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QR 13
June 1969

PLANETARY QUARANTINE

# SANDIA LABORATORIES QUARTERLY REPORT - PLANETARY QUARANTINE PROGRAM

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# Sandia Laboratories Quarterly Report - Planetary Quarantine Program

Thirteenth Quarterly Report of Progress

for

Period Ending June 30, 1969

Planetary Quarantine Department

Sandia Laboratories, Albuquerque, New Mexico

June 1969

Project No. 0064010

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Lunar Information System

A. Description. Due to NASA's inability to contract the programming of the lunar information system design reported in "An Interactive Computer Information System for Planetary Quarantine for Lunar Programs", Sandia Laboratories Research Report SC-RR-68-545, July, 1968, in time for it to be useful on Apollo 11, we are attempting to implement a reduced version of this design.

B. Progress. During this quarter, the programming and checkout of a reduced version of both the File Preparation Routine and Data Storage Routine reported in the above reference was completed. The differences between the reduced system and the original design are that in the revised system

1. There are no temporary files
2. There is no communications routine
3. No suit or astronaut data is handled
4. No air sampling data is handled
5. A routine is provided to handle the results of the qualitative information scheme
6. A routine is provided to summarize the qualitative information
7. A routine is provided to reproduce the various tapes used
8. The directories are stored on tape rather than disk
9. The module-building directory is not maintained.

Both the File Preparation and Data Storage Routines are operational and have been"turned over" to the PHS at Cape Kennedy. Some PHS

personnel have been trained in their usage and a brief course given for other PHS and NASA persons interested in the system.

A document describing the modified system and its usage is in preparation. This includes a brief description of the File Preparation Routine, the Data Storage Routine, The Qualitative Storage Program, The Qualitative Summary Program and the Reproduction Program. The qualitative programs are based upon the identification procedures currently used by the PHS.

The Lunar Inventory Routine, designed primarily to provide estimates of the density of terrestrial organisms on the lunar surface, is currently being programmed. When completed, it will be somewhat modified from the design given in the above reference. This routine will use the models developed in "The Chances of Retrieval of Viable Microorganisms Deposited on the Moon by Unmanned Lunar Probes", Sandia Laboratories Monograph, SC-M-68-539, August 1968, and some additional models developed to estimate organism densities from Apollo missions. It is expected that an operational version of this remaining routine will be completed by mid-July.

Sterilization Modeling and Laboratory Support Work

A. Description. This activity has as its aim the development of a sterilization model that is physically based and is consistent with all known forms of survival data.

B. Progress. Much of this quarter has been utilized in the preparation of an interim report on the progress made since the initial paper, "A Rational Model for Thermal Sterilization of Microorganisms", (Mathematical Biosciences, Vol. 2, No. 1/2, Feb. 1968), describing the kinetic death model. Substantial portions of this report have been completed. The report will cover the following three areas:

1. Theoretical developments
2. Model verification experiments, and
3. Model computerization.

The kinetic death model reported in the above reference has, since the time of that report, undergone several changes. Currently, the model assumes that any or all of the following chemical reaction types may, though they need not necessarily, be involved in spore heat inactivation:

A series of partially reversible first order reactions

$$A \rightleftarrows B \rightarrow C \qquad \text{(i)}$$

competing with an irreversible first order reaction

$$A \rightarrow D \quad \text{and an} \qquad \text{(ii)}$$

independent second order reaction

$$2E \rightarrow F. \qquad \text{(iii)}$$

From this, the model is physically based and is consistent with the generally held view that the inactivation of spores by heat is a chemical phenomenon.

Reaction types (i) and (ii) include behavior known to take place in some macromolecules within bacteria. The partial denaturation of some macromolecules is reversible whereas the subsequent or competing action of degradation is not.

There is conflicting opinion about the orders of many inactivating reactions of spore constituents. Some seem definitely to be of order higher than one under prescribed experimental conditions (notably some proteins). To allow for the possibility that such a reaction type is important to spore inactivation under some conditions, reaction type (iii) is included in the model. The model does not assume that such a reaction must take place, only that it may.

In model usage,each reaction rate (generically denoted k) is replaced by its equivalent expression

$$k = \frac{KT}{h} \; e^{-(\Delta H^{\ddagger} - T\Delta S^{\ddagger})/RT} \qquad \text{(iv)}$$

derivable from absolute reaction rate theory. Thus, each reaction rate k is replaced by two new parameters, the activation enthalpy $\Delta H^{\ddagger}$ and activa-

tion entropy $\Delta S^{\ddagger}$ of the reaction. Since there are five possible reaction rates in reaction types (i), (ii) and (iii) there are ten reaction rate parameters in the model.

In addition to these ten parameters there are four other integral parameters:

$n_1$ the number of molecules degraded by reaction type (i)

$n_2$ the number of molecules degraded by reaction type (ii)

$n_3$ the number of molecules E

$n_4$ the number of the $n_3$ molecules of type E that must be degraded by reaction type (iii) in order that the spore be inactivated

The latter two parameters appear because it is known that, in some instances, it is not necessary to denature all protein molecules of a given type to cause their function to cease. Again, the model does not assume any such thing must occur - only that it may. It is also possible for $n_3$ and $n_4$ to be equal.

Because of the large number of parameters involved, the kinetic death model may be expected to fit the many "shapes" of survivor curve data that exist (convex, concave, sigmoid and logarithmic). For this reason, fairly elaborate "verification" efforts have been made. The initial reference presents model predictions with concave and convex data taken from the literature. Sandia Laboratories Planetary Quarantine Quarterly Report, QR 9, compares model predictions with our own sigmoid data and reports the result of subjecting the model to a rigorous "verification" test with data taken in an environment experiencing a highly variable temperature during the duration of the experiment.

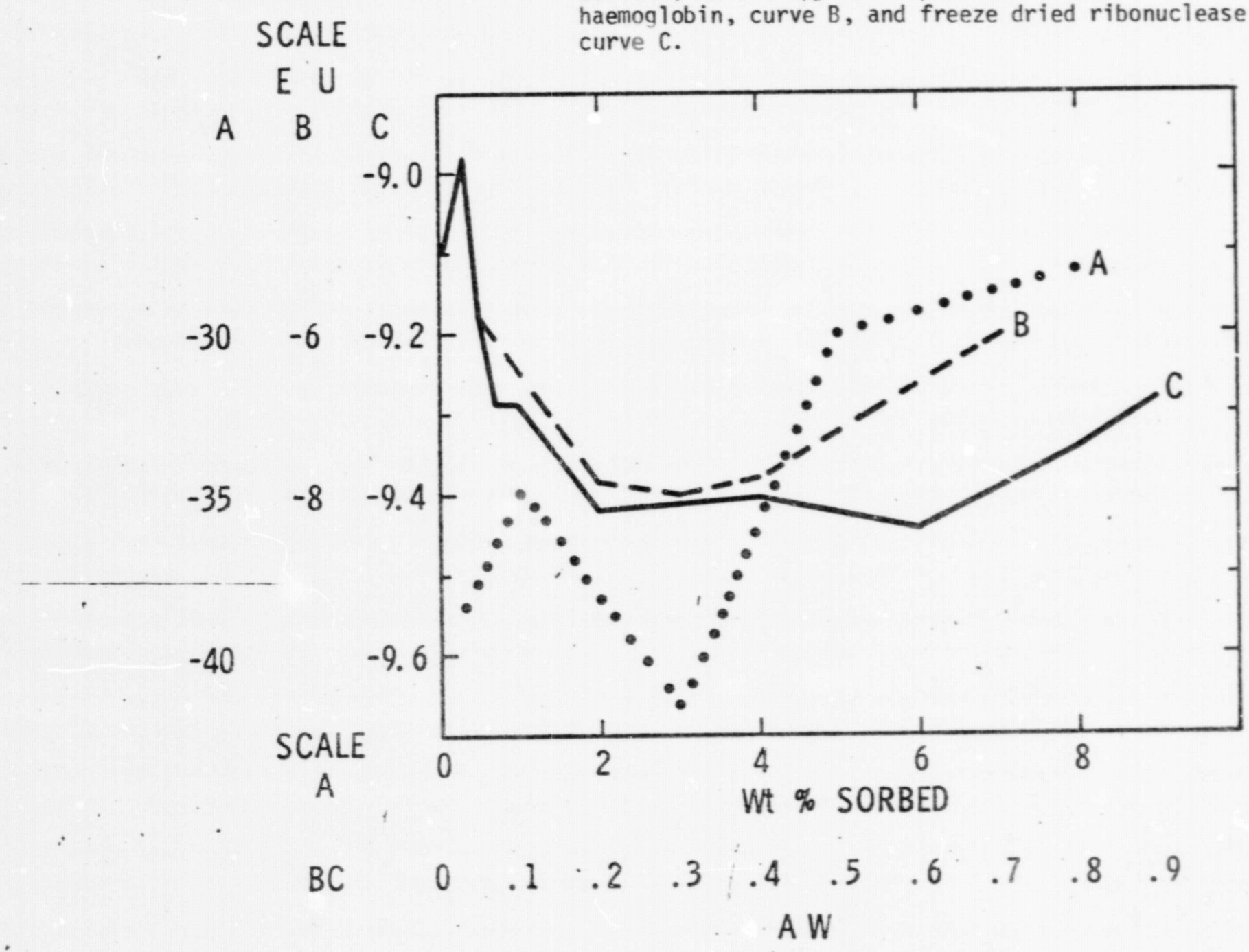
In this same report, model parameter values obtained in these "verification" efforts are compared with known activation entropy and activation enthalpy values for the denaturation of some phage DNA and some RNA taken from the literature. Nothing in any of these verification efforts suggests the model should be rejected.

