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SAFETY ANALYSIS OF X4 MULTI-TOOLED IOWA DETONATOR LOADER

J. H. AGOSTI
R. W. COURTNEY
R. G. HUNT
W. L. EASTERLING

HERCULES AEROSPACE DIVISION
HERCULES INCORPORATED
ALLEGANY BALLISTICS LABORATORY
CUMBERLAND, MARYLAND

GRUNDE R. HAUGETO, PROJECT ENGINEER
ARRADCOM, DOVER, NEW JERSEY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A safety analysis has been performed on the X4 multi-tooled Iowa detonator loader. The operations, equipment and personnel hazards were considered. The loader is a press loading and assembly machine, designed to load and assemble four detonators simultaneously using NOL-130, lead azide, and RDX explosives. Potential hazards were identified and recommendations were made for reducing the probability of fire or explosion and for reducing the severity of an incident should one occur. Accident expectancies were established and

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20. ABSTRACT (Continued)

compared with goals set forth in DRCPM-PBM Memorandum 385-3. Additional tests and analyses were recommended where warranted.

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CAUTION

Conclusions presented in this hazards analysis report are based upon the design, materials of construction, operating conditions, process materials and procedures as they existed at the time of the analysis (or as they were presented to Hercules for analysis). If changes in any of these parameters occur in the future, the conclusions of this hazard analysis may be invalidated.

SUMMARY

The objectives of this report were to investigate the design and operation of the X4 multi-tooled Iowa detonator loader (located at Iowa Army Ammunition Plant), and to (1) identify critical areas where a potential hazard could result in a fire or explosion, (2) evaluate the hazards to operating personnel in the event of an incident, and (3) provide design criteria to eliminate or control the hazards.

The potential hazards to personnel and equipment were identified and were classified into hazard categories in accordance with DRCPM-PBM Memorandum 385-3. Results of this study show that:

1. The accident expectancy in category IIA (critical) for the loader is 1.5×10^{-5} accidents per facility hour, which exceeds the design goal of no more than 1×10^{-5} accidents per facility hour.

2. Operating personnel are exposed to category IIIB (marginal) hazards during operation of the loader. The design goal is that operators be exposed to no greater hazard than category IV (negligible).

3. The loader contains bronze (copper alloy) bearings* which can become contaminated with lead azide and can form a compound more sensitive than lead azide.

4. The loader must be kept free of contamination while in operation to prevent the propagation of a fire or explosion along the path of the contamination from one station to the next.

5. To minimize the potential for personnel injury during manual handling of explosives during maintenance operations in shutdown periods, operating safety procedures must be strictly adhered to.

6. Because alcohol and other solvents are used during cleanup operations for this loader, electrical equipment associated with the loader (particularly that used in exhaust ventilation systems) should be classified as Class I, Division 1, Group D atmos, [illegible] in accordance with electrical equipment and hazards environment classifications, in addition to the currently specified Class II, Division I, Group G dust service. The temperature identification number should be T5.**

To develop an optimum system with minimum hazards to personnel and equipment, it is recommended that work in the following areas be considered

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*It is noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that IAAP has used bronze bearings for many years with no incidents.

**Per NEC Code, Table 500-2(b), National Fire Code, Volume Six (1975).

to achieve the design safety goal of less than 1×10^{-5} accidents per facility hour for category IIA.

1. Determine through testing the spacing required between detonators to prevent propagation and to minimize tooling damage.

2. Disassemble the loader after it has been working for a number of hours to determine if the interior has become contaminated. If contamination has occurred, use seals or positive pressure technology to prevent future contamination.*

3. After a hazards analysis has been conducted for each subsystem in the loader bay, perform a total system hazard analysis (TSHA) and an operating and support hazard analysis (OSHA). [The TSHA considers the interrelationships between the various subsystems (i.e., cup feeding, detonator loading, explosive receiving and handling, and safety of operations. The OSHA provides a review of all procedures (operating, maintenance, and inspection) used to operate the system.]

4. Replace bronze bearings in the loader with bearings made of compatible materials (e.g., materials that, when contaminated with lead azide, will not form compounds more sensitive than lead azide).

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*Inspection of a similar single-station loader has shown no contamination, according to correspondence to Hercules from Vinvent A. Latuso of ARRADCOM dated July 8, 1980.

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INTRODUCTION

Iowa Army Ammunition Plant (IAAP), Middletown, Iowa, is presently developing an X4 multi-tooled Iowa detonator loader to increase the capacity of their detonator loading line. This loader which is essentially a highly modified version of an Iowa loader, is in the production prototype stage. The rotating equipment is a press loading and assembly machine designed to load and assemble four detonators per index at a speed of 35 to 45 cycles per minute. The detonators are loaded with NOL-130, lead azide, and RDX explosives.

A safety analysis has been performed on the equipment. Sensitivity data of the explosives involved in the analysis were previously published[1] by Allegany Ballistics Laboratory. The analysis was performed in accordance with DRCPM-PBM Memorandum 385-3, ARMCOM Regulation No. 385-4, applicable parent regulations MIL-STD-882 and AR385-16, and the contract scope of work. The objectives of the contract have been satisfied through the use of the Hercules Hazards Evaluation and Risk Control Program (HERC®). This quantitative technique, developed by Hercules in 1958, has been generally accepted throughout the industry as a practical and cost-effective method of evaluating industrial hazards.

The process information used by Hercules to provide the hazard evaluation was based on the following sources: (1) equipment manual for X4 series Iowa loader, (2) equipment technical data package specifications for DARCOM Project No. 5782765, Exp.-Line 4A L/A/P Detonator Facilities, (3) drawings supplied by IAAP, and (4) information obtained from IAAP personnel. A list of drawings and documents used in this analysis is found in Appendix A.

This report includes (1) a description of the loader, (2) a listing of the potential hazards associated with the loader, (3) classification of the potential hazards, (4) a discussion of the hazards to personnel during loader operation, (5) a comparison of subsystem (X4 loader) accident expectancy with the design goals of DRCPM-PBM Memorandum 385-3, and (6) recommendations for corrective action to reduce the hazard level associated with the subsystem.

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[1] Groce, T. A., et al., "Hazards Analysis of Detonator Charging System," AO 8174-520-03-001, Allegany Ballistics Laboratory, Cumberland, MD, 1973.

DISCUSSION

DESCRIPTION OF LOADER OPERATION

The function of the A4 Iowa loader is to load and assemble the M-55 detonator, a small aluminum cup capped with aluminum foil containing three consolidated explosives. The rotating body of the loader is manufactured by Swanson Erie Company and is powered by a 3 HP, 1750 rpm motor with a variable pitch sleeve driving a shaft through an air clutch and brake system. There are 24 work stations around the machine for different operations, with each station capable of producing a group of four detonators. The machine can operate at variable speeds and can produce detonators at a rate of approximately 200 per minute. All stations operate simultaneously; i.e., each indexing step moves the machine 1/24 revolution, and a new batch of detonators is started through the process after each indexing step.

The operations start at station 1 where aluminum cups from a cup feeding mechanism are positioned on the indexing table. The cups are placed in tooling blocks in groups of four by means of vacuum entrapment. The table is then indexed, moving the cups to station 2 where the operation continues on the first load of cups while a second load of cups is loaded at station 1. At station 2, a powder guide is placed over each cup and is held in place by a spring plunger pin which uses a pick and place mechanism. From here the aluminum cups are indexed through station 3 (an access door station) and into position at stations 4 and 5, where metering of the first explosive takes place. In this explosive filling operation, a phenolic spoon* scoops the primer material (NOL-130 explosive) from an aluminum bowl. The spoon is lifted and the excess explosive is removed from the spoon by a velostat doctor blade. Then the remaining explosive is dropped into a powder chute. The explosive passes through the powder guide and into the detonator cup.

At station 7 the NOL-130 explosive is compressed to approximately 580 MPa (84,000 psi) in the detonator cup.

After passing through another access door station, the cups are indexed to stations 9 and 10 where lead azide is dispensed from a feed hopper into the detonator cups. In metering of this explosive, a volumetric ball feeding mechanism is used in which the lead azide is gravity fed from a hopper into volumetric sized holes drilled into four balls attached to a shaft. Rotation of the shaft results in a turnover of the balls and emptying of the explosive into the detonators.

At station 11 the lead azide in the cups is compressed to approximately 103.4 MPa (15,000 psi). The operation at this station is similar to that at station 7, and a hydraulic system is used for controlling the pressure which is developed by the mechanical action of the loader.

At station 12 aspirators are used to remove from the powder guides any loose explosive that was not consolidated during the compression operations. After this vacuum cleanup operation is performed, the table is

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*It is noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that the spoon material has been changed to stainless steel.

indexed and the detonators are transferred to station 13. Here the powder guides are removed from the tool block and placed on the rest posts. A pick and place mechanism working in reverse of that at station 2 is used for this removal operation.

At station 14 RDX pellets are fed into the sliding pellet feeder and are transferred over the detonator cups where the pellets are ejected by a ram. The RDX is next compressed to approximately 69 MPa (10,000 psi) at station 15 by an air driven hydraulic pump and press arrangement similar to those at the previous compression stations. After compression, extraneous explosive is removed by the aspirator at station 16.

After the explosive metering and compression operations, the detonators are capped with foil which is stripped from reels and fed through rolls and cutting dies. Foil is placed into the detonator cup located on the explosive beneath the lip of the cup, thus enabling the cup to be crimped. After the lip of the cup has been raised above the upper edge of the crimping tool block, a crimping tool is lowered. The cup is crimped over the foil disc to 45° at station 19 and is crimped to 90° at station 21. After the crimping operation, the detonator cup is raised from the tool block and moved upward into a rubber O-ring held by the transfer tool. The transfer tool is then positioned over the carrying card and the detonator cups are then transferred to the metal carrying card, where they are moved to the accept-reject station. Detonator cups which have been deemed unacceptable at any step in the process are ejected from the carrying card with compressed air and allowed to fall down a pipe chute into a reject container. Next, the card is pushed off the machine by a ram into a conveyor for final packout operations.

MATERIAL SENSITIVITY

Explosives used in the detonators are described in table 1. Two of these explosives (NOL-130 and lead azide) are primary explosives[2] which are extremely sensitive to mechanical action, shock or electrical energy. These explosives will detonate rather than deflagrate or burn when initiated because the rate of advance of the reaction zone into the unreacted material will exceed the velocity of sound in the unreacted material. The third (RDX) is considered to be a secondary high explosive (sensitive to initiation) which can be detonated by the explosive shock from a primary explosive. The sensitivity characteristics of these explosives in the detonator were reported in previous reports; therefore no sensitivity tests were performed during this study.

Applicable data generated earlier by Hercules are summarized in tables 1 through 5. Probit curves were developed from the friction, impact and electrostatic discharge material response test results and were used to

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[2] Engineering Design handbook, Ammunition Series Fuzes, Headquarters, U. S. Army Materiel Command, AMCP 706-210, November 1969.

determine probability of initiation in the analysis of the loader. These curves are shown as Appendix B.

Table 1. Explosive materials used in M55 detonators

Explosive	Description	Weight (mg)
NOL-130	Composition: 40% lead styphnate 20% lead azide 20% barium nitrate 15% antimony sulfide 5% tetracene	15
Lead azide	This composition will form extremely sensitive and dangerous copper azide in presence of moisture with copper	52
RDX	This explosive is considered to be the second most powerful standard military explosive.*	19
	TOTAL	86

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*Military Explosives, Department of the Army and the Air Force Technical Manual, TM 9-1300-214 to 11A-1-34, 1967.

The threshold initiation levels (TIL) for impact, friction, electrostatic discharge, and impingement of the explosives used in the detonators are shown in table 2.

Impingement

Table 3 shows the results of impingement tests (previously conducted) for the explosives used in the detonator. Neither NOL-130 nor RDX could be initiated when tested with air stream velocities up to 346 m/s (68,000 ft per min). However a threshold initiation level was established for lead azide at 42 m/s (8250 ft per min). Because of the impingement sensitivity of lead azide, the air stream velocity in the dust pickup system (aspirator) should be limited to 42 m/s (8250 ft per min).

Dust Explosibility

Table 4 shows the results of dust explosibility tests (previously conducted) for NOL-130. The minimum energy required to initiate the dust is the same as that required for initiation of the explosive by electrostatic discharge. The minimum dust concentration required for initiation of NOL-130

Table 2. Threshond initiation levels* for detonator explosives

Test	Explosive		
	NOL-130	Lead Azide	RDX
Impact, J/m^2 (ft-lb/in.^{2})	1808 (0.86)	22,070 (10.5)	27,070 (12.88)
Sliding Friction, GPa (psi)			
Steel/steel @ 0.04 m/s (1/8 fps)	0.19 (27,500)	0.27 (39,200)	-
@ 0.15 m/s (1/2 fps)	0.13 (19,300)	0.20 (28,300)	-
@ 0.31 m/s (1 fps)	0.05 (7,250)	-	0.46 (66,700)
@ 0.61 m/s (2 fps)	-	-	0.45 (65,250)
Steel/Al @ 0.0- m/s (1/8 fps)	0.11 (15,400)	-	-
@ 0.15 m/s (1/2 fps	0.07 (10,200)	-	-
@ 2.4 m/s (8 fps)	-	0.31 (44,300)	0.36 (52,000)
@ 3.1 m/s (10 fps)	-	0.23 (33,600)	0.33 (48,400)
Impingement			
Particle weight, gram (ounce)	0.5 (0.018)	0.5 (0.018)	15 (0.53)
Velocity, m/s (ft/min)	345.7 (>68,000)	42 (8,250)	345.7 (>68,000)
Electrostatic Discharge, joules	0.0022	0.0028	0.50

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*Threshold initiation level (TIL) is the highest level established in a series of tests at which no initiations occurred in at least 10 consecutive tests; i.e., initiations were observed to occur at the next highest test level. TIL is usually stated to be at the level where probability of initiation is 0.034, corresponding to no initiations in 20 tests.

Table 3. Impingement initiation test results

Explosive	Air stream velocity m/s	Air stream velocity ft/min	Tials	Shots	Results
NOL-130	33.0	6,500	1	0	
	63.0	12,400	1	0	
	122.5	24,100	1	0	
	175.4	34,500	1	0	
	345.7	68,000	10	0	TIL
Lead azide	33.0	6,500	4	0	
	42.0	6,250	10	0	TIL
	47.0	9,200	1	1	No noise
	63.0	12,400	1	1	Slight noise
RDX	345.0	68,000	10	0	TIL

Table 4. Dust explosibility test results for NOL-130

Minimum concentration[a]	0.037 kg/m^3 (0.37 oz/ft^3)
Minimum energy[b]	0.0028 joules
Total volatiles	0.05%

	Concentration, kg/m^3 (oz/ft^3) 0.5	1.0	2.0
Maximum pressure, GPa (psig)[c]	$1x10^{-9}$ (20	$3.4x10^{-4}$ (49)	$6.2x10^{-4}$ (90)
Average rate of pressure rise, GPa/s (psig/sec)[c]	0.002 (301)	0.014 (2093)	0.032 (4709)
Maximum rate of pressure rise, GPA/s (psig/sec)[c]	0.004 (573)	0.030 (4410)	0.135 (19580)

[a]Lower explosive limit. Ignition source, continuous 24-watt spark.

[b]Minimum energy determined by variable spark discharge at twice the minimum concentration.

[c]Average of three tests.

is 0.37 kg/m^3 (0.37 oz/ft^3). In-process concentrations of dust would not be expected to be as high as this minimum.

Electrostatic Charge Generation

In a previous study, the electrostatic charge generation potential of the detonator explosives and the specific conductivities of NOL-130 and lead azide were determined. The bulk resistivity was determined by placing a sample of NOL-130 or lead azide between two electrodes and measuring the resistance with a Keithley electrometer and then calculating the specific conductivity. The bulk resistivity of both NOL-130 and lead azide was greater then 10^{14} ohms. The specific conductivity for NOL-130 was less than 1.5 x 10^{-15} mhos per cm and for lead azide it was less than 8 x 10^{-16} mhos per cm (see table 5).

HAZARDS ANALYSIS OF LOADER

Table 6 shows the accident expectancy (50% confidence) for each hazard category of the X4 loader and table 7 shows the accident expectancy for each hazard identified for the loader. Table 8 shows the time between accidents for each category and is another format for presenting expectancy information that is suggested by DRCPM-PBM Memorandum 385-3.

Table 9 shows the result of a subsystem hazard analysis (SSHA) conducted for the loader. These data identify the potential hazards associated with the X4 loader, indicate the probability (95% confidence) of a fire or explosion associated with each hazard, and categorize each potential hazard or accordance with DRCPM-PBM Memorandum 385-3. A more detailed explanation of the information contained in these tables may be found in Appendix C. In addition to the fact sheets, it was required that ARMCOM Form 153-R be prepared. Table 10 presents the completed form for each accident category for the mean probability of an accident occurring per man hour or facility hour.

It should be noted that DRCPM-PBM Memorandum 385-3 specifies that these design goals are for a "project," so that the design goals would apply to the entire M55 detonator manufacturing system. However, for the purposes of this analysis, only the X4 loader is being considered relative to the design goals

There were no category I, II-B or IV hazards identified. The accident expectancy met design goals for categories III-A and III-B. For category II-A, the design goal was exceeded due primarily to the potential hazard (stations 4 and 5) of the spoon (or the setscrews securing the spoon to the holder) impacting the guide chute if the screws fail or loosen.* If a redundant method for securing the spoons is used and if the setscrews are potted to prevent loosening, then the expectancy for category II-A can be reduced to 1.9 x 10^{-7} accidents per facility hour, which meets the design goal.

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*In similar single-tooled machines, no incidents of this type have been detected while producing millions of detonators, according to correspondence from Vincent A. Latuso of ARRADCOM dated July 8, 1980.

Table 5. Electrostatic characteristics of NOL-130 and lead azide

	NOL-130	Lead Azide
Bulk resistivity	10^{14} ohms	10^{14} ohms
Sample thickness	0.58 cm	0.20 cm
Conductivity*	$<1.5 \times 10^{-15}$ mho/cm	$<8 \times 10^{-16}$ mho/cm

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*Using the relationship that conductivity = $(1/R)$ (ℓ/A) where R is the bulk resistivity, ℓ is the sample thickness, and A is the area of the sample.

Table 6. Accident expectancy summary for loader

	Accidents expected per facility hour		Accidents expected per man hour	
Hazard category	Design goal	From SSHA	Design goal	From SSHA
IA	$<1 \times 10^{-6}$	None identified		
IB			$<1 \times 10^{-7}$	None identified
IIA	$<1 \times 10^{-5}$	1.4×10^{-5}		
IIB*			$<1 \times 10^{-6}$*	None identified
IIIA	$<1 \times 10^{-3}$	2.23×10^{-5}		
IIIB*			$<1 \times 10^{-6}$*	1.4×10^{-7}
IV	1	None identified	1	None identified

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*The sum of the probabilities of IIB and IIIB shall be 1×10^{-6} or less.

Table 7. Iowa X4 loader accident expectancy

Hazard category		Potential initiation hazard	Accidents per Facility hour	Accidents per Man hour
		Station 1		
III-A	1.	Friction between cup press tool and tool block when tool block is contaminated.	1.6×10^{-5}	
		Station 2		
III-A	1.	Guide is picked up from storage post and placed on tool block		
		(Powder guide is dropped from tool.)	1.6×10^{-18}	
III-A	2.	Friction between powder guide and placement tool finger due to misalignment.	8×10^{-10}	
III-A	3.	Normal friction occurs between powder guide and placement tool finger.	8×10^{-21}	
III-B	4.	Operator drops powder guide during check of handler		1.6×10^{-9}
		Stations 4 and 5		
II-A	1.	Friction between doctor blade and spoon (normal)	6×10^{-12}	
II-A	2.	Friction between doctor blade and spoon (abnormal)	6×10^{-15}	
II-A	3.	Normal operation of bearing	1.4×10^{-10}	
II-A	4.	Spoon falls down into guide chute	1.4×10^{-5}	
III-B	5.	Doctor blade slide contaminated		1×10^{-7}
		Station 7		
III-A	1.	Friction between tool and powder guide	8×10^{-8}	
III-A	2.	Tool impacts powder guide due to misalignment	8×10^{-8}	
III-A	3.	Tool impacts tool block when P.G. not present	4×10^{-18}	
III-A	4.	RAM tool breaks during compression	4.8×10^{-8}	

Table 7 (cont'd.)

