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INERT CARRIER PROCESS APPLICATION TO HMX NITROLYSIS AND RECRYSTALLIZATION

Volume III: HMX Economic Analysis

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SUMMARY

This report covers the economic analysis work performed under task III of contract No. DAAA21-75-C-0251. The analysis is an order of magnitude cost analysis for the manufacture of HMX by the DADN process and the purification and recrystallization of that HMX. The analysis is based on the use of the ICP techniques for both the manufacture and the recrystallization of HMX, and includes the cost of acid plants for reconstituting the spent acids and for pollution control.

The DADN-HMX manufacturing process is based on a new chemical system developed by the Feltman Research Laboratories, Picatinny Arsenal. This system has three steps. Hexamine is acetylated to DAPT, which is converted to DADN by a nitric acid-sulfuric acid nitrolysis medium in the second step. The DADN is converted to HMX in a nitric acid-polyphosphoric acid nitrolysis medium in the third step. The purification and recrystallization of the crude HMX is based on a solvent-nonsolvent precipitation system using DMSO and water which produces beta polymorph HMX crystals in controlled sizes.

Operating and capital costs are derived for production rates of 500,000 and 2,000,000 lb of HMX/month under two different processing conditions and the recrystallization of crude HMX to class 4 and class 5 size crystals. These costs are used in preparing economic analyses in accordance with AR 37-13, format A.

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INTRODUCTION

The economic analysis presented in this volume is based on CSD estimates of facility and operating costs, product yields (based on pilot plant runs and laboratory results), and utilities and labor requirements. Costs for pollution control are included.

The objectives of this volume are to present:

- A. An estimate of the cost of producing HMX by the DADN process in ICP plants sized to produce both 500,000 and 2,000,000 lb of HMX/month based on the current DADN state of the art ("current process").
- B. The estimates of economic benefits of obvious improvements to the process which can be incorporated during pilot plant process engineering studies ("optimized process").
- C. Estimates of capital costs for manufacturing lines, supporting acid plants, and recrystallization lines for the processing conditions outlined in A and B above for both production rates.
- D. Estimates of the capital expenditures and program costs for an 18-year DADN-HMX process development and manufacturing program. This includes estimates of both "inside battery limits" and "outside battery limits" for "grass root" plants producing 500,000 and 2,000,000 lb of HMX/month.

SYSTEM DESCRIPTION

The flow diagram of a 500,000 lb/month HMX production line, shown in figure 1, is the processing system used to develop capital costs. Each of the three chemical reaction steps is conducted in a pair of dispersers. The second disperser of each pair discharges into a separator. Each disperser system consists of a disperser tank, heat exchanger, and pump. Each pair of pumps is served by a seal flush system. These components constitute the basic ICP system and the rest of the equipment indicated in the flow diagram is peripheral equipment and interconnecting plumbing.

Flow rates for each numbered stream in the flow diagram are contained in Tables 5 and 6.

Hexamine (line 1) is metered into disperser No. 1, where it finds a highly agitated two-phase system; the carrier phase and the reactants phase. The reactants phase is in the nature of tiny droplets of material constantly joining and being broken apart to form new droplets. The hexamine and the other reactant streams feeding disperser No. 1 are instantly and intimately mixed. The acetylating agent (line 2), returning carrier (line 21), as well as the one-third product return with NH_3 and H_2O (line 4), are constantly being recirculated through the dispersers which provide stay time for the reaction. The associated heat exchangers remove the heat of reaction as well as the heat introduced from the pumps. The second disperser provides additional stay time for the reaction.

The crude DAPT produced is in an acetic acid solution and goes directly to the next step in the "current process" system, as pictured in the flow diagram. Equipment for the purification of the DAPT used in the "optimized process" is indicated by the dotted lines. In the current process, the crude DAPT is metered into disperser No. 3 (line 8), along with its nitrating acids, 98 percent nitric and 93 percent sulfuric (lines 9, 10). This system is almost exactly the same as the one in the first pair of dispersers. In the optimized process, crystallized DAPT is fed by a solids feeder. Line 25 from both dispersers (as well as line 44 from the third disperser pair)

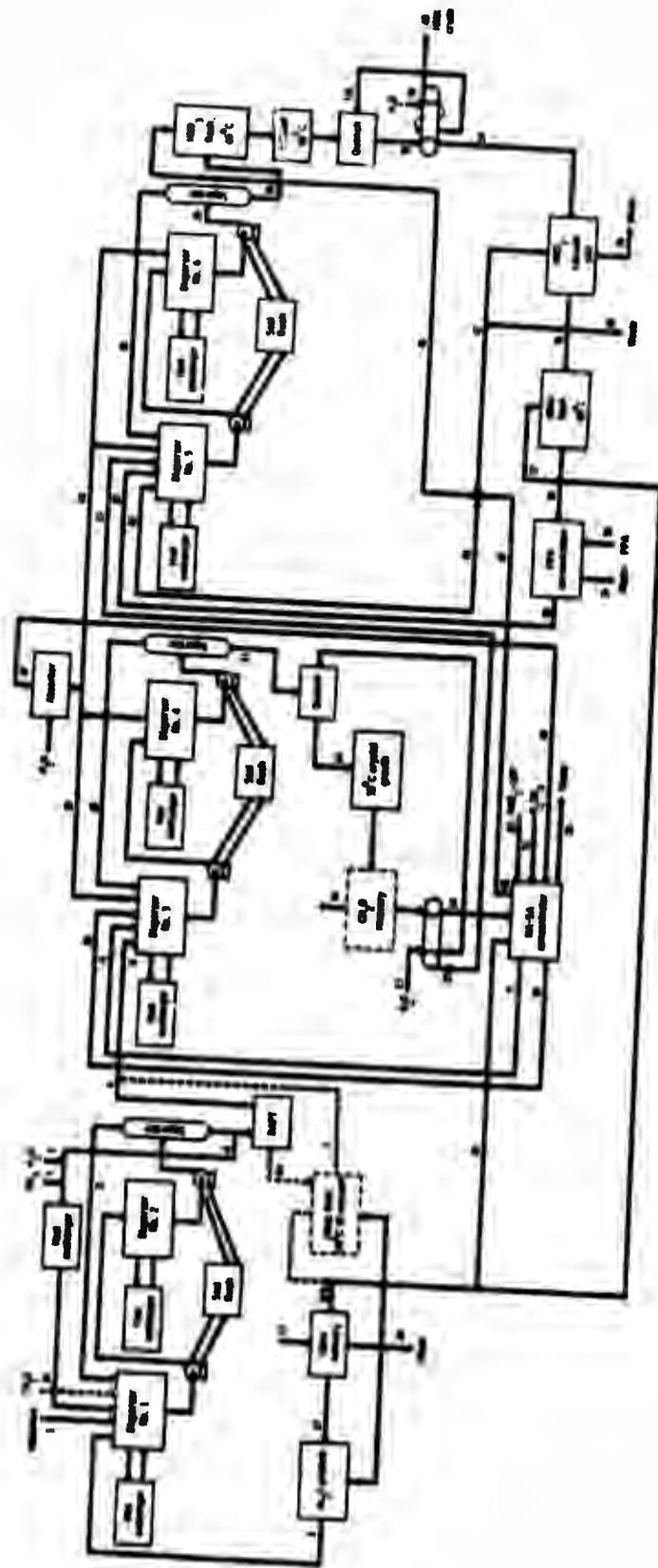


Figure 1. HMX Manufacturing Flow - DADN Process.

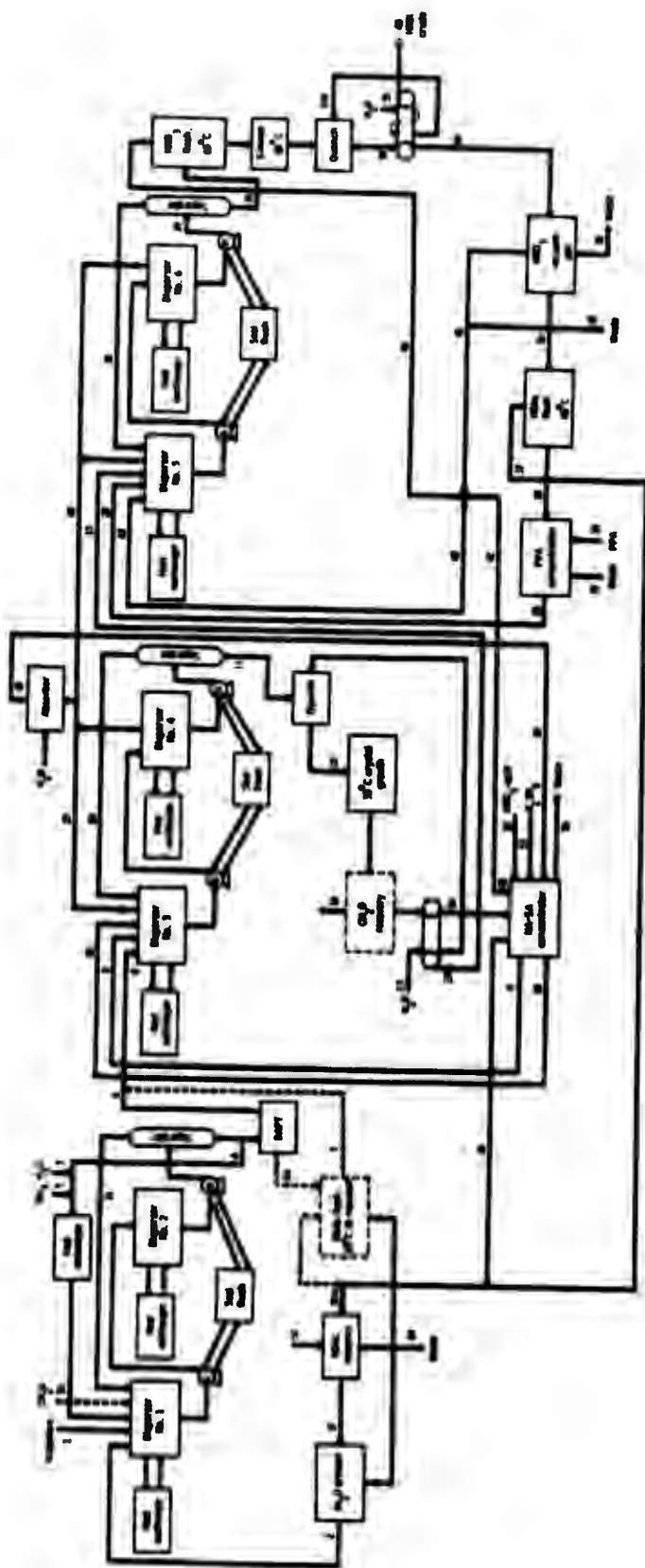


Figure 1. HMX Manufacturing Flow - DADN Process.

carries NO_x to the absorber, which sends 60-percent nitric acid to the concentrator (line 49). The output from the second disperser enters the relatively large diameter separator where turbulent flow ceases and the two liquid phases separate. The lighter heptane phase is returned to the system (line 20) while the mixed acid stream with its product in solution (line 11) enters a water quench which precipitates the product from solution. The product enters a tank by line 12 to promote crystal growth for efficient filtration. The spent acids from the belt filter are sent to the NA-SA concentrator (line 14). The product is washed on the filter to remove acid and then dried. Slightly acidic wash water is used in the quench. In the optimized process, a formaldehyde recovery unit between the crystal growth tank and the belt filter (shown in dotted lines) recovers formaldehyde for recycle to disperser No. 1.

The washed and dried DADN product enters disperser No. 5 in the last phase of the system, the DADN-HMX nitrolysis. The last pair of dispersers are operated as a closed system, under slight pressure (less than 30 psig) with a condenser (not pictured) on line 44 to recover HNO_3 vapors. The solids are metered in along with the nitrolysis agents, PPA and 99 percent nitric acid, through lines 43, 28, and 15. Again, the second disperser of the pair, (No. 6), adds stay time for the reaction. Product/acid is separated (line 31), while carrier is returned to disperser No. 5 by line 30. The product/acid mixture enters a nitric acid flash unit, where about half of the nitric acid is recovered. This saves this acid from having to be quenched and permits the high temperature simmer tank, which follows, to destroy unwanted, and possibly dangerous side products from the reaction. (Simmering could take place after filtration.) After a 1-hr simmer period, the product/acid goes to the quench where the PPA is hydrolyzed, and the HMX comes entirely out of solution.

A belt filter both removes the acid from the product and washes the crude HMX free from most of the acid. The filtered acid is sent for complete

nitric acid removal in the vacuum still, acetic acid removal, and PPA concentration, by line 34. The product, wet with acid solution, leaves the production line by line 48 for storage in preparation for recrystallization to the beta polymorph and the desired crystal size.

STUDY ASSUMPTIONS

The following assumptions are used for this study:

- A. Acid plant capital costs are based on costs developed in CSD report No. 2521-FTR^a. Plant costs are adjusted for needed capacity in accordance with the sixth-tenths rule. Acid plants are sized to meet HMX production line requirements.
- B. Real estate for the plants and associated facilities is available at no cost at present AAPs.
- C. Certain support facilities; such as process water treatment plants, cooling water, electrical generating plants, and power distribution systems; with sufficient capability to support the new HMX plants are in existence and are sunk costs. Estimated plant costs include inside battery limit power and steam and water distribution systems. Site preparation costs are not included.
- D. The HMX plants, and facilities in direct support such as acid plants and pollution control, are grass root facilities constructed specifically for the manufacture of HMX. General supporting facilities are not included in the capital expenditure estimates.
- E. The "grass roots" HMX plant will include all processing steps from receipt of raw material through recrystallization of manufactured HMX.
- F. Product molar yields for each processing step for each of three different levels of the state of the art (i.e., nonoptimized pilot plant; current process plant; and optimized, improved processing plant) are listed in Table 1. Table 2 lists raw material molar requirements per mole of hexamine for each of the yields. Table 3 lists the weights of the various reactants needed to produce 1 lb of HMX for the three different state-of-the-art yields. The current process and optimized process yields are estimates derived

^a CSD Report 2521-FTR, "Comparative Study of Dehydrating Process in the Manufacture of Nitrocellulose," Final Report, Contract No. DAAA21-74-C-0461, 31 July 1975.

TABLE 1. PROCESS STEP MOLAR RATIO YIELDS
(DIFFERING STATES OF THE ART)

Step No.	Step name	Theoretical yield, (percent)	Pilot plant yield, (percent)	Current process yield, ^a (percent)	Optimized Process yield, ^b (percent)
1	Hexamine-DAPT	120	110	110	130
2	DAPT-DADN	100	78	81.8	95
1 to 2	Hexamine-DADN	120	85.8	90	123.5
3	DADN-HMX	100	75 ^c	85	85
4	HMX recrystallization	100	99	99	99
1 through 3	Hexamine to HMX	120	64.4	76.5	105
	Hexamine to recrystallization	120	63.8	75.7	104

^aImprovements over laboratory procedures; improve process conditions, prevent loss of HNO₃ in step 3.

^bImprovements - recycle formaldehyde, step 2 to step 1; reduce sulfuric and nitric acid requirements by purification of DAPT.

^cWhen the economic analysis was started, pilot plant runs for step 3 had not been made. DADN to HMX yields estimated from laboratory data. A yield of 67.5 percent was obtained in pilot plant run P-105. During this run DADN was dissolved in the nitric acid for convenience in feeding into a pressurized system. This resulted in a loss of yield, which amounts to as much as 10 percent according to recent studies at Picatinny. Consequently, the 75 percent is a good estimate.

TABLE 2. MOLAR REQUIREMENTS FOR CHEMICALS PER MOLE OF HEXAMINE
VERSUS VARIATIONS IN YIELDS BY STEP

Step No./ name	Reactant	CSD pilot Plant yield		Current process yield		Optimized process yield	
		In	Out	In	Out	In	Out
1/hexamine to DAPT	Hexamine	1.0		1.0		1.0	
	Acetic anhydride	2.5		2.5		2.67	
	Water	4.0		4.0		4.0	
	Ammonia	.8		.8		1.2	
	DAPT		1.10		1.10		1.30
2/DAPT to DADN	DAPT	1.10		1.10		1.30	
	HNO ₃ (99 percent)	5.0		5.0		3.80	
	H ₂ SO ₄ (93 percent)	20.0		20.0		6.00	
	DADN		.858		.9		1.235
3/DADN to HMX	DADN	.858		.9		1.235	
	HNO ₃	14.47		15.18		20.83	
	PPA ^a	12.15		12.74		17.50	
	HMX		.644		.765		1.05
4/recrystallization	HMX (Alpha)		.644		.765		1.05
	HMX (Beta)				.757		1.04

^a Measured as P₂O₅

TABLE 3. DADN-HMX PROCESSING - RAW MATERIALS NEEDED TO PRODUCE
1 lb OF HMX UNDER DIFFERENT PROCESS BASES

Step No./ name	Reactant	CSD Pilot Plant, (lb)		Current process, (lb)		Optimized process, (lb)	
		In	Out	In	Out	In	Out
1/hexamine to DAPT	Hexamine		.735				
	Acetic anhydride	1.34		1.128		.45	
	Water	.38		.319		.86	
	Ammonia	.071		.06		.23	
	DAPT		1.21		1.02	.071	.88
2/DAPT to DADN	DAPT	1.21		1.02		.88	
	HNO ₃ (99 percent)	1.67		1.41		.78	
	H ₂ SO ₄ (93 percent)	11.04		9.33		2.03	
	DADN		1.3		1.16		1.16
3/DADN to HMX	DADN	1.3		1.16		1.16	
	HNO ₃ (99 percent)	4.83		4.27		1.16	
	PPA (115 percent)	10.87		9.60		4.27	
	HMX		1.0		1.0		1.0
4/recrystallization	HMX (Alpha)	1.0		1.0		1.0	
	HMX (Beta)		.99		.99		.99

- from laboratory work (both at CSD and Picatinny) as well as pilot plant runs during the contract. Costs for laboratory yields or pilot plant are not presented, since they will be higher than the costs for either of the other two bases for calculation.
- G. Raw material, labor, utility, and overhead costs remain constant during the economic life of the plants and are tabulated in Table 4. Raw material cost figures are, in general, those used in "Cost Estimates of DADN-HMX Process"^b. Although these costs may have changed during the past year, they are used to facilitate comparison with the 3 January 1975 study.
 - H. Production rates are computed on the basis of operating 24 hr/day 27.5 days/month, (i.e., 758 lb of HMX/hr for the 500,000 lb/month plant, and 3030 lb of HMX/hr for the 2,000,000 lb/month plant).
 - I. An SAR plant is not needed for the DADN-HMX system, since oleum is not required. Sulfuric acid (93 percent) is used in the nitration of DAPT to DADN.
 - J. Nitric and sulfuric acids will be concentrated in a unit similar to a NAC/SAC. Spent nitric acid will be concentrated to 99 percent, spent sulfuric acid to 93 percent. The capacity of this plant will be defined for this study as the combined output of both concentrated sulfuric acid and concentrated nitric acid. The assumptions are also made that the AOP acid (70-percent nitric acid) added to the system to replace the nitric acid consumed and lost is concentrated in the NA-SA concentrator, and that the nitric acid from the NA-SA concentrator used in the third step (nitrolysis of DADN to HMX) does not contain any sulfuric acid. The cost of such a plant will be the same as for an NAC/SAC of the same output capacity.
 - K. The ICP HMX plant is an automated plant. Remote control and remote monitoring permits operation with a minimum number of operators.

