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PROJECTILE IMPACT IGNITION CHARACTERISTICS OF PROPELLANTS

FINAL REPORT

W. H. ANDERSEN

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SHOCK HYDRODYNAMICS DIVISION
WHITTAKER CORPORATION
4716 VINELAND AVENUE
NORTH HOLLYWOOD, CA 91602

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The results of an investigation of the projectile impact ignition characteristics of propellants are described. Impact tests were conducted on two composite explosive propellants to determine effect of material porosity and particle size on initiation characteristics. The tests were conducted by firing different diameter, flat-nosed brass projectiles into small cylinders of the propellant at various velocities and observing the impact reaction by various sensors.

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The general behavior of the propellants to impact was the same as the standard propellant. Porosity sensitized the propellant to both impact burning and detonation, but the effect was relatively small. On the other hand, the presence of large explosive particles had a very large effect on sensitizing the propellant to impact burning and detonation.

The results of the studies resulted in the development of a semiquantitative model that appears to have great practical utility in predicting impact and shock initiation behavior over a wide range of conditions on the basis of the results of one or two relatively simple experiments. In addition, various aspects of impact ignition were examined in quantitiative detail.

TABLE OF CONTENTS

Page

1. INTRODUCTION 5

2. EXPERIMENTAL IMPACT STUDIES 5

3. ANALYSIS OF SHOCK INITIATION MECHANISM 9

3.1 Model For Calculating Critical Shock Initiation 9

3.1.1 Effect of Explosive Thickness on Initiation Behavior . . 12

3.1.2 Alternative Model Development 12

3.2 Other Analytical Studies 13

3.2.1 Energy Partition in an Impacted Composite Propellant . . 13

3.2.2 Miscellaneous Studies 13

4. CONCLUSIONS 13

REFERENCES 18

APPENDIX A. Publications and Reports Published 19

APPENDIX B. Participating Scientific Personnel 19

LIST OF FIGURES

Figure | Page

1 Impact Initiation Behavior of the Porous Propellant. 6

2 Impact Initiation Behavior of the Coarse (Large Particle) Propellant. 7

3 Impact Initiation Behavior of the Composite Explosive Propellant. 8

4 Calculated and Experimental Run Distance to Detonation for PBX-9404 and TATB. 10

5 Calculated and Experimental Run Distance to Detonation for PETN, Pressed and Cast TNT, and Composite HMX Explosive. 11

6 Computed Shock Compression of the Propellant Ingredients 14

7 Computed Shock Temperature vs Pressure. 14

8 Computed Shock Hugoniot of the Composite Propellant 15

9 Shock Hugoniots and Impact Properties of HMX and Composite Propellant with a Brass Projectile. 16

1. INTRODUCTION

The response of an explosive or propellant to projectile impact or shock depends on the initiation characteristics of the material. However initiation is a complex phenonenon, and inspite of significant effort over the years there is still much to be learned on the subject.

For the past three years Shock Hydrodynamics has been conducting studies toward obtaining a more basic and improved understanding of impact ignition, and the factors that control impact sensitivity of propellants. This investigation follows an earlier program on the subject (ref. 1). Significant findings of a fundamental nature have been obtained. These findings have resulted in the development of a semiquantitative model that appears to have great practical utility in predicting shock initiation behavior over a wide range of conditions on the basis of the results of one or two relatively simple experiments. In addition, various aspects of impact ignition were examined in quantitative detail, and impact sensitivity data were obtained on two additional special propellants.

This report summarizes the results of the studies. This summary is relatively brief however, since most of the work has been published (or is in press). Details of the work are available in the original papers.

2. EXPERIMENTAL IMPACT STUDIES

In the initial program experimental projectile impact tests were conducted on various propellants to obtain a data base for examining the problem. The propellants included a composite explosive propellant (ref. 2), and a single, double and triple base propellant (ref. 3) to study the effect of composition on impact behavior.

In the present program a similar study was made of the effect of particle size and material porosity on impact behavior (ref. 4). To have a basis for comparison, the same composite explosive propellant as used in the earlier studies was employed, except for independent changes in particle size and porosity. The experimental tests were conducted in the same general manner as before. Briefly, the impact sensitivity of the propellants was studied by impacting a flat end of the samples using flat-ended cylindrical brass projectiles of different diameters (0.22, 0.257 and 0.50 caliber) fired from guns at various velocities and observing the impact reaction by an open-shutter camera, a photocell, post inspection, and weighing of the propellant fragments. The relation of the observed features of the camera pictures and photocell records to the response characteristics of the impacted propellant sample was discussed before, as was also the measurement of the projectile impacr velocity.

The results of the tests for a propellant containing 10% porosity are summarized in Fig. 1. The results for a propellant whose average particle diameter was a factor of 22 times larger than the standard propellant are shown in Fig. 2. As a basis for comparison, Fig. 3 (from ref. 2) shows the impact initiation behavior of the standard composite propellant. It may be seen that the general behavior of both the porous and coarse (large particle size) propellant to impact is similar to that obtained on the standard propellant. The porosity sensitized the propellant to both burning and detonation at large projectile