Hazard category		Potential initiation hazard	Accidents per Facility hour	Accidents per Man hour
		Stations 9 and 10		
II-A	1.	Dispenser seal on azide dispenser becomes worn	6×10^{-9}	
III-B	2.	Initiation of lead azioe occurs due to ESD from ungrounded operator		3.6×10^{-12}
III-B	3.	Initiation occurs during adjustment of set screws		5.6×10^{-11}
III-B	4.	Initiation occurs during placement of container on platform		$< 6 \times 10^{-15}$
II-A	5.	Impingement occurs while dumping	1.2×10^{-19}	
		Station 11		
III-A	1.	Friction occurs between tool and powder guide	8×10^{-8}	
III-A	2.	Tool impacts P.G. due to misalignment	8×10^{-8}	
III-A	3.	Tool impacts tool block when P.G. not present	4×10^{-18}	
III-A	4.	RAM tool breaks during compression	4.8×10^{-8}	
III-A	5.	RAM tool impacts broken RAM from NOL station	8×10^{-7}	
		Stations 12, 16, 20, and 24		
III-A	1.	ESD occurs between vacuum tool and tool block	4×10^{-9}	
III-A	2.	Vacuum tool impacts a broken tool	3.0×10^{-13}	
III-A	3.	Friction between vacuum tool and P.G. (normal)	6×10^{-14}	
III-A	4.	Friction between vacuum tool and P.G. (abnormal)	8.8×10^{-18}	
III-A	5.	Friction occurs in bearing	8×10^{-11}	

Table 7 (cont'd.)

Hazard category	Potential iniriation hazard	Accidents per Facility hour	Accidents per Man hour
	Station 13		
III-A	1. Powder guide is dropped to indexing table	1.6×10^{-18}	
III-A	2. ESD occurs when removing P.G.	$<2 \times 10^{-15}$	
III-A	3. Friction occurs when P.G. removed with broken tool present	8×10^{-7}	
III-A	4. Tool not raised resulting in P.G. being dropped	8×10^{-8}	
III-A	5. Tool not raised resulting in impact	3.2×10^{-13}	
III-A	6. Friction occurs between removed tool finger and P.G.	8×10^{-21}	
III-A	7. Friction occurs between slider block and tool support	4×10^{-6}	
	Station 14		
II-A	1. Friction of pellet on slide occurs due to misalignment of pellet slide	6.4×10^{-10}	
II-A	2. Pellet punch tool impacts pellet slide	2×10^{-8}	
II-A	3. Pellet punch tool impacts tool block	8×10^{-8}	
II-A	4. Friction of tool on tool block occurs	8×10^{-8}	
III-B	5. Friction initiation occurs during replacement of pellet tubes		2.6×10^{-8}
	Station 15		
III-A	1. Tool compresses RDX and checks powder height	4×10^{-18}	
	Station 17		
III-A	1. Friction of foil disc on cup	2×10^{-8}	
III-B	2. Friction initiation occurs during replacement of worn punches and dies		1.4×10^{-8}

Table 7 (Cont'd.)

Hazard category	Potential initiation hazard	Accidents per Facility hour	Accidents per Man hour
	Stations 19 to 21		
III-A	1. Initiation of detonator occurs during crimping		
	a. Foil disc failure occurs	$1.1 \times 1C^{-11}$	
	b. Detonator cup stuck in tooling or backup mechanism stuck	2×10^{-7}	
	Station 23		
III-B	1. Initiation of explosive occurs during changing of rubber chucks		$<2 \times 10^{-15}$
	Summary		
I	None		
II-A	Total: Hazard Category II-A	1.4×10^{-5}	
III-A	Total: Hazard Cateogry III-A	2.2×10^{-5}	
III-B	Total: Hazard Category III-B		1.4×10^{-7}

Table 8. Expected time between accidents

		Probability of accident	Expected time between accidents
Category I	- None identified		
Category II-A			
Worst case	- 95% LCL	1.66×10^{-5} per facility hour	60,255 facility hours
Mean	- 50%	1.42×10^{-5} per facility hour	70,488 facility hours
Better case	- 95% UCL	1.25×10^{-5} per facility hour	80,721 facility hours
Category II-B	- None identified		
Category III-A			
Worst case	- 95% LCL	9.53×10^{-3} per facility hour	105 facility hours
Mean	- 50%	2.23×10^{-5} per facility hour	44,800 facility hours
Better case	- 95% UCL	1.12×10^{-5} per facility hour	89,495 facility hours
Category III-B			
Worst case	- 95% LCL	9.25×10^{-5} per man hour	10,810 man hours
Mean	- 50%	1.42×10^{-7} per man hour	7.04×10^{6} per man hour
Better case	- 95% UCL	7.11×10^{-8} per man hour	1.41×10^{7} per man hour
Category IV	- None identified		

NOTE: All cases are for X4 loader subsystem as analyzed; i.e., no recommended changes made. Expected time between accidents should be substantially increased if the suggested changes are made to the subsystem.

In the analysis of the process operations of the loader, the areas of primary concern are those in which personnel can be injured and those areas where initiation of the explosives can result in severe equipment damage. The following sections discuss in detail these areas of concern.

Design Approach to Control of Personnel Exposure

Potential injury to personnel during operation of the loader has been minimized by the design of the loader and by safety restraints incorporated into the operating procedures. To protect personnel in the vicinity of the loader in event of a detonation, the operating areas of the machine have been totally enclosed by a protective shield. A transparent Plexiglas®/Lexan® barrier surrounds the loader at all stations except the explosive dispensing and consolidation stations which are enclosed by steel barricades having observation windows to observe process operations. Additionally, those stations in which the bulk of the explosive is processed incorporate vertical venting to ensure escape of gases in the event a detonation within the barricade occurs.

To minimize potential injury to the operators performing explosive replenishment operations, refill operations are limited to handling the more hazardous of the explosives, NOL-130 and lead azide, in two ounce increments. Further, all explosives contained in the machine are enclosed in barricades which have been designed and tested for the explosive quantity involved so as to present no hazard to operating personnel in the immediate area.

Potential Hazards to Personnel

During the manufacture of the detonators, injury to personnel can occur primarily in four ways: (1) during manual refilling of explosives in the detonator loading machine, (2) during maintenance of the system or during "process upset" conditions where operators may adjust or attempt to adjust a portion of the mechanism within the shielded area of the loader, (3) during daily cleaning of the machine, cleaning of the aspirator collector system, and removal of defective detonators, and (4) from an initiation within the machine by which injury results from projectiles emitted from an internal detonation or where injury results from the reactions of an operator after an explosion within the loader.

Manual Explosive Handling - Manual handling of the explosive material occurs during replenishment of the NOL-130 bowl, refilling the lead azide and replacement of the RDX cartridge tubes.

In refilling the NOL-130 scooper bowl, a conductive rubber receptacle holding two ounces of explosive is manually placed inside the foyer of the NOL-130 barricade on the dumping platform. The outside gate of the barricade is then closed and the inner gate of this primer barricade is opened. The explosive is then dumped into the scooper bowl by manual rotation of an external handle which is mechanically linked to the dumping platform. This operation is then repeated to load the second scooper bowl.

Replenishment of the lead azide dispenser is performed using a procedure which is approximately the same as that used when replenishing NOL-130. The primary difference is that the carrier is placed in the dumping platform and is secured with surgical tubing prior to dumping.

The events which could result in potential injury during manual handling of explosives are as follows:

1. Electrostatic discharge from the operator. Because a human being can typically accumulate an electrical charge of 0.013 joule, which is much greater than the TIL's for NOL-130 and lead azide (0.0022 and 0.028 joule, respectively) it is essential that personnel and equipment be grounded at all times to prevent an electrostatic discharge from occurring. Under such grounded conditions, the expectancy of a fire or explosion resulting from the potential hazard would be relatively low at 3.6×10^{-12} per man hour.

2. Dropping the explosive container while carrying it to the machine. Caution should be exercised by operators when handling containers of explosives because dropping could possibly initiate the explosive, thus causing injury. The impact energy developed by an inadvertently dropped container would be approximately 6300 J/m^2 (3 ft-lb/in.^{2}) which is substantially less than the material response (rubber/steel) for NOL-130 which is greater than 2.9×10^5 J/m^2 (136 ft-lb/in.^{2}). A safety margin of 45 and an expectancy of 1×10^{-10} accidents per man hour exists for this potential hazard.

3. Friction occurring when the receptacle is placed onto a contaminated platform within the barricade. Because of the relatively low frictional force encountered during this operation and the use of a conductive rubber container, the expectancy of an accident resulting from this potential hazard is considered to be remote (5×10^{-16} accidents per man hour).

4. Impingement of the explosive when dumping the explosive from the carrying receptacle into its' respective container. Because the TIL for lead azide impingement is 41.9 m/s (8250 ft/min) and the free-fall impingement velocity during dumping would be less than 1.5 m/s (300 ft/min) the expectancy for a potential accident as a result of impingement is less than 1.2×10^{-9} accidents per facility hour.

Because the gate is closed between the operator and the explosive being dumped, the probability of personnel injury resulting from debris caused by an explosion during the dumping operation is considered to be remote. However, a bright flash would occur from initiation of the explosive in the receptacle and the explosive in the powder scooper. If witnessed by an operator through the observation window, this bright flash could possibly result in eye injury or temporary blindness. Additionally, secondary actions of the operator reacting away from such an incident could also lead to potential injury depending upon the proximity of other equipment or personnel behind the operator. For these reasons, and to minimize any potential explosion, the total quantity of explosive placed in the powder scooper at any one time must be strictly regulated and maintained within the limit capabilities of the barricade and the observation window. Additionally, safety interlocks which ensure proper gate movement should be periodically checked to ensure proper functioning.

RDX is fed to the detonators from a row of eight stainless steel tubes. Refilling of this station with RDX is performed by manual replacement of the empty tubes with a rack of tubes filled with RDX pellets.

The primary hazards of concern during this operation are (1) the direct initiation of the pellets, or (2) initiation of explosive contamination surrounding the rack area with subsequent initiation of the pellets. With friction occurring between metallic surfaces, an in-process potential of 0.3 GPa (48K psi) at 0.15 m/s (0.5 fps) was compared to the material response TIL of 0.46 GPa (67K psi) at 0.3 m/s (1 fps) for RDX and a safety margin of 0.4 was calculated. From the overall probability of explosion (5×10^{-9}), an expectancy of 3.9×10^{-8} accidents per man hour was derived for the event. To maintain the expectancy level, extreme care must be exercised by the operator during this refill operation to eliminate any impact or friction stimuli which could result from faulty handling procedures. Additionally, the rack replacement area must be kept free of contamination so that initiation cannot result from inadvertent contact between contaminated parts.

<u>Maintenance/Process Upset Conditions</u> - Maintenance and process upset conditions are conducive to personnel injury primarily as a result of the contaminated conditions which may exist in the equipment and the exposure of personnel to unbarricaded machine parts. In maintenance operations, the tightening or removal of a contaminated bolt can be particularly hazardous due to the small area of potential contact and the resulting high stress energy placed on any contaminant present. During process upset, corrections and equipment adjustments should not be attempted without thoroughly cleaning the equipment. To minimize potential injuries, careful clean-up should be required before maintenance operations. Exposed threads should be potted to prevent contamination. Emergency maintenance should be performed with the proper awareness that all surfaces may be contaminated with explosive.

Because the in-process potential for maintenance operations and process upset conditions will frequently be greater than the material response of the explosive, no safety margin will exist and the probability of initiation will be one. If the process upset occurs as a result of equipment failure (the event probability will equal the failure rate; i.e., 7×10^{-6}) and the presence of explosive is due to operator error (fails to follow procedure and does not clean prior to maintenance; i.e., 1×10^{-6}), the total probability of explosion can be as low as 7×10^{-12} which would lead to an expectancy of 5.6×10^{-11} accidents per man hour.

Clean-Up Operations - Daily clean-up operations can become occasions for personnel injury depending on the operator's attitude because of the existing potential for an explosive incident. These operations generally occur at the end of a shift, at which time operators tend to become lax and less than normally conscious of the safety requirements for the task at hand. Additionally, another potential initiation hazard exists during clean-up with the use of alcohol. Alcohol is hazardous because its vapors will combine with air to form a combustible mixture. Within its flammability limits, alcohol can be initiated by an electrostatic discharge at an energy level which is one-tenth of that required to initiate lead azide. Therefore it is imperative that adequate ventilation be maintained during clean-up operations when alcohol is being used.

All electric motors and electrically operated components have been specified on the drawings as explosion proof in accordance with the NEC for Class II, Division I, Group G for hazardous locations. This classification is not adequate for operating conditions in the presence of flammable vapors. Therefore if alcohol or other solvents are to be used for cleanup operations, electrical utilities and assemblies, particularly those for exhaust ventilation systems should include the hazards classification for a Class I, Division I, Group D atmosphere. Temperature identification number should be T5.*

Personnel Injury Resulting From Machine Incident - Due to the presence of the barricade system which is designed to withstand an explosion of its explosive ingredients, and the presence of the plastic screen around the loader, the probability of a projectile being emitted by an initial explosion in the machine is considered to be low. However, because the hopper is designed to be larger than its operating capacity to minimize spillage, it is possible that excessive quantities of explosive can be added to the machine. This would reduce the effectiveness of the barricade. To prevent this occurrence it is emphasized that strict adherence to procedures must be enforced and that no more than the specified quantity of explosive can be allowed to be added to any container in the barricade.

Equipment Hazards - Potential initiation hazards to the equipment are of concern because explosive initiation within the equipment could result in severe equipment damage with resulting downtime and in potential personnel injury. Hazards to the equipment are listed in tables 9 and 10.

The new loader design processes four detonators simultaneously in every station, moving the groups of four progressively from one station to the next. To reduce severity of an incident, there must not be a propagation link between these stations or a propagation link between any detonator

*The National Electrical Code, Table 500-2(b), National Fire Code, Volume Six, 1975.

and an explosive hopper. Therefore, the table and path of the detonator must be kept in a condition in which an explosion cannot propagate due to the presence of contamination. The detonators must be separated to a distance that explosion of one will not propagate to the adjacent detonator. Explosive filling operations should be such that an intermediate operation or piece of equipment will ensure that a continuous chain of explosive does not exist between any detonator being processed and the site of an explosion. It is suggested that the filling station be examined closely to determine what modifications, if any, would be required to prevent an incident from propagating to the explosive in the bowl if initiation of the detonator occurred during filling operations.

Accumulation of explosive in the interior of the turntable could possibly result in major equipment damage and injury to operating and maintenance personnel. This accumulation of explosive in the inner workings of the machine would be increased if the solvent used for clean-up is allowed to flow into the machine interior and carry explosive along with the solvent. Therefore, it is recommended that the prototype machine be disassembled after a period of working time to determine if contamination of the interior has occurred. If contamination is apparent, seals or positive pressure technology must be utilized to prevent future contamination.

Explosive Dispensing - The first phase of the detonator loading operation where explosive material is present in the 24 station indexing machine is the loading of NOL-130 primer into the detonator cup at stations 4 and 5. Potential hazards within stations 4 and 5 include those resulting from manual replenishment operations and those resulting from detonator loading operations.

During explosive refill operations mechanical initiation stimuli are present which could result in equipment damage. Potential sources of localized initiations are primarily available from frictional stimuli within the linkages of the dumping mechanism and impact stimuli resulting from equipment failure. Because of the short distance the explosive falls during the dumping operation, initiation of the explosive from impingement with the bowl is considered to be highly unlkiely.

During the volume measurements of the NOL-130 for the detonator, an initiation stimulus is generated by the friction resulting from contact of the doctor blade with the spoon and friction occurring within the bearings.

The possibility of initiation due to friction between the scraper bar and spoon is very remote since the scraper bar is made of conductive Velostat and the spoon is made of a phenolic molding compound.* When the process potential between the sliding surfaces of 0.02 GPa (2500 psi) at 0.15 m/s (0.5 fps) is compared to the material response for NOL-130 using similar materials and the same velocity, the safety margin is found to be 37 and the probability of explosion is found to be less than 5×10^{-16}. For this event

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*It is noted in correspondence dated July 8, 1980 from Vincent A. Latuso of ARRADCOM that the spoon material is being changed to stainless steel. This will not change the friction process potential, because the controlling factor is the yield strength of velostat.

the expectancy is 6 x 10^{-15} accidents per facility hour. Although the spoon is made of phenolic molding compound and no conductivity requirement is specified on its drawing (4A-22-T639), there is no electrostatic hazard since the maximum charge that should accumulate on the spoon is 2.8 x 10^{-6} joules and the sensitivity response of NOL-130 to electrostatic discharge is 2.2 x 10^{-3} joules.

In the analysis of this operation, it was found that a failure of setscrews on the spoon could cause impact events by allowing the spoon or the setscrews to fall and strike contaminated surfaces. If this occurs, a process potential of greater than 1.3 x 10^4 J/m^2 (6 ft-lb/in.^{2}) could be obtained. This is greater than the impact TIL of NOL-130, which is 3.5 x 10^3 J/m^2 (1.7 ft-lb/in.^{2}), calculated by converting steel-to-steel data to phenolic-to steel.* This potential hazard has been classified as II-A because expected repair time would be more than three days.** This potential hazard will create an accident expectancy of 1.4 x 10^{-5} accident per facility hour which will not meet the design goal of 10^{-5} accidents per facility hour in PBM Memorandum 385-5. To ensure compliance with the specification, it is recommended that a redundant method of securing the spoons to the holders be used and that potting be applied to any setscrews to prevent loosening. In the event that this total station is changed to a modular arrangement in which repair could be effected within three days, this classification would be downgraded to a category III-A hazard.

The primary potential hazard encountered during the metering of lead azide is friction which occurs between the seal and the rotating ball. If the seal becomes worn, lead azide will be allowed to build up on rotating surfaces. If an initiation should occur in a build-up of explosives, severe equipment damage would be the result. For the potential hazard, an explosion probability was determined to be 1.5 x 10^{-9} and an accident expectancy was determined to be 6 x 10^{-9} per facility hour. To assure that these low probabilities continue to exist, normal maintenance procedures, which call for seal refurbishment every 10,000 cycles, should be followed exactly. These procedures should be evaluated at periodic intervals to assure that this refurbishment schedule is adequate to prevent buildup of significant amounts of explosives on the rotating surface. It is necessary that explosives entering the feeder be free of foreign materials because particles of foreign material could become lodged in the seal resulting in excessive friction or could damage the seal which might allow excessive buildup of explosives on the ball.

NOTES: 1. A dispenser of a different design is being evaluated, according to correspondence dated July 8, 1980 from Vincent A latuso of ARRADCOM.

2. 10,000 cycles are equivalent to 4 hours 10 min. of operation at a rate of 40 cycles per minute.

In this station, and in other stations of the loader, Garlock bearings are used which can become contaminated with lead azide. These bearings are

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*It was noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that consideration was being given to changing to stainless steel spoons. Because the probability of initiation is one for both phenolic material and steel material and the event probability is the same regardless of material, the accident expectancy would be unchanged by using stainless steel spoons.

**Experience on single tooled loaders indicate that repair to these machines usually takes less than one shift, according to correspondence dated July 8 1980 from Vincent A. Latuso of ARRADCOM.

made up of three bonded layers which contain a middle layer of porous bronze in which the pores are filled with a mizture of polytetrafluoroethylene (TFE) lead mixture and a surface layer of about 0.001 inch thick of the same TFE-lead mixture. In operation, the outer coating of the sleeve type bearings will wear and expose the bronze to contamination with lead azide. ARMCOM supplements on Form 47-R state that lead azide should not be exposed to copper or alloys containing copper because of the possible formation of other azides more sensitive than lead azide. It is recommended that these bearings be replaced by a material more compatible with lead azide.*

The primary hazards associated with the placement of RDX pellets in the detonator are those resulting from equipment failure or equipment alignment which could impart friction and impact stimuli to the explosive. These potential hazards as listed under stations 14 and 15 of table 9 have accident expectancies ranging from 8×10^{-8} to 4×10^{-18} accidents per facility hour. These expectancies are within the design goals of the specification and can be minimized by the planned daily equipment checks to ensure that the pellet slide moves freely; i.e., is free from binding. As part of the daily check it is recommended that a visual inspection of the tool which punches the pellet downward into the detonator cup be performed. This will ensure that working alignment is proper and that contact is not being made with the pellet slide.

<u>Material Consolidation</u> - Compaction of the explosives into the detonator cup is performed in three different pressing operations using tool steel punches energized by the mechanical action of the center post of the press, and controlled by air cylinders. Compaction pressures on the explosives are approximately 0.5 GPa (85,000 psi) for NOL-130, 0.10 GPa (15,000 psi) for lead azide and 0.07 GPa (10,000 psi) for the RDX pellet.

Potential initiation hazards during these operations can result from misalignment of the powder guide, overpressurization, pressurizing when no detonator cup is present and pressurization when a defective detonator is present. During these operations, the in-process potential of 4.1 GPa (600K psi) at 1.0 m/s (3.3 fps) greatly exceeds the friction material response of 0.13 GPa (19K psi) at 0.15 m/s (0.5 fps) for NOL-130 and the material response for friction of 0.2 GPa (28K psi) at 0.15 m/s (0.5 fps) for lead azide for the potential hazard due to misalignment of the powder guide. For this event, the accident expectancy is 8×10^{-8} accidents per facility hour.

If the cup is deformed when the explosive is added, the compression ram could possibly impose abnormal impact and friction stimuli on the explosive material trapped in the crumpled area of the detonator. Because ignition of any explosive material would be expected to result in only minor damage to the equipment, the hazards associated with the compression operations have been classed as category III-A hazards.

The identified potential initiation accident expectancies for these ram pressing stations are within the design goal of PBM Memorandum 385-3 and range from 8×10^{-7} to 4×10^{-18} accidents per facility hour.