^b "Cost Estimate of DADN-HMX Process," R. W. Hutchinson and R. Motto, Picatinny Arsenal, 3 January 1975.

TABLE 4. COSTS FOR RAW MATERIAL, RECYCLE, UTILITY,
LABOR, AND OVERHEAD

	<u>Cost, (dollars/lb)</u>
<u>Raw Materials</u>	
Hexamine	.2822
Acetic acid (makeup)	.1415
Ammonia	.1001
Sulfuric acid makeup	.0239
Nitric acid makeup	.0439
Polyphosphoric acid makeup	.2529 ^a
Heptane, industrial (42.5¢/gal)	.0749
FC-48 Fluorinert	13.90
Dimethylsulfoxide	.33
<u>Recycle</u>	
Acetic acid recovery	.0185
Acetic acid concentration	.0166
Acetic anhydride production	.0141
Nitric acid	.0029
Sulfuric acid	.0050
Polyphosphoric acid	.00907
Dimethylsulfoxide	.44
<u>Utilities</u>	
Process water	.0519/1000 gal
Cooling water	.01/1000 gal
Steam	2.38/1000 lb
Electricity	.0167/Kw-hr
<u>Labor</u>	
Direct - \$5.50/hr; direct supervision - \$9.25/hr	
<u>Overhead</u>	
150 percent of direct labor cost = \$ 8.25/hr of direct labor	
\$13.88/hr of direct supervision	

^aCurrent cost of commercial and food grade PPA (white acid) is \$.2529/lb FOB at a manufacturing plant in Newark, CA. The Picatinny 3 January 1975 analysis appears to be based on the use of agricultural grade phosphoric acid (black acid) as makeup, which is concentrated in the PPA concentration plant.

- L. One percent of the acids used in the manufacture of HMX by the DADN route are lost to waste water streams due to handling, concentration, and washing of products. This acid loss includes the pollution load generated by the acid plants. Acid losses due to side reactions are in addition to this loss. The pollution load generated by the HMX plant and direct supporting facilities are handled in common integrated pollution control facilities. (Loss of various acids to sewer for modern continuous nitrocellulose manufacturing systems range from .2 to 2.4 percent. A 1-percent loss of all acids is assumed to simplify first cut calculations and to generate ROM capital and operating costs for pollution control equipment).
- M. NO_x fumes are absorbed in an absorbing system with less than 200-ppm NO_x in the discharge. The absorber output consists of a 60-percent nitric acid stream which is concentrated to 99 percent in the NA-SA concentrator.
- N. A facility to concentrate polyphosphoric acid costs one and a half times as much as an NAC/SAC of the same output capacity plus costs of necessary vacuum equipment. This results from the very high temperatures needed to concentrate PPA, the highly corrosive nature of hot PPA, and the apparent need for concentration under vacuum.
- O. Facilities to recover and remove water from acetic acid and the plant to produce acetic anhydride each cost the same as an NAC/SAC of the same daily capacity.
- P. The cost of manufacturing plant accessory equipment is equal to 25 percent of the cost of major items of equipment.
- Q. All plant facility costs are given as 1975 costs; 1975 NAC/SAC and AUP plant costs are used as base costs for all acid plants.
- R. The process improvements that constitute the primary differences between the current process and the optimized process are:
 - 1. Purification of the DAPT by removal of acetic acid, ammonium acetate, water, and anticake without loss of DAPT. This permits marked reduction in the quantity of sulfuric acid needed for DAPT to DADN reaction, as well as a moderate

reduction in the nitric acid. Additionally, nitration of pure DAPT increases yield to 95 from 81.8 percent. The cost to purify DAPT is assumed to be one third the cost of the acid saved.

2. Recovery of the formaldehyde produced in the DAPT-DADN nitrolysis and its recycle to the acetylation step for reaction with ammonium acetate to form hexamine. The cost of recovering and recycling the formaldehyde is assumed to be equal to one half the cost of the hexamine saved.
 3. Reducing the amount of sulfuric and nitric acids needed for the DAPT-DADN step because the DAPT is purified. This reduces the size and costs of acid concentrating facilities, as well as the costs of operating such facilities.
- S. The following minor assumptions were used throughout the economic study. In some instances, these assumptions have been made because data necessary for more exact estimates are lacking. In others, they are based on ratios used in the CSD laboratory or pilot plant work. They do not agree in all cases with assumptions apparently used by Picatinny personnel to prepare Reference b.
1. About one-third of the output stream from the acetylation reaction is returned for reaction with ammonia to form ammonium acetate.
 2. Nitric acid consumption varies with yield, and the excess nitric acid entering into the reaction that is not shown to be present in the spent acid by laboratory analysis or supporting data, or calculated to be in a waste stream, is assumed to be converted to NO_x for recovery in an absorber and return to the system. For this reason NO_x figures may appear to be high.
 3. Carrier loss is assumed to be one-tenth of 1 percent.
- T. The following items listed in AR No. 37-13 are not included in the economic analysis for the reasons cited below.
1. Cost of Government personnel. Government personnel are not directly involved in the manufacture of HMX, nor assigned specifically to the AAP to support HMX production. These personnel are not directly involved in the manufacturing

activity but perform administrative, financial, and inspection functions which will be carried out at the AAP regardless of the presence or absence of an HMX plant, although minor additions to the Government staff may be required by an HMX plant.

2. Variation in overhead costs by site or system capacity. A constant overhead rate of 150 percent is used. This overhead rate is stated to be the one in effect at Indiana APP. Many of the overhead functions, such as warehousing, on-site transportation, and maintenance will vary directly with the capacity of the HMX plants. Others, such as communications, local procurement, and medical and fire protection will not vary directly with plant size. For the purpose of this study, all overhead functions are assumed to vary directly with HMX manufacturing plant capacity, and to remain constant throughout the economic life of the plant.
3. Variation of direct labor cost by site. A constant direct labor cost of \$5.50/hr and direct supervision labor cost of \$9.25/hr for the Indiana plant has been used. The direct labor cost is assumed to be constant through the economic life of the plant.

MATERIAL BALANCES

The manufacturing flow for HMX by the DADN process is shown in Figure 1. Flow rates and material balances for the current process are shown in Table 5, and for the optimized process in Table 6. Tables 5 and 6 were developed on the basis of the production of 100 lb of HMX/hr, and each item on the tables must be multiplied by a factor of 7.58 to yield the flow rate (758 lb/hr) necessary to produce 500,000 lb of HMX/month.

A comparison of Tables 5 and 6 shows that the purification of DAPT results in a marked reduction in the amount of sulfuric acid needed for the DAPT-DADN nitration (stream 10) and a substantial reduction in the amount of nitric acid (stream 9). The resulting reduction in NA-SA concentration capacity reduces the capital investment required. The cost per pound of acid concentrated is assumed to be independent of the amount of acid concentrated, since the amount of energy needed to concentrate a pound of acid does not vary with the daily capacity of the concentrator. The same reasoning applies to the recovery of acetic acid and the production of acetic anhydride. A review of Tables 5 and 6 shows that in the third step (nitrolysis of DADN to HMX) the flow rates for each stream are the same, and that there are no differences between the current process and optimized process material balances for this step. When the economic analysis was started and the basic material balance data were generated, it appeared that an 85-percent yield for this step was as high as could be reasonably expected with the PPA-nitric acid system and was at the upper end of laboratory experience. Data on other nitrolysis systems were even less firm than data on the PPA-nitric acid system, and other systems were not considered. Data from the last pilot plant run (run P-105) have shown this to be a reasonable assumption, since an overall yield (crude product yield times purity of crude product) for that run was 67.5 percent, although no attempt was made to optimize processing conditions, and the DADN was dissolved in the nitric acid for convenience of feeding, rather than fed as a solid. Solid feeding would increase yields by up to 10 percent. Other improvements, not considered in detail in this analysis, that may have a significant cost reduction if proved feasible are (1) a reduction in the amount of ice water needed for the quench to

TABLE 5. HMX PROCESS MATERIAL BALANCE
(Current Process Basis)
(Sheet 1 of 2)

Chemical	1	2	3	4	5	6	7	8	9	10	11	12	13
Hexamine	61.9						Not used						
Anticaking	3.3			1.2		3.3		3.3			3.3	3.3	
Ac ₂ O		113.4											
H ₂ O			32.0	8.7	6.0	26.1		26.1	1.4	65.7	93.2	1347.9	1254.7
MM ₃													
MM ₂ AcO				5.8		17.4		17.4			17.4	17.4	
DAPT				31.6		104		104	140.4			18.8 ^a	
HNO ₃ (100 percent)												33.7	
Nitrate waste												11.2	
H ₂ SO ₄ (100 percent)										873		873	
Sulfate wastes													
DADN													
AcOH				25.3		68.9		68.9			116	116	
Heptane													
NOx													
FC48													
FPA													
H ₃ PO ₄													
HMX													
CH ₂ O													
Total	55.2	113.4	32.0	72.6	6.0	227.0	7.3	227.0	141.8	938.7	1254.7	2509.4	1254.7

Chemical	14	15	16	17	18	19	20	21	22	23	24	25	26
Hexamine													
Anticaking													
Ac ₂ O													
H ₂ O													
MM ₃													
MM ₂ AcO													
DAPT													
HNO ₃ (100 percent)													
Nitrate waste													
H ₂ SO ₄ (100 percent)													
Sulfate wastes													
DADN													
AcOH													
Heptane													
NOx													
FC48													
FPA													
H ₃ PO ₄													
HMX													
CH ₂ O													
Total	2396.7	116	133.4	133.4	133.4	133.4	17.4	17.4	167.1	938.7	121.4	39.3	1370.9

Stream No. (lb/hr for 100 lb/hr mix)

Chemical	27	28	29	30	31	32	33	33a	34	35	36	37	37a	38
Hexamine														
Anticaking														
Ac ₂ O														
H ₂ O														
NI ₃														
NI ₄ AcO														
DAPI														
NI ₂ O ₃ (100 percent)														
Nitrate waste														
H ₂ SO ₄ (100 percent)														
Sulfate wastes														
DADN														
AcOH														
Heptane														
NOx														
PCAS														
PFA														
H ₃ PO ₄														
NI ₂ X														
CH ₂ O														
Total	960	960	1495.3	17.4	1477.9	1426.8	165.3	165.1	1318	1.2	1157.5	34.4	116.7	1123.1
Hot used														
Chemical	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Hexamine														
Anticaking														
Ac ₂ O														
H ₂ O														
NI ₃														
NI ₄ AcO														
DAPI														
NI ₂ O ₃ (100 percent)														
Nitrate waste														
H ₂ SO ₄ (100 percent)														
Sulfate wastes														
DADN														
AcOH														
Heptane														
NOx														
PCAS														
PFA														
H ₃ PO ₄														
NI ₂ X														
CH ₂ O														
Total	147.6	186.4	160.3	4.2	4.2	34.0	82.3	82.3	.02	30.0	48.9	73.3	1.1	17.9
Hot used														
Chemical	27	28	29	30	31	32	33	33a	34	35	36	37	37a	38
Hexamine														
Anticaking														
Ac ₂ O														
H ₂ O														
NI ₃														
NI ₄ AcO														
DAPI														
NI ₂ O ₃ (100 percent)														
Nitrate waste														
H ₂ SO ₄ (100 percent)														
Sulfate wastes														
DADN														
AcOH														
Heptane														
NOx														
PCAS														
PFA														
H ₃ PO ₄														
NI ₂ X														
CH ₂ O														
Total	179.9	186.4	160.3	79.3	426.0	34.0	164.6	122.2	.02	133.4	122.2	12.0	15.3	35.8
Hot used														

NOTE: Stream numbers correspond to those on Figure 1

- a Residual or decomposed DAPI.
- b Includes 7.1 lb NI₄NO₃ from NI₄AcO.
- c (NI₄)₂SO₄ from NI₄AcO.
- d Unreacted or decomposed DADN.

TABLE 6. HMX PROCESS MATERIAL BALANCE
(Optimized Process Basis)
(Sheet 1 of 2)

Chemical	1	2	3	4	5	6	7	8	9	10	11	12	13
Hexamine	45.0												
Anticaking	2.4			.8		2.4							
Ac ₂ O		87.5	23.0	6.4	7.1	12.8			.8	14.2	22.1	370.7	348.6
H ₂ O													
NH ₃				0		0							
NH ₄ AcO				29.3		88	88	88	77.2		4.7 ^a	4.7 ^a	
DAPT											2.0	2.0	
HNO ₃ (100 percent)											4.1	4.1	
Nitrate waste											188.8	188.8	
H ₂ SO ₄ (100 percent)													
Sulfate wastes													
DADN											115	115	
AcOH				24.5		50.3							
Heptane													
NOx													
FC48													
PPA													
H ₃ PO ₄													
HMX													
CH ₂ O	47.4	87.5	23.0	61.0	7.1	159.6	88	88	78.0	203.0	348.6	697.2	348.6
Total						6.1					11.9	11.9	

Chemical	14	15	16	17	18	19	20	21	22	23	24	25	26
Hexamine													
Anticaking													
Ac ₂ O													
H ₂ O	370.7								40.2		46.4		430.8
NH ₃													
NH ₄ AcO													
DAPT													
HNO ₃ (100 percent)	4.7 ^a												4.7 ^a
Nitrate waste	2.0												1.5
H ₂ SO ₄ (100 percent)	4.1												4.1
Sulfate wastes	188.8												1.9
DADN		115											
AcOH				102.9							1.0		
Heptane							17.4	17.4			.01	31.5	.01
NOx													
FC48													
PPA													
H ₃ PO ₄													
HMX													
CH ₂ O	570.3	115	11.9	102.9			17.4	17.4	134.1	Not used	6.1	32.5	443.0
Total											55.9		

TABLE 6. HMX PROCESS MATERIAL BALANCE
(Optimized Process Basis)
(Sheet 2 of 2)

Chemical	27	28	29	30	31	32	33	34	35	36	37	37a	38
Hexamine													
Anticaking	Not used												
Ac ₂ O													
H ₂ O			14.8		14.8	150.1	165.3	135.3	5.4	1.0	4.4		4.4
NI ₃													
NI ₂ AcO													
DAPT													
NO ₂ (100 percent)			347.3		347.3	160.9	3.4	160.5	.2	4.3			4.3
Nitrate waste			4.3		4.3			4.3					
H ₂ SO ₄ (100 percent)													
Sulfate wastes			17.0 ^b		17.0 ^b	17.0 ^b		17.0 ^b		17.0 ^b			17.0 ^b
DADN			34.5		34.5	34.5	.8	34.4		34.4		84.7	
AcOH													
Heptane													
NO _x			17.4		17.4			.02					
PCAS			960		960								
PTA													
H ₃ PO ₄			100		100					1101.8			1101.8
NI ₂													
CH ₂ O													
Total	960	960	1495.3	17.4	1477.9	1426.8	165.3	165.1	1.2	1151.5	34.4	84.7	1123.1
Chemical	39	40	41	42	43	44	45	46	48	49	50	51	52
Hexamine													
Anticaking													
Ac ₂ O													
H ₂ O	147.6			4.2	4.2				30	44.3		.14	18.2
NI ₃													
NI ₂ AcO													
DAPT													
NO ₂ (100 percent)									.4				
Nitrate waste	4.3												
H ₂ SO ₄ (100 percent)													
Sulfate wastes												1.9	
DADN	17.0 ^b												
AcOH									.1				18.2
Heptane													
NO _x										66.5			
PCAS													
PTA													
H ₃ PO ₄											12.1		
NI ₂	11.0								2.9				
CH ₂ O									100				
Total	179.9	186.4	160.3	79.3	426.0	34.0	Not used	Not used	133.4	100.8	12.1	2.0	36.4

NOTE: Stream numbers correspond to those on Figure 1.

^a Residual or decomposed DAPT

^b Residual or decomposed DADN

precipitate the DADN from the acid solution and (2) the use of N_2O_5 instead of polyphosphoric acid in the DADN-HMX nitrolysis.

Reducing the DADN quench would not only reduce the amount of energy needed to recover the acids, but would also reduce refrigeration requirements. Replacing the PPA with N_2O_5 may reduce the anticipated high facility and operating costs for PPA recovery and some nitric acid costs. The facility and operating costs for an N_2O_5 installation are unknown at this time, but they are believed to be lower than costs for the PPA-nitric acid system. Material balances for these two processing improvements have not been made.

MANUFACTURING REQUIREMENTS

Table 7 lists the estimated facility and raw material requirements necessary to produce 500,000 and 2,000,000 lb of HMX/month under both current process and optimized process conditions. These manufacturing requirements are derived from the material flows tabulated in Tables 5 and 6. Of particular interest is the marked drop in sulfuric acid makeup and concentration requirements resulting from purification of DAPT, and the significant reduction in hexamine requirement occasioned by the recovery and recycle of formaldehyde from the DAPT-DADN reaction. These two-process improvements also result in a significant reduction in the pollution load generated.

TABLE 7. MANUFACTURING REQUIREMENTS FOR HMX-DADN PROCESS
(LESS RECRYSTALLIZATION)

	Current process		Optimized process	
	500K lb/ month	2000K lb/ month	500K lb/ month	2000K lb/ month
Hexamine, technical grade (95 percent pure), (tons/day)	5.93	23.71	4.31	17.23
AOP nitric acid (70 percent), (tons/day)	15.2	60.8	12.2	48.8
Nitric acid concentration capacity (99 percent), (tons/day)	19.8	79.2	13.1	52.4
Nitric acid loss, (lb/day)	4475	17,901	1910	7640
Sulfuric acid (93 percent) (makeup), (lb/day)	2777	11,111	370	1479
Sulfuric acid concentration (93 percent), (tons/day)	85.4	341.5	18.5	73.9
NA-SA concentration capacity, (tons/day)	105.1	420.4	31.6	126.4
Acetic acid (makeup), (lb/day)	3256	13,206	3493	13,971
Acetic acid recovery, (tons/day)	12.2	49	9.6	38.4
Acetic anhydride production, (tons/day)	10	41	8	32
Actic acid loss, (lb/day)	236	946	200	800
Polyphosphoric acid (makeup) (115 percent), (lb/day)	2197	8790	2197	8790
Polyphosphoric acid concentration (115 percent), (tons/day)	87.2	349.3	87.2	349.3
Phosphoric acid loss,	2429	10,116	2429	10,116
Ammonia, (tons/day)	.56	2.24	.65	2.6
Heptane loss and makeup, (gal/month)	31	124	31	124
FC-48 loss and makeup, (gal/month)	5.8	23.2	5.8	23.2
Manufacturing waste water treatment (includes wastes from acid plants), (millions of gal/month)	.934	3.7	.37	1.5

OPERATING COSTS

Raw Materials

Table 8 lists the estimated raw material costs to produce a pound of HMX by both the current and optimized processes. Raw material costs for the optimized process are estimated to be \$.0671/lb of HMX less than those for the current process, or a savings of some \$402,600/year for each line producing 500,000 lb of HMX/month.

