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EVALUATION OF HANFORD BASIC THERMOLUMINESCENCE DOSIMETER

R. L. Kathren

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DUN		
37. CD Corbit	1704H	100H
38. TE Dabrowski	1704H	100H
39. JG Myers	1704H	100H
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PRELIMINARY REPORT

This report contains information of a preliminary nature prepared in the course of work under Atomic Energy Commission Contract AT(45-1)-1830. This information is subject to correction or modification upon the collection and evaluation of additional data.

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON
operated by
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for the
UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

TABLE OF CONTENTS PAGE

EVALUATION OF HANFORD BASIC THERMOLUMINESCENT DOSIMETER

R. L. Kathren

1.0 INTRODUCTION

In January, 1970, the initial shipment of the Hanford Basic Thermoluminescent Dosimeter (Hanford Drawing H-3-29808) was received for testing. This dosimeter was designed for monitoring photon exposure to personnel reasonably expected to receive less than ten percent the quarterly dose limits specified in AECM Chapter 0524.

Since the dosimeter had never been evaluated and was to provide information of potential epidemiological or medico-legal significance, an extensive testing and evaluation program was carried out within the limitations of time and dosimeters allocated for this purpose. This document is a report of the findings, and includes recommendations for future study. It does not, however, make any comparison of this dosimeter with the Hanford Film Badge Dosimeter, nor does it provide recommendations for improving the system.

2.0 DESCRIPTION

The primary dosimeter is a ^7LiF block sealed in a modified phenylene oxide plastic card (Figure 1) approximately the same size and shape as the Hanford security credential. The dosimeter card is designed to be worn in a clear plastic pouch, overlain with the security credential. The plastic card contains two different ^7LiF TL materials; an 8 mm diameter ^7LiF-teflon disc and a ^7LiF block 3.2 mm square and 0.9 mm thick. The ^7LiF block is encased in teflon tape sealed into the plastic card; it serves as the primary dosimeter. Readout is accomplished without removal of the block from the card in a modified Harshaw Model 2000 reader (Figure 2). The reader drawer was altered to accept the card and position the TL block under the photomultiplier tube; a circular heating piston is maintained at a constant 300^{0}C, and, for readout, is raised into contact position with the block. Readout cycle is 20 seconds, after which the heater drops away from the dosimeter. Integral light output is measured, rather than glow peak, and glow curves are not recorded (at present). Annealing other than that provided by the readout is not expected to be required if the dosimeters are held for four weeks before reuse. The teflon disc is sealed into the plastic, and is used only as a backup or secondary dosimeter, since in manually removing the disc from the plastic card prior to readout, the dosimeter card is destroyed. Readout of the disc is accomplished on a modified Con-Rad reader.

Positive identification of each dosimeter card is accomplished by punching a five digit number--in most cases the unique employee identification number--across the upper portion of the badge. The number can be read out directly. A return address for lost dosimeters is embossed into one side of the card. Identification of dosimeter cards by color can be accomplished in the fully assembled package, since the dosimeter card is slightly longer than the security credential, and also shows through the various holes punched in the security credential.

3.0 PRELIMINARY PREPARATION

Approximately 425 dosimeter cards were received from the vendor. Of this number, 360 were reader annealed and the readings recorded. The mean reading as received was 1.087 reader units with a standard deviation of 0.14 units; the range was 0.734 to 1.611. Reader dark current was about 0.3 units, or 30% of the total reading. The constancy of readout and reader performance were, in general, excellent, although a small amount of reader drift ($\leq$ 5%) was noted.

A quick check of the response of the ^{7}LiF block to gamma radiation was made, and a linear relationship obtained. From this data, the equivalent radiation exposure of the reader dark current was estimated at 70 mR.

Dosimeters to be used for evaluating response were set aside for a four week period, as recommended by the development group. Structural and other non-exposure tests were begun immediately.

4.0 READER

A Harshaw Model 2000 Series Thermoluminescence Reader had already been modified for use with the TL dosimeter card. Modifications included an improved and more stable power supply, addition of a semi-automatic reader feature, and mechanical changes to the drawer-heater mechanism, adapting it to the dosimeter card. Additional refinements to the reader were made subsequent to the basic evaluation study, and these further improved the capabilities of the unit, as indicated below.

Few difficulties were encountered with the reader. A small amount of random drift was noted, but this was in all cases <5%. Human factors engineering, particularly with respect to placement and identification of switches, could have been improved, as could the method of inserting the dosimeter card into the reader. Heater alignment and size problems, which resulted in the heater block actually making contact with the dosimeter card, were apparently corrected by modifications made after the testing program; the new heater block is 0.55 cm in diameter and an indicating light and automatic switch are provided to ensure that the drawer is properly closed.

The reader was found to be sensitive to external radiation fields. Levels as low as 0.1 mR/hr could cause a significant response--perhaps on the order of 50 mR equivalent reading. Therefore, the reader should not be used in high background areas, or in areas where large background radiation fluctuations (e.g. 2-3 times normal) occur.

5.0 STRUCTURAL AND WEAR TESTS

The dosimeter card, new pouch, and clip assembly were subjected to various structural and wear tests. Twenty of the dosimeter cards were subjected to flexing (~45^0 bend) 50-60 times. In eleven of these, the covering over the teflon disc partially or wholly separated, and in one, the plastic dosimeter card cracked from the edge to the location of the disc. These cards did not have numbers punched in them. Cards with numbers would break or crack across the numbers, and perhaps over the teflon disc also, when flexed to the same extent only 15-20 times.

However, when the TL dosimeter card, security credential, and pouch are all assembled, the resultant package is highly resistant to flexing; no breaks or untoward effects were noted even after 150 flexings; similarly, twisting or similar activity had no ill effect.

The new snap closure worked well, but was poorly designed from a human factors standpoint. It was difficult to open with the fingers, and was not easily gripped to the clothing. Nearly half of those wearing the badge for a seven week period expressed dissatisfaction with the clip.

6.0 RADIOLOGICAL EVALUATION: ^{7}LiF BLOCKS

6.1 RANGE, LINEARITY AND SENSITIVITY

Four weeks after reader annealing, paired exposures were made to photon sources with E_{Eff} ~0.84 MeV over the range 0.01 to 10^4 R. Readout was accomplished with the Harshaw reader as originally modified, and results are shown in Figure 3.

The flattening or tail off noted at exposure levels below about 100 mR was apparently a statistical phenomenon caused by the variation of background dosimeter readings and the small number of dosimeters used at each exposure level. As noted above, these varied by about ± 30%, corresponding to an exposure of ± 60 mR. Hence, the minimum detectable level was originally thought to be about 60 mR.

