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**PERFORMANCE TESTING OF THE
19-mm SMOOTHBORE GUN SYSTEM #5**

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PERFORMANCE TESTING OF THE 19-mm SMOOTHBORE GUN SYSTEM #5

ABSTRACT

A smoothbore 19-mm $\times$ 41 caliber, free recoiling gun system has been assembled and tested. The system will be used to impart high peak dynamic stress waves in mounted target materials that are stationary before impact. These waves, elastic and elastic-plastic in behavior, are produced by impacts from the gun ranging in velocities up to 1 mm/ μ sec. The target reactions will be primarily recorded with the VISAR (velocity interferometer system for any reflector) system; but any one or any combination of the following diagnostic techniques may be used: the axial-symmetric-magnetic (ASM) probe, spatial pins, high speed photography, a capacitor gauge, or a Manganin gauge. This report provides the foundation for safety note calculations and for operational safety procedures required for a gun system of this type.

INTRODUCTION

A smoothbore 19-mm $\times$ 41 caliber, free recoiling gun system (System #5) has been designed, constructed, and performance tested. It will be used in the equation-of-state/material studies program laboratory in Bldg. 341. The gun system, shown in Figs. 1-4, was designed to provide impacting characteristics that will create high-stress elastic and elastic-plastic waves in various materials. Target reactions will be primarily recorded with the VISAR (velocity interferometer system for any reflector) system but the axial-symmetric-magnetic (ASM) probe, spatial pins, high speed photography, capacitor gauge, or Manganin gauge may also be used.

An extensive 69-shot test series was conducted that established the physical operating characteristics. Graphs predicting the ballistic performance were generated from the test data. The Operational Safety Procedure (341.9) involving this gun in Bldg. 341 experiments was developed and is included as Appendix A. The Mechanical Engineering Department used the test data for their safety note calculations.

THE 19-mm GUN SYSTEM

The unique characteristics of the 19-mm gun system are:

- A free recoiling gun that imparts no motion in the target before impact (Fig. 3).

Fig. 1. Engineering layout of 19-mm Gun System #5. Figure 2 shows a parts key.