Method of Calculation of Selected Costs

Phosphoric Acid Concentration Costs - The concentration of phosphoric acid to PPA for recycling is the major material cost in the nitrolysis of DADN to HMX, and the second largest material cost in the overall process. Actual operation data and costs for a PPA recovery system suitable for the DADN-HMX chemistry are nonexistent, since only limited laboratory work has been carried out to prove the feasibility of such a concept. Both Picatinny Arsenal and CSD have done work in this area.

To develop the concentration costs reported here, it was assumed that the spent phosphoric acid contained in stream 38 (Figure 1) was heated to 280°C under a vacuum ranging down to 5mm Hg absolute. The computations further assumed that this heating took place in stages in different concentrating vessels, under increasingly high temperatures and vacuum to reduce vacuum pumping requirements. Multiple single stage mechanical vacuum pumps were used for each stage, since cost and performance data on such pumps were readily available. Operating costs for other vacuum systems should not be significantly different. For each stage, the criterion for selecting the number and size of pumps needed was minimum utility requirements. Vacuum manifolds connecting the pumps to the concentration stage, assumed to be 200-ft long, were sized to minimize manifold pumping effects.

For each stage the heating and utility requirements to remove and condense the vapors were calculated. The energy needed to remove the molecular water necessary to convert H_3PO_4 (orthophosphoric acid) to $H_4P_2O_7$ (pyrophosphoric acid) was computed from differences in heats of formation and

TABLE 8. MATERIAL COSTS PER POUND OF HMX MANUFACTURED BY THE DADN PROCESS

Material	Current process,			Optimized process,		
	(lb/lb HMX)	(cents/lb)	(cents/lb HMX)	(lb/lb HMX)	(cents/lb)	(cents/lb HMX)
Hexamine	.619	28.22	17.47	.45	28.22	12.70
Formaldehyde recovery	—	—	—	—	—	2.38
Acetic acid makeup	.179	14.15	2.53	.182	14.15	2.66
Acetic acid recovery and anhydride production	1.134	4.92	5.58	.875	4.92	4.31
Sulfuric acid makeup (100 percent acid)	.142	2.39	.34	.019	2.39	.05
Sulfuric acid concentration	8.73	.50	4.37	1.89	.50	.95
Ammonia	.06	10.01	.60	.071	10.01	.71
Nitric acid makeup (100 percent acid)	.762	4.39	3.35	.529	4.39	2.32
Nitric acid concentration	1.404	.29	.41	.772	.29	.22
Heptane	.00035	7.49	.00026	.00035	7.49	.00026
DAPT purification	—	—	—	—	—	1.64
DADN (subtotal)	1.16	29.87	(34.65)	1.16	24.09	(27.94)
PPA makeup ^b	.12	25.29 ^a	3.03	.12	25.29 ^a	3.03
H ₃ PO ₄ concentration	9.60	.91	8.71	9.60	.91	8.71
Nitric acid makeup (100 percent acid)	.41	4.39	1.80	.41	4.39	1.80
Nitric acid concentration	.75	.29	.22	.751	.29	.22
Nitric acid flash	1.864	.102	.19	1.864	.102	.19
Nitric acid vacuum still	1.60	.225	.37	1.60	.225	.37
FC-48	.0002	13.90	.28	.0002	13.90	.28
Materials, DADN-HMX			(14.6)			(14.6)
nitrolysis (subtotal)			(14.6)			(14.6)
HMX materials, (cents/lb)			42.25			42.54

^a Although the cost of 9.08 cents/lb of PPA is used in the Picatinny 3 January 1975 analysis, current cost of PPA in large quantities, FOB Newark, CA is 25.29 cents/lb and is used in this analysis. Using a PPA cost of 9.08 cents/lb would reduce the material costs for HMX by 1.95 cents/lb for both current process and optimized process.

^b Concentration of H₃PO₄ in spent acid to 115 percent PPA

amounts to 670 Btu/lb of H_3PO_4 . It was also assumed that all the orthophosphoric acid was converted to the pyro form. No attempt was made to calculate the energy needed to condense from the pyro to higher acids. These assumptions are believed to be reasonable first cut assumptions, yielding results that will approximate the actual requirements when they have been determined experimentally. Some orthophosphoric acid is present in PPA and is not converted to the pyro form of the acid, and the energy required to remove water from the pyro acid to form the higher condensed acids should be less than that needed to condense the ortho acid to the pyro acid.

Since the PPA at the end of concentration is at $280^{\circ}C$, and must be cooled before being used, it was assumed that most of this heat would be available for heating incoming acid.

Nitric Acid and Sulfuric Acid Concentration Costs

Both nitric acid and sulfuric acid are concentrated by the removal of water. Nitric acid is also removed from the spent nitric acid-phosphoric acid mixture which is water-free and consists largely of high strength phosphoric acid. Recovery of nitric acid from this mixture is discussed in a later section.

An acid concentrating system essentially identical to an NAC/SAC should meet the sulfuric acid/nitric acid concentrating requirements of the DADN-HMX system. This equipment, however, should be capable of providing nitric acid essentially free of sulfuric acid to the DADN-HMX nitrolysis portion of the system. Sulfuric acid is detrimental to this nitrolysis, but the amount that can be tolerated has not been determined.

Operating costs for concentration of sulfuric acid and nitric acid were taken from Reference b.

Nitric Acid Flash and Vacuum Still Recovery Costs

The operating costs to recover nitric acid by flash and vacuum still were calculated by determining the vacuum pumping utility costs for each process, plus the heat needed to vaporize the nitric acid. It was assumed

that the flash evaporator would operate under a pressure of 320 mm Hg and the vacuum still under a pressure 50mm Hg absolute.

Other Acid Costs

The operating costs of recovering acetic acid and providing acetic anhydride were taken from Reference b.

Labor

The estimate of labor needed to operate a 500,000 lb/month HMX current process plant, including acid plant labor, is shown in Figure 2. The concept of the ICP lends itself to very simple remote and automatic control. A production plant can be operated from a central control room by one person. It is estimated that the complete plant, including acid plant, will need a total of ten operators and two supervisors per shift. A review of Table 7, Manufacturing Requirements, shows that several of the acid plants (i.e., the AOP, acetic acid recovery, and acetic anhydride production plants), are very small plants. A common operator has been assigned to the acetic acid recovery and acetic anhydride plants with a separate operator for the AOP plant. This arrangement should also be adequate for the larger throughputs required by the 2,000,000 lb/month production rate. A separate operator is also included for vacuum systems needed for the acid plants and the HNO_3 flash and vacuum still recovery systems shown in the DADN-HMX nitration step of Figure 1. Regardless of the vacuum system actually used, operating labor will be required to monitor performance, adjust flows, etc.

Increasing plant capacity to 2,000,000 lb of HMX/month would about double HMX manufacturing labor force. The 2,000,000 lb/month plant will consist of four 500,000 lb/month lines, but savings in labor in the material handling areas of the manufacturing plant would accrue from a combined operation. It is estimated that a crew of two persons for raw materials handling would meet the needs of the four lines, and that two crews of two persons would be adequate for handling the HMX output of the four lines. A general foreman to coordinate the overall operation, as well as a foreman for each of the lines, would be needed. Only a small increase in labor requirements will be required in the acid plant areas to support the

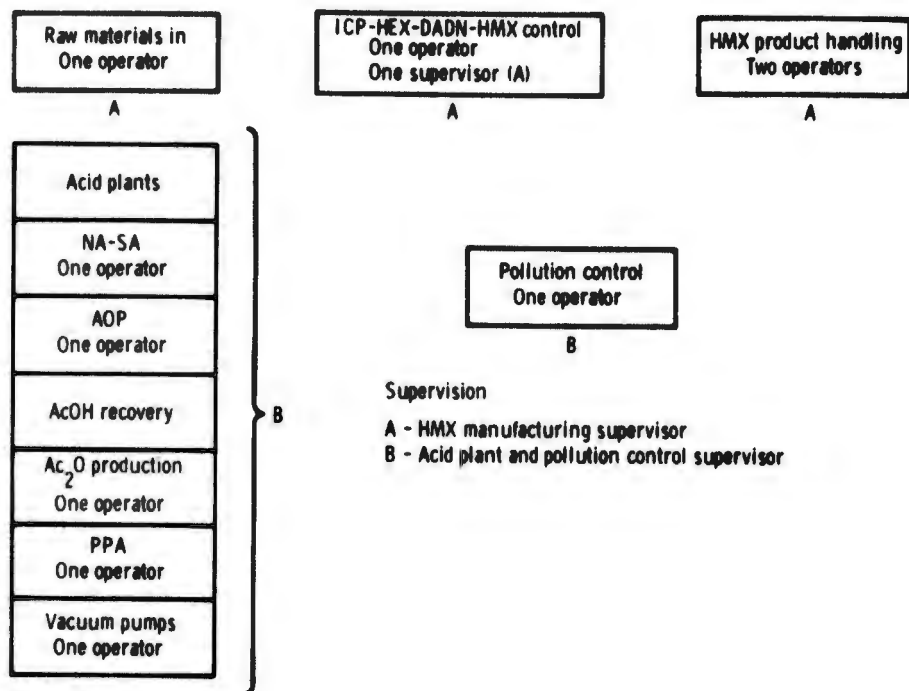


Figure 2. Estimate of Labor Required for DADN-HMX Process (500,000 lb/month)

2,000,000 lb/month rate, since quadrupling the size of an acid plant does not require four times the labor force to operate it. The same situation will occur in the pollution control area.

There will be a little difference in the labor required to operate a large optimized process plant as compared to that needed to operate a current process plant, due to a smaller NA-SA concentrator required and the reduced pollution load.

Table 9 shows the estimated labor and labor costs for both a 500,000 and 2,000,000 lb/month HMX production plant under current process and optimized process conditions.

Further labor savings may be obtained by designing one 2,000,000 lb/month HMX line with a variable rate capability down to 500,000 lb/month.

TABLE 9. ESTIMATE OF LABOR REQUIREMENTS AND COSTS
(DADN-HMX MANUFACTURE)

Labor station	Current process			Optimized process		
	500K lb/month Opera- tors	2000K lb/month Super- visors	2000K lb/month Opera- tors	500K lb/month Opera- tors	2000K lb/month Super- visors	2000K lb/month Opera- tors
Raw materials handling	1	X	2	1	X	2
HEX-DADN-HMX ICP operation	1	1 X	4	1	1 X	4
HMX handling	2	X	4	2	X	4
Acid plants						
NA-SA	1	1 XX	2	1	1 XX	1
AOP	1	XX	2	1	XX	1
AcOH recovery	1	XX	1	1	XX	1
Ac ₂ O production	1 XXX	XX	1 XXX	1 XXX	XX	1 XXX
PPA	XXX		XXX	XXX		XXX
Vacuum pumps (system)	1	XX	2	1	XX	2
Pollution control	1	XX	2	1	XX	2
Combined plant supervisor	1	XX	2	1	XX	1
Totals	10	2	20	10	2	18
Hourly cost, (dollars)	55.00	18.50	110.00	55.00	18.50	99.00
at \$5.50/hr		73.50			73.50	
at \$9.25/hr						
Total direct labor cost, (dollars)		55.50			55.50	
Overhead at 150 percent		83.25			83.25	
Total labor cost, dollars/hr		143.75			143.75	
Cost, cents/lb HMX		24.24			24.24	

X and XX indicate stations supervised by the same supervisor(s)

XXX Common operator

This is a unique feature of the ICP which should be considered at a later date.

Estimate of Pollution Control Operating Costs

The waste water streams generated by the DADN-HMX process are shown in Figure 1 as streams 24, 26, 35, 39, and 47. The uncontaminated cooling water should not require treatment. Not considered in this analysis are specialized waste water streams, such as boiler and cooling tower blowdowns, or boiler water treatment waste streams.

The DADN-HMX process waste water streams for 500,000 lb of HMX manufacture per month, for both the current process and the optimized process conditions, are summarized in Table 10. The pollutant rates for 2,000,000 lb of HMX/month would be four times those shown for each process condition. Not included in Table 10 are the acids leaving with the crude HMX (stream 48) which become pollutants in the purification/recrystallization area. These amount to 2.7 lb/hr of nitric acid, 19.8 lb/hr phosphoric acid, and .7 lb/hr acetic acid. Using a counter-current wash on a vacuum belt filter, these acids should be reduced to acceptable levels by less than 100 gal/hr of water.

The waste streams from the DADN-HMX process contain both organic and inorganic substances. It may be possible to recover the FC-48 inert carrier of stream 47 and return it to the system without loss, thus slightly reducing the product cost.

The waste water pollution abatement steps selected for costing in this analysis are: (1) filtering to remove hexamine anticake, (2) absorption of the organics in the waste water streams (including the acetic acid) in an activated carbon filter, (3) removal of inorganic ions in an ion exchange system, and (4) drying of the ion exchange regenerant waste water streams to recover the chemicals contained therein.

It is reported that activated carbon filters remove up to 98 percent of the organics in a waste stream, and that soluble organics can be reduced to

TABLE 10. DADN-HMX - POLLUTION RATES/HR^a

Stream No./process condition	Flow rate, (gal/hr)	HNO ₃ , (lb/hr)	H ₂ SO ₄ , (lb/hr)	H ₃ PO ₄ , (lb/hr)	ACOH, (lb/hr)	NH ₄ NO ₃ , (lb/hr)	(NH ₄) ₂ SO ₄ waste, (lb/hr)	Nitrate waste, (lb/hr)	Organics, (lb/hr)	Anticakes, (lb/hr)
24										
Current process	109.2				9.1					
Optimized process	42.2				7.6				.1	18.2
26										
Current process	1176.0	10.6	65.9			53.8	55.3	84.9	288.2	25.0
Optimized process	391.5	11.4	14.4					31.1	35.7	
35										
Current process	.9	1.5								
Optimized process	.9	1.5								
39										
Current process	134.1			83.4				32.6	128.9	
Optimized process	134.1			83.4				32.6	128.9	
47										
Current process									.2	
Optimized process									.2	
Total										
Current process	1420.2	12.1	65.9	83.4	9.1	53.8	55.3	117.5	417.3	25.0
Optimized process	568.7	12.9	14.4	83.4	7.6			63.7	164.7	18.2

^a500,000 lb of HMX/month rate

^bIncludes all nitrate wastes from reactions except NH₄NO₃ as equivalent HNO₃

^cIncludes unreacted hexamine, DAPT, and DADN, plus waste heptane and FC-48 inert carriers, and formaldehyde

as low as 1 part per million. The activated carbon filters can be reactivated thermally by steam, and the recovered organics collected, and burned in a furnace to recover their energy content. A two-stage ion exchange system will remove both anions and cations. The ion exchange regeneration waste water streams will be dried in a multiple effect evaporator with a solids handling section and a vacuum filter drier.

According to pollution abatement literature, the cost of operating an activated carbon filter, including regeneration and carbon makeup, is about \$.10/1000 gal of water treated. Since the waste water streams contain a fairly heavy organic load of approximately 3 percent, the activated carbon filter operating cost will be taken at \$.15/1000 gal treated. No allowance will be taken for the fuel value of the recovered organics. Filtering to remove the hexamine anticake is assumed at \$.01/1000 gal of water treated.

Operating costs for the ion exchange system and the drying of the ion exchange waste waters are derived from costs developed in Reference a for a Desal type weak electrolyte ion exchange system.

Table 11 shows the composition of the ion exchange waste streams generated using ammonia and nitric acid as the regenerants, as well as estimates of the quantities and costs of the regenerants used. A minor assumption was made in the optimized process that only enough ammonia is introduced into the system to form hexamine by reacting with the formaldehyde generated in the hexamine acetylation and the DAPT nitration. Consequently, it is also assumed that no ammonium nitrate or ammonium sulfate is generated nor present in the waste streams. This permits a single stage ion exchange system to be used to recover waste chemicals in the optimized process condition, since there are no cations to recover.

About three times as much ion exchange regenerant waste water results from the current process as from the optimized process. This is due primarily to the larger amount of sulfate present in the manufacturing waste stream and the increased volume of ammonia solution and wash water needed to regenerate the exchange resin. Ion exchange chemicals will cost

TABLE 11. ION EXCHANGE REGENERATION DADN-HMX WASTE STREAM^a

Ion	Current process			Optimized process		
	Ion weight, (lb)	Regenerant/lb	IX output/lb	Ion weight, (lb)	Regenerant/lb	IX output/lb
NO ₃ ⁻	86,572	NH ₃ /23,738	NH ₄ NO ₃ /111,760	49,896	NH ₃ /13,681	NH ₄ NO ₃ /64,382
SO ₄ ⁻	69,150	NH ₃ /24,491	(NH ₃) ₂ SO ₄ /95,081	9,310	NH ₃ /3,297	(NH ₄) ₂ SO ₄ /12,801
H ₂ PO ₄ ⁻	54,482	NH ₃ /9548	NH ₄ H ₂ PO ₄ /64,592	54,482	NH ₃ /9548	NH ₄ H ₂ PO ₄ /64,592
NH ₄ ⁺	17,943	HNO ₃ /62,800	NH ₄ NO ₃ /79,747	-	-	-
H ₂ O			301K gal			98.5K gal
Regenerant totals		NH ₃ 57,777			NH ₃ 26,526	
		HNO ₃ 62,800			CO ₂ 6849	
		CO ₂ ^b 14,917				
	Cost NH ₃ at \$.10/lb = \$5,777.70				\$ 2,652.60	
	Cost HNO ₃ at \$.0439/lb = \$2,756.92				-	
	Cost CO ₂ ^b at \$160/ton = \$1,193.35				\$ 574.92	
	Total chemical cost = \$9,727.97				\$ 3,200.52	
	IX cost/lb HMX = \$.0195				\$.0064	

^a 500,000 lb of HMX/month monthly rates

^b Assume anion stage operates as a DeSol IX using gaseous CO₂ in carbonation step, 10 percent makeup, at \$160/ton in cylinders.

approximately \$.0195/lb of HMX under the current process and about \$.0064/lb of HMX for the optimized process. Deionized water from the ion exchange plant will be recycled as process water.

Table 12 presents an estimate of the value of the chemicals that can be recovered from the ion exchange waste waters. The prices given are for dry chemicals. Although these chemicals will be mixed, they should be saleable as dry, mixed fertilizer. Credit for their value is taken in the economic analysis to the extent that they are assumed to offset the cost of pollution control. No materials are charged against the product for pollution control.

Table 13 gives an estimate of the overall operating costs for removing pollutants from the DADN-HMX manufacturing process waste waters. Labor has already been considered in Table 9. Fuel costs to dry the ion exchange waste streams are based on the use of coal to generate steam for a multiple effect evaporator and a vacuum filter drier.

Not included in the above tables is the cost of treating the waste acids leaving the manufacturing system with the crude HMX. These will be removed in the recrystallization area. It is apparent that the operating costs to remove these acids from the small waste water stream from the recrystallization area would not exceed the value of the chemicals recovered and that the cost of treating this stream would not change the product cost significantly.

Discounting labor, water pollution abatement per pound of HMX produced should generate cost savings of about \$.0037 for the current process, and \$.0096 for the optimized process, providing that recovered chemicals can be disposed of at normal market prices; it would cost a maximum of about \$.03/lb of HMX if the chemicals were given away.