<u>Detonator Cup Sealing</u> - Sealing of the detonator cup is performed by placement of a foil disc onto the explosive in the cup and by crimping of the aluminum cup over the foil. Initiation of the explosive in the detonator

*It is noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that IAAP has used bronze bearings for many years with no incidents.

can occur from friction and impact stimuli during these operations. During the placement of the foil into the cup, friction occurs between the aluminum surfaces of the cup and the foil with in-process energy potentials of 0.03 GPa (5K psi) at 0.15 m/s (0.5 fps) being obtained with resulting safety margins varying from 2 to 10. The accident expectancy for placement of the foil on the cup is 2×10^{-8} accidents per facility hour.

If aspiration of the detonator cup was not satisfactorily performed during the previous operation, explosive contamination will be present during foil placement and during crimping operations. This would result in a friction stimulus being introduced to the detonator cup through contact of the foil disc and cup during foil placement, and would also result in a friction stimulus occurring within the folds of the cup during the crimping process. To minimize the probability of occurrence of these potential hazards, it is recommended that the aspirating stations be inspected on a daily basis to ensure adequate removal of excess explosive material from the cup. During the crimping operation, the process potential energy for friction between the aluminum and steel surfaces can be as high as 0.1 GPa (15K psi) at 0.09 m/s (0.3 fps). When compared to the material response for RDX a safety margin of 3 and a probability of 6.2×10^{-11} that an explosion will occur are observed.

Impact and friction initiation of the explosive can possibly occur during placement of the foil or crimping of the cup if either the cup or the hydraulically-actuated backup linkages become stuck in one position. If this should occur, the foil placement punch or crimping tool will be lowered by action of cams to a fixed position, resulting in impact or friction between the cup and the punch. The accident expectancies for the crimping operation range from 2×10^{-7} accidents per facility hour for the event in which the cup becomes stuck in position to 1.1×10^{-11} accidents per facility hour for the crimping event in which failure of the foil occurs. To minimize the probability of occurrence of these potentially hazardous events, it is recommended (1) that the tooling be inspected frequently to assure that no defects which could cause sticking are present, and (2) that the hydraulic backup system be tested periodically to make certain that it is free to move.

<u>Aspiration Station</u> - In the aspirator system, all lines should be grounded and should be as short as possible to prevent the accumulation of any explosive fines and to minimize buildup of electrostatic charges. Frequent changes of the trap are recommended. The use of a glass trap, as denoted in the equipment data specification manual, is not recommended for the containment of explosive materials. It is recommended that the glass bottle be replaced with a suitable conductive plastic material to prevent discharge of glass splinters in the event that an explosion occurs during operating or maintenance operations.

Additionally, it is recommended that all aspirating stations be checked daily for proper operation. The use of sensors should be considered to ensure that all stations are functioning as intended. Inadequate pickup by the aspirator will permit contaminated conditions to exist at all stations of the loader which will contribute to initiation.

Defective Detonator Disposal - Defective detonators are removed from the work station and dropped through a steel chute into disposable containers which contain water. Because the steel enclosure surrounds the disposable containers and because the detonators fall into a water filled container, no major hazards were identified for this system. These containers are replaced with clean containers at periodic intervals during the day with a maximum of 200 allowed to accumulate. It is noted that detonators could be rejected after sealing which would make them watertight, and therefore could still be subject to detonation. Therefore, manual handling of the reject container and detonators should be performed with extreme caution.

CONCLUSIONS AND RECOMMENDATIONS

A hazard evaluation and safety study has been conducted on the Multi-tooled Iowa detonator loader in compliance with contract requirements. As analyzed, the detonator loader does not meet the requirements of the contract specifications in three areas. These are: (1) compliance to the design goal of 1×10^{-5} accidents per facility hour for a class II-A hazard, (2) the use of copper alloy materials in sleeve bearings, and (3) the exposure of operators to hazards more severe than a Class IV hazard. These deviations from the specifications have been addressed in greater detail in the report body.

1. Personal Injury Due to Fire or Explosion

Four areas are of concern which could result in personal injury due to fire or explosion during process operations. These are (1) during replenishment of explosives to the detonator receivers, (2) during maintenance of the system or during "process upset" conditions where operators remove the shield to correct problems, (3) during daily cleaning of the machine and aspirators and during removal of defective detonators, and (4) from an initiation within the machine where injury results from emitted projectiles or from secondary reactions of the operator.

The loading of the explosive hoppers is of concern due to the sensitive nature of the explosives and the possibility of injury if detonation should occur. Prevention of problems in this area requires rigid procedure control and operator grounding to prevent initiation from static electricity.

The second problem of injury during maintenance requires (1) potting of exposed threads, bolts, etc. to prevent explosive contamination and subsequent initiation during adjustment by personnel, and (2) rigid control of tools to prevent initiation by impact of dropped tools or initiation during start-up as a result of tools having been left in the process.

The hazards associated with cleaning the aspirators can result from the initation during cleaning of any explosive dust retained in the tooling, the possibility of an incident resulting from the use of alcohol to clean lines with insufficient ventilation, and the hazard of an exploding glass container when cleaning the aspirator trap. Proper precautions and safety procedures must be employed during these operations to reduce the potential for an injury. The glass jar of the aspirator trap should be replaced with a jar fabricated from a conductive plastic material which is compatible with the explosives. Additionally, procedures for proper handling of the reject detonators must be rigidly enforced during manual removal from the machine and during transfer to the disposal location. Rejects should not be manually removed from the machine while the machine is operating and procedures for limiting the quantity of rejects within a reject container should be enforced.

Injury to personnel from explosions within the machine can occur if operators block off safety interlocks when refilling the explosive container or performing adjustments within the shield. This type of activity should not be tolerated. If an explosion which occurs within the shielded portion of the machine is witnessed by an operator, temporary blindness or possibly eye damage to the operator could result. Also, the operator could react suddenly away from the machine and possibly strike other equipment or other personnel. Therefore, protective eye wear should be worn during performance of certain operations when the operator is in close proximity to the machine and observing an operation, such as that of explosive replenishment.

All electric motors and components are specified as explosion proof class II which is satisfactory for dust but not for operating in the presence of flammable vapors. Therefore, if alcohol or other solvents are to be used near any electrical utilities or assemblies the electrical equipment should be classified explosion proof Class I, Group D.

2. Equipment Damage

The new loader processes four detonators simultaneously from one station to the next. To reduce severity of an incident, there must not be a propagation link between stations or a propagation link between any detonator and an explosive hopper. Therefore, the table and path of the detonators must be maintained such that an explosion cannot propagate due to the presence of contamination. A continuous chain of explosive does exist at the NOL-130 dispensing station. It is suggested that this station be examined closely to determine what modification would be required to prevent an incident from propagating to the explosive in the bowl if initiation of the detonator occurred during loading operations.

Because of the susceptibility of NOL-130 to initiation by impact, potential hazards which can provide impact stimuli to the explosive should be minimized. An impact stimulus to the NOL-130 in the Cargile container can occur from a dropped spoon or from a setscrew used to secure spoons to the holder. This potential hazard will create an accident expectancy of 1.4×10^{-5} accidents per facility hour which will not meet the design goal of 1×10^{-5} accidents per facility hour for a category II-A hazard in PBM Memorandum 385-3. To reduce this accident expectancy, it is recommended that a redundant means be employed to secure the spoons to the holder and that the present setscrews securing the spoons to the holder be sealed with a thread adhesive and be potted to prevent them from loosening and falling.

3. Localized Reactions

Localized reactions during process operations resulting from frictional stimuli within the linkages of moving equipment can be reduced by the elimination of metal-to-metal contact.

Additional localized reactions may occur after a period of operation due to the reaction of lead azide contamination with bronze material used in the sleeve bearings of the loader. Since copper/bronze will react with lead azide to form a more sensitive azide component, it is recommended that the use of Garlock bearings containing bronze be replaced with bearings containing a more compatible material.*

*It is noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that IAAP has used bronze bearings for many years with no incidents.

During the manufacture of detonators on the indexing tabs, automatic inspections are performed at several stations to check for the presence of a detonator cup and to check for the proper height of explosive in the cup. There is only one automatic discharge point, however, and this is located at a station which follows the crimping station. Thus, the detonators must travel through the processing stations even though the surface level may be high or the cup may be stuck, damaged, or missing. It is suggested that changes be considered to provide for automatic discharge of a detonator at any stage of the process and automatic disabling of tools and feed mechanisms at a station from which the detonator has been discharged. The basis for this suggestion is the assumption that fewer detonations will occur if reject detonators are discharged immediately after being detected rather than continuing through the process to a single discharge point.*

4. Major Equipment Damage

Accumulation of explosive into the interior of the turntable could possibly result in major equipment damage and injury to operating and maintenance personnel. Therefore, it is recommended that the prototype machine be disassembled after a period of working time to determine if contamination of the interior has occurred. If contamination is apparent, seals or positive pressure technology must be utilized to prevent future contamination.

*It was noted in correspondence dated July 8, 1980 to Hercules from Vincent A. Latuso of ARRADCOM that inspections for height of explosives are conducted at several stations, that detonators are rejected if heights are not within tolerances of ±0.004 in., and that the machine shuts down automatically if the lead azide height is exceeded by 0.030 in. If the lead azide height is exceeded by 0.050 in., the detonator is removed manually.

Table 9. Engineering analysis/hazard evaluation of X4 loader

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 1 Place Detonator Cup	Friction between cup press tool & tool block when tool block is contaminated	Friction S/Al	Nol 130	5 K psi 3.3 fps 3.4×10^{-2} GPa 1.0 m/s	10 K psi 0.5 fps 0.07 GPa 0.15 m/s	<1	1	4×10^{-6}	1	4×10^{-6}	4×10^{-6} (1,2)	III-A
		Friction S/Al	Lead Azide	5 K psi 3.3 fps 3.4×10^{-2} GPA 1.0m/s	70 K psi 3.3 fps 0.48 GPa 1 m/s	13	1	4×10^{-6}	~1 3×10^{-5}	(4×10^{-6}) 1.2×10^{-10}	(4×10^{-6}) (1) 1.2×10^{-10} (2)	III-A
		Friction S/Al	RDX	5 K psi 3.3 fps 3.4×10^{-2} GPa 1.0 m/s	48 K psi 10 fps 3.3×10^{-1} GPa 3.0 m/s	8.6	1	4×10^{-6}	(4×10^{-1}) 5×10^{-16}	(8×10^{-7}) 2×10^{-21}	(8×10^{-7}) 2×10^{-21}	III-A
Station 2 Powder Guide Placement	1) Guide is picked up from storage post and placed on tool block	Impact TS/S	Nol 130	2.0×10^{-2} Ft-lb/in^2 41 J/m^2	.85 Ft-lb/in^2 1.8×10^3 J/m^2	41	1×10^{-4}	4×10^{-6}	(4.0×10^{-4}) 1×10^{-9}	(1.6×10^{-13}) 4×10^{-19}	(1.6×10^{-13}) 4×10^{-19}	III-A
	P.G. is dropped from tool onto contaminated tool block	Impact TS/S	Lead Azide	2.0×10^{-2} Ft-lb/in^2 41 J/m^2	10.5 Ft-lb/in^2 2.2×10^4 J/m^2	524	1×10^{-4}	4×10^{-6}	$<1\times10^{-9}$	4×10^{-19}	4×10^{-19}	III-A
		Impact TS/TS	RDX	2.0×10^{-2} Ft-lb/in^2 41 J/m^2	13 Ft-lb/in^2 2.7×10^4 J/m^2	649	1×10^{-4}	4×10^{-6}	$<5\times10^{-16}$	2×10^{-25}	2×10^{-25}	III-A

(1) At 95% confidence
(2) At 50% confidence

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (i_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 2 cont.	2) Friction between powder guide & placement tool finger due to misalignment (Abnormal)	Friction TS/TS	Nol 130	144 K psi 0.6 fps 0.99 GPa 0.18 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	$5x10^{-5}$	$4x10^{-6}$	1	$2x10^{-10}$	$2x10^{-10}$ (1,2)	III-A
	Contamination present due to improper cleaning	Friction TS/TS	Lead Azide	144 K psi 0.6 fps 0.99 GPa 0.18 m/s	28 K psi 0.5 fps 0.26 GPa 0.15 m/s	0	$5x10^{-5}$	$4x10^{-6}$	1	$2x10^{-10}$	$2x10^{-10}$	III-A
		Friction TS/TS	RDX	144 K psi 0.6 fps 0.99 GPa 0.18 m/s	66 K psi 1.0 fps 0.46 GPa 0.3 m/s	0	$5x10^{-5}$	$4x10^{-6}$	1	$2x10^{-10}$	$2x10^{-10}$	III-A
	3) Friction between powder guide & placement tool finger	Friction S/S	Nol 130	3 psi 0.6 fps $2.1x10^{-5}$ GPa 0.18 m/s	19 K psi 0.5 fps 0.13 GPa 0.5 m/s	>1000	1	$4x10^{-6}$	$<5x10^{-16}$	$2x10^{-21}$	$2x10^{-21}$	III-A
	Contamination present due to improper cleaning	Friction S/S	Lead Azide	3 psi 0.6 fps $2.1x10^{-5}$ GPa 0.16 m/s	28 K psi 0.5 fps 0.26 GPa 0.15 m/s	>1000	1	$4x10^{-6}$	$<5x10^{-16}$	$2x10^{-21}$	$2x10^{-21}$	III-A
		Friction S/S	RDX	3 psi 0.6 fps $2.1x10^{-5}$ GPa 0.18 m/s	66 K psi 1.0 fps 0.46 GPa 0.3 m/s	>1000	1	$4x10^{-6}$	$<5x10^{-16}$	$2x10^{-21}$	$2x10^{-21}$	III-A
	Operator drops powder guide during check for proper holding action of handler.	Impact S/S	Nol 130	>.86 ft lb/in^2 $>1.8x10^3$ j/m^2	.86 ft lb/in^2 $1.8x10^3$ j/m^2	0	$1x10^{-4}$	$4x10^{-6}$	1	$4x10^{-10}$	$4x10^{-10}$	III-B

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_μ)	MATERIAL PRESENT (C_μ)	INITIATION (I_μ)	FIRE (F_μ)	EXPLOSION (X_μ)	HAZARD CATEGORY
Stations 4 & 5												
NOL-130 Dispenser (Cargile Scoop)	Spoon scoops Nol-130, swraper along a doctor blade then drops sample into a powder guide											
	1) Friction between doctor blade and spoon	Friction Phenolic/ Velostat	Nol 130	2.5 K psi 0.5 fps $1.7x10^{-2}$ GPa @ 0.15 m/s	19 K psi[3] 0.5 fps 0.13 GPa 0.15 m/s	7	1	1	$<5x10^{-16}$	$<5x10^{-16}$	$<5x10^{-16}$	[1,2] II-A
	2) Friction between doctor blade and spoon (misalignment of doctor blade)	Friction Phenolic/ Velostat	Nol 130	7.5 K psi 0.5 fps $5.2x10^{-2}$ GPa 0.15 m/s	19 K psi[3] 0.5 fps 0.13 GPa 0.15 m/s	3	$1x10^{-3}$	1	$<5x10^{-16}$	$<5x10^{-19}$	$<5x10^{-19}$	II-A
	3) Normal operation; Bearing contaminated	Friction S/Bronze	Nol 130	5 K psi 0.1 fps 0.03 GPa 0.03 m/s	19 K psi[3] 0.5 fps 0.13 GPa 0.15 m/s	4	1	1	$5x10^{-16}$	$5x10^{-16}$	$5x10^{-16}$	II-A
	4) Spoon and/or set screw falls down into guide chute	Impact S/Phenolic	Nol 130	>6 ft-lb/ in2	.86 ft- lb/in^2 [3]	0	$3.6x10^{-6}$	1	1	$3.6x10^{-6}$	$3.6x10^{-6}$	II-A
				>1.3x104 J/m^2	1.9x10^3 J/m^2							
	5) Maintenance operation Doctor blade slide contaminated.	Friction S/S	Nol 130	48 K psi 0.5 fps 0.33 GPa 0.15 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	$2.5x10^{-2}$ [4]	$4x10^{-6}$	1	$1x10^{-7}$	$1x10^{-7}$	III-B

(3) Steel/steel components of construction.
(4) Assumed maintenance required once per 40 hrs. of operation.

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	ENGINEERING ANALYSIS: COMBUST	ENGINEERING ANALYSIS: PROCESS POTENTIAL	ENGINEERING ANALYSIS: MATERIAL RESPONSE	ENGINEERING ANALYSIS: SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	PROBABILITIES: MATERIAL PRESENT (C_p)	PROBABILITIES: INITIATION (I_p)	PROBABILITIES: FIRE (F_p)	PROBABILITIES: EXPLOSION (X_p)	HAZARD CATEGORY
Station 7 Hol-130 RAM	Tool compresses Hol-130 sample to 82,000 psi											
	1) Friction between tool and powder guide due to misalignment of P.C.	Friction TS/TS	Hol 130	600 K psi 3.1 fps 4.1 GPa 1.0 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$ (1,2)	IIIA
	2) Tool impacts powder guide due to misalignment	Impact TS/TS	Hol 130	>.86 ft-lb/in^2 >1.8x10^3 J/m^2	0.86 ft-lb/in^2 1.8x10^3 J/m^2	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	IIIA
	3) Tool impacts tool block when P.C. not present to aid in alignment	Impact TS/TS	Hol 130	>.86 ft-lb/in^2 >1.8x10^3 J/m^2	0.86 ft-lb/in^2 1.8x10^3 J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$	IIIA

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_μ)	MATERIAL PRESENT (C_μ)	INITIATION (I_μ)	FIRE (F_μ)	EXPLOSION (X_μ)	
Station 7 cont.	4) RAM tool breaks during compression. (A sudden relief against hydraulic push could cause fast upward movement of detonator) friction of detonator cup and tool block	Friction TS/At	Hot 130	15 K psi 0.5 fps 0.10 GPa 0.15 m/s	10 K psi 0.5 fps 0.07 GPa 0.15 m/s	0	2×10^{-7}	1	2.2×10^{-1} (1) 6×10^{-2} (2)	(4.4×10^{-8}) 1.2×10^{-8}	(4.4×10^{-8}) 1.2×10^{-8} (2)	(1) IIIA

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	
Station 9 & 10												
Lead Azide Dispenser (Ball Feeder)	1) Dispenser seal on azide dispenser becomes worn. Friction between seal and dispenser.	Friction S/Velostat	Lead Azide	7.5 K psi 0.7 fps .05 GPa 0.2 m/s	28K psi (3) .5 fps .26 GPa .15 m/s	2.7	$5x10^{-6}$	1	$1.2x10^{-1}$ $3x10^{-4}$	$6x10^{-7}$ $1.5x10^{-9}$	$6x10^{-7}$ (1) $1.5x10^{-9}$ (2)	II-A
	2) Initiation of lead azide occurs due to ESD from ungrounded operator	ESD	Lead Azide	.012j	.0028j	0	$1x10^{-7}$	$1x10^{-6}$	1	$1x10^{-13}$	$1x10^{-13}$	III-B
	3) Initiation occurs during adjustment of set screws during azide dispenser removal and/or adjustment	Friction S/S	Lead Azide	52 K psi @ .5 fps .36 GPa @ .15 m/s	28 K psi @ .5 fps .2 GPa @ .15 m/s	0	$7x10^{-6}$	$1x10^{-6}$	1	$7x10^{-12}$	$7x10^{-12}$	III-B
	4) Initiation of lead azide occurs while placing container on dumping platform.	Friction S/rubber	Lead Azide	2 K psi @ .5 fps .01 GPa @ .15 m/s	28 K psi (3) @ .5 fps .2 GPa @ .15 m/s	>14	1	1	2x10-7 <5x10-16	2x10-7 <5x10-16	$2x10^{-7}$ <5x10-16	III-B
	5) Impingement of lead azide occurs while dumping container.	Impingement	Lead Azide	<300 fpm <92 m/m	8250 fpm 2516 m/m	>27	1	1	<1x10-20	<1x10-20	<1x10-20	II-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	
Station 11 Lead Azide RAM	Tool compresses lead azide sample to 15,000 psi and check powder height	Friction TS/TS	Nol 130	600 K psi 3.3 fps 4.1 GPa 1.0 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$ (1,2)	IIIA
	1) Friction occurs between tool and powder guide due to misalignment	Friction TS/TS	Lead Azide	600 K psi 3.3 fps 4.1 GPa 1.0 m/s	28 K psi 0.5 fps 0.2 GPa 0.15 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	IIIA
	2) Tool impacts powder guide due to misalignment	Impact TS/TS	Nol 130	>.86 ft-lb/in^2 >1.8x10^3 J/m^2 5x10^{-3}m	0.86 ft-lb/in^2 1.8x10^3 J/m^2	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	IIIA
		Impact TS/TS	Lead Azide	>10.5 ft-lb/in^2 >2.2x10^4 J/m^2	10.5 ft-lb/in^2 2.2x10^4 J/m^2	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	IIIA
	1) Tool impacts test block when P.G. not present to aid in alignment	Impact TS/TS	Nol 130	≥.86 ft-lb/in^2 >1.8x10^3 J/m^2	0.86 ft-lb/in^2 1.8x10^3 J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$	IIIA
		Impact TS/TS	Lead Azide	>10.5 ft-lb/in^2 >2.2x10^4 J/m^2	10.5 ft-lb/in^2 2.2x10^4 J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$	IIIA