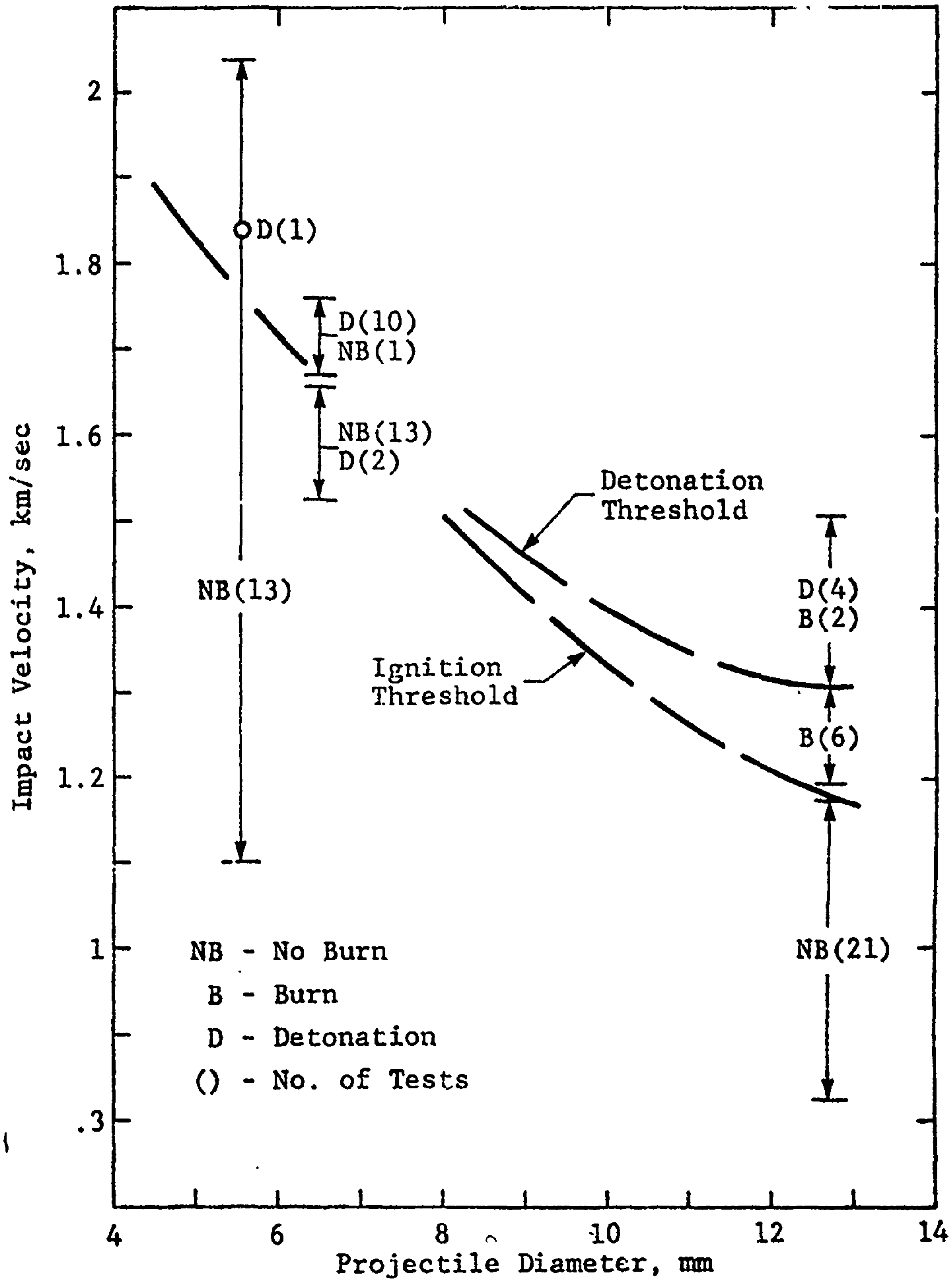

Figure 1. Impact Initiation Behavior of the Porous Propellant.