Item, Part Number, and Description

Item	Part Number	Description
40	34207	SHOOT
41	12-12333	STAND
42	12-12334	ROUNDABOUT BASE #2
43	12-106374	SLIP RING PLATE #1
44	12-106375	ELECTRONIC PLATE #2
45	12-106376	ELECTRONIC PLATE #3
46	12-106377	WHEEL PLATE #1
47	12-106378	VIEW PORT EXTENDER
48	12-106379	WHEEL PLATE #2
49	12-106380	WHEEL PLATE #3
50	12-106381	WHEEL PLATE #4
51	12-106382	WHEEL PLATE #5
52	12-106383	WHEEL PLATE #6
53	12-106384	WHEEL PLATE #7
54	12-106385	WHEEL PLATE #8
55	12-106386	WHEEL PLATE #9
56	12-106387	WHEEL PLATE #10
57	12-106388	WHEEL PLATE #11
58	12-106389	WHEEL PLATE #12
59	12-106390	WHEEL PLATE #13
60	12-106391	WHEEL PLATE #14
61	12-106392	WHEEL PLATE #15
62	12-106393	WHEEL PLATE #16
63	12-106394	WHEEL PLATE #17
64	12-106395	WHEEL PLATE #18
65	12-106396	WHEEL PLATE #19
66	12-106397	WHEEL PLATE #20
67	12-106398	WHEEL PLATE #21
68	12-106399	WHEEL PLATE #22
69	12-106400	WHEEL PLATE #23
70	12-106401	WHEEL PLATE #24
71	12-106402	WHEEL PLATE #25
72	12-106403	WHEEL PLATE #26
73	12-106404	WHEEL PLATE #27
74	12-106405	WHEEL PLATE #28
75	12-106406	WHEEL PLATE #29
76	12-106407	WHEEL PLATE #30
77	12-106408	WHEEL PLATE #31
78	12-106409	WHEEL PLATE #32
79	12-106410	WHEEL PLATE #33
80	12-106411	WHEEL PLATE #34
81	12-106412	WHEEL PLATE #35
82	12-106413	WHEEL PLATE #36
83	12-106414	WHEEL PLATE #37
84	12-106415	WHEEL PLATE #38
85	12-106416	WHEEL PLATE #39
86	12-106417	WHEEL PLATE #40
87	12-106418	WHEEL PLATE #41
88	12-106419	WHEEL PLATE #42
89	12-106420	WHEEL PLATE #43
90	12-106421	WHEEL PLATE #44
91	12-106422	WHEEL PLATE #45
92	12-106423	WHEEL PLATE #46
93	12-106424	WHEEL PLATE #47
94	12-106425	WHEEL PLATE #48
95	12-106426	WHEEL PLATE #49
96	12-106427	WHEEL PLATE #50
97	12-106428	WHEEL PLATE #51
98	12-106429	WHEEL PLATE #52
99	12-106430	WHEEL PLATE #53
100	12-106431	WHEEL PLATE #54
101	12-106432	WHEEL PLATE #55
102	12-106433	WHEEL PLATE #56
103	12-106434	WHEEL PLATE #57
104	12-106435	WHEEL PLATE #58
105	12-106436	WHEEL PLATE #59
106	12-106437	WHEEL PLATE #60
107	12-106438	WHEEL PLATE #61
108	12-106439	WHEEL PLATE #62
109	12-106440	WHEEL PLATE #63
110	12-106441	WHEEL PLATE #64
111	12-106442	WHEEL PLATE #65
112	12-106443	WHEEL PLATE #66
113	12-106444	WHEEL PLATE #67
114	12-106445	WHEEL PLATE #68
115	12-106446	WHEEL PLATE #69
116	12-106447	WHEEL PLATE #70
117	12-106448	WHEEL PLATE #71
118	12-106449	WHEEL PLATE #72
119	12-106450	WHEEL PLATE #73
120	12-106451	WHEEL PLATE #74
121	12-106452	WHEEL PLATE #75
122	12-106453	WHEEL PLATE #76
123	12-106454	WHEEL PLATE #77
124	12-106455	WHEEL PLATE #78
125	12-106456	WHEEL PLATE #79
126	12-106457	WHEEL PLATE #80
127	12-106458	WHEEL PLATE #81
128	12-106459	WHEEL PLATE #82
129	12-106460	WHEEL PLATE #83
130	12-106461	WHEEL PLATE #84
131	12-106462	WHEEL PLATE #85
132	12-106463	WHEEL PLATE #86
133	12-106464	WHEEL PLATE #87
134	12-106465	WHEEL PLATE #88
135	12-106466	WHEEL PLATE #89
136	12-106467	WHEEL PLATE #90
137	12-106468	WHEEL PLATE #91
138	12-106469	WHEEL PLATE #92
139	12-106470	WHEEL PLATE #93
140	12-106471	WHEEL PLATE #94
141	12-106472	WHEEL PLATE #95
142	12-106473	WHEEL PLATE #96
143	12-106474	WHEEL PLATE #97
144	12-106475	WHEEL PLATE #98
145	12-106476	WHEEL PLATE #99
146	12-106477	WHEEL PLATE #100
147	12-106478	WHEEL PLATE #101
148	12-106479	WHEEL PLATE #102
149	12-106480	WHEEL PLATE #103
150	12-106481	WHEEL PLATE #104
151	12-106482	WHEEL PLATE #105
152	12-106483	WHEEL PLATE #106
153	12-106484	WHEEL PLATE #107
154	12-106485	WHEEL PLATE #108
155	12-106486	WHEEL PLATE #109
156	12-106487	WHEEL PLATE #110
157	12-106488	WHEEL PLATE #111
158	12-106489	WHEEL PLATE #112
159	12-106490	WHEEL PLATE #113
160	12-106491	WHEEL PLATE #114
161	12-106492	WHEEL PLATE #115
162	12-106493	WHEEL PLATE #116
163	12-106494	WHEEL PLATE #117
164	12-106495	WHEEL PLATE #118
165	12-106496	WHEEL PLATE #119
166	12-106497	WHEEL PLATE #120
167	12-106498	WHEEL PLATE #121
168	12-106499	WHEEL PLATE #122
169	12-106500	WHEEL PLATE #123
170	12-106501	WHEEL PLATE #124
171	12-106502	WHEEL PLATE #125
172	12-106503	WHEEL PLATE #126
173	12-106504	WHEEL PLATE #127
174	12-106505	WHEEL PLATE #128
175	12-106506	WHEEL PLATE #129
176	12-106507	WHEEL PLATE #130
177	12-106508	WHEEL PLATE #131
178	12-106509	WHEEL PLATE #132
179	12-106510	WHEEL PLATE #133
180	12-106511	WHEEL PLATE #134
181	12-106512	WHEEL PLATE #135
182	12-106513	WHEEL PLATE #136
183	12-106514	WHEEL PLATE #137
184	12-106515	WHEEL PLATE #138
185	12-106516	WHEEL PLATE #139
186	12-106517	WHEEL PLATE #140
187	12-106518	WHEEL PLATE #141
188	12-106519	WHEEL PLATE #142
189	12-106520	WHEEL PLATE #143
190	12-106521	WHEEL PLATE #144
191	12-106522	WHEEL PLATE #145
192	12-106523	WHEEL PLATE #146
193	12-106524	WHEEL PLATE #147
194	12-106525	WHEEL PLATE #148
195	12-106526	WHEEL PLATE #149
196	12-106527	WHEEL PLATE #150
197	12-106528	WHEEL PLATE #151
198	12-106529	WHEEL PLATE #152
199	12-106530	WHEEL PLATE #153
200	12-106531	WHEEL PLATE #154
201	12-106532	WHEEL PLATE #155
202	12-106533	WHEEL PLATE #156
203	12-106534	WHEEL PLATE #157
204	12-106535	WHEEL PLATE #158
205	12-106536	WHEEL PLATE #159
206	12-106537	WHEEL PLATE #160
207	12-106538	WHEEL PLATE #161
208	12-106539	WHEEL PLATE #162
209	12-106540	WHEEL PLATE #163
210	12-106541	WHEEL PLATE #164
211	12-106542	WHEEL PLATE #165
212	12-106543	WHEEL PLATE #166
213	12-106544	WHEEL PLATE #167
214	12-106545	WHEEL PLATE #168
215	12-106546	WHEEL PLATE #169
216	12-106547	WHEEL PLATE #170
217	12-106548	WHEEL PLATE #171
218	12-106549	WHEEL PLATE #172
219	12-106550	WHEEL PLATE #173
220	12-106551	WHEEL PLATE #174
221	12-106552	WHEEL PLATE #175
222	12-106553	WHEEL PLATE #176
223	12-106554	WHEEL PLATE #177
224	12-106555	WHEEL PLATE #178
225	12-106556	WHEEL PLATE #179
226	12-106557	WHEEL PLATE #180
227	12-106558	WHEEL PLATE #181
228	12-106559	WHEEL PLATE #182
229	12-106560	WHEEL PLATE #183
230	12-106561	WHEEL PLATE #184
231	12-106562	WHEEL PLATE #185
232	12-106563	WHEEL PLATE #186
233	12-106564	WHEEL PLATE #187
234	12-106565	WHEEL PLATE #188
235	12-106566	WHEEL PLATE #189
236	12-106567	WHEEL PLATE #190
237	12-106568	WHEEL PLATE #191
238	12-106569	WHEEL PLATE #192
239	12-106570	WHEEL PLATE #193
240	12-106571	WHEEL PLATE #194
241	12-106572	WHEEL PLATE #195
242	12-106573	WHEEL PLATE #196
243	12-106574	WHEEL PLATE #197
244	12-106575	WHEEL PLATE #198
245	12-106576	WHEEL PLATE #199
246	12-106577	WHEEL PLATE #200
247	12-106578	WHEEL PLATE #201
248	12-106579	WHEEL PLATE #202
249	12-106580	WHEEL PLATE #203
250	12-106581	WHEEL PLATE #204
251	12-106582	WHEEL PLATE #205
252	12-106583	WHEEL PLATE #206
253	12-106584	WHEEL PLATE #207
254	12-106585	WHEEL PLATE #208
255	12-106586	WHEEL PLATE #209
256	12-106587	WHEEL PLATE #210
257	12-106588	WHEEL PLATE #211
258	12-106589	WHEEL PLATE #212
259	12-106590	WHEEL PLATE #213
260	12-106591	WHEEL PLATE #214
261	12-106592	WHEEL PLATE #215
262	12-106593	WHEEL PLATE #216
263	12-106594	WHEEL PLATE #217
264	12-106595	WHEEL PLATE #218
265	12-106596	WHEEL PLATE #219
266	12-106597	WHEEL PLATE #220
267	12-106598	WHEEL PLATE #221
268	12-106599	WHEEL PLATE #222
269	12-106600	WHEEL PLATE #223
270	12-106601	WHEEL PLATE #224
271	12-106602	WHEEL PLATE #225
272	12-106603	WHEEL PLATE #226
273	12-106604	WHEEL PLATE #227
274	12-106605	WHEEL PLATE #228
275	12-106606	WHEEL PLATE #229
276	12-106607	WHEEL PLATE #230
277	12-106608	WHEEL PLATE #231
278	12-106609	WHEEL PLATE #232
279	12-106610	WHEEL PLATE #233
280	12-106611	WHEEL PLATE #234
281	12-106612	WHEEL PLATE #235
282	12-106613	WHEEL PLATE #236
283	12-106614	WHEEL PLATE #237
284	12-106615	WHEEL PLATE #238
285	12-106616	WHEEL PLATE #239
286	12-106617	WHEEL PLATE #240
287	12-106618	WHEEL PLATE #241
288	12-106619	WHEEL PLATE #242
289	12-106620	WHEEL PLATE #243
290	12-106621	WHEEL PLATE #244
291	12-106622	WHEEL PLATE #245
292	12-106623	WHEEL PLATE #246
293	12-106624	WHEEL PLATE #247
294	12-106625	WHEEL PLATE #248
295	12-106626	WHEEL PLATE #249
296	12-106627	WHEEL PLATE #250
297	12-106628	WHEEL PLATE #251
298	12-106629	WHEEL PLATE #252
299	12-106630	WHEEL PLATE #253
300	12-106631	WHEEL PLATE #254
301	12-106632	WHEEL PLATE #255
302	12-106633	WHEEL PLATE #256
303	12-106634	WHEEL PLATE #257
304	12-106635	WHEEL PLATE #258
305	12-106636	WHEEL PLATE #259
306	12-106637	WHEEL PLATE #260
307	12-106638	WHEEL PLATE #261
308	12-106639	WHEEL PLATE #262
309	12-106640	WHEEL PLATE #263
310	12-106641	WHEEL PLATE #264
311	12-106642	WHEEL PLATE #265
312	12-106643	WHEEL PLATE #266
313	12-106644	WHEEL PLATE #267
314	12-106645	WHEEL PLATE #268
315	12-106646	WHEEL PLATE #269
316	12-106647	WHEEL PLATE #270
317	12-106648	WHEEL PLATE #271
318	12-106649	WHEEL PLATE #272
319	12-106650	WHEEL PLATE #273
320	12-106651	WHEEL PLATE #274
321	12-106652	WHEEL PLATE #275
322	12-106653	WHEEL PLATE #276
323	12-106654	WHEEL PLATE #277
324	12-106655	WHEEL PLATE #278
325	12-106656	WHEEL PLATE #279
326	12-106657	WHEEL PLATE #280
327	12-106658	WHEEL PLATE #281
328	12-106659	WHEEL PLATE #282
329	12-106660	WHEEL PLATE #283
330	12-106661	WHEEL PLATE #284
331	12-106662	WHEEL PLATE #285
332	12-106663	WHEEL PLATE #286
333	12-106664	WHEEL PLATE #287
334	12-106665	WHEEL PLATE #288
335	12-106666	WHEEL PLATE #289
336	12-106667	WHEEL PLATE #290
337	12-106668	WHEEL PLATE #291
338	12-106669	WHEEL PLATE #292
339	12-106670	WHEEL PLATE #293
340	12-106671	WHEEL PLATE #294
341	12-106672	WHEEL PLATE #295
342	12-106673	WHEEL PLATE #296
343	12-106674	WHEEL PLATE #297
344	12-1