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	
Station 11 (cont.)	4) RAM tool breaks during compression (A sudden relief against hydraulic push could cause fast upward movement of detonator) Friction of detonator cup and tool block	Friction TS/Al S/Al	Nol 130	15 K psi 0.5 fps 0.10 GPa 0.15 m/s	10 K psi 0.5 fps 0.07 GPa 0.15 m/s	0	$2x10^{-7}$	1	$(2.2x10^{-1})$ $6x10^{-2}$	$(4.4x10^{-8})$ $1.2x10^{-8}$	$(4.4x10^{-8})$ (1) $1.2x10^{-8}$ (2)	IIIA
		Friction TS/Al S/S	Lead Azide	15 K psi 0.5 fps 0.10 GPa 0.15 m/s	28 K psi 0.5 fps 0.26 GPa 0.15 m/s	(3) 0.9	$2x10^{-7}$	1	$(1.6x10^{-1})$ $8x10^{-3}$	$(3.2x10^{-8})$ $1.6x10^{-9}$	$(3.2x10^{-8})$ $1.6x10^{-9}$	IIIA
	5) RAM tool impacts broken RAM from Nol 130 RAM Station	Impact TS/TS	Nol 130	$\geq$ .86 ft-lb/in $1.8x10^3$ J/m^2	0.86 ft-lb/in^2 $1.8x10^3$ J/m^2	0	$2x10^{-7}$	1	1	$2x10^{-7}$	$2x10^{-7}$	IIIA
		Impact TS/TS	Lead Azide	$\geq$10.5 ft-lb/in^2 $\geq 2.2x10^4$ J/m^2	10.5 ft-lb/in^2 8.2 in $2.2x10^4$ J/m^2	0	$2x10^{-7}$	1	1	$2x10^{-7}$	$2x10^{-7}$	IIIA

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	
Station 12616 Vacuum Clean Station	The vacuum cleaning system draws material out of area											
	1) ESD between vacuum tool and tool block improper grounding	ESD	Lead Azide	.004 J	.0028 J	0	$1x10^{-3}$	$4x10^{-6}$	1	$4x10^{-9}$	$4x10^{-9}$ (1,2)	IIIA
		ESD	Nol 130	.004 J	.0022 J	0	$1x10^{-3}$	$4x10^{-6}$	1	$4x10^{-9}$	$4x10^{-9}$	IIIA
	2) Vacuum tool would impact a broken RAM tool from previous station	Impact TS/S	Lead Azide	>10.5 ft-lb/in^2 -2.2x10^4 J/m^2	10.5 ft-lb/in^2 2.2x10^4 J/m^2	0	$2x10^{-8}$	$4x10^{-6}$	1	$8x10^{-14}$	$8x10^{-14}$	IIIA

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	ENGINEERING ANALYSIS: COMBUST.	ENGINEERING ANALYSIS: PROCESS POTENTIAL	ENGINEERING ANALYSIS: MATERIAL RESPONSE	ENGINEERING ANALYSIS: SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	PROBABILITIES: MATERIAL PRESENT (C_p)	PROBABILITIES: INITIATION (I_p)	PROBABILITIES: FIRE (F_p)	PROBABILITIES: EXPLOSION (X_p)	HAZARD CATEGORY
Station 12&16 (cont.)	3) Friction between vacuum tool and P.G. (Normal)	Friction S/Rubber	Nol 130	2 K psi 1.3 f/s .01 GPa .4 m/s	19 K psi(3) .5 f/s .13 GPa .15 m/s	10	1	$4x10^{-6}$	$1x10^{-3}$ $3.8x10^{-9}$	$4x10^{-9}$ $1.5x10^{-14}$	$4x10^{-9}$(1) $1.5x10^{-14}$(2)	III-A
		Friction S/Rubber	Lead Azide	2 K psi 1.3 f/s .01 GPa .4 m/s	28K psi(3) .5 f/s .26 GPa .15 m/s	>14	1	4x10-6	$2x10^{-7}$ $5x10^{-16}$	$8x10^{-13}$ $2x10^{-21}$	$8x10^{-13}$ $2x10^{-21}$	III-A
	4) Friction between vacuum tool and P.G. (Abnormal)	Friction S/Rubber	Nol 130	6 K psi 1.3 f/s .03 GPa .4 m/s	19 K psi(3) .5 f/s .13 GPa .15 m/s	>3	2x10-8	4x10-6	$8x10^{-3}$ $3x10^{-5}$	$6.4x10^{-16}$ $2.4x10^{-18}$	$6.4x10^{-16}$ $2.4x10^{-18}$	III-A
		Friction S/Rubber	Lead Azide	6 K psi 1.3 f/s .03 GPa .4 m/s	28 K psi(3) .5 f/s .26 GPa .15 m/s	>4	2x10-8	4x10-6	$1x10^{-5}$ $3x10^{-14}$	$8x10^{-19}$ $2.4x10^{-27}$	$8x10^{-19}$ $2.4x10^{-27}$	III-A
	5) Friction in bearing (bearing fails)	Friction S/Bronze	Nol 130	60 K psi 1.3 fps 0.3 GPa .4 m/s	19 K psi(3) 0.5 fps 0.1 GPa 0.15 m/s	0	$2.6x10^{-6}$	$4x10^{-6}$	1	$1x10^{-11}$	$1x10^{-11}$	III-A
		Friction S/Bronze	Lead Azide	60 K psi 1.3 fps 0.39 GPa .4 m/s	28 K psi(3) 0.5 fps 0.? GPa 0.15 m/s	0	$2.6x10^{-6}$	$4x10^{-6}$	1	$1x10^{-11}$	$1x10^{-11}$	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 13 Powder Guide Removal	1) Guide is picked from tool block and placed on storage post	Impact TS/S	Nol 130	2.0×10^{-2} ft-lb/in^2 41 J/m^2	$.86\times10^{-1}$ ft-lb/in^2 1.8×10^3 J/m^2	41	1×10^{-4}	4×10^{-6}	(4.0×10^{-4}) 1×10^{-9}	(1.6×10^{-13}) 4×10^{-19}	(1.6×10^{-13})(1) 4×10^{-19}(2)	III-A
	Powder guide is dropped to indexing table. Table or P.G. contaminated	Impact TS/S	Lead Azide	2.0×10^{-2} ft-lb/in^2 41 J/m^2	10.5 ft-lb/in^2 2.2×10^4 J/m^2	524	1×10^{-4}	4×10^{-6}	1×10^{-9}	4×10^{-19}	4×10^{-19}	III-A
	2) ESD occurs when removing P.G. (Charged during vacuum cleaning)	ESD	Nol 130	8.4×10^{-6} J	2.2×10^{-3} J	260	1	1	(1×10^{-9}) 5×10^{-16}	(1×10^{-9}) 5×10^{-16}	(1×10^{-9}) 5×10^{-16}	III-A
		ESD	Lead Azide	8.4×10^{-6} J	2.8×10^{-3} J	330	1	1	(1×10^{-7}) $<5\times10^{-16}$	(1×10^{-7}) $<5\times10^{-16}$	(1×10^{-7}) $<5\times10^{-16}$	III-A
	3) Friction would occur if the P.G. were removed while a broken RAM tool from lead azide station was in the P.G.	Friction TS/TS	Nol 130	600 K psi 0.6 fps 4.1 GPa 0.18 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	2×10^{-7}	1	1	2×10^{-7}	2×10^{-7}	III-A
		Friction TS/TS	Lead Azide	600 K psi 0.6 fps 4.1 GPa 0.18 m/s	28 K psi 0.5 fps 0.2 GPa 0.15 m/s	0	2×10^{-7}	1	1	2×10^{-7}	2×10^{-7}	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 11 cont.	4) If a failure occurs in vertical arm of removal tool then A) tool not raised so powder guide dragged from tool block	Friction TS/TS	Nol 130	600 K psi 0.6 fps 4.1 GPa 0.18	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$ (1,2)	III-A
		Friction TS/TS	Lead Azide	600 K psi 0.6 fps 4.1 GPa 0.18	28 K psi 0.5 fps 0.2 GPa 0.15 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	III-A
	5) tool not raised so tool and P.G. impacts powder guide storage post	Impact TS/S	Nol 130	.8 ft-lb/in² $1.3x10^3$ J/m²	[illegible] ft-lb/in² $1.3x10^3$ J/m²	0	$2x10^{-8}$	$4x10^{-6}$	1	$8x10^{-14}$	$8x10^{-14}$	III-A
		Impact TS/S	Lead Azide	10.5 ft-lb/in² $2.2x10^4$ J/m²	10.5 ft-lb/in² $2.2x10^4$ J/m²		$2x10^{-8}$	$4x10^{-6}$	1	$8x10^{-14}$	$8x10^{-14}$	III-A
	6) Friction of finger of removal tool with P.G. if P.G. not vacuumed at previous station	Friction TS/TS	Nol 130	3 psi 0.6 fps $2.1x10^{-5}$ GPa 0.18 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	1000 1000	1	$4x10^{-6}$	$5x10^{-16}$	$2x10^{-21}$	$2x10^{-21}$	III-A
		Friction TS/TS	Lead Azide	3 psi 0.6 fps $2.1x10^{-5}$ GPa 0.18 m/s	28 K psi 0.5 fps 0.15 GPa 0.15 m/s		1	$4x10^{-6}$	5x10[illegible]	$2x10^{-21}$	$2x10^{-21}$	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 13 cont.	7) Normal friction between tool slider block and tool support	Friction S/S	Nol 130	48 K psi 1 fps 0.33 GPa 0.3 m/s	19 K psi 0.5 fps 0.13 GPa 0.15 m/s	0	1	$4x10^{-6}$	1	$4x10^{-6}$	$4x10^{-6}$ (1,2)	III-A
		Friction S/S	Lead Azide	48 K psi 1 fps 0.33 GPa 0.3 m/s	28 K psi 0.5 fps 0.15 GPa 0.15	0	1	$4x10^{-6}$	1	$4x10^{-6}$	$4x10^{-6}$	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 16 RDX Pellet Feeder	Gravity feed tube deposits RDX pellet onto a reciprocating slider which moves the pellet to a position above the tool block. At this point, a tool pushes the pellet into the detonator cup. 1) If pellet slide is misaligned, the pellet will not seat in slide hole Friction (shear) of pellet on slide	Friction TS/S	RDX	48 K psi 3.3 f/s .3 GPa 1.0 m/s	65 K psi 2 f/s .45 GPa .6 m/s .45	2.7	$2x10^{-8}$	1	$(2x10^{-1})$ $8x10^{-3}$	$(4x10^{-9})$ $1.6x10^{-10}$	$(4x10^{-9})$ (1) $1.6x10^{-10}$ (2)	II-A
	2) Pellet punch tool impacts pellet slide due to misalignment	Impact TS/TS	RDX	>13 ft-lb/in^2 $2.7x10^4$ J.m^2	13 ft-lb/in^2 $2.7x10^4$ J/m^2 26 cm	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	II-A
	3) Pellet punch tool impacts tool block and presses RDX pellet due to improper index of table	Impact TS/TS	RDX	>13 ft-lb/in^2 $2.7x10^4$ J/m^2	13 ft-lb/in^2 $2.7x10^4$ J/m^2	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	II-A
	4) Friction of tool on tool block if tool does not retract to home position	Friction TS/TS	RDX	600 K psi 3.3 f/s 3.8 GPa 1.0 m/s	65 K psi 2 f/s .45 GPa .6 m/s	0	$2x10^{-8}$	1	1	$2x10^{-8}$	$2x10^{-8}$	II-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 14 (Cont'd.)	5) Friction initiation results during manual replacement of pellet tubes.	Friction S/S	RDX	58 K psi @ .5 fps .3 GPa @ .15 m/s	67 K psi @ 1 fps .46 GPa @ .3 m/s	0.4	1	$1x10^{-6}$	$(2x10^{-1})$ $5x10^{-9}$	$2x10^{-7}$ $5x10^{-9}$	$2x10^{-7}$ $5x10^{-9}$	III-B
Station 15 RDX Ram	Tool compresses RDX to 10,000 psi and checks powder height 1) Tool impacts tool block due to misalignment (Abnormal)	Impact TS/TS	Mol 130	$1.4x10^4$ ft-lb/in^2 $2.9x10^7$ J/m^2	0.86 ft-lb/in^2 $1. x10^3$ J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$ (1,2)	III-A
		Impact TS/TS	Lead Azide	$1.4x10^4$ ft-lb/in^2 $2.9x10^7$ J/m^2	10.5 ft-lb/in^2 $2.2x10^4$ J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$	III-A
		Impact TS/TS	RDX	$1.4x10^4$ ft-lb/in^2 $2.9x10^7$ J/m2	13 ft-lb/in^2 $2.7x10^4$ J/m^2	0	$1x10^{-18}$	1	1	$1x10^{-18}$	$1x10^{-18}$	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_p)	MATERIAL PRESENT (C_p)	INITIATION (I_p)	FIRE (F_p)	EXPLOSION (X_p)	HAZARD CATEGORY
Station 1/ Place Foil Disc	1. Friction of foil disc on cup	Friction Al/Al	NOL-130	5 K psi 0.5 f/s .03 GPa .15 m/s	10 K psi(5) 0.5 f/s .07 GPa .15 m/s	2	1	1×10^{-3}	(3.3×10^{-5}) 1×10^{-12}	(3.3×10^{-8}) 1×10^{-15}	(3.3×10^{-8})(1) 1×10^{-15}(2)	III-A
		Friction Al/Al	Lead Azide	5 K psi .5 f/s .01 GPa .15 m/s	70 K psi(5) 3.3 f/s .48 GPa 1 m/s	13	1	1×10^{-3}	$(2.3 \times 10^{-[illegible]})$ 5×10^{-6}	$(2.3 \times 10^{-[illegible]})$ 5×10^{-9}	(2.3×10^{-5}) 5×10^{-9}	III-A
		Friction Al/Al	HDX	5 K psi .5 f/s .03 GPa .15 m/s	52 K psi(5) 8 f/s .4 GPa 2.4 m/s	10	1	1×10^{-3}	(4×10^{-1}) 7.5×10^{-11}	(4×10^{-4}) 7.5×10^{-14}	(4×10^{-4}) 7.5×10^{-14}	III-A
	2. Friction initiation occurs during replacement of worn punches and dies at foil feeding station	Friction S/S	NOL-130	48 K psi .5 f/s .33 GPa .15 m/s	19 K psi(3) 0.5 f/s .13 GPa .15 m/s	0	1.7×10^{-3}	1×10^{-6}	1	1.7×10^{-9}	1.7×10^{-9}	III-B

(5) Based on steel/Al materials of construction

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS: INITIATION MODE	COMBUST.	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	PROBABILITIES: EVENT (E_μ)	MATERIAL PRESENT (C_μ)	INITIATION (I_μ)	FIRE (F_μ)	EXPLOSION (X_μ)	HAZARD CATEGORY
Station 19 to 21	1. Initiation of detonator occurs during crimping											
	a. Failure of foil disc occurs during or prior to crimping.	Friction S/Al	RDX	5 K psi @ .1 fps .03 GPa @ .09 m/s	52 K psi @ 8 fps .4 GPa @ 2.4 m/s	(1) 10	$3.3x10^{-6}$	1	$2x10^{-1}$ $3x10^{-10}$	$6.6x10^{-7}$ $9.9x10^{-16}$	$6.6x10^{-7}$ (1) $9.9x10^{-16}$	(2) III-A
	b. Surface of explosive high due to cup being stuck in holder or due to failure of hydraulic relief system.	Friction S/Al	RDX	15 K psi @ .3 fps .1 GPa @ .09 m/s	52 K psi @ 8 fps .4 GPa @ 2.4 m/s	3	$6.2x10^{-6}$	1	$2x10^{-1}$ $1x10^{-5}$	$1.2x10^{-6}$ $6.2x10^{-11}$	$1.2x10^{-6}$ $6.2x10^{-11}$	III-A
		Friction S/Al	Lead Azide	15 K psi @ .3 fps .1 GPa @ .09 m/s	70K psi @ 3.3 fps .48 GPa @ 1.0 m/s	5	$6.2x10^{-6}$	1	$8x10^{-3}$	$5x10^{-8}$	$5x10^{-8}$	III-A

Table 9 (cont'd.)

OPERATION	POTENTIAL INITIATION HAZARD	ENGINEERING ANALYSIS					PROBABILITIES					HAZARD CATEGORY
		INITIATION MODE	COMBUST	PROCESS POTENTIAL	MATERIAL RESPONSE	SAFETY MARGIN	EVENT (E_μ)	MATERIAL PRESENT (C_μ)	INITIATION (I_μ)	FIRE (F_μ)	EXPLOSION (X_μ)	
Station 21	Initiation of explosive occurs during changing of rubber chucks	Friction S/rubber	RDL-130	2 K psi @ .5 fps .01 GPa @ .15 m/s	19 K psi[3] @ .5 fps .13 GPa @ .15 m/s	10	1	1	$<5\times10^{-16}$	$<5\times10^{-16}$	$<5\times10^{-16}$ [1,2]	III-B

(1) At 95% confidence
(2) At 50% confidence
(3) Steel/steel components of construction
(4) Assumed maintenance required once per 40 hours of operation
(5) Based on steel/Al materials of construction

Table 10. Iowa X4 detonator loader

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.:
REV DATE:
PAGE 1 OF 17
DATE: STARTED: COMPL:
PROJ NO.:
SYSTEM: Iowa Loader
SUBSYSTEM: Station 1
ANALYST: R. W. Courtney

ITEM NO a	NOMEN AND PART NO b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
1	Cup Loading Station	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction between cup press tool and tool block when block is contaminated	IIIA	Clean area regularly in order to prevent accumulation of material.	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environment, Design Deficiencies, Incompatibility

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

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ARMCOMR 385-4

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS
(ARMCOMR 385-4)

REV NO. | REV DATE | PAGE 2 OF 17 | DATE: STARTED | COMPL

PROJ NO. | SYSTEM: Iowa Leader | SUBSYSTEM: Station 2 | ANALYST: R. W. Courtney

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
2	Powder Guide Placement	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Impact of guide on tool block	IIIA		
		Normal		Low	Explosion	2. Friction between powder guide and placement tool finger due to misalignment	IIIA		
		Normal		Low	Explosion	3. Contamination due to improper cleaning	IIIA	Clean area of all spills	
		Maintenance		Low	Explosion	4. Impact initiation if operator drops powder guide	IIIB		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

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Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.: | REV DATE: | PAGE 3 OF 17 | DATE: STARTED / COMPL

PROJ NO.: | SYSTEM: Iowa Loader | SUBSYSTEM: Stations 4 and 5 | ANALYST: R. W. Courtney

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
3	NOL-130 Dispenser	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction between doctor blade and spoon.	IIA		
		Normal		Low	Explosion	2. Bearing contaminated	IIA	Clean all parts thoroughly during shutdown periods	
		Normal		Low	Explosion	3. Spoon falls into guide chute	IIA	Use redundant securement methods	
		Maintenance		Low	Explosion	4. Doctor blade slide contaminated.	IIIB	Clean all parts thoroughly during shutdown periods	

[1] Includes Logistics Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 4 OF 17	DATE STARTED	DATE COMPL

PROJ NO.:

SYSTEM: Iowa Loader

SUBSYSTEM: Station 7

ANALYST: R. W. Courtney, T. M. Aronson

ITEM NO a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
4	NOL-130 RAM	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction between tool and powder guide due to mis-alignment	IIIA	Check machine components regularly	
		Normal		Low	Explosion	2. Tool impacts powder guide due to mis-alignment	IIIA		
		Normal		Low	Explosion	3. Tool impacts tool block when powder guide not present to aid in alignment	IIIA		
		Normal		Low	Explosion	4. Friction of detonator cup and tool block when RAM tool breaks.	IIIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

ARMCOMR 385-4

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

PROJ NO.	SYSTEM	SUBSYSTEM	REV NO.	REV DATE	PAGE	DATE STARTED	DATE COMPL	ANALYST
	Iowa Loader	Stations 9 and 10			5 of 17			T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
5	Lead Azide Dispenser	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Dispenser seal on azide dispenser becomes worn. Friction between seal and dispenser.	IIA	Replace seal at regular intervals	
		Maintenance		Low	Explosion	2. Initiation of lead azide occurs due to ESD from ungrounded operator	IIIB	Operators should be grounded	
		Maintenance		Low	Explosion	3. Initiation occurs during adjustment of set screws during azide dispenser removal	IIIB	Area should be decontaminated before maintenance	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

ARMCOMR 385-4

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS
(ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 6 OF 17	DATE STARTED	DATE COMPL

PROJ NO.	SYSTEM	SUBSYSTEM	ANALYST
	Iowa Loader	Stations 9 and 10	J. Agosti

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
5	Lead Azide Dispenser (cont'd.)	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	4. Initiation occurs while placing container on dumping platform.	III-B	Keep contact surfaces clean.	
		Normal		Low	Explosion	5. Impingement of lead azide occurs while dumping container	II-A		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following.
Low = Low Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 1 OF 17	DATE: STARTED	DATE: COMPL

