NUCLEAR METALS INC.

March 1, 1982

To: Mr. John D. Kinneman
U. S. Nuclear Regulatory Commission
Region I

From: David J. Allard and Frank J. Vumbaco

Subject: Report on 1981 Last Quarter Skin Dose to an NMI Employee

This report is being submitted as per our February 16, 1982 telephone conversation/letter and 10 CFR 20.405. It is a summary of an initial investigation into a Vendor reported skin dose of 8,100 mREM to one of our Melting and Casting Technicians. Even though the investigation to date has been extensive, it will be ongoing into the future. As additional information is obtained, it will be forwarded accordingly.

Appendix I contains a breakdown of doses assigned by R. S. Landauer, Jr. and Company (Vendor), to the individual's film badges throughout the quarter. It should be noted that the badges were assigned to the individual for a two-week period, therefore, latent image fading is no doubt quite negligible. In addition, two reports have notes indicating that respective film badges were contaminated. Our Vendor determines this through direct contamination measurements of the film envelope and manual observations of density patterns/distributions on the processed film (1). If the values reported for the two contaminated badges are omitted, and the remaining values assumed to be valid and averaged over the quarter, one obtains 7,425 mREM for a quarterly skin dose. Reviewing official time sheets and records of specific tasks performed by the subject individual, this latter statement seems quite reasonable. He (individual) had done nothing different during the periods when contaminated badges were reported, than the rest of the quarter.

This problem of contaminated film badges is no doubt a factor that is leading to an overestimate of all Melting/Casting Technician exposures. During the late summer of 1981 our dosimetry reports indicated a number of contaminated film badges for this group of employees. In an effort to rectify this situation, the solution was to begin placing film badges in small plastic bags. The employees attach them daily to their uniform shirt pockets with safety pins positioned at the <u>top</u> of the bag. This managed to eliminate most of the contamination problem. However, some bags still get torn and film badges get contaminated (as seen in the Appendix I data). The last

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quarter 1981 film badges of the subject individual were all in plastic bags. A recent survey of plastic bags from the Melting and Casting area indicates one of several problems with the "solution". Figure 1 shows a histogram of levels of contamination on a group of bags after two weeks of use. This is the first problem. To get a handle on the magnitude, six unused film badges were placed in used plastic bags for one week. The bags were selected from the distribution shown in Figure 1. Reports on these films indicate that the bags themselves will cause readings ranging from "minimal" to 480 mREM (beta-gamma) in a one week period. With Melting and Casting operations at present, direct lifting of contaminated graphite crucibles cannot be avoided. Therefore, contamination of protective plastic bags cannot be avoided without operational changes.

The second problem these plastic bags pose is that of the position of film badges when Melting and Casting Technicians are being exposed. As stated in Item 9 of our September 1, 1974 License Renewal under Casting Operations: "localized radiation levels approximating 1 REM/hr (principally beta-rays) may occur within the area in such locations as inside the furnaces, inside vented enclosures, or adjacent to castings or charge stock". This situation has always been known to the employees and our Health Physics Department. Unfortunately, the employee's posture when working on the above stated items, and respective position of his film badge, was not correlated when the use of bags began. Prior to informing the subject individual of his potential overexposure, the writers wanted to observe his work habits without bias. It was noted that whenever the subject individual (or other technicians) worked on any of the above items, they were bending over them. Furthermore, the plastic bags pinned at the top and to their shirt pockets caused the film badge to fall four to six inches away from the trunk of the body and closer to the radiating source. Past practice of clipping the badge to the pocket did not cause such large distance discrepancy, with respect to the dosimeter and the individual(s). The accuracy problem this situation has caused can be inferred from Figure 2. The graphite crucibles depicted are the most significant source of exposure in the Melting and Casting area. This is due to a quantity of uranium-decay products physically separating in the melt and being left in the crucible after the molten metal is poured from the bottom. When Melting and Casting Technicians work on the crucibles (i.e. vacuuming, precoating interior surfaces, loading a metal charge for alloying) they are bending over and reaching into the crucible. It is clear that badge distance discrepancies can cause large errors in dose measurements. Most importantly, it can be seen from Figure 2 that only a small fraction of the skin is being irradiated to the maximum, as indicated by a dosimeter. We estimate that one-seventh (1/7) of the subject individual's skin is receiving maximum exposure.

The above stated situation of film badge positioning has caused, what we feel has been a large unexpected increase in Vendor reported doses to Melting and Casting Technicians. The problem was compounded by

past reporting procedures of the Vendor. It can be seen in Appendix I that actual reports on dosimetry were received on an untimely basis. High values for an exposure period would be called in to Health Physics, but cumulative quarterly totals would not be. Not expecting to have any Melting and Casting Technicians exceed a quarterly skin dose limit, based on past experience, cumulative totals were not done during the last quarter of 1981.