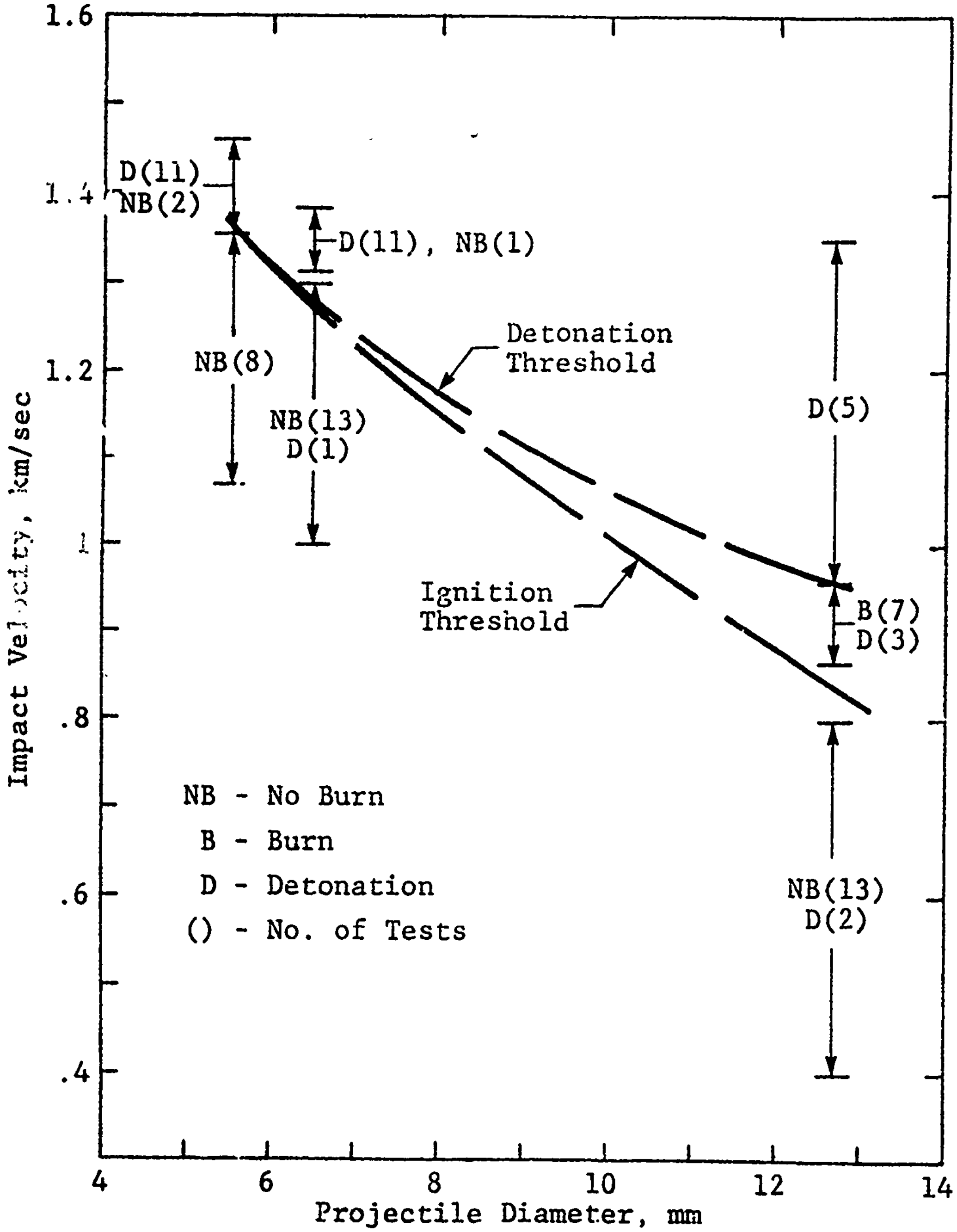

Figure 2. Impact Initiation Behavior of the Coarse (Large Particle) Propellant.

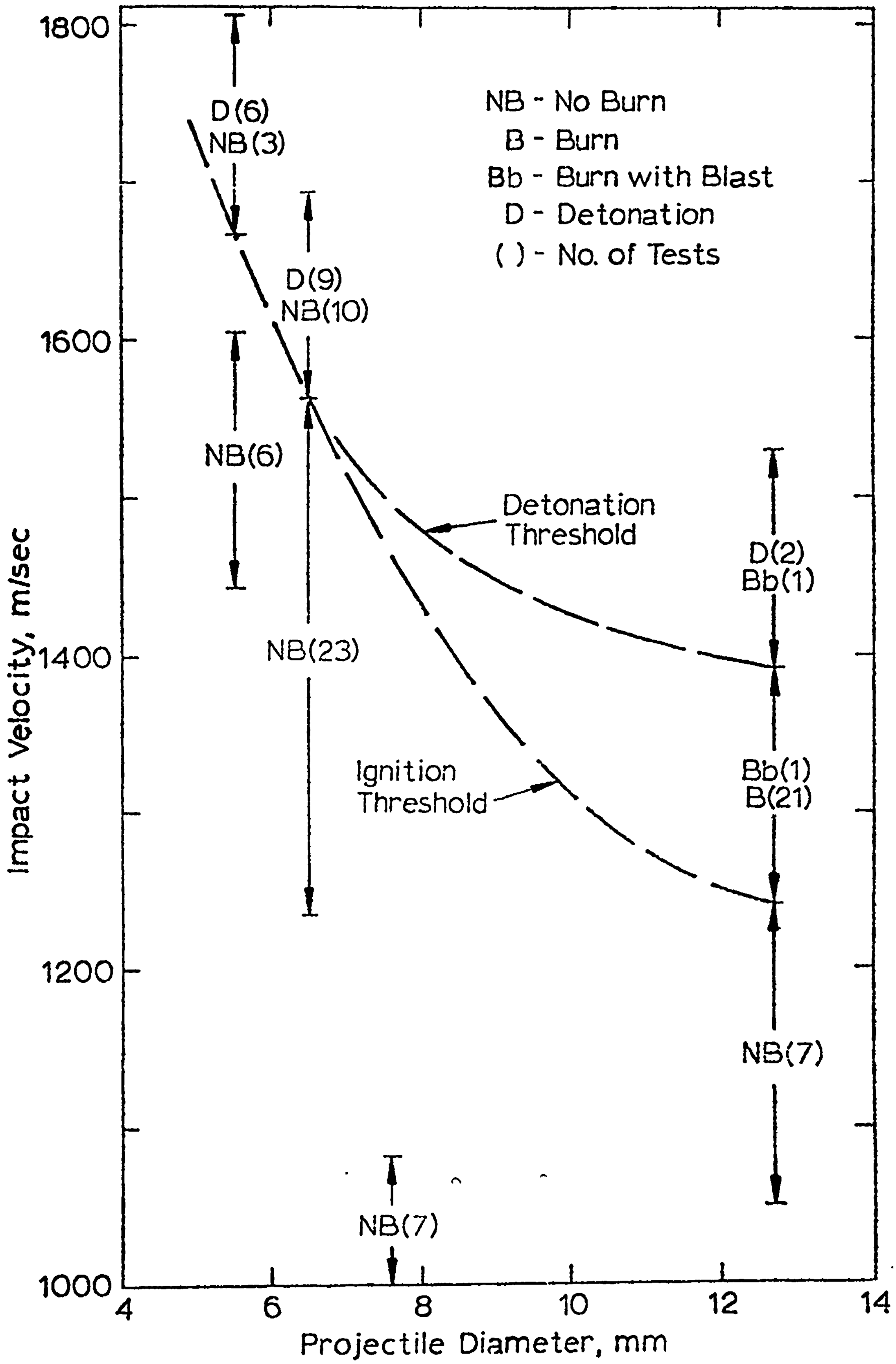

Figure 3. Impact Ignition Behavior of the Standard Composite Propellant.

diameter, but the effect was relatively small. The effect was negligible at small projectile diameter. On the other hand, the presence of large explosive particles had a very large effect on sensitizing the propellant to impact burning and detonation at all projectile diameters.

