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ULTRASONIC WELD SEALING OF M55 STAB DETONATORS

PHILIP C. KRAUSE
SONOBOND CORPORATION
200 E. ROSEDALE AVENUE
WEST CHESTER, PENNSYLVANIA 19380

PAUL MONTELEONE
PROJECT ENGINEER
ARRADCOM

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LARGE CALIBER
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DOVER, NEW JERSEY

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Ultrasonic ring welding was investigated as a means for hermetically sealing the M55 detonator, in an effort to find a more economical, less labor-intensive method of sealing. The current method utilizes the manual application of lacquer for sealing, which is tedious, subject to non-uniformity and requires a separate work station. Ultrasonic welding did not provide reproducible leak-tight welds because of the lack of rigid support in the detonator configuration for adequate clamping force applica-

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20. Abstract Continued:
tion during welding. An alternative which would offer a higher probability of success, would be to alter the detonator configuration to provide an outside flange on the cup, so that the cover disc can be welded to the flange. In this configuration, a solid anvil can support the flange thereby enabling the application of a suitable clamping force.

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ACKNOWLEDGEMENT

Acknowledgement is made of the supplementary contributions of the following organizations:

1. AMCOM, Inc., Atglen, Pennsylvania, for the facility and services for handling explosive materials.

2. Universal Technical Testing Laboratories, Inc., Collingdale, Pennsylvania, for helium leak testing of the M55 stab detonators.

3. Design and Engineering Evaluations, Laurel Springs, New Jersey, for hazard analysis of the ultrasonic welding equipment and the process.

INTRODUCTION

This investigation was undertaken to determine the feasibility of hermetically sealing M55 stab detonators by means of ultrasonic ring welding and to assemble an ultrasonic ring welder with appropriate tooling for this application. The ultimate objective was to design, develop and fabricate production equipment for sealing these detonators at the rate of 200 parts per minute.

The M55 detonator, used in a variety of weapons systems, was designed for crimping and sealing after loading. The standard process consisted of loading the cup with the primary powders, blanking an aluminum disc and locating it over the compacted powders, then crimping the wall of the cup in two stages to 90 degrees, thereby capturing the disc. The detonators were then placed into a temporary pack, moved to a second area and sealed and color coded with green lacquer to identify the output end.

The advantage of ultrasonic ring welding would be that the sealing could be accomplished on the loading machine or in the loading area, thereby eliminating the need for labor-intensive and time-consuming extra handling and paint operations. Additionally, the need for venting and drying systems and lacquer viscosity monitoring would be eliminated.

Capabilities of Ultrasonic Ring Welding

Ultrasonic ring welding has been successfully used for sealing a variety of small ordnance devices containing explosives, propellants, pyrotechnics, primers, fuses and other sensitive contents (Ref. 1-16.) The process reliably seals such materials in metal capsules by producing a complete peripheral metallurgical weld with a single hit, usually of less than one second duration. No heat is applied and no fluxes or filler metals are used. Bonding occurs from the combined static and vibratory stresses induced between the mating members. These stresses disrupt surface films and promote adhesion of the bare metals. When made under appropriate welding conditions, the welds are leak-tight, durable and impervious to moisture, heat or solvent vapor. Because the bonds are metallurgical, they provide devices with unlimited shelf life.

Figure 1 illustrates cross sections of representative containers that have been successfully weld-sealed by this method and Figure 2 provides photographs pf some of the actual hardware. Certain of these containers have been welded in pilot runs of more than one thousand parts. In helium leak tests, they have reproducibly shown leak rates of substantially less than 10^{-6} cc per minute at STP. One group of containers (Ref. 17) filled with M5 flake propellant was temperature cycled for periods up to 15 days and then exposed to solvent-saturated atmosphere (acetone and cyclohexane) for an additional 11 to 15 days. Subsequent closed bomb tests of the propellant indicated the ultrasonic seal to be 100 percent effective against solvent contamination.

No unusual hazards are involved with ultrasonic activation of sensitive materials. No electrical current passes through the joint and no external heat is used. Some heating of the weld metal occurs from absorption of the vibratory energy, but this is very transient and localized at the weld interface and is not sufficient to detonate even the most sensitive materials. Static loading is applied to the container, but not to the contents and it does not induce ignition.

A wide variety of sensitive materials, such as those listed in Table 1, have been ultrasonically weld-encapsulated or otherwise exposed to ultrasonic energy and there has been no known incident of detonation or ignition. For safety evaluation, grains of detonable materials have been intentionally sprinkled on the interface between metal components before welding and no detonation has occurred.

Ultrasonic ring welding therefore appeared to offer advantages over the crimp and lacquer process for sealing the M55 detonators; in particular, it should provide:

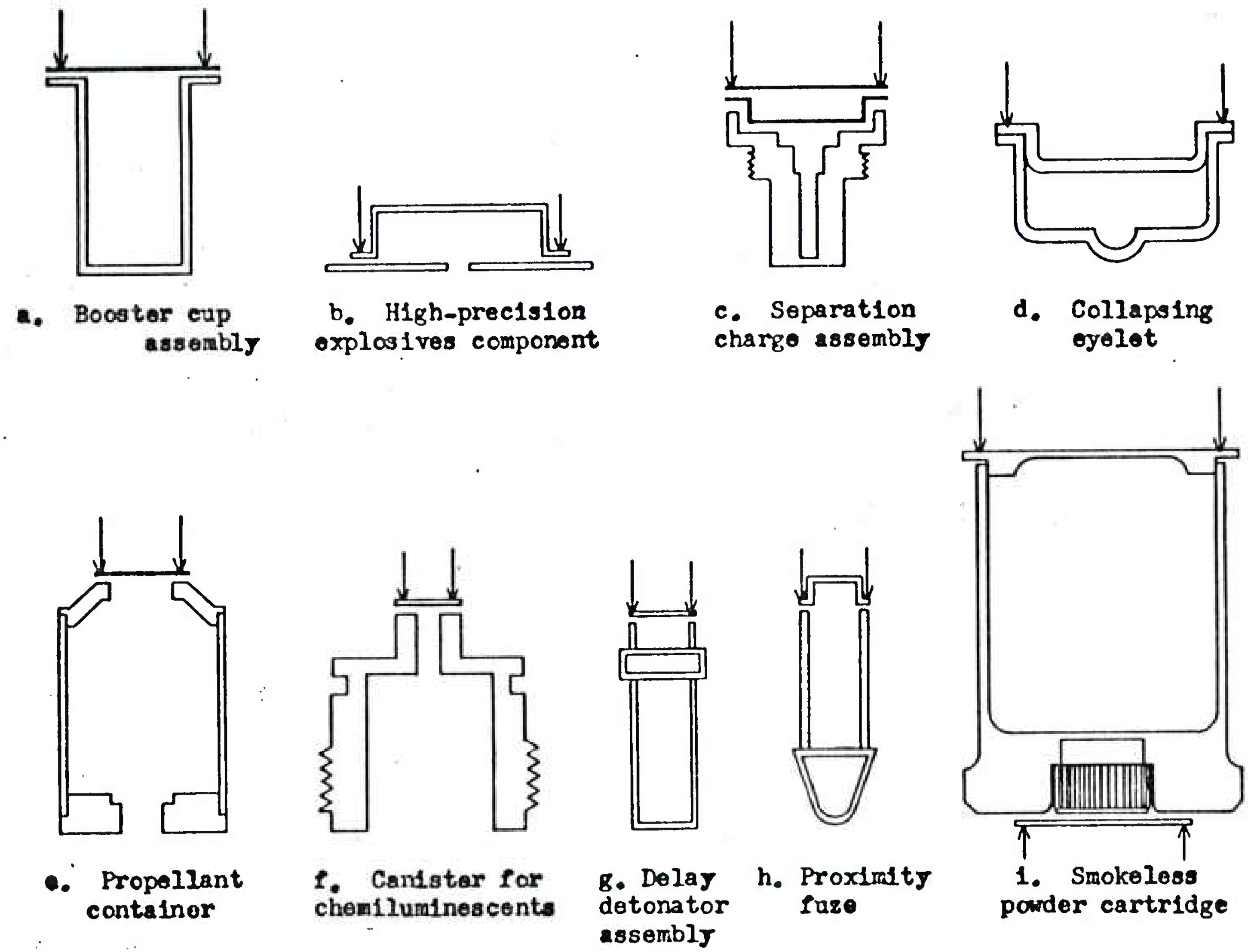

Figure 1. Representative container geometries for ultrasonic weld sealing. (Not to scale; arrows indicate location of weld periphery)

Figure 2. Typical ultrasonically weld-sealed containers.

TABLE 1. EXPLOSIVE AND REACTIVE MATERIALS WHICH HAVE BEEN ULTRASONICALLY ACTIVATED WITHOUT COMBUSTION OR DETONATION

Material or Mixture	Designation or Components
REACTIVE CHEMICALS	Lithium aluminum hydride Magnesium hydride Bromine trifluoride Nitronium perchlorate Fluoboric acid Inhibited red fuming nitric acid (IRFNA)
PYROTECHNICS	
SAW matches	Phosphorus sesquisulfide, red phosphorus and potassium chlorate
Black powder	FFFFG
Tracer igniter	Magnesium and barium peroxide
Igniter compositions	Boron, lead dioxide, and Viton A AIA (ferric oxide, zirconium)
Pyrotechnic smoke	Potassium chlorate, sulfur, and dyes
Delay compositions	Tungsten, barium perchlorate, and ammonium perchlorate Manganese, barium chromate, and lead chromate
Flare compositions	Magnesium, sodium nitrate, organic binder
PROPELLANTS	
High energy	75% to 85% HMX
Double-base	M5 and M9
Single-base	M10
Fluorocarbon	Aluminum, Teflon, and ammonium perchlorate
HIGH EXPLOSIVES	Octol (75:25 and 80:20 HMX/TNT), RDX, Tetryl, PETN
PRIMERS	
Cannon	Lead azide
Electric	Red phosphorus, barium nitrate, and graphite
Pistol Shot	Lead styphnate, tetracene, barium nitrate
Stab	NOL-130

1. Elimination of the lacquer application with its attendant handling and curing problems.

2. Increased production rates and reduced production costs.

3. Extended shelf life.

4. Reduced end item dud rate.

Approach

The program originally envisioned consisted of two phases. Phase 1 was a feasibility study which involved the assembly of laboratory-type ultrasonic ring welding equipment appropriate for sealing the M55 stab detonators, evaluation of welding process parameters, welding of sample quantities of inert and live detonators, evaluation of the welded assemblies and projection of equipment and techniques for production welding of the devices. Phase 11 was to involve the development and test of production equipment for this application. This report covers Phase 1 only.

The M55 stab detonator consists of a cup loaded with three separate explosive charges and a cover disc over which the edges of the cup are crimped. The geometry is shown in Figure 3.

From the outset, it was recognized that this was a difficult geometry to weld ultrasonically. As noted in Figure 1, all previous ring welding of small containers had involved an outward flange which could be rigidly supported in a welder anvil fixture or a rigid wall to which the cover could be welded. A moderate clamping force is required to effect good acoustic coupling between the welding tip and the parts to be welded and rigid support is essential to provide positive reaction to the clamping force application. With the M55 detonator as designed, the only support would be the explosive charges loaded in the cup and there was some skepticism as to whether these materials would provide the necessary rigidity.

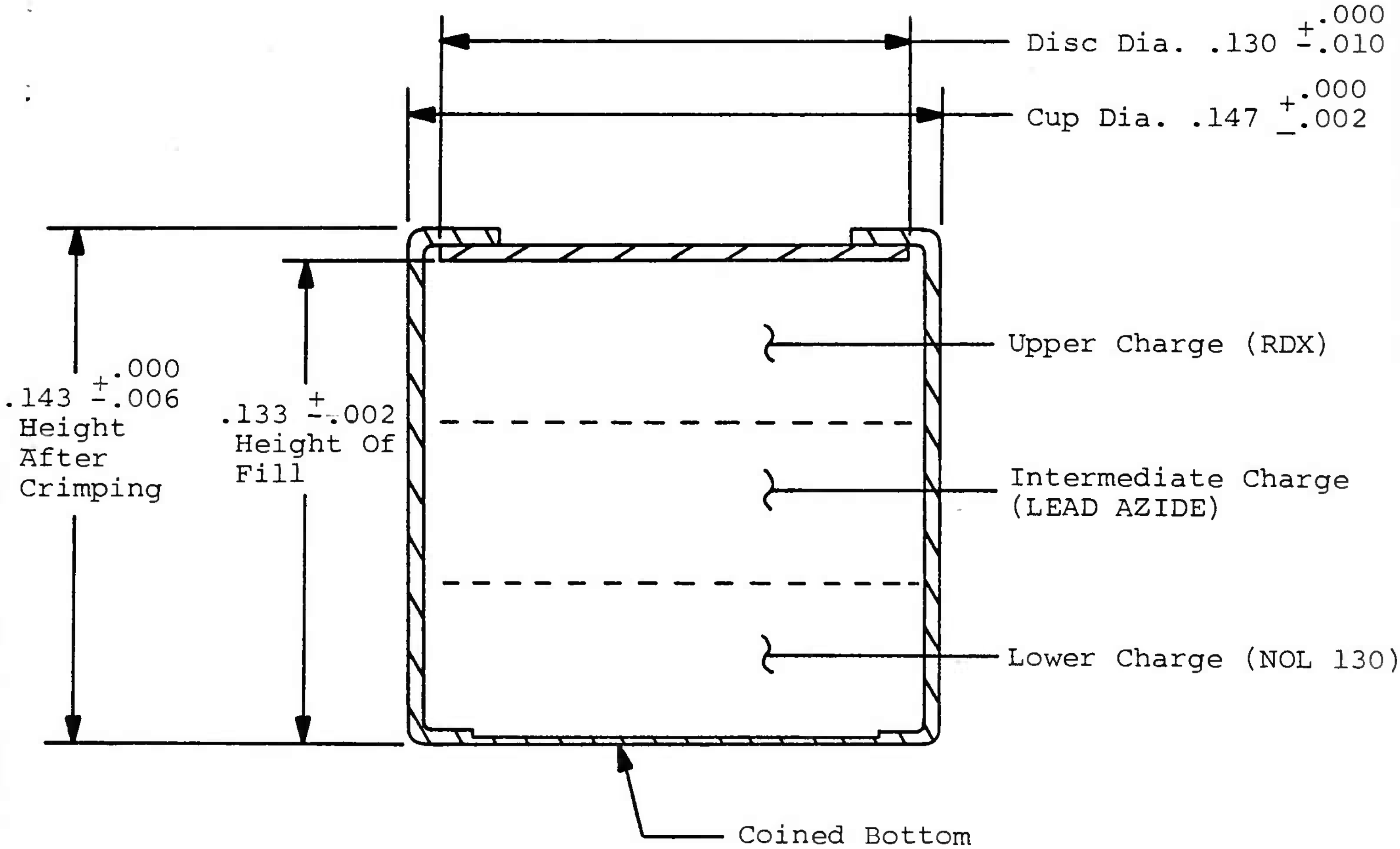

Figure 3. Geometry of M55 stab detonator

Some consideration was given to the redesign of the detonator to provide an outward flange on the cup which would ensure reproducible welding. If desireable, the flange could be re-formed to a cylindrical shape after welding. Figure 4, for example, shows a procedure that has been successfully used for this type of welding. The containers were reproducibly leak-tight even after re-forming.