The previous discussion has been focused on events leading to the subject individual receiving a reported 8,100 mREM skin dose for the last quarter of 1981. The remaining body of the report will be a summary of our experiments/evaluation of film badge response to mixed beta/low energy gamma and x-ray fields, appropriate modification of reported doses, a summary of discussions with the subject individual, and corrective actions to date and planned for the future.

After we received the dosimetry report of January 18, 1982 showing a potential overexposure, efforts were undertaken to verify the Vendor's dosimetry. Dr. George Chabot was hired at that time as a consultant to NMI. Discussions with Dr. Chabot led us to setting up a crucible horizontally in a fume hood, and measuring a beta dose rate (at 10.75 inches) with his NBS traceable extrapolation chamber/electrometer. A series of test film badges were then irradiated singularly at that point (with and without backscatter) through a range of values exceeding the highest two-week reported dose to the subject individual. A series of film badges from the same batch were similarly irradiated (through 7 mg/cm^2) with a depleted uranium (DU) metal slab recently calibrated by Dr. Jack Pruitt at NBS. Figure 3 illustrates the results after our Vendor "blindly" processed these films. The crucible irradiations are more appropriate with respect to environmental conditions and standardized conditions (2,3,4,5). The DU slab irradiations were done to monitor any unaccounted film processing changes on the part of our Vendor from batch to batch. That is, any change in the least-squares line of slab irradiations would cause a similar change in the line for the crucible irradiations. The latter is assumed to be a true beta surface dose delivered/observed Vendor reading relation. To see how our Vendor has performed lately, we overlaid tracing paper on Figure 3 and plotted data from a series of slab irradiations performed on January 14, 1982. The trace (Figure 4) was adjusted to line up with the slab irradiation data of February 3, 1982, and an "expectation" absolute relation line was drawn in. As can be seen from Figures 3 and 4 the Vendor beta dose readings have overstated and understated the true surface dose by about the same magnitude in these two cases. For these reasons we believe our Vendor's calibrations provides a quite accurate indication of beta <u>skin surface</u> dose under controlled conditions.

Additional experiments we've performed since January involved irradiation of many of our Vendor's film badges behind pieces of NMI uniform shirts and pants, plastic used to "bag" film badges in the Melting and Casting area, and plastic and glass safety glasses used by

employees. The relative percent change in reported beta doses of the above, and unattenuated badges, is tabulated in Appendix II. These irradiations were done on the DU slab with 7 mg/cm^2 of tissue eqivalent covering. Similar measurements were made with an ionization chamber and a crucible through a uniform shirt and pants. These results are also tabulated in Appendix II and no doubt are more representative of actual conditions. The DU slab appears to have a "harder" beta spectrum.

At this point a brief discourse regarding the subject individual's, Vendor reported, gamma (photon) dose is in order. The source material processed here at NMI is strictly purified depleted uranium, devoid of high enery gamma emitters (i.e. Radium-226 decay products). An examination of the decay products in equilibrium shows little yield of photons above 90 KeV on a weighted specific activity basis (6). Further, most Bremsstrahlung from betas emitted by decay products would be expected to be in the same energy range. A recent investigation by one of the writers, performed over a one year period, indicates that the Vendor's GARDRAY film badge over-responds to photons in this energy region (7). This is no doubt due to the high photoelectric cross-section of silver halide, despite the use of flattening filters in the badge. An appropriate correction to the subject individual's "gamma" dose would involve a straight line function with "m" equal to 1.17 and "b" equal to 33.5 mREM. This problem relating to our Vendor's mixed field accuracy has not yet been directly addressed, with respect to photons. However, the NRC may have an indication of their (Vendor) performance in the University of Michigan Study (2). In addition to the over-response of these film badges to just low energy photons, there are some theoretical problems with mixed field dosimetry using their film badges. In conversations with our Vendor it has been stated that the GARDRAY badge has 375 mg/cm^2 total, of plastic and aluminum, over the region of film where the photon film density measurements are made (8). Examining a beta range (mg/cm^2) versus energy curve indicates that 1100 mg/cm^2 would be required to stop the most energetic betas from Protactinium-234m (6). Betas degraded in energy may cause an additional film darkening behind the 375 mg/cm^2 region that is not proportional on a RAD to RAD basis (9). If this is happening, our Vendor may be further overestimating photon doses. We have not investigated this problem to date.