3. ANALYSIS OF SHOCK INITIATION MECHANISM

Throughout the program analytical studies were conducted on various processes that may be involved in the ignition and reaction buildup in an impacted propellant in an effort to describe the initiation event on a more quantitative basis. These studies culminated in the recent development of a semi-quantitative model that appears to have great practical utility in describing impact (and shock) initiation over a wide range of conditions on the basis of the results of one or two relatively simple experiments. In addition, various aspects of impact initiation were examined in some detail.

3.1 MODEL FOR CALCULATING CRITICAL SHOCK INITIATION

An approximate model for pressure buildup behind the front of an initiating shock wave was developed (ref. 5). This model leads to the widely used P^2t initiation criterion, but the pressure index is not limited to a value of two. Expressions for wave run time and distance to detonation were also obtained. The model can be used in several ways. If the value of C in the equation

$$P^2t = C \qquad (1)$$

is known from experiment (or can be estimated theoretically) and the shock Hugoniot is also known, then the run time and distance to detonation can be calculated as a function of shock pressure. Figure 4 shows the run distance (X_d) calculated for PBX-9404 in this manner in comparison with published experimental data. The agreement is quite good considering the complexity of the problem. However, based on the other results the small difference between the two curves could also be due in part to uncertainties in the value of C, the shock Hugoniot, or experimental run distance. One significant result of the model is that it predicts the correct general relationship between wave run time and distance to detonation and initiating shock pressure.

The experimental evaluation of C requires extensive effort. On the other hand, the measurement of X_d at one pressure is relatively simple. A second important result of the model is that this one measurement can be used in conjunction with the equations to evaluate both C and the X_d (and t_d) vs P relationship. That is, both the entire critical shock initiation conditions and run distance to detonation can be estimated on the basis of one measurement. The shock Hugoniot must also be known, but this can often be estimated satisfactorily if it is not known since it is largely a function of charge density. Figure 4 shows the theoretical run distance relationship obtained for TATB based on this procedure of using one X_d measurement. Again there is a small deviation from the experimental curve. The calculated value of C is 10,170 kbar^2 µsec, which agrees well with the value of 9,920 obtained from the critical energy given by Walker and Wasley (ref. 6).

Figure 5 shows the results of using the same procedure to estimate X_d vs P for PETN at three different charge densities. The agreement between theory and

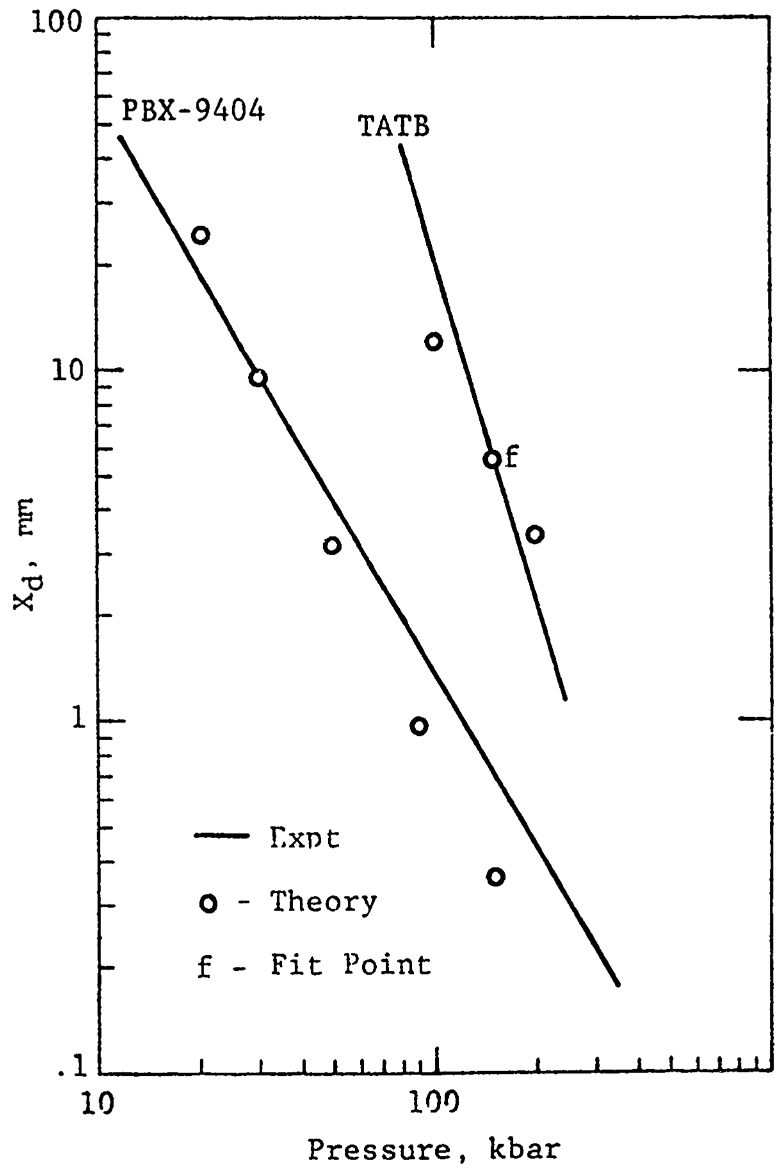

Figure 4. Calculated and Experimental Run Distance to Detonation for PBX-9404 and TATB.

