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MINUTES

of the Second EXPLOSIVES SAFETY SEMINAR on HIGH-ENERGY SOLID PROPELLANTS

Held at the
Redstone Arsenal, Huntsville, Alabama
on
12-14 July 1960

Armed Services Explosives Safety Board
Washington 25, D. C.

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PREFACE

Most of the discussion at the Seminar required no security classification. Certain discussions were classified "Confidential." Each page of these minutes has been stamped to indicate whether or not it contains "Confidential" information or is "Unclassified."

Further exchange of information on how to prevent explosive accidents is encouraged. It is suggested that any questions on portions of discussions be directed to the appropriate speakers, or their sponsoring agencies, rather than to the Armed Services Explosives Safety Board. This will expedite answers and will promote direct exchange of information between principals, which can be so effective in promoting safety.

Please advise the Armed Services Explosives Safety Board of any corrections to be made in these minutes, and errata sheets will be prepared.

The contribution to the cause of promoting explosives safety, by those who devoted valuable time and effort to this Seminar, is very much appreciated.

A. W. HAMILTON
Colonel, OC, USA
Chairman
Armed Services Explosives Safety Board

PARTICIPANTS

Name	Activity
Ackerman, Mr. H.	ARDC, Andrews AFB, Md.
Ahlgren, Mr. Chas.	Army Chemical Center, Md.
Albrecht, Mr. Geo. H.	Johns Hopkins University
Atkisson, Mr. J. B.	Jet Propulsion Lab, CalTech, Pasadena, Calif.
Averill, Mr. C. F.	Grinnell Corp.
Ball, Dr. A. M.	Hercules Powder Co.
Ball, Lt. K. O. W.	Ballistic Missile Div., Dept. of the Air Force
Barr, Mr. C. J.	Olin Mathieson Chemical
Barton, CWO E. E.	AFSWC, Kirtland AFB, N. M.
Belmont, Maj. A. J.	AEC, Wash., D. C.
Bice, Mr. H. C.	E. I. du Pont de Nemours & Co.
Bishoff, Mr. F. M.	OCO, Dept. of the Army
Blackburn, Mr. H. C.	CML, Dept. of the Army
Breeding, Mr. C. A.	ASESB
Brinkley, Mr. H. L.	ORDSO, Dept. of the Army
Brzezinski, Mr. S. J.	BuWeps, Dept. of the Navy
Burket, Dr. S. C.	Aerojet-General Corp.
Buxton, Mr. W. W.	Aerojet-General Corp.
Carleton, Mr. L. T.	Aerojet-General Corp.
Cascio, Mr. J. S.	NWL Dahlgren, Va.
Chelko, Mr. L. J.	NASA
Cole, Mr. J.	Aberdeen Proving Ground, Md.
Comisky, Capt. B. J., Jr.	Longhorn Ordnance Works, Texas
Connelly, Mr. J. W.	CNO, Dept. of the Navy

Cotner, Mr. G. R.	NOTS China Lake, Calif.
Cox, Mr. E. W.	LPIA, Johns Hopkins University
Crawford, Mr. J. R.	Thiokol Chemical Corp.
Crowder, Mr. V. D.	PMR Point Mugu, Calif.
Cunningham, Mr. J. C	Arnold Engineering Dev. Ctr.
Davidson, Mr. T.	ARGMA Redstone Arsenal
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Deans, Mr. H.	CRDSO, Dept. of the Army
Del Mar, Lt. Col. H. R.	AOMC, Redstone Arsenal
Dodgen, Cdr. J. E.	NPP Indian Head, Md.
Donaldson, Mr. P. A.	NOTS China Lake, Calif.
Drager, Mr. H. W.	DASA Field Command, Sandia Base
Dreyer, Capt. O. F.	BuWeps, Dept. of the Navy
Driscoll, Capt. T. W.	Ravenna Arsenal, Ohio
Duguid, Dr. R. H.	AEHL, Army Chemical Center, Md.
Dyer, Mr. H. C.	AOMC, Redstone Arsenal
Earl, Mr. W. A.	ALOO, USAEC
Economy, Mr. Gus	OOAMA, Hill AFB, Utah
Eilerman, Mr. R. N.	NASA, Huntsville, Ala.
Endsley, Mr. D. E.	Hq USAF, Wash., D. C.
Erway, Dr. John	OSWAC, Dover, N. J.
Estus, Mr. L.	Hercules Powder Co.
Fawcett, Mr. E. M.	Hercules Powder Co.
Ferrell, Mr. Elmer	ARGMA, Redstone Arsenal
Fleming, Dr. F. A.	Minn. Mining & Mfg. Co.

Fox, Mr. R. D.	Dow Chemical Co.
Gaylord, Mr. A.	Aerojet-General Corp.
Graham, Mr. D. I., Jr.	ARGMA, Redstone Arsenal
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Hamilton, Col. A. W.	ASESB
Haney, Mr. C. J.	DASA, Wash., D. C.
Haninger, Mr. V. E.	ICC
Hankins, Mr. B.	ABMA, Redstone Arsenal
Harbarger, Mr. J. F.	Thiokol Chemical Corp.
Harrington, Mr. J. L.	Hayes Aircraft Corp.
Hayden, Mr. W. G.	Thiokol Chemical Corp.
Heeseman, Mr. Adolph	Grand Central Rocket Co.
Herczogh, Mr. J. H.	OCT, Dept. of the Army
Herman, Mr. Robert C.	ASESB ✓
Hickerson, Mr. Ora D.	Iowa Ordnance Plant
Hikel, Col. T. R., USAF (Ret.)	Boeing Airplane Co.
Hill, Mr. T. P.	Day & Zimmerman, Inc.
Hindle, Mr. R. R.	NASA
Hinrichs, Mr. H.	ARGMA, Redstone Arsenal
Hinson, Mr. P. C.	Iowa Ordnance Plant
Holmes, Mr. W. C., Jr.	Boeing Airplane Co.
Hough, Mr. F. Z.	BuWeps, Dept. of the Navy
Jezek, Mr. Louis	OCO, Dept. of the Army
Johnson, Dr. O. H.	BuWeps, Dept. of the Navy

Julian, Mr. E. C.	NOTS China Lake, Calif.
McKenna, Mr. W. G.	Bureau of Explosives
Kilgore, Mr. D. B.	AMC, Wright-Patterson AFB, Ohio
Kincannon, Mr. M. T.	DASA,Field Command, Sandia Base
King, Mr. P. V.	Aberdeen Proving Ground, Md.
Kinkel, Mr. G. A.	NOTS China Lake, Calif.
Kirby, Maj. R. D.	AF Plant 66, McGregor, Texas
Knapp, Dr. C. L.	ESSO Research & Engr. Co.
Lang, Mr. Robert	OAC, Joliet, Ill.
Lay, Mr. C. W.	Radford Arsenal
Leigh, Mr. C. S.	AMCEL Propulsion, Inc.
Lerwill, Mr. R. J.	R&D Command, Army Chemical Corps
Leyrer, Mr. H. J.	Ralph Parsons Co.
Lineberry, Mr. L. M.	Pan American World Airways, Cape Canaveral
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McCarty, Capt. M. D.	AFSWC, Kirtland AFB, N. M.
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McComb, Mr. T. M., Jr.	NASA
McCullough, Cdr. H. R.	BuWeps, Dept. of the Navy
McDowell, Mr. R. C.	OCO, Dept. of the Army
McElroy, Mr. S. H.	NWL Dahlgren, Va.
McGuffie, Capt. J. T.	Iowa Ordnance Plant
Mann, Mr. B. C.	NPP Indian Head, Md.
Marsh, Mr. H. N.	ASESB

Mays, Mr. Frank	White Sands Missile Range
Messersmith, Mr. E.	Rocketdyne
Miller, Mr. D. E.	Office of the General Counsel, Dept. of the Army
Minnich, Mr. B. H.	Rocketdyne
Mitchell, Mr. C. W.	ABMA, Redstone Arsenal
Moder, Mr. C. L.	Picatinny Arsenal
Molloy, Mr. J. J.	Rocketdyne
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Patteson, Mr. J. W.	Radford Arsenal, Va.
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Queen, Mr. W. G.	OCO, Dept. of the Army
Reddings, Mr. P.	ABMA, Redstone Arsenal
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Richardson, Mr. R. H.	Hercules Powder Co.
Ridosko, Mr. J.	AFSWC, Kirtland AFB, N. M.
Roberts, Mr. L. L.	NASA, Huntsville, Ala.
Roylance, Mr. H. M.	BuWeps, Dept. of the Navy

Rumbel, Mr. K. E.	Atlantic Research Corp.
Saffian, Mr. L. W.	Picatinny Arsenal
Schaefer, Mr. W. E.	E. I. du Pont de Nemours & Co.
Schnier, Mr. G. A.	American Potash & Chemical
Schultheis, Mr. Frank	White Sands Missile Range
Settles, Mr. J. F.	Hercules Powder Co.
Shouldice, Mr. Darcy	United Technology Corp.
Siklosi, Mr. A. E.	Picatinny Arsenal
Skovgard, Mr. F. E.	Grand Central Rocket Co.
Skogstad, Mr. Leif	Rocketdyne
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Smith, Mr. H. H.	Air Research Organization, Inc.
Smith, Lt. Cdr. H. L.	BuWeps, Dept. of the Navy
Smith, Mr. R. G.	NASA, Huntsville, Ala.
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Stevenson, Mr. K.	Rohm & Haas Co.
Stewart, Lt. Col. E.	Deputy IG for Safety, Hq, USAF
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Uline, Mr. W. A.	Bendix Corp., Huntsville, Ala.
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Umlauf, Maj. J. L.	Ballistic Missile Div., Dept. of the Air Force
Van Landingham, Mr. E. E., Jr.	NASA
Van Patten, Mr. E. W.	OSWAC, Dover, N. J.

Vernon, Mr. T. E.	OOAMA, Hill AFB, Utah
Visnov, Mr. M.	Frankford Arsenal
Voegtly, Mr. R. O.	Callery Chemical Co.
Wachtell, Mr. S.	Picatinny Arsenal
Wainright, Mr. R. B.	American Cyanamid Co.
Waite, Mr. J.	ABMA, Redstone Arsenal
Watz, Mr. J. O.	ABMA, Redstone Arsenal
Webb, Mr. C. E.	NWL Dahlgren, Va.
Webb, Mr. J. E.	ARGMA, Redstone Arsenal
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Whitfield, Capt. M. L.	DASA
Wigger, Mr. G. F.	OCE, Dept. of the Army
Wilkenson, Mr. T. H.	DCS/Personnel, Dept. of the Army
Williams, Mary M.	NOTS China Lake, Calif.
Williams, Mr. R. O.	Pan American World Airways
Wilson, Mr. A. W.	Dow Chemical Co.
Wright, Mr. D.	ARGMA, Redstone Arsenal
Wysor, Mr. R. B.	Hayes Aircraft Corp.
Young, Mr. R. E.	Picatinny Arsenal

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Col. A. W. Hamilton, OC, USA, Chairman, ASESB: General Schomburg, Mr. Marsh, Col. McCloskey and gentlemen, I am Col. Hamilton, Chairman of the Armed Services Explosives Safety Board, the agency which is sponsoring this meeting. I will be acting as moderator which means that I will be up in front of you every few minutes just about like a TV commercial. I promise you that I'll keep the commercials as short as possible. Our hosts for this conference are the Army Ordnance Missile Command and the Redstone Arsenal. It's a pleasure to present the Commanding Officer of the Redstone Arsenal, Col. McCloskey.

Col. O. T. McCloskey, OC, USA, Commanding Officer, Redstone Arsenal: Gentlemen, it's with pleasure that I welcome you to Redstone Arsenal. For some of you this may be your first visit, for others it's one of many visits, but to all of you I'm delighted that you are here. We're privileged to be the hosts for the Safety Seminar on High-Energy Solid Propellants. We want your visit to be interesting, pleasant and profitable and we feel that it will be and if at any time during your stay here, I or any of my staff can be of assistance, do not hesitate to call upon me. I've reviewed your agenda, feel that it is extremely important and informative. Again, welcome to Redstone Arsenal and at this time it gives me great pleasure to present to you the Commanding General of the Army Ordnance Missile Command, Major General August Schomburg.

Major General August Schomburg, USA, Commanding General, US Army Ordnance Missile Command: Thank you. I think I'd like to be a little philosophical to start off here. You know competition is a fine thing, as a matter of fact it's the American way of life. Just recently I've had some discussions here regarding the way we do our business and the way we contract with industry in the use of cost plus fixed fee contracts and firms that do almost all of their business with the Government and how perhaps some of them lose a little incentive when they do too much of that type of work, so once again I say competition is a fine thing. It's probably a fine thing even among the Services to a certain extent. I'm not sure that the competition between say Bomarc and Hercules or Polaris and our own Pershing, there's even some good there. Certainly the competition between Zeus and our own ICBM's and IRBM's, this is going to help all of these missiles. They will be better as a result I'm quite sure. But you people are unique, I don't think you have any room for competition. I'm sure you have many lost-time accidents and that sort of thing yes, but that's only a yardstick to see how we're doing. But the fact that you're all here today I think is good proof that we don't have room for competition in the explosives safety business. The fact that you're here on a basis of free interchange of information is ample proof of that and of course, this idea has caught hold. I know you met last year at the Naval Propellant Plant and had a fine successful meeting there with a hundred people present. I think your meeting this year is almost twice that big so there is no question about how this has caught hold. Of course the fact that you are here this year, I think we have to thank our good friend Henry Marsh. I understand it was his idea to come here this year, so Henry, at least from me personally, thank you very much. Back to competition a little bit, I was rather amused yesterday, I was going over part of your schedule, as you know tomorrow afternoon we want to show you around this place and I see you're going to one of the test sites and I think this will be good. The test site that we blew up last year, you're going to get all the information about it. You'll be shown just how not to build a test stand, in this particular case we were testing a solid propellant motor and we ended up by laying a ton of concrete on top of our instrument van. But talking about competition again, you're not going to get quite the whole story. The motor that blew this one up is a pet of ours and we're not going to tell you which one it was I understand, but we'll take a lot of pleasure nevertheless in showing you around the Arsenal here. I'm certainly pleased that you're here for that. Your agenda looks most impressive and of course this is just the kind of thing we need, a complete interchange of information so all of us can do this job better. A most successful meeting to you.

Col. Hamilton: We'll now hear from a gentleman who is very well known to most of you. For many many years he was the Manager of the Smokeless Powder Division, Hercules Powder Co. and he recently served as Deputy Assistant Secretary of the Army for Logistics. At the present time he is the Vice President of the American Ordnance Association in charge of all its technical committees and is a consultant to the Secretary of the Army and to the Armed Services Explosives Safety Board, Mr. Henry Marsh.

Mr. Henry Marsh, Vice-President, AOA: General Schomburg, Col. Hamilton, it's always a pleasure to get together with a bunch of people who's primary interest is improving the safety situation. Any time that we play around with things that are hazardous and dangerous, we have safety problems. It's nice to have all of you here, it's nice to see so many old friends and I hope maybe I'll get better acquainted with more of you before we get through. We had our first ASESB Seminar at Indian Head last year and there was a question raised whether we should have another one. There have been things that have happened and there has been technological progress and so there is a good reason for getting the crowd together again. We are happy that Redstone was willing to have us down here and to make use of these very excellent facilities and we thank them for their hospitality in letting us come. This morning the weather seems to be all right and we hope that it stays that way. The big thing is that we do want all of you to exchange safety information early and alert one another to the possibilities of trouble in order to develop the best practice that may save a life. May I for the Board, welcome you to this second meeting. May I urge free and open discussion, please do not for company advantage, hold back any evidence or facts that will improve the overall safety picture. During the past three months, one of the first tests in a proposed series has raised a most serious question as to the efficiency of dividing walls in the prevention of propagation. While there is still insufficient evidence on which to base any firm conclusions, the results were sufficiently startling that the Board will submit an interim report as a warning to each of you. Our thanks to all of you for coming to the Seminar and giving your time to attend. A glance at the program shows that there are lots of interesting subjects to discuss and Redstone has kindly arranged a plant tour.

Col. Hamilton: At this time we'll have a few words from Mr. Donald E. Miller from the General Counsel's Office, Office, Secretary of the Army.

Mr. D. E. Miller, Office of General Counsel, Office, Secretary of the Army: Thank you Col. Hamilton. The Attorney General has held that activities of committees such as this seminar are subject to the anti-trust laws and the persons participating are not immune from prosecution under such laws. The Department of Justice takes the position it retains complete freedom to institute proceedings either civil, criminal or both in event he considers that actions of any committee meetings are being used to unlawful private end. The Attorney General has established certain criteria which are attendant to minimize the possibility of violating the anti-trust laws. These standards have been incorporated in DOD regulations and are being followed today. The Assistant Secretary of the Army in addition considers this seminar to be of such great importance, that as an additional safeguard, he has requested that the General Counsel of the Department of the Army provide counsel for these meetings. I am Assistant to the General Counsel and have been designated to represent the Office of the General Counsel of the Department of the Army to provide counsel at this seminar. The agenda has been made sufficiently broad so that matter related to the topics of the seminar under consideration can be freely discussed. My presence at this seminar is not intended in any manner to limit full and free discussion of the topics under consideration, but rather to promote such discussion. My primary purpose in attending the seminar is to protect both Government personnel and industry members from inadvertent consideration of any subject which might bring the seminar activities within some aspect of the anti-trust laws. Contrary to popular belief, everyone thinks attornies talk all the time, this will be the last thing you'll hear from me for three days. Thank you.

Col. Hamilton: Gentlemen, at this time I'd like to present the assistant moderator, Mr. John W. Lowell. Mr. Lowell who from the Washington end did most of the work in putting this seminar together, writing all the letters, preparing the agenda, etc. Mr. Louis Jezek representing the Department of the Army, Mr. Herbert Roylance, Department of the Navy, Mr. Donald Endsley, Department of the Air Force and Mr. Henry Dyer, Army Ordnance Missile Command. The first of our technical discussions, the subject is detonability of ammonium perchlorate and desensitization of propellant ingredients, such as light metal hydrides during processing and storage. Mr. C. James Barr, Manager, Development & Engineering Branch, Olin Mathieson Chemical Corp.

Mr. C. James Barr, Mgr, Development & Engineering Br., Olin Mathieson Chemical Corp.: I want to present two topics for your consideration this morning, both of which are particularly pertinent for a gathering such as ours. The first of these, the detonability of ammonium perchlorate and propagation of the detonation, are most important to our present generation of solid propellants. The second topic, dealing with the desensitization of novel energetic propellant additives is becoming of more importance and will certainly represent a real problem in the next generation of solid propellants. In connection with each of these subjects, specifically, and relative to this seminar as a whole, I would remind you that the bulletins of the 16th JANAF meeting, recently concluded in Dallas, are very definitely recommended reading for all of you. For example, the familiar card gap sensitivity test is discussed by Brandon of Rohm & Haas with emphasis on relationship between the geometry of the donor and acceptor charges and card thickness. Another paper suggests approaches to new understanding of the phenomenon of the transition from deflagration to detonation, using a combination of data from the closed bomb and strand burner. This work is described by Wachtell and McKnight of Picatinny Arsenal. All of the processing persons participating are not immune from prosecution under such laws. The Department of Justice takes the position it retains complete freedom to institute proceedings either civil, criminal or both in event he considers that actions of any committee meetings are being used to unlawful private end. The Attorney General has established certain criteria which are attendant to minimize the possibility of violating the anti-trust laws. These standards have been incorporated in DOD regulations and are being followed today. The Assistant Secretary of the Army in addition considers this seminar to be of such great importance, that as an additional safeguard, he has requested that the General Counsel of the Department of the Army provide counsel for these meetings. I am Assistant to the General Counsel and have been designated to represent the Office of the General Counsel of the Department of the Army to provide counsel at this seminar. The agenda has been made sufficiently broad so that matter related to the topics of the seminar under consideration can be freely discussed. My presence at this seminar is not intended in any manner to limit full and free discussion of the topics under consideration, but rather to promote such discussion. My primary purpose in attending the seminar is to protect both Government personnel and industry members from inadvertent consideration of any subject which might bring the seminar activities within some aspect of the anti-trust laws. Contrary to popular belief, everyone thinks attornies talk all the time, this will be the last thing you'll hear from me for three days. Thank you.

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During the course of a redesign of a continuous propellant processing pilot facility at OM, however, we decided to get some information on problems which we recognized in methods of material transfer between ingredient feeders and the continuous mixer. (I will describe this continuous process, the "Fluid Ball" casting process, in some detail this afternoon in connection with another subject. Briefly, however, in the Fluid Ball operation, we combine with precise metering our ball powder and a liquid explosive plasticizer with aluminum and APC in a continuous mix, cast technique.) We were interested in defining limiting sizes for transfer systems to the continuous mixer. Accordingly, we set up a work outline to define the effects of a detonation within any one of the bulks of ingredients or mixed propellant on the others. Considering only ammonium perchlorate at this time, I can outline the preliminary tests and their results which are now available. Work to date has been carried out using 2 and 3 inch diameter by 4 ft. cardboard tubes, loaded loosely or packed with up to 40 pounds of 35-40 APC. The loaded tubes were placed in the horizontal position in the test area, either on the ground or on point supports. Up to four sections of tubing were coupled to achieve a maximum axial test length of continuous APC of about 200 inches. Variations from this arrangement included the use of 90° bends of both tube material and polyethylene, open tubes in which a one-inch wide slot was cut along the top length, and intermediate axial sleeves of polyethylene. Detonation of the APC was accomplished through the initiation of booster charges of 100 and 200 grams with a no. 6 blasting cap. The first tests employed PR-9 as the booster (33% Comp. B, 67% #3 grained AN), but later tests standardized on 200 gram charges of tetryl. Some preliminary conclusions may be drawn from the data from these limited tests. 1 - The critical diameter of tubes confining a static bed of 40 ammonium perchlorate is something less than 2 inches. Critical diameter is defined here as that diameter which must be employed to give a reasonable guarantee that a detonation in one end of the stream will not propagate from the source through the bed of material. In all tests with 3 inch tubes, detonations were established and propagated the full 200 inch length. Some detonations were established in 2 inch tubes; propagation in this case, however, ceased at about 100 inches. 2 - No reliance can be placed on 90° bends stopping a detonation in conduits carrying ammonium perchlorate. In each test, the detonation wave transferred round the bends and traveled on down the tube. It may be that propagation continued in our case because we are dealing here with detonation rates which are relatively low (1800-2200 m/sec), compared with the usual high explosive materials with which such bends are reportedly effective (tetryl - 7900 m/sec, HMX - 9300 m/sec). 3 - If critical diameters are exceeded, no reliance can be placed on employing an open or slotted rather than closed tube. There is similar reluctance toward the use of a non-circular or U-shape channel of equivalent diameter, although the latter cross-section has not been studied. 4 - When the critical diameter is exceeded, a detonation will travel the full length of the tube regardless of its length. 5 - An intermediate sleeve of light blow-out material such as polyethylene is ineffective in halting propagation of a detonation.

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The above conclusions, although drawn from some 20 tests, are causing us to consider very carefully the design of our APC handling system in the continuous Fluid Ball propellant process. We intend to obtain more data before finalizing our design. In addition, we are examining the feed stream which, according to our process, consists of a blend of the ball powder and the aluminum components, as well as the liquid stream consisting of the explosive plasticizer. In conclusion, I want to emphasize that there is no doubt in our minds that ammonium perchlorate, coated only with 0.2% tricalcium phosphate and containing no organic fuel impurity, can be detonated. There has been some feeling that you have to have a fuel impurity admixed in order to have a real hazard at hand. We don't believe this is true, and have good evidence to support this belief.

Dr. A. M. Ball, Hercules Powder Co.: Have you done any work on thin layers as you get on a Syntron feeder?

Mr. Barr: No sir, only in the extremes of which I spoke which would be yea big or spread out in a channel maybe yea wide and yea thick, no thin layers yet. How thin did you have in mind?

Dr. Ball: I'm not a Syntron man, this is not a commercial talk, I have seen Syntron vibrators carrying a fairly thin film of the stuff down at a pretty good flow rate and if it should turn out that a thin layer will not propagate whereas a screw or something else would, that might be an answer to your problem. One other point, you mentioned your ammonium perchlorate was .2 of a per cent of TCP, that is an appreciable amount of fuel.

Mr. Barr: Not in the category that one ordinarily thinks of a fuel as being hydrocarbon or an organic coating, I agree there are the characteristics of a fuel but I wanted to point out that we did not have for example any hydrocarbon material.

Dr. Ball: A number of people have worked in ammonium perchlorate that went with a little bit of organic material and as far as sensitizing ammonium perchlorate, a little bit of the stuff is a whole lot more than a lot.

Col. Hamilton: Any other comments from the floor? Mr. Barr.

Mr. Barr: This is the Confidential portion of my presentation. In the few minutes left this morning, I want to remind you of a problem upon which most of us are working and to summarize some of the gains being made in the area. We are in the first phase of a propellant performance gap extending over the next six to eight years. There exist today operational solid propellants at the delivered specific impulse level of 255 sec, with a fair density around 0.062 lb/in^3. From now on, in the interim until the availability of the ultimate chemical solid propellant system delivering on the order of 300 sec is available, we are faced with a real performance gap in solid propellants. One way which appears to be available to us to improve present generation solid propellants requires the use of energetic additives such as the light metal hydrides in today's binder/oxidizer systems. I would point out here that the ultimate system referred to is considered to be a polymer or a combination of polymers in which the energetic atoms and groups have been integrally combined, both as fuel and

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oxidizer. A major problem in the use of these high energy additives arises generally by the very reason of their ability to contribute energy. In the case of lithium aluminum hydride, for example, while we may calculate impulse gains of 15 to 20 sec, we usually find that it is incompatible with the other components of the system. The term incompatible here must be defined to include a number of sensitivities. We are concerned first with the chemical compatibility or non-reactivity of the additive with the propellant matrix, oxidizer or other additives in the raw, uncured stage. This criterion again becomes important when the temperature of the raw propellant is raised to effect its cure. The reactivity of the additive may lead to anything ranging from the production of minor voids in the finished grain to a system which deflagrates in the mixer. An extension of this requirement for non-reactive additives is into the area of long term storage at ambient or elevated temperatures, or under cycling conditions. A second aspect of hazard which is particularly troublesome to the development of the interim increased energy propellants is the sensitivity to impact or shock which these additives confer upon their mixture with other ingredients of the propellant. Impact sensitivities as measured by the standard Bureau of Mines drop weight tester, are very frequently at levels precluding their use or, at the best, very marginal with respect to safety in processing. Another important problem area exemplified by the beryllium-based fuels is that of toxicity, or personnel health hazards. To some extent we have been concerned with this problem in the development of borane compounds for solid propellants, but to a markedly less degree than would be the case for beryllium compounds. In summary, then, the problem one accepts with the use of energetic additives to increase the performance of today's propellants is primarily that of preserving the materials in an unreacted state prior to their programmed combustion. Now, what are we doing with the problem? The majority of the approaches to solution of the problem are based on a physical encapsulation of particles of the additive. To encapsulate may denote a complete surface coating or only a partial one. Secondly, we can consider the more drastic step of utilizing the reactive material in conjunction with a new binder or matrix which is chemically compatible, readily available and promising of fairly rapid development. Thirdly, we may consider alloying techniques as in the case of lithium and aluminum. In the case of lithium perchlorate, a new kind of incompatibility arises through its extreme hygroscopicity. Considerable improvement has been obtained in utilizing the material as an eutectic with ammonium perchlorate. An additional approach, again a major departure from one such as simple coating, is in the combination of materials chemically with the principal fuel or oxidizer in a manner such that the reaction does not destroy the energy characteristics of the additive. This approach, which actually is a big step toward the ultimate chemical propellant system, is best represented today by the effort being spent on borane polymers. For a rapid and moderately up to date review of what is being done to utilize additives such as the light metal hydrides, I would again refer you to the bulletin of the recent JANAF Solid Propellant Group meeting in Dallas. More detailed summaries of progress among the many contractors may be found in their published reports circulated by SPIA. Running quickly down the list of some of the more pertinent effort which has been reported: Aerojet has been making good progress in desensitizing $LiAlH_4$ and $LiBH_4$, particularly since macrocrystalline particles have become available. Coating agents employed by Aerojet and others have included epoxy resins, polyacrylates, curable liquid rubbers, polyethylene

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and vapor deposited metal. The latter technique has been used to put several per cent of aluminum on macrocrystalline $LiAlH_4$. The same technique has been applied to MgH_2. It should be pointed out here that there is considerable advantage, possibly 8 or 10 seconds, gained by using aluminum to encapsulate rather than a relatively inert coating such as an organic resin. Hughes Tool is doing some interesting work in the utilization of the perfluoromethacrylates as a stabilizing coating for certain hydrides. This work has given indication of developing beyond the stage of a simple coating into a new castable solid propellant in which the polyfluoro material becomes the matrix. National Research Corp. is reporting a program in which a number of additives are being coated with magnesium as well as aluminum. Some success is again reported on the coating of $LiAlH_4$, $LiBH_4$, hydrazine nitrate and nitronium perchlorate. A second approach at National Cash Register depends on the in situ polymerization of monomeric coatings. Alternately, solutions of the coating polymers in low boiling solvents are being employed. Still another technique is being studied by Ethyl Corp. Here, an organometallic compound deposited around the particle is subsequently thermally decomposed to leave a metallic coating. Molybdenum hexacrbonyl is one such material, decomposing at 170 to 180°C to a thin film of metal. Various aluminum organometallics have been employed unsuccessfully. A technique employed by Rohm & Haas and others depends upon dusting the particles with resins such as polyvinylchloride followed by heating to 150°C or so to flow the molten dust around the particle. Both Minn. Mining & Mfg. and Atlantic Research are studying liquid encapsulation in tiny aluminum containers. The materials reported include tetranitromethane and nitrogen tetroxide. Thiokol and others are studying the problem of incorporating nitronium perchlorate. The major problem, as with lithium perchlorate, lies in its sensitivity to moisture. In contrast to lithium perchlorate, however, the nitronium material decomposes into its parent acids. JPL is pursuing a study of the coating of reactive materials with thin films of silicon, silicon monoxide, magnesium fluoride and relatively high molecular weight distillable polymers, as well as the vapor deposition of metals. There are many other specific investigations and investigators than those to which I have referred. Further, there are a number of very pertinent effects on the performance of propellants containing desensitized energetic additives other than that of increased stability to impact, moisture, heat, chemical reaction, etc. Not the least of these are effects on burning rate and physical properties. Again, I refer to the great variety of published classified literature on the general subject, should you wish a more complete review of the subject. What I have presented does, I believe, indicate the extent and type of attention being given to problems associated with the use of novel, energetic additives to increase the present day performance level of solid propellants.

Col. Hamilton: Any comments.

Dr. O. H. Johnson, Bureau of Naval Weapons, D/N: We're supporting the research aspects of some of this material you discussed. We're very much interested in it, and we have our fingers crossed. There is a very severe safety problem that I wonder if the rocket motor people have thought about. Our Polaris people thought so much about it they say they will not have an encapsulated ingredient in a Polaris engine. The problem is this, you have a capsule of a very reactive

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material in a very thin envelope in various degrees of fragility. If during processing or in storage, one of these capsules breaks, what can happen. In the case of ammonium perchlorate, it's hypergolic with the rest of the ingredients, you're going to set your motor on fire. In the case of light metal hydrides, it's not hypergolic but various degrees of reactivity. The degree of reactivity which can be hypergolic depends upon your matrix. I was going to ask you whether all of your work was done with a nitro-cellulose matrix. On the other hand, the gain in ISP is quite substantial as you pointed out, so it appears that it is one of these things that perhaps is a long shot that we have to carry thru anyway. These nitro capsules of aluminum apparently can be sealed so they are air-tight, I think some of our contractors have demonstrated that. They can put nitronium perchlorate or tetronitromethane or other things in them but now they're fragile. How are you going to process them into propellant. You certainly can't use a sigma mixer or some of the common things that people use, I'm just wondering if you people have thought about this problem.

Mr. Barr: I will talk a little this afternoon about the fluid ball operation which lends itself to an extremely low work dispersion of materials like this.

Dr. Johnson: We certainly would appreciate your comments and guidance because we have a fair effort in this field and if it's going to be water down the drain, we'd like to know about it, on the other hand, the theoretical gain is quite substantial.

Mr. Barr: I would point that we had a great big Boron bubble burst in the liquid field not too long ago, we think we are on firmer ground in the case of solid systems either oxidized to the O or to the N systems but I would just offer as a word of caution that maybe our thermo chemistry will go to pot on lithium aluminum hydride and other things also. However, this is not probable.

Col. Hamilton: Any more questions?

Dr. C. L. Knapp, ESSO Research & Engr. Co.: We're interested in higher energy systems that might be put together in such ways and we have noted this one, that if one coated particle fails, probably it will have enough energy to set the whole thing off. So aside from mechanical working, you have a statistical problem that it is exceedingly difficult to put this system together in such a manner that each one of the particles is completely coated. But if one recognizes that problem he goes along and tries to do it. There's a second one that is interesting, I'm sure you're aware of it, but Ordnance may not be. The reason for using metals is that they are much more impervious. If you go thru an analysis and experimentation with liquids or with anything that has an appreciable vapor pressure, you'll find that well before the normal and useful storage life is over, enough vapor will migrate thru almost any plastic to cause reaction and destroy your system and that's the reasor I'm sure most people are now going to metals where there is an appreciable vapor pressure either of the material contained or in the case of nitronium perchlorate which absorbed water vapor from the outside, you need that impervious barrier to prevent water from coming in from the outside.

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Mr. Barr: Yes, that's right the migration over a long period of time or diffusion is a matter of concern as is the simple statistical fact that a few particles may rupture and initiate a whole mass. I don't have any other solution tho, to this performance gap other than for example metal alloys or good capsulation.

Mr. K. E. Rumbel, Atlantic Research Corp.: I'd like to go back to the first part of your presentation. You mentioned TCP, Dr. Ball commented on that. Sometimes TCP means tryfluorescen phosphate, sometimes trichrystal phosphate.

Dr. Ball: One of our operators calls it triteryphosphate.

Mr. Rumbel: I wondered if you and Dr. Ball were meaning the same thing.

Mr. Barr: I'm speaking of calcium.

Mr. J. B. Atkisson, Jet Propulsion Lab: In the coating ammonium perchlorate with magnesium vapor process we ran into a pyroforic condition leading to a detonation.

Mr. Barr: We have observed the same thing in our laboratory. Have you solved the matter of doing it safely?

Col. Hamilton: Thank you very much Mr. Barr. The next subject, laboratory operations - screening, grinding, mixing, design of remote and shielded operations and hazards from radioactive propellant components. We have two speakers, the first of which will be Mr. Lee T. Carleton of Aerojet-General Corp.

Mr. L. T. Carleton, Aerojet-General Corp.: I want to speak briefly about two topics, the discussion of composition in the first topics will be classified Confidential, otherwise the talk is unclassified. I want to talk first about the development of a laboratory mixer under the sponsorship of the Navy. Many solid propellant systems based on advanced components are unusually sensitive during certain phases of their processing history. For example, propellants made from nitropolymer binders, ammonium perchlorate oxidizer and coated lithium aluminum hydride may be considered hazardous during mixing and casting because of their shock sensitivity. In order to prepare small test specimens of this propellant, we've developed apparatus for mixing and casting small charges of these propellants by remote control. At this time, considerable experience with this apparatus has demonstrated its safety and utility. The equipment and methods are expected to be applicable to other sensitive propellant systems. Apparatus and Facilities - The assembled apparatus is shown in the figure. The upper part is the mixer, consisting of a stainless steel cylinder with a motor-driven, spiral stirrer. There is ample clearance between stirrer and walls. A dispenser for solids and a valve leading to a nitrogen supply and to vacuum are attached. The mixer surmounts a casting bell, but mixer and bell are separated by an aluminum diaphragm clamped in a flange. A cutter is provided to break the diaphragm after mixing is completed. The capacity of the mixer is 1 lb., but to date it has been used for 100 gram charges. For remote operation, the mixer is set on a laboratory bench in an isolated room. It is controlled from the adjoining room, being viewed by the operator through two oblique mirrors. A wall covered on each side by 3/8 in. steel plates separates the two rooms.

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Operation - The first steps of loading the mixer may be performed by direct handling with no hazard. The operator works behind an ordinary laboratory shield. The nitropolymer fuel is first weighed in. The oxidizer is charged next, using a special polyethylene dispenser fitted into the mixer. The vibrator is started to shake in the entire charge, and then the mixer is switched on. To begin the sensitive phase of operations, the operator attaches the special dispenser for powdered $LiAlH_4$. Cords are provided for operating the dispenser and the diaphragm cutter. The operator takes his position in the adjoining control room. He watches the mixer through mirrors, and performs the following steps: apply vacuum to both mixer and casting bell; add $LiAlH_4$ while stirring, and mix for 10 minutes more; break diaphragm, and cast propellant into mold or small motor; vibrate while casting, to settle propellant and remove bubbles; blanket with nitrogen and leave overnight; the casting will cure partially before removal. Evaluation - About 15 mixes have been performed in the apparatus described. It is necessary to test a variety of methods for protecting $LiAlH_4$ in propellant formulations - some successful and some unsuccessful. One fire was initiated by friction, but was successfully controlled. The fire occurred in the remote control phase of operation, and there was no hazard to personnel. Radioactive materials in propellant processing - At present, the main use of radioactive materials in propellant technology has been as sources of radiation, rather than as components of propellant. An exception is the studies of mixing efficiency, in which radioactive tracers have actually been incorporated in propellant mixes. Otherwise, radiation has been used chiefly for radiological inspection of grains, as a curing initiator, and for damage studies. For several years, Aerojet has studied the applications of high energy radiation to propellant curing and damage, under contracts with the Air Force. We have gained much experience in handling solid propellants in close proximity to radioactive materials. It is useful to review the methods used. Facilities - the source used most recently for irradiation of propellant is a cylindrical cage of rods, containing (originally) 10,000 curies of Cobalt-60. The cylindrical cage is 20 inches high and 5 inches in diameter. These dimensions allow the irradiation of small propellant grains, as well as packages of test specimens, inside the cylinder. Specimens may also be irradiated in selected positions outside of the cylinder. The current average dose rates are 7×10^5 rep/hr inside the cylinder, and 2×10^5 rep/hr in the outer positions. The design of the facility housing this source is based entirely on the principle of protection. Protection is achieved by shielding, by providing emergency devices, and by regulating access. In planning this protection, it was necessary to consider both radiation hazards and the hazards of a violent reaction of propellant, as well as possible interactions of the two. Ample earth-shielding is assured by mounting the Co^{60} source on a platform in the lower portion of a well 20 feet deep and 20 inches in diameter. A snug fitting steel casing fits into the lower half of the well, designed to retain radioactive fragments from any violent reaction. The top of the well is covered by a four inch thickness of lead. A lateral passage near the top vents the well through a water seal. In an emergency, the platform on which the source is mounted may be quickly dropped or scrammed, through a distance of 30 inches. The mechanism is actuated by an electric signal, e.g., from a thermocouple or pressure sensing device. This action effectively removes the source from proximity with the sample being irradiated, which remains in

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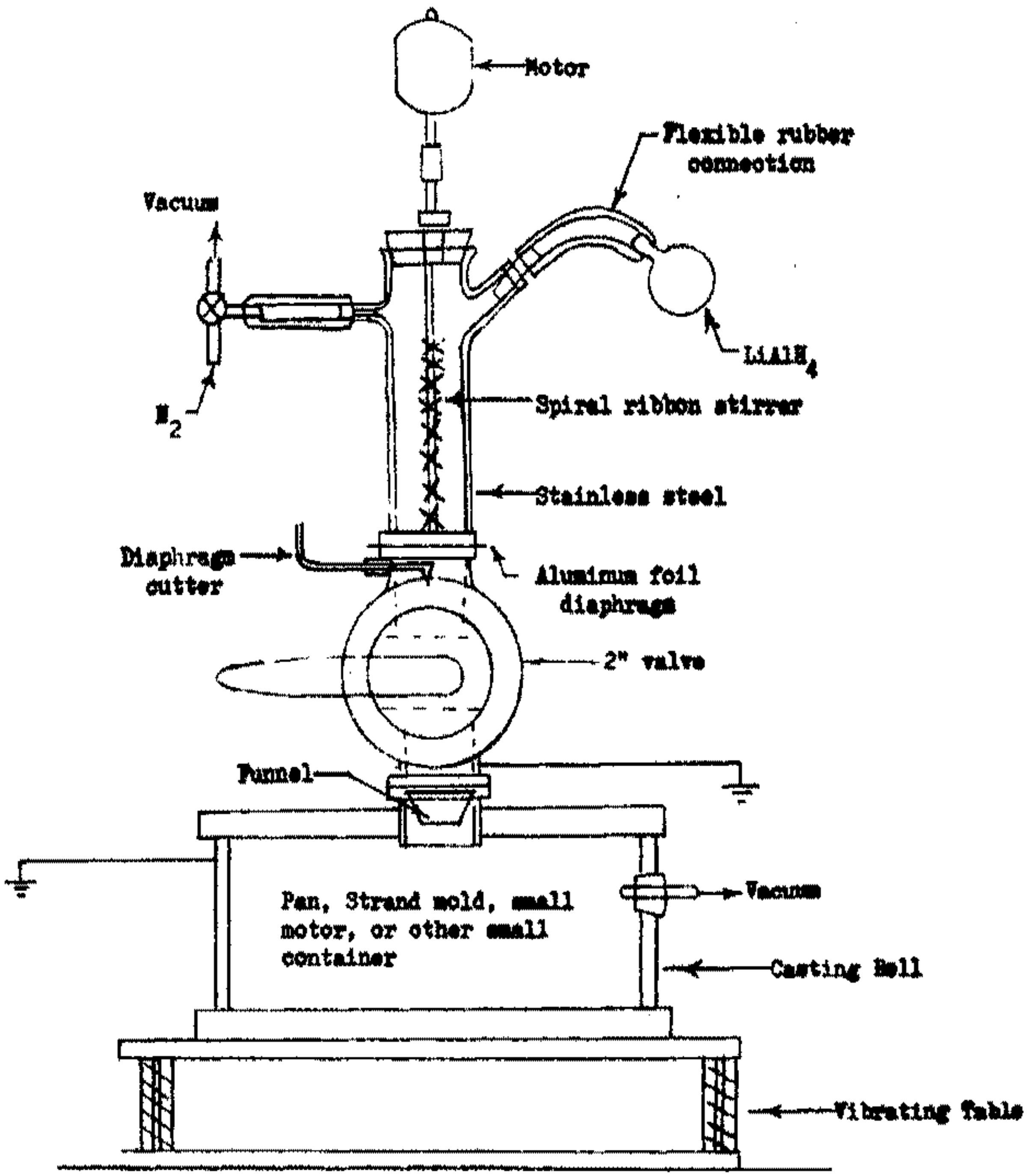
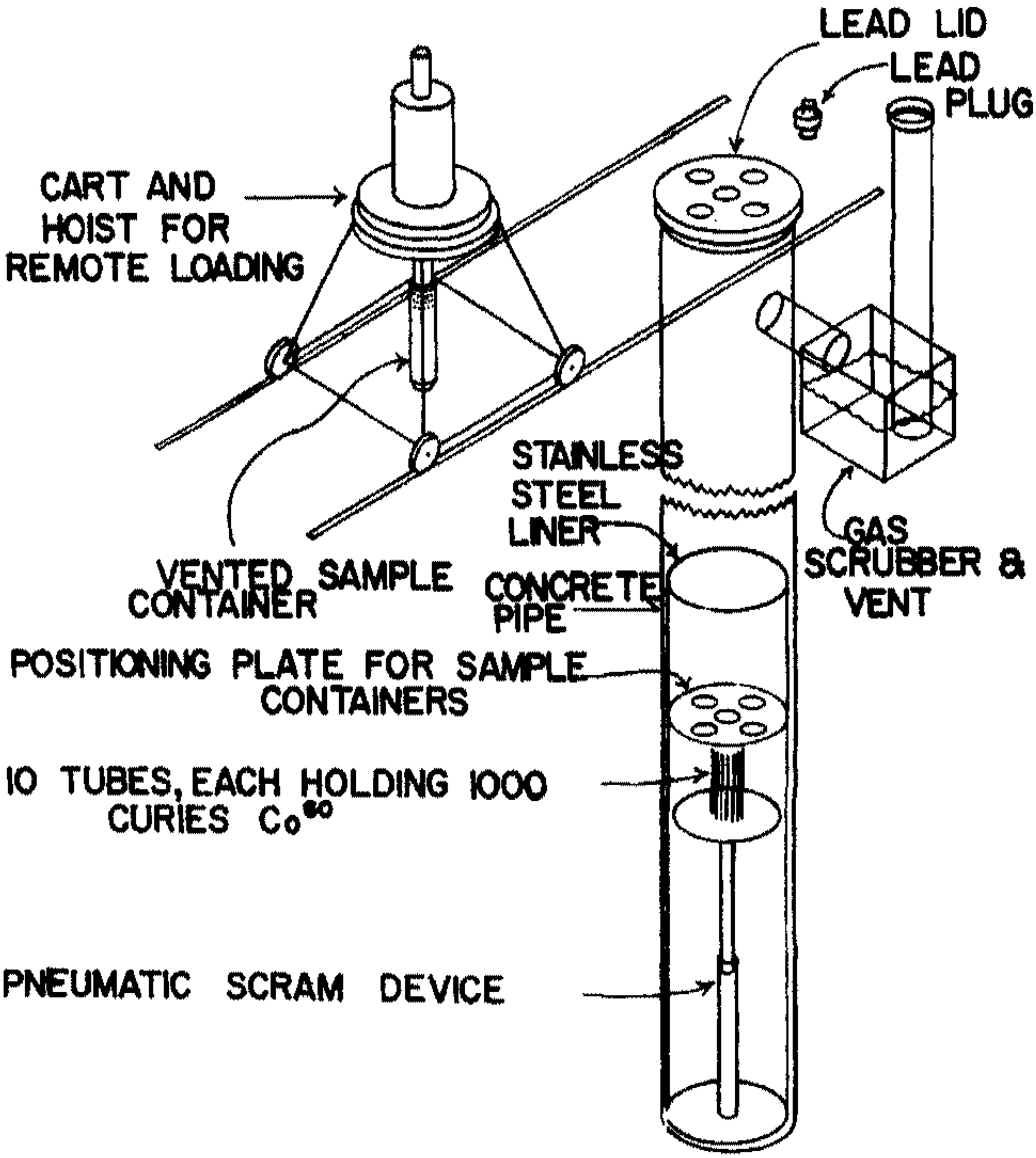
SCHEMATIC DIAGRAM OF

100g REMOTE MIXER FOR $LiAlH_4$/NPU/NH_4ClO_4 PROPELLANTS



10,000 CURIE Co^{60} SOURCE



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its original position. As a further emergency measure, the well may be immediately flooded with water by a high capacity pump. Further safeguards are provided by controlling access to the facility. Sample containers are loaded into the well through openings in the massive lid by means of a movable hoist. The hoist moves on rails back to the operator's position in a zone of low radiation. The operator does not approach the top of the well, and hence is always shielded by earth. All of this equipment is enclosed in a frame shelter with a single door. Outside of the structure is a chain link fence, which in turn is surrounded by earth embankments, with only one entrance. Both the shelter and the gate are provided with locks, and are normally locked, except when operators are working inside. Control of keys is strictly regulated. The entrance through the earth embankment is chained off and posted with warning signs. In addition, a burglar alarm is provided to signal any unauthorized entrance into the building. Experience - In more than one year's experience of irradiating solid propellants in this facility, there have been no fires and no scrams. The only emergencies have been due to occasional mechanical failures. It has only been necessary to flood the well for repairs, or for routine tests. Propellant and propellant components have been repeatedly given radiation doses of more than 10^7 rep without mishap. This experience indicates strongly that solid propellants may be safely processed by high energy radiation, or handled in radiation fields. The conventional precautions for handling propellant and radiation sources appear to be sufficient.

Dr. S. C. Burket, Aerojet-General Corp.: I'd like to describe for you some equipment and some tests which we have made relating to the handling of both explosive hazards and fire hazards, to describe a shield which we are using in our laboratories for mixing one pound batches of propellant which is primarily a fire hazard and also to describe some gloves which we are planning to use with explosive materials of half a gram or less. May I have the first slide please. The top photo shows the shield right next to the set-up which is inside it. The set-up includes a spiral laboratory mixer, with a capacity of approximately one pound, set in an oil bath. This is mounted inside the shield as shown. Here is what the shield looks like when the operator stands in front of it with everything closed. The side sliding doors are pushed aside here to show how it looks when the operator is making his experimental set-up. The shield was tested using a cardboard mock-up before it was constructed. The people who have in the past mixed lab batches without a qualm out in the open laboratory bench actually asked for these, we have approximately a dozen in operation now and we have no problem in getting people to use them. Apparently, therefore, they are practical. The center pane here which provides the direct protection is about 18" wide, the operator can perform any normal operation inside without major difficulty. Ordinary safety glass, 1/4" automobile safety glass is used for the windows, you can use as many panes as you like, maybe two, three or four panes, in general separated by 1/4" rubber spacers. The shield is constructed of 1/8" mild steel, the doors are 3/16" mild steel, the bearings on which the doors slide are simply roller skate wheels. The whole thing weighs about 175 pounds and has cost us, for the 12 that we have made, approximately two dollars a pound. It would appear that these are useful for more than simply protection against fire hazard, therefore we conducted tests to see what the limits might be, or what we might be able to expect in the way of protection. The next one shows the experimental

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set-up, which was placed on 2" planks to simulate the laboratory bench top. It was placed at the proper distance away from the wall to simulate the actual set-up in the laboratory and explosive charges were placed inside, as shown here, to simulate the approximate distance from the shield wall and the laboratory wall. You'll see that the mixer used is a glass wall mixer, not a stainless steel mixer. The blades inside are simply spiral blades similar to those shown by Mr. Carleton. A series of tests were made starting with an ordinary 8½ gram tetryl booster and working up thru 50, 100 and 400 grams of C4 mounted in the positions shown here. The can is to simulate an oil bath. The next slide shows what happened to the three panes of safety glass that were used as protection in the blast of 100 grams of C4. The 1/8" steel mesh which comes in front of the glass prevented any expansion of the panes out so that an operator if he had been in front would not have been hit. There was some spalling of glass fragments in the case of the 400 gram charge but the fragments had very low velocity, a plywood board held two feet in front of these panes of glass showed no scoring whatsoever. The next slide shows the condition of the shield after a blast with 400 grams of C4. Our present plans are to use this shield only with small quantities of explosives but we did wish to see how far it could be tested before failure occurred. There is a base plate underneath made of 1/4" steel to prevent the blast, if a blast occurs, from going under the shield and coming out and damaging the operator. The top and the back are left free for blast relief. The shield moves forward with considerable force when you put as much as 400 grams of C4 there so that if it were to be used for explosive protection, it would be wise to restrain the shield. We have used heavy steel springs, mounted approximately centrally, to hold the shield back against the wall. Even with the 400 grams the glass bowed but did not completely shatter, it stayed together, there simply was some spalling as mentioned earlier. The next slide shows what happened in the test of some gloves we were testing for use with quantities of explosives of 1/2 gram or less. A #8 blasting cap was mounted between the gloves in a small erlenmeyer flask. The gloves were positioned to simulate the position of hands actually holding the cap, a simulated human hand constructed of chicken bones and rubber gloves was placed inside various types of gloves, and they were then tested in this manner. This shows what happens to heavy asbestos gloves when tested in this way, apparently they are not suitable for use to protect against a #8 blasting cap, which corresponds to about 1/2 gram of high explosive. The next slide shows the original set-up, this represents the actual arrangement that we plan to use. The best glove appears to be leather, specially constructed for our purpose, there are thin leather gloves that go directly over the hands, these are then inserted in the gauntleted gloves shown here and a pad is placed over the palm. Under these conditions, there was no penetration of the rubber gloves inside used to simulate the hand. Furthermore, there was no penetration of the inner pair of gloves with a #8 blasting cap. Actually this is not as clumsy as it looks. It is possible to work much more easily with these than it is to work with tongs. If you use the heavy asbestos gloves it's possible to work with tongs if you keep the exploding object at least 6" away from the gloves. Are there any questions on these?

Mr. L. W. Saffian, Picatinny Arsenal: In the first presentation, Mr. Carleton spoke of a steel mixer and your tests apparently run with a glass mixer?

Dr. Burket: That is correct.

Mr. Saffian: Did you run similar tests with a steel mixer?

Dr. Burket: No, we would not plan to use a steel mixer if we felt that there was going to be any kind of an explosion hazard, because the missile problem is much greater. We have made tests with steel missiles and find that with a one pound charge you just about have to have an inch of steel to prevent missile damage. 3/4" doesn't quite give way but it doesn't look very safe, so for a one pound metal mixer we would want to use 1" steel.

Mr. Saffian: One more thing, we found that butesite core lucite was a very effective window material. I was wondering whether you tried that.

Dr. Burket: I was talking to someone not long ago, I can't recall who, who said whatever you do, don't use lucite because they had conducted some tests in which the lucite had shattered and sent plastic needles all around the room penetrating 1" wooden boards and we were just a little leery of trying it. Maybe unjustifiably, but we have avoided using lucite where we felt there was an actual explosion hazard.

Mr. Paul D. Nance, Thiokol, Utah Div.: A comment on your gloves, I noticed in one visit in an explosives facility where the common practice was to use a butcher's glove, steel mesh interlaced glove over cotton and this in their experience had provided very excellent shielding, usually worn under a leather glove, so they would have a less bulky arrangement. Have you tested that?

Dr. Burket: Yes we did. The hole in the steel mesh was considerably larger than the hole you saw in the asbestos. This is with a #8 blasting cap, I don't know with what level of explosives they may have used. We were specifically using the #8 blasting cap as the test medium and it was in direct contact. I don't know whether they were mounting them in the same way. It was actually held next to the glove.

Mr. Nance: What were you wearing under the glove?

Dr. Burket: There were two gloves, a relatively thin leather glove under the heavy welder type glove with a leather patch in front. We'd be very glad to furnish details to anyone who is interested, of either the laboratory shield or the gloves. The gloves that we are going to use are being made on special order. We'd be very glad to provide the specifications to anyone who might be interested.

Mr. Harmon, NASA: I hope my question won't prove embarrassing. Was any of your equipment involved in your accident earlier this year?

Dr. Burket: I would say that most of this investigation was stimulated by our accident early this year.

Mr. R. D. Fox, Dow Chemical Co.: We're interested in the remote handling and processing of very experimental motors of a half pound to one pound scale and we were wondering if anyone had any ideas or any particular gimmicks they were employing for the transporting and the handling of the cured grain after it has been cured in its mold, how the mold is disassembled and the motor is prepared for firing on the thrust stand in a remote manner such that the technician or personnel are not exposed in any way to the accidental ignition of this very experimental grain.

Dr. Burket: We haven't gotten to this point ourselves with the handling of materials that we regard as that sensitive, but we are planning to set up a laboratory in which such propellants are tested. Thiokol I know has a master-slave set-up that they might want to comment on, I don't know. We are setting up a similar facility ourselves.

Mr. Jezek, OCO: Do I understand that you conducted your experiments only with high explosives on this particular shield, is that correct?

Dr. Burket: We were using C4.

Mr. Jezek: Were there any materials used that would produce a fire hazard? What I have in mind is that you say that the top and back of this thing is open, in the event that you should have a fire in this particular barrier, how far would the man be protected from the flame coming around the ends or from the top and hitting the ceiling and coming down?

Dr. Burket: We tried a simulated fire, i.e., loading the mixer with one of our nitropolyurethane propellants and igniting it and there was no travel of flame outside the shield at all. In other words, the man was completely protected. As long as the sliding doors are closed, there is no exposure whatsoever.

Mr. Jezek: Another question, why do you have to have glass on this barrier, does a man observe the operation?

Dr. Burket: This is probably just a sore point with most experimenters, they just want to see what's going on and then too when you're setting it up, it's awfully hard to set it up if you can't see what's going on. If you can set things up so that he can see what he is doing and be protected, then I think this is desirable.

AMMONIUM PERCHLORATE --- ZERO INITIATION CURVE FOR IMPACTING ENERGY VS. IMPACTED AREA

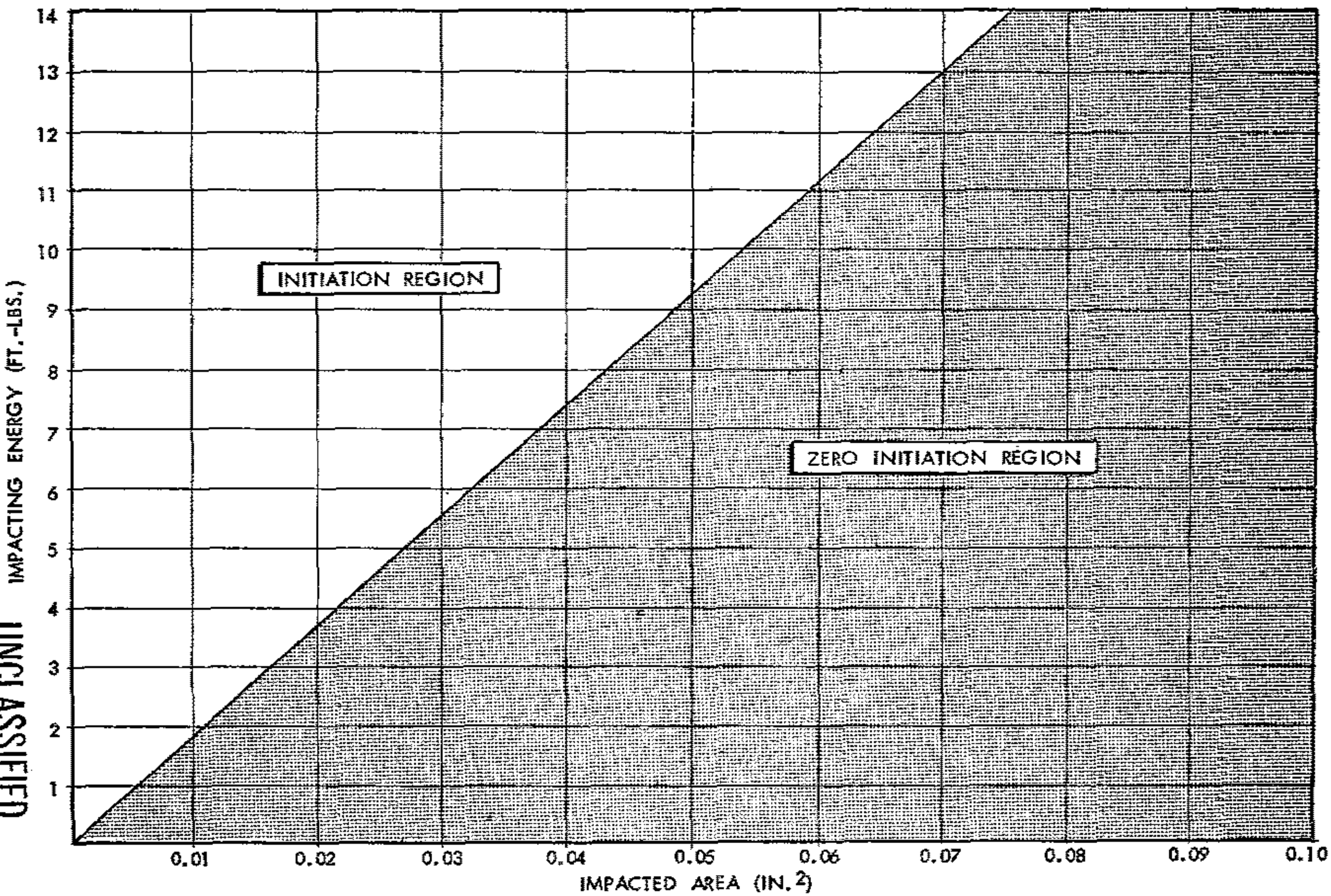


FIGURE 1

UNCLASSIFIED

UNCLASSIFIED

Col. Hamilton: Any other questions or comments? Thank you very much Dr. Burket. The next item is 'new test method for hazard evaluation for processing cast double base propellants.' Mr. R. H. Richardson, Hercules Powder Co., Allegany Ballistics Laboratory.

Mr. R. H. Richardson, Hercules Powder Co., Allegany Ballistics Lab: Before we begin, I would like to note that the title given in the agenda of this meeting may be misleading. The primary purpose of this talk is to present a method of detecting and eliminating process hazards before an ingredient or new process is utilized in the manufacture of cast double base propellant. Such an approach was considered an essential part of the research, design, development and production of solid propellants since it is necessary to ensure the safety of these products during manufacture, handling, and storage. The need to know how to safely manufacture combustible materials is obvious in terms of human life and plant investment. This is particularly true at ABL since we are constantly confronted with new ingredients, and propellant processing techniques for which there is little or no information available. Prior to 1958, ABL employed what we shall call the relative method of establishing if new materials would constitute a hazard. The relative method as used at ABL consisted of two requirements, tests and process experience. The tests used for this method were impact, friction, electrostatic discharge and shock. The test components and samples were standardized for comparison purposes. The test data were obtained under exacting procedures to ensure reproductibility and were usually reported in terms of the 50% probability level. The end result of these tests was the direct comparison of the data to estimate the relative sensitivity of one material to another material. Obviously, the comparison of results would not be meaningful without process experience with the materials used as the basis for comparison. Therefore, with this method any given process has to be initially operated without the benefit of knowledge of the safety of the operation because no prior experience is available. Thus the relative method could only be considered adequate after experience is gained; if no changes in the process occur and if new materials are not relatively more sensitive. This method became inadequate at ABL in 1958 when new materials exhibited a lower relative sensitivity than past materials; which put us in a position where we had no process experience using materials at this level of sensitivity. Also we had to consider the fact that this method could not determine if the new materials were near or below the initiation threshold since the data were in abstract numbers obtained under conditions that in many cases did not exist in the process. With these problems in mind, we considered a different approach to hazards assessment. The purpose of this new method was to be able to directly apply test data to the process. The application method has two requirements; the assessment of the process and tests. The purpose of the assessment of the process is to establish what the potential hazards are, where they occur, the conditions under which the hazards occur and where applicable establish the potential energy, power, and force. The assessment of the process will also point out what tests are necessary to simulate the potential hazards. As the tests themselves must in turn simulate process conditions, the test data must be in terms applicable to the process and establish the zero initiation level since we must know the level where initiation will not occur. The end result of this work would be a series of curves. An example is shown in Figure I.

For example if the process survey showed some phase of the handling of ammonium perchlorate to have a potential impact energy of 10 ft-lbs. delivered over 0.02 in.^{2}, this point would fall above the shaded zero initiation region and would be considered a hazardous operation. Subsequent steps would then be taken to reduce the energy or increase the area to below the initiation point. In utilizing the application method, we first considered the ideal approach of eliminating the initiation of combustion and thereby eliminating the possibility of explosion and detonation occurring as a result of the initiation of combustion. However, from a practical viewpoint such an approach would be very time consuming to be considered for initial use. In addition, if we consider the human factor in the process it is difficult if not impossible to positively eliminate the initiation of combustion. With this in mind, we have used an approach which incorporates the obvious advantage of eliminating combustion whenever possible, but does not have to initially rely on the elimination of combustion as the only means of eliminating possible hazards. The program utilizing this approach is shown in Table I.

