SAFE SEPARATION DISTANCE OF 81mm MORTARS BY ANALOGY TO THE M374 SERIES TESTING

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ABSTRACT

Safety regulations require a safe separation distance between ammunition items to prevent propagation between buildings or between bays when conveyors are used to transport such items. Establishing such a distance usually requires testing to obtain the 50 samples necessary for statistically acceptable data. This paper presents the rationale used to avoid testing the new generation M821E1/M889E1 81mm mortars by comparing the velocities, and fragment weights from arena tests, configurations, and projectile physical parameters with the older M374 Series 81mm mortar. The M374 mortar was extensively tested in several configurations and use of the new 81mm mortar safe separation distance data established by this analogy allows production of the new mortar on existing production lines without conducting testing and expending costly items.

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SAFE SEPARATION DISTANCE OF 81mm MORTARS BY ANALOGY TO THE M374 SERIES TESTING

BACKGROUND

Ammunition and explosive items, or groups of items that are transported from one operating building to another, or from bay to bay within an operating building shall be separated to preclude the establishment of a path for the propagation of an explosion or fire between the buildings or bays. This requirement is imposed by the Army Material Command regulation AMC-R 385-100. A minimum spacing of intraline distance is to be used unless statistically acceptable testing is conducted to show that the non-propagation distance is less than intraline distance.

An extensive series of tests was conducted in the 1970's and 1980's to determine this reduced non-propagation distance for numerous ammunition items, bulk explosives and explosive components. These tests were conducted under Manufacturing Methods and Technology (MMT) Projects 57X4201, 57X4288 and 58X4288, for the Project Manager for Munitions Production Base Modernization and Expansion as part of their Army-wide facility modernization program.

Under the above programs testing was conducted to determine the minimum safe separation distance of 81mm HE mortar rounds in various configurations. These results were approved by the AMC Field Safety Activity and applied at both Kansas and Milan Army Ammunition Plants. The items tested were the M374 HE Cartridge, M374A1 HE Projectile, and the M374A2E1 HE Projectile.

Recently, new 81mm HE mortar rounds have been developed: the M821E1 and M889E1. These items, which are identical to each other except for the fuzing, are very similar to the M374 series, except for a lower explosive weight and a different projectile body material. These rounds were developed to improve the fragmentation (numbers of fragments and pattern) of the 81mm mortar.

Use of intraline distances to separate these items during production is unacceptable if design production rates are to be met. The cost of these new 81mm rounds, which are not yet in production, is high and safe separation distance testing typically requires 25 confirmatory tests for each configuration with a donor and two acceptors to obtain the 50 data points necessary for statistically acceptable distances (i.e, a probability of detonation of less than 10% with a confidence level of at least .95). This is in addition to exploratory testing to establish a starting point for the confirmatory tests. These rounds were being "hand-produced" at the time of this study to fulfill other testing requirements. Waiting for the necessary number of rounds would have necessitated testing at a much later date, possibly impacting set-up of the production lines.

Since these rounds are similar to the older M374 series, a preliminary evaluation of the configurations indicated that the safe separation distance of the M374 series is applicable to the newer M821E1 and M889E1 rounds. A detailed analysis of applicable parameters is presented in this paper. The previously established M374 series safe separation distances are presented along with drawings and descriptions of the M374, and M821E1/M889E1 rounds. A rationale for using the established safe separation distance for the newer rounds is developed.

A successful analogy and application of previously established distances as adequate for the new rounds will result in a large cost savings by avoiding the testing, test items and hardware, and engineering labor that would have been required. In addition establishing the safe separation distance at this time will avoid a late impact on the production line "design".

M374 SERIES SAFE SEPARATION DISTANCES

Previous testing conducted on the M374, M374A1 and M374A2E1 81mm HE mortars in various configurations is detailed in references 1, 2 and 3. The configurations, items as tested, other parameters and results are provided below. Results are summarized in Table 1.

M374 HE Cartridge

The projectile body for the M374 cartridge is shown in Figure 1. The projectile body is identical for the M374, M374A1 and M374A2E1. It was tested in the vertical position with and without 2 inch diameter aluminum (6061 T6) interrupter bars (Figure 2). The M374 projectile body is loaded with 2.1 lb of Composition B. The safe separation distance was an 8 inch separation with the 2 inch aluminum bar based on a total of 62 samples (including 22 at a 7 inch spacing) without propagation of detonation, The actual test configuration was conducted without the 2 inch shield; however, for additional safety the 8" distance with the shield was utilized. This corresponds to a probability of detonation of 5.6% at a 95% confidence level.

M374A1 Projectile

The M374A1 projectile body as shown in Figure 1 was tested in the single item and 72 projectile pallet configurations. The single projectile configuration simulated the transporting of items in the vertical position on a powered link-belt conveyor (Figure 3). The pallet configuration, with 72 projectiles in a 6 by 12 matrix (with 0.83 inch lateral spacing) simulated transport of the pallets on a power roller conveyor (Figure 4). These configurations were derived from Load, Assemble, and Pack (LAP) areas at Milan AAP. The M374A1 projectile contains 2.1 lb of Composition B.

Results obtained for the single projectile resulted in an approved safe separation distance of 18 inches between items with no shielding and for the 72 projectile pallet configuration a spacing of 30 feet unshielded.