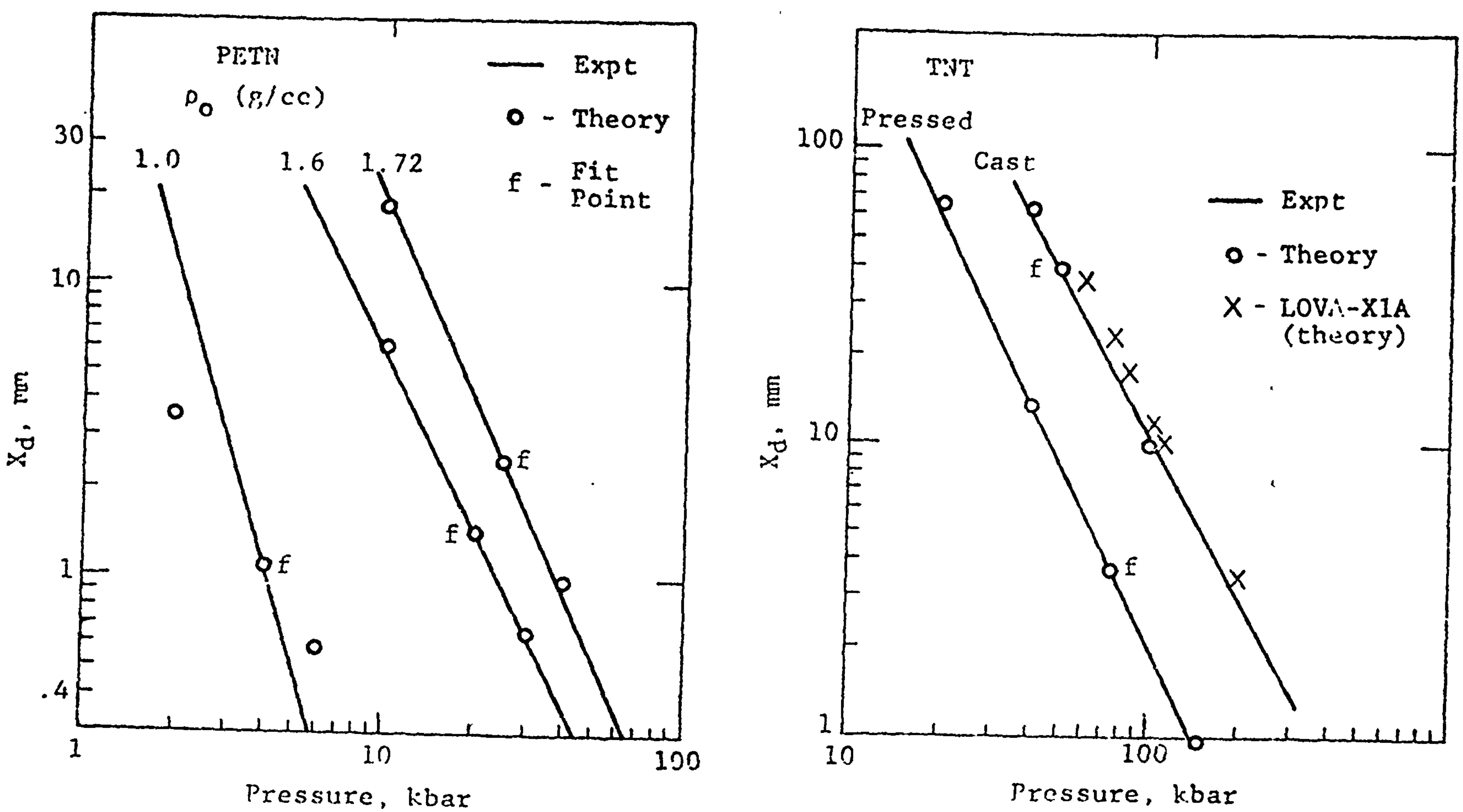

Figure 5. Calculated and Experimental Run Distance to Detonation for PETN, Pressed and Cast TNT, and Composite HMX Explosive.

experiment is excellent at the two higher densities, but there is some deviation (as before) at the lower density. Lee and Tarver (ref. 7) also found deviation, and suggested that the shock Hugoniot may be in error at this charge density. Figure 5 shows the results of using the same procedure to also estimate X_d vs P for pressed and cast TNT. Again the agreement between experiment and theory is excellent.

The preceding procedure of using one measurement of X_d to estimate both C and X_d vs P assumes that critical shock initiation conditions obey Eq. (1). However it is known experimentally that this equation is sometimes only an approximation to experimental data. According to the model, a more general relationship is of the form

$$P^k t = C_1 \tag{2}$$

where k and C_1 are experimental constants. Depending on material properties and conditions the value of k may differ from 2. Thus a possibly more accurate use of the model than just described would be to make use of two different measurements of X_d (at different P). This would allow the evaluation of k and C_1, as well as the entire X_d (and t_d) vs P relationship.