Air Pollution Control Operating Costs - The only air pollutant considered in this section is NO_x fumes generated by the nitration and nitrolysis reactions. Modern acid plants are fitted with integral air pollution control equipment, which is included in the capital costs of the plants.

TABLE 12. VALUE OF RECOVERED CHEMICALS

Chemical	Current process				Optimized process			
	Amount, (lb)	Amount, (tons)	Value, (dollars)	HMX value/lb, (cents)	Amount, (lb)	Amount, (tons)	Value, (dollars)	HMX value/lb, (cents)
NH_4NO_3^a	111,760	55.9	5085	1.02	64,382	32.2	2929	.59
$(\text{NH}_4)_2\text{SO}_4^b$	95,081	47.5	2852	.57	12,801	6.4	384	.08
$\text{NH}_4\text{H}_2\text{PO}_4^c$	64,592	32.3	5167	1.03	64,592	32.3	5167	1.03
Total	-	-	13,104	2.62	-	-	8480	1.70

^aAt \$91/ton

^bAt \$60/ton

^cAt \$160/ton (monoammonium phosphate)

TABLE 13. ESTIMATE OF OVERALL OPERATING COSTS
(WASTE WATER POLLUTION CONTROL)^a

Item	Cost, (cents/lb of HMX)	
	Current process	Optimized process
Anticake filter	.002	.0008
Activated carbon filter	.03	.01
Ion exchange chemicals ^b	1.95	.64
Pumping	.01	.01
Multiple effect evaporator and dryer fuel	.27	.09
Subtotal	2.26	.75
Less: value of recovered chemicals ^c	2.62	1.70
Water pollution Abatement costs Cents/lb HMX	-.36	-.95
Amount costed in product	.00	.00

^aPollution abatement labor included in Table 9

^bFrom Table 11

^cFrom Table 12

The NO_x emissions observed during pilot plant runs were extremely small, even less than observed in laboratory nitrations. Based on these observations, it would appear that operating costs for NO_x abatement will be very low. Further, NO_x pollution abatement costs for nitrocellulose manufacture were calculated at \$.0002/lb of nitrocellulose. NO_x pollution abatement costs for the DADN-HMX process should be lower per pound of product than for NC.

For this estimate, NO_x pollution abatement operating costs will be ignored since they are not significant.

Utility Costs - The utility costs tabulated on Table 14 are for those utilities necessary to operate the DADN-HMX processing equipment. These costs cover primarily the (1) operation of disperser pumps, (2) refrigeration necessary to maintain processing temperatures, (3) process tank agitators, (4) belt filter vacuum and drive motors, and (5) miscellaneous pumps.

Utility costs for acid recovery and concentration are included in the acid recycle costs shown on Table 8.

Electrical energy is costed at the rate of \$.0167/kw-hr, and cooling water at \$.01/1000 gal. Since water from the ion exchange units would be returned to the system as process water, process water costs are included in the water pollution control costs.

TABLE 14. HMX PROCESSING UTILITY COSTS^a

	Current process, (kw)	Optimized process, (kw)
HEX-DADN		
Disperser pumps	400	400
Belt feeder	2	2
Belt filter	40	40
Crystal growth tank	5	5
Quench tank	3	3
Miscellaneous small pumps	20	20
DADN-HMX		
Disperser pumps	280	280
Solids feeder	2	2
Quency tank	3	3
Belt filter	40	40
Simmer tank agitators	6	6
Miscellaneous small pumps	20	20
General use		
Refrigeration	558	488
Air compressor	5	5
Total	1384	1314
Electricity, (cost/hr) at \$.0167/kw-hr	\$23.11	\$21.94
Cost/lb of HMX, (cents)	3.05	2.89
Process cooling water, (gal/hr)	4300	4300
Cost at \$.01/1000 gal, (cents)	4.3	4.3
Cost/lb of HMX, (cents)	.006	.006
Total cost, (cents/lb of HMX)	3.06	2.9

^aTable 8 includes utility costs for (1) acid concentration included in acid recycle costs and (2) purification of DAPT and recovery of formaldehyde. Table 13 includes pollution control utility costs.

HMX MANUFACTURING COSTS

Table 15 summarizes the manufacturing costs for the DADN-HMX process. Material costs and pollution control operating costs for a particular process condition are held constant and are not dependent on production rate. Labor costs will vary with production rate as shown in Table 9. The recurring costs used in the overall economic analysis will be based on these costs.

TABLE 15. HMX MANUFACTURING COSTS

Cost element	Current process production rate, (lb/month)		Optimized process production rate, (lb/month)	
	500K	2000K	500K	2000K
Materials, (cents/lb HMX) ^a	49.25	49.25	42.54	42.54
Labor, (cents/lb HMX) ^b	24.24	13.7	24.24	12.75
Pollution control (cents/lb) ^c	0.0	0.0	0.0	0.0
Utilities, (cents/lb) ^d	3.06	3.06	2.90	2.90
Total cost, (cents/lb)	<u>76.55</u>	<u>66.01</u>	<u>69.68</u>	<u>58.19</u>

^aFrom Table 8

^bFrom Table 9

^cFrom Table 13

^dFrom Table 14

FACILITY COSTS

Manufacturing Facility Costs

The HMX facility costs are based on the estimated cost of major pieces of equipment needed to carry out each of the processing steps shown on the flow diagram (Figure 1). Equipment was sized from flow rates tabulated in Tables 5 and 6, taking due account of fluid densities, stay times needed, etc. Pumps were sized to change the volume of the largest disperser in about 20 sec. The same size pump was used for all dispersers and the seal flush systems. Vacuum pumps were sized to handle the computed volume of gases or vapors that would be generated. In those process equipments where a gas or vapor was to be removed from a fluid, costs for tall, narrow towers were used. When possible, the cost of equipments was based on items of the same, or similar nature, that had been purchased by CSD. Current catalogue prices were used when possible. An allowance was made for Teflon lining of major pieces of process equipment. Equipment pricing was based on construction from 316L stainless steel and explosion proof motors. The costs of some tanks were computed from commercial tank catalogues. In all instances, where 1975 costs were not available, costs were updated to 1975 costs by the use of the M&S equipment cost index published bimonthly in Chemical Engineering.

The costs of much of the equipment listed in Tables 16 and 17 were generated from curves included in the article "How to Estimate the Cost of Pilot Plant Equipment".^c In general, the equipment cost curves presented covered equipment of adequate capacity to meet the needs of the 500,000 lb/month HMX lines specified in the contract. An allowance of 25 percent of the estimated cost of the major items of equipment is included to cover the costs of minor equipment, such as circulating pumps, minor heat exchangers, small receiving tanks, etc.

^c "How to Estimate the Cost of Pilot Plant," Chemical Engineering, February 1970.

TABLE 16. ESTIMATE OF PROCESSING EQUIPMENT COSTS^a

Item	Current process		Optimized process	
	Equipment unit cost, (dollars)	Total equipment cost, (dollars)	Equipment unit cost, (dollars)	Total equipment cost, (dollars)
Solids feeder (1)	19,610	19,610	19,610	19,610
Disperser (1)	8509	8509	8509	8509
Disperser (1)	13,970	13,970	13,970	13,970
Disperser (1)	30,973	30,973	30,973	30,973
Disperser (1)	21,150	21,150	21,150	21,150
Pumps (10)	4100	41,000	4100	41,000
Heat exchangers (10)	7000	70,000	7000	70,000
Seal flush systems (2)	16,680	33,360	16,680	33,360
Separators (2)	26,400	52,800	26,400	52,800
Level control systems (11)	5000	55,000	5000	55,000
Belt filter (1)	43,670	43,670	43,670	43,670
Vacuum pumps	11,845	11,845	11,845	11,845
AcOH flash still	—	—	98,090	98,090
Vacuum pumps (2)	—	—	5257	10,514
Crystal growth tank (1)	18,750	18,750	18,750	18,750
Quench tank (1)	33,000	33,000	33,000	33,000
NH ₃ addition and heat exchanger (1)	14,000	14,000	14,000	14,000
CH ₂ O removal	—	—	33,700	33,700
Refrigeration	79,120	79,120	79,120	79,120
Air compressor - control air (1)	2000	2000	2000	2000
Subtotal		548,757		691,061
Miscellaneous small equipment at 25 percent of above		137,189		172,765
Subtotal		685,946		863,826
Erection (11 percent)		75,454		95,021
Piping, process and utility (80 percent)		548,757		691,061
Electrical (15 percent)		102,892		129,574
Instrumentation (26 percent)		178,346		224,595
Insulation (15 percent)		102,892		129,574
Painting (10 percent)		68,595		86,383
Engineering (45 percent)		308,676		388,722
Total		2,071,558		2,608,756

^a500,000 lb of HMX/month, single line, hexamine-DADN step

TABLE 17. ESTIMATE OF PROCESSING EQUIPMENT COSTS^a

Item	Current process		Optimized process	
	Equipment unit cost, (dollars)	Total equipment cost, (dollars)	Equipment unit cost, (dollars)	Total equipment cost, (dollars)
Solids feeder (1)	19,610	19,610	19,610	19,610
Disperser (1)	20,600	20,600	20,600	20,600
Disperser (1)	31,200	31,200	31,200	31,200
Pumps (6)	4100	24,600	4100	24,600
Heat exchanger (6)	9000	54,000	9000	54,000
Seal flush systems (1)	33,360	33,360	33,360	33,360
Level controls (10)	5000	50,000	5000	50,000
Separator (1)	26,400	26,400	26,400	26,400
Simmer tanks (3)	28,805	86,415	28,805	86,415
Quench tank (1)	33,000	33,000	33,000	33,000
Belt filter (1)	87,338	87,338	87,338	87,338
Vacuum pump (1)	11,845	11,845	11,845	11,845
AcOH flash still (1)	140,300	140,300	140,300	140,300
Vacuum pumps (1)	3400	3400	3400	3400
HNO ₃ flash tank (1)	95,820	95,820	95,820	95,820
Vacuum pump and pipe (1)	11,800	11,800	11,800	11,800
HNO ₃ condensers (2)	2500	5000	2500	5000
HNO ₃ still (1)	115,600	115,600	115,600	115,600
Vacuum pumps (3)	13,000	39,000	13,000	39,000
Subtotal		889,288		889,288
Miscellaneous small equipment at 25 percent of total		222,322		222,322
Subtotal		1,111,610		1,111,610
Erection (11 percent)		122,277		122,277
Piping, process and utility (80 percent)		889,288		889,288
Electrical (15 percent)		166,741		166,741
Instrumentation (26 percent)		289,019		289,019
Insulation (15 percent)		166,741		166,741
Painting (10 percent)		111,161		111,161
Engineering (45 percent)		500,255		500,255
Total		3,357,062		3,357,062

^a500,000 lb HMX/month, single line, DADN-HMX nitrolysis step

The cost of installed, operable processing equipment was estimated from the sum of the cost of the individual items of processing equipment and the percentage allowances for the various items of work shown on the tables which are from Reference c.

Table 16 lists the equipment priced for the hexamine-DADN portion of the overall manufacturing line, together with work area percentage costs, for both the current process and optimized process lines. Table 17 lists the same items for the DADN-HMX nitrolysis portion of the overall process.

Manufacturing building costs were determined by estimating the physical size of each of the major equipment items and determining the size of the building needed to house that equipment, assuming that the equipment occupies 20 percent of the floor space of the building. A separate 150 ft² barricaded, remote control room, controlling the entire manufacturing line, is included.

The square footage cost of the manufacturing buildings was estimated by escalating the cost per square foot of a processing building constructed in 1963 at Coyote Center, California. The building selected is a steel frame structure with a heavy concrete floor, and light, insulated walls and roof. Designed for the cure of Titan III booster segments, it contains power, ventilation, water, sprinkling system, plus some instrumentation and control. When built in 1963, the cost was \$9.611/ft². Updating that cost to 1975, using the Chemical Engineering Plant Cost Index gives a building cost of \$17.117/ft². This cost was used for manufacturing line buildings and the storage buildings for raw materials and product.

The in-process storage building was based on the use of 30-gal drums to handle the alpha HMX between the manufacturing line and the purification line. Drums were stored one high, and occupied 25 percent of the usable floor space. Acid in-process storage tanks with sufficient capacity for

about a 12-hr operation were also costed. Final product storage was sized for 3 months plant output, in 30-gal drums (each holding 200 lb) of HMX, stacked two high on pallets, with the drum pallets occupying 60 percent of the usable floor space.

The contract calls for estimating the cost of 60 days storage for critical raw materials. With the bringing on line of new large nitrogen fixation plants by the chemical industry during the past 2 years or so, ammonia does not appear to be a critical material at this time. Sulfuric acid is in ready supply, with large quantities of sulfur available for the manufacture of the acid. Nitric acid would not be a critical raw material, since the costing for this plant includes an AOP plant to manufacture nitric acid as needed. Investigations show that polyphosphoric acid will not be in critical supply, since even a 2 million lb/month line would require a relatively small percentage of the PPA capacity of even one plant for operation.

Hexamine is the other raw material, and capacity for storage of 60 days supply is included, even though it is not believed to be a critical item of supply. Storage for hexamine was calculated on the basis of 300 lb of hexamine per 55-gal drum, with drums on pallets stacked four high, and 60 percent of the floor space of the storage area being used for hexamine storage.

Control room costs were developed on the basis of a barricaded, earth covered mixer station control station built at the Coyote Center in 1960 at a cost of \$95.61/ft², including process equipment. Subtracting the cost of mechanical processing equipment used with the mixer that was installed when the control building was built gives a building cost of \$67.27/ft². This cost includes control and process monitoring instrumentation and closed circuit TV. Adding 10 percent for interconnecting cabling and escalating costs to 1975 by the Chemical Engineering Plant Cost Index gives a cost of \$132.00/ft², or a total cost of \$19,800 for a 150-ft² control room. Manufacturing building costs are summarized on Table 18.

TABLE 18. BUILDING COST SUMMARY

Building	Size, (ft ²)	Cost/ft ² , (dollars)	Cost, (dollars)
Bulk raw materials (hexamine, 60 days)	3440	17.12	58,893
Hexamine-DADN manu- facturing building	3100	17.12	53,072
DADN-HMX manufacturing building	2200	17.12	37,664
In-process storage	768	17.12	13,148
Process control room	150	132.00	19,800
Subtotal manufacturing buildings			<u>182,577</u>
HMX bulk storage (90 days)	25,000	17.12	428,000

Acid Plant

A summary of estimated acid plant capital costs is presented in Table 19. These costs were computed as described below.

Phosphoric Acid Concentration Plant

In computing PPA concentrating plant costs, it was assumed that the plant needed to support one 500,000-lb/month HMX line would cost 1.5 times as much as an NAC/SAC of the same equivalent capacity plus the cost of the vacuum equipment needed for vacuum distillation. Vacuum equipment costs were based on the use of multiple, single stage, mechanical pumps, with a 100-percent allowance for accessory equipment, piping, and installation. Vacuum pump costs were obtained from a current catalogue. In computing the plant capital costs for a 2,000,000-lb/month HMX plant, it was assumed that a single phosphoric acid concentrating plant would support all of the four 500,000-lb/month line HMX production lines specified in the contract guidelines. The evaporator portion of the plant was computed in accordance with the six-tenths rule (based on the cost of the plant to support one line), but the cost of the vacuum portion of the plant was calculated as four times the vacuum equipment costs of the smaller plant, since four times as much vapor would have to be handled. Although this method does result in a very large number of vacuum pumps being required for the PPA plant (61 vacuum

pumps for the plant to support one 500,000-lb of HMX/month line, and 244 pumps for the 2,000,000 lb/month plant), it does give a feel for the energy required and operating and capital costs. Regardless of the vacuum system employed in the PPA concentration plant, the energy requirements and capital costs should be comparable to those generated by this concept.

Nitric Acid-Sulfuric Acid Concentration Plant

The capital cost for an NA-SA concentrator is based on those of an NAC/SAC of the same capacity. The NAC/SAC price used was \$19.5 million for a 750-ton/day NAC/SAC, which was the base price developed for use in Reference a. Adjustments to plant capacity were made by the six-tenths rule.

TABLE 19. ESTIMATED CAPITAL COSTS FOR ACID PLANTS TO SUPPORT DADN-HMX PRODUCTION (1975 COSTS)

Plant	Current process HMX lb/month		Optimized process HMX lb/month	
	500K	2000K	500K	2000K
PPA				
Capacity, (tons/day)	87.2	349.3	87.2	349.3
Evaporator costs, (K dollars)	8043	18,493	8043	18,493
Vacuum system, (K dollars)	1568	6272	1568	6272
Total, (K dollars)	9611	24,765	9611	24,765
NA-SA				
Capacity, (tons/day)	105.1	420.4	31.6	126.4
Cost, (K dollars)	5997	13,778	2916	6700
AcOH recovery				
Capacity, (tons/day)	12.2	49.0	9.6	38.4
Cost, (K dollars)	1674	3794	1427	3280
Ac₂O production				
Capacity, (tons/day)	10.3	41.2	8.0	32.0
Cost, (K dollars)	1488	3419	1279	2938
AOP				
Capacity, (tons/day)	15.2	60.8	12.2	48.8
Cost, (K dollars)	1350	3100	1183	2717

Nitric Acid Flash and Vacuum Still

Capital costs were computed from a current catalog by determining the cost of a 316 ELC tank of sufficient size to permit the flash or vacuum removal of the nitric acid vapors, plus the cost of vacuum pumps with adequate capacity to remove the acid vapors. Since the nitric acid flash and vacuum still equipment are more nearly a part of the production line than the acid plant, their costs are included with the DADN-HMX production line costs.

Acetic Acid Recovery and Acetic Anhydride

The capital costs for both the acetic acid recovery and the acetic anhydride production plants were computed by the six-tenths rule based on the cost of an NAC/SAC. Both the acetic acid recovery plant and the acetic anhydride production plant are considered to be part of the acid plant and priced as single units supporting either one or four production lines.

AOP Plant

AOP plant costs are estimated from data developed in Reference a, a \$9.6 million cost for a 400 ton/day AOP plant. Adjustments for plant capacity was made by the six-tenths rule.

Water Pollution Abatement Equipment

The pollution control equipment includes filters to remove the hexamine anticaking materials, an activated carbon filter to remove organics, and ion exchange units to remove inorganic ions from the manufacturing waste streams. A multiple effect evaporator with a solids handling section and a vacuum filter-drier recovers chemicals in the regenerative waste stream.

Capital costs for the ion exchange units, the multiple effect evaporator and vacuum filter-drier are derived from costs generated in Reference a. Anticake and activated carbon filter capital costs are derived from Reference

For all plants, water pollution abatement equipment is sized to handle the waste waters from the plant in a single set of common facilities. Costs for all units are adjusted for capacity in accordance with the six-tenths rule.

Table 20 summarizes the capital costs for water pollution abatement facilities for both 500,000 and 2,000,000 lb/month of HMX, under both current and optimized process conditions.