Table I

Hazards Assessment Program

1. Investigation of the effects of flame initiation (sustained burning, explosion or detonation) and the elimination of the resultant hazards.

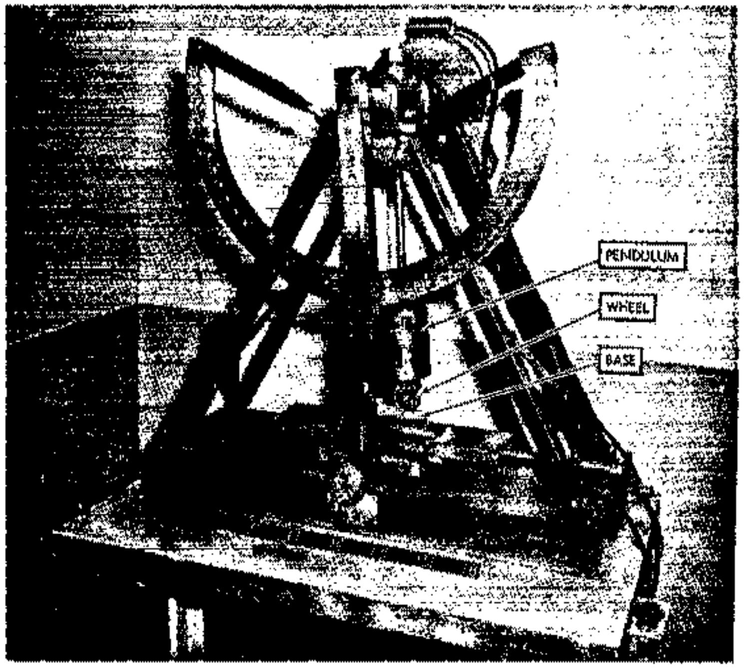
2. Establishment of the requirements for explosion and/or detonation other than flame initiation (air blast, shock, fragment impact) where indicated by phase 1 above.

3. Development of the necessary tests (impact, friction, electrostatic discharge, and low order shock) and the determination of the energy, power, force, etc. and conditions necessary to cause initiation.

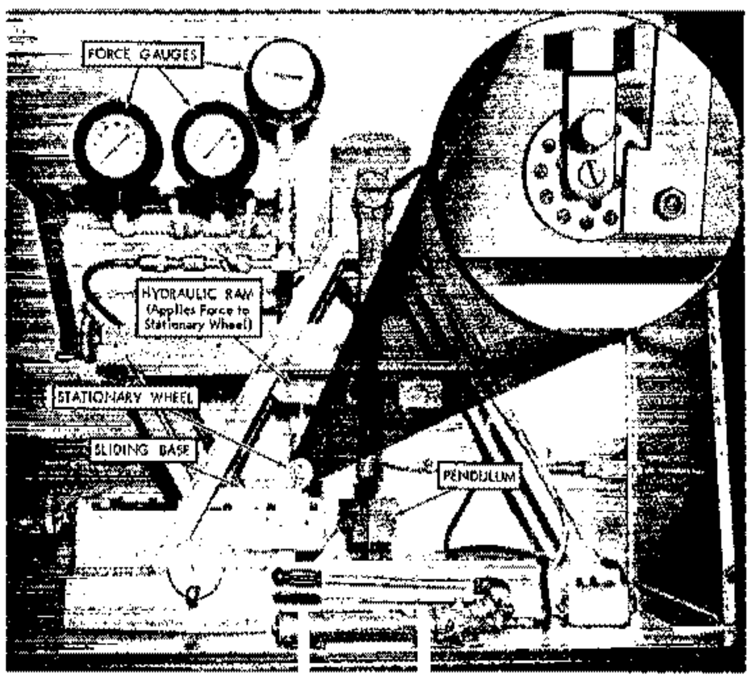
4. Establishment of the potential energy in terms of impact, friction, electrostatic discharge, and low order shock (drop) in the various phases of the process.

5. Application of results (phases 1, 2, and 3 above) to the process to establish and maintain safe manufacturing procedures and equipment design.

The first phase of this program is the investigation of the effects of flame initiation and the elimination of the resultant hazards. Emphasis was placed on this investigation since transition from burning to explosion and/or detonation was considered the major hazard confronting the process because air blast, shock and fragment impact could exist in the process only if some degree of transition had occurred as the result of the initiation of combustion. If the observed explosion or detonation hazards could be eliminated as a result of this testing or some modifications to the ingredient or process, a burning hazard could be handled since the process was adequately covered by sprinkler and deluge systems. Of course in the presence of the burning hazard, personnel must be adequately protected for example by remote operations. However, if the potential explosion or detonation hazard could not be eliminated then it would be necessary to establish the result of these hazards in relation to the materials in the immediate or adjoining processing areas. From such an investigation, it would be possible to determine what measures such as remote operation, barricades, separation, or new process design would be necessary to ensure the safety of the process. The primary purpose of phases 3 and 4 is to eliminate the initiation of combustion for the purposes we have previously discussed. We must also consider the fact that the first two phases of the program may not provide a reasonable means of eliminating the observed hazards, thus making the elimination of combustion a more attractive means. It is also necessary to know what the reaction of materials will be to such forms of initiation as impact, friction, electrostatic discharge or low order shock; such as, dropping a container of material since it is a possibility that a small amount of some material may initially explode or detonate when subjected to this type of initiation. The fifth phase of this program would obviously be carried out whenever and wherever possible. As a result of this program, we utilize seven tests that are applicable to the cast propellant process. These are the impact, friction, electrostatic, drop, deflagration to detonation transition, critical diameter for detonation, and shock fragment tests. If the data from these tests are to be applicable to the process, we have found that we must consider such factors as the time and area over which the energy is delivered, the condition of the material in the process, the materials used as the test components, temperature and sample confinement. Also when using small scale versions of the transition and shock fragment tests the critical diameter for detonation and the effect of diameter of the test material on the critical height to explosion or detonation must be considered. With two possible exceptions, the principal test equipment is similar to that used by many of you here today. These two exceptions are the friction and shock fragment tests. We initially used a small pendulum friction machine shown in Figure 2A, but as a result of this program, it was found that this machine was not a valid method of obtaining comparative frictional sensitivity data nor could the frictional energy necessary to establish the zero initiation level be determined using this machine. As a result of these findings, a sliding friction machine has been designed and fabricated at ABL (see Figure 2B). The operating principle of this machine is such that a sample is placed on a movable sliding block to which pressure is applied by a stationary wheel attached to a hydraulic ram. A weighted pendulum is dropped from a predetermined height and strikes the block with sufficient energy to slide the block. The block slides in a direction perpendicular to the vertical vector of normal force applied by the stationary wheel. The distance of slide can be regulated by an adjustable positive stop. The investigation of the sliding friction machine has shown that it can provide force data for comparison or application purposes. The machine can also provide the coefficient of friction under varying degrees of velocity and force and the sliding distance values necessary to calculate the frictional energy. Typical data obtained with the sliding friction machine are shown in Table II. As previously mentioned, the shock and fragment test is intended for those process materials for which the transition hazard cannot be eliminated. Figure 3 shows a typical small-scale shock and fragment test apparatus. The basic concept of the test is such that an applicable donor is used to provide air blast and/or shock of the magnitude that could be experienced in the process. Then by moving



"A" - ABL Pendulum Friction Machine



"B" - ABL Sliding Friction Machine

FIGURE 2
ABL Friction Machines

TABLE II

SLIDING FRICTION MACHINE DATA

Test Sample	Zero Initiation Level		
	Coefficient of Friction	Force (lbs.)	Energy (ft.-lbs.)
Ingredients			
Nitrocellulose	0.14	36	0.42
Ammonium Perchlorate	0.16	< 2	< 0.03
Casting Powder			
Single-Base	0.08	343	2.30
Double-Base	0.07	268	1.60
Composite-Modified Double-Base	0.15	157	2.00
Cast Propellant			
Double-Base	0.08	583	3.90
Composite-Modified Double-Base	0.08	364	2.40

the test sample, known as the acceptor various distances from the donor the critical separation for detonation, explosion and/or deflagration of the acceptor can be determined. The effect of fragments on the acceptor resulting from explosions or detonation can be obtained by inhibiting the donor. The effect of fragments can be studied in the presence or absence of air blast and shock by moving the acceptor to a distance where air blast and shock are either effective or non-effective. The results of fragments are usually reported in terms of their effect, and the attenuation necessary to eliminate the observed hazard. Fortunately, it has not been necessary for ABL to use this test in relation to the present cast propellant process since results from the other tests have been sufficient to maintain the safety of the process. The test has however, been used as a small-scale propagation test for finished propellants and has shown that detonation fragments are the greatest hazard as the propellants must be one diameter or closer to the donor to be detonated by shock. So much for the test themselves. I would like to discuss at this point the first investigation at ABL employing phases of the application method which I think will demonstrate the application of some of the tests and allow the presentation of some information of general interest. Specifically, we will deal with ammonium perchlorate and its influence on the mixing phase of casting powder manufacture which is a part of the cast propellant process. As can be seen in Part A of Table III, ammonium perchlorate is more friction sensitive than other associated ingredients. In addition, it was determined that the handling of dry AP could generate an electrostatic voltage which may ignite the volatile solvents in the mixer if poured in dry. Part B of Table III further demonstrates the possible friction hazard of ammonium perchlorate in that a mixture of ammonium perchlorate and nitrocellulose is more sensitive than either single ingredient. It was determined that wetting ammonium perchlorate with the volatile solvents used in the manufacture of casting powder would significantly reduce the friction and electrostatic generating hazard associated with handling dry ammonium perchlorate. These data are shown in Part C of Table III. The resulting increase in impact and electrostatic discharge sensitivity of the AP/solvent mixture was not considered hazardous based on the surveys of the potential energy available in this phase of the process. Since the wetness of AP could not be ensured in the vicinity of the mixer shaft glands, metal bushings were replaced with Teflon bushings to reduce the friction hazard. Since ammonium perchlorate had to be initially handled dry prior to wetting with solvents, the transition hazard was also investigated to establish the material handling conditions (see Table IV). From this investigation, we concluded that dry ammonium perchlorate could be considered a fire hazard if the containers in which the ammonium perchlorate is handled are equal to or greater than 4 inches in diameter and filled to a height of 24 inches or less. Transition work with solvent wet ammonium perchlorate showed that at solvent concentrations of approximately 10%, ammonium perchlorate would transit to detonation at applicable heights (Table IV). However, it was determined that this adverse effect could be eliminated by adding the ammonium perchlorate to the solvent to ensure the solvent phase of the mixture is always above 20%. It is interesting to note that the shock sensitivity also follows the same pattern as the transition characteristics when AP is wetted with volatile solvent in the range of 0-20% (Table IV). This effect of volatile solvent on the transition characteristics of ammonium perchlorate was of particular interest since it indicated that if casting powder mixes containing ammonium perchlorate were made using the normal size mixers and mix

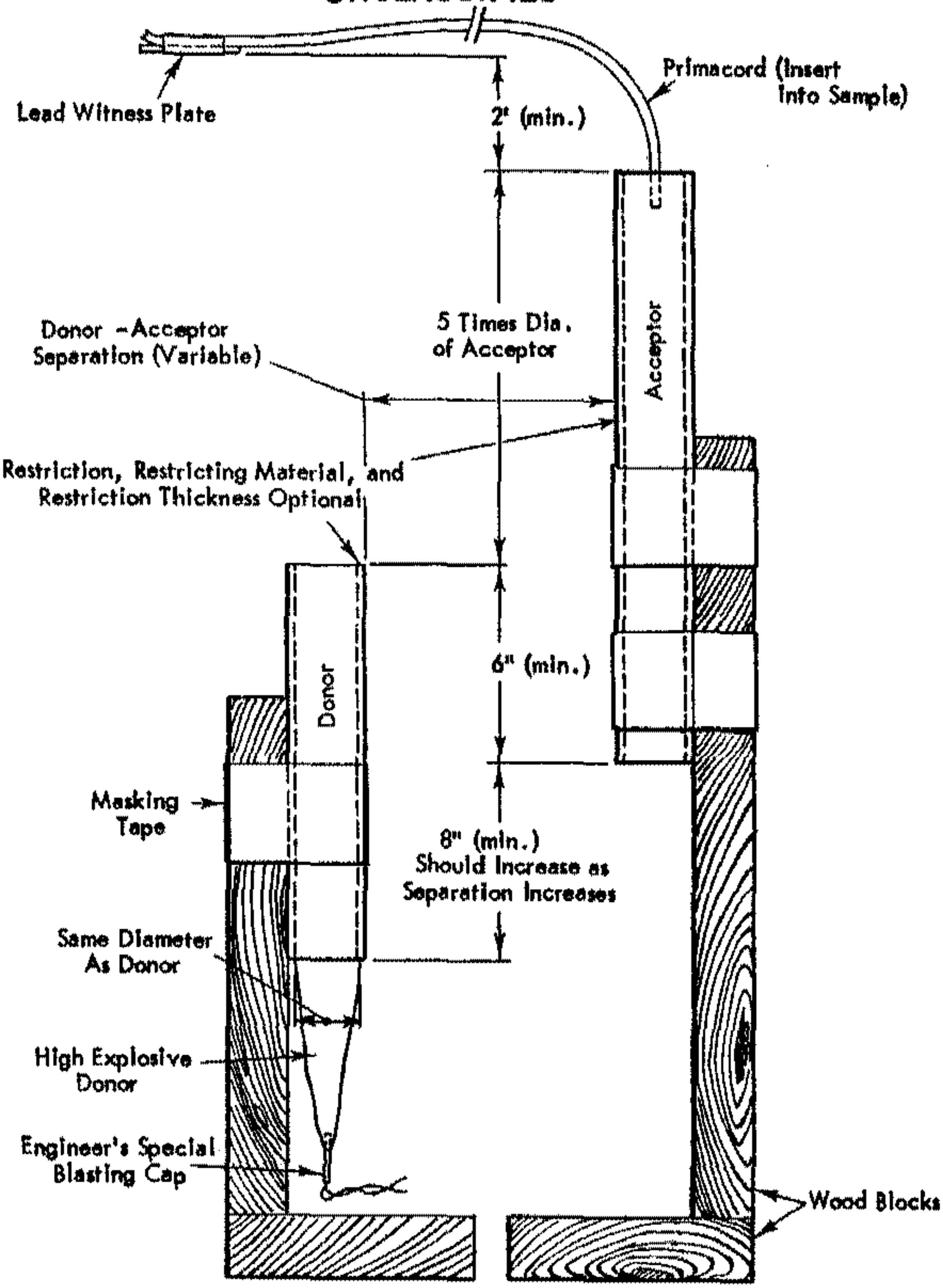


FIGURE 3
Small-Scale Shock and Fragment Impact Test Assembly

TABLE III

SENSITIVITY TEST DATA

	Sample	Sample Test Condition	Zero Initiation Energy: Impact [a] (ft.-lbs.)	Zero Initiation Energy: Electrostatic Discharge (joules)	50% Probability [b] Friction (cm.)	Electrostatic Potential (volts/lbs.)
A	AP	Dry	> 17.5	> 5.0	16	100
A	NC/Alcohol	70/30	5.0	0.01	> 53	0
A	NG	100%	4.0	> 3.0	> 53	0
A	Al	Dry	> 17.5	1.25	> 53	0
B	NC	Dry	6.0	0.01	22	-
B	AP/NC	Dry 50/50	5.0	1.25	6	-
B	AP/Al	Dry 50/50	> 17.5	1.25	35	-
B	NC/Al	Dry 50/50	> 17.5	0.25	40	-
C	AP/Acetone	80/20	6.0	0.001 [c]	40	0
C	AP/Alcohol	80/20	6.0	0.075 [c]	40	0

[a] Data obtained using a constant impact area (0.2 in.^{2}) and tested in an unconfined state.

[b] Data obtained using pendulum friction machine.

[c] Testing resulted in a joule level considerably higher than given here, but it is assumed that these mixtures could at some point above the mixture be ignited at the same energy level as the individual solvents.

TABLE IV

SENSITIVITY TEST DATA

Sample	Sample Test Condition	Critical Diameter (I.D.) Confined (inches)	Critical Diameter (I.D.) Unconfined (inches)	Deflagration to Detonation Transition[a] Critical Height Explosion (inches)	Deflagration to Detonation Transition[a] Critical Height Detonation (inches)	Minimum[b] Cap Size For Detonation	Detonation Velocity (m/s)
AP	Dry	< 2.0	< 4.0	12	> 24	H	3,400
AP/Acetone	95/5	< 2.0	< 4.0	< 24	> 24	-	-
	90/10	< 2.0	< 4.0	< 11	11	B	-
	80/15	< 2.0	< 4.0	> 12	> 24	6	-
	80/20	< 2.0	< 4.0	> 12	> 24	> J-2	4,500
AP/Alcohol	90/10	< 2.0	< 4.0	< 5	5	B	-
	85/15	< 2.0	< 4.0	< 5	5	E	-
	80/20	< 2.0	< 4.0	< 24	> 24	> J-2	4,200

[a] All tests were carried out confined using 2 inch schedule 40 pipe. The DDT tests were carried out with one end capped and ignited at the closed end.

[b] This cap size represents the cap size below which detonation of the test material will not occur.

heights in use at that time, that transition to explosion or detonation could occur as a result of flame initiation. Subsequent testing of various mixes containing ammonium perchlorate and using the normal solvent system, showed that, these mixes would transit to detonation as the result of flame initiation at diameters and mix heights used in casting powder manufacture. The results of a typical mix can be seen by referring to Green Mix No. I in Table V. It is obvious from this data that transition to detonation can occur when the ammonium perchlorate is added to the mix and that mixing time does not affect the transition hazard. During the course of this work, it was noted that a portion of the ammonium perchlorate was not incorporated within the nitrocellulose. It was also observed that during the initial transition period the unincorporated ammonium perchlorate as the only material being consumed by the induced deflagration. Therefore, we concluded that ammonium perchlorate must be incorporated within the nitrocellulose in such a manner as to take advantage of most of the available solvent. It also appears reasonable that the incorporation of the AP must be rapid since the period immediately after the addition of AP is the most likely time of initiation. Subsequent investigations, showed that the prior slurrying of the ammonium perchlorate with not less than 20% acetone and by using an acetone rich solvent for casting powder manufacture, the previously observed detonation hazard could be reduced to an explosion hazard for a given height and diameter (see Table V, Green Mix No. II). The next step was to establish the critical height to explosion vs charge diameter relationship (Table VI). These data were then used to establish the safe mix heights (no explosion) for the various size mixers in use at ABL. A similar approach has been used at ABL to investigate other energetic materials and their combinations throughout the cast propellant process. The applicability of this approach has been further demonstrated in the case of mixer fires. ABL has experienced initiation in the mixer as the result of foreign material and mixer shaft malalignment on five different occasions and all resulted in fires which were subsequently extinguished by deluge and sprinkler systems, with no damage to the facilities. These mixes were made in accordance with data obtained from a hazard evaluation using the same tests and approach as discussed here today. On the basis of our experience with the hazards assessment program to date, we have concluded that: the application method of hazards assessment is more realistic, reliable and applicable than the previously used relative method. Impact, friction, electrostatic discharge, low order shock, critical diameter, deflagration to detonation transition, and shock and fragment tests, singularly or in various combinations, are applicable methods of performing a valid hazards assessment of the cast propellant process. Of these tests, the low order shock, critical diameter, deflagration to detonation transition, and shock fragment tests are applicable as hazard classification tests for finished cast propellants. When employing these tests, it is necessary to obtain the data under conditions duplicating those in the process or to establish the effect of such factors as the time and area over which the energy is delivered, particle size and thickness of the test sample, materials of construction, temperature and sample confinement so the test data can be directly applied to the process. The investigation of the introduction of ammonium perchlorate and other energetic materials has resulted in the establishment of safer manufacturing methods for composite-modified double base propellants which represent some of the most energetic solid propellants now in use. Furthermore, this program is in part responsible for ABL's excellent safety record in producing solid propellant products.

TABLE V

CASTING POWDER MIX SENSITIVITY DATA

Sample	Sample Test Condition	Deflagration to Detonation Transition Data[a] — Critical Height: Explosion (inches)	Deflagration to Detonation Transition Data[a] — Critical Height: Detonation (inches)	Critical Diameter (inches)	Detonation Velocity (m/s)
Green Mix No. I	NC/NG/Solv.	< 24	> 24	< 2.0	2,750
(23% Volatile Solvent	NC/NG/Solv.	< 24	> 24	< 2.0	-
Alc./Ace./ 65/35)	NC/NG/Al/AP/Solv.				
	1/2 min. after AP add	< 5	5	< 2.0	3,400
	60 min. after AP add	< 5	5	< 2.0	3,400
	End of mix	< 5	5	< 2.0	3,400
Green Mix No. II[b]	NC/NG/Solv.	< 24	> 24	< 2.0	2,750
(23% Volatile Solvent	NC/NG/Al/Solv.	< 24	> 24	< 2.0	-
Alc./Ace./ 40/60)	NC/NG/Al/AP/Solv.				
	1/2 min. after AP add	< 24	> 24	< 2.0	3,400
	60 min. after AP add	< 24	> 24	< 2.0	3,400
	End of mix	< 24	> 24	< 2.0	3,400

[a] All test were carried out confined using 2 inch schedule 40 pipe. The DDT tests were carried out with one end capped and ignited at the closed end.

[b] Final composition same as Green Mix No. I.

TABLE VI

EFFECT OF DIAMETER ON CRITICAL HEIGHT [a]

Sample	Diameter (inches)	Critical Height for: Explosion, No Container Damage (inches)	Critical Height for: Explosion, Container Damage (inches)	Critical Height for: Detonation (inches)
Green Mix No. III [b] (20% Volatile Solv. Alcohol/Acetone, 40/60 1/2 min. After AP Add)	2	0	5	17
	4	2	9	> 24
	8	14	16	> 24
	12	18	> 21	> 24

[a] All tests were performed in a confined state using schedule 40 pipe with one end capped and ignited at the closed end.

[b] Final composition same as Green Mix No I.

Mr. Fox: First of all I wanted to get your opinion of the reliability and reproducibility of this friction machine you have showed us today and along with that, I would like to ask a few questions about its design. What are the materials and construction of the block and the wheel and what surface finish do you have on both the wheel and the block?

Mr. Richardson: I'll first answer this question by saying this, that in the process we have considerable surfaces and considerable hardness in finish to contend with and we do, where applicable, employ such surfaces and hardness in finish. The test machines you saw today and for normal general use if for metal purposes, we use a B82 hardness which is common for stainless steels used in our process, also the finish is about 64 microinch which is comparable to a machine finish. I might add that there is a report out on that in which we go thru this in considerable detail explaining to you why we use these different materials and which one we decided to use initially because it was equal to or approximated most of the conditions in the process. The reliability of the machine is quite good with the same operator, etc., and as far as the reliability, you probably realize that the reliability is built in the operator. It's his knack to determine the shock and the failure which gives you your reliability. Along this line, we're also working on a method by which we can detect this thru gaseous phase. In other words, measuring your thermo conductivity of the gas or function of air in the room at the same time. It looks quite promising and eliminates the operator problem that a lot of people do have in this field.

Dr. Knapp: I was very impressed by your friction tester; we have one somewhat similar in principle but not near as elaborate and probably not as reliable. The one thing that astonished me was the extremely high sensitivity of ammonium perchlorate. Does that agree with the general experience of ammonium perchlorate, it wouldn't in my knowledge, but I don't really know much about it?

Mr. Richardson: This data you saw was done at 6 ft. per sec. or greater. Actually 2 to 6 ft. per sec., you'll get about the same answer since the effective velocity on coefficient of friction is about linear, practically horizontal at this point and then it starts to curve up as you leave zero to 2 and even in this case, I think our figures up to approximately close to zero are about 60 to 70 pounds force will still initiate AP. Again, you have to consider sample thickness or, there are a lot of people that will use a much larger particle size or some common particle size which you have to watch. You should use what you have in the process and this AP size I think is 15 - 20 micron and is a monolayer as best we can approach it. We tried to spread it out as thin as possible because this really does approach what you have in the process if you spill the material or you have a mixer clearance or gland clearance in the mixer cell.

Dr. Knapp: Have you had ammonium perchlorate ignite by itself apparently by friction when nothing else was present?

Mr. Richardson: Oh yes.

Mr. Nance: A couple of points, I noticed in one of your curves that your material seemed to be more sensitive to detonation, it was one of your critical heights using schedule 40, you ran 10 to 20% acetone and then it tappered off again, is this your general experience?

Mr. Richardson: That's right.

Mr. Nance: In other words about 90% perchlorate you find could be much more sensitive?

Mr. Richardson: That's right. Possibly some reliance of the O_2 balance but we haven't gone into this part of it.

Mr. Nance: We have generally the same thing in our propellants. My other comment, all of your tests were apparently made using the same booster configuration. Do you run any tests on the minimum booster, does the booster affect this critical height?

Mr. Richardson: Do you mean -

Mr. Nance: The detonating charge.

Mr. Richardson: In transition work, it is not a detonating charge, it is a squib.

Mr. Nance: You have no explosive associated with your squib in the bottom of your pipe?

Mr. Richardson: No sir.

Mr. Nance: And have you run any tests at all with the detonator?

Mr. Richardson: Oh yes, quite a few.

Mr. Nance: I was wondering if this affected one, the critical diameter and the critical height, if you used a bigger booster and donor charge on the end of the perchlorate?

Mr. Richardson: We don't actually determine the critical height if you use a donor because if it will detonate and you're over critical diameter, its height particularly for porous materials, is probably a fraction of an inch before it starts to detonate and then it's linear, it will detonate at a constant rate.

Mr. Nance: I observed you went to some fairly great heights on some of your tests before you got detonation.

Mr. Richardson: That was with a squib, a flame initiation, there was no detonator involved whatsoever.

Mr. Nance: How much detonator work have you done?

Mr. Richardson: I would say about two years work.

Mr. Nance: Well, that's subject for another conference.

Mr. L. J. Ullian, AFMTC, Patrick AFB: I realize that the main part of your talk was on processing but you did get into the area of finished products and you made mention of the fact that only crackpots put donors on these things. I'm afraid that at all the flight test centers where we fly these things for the first time, we put destruct charges of up to 1, 4, 5, 6, sometimes 10 lbs. of high explosives and I'm afraid our experience has been, you people claim they're class 2, that they actually detonate or something similar that is giving us the same amount of damage and I wonder if you people are considering, all of the propellant manufacturers in this problem area with respect to your finished propellant, that we do stick to explosive charges on these things to destruct them and we aren't crackpots for doing it I don't think.

Mr. Richardson: We weren't referring to anybody in the room, we're talking about a process problem where we don't really want to consider this fact. If we do, I think you'll find that every material that we handle and, I think most everybody else, can be detonated if enough shock is present or the critical diameter is exceeded. As far as that goes, again we're talking about process and if we talk about hazard classification itself, it's written into all the rules and regulations that you start to use and you do use primarily boosters. Again these people must consider this because they have to consider sabotage and crackpots, crackpots who might like to see a big 4th before the 4th of July. I mean someone that's really off his rocker, but not the people involved in the testing because they have to consider this fact and people in ICC have to consider this also. As far as the propellant itself, we certainly do consider this and I think that everybody in the field will have to consider the more energetic these become, they're going to be easier to detonate and the critical diameters are going to be quite smaller, and that we're going to have to learn to live with it. I don't know that we'll be able to find an easy solution to it, although there is work going on at the Ballistics Laboratory along this line.

Col. Hamilton: The next item on the agenda is a report of comparative tests of barricade materials by Dr. Knapp.

Dr. Knapp: Observation windows and blast mats were exposed to test explosions to furnish design data for a facility for research work on high energy propellants. Limited comparative tests were made on steel plate and sand barricades. Tests were run to determine the ability of the materials to withstand a detonation in which metal fragments were generated, since such an explosion represents the most severe accident that might occur with a propellant. It was found that polymethyl methacrylate (plexiglas) is superior to bullet-proof glass for windows. Also, covering the edges of windows markedly increases strength. A window made of two 4" thick panes of plexiglas withstood an explosion of 10 lbs. of C-4 explosive contained in a steel pipe to furnish fragments. Blast mats were found to be less effective than steel plate on a pound for pound basis; two layers of blast mats made of 5/8" steel cable gave borderline protection against an explosion of 2 lbs.

of C-4 explosive. A barricade of sand 36" thick retained by 3" plank walls absorbed the blast and all fragments from an explosion of 20 lbs. of C-4 contained in a heavy steel pipe. In connection with an ARPA contract to develop high energy solid rocket propellants, Esso Research & Engineering Co. designed preparation and test facilities for the handling of propellants in quantities up to an amount having an energy release equivalent to about 20 lbs. of C-4 explosive. At this level, it is clearly feasible to furnish barricades sufficient to completely retain the worst possible accident, which would be a high order detonation. Because of the experimental nature of the work, laboratories were designed for maximum flexibility of operation. It seemed important to be able to directly observe reactions and processes wherever possible, thereby making the use of adequate viewing windows important. In the test firing of small rocket motors, it was necessary to reduce the noise problem as much as possible because of the nearby location of other experimental work not connected with propellants. For the chemical synthesis of new propellant ingredients, and the preparation of small motor grains, a building was designed to contain five test cells built with 16" double reinforced concrete walls and ceiling. Three cells will be ten feet wide by 13½ feet long, with an 8½ foot ceiling; two will have a ceiling at 15 ft. to allow room for special pilot plant equipment. All corners will be constructed with a fillet for added strength. The end of each cell will be open, facing a three foot thick vertical earth barricade, fifteen feet high, retained by wooden plank walls. Each cell will have three observation windows. To attain high strength, considerable thickness is needed. The transmission of cracks through the window is a source of weakness, so separate layers have an advantage. An effective window design, which was developed from the tests reported in this paper, is illustrated in the first attached figure. It consists of two 4" thick panes of plexiglas, 18" x 24" in area, separated by 3" of air space. A steel cover plate overlaps the edges 3" on each side, to protect the relatively weak edges from chipping. Test firing of small rocket motors will be done within an 18' steel sphere made of ½" steel plate. The walls of the sphere will be protected from projectiles from possible explosions of test motors by two layers of blast mat woven from 5/8" steel cable. Test motors will be fired in a vertical position, with the nozzle pointing upward. The nozzles will be held in position by a shear ring that is designed to allow the nozzle to be expelled before a pressure build-up could burst the motor case. Two thicknesses of 1" steel plate will be placed at the top of the sphere to prevent expelled nozzles from damaging the inner surface of the sphere. Storage of propellant components will be in a series of containers set in the ground; each container will be approximately 18" wide and 2½' deep, and will be separated from adjacent containers by 8' of earth. The layout of the entire facility is shown in the second attached figure. The concrete test cell structure was designed on the basis of information contained in "The Fundamentals of Protective Design", a Confidential report published by the Army Corps of Engineers. The sphere shell thickness was calculated by a formula developed by Mr. F. A. Loving of the DuPont Co. (I.E.C. 49, 1744 (1957)). No corresponding sources of information were found for blast mats or observation windows, and for this reason tests on these materials were run as described in the following section of this paper. A few tests were also made on steel plate and on a sandbag-filled wall. Specimens and test conditions were chosen to represent the worst hazard in propellant work, which is a high order detonation in a heavy-walled container that bursts to give large fragments traveling at high velocity. Such an accident could occur in a mixer, or in test-firing a motor. To give high order detonations, a highly brisant military demolition explosive, Composition C-4 was used. The explosive was packed into schedule 80 steel pipe to give the desired fragments. All test samples were centered on a line perpendicular to the sample face and to the center of the pipe containing the explosive, so that a maximum number of fragments would hit the test sample from a 90° angle of approach. Test windows were mounted in a 3" armor plate wall in a test area that is operated by the Explosive & Propellant Laboratories of Picatinny Arsenal. Explosive charges were mounted on a wooden post five feet from the window, and other barricade materials such as steel plate and blast mats were arranged in a circle around the charge so as to test several materials with each explosion. Initial tests were run on windows with no edge protection. Later tests were with frames that gave edge protection; one design used two 4" thick panes separated by a 3" gap, in another an 8" window was built up of one 4" and four 1" layers. The first window test was of an uncased 4" plexiglas window backed by a ¼" sheet of plexiglas spaced 2" away. Fragments from a 1 lb. C-4 test shot gouged the face and cracked the window but no material was spalled from the face opposite from the explosion. The most severe damage was at the edges. The effect of covering the edges is shown by comparing the attached figures 3 and 4 from comparable test shots; figure 4 is from the following series of test shots in which all window edges were protected. The 1 lb. test of the uncased window was followed by a 2 lb. explosion against the same window. Where new fragments hit areas close to those hit in the first test, the window was broken and pieces spalled from the back and broke the ¼" back-up pane. New fragments that hit an area previously untouched only gouged the face. Going up to a 5 lb. C-4 shot, a new 4" plexiglas window was shattered, and fragments penetrated it completely. The window experiments were then set up in steel frames and several tests made as shown in the following table:

Windows	Size of C-4 Explosive Sample (Packed in steel pipe)
Two 4" plexiglas layers 3" separation, edges of front window covered.	2 lb., 10 lb., 20 lb.
As above, but 4" bullet-proof glass replacing plexiglas in the window toward the explosion.	2 lb.
Eight inch plexiglas window, of one 4" plus four 1" layers.	20 lb.

The tests clearly showed the superiority of plexiglas over bullet-proof glass. Two successive 2 lb. test shots only cracked and gouged the face of the 4" plexiglas window; no material was spalled from the back side of this window and of course the back-up window was untouched. On removal from the frame, the window was still intact. By contrast, the 4" bullet-proof glass window was shattered by a 2 lb. test shot. Most of the back lamination was spalled off in sharp fragments. The back-up plexiglas window was scarred by the glass particles, but did not spall or crack. The comparison of plexiglas and glass windows is shown in the attached figures 4 and 5. The top limit of the assembly of two 4" plexiglas windows is about 10 lb. of C-4 or equivalent. The explosion of 10 lb. of C-4 did not break the exposed window, although it was gouged on the face and was cracked (figure 6). At 20 lb. of C-4, fragments penetrated both windows (Figure 7). A similar result was obtained at 20 lb. with the 8" laminated plexiglas window. Since the separate 4" windows allows greater flexibility in repairs, etc., the failure of the 8" window to show any marked advantage in strength eliminated it from consideration. Blast mat samples were 3 ft. square, woven from 5/8" steel cable. In the tests, two thicknesses of mat were hung in a support frame and placed 6' from the test explosion. The mats were much less effective than was expected in view of their widespread use for blast and fragment protection. Even in a test with 1 lb. of C-4, some fragments passed through the two mats (Figure 8). However, the fragments that passed through had lost practically all of their energy and failed to penetrate a 1/16" back-up plate. At 2 lb. and 5 lb., penetration was about the same as with the 1 lb. test; in these experiments, run earlier, no back-up plate was used to measure the energy of the fragments that had penetrated the mats. In a test with 20 lb. of C-4, the blast mats were badly cut up, by fragments as large as 3" in diameter that passed completely through both mats and a 1/16" back-up plate (Figure 9). It was concluded that the blast mats could be used to protect the walls of the rocket motor test sphere only with tests using propellants in amounts up to 2 lbs. With higher amounts of propellant, additional barricade material would be needed, preferably steel plate. On a lb./lb. basis, the barrier formed by two blast mats made of 5/8" cable should be equivalent to a steel plate about 0.8" thick. As a comparison of data in this section with the following section will show, the blast mat is less effective than steel plate, even at equivalent weight per square foot. Accordingly, blast mat is chiefly of use where flexibility is important, or where the ability to dissipate gases after a blast is of interest. Penetration of the blast mat by small particles from relatively small test shots is almost certainly due to local variations in thickness that are a necessary result of the woven construction. Cold-rolled steel plate was tested in 1" and 2" thickness. The results of the tests show a regular pattern of increased depth of penetration with increased size of explosion; however, the required steel thickness does not increase linearly with the size of the explosion. Data are shown in the following table:

Resistance of Steel Plate to Fragments from Explosions

Pounds Explosive	Max. Depth of Gouges in Steel Plate
1	1/4"
2	1/2"
5	3/4"
10	1"

To simulate the barricade designed for blast retention at the back end of the test cells, a test wall segment four feet square was made of two 3" layers of plank separated by a 36" gap filled with sandbags. This was tested only at the 20 lb. C-4 level. The front face of the wall was broken, and the sandbags torn up to a large degree, but the back wall was intact and no fragments reached

ABILITY OF MATERIALS TO WITHSTAND EXPLOSIONS (1)

(Presence of Metal Fragments)

Material	Quantity of C-4 Explosive - Schedule 80 Pipe Size (2)				
	1 Lb. C-4 - 2.5" Pipe	2 Lb. C-4 - 4" Pipe	5 Lb. C-4 - 6" Pipe	10 Lb. C-4 - 8" Pipe	20 Lb. C-4 - 8" Pipe
12" x 18" x 4" Plexiglas, Uncased	Cracked and gouged. 1/4" back-up pane intact.	Shattered where hit by 1 lb. shot. Held where hit in new spot.	Penetrated and shattered.	----	----
Double 4" Plexiglas steel-cased 3" spacing	----	Front pane cracked. No spalling.	----	Front pane cracked. No spalling.	Both panes penetrated.
8" laminated Plexiglas, four 1" panes, one 4" pane, steel-cased	----	----	----	----	Penetrated and shattered.
4" laminated plate glass, steel-cased	----	Shattered but not penetrated. Entire rear layer spalled into sharp fragments.	----	----	----
2 blast mats of 5/8" steel cable, 3' square, 1' apart	Fragments pierced both mats, but could not then pierce 1/16" sheet steel.	Mats damaged slightly.	Mats damaged slightly.	Moderately severe damage.	Large fragments penetrated mats and 1/16" back-up plate.
Steel plate 1" thick	1/4" gouges. No bulges.	1/2" gouges. Bulged.	3/4 gouges. Cracked.	3/4" gouges. Cracks, bulges.	Cut through where hit hardest.
Steel plate 2" thick	1/4" gouges.	1/2" gouges.	3/4 gouges.	3/4" to 1" gouges.	----
Sandbag wall 3' thick, faced with 3" planks	----	----	----	----	Front planks smashed. Bags scattered. Rear planks intact. No penetration.

(1) 5-6 feet between center of explosion and test piece.

(2) Largest fragments ca. 4 oz., avg. 1-2 oz.

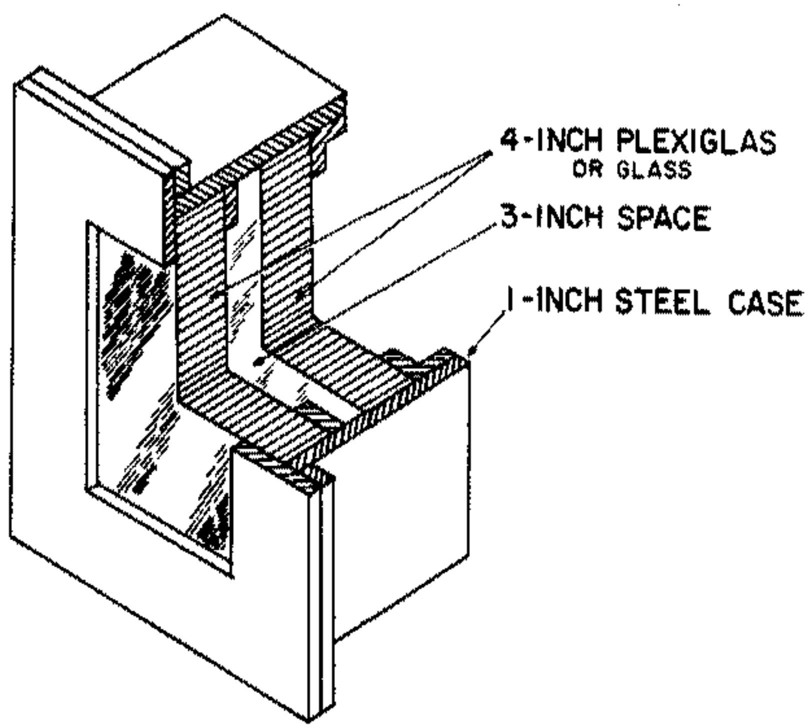

4-INCH PLEXIGLAS
OR GLASS
3-INCH SPACE
1-INCH STEEL CASE
TEST WINDOW

FIGURE 1

NEW PROPELLANT RESEARCH FACILITY

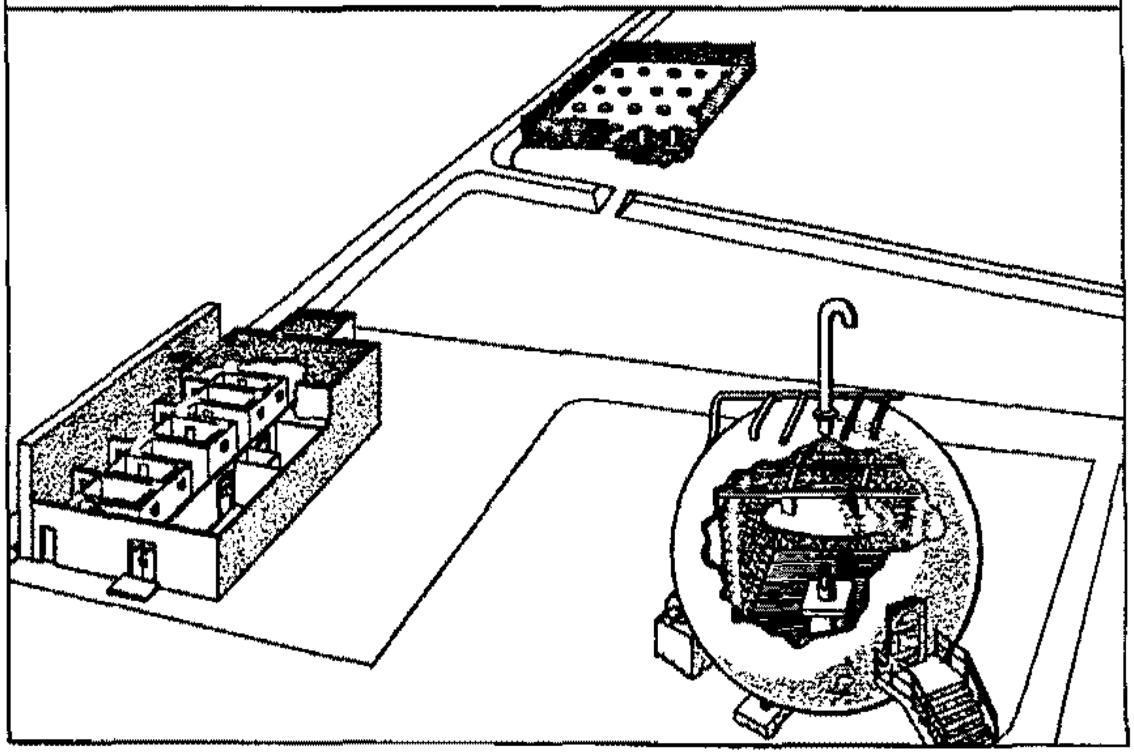


FIGURE 2

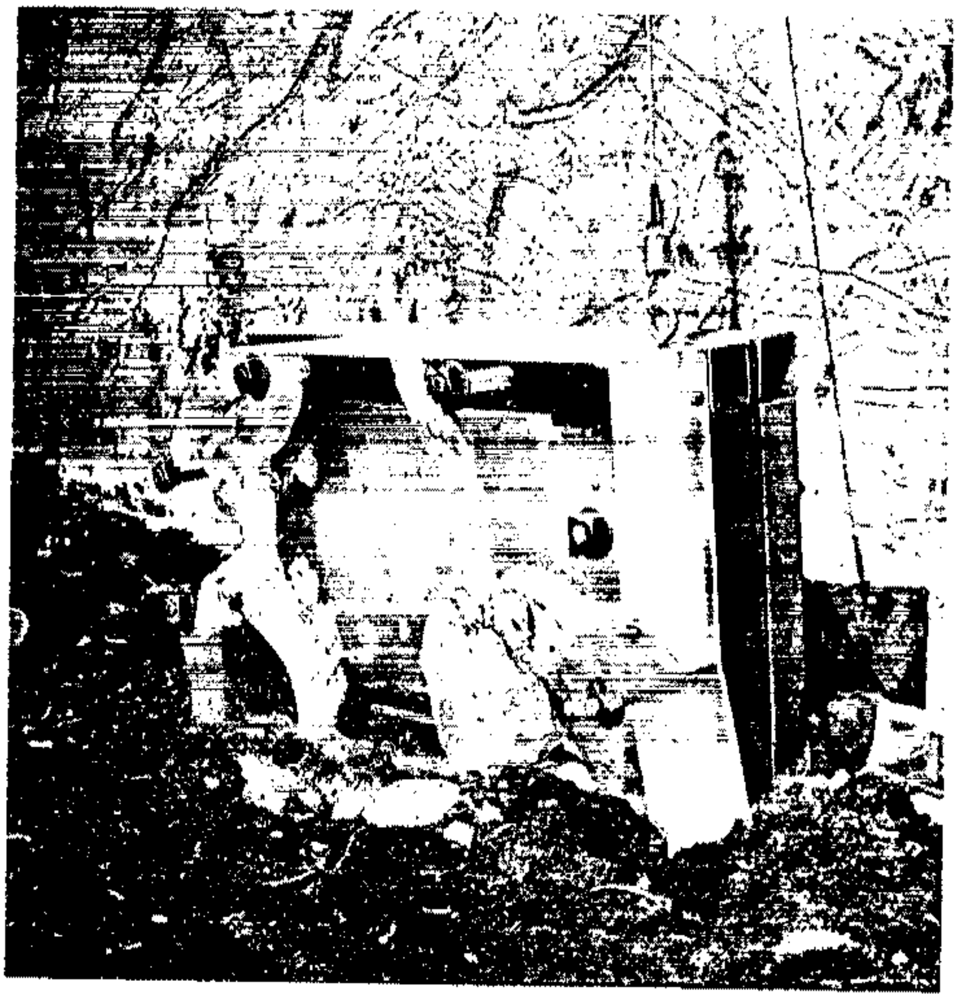


FIGURE 3

Test of Uncased 4" Plexiglas
Windows; 1 lb. C-4 Explosive

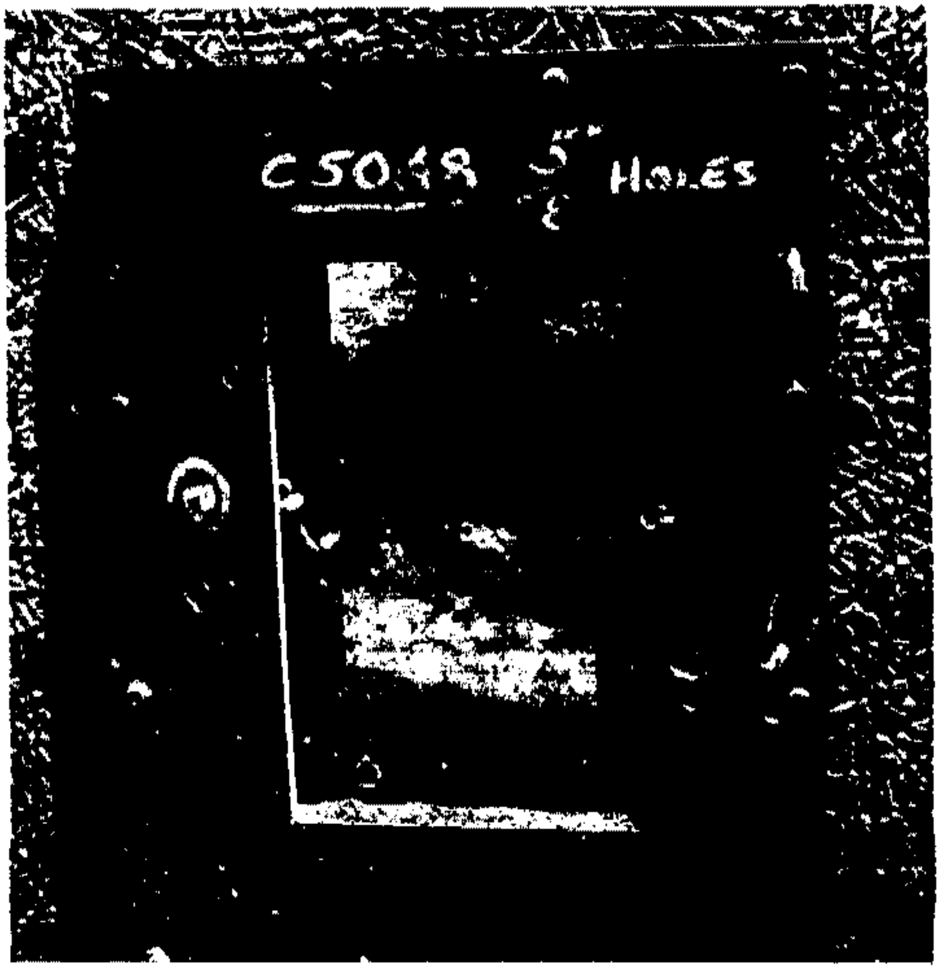


FIGURE 4

Test of 4" Plexiglas Window; 2 lb.
C-4 Explosive

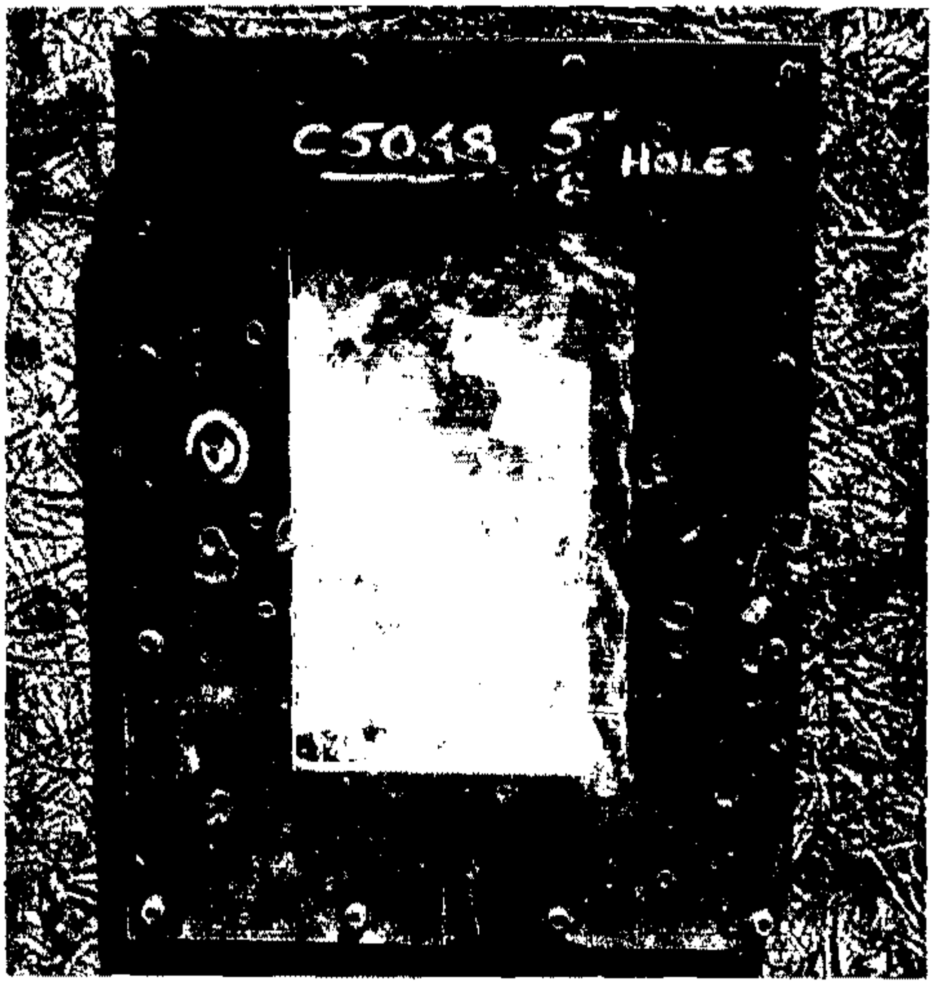


FIGURE 5

Test of 4" Bullet-proof Glass
Window; 2 lb. C-4 Explosive

FIGURE 6

Test of 4" Plexiglas Window;
10 lb. C-4 Explosive

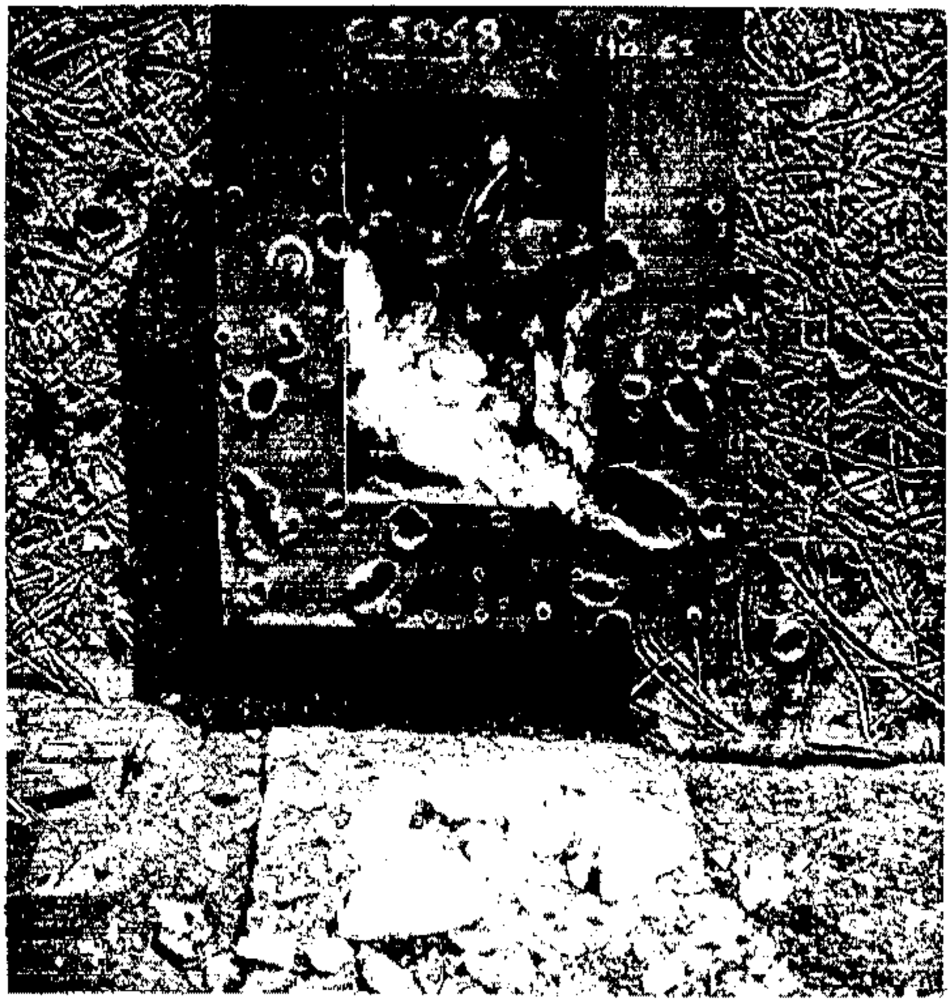


FIGURE 7

Test of 4" Plexiglas Window
20 lb. of C-4 Explosive

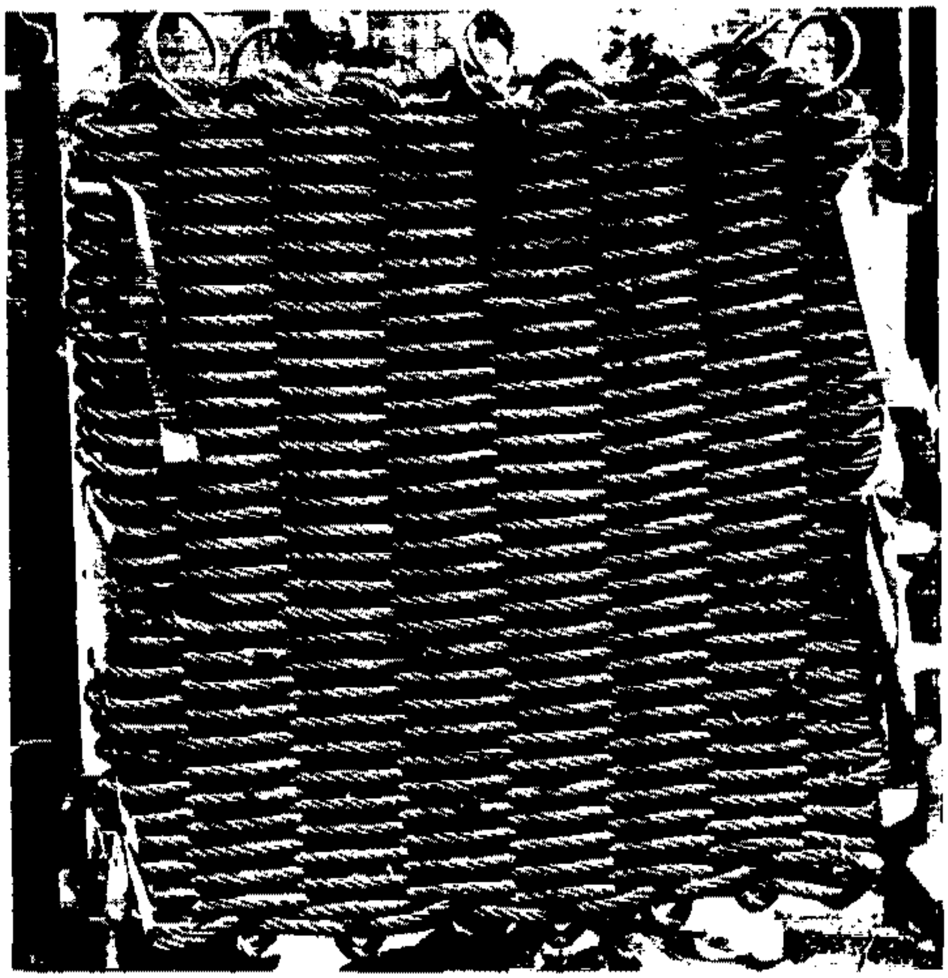


FIGURE 8

Test of Blast Mats Made of 5/8"
Cable; 1 lb. C-4 Explosive

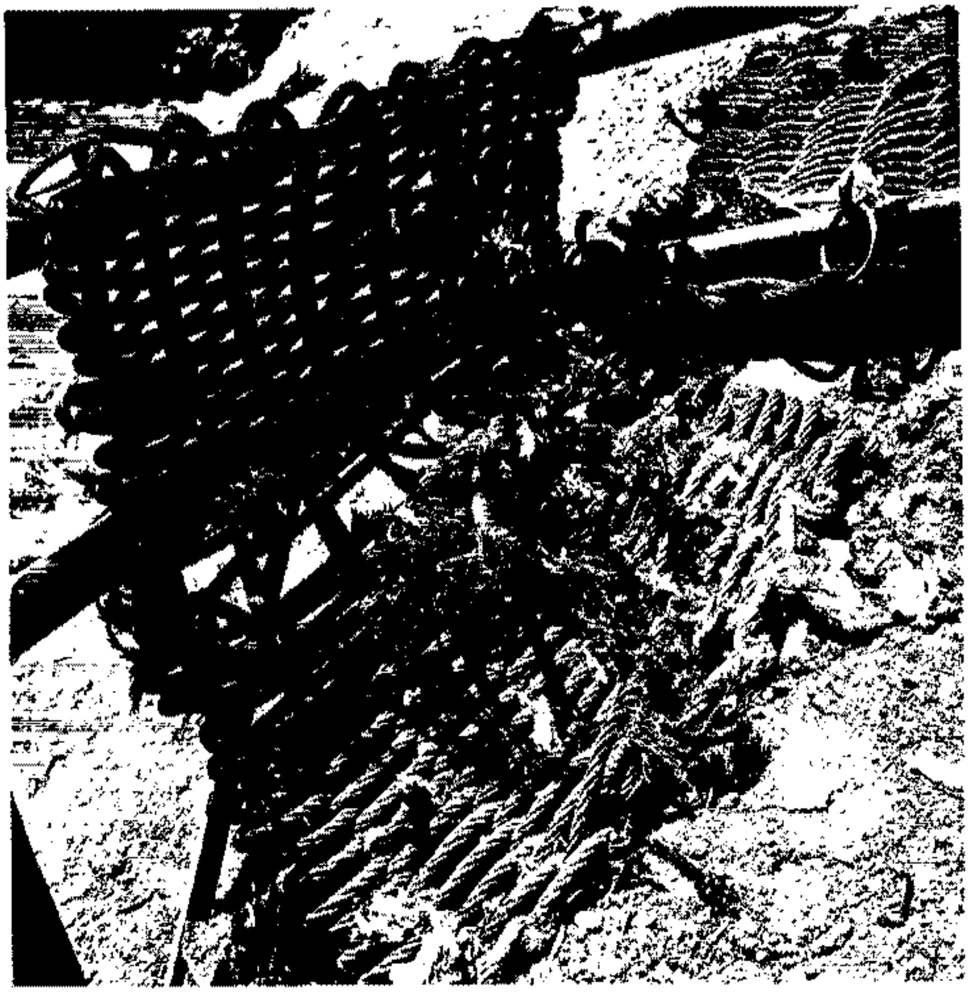


FIGURE 9

Test of Blast Mats Made of 5/8"
Cable; 20 lb. C-4 Explosive

its surface. Conclusions - The limited number of tests reported in this paper clearly do not rigidly define the capability of the test materials to withstand explosions. However, several points were clearly established and gave the needed information for design of the new facility, 1) plexiglas is superior to glass for observation windows. A window assembled from two 4" thick plexiglas panes, with 3" spacing between panes, stopped fragments from an explosion of 10 lbs. of C-4 explosive. At higher levels, the window should be completely covered with steel plate. 2) covering the edges of windows with steel plate markedly increases the window strength in explosions with blast fragments. 3) blast mat is less effective than steel plate on a pound-for-pound basis. Two layers of blast mat made from 5/8" cables absorb most of the energy from fragments originated by a detonation 5 lb. of C-4 explosive. The double layer of mat is thus considered suitable for protecting adjacent structures for explosions equivalent to up to 2 lbs. of C-4, but would not be adequate for protection of personnel. With quantities above 2 lb. C-4 equivalent, the blast mat should be backed by steel plate. 4) damage to the test samples and to the armor plate wall was very much greater at points where projectiles hit from a 90^{o} approach angle. This makes it possible to have a safety factor for windows, for example, by locating any possible source of explosion in a position such that a line from this spot to the window makes as large an angle as possible with a line perpendicular to the windows. A detailed summary is attached.

Mr. D. E. Endsley, Hq USAF: I was wondering what the distance the donor was in the mat test?

Dr. Knapp: Five feet.

Dr. Ball: Were these mats back to back or was there any spacing between them?

Dr. Knapp: A foot between them, hanging free.

Col. Hamilton: Our next subject is toxic hazards associated with solid propellants, Dr. Duguid, Army Chemical Center.