Additional studies with exposures of 200 and 90 mR indicated that the ^{7}LiF block was linear in response, at least down to 90 mR, and that the deviations noted were a result of dosimeter background variations. The evaluation was rerun after the reader was refined, and the data are shown in Figure 4. Far less variation was noted in background readings of controls. With the refined reader, variation dropped to < ± 8%, and 20 mR was easily detectable. For a group of 10 dosimeters exposed to 20 mR, the variation in light output from the mean was + 65, - 30%, resulting in a dose interpretation range of 14 to 33 mR. Although data were not taken at 10 mR, the response is probably linear down to that level, but for practical purposes pending completion of the statistical analysis, 20 mR was considered to be the minimum level of detection.

Supralinearity began about 200 R, but was not significant until much higher levels were reached. At 1,000 R, the overresponse from supralinearity was only 10%; at 10,000 R, 100%.

6.2 PRECISION

The rather lengthy required holding time after reader annealing precluded evaluation of the precision of an individual ^{7}LiF block. However, the precision of a group was evaluated by exposing a group of 10 dosimeters simultaneously to photons from ^{226}Ra in equilibrium with daughters. Data were obtained at 90 mR and 5 R with the reader as originally received and are summarized in Table I below. Additional data were obtained at 20 and 100 mR with the final version of the reader; these data are also included in Table I.

TABLE I

Precision of ^{7}LiF Block

Exposure	Number Exposed	Mean Net Reading	Range of Readings	Standard Deviation	Comments
90 mR	10	0.676 (84 mR)	0.538-0.780 (64-96 mR)	0.078 (8 mR)	Read on Reader as Originally Received
5 R	10	41.0 (5.1 R)	38.8-45.1 (4.9-5.5 R)	2.5 (0.3R)	
20 mR	10	0.024 (20 mR)	0.015-0.038 (13-33 mR)	0.0007 (6 mR)	Read on Final Version of Reader
100 mR	10	0.125 (100 mR)	0.090-0.145 (74-120 mR)	0.013 (11 mR)	

The data from Table I clearly show that even with the reader as originally received, and using a previous calibration curve (Figure 3), 90 mR ± 25% should be readily detected at the 95% confidence level. With the final version of the reader, similar precision was obtained at both 20 mR and 100 mR. It should be noted that half of the dosimeters read out on the final version of the reader were read by two different individuals on different days.

6.3 ENERGY AND ANGULAR DEPENDENCE

Photon energy dependence was determined over the range 16 keV to 1.25 MeV, and is shown in Figure 5. Pairs of dosimeters were used at an exposure level of 400 mR. Response was flat to within ± 15% over the range 22-1250 keV_{Eff}. At the low energy end, the response is somewhat lower than that seen with the bare ^{7}LiF block. This is an expected result of attenuation from the material (teflon tape, security credential, pouch) overlying the block.

Angular dependence was studied by paired exposures to 200 mR from ^{60}Co over a 2π (180°) arc, with data being obtained at 15° increments. Preliminary analysis indicated angular dependence ≤ ± 10% based on the average of two exposures.

6.4 EXTRANEOUS RADIATION RESPONSE

The response to beta, neutron, visible light, and ultrasound were also evaluated. Thermal neutron exposures were made with a ^{239}PuBe source in the NBS type Sigma Pile; exposures were to fluences up to 10^7 n/cm^2. No thermal neutron response was detected at these exposure levels. Fast neutron exposures were made to a ^{239}PuBe spectrum (E_{Av} ∿4.5 MeV) at levels ≤ 10^7 n/cm^2; no fast neutron response was detected.

Beta response was checked by exposure to beta spectra from both ^{Nat}U and ^{90}Sr-Y. In both cases, the light output per rad was about half that of a comparable photon dose. In Figure 6, the data are plotted; note that the beta response curve did not tend to flatten out below 100 mrad, supporting the conclusions cited in Section 6.1 above.

Exposure to visible light provoked considerable response. Again, paired TLD's were used, and exposures made to both natural light and fluorescent light. Two groups of TLD's were used: one unexposed, and the other exposed to 300 mR of photons from ^{226}Ra + daughters. Only the dosimeter card was exposed to visible light. The net light output as a result of exposure to visible light is shown in Figure 7; although insufficient data are available, there appears to be a saturation phenomenon above about 10^4 foot-candle-hours. Photon irradiation of the ^{7}LiF prior to the exposure to visible light appeared to have little effect on response.

The data suggest that light would have only a slight effect on the ^{7}LiF. This effect would be further mitigated by shielding from the security credential in the fully assembled package. However, the potential adverse effect of light should be noted, and further study is indicated.

Several dosimeter cards were held near operating ultrasonic degreaser and medical ultrasonic units for up to two hours. No response was noted.

6.5 ENVIRONMENTAL EFFECTS

Several environmental effects were studied as independent variables, including temperature, humidity, organic solvents, and physical damage to the ^{7}LiF block. For the temperature tests, paired dosimeters were placed in the environmental chamber at a fairly constant relative humidity (∿35%) and allowed to equilibrate by holding for at least one hour prior to exposure with ∿800 mR from ^{60}Co. The data indicated ≤ 10% temperature dependence over the range -32 to 49°C (0-120°F).

A similar study was made with paired dosimeters held at 25 ± 2°C and relative humidities of 10, 30, 50, 65, 80 and 95%. The dosimeters were allowed to equilibrate for 18 hours prior to exposure to ∿800 mR from ^{60}Co. No humidity dependence was noted.

Soaking dosimeter cards in acetone, ethanol, 1,1,1-trichloroethylene, or methylethyl ketone for a few seconds had no effect on the readout of previously exposed dosimeters. Immersion in water for up to one hour also had no effect. Exposed dosimeters run through the plant laundry, when read out, had about two-thirds the light output of similarly exposed controls. The same reduction in light output per unit exposure was noted when the ^{7}LiF block was physically crushed by a hammer blow.

6.6 FADING

A series of exposed dosimeter cards were held up for 35 days (see 5.8, infra) with no fading (reduction of light output). A second series of paired dosimeters was held at 46 ± 3°C (115 ± 5°F) for up to 5 days and compared with controls held at 22 ± 3° (72 ± 5°F); no fading was observed.

6.7 ANNEALING

Since the modified phenylene oxide plastic used for the dosimeter card will deform in a few minutes at 100°C, the use of the manufacturer's recommended annealing procedure for the ^{7}LiF blocks is precluded unless these are removed from the card. Removal, of course, would destroy the dosimeter card, and make the use of this system economically prohibitive. Hence, the dosimeter was designed to be used with no other annealing procedure than that provided by readout. Before the dosimeters are reused, a four week holding period should follow the readout.