As suggested, the model is completely computerized and capable of predicting survivors as a function of time in highly variable temperature environments.

Since the notion of "water activity" has become better defined and is assuming increasing importance in the phenomenon of heat inactivation of spores, the relationship between the kinetic death model and water activity is being examined.

The theoretical basis for the inclusion of $a_w$ as an environmental parameter is the change in the entropy of activation induced by the sorption of $H_2O$ by macromolecules. Using data from P.H.S., Cincinnati, (J.E.Campbell, et.al., Ecology and Thermal Inactivation of Microbes in and on Interplanetary Space Vehicle Components, Fourteenth Quarterly Report of Progress, U.S.P.H.S., Cincinnati, March (1969)), and assuming the single structure lst order kinetics for the sterilization mechanism required by their reporting of the data we have been able to construct a "theoretical entropy of $H_2O$ sorption" vs $a_w$ curve for the sterilization mechanism. In Fig. 1 this curve is compared to observed entropy of $H_2O$ sorption for lypholyzed haemoglobin and ribonuclease. It should also be pointed out that utilizing the ribonuclease and haemoglobin data with the model, the dependence of survivors on water activity takes the same

Figure 1. Comparison of theoretical entropy of activation as a function of $a_w$ for B. subtilis var niger, curve A, to entropy of sorption of freeze dried haemoglobin, curve B, and freeze dried ribonuclease, curve C.



form as that resulting from the P.H.S. work. Since it appears that available water affects chemical reaction activation entropies and enthalpies, and since the form of this affectation for some organic substances combined with the model yields the same form as known survival results, it seems reasonable to suppose that survivor dependence upon available water can be incorporated into the kinetic model through its effects on activation entropies and enthalpies.

It has been proposed that the major reason that survivor curves deviate from "natural" logarithmic behavior is a variation of available water with time, either in preparation or during heating. Since similar but, to date, less striking behavior is noted with the availability of calcium ions and dipicolinic acid, one may reasonably question how major a cause of survivor curve deviations water is. To determine whether water is the sole cause of nonlogarithmic survivor curves, both a logarithmic stock and our previously reported (QR 9) sigmoid stock of Bacillus subtilis var. niger were heated simultaneously in the same oven. The logarithmically behaving stock is a daughter stock cultivated from the tail of the original sigmoid behaving stock. Both were prepared, to within control limits, in precisely the same fashion. Since the original stock and daughter stock were prepared in the same fashion and heated together in the same oven, the presumption is that both stocks have seen the same amount of available water in preparation and thermal treatment. In both cases the initial loading was in the area of $10^8$. The results are shown in Figure 2. The Δ

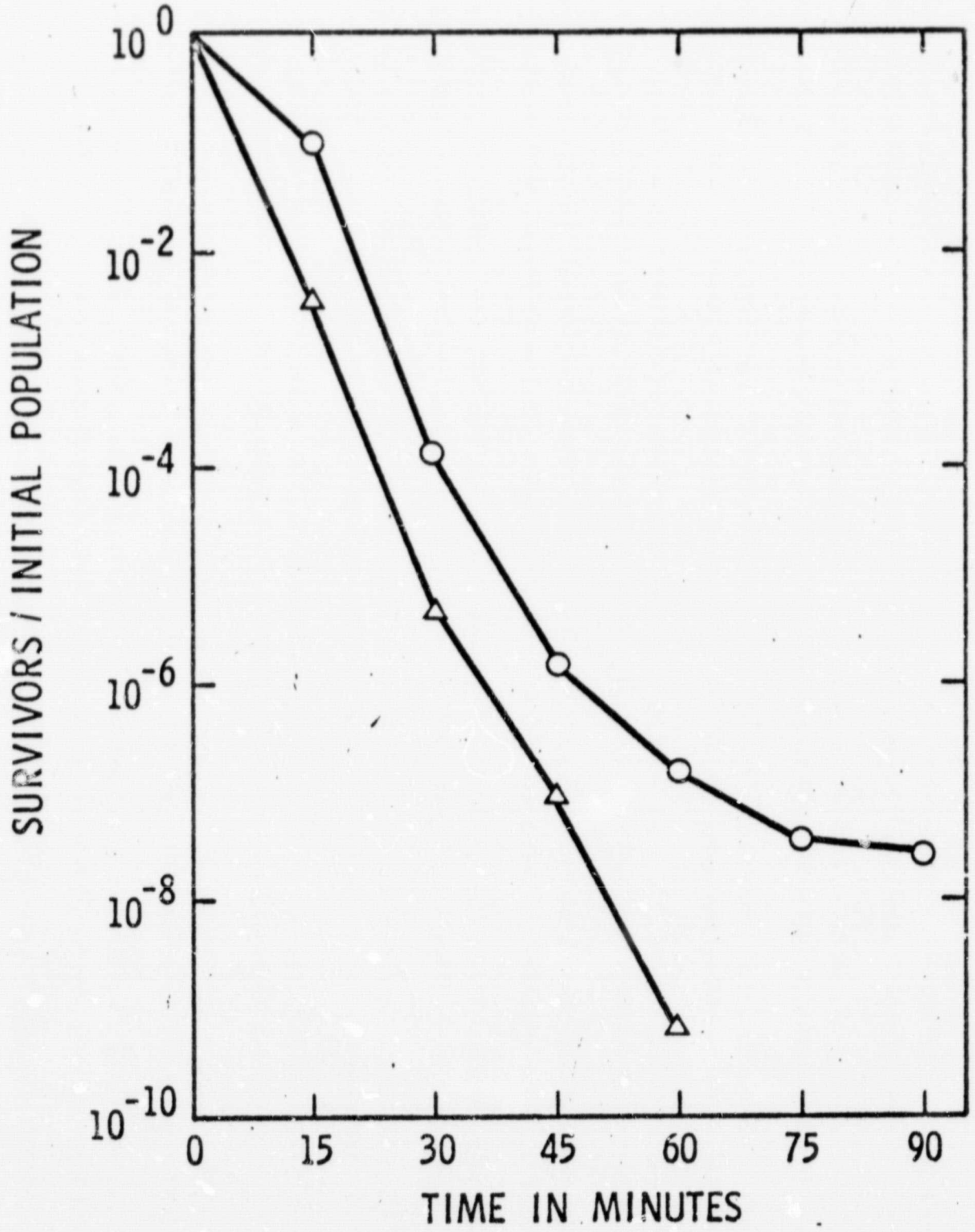



Figure 2. Comparison of survivor curves for parent tailing stock of B. subtilis var. niger, O, to straight line daughter stock Δ.

below $10^{-9}$ indicates one colony from eight samples with a $3 \times 10^{8}$ loading and no growth at sample times beyond 60 minutes. Since the daughter stock was isolated from the tail of the original stock and behaves like the upper portion when heated, it seems reasonable to assume that the original stock was genetically homogeneous. Then, if the above presumption is correct, and we have no reason to doubt it, water activity as it is currently defined cannot be the sole cause of non-logarithmic survivor curves. Additionally, it would seem that one may expect considerable deviations from logarithmic survivor curves that are unattributable to water activity.