Dr. R. N. Duguid, Scientific Director, USAEHL, Army Chemical Center, Md.: When one begins to examine the subject of toxic health hazards associated with the manufacturing, handling and use of rocket propellants, whether they be liquids or solids, one is inclined to assume that because the term rocket propellant connotes the unusual, the hazards must also be unusual. A term sometimes heard in referring to these materials is "exotic." In some cases this assumption proves to be correct. More often, perhaps, as one proceeds carefully and objectively to pursue the subject, the less exotic many of these materials and their toxic health hazards in reality become. With the liquid fuels and oxidizers, for example, in retrospect, it is rather clear that their toxic properties in many cases either were well known before they were applied to the missile field, or that their toxicity could be determined reasonably well without great difficulty. Furthermore, it has been demonstrated with the liquid propellants that the health of the persons producing and handling these chemicals has not been jeopardized to any great extent. This good safety record can be attributed principally to three factors - first, recognition of the physical, chemical and toxic properties of these agents when setting up standing operating procedures; second, designation of specific protective measures and equipment with due regard for these properties; and third, education and supervision of workers. It is a fundamental industrial hygiene principle that some knowledge of the conditions of manufacture, handling and use of a toxic chemical must be acquired if the health hazards are to be intelligently evaluated. Thus the industrial hygienist and the physician must approach the question of toxic hazard associated with exposure to these fuels not only with an understanding of the toxicologic properties of the chemicals, but also with some idea of their chemical and physical properties and the production methods, even though these be highly complex in nature. From this point of view therefore, the classification of solid rocket propellants that recognizes double base propellants and composite propellants serves a very useful purpose. A typical double base propellant, as you well know, contains mostly nitrocellulose and nitroglycerine, with relatively small amounts of other chemical additives. Here the chemical of principal concern from the viewpoint of toxic health hazard is nitroglycerine, about which much has been learned from experience in the chemical and munitions industries. Nitroglycerine is not only absorbed through the lungs if contaminated air is breathed, but it is readily absorbed through the intact skin. It will pass through certain types of so-called impermeable materials commonly used in protective gloves and clothing and thus come in contact with the skin. It is also absorbed through the digestive tract even in minute amounts. Nitroglycerine if taken into the body in sufficient amount is a systemic poison and causes marked dilatation of the blood vessels which leads to a fall in blood pressure. Because of this property it is used in small doses therapeutically in certain types of heart disease. Nitroglycerine characteristically causes severe headache, but if the exposure is continuous a tolerance develops so that the headache disappears. It is common knowledge among nitroglycerine workers that they lose their tolerance over weekends when they are away from work and that the headache returns on Monday morning upon return to work. This has lead to the common practice in past years, particularly among dynamite workers, of rubbing some of the chemical in the hatband thereby assuring that some off-duty absorption of nitroglycerine would take place and the tolerance would not be lost. Now the worker could return on Monday morning and remain headache-free. Unfortunately, in a few instances, after prolonged exposure of this sort, serious consequences developed. The headache of the worker is explained on the basis of the dilating action of the chemical on blood vessels in the brain. Continued exposure, if long enough in sufficient amounts, may produce progressive lowering of the blood pressure and finally collapse of the circulatory system. This suggests one of the means of prevention, not as a substitute for other controls, but as a supplement; namely, periodic measurement of blood pressure of nitroglycerine workers with a careful investigation into the conditions of the work environment, including the work habits of the individual concerned, in the event a sustained downward trend in blood pressure is detected on successive examinations. Among some of the other manifestations of nitroglycerine exposure are central nervous system symptoms and skin eruptions. This brief resume of the toxic manifestations associated with nitroglycerine exposure is based on knowledge that has been available for many years. Yet there is a tendency, particularly with chemicals whose application is largely military, for this type of knowledge to be forgotten or overlooked. For example, a recently published book on solid rocket propellants contains a single statement, relating to toxicity, that nitroglycerine is a skin irritant having an MAC*of 0.5 ppm. It is suggested that in the interest of health protection, the following statement might well have been added: "Nitroglycerine is also a systemic poison which enters the body by inhalation, ingestion or skin absorption. Minute amounts produce toxic effects." Briefly, prevention of nitroglycerine intoxication depends upon well designed and properly engineered operations with ventilation sufficient to maintain hygienic air; housekeeping and personal protective measures directed toward the prevention of skin contact and accidental ingestion of the material; periodic industrial hygiene surveys; medical surveillance over the health of the workers; health education; and careful supervision of all operations in which actual exposure to this chemical is possible. The composite propellants comprise a great variety of chemicals, both among those currently being manufactured and those showing promise for the future. Those currently being used are chiefly resinous fuel binders, either plastics or synthetic rubbers, to which are added inorganic crystalline oxidizers, such as ammonium perchlorate, and small amounts of chemical additives. In general, the toxic properties of these fuels, their oxidizing agents and the chemical additives are perhaps of secondary importance when viewed along with the fire and explosion hazards. In this regard, it is fortunate that the care which must be exercised and the procedures employed to prevent accidental ignition of these materials in many instances accomplish, at the same time, control of the toxic hazard. This is, however, not always true. Both the fuel binders and the chemical additives are not without certain toxic properties. For example, among the plastic fuel binders, skin contact with the uncured epoxy resins is noted for producing dermatitis as well as other skin damage. Also the amines used in their cure are skin irritants. The cured epoxy resins, if free from residual monomers and amines, are inert. The acids or amines used in curing the phenolic resins are also skin irritants and present handling problems. Styrene monomer which is found in many of the polystyrene fuels is an irritating and moderately toxic material. It has an MAC of 200 ppm and must therefore be handled with adequate ventilation and under hygienic conditions. The isocyanate used with polyurethane fuel has a relatively high toxicity and its use also requires adequate ventilation and the employment of suitable precautionary measures to prevent personnel exposure. The curing catalysts and other chemical additives used with the polysulfide rubbers possess irritant and toxic properties and must be handled accordingly. These, briefly, are a few of the chemicals which are currently being used in the composite solid propellants themselves and which may produce adverse health effects. Possibly as important as the health hazards from the handling of these chemicals, and perhaps more so, are the relatively conventional industrial health hazards which are associated with fabrication and processing of a solid propellant motor. The more important of these are listed in Table I along with the exposures incident to each, the principal health interest, and the controls. The following slides depict various steps in the fabrication of a solid rocket motor; each of which involves one or more health hazards: hot degreasing, blast cleaning of a rocket case, lining a motor case, transfer of oxidizer to mixer, removal of propellant from mixer, casting facility, radiographing of finished motor. Regarding the toxic properties of the newer chemicals which may find application in the solid propellant field in the future, an important generalization

*Maximum Allowable Concentration in air for an 8-hour daily exposure.

can be made. Namely, in most instances the information developed relative to the toxic properties of new agents is that which comes from animal experimentation. However, caution must always be used in applying this type of knowledge to humans. A noted example of this is beryllium which has certain attractive properties to the solid propellant technologists. Some of you may know that in 1943, this chemical was identified by competent investigators in a widely distributed publication as essentially without toxic properties on the basis of review of the literature up to that time, supplemented by animal experimentation. Simultaneously workers in the fluorescent lamp industry where a beryllium phosphor was used were developing chronic beryllium disease of the lungs, a most serious, mysterious, and often fatal process. A great deal of investigative work relating to the toxicity of beryllium has been done since that time. As a result, this material is looked upon as perhaps the most toxic of the metals and extreme caution is necessary to assure health hazard control whenever it is used or handled. Of importance here, is the fact that to the present time investigators have been unable to reproduce in animals the identical chronic lung disease which is so dangerous in humans. The toxicologic information developed through animal experimentation is of course extremely useful providing its limitations are not forgotten. Among the newer chemicals are the light metals including boron, beryllium, lithium, aluminum and magnesium in various forms including the powdered metal, organometallic compounds and hydrides. Of these metals, the toxicity of the boron and beryllium compounds are the most important. The gaseous diborane exerts its effect primarily on the lungs but the higher hydrides and the organboron compounds affect the central nervous system leading in severe cases to muscle spasms and convulsions. Damage to the liver and kidney also may occur. These materials are absorbed through the lungs, skin and digestive tract. Beryllium, as already mentioned, produces serious chronic lung disease. It also produces an acute type of lung disease, and has been shown to possess certain systemic toxic properties. Further, it produces an unusual type of skin lesion. Lithium, magnesium and aluminum are other metals which may be mentioned. None of these, however, is particularly noteworthy as regards toxicity. A very important question in any discussion of toxic health hazards from solid rocket propellants concerns the products of combustion and their possible toxic effects on humans if they are breathed. With respect to this it can be stated that the chemical nature of the combustion products of solid propellants is influenced by the chemical composition of the propellant and by the conditions of combustion, for example, combustion and reaction temperatures, and oxidative conditions. It is therefore difficult to obtain a complete and exact chemical analysis of the combustion products of any propellant system. However, the major constituents of the combustion products of a propellant system can be predicted with a reasonable degree of accuracy if one has sufficient data regarding the chemical composition of the propellant. Accordingly, from the combustion of a hydrocarbon propellant, one would expect to find carbon monoxide noted for its ability to deprive tissues of oxygen. If the propellant contains nitrogen, the oxides of nitrogen, including the very toxic nitrogen dioxide, will be produced. The latter if breathed in sufficient amounts produces the characteristic and oftentimes fatal, edema of the lungs. A sulfur-containing propellant when combusted will produce toxic and irritant gases, including sulfur dioxide, sulfur trioxide and hydrogen sulfide.

OPERATION	EXPOSURE (Figures shown are MAC Values)	PRINCIPAL HEALTH INTEREST	CONTROLS
Arc and acetylene welding	Metal and flux fumes, oxides of nitrogen (5 ppm), carbon monoxide (100 ppm), infrared and ultraviolet radiation	Lungs, Eyes	Welding helmets, exhaust or general ventilation, respirators, shields
Blast cleaning	Metallic and abrasive dusts	Lungs	Enclosed blasting cabinets, protective clothing, respirators
Cold degreasing	Methylene chloride (500 ppm)	Lungs, Skin	Exhaust or general ventilation, respirators
Hot degreasing	Trichloroethylene (200 ppm)	Lungs, Skin	Properly engineered degreasers with condensing mechanism, ventilation and respirators if required
Grinding of oxidizer	Oxidizer dusts	Lungs, Skin	Isolated room - remote control, respirators
Case lining	Volatile solvent	Lungs	General ventilation
Spray painting	Paint mists - thinner vapors	Lungs	Ventilated spray booth, respirators
Radiographing of finished motor	Ionizing radiation	Whole body	Protective barriers, personnel monitoring

TABLE I

UNCLASSIFIED

EXHAUST COMPOSITION

SOLID ROCKET FUELS CONTAINING METALS

METAL	POSSIBLE CONSTITUENTS				
	OXIDE	HALIDES	HYDROXIDE	NITRIDE	FREE METAL
Boron	B_2O_3	BCl_3	-	BN	B
Toxicity	-	H	-	-	M
Beryllium	BeO	BeF_2	$Be(OH)_2$	Be_3N_2	Be
Toxicity	H	$2 \mu g/m^3$	H	-	$2 \mu g/m^3$
Aluminum	Al_2O_3	$AlCl_3$	$Al(OH)_3$	AlN	Al
Toxicity	L	L	-	-	L
Magnesium	MgO	$MgBr_2$	$Mg(OH)_2$	Mg_3N_2	Mg
Toxicity	L	-	L	-	M
Lithium	Li_2O	LiF	LiOH	Li_3N	Li
Toxicity	-	H	M	-	L

Legend: L - Low M - Medium H - High µg - microgram

TABLE II

If the propellant contains chlorine, the combustion products will contain hydrochloric acid and chlorine, both of which are capable of producing adverse health effects. In the case of propellants containing metallic atoms, the combustion products will contain the metal in the forms shown in Table II. In conclusion, the variety of chemicals and processes used in the solid rocket propellant field requires alertness on the part of all concerned not only to the hazards resulting from the physical properties of these chemicals and processes, but also the toxic health hazards. Health protection among those concerned with the development, manufacture and use of these propellants calls for the application of the three E's of accident prevention - namely, engineering, education and enforcement. In addition to these well known areas of prevention it is important that periodic industrial hygiene surveys of the work environment be made to determine if the concentration of the chemicals in the air, and skin contact, are adequately controlled. Many of the toxic chemicals produce their harmful effects only after prolonged and repeated exposures to low concentrations or small amounts of the materials. Therefore, the absence of toxic symptoms at any one time cannot be accepted as proof that a harmful exposure does not exist. Such chronic exposures can be evaluated only by adequate industrial hygiene surveys of the work environment and periodic medical surveillance of the health of the individuals working with these materials.

Dr. Johnson: Concerning the toxicity of beryllium, I think you're all aware of the study now underway at Atlantic Research, I think the fate of beryllium as far as the Navy is concerned will ride or fall on this study. At the moment we take a dim view of it, it's an Air Force sponsored thing monitored by the Aeromedical Laboratory at Wright Field. The one that concerns us at the moment is the ARPA contractor and some of our service labs like the Rohm & Haas Lab right here at Redstone, Esso, Dow, Rocketdyne, etc., on NS chemistry are fluorene bonded to oxygen or sulphur. There has been a preliminary study of the toxicity of difluorourea at Dow on an Air Force contract and it's poisonous as the very dickens. The vapors will blind rabbits in just a few minutes. I think this field which is one of the most promising fields for propellant ingredients for the 1965-70 area is going to have to be watched very closely by the safety people.

Dr. Duguid: I might just mention in connection with this effort that you first mentioned, I think they are getting some guidance from the people who have done the original work on beryllium up at M.I.T. That would tend to give you a little assurance that they won't go off half cocked.

Mr. K. E. Rumbel, Atlantic Research Corp: We're carrying out this program that has been mentioned here. The program is sponsored by ARPA and the Air Force jointly and is administered by Edwards AFB with the medical aspects of the program being monitored by Wright Field medical people. We have Dr. Harry Harvey of M.I.T. as a consultant on the project with respect to beryllium toxicity. The program is sort of a two part program with respect to, first the evaluation of propulsive capabilities of beryllium as a propellant ingredient and secondly, actual animal exposures in a closed testing tunnel to determine the behavior of animals - rabbits and dogs - when exposed to actual combustion products from beryllium containing propellants. Exposures have been made, the assessment of results is far from complete, two groups of exposed rabbits are currently being followed carefully, much clinical work will have to be done yet before they assess results. In passing I might add one of the early results is a clear indication that the hydrochloric acid content of the combustion product is causing the rabbits as much trouble as anything else right now.

Col. Hamilton: Any other comments? Thank you very much Dr. Duguid. The next item is determination of propellants and safety design criteria for manufacture and storage. Mr. Saffian from Picatinny Arsenal.

Mr. L. W. Saffian, Picatinny Arsenal: At last year's explosives safety seminar conducted at the Naval Propellant Plant, a paper was presented outlining the various phases of Picatinny Arsenal's safety design criteria program. This work dealt with a consideration of propagation of detonation by blast effects and by fragment effects. It was possible on the basis of experimental and accident data amassed over the years to establish a distance beyond which propagation would not occur, assuming no effective missiles were produced by the donor explosion. It was also possible, on the basis of a good deal of experimental work done in Great Britain and in this country, to establish a basis on which we could calculate the gross mass detonability characteristics of explosive systems (i.e., the possibility of mass detonation due to fragment impact occurring in cases of adjacent explosive systems made up of explosive-containing items). In the large majority of the actual cases calculated, predictions as to mass detonability coincided with recommendations for handling given in the Ordnance Safety Manual, these recommendations being based on experience or incidents which have occurred in manufacturing or loading plants, and storage depots. Up to this point the studies relating to detonation by fragment impact were concerned primarily with development of what may be thought of as an initial screening procedure for determining whether or not a possibility of propagation of explosion due to fragment impact exists. For this purpose the severest conditions were assumed, e.g., no consideration was given to the effects of distance of separation between the acceptor and donor nor to shielding other than that which the acceptor supplies by virtue of its own minimum casing thickness. Since the general relationships involved were outlined in some detail at the last safety seminar, I will review them only briefly at this time. (Slide 1) Equation 1 permits us to calculate the initial velocity of fragments as a function of explosive output and charge to casing weight ratio. Equation 2 gives us the number of fragments larger than mass (m) as a function of (m), donor casing weight, thickness and inside diameter, and an explosive constant (B). Equation 2a gives us the mass of the largest fragment produced by the donor detonation as a function of donor casing weight, thickness and inside diameter, and explosive constant. Equation 3 gives us the boundary velocity, or striking velocity below which no detonation in the acceptor will occur, as a function of acceptor casing thickness, fragment mass and acceptor explosive sensitivity constant (K_f). Finally equation 3a gives us the minimum boundary velocity required for detonation of given acceptor by fragment from a given donor as a function of explosive sensitivity constant (K_f), acceptor casing thickness and the mass of the largest fragment produced by the explosion of a given donor. The ratio of $V_o/V_{b_{min}}$ (Slide 1A) serves as a criterion for predicting the gross mass detonability characteristics of explosive systems.

If this ratio is smaller than 1, then the detonation by fragment impact will not occur. On the other hand if this ratio of initial velocity to boundary velocity is equal to or larger than 1, then there is a possibility of detonation by fragment impact. It is the intent of this presentation to go further into a primary objective of our studies, which is to develop relationships to permit the calculation of safe distances in terms of probability of high order detonation occurrence or risk of propagation of detonation by fragment impact at these distances. Having calculated such probability factors (e.g. striking probability of fragments) we could then establish design distances depending on the degree of risk, if any, that can be tolerated, as well as acceptor casing and/or supplementary shielding. For the sake of simplicity and convenience a graphical representation of these relationships was set up, which is shown schematically on the next series of slides. The plot presented on Slide 2 is based on equation 4. It relates fragment striking velocity (V_s) with fragment mass (m) at any distance from the detonation source (d) (constant distance lines - d_m being limiting distance at which detonation will occur). Each plot is made for a single value of initial velocity of donor fragments (V_o). A series of plots like the one presented on Slide 2 can be prepared for different values of (V_o). The constant (k) is a function of the presented area to fragment mass ratio, density of air, and air drag coefficient. Although it was found experimentally that the (k) value is somewhat higher for thin cased items than for heavier cased ones (the difference being about 20%),[1] the variations within each one of these general categories are comparatively small.[2] While Slide 2 indicates the velocity of the fragments at any particular distance from the donor, Slide 3 is a schematic representation of equation 3 which tells us what minimum velocity a fragment must have in order to detonate a given acceptor separated from the donor by that distance. This plot relates the boundary velocity (minimum striking velocity at which a high order detonation will occur) with fragment mass (m) and acceptor casing thickness (t_a) and/or thickness of shielding in front of acceptor charge. The graph is plotted for a single explosive sensitivity (expressed in terms of the sensitivity constant (K_f), discussed previously). When we combine the plots from Slides 2 and 3 as shown on Slide 4 we obtain useful relationships. Slide 4 relates striking velocity (or boundary velocity) of a fragment with fragment mass at various distances (d) and acceptor casing thickness (t_a). If we now equate the boundary velocity of a fragment to its striking velocity, it becomes possible to find the minimum effective mass of a fragment produced by the donor explosive that will cause a high order detonation in the acceptor charge at any distance from the donor (d) and/or shielding of the acceptor (t). Therefore, according to equation 2 we can calculate the number of such effective fragments produced at any distance from the donor charge. It is of interest to note the limiting case which is shown by equation 4a on Slide 4. This indicates the maximum distance (d_m) at which propagation by fragment impact can occur for a given donor - acceptor situation. This is the distance at which the largest fragment (m_{max}) produced by the donor strikes the acceptor at the minimum velocity ($V_{b_{min}}$)

[1] BRL Rpt No. 468: L.H. Thomas; Computing the Effect of Distance on Damage by Fragments.

[2] BRL Rpt No. 472: K.S. Jones; Vulnerability of Simulated Missile Warheads.

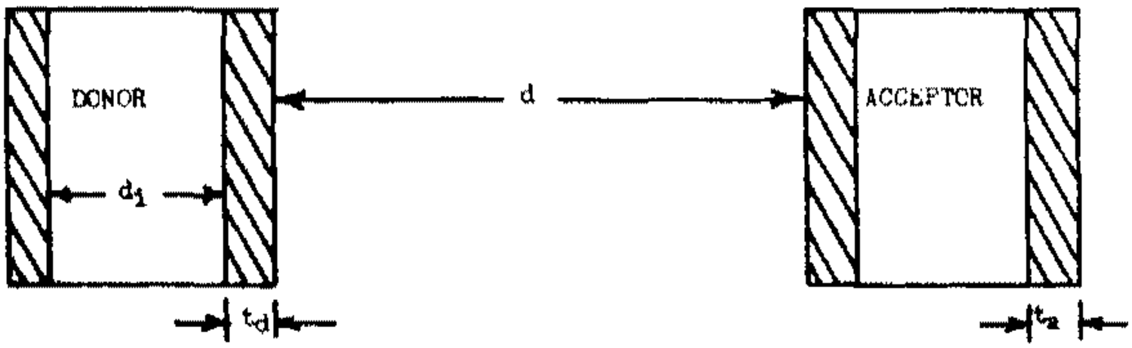
required for detonation. It should be noted further that in terms of probability of acceptor detonation this is a boundary situation representing minimum probability of acceptor detonation occurrence, i.e., maximum distance, minimum boundary velocity, and minimum number of effective fragments (the single largest donor fragment). At greater distances and/or lower velocities, the probability of acceptor detonation is therefore presumed to be zero. We can now consider the general case of reducing design distances from the limiting distance value (as expressed by equation 4a) and/or shielding thickness by accepting a certain risk or probability of the possibility of high order detonation occurrence. The probable number of effective hits (i.e., hits which upon striking the acceptor charge will cause high order detonation) by impacting fragments may be expressed by equations 5 and 5a, Slide 5[3]. As can be seen from this equation, the probability per unit area is dependent upon the number of effective fragments (N_x) (obtained from equation 2 previously discussed) and the distance between the donor and acceptor charges. Included in the equation is a constant (g), which depends on the spacial angular distribution of fragments. For most of our purposes a single value of (g) may be used without serious error. The plot shown on Slide 5 relates the distance between the donor and acceptor charges (d), shielding (t), and probability (E) of high order detonation occurrence for a single explosive system. A zero probability curve (E_0) indicates a relationship between the distance (d) and shielding (t) beyond which no high order detonation is possible. This line represents the limiting case mentioned earlier. The higher the probability level that could be tolerated, the lower the distance-shielding combination necessary. This relationship permits us, with a fairly reasonable degree of accuracy, to predict the necessary separation and/or shielding between two explosive systems at any degree of probability of high order detonation occurrence. To compose such a relationship (as presented on Slide 5) all that would be necessary is knowledge of the geometry of the system and the previously discussed explosive properties relating to sensitivity and output. The relationships which have been outlined permit one to predict the potential propagation characteristics of explosive systems, as well as to establish a design basis for prevention of propagation. A detailed presentation of the relationships involved and the calculation procedure, as well as illustrative examples, are contained in a forthcoming technical report.[4] Relationships are outlined which permit the calculation of safe distances for prevention of propagation of detonation due to fragment impact between adjacent, potentially mass detonating systems, for any assumed degree of risk and degree of acceptor shielding. These relationships permit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding and/or separation distances for any other degree of tolerable risk. All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems. A simple method for graphically representing the relationships has been presented.

[3] R. I. Mott: A Theory of Fragmentation AOR Group Memo 113 (British)

[4] R.M. Rindner and S. Wachtell; Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations - Rpt. No. 3; Safe Distances and Shielding for Prevention of Propagation of Detonation by Fragment Impact (to be published).

SLIDE 1 & 1a

SCHEMATIC REPRESENTATION OF DONOR-ACCEPTOR RELATIONSHIPS GOVERNING PROPAGATION BY FRAGMENT IMPACT



$V_o = f\,(E')(E/C)$ - - - - - - - - - (1)

- V_o = initial fragment velocity
- E' = explosive output constant
- E/C = explosives/casing weight ratio

$N_x = f\,(B)(C)(t_d)(d_i)(m)$ - - - - (2)

- N_x = number of fragments greater than mass (m)
- m = mass of fragment produced by donor detonation
- B = constant depending on donor explosive and casing material
- C = donor casing weight
- t_d = donor casing thickness
- d_i = inside diameter of donor casing

$m_{max} = f\,(B)(C)(t_d)(d_i)$ - - - - (2a)

- m_{max} = mass of largest fragment produced by donor detonation.

$V_b = f\,(K_f)(t_a)(m)$ - - - - - - (3)

- V_b = boundary velocity or fragment striking velocity of mass, m, below which high order detonation of the acceptor will not occur.
- K_f = explosive sensitivity constant
- t_a = acceptor casing thickness

$V_{b_{min}} = f\,(K_f)(t_a)(m_{max})$ - - - - - (3a)

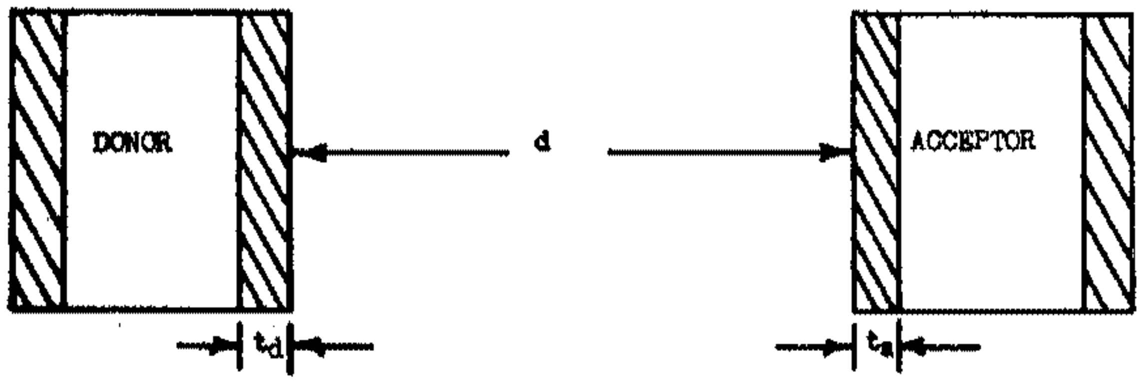
- $V_{b_{min}}$ = minimum boundary velocity required for detonation of given acceptor by fragment from given donor.

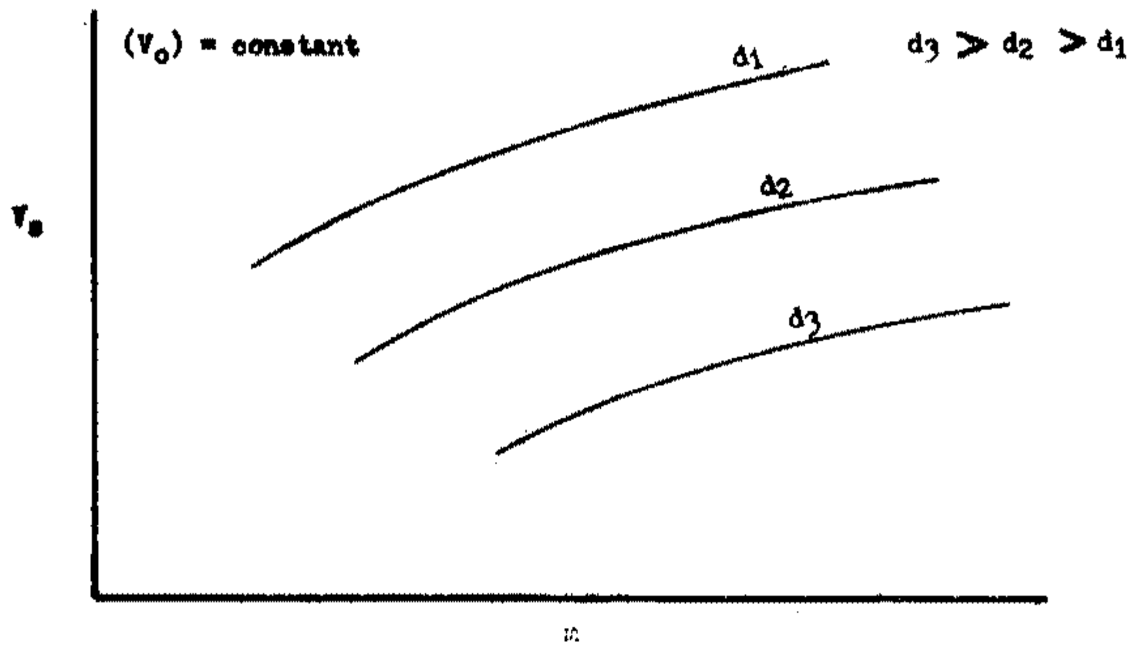
If $\frac{V_o}{V_{b_{min}}} < 1$; detonation by fragment impact will not occur.

If $\frac{V_o}{V_{b_{min}}} \geq 1$; possibility of detonation by fragment impact exists.

SLIDE 2

STRIKING VELOCITY OF A FRAGMENT AS A FUNCTION OF FRAGMENT MASS AND DISTANCE



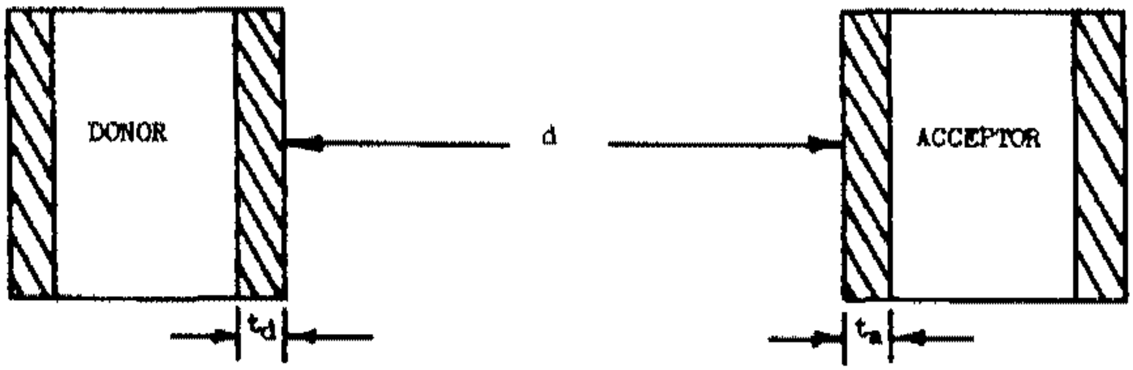


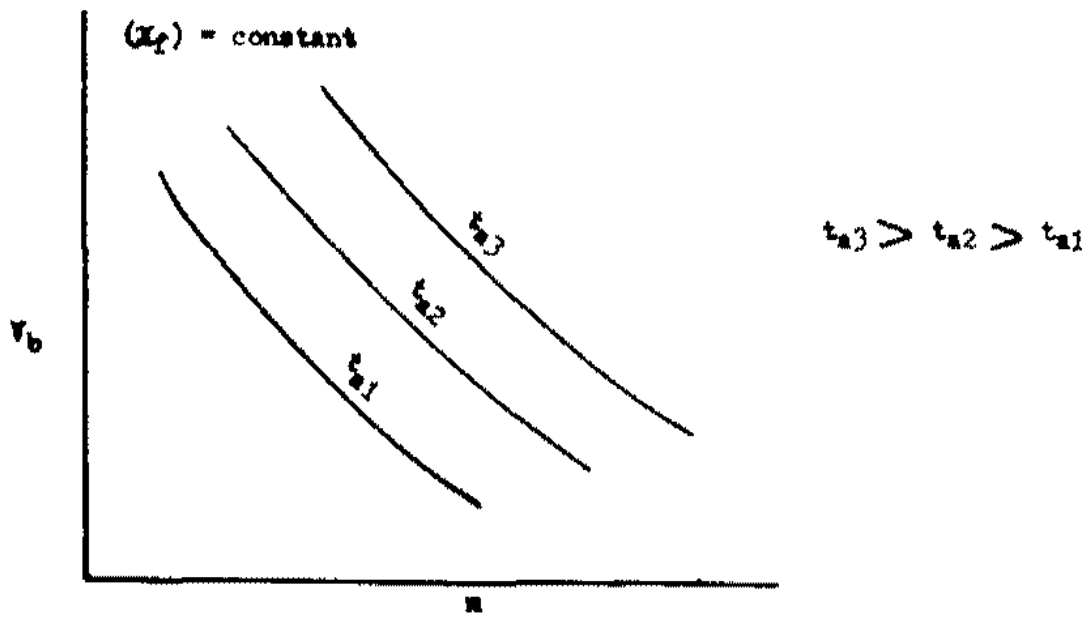
$$d = f\ (k)(V_o/V_s)(m) \text{ - - - - - - - - - - - - - - } (4)$$

- d = distance from the donor charge
- k = constant depending on fragment size, shape, air density and drag coefficient
- V_s = striking velocity of fragment at a distance d

SLIDE 3

BOUNDARY VELOCITY OF A FRAGMENT AS A FUNCTION OF FRAGMENT MASS AND ACCEPTOR SHIELDING

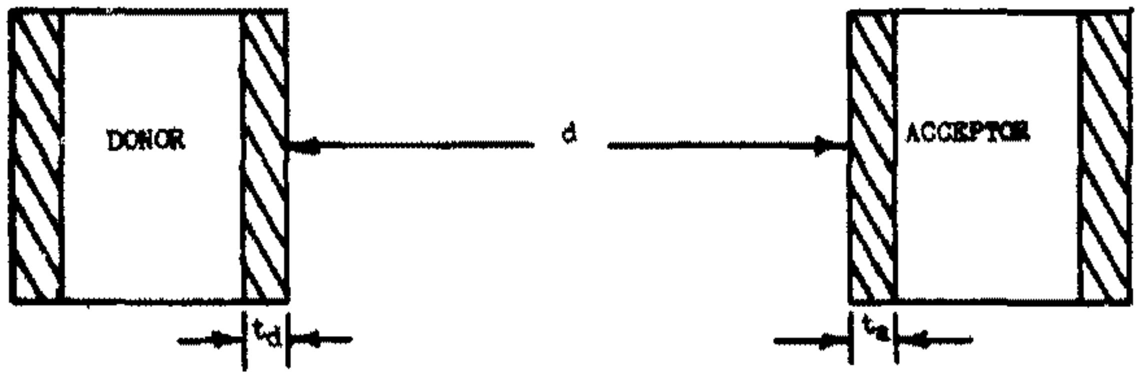


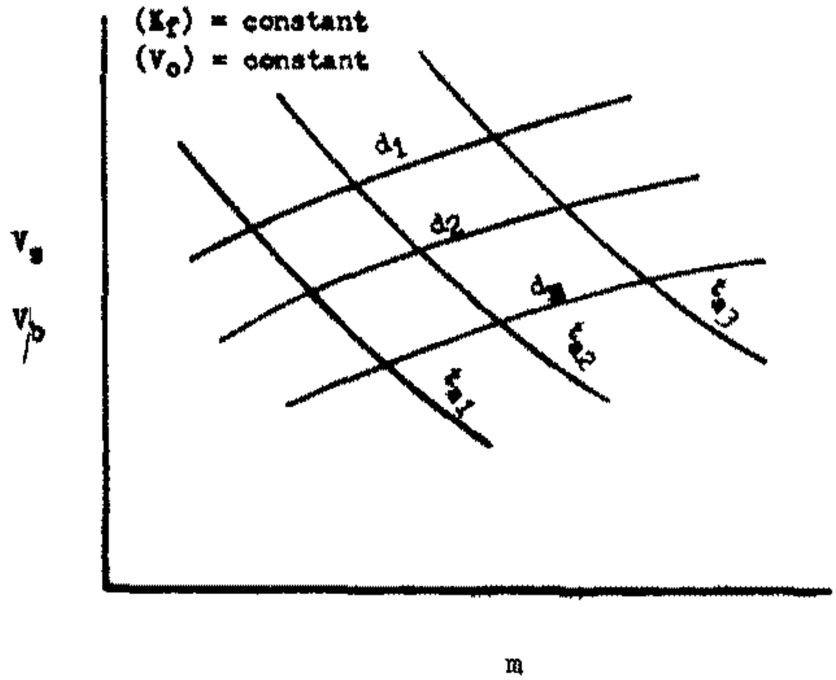


$V_b = f\ (K_f)(t_a)(M)$ - - - - - - - - - - - - - (3)

SLIDE 4

MINIMUM EFFECTIVE FRAGMENT MASS AND CORRESPONDING VELOCITY AS A FUNCTION OF DISTANCE AND SHIELDING



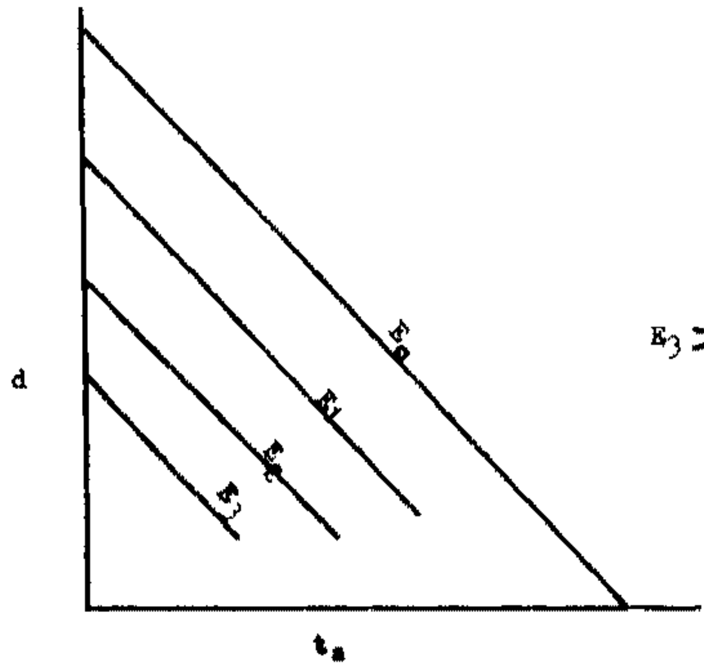


$d_m = f\ (k)(V_o/V_b)_{min}(m_{max})$ - - - - - - - - - - - - - - - - - (4a)

Where d_m = maximum distance from given donor charge at which detonation of given acceptor is possible.

SLIDE 5

PROBABILITY OF DETONATION OCCURRENCE AS A FUNCTION OF DISTANCE AND SHIELDING



$E_3 > E_2 > E_1$

E_0 - Zero probability curve

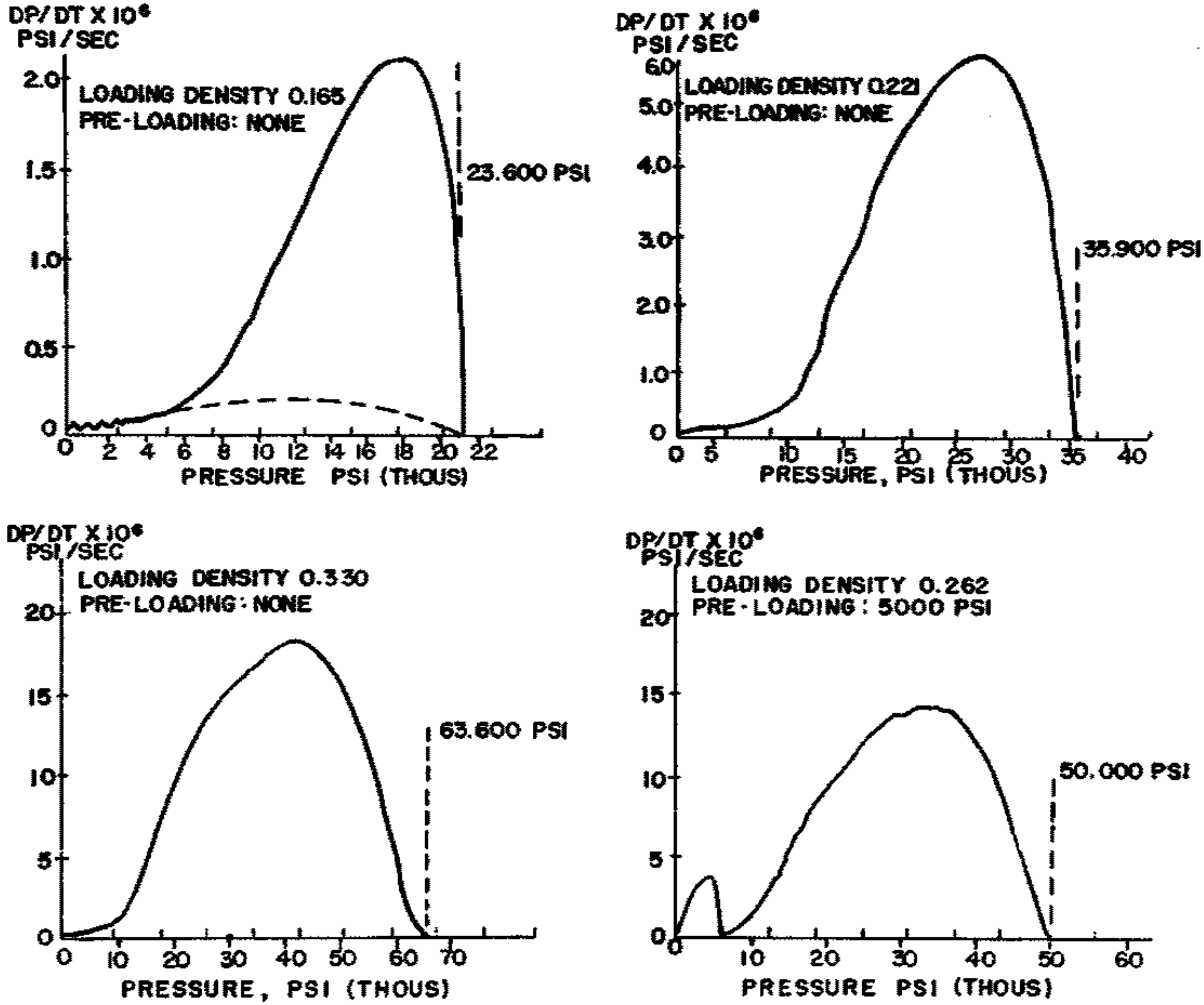
$$P/A = f(N_x)(d)(g) \text{ - - - - - - - - - - } (5)$$

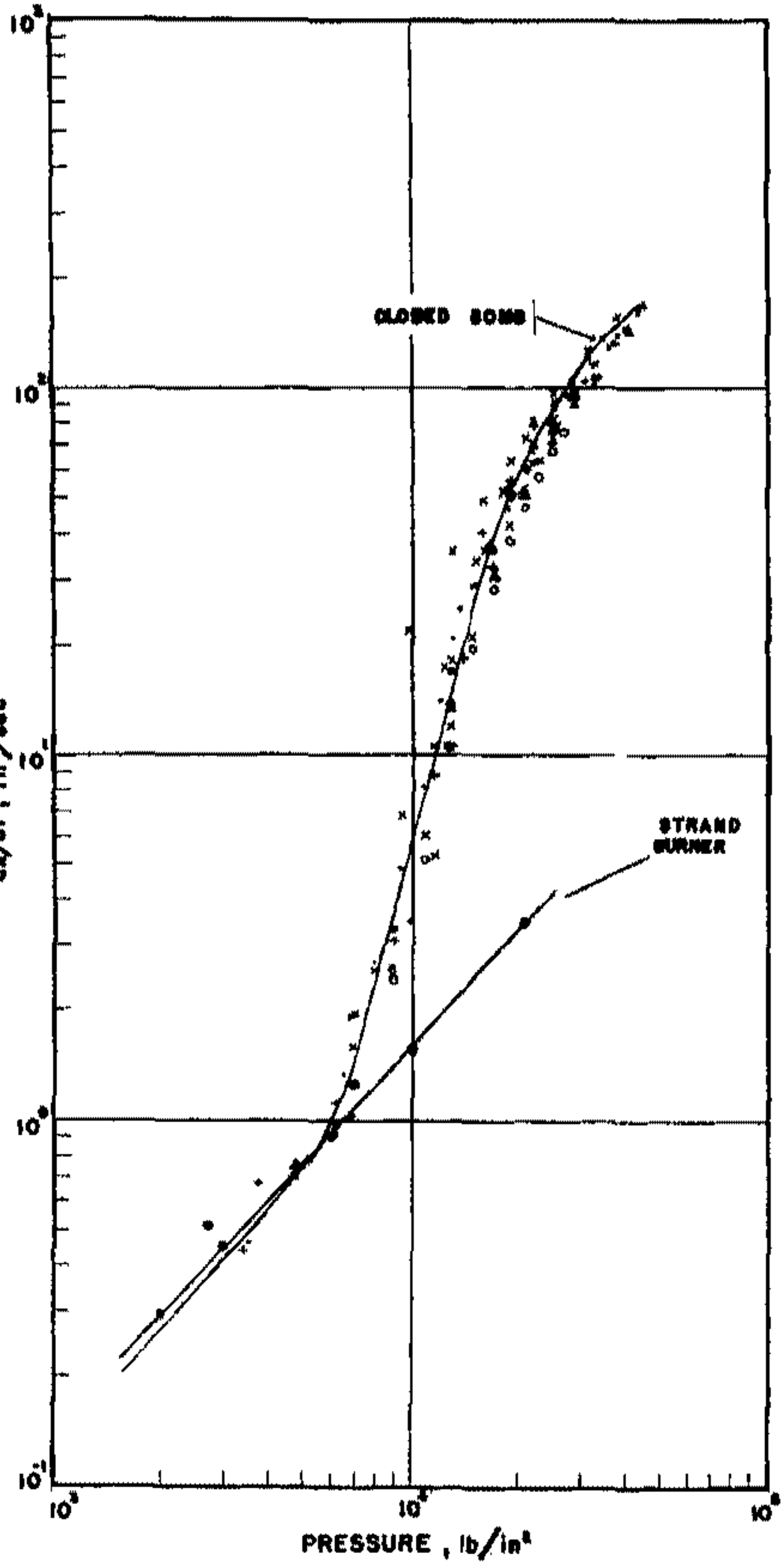
$$E = f(P) \text{ - - - - - - - - - - - - - - } (5a)$$

P/A = Probable number of effective hits per unit area.
N_x = Total number of effective fragments.
d = Distance between donor and acceptor charge.
g = Factor governing the distribution of fragments.
E = Probability of high order detonation occurrence in the acceptor.

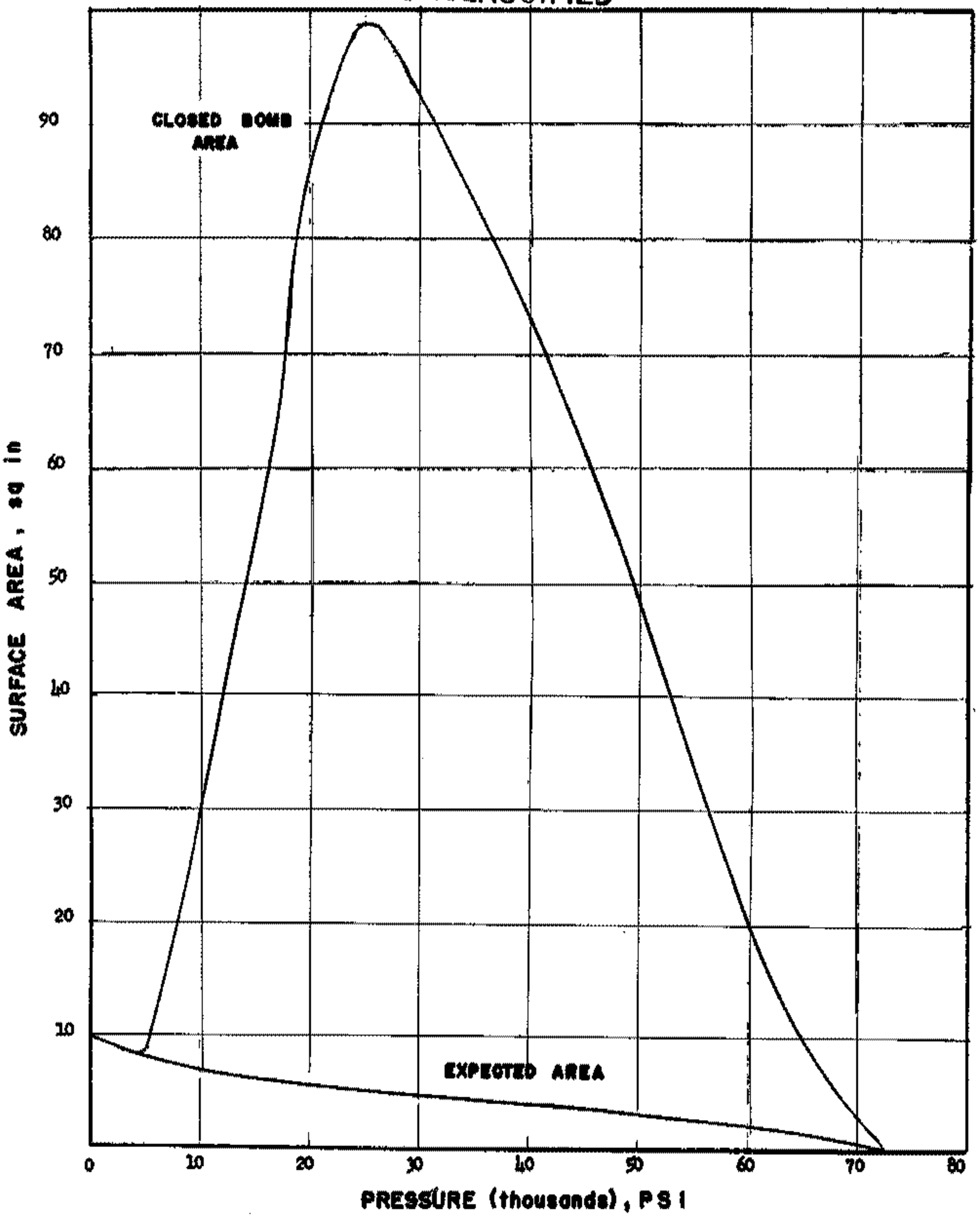
Mr. S. Wachtell, Picatinny Arsenal: A quantitative approach to the classification of high energy propellants and explosives according to their susceptibility to undergo transition to detonation has shown promising results. Many of the materials tested thus far show a critical pressure above which this transition can occur. The method involves the burning of large solid cylinders of the material under consideration, in a closed bomb at high pressure. At a pressure which is characteristic for each composition and condition, the burning rate vs pressure curve obtained shows a marked deviation from the results predicted from strand burning tests. This deviation is indicative of a pre-detonation reaction which takes place in the explosive which could proceed into detonation if sufficient material were available. The pressure at which this deviation begins and the rate at which it occurs can be used as the basis for classification of detonability. In the firing of large missile motors, a property of the propellant of serious concern is the possibility of transition from normal burning to detonation. While every effort is made to assure the quality of each motor manufactured, the possibility exists that some condition may have developed in manufacture handling or storage which could lead to high pressures and initiation of transition. As the energy content of formulations are increased, the possibility of transition occurring becomes more likely. Existing sensitivity tests are highly inadequate for measuring this property. Impact sensitivity, for example, indicates that some polysulfide-perchlorate composite propellants are in the same range of sensitivity as tetryl, while on the other hand, it is generally impossible to detonate them even with large contact explosive charges. Card gap tests and booster sensitivity tests come a little closer to realism in that they give information on shock sensitivity and critical diameters. None of the existing techniques gives any information about the susceptibility to transition from deflagration to detonation. The techniques we are presenting here we believe are capable of quantitatively measuring the susceptibility of a solid propellant to undergo transition to detonation. It is generally agreed that for transition to take place in a burning explosive the formation of a shock front is necessary; and that a shock front will form in a deflagration explosive if the pressure surges resulting from deflagration are exponential. These conditions have been obtained experimentally by a number of workers in the field by using ground or shredded composite stocks. Hyndman (of Rohm & Haas) was able to show transformation to detonation by burning ground propellant, packed in a tube and contained in a closed bomb. Cibson (at the Bureau of Mines) claims to have obtained transition to detonation from shredded composite pressed into heavy walled steel tubes. In both of these cases the mechanism of DDT proposed by Dr. Kistiakowsky applied. This mechanism consists of: 1) local ignition followed by the flow of products of combustion through the bed, 2) formation of a shock wave and subsequent intensification by rising pressure and temperature until it is strong enough to initiate burning as a result of its passage, 3) further intensification by products of combustion until the shock wave reaches the stable velocity of detonation of the bed. The transition is considered to be essentially a physical process in which the velocity of the shock front increases smoothly from its first appearance until it reaches stable detonation velocity. However, while the linear burning rate of the bed of burning material increases to a rate of several thousand meters per second, the burning rate at which the individual particles are consumed is only in the range of several hundred inches per second. While this mechanism was applied to granular material, why should it not apply as well to composite or homogeneous propellants, if the growth of the shock front is accompanied by an increasing break-up of the surface of the propellant. In the light of some experience with certain cannon propellant in closed bomb tests, in which unpredictably high rates of change of pressure were encountered, it was considered possible that this technique could be extended to the study of explosives and high energy rocket propellants. It had been observed in previous cases of high bomb pressures, that the deviation of the propellant from its normal burning action started at a specific pressure. This pressure appeared to be typical of a specific lot of propellant and could be reproduced for each lot of material tested. Since the burning rate laws have been shown to hold for these propellants a (reasonable) explanation for this apparent increase in burning rate is that it resulted from surface cracking of the grains under the pressure and thermal stress of the reaction. If this is the initial step in the transition from deflagration to detonation, and it must occur if the surface burning theory is valid, then the rate at which the surface area increases can be measured in the closed bomb. The measurement of linear burning rate in a closed bomb has been standard procedure for many years (references 6 and 7). From a consideration of the original geometry of a grain of material and a knowledge of rate of change of pressure in the bomb when the grain is burned, the linear burning rate at any particular pressure can be calculated. This calculation assumes that the grain is ignited uniformly over its entire surface and always burns normal to that surface. However, if surface cracking or crazing of a grain should occur with a resulting increase in burning surface, the calculated linear burning rate of the material from the closed bomb test will be far in excess of the value expected and the increase in surface area can be calculated from this apparent increase in linear burning rate. To determine whether this method would throw any light on the burning of high explosives, cylinders of TNT were prepared with diameters of 1" or more and lengths of from 1" to 3". These cylinders were machined from solid blocks of TNT which had been carefully cast to make certain that they contained no voids or porosity. All the cylinders were machined from the same block and were considered to have approximately the same crystalline structure. These cylinders were placed in a standard 200cc closed bomb with a reinforced cylinder wall and ignited with a small amount of black powder and M1A1 squibb. Tracings of typical oscillograms resulting from the firings are shown in Slide 1. These represent a series of firings made with cylinders of TNT at various loading densities. In examining these tracings it must be born in mind that the standard closed bomb instrumentation produces an oscillogram of DP/DT vs P and that the horizontal axis represents P and the vertical axis represents rate of change of P. The scale is varied to have the trace fill the oscillogram. The calculated scales of P and DP/DT are added to the tracings. It will be noted that a pronounced change in direction occurs in every case in the range of P = 6,000 - 8,000 PSI. Calculated (apparent) linear burning rates vs pressure for each firing are shown in Slide 2. An average line is drawn for burning rate vs pressure. At low pressures, the error in the closed bomb measurement is fairly large especially for high loading densities. Therefore, fairly wide scatter of the prints below 8,000 psi is expected. In order to establish the true burning rate for TNT, strands 1/8" x 1/8" x 7" long were prepared by cutting them from a block of TNT similar to the one used previously (to eliminate the possibility of porosity) and burned in a strand burner using the standard technique at pressures of from 1,000 psi to 20,000 psi. These results show that the closed bomb rate of burning approximately coincides with the strand burner result up to about 6,000 psi and then curves sharply upward. This apparent increase in burning rate is consistent with the assumption of an increase in burning surface which occurs on the cylinder due to surface crazing or cracking. Slide 3 shows a graph of the expected surface area vs pressure due to consumption of the TNT in the bomb (assuming normal burning of the grain) and the actual surface area of the crazed TNT calculated from the DP/DT of the bomb test and the actual linear burning rate of the TNT. This shows for TNT an increase in surface area of as much as close to 20 times. It was noted that at higher pressures, the slope of the closed bomb burning rate curve starts to level off. This leveling off seems to be inversely proportional to the loading density of the TNT used. In order to probe this high pressure area better, without incurring the danger of too much high explosive in the bomb, a technique was devised whereby a quantity of thin sheets of very fast burning propellant were loaded into the bomb and ignited before the TNT cylinders. This gives a high pressure to the bomb in very short time and the sheet propellant completes burning before any appreciable part of the TNT cylinder burns. This technique permits a larger mass of TNT to be present at higher pressure. Measurements using this technique showed an increase in the slope of the upper part of the closed bomb curve but did not change the location of the middle part of the curve. This indicates that there is possibly some minimum mass of explosive necessary to maintain the formation of increasing burning surface. Further work will be done to investigate this. Cylinders of Composition B which had been prepared in a manner similar to the TNT were then burned in the bomb at varying loading densities. In order to obtain adequate ignition of the Comp. B it was necessary to use a small amount of sheet propellant as igniter. This masked that part of the curve below about 5,000 psi. However, strands cut from the same block of Comp. B as the cylinders were burned in the strand burner to obtain the normal burning rate vs pressure curve. Slide 4 shows that the break in the Comp. B curve occurs about 4,000 - 5,000 psi. The slope of the closed bomb curve past the transition may be even greater than that obtained for TNT. The surface area vs pressure curves for calculated normal burning vs actual closed bomb burning of a sample of Comp. B are given in Slide 5. In order to establish the applicability of this technique to high energy propellants, a sample of ARP propellant was subjected to this closed bomb test. Slide 6 shows the results of a series with increasing loading densities up to about .43 with and without preloading. At .43 loading density, when preloaded with sheet propellant, a change in slope occurred at about 35,000 - 40,000 psi similar to those which were obtained for TNT and Comp. B. This was accompanied by a disintegration of one of the seals in the bomb due to the extremely high heat and DP/DT. Unfortunately, each time conditions were used in which the transition was expected to show, the rate of pressure rise was so great that some part of the bomb seal was destroyed and the trace lost. A bomb is being designed in which we hope to hold the pressures produced and measure transition pressures similar to those obtained for TNT and Comp. B. This slide shows a plot of linear burning rate vs pressure calculated from the available data for the ARP propellant with and without preloading. The linear burning rates obtained with the strand burner are almost coincident with those calculated from the closed bomb at pressures above 10,000 psi. Additional data has been obtained for a specially prepared batch of experimental high energy propellant. Slide 7 shows data which has been obtained for this material. This sample shows a definite transition pressure at about 16,000 psi. Also the slope of the transition curve is quite steep, indicating a marked increase in surface area. Note, however, that the slope of this curve levels off near the top for some of the test runs. This we believe to be a mass effect. When charges of different diameter were burned, we calculated that this leveling off takes place at the same diameter although in higher loading density tests this occurs at higher pressure. For this sample the minimum diameter necessary to sustain this pre-detonation reaction appears to be about 1 inch. In the present stage of development our equipment can test those materials which have transition pressures below 35,000 psi. With equipment capable of holding higher pressures, we hope to extend this limit much higher. This will permit us to classify most of the existing propellants. It would appear from results of these tests that for each of the materials studied, there is a critical pressure above which the transition from deflagration to detonation can occur. This is the result of a surface cracking or crazing which increases the burning surface to a point where a shock front can form. The existence of this condition is considered necessary for DDT to occur. If sufficient explosive material were available, the shock front could reach sufficient intensity to establish a stable detonation front in the explosive. The application of this test to explosives and propellants will give us a basis for a quantitative evaluation of these materials in terms of the critical transition pressure and the slope of the transition curve. By establishing these parameters for each explosive or propellant it will be possible to classify these materials as to the severity of the conditions to which they can be subjected before the danger of DDT will exist. It will also make possible a study of the effects temperature, porosity, particle size, crystal size and other physical variables on the detonability of existing propellants as well as for new materials as they are developed before going into large scale manufacture. The application of this technique to the development of new propellants will also make it comparatively simple to study the effects of formulation modifications on the detonability of high energy materials, and make possible the development of safer solid propellant motors. This program is being continued with the broad objective of establishing on a firm basis the applications stated. To achieve this the immediate specific objectives are as follows: 1) Improvement of bomb design and instrumentation so that existing and newly developed high energy propellants can be evaluated. This will require pressures in the order of 400,000 psi. The sensitivity of the transducer will be improved to more accurately sense the extremely high DP/DT values which must be measured. 2) Existing explosives and propellant will be subjected to this test and a classification of sensitivity made. The effects of temperature and physical condition on its sensitivity to DDT will be determined as part of the evaluation of each propellant or explosive.