Fifty-three data points were obtained for the "single" projectile and 52 for the pallet configuration, resulting in probabilities of detonation of 6.6 and 6.7 percent, respectively, at a 95% confidence level.

M374A2E1 Projectile

Figure 1 is a drawing of the M374A2E1 mortar (projectile body). Tests were conducted with the projectiles in a horizontal position in a transfer pallet and two-inch thick aluminum (6061 T6) shields 4 inches high by 14 inches long on a simulated roller conveyor, as shown in Figure 5. This configuration was tested to verify that propagation would not occur on transfer pallets designed by Ingersoll-Rand for use in the Automated Assembly and Packout Line at Kansas AAP. The operations involved were facing of the fuze well, assembly of fuzes, and attaching propelling charges to the fin housing. The M374A2E1 is loaded with 2.1 lb of Composition B.

Since a shielded 8 inch spacing for the M372 cartridge in the vertical position was verified previously, these tests were conducted at an 8.8 inch spacing (the additional 0.8 inch to accommodate the operational heads of the work station equipment). Forty-four tests were conducted, yielding 88 data points. This corresponds to a probability of propagation of 3.9 percent at a 95% confidence level.

DESCRIPTION OF THE 81mm M821E1 AND M889E1 HE PROJECTILES

The M821E1 and M889E1 projectile body is shown in Figures 6a and 6b. The difference between the two is the M821E1 has the M734 multi-option fuze while the M889E1 has the M935 point detonating fuze. They are designed to be more lethal through the use of high fragmentation steel with an explosive load of 1.72 lb of Composition B. The increased lethality comes from the production of more fragments, even though the fragments do not have increased velocity. Increased fragmentation results in a higher probability of a hit at a given distance.

The physical differences in the M821E1/M889E1 from the M374 series are shown in Table 2. The new rounds, M821E1/M889E1, have a smaller explosive load, slightly thicker casing, and a longer length of explosive. The casing for the M374 is 1340 steel, cold-worked, while the newer rounds are high fragmentation steel known as HF1. The production of more fragments and therefore, increased lethality is due to the casing material and a longer effective warhead length.

RATIONALE FOR M821E1/M889E1 SAFE SEPARATION DISTANCE

Propagation between cased rounds when separated by an air space is caused primarily by fragment impact. The blast pressure alone will not result in propagation since there is an air space between mortar rounds. This is sufficient to prevent crushing of the item which could initiate the acceptor round. The tests of the M374 series mortar verify this fact. Also, the shield impact on the acceptor did not cause propagation, In the case of the new M821E1/M889E1 mortars propagation will not occur due to shield impact. The lower explosive weight will mean a lower velocity for the shield and the casing of the M821E1/M889E1 is thicker, thus it can absorb more energy before deforming enough to crush the explosive and initiate the explosive.

The rationale presented herein will address the fragments produced by the donor round and will show that since propagation (within acceptable statistical criteria) did not occur for the spacings and configurations of the M374 series, it will not occur for the M821E1/M889E1 with the same spacings and configurations.

Terminal Effects Data for the M374A2 81mm mortar was obtained from the Joint Munitions Effectiveness Manual (JMEM). This data is generated from a series of arena tests, and is the same for the M374, M374A1 and M374A2E1 since the warhead is identical. Terminal Effects Data for the M821E1/M889E1, not yet published, was also obtained. In an arena test, an item is detonated horizontally. Fragments are collected in panels in a 180° arc from the nose to the tail. This arc is divided into polar zones. Fragment weights are recorded and velocities measured. Symmetry of the round is assumed. Data is then entered into an established program which generates the fragment data for the entire item. This data is used to determine an item's effectiveness.

In studying the Terminal Effects Data, it can be seen that the M821E1/M889E1 is indeed more effective. With the use of high fragmentation steel (HF1) more fragments are produced with a smaller explosive fill, 1.72 lb of Composition B versus 2.1 lb for the M374. This greater number of fragments are also produced in zones more likely to result in a hit. This is due to the shape of the new mortar projectile.

The M374 series warhead, which weighs 5.05 lb, produces 30,913 grains, or 4.4 lb, of fragments. The M821E1/M889E1, weighing 5.90 lb, produces 34,322 grains, or 4.9 lb, of fragments. The number of fragments from the M374 is 2,811, while the M821E1/M889E1 produces 6,432. The largest fragment produced by the M374 is 155 grains and for the M821E1/M889E1 it is 143.5 grains, but more importantly the size of the fragments are smaller for the new mortar round. From Table 3 it can be seen that for the M821E1/M889E1 a higher percentage of the fragments are in the smaller size range. Thus, more than twice the number of fragments is produced at the expense of the fragment weights. Since the energy associated with the fragment is $1/2MV^2$, smaller fragments have less energy at the same velocity.

The peak velocities of the fragments from the M821E1/M889E1 are lower. The largest velocity for the M374 is 2125 m/s (6,972 fps); for the M821E1/M889E1 it is 1689 m/s (5,540 fps). Higher velocities from a particular round are associated with the smaller fragments. Table 4, velocities of the two new mortar rounds by zone, shows that the new rounds do not produce maximum velocities as high as the M374. The new rounds do have higher velocities at the nose and near the tail of the projectile; however, since propagation of the M374 acceptors did not occur at velocities near 7,000 fps, it will not occur at velocities less than half of that. Also, these fragments are not hitting at normal angles as are those emanating from the center of the round. From the above rationale, it can be seen that the new rounds M821E1/M889E1 produce fragments which are generally smaller in size with lower velocities.

