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ECONOMIC ANALYSIS:
TUBE WEAR STUDY FOR THE
M198 AND M110A2 HOWITZERS



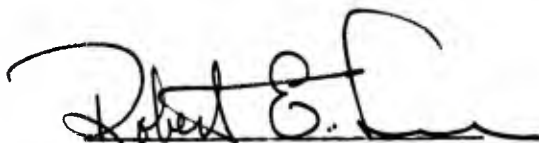
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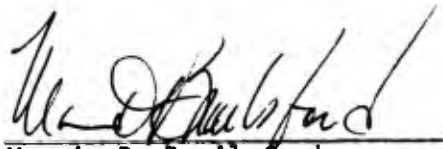
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Prepared by:

Ms. Lisa Imbriglio



Mr. Robert E. Lee
C, Cost Analysis Division
Systems Evaluation Office



Marvin D. Brailsford
COL, GS
C, Systems Evaluation Office

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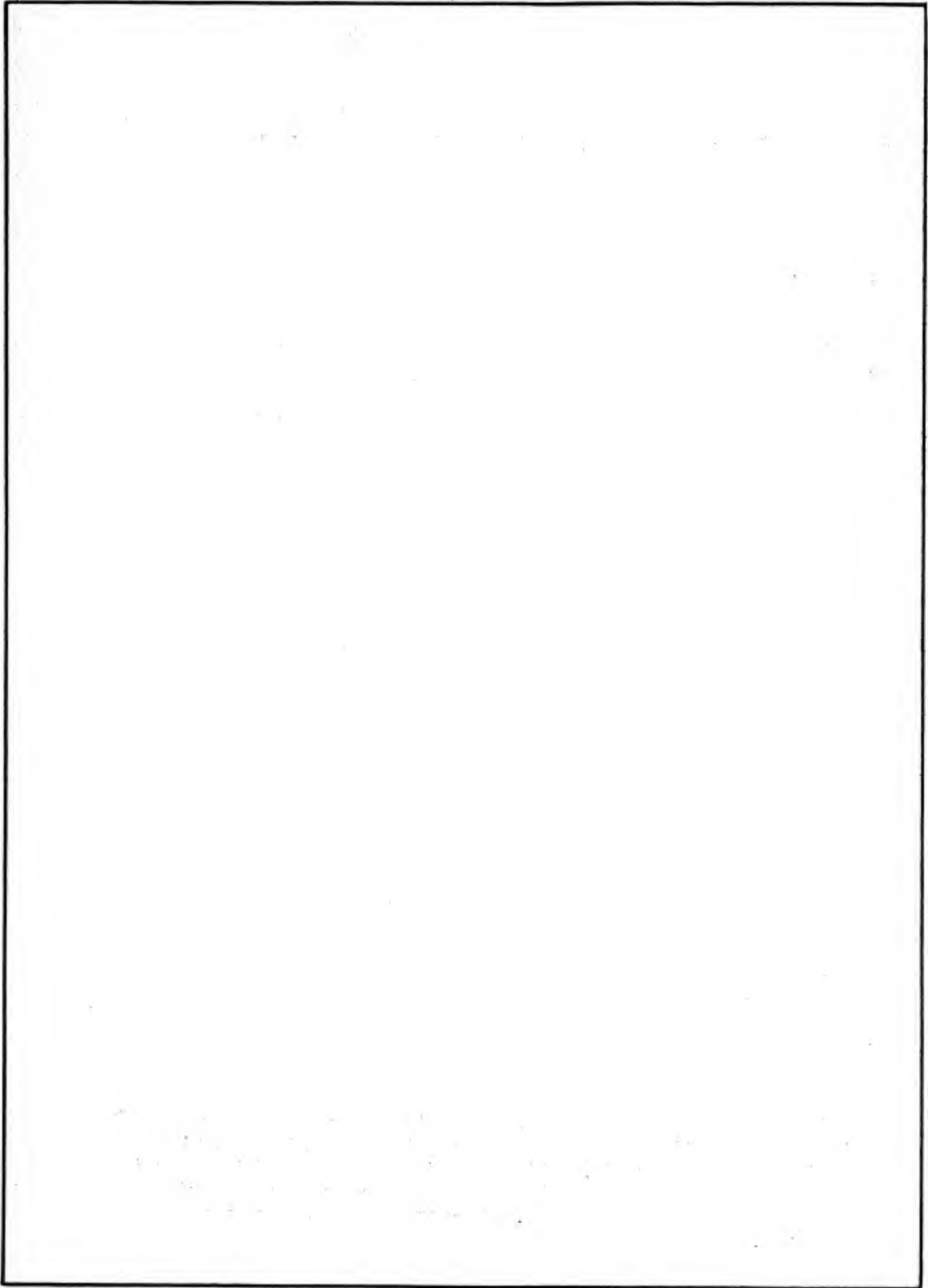
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SUMMARY

The study is an economic analysis which investigates the cost implications of improved tube wear for large caliber gun tubes. A status quo or base case is compared to several alternatives. The savings generated by the alternatives are used to calculate R&D dollars that could be justifiably expended in pursuing technologies that reduce tube wear and erosion. Peacetime and Wartime are examined. A typical European Scenario is used in the wartime analysis. A conclusion is that the planned budget for the Wear and Erosion R&D Program at ARRADCOM is reasonable and should provide a minimum of a 10% return on investment.

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INTRODUCTION

Money is currently being spent for researching wear and erosion in both small and large caliber weapon barrels and tubes with a projected outcome of increasing tube wear life. The purpose of this economic analysis is to determine estimates of R&D expenditures for studying decreasing wear and erosion in 155mm and 8 inch artillery tubes that will result in a worthwhile return on investment (10%) to the Department of the Army.

BACKGROUND

Erosion in gun barrels and tubes, caused by normal firing, is the progressive deterioration of the bore surface and the enlargement of the bore and is caused by the simultaneous action of thermal, mechanical, and chemical processes. The primary cause is the extremely high bore surface temperatures generated by the burning propellant. High pressures and rotating band stresses are additional causes of the erosion process. Erosion ultimately results in loss in the muzzle velocity, range, and accuracy of the projectile thereby reducing the weapon system effectiveness.

The Wear and Erosion Program at ARRADCOM provides for researching erosion mechanisms and is concerned with controlling and reducing gun barrel wear in large and small caliber weapons. Another program goal is to extend the state-of-the-art in wear and erosion technology for future weapons. Because heat input to the gun barrel surface is the major cause of erosion, efforts are being directed toward decreasing the heat input and increasing thermal resistance at the bore surface.

SCOPE OF STUDY

Cost impacts of increased tube life for the 155mm and the 8 inch Howitzer tubes are studied. Specifically, the tubes for the M199 cannon (belonging to the M198 towed Howitzer) and for the M201A1 cannon (belonging to the M110A2 Howitzer) are subjects of the analysis. Both peacetime costs and costs incurred for a specified European Scenario are considered. Sensitivity analyses and a benefits analysis are presented.

METHODOLOGY

An economic analysis is performed. A status quo or base case is compared to several alternatives, and R&D expenditures which result in a 10% return on investment are calculated. The status quo is defined to represent procurement of the current tubes (155mm M198 Howitzer and 8" M110A2 Howitzer tubes) with no provision for a program to research and develop techniques that increase tube wear life. The alternatives to the status quo include an R&D Wear and Erosion program which results in the development of improved tube life; various levels of increase in tube life and tube cost are considered. Engineering expertise is utilized to determine costs for improved longer lasting tubes.

ASSUMPTIONS AND CONSTRAINTS

All costs are in FY80 constant dollars.

The study is limited to the M198 Howitzer tubes (155mm) and the M110A2 Howitzer tubes (8 inch).

Money expended in the 3-year R&D Wear and Erosion programs presented brings about technological advances which result in the production of gun tubes having increased wear life.

When tube wear life is increased, fewer spare tubes need to be produced. Also, tube wear life and the number of spare tubes produced vary inversely (e.g., if tube life is doubled, half the number of spare tubes need to be produced).

Increasing wear life up to the fatigue life of the tube is considered.

Transportation and other logistics costs are not addressed.

The total R&D program dollars for each alternative are expended in the following manner:

Year 1 - 56.6%
Year 2 - 34.4%
Year 3 - 9.0%

This estimate of R&D expenditure rates was taken from the DARCOM Inflation Guidance dated 18 January 1980.

COST SUMMARY

A variety of factors affect the answer to the question: What amount of R&D expenditures for studying wear and erosion in 155mm and 8 inch artillery tubes will result in a worthwhile return on investment (10%) to the Department of the Army? For all R&D expenditures discussed, it is important to note that a 10% return on investment is contingent on the success of the wear and erosion technology. Among these factors are:

Peacetime:

- increase in tube cost
- annual peacetime demand
- number of years of benefit from improved tubes
- increase in wear life of a tube

European Scenario:

- daily firing rate of the Howitzers
- distribution of charges used
- increase in tube cost
- increase in wear life of a tube
- weapon quantities required for the scenario
- artillery loss rates

In peacetime the R&D expenditure resulting in a 10% return varies from approximately \$2 million to \$6 million. When annual peacetime demand is doubled, this range increases to \$4 to \$12 million.

For the European Scenario presented, R&D expenditures range from approximately \$2 to \$3 million. When increased daily firing rates are used in the sensitivity analysis, the R&D expenditures increase to \$4 million to \$5 million. These R&D expenditures represent the amount of money that can be spent in a 3-year period (years 1, 2, and 3) so that a 10% return will be realized if a war occurs in the fourth year.

When wartime and peacetime are analyzed together, the R&D expenditure yielding a 10% return increases. For the wartime and peacetime combined analysis, the following structure is considered: A 3-year R&D program, followed by a 120 day war in the fourth year, and 10, 15, or 20 years of peacetime following the war. (Note: Placing the war in a different year, year 15 for example, does not significantly impact the R&D expenditure of years 1, 2, and 3). In the combined analysis the R&D expenditure yielding a 10% return is about \$4 million to \$16 million. It should also be noted that if additional wars or additional periods of peacetime are added to the analysis, then the R&D expenditures yielding a 10% return will increase.

The study is structured to generate conservative estimates. Only savings in the M198 and M110A2 Howitzer tube costs are considered. Savings in transportation, logistics implications, and other large and small caliber weapons are not addressed.

The projected budget for the Wear and Erosion R&D effort for the large caliber weapons is approximately \$2 million per year through FY85, a six year period. (Note: If the 3-year RDT&E program structure utilized in this study is spread out over a 6-year period rather than a 3 year period, no significant change in expenditures would result. RDT&E spend-out rates show that 97% of the R&D expenditures is spent in the first 3 years). This money will be used for researching coatings, liners, and wear reducing additives. The weapons that will benefit from the technology developed from this program include not only the 155mm M198 Howitzer and 8 inch M110A2 Howitzer, but also the 105mm and 120mm tank guns and the new self-propelled ESPAWS.