However, such a change in the final geometry of the detonator would require modification of the weapons systems in which the M55 is used and the flange approach was not feasible. The welding studies were therefore undertaken withcut altering the M55 geometry.

An available ultrasonic ring welder was modified to accomodate tooling for the detonator and was installed in a safety enclosure for operator protection in welding live units. In addition, a safety analysis of the equipment and process was made by an outside agency.

Using the equipment, preliminary weld evaluation was carried out in the Sonobond Laboratory with inert-loaded detonators to check out the tooling and establish welding parameters. Subsequently, live detonators were welded in a facility equipped to handle explosive materials. The welded samples were evaluated for dimensional accuracy and for leaktightness by gross leak and fine leak tests.

Meanwhile, a study was made of production equipment for assembling the M55 detonators and it was established that an ultrasonic ring welder could be installed as one station in an Iowa loader.

EQUIPMENT

Ultrasonic Ring Welder

The welding equipment used to seal the detonators was an ultrasonic ring welder Model MR-2812 (Figure 5,) which operated at an ultrasonic frequency of 28 kilohertz and with a maximum power capacity of 1200 RF watts input to the transducers. This machine consisted

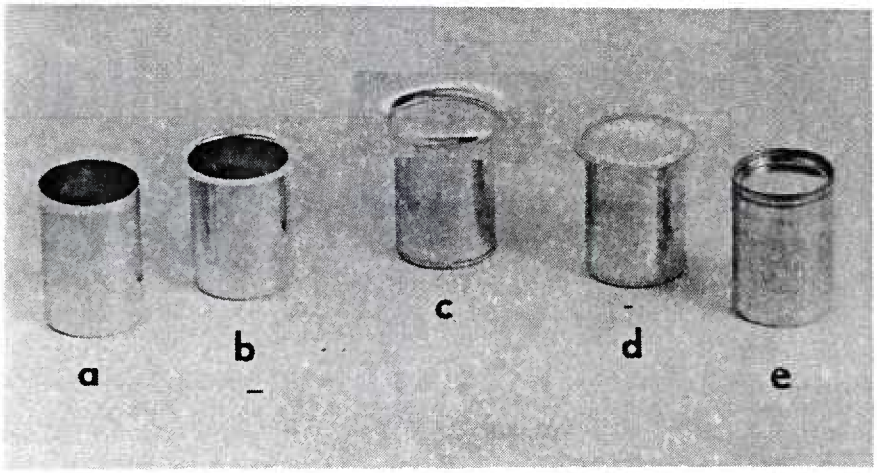

Figure 4. Welding and re-forming of cylindrical cup.

a. Initial cylindrical cup

b. Flange formed on cup

c. Cover welded to flange

d. Cover trimmed to flange periphery

e. Flange re-formed to cylindrical shape

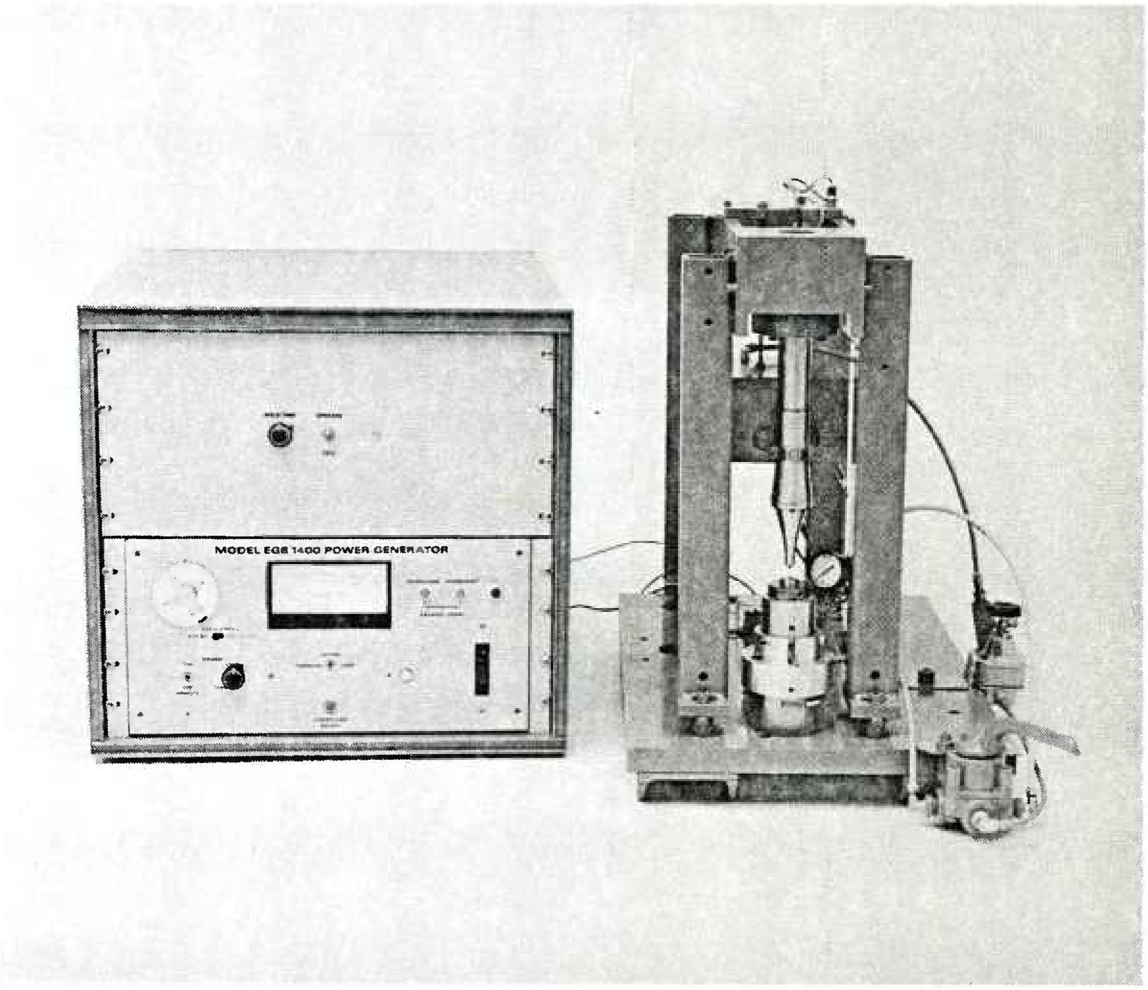

Figure 5. Ultrasonic ring welder Model 2812 with EGB 1400 frequency converter.

of two major assemblies: an ultrasonic welding head and a frequency converter to supply the necessary high-frequency electrical power to drive the head. The welding head was enclosed in a safety housing and the frequency converter, which contained the essential welding controls, could be remotely located, with only light-weight cable connections between the two units. Specifications for the equipment are provided in Table 2.

The welding head incorporated an acoustic system such as that shown schematically in Figure 6; the actual hardware is illustrated in Figure 7. In this arrangement, two axial transducer-coupling assemblies affixed to a hollow reed are driven out of phase to induce torsional vibration of the reed. At the lower end of the reed is an exponential horn which amplifies the vibratory displacement and is terminated with a hollow circular welding tip, designed specifically for the M55 detonator geometry (Figure 8.) The tip vibrates torsionally (in cookie-cutter fashion) in a plane parallel to the weld interface, thus producing the complete peripheral weld.

This acoustic system was installed in the welder frame via a force-insensitive mount which ensured that negligible energy was lost to the supporting structure and that the operating frequency did not shift when clamping force was applied.

An anvil was initially designed to support the workpiece. During early welding of inert-loaded detonators, ruptures occurred on the bottom periphery of the M55 containers. It was suspected that these ruptures may have been caused by the tooling. The original anvil was therefore replaced with a nest from the Iowa loader (Figure 9) which significantly improved performance. Use of the Iowa loader nest had the added advantage of providing interface capabilies with production equipment.

The anvil was pneumatically activated so that it could be raised and lowered during the welding cycle. The complete cycle consisted of raising the anvil with

TABLE 2. SPECIFICATIONS FOR ULTRASONIC RING WELDER MODEL MR-2812

ULTRASONIC RING WELDING HEAD

Frequency (nominal)	28 kilohertz
Maximum Power-Handling Capacity	1200 RF watts
Transducers (Two)	Center-bolt piezoelectric ceramic
Torsional Horn	Inconel 718, custom-designed Interchangeable
Welding Tip	Custom-designed Brazed to torsional horn
Clamping Force System	Pneumatic Continuously adjustable 50 to 400 pounds
Construction	Welded tubular steel frame Modular assembly of ultrasonic welding system
Cooling	3 scfm clean, dry, oil-free air at 80 psig

FREQUENCY CONVERTER

Input Power Requirements	120 volts AC, 50/60 hertz Single-phase, 20 amperes
Line Power	2.5 KVA
Output Frequency (nominal)	28 kilohertz
Vernier Frequency Adjustment	± 1500 hertz
Output Power	100-1200 RF watts
Output Power Regulation	Constant within ± 10% line voltage
Power Meter Range	0 to 2000 RF watts 1.5 seconds response time
Power Control	Continuously variable
Overload Protection	Magnetic circuit breaker on input Instantaneous shutdown on output
Weld Time	0.01 to 10.0 seconds Digitally set in 0.01 increments

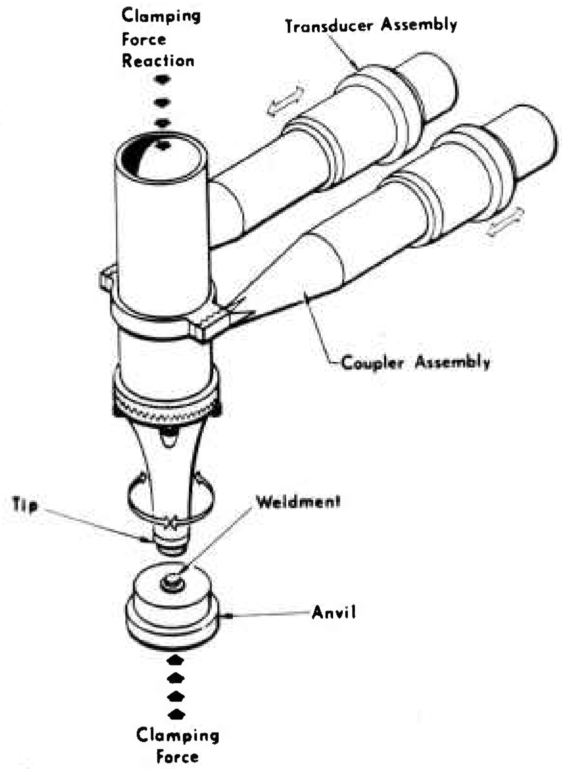

Figure 6. Schematic diagram of ultrasonic ring welding system.

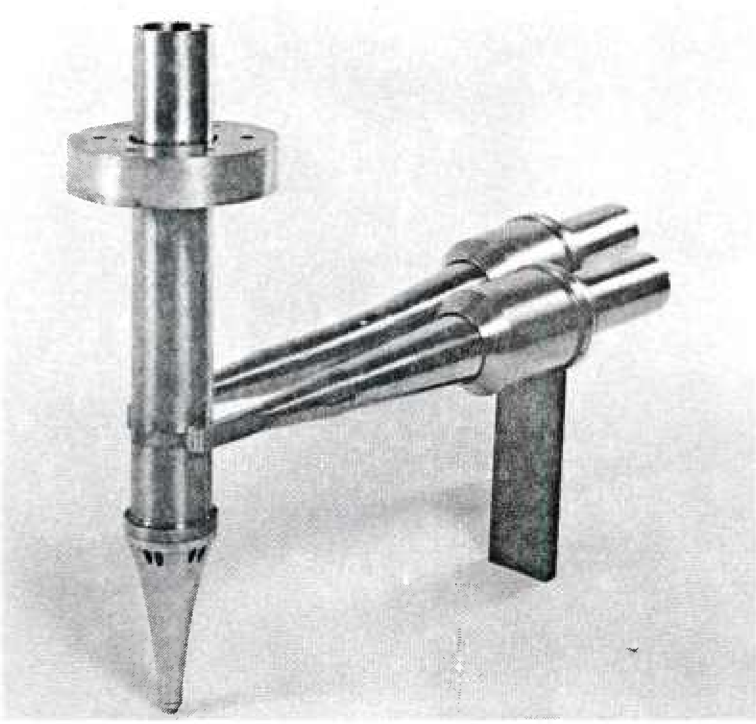

Figure 7. Acoustic system for an ultrasonic ring welder.