Qualitative Sampling Model

A. Description. The ability to confidently and economically determine what types of bacteria are present on various portions of an Apollo mission depends upon several factors. One such factor is the determination of the number of samples that must be taken to insure that all types of interest are identified with some prescribed probability.

B. Progress. A document, "A Model for the Quantification of the Qualitative Microbial Sampling Problem", Sandia Laboratories Research Report, SC-RR-69-310, was published this quarter. The nature of the model has been reported on previously in Quarterly Report QR 10. It was designed to apply to the procedures currently being used in sampling Apollo spacecraft.

The end product of the model may be described as follows. Let N represent the number of categories of organisms that one would be interested in identifying were they present on the Apollo craft, and let n be the number of colonies resulting from sampling that are identified. Here category may refer to species, genus, "group", strain, or any other divisions deemed appropriate. If $P_{n,N}$ is used to denote the probability that all N categories are identified (if present) after n colonies have been identified, one may ask what smallest number $\tilde{n}$ of colonies must be identified before

$$P_{\tilde{n},N} \geq \alpha.$$

Some representative results for $\tilde{n}$ are:

| N \ α | 0.80 | 0.90 | 0.99 |
|---|---|---|---|
| 50 | 271 | 309 | 426 |
| 100 | 611 | 686 | 921 |
| 200 | 1360 | 1510 | 1980 |
| 500 | 3858 | 4233 | 5408 |
| 2000 | 18202 | 19703 | 24403 |

Using results such as these, one can draw the following conclusions. The two-thousand colonies now being identified allow identification of 200 organism categories with a probability in excess of 0.99. Thus, the somewhat fewer than 100 categories now deemed to be of concern may be identified with an even higher probability using current procedures. Should these categories be subdivided by more than a factor of two, the probability of identification of all (if present) would drop below 0.99. If the number of categories of interest does not change appreciably, the identification of half the current number of colonies will allow identification of all categories of concern with probability in excess of 0.99.

Given the nature of the uncertainties about some model parameters and assumptions, as described in the above reference, it would seem that the current sampling program provides a reasonable safety factor in estimating the likelihood that all categories of organisms of concern have been identified.

Bioburden Experimentation and Modeling

A. Description. Models for the estimation of spacecraft bioburdens are needed for use in "clean" and "dirty" areas associated with NASA missions. One such model has been developed and is described in SC-RR-69-23, "The Determination of Quantitative Microbial Sampling Requirements for Apollo Modules". An experimental program is in progress which should yield data for verification of this model and guide parameter selection for future models.

The general problem of estimating the number of microbes on an object in a clean room must be solved subject to the constraints that only certain surfaces of the object can be directly sampled and that these surfaces can be sampled only at specific times. Selected environmental samples such as number of microbes per cubic meter or number of particles per cubic meter or number of mechanical contacts made with the object, however, can be made. Subject to these constraints, there are two basic problems - knowing what is on the sampled surfaces, how do we predict what is on inaccessible surfaces and knowing what is on the object at a particular time, how do we predict what is on the object at a later time. This general problem is reduced to the specific ones by attempting to understand how microorganisms get on an object in a clean room by deposition from airflow and by deposition from mechanical contact; and how microorganisms are removed from an object in a clean room by airflow, by vibration, by death, and by mechanical contact. Using such knowledge, the validity of the model

referenced above may be investigated. Should the model prove reasonable the first of the two basic problems is solvable and a conceptually straightforward extension of the model can be used to solve the second. With the experimentation in progress we are addressing the problem of deposition of microorganisms by airflow.

Using the vertical laminar downflow research facility described in QR 11, a number of experiments have been performed to elucidate the effects of various parameters on the particle collection efficiency of an object exposed to an aerosol. This was done using flow conditions approximating those in a laminar flow clean room.

B. Progress.

1. Test of Procedures and Materials

The first phase of experimentation was concerned with evaluating the room and the test procedures and materials to be used.

Constancy of Aerosol

One of the first points of interest was to determine how evenly the aerosol was distributed over the test area in the room. Membrane (Millipore) filters were used to sample representative locations in the room. In no case did the variation in the density of the aerosol at each sampling site exceed 15% variation from the mean density calculated by averaging the density at all sites.

Charged Aerosol Effects

Because the aerosol was formed by separating individual particles from a mass of particles, we were concerned that the

particles might be either predominantly negatively or positively charged. An experiment was designed to determine if the particles had predominately one charge on them since this conceivably could affect some of the collection efficiency measurements.

An insulated stand was assembled with three test plates exposed to the airstream. The test plates were made of polished metal foil. The left plate was charged to -5000 volts, the center plate was left uncharged and the right plate was charged to +5000 volts. Although the number of particles on the high voltage plates was three times the number on the uncharged plate, there were approximately equal numbers of positively and negatively charged particles,as is the case with most normal aerosols.[1,2,3]

Effects of Different Surface Materials

One additional point of concern was that different surface materials might have different collection efficiencies. Test surfaces of polished metal, glass and glass coated with approximately a .005 inch thick layer of machine oil, were used. Two plates of each surface except the oiled plate were used, so that position effects might be averaged. The results indicated that no

---

1 N.A.Fuchs, The Mechanics of Aerosols ,1964,p.177.

2 T.Gillespie,"Electric Charge Effects in Aerosol Collection Phenomena"in Aerodynamic Capture of Particles, ed. E. G. Richardson, 1960, p.44.

3 W.B.Kunkel,"The Static Electrification of Dust Particles on Dispersion Into a Cloud", J. Appl. Phys.,1950, 21, p.820.

significant difference in collection efficiency existed between any of the three radically different surface types. Assuming that the oil layer was adhesive enough that any particles contacting it adhered, the experiment also indicated that if a particle hit either of the other surfaces used, it remained on that surface.

2. Experimentation for Modeling

The second phase of experimentation was concerned with measuring the effect of various parameters on collection efficiency of objects. The parameters measured were:

a. angle from horizontal versus collection efficiency for a given size square flat plate,

b. size along the edge versus collection efficiency for various size squares exposed horizontally to the airstream, and

c. diameter versus collection efficiency for various sized circular plates exposed horizontally to the airstream.

These experiments are described below.

Angle to the Horizontal vs. Collection Efficiency for 1" x 1" Glass Plates

An experiment of interest for modeling was to place flat plates at various angles to the flow to determine variations in the number

of particles collected and how the collection efficiencies changed. One inch by one inch square glass plates were used.

The results shown in Figure 3 indicate that the number of particles collected closely follows a cosine curve. The collection efficiencies are shown in Figure 4.

Size of Square Sampling Surfaces vs. Collection Efficiency

Various results in the literature[1,2] indicate that for some simple shapes - namely flat ribbons, cylinders and spheres - for a given particle size and a given airflow rate, the collection efficiency decreases as the size of the object is increased.

It was not clear whether these generalizations also carried over for other simple shapes. Therefore, an experiment was conducted to examine this effect. The results of the experiment for flat squares is shown in Figure 5. The horizontal axis is plotted as $\log \frac{1}{L}$ where L is the dimension of the square along an edge.

From the shape of the curve of Figure 5 one sees that the same effects discussed above hold.

Diameter of Circular Discs vs. Collection Efficiency

The experiment was repeated for circular flat plates of various diameters. The results are summarized in Figure 6.

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[1] C.N.Davies, and C.V.Peetz,"Impingement of Particles on a Transverse Cylinder", Proc. R. Soc. A., 1955, p. 269.

[2] N.A.Fuchs, The Mechanics of Aerosols, 1964, p. 159.

Number of Particles Collected on 1" x 1" Glass Plates

vs.