It may also be noted that if the value of C in Eq. (1) (or k and C_1 in Eq. 2) and the X_d vs P relationship are known experimentally, the model can be used to determine the shock Hugoniot of the material. It is sometimes difficult to directly measure the (inert) shock Hugoniot of an explosive accurately, because of the effect of energy release brought on by the shock wave.

3.1.1 Effect of Explosive Thickness on Initiation Behavior

The effect of material thickness on initiation behavior is of practical importance, and can be calculated using the model. The burning obtained on the standard composite propellant at the lowest critical velocity at large projectile diameter (Fig. 3) resulted because the sample thickness was less than the run distance to detonation at that impact velocity. Figure 5 shows calculated run distance for this propellant, based on experimental P^2t = 12,080 kbar^2 μsec. At a projectile diameter (d_p) of 5.56 mm, t_b = 0.946 μsec, P_s = 113 kbar, and X_d = 10.13 mm (the value of t_b is identical to pressure duration at critical conditions). At d_p = 6.5 mm, t_b = 1.105 μsec, P_s = 104.6 kbar, and X_d = 11.8 mm. Thus at these two projectile diameters the calculated X_d is less than the sample thickness (19.05 mm). and the impact initiation should result in detonation of the material (as was observed).

At d_p= 12.7 mm, however, t_b = 2.16 μsec, P_s = 74.78 kbar, and X_d = 23.16 mm. The theoretical X_d necessary for detonation is thus larger than sample thickness, and only a burning reaction should be obtained (and was observed). When the impact pressure is increased to 86 kbar, however (Table 1, ref. 2), t_b = 1.633 μsec and X_d = 17.42 mm. This value X_d is less than sample thickness, and thus a detonation should be produced under this condition (and was observed). These results indicate that the developed model has great potential for accurately describing the impact initiation characteristics of explosives and propellants.

3.1.2 Alternative Model Development

Before the development of the model just described, rudiments of an alternative model were developed to explain the P^2t initiation criterion (ref. 8, 9). In this model it was postulated that ignition delay between initially-reacted hot spots and adjacent unburned material was the cause of the critical initiation criterion. The development led to a number of interesting aspects of the problem. However it is presently believed that the model just described is more valid and also more encompassing, since it describes the time and distance for the reaction to build up into detonation as well as the critical condition for inducing the sustained reaction. The model could not have been developed without the extensive effort exerted in the ref. 8, 9 studies.

3.2 OTHER ANALYTICAL STUDIES

During the program a number of other analytical studies were conducted on various aspects of impact ignition.

3.2.1 Energy Partition in an Impacted Composite Propellant

A detailed examination was made of energy partition in an impacted or shocked solid composite propellant (ref. 10). The shock temperature of the individual components (explosive and binder) can differ because the compressibilities of the ingredients usually differ. Figure 6 shows the computed shock compression of the components of the composite propellant of Fig. 3; and Fig. 7 shows the computed shock temperature. The calculation of the shock Hugoniot of a composite propellant from the experimental Hugoniot of the components was described. Figure 8 shows that the calculated Hugoniot of the composite propellant of Fig. 3 is in good agreement with experiment. Figure 9 shows how the addition of a binder to an explosive (to form a propellant) reduces the impact pressure exerted on the explosive for an impact velocity of 1400 m/sec. The binder thus reduces the impact sensitivity of the explosive.

3.2.2 Miscellaneous Studies

The sensitivity of a propellant to a specified shock pressure can vary, depending on the time history of pressure application, and the dimensions of the material sample. Different test methods usually produce different pressure histories. The problem was discussed in ref. 11, and the projectile impact sensitivity of the composite propellant of Fig. 3 compared with other test methods and explosive materials.

In ref. 12 a new and improved method of estimating the adiabatic exponent of the detonation products of an explosive was discussed. It was shown why conventional computational methods usually have difficulty in accurately calculating the detonation properties of special explosive compositions that give a preponderance of either water, carbon dioxide or fluorine compound as the detonation products. This paper seemed to stir quite a little interest in the explosive community.

Some other miscellaneous studies were also conducted related the formation and nature of hot spots that are produced by impact and shock. These studies did not reach the stage that tangible results were produced, but some of the work may eventually bear fruit.

4. CONCLUSIONS

The results of this investigation have provided new experimental information and improved understanding regarding impact ignition. The findings have resulted in the development of a semiquantitative model that appears to have great practical utility in predicting shock initiation behavior over a wide range of conditions

