(4)

AD

AD-E402 077

Contractor Report ARAED-CR-90009

AD-A225 626

ADIABATIC COMPRESSION INITIATION CHARACTERISTICS OF LIQUID PROPELLANT NITROMETHANE UNDER DYNAMIC FILL CONDITIONS

W. R. Herrera
N. A. Messina
Southwest Research Institute
San Antonio, TX 78228-0510

W. O. Seals
ARDEC
Project Engineering

August 1990

US ARMY
ARMAMENT MUNITIONS
& CHEMICAL COMMAND
ARMAMENT RDE CENTER

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Armament Engineering Directorate

Picatinny Arsenal, New Jersey

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER 01-2512	5. MONITORING ORGANIZATION REPORT NUMBER Contractor Report ARAED-CR-90009
6a. NAME OF PERFORMING ORGANIZATION Southwest Research Institute; 6b. OFFICE SYMBOL	7a. NAME OF MONITORING ORGANIZATION ARDEC, AED
6c. ADDRESS (CITY, STATE, AND ZIP CODE) San Antonio, Texas 78228-0510	7b. ADDRESS (CITY, STATE, AND ZIP CODE) Energetics and Warheads Div. (SMCAR-AEE) Picatinny Arsenal, NJ 07806-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br; 8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAA21-88-R-0084
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (INCLUDE SECURITY CLASSIFICATION)
ADIABATIC COMPRESSION INITIATION CHARACTERISTICS OF LIQUID PROPELLANT NITROMETHANE UNDER DYNAMIC FILL CONDITIONS

12. PERSONAL AUTHOR(S)
W.R. Herrera and N.A. Messina, Southwest Research Institute; W. O. Seals, ARDEC Project Engineer

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (YEAR, MONTH, DAY)	15. PAGE COUNT
Final	FROM 3/27/89 TO 8/4/89	August 1990	42

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)
FIELD	GROUP	SUB-GROUP	Nitromethane, Han-based propellants, Adiabatic compression, TEXS systems, Kinematic viscosity, Bubbles

19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

SwRI used Princeton Combustion Research Laboratories (PCRL) to perform the designated tasks. Based upon their results of their limited laboratory-scale experiments in the field engineering assessments and preliminary findings from TEXS system modeling, PCRL concluded that the use of nitromethane in Tactical Explosive System is probably safe. PCRL has also advised that any hazards that may exist can be minimized by taking the following recommendations:

1. Change off-loading nozzle valve to the type that shuts more slowly.
2. Make sure that the 1.5 in. connecting pipe is PE (expandable) and not steel or other heavy walled pipe.
3. Make sure that all valves in the 1.5 in. are wide open types and not constructed of steel.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL I. HAZENDARI	22b. TELEPHONE (INCLUDE AREA CODE) 201 724-3316; 22c. OFFICE SYMBOL SMCAR-IMI-I

DD FORM 1473, 84 MAR

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

INTRODUCTION

Southwest Research Institute (SwRI) was contracted under DOD Contract DAAA21-88-R-0021, Delivery Order 0003 to perform the following tasks:

1. Provide data on physical properties of nitromethane that are important in characterizing hydrodynamic surge pressure during dynamic fill processes and in characterizing bubbler collapse processes. Such data includes kinematic viscosity, vapor pressure, gas solubility (N, air), and compressibility. These physical properties are desired at cold and hot temperature extremes (-25°F to 126°F).

2. Conduct theoretical analysis of adiabatic compression phenomenon of bubbles in liquid nitromethane associated with hydrodynamic surge pressure wave in nominal dynamic fill operations by utilizing available experimental data and empirical correlations.

3. Conduct limited essential lab-scale experiments with government-furnished material (GFM) nitromethane sample for confirmation of Item 2 above.

4. Provide preliminary hazards statement based on results of Items 1, 2, and 3 available. This preliminary hazards statement will be refined at the conclusion of the program effort.

5. Define "Phase II" Program Plan to establish safe operating corridor in multiparameter space for dynamic fill process of nitromethane, to account for a typical or pathological performance. This must take into account "what if" scenarios to properly answer personnel safety concerns.

TASKS PERFORMED

With the concurrence of U.S. Army Armament, Munition and Chemical Command, Picatinny Arsenal, New Jersey, SwRI used Princeton Combustion Research Laboratories (PCRL) to perform the designated tasks. PCRL has key technical personnel, equipment and facilities that were essential to the proposed study. During the past several years, PCRL has conducted experimental investigations on the sensitivity of liquid propellants to compression ignition. This phenomenon has been identified as one of the potential sources of secondary ignition hazard as relates to the TEXS environment. Here we define secondary ignition as any ignition due to sources other than the desired direct initiation. In particular, compression ignition is that secondary ignition arising from hot spot development associated with bubble collapse under compressive loading of the liquid nitromethane charge associated with hydrodynamic surge pressure waves. These bubbles may be brought into the TEXS pipeline from fill lines during the prefiring nitromethane dynamic filling process or may be formed by cavitation during the filling process.

The extent to which real fluid effects moderate the bubble dynamics needs to be quantified, especially at temperature extremes. Bubbles in the liquid nitromethane charge may contain reactive vapor or a mixture of permanent gas and vapor.

PCRL has the equipment and instrumentation necessary to characterize the kinematic viscosity, vapor pressure, gas solubility (N_2, air), and compressibility of nitromethane at cold and hot temperature extremes. In those instances where the desired data are available in the literature [government-furnished material (GFM) compendium of nitromethane data], these data will be used to supplement the PCRL-generated data. PCRL has generated such data in the past on hydroxyl ammonium nitrate (HAN)-based liquid monopropellants.

PCRL conducted limited essential laboratory-scale experiments with GFM-furnished nitromethane for confirming the response to nitromethane to the hydrodynamic surge pressure wave in nominal dynamic fill operations in TEXS application. A specialized dynamic flow fixture is operational at PCRL for obtaining flow characteristics (volumetric flow rates, water-hammer hydraulic effects, etc.) at various conditioning temperatures in the range -25°F to 126°F. A transparent chamber permits high-speed cinematography of the dynamic flow tests.

PCRL attended program briefing meetings held in Monroe, Louisiana, Yuma, Arizona, and Dover, New Jersey, and gave a presentation (Appendix A) in fulfillment of the contractual tasks.

CONCLUSIONS

Based upon the results of their limited laboratory-scale experiments, PCRL concluded that the use of nitromethane in TEXS is probably safe. PCRL has also advised that any hazards that may exist can be minimized by taking the following recommendations:

1) Change off-loading nozzle valve to the type that shuts more slowly.

2) Make sure that the 1.5-in. connecting pipe is PE (expandable) and not steel or other heavy walled pipe.

3) Make sure that all valves in the 1.5-in. pipe are wide open types and not constructed of steel.

APPENDIX A
PRESENTATION BY
PRINCETON COMBUSTION RESEARCH LABORATORIES

PRINCETON COMBUSTION RESEARCH LABORATORIES, INC.

INVESTIGATION OF NM SAFETY FOR TEXS SYSTEM[+]

DR. NEALE A. MESSINA, DR. MARTIN SUMMERFIELD
& DR. MAREK TARCZYNSKI

PRINCETON COMBUSTION RESEARCH LABORATORIES, INC.
MONMOUTH JUNCTION, NJ

25 JULY 1989

+ CONDUCTED ON P.O. 65620 ON PRIME CONTRACT DAAA21-88-D-0021; MR. WILLIAM SEALS, COTR, U.S. ARMY ARDEC, PICATINNY ARSENAL, NJ

OBJECTIVES OF PCRL WORK (BASED ON CONTRACT SOW)

1. PROVIDE DATA ON PHYSICAL PROPERTIES OF NM THAT ARE IMPORTANT IN CHARACTERIZING HYDRODYNAMIC SURGE PRESSURE DURING DYNAMIC FILL PROCESS AND IN CHARACTERIZING BUBBLE COLLAPSE PROCESS.

