



Ballistic Evaluation of Magnesium Alloy AZ31B

**by Tyrone L. Jones, Richard D. DeLorme, Matthew S. Burkins,
and William A. Gooch**

ARL-TR-4077

April 2007

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

DESTRUCTION NOTICE—Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-4077**April 2007**

Ballistic Evaluation of Magnesium Alloy AZ31B

Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch
Weapons and Materials Research Directorate, ARL

Richard D. DeLorme
Magnesium Elektron North America, Inc.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) April 2007		2. REPORT TYPE Final		3. DATES COVERED (From - To) August 2006 through January 2007	
4. TITLE AND SUBTITLE Ballistic Evaluation of Magnesium Alloy AZ31B				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch (all of ARL); Richard D. DeLorme (MENA)				5d. PROJECT NUMBER 1L162618AH80	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons and Materials Research Directorate Aberdeen Proving Ground, MD 21005-5067				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-4077	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Wrought magnesium alloys, which maintain various niche market applications because of their unique properties, have been the subject of a heightened level of research and development for potential application in the automotive market; however, few data are available about their ballistic properties. In order to fill this gap, the U.S. Army Research Laboratory (ARL) and Magnesium Elektron North America (MENA), Inc., conducted a cooperative effort to evaluate magnesium alloy AZ31B, which was commercially available in a wrought form. MENA produced the rolled product and conducted the mechanical testing, and ARL performed the ballistic testing. Some limited ballistic data are provided for this alloy in both the H24 and O tempers.					
15. SUBJECT TERMS AZ31B; ballistic performance; magnesium					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 20	19a. NAME OF RESPONSIBLE PERSON Tyrone L. Jones
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (Include area code) 410-278-6223

Contents

List of Figures	iv
List of Tables	iv
1. Introduction	1
2. Experimental Procedures	3
3. Experimental Results	5
4. Conclusions	5
5. References	7
Distribution List	8

List of Figures

Figure 1. Specific strength of magnesium versus aluminum alloy armor plate (2).....	1
Figure 2. Specific stiffness of magnesium versus aluminum alloy armor plate (2).	2
Figure 3. 0.30-cal APM2 armor-piercing projectile.	4
Figure 4. 0.50-cal APM2 armor-piercing projectile.	4
Figure 5. Fragment-simulating projectile.	4

List of Tables

Table 1. Selected metal alloy physical properties (1).....	2
Table 2. Specific damping capacity (4).	2
Table 3. Alloy AZ31B chemical composition limits (weight percent).....	3
Table 4. Actual tensile properties for magnesium alloy plates tested.....	3
Table 5. Ballistic testing results.	5

1. Introduction

Magnesium-based alloys are of current interest to the United States military community because they represent the lightest of all structural metal alloys. The density of magnesium is approximately 35% lower than aluminum and approximately 77% lower than steel (1). The moderate strength of commercially available wrought magnesium alloy plate, coupled with relatively low density, translates into a specific strength that is roughly equivalent with aluminum armor alloys as shown in figure 1, where TUS and TYS represent the tensile ultimate strength and tensile yield strength, respectively.

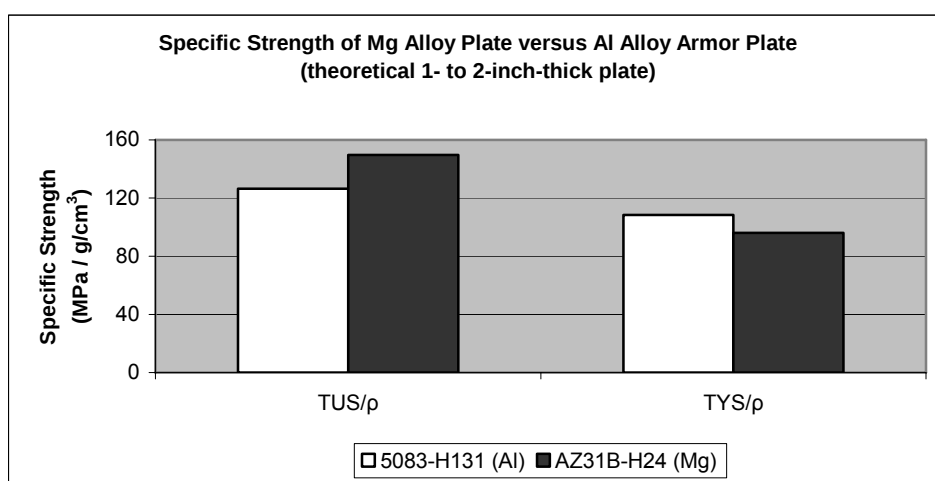


Figure 1. Specific strength of magnesium versus aluminum alloy armor plate (2).