Analyzing the fragment mass distribution from Table 3 shows that for the M821E1/M889E1 98 percent of fragments weigh less than 25 grains. For the M374, 98.5 percent of fragments weigh less than 100 grains. Thus, taking these as the maximum fragment weights, and utilizing the maximum velocities, the associated energies for the M374 and M821E1/M889E1 are 10,802 and 1,705 ft-lb, respectively. This does not happen; therefore, we can say that fragments from the new rounds will have kinetic energies less than the M374.

Since propagation did not occur, within statistically acceptable limits, with the M374 series mortars, the same safe separation distances, with identical configurations/shielding, can be applied to the M821E1/M889E1 mortars.

CONCLUSIONS

- The M821E1/M889E1 mortars produce more fragments but with smaller size and generally lower velocities.

- Propagation between M821E1/M889E1 81mm mortar rounds will not occur, within the acceptable statistical limits previously mentioned, when in the same configuration/shielding as the M374 series 81mm mortar.

REFERENCES

1. Anderson, O.F. and Badowski, W.J., Test Report - Propagation of Detonation of Cartridge 81mm, HE, M374 Series, Picatinny Arsenal Laboratory Report, Picatinny Arsenal, NJ, April 1971.

2. Anderson, O.F., et al, Eight-Inch separation Propagation Tests for Cartridge, 81mm, HE, M374A2E1 and Projectile 81mm, HE, M374, Picatinny Arsenal Technical Report 4773, Picatinny Arsenal, NJ, June 1975.

3. Koger, D., and Stirrat, W., Determination of Minimum Non-Propagation Distance of 81mm M374A1 Projectiles, Technical Report ARLCD-TR-78021, U.S. Army Armament Research and Development Command, Picatinny Arsenal, NJ, April 1978.

4. Healy, J., et al, Primary Fragment Characteristics and Impact Effects on Protective Barriers, Picatinny Arsenal Technical Report 4903, Picatinny Arsenal, NJ, December 1975.

TABLE 1. Approved Safe Separation Distance for the 81mm Mortar

Item	Configuration	Shield	Spacing
M374	Single cartridges in vertical position in holding fixture	2 inch diameter aluminum bars	8 in
M374A1	Single projectiles on simulated link-belt conveyor	None	18 in
M374A1	Transfer pallet with 6 x 12 matrix of 72 projectiles	None	30 ft
M374A2E1	Single projectiles in horizontal position in transfer pallet on conveyor	2 in thick x 4 in high aluminum	8.8 in

TABLE 2. Comparison of 81mm Mortar Projectile Design Parameters

	M374	M821/889
Explosive Fill	Composition B	Composition B
Explosive Weight, lb	2.1	1.72
Casing Thickness, in. (at center of round)	0.220	0.260
Maximum Casing Thickness, in.	0.235	0.290
Length of Explosive Fill, in. (approximate)	8.37	8.87

TABLE 3. Fragment Mass Distribution

Mass Interval, grains	M374 Series	Percent of Total Fragments	M821E1/ M889E1	Percent of Total Fragments
0.5 - 1.00	390	14	817	12.5
1.00 - 2.00	552	19.5	1601	25
2.00 - 8.00	964	34.5	2929	45.5
8.00 - 10.00	147	5	363	5.5
10.00 - 25.00	437	15.5	591	9
25.00 - 35.00	127	4.5	65	1
35.00 - 50.00	98	3.5	25	<1
50.00 - 100.00	59	2	14	<1
Over 100.00	37	1.5	27	<1
TOTAL FRAGMENTS	2811		6432	

TABLE 4. Velocity, V_m, of Fragments for 81mm Mortars, fps

ZONE	DEGREES	M374	M821/889
1	0 - 2.5	-	3880
2	2.5 - 7.5	-	3150
3	7.5 - 12.5	-	3070
4	12.5 - 17.5	1326	2250
5	17.5 - 22.5	-	2570
6	22.5 - 27.5	1490	3170
7	27.5 - 32.5	1591	2650
8	32.5 - 37.5	-	2430
9	37.5 - 42.5	2198	3120
10	42.5 - 47.5	2251	2730
11	47.5 - 52.5	2054	3360
12	52.5 - 57.5	2444	3200
13	57.5 - 62.5	3160	4090
14	62.5 - 67.5	4006	4430
15	67.5 - 72.5	4164	4570
16	72.5 - 77.5	4433	4700
17	77.5 - 82.5	4705	4840
18	82.5 - 87.5	4987	5340
19	87.5 - 92.5	5204	5300
20	92.5 - 97.5	5105	5430
21	97.5 - 102.5	5834	5540*
22	102.5 - 107.5	6605	5440
23	107.5 - 112.5	6322	4940
24	112.5 - 117.5	6972*	4650
25	117.5 - 122.5	5732	4310
26	122.5 - 127.5	4210	3480
27	127.5 - 132.5	3543	4150
28	132.5 - 137.5	2795	3650
29	137.5 - 142.5	2247	2310
30	142.5 - 147.5	1578	2430
31	147.5 - 152.5	1716	1510
32	152.5 - 157.5	1755	1870
33	157.5 - 162.5	1601	1530
34	162.5 - 167.5	1545	1420
35	167.5 - 172.5	1440	1370
36	172.5 - 177.5	1263	1210
37	177.5 - 180.0	-	1130