Fig. 3. Closeup of gun and experimental holder.

Fig. 4. Major component layout.

- An optimized bore size that allows sufficient time to measure the free surface velocity while it is loaded in a one-dimensional configuration, yet minimizes the kinetic energy of the resulting catch tank debris.
- A target-mounting location that allows for open viewing (laser, camera optics, etc.) of both the front and rear surface of the target.
- A debris catcher tank that yields the minimum impulse in the mounting mechanism for the designed tank length.
- A combined shrapnel and vacuum tank (Fig. 4) that allows firing the system at its maximum loading in the manned laser laboratory area of Bldg. 341.

The immediate use for the gun system will be to establish the working parameters for the VISAR free-surface measuring techniques. A similar, 40-mm gun system (System #6) with higher peak stress capabilities and glove box containment is scheduled for installation in Bldg. 332 for measurements involving plutonium.

TEST SERIES OBJECTIVES

The #5 system was assembled in the Bldg. 341 main bay hut and moved into vault 2 for unmanned maximum pressure testing and evaluation. The testing series was based on the following objectives. (1) Conduct test firings to determine the safe maximum breech pressure for the manned area laboratories. (2) Determine and list the required step-by-step firing procedure in order to establish an Operational Safety Procedure. (3) Install, check out, and debug the safety interlock system. (4) Check out and tune the mechanical apparatus, including the recoil padding, target mounting, barrel supports, and spark velocity wire configurations. (5) Establish the catcher tank effects on the mountings and tank attachment. (6) Check out the vacuum system, its interlocks, leak locations, and rate of rise. (7) Measure the principal gun parts before and after each firing to determine the set or plastic deformation. The modified receiver section and the barrel were both subjected to postshot measurements. A five-shot series at a peak breech pressure above the operating range was performed. (8) Optimize the sabot design for considerations of the length-to-diameter ratio, strength-to-mass ratio, stagnant void evaluation, propellant pressure sealing, and static vacuum sealing. (9) Gather enough data to develop graphs for determining parameters of safe ballistic performance.

TEST SERIES RESULTS

Table 1 lists the data gathered from the 69 test shots. Test objectives one through eight had to do with the physical operation of the gun system. During the test series, the first eight objectives were satisfied and the required operational modifications to the mechanisms and electronic controls were performed. Test objective nine

Table 1. Data from test series.