Although limitations of time and numbers of available dosimeters prevented a full study of the reader annealing, sufficient data were obtained to demonstrate the validity of this procedure, with one extremely important reservation: the prior exposure history must be less than 10R or, preferably 1 to 2 R. Dosimeters exposed to greater than a few R are not totally annealed by the readout procedure, and retain a varying amount of stored energy which will appear on subsequent readout. Sensitivity (i.e. light output per unit exposure) changes may also occur. It is not known at this time whether the effect is dependent only on the immediately preceding exposure, or the total prior exposure history of the ^{7}LiF block. In any event, the more conservative approach is suggested pending additional study.

The four week holding time after reader annealing does not seem to be a rigid requirement. Preliminary data are available that indicate that a two or three week period may be adequate to return the dosimeters to their previous level of sensitivity.

To avoid the holding period entirely annealing for 24 hours at 80°C followed by a 72 hour hold was suggested. This procedure was found to be unsatisfactory; sensitivity was considerably reduced, and precision, even for exposures of several hundred mR, was poor. In many instances, no meaningful data could be obtained.

6.8 INTERRELATIONSHIP OF VARIABLES

The interdependence of six variables--temperature, humidity, angle of incidence, days to readout and the two annealing procedures--was evaluated by exposing two replicates in a 2^5 factorial experiment. Other than the problems with the 80°C - 24 hour anneal noted in Section 6.7 above, no interrelationships among variables were found.

7.0 ^{7}LiF - TEFLON DISCS

These were included in the dosimeter card (Figure 1), which was designed with a depression to fit the 8 mm diameter disc. The disc was covered with a small amount of plastic solvent sealed to the main piece of of the dosimeter card.

The ^{7}LiF - teflon disc was included for back-up capability, and would be read only in special situations. Removal of the disc was found to be very difficult, for the method of sealing caused some of the plastic from the dosimeter card to adhere. An inordinate amount of time and care was required to remove and clean the disc. Even so, in many cases, removal could not be accomplished without physically damaging the disc. This factor, plus the data obtained in earlier studies with ^{7}LiF - teflon and the 8 mm diameter discs led to the decision to not evaluate the discs.

A background check was made as well as a dose-response curve, using the modified Con-Rad reader. Background was reasonably constant at about 100 ± 20 reader units. A response curve to high energy photons (∿1 MeV) is shown in Figure 8. Supralinearity was not noted below 100 R.

8.0 FIELD TEST

One hundred twenty-four fully assembled dosimeters were issued to Hanford contractor personnel selected by a semi-random procedure; these were worn for about one month. The dosimeters were issued to the field in the newly designed pouch--not the one shown in Figure 1. This short test was expected to provide information on wear, unusual response, acceptance by personnel, and other contingencies.

Personnel who participated in the test were requested to fill out brief questionnaires anonymously, 89 returns were received, and the results are summarized below. Details are given in Appendix A.

In general, acceptance was overwhelmingly favorable. Personnel found the badge comfortable to wear (87), more so than the film badge dosimeter (71). Few noted any tearing or physical damage. However, about 43% of the respondents noted problems with the clip. Of the 48 who offered comments, 13 liked all features of the TLD badge better than the film badge dosimeter, 1 preferred the film badge dosimeter, and 34 criticized the clip. The clip arrangement has since been modified, and in addition, the existing Hanford pouch was made available for use with the dosimeter.

No excessive wear or structural defects were noted. Two badges were lost, but this problem should be resolved by the changes in the clip. One badge, worn by a welder, had some material spattered onto the pouch but otherwise was in excellent condition.

Upon readout, 12 badges (approximately 10%) showed exposures ≥ 100 mR; each of these was investigated and in all cases except perhaps one, the exposure was considered reasonable in view of the work assignment of the wearer. The one questionable badge was worn by a welder, and may have responded to the intense light associated with welding operations. Some individuals in the reactor areas also wore pocket ionization chambers and/or ^{7}LiF blocks issued and interpreted independently by Douglas-United Nuclear health physics personnel. These data are tabulated in Table II for dosimeters with exposure indications of ≥ 50 mR.

TABLE II

Comparison of Dosimeter Results

Identification	Interpretation, mR Basic TLD	Interpretation, mR DUN TLD	Pocket Chamber
J 0065	360	345	430
J 0072	120	116	115
J 0077	360	350	450
J 0079	50	18	65
J 0080	50	28	80
J 0081	90	65	0
J 0087	400	380	0

The data in Table II show excellent agreement between the TLD dosimeters, with less consistent response from the pocket chambers.

9.0 DISCUSSION AND CONCLUSIONS

The results presented above indicate the basic dosimeter system is an excellent personnel dosimeter for ionizing photon radiation. Most problems that have been encountered were minor, and were cleared up by subsequent mechanical changes. However, the construction of the dosimeter card may preclude use of the "backup" dosimeter. A thorough statistical evaluation of available data is now in progress, and results should provide more precise and conclusive indications of the capabilities of the basic dosimeter.

Additional study is recommended along the following lines:

1) A fading study--i.e. light output per unit exposure as a function of time after irradiation--over a period of at least a year.
2) Sensitivity as a function of time after reader annealing, with an eye towards delineating more fully the effects of reader annealing.
3) Reproducibility (precision) of individual dosimeters at various exposure levels.
4) The effect of prior dose history on sensitivity and accuracy.

10. ACKNOWLEDGEMENTS

The basic TL dosimeter was designed by members of the Radiological Physics Section, Battelle-Northwest. Thanks are due all Hanford contractor health physics personnel who participated in the wear test. Special thanks are due T. Dabrowski, Douglas-United Nuclear, who ran the independent field study, J. P. Corley and T. A. Beetle, Battelle-Northwest, and especially to Gary L. Webb, Battelle-Northwest, for technical assistance with readout, interpretation, and other phases of the evaluation program.

APPENDIX

RESULTS OF FIELD WEAR TEST QUESTIONNAIRE

1. Was the badge comfortable to wear? More so than the film badge?

   Yes 87 No 2 Yes 71 No 18

2. Did you have any problems with the clip?

   Yes 39 No 50

3. Did you notice any coloring or tearing of the envelope, or did it become excessively dirty? Yes 5 No 84

4. Did the badge appear to have good balance?

   Yes 82 No 7

5. Did you notice any breaking or tearing of the insert card?

   Yes 2 No 87

6. Do you recall subjecting the badge to any unusual stress, such as unusual pressure or shock? Yes 5 No 84

7. Any other comments you may have.

   41 - No comment.