CLOSED BOMB TEST
TNT

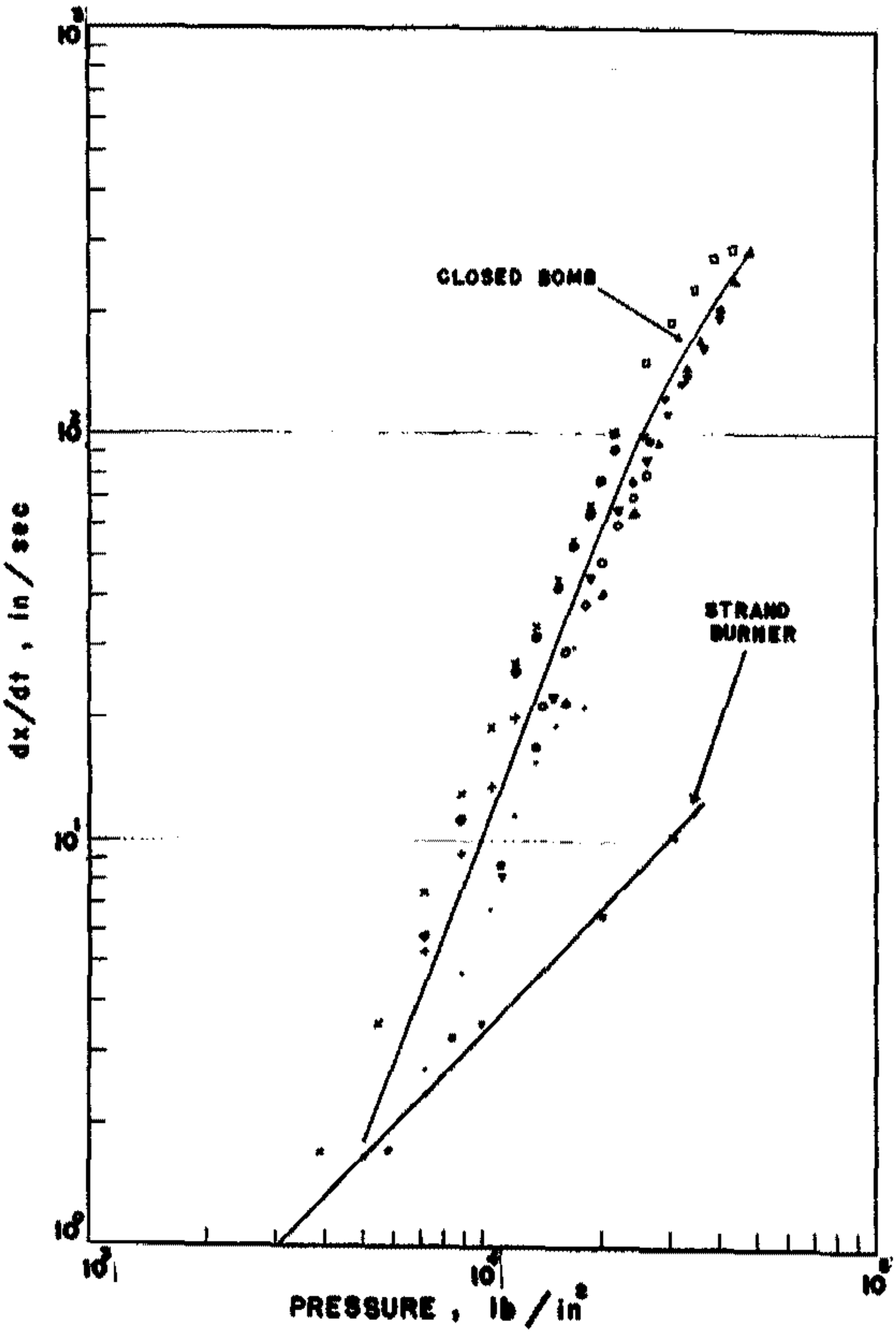




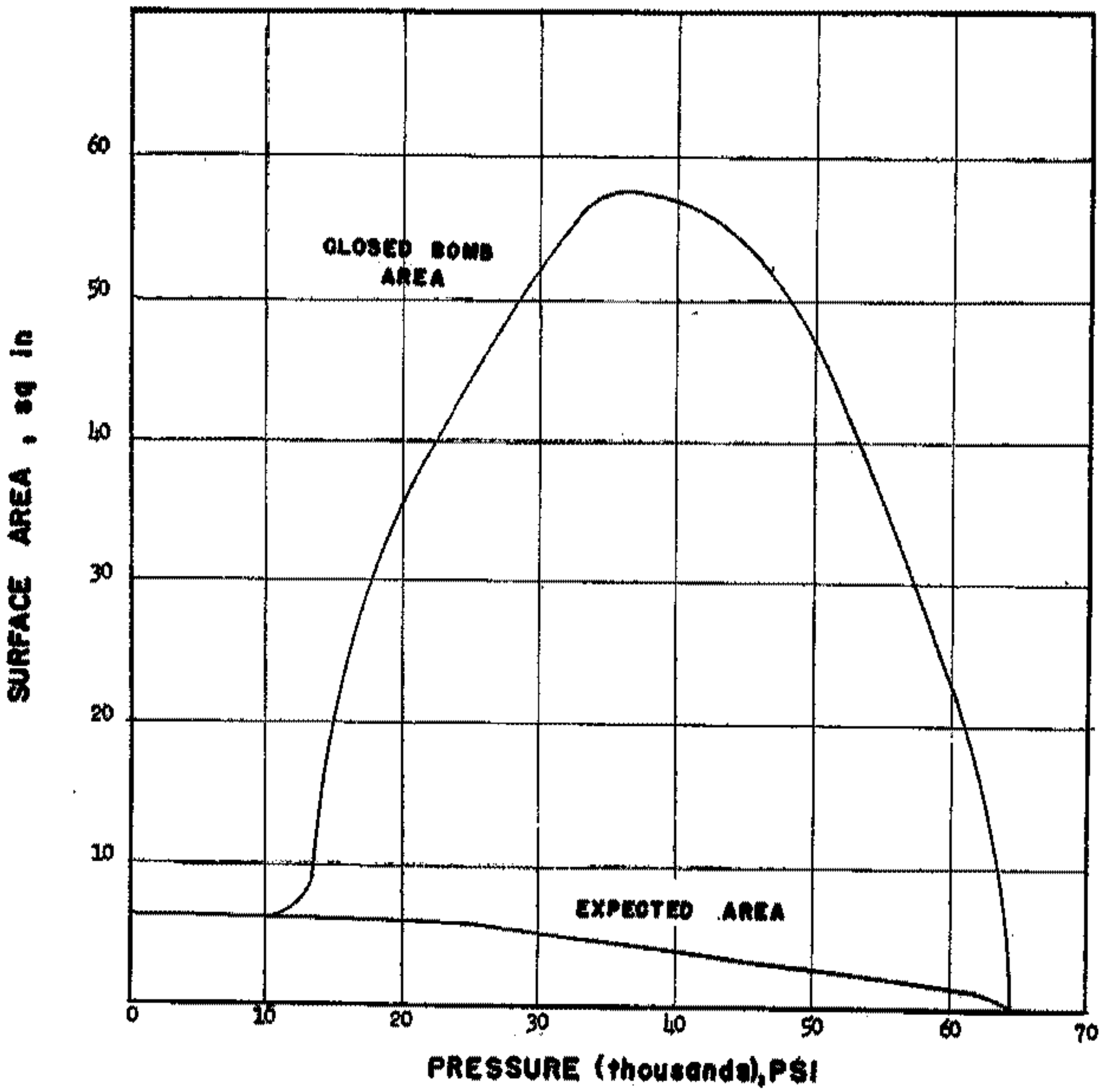
LINEAR BURNING RATES OF T N T OBTAINED WITH CLOSED BOMB AND STRAND BURNER



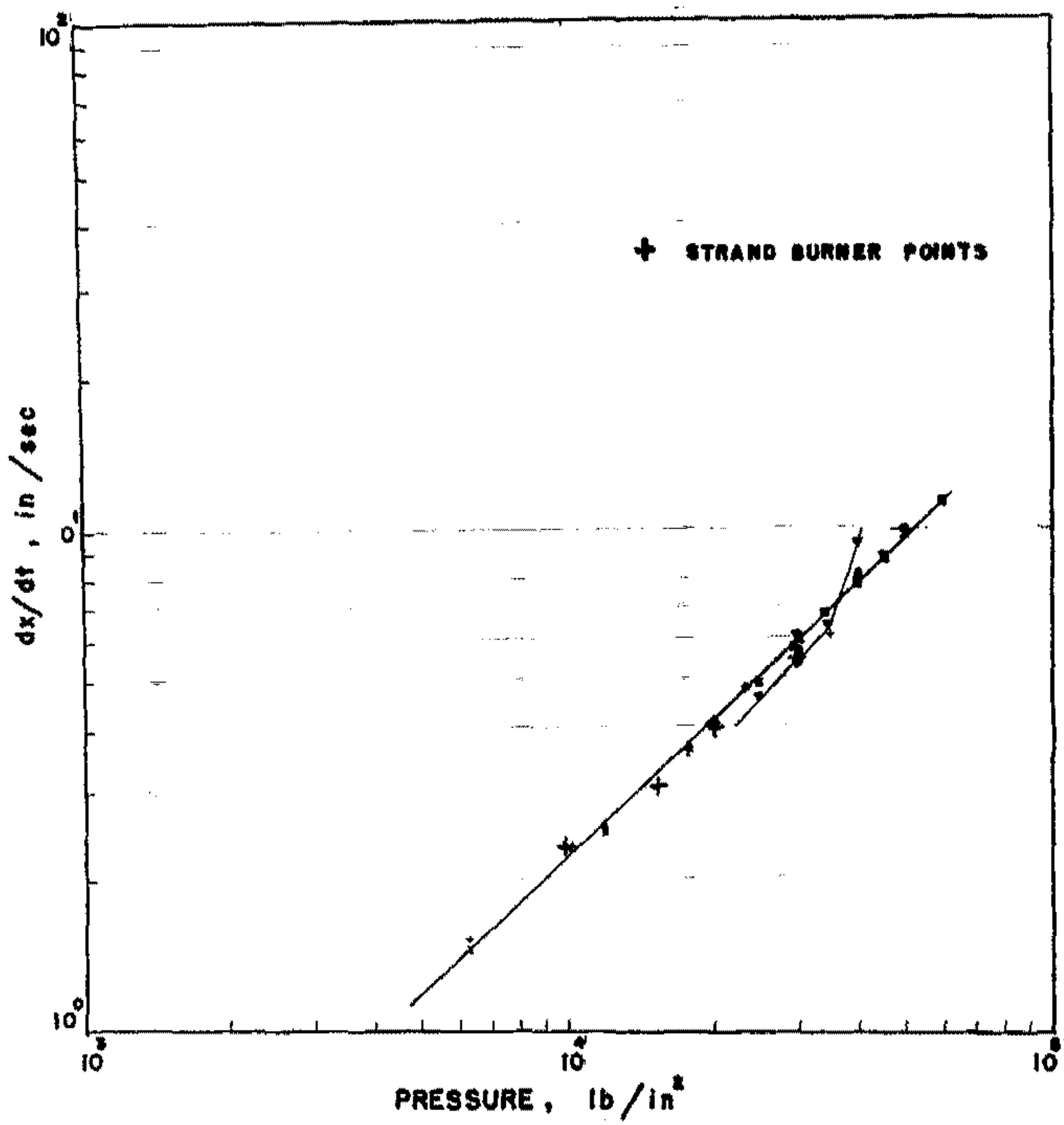
EXPECTED SURFACE AREA VS ACTUAL AREA OBTAINED FOR TNT CYLINDER BURNED IN CLOSED BOMB



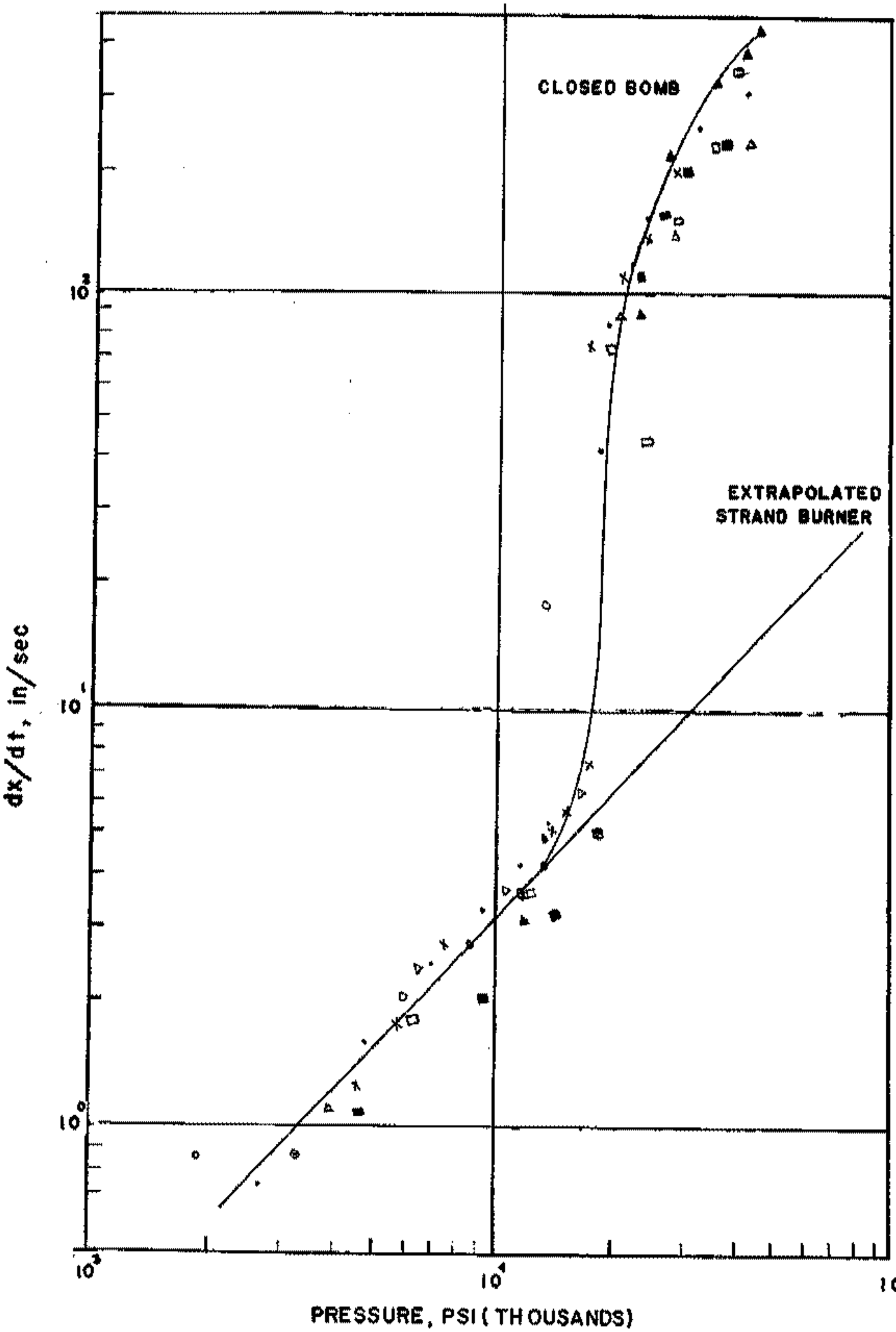
LINEAR BURNING RATES OF COMPOSITION B OBTAINED WITH CLOSED BOMB AND STRAND BURNER



EXPECTED SURFACE AREA VS ACTUAL AREA OBTAINED FOR COMPOSITION B CYLINDER BURNED IN CLOSED BOMB



LINEAR BURNING RATES OF ARP PROPELLANT OBTAINED WITH CLOSED BOMB AND STRAND BURNER



LINEAR BURNING RATE OF EXPERIMENTAL PROPELLANT
OBTAINED WITH CLOSED BOMB

Col. Hamilton: Thank you Mr. Wachtell. Apparently I got some wrong information, Mr. Wachtell's talk is actually more closely related to a talk that comes up tomorrow than it was to Mr. Saffian's talk. We're going to have a discussion tomorrow morning on the transition from deflagration to detonation. It's quite possible that the questions raised at this time may be answered in the talk tomorrow so if everyone is willing, let's hold off the question period on Mr. Wachtell's talk until Dr. Noonan of the Naval Ordnance Laboratory makes his talk tomorrow morning and then we can get all these questions on this one subject taken care of at the same time. Mr. Saffian, we missed out on a question period on your talk. Are there any questions? Thank you Mr. Saffian. Closely related to Mr. Saffian's talk is something that the ASESB has gotten into recently as a result of some tests that were conducted by the Ordnance Corps of the Army. I'd like to ask Mr. Herman of the ASESB Staff to give you a briefing on a test program that we have on at the present time.

Mr. R. C. Herman, ASESB: Until recently very little thought has been given to the use of dividing walls for anything other than prevention of mass detonation. In other words, to separate your two quantities so that you would not have a simultaneous detonation of the two quantities at one time. Because of construction and the items that we are dealing with, etc., it was decided that it was necessary to look into this more deeply to determine what quantities the dividing walls could stand up under to prevent a mass detonation as well as a communication at any time interval afterward. In connection with this a test was conducted recently in a former pelleting building which is a standard Army Ordnance building that had a 12" reinforced concrete wall on three sides, the roof was of light construction and the fourth wall was a light blow-out type of panel. There was approximately 2,000 lbs. of explosives placed inside of this cubicle and on the three sides outside of the concrete walls, acceptor charges were placed and separated from each other by sandbags to determine the effect. After the primary charge was detonated, there was a simultaneous communication to acceptor charges on two sides of this wall within a period of approximately 4 to 10 milliseconds. This of course was somewhat of a shock because we had always anticipated that a 12" reinforced concrete wall was good for 5,000 pounds based on earlier tests which had been conducted. Of course this immediately caused a great deal of concern. It was anticipated at that time that additional tests would be run involving 1500 pounds. However, the cubicle which was set aside for this purpose was a little too close and became damaged to a point where they felt it would not give true results and it was decided not to conduct it. I understand, however, that this test is to be conducted probably in September repeating this original test only using 1500 pounds within the cubicle. At the same time the Air Force has instituted a program to determine the maximum number of explosive weapons which may be stored in single cubicles of multi-cubicle magazines with reasonable assurance that an accidental explosion within that cubicle will not propagate to adjoining cubicles. I understand that construction is progressing on this and that the first calibration test is scheduled for sometime this week and the actual tests are due to get underway in September and will proceed probably on the basis of one test per month or something on this order. In addition to this the Board has attempted to extend this program by a series of tests utilizing various quantities of explosives ranging from 500 to 5000 pounds with different separation distances of these quantities from the walls and also with different wall thicknesses to try to bracket an area to find out just how good the walls are. These tests will be repeated, two tests will be conducted with items with low fragmentation and two additional tests, exact duplicates, with high fragmentation items. The preliminary planning on the third phase has just begun, one of the big problems of course is money and we don't know just how far we can carry this program but we do hope to be able to carry it to a conclusion so that we will have some excellent data upon which to base recommendations for separations using dividing walls.

Mr. Barr: Would you repeat the relative locations of these acceptor charges?

Mr. Herman: These charges were located outside of the concrete walls and spaced with approximately three feet of air space between them and the wall. These acceptor charges were placed outside of each wall and then each acceptor charge was separated from the next adjacent charge by a barricade so in event you had one detonate you wouldn't propagate to the entire bunch. There is one point in connection with this test that I might bring out. There was a little concern after the test was conducted because a standard dividing wall is supposed to have the reinforcing rods staggered on opposite faces. In this particular case after the test it was found that during construction the rods were not staggered, they were placed exactly opposite each other. However, we felt that the damage was so great, the destruction so great, that this didn't really materially affect the results of the test.

Dr. Ball: In setting up further work, have you considered at all the possibility of having double walls so that while you're sacrificing the first wall you have a second wall to catch the pieces.

Mr. Herman: There is thought being given to this and I believe there is anticipated perhaps some small scale work to determine fillers of some type that may be used in sandwich wall construction that may assist in the same job of stopping fragments from the first wall and things like this, absorbing some of the energy.

Mr. Endsley: In respect to Dr. Ball's question, there will be some data available from the Air Force test inasmuch as they have parallel walls in series and they have some staggered on opposite sides of 18" and 36" concrete divider wall. There should be some valuable data from the Air Force tests.

Mr. Richardson: What is the time limit when you don't consider it any more of a problem of propagation? My reason for this question is if you're just talking about detonation or the fragments that result from detonation, you also have to consider that we might have some materials that will be initiated initially by flame and later transit to detonation.

Mr. Herman: I think primarily in this case the pressure traces only showed one peak and we decided that this could be considered as a simultaneous detonation. Where this would break off, whether it would be 15 milliseconds or more, it would depend somewhat upon what your charge was, how long the rise time was on it.

Mr. D. I. Graham, Jr., Redstone Arsenal: I was wondering, did you have a monolithically poured floor all the way thru from one charge to another?

Mr. Herman: No, the donor charges were not on a floor, these were outside of the building.

Mr. Graham: They were not on concrete?

Mr. Herman: They were on dirt outside of the building.

Col. Hamilton: Thank you Mr. Herman. The next item is 'evaluation of processing hazard and pneumatic conveying of hazardous materials' by Mr. Settles, Hercules Powder Co.

Mr. J. E. Settles, Hercules Powder Co.: There is a pronounced trend in American industry to do things automatically in order to decrease the man-hours of production labor required per pound of product and thereby lower the cost. In the explosives industry, of which the manufacture of solid propellants is a part, automation should yield the same sort of savings in man-hours of production labor per pound of product, and as a bonus, savings of man-hours per pound in exposure to hazardous conditions; provided that the cost in dollars or hours lost by personal injury during the production of a pound of product is not increased by the automation. It is this proviso, in particular, that has delayed the introduction of continuous processes and that keeps safety engineers in business evaluating the probable added hazards of process improvements. In the manufacture of smokeless powder by the solvent extrusion process, and also in the loading of molds in the cast double base process, there are intra-plant transportation steps, resulting from the separation of operating buildings, that require a sequence loading of containers, trucking of loaded containers from here to there and unloading of the containers. The possibility of using pneumatic conveying to replace or minimize this sequence of operation in the moving of sensitive materials was recognized as early as 1944 and pneumatic conveyors have been used without significant incident at Anniston Ordnance Works, Blue Grass Ordnance Works, Ravenna Arsenal, Letterkenny, Naval Propellant Plant, Indian Head, Alabama Ordnance Works and Indiana Ordnance Works to move smokeless powder, TNT and other sensitive materials. Fires have been reported but in no instance propagation; and it is interesting to note none of the fires were attributed to malfunctioning of the basic equipment. Several fires were reported in an operation involving demilitarization of small arms ammunition at Anniston Ordnance Works. Some of these fires occurred within 3 feet of the charging hopper and there was a continuous flow of propellant from the point of the fire into the hopper. On the precautionary side, it should be stated that critical design and operating details were not obtained for the systems that have been used. It is known that safe and satisfactory operation of a pneumatic conveying system must meet specific requirements on maintenance of minimum air velocities and on elimination of electro-static potentials in the system. Precautions should also be taken to guard against the possibility of foreign material being introduced in the system. I am going to discuss some of the factors affecting each of these requirements. The discussion will deal principally with gun propellants and granulated casting powders which are used in cast double-base rockets. However, I believe the principles behind many of the controlling factors may be applied to the conveying of other sensitive materials. There are three general types of pneumatic conveyors, namely (1) low velocity air conveyors, (2) high velocity air conveyors, and (3) pneumatic-tube conveyors. Air-conveying systems of both low and high velocity types include the following elements: an air mover which may be a form of exhauster, compressor, or blower; a conveying pipe; a feeding device or suction nozzle; and a discharge device where the material is separated from the conveying air. The discharge may be an open end of pipe, a screened bin, a cyclone separator, or a rotary valve or air locks. The pneumatic-tube conveyor is a conveyor of small items enclosed in a container which is built to fit the tube closely and which is forced through the conveyor tube by air pressure. Materials can be conveyed equally well by a suction or a pressure system since the conveying effect is due to the air velocity or the carrying power of air in motion. In a pneumatic conveying system the air velocity is controlled by pressure drop and the laws of fluid flow represented in Bernoulli's Theorem; and if a density factor is applied to pounds per minute the resultant is cubic feet per minute. Material flow is controlled by the feed rate in pounds per minute; therefore it is possible to determine the pounds of material per pound of air -- or better, the cubic feet of air. The point should not be missed that the materials do not arrive at the end of a system in the same air in which they started. If the material velocity were to equal the velocity of the conveying air the material would drop to the bottom of the conveying tube. The material is kept in suspension by the differential velocity. For every substance that can be pneumatically conveyed, there is a minimum velocity of air that must be maintained just to move the material. Experience has demonstrated that with a low velocity system (3,000 to 7,500 f.p.m.) the cubic feet of air required to convey a pound of material varies from approximately 40 cubic feet per pound of material for compact materials to 90 cubic feet per pound of light, fluffy material. By trial and error, it was determined most propellant granulations will require minimum air stream velocities of 3,000 to 3,500 f.p.m. to satisfactorily move the material. An explosion in a powder blending operation at Radford Arsenal several years ago resulted in a preliminary study which indicated much less personnel exposure in a hazardous operation would result if pneumatic conveying were utilized; and there was also a potential for operating economics. These same advantages also seemed to be possible at Allegany Ballistics Laboratory and at Hercules Powder Company's Bacchus Works in the movement of casting powders from the shipping container to mold loading operations. All of these requirements made mandatory careful assessment of the hazards of pneumatic conveying, which was done concurrently at Radford and A.B.L. with complete coordination of the programs. Of major concern in considering the pneumatic conveying of sensitive materials is to determine the conditions that will result in a fire and to define those conditions as exactly as possible. It has been found two principal precautions are necessary. Accumulation of electrostatic potentials are a continual hazard in a pneumatic conveying system and must be minimized in every possible way. Foreign material is a continual source of hazard in any propellant manufacturing process and it is equally undesirable in a pneumatic conveying system. Let us consider first the elimination of electrostatic potentials. It has been found the amount of static electricity that will be generated in a pneumatic conveying system is affected by: (1) the formula of the propellant being conveyed; (2) the effectiveness of the system grounding; (3) the relative humidity of the conveying atmosphere; (4) the velocity of the air in the conveying system; and (5) the pounds of propellant per cubic foot of volume in the conveying system. We will give more detailed consideration to each of these five factors; however, let us first review some basic considerations. Statis electricity is generated when an insulator experiences friction with another material, either an insulator or conductor. The static charge resides on the surface of the insulator. Propellant granules are insulators and will develop an electrostatic charge from friction with the conveying tube or from friction with the conveying air. Of these two the friction with the air is probably the more important and I have data on this effect which I will present a little later. The effect of the propellant formulation on electrostatic conditions is a function of the nitrocellulose content, the content of a powdered metal, such as aluminum, and the graphite coating on the granules. The minimizing of electrostatic generation in a pneumatic conveying system is adversely affected by increasing the nitrocellulose content of the propellant being conveyed. An investigation by the Process Research Group at Allegany Ballistics Laboratory developed data indicating that for one set of test conditions (i.e.: for a specific combination of conditions for air velocity, propellant velocity, conveying distance, humidity conditions and system grounding) that a 30% nitrocellulose content resulted in a 250 volt generation of static electricity at the lower end of a plotted curve and an 85% nitrocellulose content resulted in an 860 volt level of static at the upper end of a plotted curve. It was observed that the intervening curve was almost linear. It should be noted that the actual voltage of static that will be generated will be strongly affected by changes in the combination of conditions that exist in the conveying system. However, the effect of varying the nitrocellulose content in the formula may be summarized with the following generality: A three-fold increase in that portion of the static charge that is attributable to the nitrocellulose in the formula. This effect appears to be valid only to the 85% nitrocellulose level. Above that level there is little additional effect from an increased percentage. The aluminum content of a powder formula and graphite coating on propellant granules have a very desirable effect on minimizing electrostatic accumulations. The aluminum and the graphite make the powder conductive and the static charge leaks off at each contact with the grounded tube. An investigation by the Production Engineering Group at Radford Arsenal was summarized as follows: "The electrostatic investigation revealed that no detectable accumulation of static electricity was developed by propellants which had received a coating of graphite or by high energy propellants which contained at least 10% powdered aluminum." The above statement was found to be true for several double and triple-base formulas with air stream velocities ranging from 6000 f.p.m. to 9500 f.p.m., propellant feed rates that varied from 5 pounds to 40 pounds per minute and relative humidity conditions in the conveying system that varied from 30% to 40%. The effect of a propellant formula on electrostatic generation may be clarified with this thought: insulators may pick up a positive charge or a negative charge when subjected to friction. The friction doesn't create the charge; it facilitates the transfer of free electrons. Materials have been arranged in an electrostatic potential series, known as the triboelectric series, and greatest charges result when friction is applied to materials with the greatest difference in position in the series; in other words, if two insulators with the same electrostatic potential are rubbed little or no charge will be generated. Considering propellant granules in a conveying air stream, the nitrocellulose and the air are widely different in electrostatic potential. The potential difference is decreased by plasticizers, such as nitroglycerin, which is the reason why double-base formulas develop smaller electrostatic charges than single-base formulas. The second factor that strongly affects the generation of electrostatic potentials in a pneumatic conveying system is the adequacy of the grounding. The Production Engineering Group at Radford Arsenal investigated the effects of grounding and the results of their studies are summarized as follows: The highest level of static electricity was generated when the conveying system was insulated and when conveying single-base casting powder (containing more than 85% nitrocellulose). A 14,000 volt level was reached with the system insulated. The same propellant with the same feed rate and air velocity generated approximately 11,500 volts with the system grounded. It was concluded from these and other data that grounding a system will reduce accumulation of static electricity but will not eliminate it. It should be noted that the resistance to ground in the Radford system was determined to be 4,000 ohms. Data from a study made at Indiana Arsenal were more optimistic concerning results obtainable from system grounding. The Indiana study reported as follows: "No static charge could be detected with an adequately grounded conveying system; however, with an inadequate ground or no ground, dangerous static charges were produced by pneumatic conveying finished propellant grains." It cannot be expected that grounding will be completely effective if the propellant is insulated or if the propellant acts as an insulator. In any case, it is certain that if the conveying tube is not grounded it will develop an electrostatic potential. Then if operating personnel inadvertently ground it the potential will be discharged with a possibility the results will be serious. The third factor that should be considered in attempts to minimize electrostatic potentials in a conveying system is the effect of increasing the relative humidity. Studies conducted at Radford Arsenal indicate static accumulations on propellant being conveyed can be effectively dissipated by maintaining the relative humidity of the atmosphere inside the conveying system above 80%. The high level of relative humidity was maintained during the investigational work by steam injection. Laboratory analyses of propellants subjected to this high level of relative humidity indicate the dwell time in the system was sufficiently short to prevent the level of total volatiles in the propellants increasing beyond specifications. It is, of course, academic that the dwell time in the system is a variable; and it is a function of length of system, conveying air velocity, propellant granule size and rate of loading. The Radford pilot plant system is 100 feet long and dwell times measured varied from 750 milliseconds to 3 seconds. For propellant formulas that are very sensitive to high humidity atmospheres more sophisticated methods, such as ionization of the air stream, may be used. It is known that ionization is effective, however, at this time I have no data on such systems. Now let us consider static charges as a function of air velocity in the conveying system. Investigations at Allegany Ballistics Laboratory revealed that increases in the velocity of the conveying air stream would result in an appreciable increase in the electrostatic potential of the atmosphere in the receptacle that receives the powder at the end of the conveying system. The effect was most noticeable during the conveying of powder formulas with a high nitrocellulose content. A digest of the data showed that a 3000 f.p.m. increase in air velocity resulted in an electrostatic increase of 1000 volts when conveying single-base propellant (high nitrocellulose content). An electrostatic accumulation of less than 500 volts was experienced when double-base propellants were being conveyed. There was a much smaller increase in the electrostatic potential on the propellant in the receiving container than in the atmosphere over the propellant. A 3,000 f.p.m. increase in air stream velocity resulted in a voltage increase on the propellant of approximately 500 volts for a single-base formula. The data also revealed a very linear relationship between length of the conveying system and the electrostatic potentials developed in the powder receiving container. Again, the largest potential was developed in the atmosphere over the propellant in the receiving container. Graphic presentation of the atmosphere voltage plotted 1600 volts at a distance of 25 feet and 8700 volts at a distance of 250 feet. Intervening points resulted in almost a straight line graph. A level of 250 volts was plotted at the 25 foot distance for the effect on the propellant in the receiving container; and 3750 volts was plotted at the 250 foot distance. Intervening points were quite linear. And the fifth factor to be considered is the effect on electrostatic accumulations as a result of varying the amount of propellant per cubic foot of volume in conveying system. The electrostatic potential in the atmosphere of the powder receiving container is appreciably affected by the amount of powder being conveyed per unit of time -- or the pounds of powder existing in the conveying system per cubic volume of the system. For a condition where one-tenth of a pound of powder was being conveyed per cubic foot of conveying system voltage levels between 5000 and 5500 volts were recorded. An increase in loading to four-tenths of a pound per cubic foot resulted in a decrease to 4200 volts. Loading at six-tenths of a pound per cubic foot reduced the potential to 2400 volts. Similar decreases were recorded for three separate trials. The electrostatic potential in the powder bed of the receiving container was also affected by the loading on the system, however, to a much smaller degree. The total effect on the static voltage level in the powder bed for an increase of five-tenths of a pound per cubic foot of conveying volume was 600 to 700 volts decrease. We have given considerable attention to minimizing electrostatic hazards in pneumatic conveying. Let us consider briefly the hazard of foreign material. Operating personnel should thoroughly understand that while energy in the form of rapidly moving air is being applied to a system, foreign material can be committed with no chance of recovery, in a very short time. The foreign material may include nuts, bolts, road gravel, dirt, grease, identification badges, personal clothing, lids from powder boxes, tools, etc. These extraneous items may result in hazardous conditions that jeopardize safety by creating unacceptable levels of friction and impact; or they may cause a functional unbalance of the system that results in unnecessary maintenance and work stoppage. The design engineers can assist with the foreign material problem by providing scalper screens over the feed hoppers, metal detectors at a point in the operation that will prevent metallic items getting into the conveying air stream, and by careful design of pick-up nozzles. Operating supervisors can further mitigate the problem by careful training of operating personnel and continual rechecking of the day-to-day work practices of their personnel. This alertness on the part of the operating supervisor is emphasized because if all other problems involved in pneumatic conveying of sensitive materials are completely solved, it may be expected the hazard of foreign material will always be present to some degree. We may do everything humanly possible to prevent fires occurring in a pneumatic conveying system but the question still must be answered of what will happen should a fire occur. What will be the extent of the fire and can a system be designed so that fire will not propagate? Investigations have proved that if a certain minimum differential is maintained between the velocity at which the air is moving through the system and the velocity at which the propellant moves through the system the flame on any pre-ignited granules of propellant will be "snuffed out" upon entering the system and it is not possible to propagate a combustion throughout the system. The minimum differential that must be maintained between the velocity of the air stream and the velocity of the propellant was developed from pilot scale investigations at Radford Arsenal. Studies of flame propagation within a pneumatic conveying system revealed the ignition of a propellant stream is not possible with the flame from a 2000°F. oxyacetylene welding torch when a minimum air stream velocity of 6000 f.p.m. is maintained. These tests were conducted in a 3½ inch horizontal steel conduit using the following procedure: Approximately one pound of propellant was introduced into the horizontal steel conduit at the minimum conveying velocity. The propellant passed through the flame of an oxyacetylene welding torch located 14 feet downstream from the point of propellant introduction. This procedure was repeated and the velocity of the air stream was increased until the propellant could not be ignited by the flame of the oxyacetylene torch. The investigation covered twelve different granulations of single, double and triple-base formulas. Since ignitability varies with propellant formula, it should be considered a possibility that more sensitive formulas will require higher air stream-propellant differential velocities to assure no propagation. It may be of interest to review quickly some of the actual data which was developed for specific formulas and granulation sizes. I have prepared a slide presenting most of the data. You will notice the double-base casting powder formula, in a granule size approximately .035" in diameter by .035" in length required a minimum conveying velocity of 3500 f.p.m. Under this condition, the air-propellant velocity differential was 1600 f.p.m. and ignition was accomplished with upstream propagation of the flame. With an air stream velocity of about 5000 f.p.m. and a velocity differential of 2100 f.p.m. ignition was accomplished, followed by "snuff-out" of the flame. With an air stream velocity of 5500 f.p.m. and a velocity differential of 2250 f.p.m., it was not possible to ignite the propellant stream. The single-base casting powder formula, with a granule size approximately the same as double-base, was also ignited and upstream flame propagation resulted when the conveying velocity was 3500 f.p.m., and the velocity differential was 1600 f.p.m. However, when the conveying velocity was increased to 4000 f.p.m. and the velocity differential was 1800 f.p.m., it was not possible to ignite the single-base powder. The highest velocity differential was necessary for a casting powder formula containing 40% nitrocellulose, 30% ammonium perchlorate, 29% aluminum and 1% NDPA. This formula burned and upstream propagation occurred at a velocity differential of 2300 f.p.m. At a differential of 2660 f.p.m. an ignition occurred but it was followed by a "snuff-out." The conveying velocity was 5000 f.p.m. when the "snuff-out" differential was obtained. The conditions existing at "snuff-out" may be further clarified by considering powder burning in a pneumatic conveying system as being the same as powder burning in unconfined wind with a velocity equal to the differential velocity existing in the conveying system. Therefore, the differential velocity is important in three ways: (1) It keeps the powder in suspension in the conveying system; (2) It extinguishes a fire, should one occur; and (3) It also generates static electricity. It should be noted the data just discussed required an air stream velocity of no greater than 5500 f.p.m. to obtain "snuff-out." In designing a conveying system for the formulas mentioned it would be considered advisable to inject a safety factor of at least 500 f.p.m., which would mean utilization of a minimum conveying velocity of 6000 f.p.m. There is another factor to be considered. We have been discussing a condition where a stream of propellant that is being conveyed by an air stream moving at 6000 f.p.m. is subjected to a 2000 F. flame. If the heat source were applied at the downstream end of the pneumatic system where the propellant is at rest, a fire of explosive proportions is certain to occur. In attempting to conjecture what the results would be of such a fire or explosion it becomes obvious some sort of safety back-up precautions are highly desirable. Visualize the conditions that develop as a result of a fire at the downstream end of a pneumatic conveying system: There is an air stream traveling at a minimum of 6000 f.p.m. moving through the system. However, a fire or explosion at the downstream end would create counter-forces that would move at some unknown velocity. If this counterforce were moving at a subsonic velocity of only 50 meters per second, that would be 9840 f.p.m., which would far exceed the velocity of the conveying air. The minimum severity would probably be upstream propagation of the fire through the propellant stream. The maximum severity would be wrecking of the conveyor system and under this condition the limits of propagation would be in the hands of fate. The approach which has been taken at Radford Arsenal to control a condition of minimum severity and prevent upstream propagation of such a fire, is utilization of an intermittent feeding technique. The Radford application will be production scale equipment and installation will be completed within the next 60 days in a mold loading building in their Cast Propellant Area. The intermittent feeding will be accomplished by means of two pairs of peristalic valves located in a draw-through, or vacuum, conveying system. The valves are simply two rubber bags located about 18 inches apart in a 6 inch diameter pipe. The bags can be extended by air pressure to fill the pipe and block any movement of material in the pipe. When pressure is released, the bags deflate and the pipe is open. The bags open and close in sequence in response to controlled timing at a rate of ten cycles per minute. In the Radford application, when the upstream valve opens, double-base casting powder will flow by gravity from a feed hopper into the space between the two valves. The upstream valve will then close and in proper sequence the downstream valve will open, permitting the casting powder to feed into the pneumatic conveying system. The system is 70 feet long and the conveying air will be maintained above a minimum velocity of 7000 f.p.m. It has been determined each slug of powder will clear the system within 3 seconds. The powder is removed from the pneumatic conveying system by means of a tangential separator. A second set of peristalic valves will be located beneath the separator to permit removal of the casting powder. By steam injection, the relative humidity in the conveying system will be maintained above 80% to minimize electrostatic hazards. It is believed neither upstream nor downstream propagation of flame will be possible in the Radford system when double-base casting powder is being conveyed, short of an explosion that would have sufficient force to wreck the system. We believe a pneumatic conveying system which incorporates all the

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features I have described will be a safe and efficient system for conveying a number of single, double and triple-base formulas and for conveying casting powder of single or double-base formulas and formulas containing aluminum and ammonium perchlorate. The system will include: 1) Scalper screens and a metal detection device; 2) Adequate grounding; 3) Humidity control of the atmosphere inside the conveyor; 4) A minimum conveying air velocity of 6000 f.p.m.; 5) Feeding rates that will minimize electrostatic accumulations; and 6) Peristalic interruption of the feed stream. I would like to close with a comment that reflects a personal opinion. The efforts of too many of our safety engineers are being monopolized by routine inspection assignments. I hasten to emphasize I am not belittling safety inspections. Such inspections are a vital part of any well rounded safety program. However, the inspection routines can be adequately handled by alert, intelligent technicians. Any safety man who is capable of handling complicated engineering problems can find literally thousands of challenging questions in safety work that are in pressing need of answers. The whole industry loses when the safety engineers do not devote their time to engineering work.

Col. Hamilton: We'll begin this morning with a subject carried over from yesterday afternoon 'combining energetic and hazardous ingredients in the development and application of the "Fluid Ball" process to conventional and composite double base propellants' by Mr. Barr, Olin Mathieson.

Mr. Barr: Olin Mathieson, in its development of the "Fluid Ball" propellant process over the past several years, has succeeded in combining a number of rather energetic and sensitive materials into a castable, case-bondable propellant according to either batch or continuous techniques. In our current operations, we are loading formulations containing primarily nitrocellulose (NC), ammonium perchlorate (APC), aluminum, and an explosive plasticizer such as triethyleneglycol dinitrate (TEGDN) or nitroglycerin (NG). The nitrocellulose is added in the form of our fine diameter "Ball Powder" in the nominal size range of 0.001-0.010 in. diameter. This material, by itself, is not particularly hazardous in that it requires something on the order of one joule for electrostatic type ignition, is stable in storage over a period of several years and shows excellent performance in the usual heat stability and accelerated aging tests. When NG is employed as the explosive plasticizer, it is commonly diluted with about 20% of a non-explosive diluent, such as one of the phthalates or adipates, and in this form is satisfactorily insensitive to shock. A second explosive plasticizer, less desirable from the density standpoint and pot life of the propellant, is TEGDN. Systems based on TEGDN provide equivalent specific impulse, however, and the material is quite insensitive to shock in its pure form. The powdered aluminum is considered to offer no more problem than that of dealing with any finely sub-divided combustible material. The dusting tendencies of the raw material are eliminated through the use of a fractional per cent coating of dioctyl phthalate. In our Fluid Ball process, we normally combine into a preblend the Ball Powder which has been similarly dust proofed, and the aluminum. The sensitivity and handling characteristics of 20 to 40 micron ammonium perchlorate are well known to you, and I touched on one aspect of these yesterday, that of its detonability. The Fluid Ball propellant process is extremely simple

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in installation and operation. For the benefit of those of you who are not familiar with this rather well-known process for loading either double base or composite double base rocket motors, I shall describe briefly the elements of the technique. Let us consider first the semi-continuous operation such as we are now using. Later, I will go through the completely continuous mixing and casting version with which we are currently concerned relative to a pilot plant redesign. In a semi-continuous or batch type version, the ingredients mentioned above are combined and dispersed in a fluid system of 7,000 to 10,000 centipoises with the aid of a simple planetary mixer. The order of addition deserves comment here. The casting solution, consisting of TEGDN or diluted nitroglycerin, plus their stabilizers, are added first to the change can type mixing bowl which is utilized with this type of mixer. Ammonium perchlorate is next added to the can and mixing initiated remotely for a few minutes, at first slow and then faster rates. The last addition to the mixer is the blend of Ball Powder and aluminum. After 20 or 30 minutes of dispersion, we have achieved a fluid raw propellant containing 40 to 50% solids, which is quite stable with respect to viscosity changes or settling tendencies. A pot life of several hours is available to move the can about from mixer to casting areas, effect deaeration and to load the motor case. The casting operations are conducted on a continuous basis, depending only upon the continuous supply of full change cans from the mixing area. In the continuous operation of the Fluid Ball propellant process, we add three metering stations for feeding continuously to a small mixer the casting solution, ammonium perchlorate, and Ball Powder/aluminum blend. The mixer has a hold-up of only a few pounds of mixing propellant ingredients and discharges in response to simple level controls into the continuous deaeration and casting phase. What are the characteristics, then, of this propellant which is so simply processed? First of all, it delivers up to 255 lbF/sec/LbM specific impulse upon combustion of the energetic ingredients which have been combined and tamed into a compatible system. Its burning rate is controllable between 0.30 and 1.00 in/sec (1000 psi), temperature sensitivity is about 0.25%/°F, and its other physical and ballistic characteristics are good. The thermal and shock stabilities of Fluid Ball composite double base are quite satisfactory for most applications. Typical sensitivity data follow. These tests will be most familiar to the double base propellant people here. German test (120°C) = SP, 255 min; RF, 500+ and Defl. 500+; Autoignition = 550°F, (5 sec); Two-inch cube cracking test (80°C) = 63 days; Taliani (110°C) = 11 mm ΔP and a slope of 0.12 at 100 minutes, 23 mm and again 0.12 at 200 minutes; Brittle point = -20°F; Impact test (2 kg) = 14-18 cm. Our experience with the Fluid Ball propellant process now covers the loading of some 30,000 lb of composite double base, including 2-750 lb Nike Ajax, 4-1000 lb 1/2-scale Nike Zeus and one 7000 lb full-scale Zeus motors. In addition, we have processed about 12,000 lb of double base, ARP type, by this method of manufacture, including 11 Nike Ajax and 25 JATO motors. Summarizing, then, the Fluid Ball propellant process is an excellent method for producing a high-impulse cast-in-case solid propellant with ease and safety. With particular attention to the safety aspects of the process, note that: 1) this is simple slurry mixing with quite low order work input; 2) there is essentially no degradation of solid particles, or grinding action; 3) the raw propellant is easily deaerated to yield void-free, relatively less hazardous castings; 4) no volatile, flammable solvents are utilized, with

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their attendant fire hazard; 5) curing is accomplished below 100°F; 6) encapsulated additives may be dispersed quickly and thoroughly with a minimum of disturbance of their coatings; 7) in continuous operation, only a few pounds of ingredients are held in the mixer. Thus, the Fluid Ball process leads to a way to incorporate with maximum safety old and new energetic fuels and oxidizers, such as the light metal hydrides, into solid propellants. No operational process, particularly not the conventional composite or other composite double base processes, offers the simplicity and safety inherent in the Fluid Ball process.

Mr. B. H. Minnich, Rocketdyne: About what is the temperature sensitivity of this propellant?

Mr. Barr: According to the formulations, we must say that this varies between 0.2 and 0.28. This is not as good as we'd like to have it of course.

Mr. M. T. Stuckey, Thiokol: Didn't you have an incident with this last year, was this the same process?

Mr. Barr: Yes we did. This incident, which has since been reported, involved the first pilot operation we had set up. This was the one utilizing the three metering stations that I mentioned. As nearly as we can determine, the shock initiated in this little mixer and very probably as a result of an underfeed of the liquid metering station or an overfeed of the perchlorate system. This of course resulted in an overly dry material in the mixer.

Mr. Stuckey: The thing I'm interested in is did this thing spread from the mixer to include other materials?

Mr. Barr: Yes, everything except the blend of powder and aluminum and there were traces of that which was even unburned oddly enough.

Mr. Jezek: What type of buildings do you cure your propellant in?

Mr. Barr: At present we use the conventional tall bays, twice the size of the largest unit we might expect to be curing, these are hot air heated, however, we use them primarily for our straight composites for our gas generator propellant, since as I pointed out, these cure very close to room temperature.

Col. Hamilton: Any other questions or comments? Thank you very much Mr. Barr. The next item is 'problems encountered in continuous mixing solid propellants' by Mr. Crawford, Thiokol Chemical Corp., Longhorn Ordnance Works.

Mr. J. R. Crawford, Thiokol Chemical Corp., Longhorn Ordnance Works: The mixing of fuel compositions and oxidizers to obtain solid propellants naturally results in certain hazardous conditions. These hazards are quite similar regardless of the type mixing that is used. This paper will present a few of the safety problems and some of the solutions derived for use by Thiokol Chemical Corp., operating contractor at Longhorn Ordnance Works. I am sure all of you are quite familiar with many of these problems; however, by a discussion of these problems,

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we may provide some help to someone in an other agency in solving a problem that they are having; so if you are familiar with this subject, please bear with me as I discuss the batch method of mixing propellants. One of the prime safety problems that exists is the provision of adequate protection to the operating personnel from a potential initiation of the total quantity of materials being mixed. We, at Longhorn, have accomplished this by utilizing the remote operation technique for the mixers. We locate our personnel intraline distance from the mixing operation in a control house protected by an earthen barricade or by a barricade constructed of sandbags. The operation is set up and the procedures so written that no operating personnel are permitted within the mixer building or in the immediate vicinity during oxidizer addition and while the mixer is running. To provide the eyes necessary for observation of the operation, we utilize a closed circuit TV system. Another common problem is the elimination, or at least minimizing, of the formation of dust clouds and static electricity while adding the oxidizer to the mixer. The answer to this is a continuous electrical path to ground. We also utilize an exhaust hood positioned over the mixer to remove any stray oxidizer that will tend to form a dust cloud. This exhaust air is then filtered through a wet type collection system to remove any oxidizer from the air prior to discharge to atmosphere. The next problem is one that is present in any mixing operation - the prevention of extraneous or tramp materials from entering the mixer; and when you consider all the materials that are added together in a mixer to make a propellant, this presents a rather tedious problem. We have attempted to solve this problem by instituting a very critical surveillance program on every ingredient that goes into the mixer. Our fuel mixture is screened at colloidizing and after each processing step where extraneous material might enter, and finally is filtered through a fine mesh screen as it is introduced into the mixer bowl. The oxidizer is carefully screened and controlled at classifying and at make-up into batch lots, and the oxidizer and additive feed system at the mixer is also fitted with a mesh screen similar to that on the fuel mix addition equipment. Solid additives are inspected and packaged in mix size batches, then sealed and X-rayed prior to addition to the mixer. All tools used around the mixer are checked and accounted for prior to the mixer being run. As a final precaution, a cover is provided over the mixer during the mix cycle. There is also some hazard attendant with allowing oxidizer percentage to exceed certain prescribed limits. In order to keep the percentage of oxidizer below the prescribed limits, we utilize a forward mixing technique, whereby the oxidizer is added to the fuel which is already present in the mixer. We add the oxidizer at a controlled feed rate so that at no time do we have a high percentage of oxidizer in the propellant mix. We start with a very low percentage of oxidizer and work up to the proper percentage required for the propellant mix. This we feel gives us a maximum safety factor. It should be pointed out further that all equipment for use in and around the mixer is designed so that weldments are used whenever possible. When it is impossible to use a weldment, and we must use a fastener of one type or another, we provide safety wiring so that in the event the fastener should fail, the safety wire will hold the broken part and preclude its entry into the mixer. We also use this safety wiring technique on all pieces or equipment that come in the area around the mixer whether they be pieces of equipment designed by Thiokol or standard items purchased from outside suppliers. As an example, if we utilize a hoist over the mixer, all potential failure points on the hoist which could come off due to failure, are safety wired so that, in the event there is a failure, they cannot fall and enter the mixer. The next problem is one that is also ever present when mixing. This is the possibility of the mixer blades contacting the mixer bowl and initiating an incident. In order to minimize this danger we use a preventive maintenance approach. For example, the clearances between mixer blades and mixer bowl are checked at least once every 24 hours, and in the event the clearance readings are improper, the mixer is not operated until it has been checked and certified to be in proper operating shape. All new mixers or mixer components are inspected for any possible type of blade damage, fracture, or other imperfection prior to installation. We are currently instituting a system whereby the mixer blades and all pertinent mixer components are inspected periodically to give assurance that they are in proper working condition. The techniques used for these checks are X-ray, dye penetrant, and magnaflux where possible. All of these methods are pointed toward finding any imperfections that might exist which could possibly cause the mixer blade to fracture during a mixing cycle possibly causing an incident. Our theory is that if we can locate this trouble source early enough we can preclude, or at least certainly minimize, the possibility of this type of incident occurring. We also photograph the mixer blades and bowl, and in the event of an incident, comparison is made with previous photographs to determine if there was contact between the blade and the bowl. Another problem that always exists in this type of operation is the removal of toxic and flammable vapors, gases, fumes or dust from the mixing building or bay. We provide a powered exhaust system over the mixer bowl to carry away these fumes, gases, or vapors and discharge them to the atmosphere. In the event any of these fumes need to be removed from the air prior to discharge to atmosphere, we provide a scrubber type unit to remove the objectional materials. In order to ventilate the remainder of the building so that any of the materials that might have escaped our powered exhaust system can be discharged, we provide a powered exhaust system and a large ventilating area for the main portion of the building itself. After we have inspected our raw materials, placed them in the mixer, mixed the propellants, and poured the propellant out of the mixer, the mixer must be cleaned. This presents some small problems of its own. There is, of course, propellant remaining in the mixer, and we need to get it out without causing a fire hazard. We accomplish this by utilizing a slurry of water, detergent, and sawdust for cleaning the mixer. We do not at any time use any type flammable solvent in this cleaning operation and, of course, once the mixer has been completely cleaned, it is given a thorough visual inspection prior to further use. We, of course, have the same problems that everyone else does in the line of fire protection and fire control, and for these we utilize the usual fire protection and automatic firefighting devices that are common to our industry, deluge systems and sprinkler systems. These systems are equipped with fire detecting eyes, rate of temperature rise sensing devices and manual controls, any one of which can actuate the system. We also have interlocks built into this system that will stop the mixer in the event of a fire or, if the fire protection system is inoperative, to prevent the mixer from being started. We have done this so that we do not fold under ignited propellant if it is on the top of the mix. We feel it is better to keep the fire on top of the mix and by use of this interlock system we can do just that. This serves another purpose, in that if there is an incident and the mixer is allowed to continue to run, it would keep throwing or sluffing propellant out into the surrounding area creating a large number of smaller fires. The next two problems that we will discuss are safety problems which are unique to the batch mixing technique. One, is the prevention of sparking as a result of using scraping devices to clean parts of the mixer. In order to preclude an incident of this type we utilize the non-sparking or spark-resistant materials such as aluminum or brass for this type tool. The other problem unique to the batch method of mixing is the contamination of mixer bearing packing with propellant. To minimize this type of hazard we maintain a record of mixer running time as well as a record of the number of mixes that have been made and when either of these factors approach a pre-determined limit we install new packing. The old packing is examined for extent of contamination. By experimentation with packing materials, jute, soaked in Thiokol liquid polymer, has been found to provide longest service without contamination. Now, to operations carried out by the use of continuous mixing techniques. For anyone who might not know what is involved in continuous processing, it might be stated that the equipment utilized is made up of a 4 stage mixer/extruder which is supplied the propellant ingredients in proper proportions from loss-in-weight feeders which are controlled by maintaining the continual balance of hoppers against a constantly moving poise on a scale beam. In actual physical layout the extruder is in one bay, the feed hoppers are in another, the casting operations are in a third, and a remote control console is located in a fourth bay. In discussing the continuous process, lets follow the same general outline we followed for batch mixing. The first problem is the provision of adequate protection for operating personnel from an initiation of the total quantity of material being mixed. Here again we utilize remote operation techniques, that is, we operate from another bay, separated from the mixer by at least a double concrete wall instead of the barricade or bunker type operation center. Again no operating personnel are permitted in the mixing bay while the extruder is being run. Observation is by the closed circuit TV system. This, as you see, represents no great difference over the batch method. However, there is one point that should be stressed, that is, when mixing in a 200 gallon mixer you may have up to 2900 pounds of a class 9 material present in the mixer while in an extruder of comparable production capacity, you have only 30 pounds present at any one particular moment. This then indicates there is considerably less hazard using the continuous method. Problem number two if you recall was the minimizing of the formation of dust or static electricity during oxidizer additions. This is accomplished in the continuous method by enclosing the feed system completely to prevent the escape of any oxidizer dust. For grounding of the system, the same continuous electrical path to ground is provided. Here again there is great similarity of problems and solutions between the batch and the continuous method. For the solution of problem number three, that is the preventing of extraneous materials from entering the mixer, we utilize a system similar to the batch method with a slight variation. In the continuous method, all materials are either filtered or screened before being placed in feed hoppers or tanks. The oxidizer passes through a magnetic screen that is located between the hopper and the mixer feed. The continuous mixer is so constructed as to eliminate the possibility of tools, etc. falling into it. Even so, a tool check is regularly performed as an extra precautionary measure. On problem number four, which is the danger of the mixer blades contacting the mixing bowl wall, we have a similar hazard in the continuous method except it would be the extruder screw contacting the bore wall. If the feed screw could deflect to such a degree that contact with the extruder bore could occur, the situation would be identical to the mixer blade contacting the bowl wall. Several things could cause this type of deformation, for example, uneven feed of solids. To preclude this possibility, a differential feed interlock has been established to stop the mixer if an unbalance occurs between any of the feeders. A plugging of the extruder could also cause deflection of the screw. We protect against this possibility with a motor overload interlock device. We also make a periodic inspection of the screw diameter, screw runout, and bore alignment. These are held to extremely close tolerances. It might be well at this point to go a bit further and explain that we also have an override and alarm circuit which will shut down the entire system in the event any hazardous condition occurs. This system is so designed that if the feed rate is above or below a given range it will shut off. If there is a loss of cooling or heating water to the extruder, again it will be turned off. In the event there is a loss of vacuum or a high propellant level in the deaeration port, each of these things will activate the alarm circuit, override the entire system, and shut it off to prevent any type of an incident; and as a last precaution, in the event all these safeguards fail, and an incident results in the mixer bay, a remotely operated guillotine activates to slice off the propellant feed hoses and close off the bay thus confining the incident to that one particular bay. In the continuous method we remove toxic or flammable vapors, gases, fumes, and dust by making the system completely a closed unit. A vacuum is maintained on the final stage, primarily for deaeration, but it does serve to remove flammable or toxic vapors, gases, fumes, or dust from the system. This in essence is very similar to the batch method solution. It has merely been adapted to the design of the equipment used in the continuous method of mixing. Problem number six, reduction of fire hazard during mixer cleaning, is handled in the continuous process as it is in the batch operation. We utilize an inert solid plus detergent slurry followed by a plain detergent solution, all remotely injected into, and run through the mixer. We never at any time use a flammable solvent of any type in the cleaning operation. Fire protection for the continuous process is identical to that for the batch method, that is automatic deluge systems equipped with fire detection or temperature rise sensing devices and manual controls, any one of which can actuate the system. We again use the same interlocks which stop the continuous mixer if the deluge system is activated or will not permit starting of the continuous mixer if the fire protection system is inoperative for any reason. The last problem we discussed was a mixing hazard caused by the percentage of oxidizer going beyond a certain prescribed limit. In the continuous method, we start the fuel feed first and run until sufficient fuel is in the extruder to eliminate this condition on start up. During mixing, interlocks are provided to stop operations if the fuel feed stops. An oxidizer rich mixture <u>is</u> still possible in localized areas of the screw. It should be noted, however, that this is a very small quantity of the total mixture and temperature and pressure interlocks minimize the possibility of an incident. It might be well to note here that this is a very small percentage of a very small number, that is a small percentage of a maximum of 30 pounds, and that the construction of the extruder itself provides some protection in the event of an incident, through the providing of a blow-out ring. Up to this point we have discussed similar problems that exist between the continuous and the batch mixing type of operations. There are two problems that have arisen in the continuous mixing system that we have not previously encountered in batch mixing. In continuous mixing, a positive pressure is placed on the propellant during the mixing cycle primarily because of the screw construction involved. This presents some hazard because propellants do burn faster when they are under pressure. In order to guard against the possibility of an incident, three pressure and three temperature monitoring points have been incorporated into the mixer. These sensing devices are interlocked into the system to provide an automatic shutdown in the event of excessive pressure or pressure rise. If these devices should fail, it should be noted that the extruder die is held in place by a blow-out ring which will allow relief of pressure if necessary. Obviously, this then would create a missile hazard, but please remember that there are no personnel in this bay at the time the mixer is in operation and that there are two substantial concrete walls between the operating console and the mixer itself. Another problem that is peculiar to our continuous mixer, is the possibility of a fire caused by trace quantities of propellant, if not removed during the cleaning operations, being pinched when removing the screw. To provide maximum safety of personnel while this operation is being performed, the screw is removed remotely, and if an incident should occur, the operating personnel are protected in the control room. It must be pointed out at this time that this is not intended to be a complete list of hazards encountered in mixing of solid propellants, nor do we claim that the solutions presented are the only ones possible, or even for that matter the best ones possible. Our only intent is to present some of the problems we have encountered, with the present solutions utilized by Thiokol Chemical Corp. at Longhorn Ordnance Works. In addition to these techniques, as stated earlier, we utilize all the standard safety devices which are common throughout the industry in mixing areas such as soft wall construction, blow-out panels in rooms of some of our buildings, and substantial dividing wall techniques where applicable. The most important point, I think is that, while we have attempted to design our equipment and buildings to perform operations so that an incident would be minimized, we have also recognized the necessity for, and provided, maximum protection for our personnel. As a result of this concentrated effort by all concerned, the Ordnance forces, the operating and maintenance personnel, the administrative and clerical staff, the professional, technical, and service functions, and last, but certainly not least, the safety department, Thiokol Longhorn was able to compile the record of more than 4,500,000 man hours worked without a lost time accident. Gentlemen, I appreciate your time. Thank you very much.

Mr. Morris Nicheles, Ralph Parsons Co.: You mentioned something about removing a screw automatically, how do you do that?

Mr. Crawford: We utilize a piece of equipment which is called a screw extractor. This screw extractor is bolted onto the outlet end of the continuous extruder and is hooked onto a ring in the end of the screw and then is powered remotely to simply pull it out of the extruder bore. Does this answer your question?

Mr. Nicheles: No, it doesn't. You say it is remotely controlled from the control room.

Mr. Crawford: That's correct. The power supplied to the extractor is supplied from the control room.

Mr. Nicheles: Do you use a trolley or a conveyor or something?

Mr. Crawford: That's right, the extractor itself has incorporated into it a trolley and the screw is pulled out into a bed on the extractor which receives it.

Cdr. J. E. Dodgen, NPP Indian Head, Md.: I believe at one time you were using reverse mixing in your composite work, what was your experience in this method?

Mr. Crawford: We had rather unfortunate experience with that, in the form of an incident or two which caused us to feel that it would be better if we went to the forward mixing whereby we would not have at any one time a large concentration of the oxidizer present in the mixer. This occurred since the first of the year, we have gone to the forward mixing. If you recall, yesterday when the gentleman was speaking about the incident which occurred here, I believe he indicated they were utilizing the forward mixing technique.

Cdr. Dodgen: The other question has to do with the clearances in your continuous mixer. You talk about tolerances, what kind of tolerances are you speaking of?

Mr. Crawford: Unfortunately I am unable to give you that piece of information out of my head, I have a brochure here in another folder that I think will indicate that and I will look it up and tell you.

Cdr. Dodgen: What type mixer is it?

Mr. Crawford: It is a plastics extruder, that is the only description that is given in this brochure, it consists of a bore in which is working an extruder screw. This extruder screw is constructed in three parts, it actually has what I call four stages, a feed stage, a mix stage, a deairiation stage and a pumping stage. I have some pictures of that also if you would like to see them.

Mr. F. M. Bishoff, OCO, D/A: This is not in the form of a question, it's rather to discuss the protection that we are providing personnel involved in mixing operations. I think as each of our incidents occur we have to again re-evaluate the protection that we are providing. In the case of the Longhorn incident, it was quite fortunate that operating personnel and safety personnel had decided that the mixing personnel should be located interline distance. After that incident all of the Ordnance Corps installations and all of the contractors operating under Ordnance contracts were asked to check their mixing operations to see if the mixing operation personnel were protected either by operational shield, if small quantities were contained in the mixer, or at intraline distance if an operational shield would not be sufficient. I think the incident at Redstone here this week should make us re-evaluate our protection to personnel during R&D or pilot line mixing. I believe that there were three empty bays between the personnel and the mixer, yet the construction of the building was such that the flame went down the corridor around the wall and burned some of the individuals. So if any of you are doing R&D type mixing or pilot line mixing, the suggestion is that you make sure that flames cannot reach your personnel even tho your operational shield will protect them from blast or from missiles.

Mr. Crawford: I might indicate an additional piece of information that might be of interest to you that even in our standardization work which is small scale perhaps comparable to the operation which was taking place yesterday at the time of the initiation, are carried out remotely. Even in our small 50 gallon mixer, we operate remotely and further I might indicate that the physical layout or facilities which we use are composed of actually a steel tank located intraline distance from the building and barricaded with sandbags provided of course with a remote TV and the controls. So even in our small standardization operations, we have gone completely remote for the hazardous portion.

Dr. Ball: Two things for you and one for Mr. Bishoff. Have you given any consideration in your shutdown procedures when you have indication that there is trouble in the screw, not shutting down the whole operation, but just shutting off the oxidizer feed so that you could purge the screw with fuel and thereby having the screw containing nothing but something that won't burn?

Mr. Crawford: That sounds like a very good idea to me, if we had not investigated it in the process group, I'd say we certainly should.

Dr. Ball: Mr. Bishoff, it's my firm conviction that we're going to save more people if we quit barricading these operations and start barricading the control console. I'm convinced that a barricaded control console can be located closer in than intraline distance if it is properly constructed. Moreover, it's much easier to barricade the control console including the roof and thereby stop any fragments that may have been spending the last five minutes up in the air, the people can be very much better protected by that kind of construction.