PROJ NO.	SYSTEM	SUBSYSTEM	ANALYST
	Iowa Loader	Station 11	R. W. Courtney, T. M. Aronson

ITEM NO a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
6	Lead Azide RAM	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction between tool and powder guide due to to misalignment	IIIA	Check machine components regularly	
		Normal		Low	Explosion	2. Tool impacts powder guide due to misalignment	IIIA	Check machine components regularly	
		Normal		Low	Explosion	3. Tool impacts tool block when powder guide not present to aid in alignment.	IIIA	Check machine components regularly	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 8 OF 17	DATE STARTED	DATE COMPL

PROJ NO.	SYSTEM	SUBSYSTEM	ANALYST
	Iowa Loader	Station 11	R. W. Courtney, T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
6	Lead Azide RAM (cont'd.)	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	4. RAM tool breaks during compression	IIIA		
		Normal		Low	Explosion	5. RAM tool impacts broken RAM from NOL-130 RAM station	IIIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 9 OF 17	DATE STARTED	DATE COMPL

PROJ NO.	SYSTEM	SUBSYSTEM	ANALYST
	Iowa Loader	Station 12	R. W. Courtney, T. M. Aronson

ITEM NO a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
7	Vacuum Clean Station	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. ESD between vacuum tool and tool block	IIIA	Make sure that equipment and operators are grounded	
		Normal		Low	Explosion	2. Vacuum tool impacts a broken tool from previous station	IIIA		
		Normal		Low	Explosion	3. Friction between vacuum tool and powder guide	IIIA		
		Normal		Low	Explosion	4. Friction in bearing	IIIA	Lubricate bearing and other machine parts regularly	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

PROJ NO.	SYSTEM: Iowa Loader	REV NO.	REV DATE	SUBSYSTEM: Station 13	PAGE 10 OF 17	DATE STARTED	DATE COMPL	ANALYST: R. W. Courtney, T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
8	Powder Guide Removal	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Powder guide is dropped on indexing table	IIIA		
		Startup/ shutdown		Low	Explosion	2. ESD occurs when removing powder guide (charged during vacuum cleaning)	IIIA	Operators and equipment should be grounded.	
		Normal		Low	Explosion	3. Friction occurs when guide removed while a broken RAM tool was in powder guide	IIIA		
		Normal		Low	Explosion	4. Tool not raised so powder guide dragged from tool block	IIIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

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ARMCOMR 385-4

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)						REV NO.	REV DATE	PAGE 11 OF 17	DATE: STARTED	COMPL
PROJ NO.	SYSTEM: Iowa Loader					SUBSYSTEM: Station 13		ANALYST: R. W. Courtney, T. M. Aronson		

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
8	Powder Guide Removal (cont'd.)	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	5. Tool not raised so tool and powder guide impact powder guide storage post	IIIA		
		Normal		Low	Explosion	6. Friction of finger of removal tool with powder guide	IIIA		
		Normal		Low	Explosion	7. Normal friction between tool slider block and tool support	IIIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 12 OF 17	DATE: STARTED / COMPL
PROJ NO.	SYSTEM: Iowa Loader	SUBSYSTEM: Station 14	ANALYST: R. W. Courtney, T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
9	RDX Pellet Feeder	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction of pellet on slide if pellet slide is misaligned	IIA	Positions of machine components should be checked regularly.	
		Normal		Low	Explosion	2. Pellet punch tool impacts pellet slide due to misalignment.	IIA		
		Normal		Low	Explosion	3. Pellet punch tool impacts tool block due to improper index of table.	IIA		
		Normal		Low	Explosion	4. Friction of tool on tool block if tool does not retract to home position.	IIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	REV DATE	PAGE 13 OF 17	DATE STARTED	COMPL
PROJ NO	SYSTEM Iowa Loader	SUBSYSTEM Station 14	ANALYST J. Agosti	

ITEM NO a	NOMEN AND PART NO b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
9	RDX Pellet Feeder (cont'd.)	Normal	Operator Error	Low	Explosion	5. Friction initiation results during replacement of pellet tubes.	III-B	Keep contact surfaces clean of explosive contamination	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal, Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

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Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.	
REV DATE	
PAGE	14 of 17
DATE STARTED	
DATE COMPL	
PROJ NO.	
SYSTEM	Iowa Loader
SUBSYSTEM	Station 15
ANALYST	R. W. Courtney, T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
10	RDX RAM	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Tool impacts tool block due to mis-alignment	IIIA		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS
(ARMCOMR 385-4)

PROJ NO.	SYSTEM	REV NO.	REV DATE	PAGE 15 OF 17	DATE STARTED	DATE COMPL
	Iowa Loader					

SUBSYSTEM: Station 17

ANALYST: T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
11	Foil Disc Placement	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	1. Friction of foil disc on cup	IIIA		
		Maintenance		Low	Explosion	2. Friction initiation during replacement of worn punches and dies	IIIB		

[1] Includes Logistics Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx. 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 151 R, 1 APR 73

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS (ARMCOMR 385-4)

REV NO.:
REV DATE:
PAGE 16 OF 17
DATE: STARTED / COMPL

PROJ NO.:
SYSTEM: Iowa Loader
SUBSYSTEM: Stations 19 and 21
ANALYST: R. W. Courtney, T. M. Aronson

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE[1] c	FAILURE MODE[2] d	EST PROB[3] e	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
12	Cup Crimps	Normal	May consist of operator error and/or equipment failure.	Low	Explosion	Initiation of detonator occurs during crimping	IIIA	Ensure proper operation of aspirator stations	

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility.

[3] Enter one of the following:
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

ARMCOMR 385-4

Table 10 (cont'd.)

PRELIMINARY HAZARD ANALYSIS

(ARMCOMR 385-4)

PROJ NO.	SYSTEM	SUBSYSTEM	REV NO.	REV DATE	PAGE	DATE STARTED	DATE COMPL	ANALYST
	Iowa Loader	Station 23			17 OF 17			T. M. Aronson, J. H. Agosti

ITEM NO. a	NOMEN AND PART NO. b	OPERATING MODE c [1]	FAILURE MODE d [2]	EST PROB e [3]	FAILURE EFFECTS f	HAZARD DESCRIPTION g	HAZ CAT h	RECOMMENDED CONTROL i	AMPLIFYING REMARKS (INCLUDE VERIFICATION) j
13	Detonator Removal	Mainten-ance	May consist of operator error and/or equipment failure.	Low	Explosion	1. Initiation of explos-ive occurs during changing of rubber chucks	IIIB		

[1] Includes Logistic Phases

[2] Includes effects of Human error, Normal/Abnormal Environments, Design Deficiencies, Incompatibility

[3] Enter one of the following.
Low = Low/Remote Prob.
Medium = Approx 0.001 to 1.0001 Prob.
High = Greater than 0.001 Prob.
Unknown = Unknown Prob.

ARMCOM FORM 153-R, 1 APR 75

ARMCOMR 385-4

APPENDIX A. CUSTOMER FURNISHED INFORMATION

DATE RECEIVED	IDENT. NO.	ITEM DESCRIPTION	NO. SHEETs	STATUS CODE
9/17/79	4A22-M621	Drawing	(1)	C
	-M622	Drawing	(1)	C
	-M624	Drawing	(1)	C
	-M631	Drawing	(1)	C
	-T663	Drawing	(1, 2 of 2)	C
	-M632	Drawing	(1, 2 of 14)	C
	-M635	Drawing	(1, 2 of 11)	C
	-M637	Drawing	(1,2,3,4,6,8 of 9)	C
	-T665	Drawing	(1)	C
	-T653	Drawing	(1)	C
	-T664	Drawing	(1)	C
	-M636	Drawing	(1, 3, 4 of 4)	C
	-M638	Drawing	(1, 2 of 16)	C
	-T666	Drawing	(1)	C
	-T667	Drawing	(2)	C
	-T668	Drawing	(1)	C
	-T669	Drawing	(1)	C
	-M639	Drawing	(1, 2 of 5)	C
	-M641	Drawing	(1)	C
	-M629	Drawing	(1)	C
	-T639	Drawing	(1)	C

STATUS CODE: A. Item to be returned at Contract closeout - Proprietary
B. Item to be returned at Contract closeout - Unclassified
C. Item for information only - Return not required

APPENDIX A (CONT'D.)

DATE ECEIVED	IDENT. NO.	ITEM DESCRIPTION	SHEET NO	STATUS CODE
9/17/79	4A22-M648	Drawing	(1)	C
	-M647	Drawing	(1)	C
	-M644	Drawing	(1)	C
	-M643	Drawing	(1)	C
	-P606	Drawing	(1,2,3 of 4)	C
	-T670	Drawing	(All 4 of 4)	C
	-P605	Drawing	(1, 3 of 3)	C
	-H604	Drawing	(1)	C
	-E636	Drawing	(1)	C
	-M651	Drawing	(1)	C
	-M645	Drawing	(1)	C
	-M652	Drawing	(1)	C
	-M642	Drawing	(1, 2 of 3)	C
	-M626	Drawing	(1)	[illegible]
	-M630	Drawing	(1)	C
	-M625	Drawing	(1)	C
	-M627	Drawing	(All 8 of 8)	C
	-M628	Drawing	(1)	C
	-M629	Drawing	(2)	C
	-M626	Drawing	(1,2,3, of 18)	C

STATUS CODE: A. Item to be returned at Contract closeout - Proprietary
B. Item to be returned at Contract closeout - Unclassified
C. Item for information only - Return not required

APPENDIX A (CONT'D.)

DATE ECEIVED	IDENT. NO.	ITEM DESCRIPTION	STATUS CODE
9/7/79	Rev. 1	Equipment Technical Data Package Specifications Manual	C
9/7/79	-	Equipment Manual for X4 Series Iowa Loader	C
9/7/79	-	Operating and Maintenance Procedures (Six Sheets)	C

STATUS CODE: A. Item to be returned at Contract closeout - Proprietary
B. Item to be returned at Contract closeout - Unclassified
C. Item for information only - Return not required

APPENDIX B. PROBIT PLOTS

The data, generated by sensitivity tests performed on prior contracts by Hercules, were used to prepare probit curves by plotting percentage of test initiations versus the test energy. Probit plots were generated for friction, impact and ESD at the 50% and 95% confidence levels and are shown in Figures 2 through 18. Friction material response levels for the explosives at velocities lower than the test velocities were obtained from the friction velocity profile shown as Figure 1. These plots were then used in the analysis to determine probability of initiation for an explosive at an energy level available in the system as the in-process stimuli.