Magnesium alloys also have a relatively low elastic modulus, E , compared to other metal alloys, which translates into a relatively high specific stiffness as shown in figure 2. In general, there is a positive correlation between tensile strength and small arms ballistic performance in metal alloys. Higher stiffness typically contributes to enhanced energy absorption upon ballistic impact; therefore, one would predict a possible benefit in wrought magnesium alloy armor applications. Table 1 provides comparative physical properties of some metal alloys of interest for armor applications (2).

Shock mitigation through higher vibration damping capacity could translate into improved overall ballistic performance. Specific damping capacity (SDC) is a dimensionless value that can be used to compare various homogeneous materials.

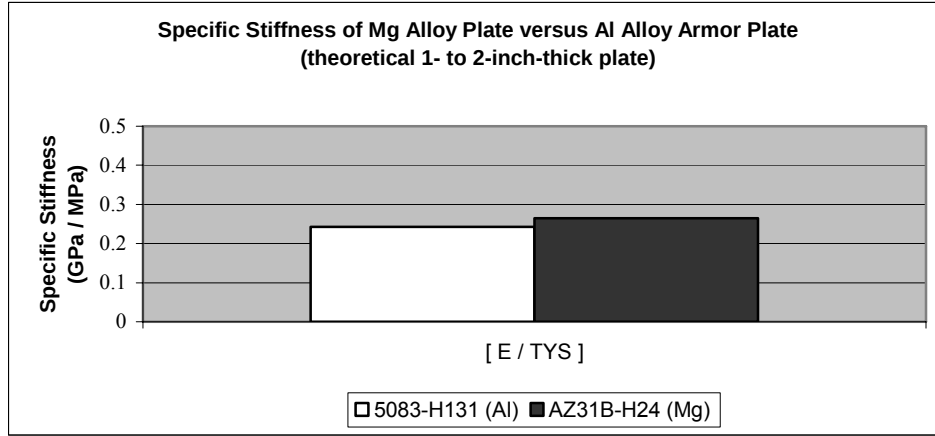


Figure 2. Specific stiffness of magnesium versus aluminum alloy armor plate (2).

Table 1. Selected metal alloy physical properties (1).

Base Metal	Metal Alloy	Density (g/cm ³)	Elastic Modulus (GPa)	Specific Modulus (GPa/g/cm ³)
Magnesium	AZ31B	1.77	45	25.4
Aluminum	5083AL	2.66	70	26.3
Steel	RHA	7.83	205	26.1

By definition, SDC is related to the “loss factor” N by equation 1:

$$SDC = 2\pi N \quad (1)$$

in which N is the ratio of energy dissipated during one cycle of harmonic stress to the maximum strain energy stored in the material during the cycle (3). Table 2 provides SDCs for some metal alloys of interest (2), which indicates that typical magnesium alloys can provide higher damping capacity than typical aluminum alloys and hardened steel.

Table 2. Specific damping capacity (2).

Metal Alloy	SDC
Typical Mg Alloys	0.4 to 1.6
Hardened Steel	0.2 to 1
Typical Aluminum Alloys	0.1 to 0.25

The desirable physical properties of magnesium alloys (i.e., low density and high damping capacity), coupled with respectable specific strength and stiffness relative to other engineering materials, are the impetus for this initial investigation into the ballistic properties of wrought magnesium alloys.

2. Experimental Procedures

Rolled plate from magnesium alloy AZ31B was selected for the subject ballistic characterization because AZ31B plate is weldable and commercially available and is specified by several governing U.S. bodies, including aerospace material specifications (AMS) and the American Society for Testing and Materials. Alloy-Temper combinations AZ31B-O and AZ31B-H24 were selected to identify any possible causal factors in ballistic performance in a comparison of the hot rolled and fully annealed plate (O condition) and the cold rolled and partially annealed plate (H24 condition).

The magnesium plate was alloyed, cast, rolled, thermally treated and tensile tested by Magnesium Elektron North America (MENA), Inc., in Madison, Illinois, in accordance with aerospace specifications AMS 4375K (AZ31B-O) and AMS 4377H (AZ31B-H24). Chemical composition limits required by these specifications for alloy AZ31B are displayed in table 3, and the actual tensile testing results are displayed in table 4 (4).

Table 3. Alloy AZ31B chemical composition limits (weight percent).

	Al	Zn	Mn	Si	Cu	Ca	Fe	Ni	Other (Each)	Other (Total)	Mg
Max	3.5	1.3	---	0.05	0.05	0.04	0.005	0.005	0.10	0.30	Balance
Min	2.5	0.7	0.20	---	---	---	---	---	---	---	

Table 4. Actual tensile properties for magnesium alloy plates tested.