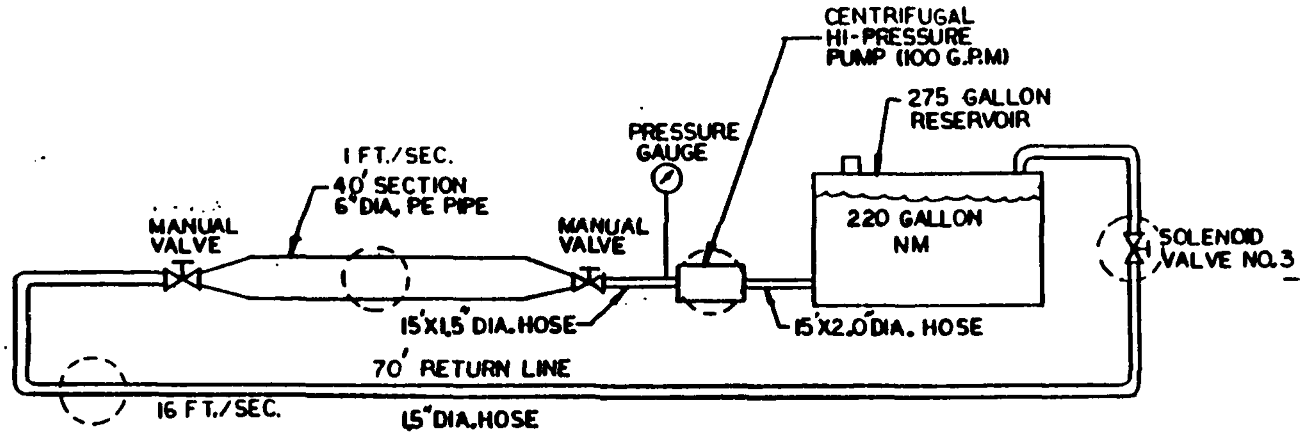
2. CONDUCT THEORETICAL ANALYSIS OF ADIABATIC COMPRESSION PHENOMENON OF BUBBLES IN LIQUID NM -- BY UTILIZING AVAILABLE EXPERIMENTAL DATA AND EMPIRICAL CORRELATIONS.

3. CONDUCT LIMITED ESSENTIAL LAB-SCALE EXPERIMENTS FOR CONFIRMATION OF ITEM 2 ABOVE.

4. PROVIDE HAZARDS JUDGMENTS RELEVANT TO TEXS SYSTEM, TEXS TEST SET-UP, AND LOADING/OFF-LOADING OF BOTH, AS REGARDS ADIABATIC COMPRESSION HAZARD.

5. DEFINE "PHASE II" PROGRAM PLAN TO ESTABLISH SAFE OPERATING CORRIDOR FOR DYNAMIC FILL PROCESS OF NM RELEVANT TO TEXS SYSTEM AND TEXS TEST SET-UP.

TEXS
HYDRAULIC HAMMER TEST SET-UP
(YUMA, ARIZONA)



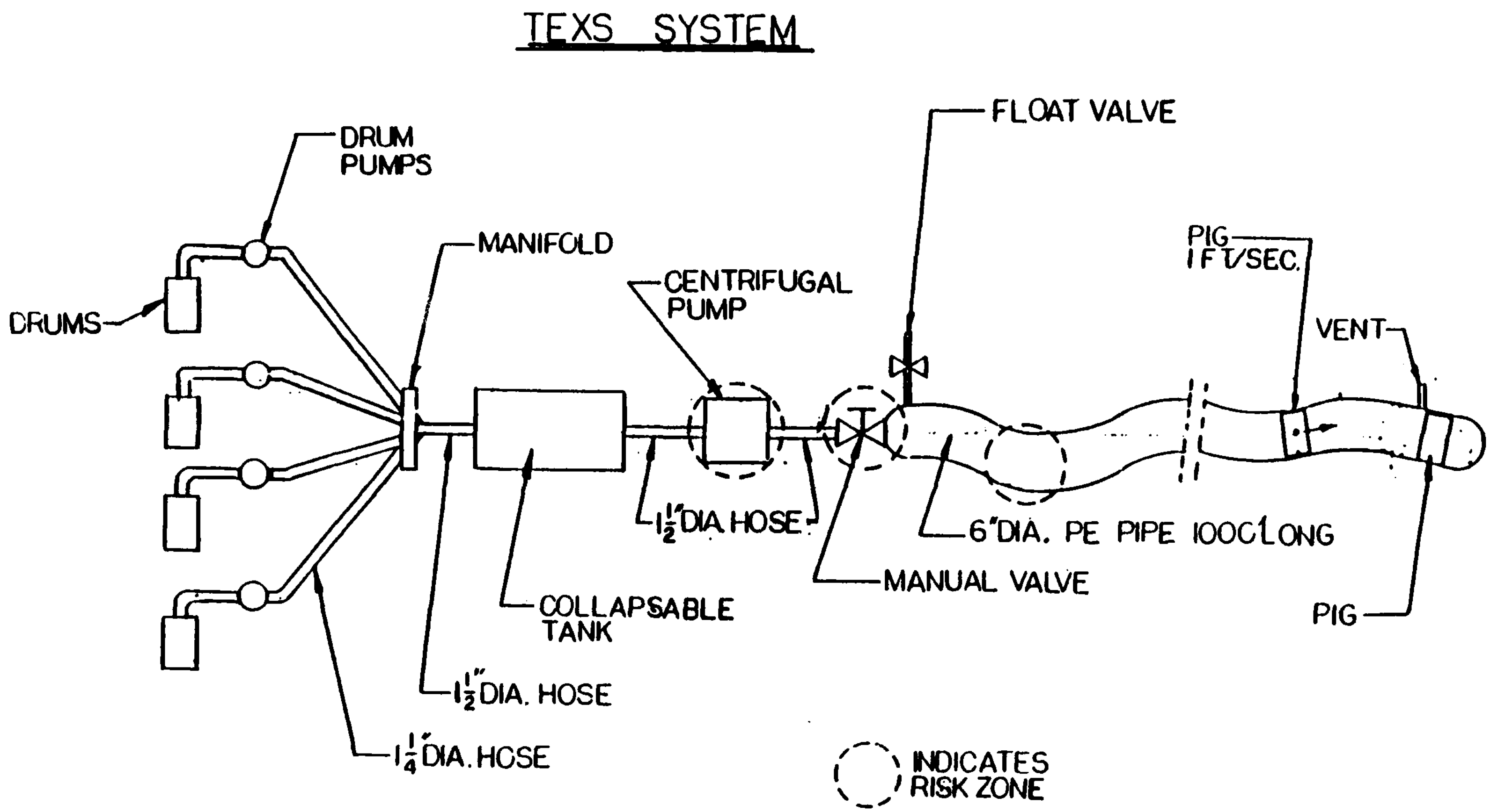
SOLENOID VALVE NO. 3 (TESTED)
1. PLUG VALVE
2. DIAPHRAGM VALVE
3. BALL VALVE

INDICATES RISK ZONES

6" PIPE
MATERIAL: PE
O.D.= 6.625"
I.D.= 6.115"

1.5" HOSE (300EPDM)
MATERIAL: NYLON & EPDM LINING
I.D.=1.5 (THK. 0.1)

CONTAMINANTS
SAND, SOAP, RUST, WATER, AMINES NOT CONSIDERED


TEXS SYSTEM
DRUM PUMPS
DRUMS
MANIFOLD
CENTRIFUGAL PUMP
FLOAT VALVE
PIG 1 FT/SEC.
VENT
1½" DIA HOSE
6" DIA. PE PIPE 1000' LONG
MANUAL VALVE
PIG
COLLAPSABLE TANK
1½" DIA. HOSE
1¼" DIA. HOSE
INDICATES RISK ZONE

SOURCES OF INFORMATION AVAILABLE TO PCRL:

1. INFORMATION FROM OFFICE OF MINES, COUNTERMINES, DEMOLITIONS (PM-MCD) OF PICATINNY ARSENAL.

2. GENERAL LITERATURE -- JOURNAL ARTICLES, HANDBOOKS, ETC.

3. LITERATURE AND SUMMARIES COMPILED BY HERSHKOWITZ FOR PM-MCD.

4. TEXS-NM SYSTEM HANDBOOK PREPARED BY ANGUS -- INCLUDING BROCHURE ON NM.

5. TEXS SYSTEM DESCRIPTION PROVIDED BY PM-MCD.

(CONTINUED)

SOURCES OF INFORMATION AVAILABLE TO PCRL: (CONT'D)

6. PCRL EXPERIMENTS AND INTERPRETATIONS:
   - A) COMPRESSION-IGNITION TESTS WITH DISPERSED ULLAGE (FINE BUBBLES) AND WITH NON-DISPERSED POCKET OF AIR
   - B) U-TUBE TESTS (NATO SPECIFICATION PROCEDURE) WITH COLLECTED ULLAGE.

7. MATH MODELING AT PCRL:
   - A) HYDRAULIC-HAMMER PRESSURE RISE FOR VARIOUS POSSIBLE CONDITIONS IN TEXS
   - B) DYNAMICS OF CAVITY COLLAPSE -- VARIOUS POSSIBILITIES.