Angle of Plate to Horizontal

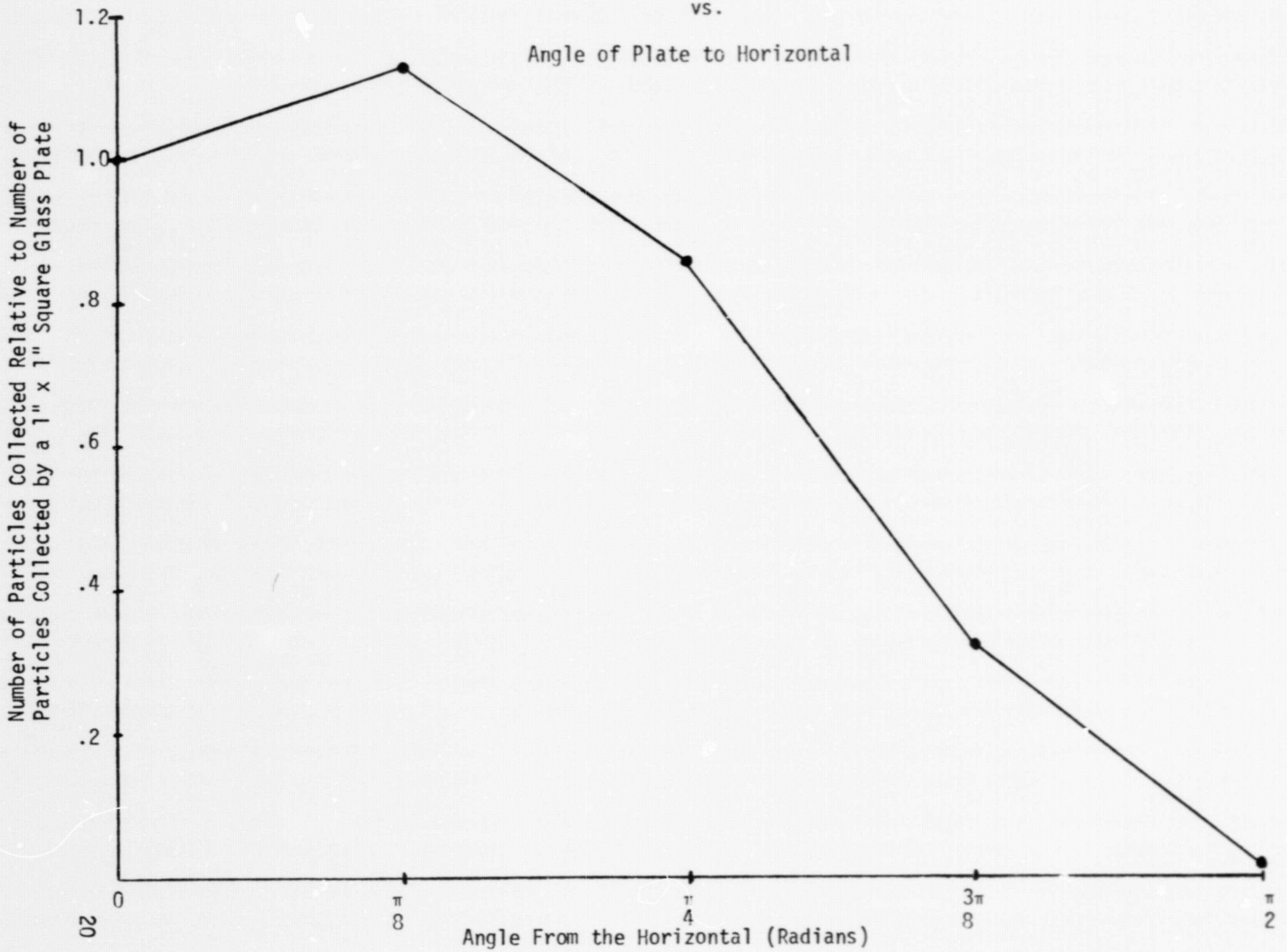



Figure 3

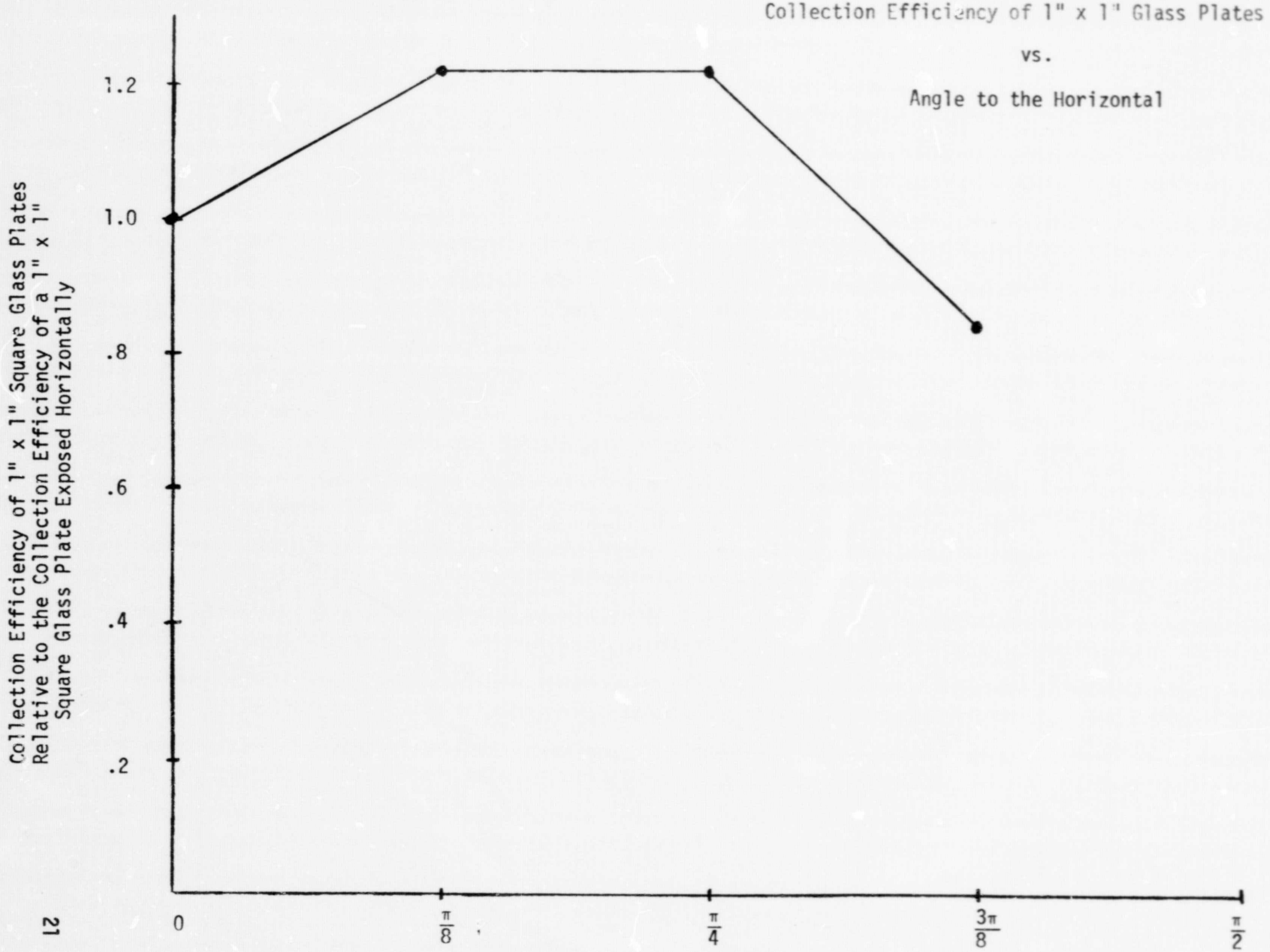

Collection Efficiency of 1" x 1" Glass Plates
vs.
Angle to the Horizontal
Collection Efficiency of 1" x 1" Square Glass Plates Relative to the Collection Efficiency of a 1" x 1" Square Glass Plate Exposed Horizontally
1.2
1.0
.8
.6
.4
.2
0
π/8
π/4
3π/8
π/2
Angle from the Horizontal (Radians)