Shot No.	Projectile type	Projectile wt (g)	Powder type	Powder load (g)	Powder wt/ projectile wt, P/W	Projectile velocity SP1-4 (mm/usec)	Output kinetic energy (J/ft-lb)	Output [powder] (J/g)	Powder energy [input] (J)	System efficiency (%)
5-1	73-101909	44.15	IMR 4320	5	0.113	0.377	3199/2360	640	20,930	15.0
5-2	73-101909	44.15	4320	7	0.159	0.478	5143/3794	735	29,302	17.5
5-3	73-101909	44.15	4320	9	0.204	0.611	8403/6198	934	37,674	22.3
5-4	73-101909	44.15	4320	5	0.113	0.361	2933/2164	587	20,930	14.0
5-5	73-101909	44.15	4320	7	0.159	0.491	5426/4003	77		
5-6	73-106929	54.59	IMR 4320	7	0.128	0.468	6096/4496	871		
5-7	73-106929	54.59	4320	9	0.165	NT				
5-8	73-106929	54.54	4320	11	0.202	NT				
5-9	w/flared fin	53.66	4320	11	0.205	0.688	12,950/9552	1177		
5-10	w/flared fin	53.78	4320	11	0.208	0.696	13,035/9615	1185		
5-11	w/flared fin	52.79	4320	11	0.208	0.684	12,592/9288	1145		
5-12	73-106929-OA	48.81	4320	11	0.225	0.7087	12,500/9219	1136		
5-13	73-106929-OA	48.84	4320	13	0.266	0.789	15,501/11,434	1192		
5-14	73-106929-OA	48.75	4320	16.5	0.338	0.914	20,763/15,315	1258		
5-15	73-108647 (3-BOSS)	95.31	4320	7	0.073	0.392	7467/5508	1067		
5-16	73-108647 (3-BOSS)	95.70	4320	9	0.094	0.485	11,477/8465	1275		
5-17	73-106929-OA	48.87	4320	9	0.184	0.599	8940/6594	993		
5-18	73-106929-OA	48.79	4320	9	0.184	0.605	9105/1716	1011		
GROUP I										
5-19	73-111890-TB1	25.047	IMR 4320	2	0.080	0.242	748/552	374	8372	8.9
5-20	73-111890-TB1	25.047	4320	5	0.200	0.436	2427/1791	485	20,930	11.6
5-21	73-111890-TB1	25.047	4320	8	0.319	0.636	5165/3810	646	33,488	15.4
5-22	73-111890-TB1	25.047	4320	11	0.439	0.888	10,070/7427	915	46,046	21.9
5-23	73-111890-TB1	25.047	4320	14	0.559	1.006	12,923/9532	923	58,604	22.1
5-24	73-111890-TB1	25.047	4320	15	0.599	1.031	13,574/10,012	905	62,790	21.6
GROUP II										
5-36	73-111890-TB1	25.045	IMR 3031	2	0.080	0.156	311/229	156	8372	3.7
5-37	73-111890-TB1	25.045	3031	5	0.200	0.447	2551/1882	510	20,930	12.2
5-38	73-111890-TB1	25.045	3031	8	0.319	0.745	7087/5227	886	33,488	21.2
5-39	73-111890-TB1	25.045	3031	11	0.439	0.973	12,089/8916	1099	46,046	26.3
5-40	73-111890-TB1	25.045	3031	14	0.559	1.078	14,838/10,945	1060	58,604	25.3
5-41	73-111890-TB1	25.045	3031	15	0.599	1.113	15,818/11,667	1054	62,790	25.2
GROUP III										
5-48	73-111890-TB1	25.032	IMR 4227	2	0.080	0.296	1118/825	559	8372	13.4
5-49	73-111890-TB1	25.032	4227	5	0.200	0.647	5342/3941	1068	20,930	25.5
5-50	73-111890-TB1	25.032	4227	8	0.319	0.902	10,383/7659	1298	33,488	31.0
5-51	73-111890-TB1	25.032	4227	11	0.439	1.110	15,724/11,600	1429	46,046	34.1
GROUP IV										
5-25	73-111890-TB2	50.06	IMR 4320	2	0.040	0.186	883/651	441	8372	10.5
5-26	73-111890-TB2	50.06	4320	5	0.100	0.362	3344/2467	669	20,930	16.0
5-27	73-111890-TB2	50.06	4320	8	0.160	0.536	7332/5408	916	33,488	21.9
5-28	73-111890-TB2	50.06	4320	11	0.220	0.738	13,900/10,253	1264	46,046	30.2
5-29	73-111890-TB2	50.06	4320	14	0.280	0.843	18,138/13,378	1295	58,604	30.9
5-30	73-111890-TB2	50.06	4320	15	0.300	0.876	19,585/14,446	1305	63,790	31.2
GROUP V										
5-42	73-111890-TB2	50.05	IMR 3031	2	0.040	0.194	960/708	480	8372	11.5
5-43	73-111890-TB2	50.05	3031	5	0.100	NT				
5-44	73-111890-TB2	50.05	3031	8	0.160	0.621	9840/7258	1230	33,488	29.4
5-45	73-111890-TB2	50.05	3031	11	0.220	0.787	15,805/11,657	1437	46,046	34.3
5-46	73-111890-TB2	50.05	3031	14	0.280	0.899	20,623/15,212	1473	58,604	35.2
5-47	73-111890-TB2	50.05	3031	15	0.300	0.933	22,212/16,384	1481	62,790	35.4
GROUP VI										
5-52	73-111890-TB2	50.06	IMR 4227	2	0.040	0.244	1519/1120	760	8372	18.1
5-53	73-111890-TB2	50.06	4227	5	0.100	0.509	6612/4877	1322	20,930	31.6
5-54	73-111890-TB2	50.06	4227	8	0.160	0.691	12,186/8989	1523	33,488	36.4
5-55	73-111890-TB2	50.06	4227	11	0.220	0.823	17,287/12,751	1571	46,046	37.5
GROUP VII										
5-31	73-108647 (3-BOSS)	95.56	IMR 4320	2	0.021	0.162	1278/943	639	8372	15.3
5-32	73-108647 (3-BOSS)	95.56	4320	5	0.052	0.291	4126/3043	825	20,930	19.7
5-33	73-108647 (3-BOSS)	95.56	4320	8	0.084	0.432	9092/6706	1136	33,488	27.2
5-34	73-108647 (3-BOSS)	95.56	4320	11	0.115	0.567	15,663/11,553	1424	46,046	34.0
5-35	73-108647 (3-BOSS)	95.56	4320	14	0.147	0.658	21,094/15,559	1507	58,604	36.0
GROUP VIII										
5-56	73-108647 (3-BOSS)	95.77	IMR 3031	2	0.021	0.167	1362/1004	681	8372	16.3
5-57	73-108647 (3-BOSS)	95.77	3031	5	0.052	0.310	4692/3461	938	20,930	22.4
5-58	73-108647 (3-BOSS)	95.77	3031	8	0.084	0.470	10,786/7956	1348	33,488	32.2
5-59	73-108647 (3-BOSS)	95.77	3031	11	0.115	NT				
5-60	73-108647 (3-BOSS)	95.77	3031	12.5	0.131	0.637	19,813/14,614	1585	52,325	37.9
GROUP IX										
5-61	73-108647 (3-BOSS)	95.79	IMR 4227	2	0.021	-0.180	1582/1167	791	8372	18.9
5-62	73-108647 (3-BOSS)	95.79	4227	5	0.052	0.384	7201/5312	1440	20,930	34.4
5-63	73-108647 (3-BOSS)	95.79	4227	8	0.084	0.501	12,258/9042	1532	33,488	36.6
GROUP X - CATCHER SERIES										
5-64	73-110825 TB1	49.765	IMR 3031	15	0.302	0.925	21,707/16,011	1447	62,790	34.6
5-65	73-110825 TB1	49.635	3031	15	0.302	0.919	21,707/16,011	1447	62,790	34.6
5-66	73-110825 TB1	49.755	3031	15	0.302	0.920	21,707/16,011	1447	62,790	34.6
5-67	73-110825 TB1	49.775	3031	15	0.302	0.916	21,707/16,011	1447	62,790	34.6
5-68	73-110825 TB1	49.651	3031	15	0.302	0.922	21,707/16,011	1447	62,790	34.6
5-69	73-110825 TB1	49.749	3031	15	0.302	0.915	21,707/16,011	1447	62,790	34.6