8. ANGUS PRESENTATIONS AT MONROE, AND ALSO HANDOUT BOOK, 20 JUNE 1989.

9. VISIT TO YUMA PROVING GROUND, OBSERVATIONS OF ACTUAL SYSTEM.

RISK ZONES OF TEXS-ANGUS NM SYSTEM CONSIDERED BY PCRL FOR SAFETY:

1. SUDDEN CLOSURE OF VALVES -- VARIOUS LOCATIONS -- AND RESULTING HYDRAULIC-HAMMER PRESSURES -- FOR VARIOUS ASSUMED CLOSING TIMES, IN MSEC.

2. EFFECT ON NEAT NM (A) WITHOUT BUBBLES AND (B) WITH SMALL VAPOR BUBBLES DUE TO CAVITATION OF NEAT NM -- SUDDEN PRESSURES FROM 1.

3. EFFECT ON NM COLUMN WHEN AIR IS PRESENT, EITHER IN FORM OF FINE BUBBLES OR IN COLLECTED POCKETS OF 5-10 CM SIZE.

4. HYDRAULIC-HAMMER DUE TO "RAPID" STOPPAGE OF PIG AT (A) ONE END AT FINISH OF FILLING AND (B) SOMEWHERE IN 6-IN DUCT -- DEFORMATION OF DUCT: CONSIDERATION ESPECIALLY OF VARIOUS STOP TIMES -- IN MSEC.

5. HYDRAULIC-HAMMER (MUCH LARGER BUT SHORTER TIME) IN 1.5-IN CONNECTING DUCT -- VARIOUS STOP TIMES, IN MSEC.

(CONTINUED)

RISK ZONES OF TEXS-ANGUS NM SYSTEM CONSIDERED BY PCRL FOR SAFETY: (CONT'D)

6. QUESTION OF DETONATION OF NM IN EITHER DUCT WHEN INITIATED PERHAPS BY EXPLOSION OF NM NEAR AIR POCKET (MUCH WEAKER THAN C-4 DONOR EXPL.)

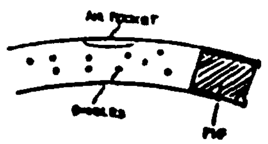
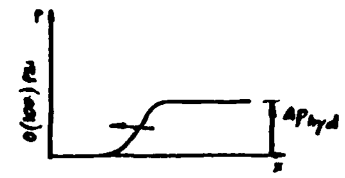
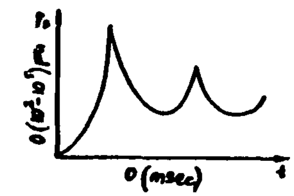
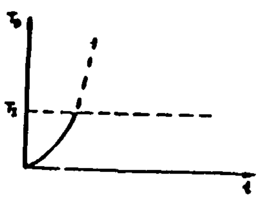
7. PROCEDURE OF OFF-LOADING, ESPECIALLY SNAP-SHUT VALVE IN OFF-NOZZLE.

8. PUMPING HAZARD: QUESTION OF CAVITATION (FINE VAPOR BUBBLES) IN (A) AIR PUMPS AND (B) TRANSFER PUMP.

9. AIR POCKETS IN PUMP HOUSINGS (STEEL); RAPID COMPRESSION.

10. EXPLOSION OF NEAR-EMPTY DRUM -- LATEST INFORMATION FROM PM-MCD ABOUT EXPLOSION OF NEAR-EMPTY DRUM AT GERMAN PLANT OF DYNAMIT NOBEL CO. IN MAY 1989.

EXPERIMENTAL STUDY OF HYDRAULIC HAMMER EFFECTS:

	TEXS	PCRL COMPRESSION TESTER	PCRL U-TUBE TESTER
	SUDDEN STOP OF THE FLOW DUE TO PIG STOP OR VALVE CLOSURE	(1) SUDDEN STOP OF THE FLOW WITH APPLIED (DRIVING) PRESSURE (2) APPLICATION OF PRESSURE FROM EXPLOSIVE CHARGE TO PRE-FILLED CHAMBER	NOT APPLICABLE
	HYDRAULIC PRESSURE WAVE TRAVELS THROUGH BUBBLY LIQUID	COMPRESSION PRESSURE IS APPLIED TO BUBBLY LIQUID	COMPRESSION OF AIR BUBBLE DUE TO PUSH PRESSURE APPLIED TO LIQUID COLUMN, WHICH ACCELERATES LIQUID.
	VIOLENT BUBBLE AND AIR POCKET COLLAPSE RESULT IN VERY HIGH BUBBLE PRESSURE AND TEMPERATURE	VIOLENT AIR AND/OR VAPOR BUBBLE COLLAPSE RESULTS IN VERY HIGH BUBBLE PRESSURE AND TEMPERATURE	AIR POCKET AT THE END OF U-TUBE IS COMPRESSED BY MOVING LIQUID, ANALOGOUS TO DYNAMIC BUBBLE COLLAPSE
	TEMPERATURE RISE OF LIQUID SURROUNDING A BUBBLE MAY RESULT IN RUNAWAY REACTION IN A LIQUID (MODIFIED BY HEAT LOSS)	TEMPERATURE RISE OF LIQUID SURROUNDING A BUBBLE MAY RESULT IN RUNAWAY REACTION IN A LIQUID (MODIFIED BY HEAT LOSS)	TEMPERATURE RISE OF LIQUID SURROUNDING A BUBBLE OR POCKET MAY RESULT IN RUNAWAY REACTION IN A LIQUID (MODIFIED BY HEAT LOSS)

CONDITIONS INVESTIGATED EXPERIMENTALLY BY PCRL

1. LIQUID NON-BUBBLY NM (NEAT) .... PCRL COMPRESSION TESTER
2. LIQUID NM WITH FINE CAVITATION BUBBLES ..... PCRL COMPRESSION TESTER
3. LIQUID NM WITH FINE AIR BUBBLES ....
   - (A) PCRL COMPRESSION TESTER (3%,10% ULLAGE)
   - (B) PCRL U-TUBE TESTER (FLAT END-PRESSURE TRANSDUCER)
4. LIQUID NM WITH LARGE AIR POCKETS .... PCRL U-TUBE TESTER (CONCAVE CUP END)

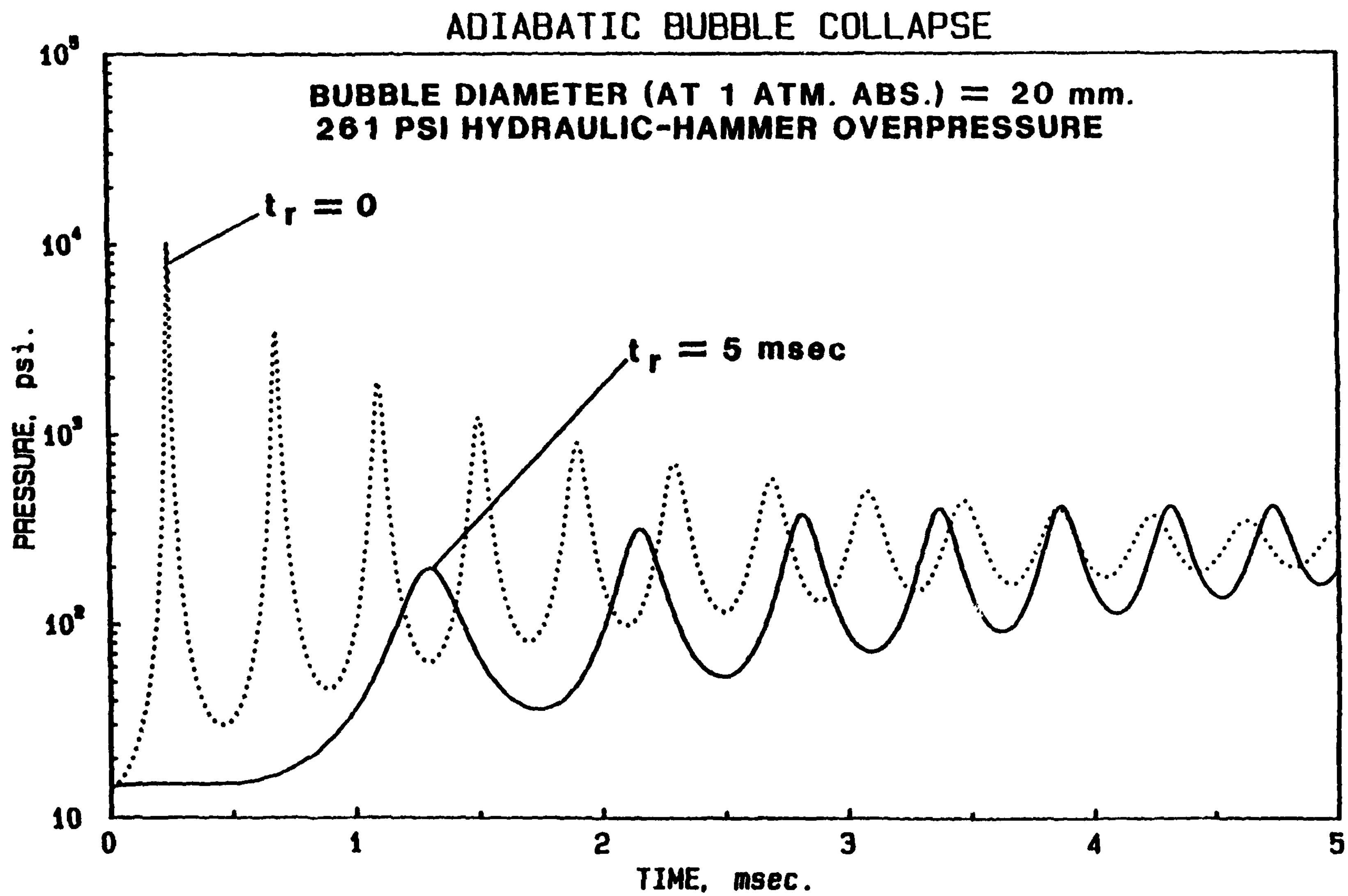
RESULTS OF CALCULATIONS FOR 6-IN DIAMETER TUBE (FLOW RATE 100 GPM OR 1 FPS)