Considering all of our data we feel some practical modifications of our Vendor's reported cumulative quarterly dose to the subject individual are reasonable and justified. One adjustment will be an increase and the remainder decreases. They are as follows:

For the 900 mREM gamma dose, a decrease by the straight line function in Reference 7;

If, $y = 900$ mREM, $b = 33.5$ mREM, and $m = 1.17$
and, $y = mx + b$
then, $900 = (1.17)x + 33.5$
$x = 741$ mREM (adjusted photon dose)

For the 7,200 mREM beta dose an increase of 0.8% for the unaccounted attenuation of the "anti-contamination" plastic bags, and a decrease of 10% for attenuation of the individual's shirt (badges worn on outside).

Adjusted Beta Dose = 7,200 + 57.6 - 720
Adjusted Beta Dose = 6,538 mREM

Total adjusted Beta-Gamma Dose = 7,279 mREM

The writers feel this is an extremely conservative adjustment of the reported skin dose to this individual. Considerations being given to the following: two reportedly contaminated film badge envelopes, an ever present degree of contamination on the plastic bags during this period of time, and the film badge positioning errors created when these bags were used. We seek the NRC's opinion so we may adjust our legal records.

In order for us to put this exposure into perspective, with respect to biological effects, we performed several calculations on the above adjusted skin surface dose. These calculations were also conservative, in that the adjusted photon dose was not altered further, because of lack of knowledge regarding the appropriate tissue attenuation and backscatter factors. The beta surface dose was adjusted by using the Theory of Loevinger and his semiempirical equations (10,11). It was done for the two dominant decay product beta spectra (i.e. Th-234 with E_{MAX} = 0.193 MeV and Pa-234m with E_{MAX} = 2.29 MeV), being unable to modify the equations for overlapping energy spectra. This results in a dose range with upper and lower limits; the actual dose is somewhere between. The equations used are as follows:

Dose at depth (i.e. to live tissue at 7 mg/cm^2):

$$D_{(x)} = D_o e^{-\nu x}$$

Average Dose to the live skin layer
(i.e. between 7 and 150 mg/cm^2):

$$\bar{D}_t = \frac{D_o}{\nu T}\left[e^{-\nu x} - e^{-\nu(x+T)}\right]$$

Where, $\nu_{Tissue} = 18.6\ (E_{MAX} - 0.036)^{-1.37}$, cm^2 g^{-1}

D_o = surface dose
$D_{(x)}$ = dose at depth
$\bar{D}_t$ = average dose to thickness T, below thickness x

The results of these calculations are informative and are summarized below for D_o = 6,538 mREM.

	Beta Dose (mREM)	Beta-Gamma Dose (mREM)
Upper limit dose to tissue at 7 mg/cm^2	6,276	7,017
Lower limit dose to tissue at 7 mg/cm^2	1,242	1,983
Upper limit dose to live skin layer	4,119	4,860
Lower limit dose to live skin layer	33	774

To date, numerous discussions have taken place with Melting and Casting Technicians, Management and the subject individual regarding our surveys and dosimetry in the area. One of the writers has personally observed the subject individual's work habits and has had a discussion lasting several hours regarding his Vendor reported doses. At that time he was reintroduced to the concepts involved with the different types of radiation which he is is exposed to in his workplace. His last quarter 1981 dosimetry was broken down into "skin" and "whole body" doses and presented to him as reported. The biological significance of these doses were reiterated with respect to risk to the various tissues involved. He understands these concepts well. Prior to the mentioning of dosimeter position he expressed a concern over "how the badge hangs into a crucible when I work on it". The individual is right handed and wears the badge on his right shirt pocket. This was verified prior to him (individual) being informed of the possible overexposure. Further, he (individual) personally feels the way badges had been placed may have caused an overestimate of his exposure. He (individual) did not seem anxious about the situation and was very willing to cooperate with any future investigations we propose.

Throughout this report numerous problems relating to dosimetry in this area have been pointed out. Mixed beta-gamma fields are difficult to resolve from a quantitative measurement perspective. However, we have made significant strides in overcoming these difficulties. We have assured ourselves that on the average our beta dosimetry is accurate under specified conditions.

Corrective measures that are in place now, and will be in place soon are as follows:

Presently Being Done

1). Film badges used by employees in the Melting and Casting area are being shipped via Federal Express to our Vendor for development and reading. Our Vendor is processing on an "Emergency Basis". (See attached Purchase Order Change). Results for the exposure period and cumulative totals are promptly called in to NMI's Health Physics Department.

2). "Anti-contamination" plastic bags protecting the film badges are monitored for contamination after each shift and changed, if required.

3). Two safety pins (one at the top and bottom) are now used to pin badges through the employee's shirt. Position on the shirt will remain the same (i.e. if the person is right handed - pinned to the right breast pocket). We feel this is a conservative estimate of the dose to the "skin of the whole body".