   13 - Liked all features better than film badge.

   1 - Preferred film badge.

   34 - Adverse comments re clip.

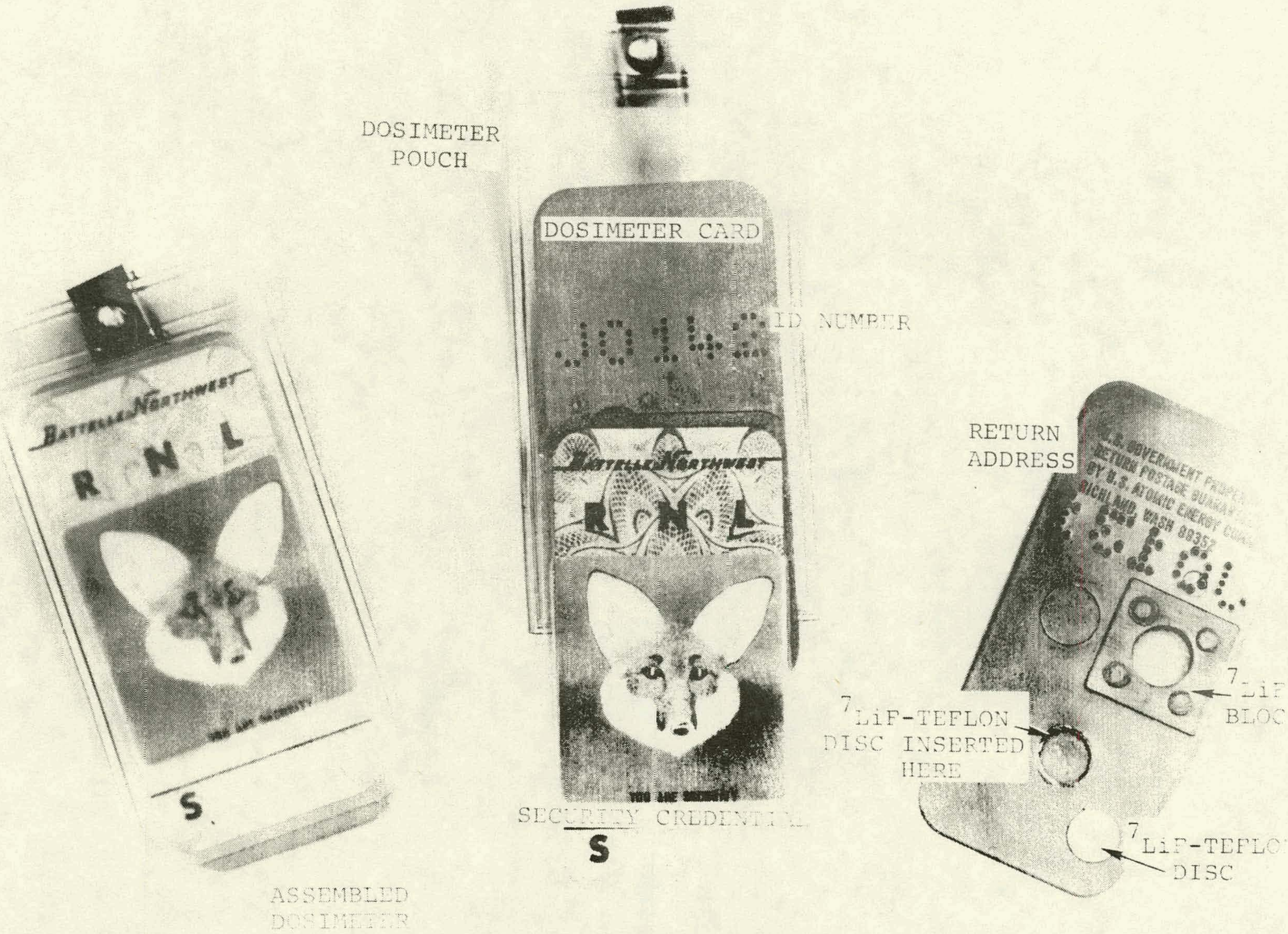
DOSIMETER POUCH
DOSIMETER CARD
ID NUMBER
RETURN ADDRESS
BATTELLE NORTHWEST
R N L
S
SECURITY CREDENTIAL
ASSEMBLED DOSIMETER
7LiF-TEFLON DISC INSERTED HERE
7LiF-TEFLON DISC

FIGURE 1

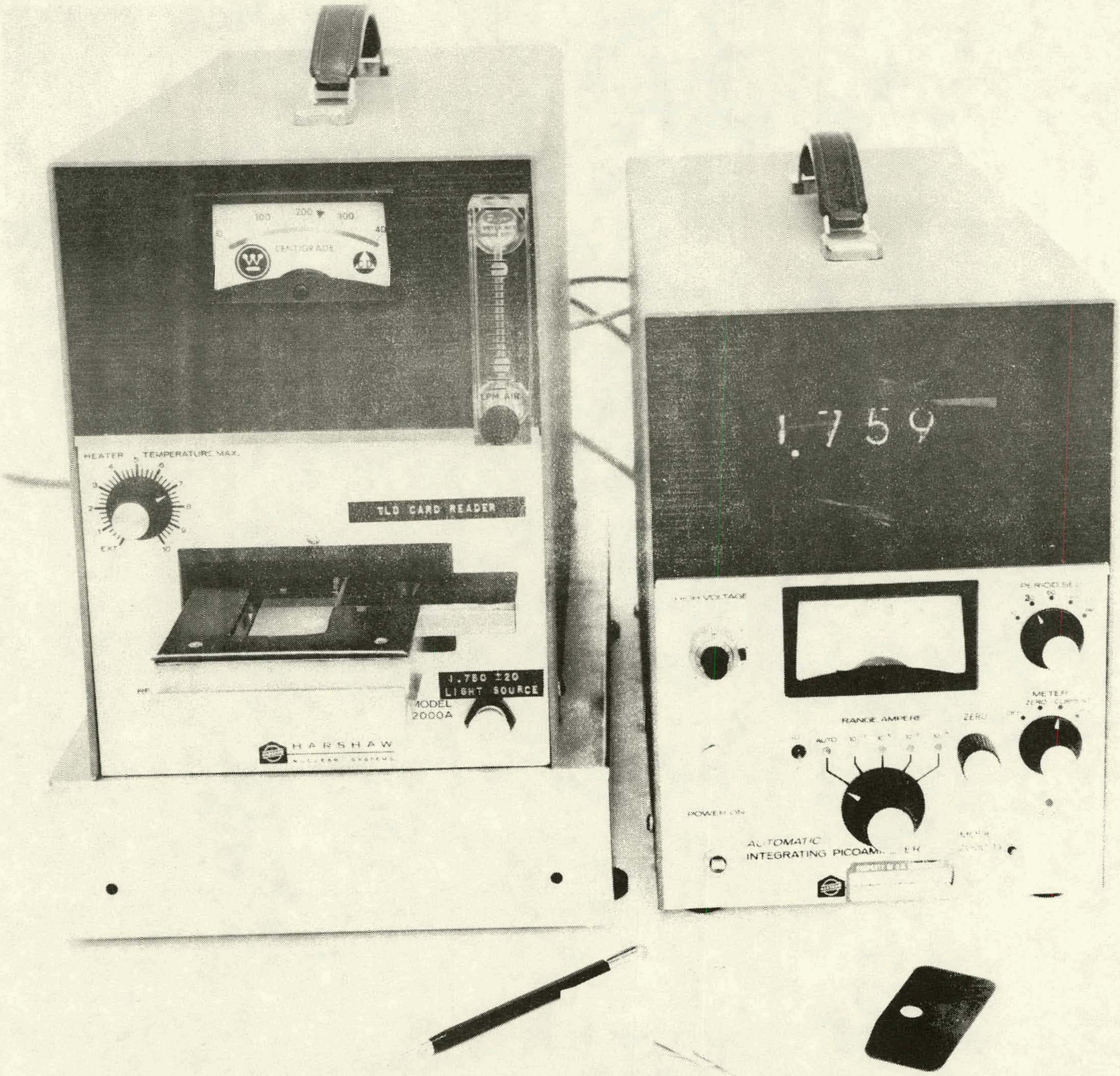
HEATER
TEMPERATURE MAX.
CENTIGRADE
LPM AIR
TLD CARD READER
1.750 ±20
LIGHT SOURCE
MODEL
2000A
HARSHAW
1.759
RANGE AMPERE
ZERO
METER
POWER ON