MATERIAL	AMPLITUDE OF HYDRAULIC HAMMER PRESSURE WAVE (PSI)	PRESSURE RISE TIME (MS)	AIR CAVITY DIAMETER (MM)	MAX CAVITY PRESSURE (PSI)
PE	10	0 (INSTANTANEOUS)	20	41
RIGID	74	0 (INSTANTANEOUS)	20	800
		1	20	400

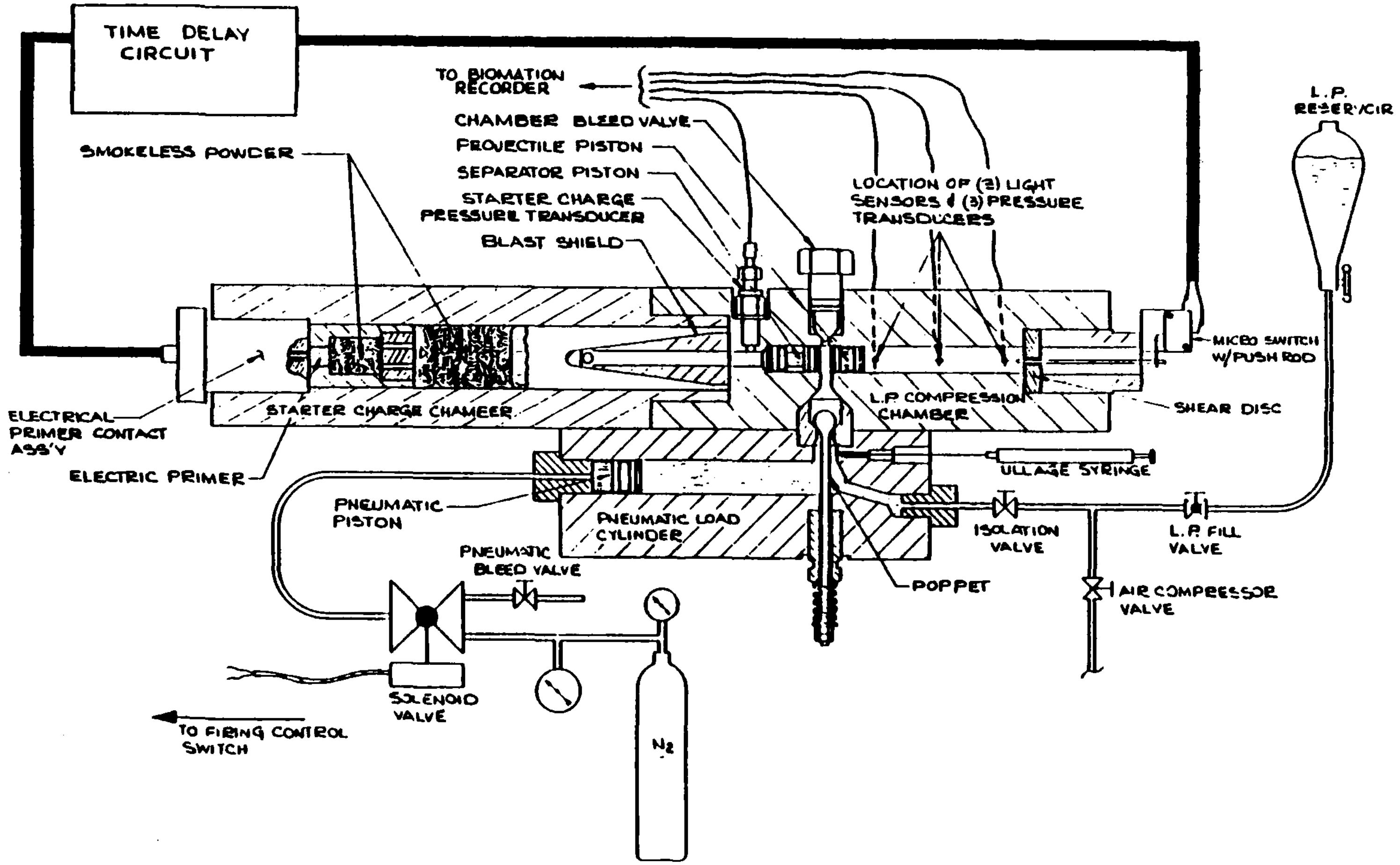
RESULTS OF CALCULATIONS FOR 1.5-IN DIAMETER HOSE (FLOW RATE 100 GPM OR 16.8 FPS)

MATERIAL	AMPLITUDE OF HYDRAULIC HAMMER WAVE PRESSURE (PSI)	PRESSURE RISE TIME (MS)	BUBBLE DIAMETER (MM)	MAX. BUBBLE PRESSURE (PSI)
PE	261	0	20	10,369 [1]
		1	20	1,294
		5	20	198 [1]
		25	20	30
STEEL	800	0	20	122,400
		1	20	4,930
		1	2	143
		5	20	369
		25	20	91
RIGID	1247	0.1	20	96,000
		1	20	8,205
		1	2	178
		5	20	548
		25	20	109

1 VIEWGRAPH EXAMPLE


ADIABATIC BUBBLE COLLAPSE
BUBBLE DIAMETER (AT 1 ATM. ABS.) = 20 mm.
261 PSI HYDRAULIC-HAMMER OVERPRESSURE
t r = 0
t r = 5 msec
PRESSURE, psi.
TIME, msec.
10
10²
10³
10⁴
10⁵
0
1
2
3
4
5