4). Whenever employees are working on graphite crucibles they will do so through newly fabricated half-inch Lexan covers (i.e. vacuuming and inverior surface coating). Figure 5 is a photograph of one of these covers. Measurements with an ionization chamber show a reduction of the dose rate from a crucible on the order of 98%.

5). Long rubberized/vinyl coats with hoods have recently been purchased. Employees will be wearing this outer gear and a plastic face shield whenever working with used crucibles or working in the interior of the induction furnaces. Again, measurements indicate a 22% reduction in dose rate using a crucible as a broad beam source. Aluminized-asbestos suits with hoods and plexiglass face shields have been ordered for when employees open furnace heads. If a Melting and Casting Technician were to reach into a hot furnace with a vinyl suit, it would melt to his arm.

6). Senior management meetings, including the VP/Technical Director and Health Physics staff, have been initiated. These meetings are held monthly and review Health Physics aspects of Melting and Casting. ALARA concepts have been introduced and will be reflected in future dosimetry reports.

Proposed Future Corrective Actions

1). Locking metal covers will be placed over crucibles while they are being removed from the Melting and Casting furnaces. This engineering effort was initiated several months ago, prior to the subject individual's "reported" overexposure. Final design has been approved and twenty of these covers are being fabricated.

2). An enclosed automated crucible cleaner/interior surface coater is being designed to eliminate technician contact time with open crucibles. Cost of the design and fabrication of this device is estimated to be close to two hundred thousand dollars. This device has been in the design phase for about a half a year now. It is a difficult engineering problem, but we are pushing the engineering firm working on it for prompt fabrication.

3). Permanent assignment of a full-time Health Physics Technician to assist with ALARA engineering in the area will occur as soon as possible.

4). Aluminum covers as a beta shield for all charge trays are being fabricated and will be utilized as soon as they are available.

SUMMARY

The key points to this report are as follows:

* As per the above discussion, we feel that the total adjusted beta-gamma dose to the subject individual is conservatively placed at 7279 mREM for the final quarter of 1981. Rational as iterated above.

* Management and technical changes, both present and planned, have been undertaken to prevent recurrence.

* The writers request NRC guidance to appropriately modify the subject individual's dosimetry record.

* The writers emphasize the fact that the practice of ALARA will be the driving force behind forthcoming reviews and subsequent changes in our operating procedures.

If any additional information is required, do not hesitate to contact the undersigned individuals.

David J. Allard
Supervisor of Health Physics

Frank J. Vumbaco, Manager
Health and Radiation Safety

DJA/FJV:dg/aj

Appendix I

The Subject Individual's Last Quarter 1981 Dosimetry*

Exposure Period	Gamma (mREM)	Beta (mREM)	Beta-Gamma (mREM)	Date Report Received	Vendor's Comments
10/1 to 10/14	150	810	960	11/23/81	
10/15 to 10/31	190	1930	2120	11/23/81	"contaminated badge"
11/1 to 11/14	250	1310	1560	12/23/81	
11/15 to 11/30	110	920	1030	12/23/81	"contaminated badge"
12/1 to 12/14	100	1220	1320	1/5/82	
12/15 to 12/31	100	1010	1110	1/18/82	
TOTALS:	900	7200	8100	1/18/82	

*As reported by R. S. Landauer, Jr. and Company (Vendor).

Appendix II

DU Metal Slab As Beta Source*

Attenuator	Relative Percent Decrease in Beta Dose
Polyester Shirt	3.1%
Polyester Pants	6.3%
"Anti-contamination" plastic bag	0.8%
Plastic Safety Glass Lens	64.5%
Glass Safety Glass Lens	80.6%

*(Apparent "hard" beta spectrum)

Used Crucible with Oxides as Beta Source*

Attentuator	Releative Percent Decrease in Beta Dose
Polyester Shirt	10%
Polyester Pants	11%

*(Apparent "softer" beta spectrum)