*Maximum Velocity

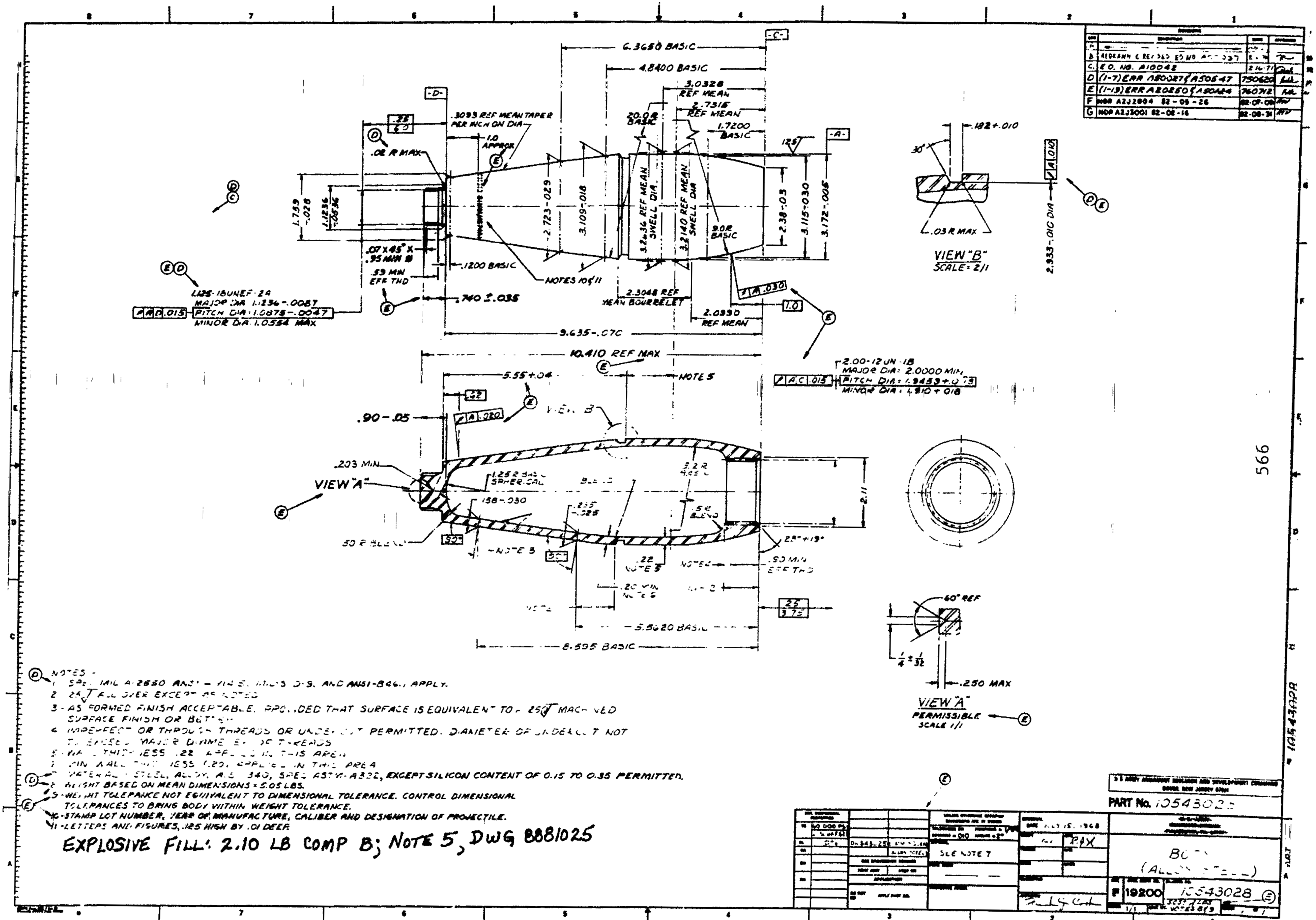
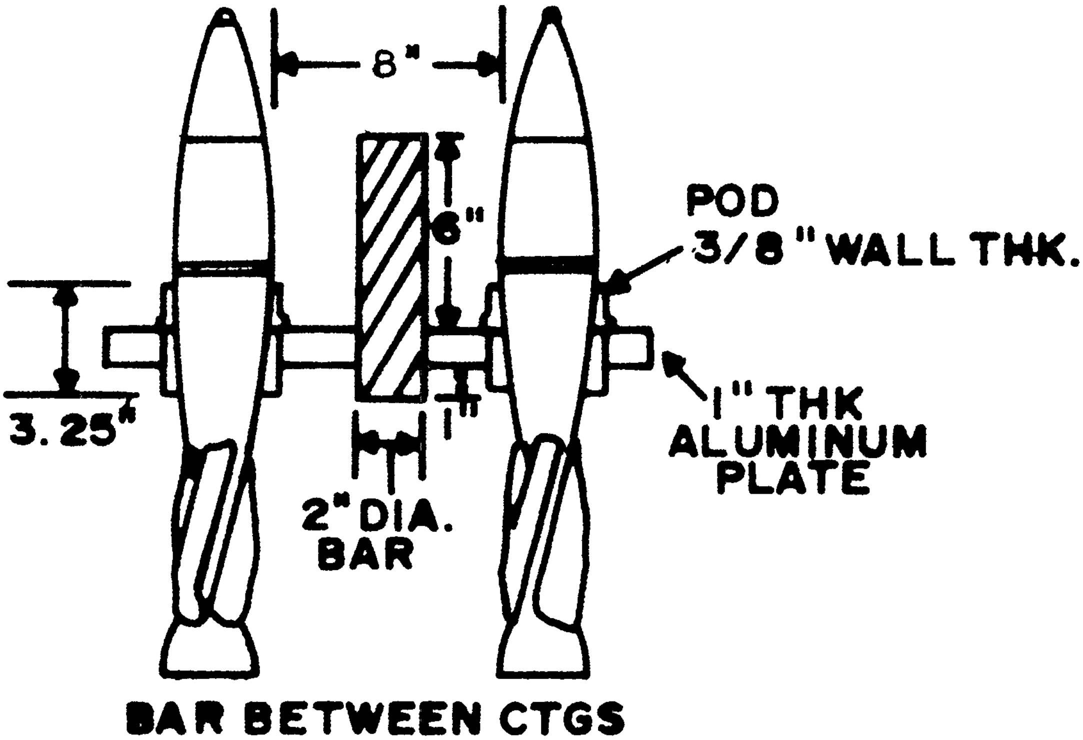