Mr. Bishoff: Dr. Ball, I don't think you've had a chance yet to read Ordnance Manual 7-230, a copy of which we gave you yesterday. That permits location of the control panel at less than interline distance if the protective construction is sufficient.

Mr. Crawford: I might further indicate something that I should have told you during the talk, i.e., that we have provided what amounts to a headache rack over the control console from which control takes place, when there is a continuous process. It is constructed of structural steel and steel grating and since we utilized an existing facility in which to install the continuous mixer, we had what amounted to a transite roof over the control bay and to minimize the possibility of what Dr. Ball is talking about a missile coming over and back down thru to your personnel, we have installed this headache rack or this steel grating overhead.

Mr. K. E. Miller, Rocketdyne: I have a question concerning possible tests you may have run on propagation of a fire or explosion down a pipeline of propellant. Have you run any tests of this type at all?

Mr. Crawford: I'm sure we have but I'm certainly not the authority on that, I believe that in one of the talks yesterday there was considerable discussion of this type of test. Am I correct in that?

Mr. Miller: I was concerned primarily with the type of propellant that you are mixing, I don't believe we had a paper on that yesterday.

Mr. Crawford: They were talking in terms of powder and high explosive.

Mr. Miller: That's right.

Mr. Crawford: We have not ourselves run any I don't believe of any particular significance.

Mr. Miller: Another question, have you had any experience with line plugging between your continuous mixer and your casting operation?

Mr. Crawford: No sir.

Mr. Miller: How do you clean the line between your mixer and your casting?

Mr. Crawford: These are fire hose type lines and generally they're of small consequence and we throw them away.

Mr. Miller: Just one more question. Is your casting operation conducted remotely?

Mr. Crawford: In the continuous process you're speaking of?

Mr. Miller: Yes.

Mr. Crawford: It is subject to being carried on remotely, as I indicated in the talk, we have the four components of the continuous mix system separated into separate bays one of which is the casting technique or the casting operation, and if I am not mistaken, we currently have personnel in that casting location if required. Of course, there should be no particular trick to make that remote, using level controls and things of this nature.

Mr. Miller: Are you casting directly from the mixer or are you casting by means of a cast can?

Mr. Crawford: We have done both.

Mr. Miller: In the case of where you cast from the mixer to the motor direct, then you would be remote in that case, is that right?

Mr. Crawford: I would say, it would be possible, but what I said was that I believe we have had personnel in there doing the casting operation, but it could be remote.

Mr. W. F. Haite, Thiokol: Some years ago a long length of casting line was tested in this manner, ten feet and some in excess of ten feet, with the initiation taking place at a sealed blind flange and also from the open end and in all their tests they got burning such as an end burner and had some considerably long burning times, a matter of minutes and this was in line with testing out the rupture section in the pipe, so that if pressure should develop a weak section would break. But they did not get anything other than normal burning with those propellants they're working with.

Mr. Crawford: At very slow rates.

Mr. Haite: That's right. They were initiated with squibs, I don't remember if they used a cap on it or not. It is reported in some of their early work, I can't recall the year now, but Longhorn personnel would know that.

Mr. Nance: Along this same line we ran some very recent tests at the Utah Div. where we were concerned with continuous processing. We ignited long tubes of fire hose of propellant with squibs and we had some guillotines along the line and by sensing the fire and activating this guillotine, it was actually possible to chop the line in two and stop the propagation of fire. So it is one of the advantages of continuous processing of this type of propellant that it doesn't apparently seem to transist from deflagration to detonation. It's a rather slow burning process and it can be simply terminated if you fairly accurate sensing equipment.

Col. Hamilton: The next talk will be by Dr. Burket of Aerojet-General, 'processing propellants containing nitrocellulose or other nitro compounds.'

Dr. Burket: I was more than a little appalled to find myself talking on the subject of nitrocellulose propellants in front of a group which contains I don't know how many people who are more familiar with nitrocellulose propellants than the Aerojet-General Corp. However, on the basis that we are mutually interested in the precautions that we are taking with the particular types of hazardous materials that we work with, I am going to go ahead and describe what we are actually doing in the way of taking safety precautions with nitrocellulose propellants, which we do work with to a small extent, and propellants containing nitro compounds, which we do work with to a fairly large extent, and which are relatively unique in the industry. The first slide shows a typical composition for a nitro-plasticized polyurethane propellant. The chemical names are all I think self-explanatory. This doesn't actually present any special problems by comparison with normal composite propellant processing, however, the two nitro-plasticizers incorporated here are different compounds from those that we are normally working with. We'll go thru some of the precautions that are used with a nitro compound. The nitro-plasticizers in general can be initiated under sufficiently rigorous initiation such as with a tetryl booster, they are treated therefor as explosives. Load limits are strictly enforced in the laboratories and storage rooms. Large quantities are stored at about 40°, the materials that are in process are stored at higher temperatures, 70° to 110°. Polyethylene containers are used in general as with most explosive materials. The pure material in normal operation is never heated above 110°. This does not mean that it can't be heated above this temperature but this is a good working maximum. After the nitro-plasticizers are dispensed they are not carried around pure, they are immediately mixed with the inert ingredients. The fuel preparation is shown here in considerable detail, the blending of the materials you'll see is done manually. All the other operations are remote, one pound mixes of these materials are prepared behind a shield that I showed you yesterday. When we get to large batches such as one gallon, we operate completely remotely. None of our propellants mixed in batches as large as one gallon are mixed any way except remotely. The one pound batches may be mixed non-remotely if we are sufficiently familiar with the materials. If they contain nitro or nitrate compounds they are mixed behind a shield, or if preliminary five gram batches of the propellant have shown excessively low impact stabilities, then they may be mixed in one of the pint Baker Perkins mixers which we have set up for remote operations. The blending of the fuel is done in a Cowles dissolver. This is done remotely also. There have been no accidents of any type. The nitro-plasticized polyurethane propellants have been made in 2,000 pound batches and the normal batch process without incident or without expectations of an incident based on the tests that we have conducted so far. The next slide shows the mix procedure that is followed, you'll notice that it is definitely the forward mix cycle. The transfer of propellant in general in all our operations is conducted remotely, in other words, if there is any shear, even the type of shear that exists in flowing thru the line, there are not personnel present in the room. I'm going to run thru these things as rapidly as possible. Of propellant formulations containing nitrocellulose, we have worked with both the nitrasol type and the cross linked polyurethane type, somewhat similar to the work that is being done at Wyandotte and BRL. This shows the type of composition, you'll note the nitrocellulose cross link material does have nitroglycerin in it. We have run into no special problems. In the processing of the plastisol grade nitrocellulose, these are the operations that must be performed. The plastisol grade nitrocellulose itself is far less sensitive than the linters nitrocellulose. When ignited it does not react the way the linters nitrocellulose does, nor does it dust as badly as the linters nitrocellulose, however, we follow in general very nearly the same precautions with the plastisol grade as we do with the linters, such as daily washdown of the room in which it is processed, etc. All operations again are remote where there is power being supplied to the nitrocellulose, either in the screening or the deagglomerating with a Cowles dissolver. In the linters nitrocellulose processing we have followed a somewhat different procedure, we use what is called a one-pot process. The nitrocellulose is not handled dry separately at any time. Mixed as received, mixed with hexane, this is placed in a pot, either a mixer, or in a Binks pot, stirred with a desensitized nitroglycerin-ethyl centralite and the santicizer 141 and is dryed in the pot. It is never removed from the pot, or handled dry. The safety tests which have been conducted on the polyurethane and the nitroplasticized polyurethane are summarized here to show the relative sensitivities of the propellant product. The nitroplasticized polyurethane of the composition shown in the first slide has the same ICC classification and a somewhat higher auto-ignition temperature than the standard polyurethane; I don't know how to explain the latter, but it has been observed many times with a variety of formulations. Neither can be initiated with the size tetryl booster that we have used, up to

35 grams, when tested using a 3" diameter grain, 3" to 6" in a 1/4" steel sleeve. It can not be initiated at 70° or 0° F.; at minus 75, it can be detonated. The witness plate on which it is mounted is definitely damaged. The impact stability is somewhat lower than that for the standard polyurethane propellants, but not excessively so, and we have not found it necessary to use special precautions with this type of propellant. This slide shows the results of our tests on the nitrasol and the cross-linked type. Other people have worked with these and have not arrived at the A classification; I don't know how entirely to account for this, but I do know that on occasion we have sent samples back to the Bureau of Explosives which we have labled A and they have reclassified them B, which may be the explanation here, perhaps we've been a little more conservative than the Bureau of Explosives. We have not tried explosive initiation tests with the cross linked nitrocellulose as yet but I would gather from the results that have been obtained elsewhere that these also will probably not be detonable at 70. At zero I'm not so sure. I believe that's all the slides. Any questions?

Dr. Ball: Would you tell us which auto-ignition temperature you're reporting here.

Dr. Burket: This is in the copper block, I think the heating rate is something like 20° F. per minute.

Dr. Ball: Instantaneous in other words. I think most of you are aware that some military specifications also call for auto-ignition tests at temperatures for one hour exposure and eight hour exposures so it needs a little more definition.

Dr. Burket: We have tried tests of this type, not with these particular materials, but we have conducted such tests. We put a thermo-couple in the propellant block, and for all practical purposes we say it is going to auto-ignite if the temperature recorded by the thermo-couple begins to rise above the temperature of the oven. These are, in general, of course, much lower for the average ammonium perchlorate propellant, for example, this happens at about 360° F. in long term storage. The auto-ignition of 500° is misleading if it is going to be exposed to the temperature for a long period of time.

Mr. Ullian, Patrick AFB: I think it was on the next to the last slide where you showed polyurethane propellant that was class B. Is this the one used in Minuteman that we've got to detonate with 100 pounds of TNT?

Dr. Burket: Yes.

Mr. Ullian: I have a comment on this nitrasol. You know that by adding I think it's somewhere between 5% more aluminum with one composition, trinitrosol, it makes a real good underwater explosive.

Mr. W. G. Queen, OCO: I noticed that you had minus 75° at the temperature at which you got detonation with a tetryl booster I presume. Is this a critical temperature, what happens at minus 60 or a spec temperature?

Dr. Burket: No, we test simply at ambient, zero and minus 75. In particular propellants, we have surveyed the region all the way down and in general we do not get detonation at minus 40 or 50, I can't recall just where it sets in, but not at minus 50.

Mr. Queen: One further question, the quantity of tetryl on the booster?

Dr. Burket: $8\frac{1}{2}$ grams.

Mr. H. M. Roylance, BuWeps, D/N: In the storage of your nitro compounds, I noticed that you specified polyethylene containers. Do you have any information on their susceptibility to initiation or ignition by sparks or something like that? What I'm getting at is that we normally store in a conductive container.

Dr. Burket: I don't see any spark data listed here. One of the problems of course in transferring materials from any container is, no matter how conductive the container itself is, tremendous charges can be built up simply as it pours out. I think the NOTS China Lake, has made tests with pouring ammonium perchlorate. For example, they have measured very high potentials in pouring ammonium perchlorate from grounded containers. I'm not just sure that the use of grounded containers in the pouring process should be regarded as a real safeguard.

Col. Hamilton: Any other questions or comments? Thank you very much Dr. Burket. The next talk will be 'Fire Detection and Control for Solid Propellants' by Mr. C. F. Averill, Grinnell Corp.

Mr. C. F. Averill, Grinnell Corp.: The advent of solid propellants has created some new and challenging fire protection problems. The burning characteristics of these fuels are such that new techniques are needed to adequately cope with the hazard. The potential damage to expensive and hard to replace equipment from a propellant fire during manufacturing operations is obvious, and the inadvertent firing of a solid propellant motor in storage or assembled on a missile can be a serious and disastrous occurence. Rapid detection of trouble is the key to preventing serious damage. The U. S. Navy Bureau of Ships recognized their special problem several years ago. If a missile in storage in a magazine aboard ship became ignited by enemy fire or by accident, there is the likelihood of adjacent missiles becoming involved, which could result in the loss of the ship. To meet this problem, the Bureau, in conjunction with the Applied Physics Laboratory of Johns Hopkins University, developed a fire protection system to control the burning of the propellant grain and, thereby, prevent ignition of adjacent missiles. Since the hazard involved in this case was a completed missile, the first usable external evidence of fire in the grain is the emission of pressure waves from the nozzle of the missile. Therefore, a pressure sensing device was used as the detector. Operation of the detector completed a circuit to a primer operated release on the water control valve which, when opened, allowed a high velocity water stream to penetrate the grain perforations to control the burning. The detector, valve, and nozzle were designed into a single compact unit, which is permanently mounted close to the nozzle of each rocket as it is mounted in the missile magazine. Power to fire the primer is supplied by small storage batteries which are contained in a battery compartment on the side of the device. After the basic research work was done on this device by the Applied Physics Lab., the Grinnell Co. was awarded a contract to develop and produce the first production models of the unit. These are now aboard ship. The problem of solid propellant fire protection seems to be divided into two categories. One involves fires in completed motors or missiles, as just described. The second covers fires that may occur during propellant manufacturing operations. The basic difference, from a fire protection viewpoint in these two categories, is that in a completed motor the grain is confined, whereas, in most manufacturing operations it is not. This question of confinement is important because it effects the burning characteristics of the propellant, as well as the first usable external evidence of fire. In the case of a confined grain the problems involved in attempting to survey the interior with a light sensing fire detector are so numerous it seems that pressure sensing is more adaptable. With an unconfined grain good surveillance is more easily achieved and light sensing devices are preferable. Many tests by several organizations have shown that water is the most successful and practical extinguishing agent for propellant fires. While the complete mechanism of extinguishment is not fully understood, it is generally agreed that cooling is the principal factor because it prevents feed back of sufficient heat energy to maintain combustion. It is desirable to get the water to the actual burning surface. It is not enough to wet a part of the surface only, as the fire will burrow into the propellant and continue to burn, being shielded from the water by the outer layer of water soaked material. This makes it essential to apply the water rapidly before the burrowing can occur. Another factor which makes rapid operation essential is that the water must reach the burning surface before the pressure of the combustion gases is sufficiently high to prevent the water from reaching the source of the fire. This means we are talking about system operation in milliseconds. There has been a need for an effective and dependable fire protection system in the propellant manufacturing industry for some time, as the many fires have shown. Many attempts have been made to fill this need, but the systems now available have many drawbacks. Recognizing this need, the Grinnell Corp. has developed new equipment which we feel can be incorporated into systems to meet many of the problems presented by solid propellant fires. Grinnell was fortunate in being able to enlist the services and talents of the American District Telegraph Company, the world leaders in fire detection equipment and knowledge, to develop the high speed detection portions of the system. What I am presenting here is more in the form of a progress report ratner than the presentation of a new system. There is still a great deal of development work to be done before all the possibilities have been explored. This development work, for the present, has been directed toward providing protection for the various propellant manufacturing operations; such as mixing, casting, core popping, cut-back, and storage. All these operations have not, as yet, been thoroughly investigated. However, enough work has been done to indicate that the principles of detection and extinguishment used and the basic devices and system involved can be applied to these operations, as well as others. It was apparent very early in the program that, in manufacturing operations, the first usable evidence of fire would be light, and since extreme speed was desired, the use of light detectors was first investigated. A photosensitive cell was selected for its simplicity, dependability, and infra-red response. The signal from these cells is carried to an amplifier made up of transistors and solid state devices. No moving parts or relays are used. This equipment was also selected for its simplicity and dependability. The photo cells themselves can be given various angles of view by providing movement within a sleeve. The field of view can thus be controlled which helps in preventing extraneous sources of light from hitting the cell and causing false operation. Also various types of light filters can be applied to narrow the band of response. This gives control over the wavelengths of light which will operate the system and helps prevent false operation. In order to further increase reliability and freedom from false alarms, "duality" has been introduced in a gate circuit such that operation will result only if all specified detecting elements receive the fire signal simultaneously. If only one or a part of the group of detectors is energized there is no operation. There is a gain control built into the amplifier, so that the sensitivity of the system can be controlled; another feature that helps overcome false operation. The amplifier transmits a signal of sufficient strength to the operating mechanism at the water control valve to operate the valve. A special valve was developed for this application. Keeping in mind the need for speed, simplicity and dependability only two moving parts are used. The body is that of a standard globe valve. The water seal is achieved by a piston entering the throat of the valve body. An "O" ring inserted in the same manner as a piston ring makes the piston water tight. A stem attached to the piston extends through the top of the valve. A swinging latch contacting this stem holds the valve in the closed position. The yoke supporting the latch has been designed to accommodate a primer so positioned that when the primer detonates the latch is forced off the stem and the water pressure under the piston opens the valve. Since all piping from the valve to the capped discharge nozzles is pre-primed with water, pressure is immediately transmitted to the nozzles forcing the caps off and water discharges from the system. This yoke can also carry auxiliary switches which are operated by movement of the latch to initiate an alarm, shut down equipment, etc. The combination of the photocell detectors, the primac valve, and the pre-primed piping are the principal factors in the extreme speed of operation. The Thiokol Chemical Co. expressed interest in such a system for their cut-back operation. Therefore, a mock-up of their cut-back machine was made at our fire test field in Providence, R. I., and propellant shavings which came from actual cut-backs, were furnished us by Thiokol and used in the test work. The most difficult situation seemed to be the case where the cutting had progressed to a point where there was an accumulation of shavings several inches deep above the cutting blade and a fire was started at the blade level by its coming in contact with a foreign material. The question was whether a concealed fire such as this could be detected in time to prevent involvement of the solid, uncut grain. Had all the shavings been consumed and no ignition of the grain occurred, we would have been satisfied. However, we were more than gratified when repeated tests showed that the fire was extinguished with only surface ignition of the grain and about one-third of the shavings remained unburned. The propellants used were of the PBAA, Poly sulphide, and Poly Urethane types. Indications are we will be as successful with other types, and we hope to have the opportunity to try them. During our study of the cut-back operation, Thiokol completed installation of a new 150 gallon vertical mixer at their Elkton, Md. plant and asked if the protection equipment could be adapted to that machine. Therefore, a mock-up of the mixer blades and top plate was made at our test field and the adaptation worked out. The installation of this system is now being completed. While there has been no fire test run on the mix, there is little doubt that the machine will be protected from damage in the event of a fire. The simplicity and compactness of the system lends itself to some rather interesting possibilities. One of these is a portable or mobile system. Since the system is fast acting, a relatively small volume of water may be all that is required. Therefore, such a system could be attached to the dolly or transporting cart which moves the grain from operation to operation, if it is felt that there is need for such protection. A self-contained power supply would be used as a power source and nitrogen would be used to pressurize the water tank. Tests to date on solid propellants show that normal water pressures, i.e., under 100 psi are adequate. However, there may be cases such as with a confined grain where, in spite of the rapid detection, higher water pressures may be required to speed up initial water flow. Our thinking has, of course, gone beyond our test work. One of our prime objectives has been to design equipment that is versatile so that, with little or no modification, it can be adapted to various job conditions. The water control valve will be available in different sizes to accommodate the differing volumes of water from one application to another. We have over 100 varieties of water discharge nozzles to select from to give the proper volume and drop characteristic for any given application. With this versatility of equipment, we feel that, with a little applied engineering, an adequate system can be designed for many of the solid propellant hazards that are now without fire protection. You will be interested to know that provision has been made to properly test the system so the operator knows it is in good working order. Some systems will be in service only when a manufacturing operation is being carried out, while others may be in service 24 hours a day. With an intermittent in service requirement, it is especially important to be able to test the system before starting the process. Special test buttons on the control unit light small incandescent lamps mounted on the detectors to simulate fire and produce a visual response on the control unit. In this fashion the optical surfaces of each group of detectors and the condition of the associated electronic circuits can be checked. Another test button is provided to check the continuity of the primer circuit. This test equipment is separate from the basic system components and, therefore, can be provided or not, as the customer chooses. However, we can visualize very few situations where the test equipment should not be considered an essential component of the system, and we strongly recommend its use. This gives you a general idea of what we have been working on and what our thoughts are for future development. We have not been working with, or for, any government agency. However, if you feel that this equipment would be useful to you and would help solve some of your fire protection problems, we would be happy to cooperate with any Government agency or private concern in working out the details for any given installation. I hope you have found this information of interest, and I wish to thank you for your kind attention.

<u>Mr. Settles</u>: If you mentioned it, I failed to catch it. What speed of response do you estimate you get with this system?

Mr. Averill: We're estimating millisecond operation. Actually we don't have at the present time any actual timing tests other than visual. The installation that is now being completed in Elkton will be filmed with a Fastax camera. For that matter, the test was run yesterday. If you're not all familiar with that type of equipment, this is a camera where the film passes the lens at the rate of about 3,000 frames per second. By counting the number of frames, from the evidence of light to the operation of water, you can get the time of system operation. Until that film has been developed and we can make the count, we don't have any specific number of milliseconds we can quote to you. But several people have witnessed the test set-up that we made of the system and it's so fast the eye has difficulty detecting any delay in time from fire to discharge of water.

Mr. Settles: So it's probably not in the nature of several hundred milliseconds, maybe down in the nature of 40, 50 or 60 milliseconds.

Mr. Averill: That would be my estimate, I've been asked to make a guess on just what speed of operation we would get and I've been thinking in my own mind in the order of 50 milliseconds.

Mr. Settles: I heartily concur in the direction you're going with your investigation and I think we need this very fast response in our power detection and extinguishing systems. However, as you get into these fast responses, there's always the problem of the speed of the water getting from the nozzle to the fire. If you're down in the neighborhood of 30 to 40 milliseconds on your response, it is entirely possible that some folks might have a condition arise where the time it takes the water to get from the nozzle to the fire is greater than your speed of response. This is just an additional precaution that might be taken.

Mr. Averill: What you say is very true, and that factor has to be taken into consideration in the applied engineering and designing of the system. Obviously the time it takes for the water to reach the seat of the fire after it leaves the nozzle is pretty much a function of the distance over which it has to travel. Therefore, of course, it is desirable to get your discharge nozzles as close to the source of fire as is physically possible. In some operations they can be very close. In other operations, due to the interference that the piping may have to operations in the area, this may not be as possible. Here, again, it is something that has to be worked out to the best advantage for each particular installation.

Dr. Knapp: I can't recall who it was, but it seems to me that last year at this meeting at Indian Head someone mentioned and showed us pictures in which they had successfully put out confined motors. They deliberately ignited them and put the fire out.

Col. Hamilton: I believe that's on the agenda later on, we'll get to that one.

Mr. Averill: I believe that was Dahlgren rather than Indian Head altho I know they have several installations at Indian Head which work on the rate of rise principle.

Dr. Knapp: I mean it was discussed at the ASESB meeting last year at Indian Head.

Col. Hamilton: The tests that are going to be discussed later were run at Dahlgren.

Mr. Ullian: Possibly my question should be deferred too, but have you done any work on systems of confined motors? If you have, what size are these systems? Are they small enough that they could be used in a missile assembly building where there are personnel and various operations going on on an assembled missile?

Mr. Averill: You've asked a two part question there really. We haven't done any test work with this particular system. We have with other systems which will be described tomorrow on completed missiles, but this new adaptation using the photo-eye and transistorized amplifier has not been applied to the completed missile as yet. We hope to do that. Answering your second question as to the size of the equipment, whether it would cause interference to operations, here again this depends on the physical arrangement of the particular set-up. The detectors themselves are about the size of your little finger, i.e., the complete detector. The photo-sensitive element is just a wafer about like your little fingernail. The mounting equipment of that makes this a cylinder about the size of your little finger. The discharge nozzles themselves are about 1½" in length and maybe 3/4" in diameter. On most of the applications we visualize, so far, we don't anticipate anything larger than a 2" pipe for protection for a given piece of equipment. Of course, if you have several pieces of equipment and you wish to protect the whole area or something like that, the supply piping could get as high as 6", but as far as the piping immediately around the object being protected is concerned, that would be 1¼" or 1½", 2" at the most so that it doesn't really occupy a lot of space. There are problems of supporting the pipe and hanging it. As was mentioned earlier, these come in where you want to get the discharge nozzles as close to the object as possible. Hanging problems have to be worked out and there is considerable applied engineering that has to be done for each installation. As I have said we have been trying to get a family of versatile components that can be put together into a system that will vary from installation to installation, but with this versatile equipment it can be adapted to the varying conditions that you'll find from even the same operation. Let's take cut-back, for example. Within the same company, like Thiokol, the conditions at Elkton would be different than they are in Utah and different than at Longhorn. Hercules' physical set-up would be different again so that you have to have this versatility in order to be able to adapt the equipment to these various conditions.

Mr. W. W. Buxton, Aerojet-General Corp.: Have you done any development work for detecting or sensing decomposition of propellant grains in storage or conditioning boxes where you want to know of this before you actually have a fire? In other words, your light sensing device would not give you any indication yet that anything is wrong, but there is some temperature rise and possibly smoking.

Mr. Averill: No, we have done nothing along that line.

Mr. Stuckey: We are the ones you're talking about on this system and we have made some tests on it in the mixer. We have put propellant in the mixer and ignited it with the igniter buried so that the sensing devices can not see the propellant until it's broken out in pretty good shape. It puts a propellant out rather easily. Normally, I'd say, it burns about half the propellant before we get it. I think one of the problems that we have here, and what I really want to say something about is whether or not these units actually should go inside the mixer. We put them in the mixer. We're going to try it out because we don't believe we can get water from outside the mixer and ever do any good with a mixer fire. We're not sure that we can do anything in the mixer, but I figure it is the one chance we have of putting a fire out, if we can get to it fast enough. One of the reasons we put this checking system in is we want to know, with the viscous material mixing around in the mixer, that these eyes can see. I think maybe by the next meeting we'll be able to give you a pretty good report on this. I'm pretty sure we can get this from siting the fire to water on the fire. My guess is quite a bit under 50 milliseconds. I don't see any reason why it shouldn't be this fast. We have a very bad problem at Elkton in the fact that our water pressure is only 40 pounds. If you had higher pressures, I think you could get even faster reaction.

Col. Hamilton: Thank you Mr. Averill. The next subject is 'transition from deflagration to detonation; gap sensitivity and calibration of gap sensitivity test' by Dr. Noonan of NOL.

Dr. E. C. Noonan, NOL White Oak, Silver Spring, Md.: For several years a small group at the Naval Ordnance Laboratory have been engaged in investigating the basic aspects of the sensitivity of high explosives and propellants. It is the purpose of this paper to outline briefly some of the work accomplished and in progress and to review the results obtained to date. At this point it should be pointed out that high explosives and propellants are not substantially different from a chemical viewpoint; the difference is in their application. Much of our work was done with high explosives but the work is equally applicable to propellants. We have learned much about desensitizing explosives from the techniques of propellant manufacture. In studying sensitivity, one must realize that the various tests employed rarely measure any basic quantity. The impact machine is a good example. Very frequently the potential energy, in foot-pounds or kilogram centimeters, is reported for the 50% point of an explosive. This has little meaning, for most of this energy never reaches the explosive sample. It appears as potential energy in the rebound of the weight and a large fraction is scattered in dissipative processes. The pressure developed at the piston-anvil interface and its duration has a good deal more to do with the sensitivity measurement, and this depends on the velocity, density and configuration of the weight. The test developed by Mr. Saffian at Picatinny will be discussed shortly. It is another example of a useful test which does not necessarily measure any basic quantity. The mode of initiation may vary from one explosive to another. Some are more sensitive to a given type of initiation than others. Deaired nitroglycerine is quite insensitive on the gap test, but it is sensitive in the impact machine. The safety record on handling leads us to respect the impact machine results. Brittle crystals tend to be sensitive to shear or to grits imbedded in them; less sensitive to the adiabatic compression of included gas bubbles. It is important for us to realize that there is no single test for sensitivity.

Rather, the tendency of the informed explosive worker is to gather as much information as he can by a variety of tests and then to assess the hazard of the explosive in question by comparison with older ones on which handling experience has accumulated. Although the impact machine leaves much to be desired as a quantitative test, impact results are always obtained on new explosives before even gram quantities are prepared. And until he learns more about the material, the worker is very careful to respect the impact machine findings. Thinly sectioned double base propellant can be made to fire at 8 cm on the Bureau of Mines machine. Yet it is not particularly sensitive to shock in more massive sections and need not be handled with the precautions taken with PETN which appears a little less sensitive on the impact machine. The intent of our sensitivity investigation is to get at the basic mechanisms of initiation; to assess the meaning of existing tests and to develop new ones of greater significance if this proves to be feasible. We have accumulated a great deal of data on both liquid and solid explosives or propellants using two "standardized" versions of the gap test. The gap test for solids has been described before this group on earlier occasions. Figure 1 illustrates the essential features of the apparatus. More details will be found in NavOrd 5788 (Ref. 1). The explosive or propellant to be tested is confined in a cold rolled steel tube 3.55 cm (1.437") wide diameter, 4.77 cm (1.875") outside diameter and 13.95 cm (5.5") long. A mild steel witness plate rests on top of the assembly. Shock loading is applied by detonating a column of two pressed tetryl pellets, density 1.63 g/cc. They are 5.08 cm (2") in diameter, 2.54 cm (1") in thickness and weigh about 78 grams. The shock is attenuated with a stack of cellulose acetate cards, each one is 0.0254 cm (0.01") thick. Cards are added or subtracted from the stack until detonation (assessed by a hole punched in the witness plate) occurs 50% of the time. In most cases the 50% point is very sharp. Removing one or two cards always results in detonation, restoring them results in failure. It is necessary to condition the samples at the same temperature and to use reproducible donor pellets to obtain reliable results. The tetryl pellets do not reach full detonation velocity under these conditions but we find that we do get reproducible results from them and that only a reasonable amount of explosive is required. The gap test as "standardized" was conceived as a screening test for solid propellants. Those which failed to detonate in direct contact with tetryl presumably had failure diameters greater than 2 inches. Those that did detonate could be classified as to sensitivity. There is nothing magic or sacred about the test configuration. It was selected according to our own conceits, or what we think is informed opinion, as providing the most useful amount of information with a reasonable size test sample. As far as initiation goes, we are interested in the impulse delivered to the explosive sample. We can determine the pressure with some degree of reliability; measurement of the duration of loading and integrating to get the energy required is still being investigated. To find the pressure we made use of the finding that a solid piece of Lucite plastic could be substituted for an equal thickness of cellulose acetate cards in the gap test. The equation of state of Lucite has been quite thoroughly investigated both here and abroad. We may write this as $P = \rho U u$ where P is pressure, ρ is density and U and u are shock and particle velocities respectively. It may help if we recast this equation in another form. Remembering that density is m/V, where m is mass and V is volume, we can write $PV = mUu = m\mu^2$ = Energy where μ^2 is a velocity squared.

Note the similarity to the ideal gas law: PV = nRT. Plots of the particle velocity in Lucite versus the shock velocity have been compiled by others, although it was necessary to add a point or two in the region of low particle velocity in our own laboratory. Figure 2 shows such a plot. The problem then resolves into measuring the shock velocity as a function of distance in a Lucite rod shock loaded by the detonation of two tetryl pellets. The configuration is, of course, comparable to the donor section of our gap test. Figure 3 shows the charge assembly used by Mr. Jaffe and Dr. Amster for the experiments. Two tetryl pellets were placed above the Lucite rod, together with a shield to reduce smoke in the observation field. Flat faces were polished on either side of the rod. Holes were drilled at intervals along the rod and probes inserted which collapse at a given pressure and complete electrical circuits. The end of the Lucite rod was immersed in a tank of water. Since the equation of state of water is well known, progress of the shock in water can be related to the pressure at the Lucite-water interface. A spark fired across a gap served as a fiducial mark to synchronize the records. Progress of the shock wave was observed by lighting the rear of the rod with an exploding wire and observation with a smear camera. Progress of the pressure wave was observed with the pressure probes which operated two oscilloscope circuits; one of these was a high resolution, raster-sweep circuit. The fiducial mark from the spark appeared on all three sets of records. For the first few centimeters of travel the probe and smear camera records coincided; later the pressure wave appeared to lag behind the shock due to the finite action time of the pressure probe switches. From the camera record the shock velocity as a function of distance the wave had travelled was determined. The corresponding particle velocity was read from Figure 2 and the pressure computed from the relation $P = \rho Uu$. The results are shown in Figures 4 and 5. Figure 4 shows that the pressure is attenuated logarithmically as a function of distance. Figure 5 shows the actual pressure as a function of distance in the Lucite rod. Remembering that the solid rod is equivalent to the card stack in the gap test, we have marked the pressures at which various explosives initiate 50% of the time in our gap test configuration. Tetryl initiates at about 15 kilobars (about 15,000 atm or 220,000 psi). Comp. B requires a higher pressure while cast TNT needs about 35 kilobars under these conditions (confinement and duration). You will note that we still have no information on the duration of the pressure pulse and theoretical considerations to tell us that this can be quite critical. Moreover there are impedance effects as the shock is transmitted from the card stack to the explosive. Two explosives may have a 50% point at exactly the same card value and still have different sensitivities because a different amount of energy may be transmitted to the different explosives because of a difference in impedance. Greater energy appears to be transmitted through a mismatch in impedance. The gap test itself still does not measure a basic quantity. But we feel it will be useful in predicting the behavior of propellants due to bullet impact, to fragment impact as in Mr. Saffian's computations, or to impact by a flying metal plate. It should also be useful in interpreting handling characteristics. What we do not have at the present time is information on the effect of loading rates. Partly in answer to the last question we are conducting a theoretical investigation. This is a purely mathematical approach which at once is highly sophisticated in some respects and naive in others. The model for the investigation being performed by Mr. Enig is shown in Figure 6. Here we have a semi-infinite layer of inert material (the gap) in contact with an explosive material. Both of these materials are given the same equation of state. The difference is that the explosive material decomposes by first order kinetics when heated and releases heat in the process. The explosive material is backed by a rigid wall at the right, while the inert material is compressed by rigid piston going from left to right. For the first computation the piston is assumed to move at constant velocity. The calculation is sophisticated in that a fine mesh is used in the involved differencing scheme and in the fact that the effects of viscosity and heat conduction are taken into account. It is strictly one dimensional. No account is taken of motion in a radial direction although there is no a priori reason why this cannot be done. It will take a great deal more machine time and we prefer to investigate the one dimensional case first. In the actual gap test there is lateral pressure relief which allows rarefaction waves to come in from the sides and attenuate the compression wave. Figure 7 shows four "frames" from what might be a motion picture of the sequence of events. The first plot shows the pressure as a function of distance some short time after the piston is set in motion. The ordinate shows the pressure, and it may be seen that a shock wave has been formed in the inert material and is progressing toward the boundary. The next plot shows the shock wave entering the explosive at some later time. A very small amount of chemical reaction has produced a small hump in the pressure just before the sharp drop in pressure at the shock front. The next frame, still later in time shows the abrupt onset of chemical reaction (detonation). A very steep shock forms. The final frame shows the detonation wave progressing to the right and a shock wave forming and going in the opposite direction back into the inert material. If the initial velocity of the piston is reduced the shock wave will progress some distance into the explosive before enough heating occurs to initiate the chemical reaction. Breakout of the detonation appears some distance to the right of the inert-explosive boundary. This situation has been observed experimentally; Sultanoff's pictures taken at Aberdeen Proving Ground are excellent examples. If the velocity of the piston is decreased still further the detonation does not occur at all or is produced when the weak shock reflects from the rigid wall. The machine program has been written in a versatile form so that we can add complications as we become more experienced. For example, the piston can enter at a constant velocity and then stop. A rarefaction wave follows the compression shock and the question is whether it will overtake the shock in time to quench the chemical reaction. A step further, the piston can enter at a constant deceleration, or we can make it an elastic piston of metal with a finite thickness and watch the vibrations and their effects as it hits the inert material. Eventually we hope to add the second dimension and make the mathematical model simulate the real gap test. We may also explore variations in the chemical reaction rate. Aeronutronics has done some work along these lines prior to our own effort. We have also investigated the transition from deflagration to detonation both experimentally and theoretically. Figure 8 shows a typical experimental setup and plots of results. Explosive is cast into a thick walled steel tube and ignited by an electrically heated nichrome wire passing through an end plug. Two types of instrumentation are used to record the events. Ionization probes enter the tube at various points. This indicates the passage of a "flame" front. A continuous nichrome wire is used to record the position of the detonation front. The front is highly conductive and connects the resistance wire with the case. Knowing the resistance of the wire as a function of length we can follow the progress of the front as more and more of the wire is shorted out of the circuit. The resistance record is shown as a function of time in the lower right hand plot. The progress of the "flame" and detonation front is shown in the upper right hand plot. Note that a low velocity regime occurs first. It is 1/2 to 1/3 as fast as detonation and much faster than ordinary deflagration. Over a 5 microsecond interval there is a sharp change to detonation. More highly resolved records of the transition have been made, and they indicate quite clearly the very sudden transition. Dr. Macek has a theory which reproduces the experimental findings. His model starts with a finite cavity at a pressure P_o. The pressure increases, due to combustion gases, at a rate approximated by $P = P_o e^{kt}$, where k is a constant and t is time. The exponentially increasing pressure sends a series of acoustic waves into the unburned explosives, eventually these coalesce to a steep shock front some distance ahead of the burning front and detonation develops. The situation is quite similar to the theoretical calculations of Mr. Enig, where the rigid piston is replaced by gaseous combustion products. We are doing similar hydrodynamic calculations on this problem. The important thing to remember is that some "run" is necessary before detonation breaks out and if the propellant thickness is less than this run, detonation is unlikely. Also, there must be sufficient confinement so that an exponentially increasing pressure can be developed; something of the order of 40,000 psi in 40 microseconds. The confinement may be either inertial or by a strong case. In most rockets the confinement is inadequate for this kind of event unless the web is very massive. Porous materials are quite different. Here the burning rate can increase very fast due to the enormous surface areas, the forces produced tend to break up more particles and produce still more surface. Transition to detonation in porous or powdered materials can therefore occur with only a short "run". Casting powder is dangerous from this standpoint, or even a small volume of porosity in a finished rocket grain. One of the things to which we have not paid enough attention is the phenomenon of break-up described by Mr. Wachtell. There is a great deal of evidence in the explosive field that this is an important mechanism in initiation. Whitbread and Holden, in England, shocked a single RDX crystal with an explosive donor. The shock wave travelled the entire length of the crystal. Detonation initiated at the far end when the material spalled off. Cachia and Whitbread (Proc. Roy. Soc., A246, 268 (1958) found that this kind of initiation occurred when the gas surrounding the material was at a low pressure; it seemed unlikely that gas heated by shock was responsible for igniting the particles. Dr. Winning at duPont has photographs of an exploding detonator immersed in a beaker of degassed nitroglycerine. Photographing the sequence shows that no explosion occurs until the shock reaches the edge of the beaker and the glass begins to break up. This is an exceedingly interesting field and one worthy of further investigation, particularly in regard to solid propellants as Mr. Wachtell showed in his presentation. Unfortunately a theoretical attack on this problem is difficult because we don't have good methods of simulating microscopic discontinuities. Theoretical treatments are invariably based on homogeneous materials. It is our conviction that continued basic research on mechanisms of initiation and growth of explosions will lead to better understanding and control of these phenomena. It is really essential to the field of high energy propellants. In the effort to produce higher impulse there is an increasing tendency to try to utilize materials that are not even high explosives, but more nearly primaries.

While these compounds may prove feasible to use in combinations with other compounds, it is obvious that we must learn a great deal more about the field of explosive sensitivity in general in order to utilize these compounds with confidence.

Mr. Jezek: Does the form of the explosive make any difference; i.e., whether it is cast or pressed?

Dr. Noonan: Yes. Pressed explosives contain more voids and are more sensitive than cast explosives on the gap test. Transition to detonation is also easier.

Mr. Nance: Have you tested any actual composite ammonium perchlorate propellants?

Dr. Noonan: Yes; we have data on a great many of them. Composites of the inert binder type (polyurethane, polysulfide rubber, plastisol binders) are quite insensitive as long as they are homogenous. If they have voids in them they become highly sensitive.

Mr. Nance: Have you obtained detonation in some of them?

Dr. Noonan: We have never obtained a detonation, using the gap test confinement and configuration, with a homogeneous composite employing an inert binder. Others claim they have, we've never been able to do it.

Mr. Nance: With your test series, what would you predict the effect of diameter on the charge would be; are you going to have to scale up your diameters?

Dr. Noonan: You are probably familiar with the fact that a large scale gap tests series was done in conjunction with NOTS and Aerojet a couple of years ago. The charges were Polaris propellants, 19 inches in diameter and 80 inches long. The booster was about 750 pounds of Comp. B and the propellant weight was more than 1300 pounds. The case and witness plates were comparable in scale to the laboratory gap test. No detonations were observed in twelve shots.

Mr. Nance: What type of pressure cell are you using to measure the shock wave progress; is it something you are making or buying?

Dr. Noonan: We buy these from the Precision Tube Co., a concern who makes thermocouples. They consist of a coaxial copper tube and wire; the insulation is stripped at one point so that the tube can collapse against the wire at a predetermined pressure. They are essentially tiny pressure switches.

Mr. Nance: When we get all these pressures required to detonate given explosives, how can we relate these to practical applications; to predict storage protection, etc.?

Dr. Noonan: I'm sorry to say that I don't know how to estimate the pressure created when a jagged fragment hits a case containing propellant. A good mechanical engineer might be able to do it, in theory it depends on many things.

But once you have information of the type that Mr. Saffian has developed for one explosive it should be possible to compare it with another explosive if both have been gap tested. I think this is the way you have to look at it.

Mr. Nance: It appears this way and it also appears that most polyurethane propellants or composites are going to be extremely insensitive as far as pressure initiation is concerned.

Dr. Noonan: Yes.

Dr. Knapp: Talking about the basics of the ignition problem it is interesting to speculate on what happens microscopically in the propellant as it is ignited. It seems to me that an awful lot of types of ignitions come down to either touching a match to it, you heat it up or you put a spark on it or something, or you distort the crystal by mechanical means by shock, by friction or something. To the extent this is true, you ought to be able to perhaps induction heat a very tiny ball bearing, or something like that, buried in the propellant as one way of initiating it. And you should be able to measure some physical property of the material itself in shear and by those two properties pretty much tell what it should do in a wide variety of types of initiation and we've had some ideas of some experiments we might run and I'd like your comments on what you think about this general idea.

Dr. Noonan: The ball bearing idea has been suggested before; the difficulty with it is that it is troublesome to get a source of electromagnetic energy with a short enough wave length so that the ball bearing can pick up enough energy in a short time. This is an interesting proposal but actually one can get at the same information by some gross experiments on propellants and use of the Frank-Kamenetsky equation.

Dr. Knapp: On the other question I wasn't talking so much about the experiment, I'm not particularly fond of the experiment, but rather do you think there are very restricted numbers of ways that microscopically the propellant does get ignited and is it perhaps first heating and second shear perhaps or something like that?

Dr. Noonan: Yes, I am sure there are a restricted number of ways. One of the things about sensitivity that leads to confusion is that explosives respond differently to different methods of energy input. Liquids are readily sensitized by gas bubbles. A liquid tested in an impact machine with a cavity striker may appear much more sensitive than if the cavity is absent and the heating is by viscous shear. Brittle crystals are more responsive to shear than to included gas bubbles. In the case of rubbery propellants the impact machine probably measures their ease of ignition rather than the combination of ease of ignition and transit to detonation. By shaving double base propellant sufficiently thin it will go at 8 cm on the Bureau of Mines machine; this is the range of nitroglycerine and more sensitive than pure PETN. Yet the handling record of finished double base propellant rockets is very good.

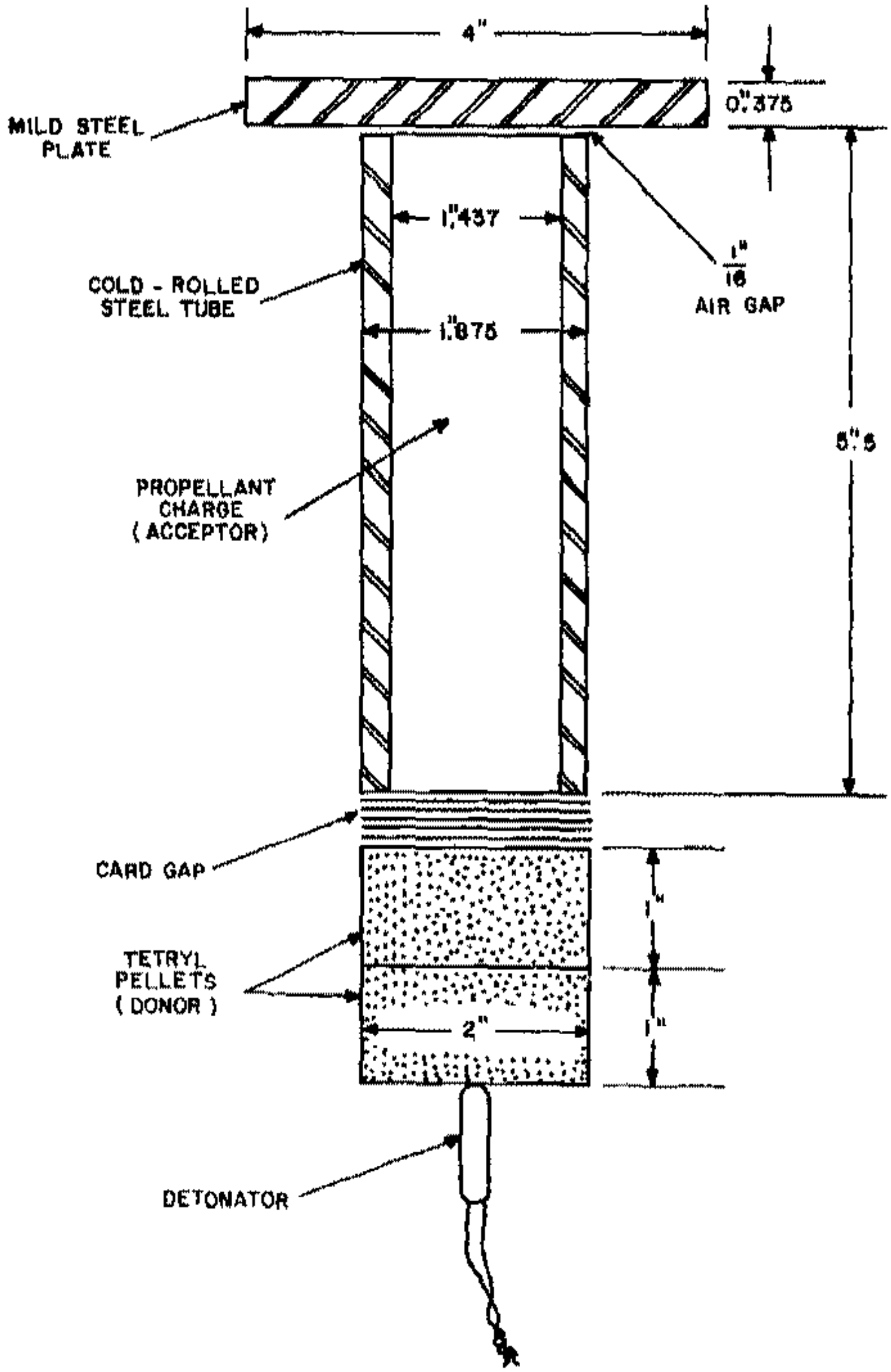

FIGURE 1. Gap Test for Solid Propellants

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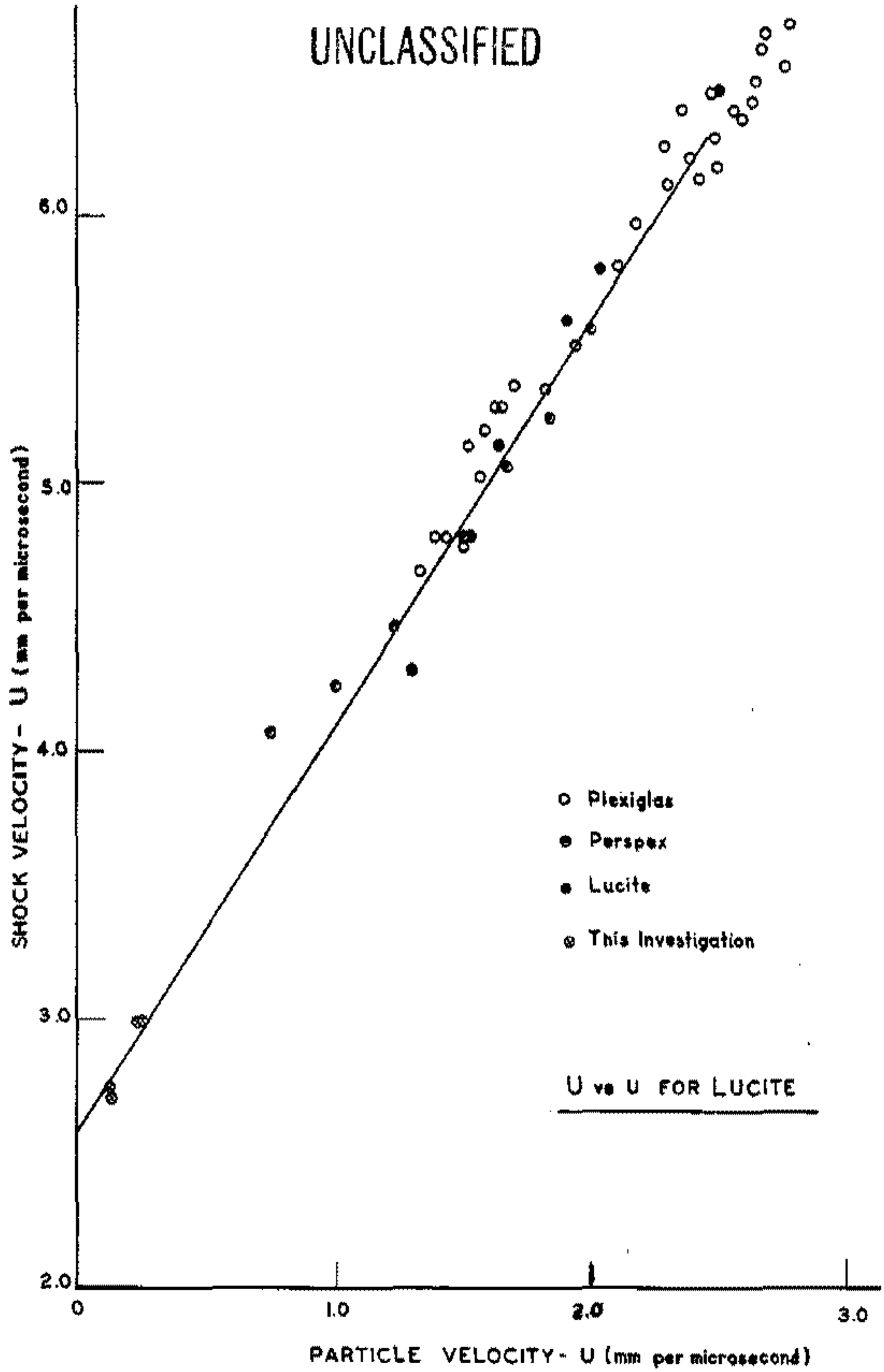

FIGURE 2. Shock versus Particle Velocity in Lucite

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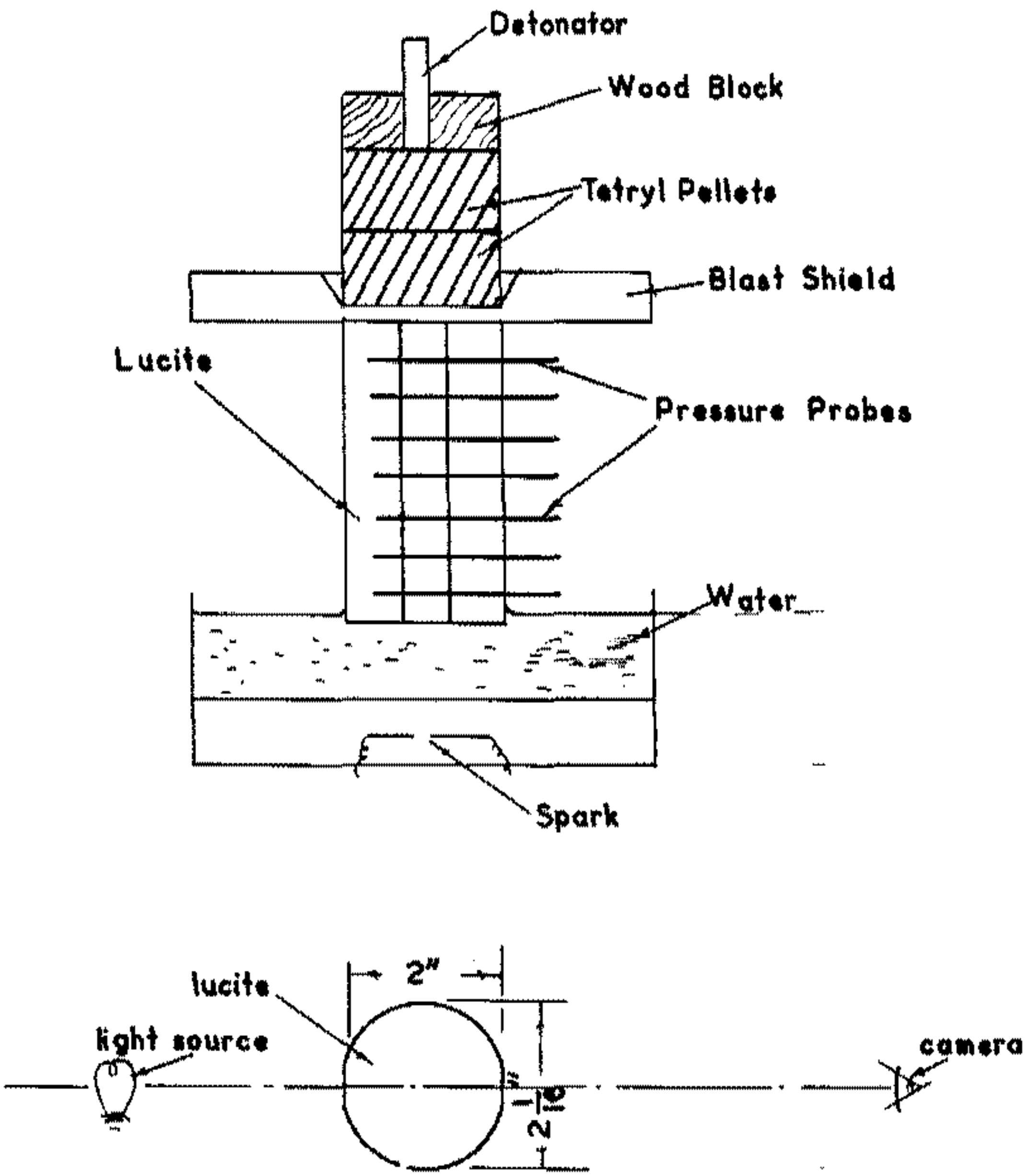

FIGURE 3. Measurement of Pressure in Lucite, loaded as in gap test.

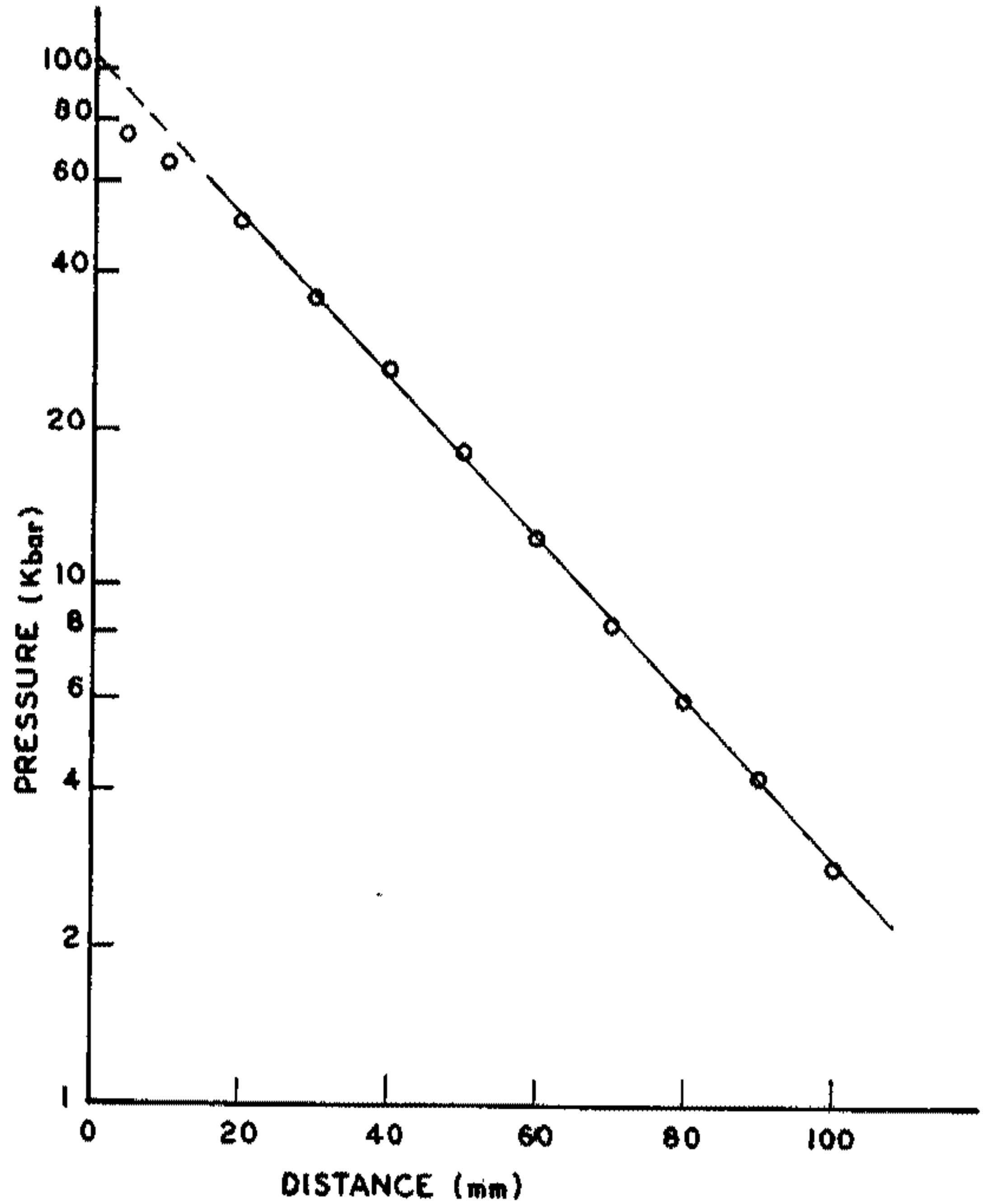

FIGURE 4. Log of Pressure versus Distance in Lucite, loaded as in gap test.

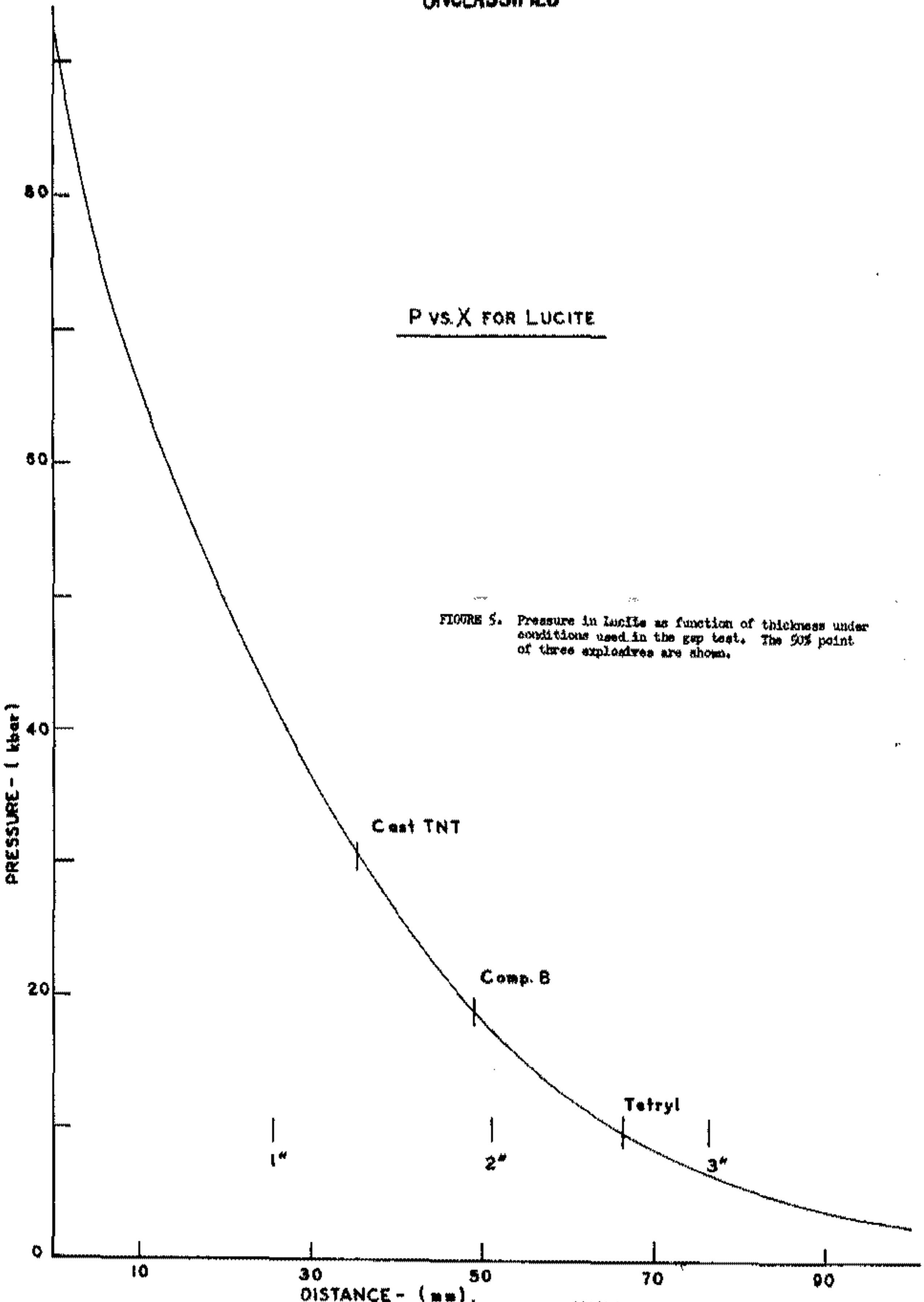

FIGURE 5. Pressure in Lucite as function of thickness under conditions used in the gap test. The 50% point of three explosives are shown.