FIGURE 2

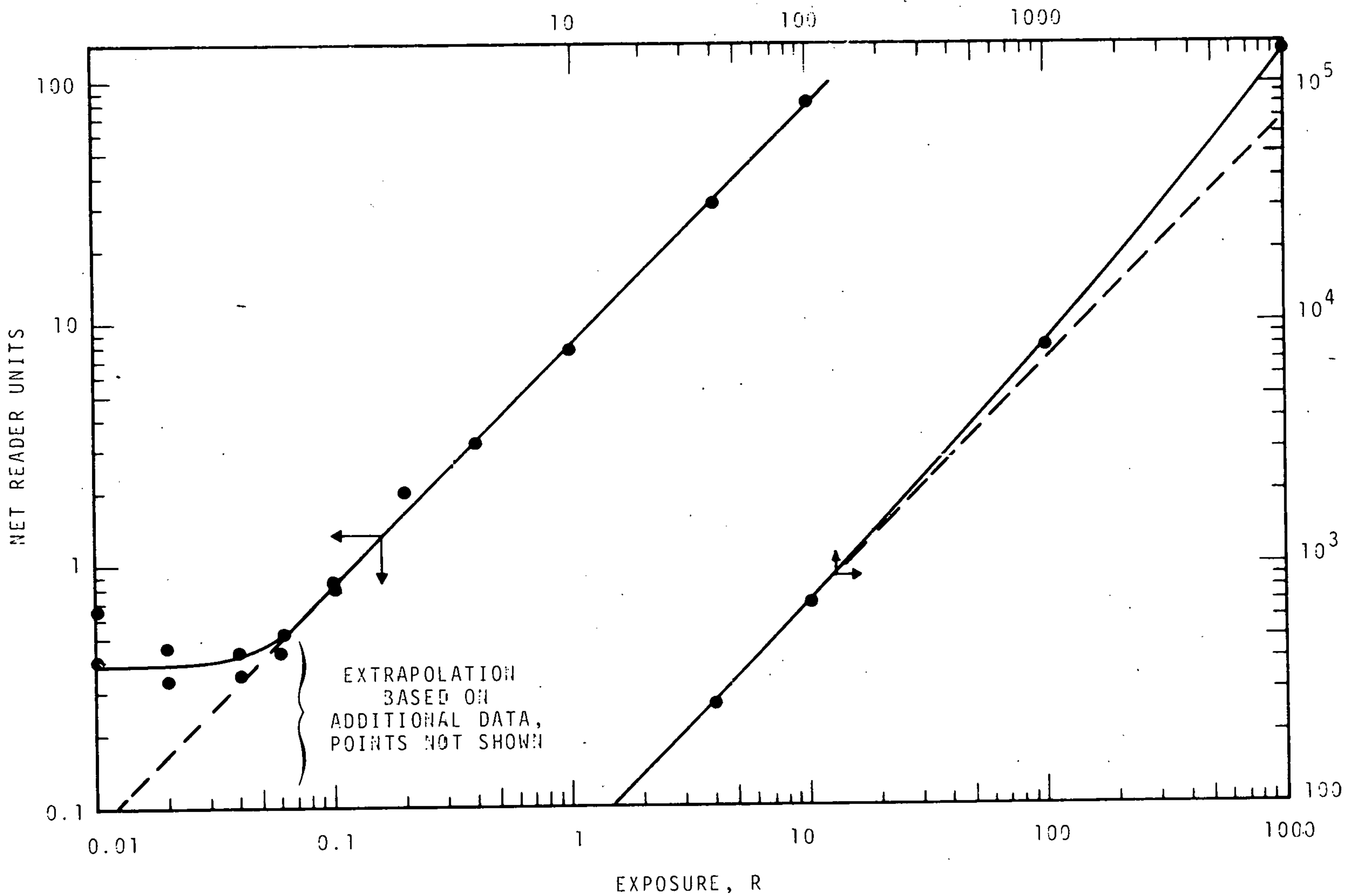

FIGURE 3. RESPONSE TO PHOTONS FROM ^{226}Ra + DAUGHTERS WITH READER AS ORIGINALLY MODIFIED

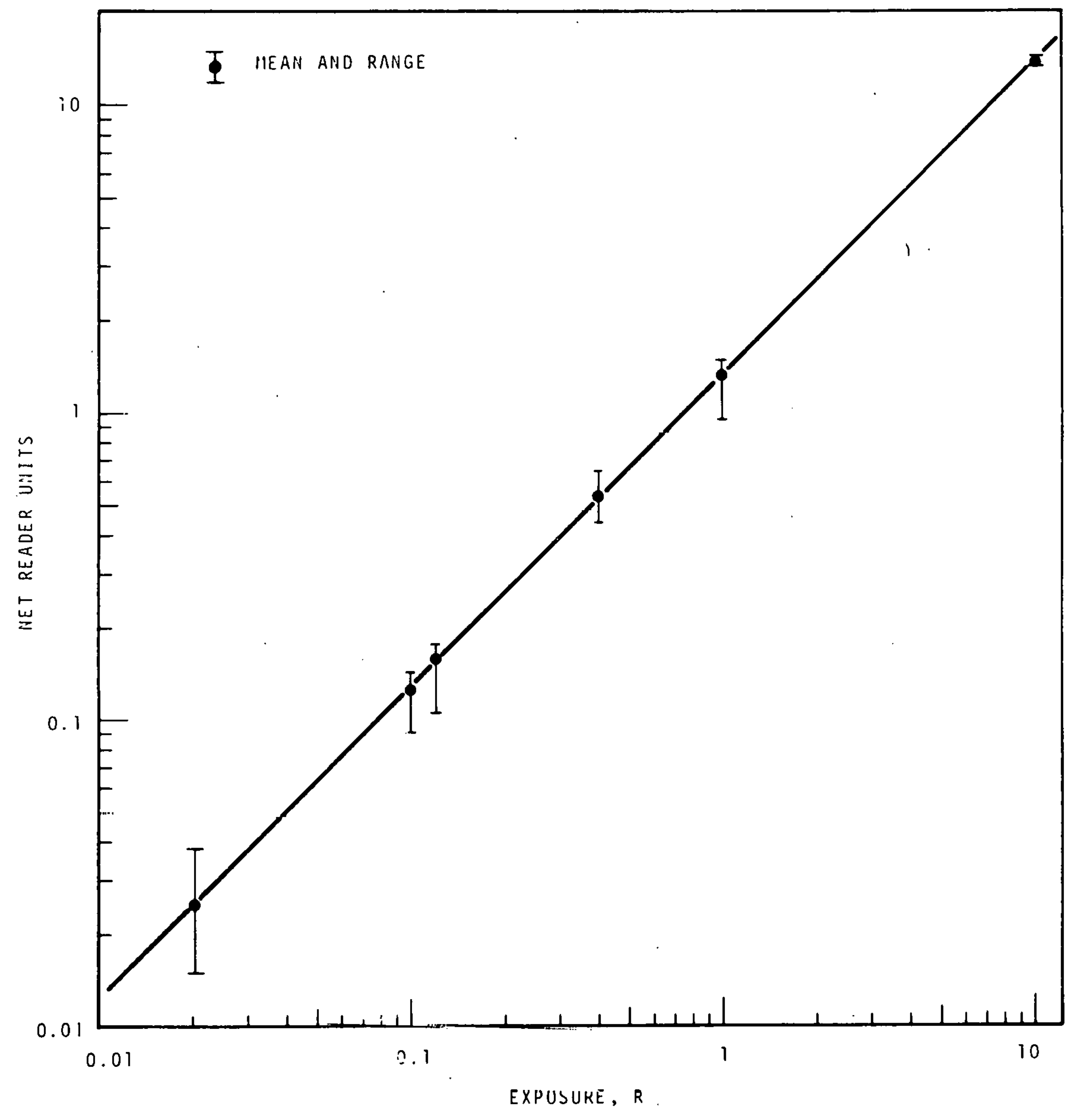