FIGURE 1. Projectile Body for 81mm M374 Series HE Mortar



6061 T6 Aluminum

FIGURE 2. Configuration for Safe Separation Distance of 81mm M374 HE (Comp B) Cartridge

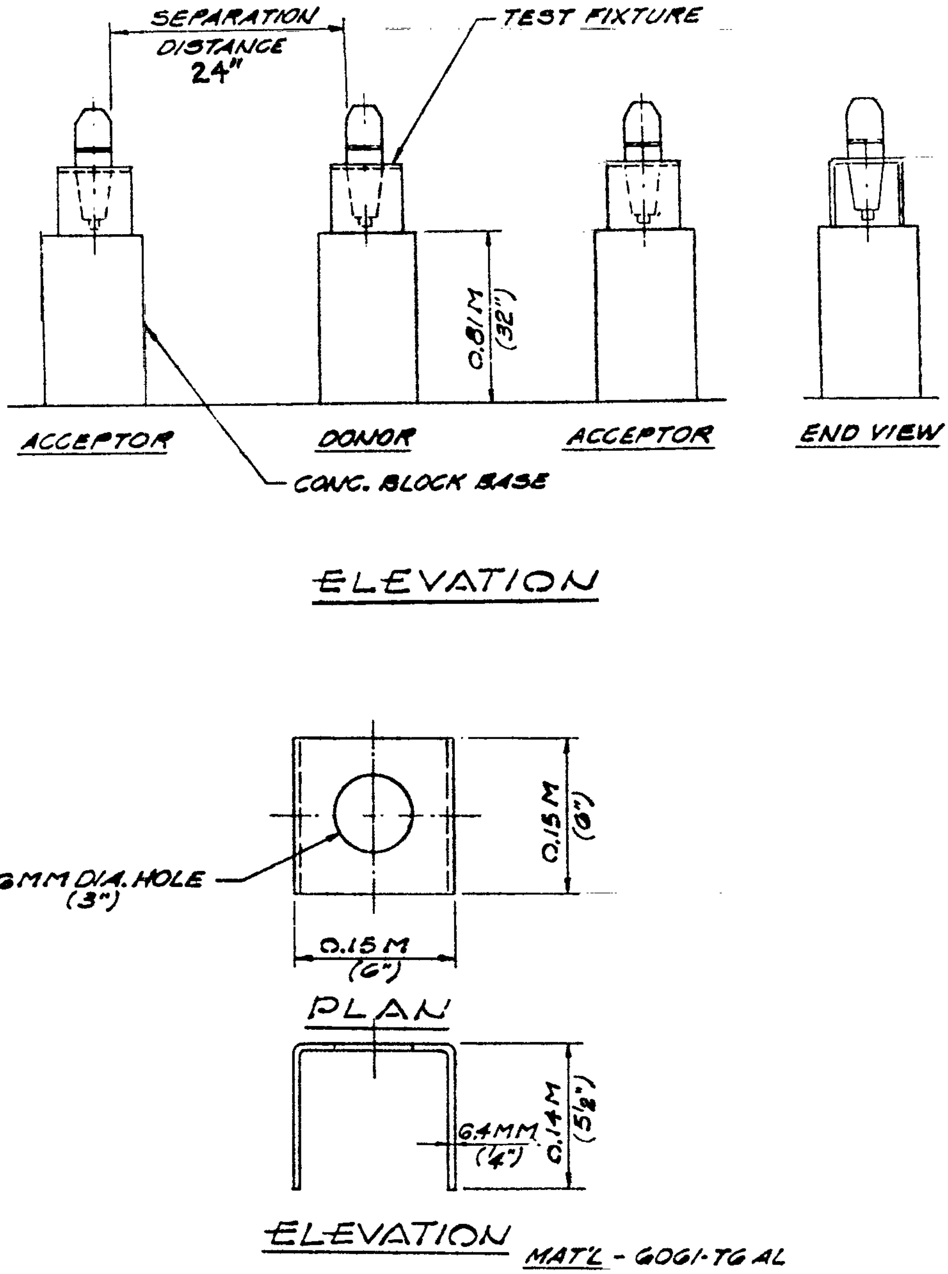


FIGURE 3. Safe Separation of Single 81mm M374A1 Projectiles on Simulated Link - Belt Conveyor