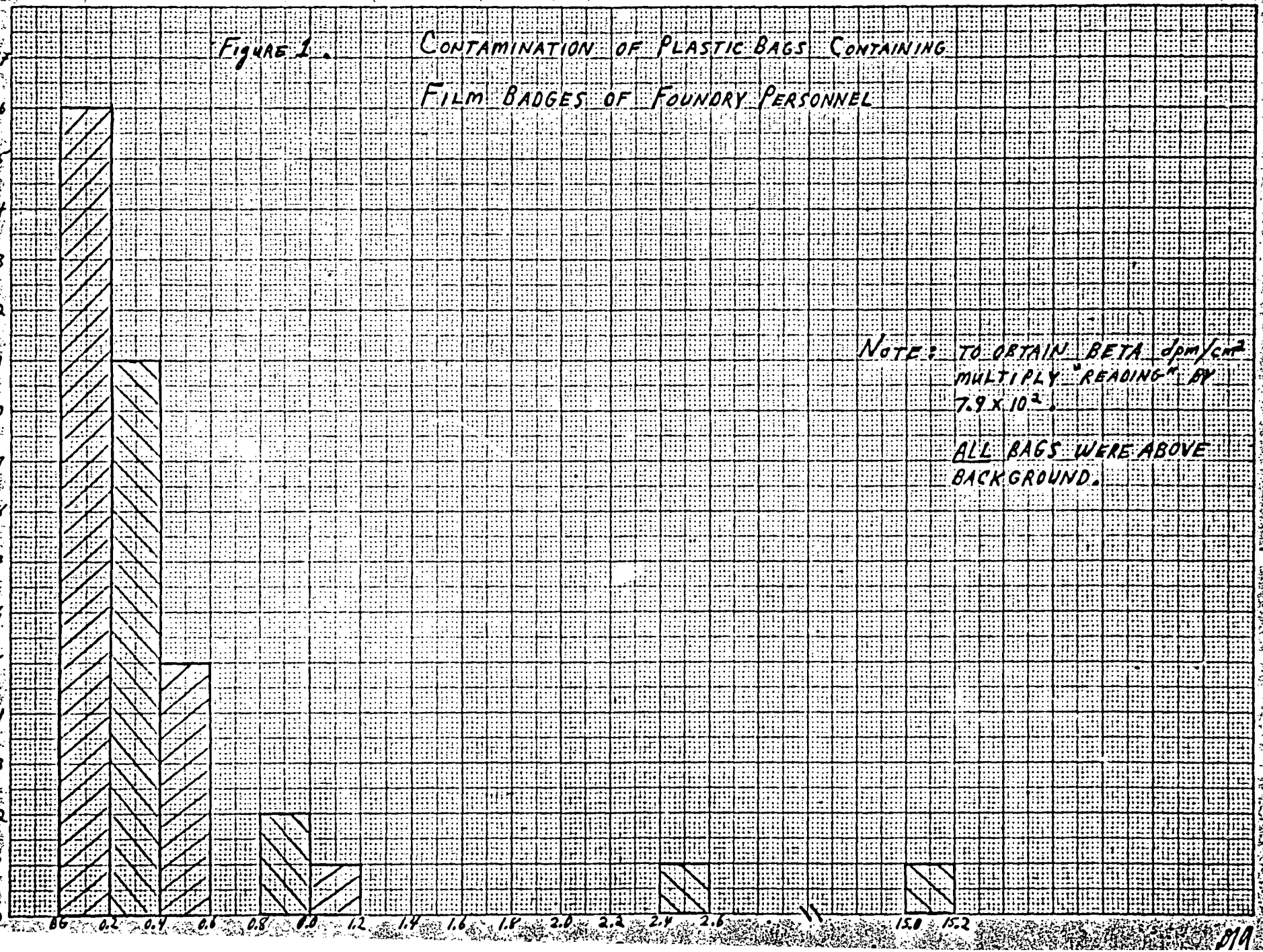


Figure 1. Contamination of Plastic Bags Containing Film Badges of Foundry Personnel