PCRL COMPRESSION TESTER



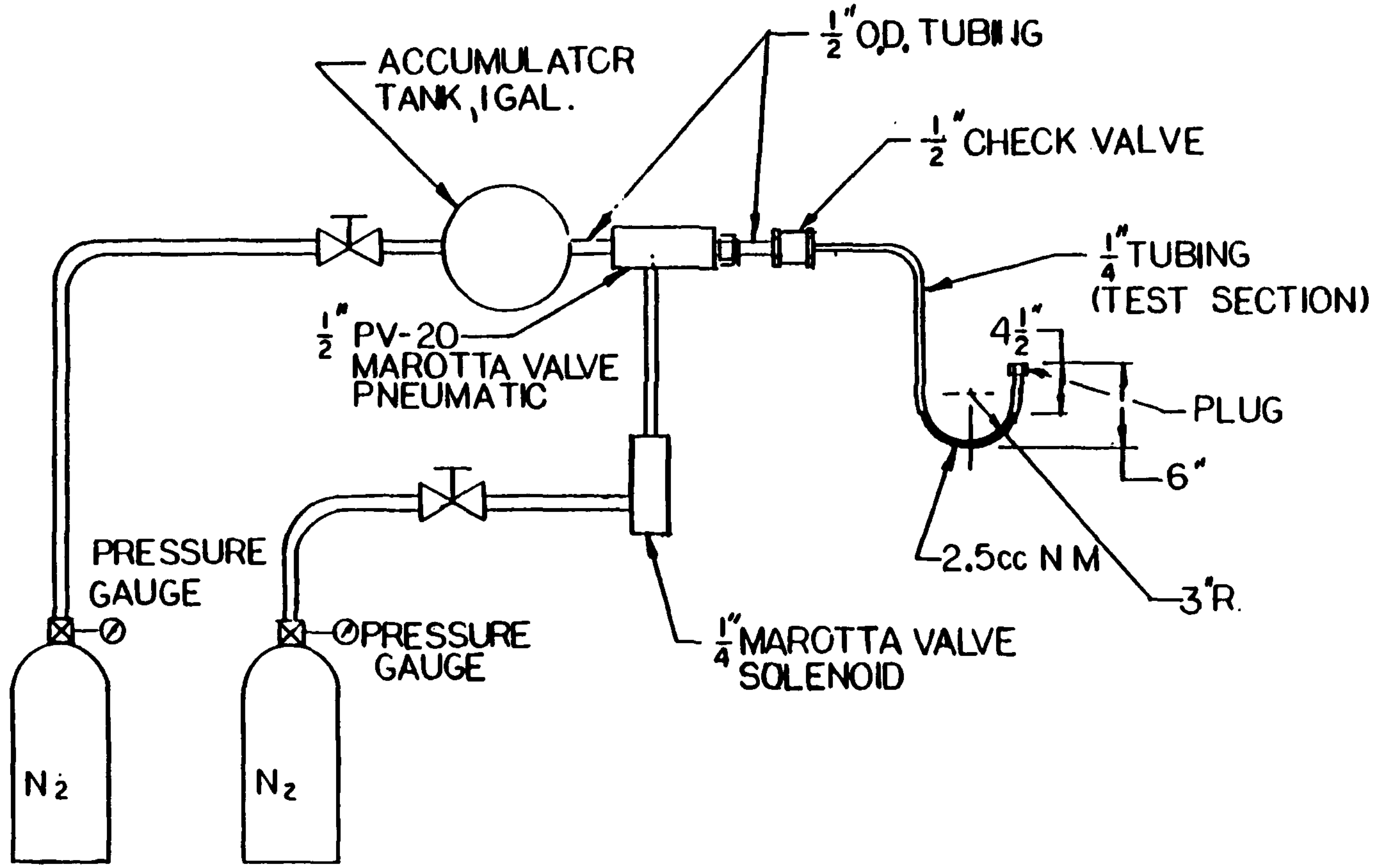
EXPERIMENTS IN PCRL COMPRESSION TESTER

CASE NO.	AIR ULLAGE CONTAINED	HYDRAULIC OVERPRESSURE (PSI)	NUMBER OF TESTS AT 20°C	55°C	63°C	RESULT
I	NEAT	1200-1300	4	--	--	B (ALL)
II	3.1% MICRO-BUBBLE	1300	3	--	--	B (ALL)
	10.0% MICRO-BUBBLE	1050-1340	2	3	--	B (ALL)
		25000[1,2]	1 (N_2)	1	--	B (ALL)
III	NM WITH 3.1% MACRO-BUBBLE	1200-1250	6	--	--	B (ALL)
	10.0% MACRO-BUBBLE	1265-1400	6	1	1	B (ALL)
		25000[1]	1	--	--	B (ALL)
			2 (N_2)	--	--	B (ALL)
	18.0% MACRO-BUBBLE	2500	--	1	--	B (ALL)
IV	>90% ULLAGE	800	1	--	--	B (ALL)
		2000	--	2	--	B (ALL)

1 VERY FAST RATE OF PRESSURIZATION -- 25 KPSI/MSEC BY IGNITION STARTER CHARGE

2 PRE-PRESSURIZED TO 400 PSI

PCRL U-TUBE TESTER



EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE)

PUSH PRESSURE (PSI)	MATERIAL	END-FITTING CUP	END-FITTING PRESSURE TRANSDUCER	MAX CAVITY PRESSURE (PSI)	RESULT
200	NM-ANGUS	CUP	--	N/M	B
	NM-ANGUS	CUP	--	N/M	B
300	NM-ANGUS	--	PT	5500	B
	NM-ANGUS	CUP	--	N/M	EXPL.
	NM-ANGUS	CUP	--	N/M	B
500	NM-ANGUS	CUP	--	N/M	EXPL.
600	NM-ANGUS	--	PT	8200	B
	NM-ANGUS	--	PT	9420	B
	NM-ANGUS	CUP	--	N/M	EXPL.
	NM-ANGUS	CUP	--	N/M	EXPL.
1250	NM-ANGUS	CUP	--	N/M	EXPL.
1300	NM-ANGUS	CUP	--	N/M	EXPL.
	NM-ANGUS	CUP	--	N/M	EXPL.
1400	NM-ANGUS	CUP	--	N/M	EXPL.
	NM-ANGUS	CUP	--	N/M	EXPL.
	NM-99+%	CUP	--	N/M	EXPL.
	NM-99+%	CUP	--	N/M	EXPL.
1350	NM-ANGUS	--	PT	15,000	B

(CONTINUED)

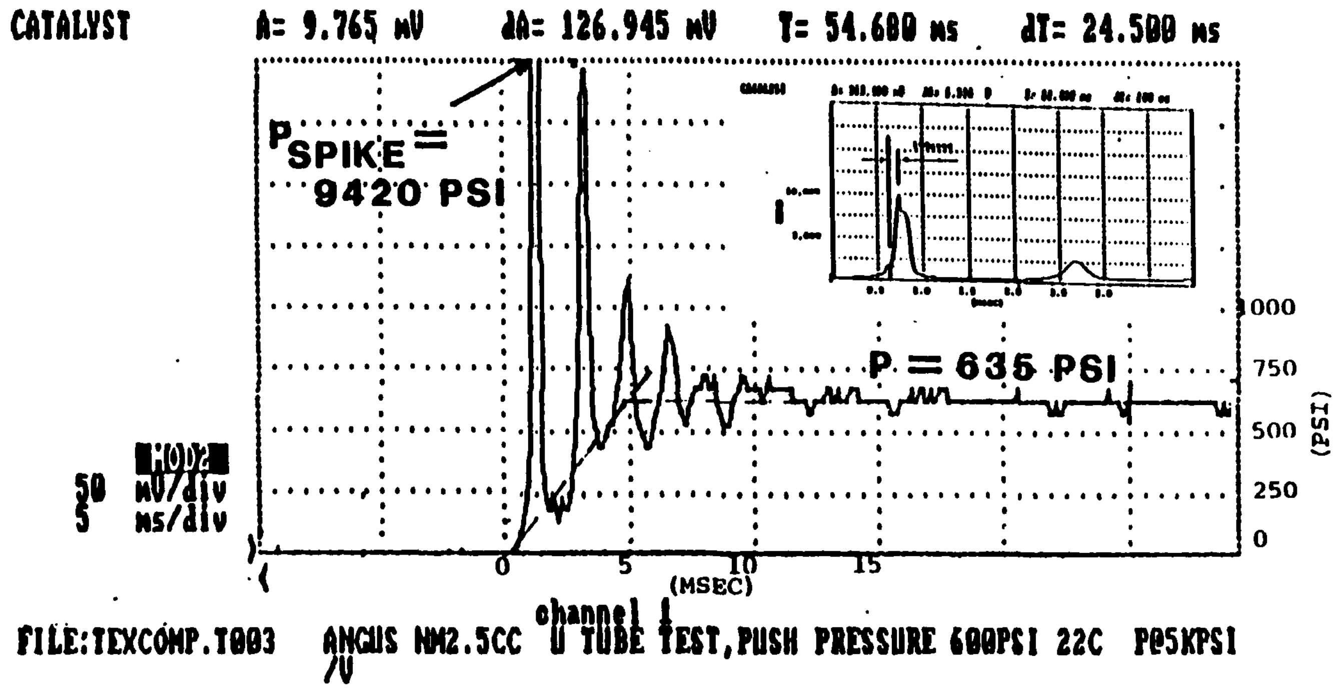
EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE) (CONT'D)

PUSH PRESSURE (PSI)	MATERIAL	END-FITTING CUP	END-FITTING PRESSURE TRANSDUCER	MAX CAVITY PRESSURE (PSI)	RESULT
300	NM-ANGUS	--	PT	5,500	B
600	NM-ANGUS	--	PT	8,200	B
	NM-ANGUS	--	PT	9,420	B
	WATER	--	PT	7,900	B
800	NM-ANGUS	--	PT	11,000	B
1,000	NM-ANGUS	--	PT	11,600	B
1,200	NM-ANGUS	--	PT	11,300	B
1,350	NM-ANGUS	--	PT	15,000	B