Figure 4

Collection Efficiency of Square Plates As a
Function of Size of the Square

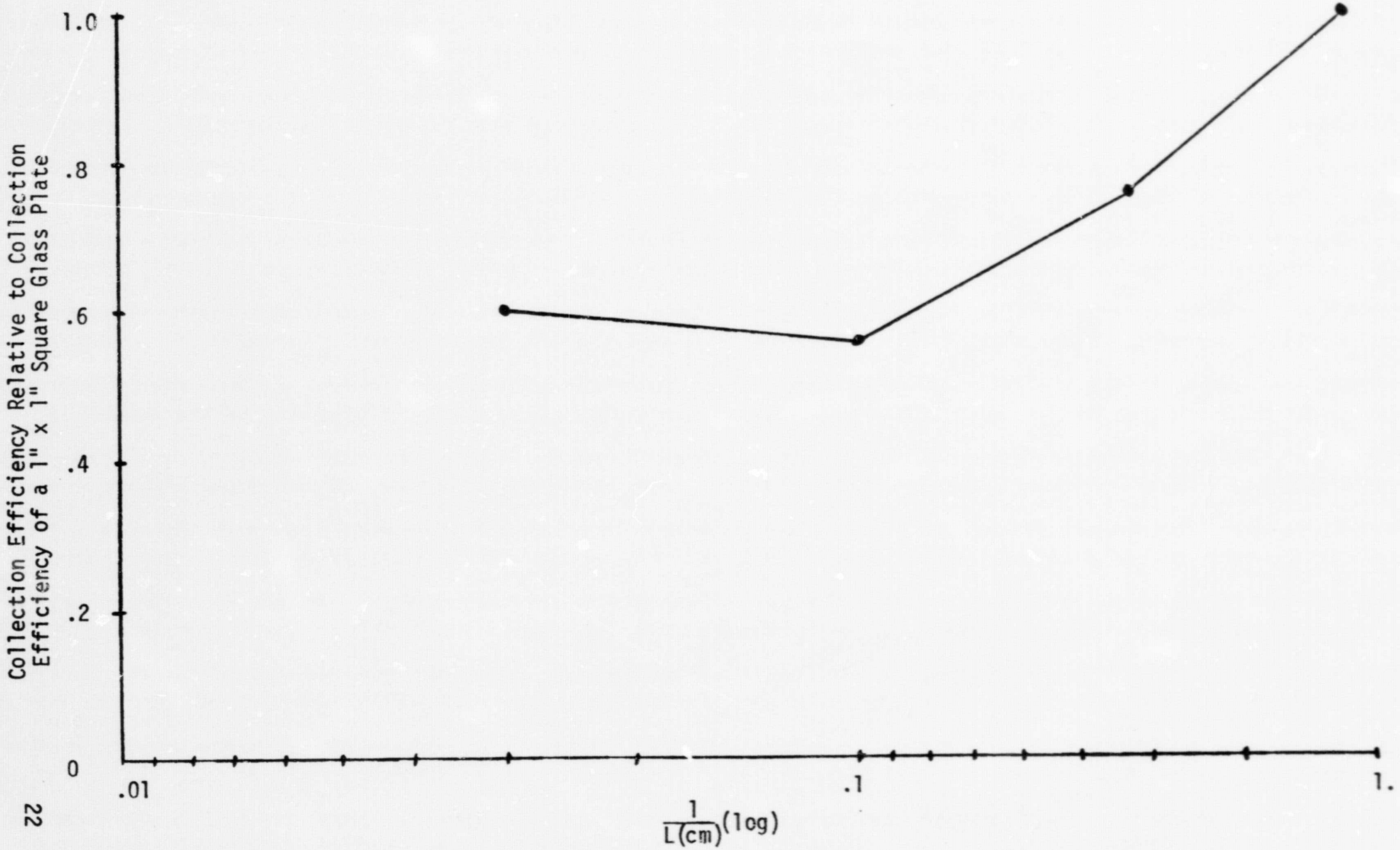



Figure 5

Collection Efficiency of Circular Discs as a Function

of the Diameter of the Disc

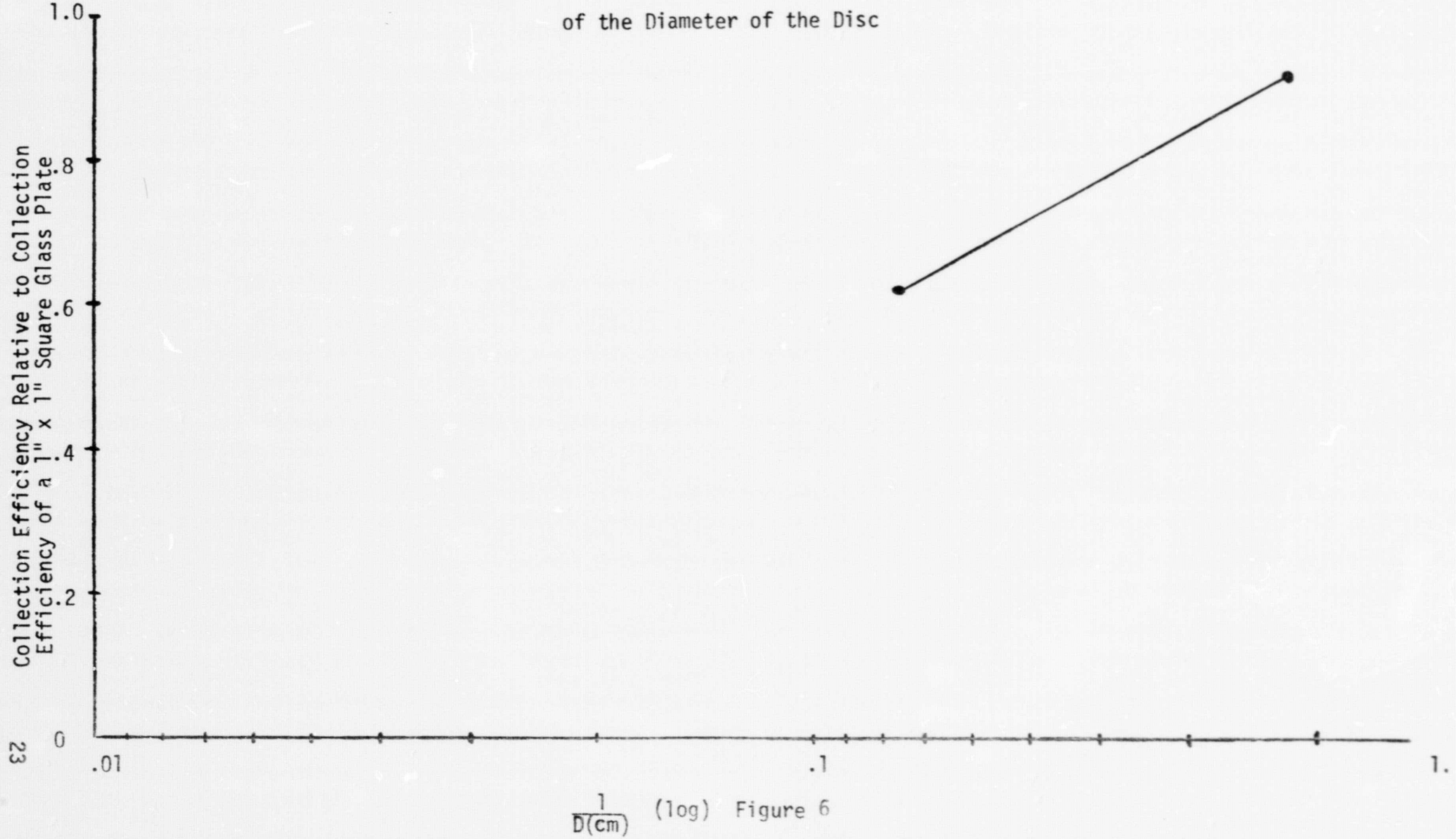



Figure 6

Over the range of diameters used, the conclusions of the previous experiment hold. One additional point of interest is that square flat plates of a certain length along an edge had almost the same collection efficiency as flat circular plates whose diameters were equal to this length.

3. Quantimet

Although the tests are simple enough to perform, the most time consuming and tedious task is counting the particles using a microscope. For example, on a typical experiment, the preparation and execution take only several hours, whereas the counting may take several days. Recently, Sandia Laboratories obtained a Quantimet. A Quantimet is an instrument manufactured by Metals Research Ltd. in Cambridge, England. The function of the instrument is to count and size particles. Preliminary counts of glass slides loaded with 10 micron diameter glass spheres indicate that the instrument can be used to eliminate the tedious task of counting and sizing, microscopically. Typical counting times on one 1" x 1" glass slide are less than 60 seconds. Whereas most of the curves have been generated with only one or two separate experiments, the Quantimet will enable enough tests to be run to obtain numbers with much less statistical variation. The instrument also makes much larger-scale tests possible.

Thermo-Radiation Sterilization (USAEC Funded)

A. Description. The thermal degradation of spacecraft components as a result of present dry heat sterilization is a problem still not completely resolved. Silver-zinc batteries, high value mylar capacitors, vidicon tubes, PBAA solid propellants, culture media, photometers and other scientific instruments suffer from high temperature environments. The purpose of the thermo-radiation study is to explore possible techniques that will reduce the dry heat time and temperature requirements for sterilization of spacecraft hardware. More specifically, the study is concerned with determining the synergistic effects of the combined application of heat and radiation.

B. Progress. The work this quarter was directed toward possible complementary effects of simultaneous gamma radiation and heat in contrast to the first quarter where base line data on individually administered lethal environments was developed.