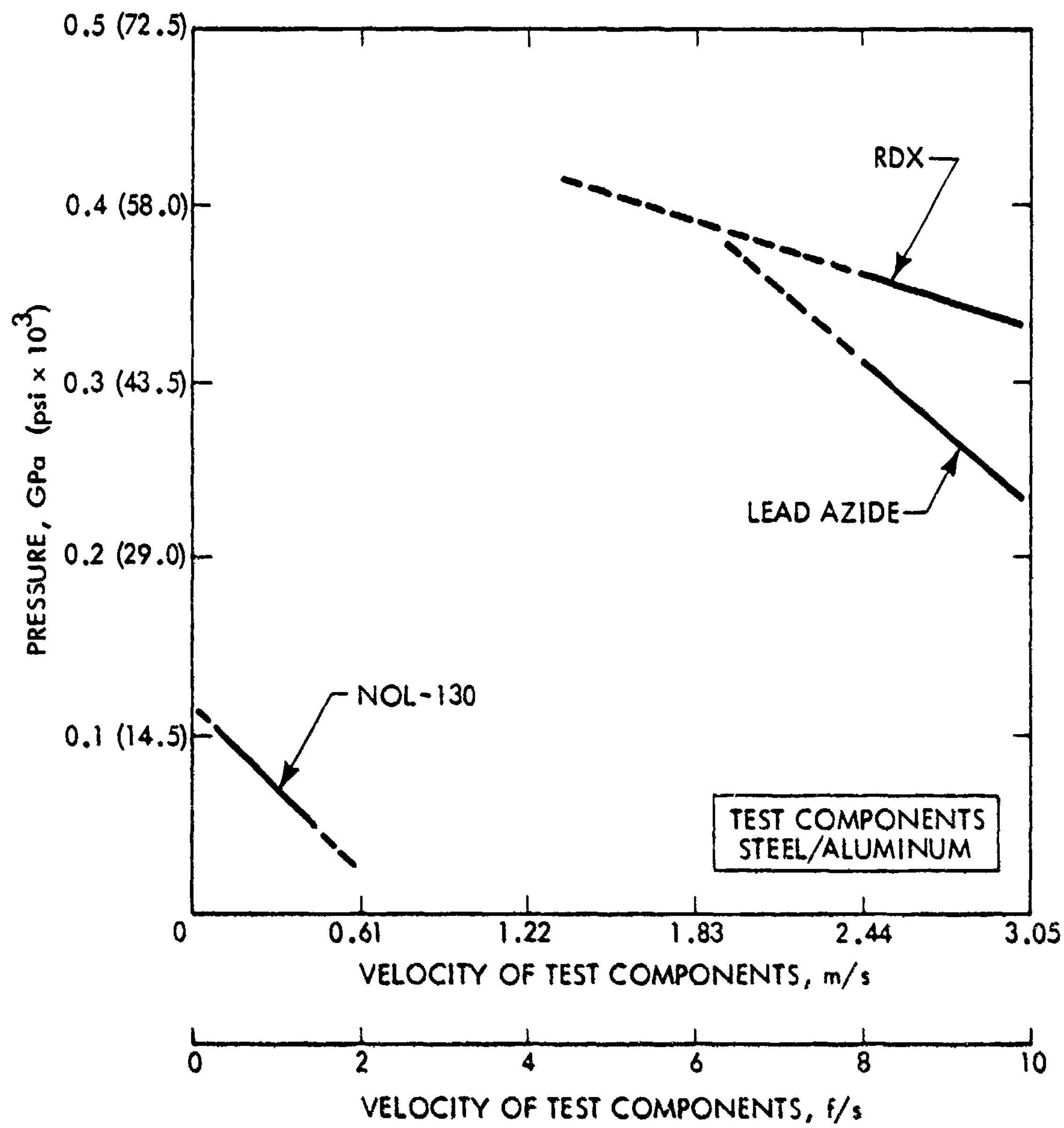

Figure 1. Friction - velocity profile

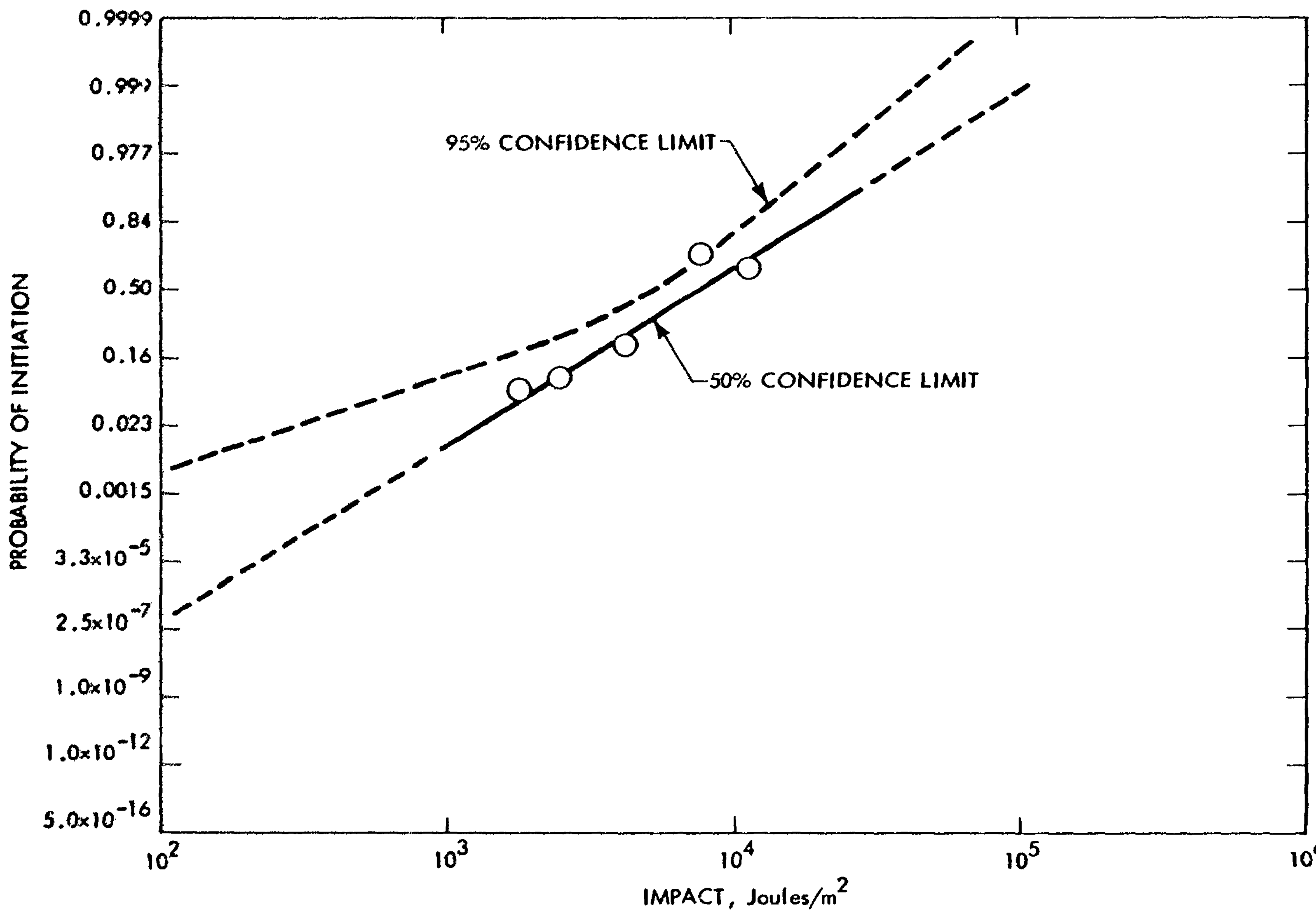

Figure 2. Impact probit data for NOL-130, steel/steel

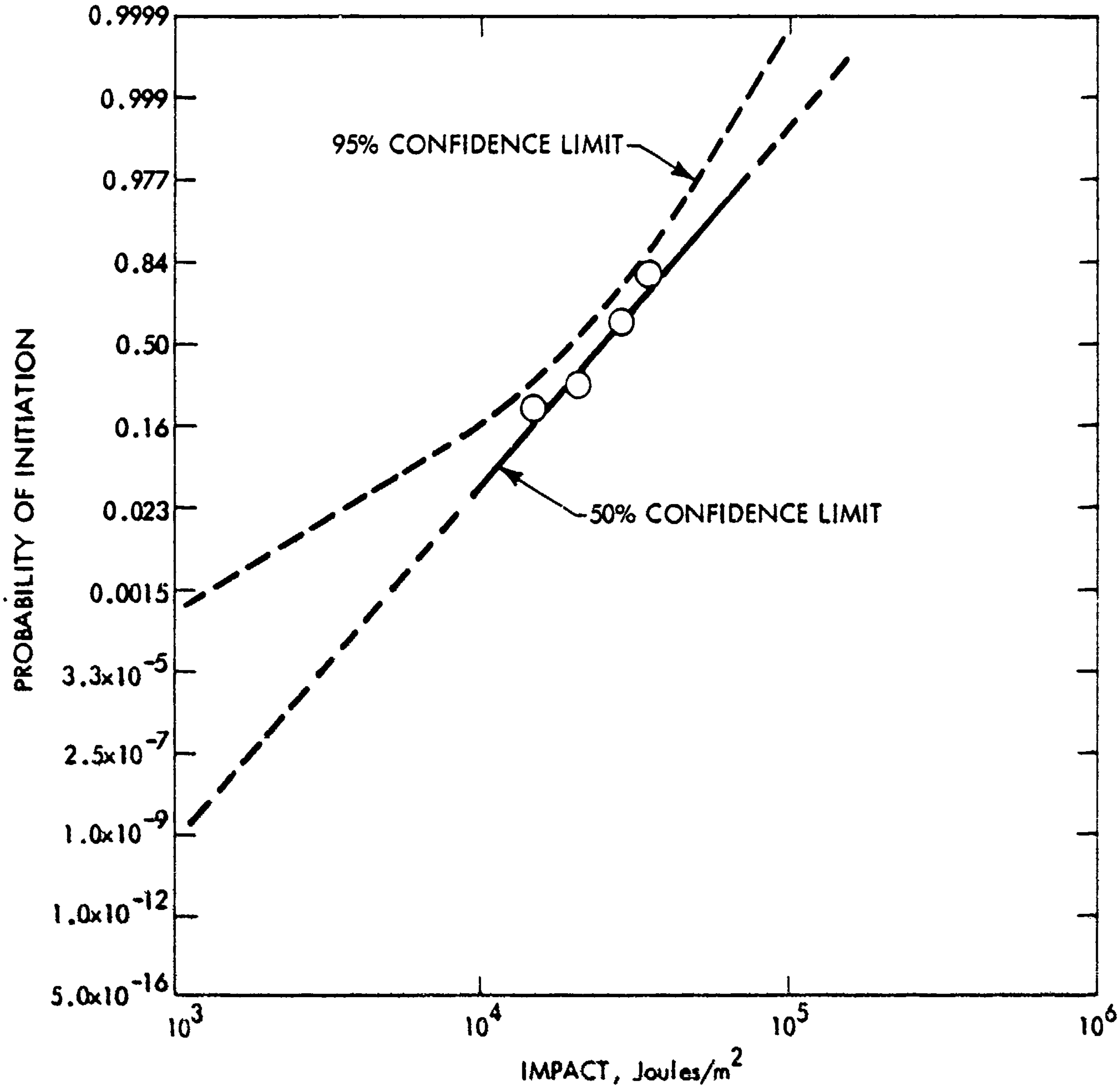

Figure 3. Impact probit data for NOL-130, steel/aluminum

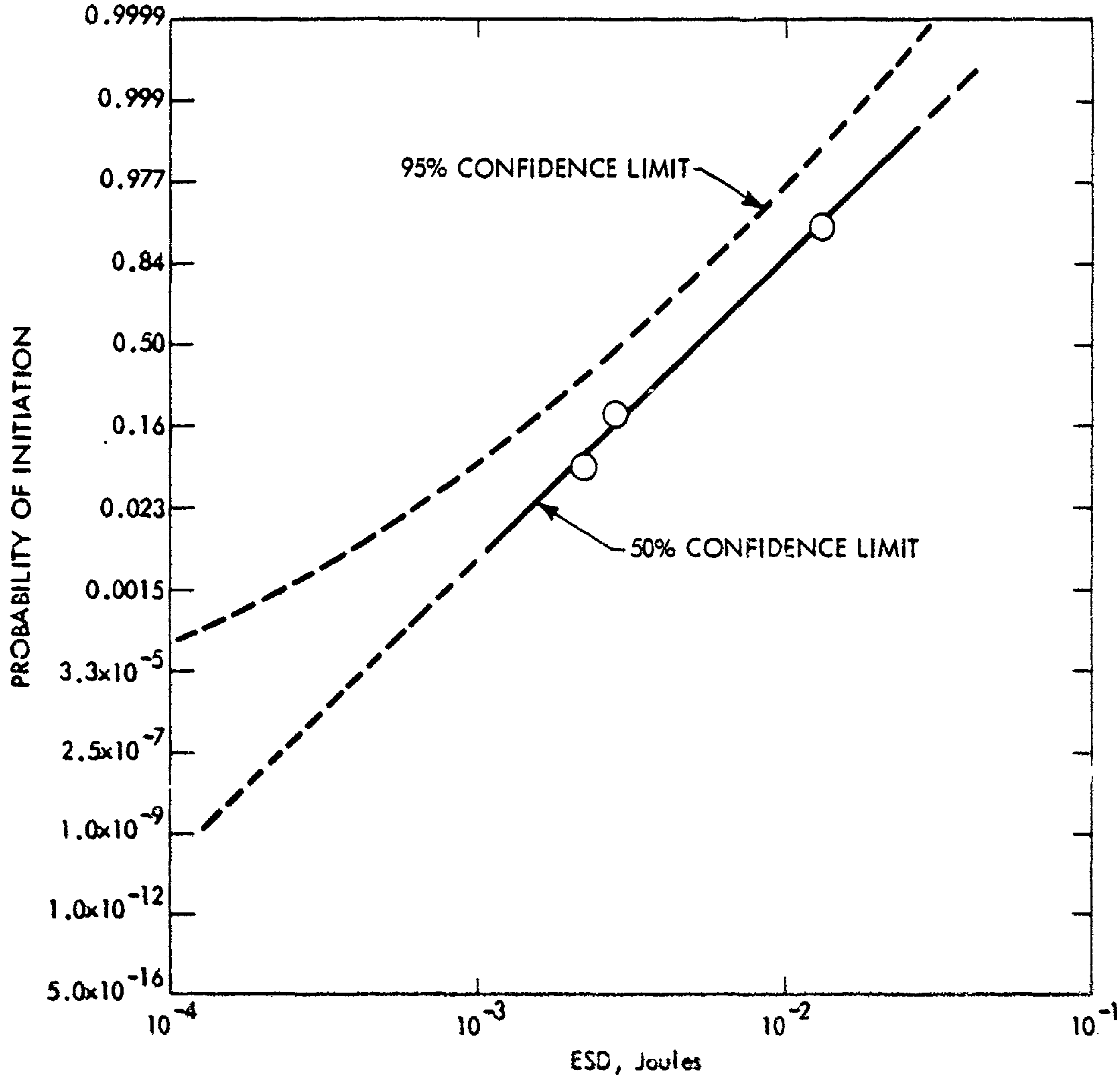

Figure 4. ESD probit data for NOL-130

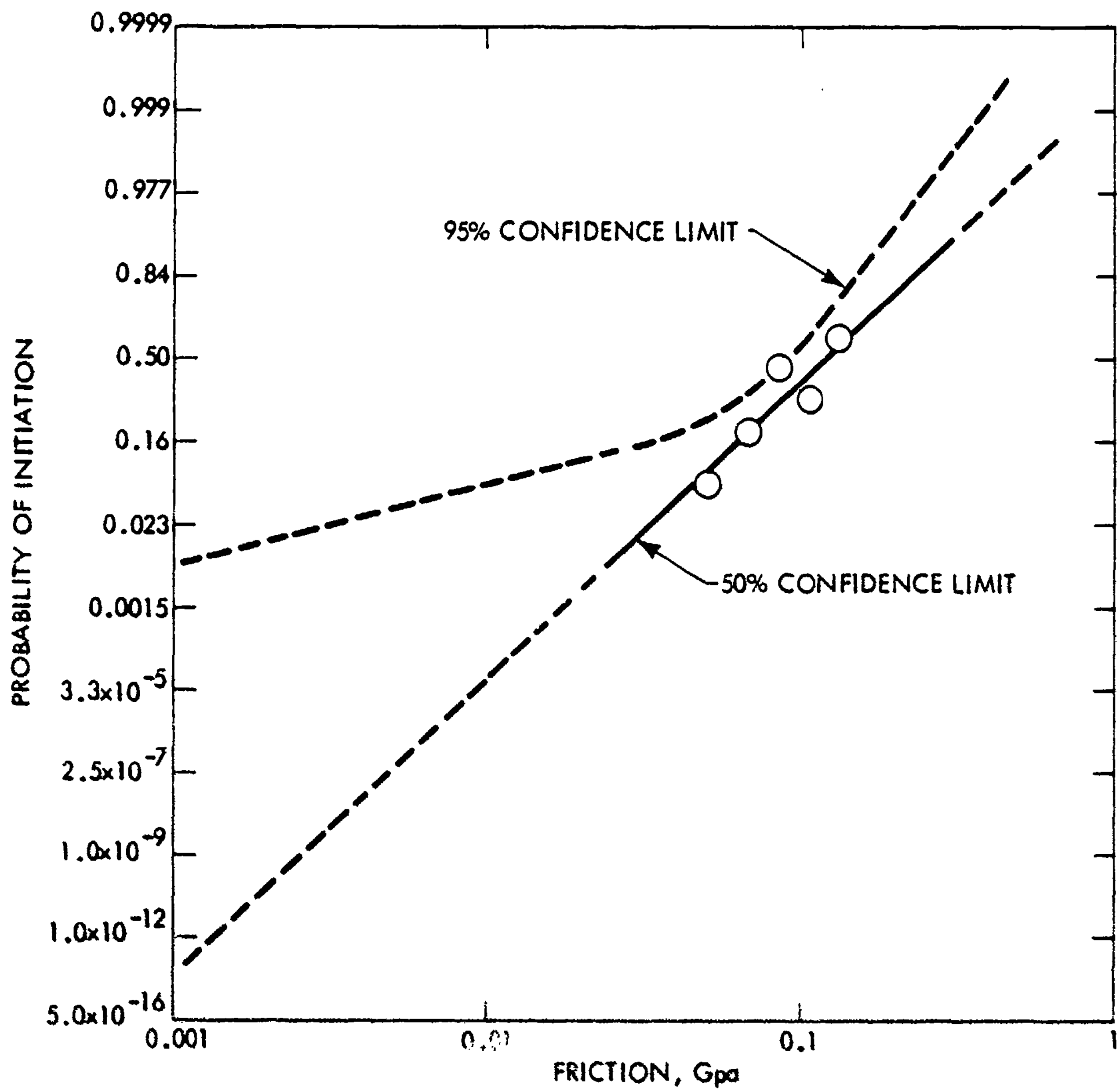

Figure 5. Friction probit data for NOL-130, steel/steel at 0.3 m/s

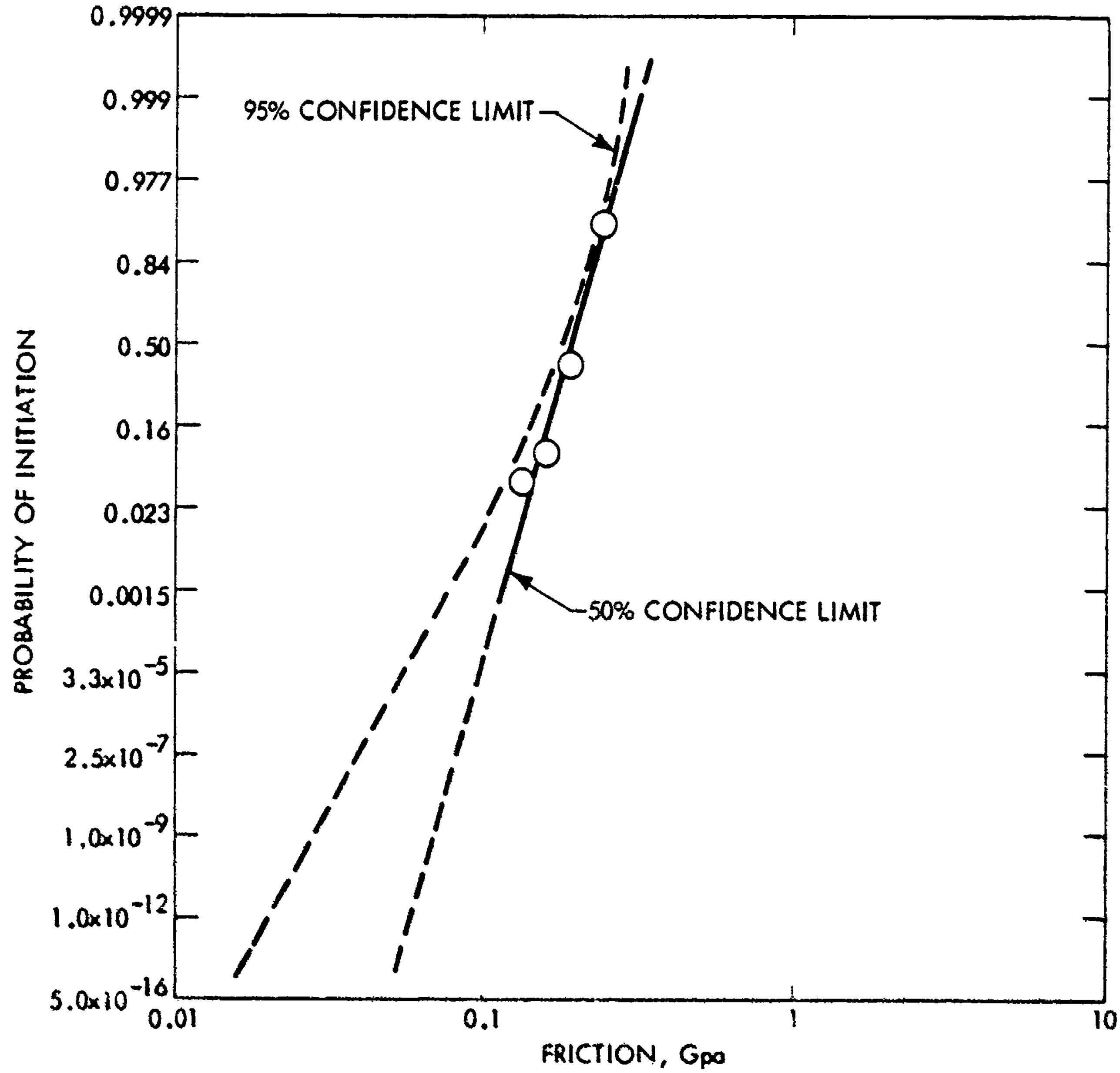

Figure 6. Friction probit data for NOL-130, steel/steel at 0.15 m/s

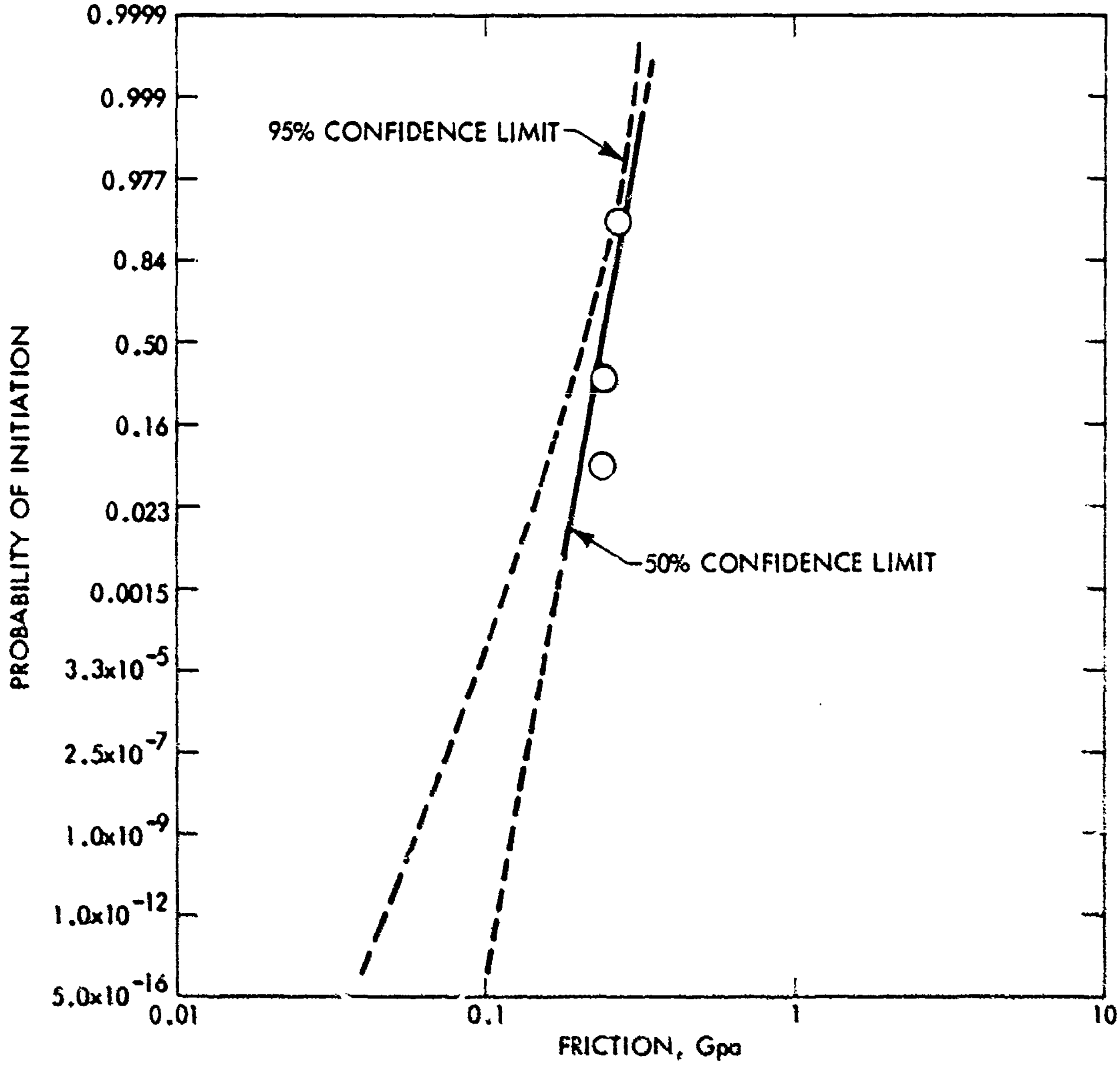

Figure 7. Friction probit data for NOL-130, steel/steel at 0.0375 m/s

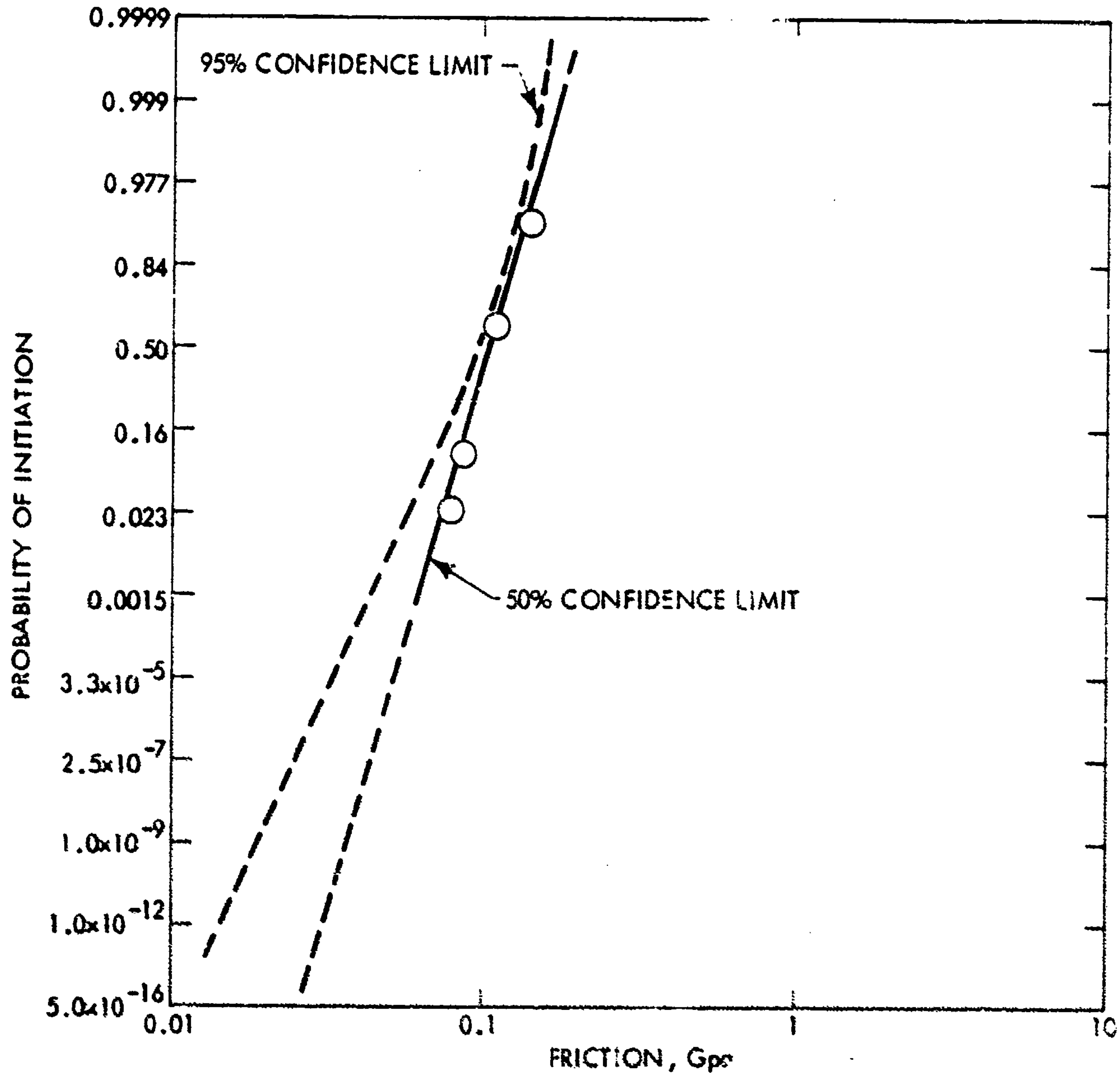

Figure 8. Friction probit data for NOL-130, steel/aluminum at 0.15 m/s

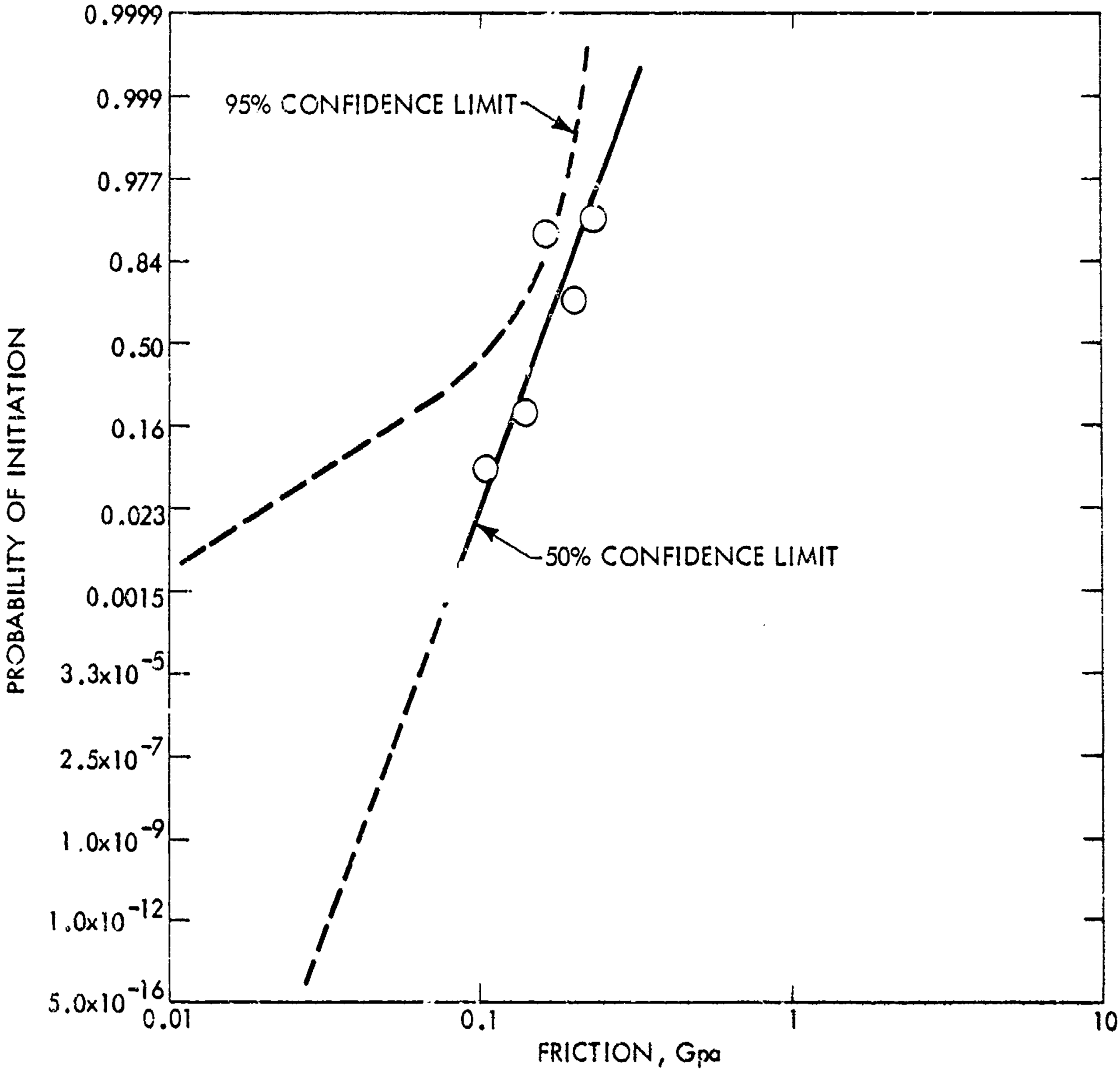

Figure 9. Friction probit data for NOL-130, steel/aluminum at 0.0375 m/s

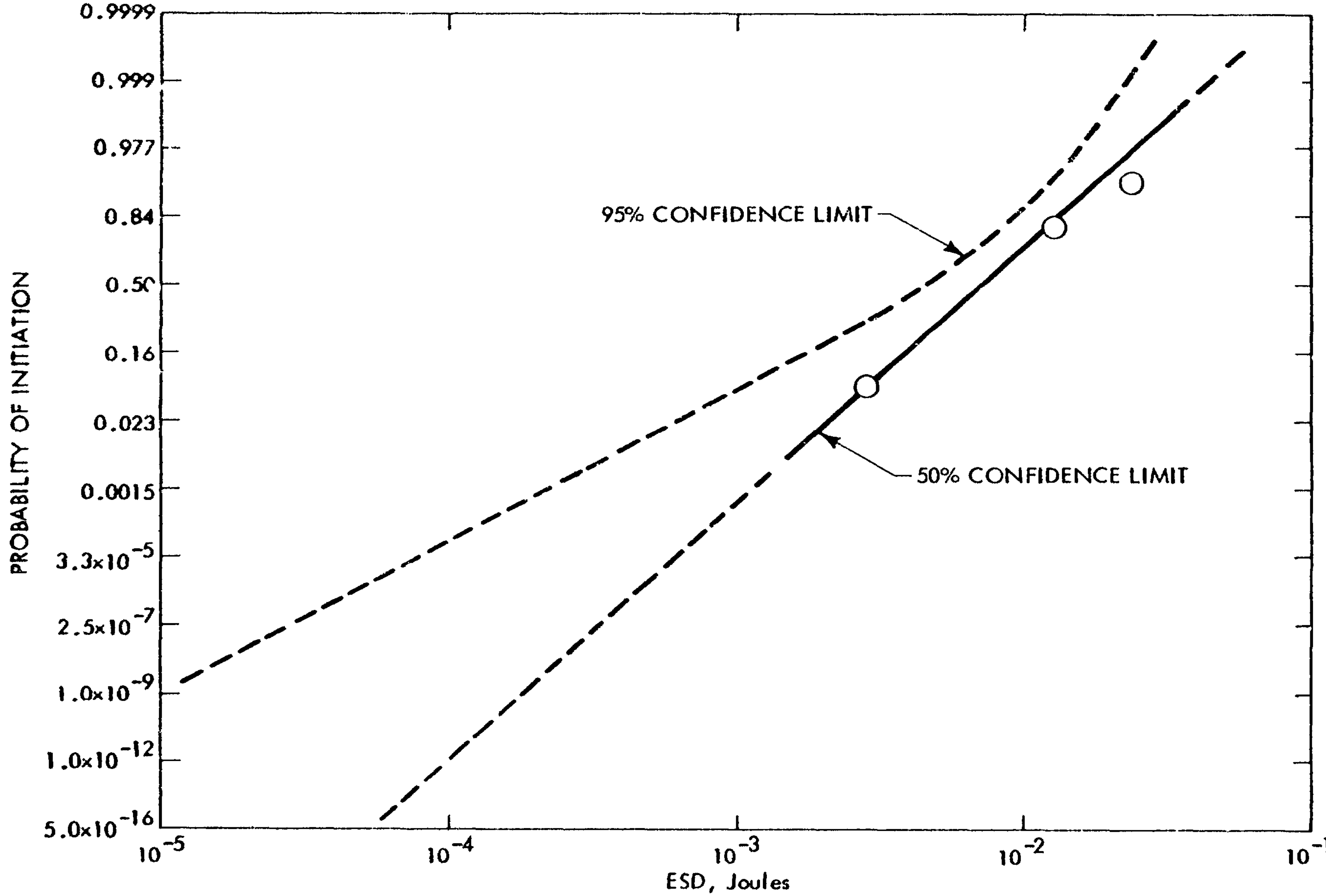

Figure 10. ESD probit data for lead azide

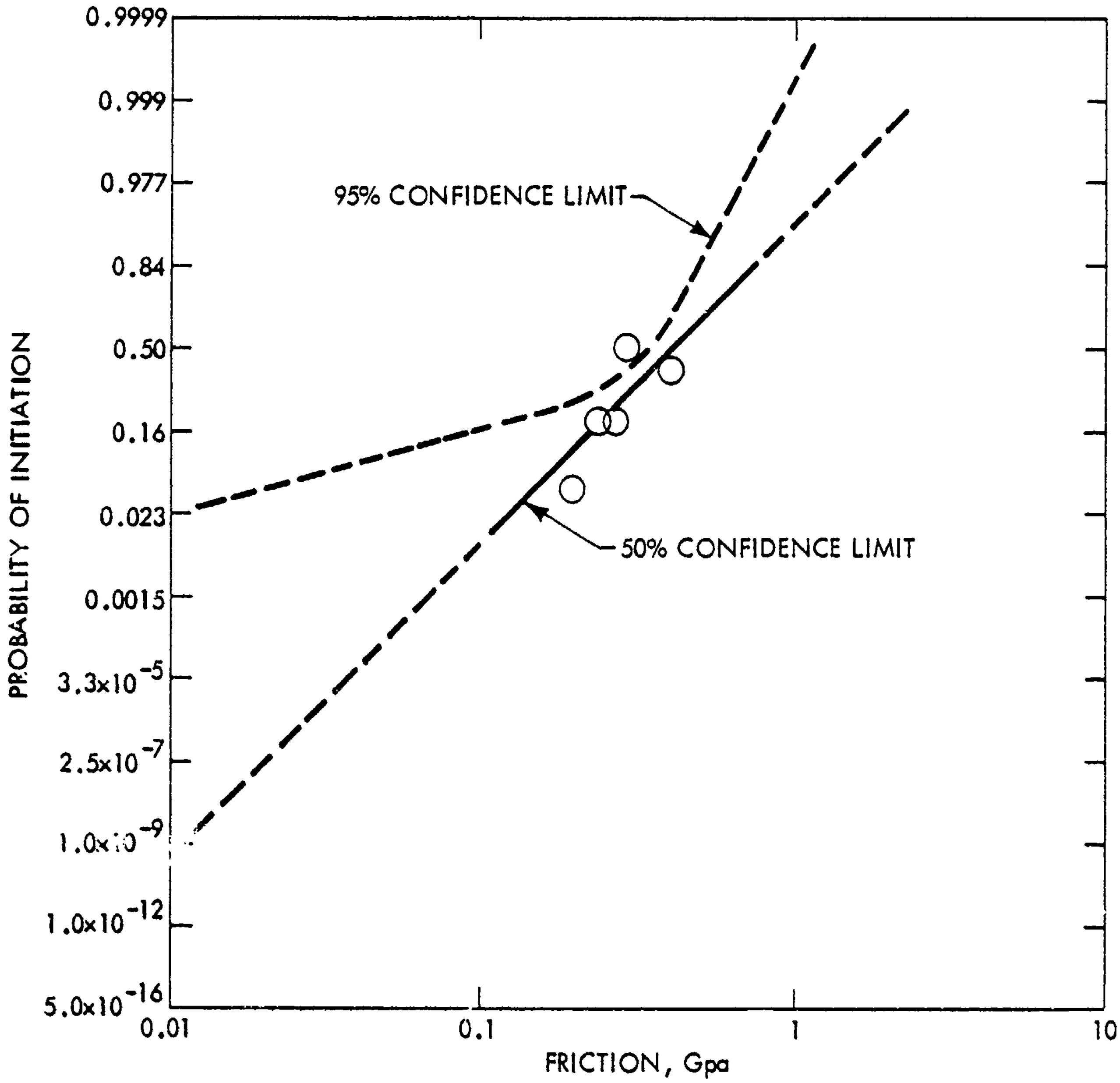

Figure 11. Friction probit data for lead azide, steel/steel at 0.15 m/s

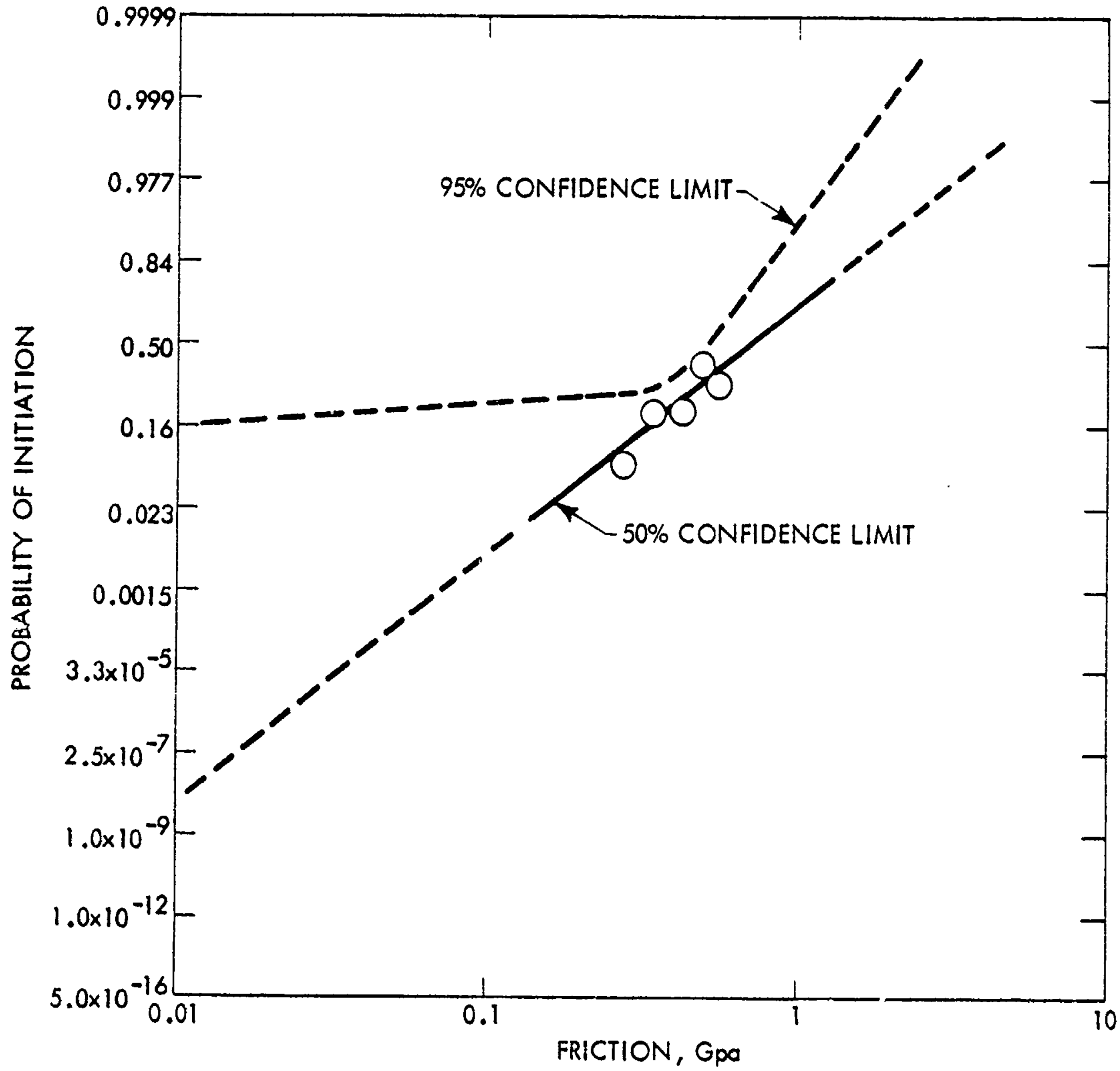

Figure 12. Friction probit data for lead azide, steel/steel at 0.0375 m/s

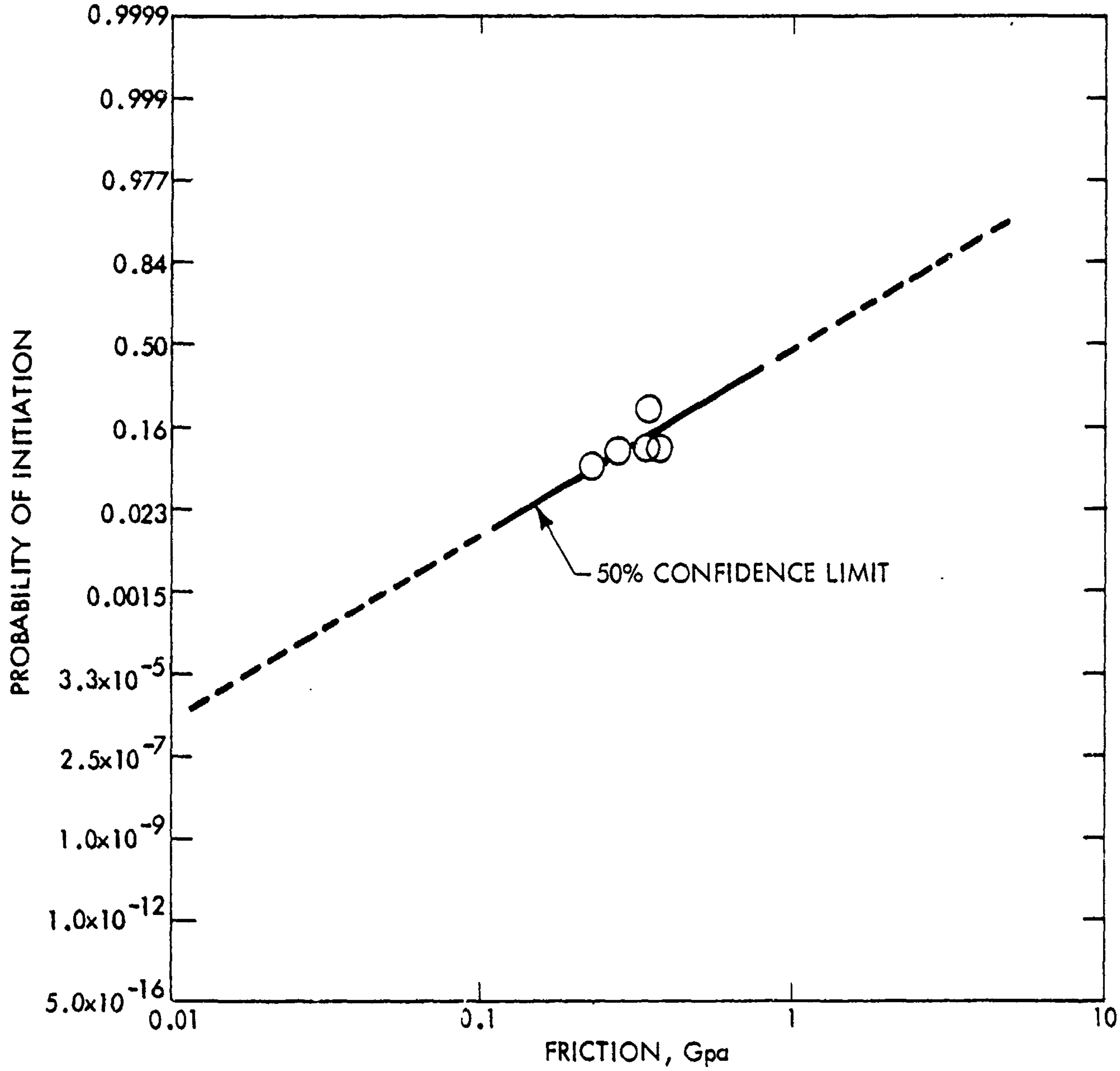

Figure 13. Friction probit data for lead azide, steel/aluminum at 3.0 m/s

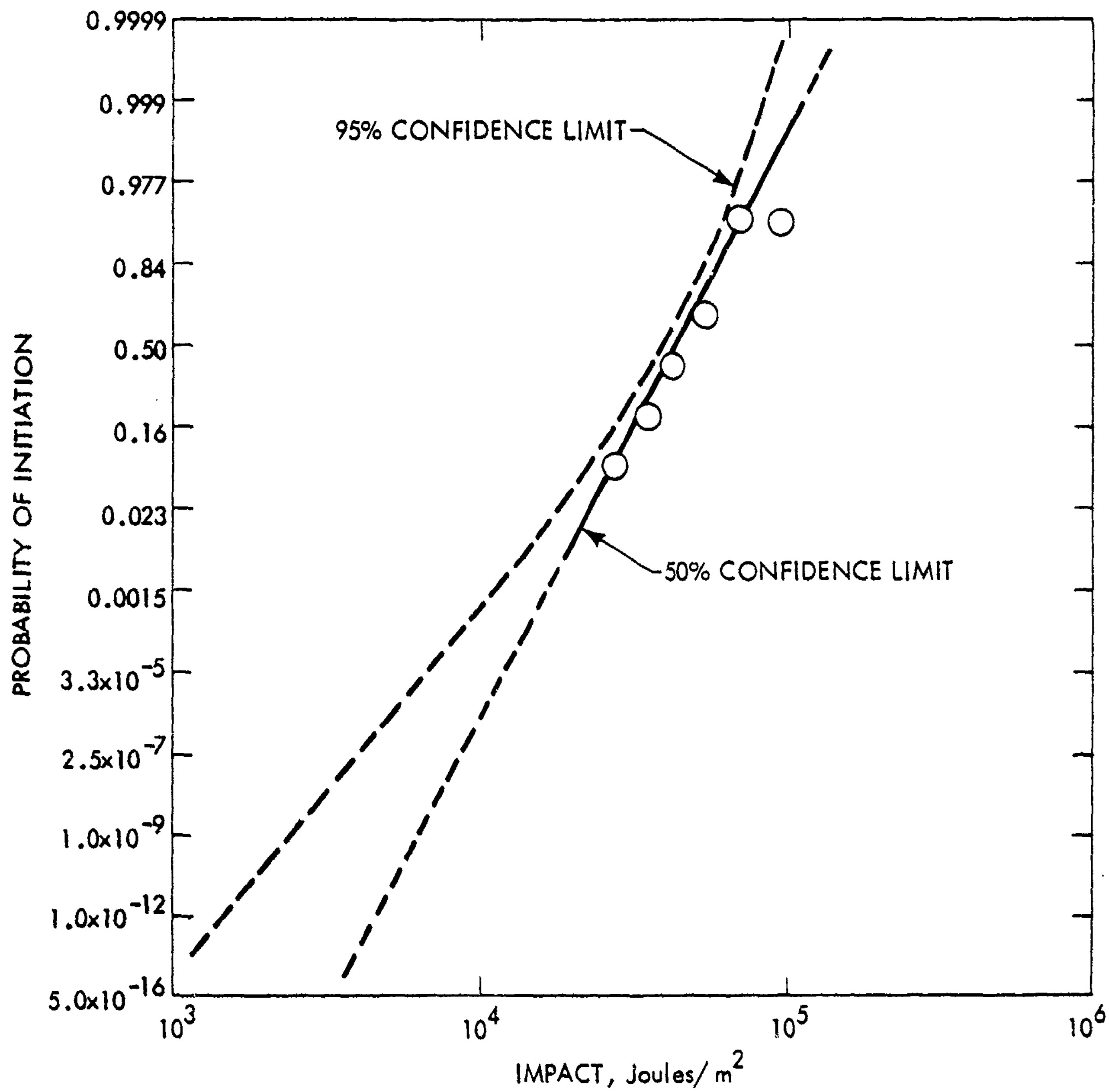

Figure 14. Impact probit data for RDX, steel/steel

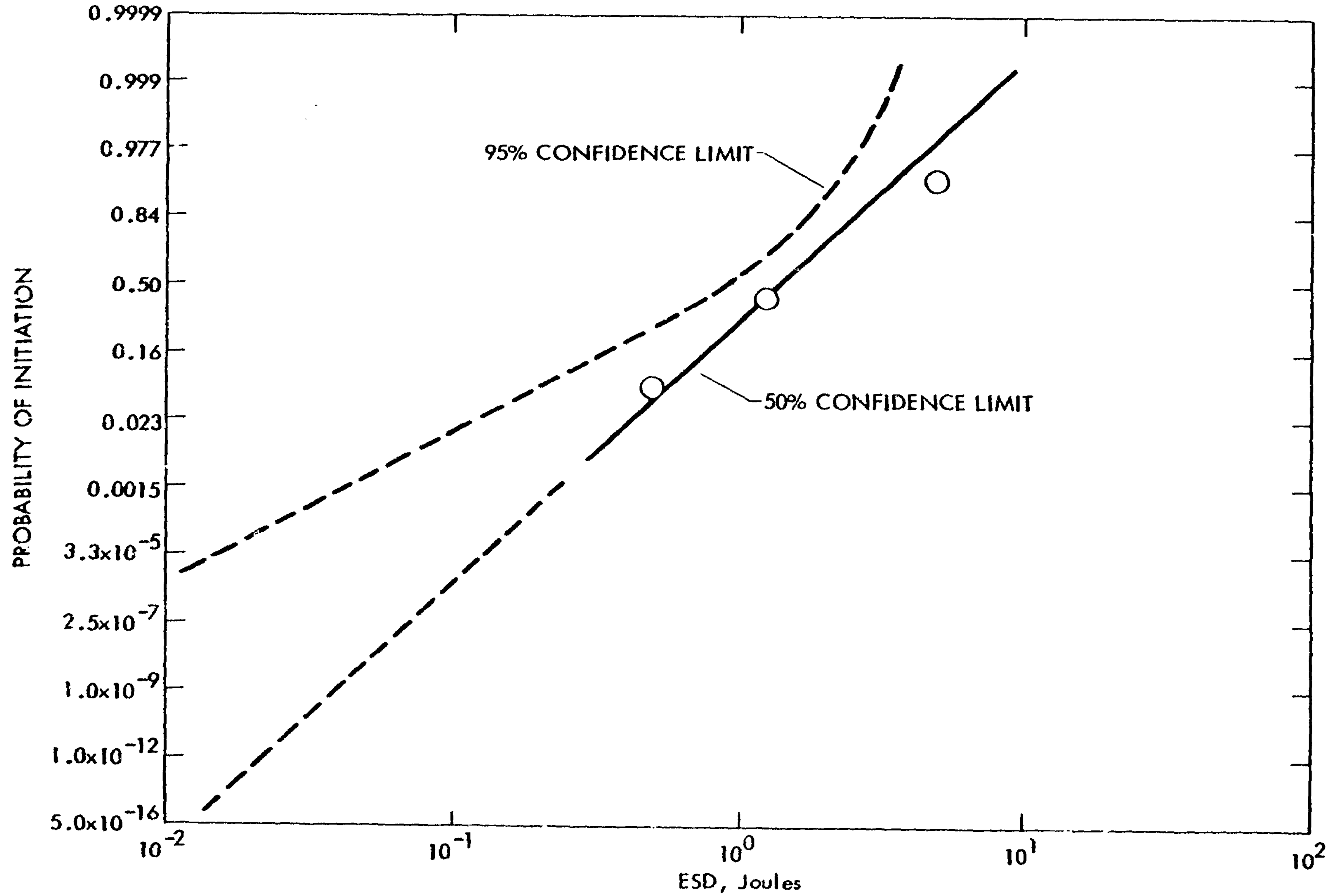

Figure 15. ESD probit data for RDX

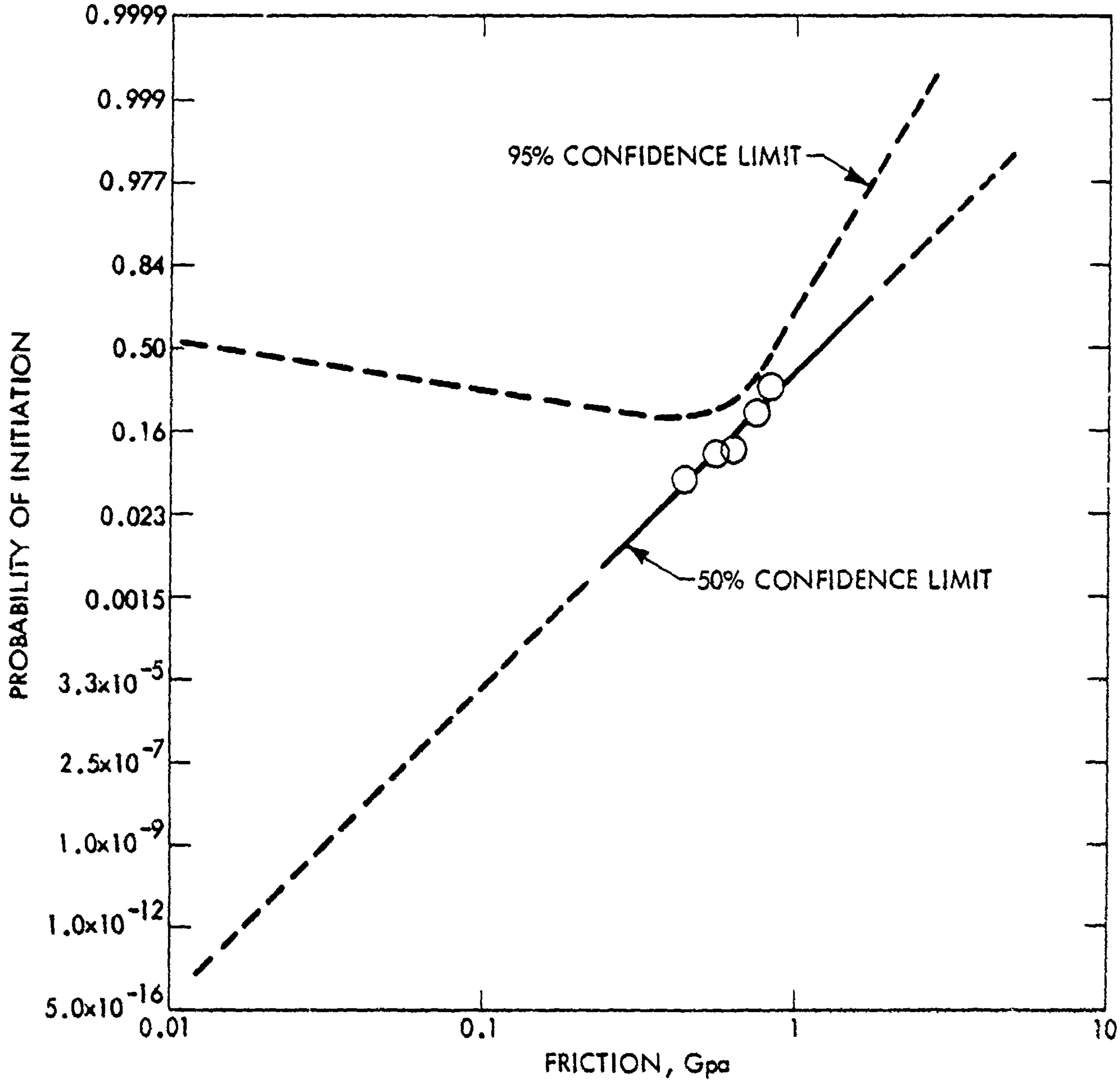

Figure 16. Friction probit data for RDX, steel/steel at 0.61 m/s

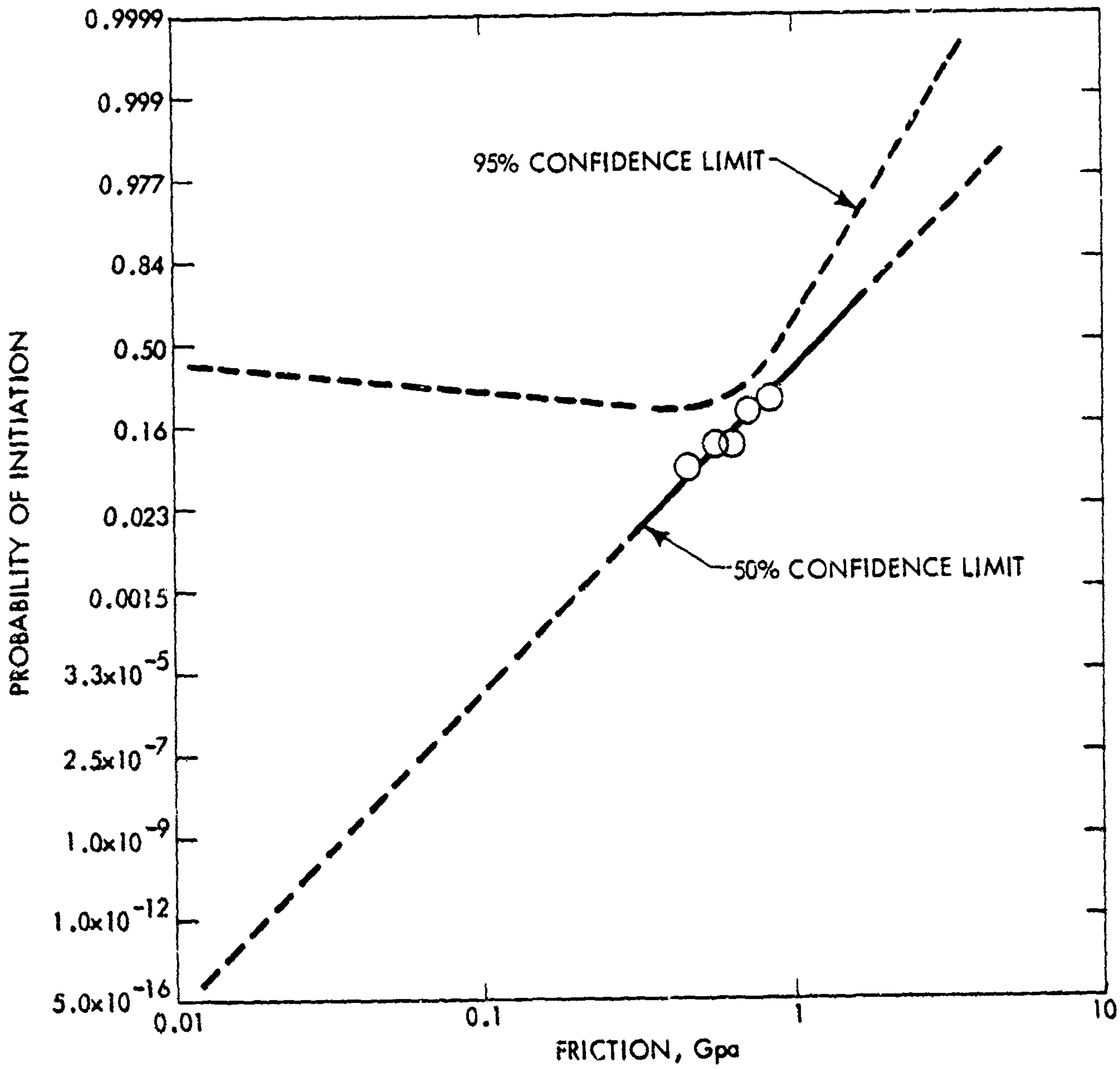

Figure 17. Friction probit data for RDX, steel/steel at 0.3 m/s

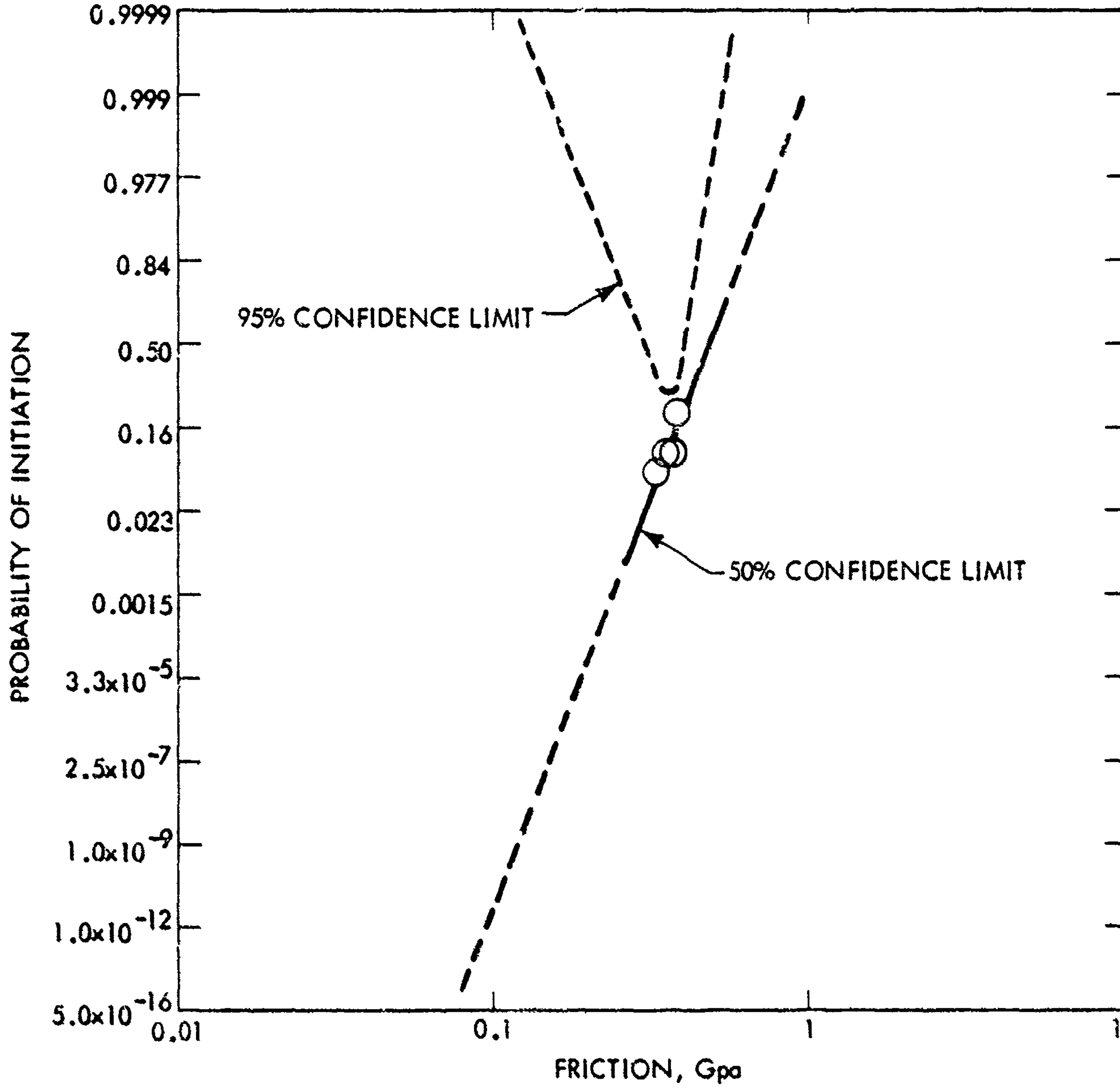

Figure 18. Friction probit data for RDX, steel/aluminum at 3.0 m/s

APPENDIX C. EXPLANATION OF HAZARD ANALYSIS TABLES

This table offers a description of the different types of entries found in the "Engineering Analysis and Hazard Evaluation" tables found in this report.

Column Title	Explanation
Operation	Processing operation being analyzed.
Potential Initiation Hazard	This column states the specific event or operation that has been determined to be potentially hazardous.
Initiation Mode	The specific mode(s) by which the event can cause initiation. In some cases an event can cause initiation by more than one mode. Examples of initiation modes include impact, friction, ESD, and impingement. Also listed here are the materials of construction associated with the potential hazard.