(CONTINUED)

U-TUBE TEST

2.5 cc NM-ANGUS PUSH PRESSURE ~ 600 PSI



$$\left.\frac{DP}{DT}\right|_{SPIKE} = 80.0 \times 10^{6}\ \frac{PSI}{SEC}$$

$$\left.\frac{DP}{DT}\right|_{CONV} = 0.15 \times 10^{6}\ \frac{PSI}{SEC}$$

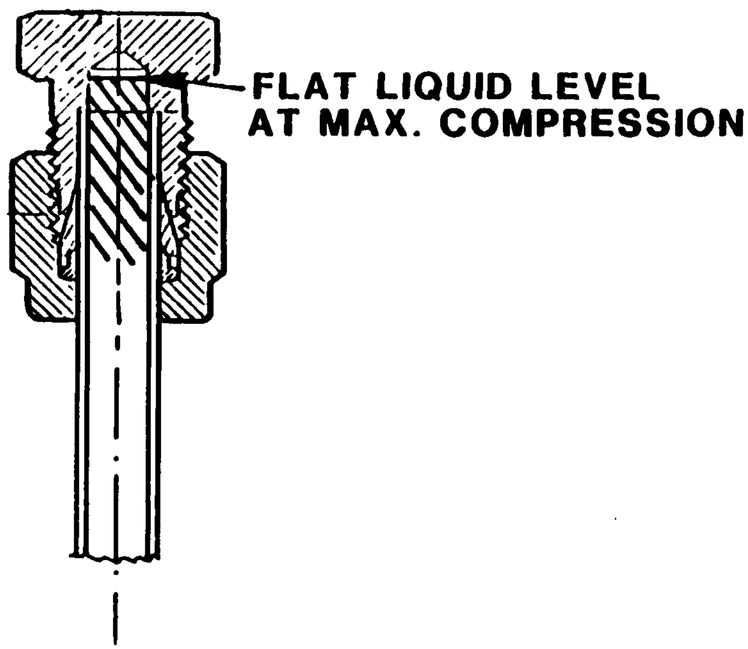
VALVE OPENING TIME $\approx$ 7 msec.

TYPICAL CAVITY VOLUME WHEN COMPRESSED TO 15,000 PSI IS 15 mm^3

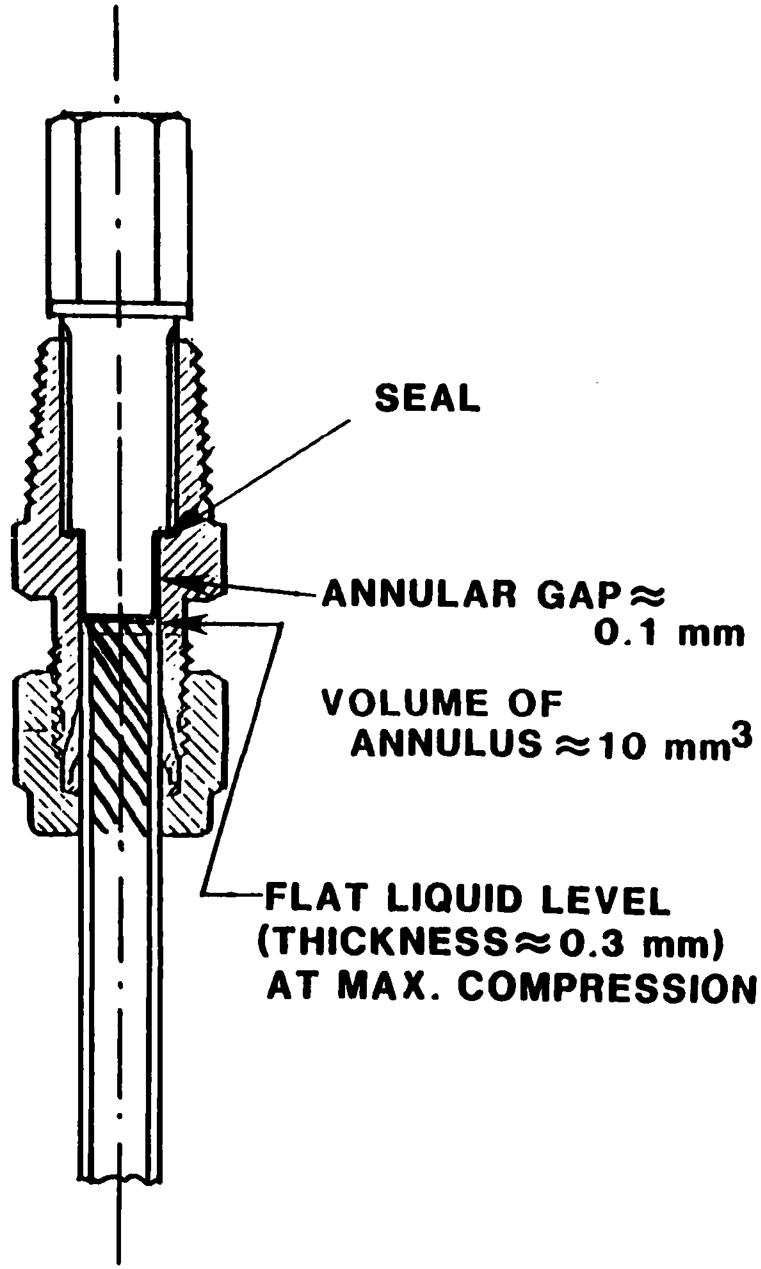
$$\tau_{COOL} \approx \frac{d^2_{CAVITY}}{\alpha_{COMPRESSED\ AIR}}$$