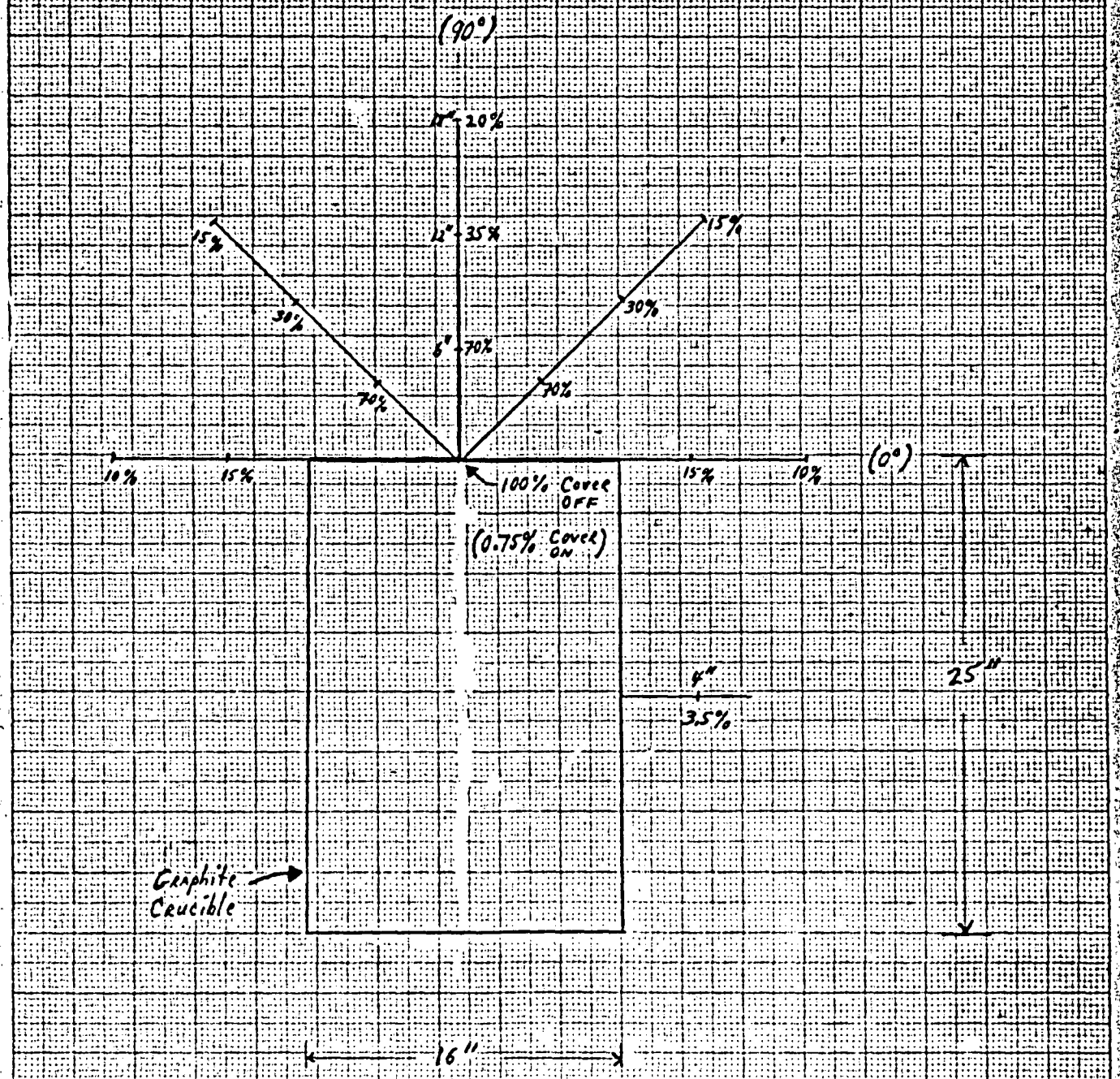
Note: To obtain beta dpm/cm² multiply "reading" by 7.9×10^2.

All bags were above background.

Attachment Sheet No. 11