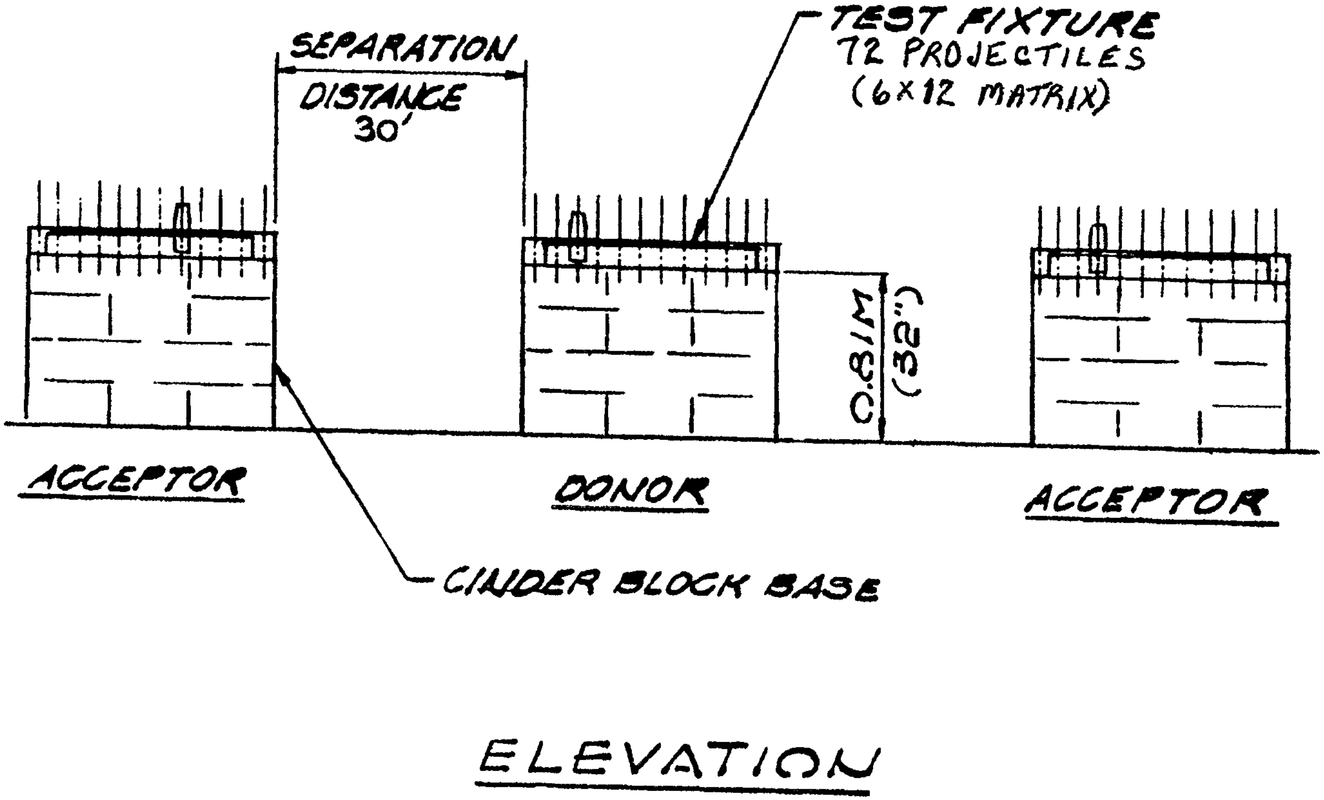


FIGURE 4. Safe Separation of 81mm M374A1 Projectile Pallets on Simulated Power Roller Conveyor.