$\approx$ 500 MSEC at d = 0.5 mm

$\approx$ 5 MSEC at d = 0.05 mm



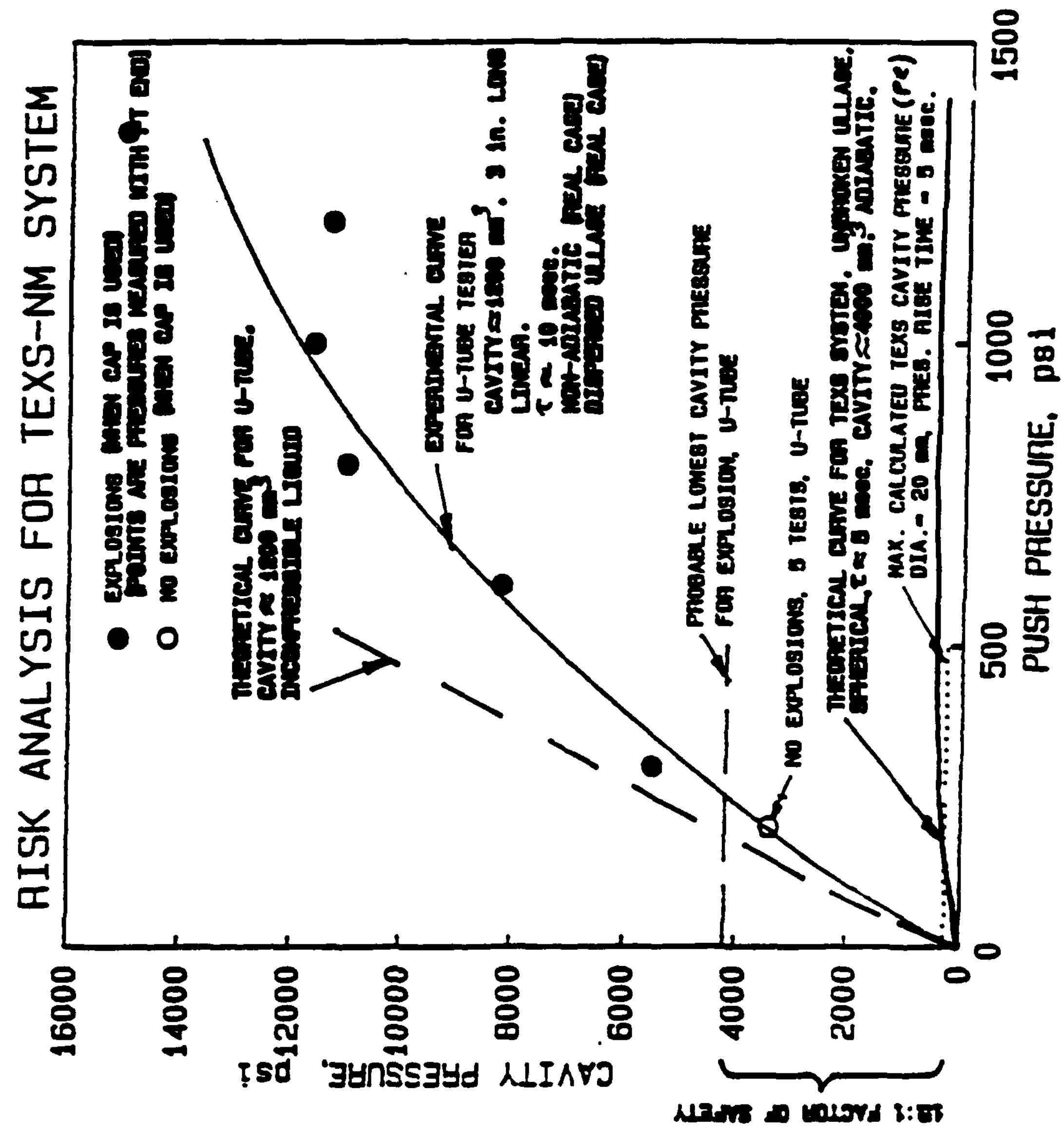
CUP END



PRESSURE TRANSDUCER END

EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE) HIGH TEMPERATURE (70°C) TESTS (CONT'D)

PUSH PRESSURE (PSI)	MATERIAL	END-FITTING CUP	END-FITTING PRESSURE TRANSDUCER	MAX CAVITY PRESSURE (PSI)	RESULT
200	NM-ANGUS	CUP	--	N/M	B
	NM-ANGUS	CUP	--	N/M	B
300	NM-ANGUS	CUP	--	N/M	B
	NM-ANGUS	CUP	--	N/M	B



RISK ANALYSIS FOR TEXS-NM SYSTEM
EXPLOSIONS (WHEN CAP IS USED) (POINTS ARE PRESSURES MEASURED WITH PT END)
NO EXPLOSIONS (WHEN CAP IS USED)
THEORETICAL CURVE FOR U-TUBE, CAVITY ≈ 1800 mm³ INCOMPRESSIBLE LIQUID
EXPERIMENTAL CURVE FOR U-TUBE TESTER CAVITY ≈ 1800 mm³, 3 in. LONG LINEAR. τ ≈ 10 msec. NON-ADIABATIC (REAL CASE) DISPERSED ULLAGE (REAL CASE)
PROBABLE LOWEST CAVITY PRESSURE FOR EXPLOSION, U-TUBE
NO EXPLOSIONS, 5 TESTS, U-TUBE
THEORETICAL CURVE FOR TEXS SYSTEM, UNBROKEN ULLAGE, SPHERICAL, τ ≈ 5 msec, CAVITY ≈ 4000 mm³ ADIABATIC.
MAX. CALCULATED TEXS CAVITY PRESSURE (Pc) DIA. = 20 mm, PRES. RISE TIME = 5 msec.
CAVITY PRESSURE, psi
16000
14000
12000
10000
8000
6000
4000
2000
0
18:1 FACTOR OF SAFETY
0
500
1000
1500
PUSH PRESSURE, psi

PCRL'S ADVICE TO THE OFFICE OF MINES, COUNTERMINES, AND DEMOLITIONS OF PICATINNY ARSENAL

1. SYSTEM IS PROBABLY SAFE -- HIGH PROBABILITY OF SAFETY -- SMALL HAZARD.

2. HAZARD CAN BE FURTHER MINIMIZED BY:
   (A) CHANGE OFF-LOADING NOZZLE VALVE TO TYPE THAT SHUTS MORE SLOWLY.
   (B) MAKE SURE THAT 1.5-IN CONNECTING PIPE IS PE (EXPANDABLE) AND NOT STEEL OR HEAVY-WALLED PIPE. WALL THICKNESS OF 0.2-IN OK.
   (C) MAKE SURE THAT ALL VALVES IN THE 1.5-IN PIPE ARE WIDE-OPEN TYPES (NOT GLOBE OR NEEDLE TYPES) AND PREFERABLY NOT STEEL.

RECOMMENDED INVESTIGATIONS TBD IN ORDER TO MAKE MORE SURE OF SAFETY:

1. CONDUCT TESTS TO SEE WHETHER 1.5-IN OR 6-IN DUCTS OF PE CAN DETONATE WHEN "HIT" BY AN EXPLOSION OF NM-AIR POCKETS. EXPERIMENTS INDICATE NO DETONATION, BUT THESE ARE IN 0.5-IN MAXIMUM DUCTS ONLY. DATA FROM JAMES AND HERSHKOWITZ LITERATURE SURVEY APPLY ONLY TO CASES WHERE DUCTS OF NM HAVE BEEN "HIT" BY DONOR EXPLOSIVES. CRITICAL DIAMETER AT 25°C REPORTED TO BE 1/2 INCH.

2. MEASURE ACTUAL WATER-HAMMER PRESSURES IN GEOMETRIES SIMILAR TO ANGUS DESIGNED TEXS SYSTEM, IN ORDER TO CHECK COMPUTATIONS OF PCRL; USE FAST-ACTING PIEZO-TYPE GAUGES TO LOOK FOR "SPIKE" OVERPRESSURES IN WATER-HAMMER WAVES (WHICH HAVE NOT BEEN MODELED).

(CONTINUED)

RECOMMENDED INVESTIGATIONS TBD IN ORDER TO MAKE MORE SURE OF SAFETY: (CONT'D)

3. FURTHER MATH MODELING:

   (A) ANALYZE PEAK ULLAGE PRESSURES FOR OTHER SHAPES OF CAVITIES, TO AUGMENT CURRENT PCRL RESULTS ON COLUMN-TYPE AND SPHERICAL CAVITIES, AND INCLUDE THE EFFECTS OF HEAT CONDUCTION TO EITHER METAL OR PE CONTAINMENT.

   (B) ANALYZE THE EFFECTS OF HIGH TEMPERATURE IN THE AIR BUBBLE OR CAVITY UNDER COMPRESSION WHEN SUCH HIGH TEMPERATURE CAUSES SURROUNDING NM LIQUID TO DECOMPOSE EXPLOSIVELY (I.E., INCLUDE CHEMICAL KINETICS OF NM AS AN EXPLOSIVE LIQUID).

   (C) ANALYZE COMPRESSION OF ULLAGE IN U-TUBE TESTER. TREAT BOTH CASES, CONCENTRATED ULLAGE AND "FROTH" ULLAGE, BY METHODS OF CASE 3(B) WITH NM AS WORKING FLUID.

4. PERFORM LABORATORY EXPERIMENTS WITH A U-TUBE TO TEST DIAGNOSTICALLY THE VALIDITY OF COMPUTER PREDICTIONS OF 3(C). (MEASURE PRESSURE AND TEMPERATURE OF COMPRESSED ULLAGE VS. TIME AND NOTE GO/NO-GO EXPLOSIONS, WITH VARIOUS CONDITIONS AND VARIOUS MODIFICATIONS OF END CLOSURES.)

DISTRIBUTION LIST

Administrator
Defense Technical Info Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22304-6145

HQDA (SARD-TR)
Washington, D.C. 20310-0001

Commander
U.S. Army Materiel Command
ATTN: AMCDRA-ST
5001 Eisenhower Avenue
Alexandria, VA 22333-0001

Commander
U.S. Army Laboratory Command
ATTN: AMSLC-DL
Adelphi, MD 20783-1145

Director
Benet Weapons Laboratory
Armament RD&E Center
U.S. Army AMCCOM
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-4050

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-ESP-L
Rock Island, IL 61299-5000

Commander
U.S. Army Aviation Systems Command
ATTN: AMSAV-DACL
4300 Goodfellow Blvd.
St. Louis, MO 63120-1798

Director
U.S. Army Aviation Research and Technology Activity
Ames Research Center
Moffett Field, CA 94035-1099

Commander
U.S. Army Missile Command
ATTN: AMSMI-RD-CS-R (DOC)
Redstone Arsenal, AL 35898-5010

Commander
U.S. Army Tank-Automotive Command
ATTN: AMSTA-TSL (Technical Library)
Warren, MI 48397-5000

Director
U.S. Army TRADOC Analysis Command
ATTN: ATAA-SL
White Sands Missile Range, NM 88002-5502

Commandant
U.S. Army Infantry School
ATTN: ATSH-CD-CSO-OR
Fort Benning, GA 31905-5660

