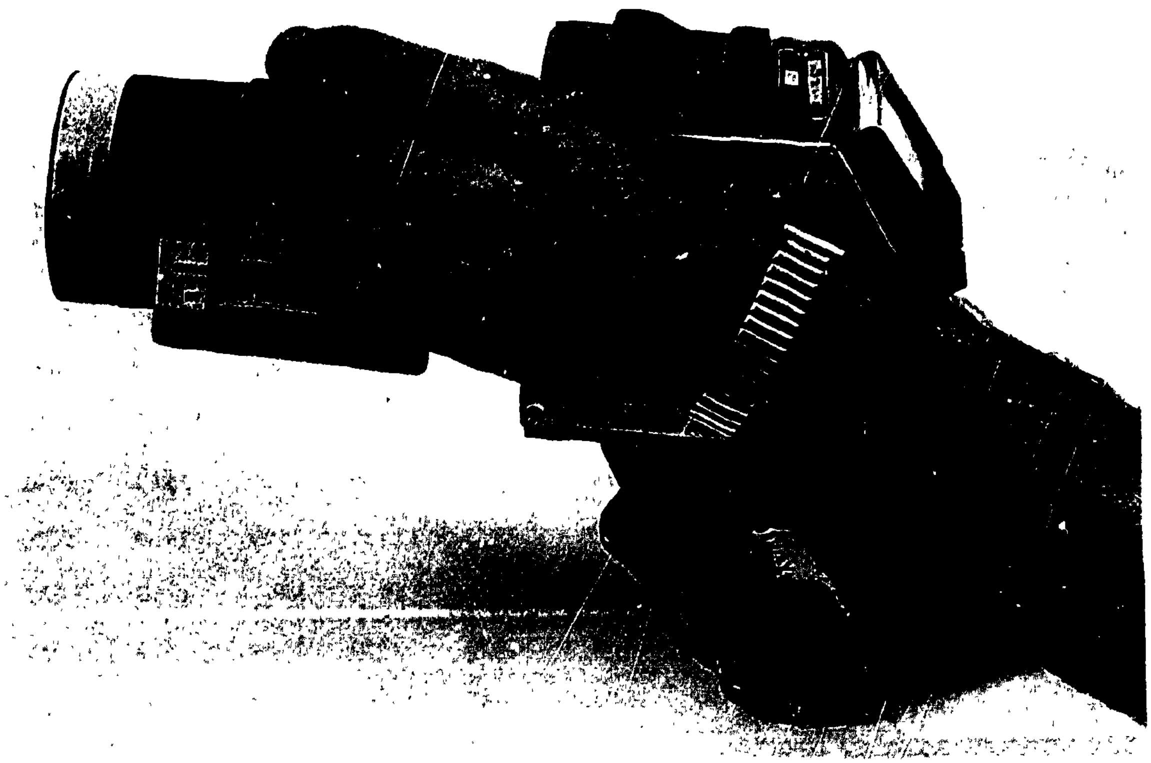

Figure 3: CPID Placement for Direct Reading of Indium Disc

Table 2. Net GMSM Open-Window Measurements of Indium Disc (cpm)

Time Post Exposure (min)	Badge X-133	Badge X-234	Badge X-233	Badge X-134	Badge X-147	Badge X-113	Badge X-128	Badge X-118	Badge X-129
23.5	109950	17950	74950	8950	28950	27950	5950	5950	2250
41.0	84950	12950	59950	6950	23950	23950	4950	4150	1950
52.0	74950	9950	49950	5450	20950	20950	4450	3450	1700
73.0	64750	8950	39950	4450	15950	15950	3050	2450	1350
98.0	44950	6950	24950	3450	11950	11450	2550	2450	1050
121.0	34950	4950	19950	2450	8950	1850	1850	1550	700
166.0	12950	2450	9450	1450	5450	4950	1150	850	550
336.0	1450	350	1050	210	650	550	110	70	50

Note: GMSM background reading = 50 cpm. Calibration factor = 3100 cpm per mR/h, Ra γ.