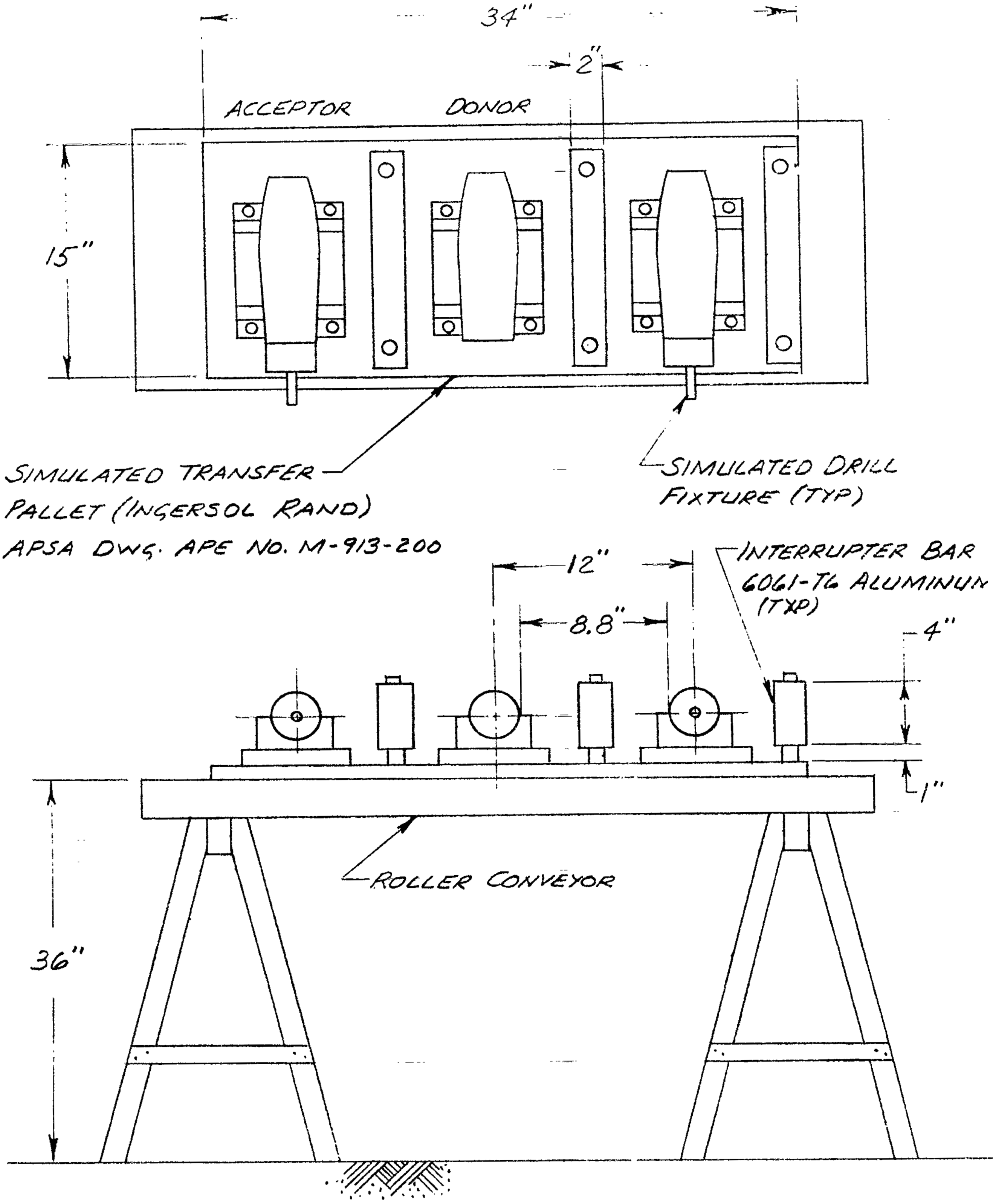


FIGURE 5. Safe Separation of 81mm M374A2E1 Projectiles on a Simulated Transfer Pallet.