Alloy-Temper	Plate Thickness (mm)	Tensile Properties		
		TUS (MPa)	TYS (MPa)	Elong (percent)
AZ31B-O	7.62	254	153	21.5
	31.50	258	151	11.5
AZ31B-H24	7.75	265	179	19.0
	76.48	262	169	9.5

Ballistic threats were selected in a manner that would allow for direct comparison to other metal alloy armor standards, particularly to aluminum alloy armor plate standards. Several weldable aluminum alloys (e.g., AA5083 and AA7039) are currently specified for use in vehicle armor systems (5, 6). The 0.30-cal (7.62 mm x 63) APM2 armor-piercing projectile is a typical small arms threat used in ballistic testing because worldwide. The fragments generated from improvised explosive devices (IEDs) are current and highly lethal threats that come in a multitude of configurations based on the device design, and use of the fragment simulating projectile (FSP) is the standard for developing armor that protects against fragment projectiles.

Ballistic testing of all magnesium alloy plate samples was performed by the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, in accordance with MIL-STD-662F,

issued 18 December 1997 (7). Ballistic results were characterized with the use of the standard V_{50} test methodology, also documented in MIL-STD-662F.

The specific ballistic threats used to test the magnesium alloy plate samples were the 0.30-cal APM2 armor-piercing projectile (8), the 0.50-cal APM2 armor-piercing projectile (9), depicted in figures 3 and 4, and the 0.22-cal, 0.50-cal, and 20-mm FSPs produced in accordance with MIL-DTL-46593B (MR), issued 6 July 2006, as depicted in figure 5.

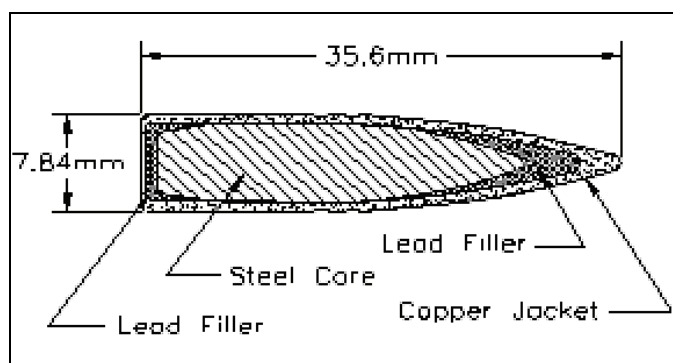


Figure 3. 0.30-cal APM2 armor-piercing projectile.

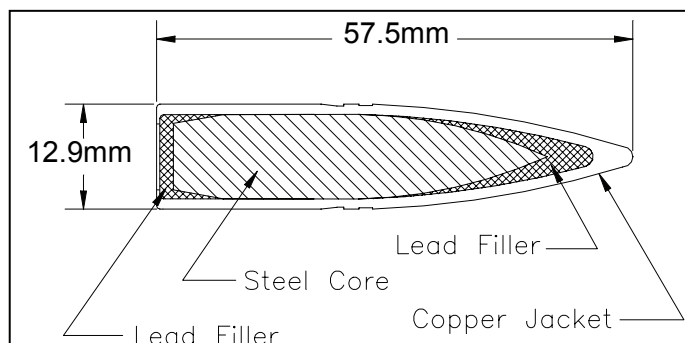


Figure 4. 0.50-cal APM2 armor-piercing projectile.

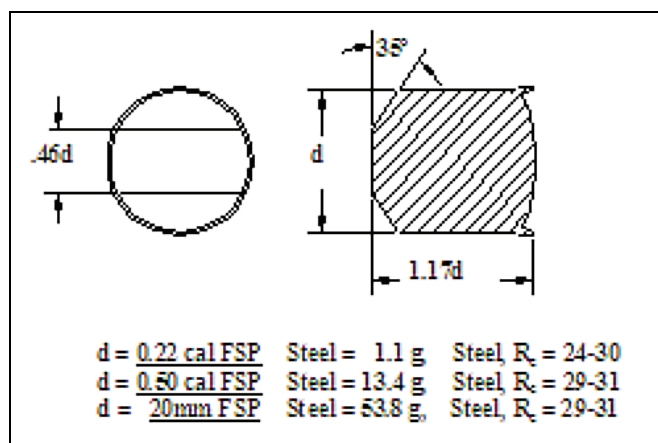


Figure 5. Fragment-simulating projectile.

3. Experimental Results

Table 5 compares the ballistic results for the AZ31B magnesium alloy plates with historical results for rolled homogenous armor (RHA) and aluminum alloy 5083 in terms of equivalent areal densities (i.e., mass per unit surface area) and in terms of the actual plate thicknesses (9).

Table 5. Ballistic testing results.