Study results indicate that increased tube life is very valuable in high intensity battles. The need to change tubes on the battlefield can be significantly reduced. Also, when annual peacetime demand is increased, longer lasting spares provide economic benefits.

The planned budget for the Wear and Erosion R&D effort is reasonable and planned R&D expenditure should provide a minimum of a 10% return to the Department of the Army.

PEACETIME ANALYSIS

To answer the question: "What amounts of R&D expenditures for decreasing wear and erosion in the 155mm M198 and 8 inch M110A2 artillery tubes will result in a worthwhile investment to the Department of the Army in peacetime?", the following information is needed about the status quo and the alternatives:

- Cost of tubes in FY80 constant dollars
- Range of increased costs for improved tubes
- Peacetime annual demand for spare tubes
- Peacetime annual demand for improved longer lasting tubes
- Wear life of tubes
- Fatigue life of tubes
- Formula which when given the savings produced by an alternative, calculates the R&D expenditure which produces a 10% Return on Investment

Status Quo

The status quo is the continued procurement of unimproved current spare tubes at the present annual peacetime demand rate. Current costs are presented in Table 1, and Table 2 displays current peacetime demand rates. The annual cost of the status quo is calculated as follows:

$$\begin{aligned}\text{Annual Cost} &= \text{Annual Cost (M198 Howitzer tubes)} + \\ &\quad \text{Annual Cost (M110A2 Howitzer tubes)} \\ &= \$985,109\end{aligned}$$

Table 3 displays Wear Life and Fatigue Life of the Status Quo tubes.

Alternatives

Six major alternatives to the status quo are considered. Each alternative is characterized by a 3-year R&D program which is followed by production of improved tubes which have increased wear life. Each alternative increases wear life by factors up to fatigue life. Table 4 describes the six alternatives.

Each alternative has 3 variations. These variations are determined by changes in the cost increases. Table 5 presents the cost variations.

Table 1. Current costs

<u>Tube</u>	A. <u>Tube cost (FY79)</u>	B. <u>Inflation factor</u>	C. <u>Tube cost (FY80) (A X B)</u>
M198 Howitzer	\$13,844 [*]	1.0860	\$15,035
M110A2 Howitzer	\$37,000 ^{**}	1.0860	\$40,182

* Based on an order of 17 tubes (10 Sep 79).

** The spare is a tube assembly which includes hoops, rails, strips and the tube itself (muzzle brake is not included). The cost is based on a quote sent to Headquarters, ARRCOM from Watervliet Procurement Directorate, April 1979, in response to an order of 150 tube assemblies that was anticipated for November 1979.

Table 2. Annual peacetime demand (Worldwide, Army)

<u>Tube</u>	<u>Demand (No. of tubes)</u>
M198 Howitzer	10.68
M110A2 Howitzer	20.52

Table 3. Wear life and Fatigue life

<u>Tube</u>	<u>Wear life (EFC)¹ no. rounds</u>	<u>Fatigue life (EFC) no. rounds</u>
M198 Howitzer	1,750 [*]	11,250
M110A2 Howitzer	1,424 ^{**}	7,500

¹EFC - Effective Full Charge

* Zone 8, M203 Charge

** Zone 9, M188E1 Charge

Table 4. Alternatives

Alternative	M198 Howitzer tube		(No. of tubes) New annual peacetime demand	M110A2 Howitzer tube		(No. of tubes) New annual peacetime demand
	Factor applied to status quo wear life	Wear life of new tube (EFC rounds)		Factor applied to status quo wear life	Wear Life of new tube (EFC rounds)	
I	2	3500	5.34	2	2848	10.26
II	3	5250	3.56	3	4272	6.84
III	4	7000	2.67	4	5696	5.13
IV	5	8750	2.14	5	7120	4.10
V	6	10,500	1.78	6	Fatigue Life +	3.42
VI	7	Fatigue Life +	1.53	6	Fatigue Life +	3.42

Table 5. Cost variations*

<u>Variation</u>	<u>M198 Howitzer tube</u>		<u>M110A2 Howitzer tube</u>	
	<u>% Cost increase</u>	<u>Tube cost</u>	<u>% Cost increase</u>	<u>Tube cost</u>
A	15	17,290	5	42,191
B	25	18,794	10	44,200
C	35	20,297	15	46,209

* Cost increases are assumed to include any additional costs incurred including extra facilities, tooling, etc.

In addition, for each variation a 10 year benefit period, 15 year benefit period, and 20 year benefit period are considered. Each benefit period is preceded by a 3 year Research and Development investment period.

Annual Cost Savings

Annual cost savings resulting from the implementation of an alternative are calculated using the following formula:

$$\text{Annual Cost Savings} = \text{Annual Cost Status Quo} - \text{Annual Cost Alternative}$$

For example, the Annual Savings for Alternative I (variation A) are calculated as follows:

$$\begin{aligned} \text{Annual Cost Savings} &= \text{Annual Cost Status Quo} - \text{Annual Cost Alternative I/A} \\ &= \$985,109 - \{ (5.34)(\$17,290) + (10.26)(\$42,191) \} \\ &= \$459,900 \end{aligned}$$

Annual Savings for all other alternative and variations are calculated in the same manner. Appendix B: "Peacetime Analysis: R&D Expenditures Yielding a 10% Return on Investment" displays Annual Cost Savings for all Alternatives and Variations (See Column H).

Formulas for Calculating R&D Expenditure

Given the savings produced by an alternative, formulas are derived that calculate the total 3-year R&D expenditure which will give a 10% Return on Investment. A separate formula is derived for the 10-year benefit plan, the 15-year benefit plan, and the 20-year benefit plan. Table 6 defines the variables which are used in the formula derivations. Derivations of formulas are based on the fact that when discounted investment is equal to discounted savings, the ROI is 10% when future dollars are discounted at a rate of 10% per annum. Discount factors are presented in Appendix C.

Table 6. Variable definitions

Variable

I	The total R&D Investment which yields a 10% return. I is expended over years 1, 2, and 3 in the following percentages: 56.6, 34.4, and 9.0 respectively.
S	The annual savings resulting from implementation of an alternative (see Appendix B, Column H).
D_m	D is the discount factor - a 10% rate is used. m is the project year. m ranges from 1 through 23.

The 10-year benefit plan consists of a 3-year R&D program which is followed by 10 years of production of improved tubes. The formula for the 10-year benefit plan is derived as follows:

$$I \{ .566 D_1 + .344 D_2 + .090 D_3 \} = S \{ D_4 + D_5 + \dots + D_{13} \}$$

$$I \{ .566 (.954) + .344 (.867) + .090 (.788) \} = S \{ 4.844 \}$$

$$I = S \{ 5.3282 \}$$

For example the annual cost savings for alternative 'I', variation 'A', is \$459,900. The total 3-year R&D investment which yields a 10% return for a 10-year benefit is calculated as follows:

$$I = S \{ 5.3282 \}$$

$$I = \$459,900 \{ 5.3282 \}$$

$$I = \$2,450,439$$

The formula for the 15-year benefit plan is derived in a similar manner:

$$I = \{ .566 D_1 + .344 D_2 + .090 D_3 \} = S \{ D_4 + D_5 + \dots + D_{18} \}$$

$$I = S \{ 6.5953 \}$$

The formula for the 20-year plan derived as above is as follows:

$$I = S \{ 7.3829 \}$$

In summary, for all alternatives and variations, Table 7 presents the range of R&D expenditures.

SENSITIVITY ANALYSIS: PEACETIME

The peacetime analysis showed that depending on a variety of factors the R&D expenditure yielding a 10% return ranged from \$2,145,235 to \$6,012,353. Tube cost, wear life, and years of benefit were the factors that varied.

The sensitivity analysis will vary the quantity of tubes procured annually. For the sensitivity analysis, annual peacetime demand is doubled. All other variables remain the same. Appendix D - 'Peacetime Sensitivity Analysis: R&D Expenditures Yielding a 10% Return on Investment' presents all data reflecting doubling of the annual peacetime demand.

Table 7. R&D expenditures

<u>Benefit plan</u>	<u>R&D expenditure (total for 3 years)</u>	
	<u>Low</u>	<u>High</u>
10-year	\$2,145,235	\$4,339,084
15-year	\$2,655,393	\$5,370,962
20-year	\$2,972,496	\$6,012,353

As the annual peacetime demand for spare tubes is doubled, the R&D expenditure that yields a 10% return is also doubled. The annual peacetime demand (i.e. quantity of spare tubes procured) is a sensitive factor deserving consideration.

EUROPEAN SCENARIO

Status Quo

A European Scenario is utilized to provide data on tube changes during a wartime situation. The scenario lasts for 120 days (begins D-Day and ends D+119). There are four groups of forces. Group #1 arrives on D-Day and stays through D+119; there are 84 M110A2 Howitzers (no M198 Howitzers) in this group. Group #2 arrives on D+30 and stays through D+119; there are 108 M198 Howitzers and 96 M110A2 Howitzers in this group. Group #3 arrives on D+60 and stays through D+119; there are 144 M198 Howitzers and 144 M110A2 Howitzers in this group. Group #4 arrives D+90 and stays through D+119; there are 288 M198 Howitzers and 108 M110A2 Howitzers in this group. Appendix E, 'European Scenario', presents detailed information about the scenario. Table 8 summarizes average daily firing rates for each weapon and for each of the four 30-day periods. Artillery loss rates are explained in Appendix E.

Appendix F presents information concerning wear life and fatigue life for the M198 and M110A2 Howitzer tubes. It should be noted that a lower zone charge will increase the wear life of the tube. For example, if the zone 6 charge M4A2 is used exclusively in the M198, then the wear life of the tube will be 35,000 rounds. If the zone 8 charge M203 is used exclusively in the M198, then the wear life will be 1,750 rounds. To determine the average wear life for the M198 Howitzer tube and the M110A2 Howitzer tube, a weighted average is calculated. A ratio is used to take charges into account that have a negligible effect on tube wear. The ratio adjusts for the zone 5 and lower charges that are used 5% of the time in the scenario. Table 9 shows calculations of average wear life for the M198 Howitzer tube and Table 10 shows corresponding calculations for the M110A2 Howitzer tube.

Appendices G and H are tube usage tables which show day by day tube use and artillery loss. Table 11 summarizes the tube changes that are made throughout the scenario for each group of forces.

Table 11 shows that a total of 55 M198 and 84 M110A2 Howitzer tubes are changed in the 120 day scenario presented. The cost of the status quo (i.e. using unimproved tubes and changing them) is calculated as follows:

Table 8. Average daily firing rates

<u>Time period</u>	<u>Howitzer</u>	<u>Firing rate (No. rounds per day)</u>
D-Day through D+29	M198	*
	M110A2	100
D+30 through D+59	M198	200
	M110A2	100
D+60 through D+89	M198	200
	M110A2	75
D+90 through D+119	M198	200
	M110A2	75

* There are no M198 Howitzers in Forces Group #1.