Initial discussions with Sandia Laboratories component organizations indicated that the threshold of radiation degradation was generally in the regime above one-megarad with only a few components sensitive to radiation doses of 350 to 500 K-rad. Based on this information, experiments were designed with total doses of less than 150 K-rads to maintain a comfortable margin below possible component degradation levels.

The initial series of experiments were performed over a temperature range of 125°C to 100°C using Bacillus subtilis var. niger spores at $10^9$ initial sample populations in a dry condition. Results of these experiments indicated that a reduction of the initial population by 90% could be accomplished in roughly 30% to 50% of the time when small doses of gamma radiation were added to the dry heat cycles. This was true at all temperatures investigated.

A summary of the simultaneous experiments appears in Figure 7 which is a comparison of D values[1] for Bacillus subtilis var. niger. The dry heat D values appear to the left of the zero or center line with a scale in hours exposure. In other words, the D value or the time to reduce the population by one log using dry heat alone was experimentally found to be 22 min. at 125°C, 4 1/2 hrs. at 105°C and 7 hrs. at 100°C. On the right of the center or zero line is the D value for radiation alone which has a value of 0.170 M-rads to reduce the population by one log. The shaded areas in Figure 7 then demonstrate the reduced thermal exposure required for sterilization when small amounts of radiation are added. At 125°C the dry heat D value was reduced from 22 min. to 12 min. by the simultaneous addition of 100 K-rads of gamma radiation. At 105°C the dry heat D value was reduced from 4 1/2 hrs. to 1 1/2 hrs.by the simultaneous addition of 100 K-rads of radiation and at 100°C the D value was reduced from 7 hrs. to 2 1/2 hrs. by the simultaneous addition of 150 K-rads of radiation.

---

[1] A D value is the time to reduce a given microbial population by 90% or one log in count at a given temperature. Used here for convenience, it is not a completely apt descriptor of the survivor curves many of which were concave in character in the ranges of one to 100 survivors.

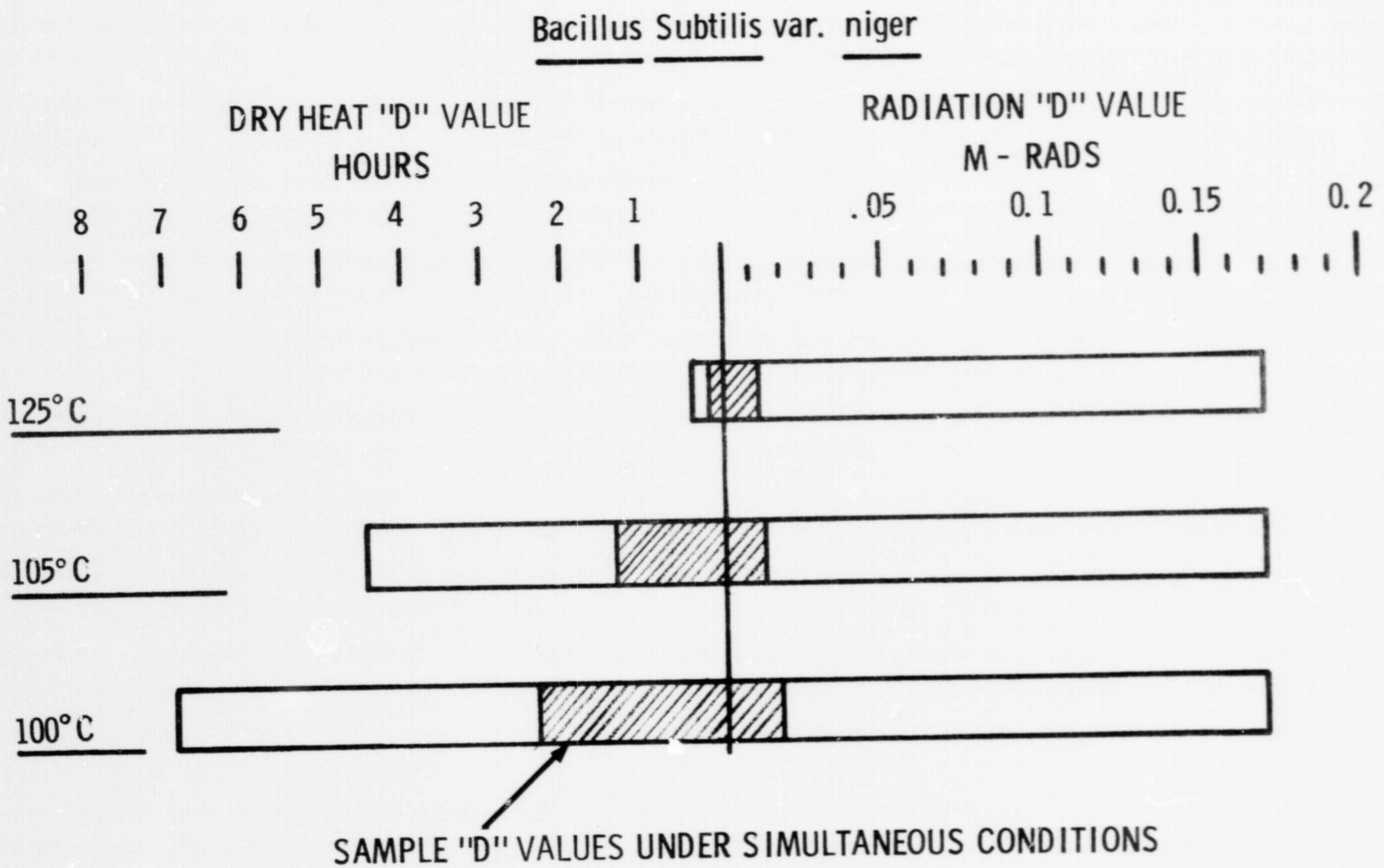

Bacillus Subtilis var. niger
DRY HEAT "D" VALUE
HOURS
8
7
6
5
4
3
2
1
RADIATION "D" VALUE
M - RADS
.05
0.1
0.15
0.2
125° C
105° C
100° C
SAMPLE "D" VALUES UNDER SIMULTANEOUS CONDITIONS

Figure 7

These results tend to indicate that sterilization at low temperatures is a practical possibility. For example, sterilization at 100°C with a small dose of radiation can be accomplished in less time than dry heat sterilization at 105°C. Continued investigation will hopefully show that the present low temperature terminal dry heat sterilization cycles can be reduced to something that holds promise for heat labile component sterilization.

It is also desirable that the applicability of this technique be demonstrated for organisms other than Bacillus subtilis var. niger. Figure 8 is a comparison of the average D values from the literature for other radiation and/or heat resistant organisms. Although many organisms seem to be characterized by either high heat resistance or high radiation resistance but not both, some, such as Clostridium sporogenes, are very resistant to both heat and radiation. Experiments to evaluate combined lethal effects of radiation and heat have begun on the organisms shown in Figure 8. Experiments using B. pumilus were performed at 105°C dry heat then repeated with simultaneous 105°C dry heat and 45 K-rads gamma radiation. The time for a 6 log reduction of population was reduced from 16 hours to 6 hours with the 45 K-rad radiation dose (Figure 9).

Briefings of this activity were made to Dr. John Brewer who visited Sandia Laboratories April 21 through 25 to observe protocol used in thermo-radiation experiments; to Planetary Quarantine Office, Washington, D. C., on April 28; to Planetary Quarantine Advisory Committee, Minneapolis, Minn. on May 28; and to the AEC Division of Isotope Development (Radiation Sterilization of Food) and the AEC Division of Biology and Medicine on June 18.