0.30-cal APM2			
Alloy-Temper	Areal Density (kg/m ²)	Plate Thickness (mm)	V50 (m/s)
Steel (RHA)	~ 55.7	7.11	524
AA5083-H131		21.03	506
AZ31B-O		31.5	511
Steel (RHA)	~ 135.2	17.22	914
AA5083-H131		50.93	853
AZ31B-H24		76.48	863

0.22-cal FSP			
Alloy-Temper	Areal Density (kg/m ²)	Plate Thickness (mm)	V50 (m/s)
Steel (RHA)	~ 13.7	1.78	366
AA5083-H131		5.18	396
AZ31B-O		7.62	417
AZ31B-H24		7.75	421

0.50-cal FSP			
Alloy-Temper	Areal Density (kg/m ²)	Plate Thickness (mm)	V50 (m/s)
Steel (RHA)	~ 55.7	7.11	718
AA5083-H131		21.03	663
AZ31B-O		31.5	639

20mm FSP			
Alloy-Temper	Areal Density (kg/m ²)	Plate Thickness (mm)	V50 (m/s)
Steel (RHA)	~ 135.2	17.22	878
AA5083-H131		50.93	1125
AZ31B-H24		76.48	897

0.50-cal APM2			
Alloy-Temper	Areal Density (kg/m ²)	Plate Thickness (mm)	V50 (m/s)
Steel (RHA)	~ 135.2	17.22	649
AA5083-H131		50.93	626
AZ31B-O		76.48	649

(Note: RHA and AA5083-H131 are historical results provided by reference 2.)

4. Conclusions

Research and development of magnesium alloys for lightweight commercial applications has generated interest in the U.S. military community for application in lightweight armor. Ballistic performance of the AZ31B magnesium alloy plate was quite comparable to that of 5083 aluminum, except for the 20-mm FSP performance, where it fell short by about 20%. In comparing the ballistic performance of the AZ31B to RHA, we saw that the results were threat dependent as well as plate thickness dependent (i.e., where the magnesium plates out-performed RHA against the 0.22-cal and 20-mm FSP and matched the RHA performance against the 0.50-cal APM2; it fell short of the RHA performance against the 0.30-cal APM2 and the 0.50-cal FSP). Because the plate samples were limited in number, the only direct comparison between AZ31B-O and AZ31B-H24 was in the 0.22-cal FSP, where the performance was almost identical.

These results are encouraging, particularly because the magnesium alloy AZ31B was designed as a general purpose engineering alloy with moderate strength, good weldability, and good corrosion resistance. By no means is AZ31B an alloy that has been optimized for ballistic performance, where higher strength without an appreciable loss in ductility would be highly desirable.

ARL and MENA are currently collaborating to generate a U.S. military ballistic specification for AZ31B plate. Efforts are currently under way to analyze and understand the ballistic defeat mechanisms associated with magnesium alloys and to characterize ballistic performance of higher strength wrought magnesium alloys, including MENA's ultra-high strength experimental alloy Elektron 675.

5. References

1. MatWeb. web site: www.MatWeb.com, June 2006.
2. O'Donnell, Robert. *Magnesium - Its Metallurgy and Applications*, PowerPoint Presentation, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Clayton South, Australia, 2005.
3. @medical technologies Advanced Materials and Technologies. web site: <http://www.amtbe.com/dampening.html>, 2006.
4. Magnesium Elektron North America, Inc. Tensile Properties Lot Acceptance Database for 5083-H131 plate and AZ31B-H24 plate, Madison, IL, 1999 through 2006.
5. U.S. Army Research Laboratory. *Armor Plate, Aluminum Alloys. Weldable 5083 and 5456*, Military Specification MIL-DTL-46027J (MR), Aberdeen Proving Ground, MD, 4 September 1998.
6. U.S. Army Research Laboratory. *Armor Plate, Aluminum Alloys, 7039*, Military Specification MIL-DTL-46063H, Aberdeen Proving Ground, MD, 14 September 1998.
7. U.S. Army Research Laboratory. *V₅₀ Ballistic Test for Armor*, Military Specification MIL-STD-662F, Aberdeen Proving Ground, MD, 18 December 1997.
8. Gooch, W. A.; Burkins, M. S. *The Analysis of Threat Projectiles for Protection of Light Tactical Vehicles*; ARL-RP-0089, U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, December 2004.
9. Mascianica, Francis. *Ballistic Technology of Lightweight Armor-1981*, AMMRC TR 81-20, May 1981.