TABLE 20. ESTIMATED CAPITAL COSTS OF WATER POLLUTION ABATEMENT EQUIPMENT DADN-HMX MANUFACTURE

Equipment	Current process HMX lb/month		Optimized process HMX lb/month	
	500K	2000K	500K	2000K
Anticake filter, (dollars)	25K	30K	25K	25K
Activated carbon filter, (dollars)	113K	259K	65K	150K
Ion exchange, (dollars)	96K	220K	28K	64K
IX waste water, drying equipment, (dollars)	92K	212K	47K	108K
Total	326K	721K	165K	347K

Air Pollution Abatement

Air pollution abatement capital costs are based on the assumption that the DADN-HMX system generates only one-half as much NO_x per pound of product as the nitration of nitrocellulose. Pilot plant runs show that the rate of NO_x generation is very low and easily controlled. The closed, pressurized system used for the DADN-HMX nitrolysis appears to suppress the rate of NO_x formation and very little NO_x is released to the air.

^d EPA Report EPA-4401/1-74-007a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Major Inorganic Products Segment of the Inorganic Chemical Manufacturing, Point Source Category," March 1974.

In estimating capital costs, the cost of an NO_x destruct system was based on costs for a 4,000,000 lb/month nitrocellulose line generated in Reference a. This cost was then halved and factored by the ratio of the weights of nitric acid used per hour in the two processes. A 2500-gal LPG tank was added to the above factored cost, as well as a cost for an absorbtion system.

The estimated cost arrived at for NO_x abatement for each line producing 500,000 lb of HMX/month is \$163,000 and \$375,000 for a plant producing 2,000,000 lb of HMX/month. Acid plant NO_x pollution abatement equipment costs are assumed to be included in the acid plant capital costs.

Total Capital Costs

Table 21 summarizes capital costs plants to meet the specified HMX production rates of 500,000 and 2,000,000 lb/month and for the two processing bases considered in this analysis.

In computing total capital costs for the 2,000,000 lb/month production rates, the HMX manufacturing line costs are four times those of the 500,000 lb/month rate. This results from the contract provision that calls for meeting the 2,000,000 lb/month manufacturing plant by the use of four modular lines producing 500,000 lb/month.

Designing the 2,000,000 lb/month plant as a single line capable of operating at a 500,000 lb/month rate, or at any desired rate in between, would be considerably less expensive than building four modular lines to meet the maximum production rate. For the current process condition, the cost of an integrated 2,000,000 lb/month HMX manufacturing line could be reduced to approximately \$15.07 million, and the optimized process condition to \$15.9 million instead of the costs shown in Table 20, (i.e., \$25.384 and \$27.094 million, respectively). This would reduce capital costs on the order of \$10 million. Acid plant costs would not be affected, since they are costed as integrated plants, sized to meet the 2,000,000 lb/month production rate. The acid plant sizes and costs would depend only on the HMX production rate, and not whether a single large, integrated plant or several smaller, modular plants are used.

TABLE 21. DADN-HMX PROCESS FACILITY COST SUMMARY
(1975 COSTS IN MILLIONS OF DOLLARS)

Item HMX manufacturing line	Current process			Optimized process			
	500K lb/month Capacity	Cost	2,000K lb/month Capacity	Cost	500K lb/month Capacity	2,000 K lb/month Capacity	Cost
Bulk material handling (Raw materials)		.059		.236			.172
Manufacturing buildings		.111		.444			.444
HEX-DADN process equipment		2.072		8.288			10.436
DADN-HMX process equipment		3.357		13.428			13.428
In-process HMX storage		.013		.052			.052
In-process acid storage tanks		.032		.128			.128
Pollution control							
Air		.163		.375			.375
Water		.326		.721			.347
Product storage (90 days)		.428		1.712			1.712
Subtotal		6.561		25.384		6.921	27.094
Acid plants							
NA-SA concentrators TPD	105.1	5.997	420.4	13.778	31.6	2.916	126.4
PPA concentrators TPD	87.2	9.611	349.3	24.765	87.2	9.611	349.3
AcOH recovery TPD	12.2	1.647	49.0	3.794	9.6	1.427	38.4
Ac ₂ O production TPD	10.3	1.488	41.2	3.419	8.0	1.279	32.0
AOP TPD	15.2	1.35	60.8	3.10	12.2	1.183	48.8
Subtotal		20.093		48.856		16.416	40.400
Total		26.654		74.240		23.337	67.494

CONSTRUCTION MATERIALS

DADN-HMX Processing Equipment

The first two processing steps in new Picatinny chemistry for the manufacture of HMX (hexamine to DAPT and DAPT to DADN) do not present any unusual construction materials problems. Stainless steels resistant to acetic anhydride, concentrated nitric acid, and sulfuric acid are available.

The ICP pilot plant uses Teflon-lined pipe ; Teflon coatings on stainless steel were used for the rest of the equipment. The Teflon coating was used primarily for its nonsticking properties in connection with other work. Teflon-lined pipes have performed in an excellent manner, showing no signs of deterioration from exposure to acetic anhydride, or to acetic, nitric, sulfuric, and polyphosphoric acids. Teflon spray on coatings has not held up satisfactorily.

The nonstick properties of Teflon are important in the third step. PPA is extremely viscous when cold, and without Teflon tends to stick and "pile up" in any cool spots in the system.

Literature investigations indicate that stainless steels with the characteristics of 316 ELC may satisfactorily withstand the corrosive effects of DADN-HMX nitrolysis medium.

Pyrex glass should be a satisfactory construction material for process equipment manufacturing DADN, and may be usable for the DADN-HMX nitrolysis step. Pyrex glass risers on the dispersers used for the third step have held up well, did not appear to be etched, and were washed clean by the return streams to the dispersers. PPA at very high temperatures, such as are encountered in concentration of phosphoric acid to PPA, does severely etch laboratory pyrex glassware. These temperatures are much higher (280°C and above) than those encountered in the nitrolysis of DADN to HMX (60° to 75°C).

All pumps used in the system are equipped with double mechanical seals with seal flush and throat flush systems. The double mechanical seals initially installed were fitted with stationary carbon inserts sealing against rotating ceramic faced stainless steel or Hastalloy seats. The carbon inserts were sealed with NBR O-rings, and the rotary seals driven by viton O-rings. The carbon inserts did not prove satisfactory, and were seriously eroded by the nitric acid sulfuric acid mixture, as well as by the PPA-nitric acid mixture. For the PPA-nitric acid runs, the stationary carbon inserts were replaced with glass-filled (25 percent) Teflon inserts and the front O-ring by a Teflon chevron seal. The rear NBR O-ring was not replaced. Based on the limited number of step 3 runs completed to date, the performance of the glass-filled Teflon inserts and the Teflon chevron rings appear to be satisfactory. The rear O-ring shows signs of deteriorating, but since it is located in an area of minimum flow, the rate is retarded. Teflon guard rings have been installed to protect the viton driver O-ring from contact with the acids, and their performance has been satisfactory so far. Additional investigations on these components are necessary. Both ceramic faced stainless steel and all ceramic seals have performed well. The only gasketing material in contact with the nitrating and nitrolysis mediums that has performed consistently well throughout the system has been white Teflon. Both sheet Teflon and molded Teflon gaskets for special fittings have been used.

One pump inlet, fabricated from type 304 stainless steel, was coated with Kynar on an experimental basis. This fitting was used only for pilot plant runs 104 and 105 and was exposed to the nitrolysis medium for a total of about 8 hr. During that time, the Kynar coating was completely stripped from the fitting, and the type 304 stainless steel was seriously corroded, turning completely black. From this example, it can be concluded that type 304 stainless steel is completely unsuited for step 3 processing equipment.

Based on experience in the pilot plant to date, CSD recommends that all process piping, heat exchangers, dispersers (or reactors), and carrier-product separation equipment be fabricated from Teflon or be fully lined with Teflon in spite of the possible adverse effects on heat transfer

rates that Teflon may bring. Those process pumps exposed to granular materials should be manufactured from 316 ELC stainless steel and Teflon lined to give satisfactory, long term service. The long term abrasive effects of granular products on Teflon linings on pump impellers is not known, but even if the Teflon lining is eroded away, 316 ELC stainless steel should provide for satisfactory pump life. Those process pumps that do not see granular materials could be manufactured from a lower grade stainless steel lined with Teflon. Pumps should be equipped with glass filled Teflon seal inserts and ceramic seals, and all gasketing materials should be white Teflon. Additional testing and investigations of construction materials, particularly those in contact with PPA-nitric acid solutions, are necessary.

Phosphoric Acid Concentrator

PPA concentrator construction materials will present problems. Hot phosphoric acid and PPA are extremely corrosive. Information on the corrosiveness of PPA at the temperatures involved in the concentration of PPA is very limited and will have to be determined as part of the concentrator design studies. From the limited information available, it appears that 316 ELC stainless steel may be able to withstand the corrosion, but extensive tests at the concentration temperatures will have to be carried out. Teflon lining could be used for at least part of the distillation system, but the feasibility of using Teflon lining throughout the distillation column has not been determined. Teflon is stable up to 275°C and may be useful. Teflon linings or coatings over less expensive construction materials could be used in the vacuum system, where temperatures are moderate. 304 or 316 stainless steels should also be suitable for the vacuum portion of the PPA concentrating system.

Nitric Acid-Sulfuric Acid Concentrator

The new NAC/SACs that are being provided to the AAPs as part of the Munitions Production Base Modernization and Expansion program are performing well and giving satisfactory service. The nitric and sulfuric acids needed for the DADN-HMX process are comparable in strengths to those generated by an NAC/SAC, and that piece of equipment should be able to meet requirements of the DADN-HMX process. Construction materials used in the NAC/SAC are not

known in detail to CSD, but these data are available to the Army. It is recommended that the construction materials used to construct the NAC/SAC be used to construct NA-SA concentrators used with the DADN-HMX process.

Acetic Acid Recovery and Acetic Anhydride Production

Acetic acid recovery and acetic anhydride production plants are in operation at Holston. CSD understands that the performance of these plants has been satisfactory, and that the designs have been made available to the Army. These designs should meet the requirements of the DADN-HMX processing system. If such designs are not available, high silicon irons, chromium-nickel stainless steels, and for certain components, aluminum and aluminum alloys can be used to construct these plants.

Pollution Control Facilities

Construction materials for pollution facilities do not present any undue problems. Waste water streams will be weak acid solutions, at or near ambient temperatures. They should not present a corrosion problem difficult to handle, although it may be necessary to use coatings on low alloy steels to keep corrosion rates within bounds. Commercially available pollution abatement equipment should be adequate to handle the pollution output of the DADN-HMX process.

AOP Plant

Modern AOP plants have been installed at the AAPs as part of the production base modernization program. A plant of similar design and using the same construction materials as those previously installed, but sized for the DADN-HMX plant needs, is assumed for this study and will be needed by a "grass roots" plant.

Recrystallization Plant

Although DMSO is a strong solvent, only minor problems with construction materials were encountered. Teflon held up well, and Teflon lining or high quality Teflon coatings protected ferrous metals from corrosion. Stainless

steels that do not rust or corrode in alternate wet-dry conditions should be used for process equipment not protected with a Teflon lining or coating. Either pure or glass-filled Teflon should be used for gasketing. In those places where Teflon seals or gaskets can not be used (such as pump shafts), silicone rubber appears to be a suitable substitute and performs well. Other rubbers in O-rings swelled excessively.

RECOMMENDED ACID AND SOLVENT RECOVERY

Phosphoric Acid

Only limited work has been done on the concentration and condensation of phosphoric acid to polyphosphoric acid. In concept, several recovery/concentration methods appear possible.

These include

- A. Thermal removal of any "free" water and continued heating to break the chemical bonds necessary to remove "molecular water" to form the condensed acids under atmospheric pressure.
- B. Absorption of condensed P_2O_5 from high temperature burning of phosphorous in the spent phosphoric acid.
- C. The same as A above under high vacuum to reduce temperatures.

Atmospheric pressure distillation of the spent phosphoric acid for concentration and formation of PPA does not appear to be practical due to the high temperatures involved; temperatures of the order of 750°C or higher would be necessary. Energy requirements would be extremely high, and at these temperatures the corrosion problems would be insurmountable. TVA has operated a carbon lined PPA concentration pilot plant in which hot combustion gases were blown through the acid to remove water. This plant operated with "black acid" (i.e., fertilizer acid) manufactured by the "wet process" which contains a high percentage of impurities that inhibit corrosion. Black acid is much less corrosive than the "white acid" needed by the DADN-HMX process. White acid is produced by burning elemental phosphorous and absorbing the resulting P_2O_5 in water or weak phosphoric acid. Further, the TVA experiment did not generate a 115-percent acid, but an acid with a concentration of about 105 percent. TVA officials do not feel that their system would be usable to generate a white acid of 115-percent concentration, primarily because of the corrosion problems.

The spent acid, or a portion of it, could be used to absorb condensed P_2O_5 to form PPA, but this would result in the generation of a large

quantity of phosphoric acid (in the neighborhood of 1100 tons/month), probably contaminated with organics, that would have to be disposed of in the commercial market. Although this process has not been priced out, it is believed that it would be more expensive than concentration by heat under vacuum.

The best means of concentrating the spent phosphoric acid is by vacuum distillation at about 280°C, primarily because of reduced corrosion. A very large vacuum system will be needed, since experience to date indicates that vacuum as low as 5 mm Hg will be needed. The time that the acid must be held at temperature to reach the equilibrium mixture of the condensed acids is not now known but may be substantial, and may require very large distillation systems. It appears to be less expensive to use a multistage distilling system, since a sizeable portion of the water can be removed at absolute pressures higher than those needed for the final step. The estimated cost of PPA concentration for this report has been based on the use of multistage distillation.

Other Acids

The Army has a great deal of experience in the concentration of nitric, sulfuric, and acetic acids, and the production of acetic anhydride. Concentration systems for acids currently being used are satisfactorily meeting the needs of the ammunition plants. There is no reason to believe that these same or similar systems will not meet fully the needs of the DADN-HMX process.

DMSO

In normal practice, DMSO is distilled from a water mixture and recovered for further use. In the recrystallization concept proposed by CSD, the water is distilled from the DMSO-water mixture, so that HMX will remain in solution in the DMSO for recycle through the recrystallization process. A DMSO-water mixture, of the composition that results after the HMX solution is quenched and the HMX is precipitated, still contains considerable HMX in solution. This mixture has a boiling temperature of about 102°C. At this temperature, excessive decomposition of both the DMSO and the HMX can be

expected during the distillation. Therefore, the distillation of the water from the DMSO-water-HMX solution must be carried out under vacuum to reduce temperatures. Distillation pressures over one-half an atmosphere should be avoided.

RECRYSTALLIZATION

Operating Costs

During the contract, CSD recrystallized class 1 HMX with an average crystal size of 160 microns. Some crystals up to 500 microns were generated, but class 4 HMX (average crystal size, 800 microns) was not made. The program started with class 5 (crystal size of 44 microns or less) and progressed to class 1 crystal size with the installed and available equipment. Theoretical work indicates that class 4 crystals can be made by operating at higher temperature (212°F) and allowing 40-min crystallization time, combined with controlled cooling and crystal seeding. Operating costs for recrystallization to class 4 HMX are higher than for other classes. In generating class 4 crystals, only 12.5 percent of the HMX in solution is precipitated from the DMSO and the remainder is recycled through the system. Higher yields are obtained for smaller crystal sizes. For class 5 crystals about 40 percent of the dissolved HMX is precipitated.

It appears that the CSD recrystallization system can produce highly uniform, rounded, HMX crystals with a narrower distribution of crystal sizes than is now called for in the specification. Preset processing conditions, which changed as crystal formation built up back pressure in the pilot plant, were adequate to meet the current specification for crystal size distribution. With automatic control of flows, much more uniform crystal sizes are anticipated.

For some specialized purposes, the availability of different, uniform crystal sizes would be advantageous. In solid propellants, for instance, increasing the solids loading increases the performance, but usually at the cost of a loss in physical properties. The availability of HMX in a number of discrete crystal sizes would permit using optimum amounts of specific crystal sizes to obtain maximum packing density without loss of physical properties. Rounding of these crystals will increase propellant fluidity, ease mixing and casting problems, and reduce mixing energy.

The present crystal size distribution within a given specification class imposes restraints on the loading that can be obtained in solid propellants and contributes to processing and safety problems. The crystal size distribution now permitted by the specification also results in nonconsistency of crystal size distribution on a lot-to-lot basis, which requires characterization of each HMX lot before it can be used in propellant production. This increases propellant processing problems as well as propellant costs.

A general description of the concept proposed by CSD for the purification and recrystallization of HMX is contained in Volume II of this report. Figure 3 is the flow diagram on which both operating and capital equipment cost estimates are based.

Operating costs were determined by sizing equipment, which determines power requirements for operation. Steam costs were calculated by determining the quantity of water to be removed by vacuum distillation from the combined solution streams. This distillation permits the recycle of HMX in the DMSO and wash solutions. Cooling loads were determined from pump heat inputs and cooling needed to control temperatures in the system.

Material costs were estimated by assuming that 90 percent of the acid contained in the water with the incoming crude HMX was removed by washing. The remaining 10 percent was neutralized with soda ash water to ensure complete removal and a neutral product for recrystallization. One tenth of 1 percent of the DMSO which passed through the distillation column each hour was assumed to be decomposed and removed from the system as organic waste. Likewise, it was assumed that 1 percent of the HMX entering the system is lost by decomposition and removed as organic waste with the DMSO decomposition products.

Pollution control costs were determined using pollution control abatement techniques similar to those described in the HMX manufacturing portion of this report, (i.e., weak electrolyte ion exchange units to remove acidic and metallic ions, evaporation of the ion exchange regenerate waste

streams in a multiple effect evaporator, and drying of the ion exchange regenerate waste chemicals for sale). Since the organic waste stream should contain very little water, an activated carbon filter is not needed. Organic wastes would be collected and burned. No cost is charged against the product for this operation, since it appears that the organic wastes can be burned in a furnace to recover their energy content. Likewise, no credit is taken for the fuel value.

Labor is estimated on the basis of a remote, automated, recrystallization operation, with one operator in the HMX manufacturing control room. This operator would be supervised by the control room supervisor. A two-person crew to handle incoming materials (HMX and soda ash) and a two-person crew to pack recrystallized HMX should be adequate for a 500,000 lb/month line. One supervisor is adequate to supervise all of the material handling. For the 2,000,000 lb/month plant two crews of two persons each, with a supervisor, should be adequate to handle the incoming material. The same crew size and supervision should be adequate for the final packing operation. One combined plant supervisor is provided for the large plant. Thus, total labor costs for the 500,000 lb/month rate would be \$91.88/hr or \$.121/lb of HMX, and \$211.25/hr or \$.07/lb for the 2,000,000lb/month rate.

Packing material for the recrystallized HMX is included in the recrystallization cost. Fiber barrels holding 200 lb dry weight of water-wet HMX are quoted on the west coast at \$5.00 each, with conductive plastic liners at \$135.00 per hundred, for a cost per drum of \$6.35. Since these are shipping drums, with only one use, the cost per pound of HMX for packing material is \$.032/lb.

For the same output capacity, a plant designed to produce class 4 HMX is larger than a plant designed to produce class 5 crystals. The class 4 size involves higher rates of flow, larger dispersers and pumps, and requires a larger, higher capacity distillation unit to remove water from the DMSO for recycle. Differences in equipment and plant capital costs between class 4 and class 5 recrystallization plants are discussed later. It appears that a

class 4 plant could be used to recrystallize to class 5 crystal size, and that the plant throughput for class 5 crystals would be higher for class 4 crystals.