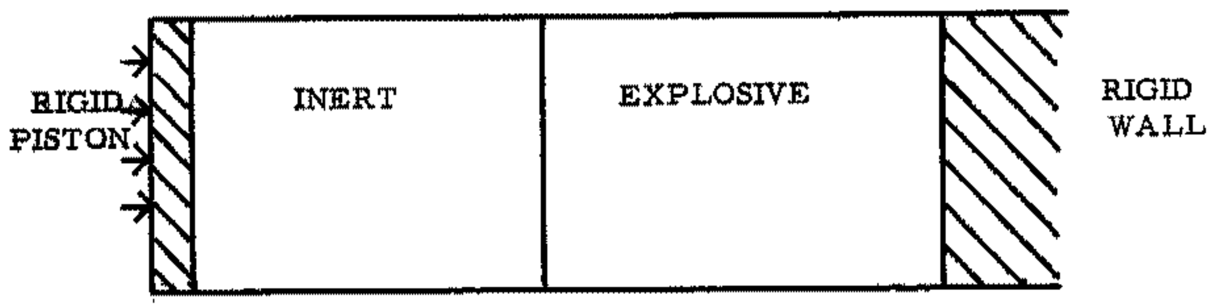

FIGURE 6. One Dimensional Model For Theoretical Treatment of Gap Test. Rigid Piston at Left Compresses Inert Material and Explosive Against Rigid Wall at Right.

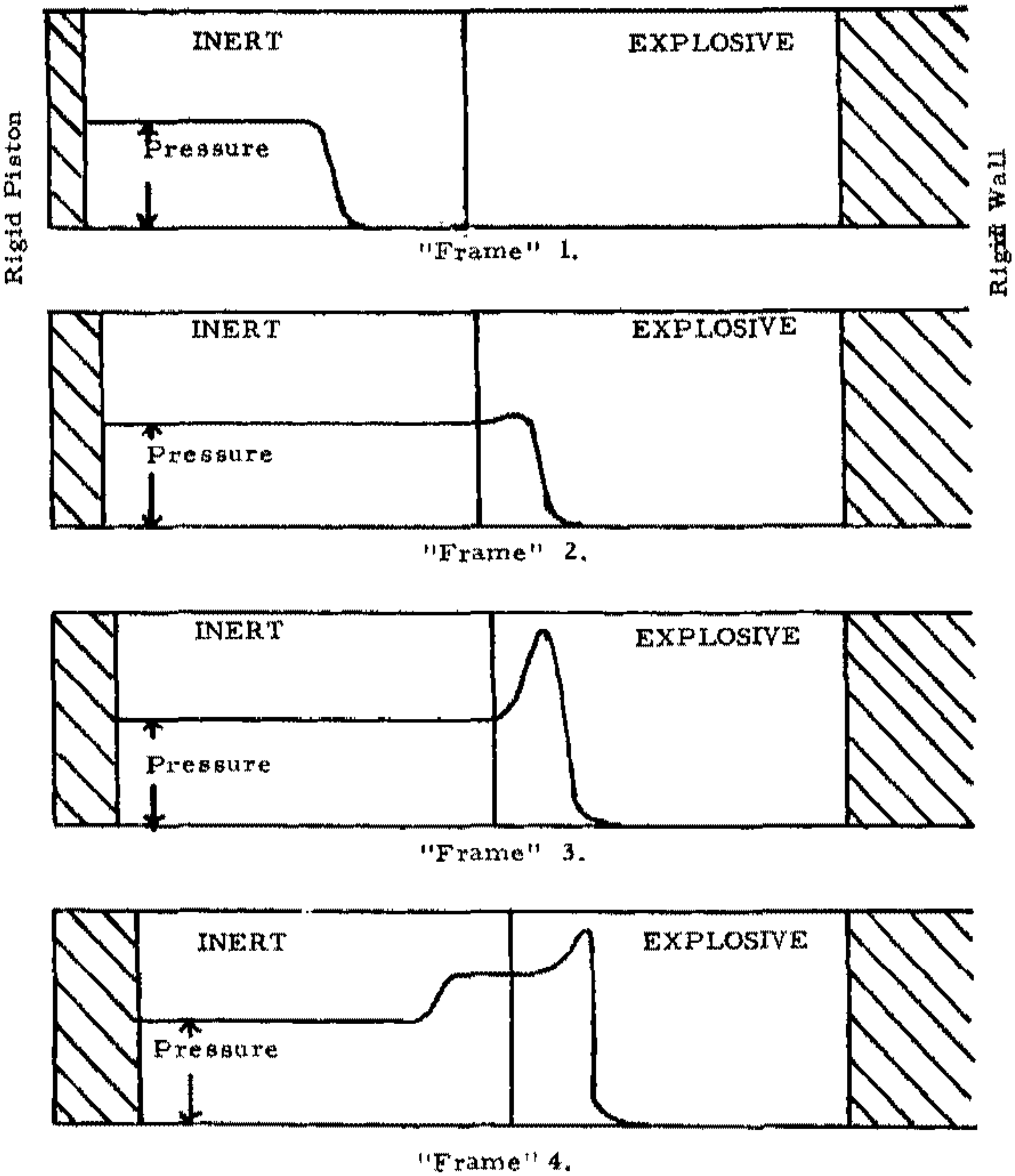

FIGURE 7. One Dimensional Theoretical Model for Gap Test. Inert Gap and explosive have the same equation of state. Progress of shock as a function of time. Piston moves at constant Velocity.

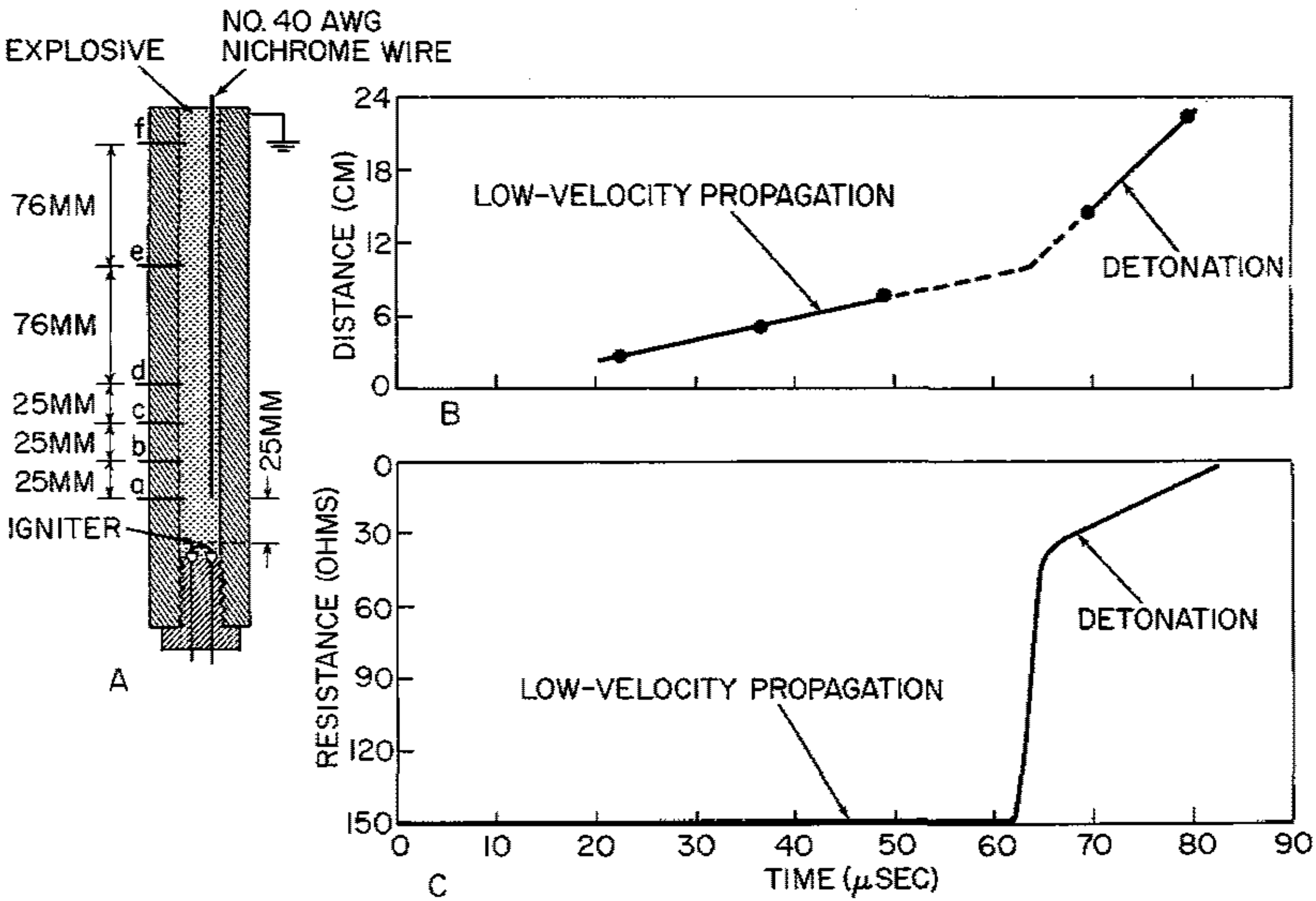

FIGURE 8

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Col. Hamilton: Thank you, Dr. Noonan. Yesterday you'll recall Mr. Wachtell also discussed the transition from deflagration to detonation and we held off the question period because of the possibility that some of the questions might be answered by Dr. Noonan. Are there any questions that any of you would like to raise in connection with Mr. Wachtell's talk on the same subject? Apparently not. The last item before we go on the tour will be 'R. F. as related to accidental ignition of electrical squibs by induced current'. Mr. Piasecki from the Jet Propulsion Laboratory.

Mr. L. R. Piasecki, JPL: (Confidential) The work represented by this paper was done primarily by Mr. Stevens of the antenna group, we felt that this was primarily a communication problem. Mr. Stevens is continuing this work and is now Section Chief of the Communications Section and will be issuing a final report. We hope this report can be downgraded and it will be available shortly. The paper I'm going to present is a look at three particular problems that the JPL had in this area, the Sergeant missile, the RTV vehicle which later became the upper stages of the Juno I and II vehicle and the on-lab R&D operations at the laboratory and the approach which we took to solve these problems. The two squibs particularly which I will be referring to and I would like to state the characteristics of now are the Dupont X201A which is a 2½ ohm 2 amp minimum firing current 10th of a watt firing power 300ths of a joule minimum firing energy and the Dupont X201E which is a lower resistance higher minimum firing current .6 of an ohm, .7 amp .3 watt but again 300ths of a joule minimum firing energy. The X201A and X201E are representative of medium power electrical squibs, various other types in common usage range from 300ths to a half a watt minimum ignition power. The significance of minimum energy and minimum power for ignition may be illultrated by considering the squib ignition temperature. Since a certain minimum temperature of the filament is required for ignition of the charge the fixed amount of electrical energy which is converted to heat energy in the filament is required for ignition. If the rate of supply of energy is too slow the filament will never reach the required temperature, since it is cooled by its surroundings. Thus there is a minimum rate of energy flow as well as a minimum total energy required to ignite the squib. These considerations show that when pulse energy typical of radar causes ignition the average power must be considered rather than the peak power unless there is sufficient energy introduced in one long pulse to cause ignition. In the case of a very long pulse the peak power should be considered. The X201s are very sensitive devices and it has been demonstrated that it makes no essential difference if energy is supplied from a direct current or radio frequency source. The conversion of electrical energy to heat energy can be just as efficient. This fact has been experimentally demonstrated many times in the specific case of electric squibs. A reasonably controlled set of experiments was run at JPL. A squib was fed from a radio frequency source via a transmission line. The amount of power flowing into the squib could be accurately measured. The results of the test at several frequencies showed the squibs ignited at approximately the power required for direct current ignition. Radio frequency energy can be supplied to a squib from a firing harness which acts as an antenna. To estimate the maximum of power which a receiving aerial can extract from the electromagnetic wave

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of energy N^S an effective area of the area can be calculated using this equation. It can be shown that a thin wire of the type shown in the shaded section here will effectively couple with a field surrounding it of a distance of the wave length over 8 and therefore the effective capture area of the wire is the length of the wire in the field times the wave length over 4. The upper equation then says that the maximum possible received power is the area times the field strength. This has been verified and is the formula for the receiving capacity of a dipole in the field. The field strength of the transmitter is equal to the radiant power where R is the distance to the source from the location of the receiver, in this case the igniter leads, and this is the power of the transmitter if its operating isotropically. Most transmitters will use an antenna which will direct this field and therefore the maximum power, they will have a gain factor here of the transmitter and this equation then gives the field strength that can be generated by a transmitter of power, you have a directional antenna and gives the field strength of the antenna oriented in the direction of the receiver. Combining these two simple equations, we have then the maximum power which can be received in the harness is equal to the power radiated by the transmitter and the isotropic divided by this capture area over for πr^2. This then gives us a maximum power that we might reasonably expect and first thing was to say that if we could limit the operation such that this would not exceed the power necessary to initiate, then we would have a perfectly safe operation. We tried this first with Sergeant, the Sergeant is a solid propellant missile which in early flight test used the X201A which is the low minimum firing current squib that I mentioned earlier. The hazard of an accidental pre-ignition of the early rounds was reduced by initially imposing the following safety requirements at White Sands Proving Ground. These regulations were based on calculation above assuming that the harness capture area is equivalent to the harness length times the quarter wave length as shown in the equation. Road blocks were set up at main access roads and road sweeps were made to maintain silence for all mobile transmitters at any frequency within a two-mile radius of the missile launcher. No stationary transmitters were allowed to operate at any frequency within six miles of the missile launch pad. No transmitter between 100 kilocycles and 1 megacycle capable of an effective radiated power in excess of 1,000 watts in the direction of the launch site and within a 25-mile radius of the missile launch was allowed to operate. No transmitter between 1 megacycle and 100 megacycles capable of radiating power in excess of 10,000 watts in the direction of the blockhouse or launcher within 25 miles of the missile launcher was allowed to operate. Transmitters located further than 25 miles of the launch site were not controlled. I think it's pretty obvious to all of you who have had experience in field operations that the White Sands Missile Range was not happy and understandably so. The requirements were very restrictive. We then attempted to imply a quick-switch to this thing, we immediately switched to the X201E which as you can tell increased our allowable power rating somewhat. To bring these requirements down to some reasonable limits that we could operate with for Sergeant, we then modified the squib assembly by switching to the X201E squib which has the higher minimum firing current allowance and in addition we put 2 watt 10 ohm resisters in line with the squib. This then raised our power

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requirement significantly to fire these. This enabled us then to reduce the RF silence requirements from two miles to ½ mile on the mobile transmitters, to reduce the RF silence requirements for stationary transmitters from 6 miles to 1½ miles and to terminate all RF silence requirements on any transmitter beyond a five-mile radius of the launch site. This of course should be recognized, was a huge thing which enabled the missile range to operate during the R&D phases of the Sergeant, it was recognized that these would be a deterrent position on a tactical missile system like Sergeant and so we went back and I'm sure there are plenty of people with Field Artillery experience here that will be happy to hear this, we went back to the firing pin. This assembly then is the initiator assembly for the Sergeant as it will go to the field. It has a pyrogen ignition system developed by Thiokol, the initiator which is of interest is a standard artillery primer which is fired by a firing pin. The firing pin is actuated by a solenoid. This enabled us then to put on the solenoid any power requirements which we would like and so we established now that you need to have 550 watts to fire the Sergeant. This then for the Sergeant solved our problem. It should be recognized of course that this is a specific fix for a specific missile. We found it was not intolerable, it did add some weight to the missiles, that the Sergeant is not significantly weight limited and therefore it was an acceptable fix and this is the way the Sergeant is going to the field. The second instance that we looked at was for the RTV cluster, this is the stage 2 of 11 motors, stage 3 of 3 motors, stage 1 of 4 motors, which went on the JUNO I vehicle which launched Explorer I and JUNO II vehicle is still flying this cluster essentially unchanged. We attempted there to apply the same formula and found that it was rather restrictive even for our operations in an R&D type operation which of course is the way we conduct the K firing as of satellites and probes. We therefore ran a series of experiments, it came out incidentally that the most critical stage in the cluster was the stage 2 and the reason for this was that because of the large cross-sectional area which the harness exposed, it was the governing factor and so we made a replica of the stage 2 complete in every detail, the stage 2 firing harness assembly which is a pair of conductors coming up from the booster, a circular harness and then 11 individual wires going to each of the 11 individual igniters in the assembly. A replica of this was made and a series of tests were run. The harness was illuminated at various radio frequencies. The harness was shielded and grounded, from the purposes of RF it appears that grounding of the shielding should be done in as many places as possible. Unfortunately, on most of these vehicles there exists a possibility for large voltage differences in the vehicle and therefore from the standpoint of EC excitation of the harness itself, the requirement was that we would ground the shielding at one place. This, therefore, eliminated the possibility for circulating current from potential differences in the assembly. To reduce the data from the series of tests and to put them in the form of a shielding effectiveness, several assumptions had to be made. In the first place, the power density incident on a harness was estimated by combining a measurement of the radio frequency source power output and assumed gain for the particular radiating antenna involved and a calculation based on the power density varying inversely as the square of the distance

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between the radiating antenna and the particular portion of the harness which was being strongly eliminated. Also since the measurements were a practical necessity made in the near zone field of the entire harness, a capture area for the harness was chosen to represent a reasonable value considering the particular test frequency and the dimensions involved. The reason for setting up the experiment in such a manner which made the determinations of shielding effectiveness subject to so many assumptions is as follows: Primarily it is desired to achieve ignition of a squib in the experiment which would then provide a fairly concrete data point. Since the ignition of a squib even in the case of a sufficient energy density over the harness area is essentially a statistical matter in the complex circuits involved, it was concluded that all measurements possible in the time allowed should be made under conditions which would provide the greatest chance of igniting the squib. It was planned that if repeatable ignition of the squibs could be obtained at close range with the higher powers available, then experiments at greater distances would be conducted. In fact, however, no squib ignition was observed during any of the experiments with the harness although the thermistric indication indicated sufficient power was available in the circuit. The thermister incidentally is a device which is about 50 ohms impedence compared to the 1 ohm or so which the squibs have which allows you to measure the power input by the rise in temperature of a bridge circuit similar to the squib bridge itself. This should not imply any doubt that a squib can be ignited by RF energy power of a level essentially the same as is required at DC for this fact has been repeatedly demonstrated in controlled experiments. And I am sure you are aware of some experiments which were run about ten years ago at the University of Alabama, I don't have the direct reference here, but it has been demonstrated that this can be done. As no ignition of the squib occurred during the series of tests, it was necessary to accept the thermister release readings as an indication of the power available to the igniters in the circuit. In certain of the tests there was a thermister indication of sufficient power available to result in an ignition, yet as stated previously, none occurred. This should be interpreted as a lack of proper impedence transformation between the source and the low impedence igniter. Again it would be expected that two RF the cabling harness which is essentially a low DC resistance system would have significant impedence of the order of perhaps 100 ohms and could be expected to couple better with a 50 ohm thermister than it could with a 1 ohm or that order of magnitude squib. This table merely gives the measured frequency, the measured radiated power that we could expect out of the transmitters which we use, the antenna gain number and then with the thermister, from these formulae we determine therefore what maximum power we might encounter. From the thermister we determine the absolute power that we actually got and by dividing these two, then we get a shielding effectiveness in the last column which as you can see has a tendency to vary as the function of the frequency in the manner which might be expected because the circuit could be expected to be tuned better at one frequency than another perhaps. From this table and from the last column there, we concluded that a 20DD or a factor of 100 gain, i.e., a factor of 100 decrement in the receiving capability as the antenna was achieved. As you can see, there is only one case where the shielding effectiveness is less than 20DD. And in all other cases it is greater than 20DD or a factor

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of 100. We therefore decided to use this factor of 100 as a safety factor. The requirement that was set up for the AMR, Cape Canaveral, was that the field strength of 125 milliwatts per meter squared could be allowed. Since the capture area of the harness in stage 2 is approximately a meter, this then says that we would allow field strength just great enough so that if we had maximum coupling, we would have a probability of firing the squib. This decrement of 100 was used as our safety pattern in this area. The regulations which resulted from this requirement are as follows. During operations involving - let me digress for a bit here - again, not only was the stage 2 found to be from theoretical considerations the most hazardous assembly, but the igniters are shipped in brass tubes completely shielded. This gives us a gain over a bare igniter not shielded of about 50DD. That is a pretty big number. And so that the only time where we were required to impose RF silence was the time the igniters were moved from the shipping container which formed an effective shield and gave us a large comfortable pad, until they were installed in the motor. The motor then was equipped with a soldered copper diaphragm, this was done again deliberately so that once the igniter was installed, we had about a 30DD pad, in terms of the ability to receive power from the igniter itself, over the case where we were waving the igniter around prior to installing it in the motor. And so the critical time that resulted here, there were two critical times, the most critical resulted during insertion as the igniter when we had to remove the shielding of it. The second was critical time and this we regarded incidentally as most because there were personnel around at that time which was another factor to be considered, of course. The second most critical time is when the igniter is installed and connected to the firing harness to effect its antenna. It was found that this was approximately 10DDs safer, believe it or not, connected to the antenna than it was when it was waving around in the air. The requirements then during igniter connection and subsequent handling of the igniter harness were as follows: at transmitters able to radiate greater than 4 megawatts were required to be off at distances of 5 kilometers or less. 400 kilowatts to 4 megawatts, 1.6 kilometers. 40 kilowatts to 400 kilowatts, ½ kilometer. 40 kilowatts, 150 meters, and 0-4 kilowatts, 100 meters. This was found to be a reasonable requirement, we establish this at Cape Canaveral, we have lived with it and we will probably continue to live with it. In addition it should be recognized that there are some other possible ways of generating magnetic fields other than the transmission, the RF. Whenever as you probably know, whenever you have a large disruption in DC or very low, frequency AC power, you have a collapsing or building up field, i.e., during the transient. I believe we ran some calculations on this. From the calculations it comes out that if you have a conductor carrying 100 amps at a distance of a meter from the receiving wire and you disrupt this surface such that it takes 100ths of a second to decay, you will generate a shield capable of producing 1,000th of a joule. This is sufficient or barely sufficient to ignite some of the lower energy items we are talking about here. In addition to that the same phenomenon occurs with lightning storms. If we assume that a lightning discharge current of 20,000 amps occurs and that this occurs in about 1000th of a second, then we find that at a distance of 10 kilometers, we have about the same order of magnitude of field. Our requirements then in addition to

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the RFR requirements for the RTV vehicle are that the gantry elevator and other high power switching circuitry would not be operated during this hazardous time. In addition, no lightning storms would be allowed within 10 kilometers. Now, unlike some other people, we found it difficult to legislate on lightning storms and so the requirement obviously was that we would stop since we couldn't stop the lightning. So operations were required to see if lightning storms approached to within 10 kilometers of the operation. This then is two of the first problems and the approach which we took. We have continued these studies by looking at the R&D operations around the JPL. These studies are still in a period of evolution, we do not at this time have all of the answers as to what requirements are necessary to be safe. The primary reason why this becomes a much more difficult problem is that in the case of the two missile systems we had a specific restrained physical condition, an electrical condition which we could study in detail. In R&D operations we have a myriad of devices of various power levels, we are connecting these to essentially random circuits for the purposes of study like this and to establish a set of rules that would prevent ignition following these kinds of ground rules would essentially grind all of our operations to a halt. I'm afraid that we must take a much more critical look at these kinds of operations. So they are in a period of evolution, the regulations which we hope to establish at the JPL for our R&D operations. We have established some regulations which, the first one, the slide shows a plot on the left of minimum distance in meters, below effective radiated power in kilowatts. We have found that in our operations we could still follow the rigorous very conservative maximum limits in terms of radiated power and so we have established this as a ground rule, it is part of the safety requirements, you are not allowed to train any antenna of significant gain or significant power in the directions where these operations are taking place. In addition we have stated that the storage area for all electric squibs and incidentally the kinds of devices we're talking about and the use we make for these things now is very myriad. We use them for much more things than initiating explosives, I believe in the next space craft which we're going to develop we have 19 squibs which we use for unfolding and erecting an antenna and these squibs are of considerably different characteristics than those which we normally consider. All of these types of squibs then are shielded against radiation, they are kept in considerably shielded storage cabinets. When we transport them to the test area, they are transported in a container, the containers are according to this recommendation, should be of copper, brass or aluminum of continuous soldered, brazed, or welded construction, the lids should have a bare metal overlap of one inch or be provided with continuous finger stock brazed contact. We are actually constructing these things of aluminum and using them as per this configuration. In addition, we are requiring twisting and shielding of all of our leads again, as probably all of you know who have been to California, we can get large ground potential differences in an area that is semi-arid as the JPL is located. And so again we recommend that the shielding be grounded at one spot to prevent ground loops and currents being carried in the shielding. As I say these regulations are in a period of evolution, I hope that at the next meeting we will have more to report and be able to make some more definitive

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recommendations. There appears to be no doubt but that squibs will be with us for a long time to come, and that these in many cases will of necessity be very sensitive devices. The main use for squibs is to provide a large output of energy for the small input. It is essentially an amplifier and so therefore, in many space applications which of course is the present large mission of the laboratory, we find that we are severely limited in the amount of weight that we can carry and that we are having to perform complex functions such as I say the large number of squibs to merely unfold and erect a solar panel. These things have to be kept lively. We can not go to some of these other approaches which people are using to be 100% safe, we can not go to an approach as we did on the Sergeant. And so these problems will be with us for a long time to come and many applications, I was discussing the bridge wire, these kinds of things do appear to be safer but they do end up requiring in many cases more weight. Perhaps not in the initiator itself but in the power supply for it. So we are still conducting experiments, we are trying to determine how we can most effectively shield these things, what reasonable requirements are. Thank you very much. If there are any questions I'll try and answer them.

Mr. Nance: Do you have any instances of actual failure in the field?

Mr. Piasecki: In all of the operations which the JPL has had, we have never had an accidental ignition of a squib by RF. There are well documented cases where other people have had these problems.

Mr. Nance: Will your reports have reference to this documentation, I'm having some difficulty in finding it?

Mr. Piasecki: It's hard to get. I think the main reason for this and I think that many of the people in the audience will bear this out is that although the probability is high in some of these failures that the cause was RF, it's not conclusive. There are other things that could have happened, a spark or something and so it is hard to get. We will make an attempt to try and get as much of this as we can in the report.

Mr. Ullian: I'd like to comment since a lot of what you've talked about we have been involved in along with you and for the information of the people involved, I'm sure you know about it. As you stated in the first part of your talk, this is a real problem with a range such as White Sands, Cape Canaveral, BMR, Point Mugu on this RF problem because as you so well pointed out, when we have to cut off all our RF sources for 2 or 3 or 4 miles around and create a silence period during this ordnance hook-up and installation, we have a numerous amount of other tests going on at the same time on other programs and there's only 24 hours in each day and we work around the clock as it is. So that every time we have to cut off one of our radiating sources, we normally knock out another test and this means we lose this many man hours and work hours that could be valuably used to complete tests. It also means in many cases that some of the data that we want to get back from the tests that we're actually protecting we can not get because we have had to cut off our telemetry equipment and various data receiving and supply

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and sources. So this RF problem, although it may seem a sidelight in some cases, the ranges involved and the people trying to get the data is probably one of the biggest headaches presently on the ranges. One comment I would like to make that we at the Center feel should be approached and has not been looked into as much as it should have been is the possibility of using less sensitive squibs. If you take a look at our sources, I'm thinking particularly of the Cape, of radiation, in many cases if we go from a squib with a max no-fire of maybe .5 up to one of no-fire of 2 amps or 1 amp, we get away from this RF problem. We can leave our sources on and not have to worry about them, even the sources on the birds themselves, the antennas closed in tests we run on the birds. And this I don't think really increases our weight in any degree of magnitude except possibly in our space probes and there are many applications as you've pointed out that I think we can go to bridge wire circuits and also use less sensitive squibs. It seems that the programmers look around and find the most sensitive squib that they can possibly get and try to use these and I sometimes wonder why.

Mr. Piasecki: I think I can perhaps answer why. The development program involved in the use of these things sometimes spans a period of years and we are recommending for all new applications that they go to a squib with no fire current as an amp or greater. I agree with you wholeheartedly that where these are available at the beginning of a development in the proper configuration, they are being used. Unfortunately there are a few of these around but not enough high minimum firing current items to answer all of the requirements and so some of the developments which have to be started earlier started using the components which were on the shelf and I think that you will see a definite trend in the future in this direction.

Mr. Gus Economy, OOAMA, Hill AFB: We are attempting to establish a project now with the Air Force of investigating RF hazards through electrically initiated items. We have run into some similar problems as you have, we have found out definitely one thing, that go no-go tests are not very reliable. We found out that after you put the squib or the igniter in a tactical configuration, then the missile becomes an antenna itself. We also find out that the Mk. 1 squib on a 2.75" rocket is very sensitive and we have put a limitation of approximately 100 feet to the, I forget which radar set it is, but there is a restriction on it. The Navy is conducting tests on it in Project Hero and they're making very good progress in it.

Mr. Piasecki: The real problem is that this is a statistical thing, there's no question but that in many things which are flying today the antenna gain is sufficient and these things are placed in a field sufficient so that power is available in the firing circuit to fire the squib. The only thing that saves us as we stated is the fact that you have a pretty lousy impedence between the antenna and the squib device itself. And this tends to be a kind of statistical problem. To these RF frequencies for instance, you can tune, and we have done this at the Cape incidentally, you can tune and increase the amount of power which the harness receives by a factor of 5. Merely by approaching it with your hand, without even touching it and touching it or moving it in any way, changes the antenna, therefore it changes the possibility of an impedence coupling. It's a real sticky problem. There's no question about that.

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Capt. Kroshay, ARGMA: In your experiments have you been able to determine what band of a frequency spectrum is possibly causing us the most trouble?

Mr. Piasecki: No, I don't think we have looked at this at all. It would appear that the high frequency could cause you more trouble from one standpoint because of the leaks, you could tell from the equation though the low frequencies have the larger effective capture area. There is something that saves you in that it is a very high frequency where it is very difficult to shield. We're having trouble requiring high transmitting power levels, so the answer is no.

Capt. Kroshay: Have your shields that you have been utilizing with the Sergeant been effective throughout the spectrum band?

Mr. Piasecki: It's been effective to the extent that we have never had a mishap as I stated earlier, but this doesn't really prove anything.

Mr. P. V. King, Aberdeen Proving Ground: We had a little experience with this problem, I guess about ten years ago and in answer to the question that was raised before, in our own field experience we had a condition where firing lines in the field got so hot as to cause burns on the fingers of people connecting them up. This was in spite of a strenuous campaign of publicity as to this as a source of hazard and the condition was a result of the use by a field group of a 50 watt mobile transmitter mounted on a jeep, 38 megacycle band I believe and when they broke radio silence to announce to people at various locations that they were about to fire, they induced enough current in the firing line to cause them to overheat and actually cause minor burns. This is one that was reported to us so we had a very near thing. We made a few rough tests with this sort of set-up and it developed that between 50 and 150 yards with the jeep roaming around aimlessly, we could generate these currents. We had done a lot of work before this and developed nomographs which considered frequency as well as radiated power because as you mentioned calculations for example with a broadcast band, radio station, for example WBAL Baltimore is dangerous theoretically for seven miles. So frequency is a consideration, I just wanted to add this, that you should not overlook your little mobile transmitters because these can cause you trouble.

Mr. Piasecki: We placed a severe limitation at White Sands on the mobile transmitters.

Dr. Johnson: Are you familiar with the work that the AEC has done in this field?

Mr. Piasecki: No I'm sorry I have not.

Dr. Johnson: This has been of prime consideration with them and they've had a big program on it. I suggest you get in touch with Dr. John Currey at Livermore as a point of contact, but you'll need S-RD clearance. Secondly, do you have contact with the people in the Navy on Project Hero?

Mr. Piasecki: Yes, I've read one or two of their reports and have the rest on request.

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Dr. Johnson: I think in the back literature of that project the accidents are documented, I know of one personally that I was near when it happened. A lot of this originates with the fuze people of course. A man doing fuze research had one go off in his hand and it was found to be induced current from the flourescent light fixtures in the ceiling about six feet away. It was an ND24 detonator.

Mr. Graham: I'm glad this gentleman added some of those examples because I have a whole file full of them in case this gentleman from Thiokol would like to look at them sometime. I might also indicate that as a lot of you have known that have been interested in this particular problem for some time, there have been numerable examples of photoflash bulbs including two warehouses full of them going off by radar. But to philosophize for a moment, I'm just wondering, all of us tend to go along and get amazed by the latest technological developments such as electronics. I frankly think the next thing we're going to do is transistorize some of these squibs if we can. But why can't we go back to a good mechanical type of ignition system which you are tending to approach in the Sergeant but of course you had a squib or igniter in there too. I think you had one, didn't you?

Mr. Piasecki: No, the final prototype Sergeant will be purely mechanical with a big 550 watt solenoid, there are no squibs.

Mr. Graham: It will be but I think the one you had on the screen had an igniter in it didn't it? In any event if you picture something just to make the point of like an alarm clock and set it and when the alarm clock goes off, the hammer comes down and strikes a match or something of some similar ridiculous point, but it would be purely mechanical. The only thing I'm afraid of is that somebody in turn would promptly put another igniter or squib in that chain someplace. But I think the real answer to this is to stop trying to make all these systems so very very fancy and go back maybe 20 years and put a nice mechanical type ignition system in these things.

Mr. Piasecki: This approach in many cases I think would be a good one, I think as we all recognize in the space program now and for some time to come till we have very large launch vehicles, weight is going to be premium and it's hard to visualize an initiating device that could compete in weight with some of these very small squibs which require very low power and so they're very attractive.

Mr. Graham: May I call your attention to the fact that they also have an alarm clock in wrist watches?

Mr. L. J. Chelko, NASA: I don't know whether you're aware of the fact that we have one section that is doing some work on ignition of solid propellants with hypergolic fluid. This is being done at altitude conditions as well.

Mr. Piasecki: I wasn't aware that you were doing the work, it has been proposed before. There you have a little of a problem that they talked about yesterday incapsulating materials - - - - - -

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Col Hamilton: Any other comments? Thank you Mr. Piasecki. The next item is a tour briefing by Mr. Henry Dyer of the Army Ordnance Missile Command.

Mr. H. C. Dyer, OAMC: I'm sorry we're not going to get to make our tour as broad as we had planned but due to the length of some discussions we had to knock out part of it. That part is the tour of the Thiokol area. We do appreciate though the invitation by Thiokol to tour their facilities. We are going to tour safety and propellant operations. After we see this we will load the buses and go to the NASA test area, the Marshal Flight Center, to see a Saturn engine cluster with the 8 engines. They're all supposed to be in place this afternoon. They will not do a test firing. After this we will go to Range 5 and at this range we will see where we had one of our big explosions on the arsenal last September. We had a work horse motor blow up and here the guides will show you one just exactly like the one that blew up and what's left of it now. While we're in these areas I'd appreciate it if you would all stay together and there will be a guide supplied by the Marshal Flight Center and Range 5 personnel to answer your questions and to brief you on their operations. Since time is going to be limited and we have a long distance to travel, it would also be appreciated if you would keep your questions down to the absolute minimum unless you absolutely have a need-to-know or you absolutely have to have the information yourself because we could get tied up all afternoon in one place. We don't plan to come back here this afternoon. Since the Marshal Flight Center is a different security organization than the Army, I will give you a tablet and I'd appreciate it if you would sign your name and the organization you are with. Also you can't take matches or lighters out when you depart from the bus, so will you leave them with the bus driver, or in your seat in the bus. Just please stay together and I think the tour will go off very successfully. Mr. Jack Niel of Thiokol would like to say a word or two about the film.

Mr. Jack Niel, Thiokol Chemical Corp: Thank you Mr. Dyer. Gentlemen, we are sorry that you're not going to be able to tour our facilities this afternoon. Some of you have not had the opportunity to be with us, I hope the next time that you're here you will come over and see us and we'll give you the personal tour rather than the 50-cent bus tour that we had planned for you this afternoon. I think somewhere we've gotten our wires crossed again, Mr. Dyer, this is not a safety film. This is a film that has been made for the Corporation called "Packaging Rocket Power." It's an overall corporate film and does not deal primarily with the Redstone Division. Redstone Divn. as most of you know started here in 1949 with 33 people in 3 buildings, it now encompasses 900 acres, 234 buildings, well, 233 after yesterday, and we have more than 1600 employees. I'm not going into any more of the operation because I think the film will be far more interesting and you are pressed for time. I'd like to repeat the invitation, the next time you are down in this area, we'd like to have you call on us.

Col. Hamilton: Good morning. As a carryover from yesterday, the first item on the agenda will be 'firing test cell design and high temperature testing' by Dr. Burket.

Dr. Burket: Gentlemen, the subject I'm talking about today is one that's more or less unique. It describes how we met the problem of testing solid propellants in the range of 300 to 500°F.; conducting storage tests, mechanical property measurements and firing of motors at temperatures from 300 to 500°F. This moves propellants up into a degree of hazard which is somewhat larger than that which we normally consider when dealing with solid composite propellants. Approximately 1,000 samples were tested and 100 motors fired in this temperature range without any damage to test facilities that we didn't expect to be damaged, and with no personnel injuries whatsoever. I'd like to start out with a presentation of the facility that we used for our test, a concrete block facility, with four bays, two on each side with a working space in between. The first slide please - each of the two bays contains two relatively inexpensive circotherm ovens; in between in the work area are the controls for the ovens and also the temperature recorders. The next slide shows the corner of the work area; the window leads directly into the test bay so it is possible to observe what is going on. The recorders are 16 point recorders, recording every 2½ seconds, so that a continuous record of the temperature was maintained for stowage tests. The procedure before conducting any mechanical property measurement tests on propellants at these high temperatures was to stow one-inch cubes for 6 hours at 300°F. If the propellant withstood this without too much difficulty, then the testing was carried further with two-inch cubes and finally with three-inch diameter grains. If the propellant passed this test with no significant weight loss, that is to say, less than 1% weight loss in 6 hours with no significant visual damage, then mechanical property testing and motor firing followed. Samples were placed in the oven by hand, and when the time came to take the samples out, the oven door was opened remotely, the electricity was turned off, and when the thermo-couple which was imbedded in the propellant sample registered 175° or 200°F., it was judged safe to go around and remove the cubes. The next slide shows the oven open with the stowage samples in place, a maximum of eight one-inch cubes was permitted in the oven at one time. They were placed in these cans, which are certainly familiar to those of you who have conducted surveillance tests with double base propellant. You see the thermo-couple leads going back out of the oven leading to the recorder. The latches on the doors were set in the usual way to open with light pressure, 5 ounces was the pressure determined. In some instances when a blow occurred, the oven doors failed to open and in that instance the sandbags around the edge absorbed the damage and there was at no time any danger to personnel. The next slide shows the oven with one of the large three-inch grains in position; these were wrapped, incidentally, in aluminum foil to simulate motor conditions. It had been found in the past that samples which are stored without some kind of wrapping or sealing do not show the same aging properties as samples which are carefully wrapped so as to prevent access by air. Thus when we are attempting to simulate motor aging, or motor storage conditions, we do wrap the samples carefully to exclude air. Only one of these was permitted in an oven at a time. The next slide shows the Instron set-up; this is the high temperature conditioning box for the Instron machine, which was used to measure the mechanical properties of the propellants at high temperature. This is a model TM instron tester. The asbestos plug here was instituted as a safety feature in place of the normally heavy plug which is located in this position. Because of the screening which was conducted on the propellants before testing on the Instron machine, there were no malfunctions of any kind during mechanical property testing. All malfunctions which did take place occurred in the stowage test or in the motor firing test. In the next slide, we see the control area for the Instron machine; this area is separated from the machine itself by a simple partition. Since the instron samples are not very large and since they were encased in the conditioning oven, it was not expected that there would be any major problem if there should be a malfunction. The operator remains in the control area during the testing of the specimen and no one is in the Instron machine area while the test specimen is at the elevated temperature. The next slide shows the interior of the conditioning oven, you see the test sample in position, here is the asbestos cloth plug, it's actually a very simple arrangement. The test samples were removed when the temperature dropped to 210° F. or lower. In general this was regarded, with the types of materials we were working with, as not an unsafe temperature. The next slide shows the close-up of the mirror which was used to observe it. The operator was not permitted to enter the test bay when the specimen was above 210°, manual loading and unloading of the specimen holders is accomplished only when the propellant is 210° or below. The operator wears a face flame shield, a flameproof laboratory coat, asbestos protective gloves and uses long tongs for removal of the specimen. Approximately 1,000 samples have been tested in this with no malfunction whatsoever. The next shows the high temperature motor test facilities; this is the thrust stand, you see it is a flexure type stand, the thrust cell here, the controls run about 50 feet through this earthen embankment to the control room. You can see the typical Sacramento gold tailings. In the early stages of the testing when tests were being conducted at only 300 to 400° F., there was no other protection than shown here. When tests were made at higher temperatures, a cage was introduced which we will see later on. This motor which is shown in position here contains about 15 lbs. of propellant. The stand was also adapted to accommodate a somewhat larger motor as shown on the next slide. This is a Falcon size motor, also fired at the high temperatures. This motor was fired for pressure only; however, other motors were fired with measurement of thrust. The steel wire cables shown here to fasten the motor down were included as an extra safety feature. The motor is shown in the oven. The motor was brought to temperature in a clamshell type oven, which is shown in the next slide, closed. This is the oven. The ends are sealed with glass cloth. The motor is brought to temperature before firing, i.e., it is brought to a propellant temperature, whatever the test temperature might be. The oven is capable of reaching temperatures as high as 700° F. In the initial tests there was no shield between the calrod unit and the motor, and the 700° temperature reached by the calrod units turned out to be a little high. After a premature ignition we introduced a steel shield between the motor and the calrod unit. The next slide shows a 15-pound motor positioned inside the oven after a premature ignition. You see the relatively small damage that is done to these ovens; they are really quite inexpensive and very easy to use, and seem to be quite effective. The blast cage, which we see in the next slide, was used to prevent the throwing of shrapnel in higher temperature firings. Here it is shown after a blow; you see how the cage bulges on the side. You see the remains of the oven here. This was not a simple premature ignition, this was an actual blow. The blast cage is constructed by simply spot welding ¼" standard wire mesh carbon steel with a channel iron frame; it's satisfactory for a low order detonation, but certainly not for a high order detonation. Large pieces of shrapnel don't go through but are contained by the cage. This completes the description of the test facility. Are there any questions?

Mr. King: In your testing of these propellants, you mentioned temperatures I think up to 500°F. How close was this to your auto-ignition temperature of the mix, have you any idea?

Dr. Burket: Well, when you start talking about auto-ignition temperatures, of course, the one that is usually quoted is the instantaneous auto-ignition temperature. The motors that were fired at 500°F. were potassium perchlorate propellant, the auto-ignition temperature would be somewhere around 700°F. Ammonium perchlorate motors have been fired, however, at temperatures as high as 400°F., which is within about 100° of the auto-ignition temperature as normally measured. Ammonium perchlorate propellants in general, unless the ammonium perchlorate has been stabilized in some way, will auto-ignite on long term storage at about 360°F., so that a 400° firing is really above the safe temperature for long term storage.

Dr. Barr: Did you also condition your igniter?

Dr. Burket: We developed a special igniter for this which was tested at temperatures up to 500°F. Since the personnel are not permitted out in the firing bay during the period of conditioning, the igniter must have been conditioned.

Dr. Barr: Is this being reported?

Dr. Burket: Yes, it is reported under an Air Force contract sponsored by the Air Force Flight Test Center.

Col. Hamilton: Thank you, Dr. Burket. The next item on the agenda, 'water injection to extinguish solid propellant fires.' This will be presented by Mr. S. H. McElroy of the NWL Dahlgren instead of Mr. Cascio who was originally scheduled.

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Mr. S. H. McElroy, Naval Weapons Laboratory, Dahlgren, Va.: Water injection systems are now being installed aboard the Navy's missile ships to extinguish solid propellant fires - fires in the form of accidental missile motor ignitions. The purpose of this paper is to review the merits of these systems and discuss the current developmental status. Before discussing water injection, however, I would like to mention that the Navy's primary developmental efforts with water injection are now centered at the Naval Weapons Laboratory. The Naval Weapons Laboratory, which was formerly known as the Naval Proving Ground, is a Navy, Bureau of Weapon's field activity. It is located on the Virginia banks of the Potomac River, about 55 miles southeast of Washington, D. C. One of the current functions of the Naval Weapons Laboratory is to evaluate the equipment and procedures used in handling and stowing missiles aboard ships to determine if potential hazards exist to personnel or ship's structure and equipment. In addition, Naval Weapons Laboratory is expected to develop and evaluate safety systems for the control of potential hazards. Of primary concern, to date, has been the problem of accidental motor ignition during missile stowage and handling prior to launch. The primary hazard presented by accidental motor ignition in a magazine is that propellants and explosive components of the affected missile and of adjacent missiles are in jeopardy. "Chain" ignitions of these components could result in loss of life and the ship. For convenience, accidental ignitions of motors have been divided into two groups: a. "Non-rupture" ignitions - These are characterized by the fact that the motor case remains intact during burning and the exhaust gases vent through designed (nozzle and igniter) vent openings. Burning may be propulsive or non-propulsive, depending upon the make-up of the missile (i.e., propulsive normally if the igniter is set to remain in the case during burning and non-propulsive if the igniter is free to blow out and thus allow gases to vent through the igniter opening as well as the nozzle. Motor pressure for a given missile, of course, is normally lower during non-propulsive burnings than during propulsive). Some foreseeable causes of non-rupture ignitions are firing of the igniter, perhaps by electromagnetic radiation or during a check-out or warm-up period, flame impingement on the grain from a fire external to the motor, and vibration of a cracked grain. b. "Rupture" ignitions - These are characterized by a rupture of the motor case permitting the propellant to burn either in the case at a substantially reduced pressure, or outside of the normal case confines. Little of the exhaust gases after rupture are vented through nozzle or igniter openings. Rupture ignitions have been so termed because it is felt that impact of the motor by a fragment would be the probable cause of the ignition and the case rupture; however, it is conceivable that case failure could also occur with other causes of ignition (inadvertent electrical ignition of a motor having a defective case or a cracked grain, cook-off of a motor grain by heat transfer through the case, etc.) Safety systems have been developed, or are being developed, to effectively control either non-rupture or rupture ignitions in a magazine and thus prevent chain ignitions. Water injection is one of these. Systems showing promise for non-rupture ignitions are: Plenum chambers with ducting, to carry off exhaust gases; sprinkler systems and venting to reduce environmental temperature and pressure; and baffling, nozzle closures and igniter covers to shield sensitive

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components from flame impingement. These various systems are represented schematically in the following slide. (Slide No. 1). Systems showing promise for rupture ignitions include the systems for electrical ignitions plus water injection. These are also represented in the slide. It should be mentioned that water injection is also of value for non-rupture ignitions where motors are stowed non-propulsively. Water injection, under current concept, is a means of applying water to the burning propellant of a motor, through the nozzle opening of the motor. Burning is diminished, or extinguished, through cooling of the propellant, rather than by smothering, or excluding oxygen. Relatively large quantities of water are needed to be effective, particularly in view of the inefficiencies in applying water to the entire burning area of the grain. A water injection system should meet the following requirements: (1) the supply of water must be adequate, (2) initial application of the water must be in terms of milliseconds, (3) the water must be injected at pressures higher than the prevailing motor pressure (for this reason, water injection is not practical for non-rupture ignitions), and (4) the system must be compatible with the grain configuration, the magazine and the motor hardware. Such factors as the number, size and spacing of grain perforations, the characteristics of seals in the motor nozzle, the diameter of the motor nozzle, the response time and capacity of the water supply system and the anticipated motor pressure during burning must all be considered. How extensive is the employment of water injection? Water injection has been considered by the Navy for the Tartar, Terrier, Talos and Polaris missiles. Tests have been performed at NWL with the Tarter, Terrier and Talos missiles. Water injection is considered practical for the Tartar motor (booster-sustainer) and the Terrier booster and systems for these are installed or are being installed aboard missile ships. Water injection of Tartar only will be considered in the remainder of this paper, primarily because of recent developments in the Tartar injection program. Early Tartar system efforts were conducted on open stands with the double base, dual thrust booster-sustainer grain manufactured by Allegheny Ballistics Laboratory. Various injection pressures, flow rates, and injection delay times were tried until it was determined that 180 gallons of water per minute, injected at a pressure range of 70 psi to 200 psi, represented suitable conditions for a shipboard system. In addition to establishing the values for a Tartar system, these tests indicated that the time required to control burning could be reduced if the water could be cycled, that is turned off for short periods of time on a repetitive, programmed basis. Tests indicated cycles of 30 seconds water on and 5 seconds of water off to be advantageous. On the basis of these tests cycling equipment was developed. One possible explanation for the benefit of cycling is the "leafing" theory. Proponents of this theory believe that the burning of propellant, under application of water, may progress in a manner that permits small pockets or appendages of burning area (similar to leaves) to develop, as shown in the following slide (Slide No. 2). The water-off time during cycling permits these pockets to burn through to the main area of the burning, whereupon water will be effective during the next on period. This is also indicated in the slide. Water injection is now being evaluated in a simulated shipboard magazine for the Mk 11 Tartar system. It will soon be evaluated in a simulated magazine for a second system, the Mk 13 Tartar system. These Tartar systems are to be installed in DDG and DLG destroyer class ships. The Mk 11 system magazine may be seen in the following slide (Slide No. 3).

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The magazine contains cells for the vertical stowage of 42 Tartar missiles. The missiles are loaded into and removed from the cells from above by means of a chain hoist. Safety systems in the magazine include an overhead sprinkler system, magazine vents, a plenum chamber and a water injection system. Although the injection system is not shown in this slide, provision for the system may be seen. The Mk 13 system magazine is similar in appearance to the Mk 11, however 40 missiles are stowed in a cell structure that rotates within the magazine. The same safety systems are employed. In both magazines missiles are stowed in a propulsive condition. They are complete with all propellant and explosive components including warheads. Approximately one-half of the magazine in each system is exposed above the ship's deck structure, consequently missiles in the magazine are somewhat vulnerable to penetration by fragment from enemy action. However, it is foreseeable that motor ignitions could result from fires in the machinery compartment of the magazine, hydraulic fires in the cells, mechanical punctures of the motor cases (as for example by a broken hoist chain) and fires in compartments adjacent to the magazine. The current concept of a water injection system for the Mk 11 and Mk 13 system magazine is shown in the next slide (Slide No. 4). This system was developed jointly by the Bureau of Weapons, the Applied Physics Laboratory of Johns Hopkins University and the Naval Weapons Laboratory. The system consists of a water supply source (fire main from the ship's pumps), a check valve, an accumulator tank contained a pressurized volume of water, a manifold system terminating in riser pipes through the plenum chamber, and a detector under each motor nozzle. The function of the accumulator tank is to supply water during pump response and fire main delay (inertia) times. It has been calculated that combined response and delay times to reach maximum flow are in order of 2 seconds for the DDG-2 fire main system. The other components shown in the system in this slide, i.e. the pressure regulating valve, the flow meter, pressure gauges and alignment fixtures were installed for test purposes only. Note that the current concept does not include cycling equipment. During the course of magazine tests, it was determined that the advantages of cycling, in terms of the reduction in time to control the burning, did not off-set the complexity and anticipated expense of cycling control equipment. The heart of the water injection system is the detector. It is in detector design that some recent developments have occurred. The detector must be selective to the extent that it will respond only to the ignition of its respective motor. It must be relatively insensitive to mechanical shock, be uneffected by salt solutions and meet numerous other requirements. Four detection principles have been considered: Infrared response, interruption of a printed circuit on the inner face of the motor case, shock wave response and blast wave (gas flow) response. Although considerable data have been collected applicable to infra-red detection an infrared detector, as such, has not been evaluated. It was foreseen that such a system would be rather complex for service use. The printed-circuit-within-the-motor concept was never persued seriously because of foreseeable development difficulties, and because such a circuit per se might offer potential ignition hazards. Schock sensitive detectors were developed by APL/JHU and the Grinnell Corporation. They employed a diaphragm shock sensing element. Squibs were employed to actuate the valve unlocking linkages. These detectors operated satisfactorily but were somewhat more complex than required for Tartar stowage. In addition, the explosive squib presented certain hazards and maintenance was

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required for the battery supplies they contained. The detector which has been selected for the Mk 11 and Mk 13 systems is blast actuated and water pressure powered. It was developed by NWL and serves a three-fold purpose: (1) it senses that a motor has ignited, (2) it acts as a valve to permit water flow, and (3) it acts as a nozzle to direct the water into the motor through the motor nozzle. An assembled view of this detector is shown in the following slide (Slide No. 5). Note the compactness of this detector and the fact that it screws into the riser pipe. A cross-section is shown in the following slide (Slide No. 6). It operates as follows: After the detector is installed, water pressure is applied to the closure piston. O-rings seal the joint between the piston and the throat of the nozzle. The pressure causes the closure piston, in turn, to press each of the lock balls between the closure piston and its recess in the nozzle throat. The tapering surfaces of the recesses direct the lock balls in toward the center, but the lower end of the actuation piston prevents motion in this direction. When the actuation piston moves down under the force of the blast the lock balls are no longer restrained from moving inward. As the closure piston is forced upward by water pressure, the lock balls are cammed toward the center. This action releases the closure piston, the lock balls, and the actuation piston, all of which are expelled with the water. An exploded view of the detector is shown in the next slide (Slide No. 7). The normal response time for this detector is 3 to 4 milliseconds. This detector will actuate on blast pressures of 11 psi or above at water pressures of 200 psi. This detector is currently being production engineered by Puget Sound Naval Shipyard. To what extent has water injection for Tartar proven effective? Approximately 14 of the tests conducted to date in the simulated magazine are indicative of the effectiveness of water injection. Tests were conducted with the original ABL double base grain and with the current Aerojet Corporation ammonium perchlorate/polyurethane propellant. In each test one motor was intentionally ignited by firing a 20mm projectile into the motor to produce rupture ignition. A passive missile was positioned in an adjacent cell. The impacted and passive missiles were assembled with simulated warheads. Of the 6 tests in which water injection was not employed, chain ignition of the passive motor occurred in one test, and cook-off temperatures in one or two warheads developed in 5 tests. Only negligible quantities of the propellant of the active motor were recovered after each test. Of the 8 tests with water injection, no chain ignitions of the passive motor occurred. Average propellant recovery was 57%. A warhead cook-off temperature developed in only one test. This occurrence was traceable to an improper manufacturing technique of a small number of cases produced. Improved manufacturing techniques have subsequently eliminated the warhead hazard. The following films show, to a degree, the difference between an accidental motor ignition (rupture) in a magazine not equipped with water injection and in one equipped with a system. In the first film, note the sympathetic ignition of the second motor as evidenced by an increase in flame and smoke. Bear in mind that had live warheads been present, these would have detonated and destroyed the magazine and perhaps the ship. The second film is taken from an angle that shows the top of the magazine only. In this test burning of the impacted motor only occurs. Note how water injection controls the burning as evidenced by the limited flame and smoke. Neither warhead in

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this test was influenced adversely. Current efforts with the Tartar system are directed toward noting effects on non-rupture ignited propulsive motors. Although water injection is not expected to be beneficial for propulsive non-rupture ignitions, at the same time it must not have adverse effects. The injection riser and detector must not appreciably impede the flow of gases into the magazine plenum chamber. While water injection, in itself, is not a cure-all for all shipboard missile stowage hazards, still it must be recognized that water injection, together with other appropriate safety systems will do much toward making potentially dangerous conditions considerably safer. The employment of water injection with other related systems, represents another step in the evolutionary process of making missiles safer for our own personnel to employ while at the same time retaining their potency toward an enemy.

Mr. Endsley: Can you identify the report or document which gives your study and tests and analysis of this work?

Mr. McElroy: There have been quite a few, I can send you the list of reports. This is a continuing program and there have been reports put out over a period of two or three years on this work. Normally we group about three or four tests in one report.

Mr. Endsley: I have another question. Do you propose to follow this technique in your prepackaged liquid engines?

Mr. McElroy: I don't think water injection has been considered for packaged liquid engines. We have considered a baffling, magazine venting, magazine sprinkling, it might be that we will have to go to water injection. Water injection is not as a rule proposed unless other things fail because it does involve piping and it means that missiles have to be fixed or stowed in definite positions, etc.

Mr. Endsley: One other question. This relates to your failure of holding this particular missile in place. Have you advanced any theories as to the volume of grain burned in this case that might have caused this failure?

Mr. McElroy: The only theory we have on this, we for these tests, don't fire flight service for flight ready missiles. We fire rejected missiles and we think there was a possibility that we had an insulator failure, the throat insulator failed, and the throat insulator blocked the nozzle, caused a high motor pressure and that in turn caused the motor to rupture and since the throat insulator was probably out of place, it eroded around the base of the missile and as soon as the base of the missile came off, for a moment we had four or five times the normal thrust develop. We had what we considered four adequate systems for holding the missile, we were holding by shoes, by the lower shoes, by the upper shoes, we also had two bands around the missile that we thought would slice into the missile if it tried to get away and caused the motor to rupture, but they didn't work that way. We were also relying on the

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top of the magazine as a last resort to hold the missile but what happened was that we got a directional blast right up on the loading cover on the top of the magazine and that caused the loading cover to come off and then we had nothing after that to hold the missile. It's interesting to note that the two vents on the side of the magazine that were set for 10 psi didn't open during this test, even though we developed on the loading cover as high as 22 psi.

Mr. Endsley: Have you estimated at what velocity this valve comes out from that water source there? Do you have a problem of getting a detonation by the missile that you are throwing into the motor grain?

Mr. McElroy: This little actuation piston is fairly small, it is aluminum, we are considering perhaps in the future, plastic. I do not believe it impedes the flow of gases out of the nozzle. However, that was the purpose of this test, to find out, and as of right now, I cannot say. But we do not believe that this is any more serious than the normal nozzle closure moisture seal which is shipped with the missile.

Mr. Buxton: I have two questions. You mentioned the four systems of restraining that you had applied there and you said we had learned a lot about restraining in this malfunction. My first question is, what additional restraining are you using now? My second question is, is this water injection system to be applied to the Polaris?

Mr. McElroy: I would like to take your second question first. I do not know that I have the information to answer that. I have heard that water injection was considered for the Polaris. I do not know whether water injection is being used currently on Polaris or not. I have heard that someone has developed a water injection system for the Polaris igniter only, I do not know whether that is true or not. The Polaris is not considered to be as vulnerable to fragment impact as Tartar missiles would be because Tartar is stored partly abovedeck whereas your Polaris would be shielded from fragments. And I think they consider that electrical ignition or ignition by the igniter would be the only hazard and that is why, I hear, they have developed the water injection system. I do not know whether it's true or not, for the igniter. In answer to your first qeustion, we are not going to rely on the shoes only. The shoes for the most part are designed to take only the normal thrust of the motor, but in this case we developed we estimate at least four times the normal thrust. This can only be done for test purposes, however, we are going to put what we call a strong-back which is a brace that runs right through the center of the missile, right under the E section, between the E section and the warhead, and then that brace will be tied in to the cell structure of the magazine. This brace will allow the missile to move about $\frac{1}{2}$" before the brace takes up the force, we want the missile to move $\frac{1}{2}$" so we can see whether the shoes would have failed or not.

Mr. Buxton: Is this just for test or is this an operational thing?

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Mr. McElroy: This is just for test. As far as operational conditions are concerned, I think you could get what you saw here.

Col. Hamilton: Thank you very much Mr. McElroy. The next item will be by Mr. Gus Economy of the Ogden Air Materiel Area and he would like to ask some questions of the group rather than make a presentation.

Mr. Gus Economy, OOAMA: We have tried the epon resins, we have tried a compound called Deadcon which is 90% metal but still has a plastic base to it. Our present solution and not a very satisfactory solution as far as high temperatures are concerned after the actual firing is the plain old GI cloth back tape. It seems to hold the thermocouple on in intimate contact with the motor case at least thru the burning period where the case itself registers temperatures no higher than 250°, above that of course, apparently the adhesive on the tape ignites and the tape goes to pot. We have had some thermocouples register up to 400 degrees before they dropped off the motor casings. But this tape is very sticky and about 4 or 5 layers of it will hold the thermocouple on for a good period of time. It does work very satisfactorily in temperature conditioning tests from minus 65 to + 140 if applied under ambient conditions. The temperature conditioning can vary from 5 or 6 hours depending on actual mass of the unit up to 3 or 4 days and we have used this procedure I believe for accelerated aging tests.

Mr. Piasecki: We have used a condenser discharge method to tack weld thermocouples to .060 aluminum in the case of loki and to .022 in the case of the scaled Sergeant, these are .022 steel cases. These tack welds we have gotten away with and have never had an incident, we have always done this with the motor restrained in the pit. The current method which we use is to do a good job of welding of the cases prior to loading and we can get away with this of course because we install and load in our facilities. This is an advantage we have. The tack welding operation gives you a good contact for the other delicate installation that has to be very carefully protected against any kind of physical handling.

Dr. Johnson: We have a small company up in Westchester, Pa. that is doing research for us on encapsulation of exotic ingredients in aluminum capsules and they weld these shut with ultrasonic vibration which involves no heating whatsoever. They can weld aluminum, copper and several other metals this way very nicely. It involves being able to get at both front and back sides of the metal. This would probably require you to weld these on before the motor's loaded, I do not know. If you ever have to do any welding that involves no heating, this is the way to do it.

Col. Hamilton: The next item on the agenda will be "Storage and Handling Problems at Cape Canaveral" by Mr. Ullian.