NO. OF
COPIES ORGANIZATION

1 DEFENSE TECHNICAL
(PDF INFORMATION CTR
ONLY) DTIC OCA
8725 JOHN J KINGMAN RD
STE 0944
FORT BELVOIR VA 22060-6218

1 US ARMY RSRCH DEV & ENG CMD
SYSTEMS OF SYSTEMS
INTEGRATION
AMSRD SS T
6000 6TH ST STE 100
FORT BELVOIR VA 22060-5608

1 DIRECTOR
US ARMY RESEARCH LAB
IMNE ALC IMS
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LAB
AMSRD ARL CI OK TL
2800 POWDER MILL RD
ADELPHI MD 20783-1197

2 DIRECTOR
US ARMY RESEARCH LAB
AMSRD ARL CS OK T
2800 POWDER MILL RD
ADELPHI MD 20783-1197

5 CDR US ARMY TACOM
ATTN AMSTA TR S T FURMANIAK
L PROKURAT FRANKS
D TEMPLETON
AMSTA TR R D HANSEN
D THOMAS
WARREN MI 48397-5000

1 PROJECT MANAGER
ABRAMS TANK SYSTEM
ATTN SFAE GCSS W ABS J ROWE
WARREN MI 48397-5000

3 CDR US ARMY RSCH OFFICE
ATTN J BAILEY K IYER K LOGAN
PO BOX 12211
RSCH TRIANGLE PARK NC 27709-2211

2 CDR NGIC
ATTN J CRIDER W GSTATTENBAUER
2055 BOULDERS RD
CHARLOTTESVILLE VA 22911-8318

NO. OF
COPIES ORGANIZATION

1 CRUSADER OPM
ATTN SFAE GCSS CR E B ROOPCHAND
BLDG 171A
PICATINNY ARSENAL NJ 07806-5000

1 DIRECTOR
DARPA
3701 NORTH FAIRFAX DR
ARLINGTON VA 22203-1714

1 PM BFVS
ATTN SFAE GCSS W BV S M KING
WARREN MI 48397-5000

1 CDR CARDEROCK DIV NSWC
ATTN CODE 28 R PETERSON
9500 MACARTHUR BLVD
W BETHESDA MD 20817-5700

1 DEPT OF NAVY OFC DIR REPORTING
PROG MGR
ADVCD AMPHIBIOUS ASSLT D ERDLEY
WASHINGTON DC 20380-0001

3 LAWRENCE LIVERMORE NATL LAB
ATTN R GOGOLEWSKI L290
R LANDINGHAM L369
JOHN REAUGH L32
PO BOX 808
LIVERMORE CA 94550

2 LOS ALAMOS NATL LAB
ATTN F ADDESSIO M BURKETT
PO BOX 1663
LOS ALAMOS NM 87545

1 NAVAL RSCH LABORATORY
ATTN CODE 6684
4555 OVERLOOK AVE SW
WASHINGTON DC 20375

5 SANDIA NATL LAB
ATTN J ASAY MS 0548
R BRANNON MS 0820
L CHHABILDAS MS 0821
D CRAWFORD ORG 0821
M FORRESTAL DIV 1551
PO BOX 5800
ALBUQUERQUE NM 87185-0307