Combustible Present	In this column, the combustible material (Nol-130, Lead Azide and RDX) are specified.
Process Potential	The process potential is the result of the determination of the process stimuli or energy that can be generated by the event. This can be determined by direct measurement, laboratory simulation, or calculation. For analyses involving design, development, or prototype equipment, process potentials are usually calculated utilizing knowledge of the equipment drawings, operating procedures and characteristics of the materials of construction (yield strengths, for example). To ensure a conservative analysis, the calculations are based on the most severe processing condition.
Material Response	The material response is listed as the threshold initiation level (i.e., the highest test level at which no initiation is evidenced in a fixed number of trials) of the combustible material. This has been established from previous initiation tests.

Column Title	Explanation
Safety Margin	The safety margin (SM) is equal to material response (MR) divided by the process potential (PP) less one. $SM = \frac{MR}{PP} - 1$
Probability of Event (E_p)	E_p is the probability of the hazardous event occurring and is numerically equal to one for normally occurring events. For abnormal events, the probability is established from the appropriate equipment or human failure rate. Equipment failure rates are obtained from one of several available data banks. Human error probabilities have been established from past history and indicate that the probability per event of an operator making an error in following procedures is 1×10^{-3}, of dropping an item is 1×10^{-4} and the probability of an accidental situation ranges from 1×10^{-3} to 1×10^{-5} depending upon the labor intensity of the operation. In many cases, the event is dependent on a combination of more than one equipment and/or human failure rates.
Probability of Combustible (C_p)	The probability of combustible (C_p) is the probability that the combustible material is present where and when the hazardous event occurs. C_p is equal to one where explosive is normally present. Where it is not normal for the combustible to be, C_p depends upon the event(s) necessary for the combustible to be present.