FIGURE 4. RESPONSE TO PHOTONS FROM ^{226}Ra + DAUGHTERS WITH FINAL VERSION OF READER

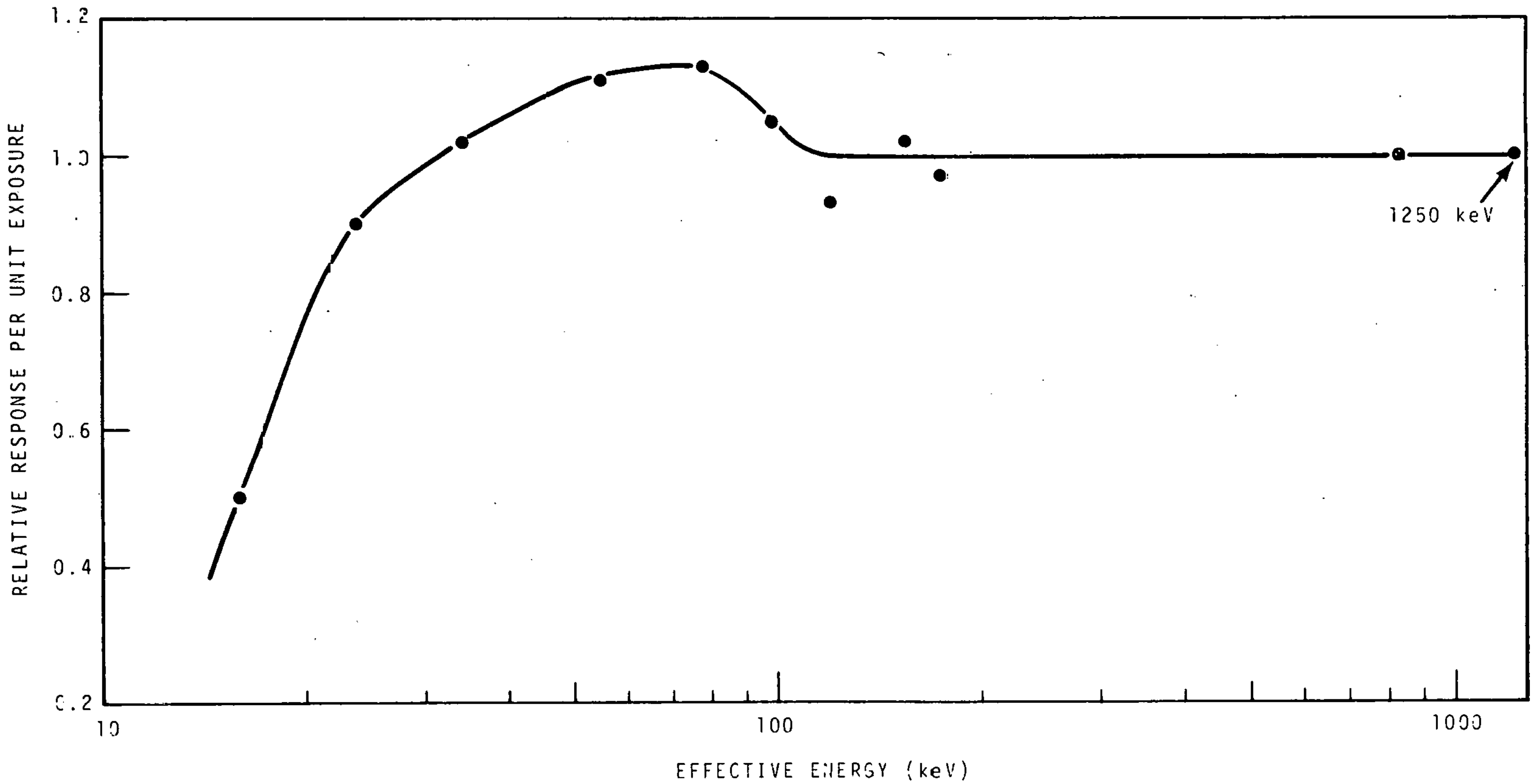

FIGURE 5. PHOTON ENERGY