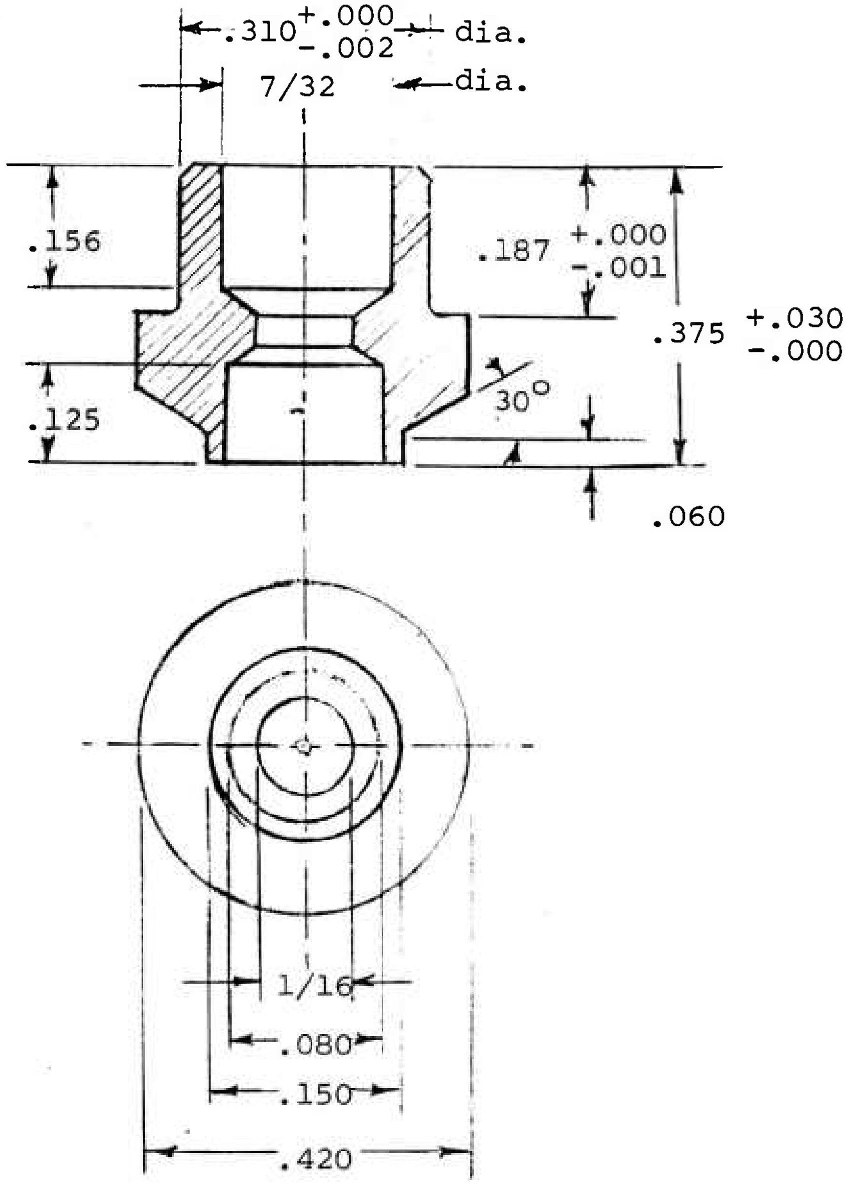

Figure 8. Ultrasonic ring welding tip for M55 detonator.

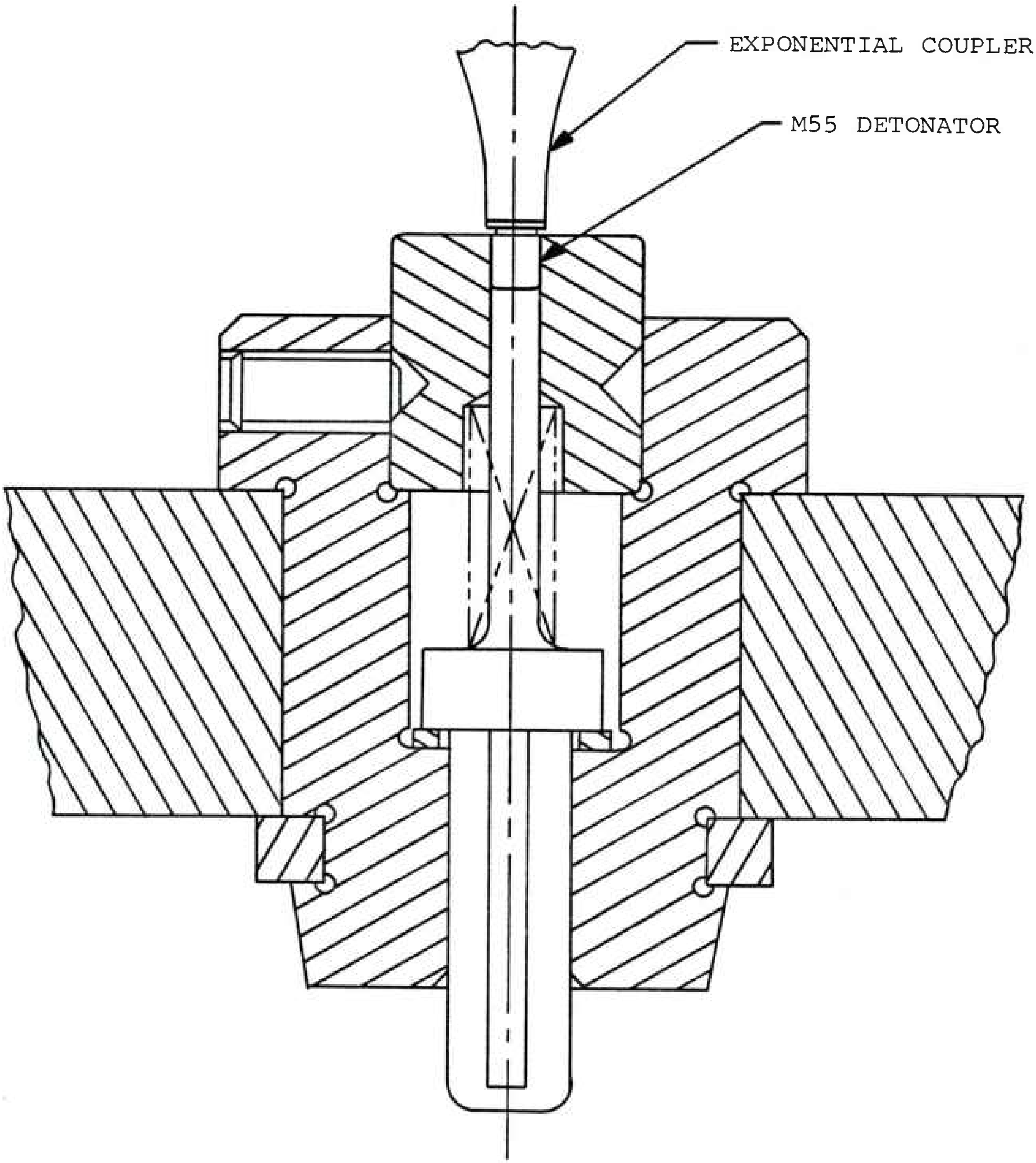

Figure 9. Geometry of Iowa loader nest assembly.

the detonator in place, so that the detonator contacted the welding tip with a preset clamping force, introduction of the ultrasonic pulse for a preset time interval, then lowering the anvil for removal of the welded part. The cycle was initiated by dual anti-tiedown, anti-repeat palm buttons located outside the protective enclosure for the welding head. Once initiated, the cycle was completed automatically.

The enclosure for the welding head was made of thick Lexan with a sliding door providing access for insertion and removal of a detonator. For operator safety, the door was closed during the welding cycle.

Adaptation for Production Processing

Early in the program, consideration was given to the possibility of incorporating the ultrasonic ring welder in a production loading and sealing sequence. For this evaluation, a visit was made to AMCOM, Inc., Atglen, Pennsylvania, to witness an Iowa loader which was being used to manufacture detonators almost identical to the M55 units.

This single-part loading system had provision for 24 nests in a rotary table that moved successively in loading, pressing, vacuum sequence. The sequence was repeated three times for loading three types of explosives into the same unit. After loading, a foil punch and insertion mechanism installed a disc cover on the filled cup. The part was then raised and the cup walls were bent inward 45 degrees and vacuumed, then bent 90 degrees over the cover and vacuumed. Finally, the part was unloaded. This equipment was stated to be capable of processing 44 parts per minute.

There was provision on the table to enable various operations to be shifted circumferentially so that an ultrasonic welding station could readily be located between the crimping and unloading stations. It also appeared feasible that an existing nest on the Iowa Loader could be used as an anvil support member for welding purposes. As previously noted, this arrangement was evaluated and found to work satisfactorily. There appeared to be no impediments to installing a modified welding head inside the Iowa loader. The frequency converter could be located outside the loader enclosure. Holes were available to accomodate the cables and air lines to the welder. A possible arrangement for the various stations is shown in Figure 10 and Figure 11 shows how an ultrasonic welding pedestal could be installed at the welding station.

ULTRASONIC WELDING OF DETONATORS

Preliminary Welding of Inert-Loaded Detonators

Initial welding of M55 stab detonators was carried out in the Sonobond Laboratory using inert-loaded detonators with the cover discs installed and the edges of the cup crimped to 90 degrees over the disc.

Effort was made to weld these assemblies as received, using the welding tip and anvil support previously described. Successful welding was not achieved. When the welding tip contacted the part and clamping force was applied, the foil disc pulled away from the edges of the detonator toward the center, leaving no material to weld to the crimped edge. Under this condition, some of the inert content was extruded out between the foil and the flange.

Larger discs were punched from 0.0035-inch-thick 1100-H19 aluminum foil and effort was made to weld these on top of the 90-degree inward flange. The material was successfully welded, but with this configuration, the flanges sometimes cracked under clamping force application. Cracks were also detected at the bottom perimeter of the cup.

It appeared that the bottom cracks may have been atributable to the anvil tooling that was used. After this tooling was replaced with the Iowa loader nest, the cracking was eliminated. The flange cracks probably occurred because the foil disc was installed on top of the flange, so that unusual force was exerted

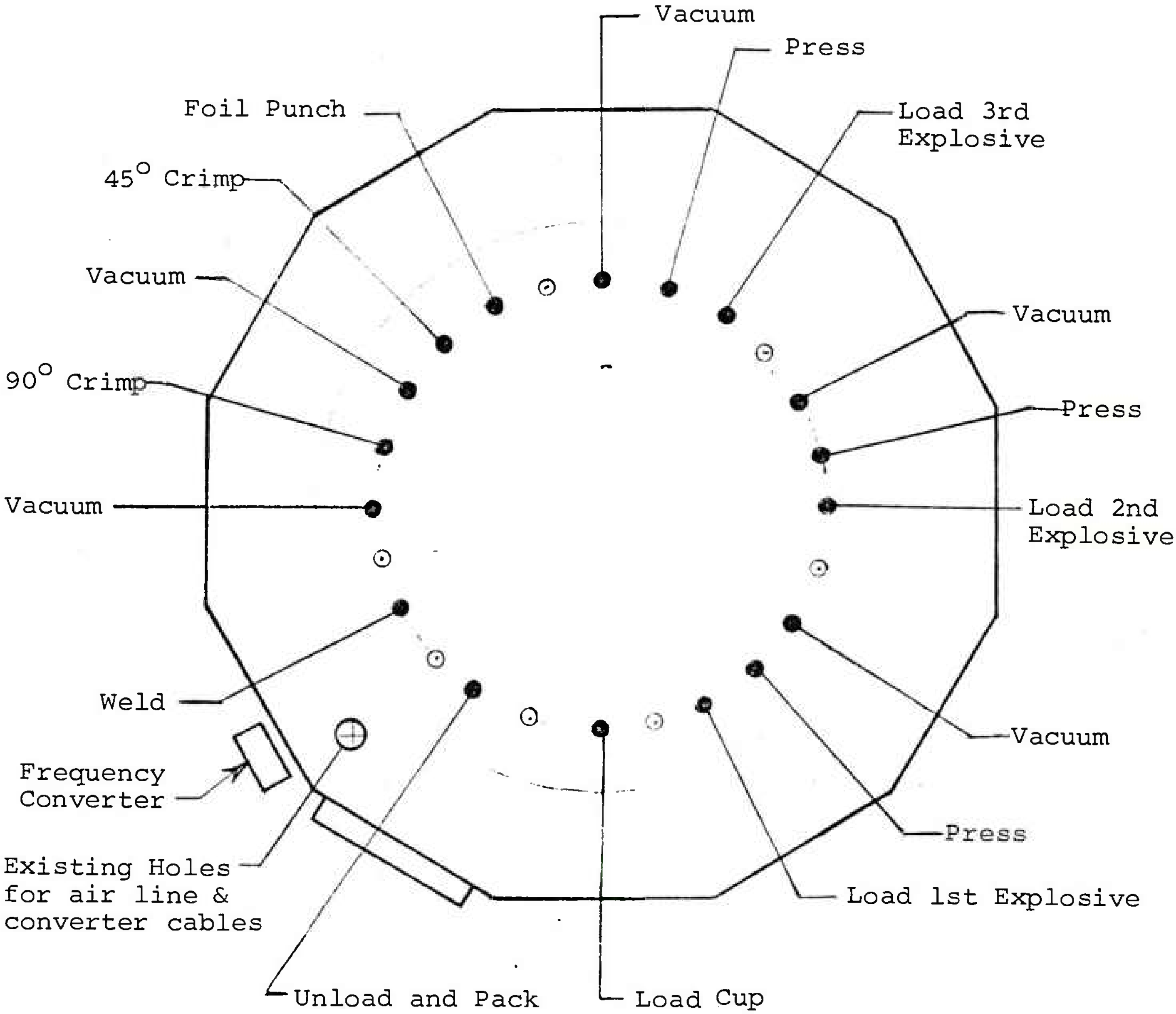

Figure 10. Plan view of Iowa Loader for assembling detonators, with ultrasonic weld station added.