## COMPARATIVE HEAT & RADIATION "D" VALUES

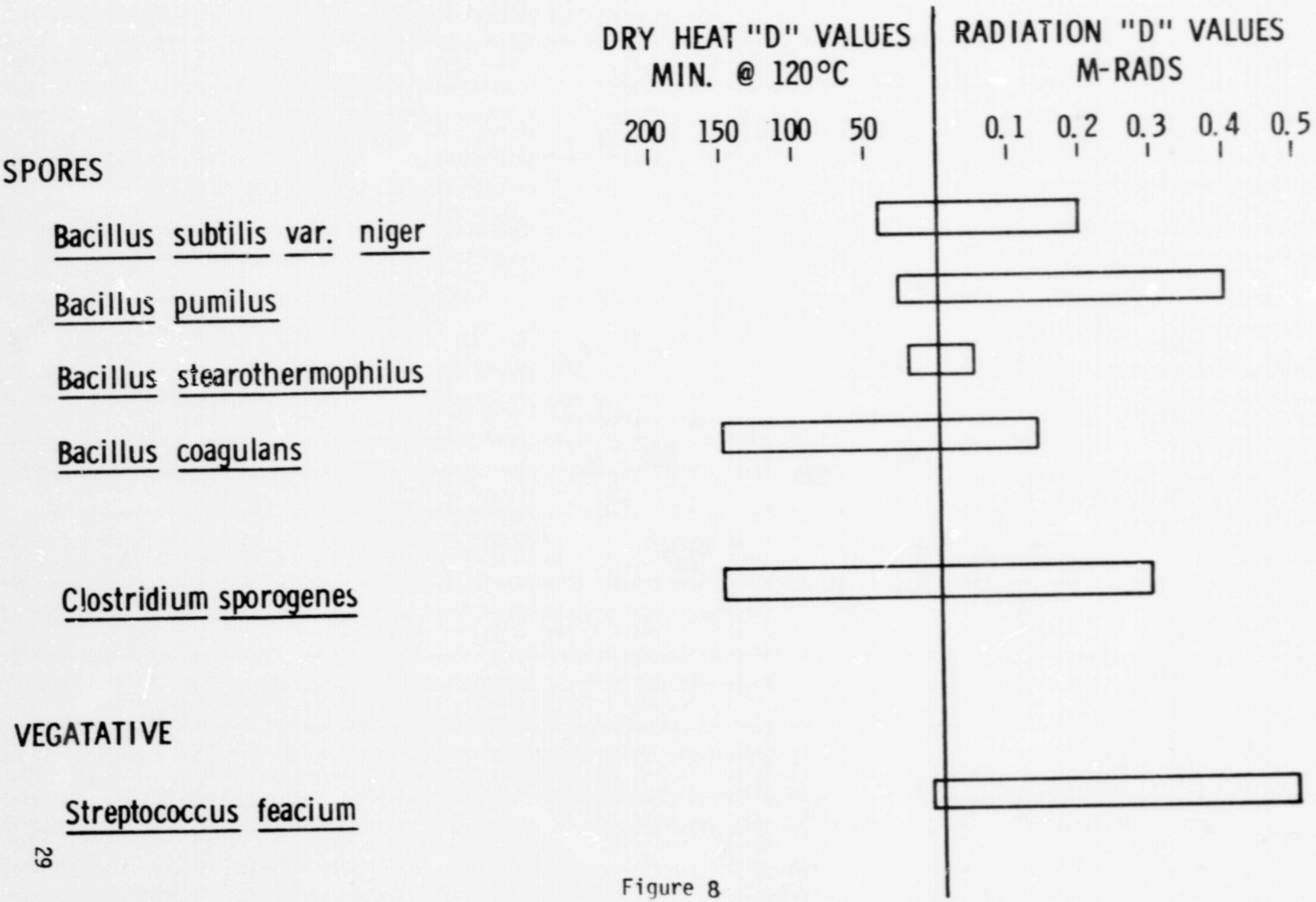



Figure 8

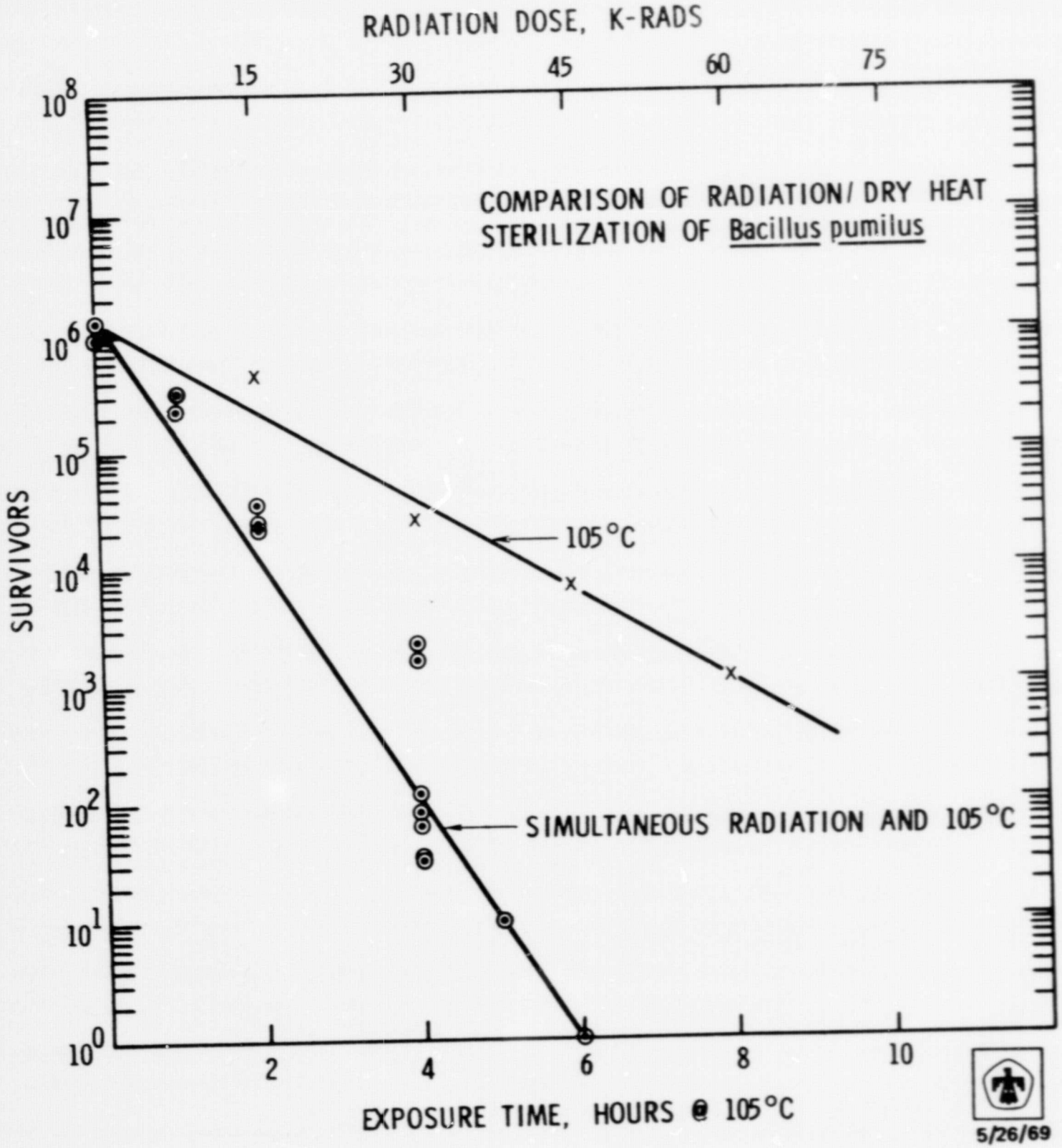

RADIATION DOSE, K-RADS
15
30
45
60
75
COMPARISON OF RADIATION/ DRY HEAT
STERILIZATION OF Bacillus pumilus
SURVIVORS
$10^8$
$10^7$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
105 °C
SIMULTANEOUS RADIATION AND 105 °C
2
4
6
8
10
EXPOSURE TIME, HOURS @ 105 °C
5/26/69

Figure 9

Evaluation of Release of Microorganisms from the Surface of the SLA During Launch

A. Description. Since the Spacecraft-Lunar Module Adaptor (SLA) contains the Lunar Module (LM) during launch one of the problems which must be considered in evaluating the microbial load which reaches the lunar surface is the possibility that microorganisms on the interior of the SLA may be transferred to the LM during launch. Because P.H.S. figures indicate that the microbial load on the LM exterior is probably of the order of $10^6$ microorganisms while the load on the interior of the SLA may approach $10^8$, even a small percentage transfer may be important.

B. Progress. An estimate of the percentage of transfer from the SLA to LM during launch was completed this quarter. This estimate was made by comparing the expected forces of adhesion and estimated vibrational forces acting on a particle attached to the interior of the SLA.

Forces of Adhesion. The forces which will hold particles on the surfaces of the interior of the SLA may depend upon many factors. Some of those which have been discussed in the literature are:

- Molecular Forces
- Electrostatic Forces
- Relative Humidity
- Temperature
- Surface Roughness
- Particle Shape and Size
- Aggregation
- Surface Contaminants
- External Field Forces
- Surface and Particle Composition
- Contact Time

Most of these factors are not completely understood and the prediction of the actual forces which cause particles to adhere to surfaces can only be approximated.