Recrystallization operating costs were estimated on the basis of recrystallizing crude HMX from the DADN-HMX process to both class 4 and class 5 size crystals. In the case of class 5 crystals, costs are estimated under two different conditions. The first condition is the formation of class 5 crystals in a plant designed for the generation of class 4 size crystals. The second condition is the recrystallization of class 5 crystals in a plant designed to form class 5 crystals. Table 22 summarizes estimates of recrystallization costs for both class 4 and class 5 crystals.

When class 5 crystals are formed in a plant designed for the production of class 4 HMX (the first condition), the reduced costs result primarily from the higher throughput of the plant when recrystallizing to class 5 size. Since about 40 percent of the HMX is precipitated when generating class 4 crystals, instead of the 12.5 percent precipitated when generating class 5 crystals, the maximum throughput of the plant for class 5 crystals is about 3.2 times as high as for class 4 crystals, and corresponds to a monthly rate of almost 1.6 million lb/month. Since labor costs would increase very little with the increase in throughput rate, the labor cost per pound of HMX decreases and is the primary reason for the reduction in cost per pound of HMX under this condition. In addition, reduced operating temperatures and steam requirements for distillation also reduce unit costs. It probably is not possible to operate the recrystallization plant continuously at this high rate, since the manufacturing plant output rate is 500,000 lb/month, and limited in-process alpha HMX storage will be provided between the HMX manufacturing line and the recrystallization line. It may be possible however, to operate an HMX manufacturing line continuously and an associated class 4 recrystallization plant on a shift basis to produce class 5 HMX. It should be possible to make class 5 HMX in a plant designed to produce class 4 size, although probably not possible to make class 4 HMX in a plant designed to produce class 5 HMX size crystals.

TABLE 22. HMX RECRYSTALLIZATION OPERATING COSTS
(COSTS IN CENTS PER POUND OF RECRYSTALLIZED HMX)

Item	Class 4 recrystallization		Class 5 recrystallization		Class 5 recrystallization	
	Class 4 plant		Class 4 plant		Class 5 plant	
	500K lb/month	2000K lb/month	500K lb/month	2000K lb/month	500K lb/month	2000K lb/month
DMSO loss	1.15	1.15	.36	.36	.36	.36
Soda ash	.08	.08	.08	.08	.08	.08
HMX decomposition/loss ^a	.71	.71	.71	.71	.71	.71
Steam	4.15	4.15	1.14	1.14	1.14	1.14
Cooling water	.0008	.0008	.0004	.0004	.0004	.0004
Electrical energy	.57	.57	.18	.18	.57	.57
IX chemicals	.003	.003	.003	.003	.003	.003
In-process containers	.03	.03	.03	.03	.03	.03
Shipping containers	3.18	3.18	3.18	3.18	3.18	3.18
Labor	12.1	7.0	3.8	2.2	12.1	7.0
Total	21.97	16.87	9.48	7.88	18.17	13.07
Round off to	22.0	16.9	9.5	7.9	18.2	13.1

^a Average of costs of current process HMX (Table 15)

The other set of class 5 recrystallization cost figures contained in Table 22 reflect the second class 5 recrystallization condition (i.e., production of class 5 crystals in a plant designed to produce class 5 HMX). In this instance, equipment is smaller than that for the class 4 plant. Since 40 percent instead of 12.5 percent of the HMX dissolved in the DMSO is precipitated, rates of flow necessary to meet the 500,000 lb/month production rate are smaller, and the distillation tower for removal of water from the DMSO is smaller. The plant in general is smaller and less expensive. The costs of steam and other utilities are also less than for the class 4 plant. Since the same number of operators would be required, labor cost per pound of HMX recrystallized would be the same for each plant. The smaller plant would not be as flexible as the one designed to produce class 4 HMX since the flow rates, heating requirements, and distillation requirements for the class 5 plant are lower.

Capital Costs

Capital costs for plants to recrystallize HMX into both class 4 and class 5 crystal sizes were computed by first estimating the capacity and size of each of the major items of equipment shown on Figure 3 for each of the plants.

The cost of major items of equipment were then estimated using data generated for the HMX manufacturing portion of the report. Where cost data were not available from other sections of this analysis, costs were developed from Reference c curves and escalated to 1975. All equipment is costed for construction from 316 stainless steel. When the cost of the major pieces of equipment was determined, the total cost was increased by 20 percent to cover the cost of small miscellaneous parts, such as small filters, hold tanks, hoppers, and heat exchange units. Installation and finishing costs were calculated from the work area factors given in Reference c.

Building costs were determined by estimating the physical size of the major pieces of equipment and calculating the building size on the basis of 20-percent occupancy of floor space. The large vacuum distillation towers

for the recovery of DMSO from the quenched solution were assumed to be placed outside the buildings. The class 4 crystallizing coil, estimated to be 20 ft in diameter and containing some 2240 ft of 5-in. stainless steel tubing, is included within the building since the rate of cooling in the coil must be accurately controlled.

The crystallizing coil to make class 5 HMX is much smaller, and would only be about 5 ft in diameter. The difference in crystallizing coil sizes for each of the plants accounts for a large part of the differences in costs between the two recrystallization buildings.

After building sizes were determined on the basis of space needed for the major items of equipment, building costs were computed on the basis of \$17.12/ft². A small receiving building (the same size as the in-process storage building in the HMX manufacturing line), a small packing building of the same size, and DMSO storage tanks sufficient for 1 week of operation are included as part of the facilities for each recrystallization plant. The cost of the 90-day product storage building is included with the HMX manufacturing facility costs.

Capital costs for water pollution abatement are scaled from the costs in Table 20 on the basis of waste water flow rates using the six-tenths rule. Air pollution should not be a problem. The primary vapor escaping should be steam, with very little or no DMSO entrained. No cost allowance has been included for air pollution abatement.

The estimated cost of the major items of equipment needed for a class 4 HMX recrystallization plant is included in Table 23, and for the class 5 plant in Table 24. Table 25 summarizes the estimated capital costs for both the class 4 and class 5 HMX recrystallization plants at production rates of 500,000 and 2,000,000 lb/month.

TABLE 23. EQUIPMENT COST: RECRYSTALLIZATION TO CLASS 4 HMX^a

	Unit cost, (dollars)	No. of units	Totals cost, (dollars)
Receiving tanks/bins	513	5	2565
Belt filter	87,338	2	174,646
Dryer	15,000	1	15,000
Dry product feeder	19,610	1	19,610
Temperature control regulators	5000	3	15,000
Flow control regulators	5000	1	5000
Liquid level controller	5000	1	5000
Metering pump units, individual	1500	7	10,000
Heat exchangers for dispersers	7000	3	21,000
Seal flush pump system	10,000	1	10,000
40-hp pump/motor assemblies	2400	2	4800
20-hp pump/motor assemblies	1800	4	7200
Steam traps			2000
Dispersers, various sizes		3	24,000
2240 ft of 5-in. stainless steel tubing	58,217		58,217
Two receiving tanks at 1000 gal	6269	2	12,538
Waste separator	26,400	1	26,400
Fractionating column	235,125		235,125
Cooling condensor	2500	2	5000
Static mixers	1000	20	20,000
Vacuum pump	13,000	7	91,000
DMSO storage tank	2500	1	2500
		Subtotal	<u>767,101</u>
+20 percent for miscellaneous small equipment			<u>153,420</u>
		Total	<u>920,521</u>
Erect (11 percent)			101,257
Piping (80 percent)			736,417
Electrical (15 percent)			138,078
Instrumentation (26 percent)			239,335
Insulation (15 percent)			138,078
Painting (10 percent)			92,052
Engineering (45 percent)			414,235
1975 price total			<u>2,779,973</u>
Round off to			<u>2,780,000</u>

^a500,000 lb of HMX/month

TABLE 24. EQUIPMENT COST: RECRYSTALLIZATION TO CLASS 5 HMX^a

Item	Unit cost, (dollars)	No. of units	Total cost, (dollars)
Receiving tanks/bins	513	5	2565
Belt filters	87,338	2	176,646
Dryer	15,000	1	15,000
Dry product feeder	19,610	1	19,610
Temperature control regulators	5000	3	15,000
Flow control regulators	5000	2	10,000
Liquid level controller	5000	1	5000
Metering pumps	1500	7	10,500
Heat exchangers	3500	3	10,500
Seal flush system	8000	1	8000
Pump assemblies, (20 hp)	1800	2	3600
Pump assemblies, (10 hp)	1400	4	5600
Steam traps	Various	Various	2000
Dispersers	Var ous	3	18,000
Stainless steel tubing for crystal precipitator, (160 ft)	10.29/ft	160	1650
Receiving tanks	6300	2	12,600
Waste separator	26,400	1	26,400
Fractionating column	83,800	1	83,800
Condensers	1250	2	2500
Static mixers	1000	2	2000
Vacuum pumps	13,000	4	52,000
DMSO storage tank	2500	1	2500
Subtotal			485,471
(plus 20 percent for miscellaneous small equipment)			97,094
Subtotal			582,565
Erection (11 percent)			64,082
Piping, (80 percent)			466,052
Electrical (15 percent)			87,385
Instrumentation (26 percent)			151,467
Insulation (15 percent)			87,385
Painting (10 percent)			58,257
Engineering (45 percent)			262,154
Total			1,759,347
Round off to			1,760,000

^a500,000 lb of HMX/month

TABLE 25. COST SUMMARY: RECRYSTALLIZATION FACILITY
(1975 DOLLARS IN MILLIONS)

Item	Cost, (millions of dollars)			
	Class 4 HMX recrystallization		Class 5 HMX recrystallization	
	500K lb/ month	2000K lb/ month	500K lb/ month	2000K lb/ month
Recrystallization equipment	2.78	11.12	1.76	7.04
Recrystallization building	.100	.400	.056	.224
Receiving building	.013	.052	.013	.052
Packing building	.013	.052	.013	.052
Pollution control	.027	.108	.027	.108
Total	2.933	11.732	1.87	7.48

ESTIMATE OF ENERGY REQUIREMENTS

Table 26 gives a "first cut" estimate of energy needs of the DADN-HMX process. The process requirements include energy for pump, feeder and filter drive motors, filter vacuum pumps, agitators, temperature control, etc., as well as energy needs for the recovery of nitric acid in streams 40 and 41 and acetic acid from streams 6A and 37 (Figure 1).

The energy requirements for the acid plants were derived in a number of ways. The energy requirements for the PPA concentrator were generated by assuming that the spent acid is heated to 280°C under vacuum with water removal occurring in stages. Energy to remove molecular water from the ortho acid so that it can condense to pyro acid was computed from the differences in the heats of formation for the two acids, plus the energy needed to vaporize removed water. The PPA concentrator electrical energy was based on using single stage vacuum pumps driven by electric motors to provide a vacuum as low as 5 mm Hg for water removal.

NA-SA energy estimates were made by factoring the steam and power needed by a 580TPD NAC/SAC at Badger AAP to the NA-SA concentrating requirements for the manufacture of 500,00 lb/month of HMX. Acetic acid concentration and acetic anhydride energy needs were factored from recovery requirements on the basis of recycle cost contained in Reference b.

TABLE 26. SUMMARY OF ENERGY REQUIREMENTS^a

Item	Current process	Optimized process
HEX-DADN		
<u>Processing</u>		
Electrical pumps, (kw)	610	610
Referigation, (tons)	247	177
Cooling water, (gal/day)	6000	6000
<u>AcOH flash/vacuum</u>		
Electrical, (kw)	—	30
Steam, (lb/hr)	—	3700
Cooling water, (gal/day)	—	4500
DADN-HMX		
<u>Processing</u>		
Electrical pumps, (kw)	351	351
Referigation, (tons)	309	309
Cooling water, (gal/day)	5000	5000
<u>HNO₃ recovery</u>		
Steam, (lb/hr)	715	715
Electrical, (kw)	150	150
Cooling water, (gal/day)	95,000	95,000
<u>AcOH flash</u>		
Steam, (lb/hr)	2000	2000
Electrical, (kw)	7.5	7.5
Cooling water, (gal/day)	1500	1500
<u>Acid plants</u>		
PPA concentration ^b		
Steam, (lb/hr)	11,000	11,000
Electrical, (kw)	2365	2365
Cooling, (gal/hr)	17,660	17,660
NA-SA concentration		
Steam, (lb/hr)	9565	2875
Electrical, (kw)	135	41
<u>AcOH recovery</u>		
Steam, (lb/hr)	3265	2569
Electrical, (kw)	10	10
<u>Ac₂O production</u>		
Steam, (lb/hr)	2760	2140
Electrical, (kw)	10	10
<u>AOP^c</u>		
Electrical, (kw)	8.9	7.1

^aDADN-HMX processing 500,000/lb month rate

^bAbout one-half at the steam should be 1000-psi saturated steam or lower pressure steam superheated to about 550°F.

^cSame export steam generated. AT AOP capacities needed, the amount of steam exported is minor.

SCHEDULE

Figure 4 shows the anticipated schedule for the program. The schedule assumes that the DADN-HMX program will be continued in R&D for 5 years from January 1976, (i.e., midway in FY 1976 at a \$2 million/year rate). Development of design criteria and plant design would be accomplished during the latter part of the R&D program. Production plant construction would start in January 1980, and be accomplished in 2 1/2 years. Production at the design rate would start at the beginning of FY 1983.

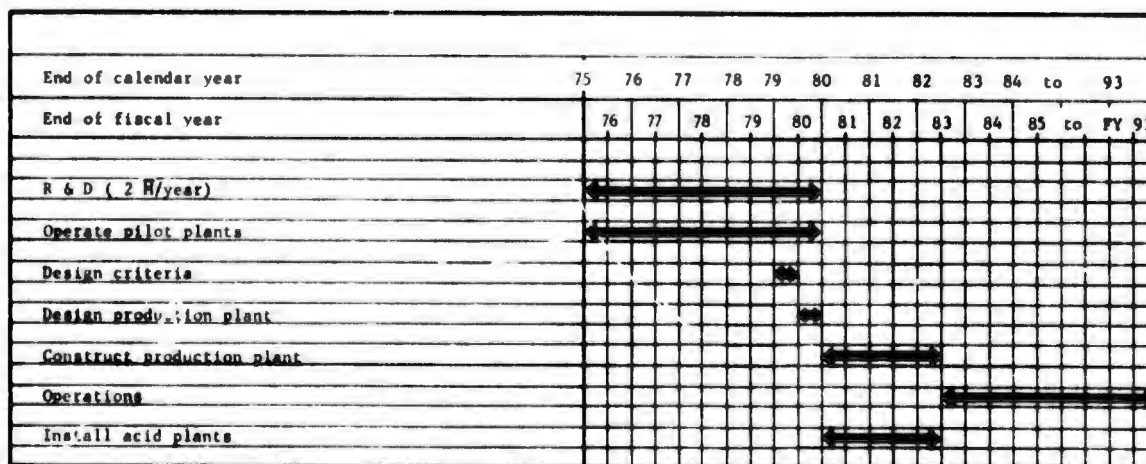


Figure 4. Anticipated program schedule
(DADN-HMX Process)

DETAILED ECONOMIC ANALYSIS

The objective of the Picatinny new chemistry program is to provide an HMX manufacturing process which will reduce per pound cost of HMX, reduce manufacturing line capital costs, and yield a relatively pure crude product which requires a minimum of purification. While the study contract involves the application of the ICP to this new HMX chemistry, there also is a provision to investigate recrystallization and purification by a new technique that permits delivery of HMX in a wide range of uniform crystal sizes. For the purpose of the economic analysis, the two parts of the overall study have been considered separately, but are combined in this section of the report.

The recrystallization portion of the program is based on the use of crude HMX containing acetic acid as delivered from the Holston process. The DADN-HMX process crude HMX will be delivered from the manufacturing lines wet with water containing a mixture of phosphoric, nitric, and acetic acids. The bulk of the acid will be phosphoric acid with smaller amounts of nitric acid and very small quantities of acetic acid. To simulate the Holston crude HMX, some of the recrystallization work accomplished under the contract was carried out with HMX wet with a weak acetic acid solution, which was essentially all removed during recrystallization. No work has been done on the recrystallization/purification of crude HMX manufactured by the Picatinny chemistry, but no problem is anticipated in the removal of those acids.

The CSD system for the recrystallization of DADN process HMX is used to develop capital and operating costs. Development of these costs has been discussed in the section on recrystallization.

Cost Sensitivities

The operating costs and capital costs generated previously and used as the basis of the detailed economic analysis were developed with the best information available at the time. All assumptions used are believed to be reasonable ones, and all functions known to be necessary to the operation of

a "grass root" plant, except utilities, are included. Material costs were based largely on those used by Picatinny Arsenal in its Economic Analysis dated 3 January 1975 (Reference b). The costs used in the Picatinny analysis that differ from the CSD analysis are those concerned with PPA. The Picatinny analysis used a cost of \$.0908/lb for this chemical. The price quoted to CSD from a plant in the San Francisco Bay Area is \$.2529/lb in bulk. Since only .12 lb is consumed per pound of HMX produced, the difference is relatively minor, amounting to \$.026/lb of HMX. A portion of this cost can be reclaimed in the pollution control area if the proper pollution control techniques are used. CSD personnel also believe the cost of recycle for PPA is overstated by Picatinny by some \$.026 lb of HMX.

As discussed earlier, the concentration of PPA is an unknown area, and one that requires intensive investigation. Spent PPA has not been concentrated on a scale that would permit firm decisions to be made as to its commercial feasibility. Repeated concentrations and nitrolyses with spent PPA have not been carried out to ensure that it can be reused. There is not even agreement on the concentrating techniques that should be used: CSD personnel believe that a high vacuum distillation is necessary. Picatinny personnel believe that a flue gas evaporator will work. All agree that hot PPA is highly corrosive and that solving the materials of construction problems will be difficult. PPA concentration and reuse appears to be the major unknown technical area in the DADN-HMX process as presently conceived. Increases in the cost of PPA because of the inability to recycle indefinitely or because of increased concentrating costs will be reflected directly in increased costs of HMX.

The cost per pound of HMX will also change directly in proportion to the cost of the other input chemicals, particularly hexamine, the highest cost material used in the DADN-HMX process. Increasing the product yields for each of the processing steps, as well as the recovery and recycle of formaldehyde from the second step, will result in a substantial decrease in the amount of hexamine needed, and reduce the per pound cost of HMX.

With the exception of the DADN-HMX nitrolysis step, all of the current process yield figures used in the analysis have been closely approached in pilot plant operations, and no difficulty in reaching them is foreseen. A DADN-HMX nitrolysis yield figure of 67.5 percent was reached in the final pilot plant run, in which DADN was dissolved in nitric acid for convenience in feeding to the pressurized system. This feeding method has been determined by Picatinny to result in a yield loss of about 10 percent, which has also been confirmed by CSD's work. Using the operating conditions of the final pilot plant run, laboratory nitrolyses show the same 67.5-percent yield. Data from laboratory nitrolyses that were made available at the end of the program showed that under different operating conditions yields of 80 percent are obtained. Thus, it appears that current process yields are almost in hand, and should be reached with a minimum of optimization work. The yield figures for the optimized process have not yet been reached, and reaching them will require considerable exploratory effort. However, they do appear reasonable with further development. Both Picatinny and LASL are approaching these yields in laboratory work.