was to gather data to perform calculations for determining the interior ballistics of the gun system. These calculations and the resulting graphs are presented in this report.

Measurements of the ultimate breech pressure and the time/position of the projectile are normally performed on any prototype large-bore military gun tube expected to be mass produced, and on any special test barrels to be used for propellant or velocity optimization.¹ However, the 19-mm gun's breech pressure was not directly measured in this test series since the barrel used is not a high production model nor is it planned for operation very near its ultimate breech pressure or rupture value.

DERIVATION OF BALLISTIC PARAMETERS

Table 1 lists the results of the 69 test shots and several values that were derived as follows.

- Projectile velocity SP1-SP4 (mm/μsec). Four electrodes positioned along the barrel near the muzzle were charged to 90 V dc and were contacted by the sabot as it traveled to the muzzle. The position of the electrodes (wire pins) was controlled by measured apertures and reporting time was recorded on time-interval counters. The positional and timing accuracy allowed a calculation of the velocity at the muzzle to $\pm 0.2\%$. Further, shots 5-64 to 5-69 indicated a reproducibility better than $\pm 0.6\%$ of design. This is near the optimal loading. Calculations involving the velocity of impact for similar gun systems yield accuracies better than $\pm 1\%$. Figures 5-7 are plots of the raw data.

- The output joules per gram of powder. This value indicates the loss of efficiency of heavy powders at reduced loads.

- The powder energy (input joules). This is the product of the mass of the powder load times the chemical energy expressed in joules per gram. The value of the heat of explosion was taken as 1000 cal/g for all three powder types.^{1,2} This is equal to 4186 J/g.

- The system efficiency. This is the ratio of the projectile kinetic energy (output) to the powder energy (input). Three types of powder were used for this series and the efficiency of each type is illustrated in Figs. 8-10. These are obtained by plotting the efficiency against the powder load factor P/W (powder load divided by the projectile weight). The heavy powders, IMR 4320 and IMR 3031, are at low efficiencies when propelling the light 25-g projectile. The curve rollover, shown in Figs. 8-10, may cause poor velocity reproducibility and may interfere with the diagnostics when unburned powder is ejected from the muzzle following the sabot. This rollover indicates the value of time to all burnt, t_b , is greater than muzzle time of the sabot.

The three powders must be used efficiently to avoid overpressure and to enable reproducibility of velocities. By recovering the brass case from each shot and studying it for overpressure indications, the maximum case loading was determined. Since the

Fig. 5. Velocity curves for IMR 4227 powder.

Fig. 6. Velocity curves for IMR 3031 powder.

Fig. 7. Velocity curves for IMR 4320 powder.

Fig. 8. Efficiency curves for IMR 4227 powder.

Fig. 9. Efficiency curves for IMR 3031 powder.

Fig. 10. Efficiency curves for IMR 4320 powder.

bursting pressure of the case is the system limit, pressure calculations serve only as a system check for safety purposes. As expected, none of the powders tested is ideal for all propellant jobs. In Fig. 11 a plot of projectile kinetic energy versus projectile mass shows the crossover of the three powder types. Most of the projectiles fired in this system will range from 50 to 90 g in weight. This is based on the 50-g sabot 73-110825 and a 40-g impactor. The diameter of the impactor is fixed at 1.78 cm and therefore a thickness at the density of iridium, 22.4 g/cm^3 , is 0.76 cm, a sufficient thickness for all shots planned thus far. The graph in Fig. 12 includes the information from Fig. 11 above 25-g projectile mass but replaces the energy scale with the velocity scale. This gives the upper limit of impactor velocity, which is safely below the case burst pressure.

BALLISTIC PRESSURE CALCULATIONS

To begin the gun system pressure calculations, the single chart method of interior ballistics³ developed by R. C. Strittmater (Fig. 13) was examined. With the aid of this chart, the ballistic efficiency, e , and the free volume expansion ratio, x , were calculated. From these, the piezometric efficiency, z ; the ballistic parameter, r ; and the space mean pressures at maximum and at muzzle time were derived. Table 2 includes these calculations for all the higher and some of the lower pressure shots in the test series. Necessary data were taken from Table 1.

Other techniques using various assumptions regarding the physical dependence of the parameters have been derived for the determination of the ballistics performance.⁴⁻⁶ Some of the techniques are tuned to large-bore guns and all of them seem most accurate at or near the maximum designed ballistic performance. In this study, the Strittmater method was used because it is based on the Mayer and Hart technique and includes the assumption that bore friction is proportional to chamber pressure. This assumption is important in calculating the performance of smoothbore guns, which may require minimum starting pressure.

Basic Equations

To find the peak breech pressure, two values must be calculated: the ballistic efficiency, e ,

$$e = \frac{\left[\frac{Y-1}{2} \right] \left[m + \frac{C}{3} + \frac{DL}{2(V \times 10^{-3})^2} \right] [V \times 10^{-3}]^2}{386(F \times 10^{-6})C} \quad (1)$$

Fig. 11. Safe working limits of the three tested powders.

Fig. 12. Cartridge case loading limits.

Fig. 13. Strittmater's chart for interior ballistics, where x is the free volume expansion ratio, y is the muzzle-to-peak pressure ratio, and z is the piezometric efficiency. Data for the 19-mm gun is indicated.