Table 9. Average wear life - M198

<u>Zone/charge</u>	A. <u>Wear life</u>	B. <u>Wear life</u>	C. <u>% Of total rounds fired</u>	(BXC) <u>wear life</u>
8/M203	1,750		5	87.5
8/M119A2	5,303		20	1060.6
7/M4A2	17,500		50	8750.0
6/M4A2	35,000		20	7000.0
5 and below	-		5	-
Total wear life before adjustment				16898.1

Calculation for adjustment:

$$\frac{16,898}{95\%} = \frac{X}{100\%}$$

$$= \underline{17,787} \text{ (weighted wear life for M198 tube)}$$

Table 10. Average wear life - M110A2

<u>A.</u> <u>Zone/charge</u>	<u>B.</u> <u>Wear life</u>	<u>% Of total C.</u> <u>rounds fired</u>	<u>(BXC)</u> <u>wear life</u>
9/M188E1	1,424	12%	170.9
8/M188	2,848	23%	655.0
7/M2	7,120	45%	3204.0
6/M2	14,240	15%	2136.0
5 and below	-	5%	-
	Total wear life before adjustment		6165.9

Calculation for adjustment:

$$\frac{6,165.9}{95\%} = \frac{X}{100\%}$$

$$= \underline{6,490} \text{ (weighted wear life for M110A2 tube)}$$

Table 11. Total tubes changed

<u>Group</u>	<u>M198 Howitzer Tube</u>		<u>M110A2 Howitzer Tube</u>	
	<u># Of tubes changed</u>	<u>Day</u>	<u># Of tubes Changed</u>	<u>Day</u>
#1	*	-	30	D+66
#2	55	D+118	54	D+106
#3	0	-	0	-
#4	0	-	0	-
Total	55		84	

* There are no M198 Howitzers in Forces, Group #1.

$$\begin{aligned} \text{Cost Status Quo} &= \text{Tube Changes M198} \times \text{Tube Cost M198} \\ &+ \text{Tube Changes M110A2} \times \text{Tube Cost M110A2} \\ &= \$4,202,213 \end{aligned}$$

Alternatives

The alternatives to the status quo involve the use of longer lasting tubes so that tube changes are not necessary in the 120 day war. Three alternatives to the status quo are considered and these are distinguished by varying tube cost increases. The structure of the three alternatives provides for a 3-year R&D program followed by the year of the 120 day war. This structure which excludes years of peacetime savings before the war, provides for a very conservative estimate of what R&D expenditures yield a 10% return on investment.

In Table 11 it should be noted that only the forces of group #1 and group #2 need to change tubes. Also, when observing the days on which these tube changes take place, it is clear that doubling tube life for both the M198 and M110A2 Howitzer tubes is sufficient to eliminate tube changes for the entire 120 day scenario.

Current procurement policy provides that new weapons are usually phased in and current equipment (i.e., serviceable stock on hand in the depots and prepositioned stock on hand in Europe) is utilized. In light of this fact, the alternatives to the status quo will only supply forces of group #1 and group #2 with howitzers having the improved tube. Forces of groups #3 and #4 will be provided with current equipment because longer lasting tubes are not needed by these forces.

Each alternative has no tube changes throughout the scenario. However, in order to facilitate no tube changes, each howitzer in forces groups #1 and #2 must be equipped with a longer lasting tube. The cost of each alternative then will be the number of howitzers utilizing improved equipment multiplied by the difference in cost between the new improved tube and the status quo current tube.

Appendix I details how cost of each alternative and savings realized by implementation of an alternative are calculated.

Again, a formula is derived which will give the total R&D expenditure (spent over a 3 year period) which will result in a 10% return on investment. The variable definitions in Table 6 apply. The formula is derived as follows:

$$I \{ .566D_1 + .344D_2 + .090D_3 \} = S\{D_4\}$$

$$I \{ .566 (.954) + .344 (.867) + .090 (.788) \} = S\{.717\}$$

$$I = S\{.7887\}$$

Table 12 presents the investments resulting in a 10% return for the alternatives 1,2, and 3 described in detail in Appendix I.

SENSITIVITY ANALYSIS: EUROPEAN SCENARIO

Status Quo

The sensitivity analysis considers increased daily firing rates and consequently increased tube changes during the scenario. All other elements of the scenario remain the same. Table 13 displays daily firing rates used for the sensitivity analysis.

Appendices J and K are the tube usage tables reflecting increased firing rates. Table 14 summarizes the tube changes that are made throughout the scenario for each group of forces, and shows that a total of 161 M198 and 126 M110A2 Howitzer tubes are changed in the 120 days.

The cost of the status quo (i.e., using unimproved tubes and changing them) is calculated as follows:

$$\begin{aligned} \text{Cost Status Quo} &= \{ \text{Tube Changes M198} \times \text{Tube Cost M198} \} \\ &+ \{ \text{Tube Changes M110A2} \times \text{Tube Cost M110A2} \} \\ &= \$7,483,567 \end{aligned}$$

Table 12. R&D investments (10% ROI)

<u>Alternative</u>	<u>Wartime savings (year No.4)</u>	<u>Total R&D investment (years 1, 2, and 3)</u>
1	3,597,053	2,836,996
2	3,073,001	2,423,676
3	2,549,057	2,010,441

Table 13. Average daily firing rates

<u>Time period</u>	<u>Howitzer</u>	<u>Firing rate (No. rounds per day)</u>
D-Day through D+29	M198	*
	M110A2	150
D+30 through D+59	M198	300
	M110A2	150
D+60 through D+89	M198	300
	M110A2	100
D+90 through D+119	M198	300
	M110A2	100

* There are no M198 Howitzers in Forces Group 1.

Table 14. Tube changes

<u>Group</u>	<u>M198 Howitzer tube</u>		<u>M110A2 Howitzer tube</u>	
	<u>No. of tubes changed</u>	<u>Day</u>	<u>No. of tubes changed</u>	<u>Day</u>
1	*	-	30 24	D+43 D+100
2	69	D+89	67	D+79
3	92	D+119	0	-
4	0	-	0	-
Total	161		121	

* There are no M198 Howitzers in Forces, Group 1.

Alternatives

The alternatives to the status quo again involve the use of longer lasting tubes so that tube changes are not necessary. As before, three alternatives distinguished by varying tube cost increases are considered, and a 3 year R&D program followed by the year of the 120 day war is the structure of the alternatives.

Table 14 shows that the forces of groups #2 and #3 need to be equipped with improved M198 Howitzer tubes and groups #1 and #2 need improved M110A2 Howitzer tubes to eliminate tube changes throughout the scenario. Again, the cost of each alternative is the number of howitzers utilizing improved equipment multiplied by the difference in cost between the new improved tube and the status quo current tube.

Appendix L details how the cost of each alternative and savings realized by implementation of an alternative are calculated.

Because the structure of the alternatives is the same for the sensitivity analysis, the formula $I = S\{.7887\}$ is used again to calculate the R&D investment values yielding a 10% return. Table 15 displays these investments for each of the three alternatives.

COMBINED PEACETIME/WARTIME SCENARIO

The previous chapters have addressed peacetime and a given European Scenario independently. The calculated R&D expenditures tell what can be spent for either a wartime or peacetime situation. In the combined peacetime/wartime analysis, a war in combination with varying years of peacetime (10, 15, and 20 years) is considered.

The following structure is utilized: A 3-year R&D program, followed by a 120 day war in the fourth year, and 10, 15, or 20 years of peacetime following the war. (Note that if the war is placed in another year, year 15 for example, rather than year 4, the R&D expenditure in the first 3 years is not significantly changed.) For consistency, the assumptions, constraints, and various data used in the independent Peacetime and European Scenario analyses, are also used for the combined analysis.

Appendix M provides detailed data for the combined analysis. The range of R&D dollars that give a 10% return on investment increase to \$4 million to \$16 million in the combined scenario.

Table 15. Sensitivity analysis - R&D investments

<u>Alternative</u>	<u>Wartime Savings (year No. 4)</u>	<u>Total R&D investment (years 1, 2, and 3)</u>
1	6,553,687	5,168,893
2	5,813,059	4,584,760
3	5,072,683	4,000,825

BENEFITS ANALYSIS

There are benefits in addition to the cost savings discussed that will result from the type of R&D effort described in this study. Following is a list of additional benefits:

- Future weapon systems with increased requirements such as the new self-propelled ESPAWS will benefit from the new technology.
- The technology base will be maintained and kept up to date.
- The Navy and Air Force will benefit from new technology.
- The NATO allies will benefit from improved weapons and free world readiness will be strengthened.
- If fewer spare tubes need to be produced, the need for additional facilities could be eliminated.
- If time and energy are not expended for changing tubes in a wartime situation, that time and energy can be more effectively expended for winning the war.

REPRESENTATIVE USE OF THE DATA

A wide range of R&D expenditures that give a 10% return on investment are generated by the economic analysis (i.e. \$2 to \$12 million for peacetime, \$2 to \$5 million for the European Scenario, and \$4 to \$16 million for the combined wartime/peacetime analysis). This wide range results from the various alternatives that could occur, and from the variety of factors which impact costs. For example, 10, 15, and 20 years of benefit are analyzed for the improved tubes. Various increases in tube cost and wear life are also considered. In the European Scenario Sensitivity Analysis, a battle of greater intensity is analyzed.

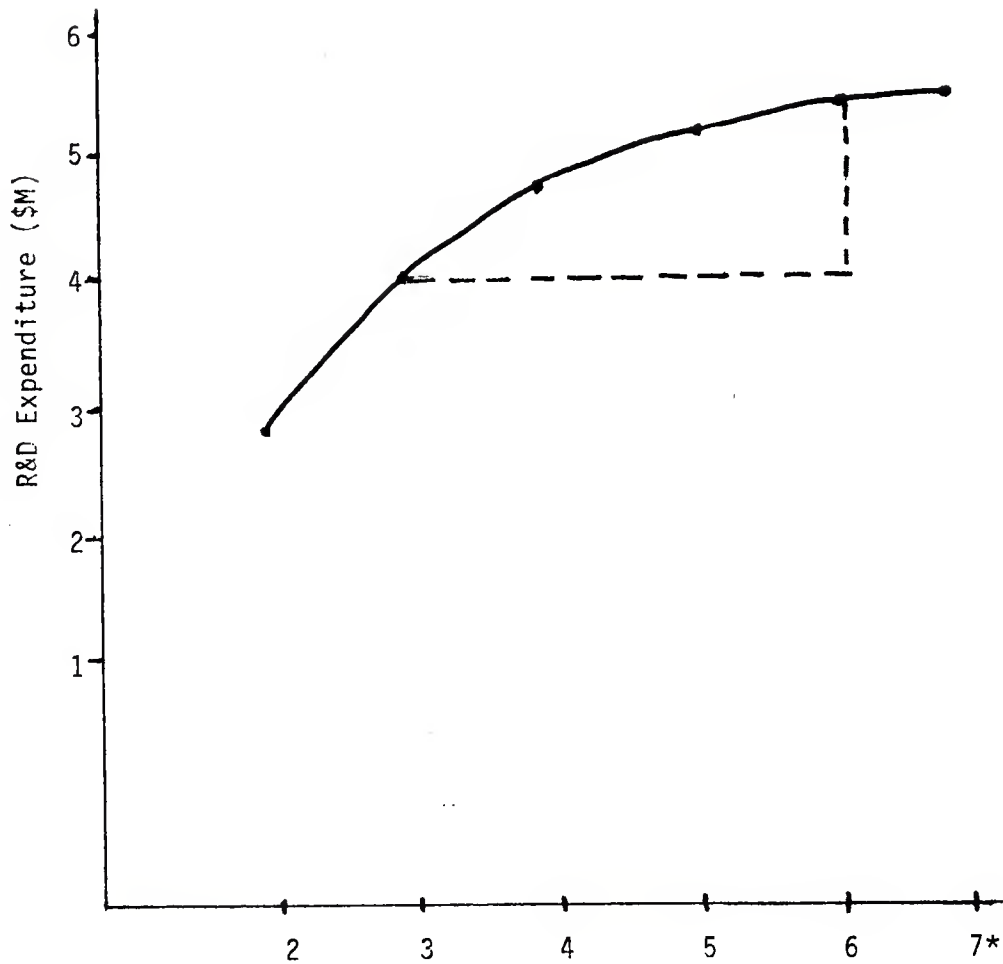
By narrowing down the alternatives and pinpointing certain factors, it is possible to also narrow down the range of R&D expenditures which yield a 10% return. Consider the following alternative (call it alternative "X"):

- only peacetime is considered
- there will be 15 years of benefit associated with new tubes

- there will be a 25% cost increase for the improved M198 Howitzer tube.
- there will be a 10% cost increase for the M110A2 Howitzer tube.