FIGURE 2.

SPACIAL DOSE DISTRIBUTION AROUND A CRUCIBLE



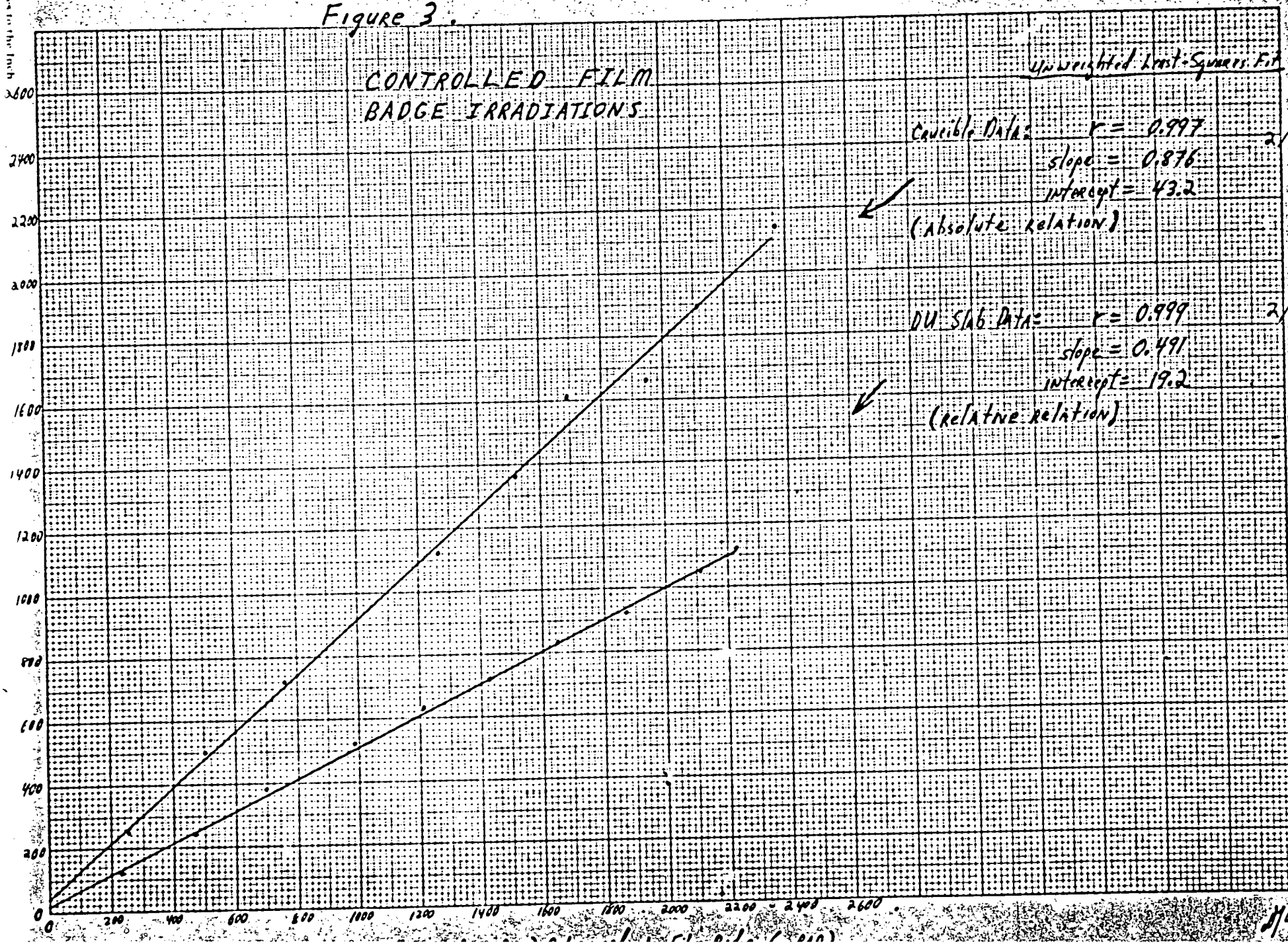
NOTE: Apparent 90° Dose-Distance Relation.