Mr. L. J. Ullian: The Air Force Missile Test Center, as part of the Air Research and Development Command, has the responsibility for flight testing

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most of the large military missile systems and many of this country's space programs. As a result of this responsibility, most of the large solid propellant systems undergo their first flight testing in near operational environments at this Center. In many instances, no advance hazard classification or handling procedures have been obtained from either testing or experience. Many of the weapons programs develop handling procedures simultaneously with flight testing at AMR. The Center supports a mixture of programs, all of which hold high priority in this country's military or space programs. For this reason, it is necessary to insure adequate protection for all of these programs, even above that which would normally be afforded in an area where only one program was being developed. A list of the various programs supported at AFMTC may be appropriate to show the range and variety of handling problems and hazards involved in flight testing these different missile systems. In the liquid propellant field, the Center supports Atlas, Titan, Thor, Jupiter and Redstone missile programs plus many space booster adaptations of these missiles. In the solid propellant field the Center supports the Minuteman, Hets - 609A, Pershing, Polaris, and used many upper stage solid propellant space motors. Looking to the future, space launches will include requirements imposed by Saturn and Nova liquid type boosters and possibly multi-million pound solid propellant space boosters. Background. In the past, the types of hazards present in handling and launching of missiles at the Cape were those of fire from liquid propellant missiles with some chance of detonation hazards if a liquid oxygen gel had time to form. Most of the solid propellants used in various programs were relatively insensitive rubber base composite propellants incapable of sustaining a detonation under any but the most extreme circumstances. Some of the propellants such as those used in Polaris are of the composite type while others such as the Matador booster were cast double base propellants of relatively low sensitivity. The past is not with us today. At the present time one program is using new high energy solid propellants and, in the near future, most, if not all, of the large solid propellant missile systems at the Cape will incorporate high energy solid propellants in their programs. Minuteman, Polaris, Hets, and Pershing systems all have present or future plans to use high energy propellants. The minuteman missile will use a third stage Class 9 propellant that can be detonated by as little as a quarter-pound of TNT and the second stage has yielded 100% TNT equivalents in donor acceptor tests using 100# blocks of TNT. The first stage has not yet been tested but all indications point to a mass detonating sensitivity that is in the same range as that of the second stage. The Polaris missiles may utilize a modified double base composite in its second stage in the near future. It is similar to the Minuteman third stage which has already been classified as a Class 9 propellant. The Hets missile is presently using two high energy double base motors with over 70% by weight of NG ≠ NC, both of which have been detonated by a $\frac{1}{4}$ to 1 lb TNT range safety destruct system. It can be seen that the era of insensitive non-detonable propellant is past and that in the future, the solid propellants that we use will be more nearly like military high explosives with regard to the sensitivity and ability to detonate. This will pose, for AFMTC and other agencies concerned with the handling and use of

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propellants, some new and unprecedented handling and safety problems for which there are no established precedants. Some of these problems will increase the need for adequate and accurate sensitivity tests, realistic hazard classification, and studies of specific handling problems that occur in the use of large solid propellant motors. Problems. At this point I would like to present a movie which illustrates one type of hazard that is present during flight testing of missiles at the Center. This is a Juno II and this one really went haywire. This thing as you can see is starting to wobble now and dance all over the sky. This is a problem. The thing is coming right back down at us, toward the blockhouse. Now can you imagine if we had a detonation if destruct action was taken on that missile when it was about 20 ft. off the ground. In this case, since it was a liquid the main thing we got was fire, very little gel of the LOX and RP which we have to have before we get a detonation. Because of the mechanism involved, it takes time to form this gel, when the bird is in the air and you rupture the tank which is what we do with a liquid bird when we take destruct action. In this one you will not be able to see the bird rise too well. Now you can see a Jupiter wobbling all over the sky. We take destruct right here, there's the destruct action being taken. Now I'm afraid, the cameraman followed the fireball up instead of the tankäge down. In the next scene you will see what happens when LOX and RP get a chance to gel and you see coming across from left to right a real pretty shock wave when part of this tankage off this missile comes back down and hits over in this corner. What has happened evidently, is the LOX and RP in the tankage has had a chance to gel. It's the same missile, you can see it gyrating. Tankage will come down and detonate and we'll get a real pretty shock from it. This was a small amount and we did get a good sized crater about 4 ft. in dia. which was about 12" thick. This is the first time this move has been shown in the whole form outside Cape Canaveral. This Atlas Able didn't perform the way it was supposed to. We had about 20,000 lb. TNT equivalent in this one and put our launch stand out of commission on this one for about 8 months. This we did get a real blast from, one of the security police was standing outside the launch danger area about 3500 ft. and he was picked up and thrown 10 ft. back by the shock wave. That piece of metal you see flying weighed about a ton and landed about 1,000 ft. away. The launch pad which was 12" thick was completely caved in - the incident completely demolished our test stand. We did for some reason, probably because it's a drag type structure and not a solid front, leave most of our erector stand and umbilical standing. This is another Titan where destruct action was inadvertently taken because of vibration. Here we got somewhere in the neighborhood of 5,000 lbs. TNT equivalent, at the most, probably less. There are no solids in these missiles. We've had Polaris do some real odd things, we used to say when one of them takes off, everybody run for the hills because we weren't sure where it was going. I don't mean this as derogatory to the Navy because I was in the Navy, but they have pretty well ironed out their problems with Polaris and are getting real good shots with it now. But like every program in which there isn't any experience, when someone says it cannot happen, the missile proves that it can. Here's another Titan, same bird, different picture. I think this movie gives you some idea of some of the problems we have down there. We do have successful launches.

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You may wonder how these cameras get such good pictures when they're so overexposed. These cameras are explosion-set and they reduce the aperture, etc. so that they can take these pictures. We got about 5,000 equivalent on this one. This updraft creates such a vacuum down here that we blow open great big steel doors and buckle them. For example, these heavy doors that you put on high voltage control rooms and generator rooms, we buckle these, tear them off their hinges and everything else, just from a straight fire. This is an Atlas night shot and you'll see another of our problems. This thing goes up and is headed right back for the blockhouse when they take destruct action. Here we got a detonation too, LOX-RP. Again somewhere between 5,000 and 10,000 lbs., probably. You may ask except for the one shot where we did a tremendous amount of damage, normally our pads from this type of incident are not out of commission more than 3 or 4 months usually. This reason for this is, if we can take destruct action while the missile is in the air - now this one you can see coming on over towards the blockhouse - but you'll find that the higher off the pad we take destruct action, the less damage we do to our concrete. Of course we do do damage to some of our light fixtures once in awhile. On the other side we knocked all our telephone poles down. On this one you can see destruct action ripping open the tankage there, both the LOX and RP tanks, so we get burning which is what we're trying to do. We're trying to do two things, we're trying to neutralize thrust immediately and we're also trying to burn up propellant and oxidizer. This one is going to sit here and burn awhile. This is when we really have trouble with our liquids, if they get a chance to sit here and burn. The interface between the LOX and RP tanks is ruptured by pressure or fire and we get a chance to mix the RP and LOX and get a gel, then we're in trouble. In this particular one, evidently the fire was down at the base. We didn't erode evidently too quickly because we didn't get the same type of TNT equivalent that we got on the one you saw on the Atlas Able, where we did erode quite quickly because the flames were up in this area. We have blast gages placed around these pads to get blast information and any of you that have a need-to-know and an interest in blast gage information on liquid and solid propellant birds we may be able to help you out. As you have seen in the movie the incidents shown are dramatic, to say the least, but it should be remembered that the type of missiles shown in these films all use liquid propellants. When destruct action is taken with a liquid propellant missile, the first occurrance is fire and no detonation will occur unless the oxidizer and fuel are given sufficient time to mix and form a gel. Because of the mechanism involved and the time that must elapse, the maximum TNT equivalent that could normally be expected is in the range of 10-20% of the total propellant weight available. Since most of the liquid propellant missiles flight tested at the Cape have approximately 250,000 pounds of propellant aboard, at time of launch, the maximum of 20% TNT equivalent is equal to about 50,000 pounds of high explosives. You must remember that this is a maximum and that in none of the incidents shown was this figure obtained. In an average incident the TNT equivalent runs somewhere in the

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neighborhood of 10-15,000 pounds. You will notice that there are no pictures of solid propellant missiles in this movie. This is not to say that we have not had our incidents with solid propellant missiles, but since in the past the propellants involved were relatively insensitive, the incidents were not as spectacular as those involving liquid propellant missiles. I am afraid this will not be the case with the new high energy propellants. For example, the Minuteman missile has some 56,000 lbs. of propellant available at the time of launch for detonation. Roughly calculated, there will be something in the neighborhood of 1-2 seconds of normal first stage burning time during which the Cape will be exposed to the Minuteman missile. Only 1000 to 2000 lbs. of propellant will be burned up during this portion of the flight so that something over 50,000 lbs. of propellant will still be available for detonation. As was stated previously, the third stage of this missile reacts violently, in fact, detonates when a ½ lb. high explosive charge is used as a donor. The destruct charge as presently conceived is a 1 lb. charge of high explosives. You may also remember that in a test of the second stage engine, a 100 lb. block set on top of the motor detonated this motor. If we take destruct action on the third stage, there is a good chance that the detonation will be transmitted to second stage and possibly the first stage. If we don't take destruct action and let the missile impact, there are indications that we still may effect a detonation. This is one of the major problems facing the Center at the present time and I used Minuteman only as an example. All of our major solid propellant missiles as they utilize high energy propellants will cause us similar headaches. We must protect other missile programs, facilities, and personnel from blast damage and at all times protect inhabited land masses outside the Cape proper. The problem is how best to accomplish this and still achieve our objectives at the Center. Another problem that develops from the same consideration is that of an inadvertent propulsive flight of a solid propellant missile that has been ignited by fire, blast or fragments from another missile that has just been destroyed. In our siting and facilities design, we must now look into the problems associated with a detonation of a large missile at some height about the ground. In the past, the liquid propellant missiles that were destroyed while in flight normally did not detonate, but with the high energy solid propellant missiles, the indications point to some type of detonation, at least as frequently as fire. You may wonder why we don't do away with our destruct systems, if we did this, we would then subject land masses outside the Cape to impacts and this we cannot tolerate. Even if we did not take destruct action, some studies have indicated that on impact we may produce a low order detonation which can cause as much damage as one of high order. To give you an idea of some of our other problems, I would briefly like to mention these -- the fact that a solid propellant missile is at all times fueled and capable of propulsive flight creates many problems in handling, transportation and facilities design. We must at all times try to prevent inadvertent propulsive flight since we don't want these missiles taking off like a runaway steam boiler. The problem of live ordnance such as igniters and destruct charges on the missile at all times is becoming more acute -- this is analogous to a fuzed bomb with only a safety pin to keep it from arming. As you all

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know, in handling ammunition and explosives we try to stay away from this concept as much as possible by separating and segregating our high explosives and igniting and fuzing devices. I am afraid that in the missile field, particularly the solid field, some people have forgotten this concept of explosive safety. Many of the new solid propellant missiles are designed to incorporate the igniter and associated ordnance on the motor at the time of manufacture. A definite problem is that of quantity distance radius involving solid propellants. With the liquid propellant missile, all we had was a stove pipe with a lot of black boxes until late in the count, approximately one hour before launch, at which time fuel and oxidizer were pumped aboard. The solid propellant missiles are handled differently in that they are always fueled and loxed and while they are sitting on an exposed launch stand or in a building, a potential hazard is always present. Therefore, the matter of appropriate siting of other launch pads becomes a major problem since there is only so much real estate available. This real estate problem is becoming critical with the many additional missile programs that are being supported at the Cape. Another problem that we encounter during the launch countdown is that of electrical checkout of the ordnance items on the solid propellant missile. Again, with the liquid propellant missile, all ordnance checkout is done before fueling and loxing. Solid propellant missiles still use the same ordnance and still require the same electrical checkout of fuzes and igniters to acquire reliability but instead of an isolated incident if the item goes off while being checked out, we may have a major catastrophe in the form of a detonation or inadvertent flight of solid propellant missiles. The R-F problem at the Cape is acute. Most programs seem determined to find the most sensitive squibs available and put these in their missiles. With the vast amounts of R-F radiating equipment at the Cape, the R-F sensitivity problem causes a considerable amount of interference with tests and also considerable R-F hazards. Solid propellant missiles of the high energy variety definitely possess some real problems and cast some real hazards on other programs at the Center. Since in many cases the problems are complex and hard to define the solutions are also complex. One area that is the basis of many problems is that of realistic hazard classification of solid propellant motors, and, in our case, particularly in the R&D phase. These classifications must not be made for political expediency, reduction of costs or to sell a product, thereby lulling personnel into a false sense of security or developing an unwarranted fear. A false classification does not help any one but I am afraid that this has been done in the past. Solutions. In general, the solutions to our problems are at best those of reducing the hazards involved to an acceptable level. As with any other ordnance work, there is always a certain amount of risk that cannot be excluded. The Center must consider two things with regard to the taking of destruct action on a missile. First, we must protect inhabited land masses outside the Cape and, second, we must try to protect all the other launch facilities and support areas on the Cape. To achieve the first, we must take destruct action and also have stringent tracking controls and finite impact prediction. To accomplish the second task, we are presently engaged in a study to determine under what conditions we can take destruct action while

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the missile is over the Cape and without endangering personnel and facilities. This includes setting up parameters for height, altitude, azimuth, and location versus peak over pressure and reflected pressure. From this study, we hope to set up control guides and destruct areas where we may destruct the missile without endangering personnel and facilities at the Cape in case of a detonation. With regard to other missile systems we may require fragmentation mats to protect other solid and liquid propellant missiles from flying fragments or burning chunks of propellant from destruct action on missiles that may detonate. The problem of inadvertent propulsive flight with an incident involving a solid propellant missile can best be handled by one of two methods, either a hold down device that is designed to withstand the total thrust produced by a particular engine or a thrust neutralizing device. There are disadvantages to both systems. The hold down system is by nature very large and bulky and not easily transferred from one area to the other -- in fact, normally it is fixed within a missile assembly building or on a pad and cannot economically be moved from one area to another and must be considered a fixed installation. Thrust neutralizers have been developed in many forms. Some motors use blast bands, other utilize the igniter well, while others have developed a ripper or can opener fixture that cuts the motor open at first movement. These methods of neutralizing thrust have some disadvantages, particularly the can opener. The can opener principle may cause a deflagration or low order detonation of the motor and if this happens in a building this may be disastrous to personnel and equipment. The problem of having live ordnance installed on the missiles at all times is one that the designers must solve. Our solution at the Cape has been to reduce the number of solid propellant missiles that arrive at CCMTA with live ordnance aboard by impounding these missiles until such time that the ordnance is taken off. We realize that in some cases the concept of live ordnance is being developed to prove out an operational procedure, but we do not feel that a test center that has the number of programs that the Cape has should be exposed to this additional hazard, particularly since most of the programs involved are in the early development phase and no experience or precedent is available to judge the hazards involved. The matter of siting of the launch facilities is one problem we have not solved yet. One solution to this problem is realistic scheduling of missile launches which would protect missiles and personnel but would not necessarily protect facilities. To protect facilities with the existing real estate available, it may become necessary to use other than inhabited building distances in some cases and replace these distances by using potential TNT equivalents with the resultant pressure characteristics versus distances. The problem of checkout of ordnance items on a solid propellant missile is similar to electrical checkout of fuzed conventional ordnance and must be handled similarly, in remote areas with adequate personnel protection and, in case of solid propellant motors, with adequate hold downs or thrust neutralizers to prevent inadvertent propulsive flight. The solution to the R-F problem can take many forms. One is to shut down the sources of the radiation, but this causes intolerable interference with other tests. A simple and positive method would seem to be requiring the use of less sensitive squibs.Where weight is no problem an ideal solution may be found in EBW systems.

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Summary. In summary, Gentlemen, I would just like to say that although the new high energy solid propellant missiles impose safety and handling problems to the industry and Government, we feel, at the Cape, that these hazards can be reduced to acceptable levels consistent with the launch operations. We do feel that industry must cooperate in trying to develop realistic approaches to the problems at hand.

Mr. Endsley: First I'd like to pose a modified question and incorporate a plea. Some time ago we had considerable difficulty in getting the other Services to support us in getting blast data at the Cape. You can see how vital it is to our program because you have facilities at this base, you have a lot of priority on some of these systems and asking people who are in the business if they can support their Service in getting as much instrumentation at these pads so we'll know what the blast radii is going to be because we're going to have to compress to the minimum. We may have to modify structures, beef up the psi load, but we need some assistance from the other Services in recognizing that this is a joint effort and give us some help in pressure readings. I wanted to ask, are the other Services forwarding you blast readings now?

Mr. Ullian: The Center through BMD has set up the blast gage program and blast research program if you want to call it this, actually it's a fact-finding program at the Cape. The other Services and missile contractors are helping us to the extent of giving a spot to put the instrumentation in and also camera coverage, power sources, etc., but as far as the instrumentation itself with respect to the blast gages, the Center is furnishing this with BMD funds. I would like to mention that if there are any gentlemen here that have a need to know, we do have a considerable amount of information, some of it in the older work and in the older explosions we don't know how valid it is, but on our later ones say the last year, we have some pretty good data. If you contact our office down there, the Missile Safety Branch of the Range Safety Division, AFMTC, we'd be glad to help you in any way. We also have fairly comprehensive reports on all of our incidents and accidents down there. We do send a copy to the ASESB and if there's anyone else that can use and has a valid need to know, we'd be glad to send you copies of these.

Mr. L. M. Lineberry, PAA: We have been following this blast data for about a year and when you develop your rockets or your plans to put these in different programs and if you do any blast data at the site and static testing, etc., we'd very much like to have this prior to sending these rockets or component parts to the Cape if at all possible. You can send this to Mr. Ullian at AFMTC and we in turn will get it. It would help us in our planning for setting out blast gages and blast instrumentation around the different complexes.

Mr. Carleton: I would be interested to hear something about the reliability of these destruct systems. Have you any instances of failure to destruct.

[redacted]

Mr. Ullian: Yes, we have but I'm afraid in most cases, it's been human error. We did have one instance of a destruct system on a Jupiter, in fact, it's one of the ones you saw. On the destruct system, on these ten cent items, through vibration, it was the same thing that actually caused a missile to go out of control on a nozzle control unit. The same item, at the same time in the destruct system through vibration, vibrated right out of its socket. Again it was a partially human error in that it was not safely tied and the destruct system did not go. We had a Snark missile one time on which the destruct system climbed with the bird, they pushed the button 3 or 4 times, the bird was heading for West Palm or somewhere, and it did't go and landed about a mile off shore in the water, luckily. Three people that were in a position to know, supposedly, stated in the resultant investigation that they had all seen the "go" switch on the destruct system in the blockhouse in the on position and also that the "go" switch in the system in the bird was in the "go" position, which means, in other words, that it was activated. The divers about six months later pulled out the destruct system and sure enough the switch was tied in the off position. So, other than that, our destruct systems have been pretty reliable. There was one incident on this Titan missile where at lift-off the destruct action was initiated. This was reliability in the wrong sense I'm afraid in that it destroyed the missile in what may have been a good flight. They traced this again to a vibration problem in one of the components in the destruct system. All in all I think our destruct systems have saved, at least at the Cape, a lot of lives. We had one other incident here last week of a Titan heading for Complex 34 which is our Saturn complex and if they hadn't taken destruct action, I think we would have lost an awful lot of construction workers. The missile was in horizontal position 100 ft. off the ground headed right for the complex.

Dr. Ball: I have a couple of comments. One of them is that on thrust termination, those devices come to you mated to the motor and that's part of the system design. Inasmuch as destruct may be also an important part of this thing, I would suggest that the people who specify the system should have this brought to their attention and that a major destruct system should be mandatory on anything that gets down to you.

Mr. Ullian: I agree wholeheartedly. If we can develop destruct systems that don't inadvertently tend to detonate our missiles we're in a lot better shape.

Dr. Ball: I don't think you should have the responsibility of trying to develop a mated destruct system. You don't have the time to do it. That should have been done and tested before the thing ever gets to you.

Mr. Ullian: We don't develop the destruct systems Dr. Ball, these are developed by the company. Usually it's a combined effort between the associate motor contractor and the air frame or prime contractor. But as I said, the area of destruct systems would be something that would be real nice if we could live without, and so in some instances I'm afraid possibly the design effort has not gone into them that should have.

Dr. Ball: Another thing that occurs to me is that if you talk to somebody who's in the business of tactical terminal ballistics, he'll tell you the best way to kill people is to have an air burst. It is quite conceivable that your range safety officers should talk to some of these folks in the other business here, if they haven't already, and get proper instructions on when to use a destruct and when not to, as I'm sure there are occasions when a destruct could do more damage if pulled in the air than allowing the missile to hit the ground.

Mr. Ullian: Very definitely, as part of my speech, I mentioned that we are in the process right now of studying this very problem, whether it's safer and will do less damage to let the missile impact and take the possibility of deflagration or the possibility of lower detonation pressure rupture or this type of thing than to maybe 100 ft. off the ground take destruct action when we know there's maybe a 50-50 chance of getting high order detonation from the whole works. This is very definitely something that we are studying and trying to come up with some definite policy and guidelines and definite criteria to give our range safety officers so that they either do take destruct action or they let it go.

Mr. Harmon, NASA: You mentioned towards the end of your talk one system was considering application of EBW for destruct. Could you tell us more about that.

Mr. Ullian: Yes, Polaris is considering, in fact they have already come in with a proposal to the office for an EBW destruct system on their second stage. This is the new second stage and it looks like a real fine system. Weightwise, they're saving some weight, the system looks like it is at least as foolproof as the old mechanical electrical systems and it is a much more simplified system.

Mr. Harmon: Do you know when that will be phased in?

Mr. Ullian: From the looks of it right now, it will be in the A2 series which is probably six months to a year off I would guess.

Mr. Richardson: I'd like to inject one thing. You talk about your destruct systems and thrust termination. In most units you'll find that this is quite a large chunk of HE in some cases. We would like to inject people thinking about linear shaped charge. We found it quite reliable, the only problem you have is you have to protect it if its on the skin of the unit since it will degrade in flight if subjected to the flight temperatures going out of the atmosphere, that's particularly for space probes. Ensign Bickford is working on it and they hope to come up with an answer very shortly. You have to worry about this because it might thrust terminate somewhere you didn't want it to, and the other thing is that even if this thing went off inadvertently, the charge is so small that people could be in the immediate vicinity and nothing coudl happen to them.

Mr. Ullian: We would sure appreciate hearing about it. We talked to some of your people about some S&A mechanisms and we appreciate hearing about it or if anybody else that is working on LSCs or any type of destruct systems that we can get some sort of assurance that we won't get a detonation to set them off.

Mr. Richardson: This is particularly true in your new propellants because the critical diameters are getting quite small and with experience so far, even this material when penetrating the propellant does not burn it. You don't have a flame problem either at this point. What will happen in the future is beyond our knowledge at this point. But the critical diameter would have to be extremely small for this thing to detonate.

Mr. Bishoff: You stated that at times there was a 5,000 or a 10,000 lb. TNT equivalency, would you care to comment on why the test stand is not destroyed?

Mr. Ullian: It's not from the standpoint of destroyed, let's put it this way, in every case we can rebuild it, in other words, we just don't take a bulldozer and cover up the old test as a hole in the ground. The test stands are very substantially built and of course they're built to withstand various overpressures depending at the time of the design criteria, submitted to the Corps or whoever is going to build it, depending on some rough calculations and theoretical calculations on just what sort of TNT equivalence we can expect. We are tending to protect our launch facilities from this type of incident. For instance, on our Atlas pads or ramps, and underneath, our launcher is either a drag type structure or that which is a refractory type structure, and is usually anywhere from 18 inches to 3 or 4 feet of concrete. Because of this on this one pad where we did in effect complete it off the test stand on pad 12, we just punched everything out. We had the sides of the pad left standing but that was all, the whole top, which was in some cases 3 ft. thick, was just pushed directly into the earth, in some cases 5 or 6 ft. into the earth, and this was from a height of 20 ft., a hollow structure. In this case as I said the missile was just about on the deck when it went off. These movies are quite deceiving as to how high these missiles are aboveground. First of all they're standing at least as high as that Saturn you saw yesterday above the ground. They're anywhere from 20 to 25 ft. aboveground. Second, normally they have lifted some amount off the ground, in other words, maybe a missile length, half a missile length, two missile lengths. Also, where the destruct action is taken and where the detonation of the gel occurs, it may occur quite a ways up in the missile, so that in effect you may be 200 to 300 ft. above the ground at the point of detonation and of course this helps too because of the decrease in the pressure waves that is radiant in this area.

Col. Hamilton: Thank you Mr. Ullian. The next item, 'tests to determine hazard classification of motors larger than 17" in diameter' by Mr. S. H. Welch of OOAMA.

Mr. S. H. Welch, OOAMA: Gentlemen and lady. The problem I want to talk to you about is one that we at Ogden Air Materiel Area have encountered in establishing the explosive hazard classification of solid propellant rocket motors larger than 17 inches in diameter. I intend to present the problem to you and then invite your discussion on the subject. Before going into the problem, perhaps some of you are wondering where the limitation of 17 inches in diameter came from. In talking with Mr. Wayne Ursenbach of the Explosives Research Group at the University of Utah, who has made some studies on this subject, and in reviewing some of the studies that have been made, there appears to be a transition in the explosive characteristics of solid propellants. The diameter of motor at which this transition occurs varies greatly and is mainly determined by the propellant composition and the maximum web thickness. However, there seems to be a concentration of motors containing various propellants in which a change in explosive characteristics occurs between 17 and 19 inches in diameter. Another factor which probably has some relationship to the 17 inch limitation is the fact that motors larger than this are a new commodity for which there is limited test data available. The problem I wish to talk about today may best be presented by asking three questions. First, what are the minimum test criteria for determining the hazard classification of large solid propellant rocket motors? Second, are data obtained from sub-scale motors valid? Third, what should the dimensions of the sub-scale motors be to provide valid data? I believe there is information available that would provide answers to these questions. The Department of Defense published a bulletin which outlines the minimum test criteria to assure uniform assignment of hazard classification to a given item by all agencies in each of the services. This bulletin is a coordinated publication and is identified as the Department of the Army Technical Bulletin 700-2, the Department of the Navy NAVORD Instruction 8020.8, or the Department of the Air Force Technical Order 11A-1-47. The test criteria outlined in this bulletin for determining hazard classification of rocket motors, shows that for motors smaller than 17 inches in diameter a total of eight full scale samples are needed. For motors larger than 17 inches in diameter the same criteria may be used except that scaled propellant grains may be used. Due to the high cost that would result if eight full size motors were used in the case of the large rocket motors, it becomes necessary to use scaled propellant grains provided the data obtained are reliable. On the basis of these considerations, the 2705th Airmunitions Wing at Ogden Air Materiel Area has undertaken a project to determine the minimum test criteria for solid propellant rocket motors larger than 17 inches in diameter and to determine whether or not it will be possible to use scaled motors and what size the scaled motors should be. The information obtained from this project will be presented for inclusion in the technical bulletin I referred to earlier. Our plan of attack on the problem will be to first review all the available data on this type of test and then if necessary conduct some tests on large rocket motors and on scaled samples. In the review of available data we would appreciate it if those of you who know of any reports on tests of this nature would give us information concerning how we can get copies of them. Also, any data on tests in which scaled samples were used may be of value in our evaluation. We have conducted explosive hazard classification tests on three large rocket motors. These were the X202D-1 and X226A-3 booster rocket motors for the Snark and the XM-51 booster rocket motor for the Bomarc. The diameter of the X202D-1 is 22 7/8 inches, the X226A-3 is 26 7/8 inches, and the XM-51 is 35 inches. In the tests conducted on the Snark boosters only full scale motors were used. A total of six X202D-1 and four X226A-3 motors were used. The tests that were conducted included the detonation of a Snark warhead when assembled in the tactical configuration, detonation of a 2¼ pound charge of composition C-3 placed against the grain of one of two rocket motors spaced 18 inches apart, detonation of ½ pound charge of composition C-3 placed against the grain of one of two motors spaced as they are on the tactical missile, detonation of one pound of composition C-3 placed against the outside of the motors case, impact sensitivity of the motor to 20MM projectile, and the effect of fire on the missile under tactical conditions. From the results of the tests the booster motors were assigned Class 2 for storage and handling and when assembled on the tactical missile. The tests on the booster for the Bomarc utilized one full scale rocket motor and four scaled motors. The dimensions of the scaled motors were as follows: A diameter equal to the diameter of a full sized motor and length equal to the diameter. The rocket motor itself had previously been classified Class 2 so our tests were to determine the classification of the motor when assembled to a tactical missile. Three of the scaled motors and the full scale motor were tested by detonating the warhead with the motor and warhead assembled in the tactical configuration. The fourth scaled motor with a warhead assembled in the tactical configuration was tested to determine the effects of fire on a missile. The effects of a warhead detonation on the three scaled motors were the same as on the full size motor. From out tests the motor assembled in the tactical configuration was assigned Class 2. We know that other tests have been run using scaled motors which used different ratios between the size of the full size and scaled units. Results of these tests will be helpful in our evaluation. If, after we review all the available data, we determine that additional tests are required, we will conduct tests on both full size and scaled motors. We will use scaled motors of various scale factors to determine what scaled size motors provide the most reliable data. For these tests, we propose to use motors which have been rejected due to defective hardware or minor defects in the propellant grain. We plan to conduct our tests using the procedure outlined in the Department of Defense bulletin for rocket motors less than 17 inches in diameter. These tests include detonation of 30 grams of tetryl against the grain of both confined and unconfined motors and the effect of fire on the motors. We will vary the amount of tetryl to determine what amount should be used. The results of these tests will determine whether or not other types of tests are required. This concludes my discussion and I suggest that we use any time that may be remaining for any comments and discussion you may have. Thank you.

<u>Mr. Herman</u>: Mr. Welch, we will attempt to get into some of these problems that you raised here in a presentation which I will give shortly, however, I would like to point out that I think it is a coincidence that this work

which the University of Utah is doing points up the fact that there is some change in the propellant when you get to these large motors. I will give during my presentation the reason that the 17" is given in this directive which you have. We can appreciate very much the problem on use of scale motors. Everyone is quite concerned with this and it is an area which we have been unable to find very much basic work being done on it. We would also be extremely interested in any problems of this type.

Mr. Welch: This is very good and I can appreciate from having been the project engineer for the tests on the Bomarc that we conducted out there, the need among the Services for a uniform procedure for testing rocket motors because as I mentioned, when we tested this, this bulletin hadn't been out and it means that everybody that runs hazard classification had to have their own procedures. I feel that in solving Mr. Ullian's problem that he presented, the best way to do it is for the Services and anybody else in industry who is involved in hazard classification of motors and propellants, to use uniform procedure so that whether we do it, or the Army or Navy, or one of the contractors, we'll all come up with the same classification on a given motor.

Mr. A. Gaylord, Aerojet-General Corp.: This problem of explosive classification of rocket motors is a very difficult and complex program. You mention using a small scale motor. We don't know what the correlation of small-scale test to large-scale tests are and this could lead to an unrealistic and perhaps unvalid results. We have been engaged in proposing explosive classification programs but we see that it is very difficult and we believe that what the approach should be is to perform tests specifically for the end items instead of having a standard test which you would apply to all missile systems. I think that what you would have to do is to evaluate the hazards to the specific systems. For instance, Polaris may have different hazards and requirements than Minuteman or Hawk or Bomarc or the other missiles.

Mr. Welch: I certainly agree with you that we don't know how valid the data will be for sub-scale motors and before we ever approved a procedure that would be incorporated in hazard classifying motors using sub-scale motors we will certainly evaluate all the data we can get from sub-scale motors and if it is valid then we'll include it, if not we'll insist on using the full-scale motors. This problem of critical diameter is one that has a lot of answers to be obtained on yet, I'm sure.

Mr. Jezek: I'd like to make a comment on this 30 grams of tetryl, it has been our experience that if you can't knock it off at 30 grams of tetryl, then it's not HE, because 30 grams of tetryl or any other HE is enough booster to kick it off.

Mr. Welch: That's my understanding from the present technical bulletin, if 30 grams won't set it off it isn't high enough explosive to be set off. We proposed changing this value and increasing to 50 grams or going to other values there to verify this. However, as I indicated, we will start off using the 30 grams.

Mr. Jezek: Another thing I'd like to point out on this TV 700-2, if you read it very carefully, you'll find out that we did not intend to use the criteria in that particular publication for tactical purposes. In other words, we didn't want to get into that part of the program. Somebody at that time when this thing was being formulated recommended that we do that. Due to the various complications that you could run into, we said that no, we'll confine this primarily to storage and secondarily for shipping purposes only.

Mr. Welch: This I understood, that 700-2 is only for bulk propellant and for the rocket motors unassembled to the missile items.

Mr. Jezek: No, not unassembled. If you have the completed bird with your HE warhead and your propellant, what we would like to know is how much contribution you would get from the propellant in the event the warhead was detonated. Ordinarily when you have an HE warhead on your bird, it's going to be a Class A item for ICC purposes and also Class 9-10 for storage purposes.

Mr. Welch: That's correct and our Bomarc tests indicated that the motor did not add to the HE of the warhead so that for siting purposes in the quantity-distance tables that were applied, the weight of the warhead only was considered as high explosive, inasmuch as our blast gages did not indicate any additional pressures resulting from the ignition motors.

Mr. Ullian: I have one comment along with Mr. Jezek's statement that may not have been made clear in my speech. Another problem in this mixing of Class 2 and Class 9 motors which is a similar problem to the one of warhead, except that the motors are normally less than the diameter apart, the diameter of the small motor. What can we do then? How much support do we get? Again this Minuteman problem, what sort of support do we get, I would like to see. For instance, the Minuteman may be extensive, but since there is no valid, it looks like scaling laws from sub-scale to full-scale. Using the Minuteman as an example, put the three stages together in the configuration, destruct the third stage and find out what does happen with the other stages, so that we do get some idea whether this thing is a big bomb. Maybe we only get 50% contribution from the first and second stages. What does happen when we mix these motors? Right now we are mixing them. In the new space birds, solid propellant ones and the tactical weapons systems we're developing, we are mixing Class 9 and 2 solid propellant motors. I think someone should start looking into some tests to determine what we are getting in the way of support from our Class 2.

Dr. Ball: As I look around this audience I seem to see a lot of people who are old enough to remember when people shot cannons, but my years tell me my eyes have been deceiving me. One thing that I wanted to comment on Mr. Ullian's talk and was chased off from was this business in hazard classification. He said something about people misclassifying stuff. I think people are misinterpreting the classification. The classifications were originally set up around gun propellants and a Class 2 item was something which under the expected exposures would not detonate but that doesn't mean at all that you cannot detonate a Class 2 item, you sure can. The same mistake cost us 50 people some years back and we have it firmly burned into us that a Class 2 item is not necessarily a non-detonating item. The classifications are set up around the anticipated exposures, the anticipated exposures may be changing but if so, then we should redefine our classification, but as of right now a Class 2 item is something that can be expected only to burn if it gets set fire to accidentally.

Mr. Ullian: I'd like to clarify my position. Dr. I agree with you wholeheartedly, but the problem is where the people in this auditorium and in the business understand this. The people, for instance, that budget for our funds and the people that we have to sell on protective design facilities if we do have a particular exposure that's different than a fire which in our particular case at the flight test range we do have. These are the people we have to convince and I'm afraid that all of us have been guilty of it and we tend both in trying to sell our products and also to try and sell weapons systems, to claim that Class 2 means fire only. In fact I can quote you some statements in the newspapers where an Admiral talked about the Polaris missile in this respect, if you can hammer on it you can set it off but set TNT next to it or do anything you want to it and all it will do is burn. I've had other people tell me this also. Unless we change our nomenclature and whether we call it Class 2 or Class 9, we have to educate these people so they realize that though we may call it Class 2 for storage and that under normal conditions, all it will do is burn, it is possible to get it to react more violently. Too many people, when you say Class 2, immediately think that all you can possibly get it to do under any circumstance is to burn. This to me is one of our problems.

Dr. Ball: I think it's a real important problem. The public certainly doesn't know what Class 2 means and I'm afraid that there may be some people in this room who haven't realized what Class 2 means. That's why I bring this up at this point instead of waiting for Mr. Herman to speak to you because I know some of you are going to get away.

Mr. Endsley: I'd like to endorse and support Dr. Ball's statement orginally, that some of the phenomenas of our enviornment has a direct effect upon the output of your system. The Air Force recognized this quite some time ago when we started getting large systems. We can no longer enjoy the luxury of saying when we put a Class 10 on a Class 2 item, the total product is a Class 10. This is readily apparent because of the mass of the propellants that we're putting aboard some of these systems. Now to resolve this problem, the development agencies, BMD is the monitor of these programs and the Hill AFB, Director of Airmunitions, had to analyze these systems on an individual basis and dependent upon the tactical enviornment. In a tactical environment is where we get the money in the ground, where we spend the money. We can enjoy the luxury if we have an ordnance depot and it's isolated and we have all of our structures built on 250,000 - 500,000 lbs., but when you get down next to a village and have to put a hole in the ground and you cannot buy all the county because of political reasons and money, you price yourself right out of the business. We have to design and we have to buy real estate based upon realistic classification and we would like to define the degree of classification to the amount of energy product at a certain distance on a blast pressure basis. We'll probably air this a little bit more as we get into Mr. Herman's statement, but you can readily see the Air Force has a big problem in our tactical situations, this is where we spend the money, we can afford luxury in our ordnance depot or R&D area or manufacturing area, but when we come to a tactical viewpoint, we have to be exacting and it has been delegated to responsible agencies to come out with this criteria.

Col. Hamilton: Any other comments or questions? This is a very important subject, there's quite a bit that's being done on it and we have three more talks on it. Thank you very much Mr. Welch. The next item 'Hazard Classification of End Items on the Basis of Test Criteria', Mr. Herman of the ASESB.

Mr. Herman: Gentlemen, I realize that everyone is quite interested in this problem of hazard classification and perhaps before I start I might give you just a little background on how this has been developing within the Board. For a number of years there was no standard classification procedures for ammunition and explosive items. Many items were classified on the basis of their similarity to other items. Most of the work was done with gun type ammunition, bombs, and things of this nature and when we got into the missile business we got into items that were different than we were used to working with and as a result the individual Services, and in many cases individual installations, were testing items using different methods. Quite frequently as you can very well see, we'd end up with the same item being used by several Services with a different classification. This caused a great deal of mix-up. The transportation people were all fouled up, the storage people didn't know who was right and the odd part of this is not the fact that there was a difference in cost, but one of the big items of expense was the fact that if an item was classified by one Service and since another Service had a different classification the remarking of the boxes cost tremendous amounts of money. Some of the boxes may be changed 3 or 4 times. Anyway we decided that the best thing for everyone concerned was to develop some type of minimum test criteria, not a test directive, but minimum tests, standardize these tests so that everyone would be using the same boosters, they would be performing the tests in the same general way. We realized that this was going to be quite an extensive problem to try to cover the entire field. So we attacked it on the basis of the existing problem at that time, we had a lot of items which we were using that were in our system but had never been properly classified. We attempted to develop a set of test criteria to meet this condition alone. We got into many variables, such as tactical configuration.

We decided that for the first go-round, we would cover the largest problem. This was transportation and storage. This work was being done about 2 or 2½ years ago, it was fairly simple until we got again into the missile program. When we got to this point, we had had a fair amount of experience in the smaller missile units, so this didn't present too big a problem. When we got into the large units, we didn't know exactly what we were going to do. We attempted to check with various people to get the information as to what had been done and how we could run these tests. One of the big items that entered into this of course was cost of the items to be tested. We had no basis for scale testing, we didn't know just how this would work out. Right around this time when we were doing this, some of the tests that were being conducted at NOTS China Lake, the so-called Beauregard tests on Polaris propellants, the tests that were mentioned this morning, that were run by the Air Force on the Snark and some of the other missiles was about the only information we had. We didn't know just how to handle these larger units, so an arbitrary figure was selected and this was purely arbitrary, 17". We felt these units below this size were cheap enough that we could afford to run a number of tests, etc. But the cost of the units much larger than this was so tremendous that we couldn't say, well you're going to have to make as many units for our tests as you're going to use in your program. So we made the recommendation that if you possibly could, following the same tests on these larger units, but if you couldn't do this, try to find out what you could do on a scale basis. As I said, this document was put out on the basis of trying to cover the items which we had in use. This made Mr. Ullian's job and many others very difficult because no tests were conducted on these items until you got to the end item. In the meantime, he had them coming through his gates with no information on them. So, following this, we are now in the process of trying to develop a set of test criteria for solid propellants during the research and development stage. We have members from each of the military departments, the ICC, Bureau of Explosives, NASA, on this group trying to work this up. So we wanted to get at first the basic problem solved. One of the requirements we have is that any new propellant which is developed, samples must be sent to the Bureau of Explosives for test. This is required in your ICC regulations. Dr. McKenna sitting up there at Perth Amboy had all these samples coming in before he knew it and there will be more in the near future, it became a major problem running these tests. In the meantime, this item has to sit at the manufacturer's facility and cannot be moved until you get some clearance to move it. So the first thing that we're trying to develop is a set of criteria which could be run on this raw propellant when it's first developed. The primary purpose of these tests is to meet the ICC requirements and, essentially, you are trying to determine whether this propellant is a prohibited propellant or not. The way we intend to do this is, there will be a set of criteria furnished, the test must be conducted in a specific order and in a certain way and there will be a form to be filled out by the people running these tests. A copy of this form will be sent to the Services concerned and to the Bureau of Explosives. From this information a tentative ICC classification can be assigned. This still does not relieve the requirement that samples must be sent to the Bureau of Explosives. This still must be done but you have gotten your material released so you can start working. At least you know that you're not working with something that in not prohibited from transportation. This is only on the basic propellant. Once you get this clearance, then you can load the motor. Perhaps you have changed the classification, we don't know. So, how are we going to ship it. We're no longer shipping bulk, we're not concerned with bulk, we have a finished cased item. In many cases, facilities are not available within the contractor's facility to run any further tests on cased items. So we run into another snag. We are making a proposal to the ICC that if land and space facilities are not available to run additional tests on this cased item, primarily this will be a bonfire test, if these tests can be conducted then you can get a tentative ICC classification on the cased items and go ahead and move it. In the event that facilities are not available, we are proposing to the ICC a new classification. This classification is one that will be "Experimental Rocket Motor, Class A". Now we've already run the test, we know this propellant is not prohibited, so we feel this is a reasonable type of classification to put on it. Now this classification is only to be used to get your test item from your plant to a place where you can test them. One other proposal right at this particular point, is that if you have a particular program in which you are merely trying to advance the state of the art and you will have 3 or 4 firings of this particular system, it would be rather ridiculous to run a whole series of classification tests to get four items to a place where they could be launched. We are proposing that in this particular situation, that these items can be shipped under this experimental rocket motor classification. This will be tied down rather tightly by number, etc. We haven't worked out these details. So far we've gotten this material out of the plant and we're getting it someplace where we can run additional tests. Then we get into the two different problems that came up here this morning. You must then conduct tests to meet these two different problems. One is when you are shipping your individual components to a place where they will be assembled, you have a hazard from only the components, but once it gets there and all of these components are placed together and becomes a complete assembly, you have entirely different problems and we don't want to classify these components in transportation based on what may happen when they're completely assembled. This is one reason why in this existing document it states that this is not intended to cover tactical configuration because of the many variables that do come into it. We are presently at a point of trying to develop the test criteria for these two phases. We have many of the problems that have been brought up here today as far as how we're going to do this. Now it's true that a lot of thought is being given to scaled tests. Now by scaled tests you'd have to define this. Do you mean actually to scale a motor down in its entirety, the nozzle, the configuration, etc. If this is the case, then you've got a whole new R&D program to go through to find out if this scale motor is comparable to the big one. And it looks like you may end up running into a situation where your test motors you're trying to develop may be more expensive than going ahead and using a full scale motors that are rejects, but the rejects are of the nature which will not change the classification or materially affect the tests which you want to conduct. We are hoping to solve some of these problems, we are attempting to get as much information as we can, we don't want to base this criteria on what we have in our hands today or what we're using today. We hope to look far enough into the future so that anything we come up with can be reasonable. We also want to leave a great big loophole in this so that as we gain additional experience in different fields, this criteria can be changed and kept up to date as we get this experience. Because quite frequently, a regulation or something of this nature comes out and it will stay in existence for ten years and at the end of the ten years its antiquated, it has no bearing on what you're trying to do. We're trying to take a fresh look at this situation and if certain tests that haven't been conducted are necessary, let's use them. If tests that we have been conducting in the past do not apply, let's don't pay any attention to them, let's draw something new, something that is reasonable. But yet we want to be very sure that when we do complete this, the information that we get back at this stage will be accurate enough so that you can start construction on facilities long before you have an end item to work with and that your facilities will give you the degree of protection which you want. We are trying to move as fast as we can on this but it's one of these things that we're trying to get information from every possible source. We're trying to do as good a job as we possibly can on this. We hope that we can complete this, we'll tentatively set a target date for the first of the year if we possibly can. We know that there is a great need for this and we're trying to do as much as we can to speed up the program, we're also trying to get the best safety that we can. There is one other little facet to this which isn't in the same group, but we have talked here quite a bit about whether an item is Class 2 or Class 9 or some other classification. What are we doing when we assign these classifications? Essentially all we're doing is recommending a distance that you want, but most of these classifications as Dr. Ball brought out this morning are based on gun propellants. So we have another group which is taking a real hard look at this to see if maybe we shouldn't have some additional classifications or different distances than what we have. We're not saying we need them, but let's look at it and see if what we have is adequate. Maybe we need something else to cover this. This is also in the preliminary stages, but we anticipate trying to get it completed as soon as possible so that you people will have better tools to work with and know a little more about what you are working with.

Col. Hamilton: I wanted to stress that with regard to conventional items of military equipment, there is a joint criteria out now which is the basis for tests. You mentioned that but I wanted to stress that again and that can be obtained if necessary from whoever it is you're doing business with in the DOD. I know there will probably be a lot of questions in connection with Mr. Herman's talk, however, the next two items are also in connection with hazard classification tests, I think the best thing to do since we're a little short on time is to run through all three of these and have all our hazard classification test questions at one time. Thank you Mr. Herman. The next is "Hazard Classification tests of the Nike Hercules and Hawk Motors", Mr. Frank Schultheis of White Sands.

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Mr. Frank Schultheis, White Sands Missile Range:

A test program was conducted at White Sands Missile Range, New Mexico at the request of the Office of Chief of Ordnance to recommend the proper explosive classification of the polysulfide-perchlorate solid propellant used in the Nike Hercules and Hawk missile systems. This program consisted of attempting to detonate the propellant with the missile warhead when in simulated missile configurations.

Important factors in selecting Nike Hercules and Hawk launching sites are the distances required between the battery elements within the sites and the distance of the sites from a populated area. These factors are dependent upon the amount and classification of explosives at the launching site. There then arises the question of the explosive classification of the polysulfide-perchlorate solid propellant within the Nike Hercules and Hawk motors. If detonation of the warhead will cause the detonation of a part or all of the solid propellant, the propellant at least in part should be given a Class 9 explosive classification. However, if the propellant will not detonate, only the warhead need be classified as a high explosive. Since the propellant, if explosive, would increase the total quantity of high explosive within a Nike Hercules missile five fold and within the Hawk system by a factor of nine, this determination has a most important bearing on the area requirements for a missile battery.

The Hawk tests included one control test of a single XM5 warhead, and one live test consisting of an XM5 warhead and two XM22 Hawk motors. The Hawk XM5 warhead is a fragmentation weapon containing 1,650 fragments, weighing 120 grains each. The bursting charge is composed of approximately 75 pounds of composition HBX-6. Total weight of the XM5 warhead is nominally 110 pounds. The Hawk XM22 motor contains a separate booster and sustainer motor within one shell. It contains approximately 600 pounds of polysulfide-perchlorate propellant, 300 pounds each in the booster and sustainer.

Detonation of an XM5 warhead alone as a control test resulted in a shallow crater 0.7 feet deep. The shallowness of the crater was due to the distance from ground level, approximately 24 inches, at which the warhead was detonated.

Detonation of the Hawk XM5 warhead, placed in the tactical spatial relationship between two Hawk XM22 motors, with the warhead again positioned approximately 24 inches above the ground, (Fig. 1) produced a shallow crater 0.5 feet deep. The physical appearance of the crater was very much like the previous crater obtained from the control test.

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Several fragments pierced the head plate and sustainer motor case of each motor. The hot metal fragments entering the sustainer propellant compartment caused the propellant to ignite and burn. Pressures and heat developed within the motor caused the motor case to break open at the area where it had been weakened by the entering fragments. (Fig. 2).

The booster section on the Hawk motors was not damaged in any way. The increase in skin temperature of the motor caused by the burning sustainer propellant was not sufficient to ignite the propellant within the boosters, and the booster plugs remained inside the nozzles.

A combination of blast from the warhead detonation and thrust due to the burning sustainer propellant caused each of the motors to be thrown outward. They landed approximately ten feet from their initial position and were each rotated approximately 180 degrees. (Fig. 3).

The Nike Hercules tests included two control tests, one with a T45 warhead alone and a second with a T45 warhead mated to an inert solid propellant sustainer motor. Five Nike Hercules live tests were conducted, each with a T45 warhead mated to a live simulated solid propellant sustainer motor. An additional control test was added after the five live tests. In this test, a container simulating a sixth motor casing, loaded with 547 pounds of Composition C, was initiated simultaneously with a T45 warhead placed in front of it. The 547 pounds of Composition C was calculated to release energy equivalent to the detonation of 25% of the polysulfide-perchlorate propellant grain. The weight of the explosive was determined by assuming that onepound of polysulfide-perchlorate propellant when detonating will yield the equivalent effect of one pound of TNT.

The Nike Hercules T45 warhead is a fragmentation weapon containing approximately 18,000 fragments weighing 140 grains each and contains approximately 600 pounds of HBX-6 high explosive. Total weight of the assembled warhead is nominally 1,100 pounds.

At the time these tests were scheduled, the XM30 Nike Hercules sustainer motors were not available for this test. Instead the old Hermes motor case and nozzle, weighing approximately 960 pounds was substituted. Approximately 2,300 pounds of polysulfide-perchlorate propellant was cast into each of five motor cases. A sixth motor was cast with inert propellant for the second control test.

Detonation of the T45 warhead in front of the inert simulated sustainer motor resulted in a crater 2.3 feet deep and 15 feet maximum diameter. The crater was again roughly circular. The warhead completely destroyed the front half of the inert motor and threw the remaining portion approximately 200 feet to the rear of its initial position. The rear portion of the inert propellant remained intact.

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The first Classification Test, detonation of the first T45 warhead mated to a live simulated sustainer motor (Fig. 4), produced a crater comparable in depth to the crater resulting from the control tests. However, the crater was considerably elongated along the line of the motor axis. The blast gage data indicated that the wave produced was greater than that produced in the two control tests. Also, it was observed that there were no remains of the motor casing or its propellant in the immediate area. The closest pieces of motor case larger than one-half square foot in area were approximately 800 feet from the test area, and burning propellant caused brush fires up to 1000 feet from the test area.

The next two tests using the T45 warhead and live simulated sustainer motor produced elongated craters similar to that of the first live test, however, pieces of the motor case and nozzle were found in and near the crater.

The fourth live test again produced an elongated crater similar to those of the three preceeding tests but not as deep. Several large fragments of the motor case and pieces of unburned propellant were found inside the crater.

The fifth live test created a crater shallower than those of previous tests. However, no large fragments of the motor case were found in the immediate test area. No variations other than the crater depth were noted.

The third control test was performed with a live T45 warhead and simulated motor containing 547 pounds of Composition C. It was calculated that the explosive strength of Composition C in this test represented that of 25% of the propellant in the XM30 motor. This test was based on the assumption that approximately 25% of the propellant had detonated in the five previous classification tests. An elongated crater 2.1 feet deep and 20 feet in diameter was produced. The cratering and blast effects of this test were simular to those of the five live tests. (Table I).

Blast was measured by a Bikini gage with twelve holes ranging in size from 0.125 to two inches in diameter. These holes were covered with 0.001 inch thick soft aluminum foil which was not calibrated. Several checks showed the foil to give consistent results. The diaphragm gage was therefore considered to be capable of indicating relative rather than absolute pressures.

Soil analysis of samples taken at each test site indicated that the composition of the ground was relatively uniform, and would yield consistent crater results.

The conclusions reached from the detonation of a T45 warhead on an assembled Nike Hercules missile were that the mean blast parameters obtained during tests with a live sustainer motor were greater than with the T45 warhead alone. This variation was due to partial detonation of the propellant.

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It was further concluded from the similarity of results between Control Tests number three and the live motor tests that the quantity of propellant which detonated in the Nike Hercules sustainer motor was approximately 25% of the contents of the motor.

From these results it was recommended to Office Chief of Ordnance that at least 25% of the polysulfide-perchlorate within the Nike Hercules sustainer motor be considered Class 9 high explosive when assembled with the T45 warhead.

The date from the Hawk motor detonations was less conclusive. The difference in crater dimensions produced by the warhead in conjunction with the motor and those produced by the warhead alone was not significant.

It is concluded that the detonation of Hawk XM5 warhead in the configuration tested using the XM22 motor will not directly cause the detonation of any part of the sustainer or booster propellant within adjacent XM22 motors.

However, the XM22 Hawk motor with separate booster and sustainer chamber has now been replaced by the XM22E7 motor which contains both the booster and sustainer propellants in the same case as single bipropellant. The propellant has been changed from polysulfide-perchlorate to polyurethane-perchlorate which may very well yield different results.

Further, the configuration tested was a less severe test of propellant sensitivity to detonation than a test in which the warhead is detonated in front of its own motor with three complete missile assemblies in a simulated tactical launcher configuration.

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Fig. 1

Fig. 2

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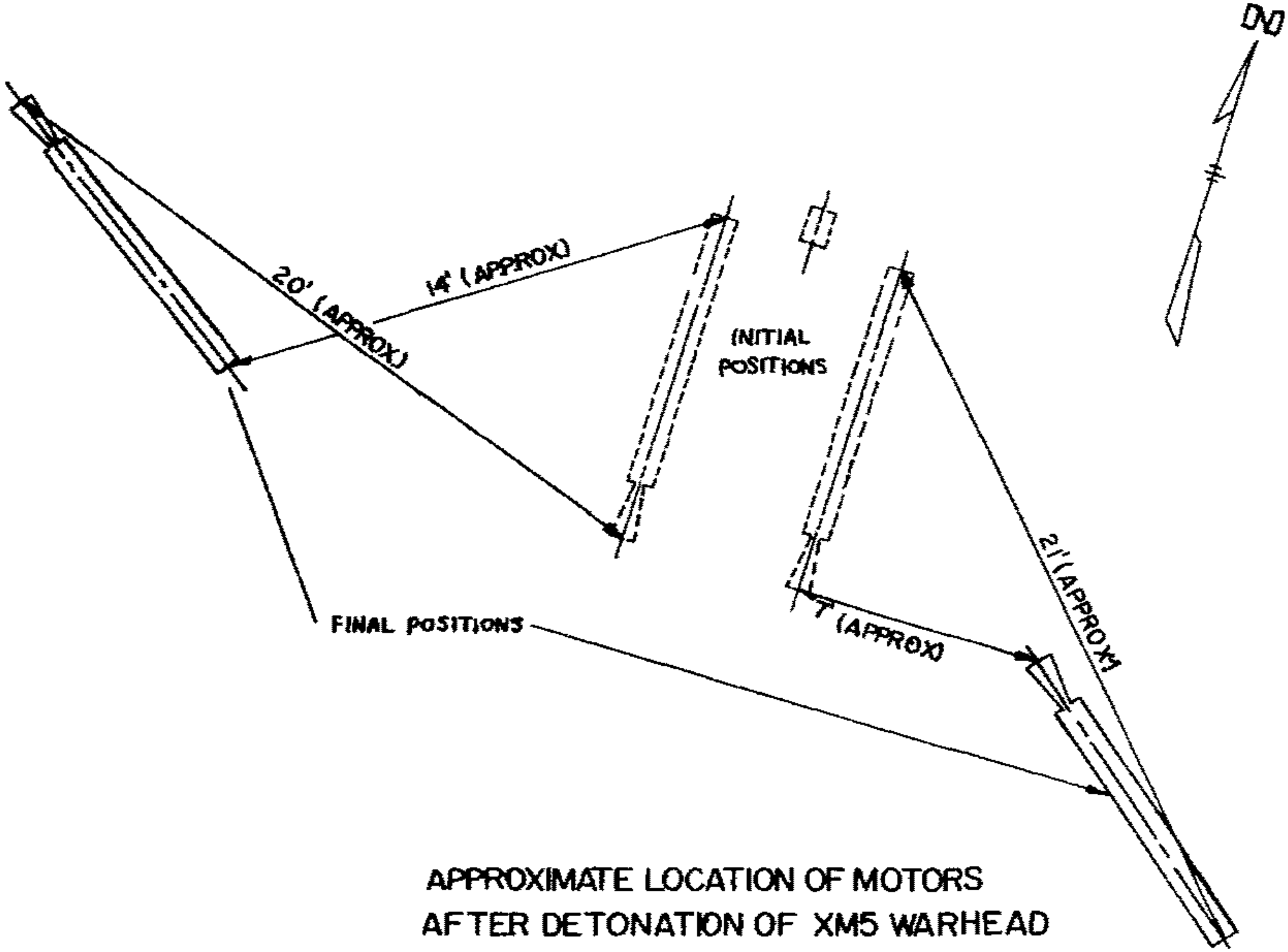

APPROXIMATE LOCATION OF MOTORS
AFTER DETONATION OF XM5 WARHEAD

Fig. 3

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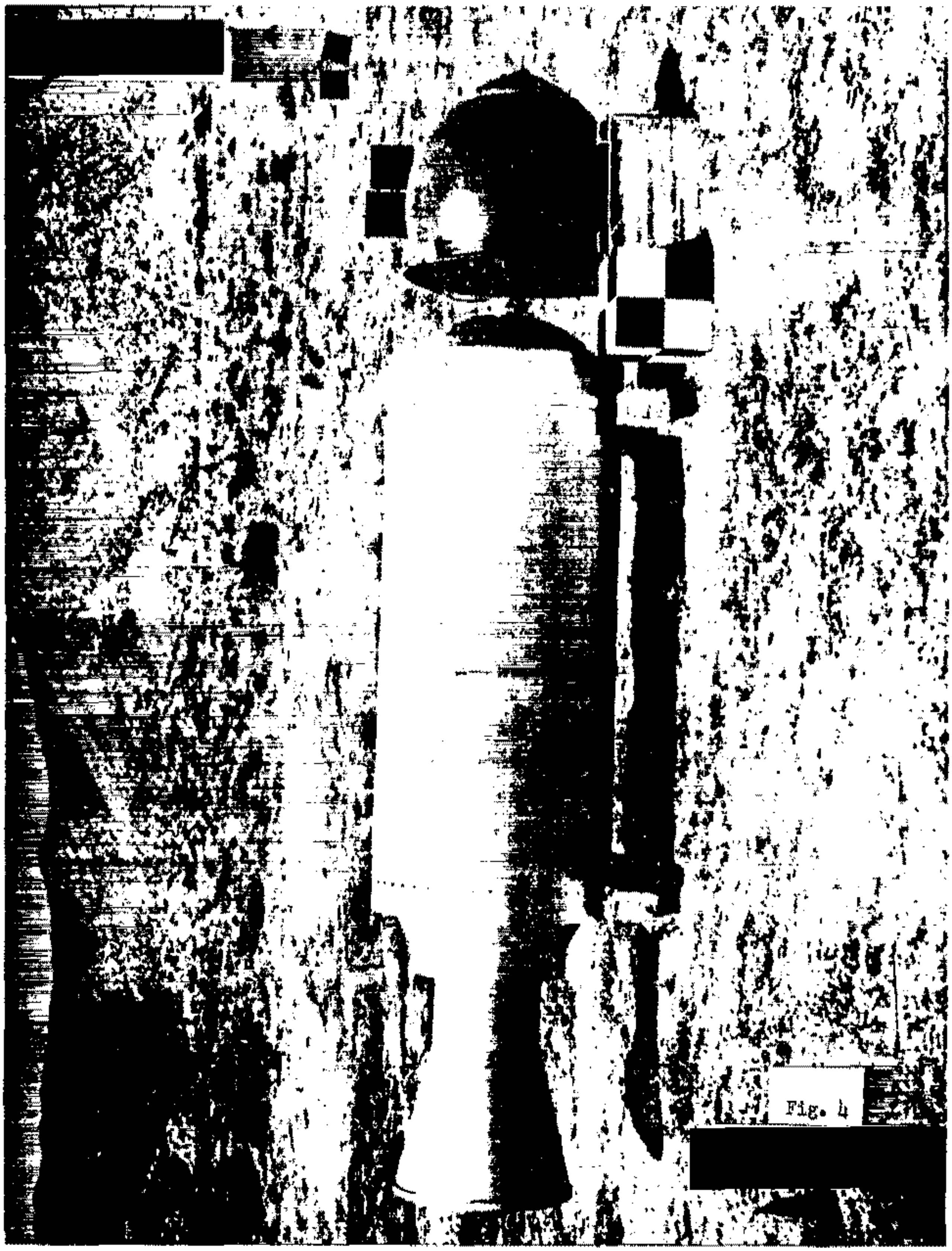

Fig. 4

RESULTS OF NIKE HERCULES CLASSIFICATION TESTS

RESULTS	CONTROL TEST I	CONTROL TEST II	CONTROL TEST III	CLASSIFICATION TEST I	CLASSIFICATION TEST II	CLASSIFICATION TEST III	CLASSIFICATION TEST IV	CLASSIFICATION TEST V
	TEST TITLE							
MAX CRATER DEPTH.	2.8 FT.	2.3 FT.	2.1 FT	2.5 FT	2.6 FT	2.6 FT	2.3 FT	1.5 FT
MAX CRATER DIA.	16.0 FT	15.0 FT	20.0 FT	20.0 FT	30.0 FT	26.0 FT	28.0 FT	32.0 FT
CRATER VOLUME	1317 FT^3	153.7 FT^3	175.5 FT^3	220.0 FT^3	199.3 FT^3	2647 FT^3	244.3 FT^3	165.6 FT^3
BIKINI GAGE								
DISTANCE FROM WH	160.0 FT	160.0 FT	160.0 FT	160.0 FT	160.0 FT	160.0 FT	160.0 FT	160.0 FT
HOLES RUPTURED	4	5	7	7	7	6	7	7

Table 1

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Lt. K. O. W. Ball, BMD (presented talk prepared by Mr. H. S. Weintraub): In order to evaluate the hazards associated with the MINUTEMAN Weapon System, a series of tests and test procedures were established* to determine an ordnance classification for the propellants used in the MINUTEMAN propulsion system. This program was to provide data to aid in the determination of the ordnance classification of the MINUTEMAN propulsion system with regard to safe handling, shipping, and storage, and to aid in evaluating the hazards associated with storage, transportation, and use of the engines and missile. Concurrently, samples of MINUTEMAN propellant were forwarded to the Bureau of Explosives, Association of American Railroads by each Associate MINUTEMAN Engine Contractor for the purpose of having the Bureau of Explosives assign ICC explosive classifications to the propellants.

After completion of exploratory laboratory testing at the Associate Engine Contractors' plants, the propellants and/or loaded engines of each of the Associate MINUTEMAN Engine Contractors was subjected to a series of field tests viz., (1) Susceptibility to detonation of propellants in ice cream carton grain size (2) Susceptibility to detonation (3) Sympathetic detonation (4) High velocity impact (5) Exposure to fire. Each of the Associate Engine Contractors conducted a susceptibility to detonation test, utilizing propellant specimens prepared by casting and curing the propellant in one quart ice cream cartons to give propellant grains approximately 3-1/2 in in diameter by 6 in in length and weighing approximately 3 lb. A 10 gram tetryl booster pellet initiated by a No. 8 blasting cap, Figure 1, was used for the test. If the propellant specimens gave evidence of detonation, additional tests were conducted utilizing a 1/8 in thick plexiglass disc, 3 in in diameter (attenuator) interposed between the tetryl pellet and the top of the propellant specimen.

*Space Technology Inc. Document GM 59.7650.3-36

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The plexiglass thickness (1/8 in increments, viz. 1/4 in thick disc 3/8 in, 1/2 in...etc) were increased until the propellant was prevented from detonating. The use of different thicknesses of plexiglass "attenuators" was accomplished in accordance with the Bruceton Statistical Procedure (AMP Report Nr. 101.1R). Adequate instrumentation was used to determine detonability of the propellant under test. In addition, propellant specimens confined by a close fitting steel sleeve, as indicated in Figure 1, were utilized where detonation of the unconfined propellant was not obtained.

At the conclusion of the ice cream carton tests, loaded engines from each of the Associate MINUTEMAN Engine Contractors were forwarded to AFFTC, Edwards Air Force Base, California, to be subjected to field tests. The tests were conducted on a high hazard test stand as indicated in Figure 2. The pressure sensing instrumentation consists of six photocon gages and six bikini gages arranged as shown in Figures 3 and 3a. The photocon gages at the 120 ft station have a 0 to 20 psi range while the remaining photocons were in the 0 to 5 psi range. All photocon gages were mounted on baffles to measure side-on overpressures and had a system accuracy of plus or minus 5 percent at full scale deflection. Three of the bikini gages were mounted to obtain side-on overpressures and three were mounted to obtain face-on overpressures.