To be more specific, the effects which temperature, aggregation, surface contaminants and contact time have on these forces have been ignored because of a paucity of data in the literature. Due to a lack of specific information about the surface of the SLA interior and the particles attached thereto, it was assumed that their combined behavior was similar to quartz on quartz and that the particles of concern were spherical.

The forces of adhesion attributable to relative humidity seem to be due to liquid surface tension. Lacking data on relative humidity a conservative value of zero was assumed for these adhesion forces.

Assuming a conservative maximum particle charge of 10 electron units, and a surface particle separation of 5 angstroms, the electrostatic adhesion force was calculated to be $5.7 \times 10^{-6}$ dynes. Assuming a particle density of 2 $gm/cm^3$ (a common assumption), the gravitational force of adhesion is a maximum of $1.0 \times 10^{-3}$ dynes.

The major adhesive force seems to be due to the molecular forces between surface molecules and the particle in question. For a particle on a flat surface, this force is approximately

$$F = \frac{A}{h^2} d$$

where d is the diameter of the (spherical) particle, h the separation distance between particle and surface and

$$A = \pi^2 \lambda N^2$$

where $\lambda$ and N are the Van der Waals constant for attraction and the number of molecules per cubic centimeter of the surface, respectively. This expression takes into account particle shape, and particle and surface composition. For quartz spheres on a quartz surface A is approximately $0.05 \times 10^{-12}$ ergs in air. This is conservative when compared with many others associated with different surface and particle compositions.

Again, using a separation distance of 5 angstroms, the force F on a particle of diameter, say, 10 microns would be about 2 dynes, making this force the dominant one of those considered.

Forces of Vibration. Vibrational forces are assumed to be the major forces involved in particle release for SLA surfaces during launch. The only data related to the vibration which the SLA experiences during launch that were available to us occur in a document entitled, "Revised LM Equipment Vibration Test Requirements Based on LTA 3 Dynamic Testing". Since these are test requirements, it is assumed that they are conservative in nature; that is, are stronger than the equipment really experiences. To be conservative, it was assumed that the maximum random vibrations which the LM experiences during launch are the same as those experienced by the SLA.

Figure 10 gives the random vibrations requirements for the X axis of the ascent and descent stage umbilical cutter. This appears to be higher by several factors than that experienced by any other piece of equipment on the LM. This leads to a mean square acceleration of 34.64 g, and this is assumed to take place at every point on the SLA during launch.

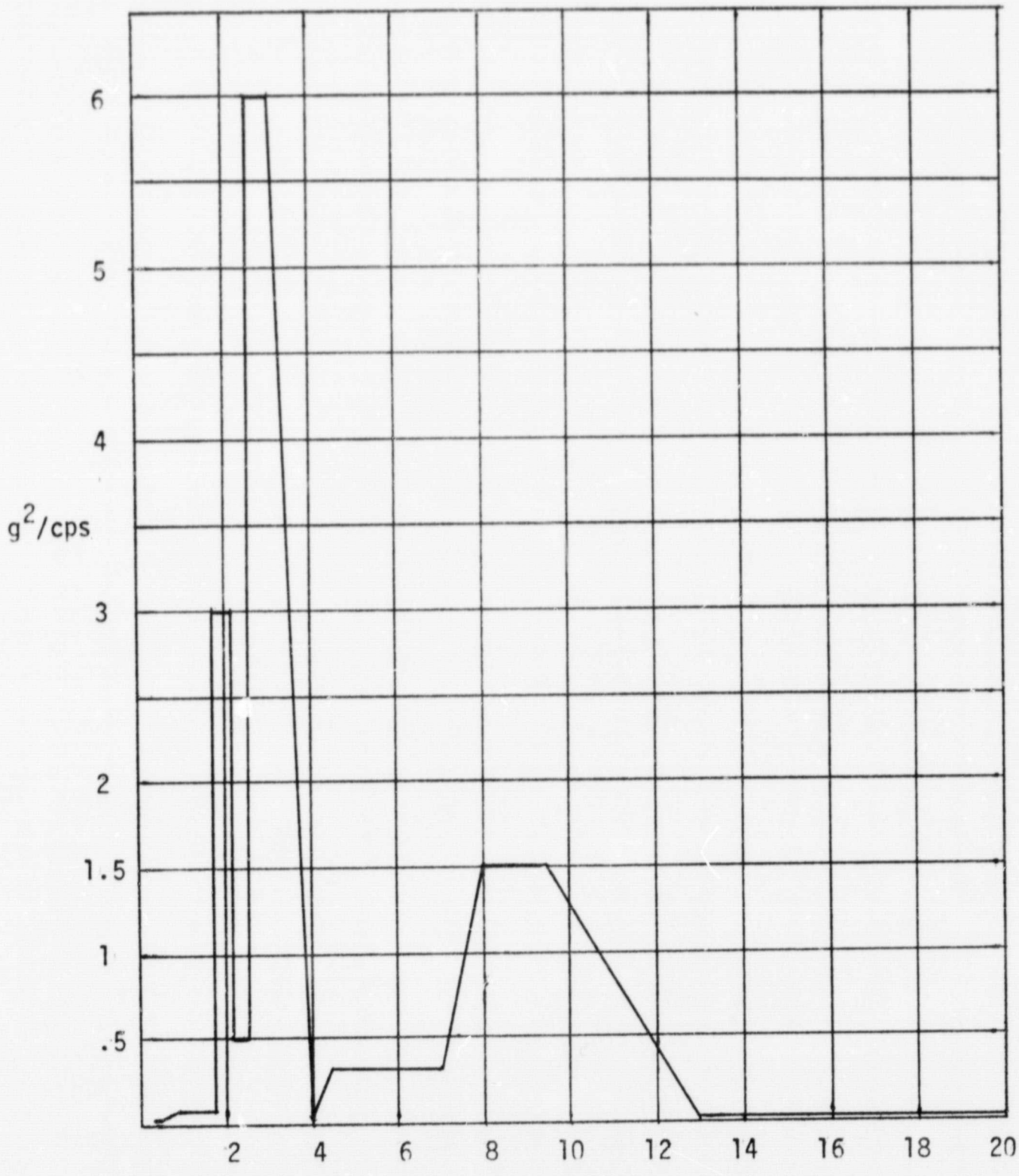



Figure 10

Using the 2 $\sigma$ estimate, we can assume that no point on the SLA sees more than a 100 g acceleration at launch.

Percentage of Interior SLA Bioburden Transferred to LM. The dominant retention force for particles with diameters between, say, 1 and 100 microns was found to be molecular in character. By assumption, the removal forces are caused by vibration. Under these circumstances, a particle of mass m will be dislodged from the surface when its acceleration, a, from vibration is such that

$$ma > \frac{Ad}{h^2} .$$

When the particle density $\rho$ = 2 gm/cm$^3$, A = 0.05 x 10$^{-12}$ ergs, and h is 5 angstroms,

$$m = \frac{1}{6} \pi d^3 \rho$$

and a = 100g,

$$d^2 > \frac{6A}{\pi h^2 \rho \cdot a} = 1.9 \times 10^{-6} \text{ cm}^2$$

or d must exceed 14 microns to be removed.

Studies have shown that naturally occurring organism bearing particles generally have diameters in the 4 to 20 micron range. By considering the size distribution of particles in a class 100,000 clean room, approximately 9% of particles with diameters between 4 and 20 microns lie between 14 and 20 microns.

Extrapolating from particles to organisms, we conclude that roughly 10% of the organisms on the SLA interior may become released during

launch. Conservatively, it may be assumed that all of these become attached to the LM, half on the descent stage exterior and half on the ascent stage exterior.

Publications

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B. A. L. Roark, "A Model for the Quantification of the Qualitative Microbial Sampling Problem", SC-RR-69-310, Sandia Laboratories Research Report, May 1969.

Presentations

A. H. D. Sivinski, "Contamination Control: Serendipity or a Discipline", presented at American Association for Contamination Control 8th Annual Technical Meeting on May 21, 1969, New York, New York.

B. W. J. Whitfield, "Monitoring for Particle Contamination on Surfaces with the Vacuum Probe Sampler", (same as above) May 20.

C. J. W. Beakley, "Production of Aerosols of Viable Particles of Different Sizes", (same as above) May 22.

D. M. E. Morris, "Acoustic Dust Feeder", (same as above) May 22.

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