Table 3: CPID Measurements of Indium Disc (mrad/hr).
(Only these five test badges could be read with the CPID.)

Time Post Exposure (min)	Badge X-133	Badge X-234	Badge X-233	Badge X-131	Badge X-247
27.0	18	6	13	8	8
47.0	13	∿2	9	∿3	∿3
55.0	11	∿2	8	∿3	∿3
78.0	9	∿2	6	∿2	∿2
103.0	4		3	∿2	∿2
131.0	4		3	∿2	
171.0	2		2	∿2	

Note: Background adjusted to 0 mrad/hr with zero adjust before measurements.

vs. dose. The best fit ($R^2 = 0.99$) over the entire dose range was obtained with a power function least squares fit given by

$$C_o = 4231\ D_n^{0.91}$$

where

C_o = GMSM count rate at t=0 and
D_n = neutron absorbed dose (rad) .

This expression best predicts the response of a GMSM over a dose range from 0 to 50 rads (0.5 gray) or approximately 0-150 rem (1.5 Sv).

A linear response function was determined to be the best fit ($R^2 = 1.00$) in the dose range < 10 rad (neutron) and is given by

$$C_o = 150 + 4050\ D_n \qquad (3)$$

where

C_o= GMSM count rate at t=0 and
D_n= neutron absorbed dose in rad .

The higher dose data were not included in this fit because they weighted the fit in the high dose range resulting in a poor fit in the lower dose range which is of main interest.

From inspection of the CPID measurements, it was concluded that meaningful readings could only be obtained in the high dose range. The sensitivity of the CPID is not sufficient for accurate measurements in the low range of interest. These data further indicate that the instrument of choice is the GMSM, readings being taken with the window open.

5.0 Discussion of Results

These results show that the indium foil in the UCC-ND Employee Identification Badge is an adequate screening device for use in separating exposed personnel from non-exposed personnel following a criticality accident. The sensitivity is such that personnel receiving

Table 4. Statistical Data for Indium Decay in Each Test Badge

Badge No.	Distance from Reactor Core (meter)	Neutron Dose (rad)	C_o (cpm)*	$\lambda(min^{-1})$	$T_{1/2}$ (min)	Correlation Coefficient R^2
X-133	1.00	45.3	163,000	0.0141	49.3	0.99
X-234	1.20 (back of phantom)		22,000	0.0124	55.9	1.00
X-233	1.23	30.7	103,000	0.0138	50.4	1.00
X-134	1.43 (back of phantom)		10,800	0.0118	58.5	1.00
X-131	1.72	16.4	39,000	0.0122	56.8	1.00
X-147	1.72	16.4	40,000	0.0127	54.6	1.00
X-113	5.36	2.0	8,500	0.0127	54.4	1.00
X-118	9.00	0.8	4,000	0.0128	54.2	0.99
X-129	9.00	0.8	3,300	0.0123	57.0	0.99

*C_o values have been rounded off.

1 rad = 0.01 gray.

neutron absorbed doses in the tenths of rad (1 mSv) range could easily be identified up to 2-3 hours post exposure.

There are two major limitations to this technique, however. They are: (1) The response of the indium foil was determined for a criticality pulse in free air. The presence of moderating materials would alter the bare fission spectra and, therefore, the indium foil response. (2) The exposure of the test badges was made with badges on the front of phantoms facing the reactor core. At distances of 1.00 m and 1.23 m test badges were also placed on the backs of phantoms. The ratios of GMSM readings were 7.4 at 1.00 m and 9.5 at 1.23 m, respectively. These results demonstrate that the relative orientation of the indium foil to the source of exposure may significantly affect foil responses. Dose estimates may be in error by up to an order of magnitude.[10,11]