1 AIR FORCE ARMAMENT LAB
ATTN AFATL DLJW W COOK
EGLIN AFB FL 32542

NO. OF
COPIES ORGANIZATION

4 INST FOR ADVNCD TECH
ATTN S BLESS H FAIR J HODGE
R SUBRAMANIAN
3925 W BRAKER LANE STE 400
AUSTIN TX 78759-5316

1 UNIV OF DAYTON RSCH INST
ATTN KLA 14 N BRAR
300 COLLEGE PARK
DAYTON OH 45469-0182

3 SOUTHWEST RSCH INST
ATTN C ANDERSON J RIEGEL
J WALKER
6220 CULEBRA RD
SAN ANTONIO TX 78238

4 US DEPT OF ENERGY
ALBANY RSCH CENTER
ATTN J HANSEN (2 CYS)
P TURNER (2 CYS)
1450 QUEEN AVE SW
ALBANY OR 97321-2198

1 BROWN UNIV
DIV OF ENGINEERING
ATTN R CLIFTON
PROVIDENCE RI 02912

2 UNIV OF CA SAN DIEGO
DEPT OF APPL MECH & ENGR
SVC RO11
ATTN S NEMAT NASSER M MEYERS
LA JOLLA CA 92093-0411

2 AERONAUTICAL RSCH ASSN
ATTN R CONTILIANO J WALKER
PO BOX 2229
50 WASHINGTON RD
PRINCETON NJ 08540

1 ALLIANT TECHSYSTEMS INC
ATTN G JOHNSON
5050 LINCOLN DR
EDINA MN 55436

1 APPLIED RSCH ASSN INC
ATTN D GRADY
4300 SAN MATEO BLVD NE STE A
ALBUQUERQUE NM 87110

1 BRIGGS COMPANY
ATTN J BACKOFEN
2668 PETERSBOROUGH ST
HERNDON VA 222071-2443

NO. OF
COPIES ORGANIZATION

3 CERCOM
ATTN R PALICKA G NELSON B CHEN
1960 WATSON WAY
VISTA CA 92083

1 CYPRESS INTERNTL
ATTN A CAPONECCHI
1201 E ABINGDON DR
ALEXANDRIA VA 22314

1 R J EICHELBERGER
409 W CATHERINE ST
BEL AIR MD 21014-3613

1 EPSTEIN AND ASSN
ATTN K EPSTEIN
2716 WEMBERLY DR
BELMONT CA 94002

1 GENERAL RSCH CORP
PO BOX 6770
SANTA BARBARA CA 93160-6770

2 GALT ALLOYS INC
ATTN S FELLOWS S GIANGIORDANO
122 CENTRAL PLAZA N
CANTON OH 44702

3 GDLS
ATTN W BURKE MZ436 21 24
G CAMPBELL MZ436 30 44
D DEBUSSCHER MZ436 20 29
38500 MOUND RD
STERLING HTS MI 48310-3200

3 GDLS
ATTN J ERIDON MZ436 21 24
W HERMAN MZ435 01 24
S PENTESCU MZ436 2124
38500 MOUND RD
STERLING HTS MI 48310-3200

1 INTERNATL RSCH ASSN
ATTN D ORPHAL
4450 BLACK AVE
PLEASANTON CA 94566

1 JET PROPULSION LAB
IMPACT PHYSICS GROUP
ATTN M ADAMS
4800 OAK GROVE DR
PASADENA CA 91109-8099

NO. OF
COPIES ORGANIZATION

3 OGARA HESS & EISENHARDT
ATTN G ALLEN D MALONE
T RUSSELL
9113 LE SAINT DR
FAIRFIELD OH 45014

2 ALLVAC OREMET FACILITY
ATTN J KOSIN B MAHONEY
530 34TH AVE SW
PO BOX 460
ALBANY OR 97321

4 POULTER LABORATORY
SRI INTERNATIONAL
ATTN D CURRAN R KLOOP
L SEAMAN D SHOCKEY
333 RAVENSWOOD AVE
MENLO PARK CA 94025

1 RMI TITANIUM CO
ATTN W LOVE
3350 BIRCH STE 210
BREA CA 92821-6267

6 RMI TITANIUM CO
ATTN J BENNETT E CHRIST
F JANOWSKI W PALLANTE
S ROBERTSON O YU
1000 WARREN AVE
NILES OH 44446

1 TIMET
ATTN J FANNING
PO BOX 2128
HENDERSON NV 89009

1 TIMET
ATTN J BARBER
1999 BROADWAY STE 4300
DENVER CO 80202

1 SIMULA INC
ATTN R WOLFFE
10016 SOUTH 51 ST ST
PHOENIX AZ 85044

3 UNITED DEFENSE LP
ATTN E BRADY R JENKINS
K STRITTMATER
PO BOX 15512
YORK PA 17405-1512

NO. OF
COPIES ORGANIZATION

1 ZERNOW TECH SVCS INC
ATTN L ZERNOW
425 W BONITA AVE STE 208
SAN DIMAS CA 91773

1 PENN STATE UNIV
ATTN DAVE SWANSON
504L APPLIED SCIENCE BLDG
STATE COLLEGE PA 16802

5 MENA
ATTN RICK DeLORME
1001 COLLEGE STREET
PO BOX 258
MADISON IL 62060

1 APPLIED RSCH LAB
ACOUSTICS PROGRAM
ATTN D SWANSON
504L APPLIED SCI BLDG
UNIVERSITY PK PA 16803

3 RITA JONES
80 PALISADE AVE
WHITE PLAINS NY 10607

1 TIAX LLC
ATTN JACOB PRETORIUS
15 ACORN PARK
CAMBRIDGE MA 02140

1 UNIV OF VIRGINIA
DEPT OF MATERIALS SCI & ENG
SCHOOL OF ENG & APPL SCIENCE
ATTN HAYDN WADLEY
B214 THORNTON HALL
116 ENGINEERS WAY
CHARLOTTESVILLE VA 22903