Probability of Initiation (I_p)	The probability of initiation is determined by statistically comparing the process potential with the results of initiation (material response) tests conducted on the combustible material. The probit curves are used in making these determinations.
Probability of Fire (F_p)	The probability is the product of all the listed probabilities. $F_p = E_p \times C_p \times I_p$

APPENDIX C (CONT'D.)

Column Title	Explanation
Probability of Explosion (X_p)	The probability of fire (F_p) multiplied by the probability of the transition of a fire to an explosion. This is evaluated by considering the critical height to explosion, confinement characteristics, quantity of explosive present, and similar data. $$X_p = E_p \times C_p \times I_p \times T_p$$
Hazard Category	Hazard severity categories as classified in DARCOM-PBM 385-3.

APPENDIX D. DETERMINATION OF PROBABILITY OF INITIATION VIA SAFETY FACTORS

Determining probability of initiation using the safety factor approach is analogous to determining reliability for stress-strain problems. The expression for determining the probability of initiation is as follows:

$$Z = \frac{PP - MR}{\sqrt{\sigma^2_{PP} + \sigma^2_{MR}}} \qquad \text{(C-1)}$$

where: PP = process potential

MR = material response

σ^2_{PP} = variation for the process potential

σ^2_{MP} = variation for the material response

Z = standard normal deviate whose value yields the probability of initiation

The safety factor is defined as:

$$\text{Safety Factor (SF)} = \frac{MR}{PP}$$

The above expression becomes:

$$Z = \frac{1 - SF}{\sqrt{(CV_{PP})^2 + (MS)^2 \, (CV_{MR})^2}} \qquad \text{(C-2)}$$

where: CV_{PP} = coefficient of variation for the process potential

CV_{MR} = coefficient of variation for the material response

The expression was adjusted to compensate for the fact that the TIL is utilized in determining the safety factor. This yields:

$$Z = \frac{1 - SF}{\sqrt{(CV_{PP})^2 + (SF)^2 \, (CV_{MR})^2}} - 1.84 \qquad \text{(C-3)}$$

The 1.84 factor is the standard normal deviate for a probability of 0.967 (1-0.033), or 0/20 tests.

The variation for the material response has been shown to be quite large compared to the variation of the process potential. Thus, equation C-3 reduces to

$$Z = \frac{1 - SF}{(SF)\ (CV_{MR})} - 1.84 \qquad \text{(C-4)}$$

The Z factor expression can then be utilized to evaluate the probability of initiation.

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