In order to dynamically calibrate the instrumentation to determine the reflection characteristics of the test stand, 100 lb Comp C charges were fired. These charges were mounted approximately 5 ft above the test stand floor to simulate the approximate position of the 100 lb booster pellet when set upon the engine being tested. The results of the calibration tests are indicated in Figure 4. The type of test being conducted on prototype subscale for full scale MINUTEMAN engines were as follows:

Susceptibility to Detonation: Tests were conducted in which full scale or prototype subscale MINUTEMAN engines were subjected to the impulse from a Comp C booster positioned approximately midway (Figure 5) between the head and aft end of the engine under test. The Comp C booster pellet (ranging from 100 lb down to 1/4 lb) were cylinders topped by a 60

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degree cone with a length to diameter ratio of the overall booster equal to two. In order to assure intimate contact between the booster pellet and the engine under test, the booster was contoured to conform with the side of the engine. The initiation of the booster pellet in all cases was accomplished with an Engineers Special blasting cap secured to the booster pellet apex. The results of the test conducted are indicated in Figure 6.

Sympathetic Detonation: In the event a detonation was obtained with an engine under test, a sympathetic detonation test was conducted by placing two like engines adjacent to each other to note if detonation to one of the engines would cause detonation to the second engine. In order to reduce the expense and hazard involved, it was decided to perform the sympathetic detonation test on a subscale engine whenever possible. Two subscale engines (493 lb of propellant) Figure 7 were subjected to a sympathetic detonation test. The subscale engines were separated by 25 inches to maintain an approximate equivalent explosive effect based on the expected output from a full scale Stage III engine. A 5 lb Comp C booster was attached to the midpoint of the case of the donor engine on the side away from the receiver engine. The booster was initiated with an engineer special blasting cap. The results of the test are indicated on the blast gage data given in Figure 8.

High Velocity Impact Sensitivity: Tests were conducted to determine the effect of impact of caliber 0.22, 0.30 and 0.50 bullets from approximately a 100 ft distance (Figure 9) into engines from each of the Associate MINUTEMAN Contractors. In all cases, the caliber 0.30 and 0.50 projectiles ignited the propellant in the engines which then continued to burn. The caliber 0.22 does not penetrate the engine case of any of the MINUTEMAN Stages.

Exposure to Fire: Tests were conducted with full scale engines from each of the Associate MINUTEMAN Engine Contractors. In each case, the engine under test had a fuel pan containing gasoline in an amount sufficient to burn for a duration of 20 minutes. The fuel pan was suspended underneath the engines under test so the top of the liquid level was approximately 6 inches

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from the bottom of the engine case. The gasoline was ignited remotely by pyrocord suspended above the fuel pan. In each case, the engine under test took fire and burned as a result of engine case failure.

The MINUTEMAN Hazard Classification Tests conducted to date, were part of an overall safety program which has attempted to investigate all the safety aspects applicable to the MINUTEMAN Weapon System and to translate the results of this investigation to safety devices and safety procedures which would assure the maximum safety for all phases of operation of the MINUTEMAN Weapon System. Additional testing of subscale prototype and full scale MINUTEMAN engines is continuing to obtain data of a more specific nature which will assist in establishing an ordnance classification for these engines.

As a result of the test conducted by the Bureau of Explosives, the polyurethane and PBAA composite propellants have been classified as Class B while the composite double base propellant has been classified as Class A, Type 3. The ICC classifications were based on the results of the tests conducted by the Bureau of Explosives in accordance with the ICC Tariff No. 10 Regulations.

The results of the MINUTEMAN Hazard classification tests indicate the composite-double base propellants to be more sensitive to an explosive impetus. However the double base propellants can only be detonated by use of an explosion booster which is set up just right for the test. In all other types of tests it appears that the composite-double base, the polyurethane and the PBAA composite propellants react analogous to the long line of Class 2 propellants which are their predecessors.

There has been in recent months, a tendency to infer that from the standpoint of safety, all large rocket engines should be transported in a non-propulsive state. Heretofore, the method usually employed for the shipment of smaller rockets or JATO's in order to prevent them from becoming propulsive if involved in an accident has been the use of thrust neutralizers, blowout plugs and a biased orientation of the rocket so the thrust

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can be dissipated. As an additional safety precaution, many rockets and JATO's are still shipped with igniters packed in separate boxes for subsequent assembly to the rocket or JATO preparatory to firing. Although somewhat effective in the past, these methods are not readily adaptable nor should they be incumbent upon the new generation of solid propellant rocket engines required for such systems as the MINUTEMAN Weapon System. The MINUTEMAN Weapon System has associated with it devices which render the engine and/or missile non-propulsive when involved in a serious accident. The MINUTEMAN Weapon System concept derives its maximum effectiveness in being shipped as a completely integrated missile wherein the reliability is built into the missile at an assembly plant and the missile shipped out (except for the warhead) ready for operational use with an absolute minimum of field adjustment.

This philosophy of minimum field adjustment is behind the very stringent hazard classification test to which the MINUTEMAN engines are being subjected. The very stringent requirements on safe and arming mechanisms and all explosive ordnance in general, is directed to assure the MINUTEMAN Weapon System being in consonance with all the safety procedures so the Weapon System will afford the absolute maximum of safety to the using service without compromise to the operational capability of the Weapon System.

Another point which cannot be too strongly emphasized is that the "probability of occurrence" of a hazard of catastrophic proportion is so remote, and the nature of failures that could occur to the system so singular in character, that the MINUTEMAN Weapon System can be considered a passive one.

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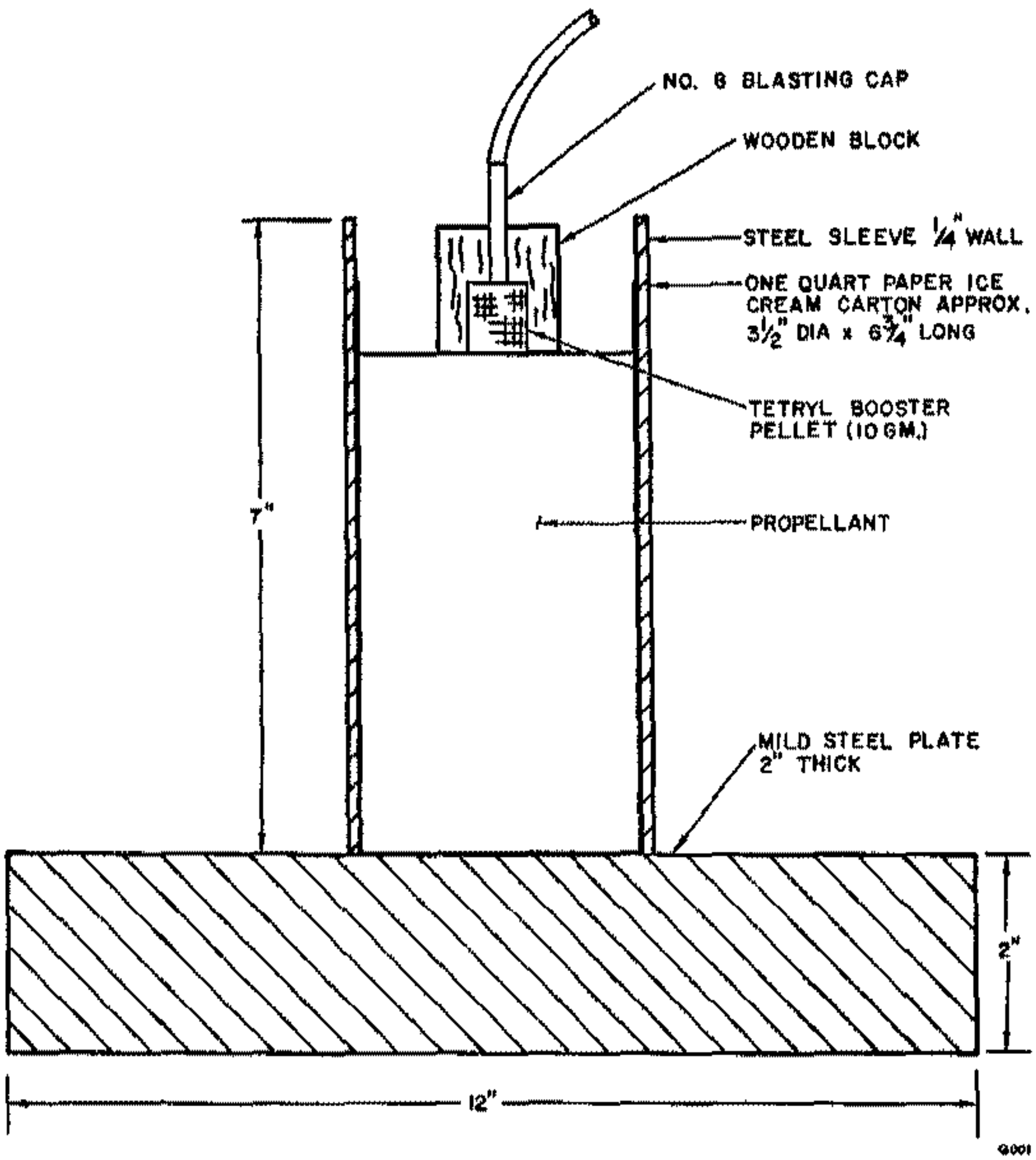

Figure 1. Section View of Field Explosive Test Setup for Susceptability to Detonation Tests.

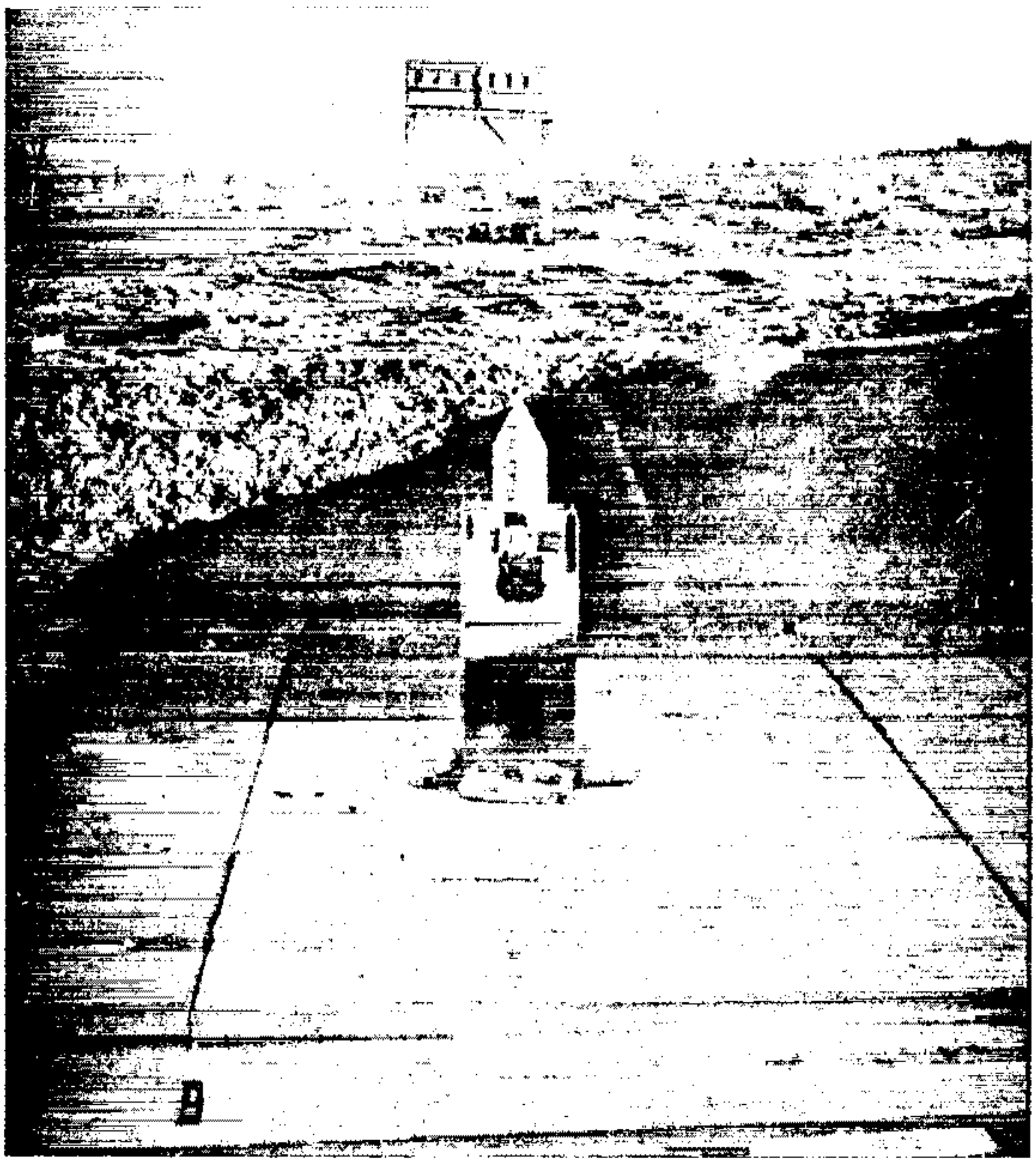

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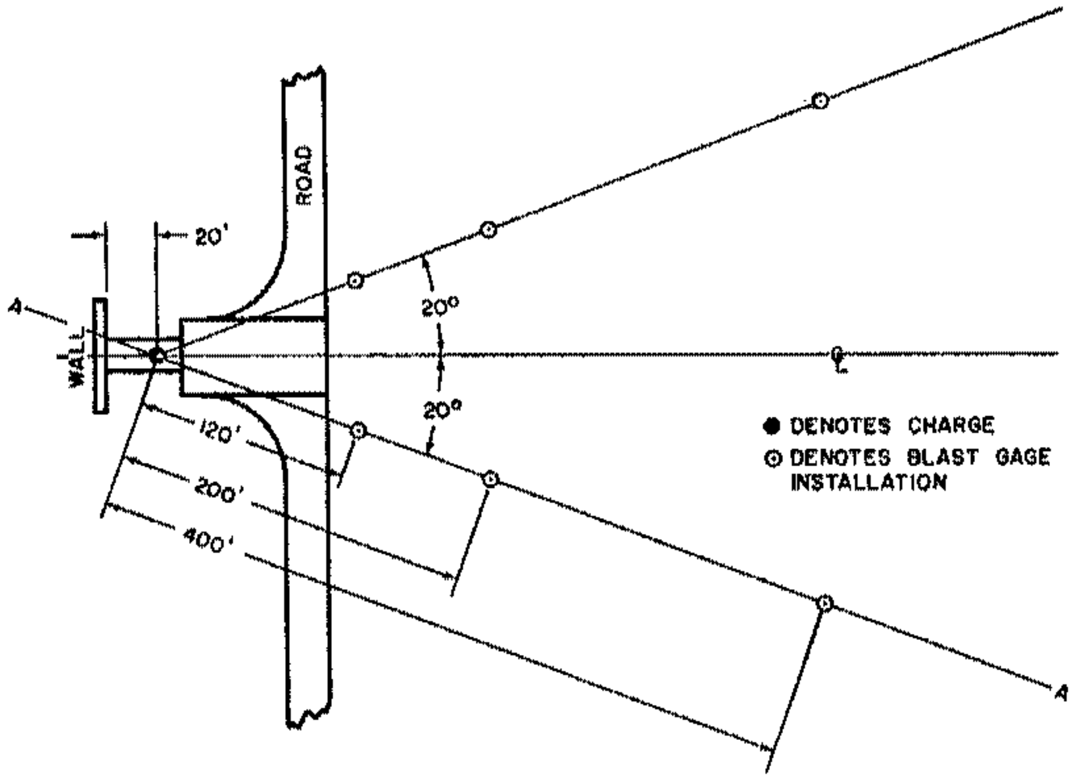
Figure 2. High Hazard Test Stand at AFFTC with 100 Pound Booster for Stand Calibration for Minuteman.

PAD 3 PLAN



SECTION A (TYP.)

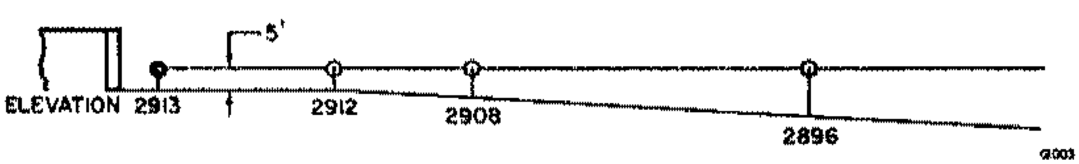


Figure 3. Location of Blast Gages on Test Stand 3
(Stands 1 & 2 are Similar)

Figure 3a. Bikini Gage Face-On at 120 Feet from 100 Pound Calibration Charge for Stand Calibration at AFFTC for Minuteman.

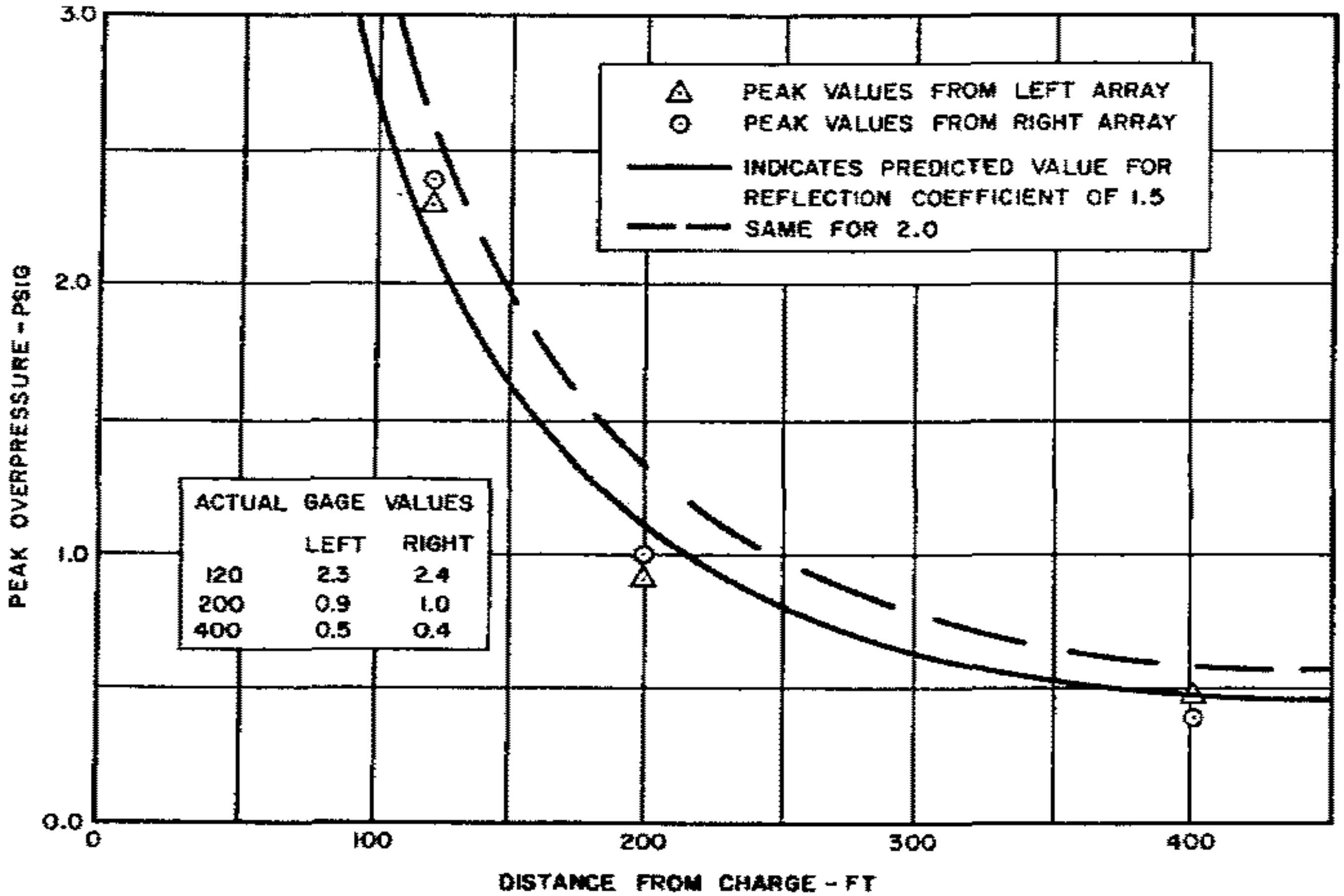


Figure 4. Calibration Test No. FC-1A Pad 3 for Minuteman Charge 100 Pounds Comp. C Fired 6 January 1960.

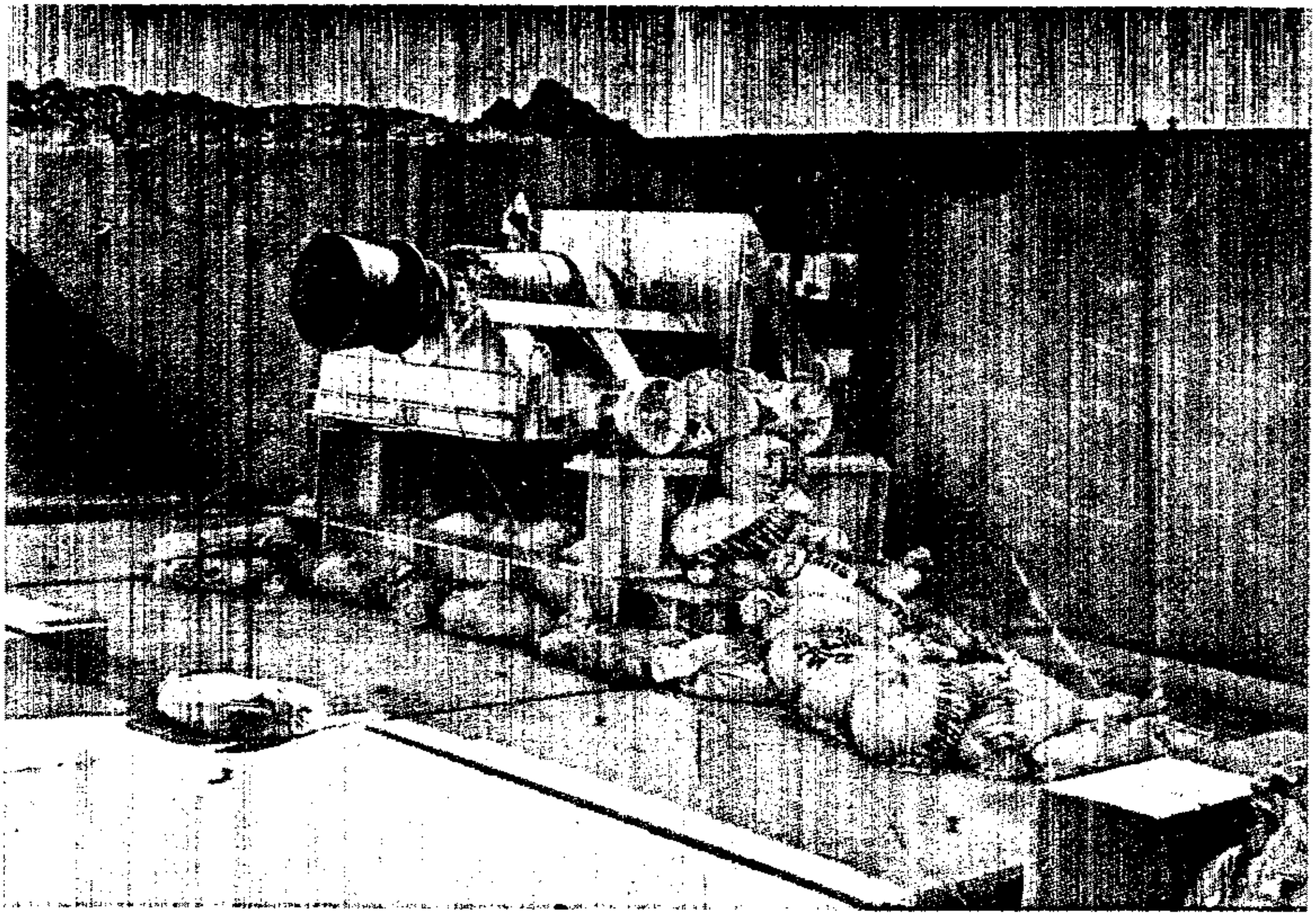


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Figure 5. **Susceptibility to Detonation Test of a Minuteman Engine Containing 500 Pounds of a Composite-Double Base Propellant. A 5 Pound Comp. C Booster is Used.**

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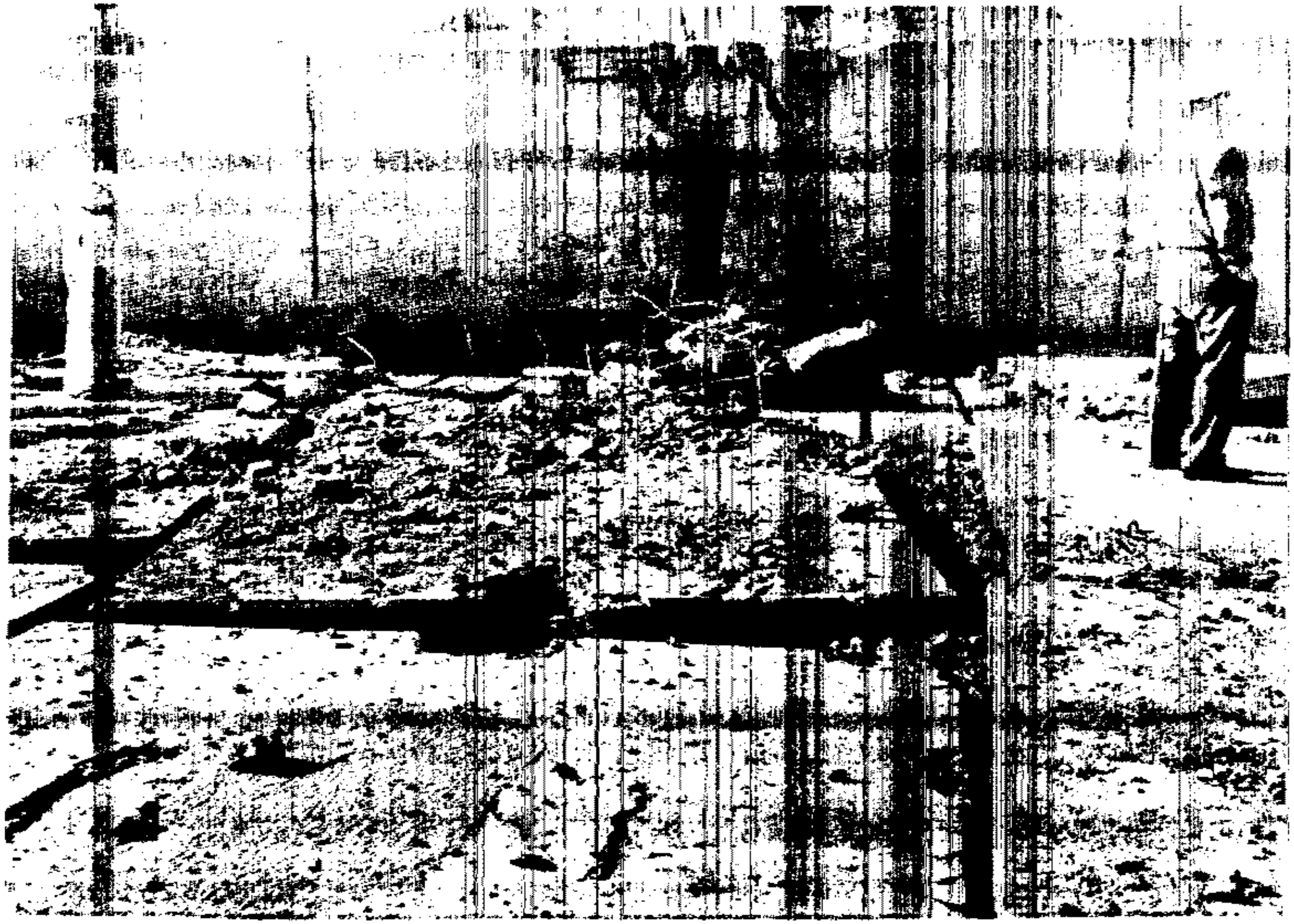

Figure 6. Results of Susceptibility to Detonation Test with a Minuteman Engine Containing 500 Pounds of a Composite-Double Base Propellant. Engine Initiated by 5 Pound Comp. C Booster.

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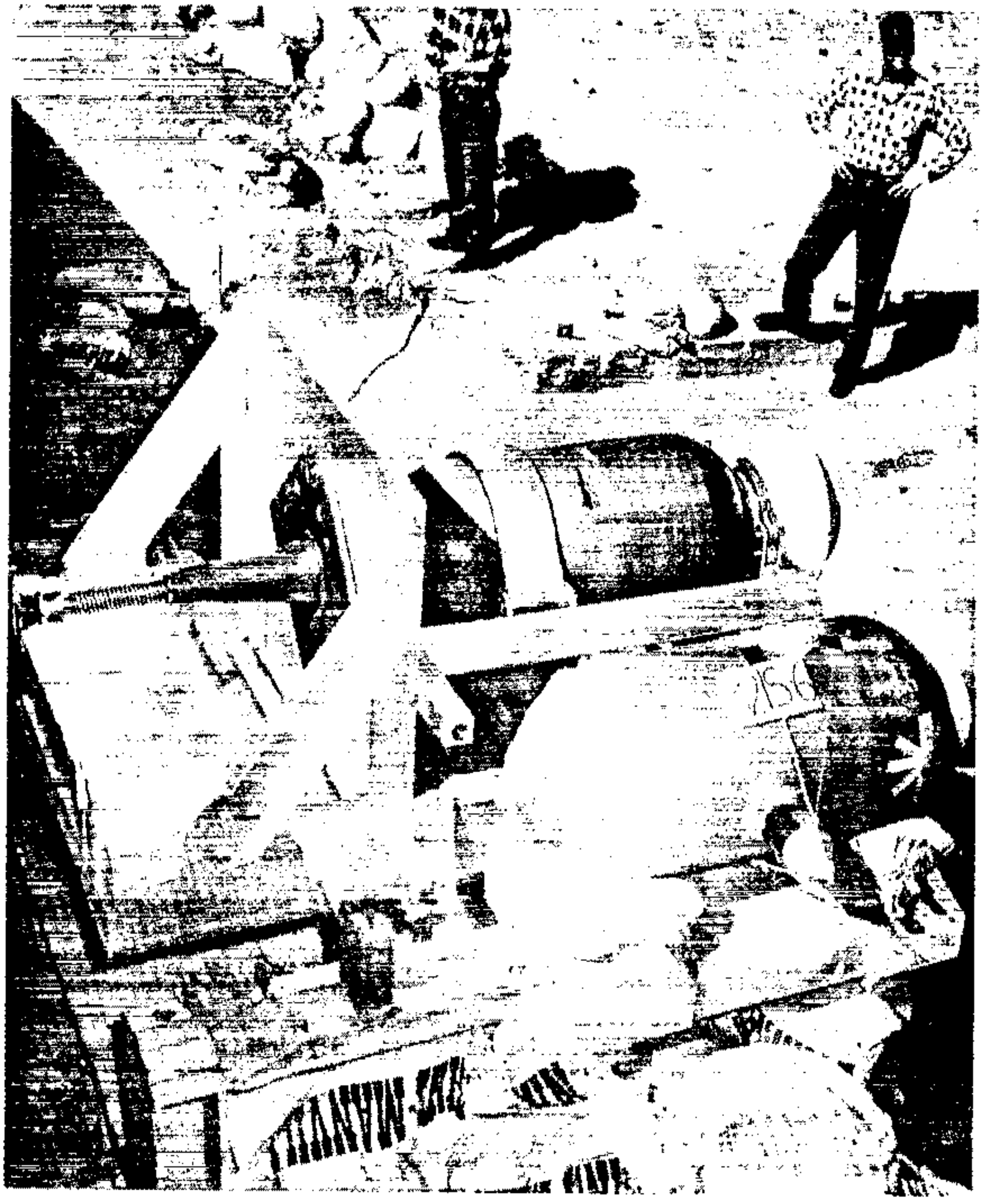

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Figure 7. Sympathetic Detonation Test for Minuteman of Two Engines Each Containing 500 Pounds of a Composite-Double Base Propellant. Booster is 5 Pounds of Comp. C.

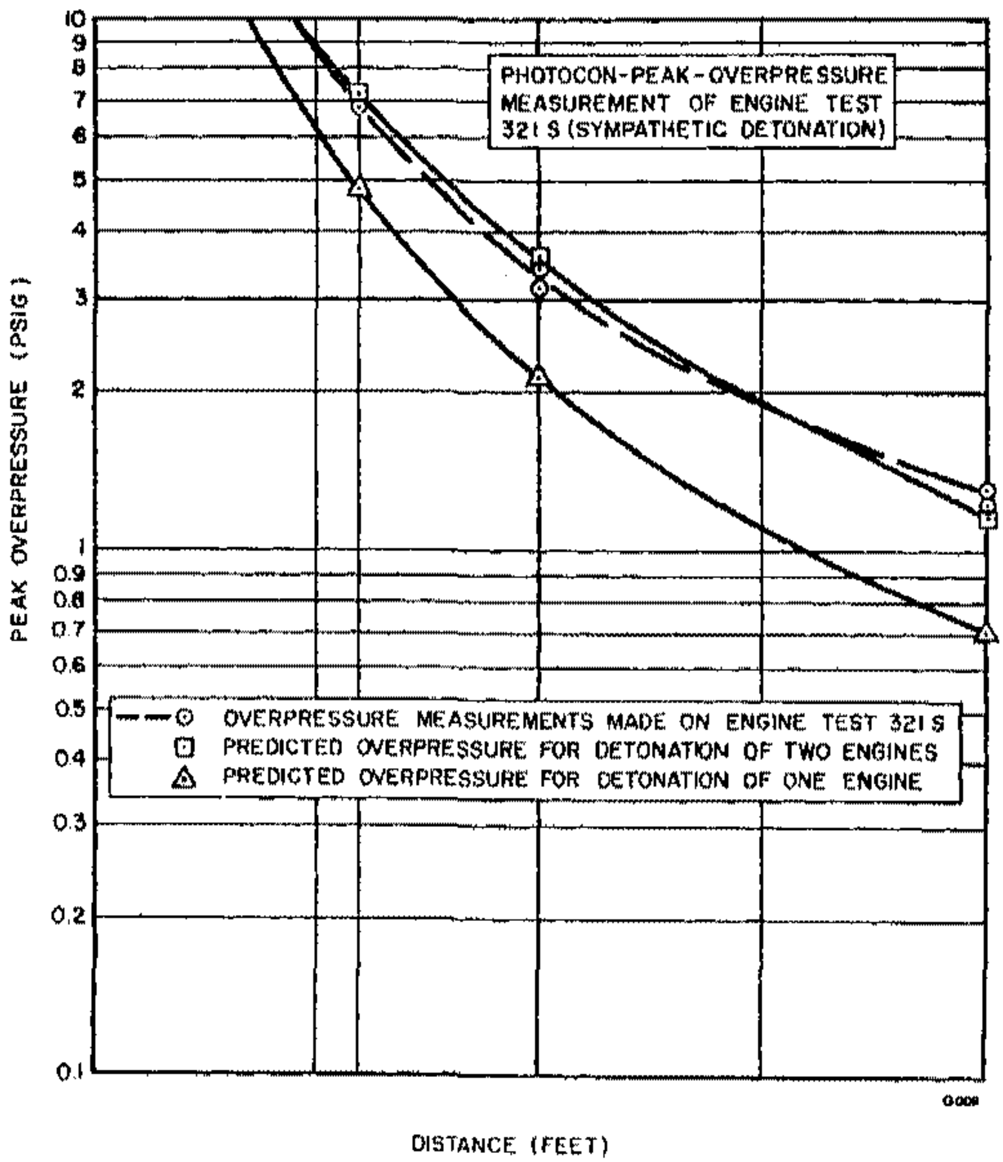

Figure 8. Test-Peak-Overpressure Measurement Versus Distance Superimposed on TNT Equivalence Plot Assuming 1.5 Reflection Coefficient.

Figure 9. High Velocity Impact Sensitivity Test (Bullett Impact) at AFFTC for Minuteman.

Lt. K. O. W. Ball, BMD: I'd like to make one comment prior to questions. Within the couple of days before I came out here, BMD got some indications on a safety problem that might arise or its already with us concerning the shipment of ammonium perchlorate in aluminum tanks. We have the impression that this is being pushed or coming upon us here and i understand Kaiser Aluminum is actively engaged in this and I was just wondering if people here were familiar with it, if this has been looked at and I'm sure most of you are familiar with the AP and aluminum non-compatibility if fire hazard or something like this does exist.

Mr. Jezek: I don't know whether the ICC will permit shipping ammonium perchlorate in aluminum containers, I think maybe Sam Nash could help us on that. Do you know anything about that Mr. Haninger, is that in conformance with your specifications?

Mr. V. E. Haninger: There's nobody that has appealed to the ICC to ship perchlorate in aluminum, as far as I know the Bureau of Explosives has never been approached on the problem. I don't think we would do it without some sort of a liner, if we do it at all.

Lt. Ball: Then my comment was just one of information, that we have been made aware of this and I thought I would pass this on.

Mr. R. P. Rice, American Potash & Chemical: We're the largest manufacturers of ammonium perchlorate and we have done some evaluation work with rocket manufacturers on shipping in bulk containers, namely, nestabin, sealbin, some evaluation work has also been done on your Kaiser bin. We have ICC approval actually to ship in aluminum tobins and inverta bins, we have not had ICC approval to ship in the Kaiser nestabin. This is purely in evaluation status right now.

Dr. Ball: For what it's worth to you, in the course of some of our dynamite operations, we had an incident where an aluminum container got hot enough in a general fire to melt and get involved in this ammonium nitrate, the results were not pleasant.

Col. Hamilton: Now are there any questions generally on the hazard classification discussions that these three gentlemen have put on.

Mr. S. W. Nash, OCO: I have a question as to definition, I noticed Mr. Herman mentioned rocket motors and then we had solid propellant motors referred to as rocket engines. Within OCO there has been a distinction made between the two, I was wondering what the consensus was here.

Mr. Herman: I believe in a meeting that we had with the ICC and the Bureau of Explosives people recently, the term motor would be used in conjunction with any solids whereas the term engine would be used in connection with any liquid fired device. I don't know whether this is in any regulation or has been spelled out.

Mr. Endsley: There was a DOD Directive that they would standardize the terms and you are correct in this interpretation.

Mr. Ullian: I've got one for my BMD cohort so to speak. First of all, with the results you have discussed and those we have reports on and the ones I discussed in my talk with the third stage and also with the second stage, I do not think there are any yet with first stage, although they're starting to trickle in. Are you considering running a test where you take either a complete sub-scale missile or the full scale missile, put it in the flight configuration and use one of the destruct charges that we plan to use and see what happens. Maybe we don't have to worry about this problem or maybe we do. See just what sort of results we're going to get. We've asked for this and I wonder if you know whether they are going to do this.

Lt. Ball: I think the best answer to that is that we are and have been considering tests along these lines. I think right now it is more of a funding question, we just don't have even the live rejects as such to put in a hole for a classification test.

Mr. Ullian: Another point I'd like to bring up and that's on this operational configuration of this missile. This is the main missile, when I talked about this live ordnance installation. We at the Cape don't argue with the S&A devices on the missile that this is a fine thing for operational and practical use. The only thing we do argue is that where there is no experience to date on the final configuration of this, as it will be shipped down to us, we have asked and we have gotten agreement to bring the first two engines and possibly more until we get experience, without any ordnance items installed, except the small thrust termination devices on the third stage. Once this experience has developed and we find out just how good these estimators are, because once in awhile even though they run all sorts of reliability tests, we get them in the field and find out they aren't as good as we claim them to be. Then I think Lt. Ball's statement will hold true, but I'm afraid that in our business we're in the process of finding out whether actually the statements and theoretical estimates are fact.

Mr. Lineberry: Each time we get in one of these seminars or conferences it seems that we get to talking on a problem and we ask about doing full-scale work and everyone says no funds. We have the ASESB here, Mr. Roylance, Mr. Endsley and Mr. Jezek and I think it behooves us to get the DOD and make these people see that full-scale testing is what we need. This is just a recommendation but I think we should push this. We have funds for everything else, even though we all claim to be poor. I think we should consider this and consider it very highly and have a report on it at probably our next meeting.

Col. Hamilton: One way to get action on that would be to direct the communication into the DOD and have it worded in such a way that you could get an ASESB recommendation on the thing or route the thing to the DOD through the ASESB so that we could put our recommendation on there to back you up.

Mr. Lineberry: We at PanAm cannot ask for this because we are the range contractors, but I think that possibly the manufacturing contractors can ask for this or even in their preliminary planning set aside a 10% or charge a 10% fund and 10% of their make-up, their manufacture to go into large scale testing. Again, that's just a recommendation.

Col. Hamilton: I would suggest that you put the recommendation in writing and route them on through the channels they will have more chance of being acted on favorably.

Lt. Ball: I have a comment along these lines. I think it is also worthwhile to consider that there's a certain point in the R&D program where it is not feasible. I think we would like to have something that we think will fly, or may fly, rather than just three engines or four engines, although they make use of the propellant composition which we anticipate will be the final article.

Mr. Welch: I wonder if I could get Lt. Ball to give us a description of these photo-con gages that he mentioned for blast pressures. We've received several reports of their tests and many of these slides shown here today and our test reports refer to photo-con gages and show where they're put but I've never heard of a photo-con gage and I don't know how it operates or any particulars about it and I've had several people ask me "what the heck's a photo-con gage."

Lt. Ball: I'm sorry, I do not have the information with me.

Unidentified: The information on the photo-con system I cannot give you, the complete name of the system is Photo-Con Dyna Gage, I think it's a Los Angeles based organization.

Mr. Nance: In talking to several of the industrial members here I can pick up at least three or four separate methods that are used in running even full-scale classification tests. As a matter of instance, one particular test mentioned a booster on an engine under 30" in diameter, full diameter weighing up to 750 lbs., cylindrical coming down on the end of the engine. On Minuteman we've got a different type of test,we're talking about a booster 150 lbs. laid on the side of the engine and coming into the side. In still another test we're talking about a ball of propellant explosive located between the engines. Obviously some standardization is much in need in this particular series of tests, but it would seem that it would be very well to have the ASESB and those industrial firms who are actively engaged in this type of work get together and come up with a standardized optimum explosives classification test method for full-scale testing.

Mr. Herman: This was exactly what I was speaking of that we're working on now, to come up with a standardized series of tests which will tie down very definitely not only the booster that you will use, the location, how it will be placed on it. Another big question that we're trying to get an answer to is what type of instrumentation do we want around this. We realize we need instruments but we want the best type but yet we don't want them too expensive, to try to get a lot of these answers that have been raised today and all of this, when this project is completed it will be very specific, it should standardize tests.

Mr. Nance: This will be very fine, I'd like to emphasize again that private industry has some pretty good men some of them that have talked here today and should be plugged in to this.

Mr. Herman: We have several proposals from industry now that we are considering in this as well as a lot of basic research like Dr. Noonan is doing and work that has been done on it. We're not limiting this to our own knowledge on this subject, we're trying to get as much information from the entire field as we possibly can.

Mr. Nance: I don't believe any contact has been made with the Thiokol Utah Division or Thiokol as a whole, I'd like to request that.

Mr. Herman: We've left this up to the individual Services to contact their contractors for the information. I had a proposal on the Minuteman, Edwards has furnished us information that they have gathered from several sources and we would welcome anything that you may have that pertains to this.

Mr. Nance: On this particular thing we actually have a contract that provides the explosives instrumentation for this particular test. The Thiokol explosives classification test has not been completed. As far as first stage Minuteman is concerned, its classified Class B based upon ice cream carton tests if you can imagine it. We have quite a bit scale-up to do.

Lt. Ball: Excuse me, the Class B I referred to was the classification given by the Explosives Bureau.

Mr. Nance: Mr. Schultheis in your run-down here you've brought out something that we've observed, you brought out the point that we had partial contribution I believe on the Nike-Hercules and you actually had a classification of Class A based on 25% of the motor content. I'd just like to comment that on many of the propellants that we have tested, the classical propellants, we have not been able to measure a classical detonation, we have not been able to look at it with a camera and high-speed instrumentation. We've not been able to measure classical velocities up in the explosive range, however, if you walk up to the test site after the test, it makes very little difference whether it went high order as people tend to refer as detonations or not, the damaging affects are there. And we've been able to detect some partial contributions from a host of propellants depending upon the condition, how big the booster is, etc. I think this very definitely has to be worked in that on most of our engines that we're testing, it's not a matter of it being Class A or Class B, it's more of a matter of how much damage is this thing going to create around the area if and when this thing is subjected to an explosive booster initiation.

Mr. Schultheis: One of the things I made from the report, namely because it might be called circumstantial evidence, is the fact that during the control tests and after the first live test the observers noted or observed a very definite difference in the blast wave, however, these eye brow calibrations sometimes don't go over too good in a technical group, but what you say is true, observation certainly tells a lot, it may be documented at times, but sometimes it's best to forget about the observations and use the facts at hand.

Mr. Jezek: I think on these Nike Hercules tests when you don't ship that propellant with the warhead, you ship it as a Class B item, if I'm wrong Mr. Queen can correct me. We were merely trying to find out in those particular tests how much contribution we would get from the propellant in the event the warhead would go. If you ship that propellant by itself, you'll find you can ship it as a Class B item. In regard to trying to classify these items in accordance with the amount of damage that can be done, to give you an example - several years ago we had some black powder that went off at one of our plants. Across the creek you had no damage at all to any of the windows but 20 miles down the valley you had glass breakage, so when we start classifying these things in accordance with the amount of damage that's going to be expected, I don't think we should get into that.

Mr. Schultheis: What I meant was let's determine the equivalent pounds of TNT that say 40,000 lbs. of propellant can contribute under certain conditions, not trying to actually say it's going to break windows ten miles away but use conventional experience and data that we have to do this.

Mr. Jezek: I think that's what the ICC classifications are for, whether you can expect damage from blast in the event of a Class A item or just a burning effect from Class B.

Mr. Nance: Lt. Ball, in your test cartons, I presume you were talking about the double base composite propellants, you were talking about plexiglass discs, the first time around I assumed these were cylinders, but the second time around I assumed they were discs placed to stop the booster from going through. Is that correct?

Lt. Ball: That's correct.

Dr. Ball: I'd like to second this plea for better definition of these tests. In particular this 30 gram tetryl test, it's pretty well established that the geometry of that 30 grams of tetryl makes quite a difference, if you have it laid out flat you get one kind of results, if you want to get the most out of it you have it in a form of a cylinder or a cylinder cone top 3 diameters long. That should be sooner or later spelled out in this test. Also we would like to know where you get a 30 gram tetryl pellet. The nominal 30 gram tetryl pellets that we have secured from somewhere or other weigh 22 grams, so it sort of looks as though somebody should be set up to make the official pellet.

Mr. Herman: The only thing I can say in answer to this Dr. Ball is that we have been using a cylindrical 30 gram pellet in all the tests that we have been conducting over the last several years and I don't know where they're coming from or who is making them, but we haven't had any difficulty. Mr. Roylance do you know where Dahlgren gets those pellets.

Mr. Roylance: No.

Mr. Jezek: They probably took them out of some reject fuzes they had, but the reason that we use the 30 gram tetryl pellet was because the average fuze that we had contained approximately that much tetryl and we feel that if you can take a 155 or a bomb or any other amount of regular high explosives, not these exotic explosives that I've hear mentioned here but the regular run of the mill explosives and you hit it with a 30 gram pellet, if it's going to go high order, it should go high order with that particular amount of tetryl.

Dr. Ball: It looks to me like you've been using the same pellet we have, we made a mistake in weighing it. I also wonder, since classically explosive hazard classifications have been based on anticipated exposure and classically the exposure has been to a magazine fire, anything beyond that was considered insignificant. Are we on firm ground in having single valued explosive hazard classifications for items that are going to have the variety of exposures we anticipate today.

Mr. Herman: Essentially we realize this and the reason we're going to have to establish different test criteria for different situations and we will have one set of criteria to cover the problem that you're faced with from the time this item was manufactured until you get to the place where you're going to assemble it or test it or something else. Another entirely different set of criteria, when you get it there and get it assembled, similar to the tests on the Hercules or Hawk where you will have large known explosive charges adjacent to it. You'll have as on the Minuteman, three different formulizations of propellant, different stages, you're going to have to have tests to predict what your hazards would be at that time which may be entirely different than the hazard that you would have on the individual item when its in storage or in transportation. We realize that we're going to have to break this down into several groups and then you'll have to decide which ones you want to apply to this particular system. You won't apply all of them across the board to every system.

Mr. Endsley: I'd like to expand just a little on this Dr. Ball. This was very true and I don't think our classification originally will stand true for all of our situations. You take the Minuteman in particular, when in a production facility, we have a large amount in one motor since we have a large amount of Class 9 material and a great volume of Class 2 material proven out by various tests. You combine the two and in an aboveground situation, we can withstand a certain blast pressure from the Class 9 item but our greatest hazard may be from the incendiary material thrown out. That is a fire brand hazard and a missile hazard which we have to discount for barricades and get distance as opposed for the small amount for Class 9 material so it is a combination dependent upon the situation whether its in production, or its in a hole in the ground and we've got a very definite situation there. You being very familiar with dynamite and cratering experience you can put dynamite in a hole and not tamp it, you'll only push the mass up the top, you'll get no action. But on the other hand if you put a few handsful of good clay in there and something else happens, entirely different. We're trying to relate this to our system dependent upon the situation and the environment. I think you're right that we have variable conditions that have to be taken into consideration.

Dr. Ball: One final comment, everyone in the industry that I have talked to says that they are real happy with this TB 700-2 document and the same document under the two other designations except for the fact that there's nothing in this document that predicts the answer once the data are in. I think from Mr. Herman's talk that he is not quite ready to give out with that answer.

Mr. Herman: The determination of the classification after you have conducted these tests will be up to the safety organization of the Service concerned and this must be in accordance with the regulation agreed to by the other two Services. Maybe today they're not interested but tomorrow they may find they have to use it. In the event that there is a disagreement between the three Services as to what the proper classification should be on these items, the regulations stipulate that it will be sent to the Board for resolution. This resolution may require additional tests, it may require more instrumentation, etc., fortunately we haven't had this come up as yet.

Dr. Ball: You all see what I mean, it's not up to the individual contractor to come up with an answer on the military classifications, he's got to wait until somebody else comes out with it. We will continue to look forward to the day when you can predict your answers from a given set of data.

Dr. Noonan: I would like to underline the business about the 30 grams of tetryl that Dr. Ball was talking about. Not only does this depend on geometry but it also depends quite markedly on the density of the tetryl since the showing yesterday, the pressure developed is rather important in whether explosive goes or doesn't go. The pressure that you get from tetryl or from any explosive is quite dependent upon pressure, it comes in not only as a density itself but because the detonation velocity varies linearly with pressure and the particle velocities depend on the shock velocity so that you wind up with something larger than a power of 3 on density. In other words, we've got a lot of spelling out to do if we're just going to use 30 grams because a real sadistic person can make this do almost anything he wants to, make it harmless or make it very dangerous.

Col. T. R. Hikel, USAF (Ret.), Boeing Airplane Co.: Boeing, as assembly and test contractor for Minuteman, is most desirous of knowing whether in event of a detonation of the third stage Hercules engine there may be a contribution from the first and second stage?

Lt. Ball: The only comment I have is that this sort of thing is being worked right now, I do not have an answer on that and I feel pretty certain no one has in terms of numbers what type of weights we're talking about here, assuming as Mr. Endsley has pointed out, certain percentage yields from the third stage, again from the second stage, then from the first stage, and this has been done, assign numbers, etc., but as far as I know a definite position has not been taken on this.

Col. Hikel: I'd like to recommend to the Air Force Member of the Board that this either be expedited and give us some valid answers or that an immediate program be established in concurrence with Mr. Lineberry's recommendation, to the effect that this be tested and tested full-scale and tested in the most expeditious manner.

Mr. Endsley: We recognize the recommendation. ARDC has the prime responsibility for this function and we had a briefing last Thursday on the Minuteman system as it related to real estate acquisition. It was the position last Thursday, that we would look at the analysis that they had completed at BMD, and ARDC has the paper in hand at the moment and it is being brought up to date and validated and they are getting a little more into the document. As a basis of this study, then we will possibly be able to take action on the recommendation. Does ARDC have anything to add to this?

Mr. Ullian: The MAB building at the Cape was designed for Class 9 and 10 criteria with about a 20% overload of the total propellant. Instead of some 56,000 lbs., the design criteria was built around 68 and 70,000 lbs. When this criteria was established, so at least at this facility we have some assurance and some plus factor of safety.

Mr. Endsley: It is a total net weight plus a 20% factor. So in the R&D area and in the production area in which Boeing is quite concerned, we have taken this into consideration. This is the reason I don't get too excited about the recommendation at this time and point out that the most important area in which we have concern at the moment, is real estate acquisitions for the holes that we're punching in the ground. We needed this data two years ago, we need it now or whenever we can get it, but for Boeing's consideration in the production plant, we are considering total product as a mass detonating item. Taking into consideration the dispersement of incendiary material that I spoke of awhile ago that we could not depend upon barricades, we had to get distance to compensate for this dispersement incendiary phenomena.

Col. Hamilton: ARDC has asked that the item on Dyna Soar utilization of solid propellants be cancelled at this time. They will bring it up when more information is available, probably next year. We have one remaining item 'high energy propellants of the future,' Dr. Shuey of Rohm & Haas.

Dr. H. Shuey, Rohm & Haas Co.: Henry Dyer asked me to give a little talk about the propellants of the future. After hearing some of the other talks I think we should start concentrating on what we have now instead of propellants of the future so you'll get out a little earlier. Basically what people have been looking for in the last 4 or 5 years in propellant research is to increase the specific impulse of the propellant systems. We have just about reached the limit of energy which we can get out of the conventional systems such as defined by the present PBA, aluminum ammonium perchlorate, or polyurethane ammonium perchlorate aluminum systems. This specific impulse is about 245 to 250. There are only two directions we can go for improving the performance of our missile systems. One for those systems which are volume limited to increase the density of the propellants and for those systems which are not volume limited and are extremely long range, to get a higher specific impulse even at the sacrifice of some density. Now, if we're going to get a higher specific impulse propellant, we're going to have to go to new materials and these new materials are going to present some rather novel hazards. For those of you who are concerned with the production of end items, when we talk about future propellants, if you're willing to stop at 1965, you can go home. Because in 1965 your end items will be what we're talking about today. There will be no really novel propellants and end item utilization by that time. To those of you who have development safety responsibilities and ICC classification responsibilities, there will be significant differences in the formulations and types of propellants which will be accepted. Basically to get higher specific impulse, one chemically tries to get materials that have weaker bonding forces and convert them into products which have higher bonding forces. If we'll think back a minute, the weaker the bonding force is, the more labile the system is going to be. If we can get a system which has essentially no energy connecting these together, then these are converted to inorganic salts like iron, fluoride, etc., and we could get quite a tremendous specific impulse. One of the few things we have learned about detonation sensitivities in the last two years is that they have a very good correlation between the ability of the chemical bond, the weakest chemical bond in the system, and the sensitivity to a shock wave which passes through that material as far as converting this to a stable state detonation. The absolute energy of the system doesn't seem to have a direct correlation with the sensitivities of detonation. It does seem to have a correlation with the ciritical diameter for detonation but the lability of the weakest bond in an energetic system very definitely appears to be correlated with the sensitivity to a shock wave passing through that material. One of the types of systems we're going to be looking forward to is a very weak bonded material such as those based on the light metal hydrides, those based on fluoriding compounds, particularly the NS bonds, which is a very attractive bond as far as energetics is concerned or we're going to have to go to materials which are presently considered incompatible as far as making a mechanical mixture. We might get around the sensitivities to detonation by making a system which requires diffusion processes to occur before detonation can be accomplished. If we could take a material like nitronium perchlorate, or perchloric acid, I don't care which, if you get a good strong oxidizer and could put this in the present bonded systems it might prove advantageous. Unfortunately, they react immediately. One of the systems which has been proposed for future considerations is the use of incapsulation techniques to incorporate such materials in the binders for higher specific impulse propellants. I'll be willing to bet anyone here that in 1965 there will be no incapsulating propellants being used in this country. If one considers that one has to have a reasonable particle size for combustion, one can compute they will have to be on the order of 10 to the 12th particles of incapsulating material in the rocket motor. If one considers that each one of these is the head of a strike-anywhere match which may go off from breaking a small hole and the fuzing-out from any friction from anything else, one can see a tremendous difficulty even if we could prepare such systems. I think they will be investigated in a laboratory for quite some time and I'm very impressed with the papers on the safety shields. I predict we'll have great use within the next two to three years for any data which may be available on safety shields, safety gloves, and devices which will protect poor innocent chemists from blowing their fingers and hands off. One prediction we might make incidentally, if we look over the chemistry for future propellants, is that we might get rid of the worse thing we have now, the sigma blade mixer. The logical extrapolation of the chemistry which is before us for the new systems shows that we will not be incorporating a higher percentage of solids into a very viscous system and it is only the incorporation of a high percentage of solids into a viscous system that requires the close tolerances and high work function of a sigma blade mixer. In all probability the propellants in the next five years will be made in top driven agitators with no submerged bearings and having very large clearances where if you must drop pieces of screen or monkey wrenches into the mixer, you will not be plagued with fires and explosions. There is another hazard which, if not really germane to this organization, is connected with it, this is the results of a fire and explosion in a novel propellant system of the future. Most of the systems which we have been dealing with give us prior to decomposition, minor oxide of nitrogen, carbon dioxide and perhaps hydrochloric acid from ammonium perchlorate. If we consider that we might have partial detonations of fires which are not completed in processing areas of the future, using materials of compositions such as hydrides of boron or heaven forbid, beryllium, or if we consider that we will have flourides whose product of decomposition is hydrogen flouride in large concentrations in areas, it may be seen that quite a number of the processing facilities which we presently have will be inadequate for the manufacture of these compounds. Furthermore, since we are trying to make more labile bonds in these compounds in all probability we will be dealing only with Class 10 materials. I would predict then that in the future the development propellants which we have will be made with operators protected in open air facilities and light cello-glass screening around the mixers so that noxious fumes from the raw materials or from the decomposition can be vented in the open air and not use the present building structures which are used for conventional propellant. As to when these propellants will be available, we are already having accidents in the laboratory on the ten (10) gram quantities. I predict that next year we will see significant accidents in the laboratory with 100 gram quantities and that in two years we will have minor detonations and fire in pilot plants with 5 lb. quantities, but I don't believe we will be in any reasonably large scale detonations or hazards until about 1964. Of the systems which appear to be most promising there are some possible advantages. There is considerable work going on among at least three organizations in the country to determine what actually causes sensitivity and therefore to devise techniques of desensitizing these new materials. It is quite obvious that we will not be manufacturing materials with sensitivities four and five times that of nitroglycerine, we had enough problems before with nitroglycerine and no one ever uses it as a liquid mono-propellant, it was always colloided with nitrocellulose. There is significant work, however, going on, particularly in the fields of NE chemistry, for desensitization of the compounds and we can look forward to having some better knowledge about the propellant systems we are presently using because of the work that is going on with the futuristic propellants. I have one or two small comments about the present systems. I would hope that in the future propellant systems, instead of rushing out immediately to a test stand to try out a new formulation comprising new materials or compositions so that one can get data, which one can give to ones salesman to go around to various Service installations to sell new rockets, that we enforce some sort of a regulation where all new material is considered Class 9 and that some of the first propellant which is made is used to determine adequately in the scientific manner the safety classification and the hazard involved in the handling of this material.

Mr. Graham: I don't have a question for Dr. Shuey but I would like to make a statement, something that he's well aware of and I think perhaps some of the members might be. In all the ARGMA contracts for the development of new propellant, it requires the test that he just mentioned. That might be useful to some of the other Services if they did the same thing.

Dr. Shuey: I'd like to stretch it one point further though, I don't like dixie cups.

Mr. Graham: I think I missed the dixie cup discussion, what do you mean by that?

Dr. Shuey: I said, when I qualified the statement, an intelligent test designed to assess the hazard involved in handling these propellants and I didn't count the dixie cup test as being an intelligent test.

Col. Hamilton: We still have a couple of minutes left to general discussion on things which relate to the seminar as a whole or the over-all broad picture.

Is there anything from the floor that would be of general interest at this time.

Mr. Ullian: Does anyone have any information or run any tests with these can opener or ripper devices for hold-downs, in other words, possibly, STL, Aerojet, Thiokol, working with the Minuteman system, on these can opener ripper devices for thrust neutralization? Has any work been done to see whether this thing is going to cause the motor to deflagrate or what's going to happen? Does it just open it up and let it burn normally or what?

Dr. Shuey: I think I've seen this little jewel you're referring to, I believe its on your static tie-down facility, however, no tests have been run. It was based upon several incidents that occurred with engines of this size; if you start the engine moving forward, it stands to reason that if you cut a small segment in it that the case is going to fall apart, it's so highly stressed, it will probably come unglued, but no tests have been run.

Mr. Bishoff: I think a word of caution is perhaps in order here. I'd like to address a few moments to the subject of atomic weapons. There is an intense interest in the safety of atomic weapons as you may well understand. This interest stems from the Office of the President all the way down through the Department of Defense, the Atomic Energy Commission, Defense Atomic Support Agency and naturally all of us and all of the department contractors. There are safety studies going on all the time on the atomic weapons systems and two of the safety standards which must be met are these; one that if involved in an accident, the atomic weapons systems shall not result in a nuclear yield and the second standard that there should not be an inadvertent launch or inadvertent drop of an atomic weapons system. I think that we have heard here in this seminar that our propellants are getting hotter and hotter, they are tending more toward high explosives than propellants that we used to know. We hear the term incapsulate with the inherent hazard that if the capsule is broken, there is a fire and we might expose the atomic warhead to a very hot propellant fire or perhaps a detonation. Now these atomic weapons are safe from a nuclear point of view but there is no real point in unnecessarily exposing them to detonations or fires which could result in the explosion of the high explosives in the atomic weapons and the release of radioactive material to the atmosphere. We have talked about the hazard of RF energy and we hear that R&D people like to use small light units which provide high energy. These are electrical or electronic components and therefore we have the hazard of RF on our hands. The word of caution that I am proposing to you is this; its necessarily vague because only you perhaps understand the relationship of the material that you're working with with a possible atomic device, so we must keep in mind in the years in the future that nothing we do in designing a propellant system shall endanger the atomic device.

Col. Hamilton: Thank you Mr. Bishoff. Gentlemen, you'll get copies of the minutes as soon as we can get them to you. We hope that, knowing the type of problems that the other people you have met here are interested in, and knowing those people who are interested in problems that are similar to yours, you will get together with them in the future, correspond with them, or set up relationships so that you can exchange information so, as new problems develop, you can exchange methods of keeping some of the safety hazards under control. We appreciate very much your coming out here and spending this time with us. We appreicate very much Mr. Henry Marsh coming down and participating in this seminar. Thank you gentlemen, the conference is ended.