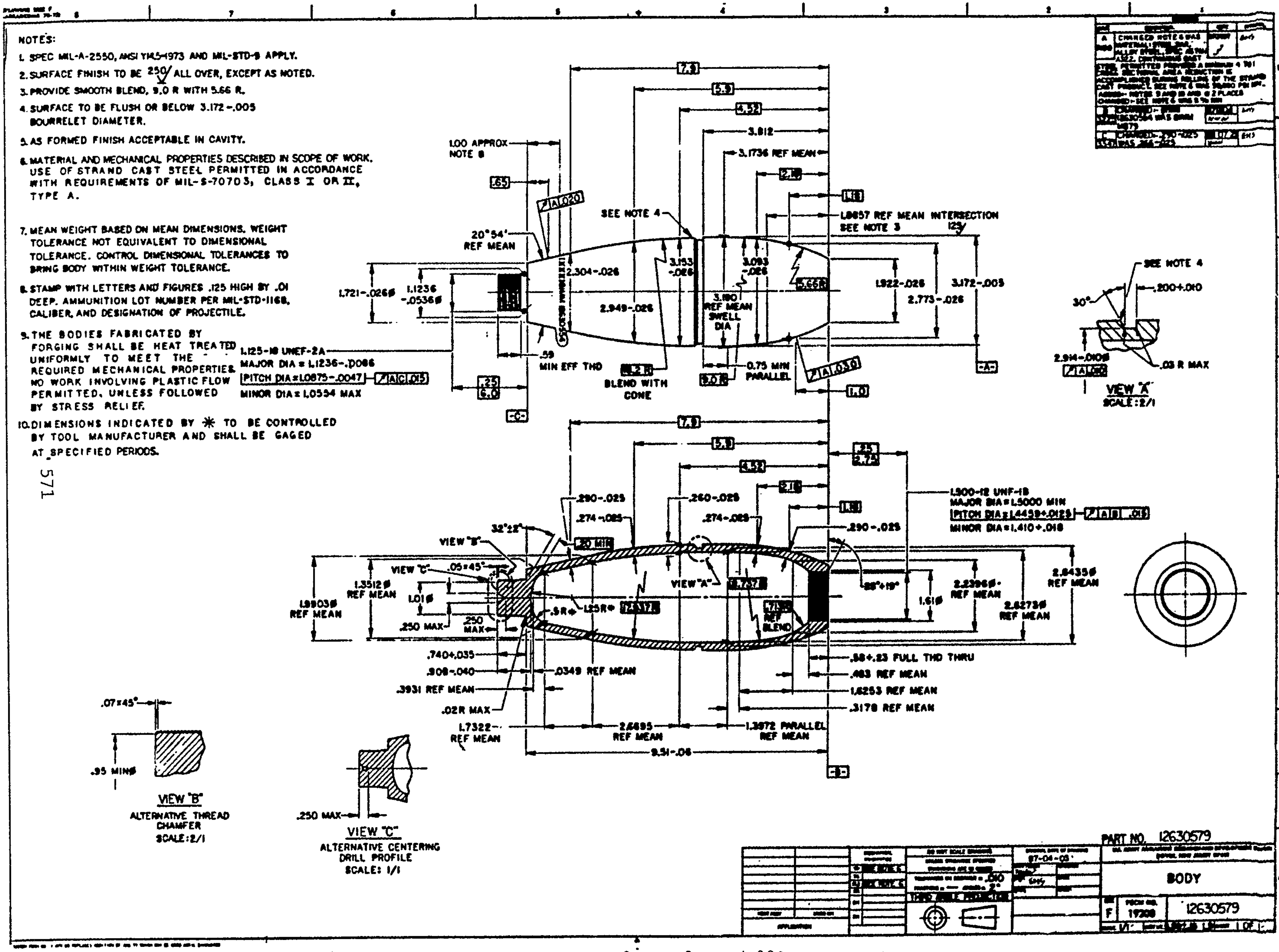


FIGURE 6a. Projectile Body for the 81mm M821E1/M889E1 HE Mortar

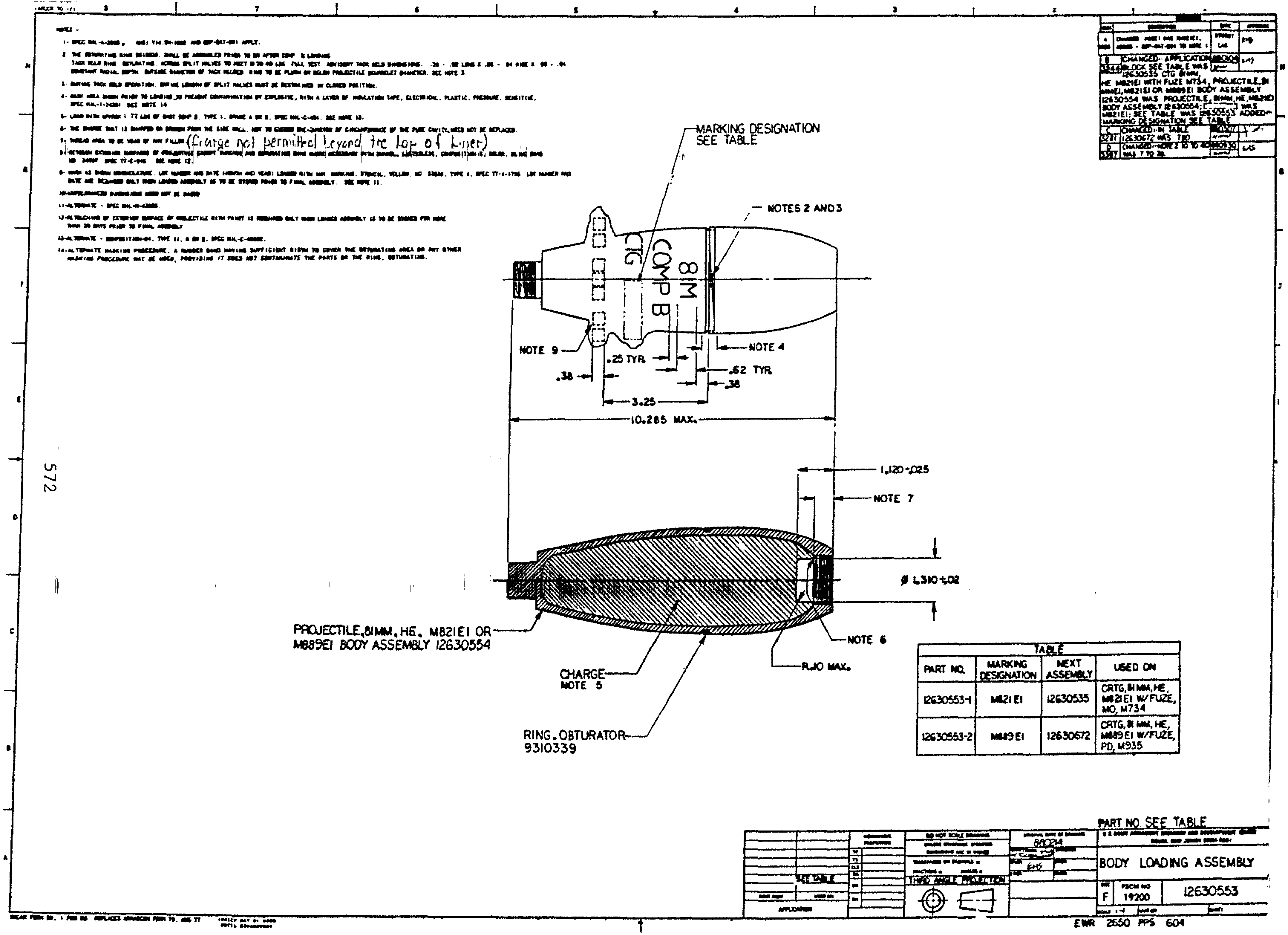


TABLE			
PART NO.	MARKING DESIGNATION	NEXT ASSEMBLY	USED ON
12630553-1	M821E1	12630535	CRTG, 81 MM, HE, M821E1 W/FUZE, MO, M734
12630553-2	M889E1	12630672	CRTG, 81 MM, HE, M889E1 W/FUZE, PD, M935

FIGURE 6b. Body Loading Drawing for the 81mm M821E1/M889E1 HE Mortar.