Scale: 1/8" = 1"

Drawing and Ion Chamber Measurements by David J. Allard

$$\dot{D}_2 = \frac{\dot{D}_1 x_1}{x_2}$$

Figure 3.



ATTACHMENT SHEET No. 13

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figure 4.

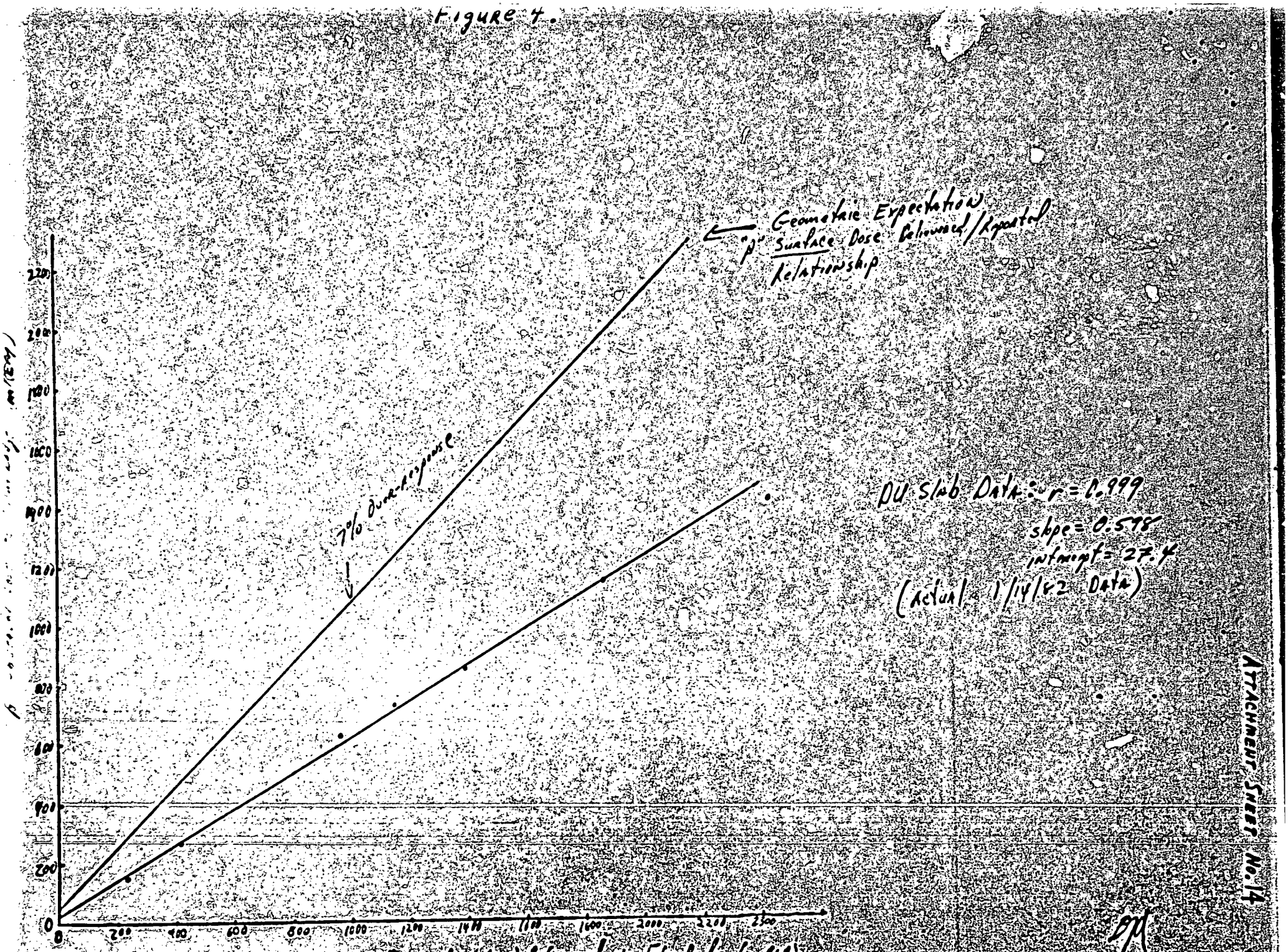

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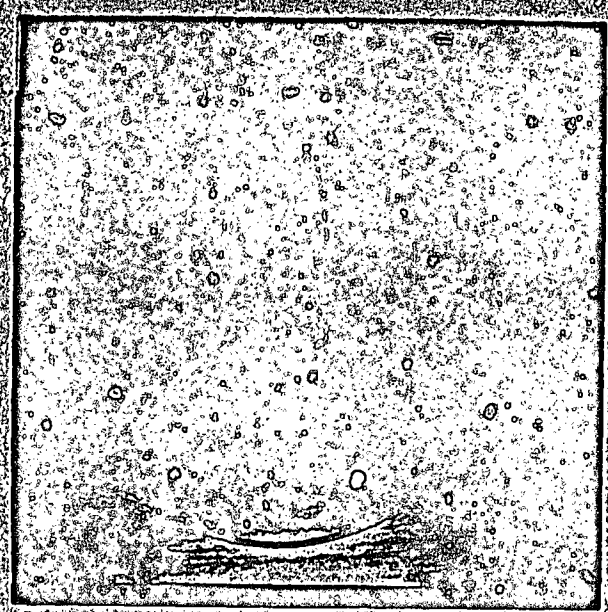
Figure 5:



Lexan crucible shield.

References

(1) McDonald, Jeanine; Private Communication. R. S. Landauer, Jr. and Company.

(2) Plato, P. and Hudson G.; "Performance Testing of Personnel Dosimetry Services", NUREG/CR-1064, January 1980.

(3) American National Standards Institute; "Criteria For Film Badge Performance", ANSI N13.7-1972.

(4) U.S. Atomic Energy Commission; "Film Badge Performance Criteria", Regulatory Guide 8.3, February 2, 1973.

(5) American National Standards Institute; "Draft American National Standard Criteria for Testing Personnel Dosimetry Performance", ANSI N13.11, July 1978.

(6) U.S. Department of H.E.W.; "Radiological Health Handbook", Revised January 1970.

(7) Allard, D. J. and Memoli, L.C.; "Quality Assurance on Commercially Supplied Dosimeters", Proceedings of the 1980 Health Physics Society Mid-year Symposium on Medical/Health Physics.

(8) Wheeler, Robert; Private Communication. R. S. Landauer, Jr. and Company.

(9) Tochilin, E. and Golden R.; "Investigations on the Relative β- to γ - Ray Sensitivity of Photographic Emulsions" Health Physics, Vol. 4, pg. 244, April 1961.

(10) Loevinger, Robert; " The Dosimetry of Beta Radiations", Radiology, Volume 62, pg. 74, January 1954.

(11) Loevinger, Robert; "The Dosimetry of Beta Sources in Tissue. The Point Source Function", Radiology, Volume 66, pg. 55, January 1956.

PURCHASE ORDER

STANDING ORDER

NUCLEAR METALS, INC.
2229 Main Street • Concord, MA 01742
Tel. (617) 369-5410 • TWX 710-347-1056

SHIP AND BILL TO

DATE 3-1-82

P.O. NUMBER
NM— 31109
PAGE 1 OF 1

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Glenwood Science Park
Glenwood, Ill 60425

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