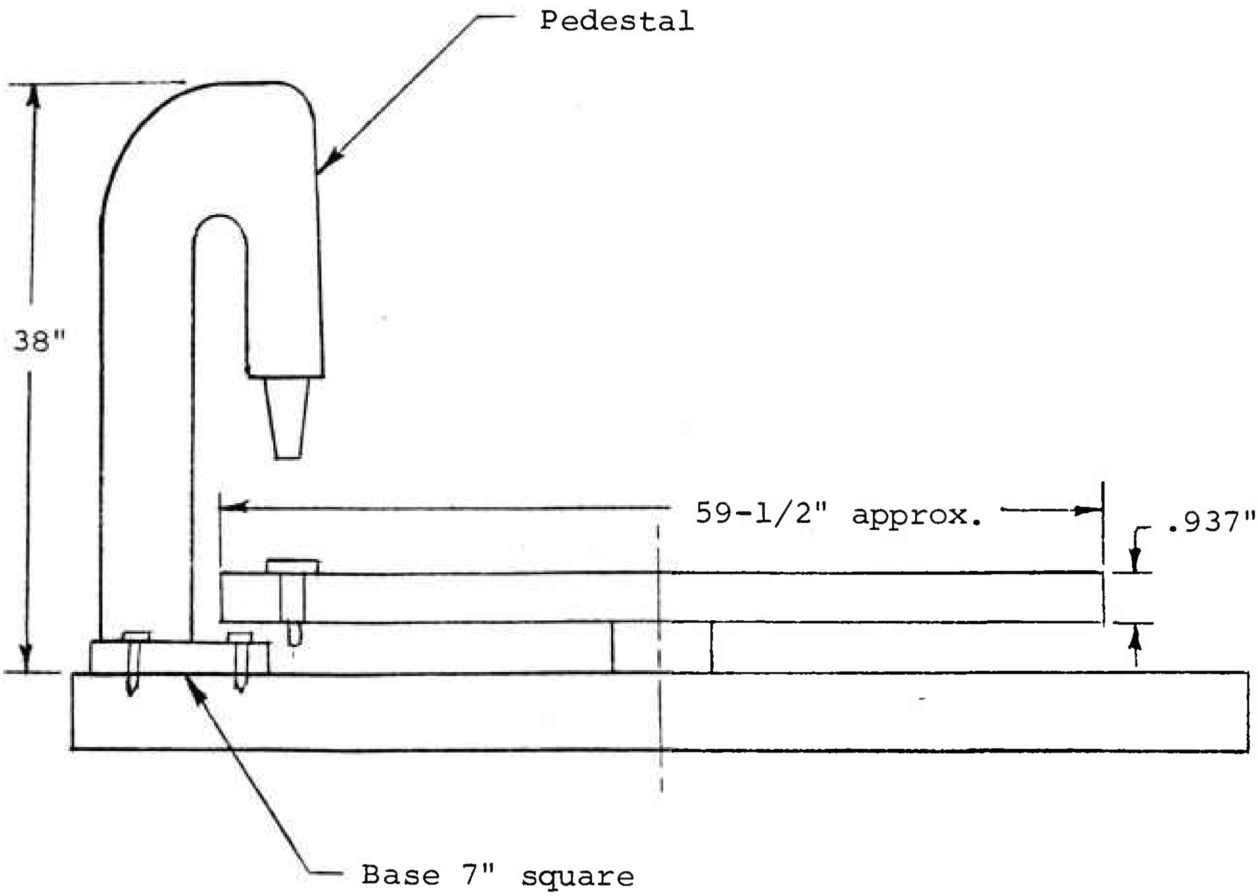

Figure 11. Side view of ultrasonic welder frame installed on Iowa Loader (not to scale).

on the flange periphery. Unflanged cups loaded with the inert material were obtained and tooling was devised to crimp the edges in two 45-degree stages after the disc was inserted.

These modifications appeared to produce good welds. Further welding of samples involved a survey of welding machine settings that were most effective in producing complete peripheral bonds. The results were evaluated primarily by gross leak tests, which involved immersion of the samples in ethylene glycol in a dessicator that was evacuated to 25-28 inches of mercury.

The established welding conditions were as follows:

Ultrasonic power: 125 RF watts

Clamping force: 20 psi

Weld time: 0.3 second

Additional welds were made at these settings using some of the originally supplied inert-loaded detonators. These were provided with foil discs of different colors to differentiate the places of manufacture.

The results of the gross leak tests on these samples are summarized in Table 3. Of 95 welded detonators, 21 (22 percent) leaked. Detonators that were crimped, but not welded, showed 60 percent leaks. This indicated that ultrasonic ring welding had a degree of effectiveness, but did not achieve the 95 percent reliability that was desired.

It was decided that further evaluation should be made on the actual explosive-loaded M55 detonators.

Welding of Live Detonators

With the approval of the Contracting Officer, the ultrasonic welding equipment was transferred to AMCOM, Inc., Atglen, Pennsylvania, a facility that was equipped and staffed to handle a wide range of explosive materials. The equipment was then enclosed in a protective housing as previously described.

TABLE 3. GROSS LEAK TESTS ON INERT-LOADED DETONATORS

Type of Foil Disk	Crimped, Not Welded No. Tested	Crimped, Not Welded No. Leaks	Crimped, Not Welded % Leaks	Crimped and Welded No. Tested	Crimped and Welded No. Leaks	Crimped and Welded % Leaks
Bare	5	2	40%	35	6	17%
Green coated (PA)	5	5	100%	30	8	27%
Yellow coated (IAAP)	5	5	100%	25	7	28%
Black paint (removed before welding) (LSAAP)	5	0	0%	5	0	0%
Totals	20	12	60%	95	21	22%

Early in the program, a hazard anal sis of the ultrasonic welding equipment and process was prepared by Design and Engineering Evaluations, Laurel Springs, New Jersey. Their analysis is included as Appendix A to this report. Before welding of the live detonators was undertaken, the analysis was revised and updated and this version is included as Appendix B. That agency concluded that the possibility of hazards from either the equipment or process was remote. Throughout the program of welding and evaluating the live detonators, all handling of the detonators was conducted exclusively by AMCOM personnel.

The explosive-loaded M55 detonators were supplied by Lone Star Army Ammunition Plant, Texarkana, Texas and by Kansas Army Ammunition Plant, Parsons, Kansas. The detonators were of three types, all of which had the cup edge crimped over the foil disc:

1. Standard production item, crimped and coated with green lacquer (Lot No. LS-DZ-4199.)

2. Crimped with plain, uncoated cover discs (Lot No. KN-E-1.)

3. Crimped, with chromated cover discs (Lot No. LS-79E-001-S418.)

A fourth type, with a lacquered cover disc, was to have been provided, but apparently this type was unavailable and it was not received for weld evaluation.

At least 1000 each of Types 2 and 3 were ultrasonically ring welded under the conditions previously established: 125 watts power, 20 psi clamping force and 0.3 second weld time.

Since dimensions of the final items are critical for assembly of the detonators into systems, a go-no go gage was fabricated to check the dimensions after welding. Basically, this was a steel plate with a precisely drilled circular hole for checking the diameter and a precisely machined square hole for checking length. All welded detonators successfully passed the dimensional checks.

For evaluation of the welds, randomly selected detonators were subjected to fine leak (helium leak) tests by Universal Technical Testing Laboratories, Inc., Collingdale, Pennsylvania. The essential equipment was transported to the AMCOM facility for these tests. A detailed description of the equipment, tests and results is provided in the report submitted by Universal Technical Testing Laboratories (Appendix C.)

The test equipment consisted of a Varian Model 925-40 "Porta-Test" mass spectrometer leak detector and helium pressurization equipment. Pressurization was accomplished with a pressure vessel which could be pressurized to 15 psi helium, a 5 cfm high vacuum pump, a thermister vacuum gage and essential manifolds.

Fifty each of four types of detonators were tested:

1. Standard production unit, crimped and lacquered (Lot No. LS-DZ-4199.)

2. Crimped and ultrasonically welded, with bare closing disc (Lot No. KN-E-1.)

3. Crimped and ultrasonically welded, with chromate green closing disc (Lot No. LS-79E-001-S418.)

4. Crimped, but unwelded, with bare closing disc (Lot No. KN-E-1.)

The fifty detonators of a single type were nested in a special aluminum chassis which was placed in the pressure vessel. The vessel was evacuated to 5000 microns vacuum and then repressurized with helium to 15 psi. This pressure was held for four hours. The helium gas was then vented to the outdoors and the pressure vessel was flushed with ambient air at 30 psi for 30 seconds, after which the pressure vessel was opened and the chassis removed. Each detonator was then individually tested for helium leakage in the mass spectrometer. The recorded relative leak rates were plotted as a function of time after removal from the pressure vessel.

The results of the helium leak tests are provided in Appendix C and summarized in the curves of Figure 12. Both types of ultrasonically welded detonators and also the units that had been crimped over plain discs, but unwelded showed approximately equivalent leak rates. The curves of Figure 12 show an initial sharp decline in leak rate, followed by a leveling off. Zero leak rate was achieved in about 25 to 33 minutes after exposure to ambient atmosphere. There was some indication that the units ultrasonically welded with plain discs were superior to those ultrasonically welded with chromated discs, but the difference is probably not significant.

However, no leakage at all was detected with any of the standard production detonators (crimped and lacquered.) This could be attributed to either of two causes: Either these units were completely leaktight to the limits of detection of the mass spectrometer (10^{-11} standard cc/sec,) or the leaks were so gross that all helium was exhausted during purging of the pressure vessel. Further testing to compare these detonators with unlacquered plain, crimped units led to the conclusion that the standard items were leakproof. (See Appendix C.)

For further evaluation, a number of the detonators that had been helium leak tested were later subjected to gross leak tests in the dessicator. Three types of detonators were thus tested:

1. Standard production (crimped and lacquered)

2. Ultrasonically welded (with plain covers)

3. Crimped only (not lacquered or welded)

In each case, the detonators were transferred to the liquid contained in a small beaker which was placed

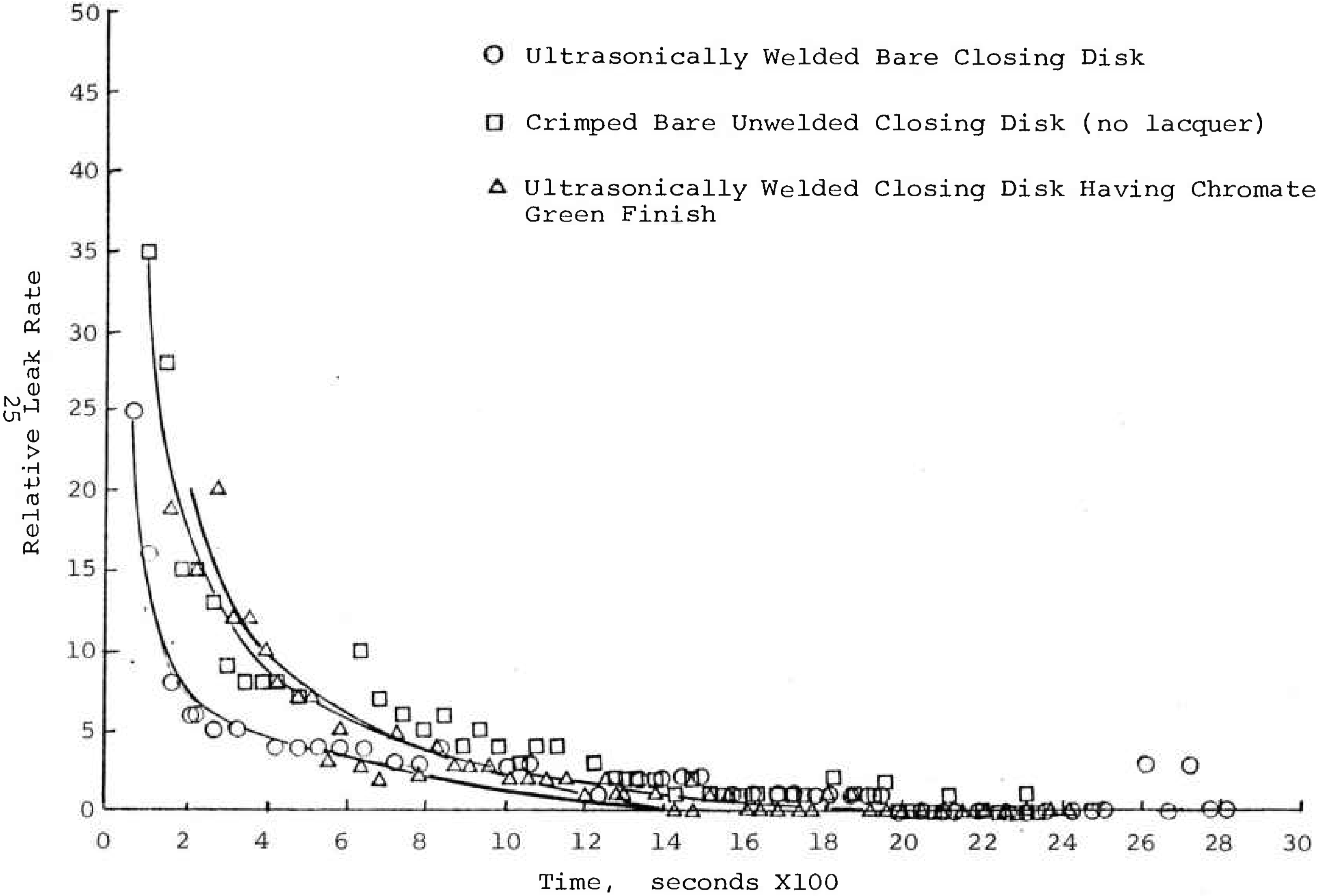

Figure 12. Relative leak rates for detonators as a function of time after removal from pressure vessel.

in the dessicator and evacuated to about 25-28 inches mercury gage reading.