Given this specific information about alternative "X", the graph in Figure 1 is obtained by using the data in Appendix B. Notice in Figure 1 that the range of R&D expenditures yielding a 10% return has been narrowed down to between \$2.8 and \$5.3 million. This range is now only dependent on the factor by which wear life is increased. For example, if wear life is increased by a factor of 5, then the R&D expenditure is about \$5 million.

The data generated can be used as a management tool for decision making as demonstrated by the following example: Figure 1 indicates that an expenditure of about \$4 million will yield a 10% return for a Wear & Erosion R&D program that increases wear life by a factor of 3. If for some reason the program is able to exceed original goals by increasing wear life by a factor of 6, then an additional \$1.3 million could be spent on the program and there would still be a 10% return on the investment.



Factor by which wear life is increased

*Six for the M110A2 Howitzer tube; 7 for the M198 Howitzer tube

Figure 1. R&D expenditures for alternative "X".

REFERENCES

1. Background information was supplied by the document Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, 29-31 March 1977, sponsored by the American Defense Preparedness Association at the US Army Armament Research and Development Command, Dover, NJ. Editors: Jean-Paul Picard and Iqbal Ahmad.
2. Technical and additional background information were supplied by the study "US Army Artillery Tube Wear Analysis" POC: Mr. John Kovacs (SEO, ARRADCOM).
3. Peacetime monthly demand rates for tubes were provided by the Material Management Directorate, Heavy Weapons Division, DRSAR-MMH, ARRCOM, Rock Island, POC: Mr. Bob Stoffer.
4. The European Scenario was provided by Requirements Analysis Division, Systems Evaluation Office, ARRADCOM, POC's: LTC Cobb and MAJ Bowman.
5. Costs for the M198 and M110A2 Howitzer tubes were supplied by the Watervliet Procurement Directorate, POC: Mr. George Webster.
6. Inflation rates and expenditure rates for research and development were obtained from DRCCP-ER Inflation Guidance, 18 January 1980.
7. Wear Life and Fatigue Life data were supplied by the Ballistics Research Lab, USA ARRADCOM, Aberdeen Proving Ground, MD, POC: Mr. Bob Lieske.
8. Engineering expertise provided probable tube cost increases.
9. Formulas used for computing R&D investments were provided by SEO, Cost Analysis Division, POC: Mr. Tom Mitsock.
10. Average Daily firing rates for the European Scenario were supplied by SEO, Systems Analysis Division, POC: Mr. Larry Ostuni.
11. The percentages of charges used in the European Scenario were supplied by SEO, Requirements Analysis Division, POC: MAJ Bowman.
12. Discount factors were obtained from the document: Economic Analysis Workshop. Source: Cost Analysis Division, SEO, ARRADCOM.

APPENDIX A

PEACETIME ANALYSIS:
R&D EXPENDITURES YIELDING A
10% RETURN ON INVESTMENT

Table A-1. R&D expenditures yielding a 10% return on investment (column I)
(Peacetime analysis)

A. Alternative	B. Variation	C. Annual tube demand (M198)	D. Tube cost (M198)	E. Annual tube demand (M110A2)	F. Tube cost (M110A2)	G. Annual cost for alternative (CXD)+(EXF)	H. * Annual cost savings	I. R&D Expenditure	10 Year benefit	15 Year benefit	20 Year benefit
I	A	5.34	17290	10.26	42191	525209	459900	2450439	3033178	3395396	
	B	5.34	18794	10.26	44200	553852	431257	2297824	2844269	3183927	
	C	5.34	20297	10.26	46209	582490	402619	2145235	2655393	2972496	
II	A	3.56	17290	6.84	42191	350138	634971	3383252	4187824	4687927	
	B	3.56	18794	6.84	44200	368235	615874	3281500	4061874	4546936	
	C	3.56	20297	6.84	46209	388327	596782	3179774	3935956	4405982	
III	A	2.67	17290	5.13	42191	262604	722505	3849651	4765137	5334182	
	B	2.67	18794	5.13	44200	276926	708183	3773341	4670679	5228444	
	C	2.67	20297	5.13	46209	291245	693864	3697046	4576241	5122729	
IV	A	2.14	17290	4.10	42191	209984	775125	4130021	5112182	5722670	
	B	2.14	18794	4.10	44200	221439	763670	4068986	5036633	5638099	
	C	2.14	20297	4.10	46209	232893	752216	4007957	4961090	5553535	
V	A	1.78	17290	3.42	42191	175069	810040	4316055	5342457	5980444	
	B	1.78	18794	3.42	44200	184617	800492	4265181	5279485	5909952	
	C	1.78	20297	3.42	46209	194164	790945	4214313	5216520	5839468	
VI	A	1.53	17290	3.42	42191	170747	814362	4339084	5370962	6012353	
	B	1.53	18794	3.42	44200	179919	805190	4290213	5310470	5944637	
	C	1.53	20297	3.42	46209	189089	796020	4241354	5249991	5876936	

* Annual cost savings = \$985,109 - Annual cost (column G) alternative

APPENDIX B
DISCOUNT FACTORS

Table B-1. Program/project year discount factors

<u>Project Year</u>	<u>10% Discount factor</u>
1	.954
2	.867
3	.788
4	.717
5	.652
6	.592
7	.538
8	.489
9	.445
10	.405
11	.368
12	.334
13	.304
14	.276
15	.251
16	.228
17	.208
18	.189
19	.172
20	.156
21	.142
22	.129
23	.117

APPENDIX C
PEACETIME SENSITIVITY ANALYSIS:
R&D EXPENDITURES YIELDING A 10% RETURN ON INVESTMENT

Table C-1. R&D expenditures yielding a 10% return on investment (column I)

(Peacetime sensitivity analysis)

A. Alternative	B. Variation	C. Annual tube demand (M198)	D. Tube cost (M198)	E. Annual tube demand (M10A2)	F. Tube cost (M10A2)	G. Annual cost for alternative (CXD)+(EXF)	H. * Annual cost savings	I. R&D expenditure		
								10 Year benefit	15 Year benefit	20 Year benefit
I	A	10.68	17290	20.52	42191	1050418	919799	4900873	6066350	6790784
	B	10.68	18794	20.52	44200	1107704	862513	4595642	5688532	6367847
	C	10.68	20297	20.52	46209	1164980	805237	4290464	5310780	5944984
II	A	7.12	17290	13.68	42191	700276	1269941	6766500	8375642	9375847
	B	7.12	18794	13.68	44200	738470	1231747	6562994	8123741	9093865
	C	7.12	20297	13.68	46209	776654	1193563	6359542	7871906	8811956
III	A	5.34	17290	10.26	42191	525208	1445009	7699297	9530268	10668357
	B	5.34	18794	10.26	44200	553852	1416365	7546676	9341352	10456681
	C	5.34	20297	10.26	46209	582490	1387728	7394092	9152482	10245457
IV	A	4.28	17290	8.20	42191	419968	1550249	8260037	10224357	11445333
	B	4.28	18794	8.20	44200	442878	1527339	8137968	10073259	11276191
	C	4.28	20297	8.20	46209	465786	1504431	8015909	9922174	11107064
V	A	3.56	17290	6.84	42191	350138	1620079	8632105	10684907	11960881
	B	3.56	18794	6.84	44200	369234	1600983	8530358	10558963	11819897
	C	3.56	20297	6.84	46209	388328	1581889	8428621	10433033	11678928
VI	A	3.06	17290	6.84	42191	341494	1628723	8678162	10741917	12024699
	B	3.06	18794	6.84	44200	359838	1610379	8580421	10620933	11889267
	C	3.06	20297	6.84	46209	378178	1592039	8482702	10499975	11753865

* Annual cost savings = \$1,970,217 - Annual cost for alternative (column G)
(Annual cost, status quo)

APPENDIX D
EUROPEAN SCENARIO

EUROPEAN SCENARIO

D-Day
through
D+29

4 Heavy divisions

4 Div X 3 Bn ea X 24 M109A2 = 288 M109A2*

4 Div X 1 Bn ea X 12 M110A2 = 48 M110A2

2 ACR (Armored cavalry regiment)

2 ACR X 1 Bn ea X 24 M109A2 = 48 M109A2

1 Corps artillery

1 Corps arty X 1 Bn ea X 24 M109A2 = 24 M109A2

1 Corps arty X 3 Bn ea X 12 M110A2 = 36 M110A2

40% of forces are lost in the first 3 days

20% of the remaining forces are lost in the rest
of the 30-day period

The daily firing rates are: M110A2 - 100 rounds

D+30
through
D+59

1 Light division

1 Div X 3 Bn ea X 24 M198 = 72 M198

1 Div X 1 Bn ea X 12 M110A2 = 12

2 Special division (1 airborne; 1 airmobile)

2 Div X 3 Bn ea X 18 M102 = 108 M102** (105mm)

2 Div X 1 Bn ea X 18 M198 = 36 M198

4 Heavy divisions

4 Div X 3 Bn ea X 24 M109A2 = 288 M109A2

4 Div X 1 Bn ea X 12 M110A2 = 48 M110A2

* The M109A2 Howitzer tube is fatigue limited and is thus excluded from the study.