The variation of the material and labor costs for the manufacture of HMX by the DADN process are estimated at +15 percent, -5 percent.

The major capital cost of the 500,000-lb/month HMX lines is the cost of the acid plant, with the PPA concentration plant accounting for about half of the acid plant costs. The PPA concentrating plant is a large plant; the art of concentrating phosphoric acid to PPA is an unknown art; and the construction materials needed to stand up in the highly corrosive environment are uncertain. All in all, the cost of this plant is subject to considerable uncertainty. However, costing it on the basis of 1.5 times the cost of an NAC/SAC of the same output capacity, plus the cost of single stage mechanical vacuum pumps to handle the volume of vapor removed during the phosphoric acid concentration process, is believed to give a conservative estimate of its cost.

Little information was available to CSD personnel on the cost of acetic acid recovery and the acetic anhydride production plants, but costing them at the same price as an NAC/SAC of equivalent output capacity is believed to be a conservative estimate.

The costs listed in Tables 19 and 21 for both the AOP and NA-SA plants should be fairly firm, since they are based on 1974 Army Modernization Program budget data, although the NA-SA will be operating under slightly different conditions than an NAC/SAC.

Capital costs, overall program costs, uniform annual costs, and average annual discounted program costs are all sensitive to changes in the cost of acid plants, since these costs are a substantial portion of the overall capital costs.

The estimated variation in costs for the acid plants and the manufacturing and recrystallization facilities is believed to be of the order of +15 percent, -0 percent, although this estimate can not be verified with the data available to date, particularly in regard to PPA concentration plants.

The estimated variation in the overall program costs developed in this study are believed to be about +15 percent, -5 percent.

The economic life of the HMX manufacturing lines, as well as the acid plants, should be of the order of 30 years with proper maintenance. Maintenance costs of the manufacturing line should be moderate. Maintenance costs of the acid plants should be higher than those of the manufacturing line, and those of the phosphoric acid concentrating plant may be considerably higher than the maintenance costs for the other acid plants.

DISCUSSION

The detailed economic analyses presented here include R&D costs not previously discussed. The \$10 million, 5-year R&D program cost included in the CSD analyses is based on information received from the office of the Project Manager, Production Base Modernization which also indicated that the program would start in the near future and extend over a period of 5 years. For convenience, the program cost has been spread evenly at the rate of \$1 million every 6 months, starting in mid-FY 1976. Twenty-five percent of the R&D costs have been allotted for recrystallization in the separate analyses. In those analyses dealing only with the manufacturing portion of the overall system, R&D costs were not decreased, however, and those results are thus slightly overstated. The same R&D costs were used in the analyses without regard to plant size or process used.

Plant construction in all cases starts in mid-FY 1981, and continues for 2-1/2 years with costs spread evenly over that period. Full-scale operation of the manufacturing lines and the recrystallization lines starts at the beginning of FY 1984 and continues for 10 years. Although it appears that all of the plants would have an economic life greater than 10 years, no terminal value was assigned after the 10-year operating period. All analyses are based on an 18-year program life, including 10 years of operation.

The CSD analyses are also based on the following definitions of IBL and OBL. IBL has been interpreted to mean the HMX manufacturing line only, not including acid plants. OBL has been interpreted to mean the HMX manufacturing line plus acid plants. Under this definition, the recrystallization lines are all IBL lines, since acid plants are not involved in their operation. As stated in the Assumptions section, CSD did not include the costs of power plants, steam generating plants, outside power or water distribution systems, road or rail networks, etc. "Grass roots" was interpreted to mean a plant construction site, ready for plant construction, with all outside services provided to the construction site.

Appendix A consists of a series of 28 format A, AR 37-17 detailed economic analyses. These format A analyses are based on CSD developed estimates of facility and operating costs. They included analyses for manufacturing only, recrystallization only, and manufacturing and recrystallization combined. The conditions covered by these analyses are both CSD processes, both production rates, IBL and OBL, and recrystallization to class 4 and to class 5 size HMX. Data from the format A analyses are summarized in Figures 5, 6, and 7. Figure 5 is a graphic summary of the analyses of the HMX manufacturing lines for both CSD processes, both production rates, and the IBL and OBL conditions; class 4 and class 5 recrystallization costs are also displayed. Figure 6 is a bar chart summary of the CSD economic analyses for combined manufacturing and class 4 recrystallization lines for the conditions stated above. Figure 7 is a bar chart summary of the CSD economic analysis for combined manufacturing and class 5 recrystallization lines for the conditions stated above.

A comparison of the IBL and OBL summaries on Figure 5 for the same production rate and process condition shows the major impact that the acid plants have on the facility costs. In general, the acid plants are estimated to cost about twice as much as the manufacturing lines with the cost of the acid plants for the optimized line always lower than for the current line. This results primarily from the marked reduction in sulfuric acid used by the optimized process. Figure 5 also shows the relatively minor facility and operating cost impact of purification. All three figures show the significant reduction in operating costs between the current and optimized processes resulting from the two system improvements considered in this analysis.

The format A analyses in Appendix A are arranged in the order of the bar summaries of Figures 5, 6, and 7.

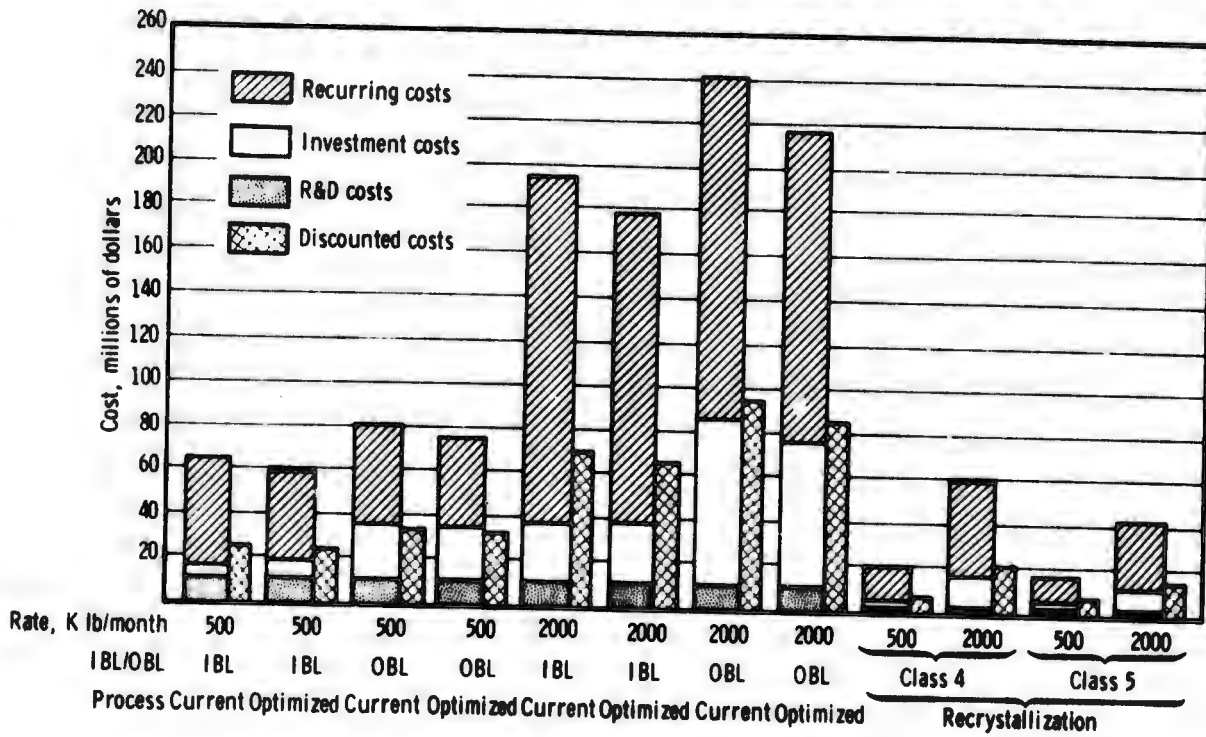


Figure 5. Program costs - DADN-HMX manufacturing lines and HMX recrystallization lines.

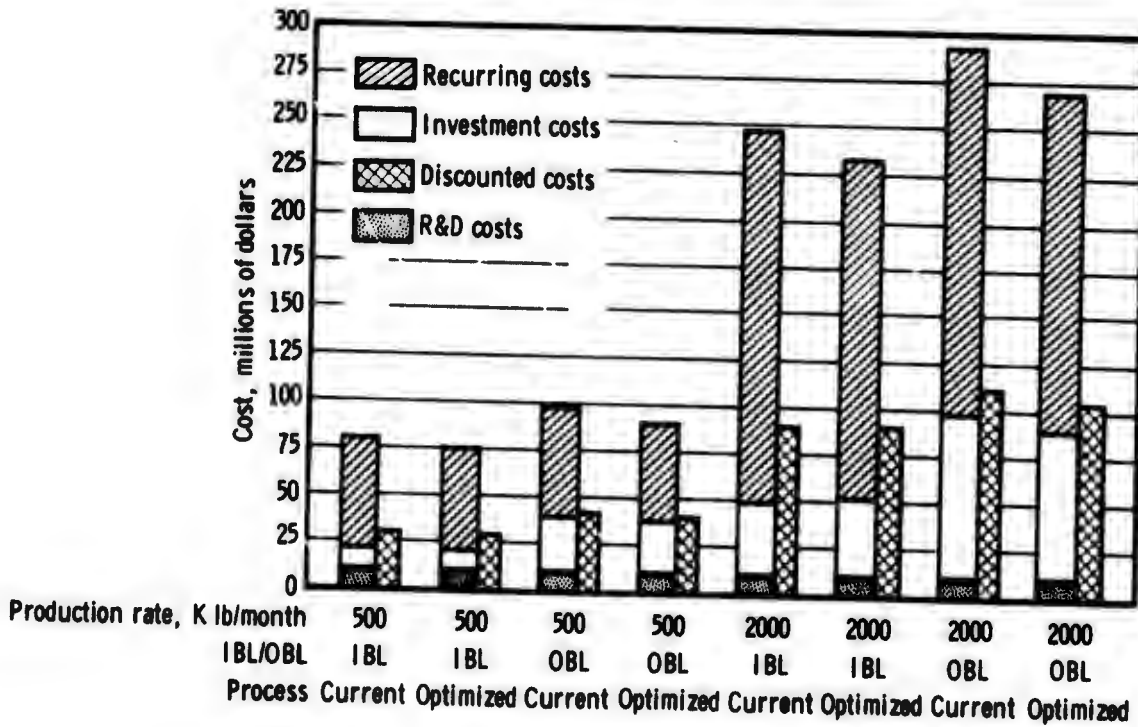


Figure 6. Program Costs - DADN-HMX manufacturing and class 4 recrystallization combined.

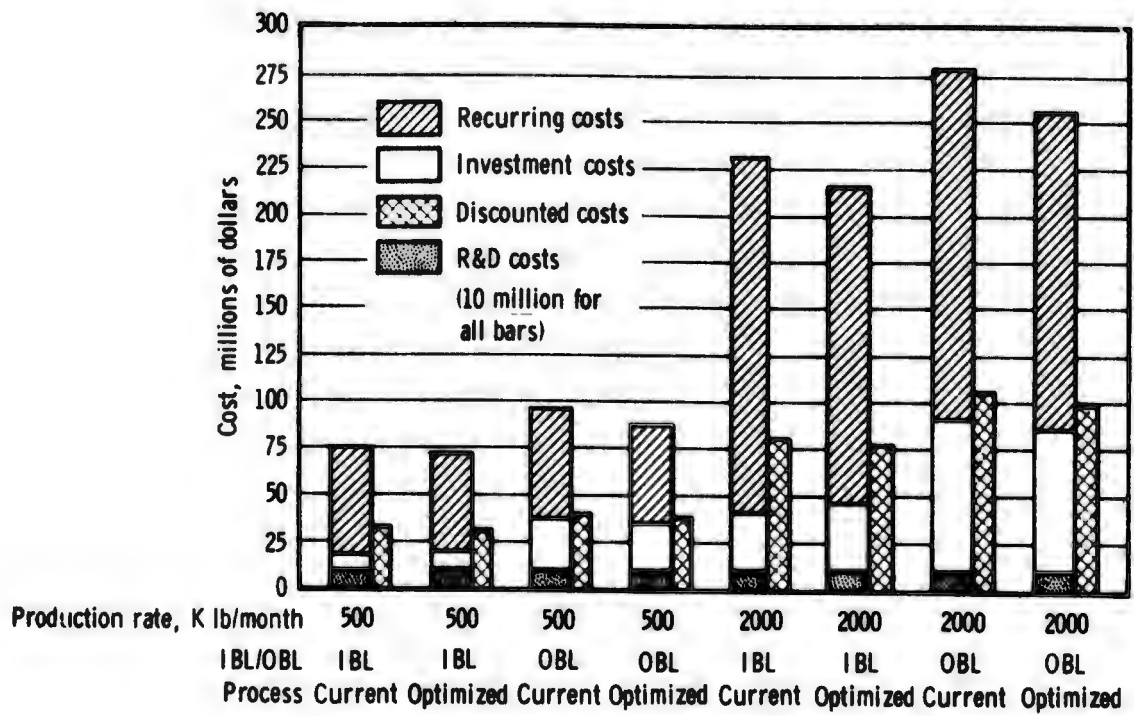


Figure 7. Program costs - DADN-HMX manufacturing and class 5 recrystallization combined.

SUMMARY OF ECONOMIC OUTPUTS

Quantifiable Economic Benefits

A. Product Costs

HMX is estimated to cost between \$1.00 and \$1.25/lb at the present time. Reference b derives a cost of \$.83/lb for the DADN-HMX process, a cost of \$1.03/lb for the Improved Bachmann process, and a cost of \$1.48/lb for the standard Bachmann process. The CSD analysis derives a cost of from \$.58 to \$.77/lb depending on the production rate and the development of HMX state of the art. The yields upon which the \$.77 figure is based have been demonstrated, or closely approached, in pilot plant or laboratory work.

B. Capital Costs

Capital costs reported by Picatinny in Reference b for the standard Bachmann process for two lines each producing 500,000 lb of HMX/month is about \$100 million, some \$80 million for the Improved Bachmann, and \$79 million for the DADN-HMX process. All of the above figures include common-use acid plants. The CSD analysis produces investment costs for a single 500,000 lb/month line, including acid plants, of either \$23.34 or \$26.65 million depending on which process is considered. The analysis also produces costs for a 2,000,000 lb/month HMX production plant, consisting of four manufacturing lines with common acid plants, of either \$67.49 or \$74.24 million, again depending on the process considered. CSD generated total investment costs, including a plant for recrystallization to class 4 HMX for each 500,000 lb/month line, range from \$29.59 million for the current process plant to \$26.27 million for the optimized process. Capital cost for plants producing class 4 recrystallization HMX at a 2,000,000 lb/month rate are \$85.97 million for the current process and \$79.23 million for the optimized process. Capital costs for plants producing class 5 HMX are \$1.06 million less for a 500,000 lb/month line and \$4.25 million less for a 2,000,000 lb/month plant.

C.

Capital costs for recrystallization only plants to produce class 4 HMX are estimated at \$2.933 million for a 500,000 lb/month plant, and \$11,732 million for a 2,000,000 lb/month plant. Plants to produce corresponding rates of class 5 are estimated at \$1.87 million and \$7.48 million.

D.

CSD estimates recrystallization costs for class 4 HMX to be \$.22/lb at a 500,000 lb/month rate and .169/lb at the 2,000,000 lb/month rate and class 5 costs to be \$.182 and \$.131 for the corresponding production rates.

E. Reduction in Annual and Discounted Annual Costs

In all instances in which comparable lines and production rates are considered, CSD generated costs are lower than the costs reported in Reference b. Reductions in these costs are significant and result from both reduced investment and operating costs.

F. Overall Operating Costs

The estimated cost generated by the CSD economic analysis to produce 1 lb of class 4 recrystallized HMX ranges from a high of \$.986/lb at 500,000 lb/month rate using the current process to a low of \$.751/lb at a 2,000,000 lb/month rate using the optimized process. Corresponding costs for class 5 HMX are \$.948 and \$.713.

Nonquantifiable Benefits

A. Recrystallization of HMX into a series of different, nearly uniform crystal sizes with a narrower size distribution than is now called for in the specification would be of value in the solid propellant field. The production of HMX sized in such a manner would permit using optimum amounts of specific crystal sizes to obtain maximum packing density without loss of physical properties. Thus, solid propellant performance could be increased.

- B. An ICP system is an inherently safe system, since hazardous products are dispersed in an inert carrier and will not propagate a detonation.

- C. Dispersal of extremely viscous fluids in an inert carrier reduces their viscosity and permits them to be pumped and mixed readily. It also appears that the corrosiveness of highly corrosive fluids is reduced somewhat by dispersal in an inert carrier.

CONCLUSIONS

The DADN-HMX system for the large scale manufacture of HMX appears to be economically competitive with the Bachmann or Improved Bachmann process. The cost per pound of purified and recrystallized HMX produced by ICP using the DADN-HMX chemistry is less than the cost of raw HMX manufactured by the Bachmann or Improved Bachmann processes.

Facility costs for an ICP plant manufacturing HMX by the DADN-HMX chemistry at a rate of 2,000,000 lb/month are less than those for either a Bachmann or Improved Bachmann process producing 1,000,000 lb of HMX/month.

The concentration of spent phosphoric acid into PPA has been accomplished only on a small laboratory scale. The feasibility of large scale concentration has not been demonstrated. The construction materials, operating costs, and losses involved in the large scale concentration of this acid must be determined by pilot plant experience. PPA procurement and concentration costs constitute a substantial portion of the DADN-HMX process material costs.

Recrystallization of Holston crude HMX by the process proposed by CSD has been demonstrated for class 1 and class 5 HMX. Recrystallization of crude to class 4 HMX by this process has not been demonstrated, although theory shows that it can be done. Purification and recrystallization of DADN-HMX process crude HMX has not been demonstrated, but should be easily accomplished. Purification and recrystallization costs should be \$.22 or less for each pound of HMX processed.

HMX can be recrystallized into different, nearly uniform crystal sizes with a narrower crystal size distribution than is now called for in the specification. Further, rounded crystals can be produced by additional processing.

Facilities for the recrystallization process proposed by CSD are of nominal cost.

In all cases, CSD estimates of facility, recurring, total annual, discounted, uniform annual, and uniform discounted annual costs for HMX manufactured by the DADN-HMX chemistry in an ICP plant are less than the corresponding costs reported in Reference b for HMX manufactured by the Bachmann or Improved Bachmann processes.

RECOMMENDATIONS

- A. Expand the CSD pilot plant into a continuous four-step pilot plant to optimize processing conditions, refine economic data, and develop design data for a production line.
- B. Commence a program to determine the feasibility, construction materials, equipment, and operating conditions necessary to concentrate spent phosphoric acid to white polyphosphoric acid adequate for the DADN-HMX nitrolysis. Determine costs for this concentration.
- C. Investigate the techniques and economics of using an N_2O_5 generator and nitric acid instead of PPA and nitric acid for the DADN-HMX nitrolysis.
- D. Investigate the techniques and economics of recovering formaldehyde from the DAPT-DADN nitration.
- E. Develop an economical technique for the purification of DAPT.