DEPENDENCE OF ^{7}LiF BLOCK IN ASSEMBLED BADGE

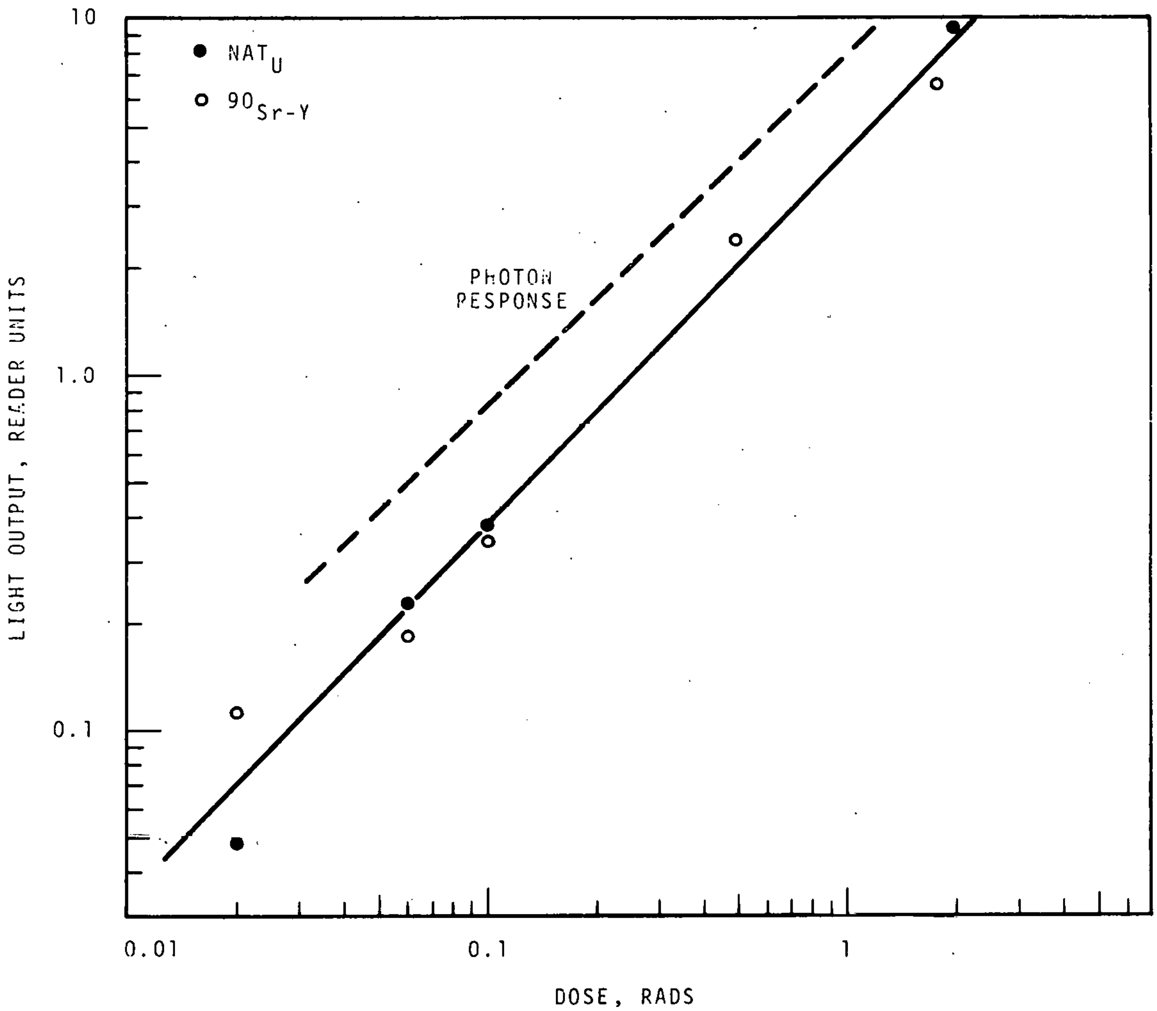

FIGURE 6. BETA RESPONSE ON ^{7}LiF IN FULLY ASSEMBLED BADGE (AVERAGE OF TWO POINTS)