** The M102 Howitzer is not considered because of low quantity.

1 Corps artillery

1 Corps arty X 1 Bn ea X 24 M109A2 = 24 M109A2
1 Corps arty X 3 Bn ea X 12 M110A2 = 36 M110A2

1 ACR

1 ACR X 1 Bn ea X 24 M109A2 = 24 M109A2
20% of forces are lost in the 30-day period
Daily firing rates are:

M198 = 200 rounds
M110A2 = 100 rounds

D+60
through
D+89

4 Heavy divisions

4 Div X 3 Bn ea X 24 M109A2 = 288 M109A2
4 Div X 1 Bn ea X 12 M110A2 = 48 M110A2

2 Light divisions

2 Div X 3 Bn ea X 24 M198 = 144 M198
2 Div X 1 Bn ea X 12 M110A2 = 24 M110A2

2 Corps artillery

2 Corps arty X 1 Bn ea X 24 M109A2 = 48 M109A2
2 Corps arty X 3 Bn ea X 12 M110A2 = 72 M110A2
20% of the forces are lost in the 30-day period
Daily firing rates are:

M198 = 200 rounds
M110A2 = 75 rounds

D+90
through
D+119

4 Light divisions

4 Div X 3 Bn ea X 24 M198 = 288 M198
4 Div X 1 Bn ea X 12 M110A2 = 48 M110A2

2 Heavy divisions

2 Div X 3 Bn ea X 24 M109A2 = 144 M109A2
2 Div X 1 Bn ea X 12 M110A2 = 24 M110A2

1 ACR

1 ACR X 1 Bn ea X 24 M109A2 = 24 M109A2

1 Corps artillery

1 Corps arty X 1 Bn ea X 24 M109A2 = 24 M109A2

1 Corps arty X 3 Bn ea X 12 M110A2 = 36 M110A2

20% of the forces are lost in the 30-day period

Daily firing rates are:

M198 200 rounds

M110A2 = 75 rounds

APPENDIX E
WEAR LIFE/FATIGUE LIFE

Table E-1. Wear life and fatigue life for the M198 Howitzer tube
(Current tube - status quo)

<u>Zone</u>	<u>Charge</u>	<u>Wear life</u>		<u>Fatigue life</u>	
		<u>Factor</u>	<u>No. rounds</u>	<u>Factor</u>	<u>No. rounds</u>
8	M203	1	1,750	1	11,250
8	M119A1	.33	5,303	.7	16,071
7	M4A2	.1	17,500	.25	45,000
6	M4A2	.05	35,000	.25	45,000
5	M4A2	*	*	.1	112,500
4	M4A2	*	*	.1	112,500
3	M4A2	*	*	.1	112,500
5	M3A1	*	*	.25	45,000
4	M3A1	*	*	.1	112,500
3	M3A1	*	*	.2	56,250

* No significant wear for these charges.

Table E-2. Wear life and fatigue life for the M110A2 Howitzer tube
(Current tube - status quo)

<u>Zone</u>	<u>Charge</u>	<u>Wear life</u>		<u>Fatigue life</u>	
		<u>Factor</u>	<u>No. rounds</u>	<u>Factor</u>	<u>No. rounds</u>
9	M188E1	1	1,424	1	7,500
8	M188	.5	2,848	.7	10,714
7	M2	.2	7,120	.7	10,714
6	M2	.1	14,240	.25	30,000
5	M2	*	*	.25	30,000
5	M1	*	*	.25	30,000
4	M1	*	*	.25	30,000
3	M1	*	*	.25	30,000
2	M1	*	*	.25	30,000
1	M1	*	*	.25	30,000

* No significant wear for these charges.

APPENDIX F
EUROPEAN SCENARIO:
TUBE USAGE TABLES FOR THE M198 HOWITZER TUBE
(STATUS QUO)

Forces Group No. 1

The forces of Group No. 1 arrive D-Day and stay through D+119 for a total of 120 days.

There are no M198 Howitzers in this group.

Forces Group No. 2

The forces of Group No. 2 arrive D+30 and stay through D+119 for a total of 90 days. There are 108 M198 Howitzers in Group No. 2. A tube is changed when the wear life (17,787 rounds) is reached. The rate of fire for D+30 through D+59 is 200 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed in this period.

There are 86 M198 Howitzers remaining in Group No. 2 at the beginning of D+60. The firing rate for D+60 through D+89 is 200 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 69 M198 Howitzers remaining in Group No. 2 at the beginning of D+90. The firing rate for D+90 through D+119 is 200 rounds per day. Twenty percent of the artillery is lost in the 30-day period. Fifty-five tubes are changed on D+118.

Forces Group No. 3

The forces of Group No. 3 arrive D+60 and stay through D+119 for a total of 60 days. There are 144 M198 Howitzers in forces Group No. 3. The rate of fire for D+60 through D+89 is 200 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 115 M198 Howitzers remaining in Group No. 3 at the beginning of D+90. The firing rate for D+90 through D+119 is 200 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 4

The forces of Group No. 4 arrive D+90 and stay through D+119 for a total of 30 days. There are 288 M198 Howitzers in forces Group No. 4. The rate of fire for D+90 through D+119 is 200 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Table F-1. European scenario for M198 Howitzers. Day 30 to Day 59,

Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+30	107	1	200
D+31	106	1	400
D+32	105	1	600
D+33	104	1	800
D+34	103	1	1000
D+35	102	1	1200
D+36	101	1	1400
D+37	100	1	1600
D+38	99	1	1800
D+39	98	1	2000
D+40	97	1	2200
D+41	96	1	2400
D+42	95	1	2600
D+43	94	1	2800
D+44	94	0	3000
D+45	93	1	3200
D+46	93	0	3400
D+47	92	1	3600
D+48	92	0	3800
D+49	91	1	4000
D+50	91	0	4200
D+51	90	1	4400
D+52	90	0	4600
D+53	89	1	4800
D+54	89	0	5000
D+55	88	1	5200
D+56	88	0	5400
D+57	87	1	5600
D+58	87	0	5800
D+59	86	1	6000

Table F-2. European scenario for M198 Howitzers, Day 60 to Day 89,
Group 2 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	85	1	6200
D+61	84	1	6400
D+62	83	1	6600
D+63	82	1	6800
D+64	81	1	7000
D+65	81	0	7200
D+66	80	1	7400
D+67	80	0	7600
D+68	79	1	7800
D+69	79	0	8000
D+70	78	1	8200
D+71	78	0	8400
D+72	77	1	8600
D+73	77	0	8800
D+74	76	1	9000
D+75	76	0	9200
D+76	75	1	9400
D+77	75	0	9600
D+78	74	1	9800
D+79	74	0	10,000
D+80	73	1	10,200
D+81	73	0	10,400
D+82	72	1	10,600
D+83	72	0	10,800
D+84	71	1	11,000
D+85	71	0	11,200
D+86	70	1	11,400
D+87	70	0	11,600
D+88	69	1	11,800
D+89	69	0	12,000

Table F-3. European scenario for M198 Howitzers, Day 90 to Day 119,

Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	68	1	12,200
D+91	68	0	12,400
D+92	67	1	12,600
D+93	67	0	12,800
D+94	66	1	13,000
D+95	66	0	13,200
D+96	65	1	13,400
D+97	65	0	13,600
D+98	64	1	13,800
D+99	64	0	14,000
D+100	63	1	14,200
D+101	63	0	14,400
D+102	62	1	14,600
D+103	62	0	14,800
D+104	61	1	15,000
D+105	61	0	15,200
D+106	60	1	15,400
D+107	60	0	15,600
D+108	59	1	15,800
D+109	59	0	16,000
D+110	58	1	16,200
D+111	58	0	16,400
D+112	57	1	16,600
D+113	57	0	16,800
D+114	56	1	17,000
D+115	56	0	17,200
D+116	56	0	17,400
D+117	55	1	17,600
D+118	55	0	17,800
D+119	55	0	200

Table F-4. European Scenario for M198 Howitzers, Day 60 to Day 89,

Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	143	1	200
D+61	142	1	400
D+62	141	1	600
D+63	140	1	800
D+64	139	1	1000
D+65	138	1	1200
D+66	137	1	1400
D+67	136	1	1600
D+68	135	1	1800
D+69	134	1	2000
D+70	133	1	2200
D+71	132	1	2400
D+72	131	1	2600
D+73	130	1	2800
D+74	129	1	3000
D+75	128	1	3200
D+76	127	1	3400
D+77	126	1	3600
D+78	125	1	3800
D+79	124	1	4000
D+80	123	1	4200
D+81	122	1	4400
D+82	121	1	4600
D+83	120	1	4800
D+84	119	1	5000
D+85	118	1	5200
D+86	117	1	5400
D+87	116	1	5600
D+88	115	1	6800
D+89	115	0	6000

Table F-5. European scenario for M198 Howitzers, Day 90 to Day 119,

Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	114	1	6200
D+91	113	1	6400
D+92	112	1	6600
D+93	111	1	6800
D+94	110	1	7000
D+95	109	1	7200
D+96	108	1	7400
D+97	107	1	7600
D+98	106	1	7800
D+99	105	1	8000
D+100	104	1	8200
D+101	103	1	8400
D+102	102	1	8600
D+103	101	1	8800
D+104	100	1	9000
D+105	99	1	9200
D+106	99	0	9400
D+107	98	1	9600
D+108	98	0	9800
D+109	97	1	10,000
D+110	97	0	10,200
D+111	96	1	10,400
D+112	96	0	10,600
D+113	95	1	10,800
D+114	95	0	11,000
D+115	94	1	11,200
D+116	94	0	11,400
D+117	93	1	11,600
D+118	93	0	11,800
D+119	92	1	12,000

Table F-6. European scenario for M198 Howitzers, Day 90 to Day 119,

Group 4 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	286	2	200
D+91	284	2	400
D+92	282	2	600
D+93	280	2	800
D+94	278	2	1000
D+95	276	2	1200
D+96	274	2	1400
D+97	272	2	1600
D+98	270	2	1800
D+99	268	2	2000
D+100	266	2	2200
D+101	264	2	2400
D+102	262	2	2600
D+103	260	2	2800
D+104	258	2	3000
D+105	256	2	3200
D+106	254	2	3400
D+107	252	2	3600
D+108	250	2	3800
D+109	248	2	4000
D+110	246	2	4200
D+111	244	2	4400
D+112	242	2	4600
D+113	240	2	4800
D+114	238	2	5000
D+115	236	2	5200
D+116	234	2	5400
D+117	232	2	5600
D+118	231	1	5800
D+119	230	1	6000

APPENDIX G
EUROPEAN SCENARIO:
TUBE USEAGE TABLES FOR THE M110A2 HOWITZER TUBE
(STATUS QUO)

Forces Group No. 1

The forces of Group No. 1 arrive D-Day and stay through D+119 for a total of 120 days. There are 84 M110A2 Howitzers in Group No. 1. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D-Day through D+29 is 100 rounds per day. Forty percent of artillery is lost in the first 3 days. Twenty percent of remaining artillery is lost by D+29. No tubes are changed.

There are 40 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+30. The firing rate for D+30 through D+59 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 32 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+60. The firing rate for D+60 through D+89 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. Thirty tubes are changed on D+66.