Early tests were made with dibutyl phthalate as the bubbling medium. However, it was believed that this liquid could possibly attack the lacquer on the standard units and make results invalid. Further tests were made in ethylene glycol, but this liquid had a murky appearance that made it difficult to see the bubbles emerging from the detonators. Consequently, tests were made in both ethylene glycol and dibutyl phthalate, as indicated in Table 4.

Initially, the ethylene glycol was only about one inch deep in the beaker and in two tests (#2 and #4) no bubbles could be observed. For subsequent tests, the beaker was filled with the ethylene glycol to provide a longer path for the bubbles to rise.

The data in Table 4 show gross leaks in both liquids for all three types of detonators. Tests #1, #3 and #8 showed leaks in the standard units, contradicting the findings of the fine leak tests where no leakage at all was detected. There was no explanation for this contradiction. Ultrasonically welded detonators (Tests #7 and #9) also showed gross leaks, as they had shown fine leaks in the helium tests.

Results of the waterproofness tests conducted at Lone Star Army Ammunition Plant were as follows:

	% Passed
100 lacquered standard	96
100 clear disc-unwelded	11
100 clear disc-welded	9
100 chromate disc-welded	36

It was thus apparent that ultrasonic welding of the M55 stab detonators in the existing geometry was ineffective in achieving the desired leaktight welds. As previously mentioned, successful welding of this geometry was questioned at the outset because

TABLE 4. GROSS LEAK TESTS ON M55 DETONATORS

Test No.	Detonators	No. Tested	Liquid	Results
1	Standard	5	Ethylene Glycol (1" deep)	Some bubbling occurred.
2	Standard	5	Ethylene Glycol	No bubbles observed.
3	Standard	5	Dibutyl Phthalate	Profuse bubbles
4	Crimped only	5	Ethylene Glycol	No bubbles observed.
5	Crimped only	5	Dibutyl Phthalate	Profuse bubbles.
6	Crimped only	5	Ethylene Glycol (full beaker)	Large bubbles formed on detonators; some fine bubbles.
7	Welded	5	Dibutyl Phthalate	Profuse bubbling at about 20" vacuum.
8	Standard	5	Ethylene Blycol	A few bubbles apparent at about 27" vacuum.
9	Welded	5	Ethylene Glycol	Bubbles appeared at about 23" vacuum.

there was no rigid anvil to support the weld zone. The explosive materials loaded into the detonators did not provide the required reaction to the clamping force. The ultrasonic energy transmitted to the inward flange/cover disc interface apparently passed through the metal and was absorbed in the contents of the cups rather than at the interface as desired.

It appeared that successful use of ultrasonic welding for sealing these detonators could be achieved only by altering the geometry of the cup to include an outward flange that could be rigidly supported on an appropriate welding anvil. As noted, such a configuration has repeatedly been successfully welded to achieve reproducibly leaktight seals, which remain leaktight even after redrawing the flange to a cylindrical geometry, as shown in Figure 4.

CONCLUSIONS AND RECOMMENDATIONS

With the M55 stab detonator in its existing geometry, reproducibly leaktight seals were not obtained by ultrasonic ring welding. Both inert-loaded and explosive-loaded detonators showed unacceptable leakage rates.

It is recommended that further consideration be given to the possibility of revising the cup geometry to provide an outward flange to which a cover disc can be ultrasonically ring welded, since this technique has been demonstrated to provide the desired results. Subsequent redrawing of the flange to a cylindrical geometry is feasible.

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APPENDIX A

PRELIMINARY HAZARD ANALYSIS
FOR THE ULTRASONIC WELDING EQUIPMENT
(M55 STAB DETONATOR)

December 15, 1978

Prepared by

Andrew R. Evans, Vice President
Design and Evaluation, Inc.
Laurel Springs, New Jersey 08021

1.0 Introduction

The intent of this analysis is to assess the hazards associated with the feasibility phase of the ultrasonic welding equipment for the M55 Stab Detonator.

This equipment is ultimately intended for incorporation into production facilities for the M55 detonator. Accordingly, the feed mechanism will be changed to accommodate production rates. In the phase covered by this analysis, it is the welding process that is being evaluated, using both dummy and live detonators.

The equipment consists of the welder and a remotely located control console. Since the console is in a protected area, personnel hazards, such as shock, are not a part of this preliminary assessment.

The principal hazards involved fall into three groups:

1. Detonation of the M55 pellet.

2. Explosion, due to high voltage and the presence of a potentially explosive atmosphere.

3. Injury due to high voltage and moving parts.

The analysis has been conducted to the format of ARMCOM 385-4 "Preliminary Hazards Analysis."

The individual hazards are delineated in Table A-1. Figures A-2 and A-3 are fault trees depicting the required logical sequence of failures leading to the major hazardous events - detonation or explosion.

2.0 Summary

The two major hazards associated with the ultrasonic welding process are continued application of ultrasonic energy which could heat, and ultimately detonate, the M55, and explosion due to the presence of an explosive atmosphere and the high voltage present at the ultrasonic transducers.

As shown in the fault tree analysis, neither of these hazards will occur as a result of a single point equipment failure, due to the interlocks designed into the system. Lesser hazards, which could result in minor injury or equipment damage, have been identified, and are shown in Table A-1. The minor injury hazard is associated with stored energy in springs, and equipment damage would generally occur due to lack of proper clamping pressure.

Operator errors, such as fingers, etc., in the weld area, also present some hazard potential due to the movement and clamping of the anvil assembly. Some positive means of safety precaution may be advisable for this hazard, although the equipment is designed to meet OSHA standards.

The identified hazards have been tabulated in Table A-1.

The Hazard categories are listed in Table A-2, which has been extracted from ARMCOM 385-4.

3.0 Discussion

Figure A-1 is a simplified functional diagram depicting the controls, mechanisms, and sensing provisions of the welding system.

The three critical functions are proper positioning and applied pressure between the work piece (the detonator) and the welding tip, the positive flow of cooling and purging air during the welding cycle, and proper timing of the welding cycle.

Proper positioning and clamping is a function of the following:

(a) Proper insertion of the workpiece (M55) into the locater disc.

(b) Proper position of the anvil assembly, accomplished by a piston actuated cam, lever and spring arrangement. When the piston drives the cam forward, a pivoted, spring-loaded lever is driven down at the cam contour end, causing the other end of the lever to raise the anvil assembly.

The anvil assembly contains a spring and a force transducer which permits setting of the clamping force.

The piston position is monitored by a microswitch, used in the interlock electronics so that welding will not commence in the absence of piston activation (which requires the presence of the air supply).

Mechanical failures in the linkage will result in failure to lift the anvil, which, in turn, may result in failure or damage to the welding horn.

The positive flow of cool air is principally required for purging purposes. The air flowing through purges the potentially explosive atmosphere from the region of high RF voltage at the ceramic wafer assembly. The air source is a facility responsibility. Filtering and routing of the air supply is a function of the welding equipment (valve and filter). Hazardous failures are those which might permit normal operation of the air piston while inhibiting flow to the transducers.

Timing of the weld cycle, which is adjustable, is set by a timing circuit in the control console. Overload and overheat interlocks are incorporated to stop the weld cycle in the event of a failure.

4.0 Conclusions and Recommendations

Initiation of the M55 detonator during the welding process represents an extremely remote hazard due to system design and interlocks. Two separate failures are required (both in electrical circuitry) to result in excessive heat. The mechanical design is such that identified failures result in insufficient or no welding contact rather than a shock load. Furthermore, taken by itself, the detonation of the M55 is not catastrophic, although it would damage equipment (the anvil assembly and the welding horn).

The presence of an explosive atmosphere would make this occurrence much more serious, however. Therefore it is essential that the hazard probability be maintained at an extremely remote level.

The presence of high voltage and the possibility of sparks are the other triggering mechanisms for an explosion in the atmosphere around the welder.

For Phase 1 of this effort, the probability of an explosive atmosphere is, itself, remote. For incorporation into a production facility, the probability must be considered as one. This will necessitate greater emphasis on the mechanical design associated with the anvil assembly control and positive assurance of cooling (purging) air flow around the high voltage area.

To protect against operator injury, procedures should be examined to ensure that operator carelessness will not result in accident situations. It may be advisable to incorporate a barrier device and another interlock to ensure that access is not possible. As an additional precaution against personnel accidents, all air lines should be securely tethered or safety wired to protect against whipping in the event of loose or broken connections.

TABLE A-1

PRELIMINARY HAZARD ANALYSIS

(ARMCOMR 385-4)

REV NO.	0
REV DATE	
PAGE	1 OF ___
DATE STARTED	
DATE COMPLETED	12/15/78
PROJECT NO.	
SYSTEM	Ultrasonic Welder
SUBSYSTEM	
ANALYST	A. R. Evans

ITEM NO.	NOMENCLATURE AND PART NO.	OPERATING MODE[1]	FAILURE MODE[2]	EST. PROB.[3]	FAILURE EFFECTS	HAZARD DESCRIPTION	HAZ. CAT.	RECOMMENDED CONTROL	AMPLIFYING REMARKS (INCLUDE VERIFICATION)
1	Filter	Operating	Clogs	Low	Loss of cooling air	Explosive atmosphere in high voltage area	IV	Positive sensing required to inhibit voltage application	Provided in design by impedance mismatch sensing.
			Defective	Low	Air unfiltered	Unfiltered air in transducer.	I		Possible damage to transducer.
2	Regulator and gage	Operating	Clogs or fails to operate	Low	Air piston will not operate.	Anvil stops (high or low).	I		Sensed by failure of microswitch to transfer.
3	Fittings	Operating or non-operating	Loose	Low	Release of air hose under pressure	Flying hose (Personnel hazard)	II	Tethering of air hoses	
4	Air hoses 3814-1	Operating or non-operating	Ruptures	Low	Release of air hose under pressure	Flying hose (Personnel hazard)	II	Tethering of air hoses	
			Leaking	Medium	Reduction in cooling air	Low air supply.	I		
5	Air supply (Facility supplied)	Operating	Under pressure or off	Low	Loss of cooling air	No air supply.	I		Will be sensed by impedance mismatch.
6	Spring (stock)	Operating	Breaks or weak	Low	Anvil has no positive return	Loose parts, misaligned anvil (possible personnel hazard)	II	Enclose spring	

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 Probability
Medium = Approx 0.001 to 1.0001 Probability
High = Greater than 0.001 Probability
Unknown = Unknown Probability

TABLE A-1
PRELIMINARY HAZARD ANALYSIS
(ARMCOMR 385-4)

REV. NO. | REV DATE | PAGE 2 OF ___ | DATE: STARTED ___ COMPLETED 12/15/78

PROJECT NO. | SYSTEM: Ultrasonic Welder | SUBSYSTEM | ANALYST: A. R. Evans

ITEM NO.	NOMENCLATURE AND PART NO.	OPERATING MODE[1]	FAILURE MODE[2]	EST. PROB.[3]	FAILURE EFFECTS	HAZARD DESCRIPTION	HAZ. CAT.	RECOMMENDED CONTROL	AMPLIFYING REMARKS (INCLUDE VERIFICATION)
7	Disc,Locator SB24375	Operating	Cracked	Medium	Work piece misaligned	Abnormal weld interface (heat)	I		Impedance mismatch
8	Lever bearing SBG-7	Operating	Falls out	Low	Lever rests on cam -may-travel or jam	Excessive clamping force if lever overtravels (equipment damage or pellet deformation).	I		
9	Shaft (pivot) SA24387	Operating	Breaks	Low	No pivot for lever - no clamping force	Equipment damage (welding horn)	I		
10	Lever spring 10-Y-25	Operating	Breaks or jams	Low	No anvil lifting or insufficient force	Equipment damage (welding horn) or poor weld	I		Impedance mismatch. Shuts down frequency converter.
11	Switch (Piston position) V3L-3-D8	Operating	Fails open	Low	Does not detect piston actuation		I		Will stop operation
			Fails closed	Low	Does not detect piston return		I		Will stop operation
12	Transducer coupler 5B24320 5B24319	Operating	Disconnected or cracked	Low	Damage to transducer	Damage to system	I		Impedance mismatch will sence and shut down frequency converter.
13	Force transducer WR75-025	Adjustment	Out of spec. (erratic)	Low	Wrong clamping pressure	Minor - probable operator confusion	I		

TABLE A-1
PRELIMINARY HAZARD ANALYSIS
(ARMCOMR 385-4)

REV. NO.	REV DATE	PAGE 3 OF ___	DATE STARTED	DATE COMPLETED 12/15/78
PROJECT NO.	SYSTEM: Ultrasonic welder	SUBSYSTEM	ANALYST: A. R. Evans	

ITEM NO.	NOMENCLATURE AND PART NO.	OPERATING MODE[1]	FAILURE MODE[2]	EST. PROB.[3]	FAILURE EFFECTS	HAZARD DESCRIPTION	HAZ. CAT.	RECOMMENDED CONTROL	AMPLIFYING REMARKS (INCLUDE VERIFICATION)
14	Connectors and cables	Operating	Loose or frayed	Low	Electrical shorts or opens	Shock (personnel)	II		Cables are shielded; connectors should be safety wired.
						Arcing (potential trigger for explosive atmosphere)	IV		Overload circuits should detect and shut down power. Same comments as above.
15	Timing circuit	Operating	Fails to cut-off	Low	Abnormal weld (heat)	Overheats detonator	II		Overload provisions should protect, and anvil should retract prior to damage.
16	Overload relay	Abnormal operating condition	Fails to activate	Low	Will not cut off power when overload occurs.	Removes a safety interlock	I	A verification test should be incorporated.	Visual indication back-up (light).