1 PACIFIC NORTHWEST NATL LAB
ATTN ERIC NYBERG
MSIN P7-82
902 BATTELLE BLVD
RICHLAND WA 99352

1 CELLULAR MATERIALS INTERNATL INC
ATTN YELLAPU MURTY
2 BOAR'S HEAD LANE
CHARLOTTESVILLE VA 22903

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND

1 DIRECTOR
US ARMY RSCH LABORATORY
ATTN AMSRD ARL CI OK (TECH LIB)
BLDG 4600

1 DIR USA EBCC
ATTN SCBRD RT
5183 BLACKHAWK RD
APG EA MD 21010-5424

1 CDR USA SBCCOM
ATTN AMSCB CII
5183 BLACKHAWK RD
APG EA MD 21010-5424

2 DIR USAMSAA
ATTN AMXSY D
AMXSY MP H COHEN
BLDG 392

2 CDR USATEC
ATTN STEAC LI LV E SANDERSON
BLDG 400

2 CDR US ARMY DTC
ATTN CSTE DTC TT T M SIMON
RYAN BLDG

2 DIR USARL
ATTN AMSRD ARL SL BB A DIETRICH
AMSRD ARL SL BE W BRUCHEY
BLDG 328

NO. OF
COPIES ORGANIZATION

63 DIRECTOR
US ARMY RSCH LABORATORY
ATTN AMSRD ARL WM B M ZOLTOSKI
AMSRD ARL WM T WRIGHT
AMSRD ARL WM M J BEATTY
AMSRD ARL WM MB D SNOHA
AMSRD ARL WM MC W ROY
R SQUILLACIOTI
AMSRD ARL WM MD B CHEESEMAN
J MONTGOMERY
AMSRD ARL WM T B BURNS P BAKER
AMSRD ARL WM TA C HOPPEL
M BURKINS (5 CYS) W GOOCH
T HAVEL D HACKBARTH
E HORWATH T JONES (10 CYS)
D KLEPONIS B LEAVY
J RUNYEON S SCHOENFELD
AMSRD ARL WM TB R SKAGGS
R BANTON
AMSRD ARL WM TC R COATES
R ANDERSON T FARRAND
K KIMSEY D SCHEFFLER
L MAGNESS S SCHRAML
R SUMMERS W WALTERS
AMSRD ARL WM TD S BILYK
T BJERKE D CASEM
J CLAYTON D DANDEKAR
M GREENFIELD Y HUANG
K IYER B LOVE H MEYER
R MUDD E RAPACKI
M RAFTENBERG M SCHIEDLER
S SEGLETES T WEERASOORIYA
AMSRD ARL WM TE C HUMMER

FOREIGN ADDRESSES

EMBASSY OF AUSTRALIA
COUNSELLOR DEFENCE SCIENCE
1601 MASSACHUSETTS AVE NW
WASHINGTON DC 20036-2273

AERONAUTICAL & MARITIME RSCH LAB
N MURMAN S CIMPOERU D PAUL
PO BOX 4331
MELBOURNE VIC 3001
AUSTRALIA

ARMSCOR
L DU PLESSIS
PRIVATE BAG X337
PRETORIA 0001
SOUTH AFRICA

BATTELLE INGENIEURTECHNICK GMBH
W FUCKE
DUESSELDORFFER STR 9
D 65760 ESCHBORN
GERMANY

DEFENCE RSCH AGENCY
FORT HALSTEAD SEVEN OAKS
KENT TN 14 7BP
UNITED KINGDOM

CARLOS III UNIV OF MADRID
C NAVARRO
ESCUELA POLTEENICA SUPERIOR
C/. BUTARQUE 15
28911 LEGANES MADRID
SPAIN

CELIUS MATERIAL TEKNIK
KARLSKOGA AB
L HELLNER
S 691 80 KARLSKOGA
SWEDEN

CENTRE D'ETUDES GRAMAT
J CAGNOUX C GALLIC
J TRANCHET
GRAMAT 46500
FRANCE

MINISTRY OF DEFENCE
DGA DSP STTC G BRAULT
4 RUE DE LA PORTE D'ISSY
00460 ARMEES
F 75015 PARIS
FRANCE

CONDAT
J KIERMEIR
MAXILLANSTR 28
8069 SCHEYERN FERNHAG
GERMANY

DEFENCE PROCUREMENT AGCY
G LAUBE W ODERMATT
BALLISTICS WPNS & COMBAT
VEHICLE TEST CTR
CH 3602 THUN
SWITZERLAND

TDW
M HELD
POSTFACH 1340
D 86523 SCHROBENHAUSEN
GERMANY

DEFENSE RSCH AGENCY
W CARSON I CROUCH C FREW
T HAWKINS B JAMES B SHRUSBSALL
PORTON DOWN
SALISBURY WITTS SP 04 OJQ
UNITED KINGDOM

DEFENCE RSCH ESTAB SUFFIELD
C WEICKERT
BOX 4000
MEDICINE HAT ALBERTA TIA 8K6
CANADA

DEFENCE RSCH ESTAB
VALCARTIER ARMAMENTS DIV
R DELAGRAVE
2459 PIE XI BLVD N
PO BOX 8800
CORCELETTE QUEBEC GOA IRO
CANADA

DEUTSCH FRANZOSISCHES
FORSCHUNGSINSTITUT ST LOUIS
H ERNST H LERR
CEDEX 5 RUE DU
GENERAL CASSAGNOU
F 68301 SAINT LOUIS
FRANCE