There are 26 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+90. The firing rate for D+90 through D+119 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 2

The forces of Group No. 2 arrive D+30 and stay through D+119 for a total of 90 days. There are 96 M110A2 Howitzers in Group No. 2. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D+30 through D+59 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 77 M110A2 Howitzers remaining in Group No. 2 at the beginning of D+60. The firing rate for D+60 through D+89 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 62 M110A2 Howitzers remaining in Group No. 2 at the beginning of D+90. The firing rate for D+90 through D+119 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. Fifty-four tubes are changed on D+106.

Forces Group No. 3

The forces of Group No. 3 arrive D+60 and stay through D+119 for a total of 60 days. There are 144 M110A2 Howitzers in Group No. 3. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D+60 through D+89 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 115 M110A2 Howitzers remaining in Group No. 3 at the beginning of D+90. The firing rate for D+90 through D+119 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 4

The forces of Group No. 4 arrive D+90 and stay through D+119 for a total of 30 days. There are 108 M110A2 Howitzers in Group No. 4. The rate of fire for D+90 through D+119 is 75 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Table G-1. European scenario for M110A2 Howitzers, D-Day to Day 29,
Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D-Day	50	34	100
D+1	50	0	299
D+2	50	0	300
D+3	49	1	400
D+4	48	1	500
D+5	48	0	600
D+6	47	1	700
D+7	47	0	800
D+8	47	0	900
D+9	46	1	1000
D+10	46	0	1100
D+11	46	0	1200
D+12	45	1	1300
D+13	45	0	1400
D+14	45	0	1500
D+15	44	1	1600
D+16	44	0	1700
D+17	44	0	1800
D+18	43	1	1900
D+19	43	0	2000
D+20	43	0	2100
D+21	42	1	2200
D+22	42	0	2300
D+23	42	0	2400
D+24	41	1	2500
D+25	41	0	2600
D+26	41	0	2700
D+27	40	1	2800
D+28	40	0	2900
D+29	40	0	3000

Table G-2. European scenario for M110A2 Howitzers, Day 30 to Day 59,

Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+30	39	1	3100
D+31	39	0	3200
D+32	39	0	3300
D+33	38	1	3400
D+34	38	0	3500
D+35	38	0	3600
D+36	37	1	3700
D+37	37	0	3800
D+38	37	0	3900
D+39	36	1	4000
D+40	36	0	4100
D+41	36	0	4200
D+42	36	0	4300
D+43	35	1	4400
D+44	35	0	4500
D+45	35	0	4600
D+46	35	0	4700
D+47	34	1	4800
D+48	34	0	4900
D+49	34	0	5000
D+50	34	0	5100
D+51	33	1	5200
D+52	33	0	5300
D+53	33	0	5400
D+54	33	0	5500
D+55	32	1	5600
D+56	32	0	5700
D+57	32	0	5800
D+58	32	0	5900
D+59	32	0	6000

Table G-3. European scenario for M110A2 Howitzers, Day 60 to Day 59,

Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	31	1	6075
D+61	31	0	6150
D+62	31	0	6225
D+63	31	0	6300
D+64	31	0	6375
D+65	30	1	6450
D+66	30	0	6525
D+67	30	0	75
D+68	30	0	150
D+69	30	0	225
D+70	29	1	300
D+71	29	0	375
D+72	29	0	450
D+73	29	0	525
D+74	29	0	600
D+75	28	1	675
D+76	28	0	750
D+77	28	0	825
D+78	28	0	900
D+79	28	0	975
D+80	27	1	1050
D+81	27	0	1125
D+82	27	0	1200
D+83	27	0	1275
D+84	27	0	1350
D+85	26	1	1425
D+86	26	0	1500
D+87	26	0	1575
D+88	26	0	1650
D+89	26	0	1725

Table G-4. European scenario for M110A2 Howitzers, Day 90 to Day 119

Group 1 forces

Day	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	25	1	1800
D+91	25	0	1875
D+92	25	0	1950
D+93	25	0	2025
D+94	25	0	2100
D+95	25	0	2175
D+96	24	1	2250
D+97	24	0	2325
D+98	24	0	2400
D+99	24	0	2475
D+100	24	0	2550
D+101	24	0	2625
D+102	23	1	2700
D+103	23	0	2775
D+104	23	0	2850
D+105	23	0	2925
D+106	23	0	3000
D+107	23	0	3075
D+108	22	1	3150
D+109	22	0	3225
D+110	22	0	3300
D+111	22	0	3375
D+112	22	0	3450
D+113	22	0	3525
D+114	21	1	3600
D+115	21	0	3675
D+116	21	0	3750
D+117	21	0	3825
D+118	21	0	3900
D+119	21	0	3975

Table G-5. European scenario for M110A2 Howitzers, Day 30 to Day 59,

Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+30	95	1	100
D+31	94	1	200
D+32	93	1	300
D+33	92	1	400
D+34	91	1	500
D+35	90	1	600
D+36	89	1	700
D+37	88	1	800
D+38	87	1	900
D+39	86	1	1000
D+40	86	0	1100
D+41	85	1	1200
D+42	85	0	1300
D+43	84	1	1400
D+44	84	0	1500
D+45	83	1	1600
D+46	83	0	1700
D+47	82	1	1800
D+48	82	0	1900
D+49	81	1	2000
D+50	81	0	2100
D+51	80	1	2200
D+52	80	0	2300
D+53	79	1	2400
D+54	79	0	2500
D+55	78	1	2600
D+56	78	0	2700
D+57	77	1	2800
D+58	77	0	2900
D+59	77	0	3000

Table G-6. European scenario for M110A2 Howitzers, Day 60 to Day 89,

Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	76	1	3075
D+61	76	0	3150
D+62	75	1	3225
D+63	75	0	3300
D+64	74	1	3375
D+65	74	0	3450
D+66	73	1	3525
D+67	73	0	3600
D+68	72	1	3675
D+69	72	0	3750
D+70	71	1	3825
D+71	71	0	3900
D+72	70	1	3975
D+73	70	0	4050
D+74	69	1	4125
D+75	69	0	4200
D+76	68	1	4275
D+77	68	0	4350
D+78	67	1	4425
D+79	67	0	4500
D+80	66	1	4575
D+81	66	0	4650
D+82	65	1	4725
D+83	65	0	4800
D+84	64	1	4875
D+85	64	0	4950
D+86	63	1	5025
D+87	63	0	5100
D+88	62	1	5175
D+89	62	0	5250

Table G-7. European scenario for M110A2 Howitzers, Day 90 to Day 119

Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	61	1	5325
D+91	61	0	5400
D+92	60	1	5475
D+93	60	0	5550
D+94	59	1	5625
D+95	59	0	5700
D+96	58	1	5775
D+97	58	0	5850
D+98	57	1	5925
D+99	57	0	6000
D+100	56	1	6075
D+101	56	0	6150
D+102	55	1	6225
D+103	55	0	6300
D+104	54	1	6375
D+105	54	0	6450
D+106	54	0	6525
D+107	53	1	75
D+108	53	0	150
D+109	53	0	225
D+110	52	1	300
D+111	52	0	375
D+112	52	0	450
D+113	51	1	525
D+114	51	0	600
D+115	51	0	675
D+116	50	1	750
D+117	50	0	825
D+118	50	0	900
D+119	50	0	975

Table G-8. European scenario for M110A2 Howitzers, Day 60 to Day 89,

Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	143	1	75
D+61	142	1	150
D+62	141	1	225
D+63	140	1	300
D+64	139	1	375
D+65	138	1	450
D+66	137	1	525
D+67	136	1	600
D+68	135	1	675
D+69	134	1	750
D+70	133	1	825
D+71	132	1	900
D+72	131	1	975
D+73	130	1	1050
D+74	129	1	1125
D+75	128	1	1200
D+76	127	1	1275
D+77	126	1	1350
D+78	125	1	1425
D+79	124	1	1500
D+80	123	1	1575
D+81	122	1	1650
D+82	121	1	1725
D+83	120	1	1800
D+84	119	1	1875
D+85	118	1	1950
D+86	117	1	2025
D+87	116	1	2100
D+88	115	1	2175
D+89	115	0	2250

Table G-9. European scenario for M110A2 Howitzers, Day 90 to Day 119

Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	114	1	2325
D+91	113	1	2400
D+92	112	1	2475
D+93	111	1	2550
D+94	110	1	2625
D+95	109	1	2700
D+96	108	1	2775
D+97	107	1	2850
D+98	106	1	2925
D+99	105	1	3000
D+100	104	1	3075
D+101	103	1	3150
D+102	102	1	3225
D+103	101	1	3300
D+104	100	1	3375
D+105	99	1	3450
D+106	98	1	3525
D+107	98	0	3600
D+108	97	1	3675
D+109	97	0	3750
D+110	96	1	3825
D+111	96	0	3900
D+112	95	1	3975
D+113	95	0	4050
D+114	94	1	4125
D+115	94	0	4200
D+116	93	1	4275
D+117	93	0	4350
D+118	92	1	4425
D+119	92	0	4500

Table G-10. European scenario for M110A2 Howitzers, Day 90 to Day 119

Group 4 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	107	1	75
D+91	106	1	105
D+92	105	1	225
D+93	104	1	300
D+94	103	1	375
D+95	102	1	450
D+96	101	1	525
D+97	100	1	600
D+98	99	1	675
D+99	98	1	750
D+100	97	1	825
D+101	96	1	900
D+102	95	1	975
D+103	94	1	1050
D+104	94	0	1125
D+105	93	1	1200
D+106	93	0	1275
D+107	92	1	1350
D+108	92	0	1425
D+109	91	1	1500
D+110	91	0	1575
D+111	90	1	1650
D+112	90	0	1725
D+113	89	1	1800
D+114	89	0	1875
D+115	88	1	1950
D+116	88	0	2025
D+117	87	1	2100
D+118	87	0	2175
D+119	86	1	2250

APPENDIX H
EUROPEAN SCENARIO:
COST OF ALTERNATIVES AND SAVINGS REALIZED

Table H-1: European scenario: Cost of alternatives and savings realized

Altn	M198 Howitzer				M110A2 Howitzer				J. Cost savings * (status quo - I)	
	A. Pct inc for tube cost	B. Difference in cost between current & new tube	C. No. of M198 howitzers in groups no. 1 and no. 2	D. Cost of improving M198's (BXC)	E. Pct inc for tube cost	F. Difference in cost between current & new tube	G. No. of M110A2 howitzers in groups no. 1 and no. 2	H. Cost of improving M110A2's (FXG)		I. Cost of the altn D+H
1	15	2255	108	243,540	5	2009	180	361,620	605,160	3,597,053
2	25	3759	108	405,972	10	4018	180	723,240	1,129,212	3,073,001
3	35	5262	108	568,296	15	6027	180	1,084,860	1,653,156	2,549,057

* Recall the cost of the status quo is calculated to be \$4,202,213 (see page 20).

APPENDIX I
EUROPEAN SCENARIO SENSITIVITY ANALYSIS:
TUBE USEAGE TABLES FOR THE M198 HOWITZER TUBE
(STATUS QUO)

Forces Group No. 1

The forces of Group No. 1 arrive D-Day and stay through D+119 for a total of 120 days.