TABLE A-2. HAZARD CATEGORIES

Hazard levels are classified by MIL-STD-882 in four categories, based upon the most severe result of personnel error, environment, design characteristics, procedural deficiencies, or subsystem or component failure or malfunction.

Category Designation	Hazard Classification and Consequences
Category I	Negligible: No personnel injury, other than medical treatment injury (first aid), or system damage expected as consequence of failure mode occurrence. NOTE: Countermeasures or controls unnecessary.
Category II	Marginal: Personnel injury, limited to temporary total disability, or non-critical system damage expected as consequence of failure mode occurrence. NOTE: A Category II hazard can be counteracted or controlled so that the system, including countermeasures, represents a Category I hazard. Countermeasures or controls will be effected within constraints of cost, schedule, and system effectiveness.
Category III	Critical: Personnel injury, which results in permanent partial disability, or critical system damage expected as consequence of failure mode occurrence. NOTE: A Category III hazard can be counteracted or controlled so that the system, including countermeasure, represents a Category I or II hazard. If the probability of occurrence of failure mode for the system is unacceptably high, Category III hazards within the system will be controlled or counteracted to assure the system, as a whole, does not represent a Category III hazard.
Category IV	Catastrophic: Death, or severe personnel injury (permanent total disability), or system loss expected as consequence of failure mode occurrences. NOTE: A Category IV hazard can be counteracted or controlled so that the system, including countermeasures, represents a Category I, II or III hazard. If the probability of occurrence of the failure mode for the system is unacceptably high, Category IV hazards within the system will be controlled or counteracted to assure the system, as a whole, does not represent a Category IV hazard.

TABLE A-2. (Cont.)

NOTE: <u>The severity of the consequence alone determines the category of hazard, irrespective of the effectiveness of control or the probability that the hazard will be transposed into an undesired event</u>.

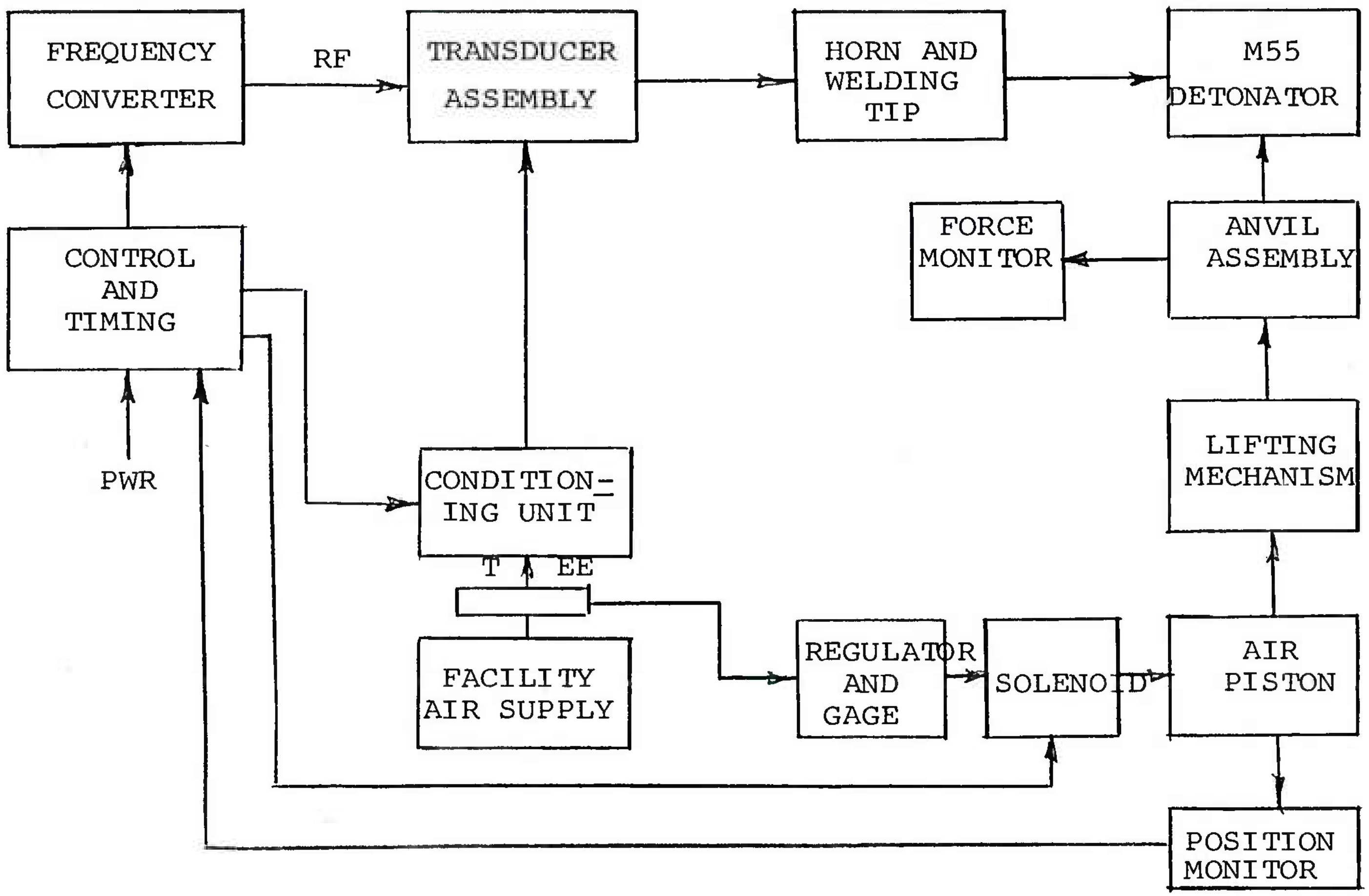

Figure A-1. Functional block diagram - ultrasonic welder.

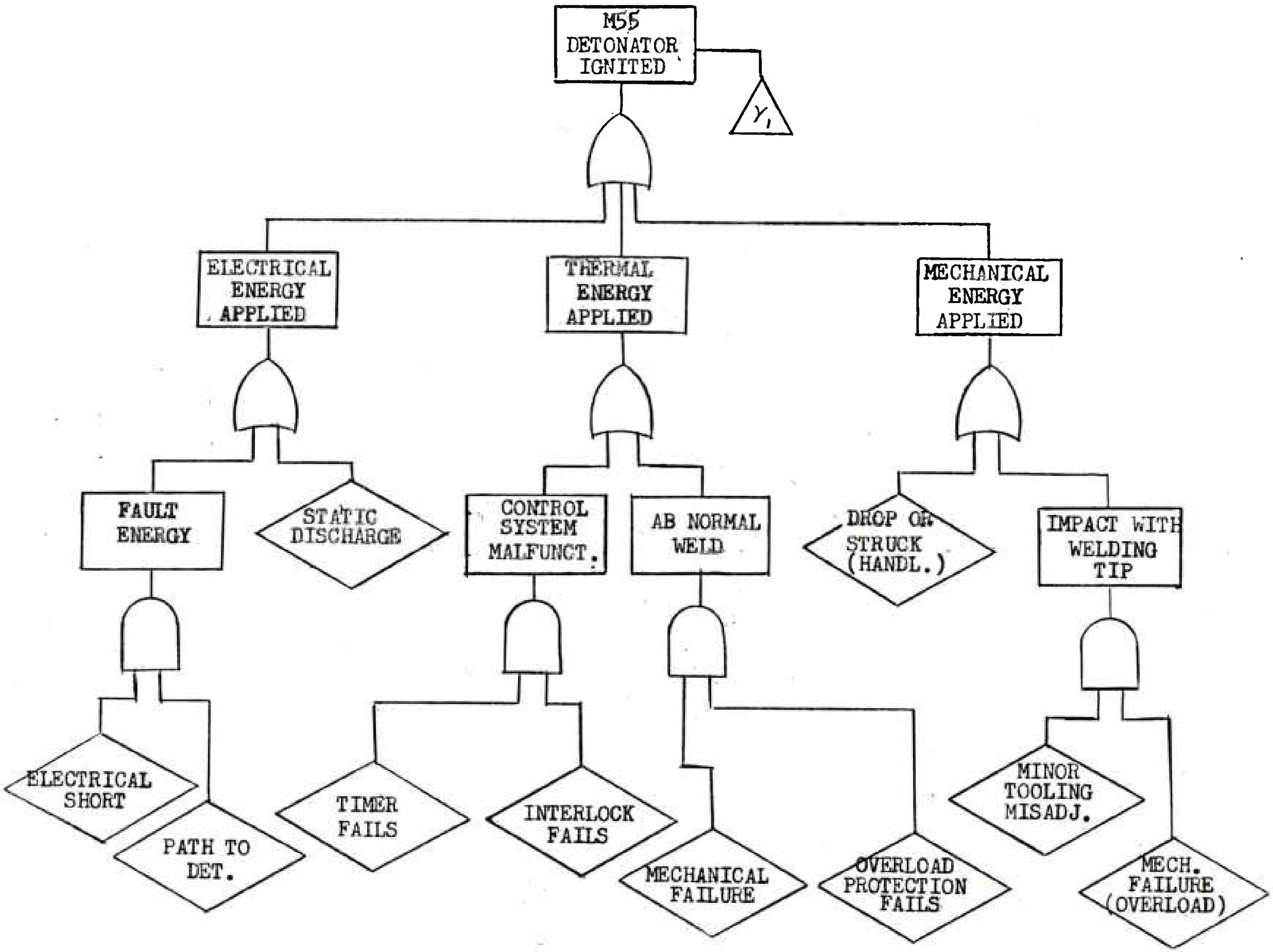

Figure A-2. Detonation fault tree.

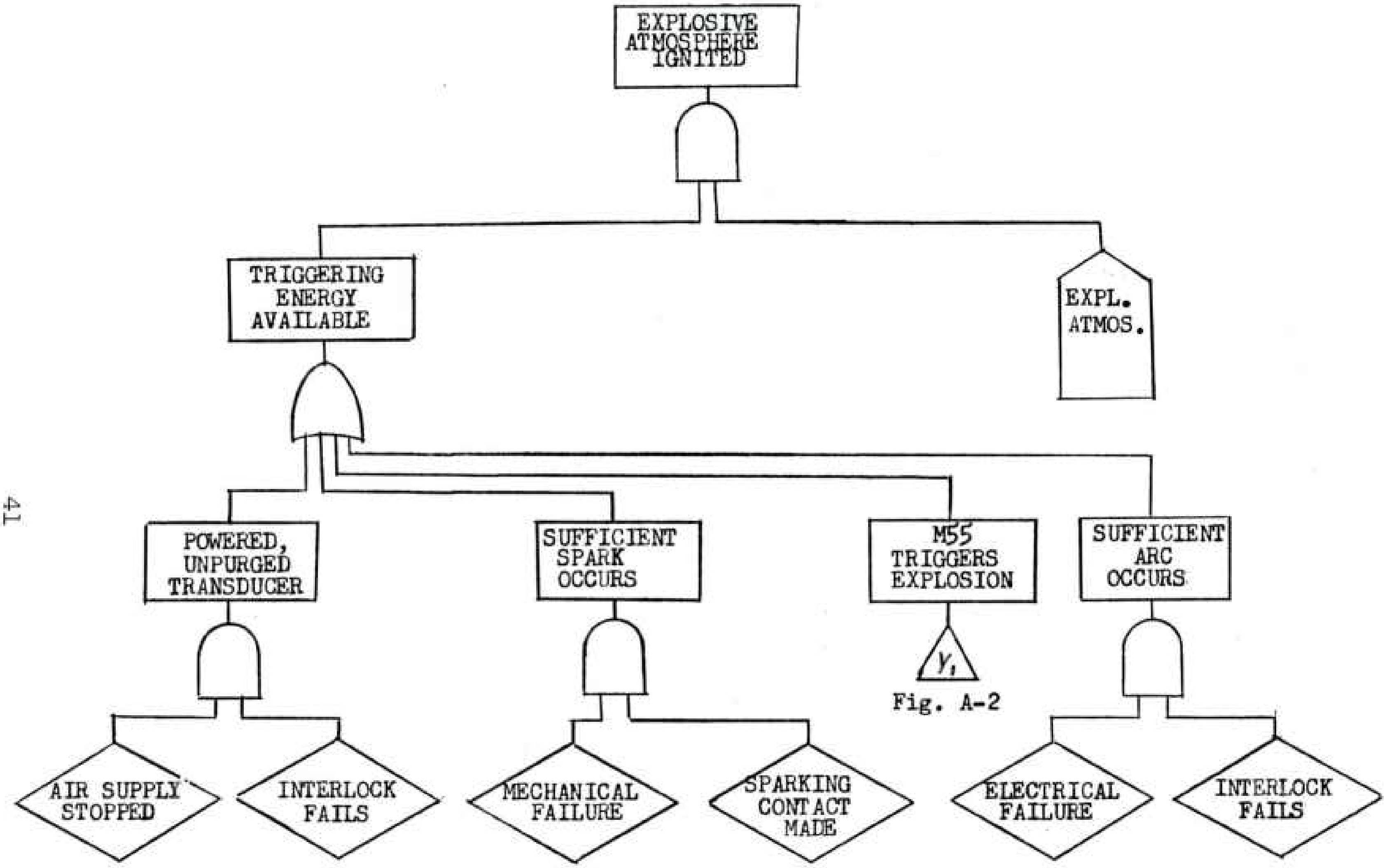

Figure A-3. Explosion fault tree.