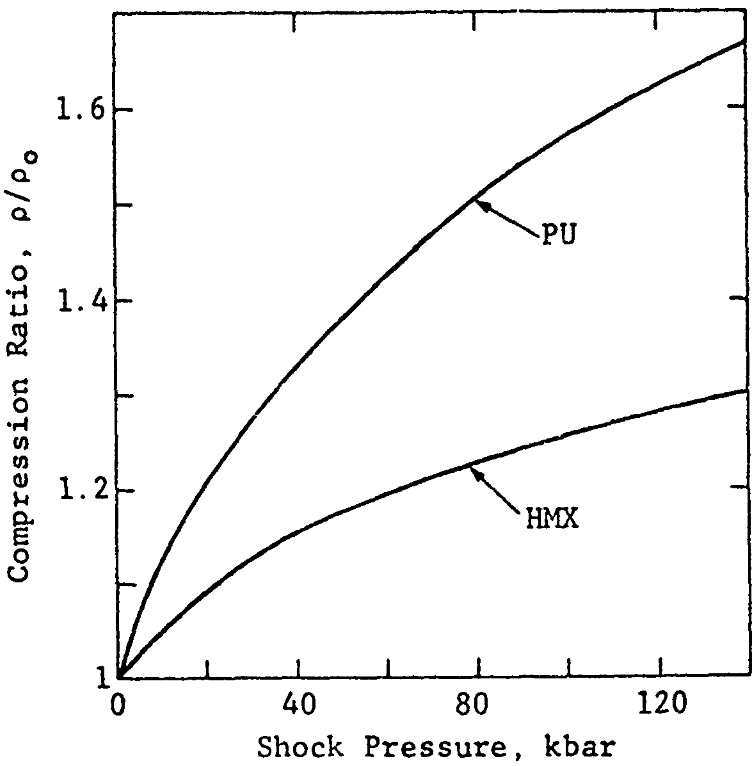

Figure 6. Computed Shock Compression of the Propellant Ingredients.

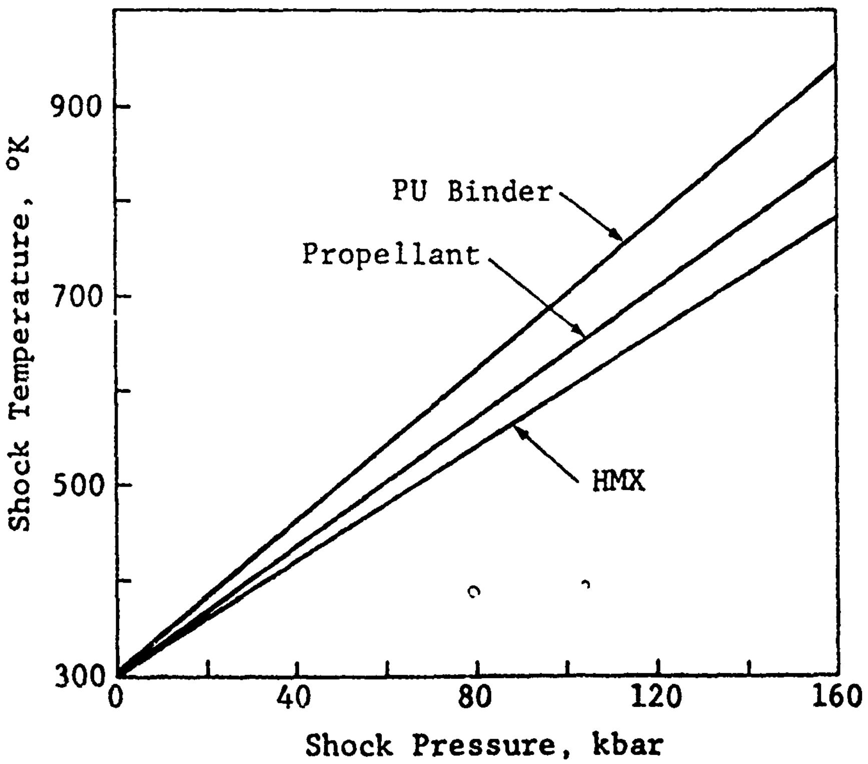

Figure 7. Computed Shock Temperature vs Pressure.