There are no M198 Howitzers in this Group.

Forces Group No. 2

The forces of Group No. 2 arrive D+30 and stay through D+119 for a total of 90 days. There are 108 M198 Howitzers in Group No. 2. A tube is changed when the wear life (17,787 rounds) is reached. The rate of fire for D+30 through D+59 is 300 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 86 M198 Howitzers remaining in Group No. 2 at the beginning of D+60. The firing rate for D+60 through D+89 is 300 rounds per day. Twenty percent of artillery is lost in the 30-day period. Sixty-nine tubes are changed on D+89.

There are 69 M198 Howitzers remaining in Group No. 2 at the beginning of D+90. The firing rate for D+90 through D+119 is 300 rounds per day. Twenty percent of the artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 3

The forces of Group No. 3 arrive D+60 and stay through D+119 for a total of 60 days. There are 144 M198 Howitzers in Group No. 3. The rate of fire for D+60 through D+89 is 300 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 115 M198 Howitzers remaining in Group No. 3 at the beginning of D+90. The firing rate for D+90 through D+119 is 300 rounds per day. Twenty percent of artillery is lost in the 30-day period. Ninety-two tubes are changed on D+119.

Forces Group No. 4

The forces of Group No. 4 arrive D+90 and stay through D+119 for a total of 30 days. There are 288 M198 Howitzers in forces Group No. 4. The rate of fire for D+90 through D+119 is 300 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Table I-1. Sensitivity analysis, European scenario,
M198 howitzers, day 30 to day 59, group 2 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+30	107	1	300
D+31	106	1	600
D+32	105	1	900
D+33	104	1	1200
D+34	103	1	1500
D+35	102	1	1800
D+36	101	1	2100
D+37	100	1	2400
D+38	99	1	2700
D+39	98	1	3000
D+40	97	1	3300
D+41	96	1	3600
D+42	95	1	3900
D+43	94	1	4200
D+44	94	0	4500
D+45	93	1	4800
D+46	93	0	5100
D+47	92	1	5400
D+48	92	0	5700
D+49	91	1	6000
D+50	91	0	6300
D+51	90	1	6600
D+52	90	0	6900
D+53	89	1	7200
D+54	89	0	7500
D+55	88	1	7800
D+56	88	0	8100
D+57	87	1	8400
D+58	87	0	8700
D+59	86	1	9000

Table I-2. Sensitivity analysis, European scenario,
M198 howitzers, day 60 to day 89, group 2 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+60	85	1	9300
D+61	84	1	9600
D+62	83	1	9900
D+63	82	1	10200
D+64	81	1	10500
D+65	81	0	10800
D+66	80	1	11100
D+67	80	0	11400
D+68	79	1	11700
D+69	79	0	12000
D+70	78	1	12300
D+71	78	0	12600
D+72	77	1	12900
D+73	77	0	13200
D+74	76	1	13500
D+75	76	0	13800
D+76	75	1	14100
D+77	75	0	14400
D+78	74	1	14700
D+79	74	0	15000
D+80	73	1	15300
D+81	73	0	15600
D+82	72	1	15900
D+83	72	0	16200
D+84	71	1	16500
D+85	71	0	16800
D+86	70	1	17100
D+87	70	0	17400
D+88	69	1	17700
D+89	69	0	18000

Table I-3. Sensitivity analysis, European scenario,
M198 howitzers, day 90 to day 119, group 2 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+90	68	1	300
D+91	68	0	600
D+92	67	1	900
D+93	67	0	1200
D+94	66	1	1500
D+95	66	0	1800
D+96	65	1	2100
D+97	65	0	2400
D+98	64	1	2700
D+99	64	0	3000
D+100	63	1	3300
D+101	63	0	3600
D+102	62	1	3900
D+103	62	0	4200
D+104	61	1	4500
D+105	61	0	4800
D+106	60	1	5100
D+107	60	0	5400
D+108	59	1	5700
D+109	59	0	6000
D+110	58	1	6300
D+111	58	0	6600
D+112	57	1	6900
D+113	57	0	7200
D+114	56	1	7500
D+115	56	0	7800
D+116	56	0	8100
D+117	55	1	8400
D+118	55	0	8700
D+119	55	0	9000

Table I-4. Sensitivity analysis, European scenario,
M198 howitzers, day 60 to day 89, group 3 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+60	143	1	300
D+61	142	1	600
D+62	141	1	900
D+63	140	1	1200
D+64	139	1	1500
D+65	138	1	1800
D+66	137	1	2100
D+67	136	1	2400
D+68	135	1	2700
D+69	134	1	3000
D+70	133	1	3300
D+71	132	1	3600
D+72	131	1	3900
D+73	130	1	4200
D+74	129	1	4500
D+75	128	1	4800
D+76	127	1	5100
D+77	126	1	5400
D+78	125	1	5700
D+79	124	1	6000
D+80	123	1	6300
D+81	122	1	6600
D+82	121	1	6900
D+83	120	1	7200
D+84	119	1	7500
D+85	118	1	7800
D+86	117	1	8100
D+87	116	1	8400
D+88	115	1	8700
D+89	115	0	9000

Table I-5. Sensitivity analysis, European scenario,
M198 howitzers, day 90 to day 119, group 3 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+90	114	1	9300
D+91	113	1	9600
D+92	112	1	9900
D+93	111	1	10200
D+94	110	1	10500
D+95	109	1	10800
D+96	108	1	11100
D+97	107	1	11400
D+98	106	1	11700
D+99	105	1	12000
D+100	104	1	12300
D+101	103	1	12600
D+102	102	1	12900
D+103	101	1	13200
D+104	100	1	13500
D+105	99	1	13800
D+106	99	0	14100
D+107	98	1	14400
D+108	98	0	14700
D+109	97	1	15000
D+110	97	0	15300
D+111	96	1	15600
D+112	96	0	15900
D+113	95	1	16200
D+114	95	0	16500
D+115	94	1	16800
D+116	94	0	17100
D+117	93	1	17400
D+118	93	0	17700
D+119	92	1	18000

Table I-6. Sensitivity analysis, European scenario,
M198 howitzers, day 90 to day 119, group 4 forces

<u>Day</u>	<u>Operating howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating howitzer</u>
D+90	286	2	300
D+91	284	2	600
D+92	282	2	900
D+93	280	2	1200
D+94	278	2	1500
D+95	276	2	1800
D+96	274	2	2100
D+97	272	2	2400
D+98	270	2	2700
D+99	268	2	3000
D+100	266	2	3300
D+101	264	2	3600
D+102	262	2	3900
D+103	260	2	4200
D+104	258	2	4500
D+105	256	2	4800
D+106	254	2	5100
D+107	252	2	5400
D+108	250	2	5700
D+109	248	2	6000
D+110	246	2	6300
D+111	244	2	6600
D+112	242	2	6900
D+113	240	2	7200
D+114	238	2	7500
D+115	236	2	7800
D+116	234	2	8100
D+117	232	2	8400
D+118	231	1	8700
D+119	230	1	9000

APPENDIX J
EUROPEAN SCENARIO SENSITIVITY ANALYSIS:
TUBE USEAGE TABLES FOR THE M110A2 HOWITZER TUBE
(STATUS QUO)

Forces Group No. 1

The forces of Group No. 1 arrive D-Day and stay through D+119 for a total of 120 days. There are 84 M110A2 Howitzers in Group No. 1. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D-Day through D+29 is 150 rounds per day. Forty percent of artillery is lost in the first 3 days. Twenty percent of remaining artillery is lost by D+29. No tubes are changed.

There are 40 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+30. The firing rate for D+30 through D+59 is 150 rounds per day. Twenty percent of artillery is lost in the 30-day period. Thirty-five tubes are changed on D+43.

There are 32 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+60. The firing rate for D+60 through D+89 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 26 M110A2 Howitzers remaining in Group No. 1 at the beginning of D+90. The firing rate for D+90 through D+119 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. Twenty-four tubes are changed on D+100.

Forces Group No. 2

The forces of Group No. 2 arrive D+30 and stay through D+119 for a total of 90 days. There are 96 M110A2 Howitzers in Group No. 2. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D+30 through D+59 is 150 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 77 M110A2 Howitzers remaining in Group No. 2 at the beginning of D+60. The firing rate for D+60 through D+89 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. Sixty-seven tubes are changed on D+79.

There are 62 M110A2 Howitzers remaining in Group No. 2 at the beginning of D+90. The firing rate for D+90 through D+119 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 3

The forces of Group No. 3 arrive D+60 and stay through D+119 for a total of 60 days. There are 144 M110A2 Howitzers in Group No. 3. A tube is changed when the wear life (6,490 rounds) is reached. The rate of fire for D+60 through D+89 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

There are 115 M110A2 Howitzers remaining in Group No. 3 at the beginning of D+90. The firing rate for D+90 through D+119 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Forces Group No. 4

The forces of Group No. 4 arrive D+90 and stay through D+119 for a total of 30 days. There are 108 M110A2 Howitzers in Group No. 4. The rate of fire for D+90 through D+119 is 100 rounds per day. Twenty percent of artillery is lost in the 30-day period. No tubes are changed.

Table J-1. Sensitivity analysis, European scenario, M110A2 Howitzers,
D-Day to Day 29, Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D-Day	50	34	150
D+1	50	0	300
D+2	50	0	450
D+3	49	1	600
D+4	48	1	750
D+5	48	0	900
D+6	47	1	1050
D+7	47	0	1200
D+8	47	0	1350
D+9	46	1	1500
D+10	46	0	1650
D+11	46	0	1800
D+12	45	1	1950
D+13	45	0	2100
D+14	45	0	2250
D+15	44	1	2400
D+16	44	0	2550
D+17	44	0	2700
D+18	43	1	2850
D+19	43	0	3000
D+20	43	0	3150
D+21	42	1	3300
D+22	42	0	3450
D+23	42	0	3600
D+24	41	1	3750
D+25	41	0	3900
D+26	41	0	4050
D+27	40	1	4200
D+28	40	0	4350
D+29	40	0	4500

Table J-2. Sensitivity analysis, European scenario, M110A2 Howitzers,
 Day 30 to Day 59, Group 1 forces

<u>Day</u>	<u>Operating Howtizers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+30	39	1	4650
D+31	39	0	4800
D+32	39	0	4950
D+33	38	1	5100
D+34	38	0	5250
D+35	38	0	5400
D+36	37	1	5550
D+37	37	0	5700
D+38	37	0	5850
D+39	36	1	6000
D+40	36	0	6150
D+41	36	0	6300
D+42	36	0	6450
D+43	35	1	6600
D+44	35	0	150
D+45	35	0	300
D+46	35	0	450
D+47	34	1	600
D+48	34	0	750
D+49	34	0	900
D+50	34	0	1050
D+51	33	1	1200
D+52	33	0	1350
D+53	33	0	1500
D+54	33	0	1650
D+55	32	1	1800
D+56	32	0	1950
D+57	32	0	2100
D+58	32	0	2250
D+59	32	0	2400