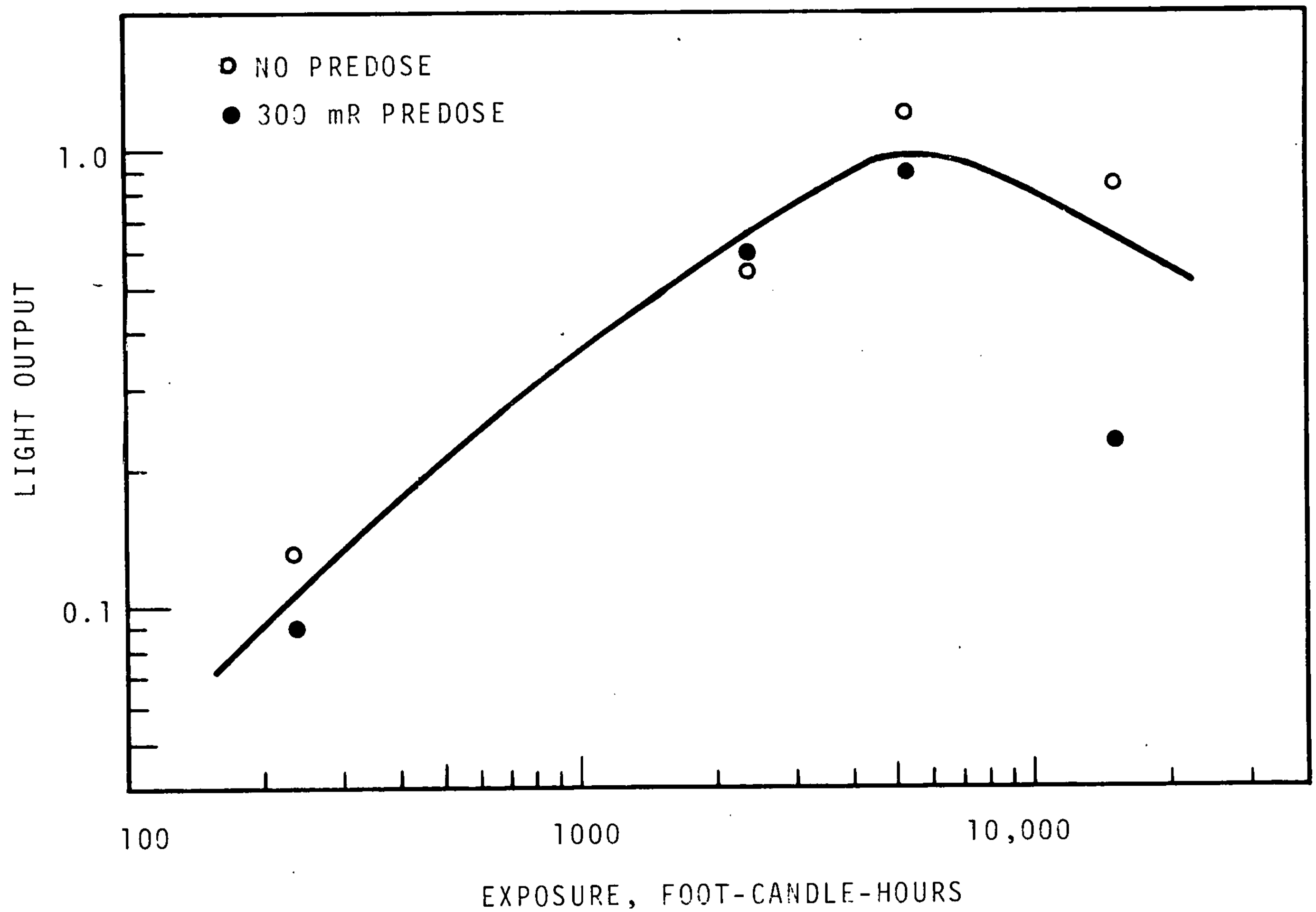

FIGURE 7. RESPONSE OF ^{7}LiF TO VISIBLE LIGHT

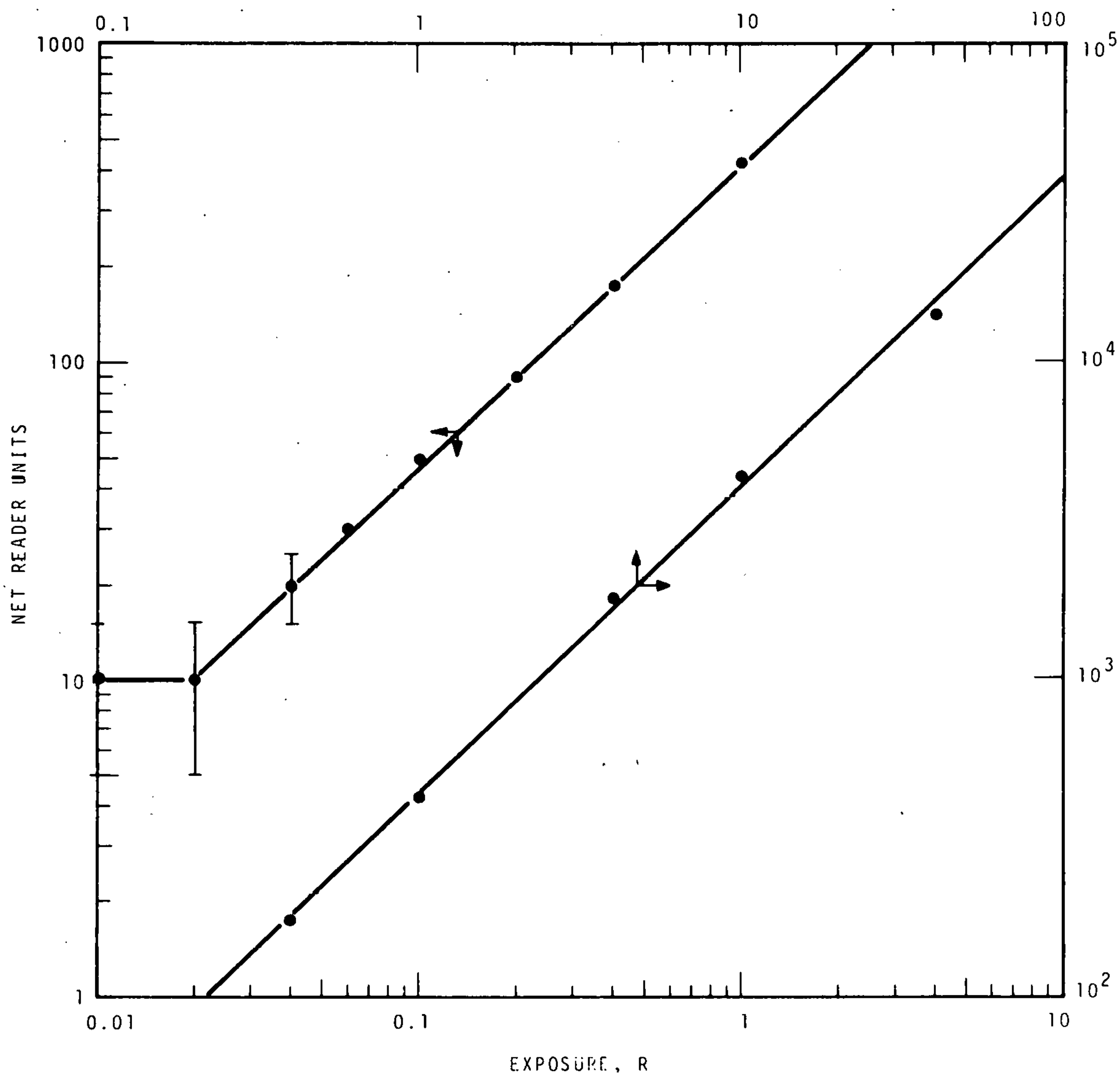

FIGURE 8. RESPONSE OF 8 mm DIAMETER ^{7}LiF-TEFLON DISCS TO PHOTONS. BRACKETS REFER TO RANGE