Table 2. Gun System #5 pressure calculations.^a

Shot No.	Projectile velocity [V] (in./sec × 10 ⁻³)	Mass of projectile [m] (lb)	Propellant spec. force (in.-lb/lb × 10 ⁶) [F]	Ballistic efficiency [e]	Expansion ratio [x]	Piezometric efficiency [z]	Powder type IMR	Mass of propellant [C] (lb)	Ratio of specific heats [γ]	P _{max} (psi)	$\frac{P_{\text{muzzle}}}{P_{\text{max}}}$ [y]	P _{mean} (at muzzle time)
5-19	9.5280	0.0552	3.88	0.3070	14.07	0.566	4320	0.0044	1.25	2698	0.387	1044
5-24	40.590	.0552	3.88	.3030	26.64	.48 ± .03	4320	.0331	1.25	24,478	.32 ± .04	7833
5-25	7.3230	.1104	3.88	.3232	14.07	.564	4320	.0044	1.25	2851	.358	1021
5-30	34.490	.1104	3.88	.3921	26.64	.432	4320	.0331	1.25	35,195	.200	7039
5-31	6.3783	.2107	3.88	.3731	14.07	.540	4320	.0044	1.25	3438	.278	956
5-35	25.907	.2107	3.88	.4305	24.88	.424	4320	.0309	1.25	36,652	.173	6341
5-36	6.1420	.0552	4.00	.2328	14.07	.58 ± .05	3031	.0044	1.24	2144	.55 ± .05	1179
5-41	43.821	.0552	4.00	.3245	26.64	.46 ± .03	3031	.0331	1.24	29,382	.29 ± .02	8521
5-42	7.6381	.1104	4.00	.3103	14.07	.566	3031	.0044	1.24	2930	.380	1113
5-47	36.734	.1104	4.00	.4107	26.64	.424	3031	.0331	1.24	40,335	.186	7502
5-56	6.5751	.2112	4.00	.3574	14.07	.552	3031	.0044	1.24	3459	.302	1045
5-60	25.080	.2112	4.00	.4215	22.65	.444	3031	.0276	1.24	32,735	.187	6121
5-64	36.419	.1097	4.00	.4019	26.64	.428 ± .002	3031	.0331	1.24	39,106	.192	7508
5-48	11.654	.0552	4.11	.3087	14.07	.566	4227	.0044	1.23	3124	.383	1196
5-51	43.703	.0552	4.11	.3823	20.80	.477	4227	.0243	1.23	26,750	.234	6259
5-52	9.607	.1104	4.11	.3520	14.07	.555	4227	.0044	1.23	3633	.309	1123
5-55	32.403	.1104	4.11	.4041	20.80	.467	4227	.0243	1.23	28,052	.208	5835
5-61	7.087	.2112	4.11	.3579	14.07	.550	4227	.0044	1.23	3727	.300	1118
5-63	19.725	0.2112	4.11	0.3933	17.89	0.496	4227	0.01764	1.23	18,468	0.234	4322

^aWhere: L = projectile travel = 30 in.
D = diameter of bore = 0.736 in.
ρ = propellant solid = 0.060 lb/in.³
U = case volume = 1.049 in.³
A = bore area = 0.425 in.²

and the free volume expansion ratio, x,

$$x = \frac{U - \frac{C}{\rho} + AL}{U - \frac{C}{\rho}} \quad (2)$$

The intersection of these values on the Strittmater chart will yield values for the piezometric efficiency, z, and the muzzle-to-peak pressure ratio, y. Knowing the value of z, one can extract the P_{max}

$$P_{max} = \frac{\frac{1}{2} \left[m + \frac{C}{3} + \frac{DL}{2(V \times 10^{-3})^2} \right] [V \times 10^{-3}]^2}{Z(386 \times 10^{-6}) \left(U - \frac{C}{\rho} + AL \right)} \quad (3)$$

Further, the value of P_m can be found by

$$P_m = y P_{max} \quad (4)$$

where the following conventional units were used by Strittmater:

Terms	Units
γ is the adjusted ratio of specific heats for each powder type: ⁷	
$\gamma_{IMR4227} = 1.23, \gamma_{IMR3031} = 1.24, \gamma_{IMR4320} = 1.25$	
F is the specific force of each propellant: ⁷	(in.-lb/lb)
$F_{IMR4227} = 4.11 \times 10^6, F_{IMR3031} = 4.00 \times 10^6, F_{IMR4320} = 3.88 \times 10^6$	
m = mass of projectile	lb
M = effective mass of projectile = $m \left[1 + \frac{10^6 DL}{2mV^2} \right]$	lb
C = mass of propellant	lb
U = case volume	in. ³
V = muzzle velocity	in./sec
A = cross-sectional area of the bore	in. ²
L = projectile travel	in.
ρ = solid propellant density ⁷	lb/in. ³
D = bore diameter	in.
386 = mass conversion factor	
P_m = space mean pressure at muzzle time	lb/in. ²
P_{max} = space mean pressure at time of maximum	lb/in. ²

Sample Calculation

A sample calculation was done using data from shot 5-35, for which:

$$\gamma = 1.25, F = 3.88 \times 10^6, m = 0.2107,$$

$$C = 0.0309, U = 1.049, V_m = 25.907 \times 10^3,$$

$$A = 0.425, L = 30.0, \rho = 0.060, D = 0.735.$$

The ballistic efficiency calculated from Eq. (1) is:

$$e = \frac{\left[\frac{1.25 - 1}{2} \right] \left[0.2107 + \frac{0.0309}{3} + \frac{(0.736)(30)}{2(25.907)^2} \right] [25.907]^2}{386(3.88) 0.0309} = 0.4305 .$$

The free volume expansion ratio calculated from Eq. (2) is:

$$x = \frac{1.049 - \frac{0.0309}{0.060} + (0.425)30}{1.049 - \frac{0.0309}{0.060}} = 24.88 .$$

By applying these e and x values to the curves plotted in Strittmater's chart³ (Fig. 13), the values for $z = 0.424$ and $y = 0.173$ were derived. From the z and y values, the pressures at maximum and at the muzzle were calculated.