APPENDIX B

HAZARDS REVIEW FOR THE ULTRASONIC WELDING EQUIPMENT (M55 STAB DETONATOR)

August 14, 1979

Prepared by

Andrew R. Evans, Vice President
Design and Evaluation, Inc.
Laurel Springs, New Jersey 08021

1.0 Purpose

This report constitutes a re-examination of the Preliminary Hazards Analysis for the Ultrasonic Welding Equipment, dated 15 December 1978.

The intent of this update was to re-assess the equipment and setup prior to the welding of live detonators.

To this end, a visit was made to the test site, and the setup was physically inspected.

In addition, the hazards previously identified were reviewed in light of the changes which have been made to the hardware and the setup.

Essentially, these changes consist of a new anvil design, addition of a cover around the transducers, a change to the detonator eject mechanism, and shield (enclosure) of the assembly for personnel protection during the welding process.

2.0 Summary

Hazards associated with exposed moving parts have been reduced or eliminated.

The test is being conducted at a facility (AMCOM) where the detonator is manufactured. Normal precautions associated with explosives handling are standard at the facility.

Any hazard, itself, is minor since only one detonator at a time will be involved for this feasibility series.

No significant hazardous conditions were detected, and the setup has been tested using inert detonators.

It is concluded that the setup is satisfactory for the feasibility welding contemplated.

It is recommended, however, that at least an informal written procedure be prepared.

3.0 Discussion

Figure B-1 depicts and describes the test setup at AMCOM.

The welding procedure consists of the following steps:

(1) Detonators are stored in the steel storage container. One package of twenty-four detonators will be available on the bench.

(2) The detonator is hand installed into the well of the anvil. This requires lifting and holding the Lexan door and placing the detonator into the well. The detonator will fit upside down (crimp down) so that for proper placement (crimp up) operator care and knowledge is required. For this limited feasibility series, this is not seen to be a problem.

(3) With the detonator in place, the Lexan door (shield) drops. The weld cycle is initiated by depressing both buttons, after which the proper cycle is automatically controlled. The anvil is raised to the horn, the weld made, and the anvil lowered.

(4) Removal of the welded detonator is accomplished by again lifting the Lexan door, depressing the eject lever, and manually removing the lifted detonator. (Depression of the level and picking up the detonator can be a one-hand operation.)

Hazards to the operator are considered minimal. The addition of shields and the present configuration result in operator exposure to only one movable part - the anvil.

Moreover, this exposure only exists while the Lexan door is held open.

The part will not move without simultaneous depression of both activate switches, and inadvertently doing this is extremely remote. There is no interlock on the Lexan door, however; therefore no one except the operator should be in the immediate vicinity during loading or unloading unless suitably instructed on the operation.

The operation is carried out in an area where the likelihood of an explosive atmosphere is extremely remote. (No other operations are taking place at the same time in the room being used.)

The welding of inert detonators was done using the same test setup. Welds obtained were all satisfactory, indicating proper operation and setting of the welding equipment.

Hazards due to the actual welding process are principally those to equipment (i.e., damage to the horn or anvil). For the reasons cited above, these hazards are considered remote.

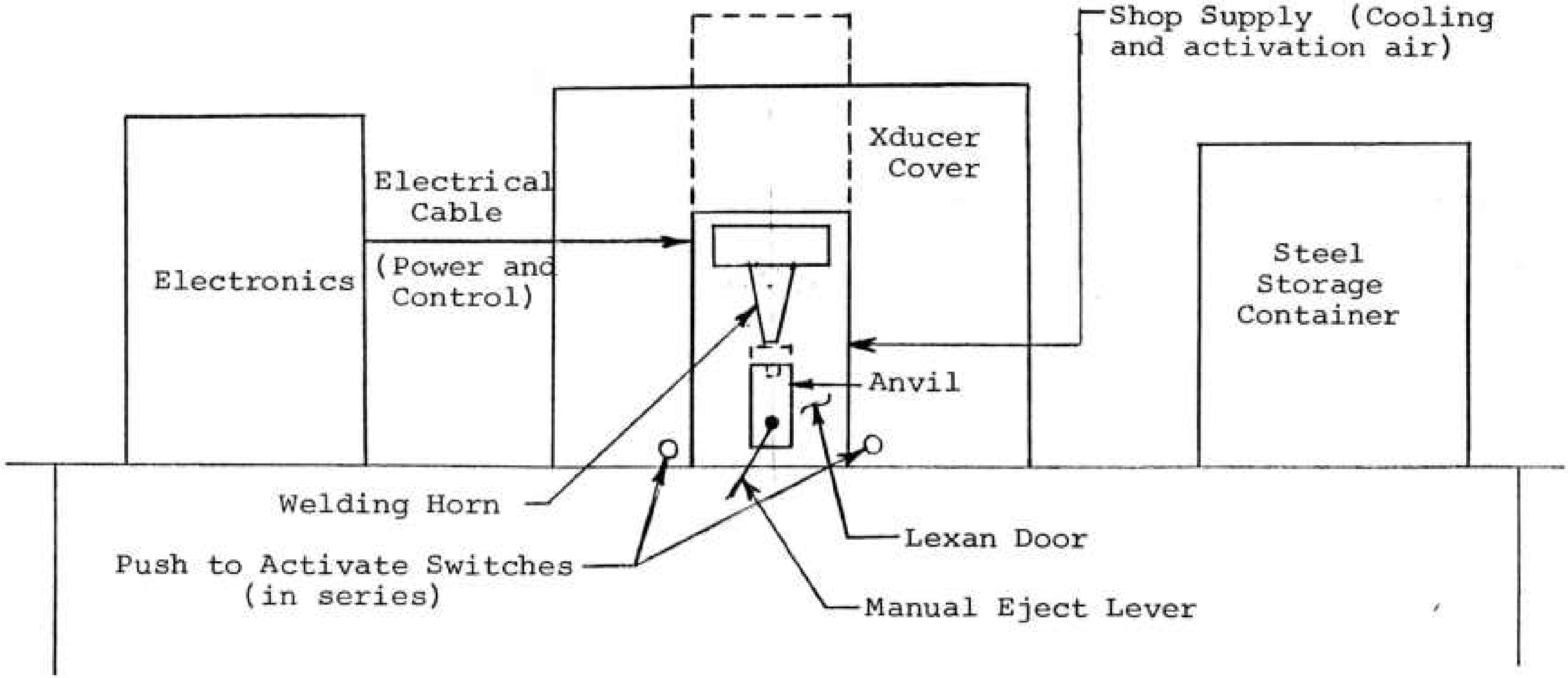

Figure B-1. Ultrasonic welding setup.

APPENDIX C

REPORT OF HELIUM LEAK DETECTION EXAMINATION RESULTS ON M55 DETONATORS

July 1980

Prepared by

Michael C. Modes
Metallurgical Engineer

Universal Technical Testing Laboratories, Inc.
Collingdale, Pennsylvania 19023

ABSTRACT

On July 1, 1980 and July 2, 1980, four lots of fifty (50) detonators each were tested by the Helium Mass Spectrometer method for hermetic seal leakage. The lots were: (A) Standard Crimped with Lacquer Finish, (B) Standard Crimped without Lacquer Finish, (C) Ultrasonically welded with Chromate Finish, (D) Ultrasonically welded without Finish.

It was found that lot (A) did not leak and that lots (B), (C), and (D) leaked equally.

INTRODUCTION

Helium is an excellent trace gas because it is the lightest of the inert gases and as a consequence readily penetrates small leaks. In addition, its presence in the atmosphere is minute (approximately 4 microns absolute) precluding the extraneous information associated with the halogen leak detection method. Helium is easily detected by a simple mass spectrometer from large leaks to leaks as small as 10^{-11} std cc/sec (equivalent to approximately a 1 cc/year leak). The equipment utilized in this examination is a Varian 925-40 "Porta-Test" mass spectrometer leak detector (MSLD).

Figure C-1 is a schematic diagram of the Porta-Test showing the relationship of the major components as viewed from the front of the unit. A major feature of the 925-40 is the interposition of the diffusion pump between the spectrometer tube and the test piece. The spectrometer tube is placed at the inlet (low-pressure) port of the pump, while the unit to be tested is connected to the fore-vacuum (higher pressure) port of the diffusion pump, as is the mechanical vacuum pump. This arrangement assures continuous pumping of the spectrometer tube, while preventing gas and condensable vapors originating at the test piece from reaching the tube. The effectiveness of this arrangement relies on the characteristics of the oil diffusion pump in pumping high molecular weight. Helium, introduced through a leak in a test piece, can diffuse fairly readily through the diffusion pump and reach the spectrometer tube, where it is detected.

TEST METHOD

Two hundred detonators, 50 each from the following four groups, were leak tested:

(1) M55 Detonator with Ultrasonically Welded Closing Disc having a Chromate Green Protective Finish (LS-79E-001-S418).

(2) M55 Detonator with a Crimped, Bare, Unwelded Closing Disc (KN-E-1).

(3) M55 Detonator with an Ultrasonically Welded Bare Closing Disc (KN-E-1).

(4) M55 Detonator from Production with a Standard Crimped Closing Disc and Lacquer Finish (LS-DZ-4199).

(Note: Because the M55 Detonator with the Welded Bare Closing Disc and Lacquer Finish was not available, group (2) was substituted as a control.)

Each group was removed from its protective packing and placed on a special aluminum chassis so that the seal of each detonator was exposed to atmosphere. Each chassis was then placed in a pressure vessel. Each pressure vessel thus contained only one group of 50 detonators.

The pressure vessel was then evacuated to 5000 microns vacuum utilizing a 5 CFM high vacuum pump and thermister vacuum gage. Utilizing a special isolation manifold, the pressure vessel was then repressurized to 15 psi helium $\pm$ 1 psi. This pressure was held for 4 hours $\pm$ 1/10 hour.

At the end of the 4 hours, the helium gas was vented to exterior atmosphere to avoid contaminating the atmosphere near the MSLD. Again utilizing the special isolation manifold, the pressure vessel was flushed with plain air at 30 psi for 30 seconds. At this point the pressure vessel was opened and the chassis containing the detonators was removed for leak testing by the MSLD.

DISCUSSION

The helium leak rate of the detonator was totally unknown before this test. In discussions with experts on the detonators, however, the general consensus was that the standard production detonator would leak at a rate greater than the ultrasonically welded detonators. The general consensus was also that the leak rate would be smaller than the rate normally used for hermetic seals (10^{-6} atm cc/sec as in Mil Std-331A, para. 3.1).

Thus a base run was required before any testing in a 100 second, 200 second, and 300 second mode could be undertaken. Based on the above discussions, it was decided that the standard production detonator would be used as the detonator for producing the data base. After bombing, the 50 standard detonators were all placed in air at atmospheric pressure and allowed to vent. An individual detonator was placed in the MSLD and the test sequence undertaken.

Part of the test sequence was to evacuate the atmosphere around the detonator to 50 millitorr before admitting the sampled helium to the diffusion pump. As discussed earlier, this was then passed through the diffusion pump to the spectrometer assembly.

A reading of 0 was recorded for the first detonator. Each detonator was then cycled in turn, each giving the same 0 reading. This procedure took 2555 seconds as shown in Table C-4.

Since it was assumed that the production detonators were never subjected to a bubble leak test to determine the presence of gross leakage, these readings could be interpreted in two ways. Either the detonator leaked so much that it lost all its helium before entering the MSLD test cycle or the detonator didn't leak at all.

Another test was required. The ultrasonically welded bare closing disc detonator was subjected to the bombing cycle. As seen in Table C-2, the first reading was 19. Considering that the relative range of the MSLD is 0-10,000, a reading of 19 at 172 seconds indicates that the detonators were by MSLD standards gross leakers. Thus, very little information under these conditions could be derived from the originally planned test sequence.

Since these examinations were intended to determine the effectiveness of the standard sealing method versus the ultrasonically welded seal, it was decided that with gross leakers under consideration all the detonators would have to be compared by running a leak rate versus time schedule. No information could be derived from the originally planned testing.