Air Force Armament Laboratory
ATTN: AFATL/DLODL
Eglin AFB, FL 32542-5000

Director
USAMSAA
ATTN: AMXSY-D
AMXSY-MP, H. Cohen
Aberdeen Proving Ground, MD 21005-5066

Commander
USATECOM
ATTN: AMSTE-TD
Aberdeen Proving Ground, MD 21005-5066

Commander
CRDEC
AMCCOM
ATTN: SMCCR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Commander
CRDEC
AMCCOM
ATTN: SMCCR-MSI
SMCCR-MU
Aberdeen Proving Ground, MD 21010-5423

Director
VLAMO
ATTN: AMSLC-VL-D
Aberdeen Proving Ground, MD 21005-5066

Director
Defense Advanced Research Projects Agency
ATTN: J. Lupo
J. Richardson
1400 Wilson Boulevard
Arlington, VA 22209

HQDA
ATTN: SARD-ZT, G. Singley
SARD-TT, I. Szkrybalo
SARD-TC, C. Church
D. Zimmerman
Washington, D.C. 20310

HQ
U.S. Army Materiel Command
ATTN: AMCICP-AD, B. Dunetz
5001 Eisenhower Avenue
Alexandria, VA 22333-0001

Commander
Materials Technology Laboratory
U.S. Army Laboratory Command
ATTN: SLCMT-MCM-SB, M. Levy
Watertown, MA 02172-0001

Commander
USACECOM R&D Technical Library
ATTN: ASQNC-ELC-I-T, Myer Center
Ft. Monmouth, NJ 07703-5000

Commander
Armament RD&E Center
U.S. Army AMCCOM
ATTN: SMCAR-IMI-I (5)
SMCAR-AEE-B, D. Downs
SMCAR-AEE-BR, B. Brodman
W. Seals
A. Beardell
SMCAR-AEE-W, N. Slagg
SMCAR-AEE, A. Bracuti
J. Lannon
M. Gupta
J. Salo
D. Chieu
SMCAR-FSS-D, L. Frauen
SMCAR-FSA-S, H. Liberman
SMCAR-FSS-DA, J. Feneck
R. Kopmann
J. Irizarry
SMCAR-CCS-C, T. Hung
SMCAR-SFS
Picatinny Arsenal, NJ 07806-5000

Director
Benet Weapons Laboratory
Armament RD&E Center
U.S. Army AMCCOM
ATTN: SMCAR-CCB, L. Johnson
SMCAR-CCB-S, F. Heiser
SMCAR-CCB-DS, E. Conroy
A. Graham
Watervliet, NY 12189-4050

Commander
U.S. Army Harry Diamond Laboratories
ATTN: SLCHD-TA-L
2800 Powder Mill Road
Adelphi, MD 20783-1145

Commander
U.S. Army Belvoir Research and Development Center
ATTN: STRBE-WC
Technical Library (Vault) B-315
Fort Belvoir, VA 22060-5606

Commander
U.S. Army Research Office
ATTN: Technical Library
P.O. Box 12211
Research Triangle Park, NC 27709-2211

Commandant
U.S. Army Field Artillery School
ATTN: ATSF-CMW
ATSF-TSM-CN, J. Spicer
Fort Sill, OK 73503

Commandant
U.S. Army Armor Center
ATTN: ATSB-CD-MLD
Fort Knox, KY 40121

Commander
Naval Surface Weapons Center
ATTN: D.A. Wilson (Code G31)
Dahlgren, VA 22448-5000

Commander
Naval Surface Weapons Center
ATTN: J. East (Code G33)
Dahlgren, VA 22448-5000

Commander
U.S. Naval Surface Weapons Center
ATTN: O. Dengrel
K. Thorsted
Silver Spring, MD 20902-5000
Commander (Code 3247)
Naval Weapons Center
Gun Systems Branch
China Lake, CA 93555-6000

Superintendent
Naval Postgraduate School
Department of Mechanical Engineering
ATTN: Code 1424, Library
Monterey, CA 93943

AFOSR/NA (L. Caveny)
Building 410
Bolling AFB
Washington, DC 20332

Commandant
USAFAS
ATTN: ATSF-TSM-CN
Fort Sill, OK 73503-5600

Director
Jet Propulsion Laboratory
ATTN: Technical Library
4800 Oak Grove Drive
Pasadena, CA 91109

Director
National Aeronautics and Space Administration
ATTN: MS-603, Technical Library
MS-86, Dr. Povinelli
21000 Brookpark Road
Lewis Research Center
Cleveland, OH 44135

Director
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, TX 77058

Central Intelligence Agency
Office of Central Reference
Dissemination Branch
Room GE-47 HQS
Washington, DC 20502

Central Intelligence Agency
ATTN: Joseph E. Backofen
HQ Room 5F22
Washington, DC 20502

Calspan Corporation
ATTN: Technical Library
P.O. Box 400
Buffalo, NY 14225

General Electric Ordnance System Division
ATTN: J. Mandzy, OP43-220
R.E. Mayer
H. West
W. Pasko
R. Pate
I. Magoon
J. Scudiere
Minh Luu
100 Plastics Avenue
Pittsfield, MA 01201-3698

General Electric Company
Armament Systems Department
ATTN: D. Maher
Burlington, VT 05401

Honeywell, Inc.
ATTN: R.E. Tompkins
MN38-330
10400 Yellow Circle Drive
Minnetonka, MN 55343

IITRI
ATTN: Library
10 West 35th Street
Chicago, IL 60616

Olin Chemicals Research
ATTN: David Gavin
P.O. Box 586
Chesire, CT 06410-0586

Paul Gough Associates
ATTN: Paul Gough
1048 South Street
Portsmouth, NH 03801-5423

Safety Consulting Engineer
ATTN: Mr. C. James Dahn
5240 Pearl Street
Rosemont, IL 60018

Sandia National Laboratories
ATTN: R. R. Rychnovsky, Div 8152
S. Griffiths, Div 8244
R. Carling, Div 8152
P.O. Box 969
Livermore, CA 94551-0969

Science Applications, Inc.
ATTN: R. Edelman
23146 Cumorah Crest
Woodland Hills, CA 91364

Science Applications International Corporation
ATTN: Dr. F.T. Phillips
Dr. Fred Su
10210 Campus Point Drive
San Diego, CA 92121

Science Applications International Corporation
ATTN: Norman Banks
4900 Waters Edge Drive
Suite 255
Raleigh, NC 27606

Sundstrand Aviation Operations
ATTN: Mr. Owen Briles
P.O. Box 7202
Rockford, IL 61125

Veritay Technology, Inc.
ATTN: E.B. Fisher
4845 Millersport Highway
P.O. Box 305
East Amherst, NY 14051-0305

Director
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20707

Director
CPIA
The Johns Hopkins University
ATTN: T. Christian
Technical Library
Johns Hopkins Road
Laurel, MD 20707

University of Illinois at Chicago
ATTN: Professor Sohail Murad
Department of Chemical Engineering
Box 4348
Chicago, IL 60680

University of Maryland at College Park
ATTN: Professor Franz Kasler
Department of Chemistry
College Park, MD 20742

University of Missouri at Columbia
ATTN: Professor R. Thompson
Department of Chemistry
Columbia, MO 65211

University of Michigan
ATTN: Professor Gerard M. Faeth
Department of Aerospace Engineering
Ann Arbor, MI 48109-3796

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
Aberdeen Proving Ground, MD 21005-5423

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-GCL (D)
Picatinny Arsenal, NJ 07806-5000

University of Missouri at Columbia
ATTN: Professor F.K. Ross Research Reactor
Columbia, MO 65211

University of Missouri at Kansas City
Department of Phisics
ATTN: Professor R.D. Murphy
1110 East 48th Street
Kansas City, MO 64110-2499

Pennsylvania State University
Department of Mechanical Engineering
ATTN: Professor K. Kuo
University Park, PA 16802

Princeton Combustion Research Laboratories, Inc.
ATTN: N.A. Messina
M. Summerfield
4275 U.S. Highway One North
Monmouth Junction. NJ 08852

University of Arkansas
Department of Chemical Engineering
ATTN J. Havens
227 Engineering Building
Fayetteville, AR 72701

University of Delaware
Department of Chemistry
ATTN: MR. James Cronin
Professor Thomas Brill
MR. Peter Spohn
Newark, DE 19711

University of Texas at Austin
Bureau of Engineering Research
ATTN: BRC EME133, Room 1.100
H. Fair
10100 Burnet Road
Austin, TX 78758

Olin Corporation
ATTN: Victor A. Corso
DR. Ronald L Dotson
24 Science Park
New Haven, CT 06511