Table J-3. Sensitivity analysis, European scenario, M110A2 Howitzers,
Day 60 to Day 89, Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	31	1	2500
D+61	31	0	2600
D+62	31	0	2700
D+63	31	0	2800
D+64	31	0	2900
D+65	30	1	3000
D+66	30	0	3100
D+67	30	0	3200
D+68	30	0	3300
D+69	30	0	3400
D+70	29	1	3500
D+71	29	0	3600
D+72	29	0	3700
D+73	29	0	3800
D+74	29	0	3900
D+75	28	1	4000
D+76	28	0	4100
D+77	28	0	4200
D+78	28	0	4300
D+79	28	0	4400
D+80	27	1	4500
D+81	27	0	4600
D+82	27	0	4700
D+83	27	0	4800
D+84	27	0	4900
D+85	26	1	5000
D+86	26	0	5100
D+87	26	0	5200
D+88	26	0	5300
D+89	26	0	5400

Table J-4. Sensitivity analysis, European scenario, M110A2 Howitzers,
Day 90 to Day 119, Group 1 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	25	1	5500
D+91	25	0	5600
D+92	25	0	5700
D+93	25	0	5900
D+94	25	0	5900
D+95	25	0	6000
D+96	24	1	6100
D+97	24	0	6200
D+98	24	0	6300
D+99	24	0	6400
D+100	24	0	6500
D+101	24	0	100
D+102	23	1	200
D+103	23	0	300
D+104	23	0	400
D+105	23	0	500
D+106	23	0	600
D+107	23	0	700
D+108	22	1	800
D+109	22	0	900
D+110	22	0	1000
D+111	22	0	1100
D+112	22	0	1200
D+113	22	0	1300
D+114	21	1	1400
D+115	21	0	1500
D+116	21	0	1600
D+117	21	0	1700
D+118	21	0	1800
D+119	21	0	1900

Table J-5. Sensitivity analysis, European scenario M110A2 Howitzers,
Day 30 to Day 59, Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+30	95	1	150
D+31	94	1	300
D+32	93	1	450
D+33	92	1	600
D+34	91	1	750
D+35	90	1	900
D+36	89	1	1050
D+37	88	1	1200
D+38	87	1	1350
D+39	86	1	1500
D+40	86	0	1650
D+41	85	1	1800
D+42	85	0	1950
D+43	84	1	2100
D+44	84	0	2250
D+45	83	1	2400
D+46	83	0	2550
D+47	82	1	2700
D+48	82	0	2850
D+49	81	1	3000
D+50	81	0	3150
D+51	80	1	3300
D+52	80	0	3450
D+53	79	1	3600
D+54	79	0	3750
D+55	78	1	3900
D+56	78	0	4050
D+57	77	1	4200
D+58	77	0	4350
D+59	77	0	4500

Table J-6. Sensitivity analysis, European scenario, M110A2 Howitzers,

Day 60 to Day 89, Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	76	1	4600
D+61	76	0	4700
D+62	75	1	4800
D+63	75	0	4900
D+64	74	1	5000
D+65	74	0	5100
D+66	73	1	5200
D+67	73	0	5300
D+68	72	1	5400
D+69	72	0	5500
D+70	71	1	5600
D+71	71	0	5700
D+72	70	1	5800
D+73	70	0	5900
D+74	69	1	6000
D+75	69	0	6100
D+76	68	1	6200
D+77	68	0	6300
D+78	67	1	6400
D+79	67	0	6500
D+80	66	1	100
D+81	66	0	200
D+82	65	1	300
D+83	65	0	400
D+84	64	1	500
D+85	64	0	600
D+86	63	1	700
D+87	63	0	800
D+88	62	1	900
D+89	62	0	1000

Table J-7. Sensitivity analysis, European scenario, M110A2 Howitzers,
Day 90 to Day 119, Group 2 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	61	1	1100
D+91	61	0	1200
D+92	60	1	1300
D+93	60	0	1400
D+94	59	1	1500
D+95	59	0	1600
D+96	58	1	1700
D+97	58	0	1800
D+98	57	1	1900
D+99	57	0	2000
D+100	56	1	2100
D+101	56	0	2200
D+102	55	1	2300
D+103	55	0	2400
D+104	54	1	2500
D+105	54	0	2600
D+106	54	0	2700
D+107	53	1	2800
D+108	53	0	2900
D+109	53	0	3000
D+110	52	1	3100
D+111	52	0	3200
D+112	52	0	3300
D+113	51	1	3400
D+114	51	0	3500
D+115	51	0	3600
D+116	50	1	3700
D+117	50	0	3800
D+118	50	0	3900
D+119	50	0	4000

Table J-8. Sensitivity analysis, European scenario, M110A2 Howitzers,
Day 60 to Day 89, Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+60	143	1	100
D+61	142	1	200
D+62	141	1	300
D+63	140	1	400
D+64	139	1	500
D+65	138	1	600
D+66	137	1	700
D+67	136	1	800
D+68	135	1	900
D+69	134	1	1000
D+70	133	1	1100
D+71	132	1	1200
D+72	131	1	1300
D+73	130	1	1400
D+74	129	1	1500
D+75	128	1	1600
D+76	127	1	1700
D+77	126	1	1800
D+78	125	1	1900
D+79	124	1	2000
D+80	123	1	2100
D+81	122	1	2200
D+82	121	1	2300
D+83	120	1	2400
D+84	119	1	2500
D+85	118	1	2600
D+86	117	1	2700
D+87	116	1	2800
D+88	115	1	2900
D+89	115	0	3000

Table J-9. Sensitivity analysis, European scenario, M110A2 Howitzers,

Day 90 to Day 119, Group 3 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	114	1	3100
D+91	113	1	3200
D+92	112	1	3300
D+93	111	1	3400
D+94	110	1	3500
D+95	109	1	3600
D+96	108	1	3700
D+97	107	1	3800
D+98	106	1	3900
D+99	105	1	4000
D+100	104	1	4100
D+101	103	1	4200
D+102	102	1	4300
D+103	101	1	4400
D+104	100	1	4500
D+105	99	1	4600
D+106	98	1	4700
D+107	98	0	4800
D+108	97	1	4900
D+109	97	0	5000
D+110	96	1	5100
D+111	96	0	5200
D+112	95	1	5300
D+113	95	0	5400
D+114	94	1	5500
D+115	94	0	5600
D+116	93	1	5700
D+117	93	0	5800
D+118	92	1	5900
D+119	92	0	6000

Table J-10. Sensitivity analysis, European scenario, M110A2 Howitzers,
Day 90 to Day 119, Group 4 forces

<u>Day</u>	<u>Operating Howitzers remaining in battle at end of day</u>	<u>Howitzers lost by end of day</u>	<u>Cumulative rounds fired for each operating Howitzer</u>
D+90	107	1	100
D+91	106	1	200
D+92	105	1	300
D+93	104	1	400
D+94	103	1	500
D+95	102	1	600
D+96	101	1	700
D+97	100	1	800
D+98	99	1	900
D+99	98	1	1000
D+100	97	1	1100
D+101	96	1	1200
D+102	95	1	1300
D+103	94	1	1400
D+104	94	0	1500
D+105	93	1	1600
D+106	93	0	1700
D+107	92	1	1800
D+108	92	0	1900
D+109	91	1	2000
D+110	91	0	2100
D+111	90	1	2200
D+112	90	0	2300
D+113	89	1	2400
D+114	89	0	2500
D+115	88	1	2600
D+116	88	0	2700
D+117	87	1	2800
D+118	87	0	2900
D+119	86	1	3000

APPENDIX K
EUROPEAN SCENARIO SENSITIVITY ANALYSIS:
COST OF ALTERNATIVES AND SAVINGS REALIZED

Table K-1. European scenario sensitivity analysis:
 Cost of alternatives and savings realized

Altn	M198 Howitzer				M110A2 Howitzer				I. Cost of the altn D+H	J. Cost savings (status quo -I) *
	A. Pct inc for tube cost	B. Difference in cost between current & new tube	C. No. of M198 howitzers in groups no. 1 and no. 2	D. Cost of improving M198's (BXC)	E. Pct inc for tube cost	F. Difference in cost between current & new tube	G. No. of M110A2 howitzers in groups no. 1 and no. 2	H. Cost of improving M110A2's (FXG)		
1	15	2255	252	568,260	5	2009	180	361,620	929,880	6,553,687
2	25	3759	252	947,268	10	4018	180	723,240	1,670,508	5,813,059
3	35	5262	252	1,326,024	15	6027	180	1,084,860	2,410,884	5,072,683

* The cost of the status quo is \$7,483,567 (see page 21).

APPENDIX L
COMBINED WARTIME/PEACETIME ANALYSIS:
R&D EXPENDITURES YIELDING A 10% RETURN ON INVESTMENT

TABLE L-1: Wartime/Peacetime Combined Analysis

<u>Peacetime Alternative/Variation</u> ¹	<u>Wartime Alternative</u> ²	<u># Years of Benefit</u>	<u>Investment³ that Yields a 10% Return</u>
I/C	3	10	3,960,266
I/C	3	15	4,424,385
I/C	3	20	4,712,687
VI/A	1	10	6,780,889
VI/A	1	15	7,719,642
VI/A	1	20	8,302,781

¹Alternative I/C has the lowest Annual Cost Savings (see Appendix B - Column H); Alternative VI/A has the highest Annual Cost Savings (see Appendix B - Column H).

²Alternative 3 has the lowest cost savings; Alternative 1 has the highest cost savings (see Appendix I - Column J).

³See page M-3 for an example of how these investments are calculated.

TABLE L-2: Wartime/Peacetime Combined Sensitivity Analysis

<u>Peacetime Alternative/Variation</u> ¹	<u>Wartime Alternative</u> ²	<u># Years of Benefit</u>	<u>Investment that Yields a 10% Return</u>
I/C	3	10	7,900,473
I/C	3	15	8,828,708
I/C	3	20	9,405,312
VI/A	1	10	13,056,697
VI/A	1	15	14,934,204
VI/A	1	20	16,100,480

¹ Alternative I/C has the lowest Annual Cost Savings for the Sensitivity Analysis; Alternative VI/A has the highest annual cost savings. (See Appendix D - Column H)

² Alternative 3 has the lowest cost savings; Alternative has the highest cost savings (see Appendix L - Column J).

Computations for the investments for the wartime/peacetime combined analysis are performed very much like the computations for the separate wartime and peacetime analysis. The following example illustrates how the investment of \$3,960,266 (page 111, 1st entry) is calculated:

$$\text{Investment } \{ .566D_1 + .334D_2 + .090D_3 \} = \text{Wartime Savings } (D_4) \\ + (\text{Peacetime Savings}) (D_5 + D_6 + \dots + D_{14})$$

$$I \{ .566(.954) + .344(.867) + .090(.788) \} = 2,549,057 (.717) \\ + 402,619 (4.403)$$

$$I = 3,960,266$$

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