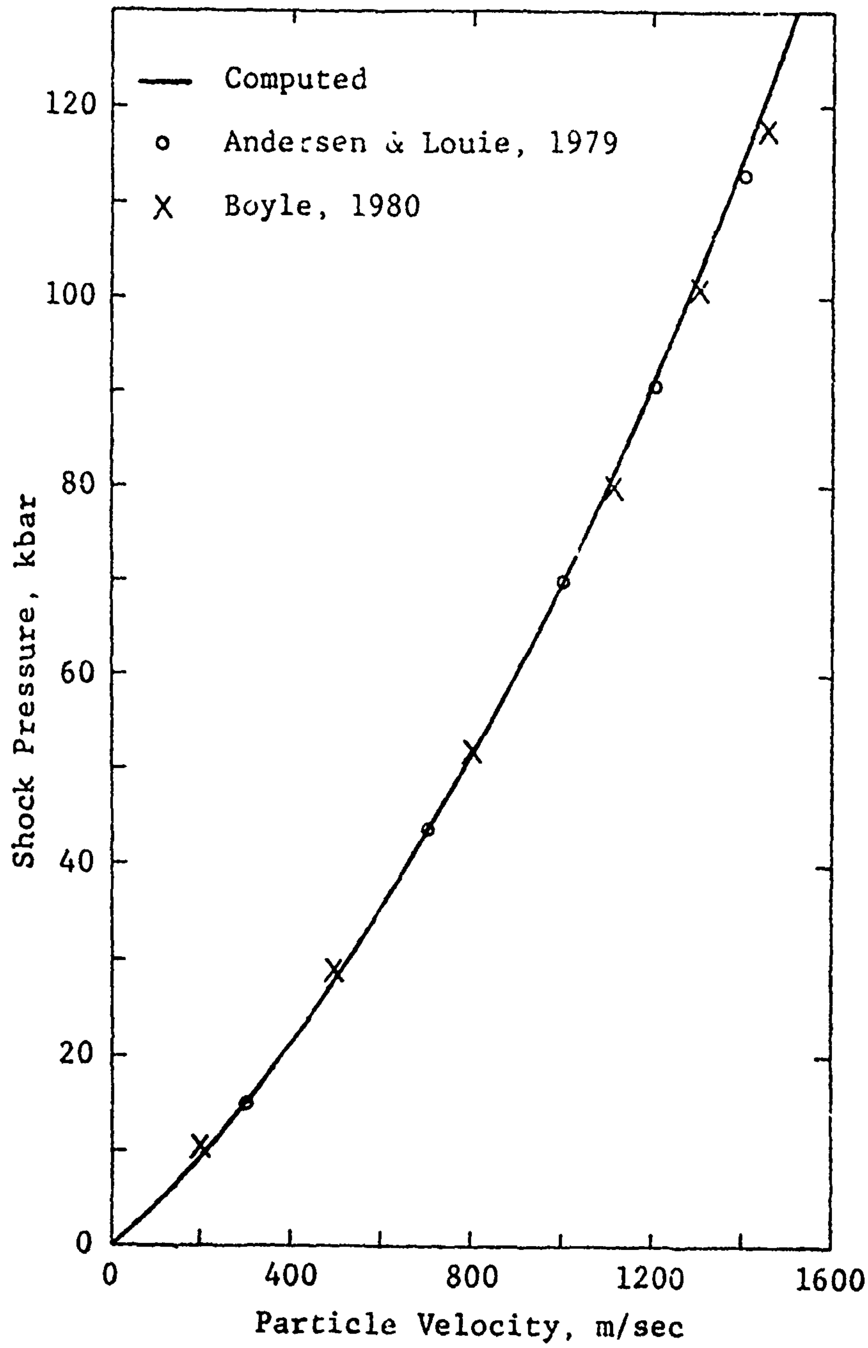

Figure 8. Computed Shock Hugoniot of the Composite Propellant.

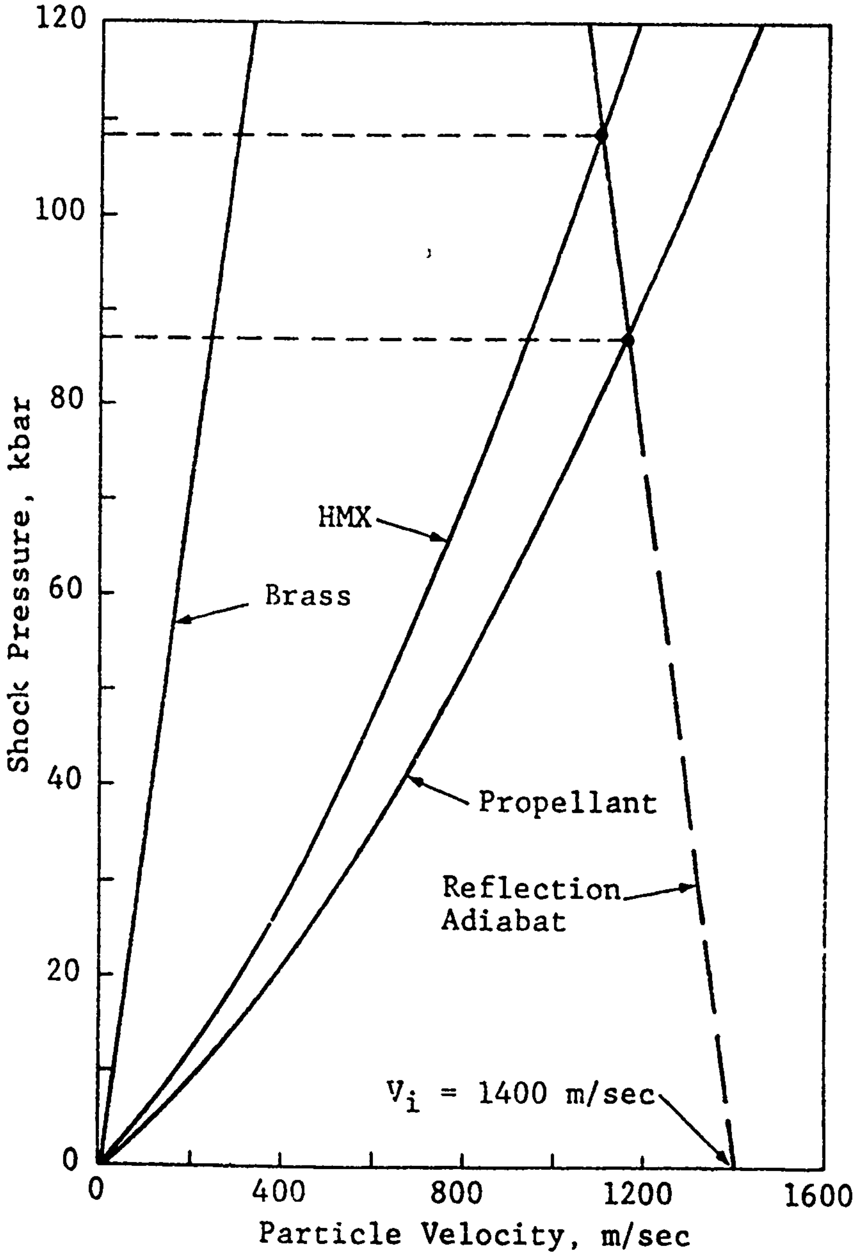

Figure 9. Shock Hugoniots and Impact Properties of HMX and Composite Propellant with a Brass Projectile.

on the basis of the results of one or two relatively simply experiments. Further studies should be conducted to further improve the model, particularly with regard to making it's predictive capability apriori in nature.

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APPENDIX A

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APPENDIX B

PARTICIPATING SCIENTIFIC PERSONNEL

W. H. Andersen
L. F. Polak
G. P. Stillman