The peak pressure calculated from Eq. (3) is:

$$P_{\max} = \frac{0.5 \left[0.2107 + \frac{0.0309}{3} + \frac{(0.735)30}{2(25.907)^2} \right] 25.907^2}{0.000386(0.424) \left[1.049 - \frac{0.0309}{0.06} + (0.425)30 \right]} = 36,652 \text{ psi}$$

and the pressure at the muzzle position from Eq. (4) is:

$$P_m = 0.173(36,652) = 6341.$$

PRESSURE AND VELOCITY — TRAVEL CURVES

If the pressure values calculated above are inserted into the Hitchcock⁴ formulas, a set of curves can be generated depicting the pressure and velocity with respect to projectile travel. To complete the calculations, two assumptions must be made: (1) the maximum pressure occurs when the projectile has traveled 1 caliber, $u = 0.736$ in. This seems consistent with other curves for high acceleration, low caliber smoothbore gun systems.

(2) The ratio of the specific energy n'/n'_0 is estimated to be 0.90. This is based on Hitchcock's revised list of values⁸ and compared favorably with the "Calculated Thermochemical Values for Standard Propellants," Table 1-1 in Ref. 1.

From these two assumptions, the experimental values from shot 5-35, and the Strittmater results, curves were generated for the following conditions (using Hitchcock's symbols⁴):

- c powder wt = 0.0309 lb
- C chamber capacity = 1.049 in.³
- V_w specific volume conversion = 27.68 in.³/lb
- A area of bore = 0.425 in.²
- u projectile travel = 0.736 in.
- U projectile travel to muzzle = 27.15 in.
- P_{muzzle} pressure = 6341 lb/in.²
- P_m pressure maximum = 36,652 lb/in.²
- $\frac{n'}{n'_0}$ ratio of specific energies = 0.90.

Calculating the value of Δ :

$$\Delta = V_w \frac{c}{C} = \frac{(27.68)0.0309}{1.049} = 0.81 ,$$

the space ratio

$$S_{\text{max}} = 1 + \left(\frac{A}{C}\right)u = 1 + \frac{0.425(0.736)}{1.049} = 1.30 ,$$

$$S_{\text{muzzle}} = 1 + \left(\frac{A}{C}\right)U = 1 + \frac{0.425(27.15)}{1.049} = 12 ,$$

the tabulated pressure at maximum

$$P_{tm} = \frac{P_m}{\left(\frac{n'}{n'_0}\right)} = \frac{36,652}{0.9} = 40,724 ,$$

and the tabulated pressure at the muzzle position.

$$P_{t \text{ muzzle}} = \frac{P_{\text{muzzle}}}{10\left(\frac{n'}{n'_0}\right)} = \frac{6341}{9} = 705 .$$

A plot of the tabulated data in Hitchcock's Table 1 allows a graphical interpolation for the values of Δ and P_{tm} (Fig. 14). From these data a value of 0.065 was established for q .

The theoretical pressure and velocity-distance curves (Fig. 15) can now be plotted by establishing a table of values for the projectile travel, u ; the space ratio, S ; the tabulated pressure, P_t (from Hitchcock's Table 4); and the tabulated velocity, v_t (from Hitchcock's Table 3). The theoretical values of $P = 10(n'/n'_0)P_t$ and the theoretical values of $v = rv_t$ are calculated where at the muzzle:

$$r = \frac{v}{v_t} = \frac{0.625}{611.3} = 0.001022.$$

CONCLUSIONS

By using the Wang system including the Card Programmer (CP-1), the values for the test series were quickly established. The pressure values listed in Table 2 are the results of these calculations. A comprehensive error analysis was not done, but a quick study established error bars spanning $\pm 10\%$.

The gun system has been moved into the laboratory in Rm. 1134 and is ready to perform. Load versus velocity curves have been prepared based on available sabots, impactors, and gunpowders.

ACKNOWLEDGMENTS

I want to thank the many people who helped bring this complex gun system to fruition. John Pruner and Charlie Brown did the mechanical engineering and Mark Summers did the electronics engineering. Mike Finley, Russ Anderson, and John O'Connor, the technician team, did an outstanding job in assembling, testing, and operating the gun system.

Fig. 14. Conditions at maximum pressure P_m for the 19-mm gun system. Values are derived from Hitchcock's Table 1,4 where Δ equals $v_w c/C$ and P_{t_m} equals $P_m/(n'/n'_0)$.

Fig. 15. Theoretical pressure and velocity-distance curves for shot 5-35. Values are derived from Hitchcock's Tables 3 and 4.⁴

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APPENDIX A
OPERATIONAL SAFETY PROCEDURE 341.9

19 MM X 41 CALIBER GUN FIRING EXPERIMENTS

A. INTRODUCTION

The 19 mm gun is a powder-only system designed around the ballistic components of the .50 cal M1 military cartridge. The breech is from a modified military barrel FSN 1A-1005-610-4350; the block is a scaled down Frankford Arsenal design, and the barrel is a smoothbore pressure tube of original design. The layout of the components is shown on LLL 73-109179. (Fig. A-2)

The system will be used to impart high dynamic stress waves in stationary-before-impact mounted target materials. Elastic/elastic-plastic waves produced by impacts ranging in velocities up to 1 mm/ μ s can be generated by the system. The target's reactions will be primarily studied by the VISAR (Velocity Interferometer System for Any Reflector) system, but any one or a combination of the following diagnostic techniques may be used: ASM (Axial-Symmetric-Magnetic) probe, spatial pins, high-speed photography, capacitor gauge, Manganin gauge.

B. SCOPE

The operation authorized by this procedure is the firing of the 19 mm gun in Room 1134 using either inert targets or special targets made from natural or depleted uranium.

The cartridge loading operation will be performed in Vault #2 in accordance with OSP 341 - Appendix D.

C. HAZARDS ANALYSIS

This experiment presents the possibility of injury to personnel from:

1. Exposure to radioactive or possible toxic material and dust produced by impact of the target material.
2. Explosion during cartridge loading and handling.
3. Fire caused by pressure impact on the target.
4. Shrapnel that could be produced by:
 - a. Firing with the tank cover open.
 - b. Firing with the tank pressure above 2 mm of Hg.
 - c. Firing with the catcher can removed.
 - d. Porthole glasses rupturing from shrapnel impact.

Injury to personnel will be prevented by:

1. Whenever radioactive or potentially toxic target materials are used the firing tank will be ventilated through a HEPA filter system. The use of Beryllium as a target material is not authorized by this OSP.
2. Cartridge loading and handling procedures are covered in OSP 341, Appendix D.
3. A CO₂ fire suppression system will be built into the firing tanks to extinguish fires caused by impact with the target.
4. The firing system will be interlocked to prevent firing with:
 - a. The tank open.
 - b. Tank pressure above 2 mm of Hg.
 - c. The catcher can removed.
 - d. The firing tank porthole glass will be inspected for pitting and defects before each shot.