Because of these limitations, under real criticality accident conditions, the indium foil in the identification badge must be considered a screening device to separate people exposed at various levels in a criticality accident. Current Department of Energy (DOE) Orders require that doses in excess of 5 rem (0.5 Sv) in any quarter must be reported within 72 hours and doses in excess of 25 rem (0.25 Sv) must be reported as soon as sufficient information is obtained.[12] Assuming that the quality factor for acute exposure to fission spectrum neutrons is 1-3, and that 3000 cpm measured with a typical GMSM ≃ 1 mR/h, it may be claimed that to a first order of approximation an open-window reading of 3000 cpm on a GMSM corresponds to an absorbed dose of 0.7 rad (2.0 rem neutrons)[13] received by the individual wearing the badge. Therefore, for the purpose of establishing screening criteria, a GMSM open-window reading (corrected for decay) of 3000 cpm will be assumed to represent a dose near the first reporting level, i.e., near 5 rem. Likewise, a reading of 30,000 cpm will be assumed to represent a dose near the second reporting level, i.e., 25 rem. In either case these values should not be interpreted as reflecting accurate dosimetric results, but they are to be used as guides in establishing criteria for grouping of personnel exposed as a result of an accidental criticality incident. DOE reporting requirements place emphasis on action at various exposure levels. Those persons exposed to greater than 25 rem (0.25 Sv), for which dosimetric assessment is required as soon as sufficient information is available, are of first importance. Second is the group where exposures are in the range of 5 to 25 rem (0.05 - 0.25 Sv), for which dosimetric assessment is required within 72 hours. Finally, is that group where exposures are less than 5 rem (0.05 Sv), for which routine quarterly reporting requirements are imposed. These screening criteria developed for the indium foil in the UCC-ND employee badge allow priority processing of dosimeters worn by persons exposed to neutrons in criticality accidents.

In order to apply these calibration results, a convenient plot of GMSM open-window count-rate vs. time post-exposure is given in Figure 4. Two action level lines are shown. It is important to first estimate the elapsed time post-exposure of the badge being checked. The open-window GMSM reading must then be evaluated against the action levels for the particular time post-exposure. If the GMSM reading is above Action Level II, that person's dosimeters should be marked for immediate processing and that person should be evaluated according to Emergency Procedure 3 of the IS&AHP Emergency Manual for persons with a foil reading greater than 10 mR/hr. If the GMSM reading is above Action Level I, but below Action Level II, the person's dosimeters should be taken and the person should go to the collection point as outlined in Procedure No. 3 of the IS&AHP Emergency Manual. If the GMSM reading is below Action Level I, no immediate processing of dosimeters is required, but foil readings greater than background should be noted so that the dosimeters of personnel in this group could be appropriately processed.