In order to determine what the zero readings of the production detonators indicated, AMCOM submitted unlacquered plain crimped detonators in place of the originally planned ultrasonically welded and lacquered detonators which could not be located. Since these had no hermetic seal, if they read zero in the MSLD it would indicate that the lacquered production detonators were gross leakers. The bombing sequence was undertaken and the detonators were placed in the MSLD. Table C-2 shows that after 60 seconds in atmosphere the bare unlacquered detonator gave a reading of 90. Even after 700 seconds, these detonators were reading 5 and 6. After 1800 seconds, readings of 1 and 2 were still evident.

The ultrasonically welded detonator with the chromate coated closing disk was run last. The results of this examination are shown in Table C-1.

CONCLUSIONS

The bare crimped and unlacquered detonators when cycled through the MSLD gave readings which lasted up to 1800 seconds after bombing. Thus, the detonator held on to the helium charges for a long time, even though no hermetic barrier was present. Thus the standard production detonator was sealed perfectly.

The two welded types of detonators leaked at rates equivalent to that of the plain crimped unlacquered detonators. This can be seen clearly in the graph of Figure C-2.

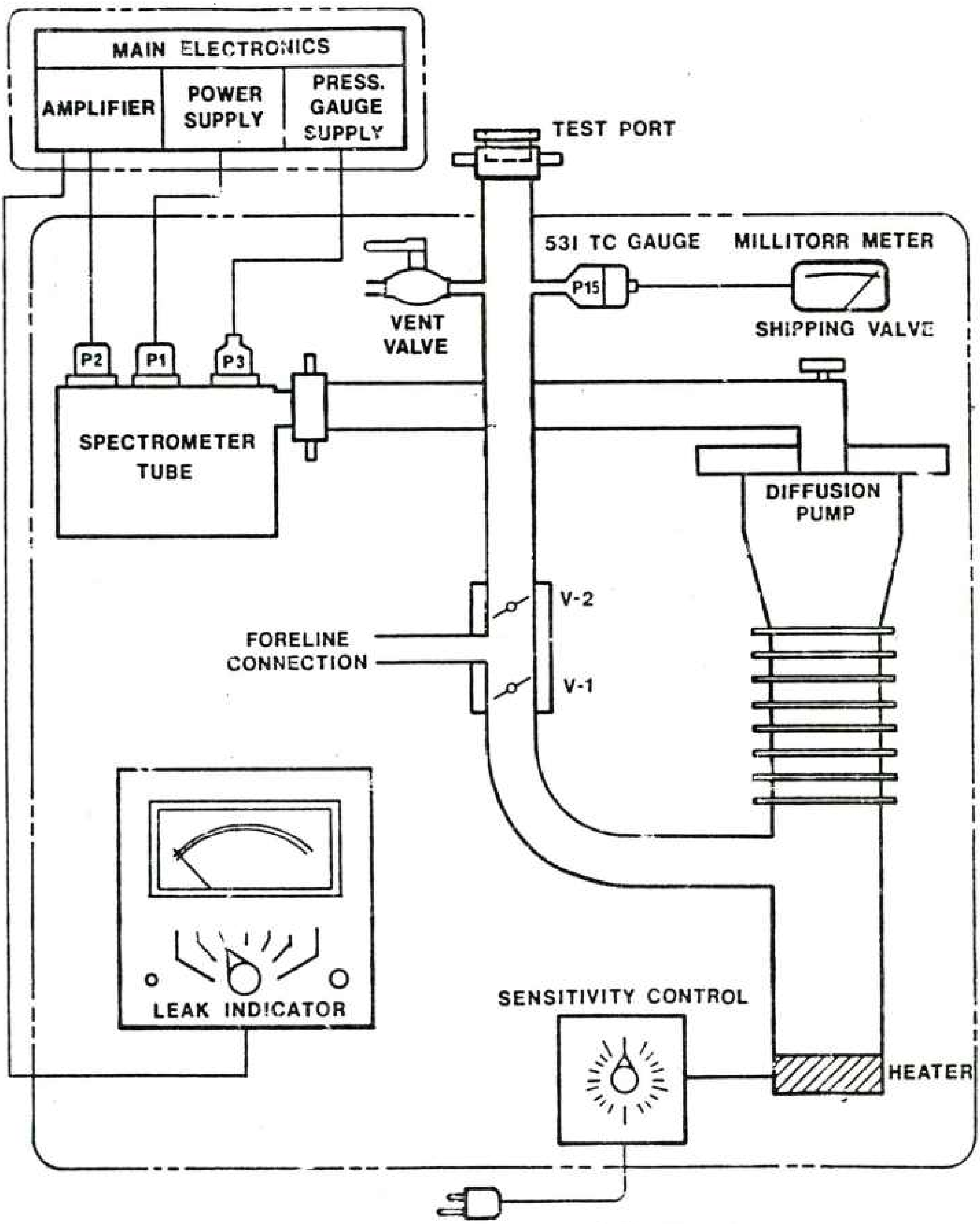

Figure C-1. Schematic Representation of the 925-40 Porta-Test.

TABLE C-1. M55 DETONATOR WITH ULTRASONICALLY WELDED CLOSING DISC HAVING CHROMATE GREEN PROTECTIVE FINISH (PN 8798333 with Mil-Std-171, No. 7.3.3 Green Finish).

Detonator Number	Relative Leak Rate	Time from Bomb (seconds)	Detonator Number	Relative Leak Rate	Time from Bomb (seconds)
1	19	172	26	1	1280
2	15	240	27	1	1300
3	20	285	28	1	1380
4	12	320	29	0	1425
5	12	365	30	0	1470
6	10	405	31	1	1520
7	8	440	32	1	1560
8	7	480	33	0	1605
9	7	520	34	0	1645
10	3	560	35	0	1690
11	5	590	36	0	1740
12	3	645	37	0	1775
13	2	690	38	1	1820
14	5	735	39	1	1875
15	2	785	40	0	1915
16	4	835	41	0	1960
17	3	875	42	0	2000
18	3	920	43	0	2050
19	3	965	44	0	2100
20	2	1015	45	0	2155
21	2	1060	46	0	2210
22	2	1110	47	0	2260
23	2	1160	48	0	2310
24	1	1205	49	0	2370
25	2	1250	50	0	2415

TABLE C-2. M55 DETONATOR WITH CRIMPED BARE UNWELDED CLOSING DISC WITHOUT ANY LACQUER FINISH (PN8798333)

Detonator Number	Relative Leak Rate	Time from Bomb (seconds)	Detonator Number	Relative Leak Rate	Time from Bomb (seconds)
1	90	60	26	3	1335
2	35	105	27	2	1385
3	27	150	28	1	1430
4	15	190	29	2	1470
5	15	235	30	1	1510
6	13	265	31	1	1550
7	9	305	32	1	1595
8	8	355	33	1	1640
9	8	395	34	1	1690
10	8	435	35	1	1730
11	7	495	36	1	1760
12	10	640	37	2	1835
13	7	690	38	1	1880
14	6	745	39	1	1925
15	5	800	40	2	1960
16	6	855	41	0	1995
17	4	900	42	0	2035
18	5	945	43	0	2080
19	4	990	44	0	2115
20	3	1035	45	1	2115
21	4	1080	46	0	2200
22	4	1135	47	0	2235
23	3	1225	48	0	2275
24	2	1265	49	1	2310
25	2	1305	50	0	2350

TABLE C-3. M55 DETONATOR WITH ULTRASONICALLY WELDED BARE CLOSING DISC (PN 8798333) WITHOUT ANY LACQUER FINISH

Detonator Number	Relative Leak Rate	Time from Bomb (seconds)	Detonator Number	Relative Leak Rate	Time from Bomb (seconds)
1	25	65	26	1	1639
2	16	115	27	1	1684
3	8	165	28	1	1738
4	6	205	29	1	1789
5	6	226	30	1	1831
6	5	278	31	1	1881
7	5	336	32	1	1923
8	4	421	33	1	1950
9	4	481	34	0	2008
10	4	535	35	0	2065
11	4	591	36	0	2115
12	4	652	37	0	2157
13	3	731	38	0	2211
14	3	788	39	0	2266
15	4	845	40	0	2318
16	-	964	41	0	2368
17	3	1014	42	0	2425
18	3	1074	43	0	2480
19	-	1134	44	0	2510
20	1	1239	45	-	2560
21	2	1344	46	3	2611
22	2	1399	47	0	2670
23	2	1454	48	3	2725
24	2	1507	49	0	2779
25	1	1589	50	0	2820

TABLE C-4. M55 DETONATOR FROM PRODUCTION WITH STANDARD CRIMPED AND LACQUERED CLOSING DISC (PN 8798331)

Detonator Number	Relative Leak Rate	Time from Bomb (seconds)	Detonator Number	Relative Leak Rate	Time from Bomb (seconds)
1	0	65	26	0	1390
2	0	120	27	0	1445
3	0	185	28	0	1485
4	0	240	29	0	1545
5	0	305	30	0	1605
6	0	355	31	0	1665
7	0	415	32	0	1715
8	0	460	33	0	1765
9	0	530	34	0	1800
10	0	580	35	0	1845
11	0	640	36	0	1895
12	0	695	37	0	1945
13	0	750	38	0	1995
14	0	820	39	0	2050
15	0	870	40	0	2105
16	0	925	41	0	2160
17	0	975	42	0	2190
18	0	1020	43	0	2225
19	0	1065	44	0	2280
20	0	1115	45	0	2340
21	0	1165	46	0	2395
22	0	1215	47	0	2445
23	0	1250	48	0	2495
24	0	1290	49	0	--
25	0	1340	50	0	2555

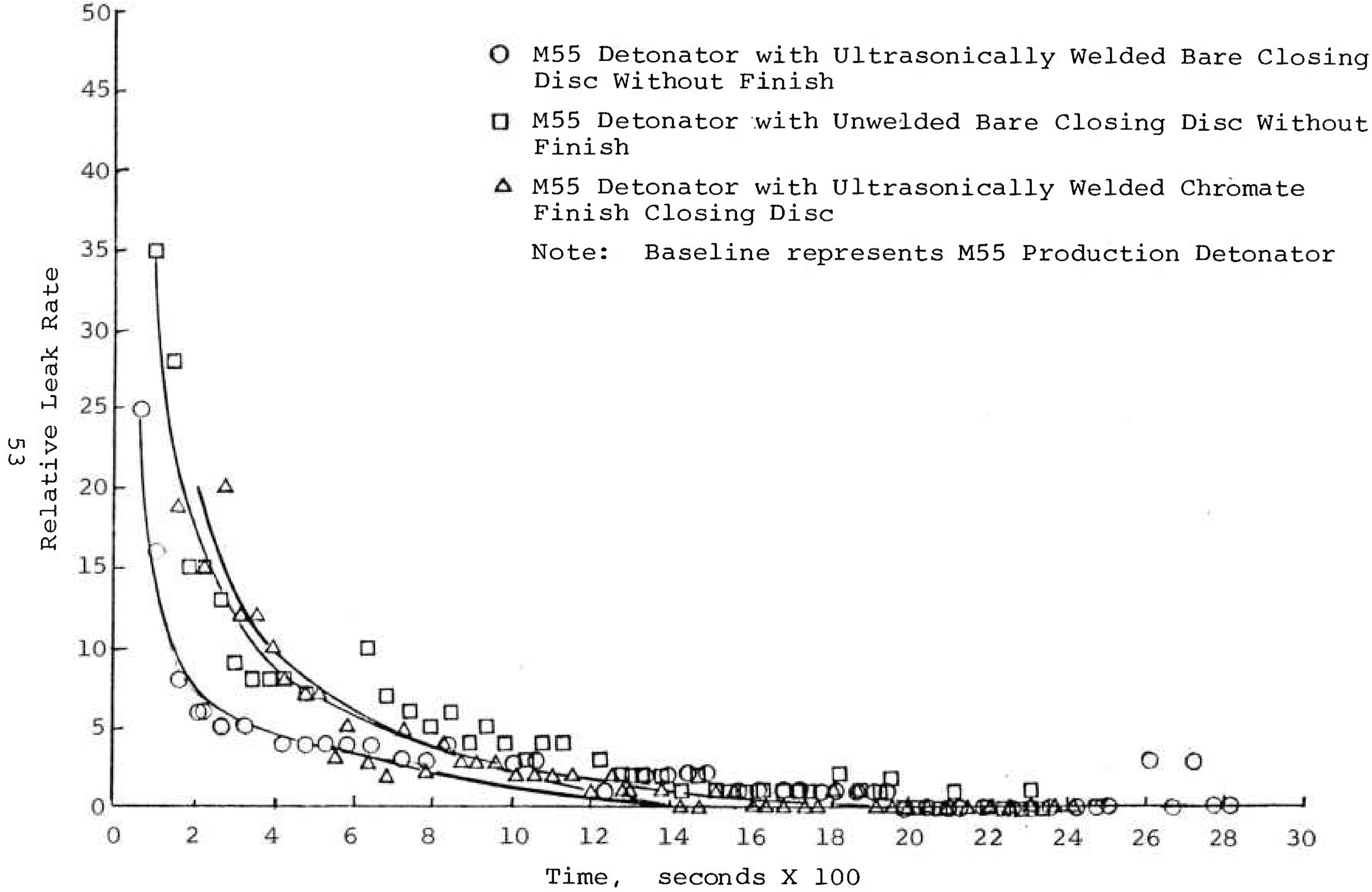

Figure C-2. Relative leak rates for detonators

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