This operation does not change the Type 1 explosive work area and low hazard severity presently assigned this room.

D. RESPONSIBILITIES

Supervisor

George T. Carpluk is responsible for assuring that all work is performed in conformance with this OSP and the LLL Health and Safety Manual. In his absence, William C. Mumper shall assume these responsibilities.

E. MATERIAL CONTROLS

1. Compounds of various metals, glasses and plastics will routinely be impacted in this gun system. These materials are considered non-toxic in their solid state. Slightly toxic dusts may be produced by the impact of firing.

Possible toxic dusts shall be cleaned up with an approved radioactive/toxic vacuum cleaner. The gun operator or experimenter shall contact the Building Hazards Control Health and Safety Technician for guidance for handling and cleanup of any possible toxic or radioactive material.

2. Ammunition loading of the .50 cal case will take place in the loading facility in Building 341, Vault 2. No more than one cartridge case containing not more than 15 gm of gunpowder shall be permitted in Room 1134 at any one time. Off-shift storage of loaded cartridges shall be in an approved explosives storage safe file or magazine.

3. The only radioactive materials authorized are natural or depleted uranium and their alloys. Storage of these materials must be maintained in a locked metal cabinet that bears a sign warning about the contents. Identify each sample in the cabinet, either directly on the sample or on the packaging cover. Keep the cabinet locked except for accountable increases or decreases of materials or inventory.
4. The Building Hazards Control Health and Safety Technician shall receive and ship all radioactive material that is used for this experiment. Transportation of radioactive material into or out of Building 341 will be controlled by the Materials Management Group.

F. OPERATION CONTROL

1. A console safety key will be required to operate the gun-firing mechanism. This key will remain in the custody of the responsible operator until the tank cover is secure and the vacuum safety interlock has been completed.
2. Visual and sonic alarms are interlocked into the system whenever the fire-permissive condition exists.
3. A manual disconnect of the gun-firing solenoid is accomplished by securing the plug to the tank top and the receptacle to the tank base. Anytime the tank is open the circuit is broken.
4. Safety interlocks monitor the following operations:
 - a. Tank lid closure.
 - b. Maximum tank-firing pressure.
 - c. Gun-firing solenoid (mechanical).
 - d. Visual and sonic alarms.
5. The Building Hazards Control Health and Safety Technician shall be contacted before the firing of any experimental shot involving impacts of radioactive parts.

G. PERSONNEL CONTROLS

A minimum of two people must be present in Room 1134 when the gun is loaded and fired. Access to Room 1134 is restricted during gun shooting because of the possible laser hazard present and is covered in OSP 341. Operation of the 19 mm gun system presents no additional hazard.

Personnel who are required to handle explosives in this experiment will be trained to perform this task safely. This training shall be recorded on RL-2999-9 and approved by the supervisor, department head and Hazards Control Explosive Safety. Smoking shall be prohibited within 10 feet of the loaded cartridge when the cartridge is exposed.

All personnel handling radioactive target material shall; wear approved Lab coats, be instructed in the proper handling of radioactive material by the Building Health and Safety Technician, and be fitted with an approved half-mask respirator.

H. EMERGENCY CONTROLS

Gun Misfire

When a misfire occurs, the operator must ascertain if the firing pin sear has been activated.

- a. If the sear has been activated or the continuity check indicates a problem inside the tank, then follow the steps below:
 - (1) Disconnect the solenoid firing cable at the tank.
 - (2) Turn off all high voltage P.S., laser P.S. and all voltage sources inside the tank.
 - (3) Remove the console key; turn vacuum pump off.
 - (4) Open the up-to-air valve on the tank, allowing the pressure to rise to atmospheric.
 - (5) Wearing safety glasses and standing to the breech end of the gun, open the tank, release the sear, then remove the breech block and case.
 - (6) If the sear has been activated and a dimple has been pressed into the primer, then empty the case of powder and carefully place the case in water to sterilize the primer. Powder from a misfired cartridge and/or unburned powder remaining after a normal shot will be stored in Vault 2 magazine in a separate container from powder supply, and later sent to Site 300 for disposal.
 - (7) If no mark appears on the primer, remove the loaded case to the loading room and:
 - (8) Dry run the system to determine the malfunction.

I. OPERATING INSTRUCTIONS

The following operational step-by-step procedure shall be followed and any change which does not increase the hazards of firing will be discussed with the responsible experimenter and the changes will be noted. Refer to OSP 341 for changes which increase the hazards of firing.

1. Align the target, set pins and complete the optical alignment and all possible dry runs.

2. Replace all glass ports that show any flaws or pits.
3. Check placement of catcher can and plates.
4. Check the proper placement of the mitt and positioning pins.
5. Check the barrel for obstructions and consider the complete path of the projectile.
6. Check the integrity of the sabot holding screw and cover plug.
7. Insert the sabot with installed impactor.
8. Have toxic materials been included in this test?
9. Insert the .005" mylar gas seal.
10. Screw in receiver section.
11. Check that loading operator has firing console safety key.
12. Bring the loaded cartridge case into Room 1134 and install it in the receiver.
13. Announce to all operators present that the gun is being loaded.
14. With the sear released, position the breech block and lock it tightly in place.
15. Lower the tank top to a clearance of approximately 12" and stop.
16. Position the sear in the firing position.
17. Check that the barrel is fully forward (in battery) position.
18. Fully lower the tank top.
19. Close the up-to-air valve.
20. Open vacuum pump.
21. Turn vacuum pump ON.
22. After Roots blower starts turn the vacuum gauge power ON.
23. Make any final alignment checks.
24. Connect visual solenoid electrical interlock on tank.
25. Complete diagnostics check list.
26. Insert console safety key and turn on.
27. Close vacuum valve.

28. Turn vacuum pump OFF.
29. Record tank pressure and turn gauge power OFF.
30. FIRE.
31. Wait at least 6 seconds for camera shutters to close and then turn off and remove console safety key.
32. After several minutes, to allow settling, open the up-to-air valve.
33. If fires are anticipated, flood the tank with CO₂ from a fitting at the up-to-air manifold.
34. If radioactive material was used in the target, ventilate the firing tank through the HEPA filter system for 5 minutes.
35. Half face respirators must be worn until the contamination levels inside the firing tank are determined, and the tank has been cleaned up.
36. An appropriate air sampler will be in continuous operation during all firing with radioactive material.

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