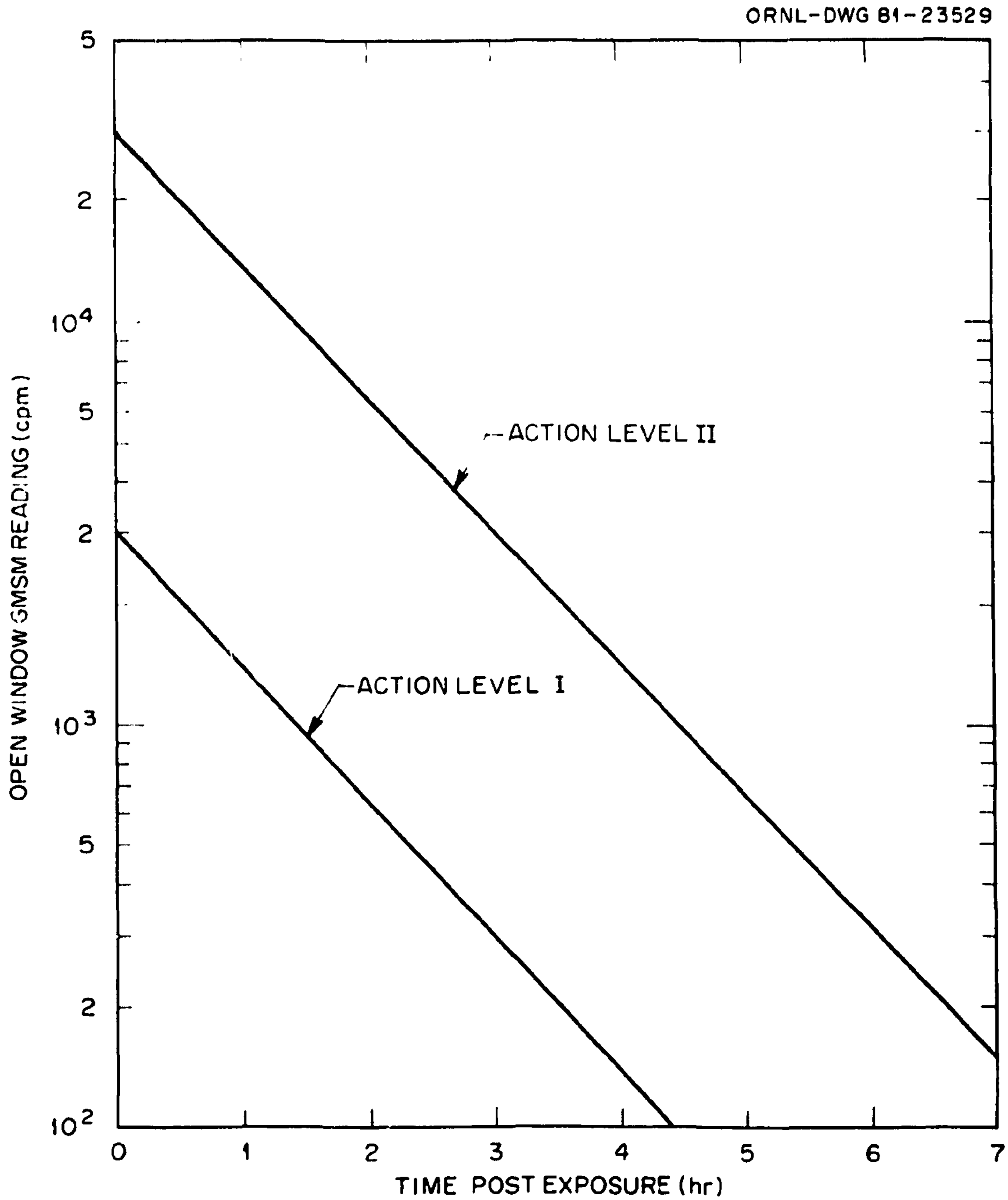

Figure 4: Open Window GMSM Reading vs. Time Post-Exposure

REFERENCES

1. J. D. McLendon, External Radiation Monitoring of Union Carbide Corporation Nuclear Division Personnel, Y/DD-268, March 1980.

2. "Personnel Survey Unit," Procedure No. 2, IS&AHP Emergency Procedure Manual, April 1981.

3. J. A. Auxier, "The Health Physics Research Reactor," Health Phys. 11, 89-93 (1965).

4. C. S. Sims and R. E. Swaja, "Personnel Dosimetry Intercomparison Studies at the Health Physics Research Reactor: A Summary (1974-1980)," Health Phys. 42, 3-18 (1982).

5. C. S. Sims and H. W. Dickson, "Nuclear Accident Dosimetry Intercomparison Studies at the Health Physics Research Reactor: A Summary (1965-1978)," Health Phys. 37, 687-699 (1979).

6. C. S. Sims and G. G. Killough, References Dosimetry for Various Health Physics Research Reactor Spectra, ORNL/TM-7748 (July 1981).

7. C. S. Sims and G. G. Killough, "Neutron Fluence to Dose Conversion Factors for the Health Physics Research Reactor," Radiation Protection 1, No. 2, pp. 133-134 (1981).

8. F. W. Sanders and J. A. Auxier, "Neutron Activation of Sodium in Anthropomorphous Phantoms," Health Phys. 8, 371-379 (1962).

9. D. C. Kocher, Radioactive Decay Data Tables, DOE/TIC-11026 (1981).

10. D. E. Hankins, A Study of Selected Criticality Dosimetry Methods, LA-3910 (1968).

11. Title 10, Code of Federal Regulations, Part 70.24, "Criticality Accident Requirements."

12. Department of Energy Manual Chapter 0545 (1974).

13. American National Standards Institute, ANSI N13.3, "Dosimetry for Criticality Accidents," 1969 (reaffirmed, 1981).