DIEHL GMBH AND CO
M SCHILDKNECHT
FISCHBACHSTRASSE 16
D 90552 ROTBENBACH AD
PEGNITZ
GERMANY

DYNAMEC RSCH AB
A PERSSON
PARADESGRND 7
SODERTALJE S151 36
SWEDEN

ETBS DSTI
P BARNIER M SALLES
ROUTE DE GUERAY
BOITE POSTALE 712
18015 BOURGES CEDEX
FRANCE

FEDERAL MINISTRY OF DEFENCE
DIR OF EQPT & TECH LAND
RUV 2
D HAUG
POSTFACH 1328
53003 BONN
GERMANY

FRANHOFFER INSTITUT FUR
KURZZEITDYNAMIK
ERNST MACH INSTITUT
V HOHLER E STRASSBURGER
R TRAM K THOMA
ECKERSTRASSE 4
D 79 104 FREIBURG
GERMANY

MINISTRY OF DEFENCE
DGA/SPART
C CANNAVO
10 PLACE GEORGES CLEMENCEAU
BP 19
F 92211 SAINT CLOUD CEDEX
FRANCE

HIGH ENERGY DENSITY RSCH CTR
V FORTOV G KANEL
IZHORSKAY STR 13/19
MOSCOW 127412
RUSSIAN REPUBLIC

INGENIEURBURO DEISENROTH
F DEISENROTH
AUF DE HARDT 33 35
D 5204 LOHMAR 1
GERMANY

INST OF CHEMICAL PHYSICS
S RAZORENOV
142432 CHERNOGOLOVKA
MOSCOW REGION
RUSSIAN REPUBLIC

INST FOR PROBLEMS IN MATERIALS SCI
S FIRSTOV B GALANOV O GRIGORIEV
V KARTUZOV V KOVTUN Y MILMAN
V TREFILOV
3 KRHYZHANOVSKY STR
252142 KIEV 142
UKRAINE

INST FOR PROBLEMS
OF STRENGTH
G STEPANOV
TIMIRY AZEVSKAYA STR 2
252014 KIEV
UKRAINE

INST OF MECH ENGR PROBLEMS
V BULATOV D INDEITSEV
Y MESCHERYAKOV
BOLSHOY 61 VO
ST PETERSBURG 199178
RUSSIAN REPUBLIC

IOFFE PHYSICO TECH INST
E DROBYSHEVSKI A KOZHUSHKO
ST PETERSBURG 194021
RUSSIAN REPUBLIC

R OGORKIEWICZ
18 TEMPLE SHEEN
LONDON SW 14 7RP
UNITED KINGDOM

MAX PLANCK INSTITUT FUR
EISENFORSCHUNG GMBH
C DERDER
MAX PLANCK STRASSE 1
40237 DUSSELDORF
GERMANY

NATL DEFENCE HDQRTS
PMO MRCV MAJ PACEY
PMO LAV A HODAK
OTTOWA ONTARIO KIA OK2
CANADA

OTO BRED A
M GUALCO
VIA VALDIOCCHI 15
I 19136 LA SPEZIA
ITALY

RAPHAEL BALLISTICS CTR
M MAYSELESS Y PARTOM
G ROSENBERG Z ROSENBERG
Y YESHURUN
BOX 2250
HAIFA 31021
ISRAEL

ROYAL MILITARY ACADEMY
E CELENS
RENAISSANCE AVE 30
B 1040 BRUSSELS
BELGIUM

ROYAL NETHERLANDS ARMY
JHOENEVELD
V D BURCHLAAN 31
PO BOX 90822
2509 LS THE HAGUE
NETHERLANDS

DEFENCE MATERIEL ADMIN
WEAPONS DIRECTORATE
A BERG
S 11588 STOCKHOLM
SWEDEN

SWEDISH DEFENCE RSCH ESTAB
DIVISION OF MATERIALS
S J SAVAGE J ERIKSON
S 172 90 STOCKHOLM
SWEDEN

SWEDISH DEFENCE RSCH ESTAB
L HOLMBERG B JANZON
P LUNDBERG
BOX 551
S 147 25 TUMBA
SWEDEN

TECHNION INST OF TECH
FACULTY OF MECH ENGINEERING
S BODNER
TECHNION CITY
HAIFA 32000
ISRAEL

TECHNISCHE UNIVERSITAT
CHEMNITZ ZWICKAU
A SCHROEDTER L KRUEGER
L MEYER
POSTFACH
D 09107 CHEMNITZ
GERMANY

TNO DEFENSE, SECURITY, AND SAFETY
ATTN H PESKE R IJSSELSTEIN
PO BOX 96864
DEN HAAS
2509G
THE NETHERLANDS

CENTRE DE RECHERCHES
ET D'ETUDES D'ARCUEIL
D BOUVART C COTTENNOT
16 BIS AVENUE PRIEUR DE
LA COTE D'OR
F 94114 ARCUEIL CEDEX
FRANCE