ABBREVIATIONS

AAP	Army Ammunition Plant
AOP	ammonia oxidation process
DADN	1,5-diacetyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane
DAPT	diacetylpentamethylenetetramine
DMSO	dimethyl sulfoxide
FOB	free on board
FY	fiscal year
HMX	cyclotetramethylene tetranitramine
IBL	inside battery limits
ICP	Inert Carrier Process
LASL	Los Alamos Scientific Laboratory
LPG	liquified petroleum gas
NAC	nitric acid concentration
NA-SA	nitric acid-sulfuric acid
NBR	nitrile-butadiene rubber
OBL	outside battery limits
PPA	polyphosphoric acid
R&D	research and development
ROM	rough order of magnitude
SAC	sulfuric acid concentration
SAR	sulfuric acid regeneration
TVA	Tennessee Valley Authority

REFERENCES

References referred to specifically in the report.

- a. CSD Report 2521-FTR, "Comparative Study of Dehydrating Processes in the Manufacture of Nitrocellulose," Final Report, Contract No. DAAA21-74-C-0461, 31 July 1975.
- b. Hutchinson, R. W. and R. Motto, "Cost Estimate of DADN-HMX process," Picatinny Arsenal, 3 January 1975.
- c. "How to Estimate the Cost of Pilot Plants," Chemical Engineering, February, 1970.
- d. EPA Report EPA-4401/1-74-007a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Major Inorganic Products Segment of the Inorganic Chemical Manufacturing, Point Source Category," March 1974.

Other References

Reports

EPA-440/1-74-009a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Major Organic Products Segment of the Organic Chemicals Manufacturing," March 1974.

Books

1. Besseliere, The Treatment of Industrial Wastes, McGraw Hill Book Company.
2. Handbook of Physics and Chemistry, 46th Edition, The Chemical Rubber Company.
3. Hardenberg, W. A. and Edward B. Brodie, Water Supply and Waste Disposal, International Text Book Company.
4. James, G. V., Water Treatment, CRC Press, International Scientific Series.
5. Lund, Herbert F., Ed., Industrial Pollution Control Handbook, McGraw Hill Book Company.

Periodicals

Chemical Marketing Reporter, November 3, 1975.

APPENDIX A
AR 37-13 FORMAT A ANALYSES

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U. S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs Current process - 500,000 lb/month HMX; manufacturing only - IBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.31		2.31	.592	1.368
1982		2.62		2.62	.538	1.410
1983		2.63		2.63	.489	1.286
1984-1993 (10 year total)			45.93	45.93	3.003	13.793
9. Totals	10.0	6.56	45.93	62.49	8.605	24.859

10a. Total Project Cost (discounted)	24,859	
10b. Uniform Annual Cost (without terminal value)		3.47
11. Less Terminal Value (discounted)	0.00	
12a. Net Total Project Cost (discounted)	24,859	
12b. Uniform Annual Cost (with terminal value)		1.381

NOTE: All costs are in millions of dollars.

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/PROGRAM
EVALUATION STUDIES
FORMAT A

13. Source/Derivation of Cost Estimates: (Use as much space as required)

a. Nonrecurring Costs:

1.) Research and Development

PM-PBM Submission, 5 year program

2.) Investment:

Economic Analysis, Report CSD-2555-FR, Contract No.
DAAA21-75-C-0251, January 1975.

b. Recurring Cost:

Economic Analysis, Report CSD-2555-FR, Contract No.
DAAA21-75-C-0251, January 1975.

c. Net Terminal Value:

None Assigned.

d. Other Considerations:

14. Name & Title of Principal Action Officer	Date
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Note: All of the second pages of the AR 37-13 Format A analyses included in Appendix A are identical. Second pages for the following analyses are not included to save costs.

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs Optimized process - 500,000 lb/month HMX; manufacturing only - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.384		2.384	.592	1.411
1982		2.77		2.77	.538	1.490
1983		2.77		2.77	.489	1.355
1984-1993 (10 year total)			41.81	41.81	3.003	12.556
9. Totals	10.0	6.921	41.81	58.73	8.605	23.814

- | | | |
|---|--------|-------|
| 10a. Total Project Cost (discounted) | 23.814 | |
| 10b. Uniform Annual Cost (without terminal value) | | 3.263 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 23.814 | |
| 12b. Uniform Annual Cost (with terminal value) | | 1.323 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 500,000 lb/month HMX; manufacturing only - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.33		6.33	.592	3.747
1982		10.662		10.662	.538	5.736
1983		10.662		10.662	.489	5.214
1984-1993 (10 year total)			45.93	45.93	3.003	13.793
9. Totals	10.0	26.654	45.93	82.58	8.605	35.492

- | | | |
|---|-------|------|
| 10a. Total Project Cost (discounted) | 35.51 | |
| 10b. Uniform Annual Cost (without terminal value) | | 4.59 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 35.51 | |
| 12b. Uniform Annual Cost (with terminal value) | | 1.97 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs Optimized process - 500,000 lb/month HMX; manufacturing only - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	4.667		5.667	.592	3.357
1982		9.335		9.335	.538	5.022
1983		9.335		9.335	.489	4.565
1984-1993 (10 year total)			41.81	41.81	3.003	12.576
9. Totals	10.0	23.337	41.81	75.15	8.605	35.522

- | | | |
|---|-------|------|
| 10a. Total Project Cost (discounted) | 35.52 | |
| 10b. Uniform Annual Cost (without terminal value) | | 4.18 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 35.52 | |
| 12b. Uniform Annual Cost (with terminal value) | | 1.81 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month HMX; manufacturing only - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.08		6.08	.592	3.599
1982		10.15		10.15	.538	5.461
1983		10.15		10.15	.489	4.963
1984-1993 (10 year total)			158.42	158.42	3.003	47.574
9. Totals	10.0	25.38	158.42	193.80	8.605	68.599

- | | | |
|---|--------|-------|
| 10a. Total Project Cost (discounted) | 68.599 | |
| 10b. Uniform Annual Cost (without terminal value) | | 10.77 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 68.599 | |
| 12b. Uniform Annual Cost (with terminal value) | | 3.81 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 2,000,000 lb/month HMX; manufacturing only - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.42		6.42	.592	3.801
1982		10.83		10.83	.538	5.827
1983		10.84		10.84	.489	5.301
1984-1993 (10 year total)			139.66	139.66	3.003	41.40
9. Totals	10.0	27.09	139.66	176.68	8.605	63.331

- | | | |
|---|--------|------|
| 10a. Total Project Cost (discounted) | 63.331 | |
| 10b. Uniform Annual Cost (without terminal value) | | 9.82 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 63.331 | |
| 12b. Uniform Annual Cost (with terminal value) | | 3.52 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month HMX; manufacturing only - OBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	14.85		15.85	.592	9.375
1982		29.70		29.70	.538	16.573
1983		29.70		29.70	.489	14.523
1984-1993 (10 year total)			158.42	158.42	3.003	47.653
9. Totals	10.0	74.25	158.42	242.67	8.605	95.129

- | | | |
|---|-------|-------|
| 10a. Total Project Cost (discounted) | 95.13 | |
| 10b. Uniform Annual Cost (without terminal value) | | 13.48 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 95.13 | |
| 12b. Uniform Annual Cost (with terminal value) | | 5.28 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs Optimized process - 2,000,000 lb/month HMX; manufacturing only - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	13.499		14.499	.592	8.583
1982		26.998		26.998	.538	14.525
1983		26.998		26.998	.489	13.202
1984-1993 (10 year total)			139.66	139.66	3.003	42.010
9. Totals	10.0	67.494	139.66	217.514	8.605	85.322

10a. Total Project Cost (discounted)	85.32	
10b. Uniform Annual Cost (without terminal value)		12.064
11. Less Terminal Value (discounted)	0.00	
12a. Net Total Project Cost (discounted)	85.32	
12b. Uniform Annual Cost (with terminal value)		4.74

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs 500,000 lb/month HMX; recrystallization only - class 4 size						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	.25			.25	.954	.239
1977	.5			.5	.867	.434
1978	.5			.5	.778	.394
1979	.5			.5	.717	.359
1980	.5			.5	.652	.326
1981	.25	.587		.837	.592	.496
1982		1.173		1.173	.538	.631
1983		1.173		1.173	.489	.574
1984-1993 (10 year total)			13.2	13.2	3.003	3.964
9. Totals	2.5	2.933	13.2	18.633	8.605	7.417

- | | | |
|---|------|-------|
| 10a. Total Project Cost (discounted) | 7.42 | |
| 10b. Uniform Annual Cost (without terminal value) | | 1.035 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 7.42 | |
| 12b. Uniform Annual Cost (with terminal value) | | .412 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs 2,000,000 lb/month HMX; recrystallization only - class 4 size						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	.25			.25	.954	.239
1977	.5			.5	.867	.434
1978	.5			.5	.778	.394
1979	.5			.5	.717	.359
1980	.5			.5	.652	.326
1981	.25	2.346		2.596	.592	1.537
1982		4.693		4.693	.538	2.525
1983		4.693		4.693	.489	2.295
1984-1993 (10 year total)			40.56	40.56	3.003	12.180
9. Totals	2.5	11.732	40.56	54.792	8.605	20.289

- | | |
|---|-------|
| 10a. Total Project Cost (discounted) | 20.29 |
| 10b. Uniform Annual Cost (without terminal value) | 3.04 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 20.29 |
| 12b. Uniform Annual Cost (with terminal value) | 1.13 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Material Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs 500,000 lb/month HMX; recrystallization only - class 5 size						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(iFY)						
1976	.25			.25	.954	.239
1977	.5			.5	.867	.434
1978	.5			.5	.778	.394
1979	.5			.5	.717	.359
1980	.5			.5	.652	.326
1981	.25	.374		.624	.592	.369
1982		.748		.748	.538	.402
1983		.748		.748	.489	.366
1984-1993 (10 year total)			10.92	10.92	3.003	3.285
9. Totals	2.5	1.87	10.92	15.29	8.605	6.174

- | | | |
|---|------|------|
| 10a. Total Project Cost (discounted) | 6.17 | |
| 10b. Uniform Annual Cost (without terminal value) | | .849 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 6.17 | |
| 12b. Uniform Annual Cost (with terminal value) | | .343 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs 2,000,000 lb/month HMX; recrystallization only - class 5 size						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	.25			.25	.954	.239
1977	.5			.5	.867	.434
1978	.5			.5	.778	.394
1979	.5			.5	.717	.359
1980	.5			.5	.652	.326
1981	.25	1.496		1.746	.592	1.034
1982		2.992		2.992	.538	1.610
1983		2.992		2.992	.489	1.463
1984-1993 (10 year total)			31.44	31.44	3.003	9.457
9. Totals	2.5	7.48	31.44	41.42	8.605	15.316

- | | | |
|---|-------|------|
| 10a. Total Project Cost (discounted) | 15.32 | |
| 10b. Uniform Annual Cost (without terminal value) | | 2.30 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 15.32 | |
| 12b. Uniform Annual Cost (with terminal value) | | .851 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 500,000 lb/month, class 4 HMX; manufacturing and recrystallization - IBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.90		2.90	.592	1.717
1982		3.80		3.80	.538	2.044
1983		3.80		3.80	.489	1.858
1984-1993 (10 year total)			59.16	59.16	3.003	17.766
9. Totals	10.0	9.494	59.16	78.654	8.605	30.387

- | | |
|---|--------|
| 10a. Total Project Cost (discounted) | 30.387 |
| 10b. Uniform Annual Cost (without terminal value) | 4.37 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 30.387 |
| 12b. Uniform Annual Cost (with terminal value) | 1.69 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 500,000 lb/month class 4 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.97		2.97	.592	1.759
1982		3.94		3.94	.538	2.120
1983		3.94		3.94	.489	1.927
1984-1993 (10 year total)			55.02	55.02	3.003	16.523
9. Totals	10.0	9.85	55.02	74.87	8.605	29.331

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|---|-------|
| 10a. Total Project Cost (discounted) | 29.33 |
| 10b. Uniform Annual Cost (without terminal value) | 4.16 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 29.33 |
| 12b. Uniform Annual Cost (with terminal value) | 1.63 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current Process - 500,000 lb/month class 4 HMX; manufacturing and recrystallization - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.92		6.92	.592	4.097
1982		11.84		11.84	.538	6.370
1983		11.84		11.84	.489	5.790
1984-1993 (10 year total)			59.13	59.13	3.003	17.757
9. Totals	10.0	29.587	59.13	98.72	8.605	41.016

- | | |
|---|--------|
| 10a. Total Project Cost (discounted) | 41.016 |
| 10b. Uniform Annual Cost (without terminal value) | 5.484 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 41.016 |
| 12b. Uniform Annual Cost (with terminal value) | 2.28 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process / Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized Process - 500,000 lb/month class 4 HMX; manufacturing and recrystallization - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.25		6.25	.592	3.70
1982		10.51		10.51	.538	5.654
1983		10.51		10.51	.489	5.139
1984-1993 (10 year total)			55.01	55.01	3.003	16.520
9. Totals	10.0	26,270	55.01	91.28	8.605	38.015

- | | | |
|---|--------|------|
| 10a. Total Project Cost (discounted) | 38.015 | |
| 10b. Uniform Annual Cost (without terminal value) | | 5.07 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 38.015 | |
| 12b. Uniform Annual Cost (with terminal value) | | 2.11 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month class 4 HMX; manufacturing and recrystallization - IBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	7.42		8.42	.592	4.985
1982		14.85		14.85	.538	7.989
1983		14.85		14.85	.489	7.262
1984-1993 (10 year total)			198.96	198.96	3.003	59.748
9. Totals	10.0	37.12	198.96	246.08	8.605	86.986

- | | |
|---|-------|
| 10a. Total Project Cost (discounted) | 86.99 |
| 10b. Uniform Annual Cost (without terminal value) | 13.67 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 86.99 |
| 12b. Uniform Annual Cost (with terminal value) | 4.83 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 2,000,000 lb/month class 4 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	7.766		8.766	.592	5.189
1982		15.530		15.530	.538	8.355
1983	1	15.530		15.530	.489	7.594
1984-1993 (10 year total)			180.24	180.24	3.003	54.126
9. Totals	10.0	38,826	180.24	229.07	8.605	82.266

- | | | |
|---|-------|-------|
| 10a. Total Project Cost (discounted) | 82.27 | |
| 10b. Uniform Annual Cost (without terminal value) | | 12.73 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 82.27 | |
| 12b. Uniform Annual Cost (with terminal value) | | 4.57 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month class 4 HMX; manufacturing and recrystallization - OBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	17.19		18.19	.592	10.768
1982		34.39		34.39	.538	18.502
1983		34.39		34.39	.489	16.817
1984-1993 (10 year total)			198.98	198.98	3.003	59.754
9. Totals	10.0	85.97	198.98	294.59	8.605	112,843

- | | | |
|---|---------|-------|
| 10a. Total Project Cost (discounted) | 112,843 | |
| 10b. Uniform Annual Cost (without terminal value) | | 16.39 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 112,843 | |
| 12b. Uniform Annual Cost (with terminal value) | | 6.27 |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann Process/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 2,000,000 lb/month class 4 HMX; manufacturing and recrystallization - OBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	15.845		16.845	.592	9.972
1982		31.690		31.69	.538	17.049
1983		31.690		31.69	.489	15.496
1984-1993 (10 year total)			180.22	180.22	3.003	54.120
9. Totals	10.0	72.225	180.22	269.445	8.605	103.64

- | | | |
|---|--------|-------|
| 10a. Total Project Cost (discounted) | 103.64 | |
| 10b. Uniform Annual Cost (without terminal value) | | 14.97 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 103.64 | |
| 12b. Uniform Annual Cost (with terminal value) | | 5.76 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 500,000 lb/month class 5 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.69		2.69	.592	1.592
1982		3.37		3.37	.538	1.813
1983		3.37		3.37	.489	1.648
1984-1993 (10 year total)			56.88	56.88	3.003	17.081
9. Totals	10.0	8.43	56.88	75.22	8.605	29.136

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|---|--------------|-------------|
| 10a. Total Project Cost (discounted) | <u>29.14</u> | |
| 10b. Uniform Annual Cost (without terminal value) | | <u>4.18</u> |
| 11. Less Terminal Value (discounted) | <u>0.00</u> | |
| 12a. Net Total Project Cost (discounted) | <u>29.14</u> | |
| 12b. Uniform Annual Cost (with terminal value) | | <u>1.62</u> |

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 500,000 lb/month class 5 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	1.758		2.758	.592	1.633
1982		3.516		3.516	.538	1.892
1983		3.517		3.517	.489	1.719
1984-1993 (10 year total)			52.74	52.74	3.003	15.838
9. Totals	10.0	8.791	52.74	71.53	8.605	28.08

- | | | |
|---|-------|------|
| 10a. Total Project Cost (discounted) | 28.08 | |
| 10b. Uniform Annual Cost (without terminal value) | | 3.97 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 28.08 | |
| 12b. Uniform Annual Cost (with terminal value) | | 1.56 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current Process - 500,000 lb/month class 5 HMX; manufacturing and recrystallization - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.705		6.705	.592	3.969
1982		11.409		11.409	.538	6.138
1983		11.410		11.410	.489	5.579
1984-1993 (10 year total)			56.88	56.88	3.003	17.081
9. Totals	10.0	28.524	56.88	95.40	8.605	39.769

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|---|-------|------|
| 10a. Total Project Cost (discounted) | 39.77 | |
| 10b. Uniform Annual Cost (without terminal value) | | 5.30 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 39.77 | |
| 12b. Uniform Annual Cost (with terminal value) | | 2.21 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 500,000 lb/month class 5 HMX; manufacturing and recrystallization - OBL						
7. Project Year	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
(FY)						
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	5.045		6.045	.592	3.579
1982		10.091		10.091	.538	5.429
1983		10.091		10.091	.489	4.934
1984-1993 (10 year total)			52.74	52.74	3.003	15.838
9. Totals	10.0	25.227	52.74	87.97	8.605	36.782

- | | | |
|---|-------|------|
| 10a. Total Project Cost (discounted) | 36.78 | |
| 10b. Uniform Annual Cost (without terminal value) | | 4.89 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 36.78 | |
| 12b. Uniform Annual Cost (with terminal value) | | 2.04 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month class 5 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	6.573		7.573	.592	4.483
1982		13.145		13.145	.538	7.072
1983		13.146		13.146	.489	6.428
1984-1993 (10 year total)			189.84	189.84	3.003	57.009
9. Totals	10.0	32.864	189.84	232.70	8.605	81.994

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|---|-------|
| 10a. Total Project Cost (discounted) | 81.99 |
| 10b. Uniform Annual Cost (without terminal value) | 12.93 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 81.99 |
| 12b. Uniform Annual Cost (with terminal value) | 4.56 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 2,000,000 lb/month class 5 HMX; manufacturing and recrystallization - IBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	6.915		7.915	.592	4.686
1982		13.830		13.830	.538	7.441
1983		13.830		13.830	.489	6.763
1984-1993 (10 year total)			171.12	171.12	3.003	51.387
9. Totals	10.0	34.575	171.12	215.69	8.605	77.279

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|---|-------|
| 10a. Total Project Cost (discounted) | 77.28 |
| 10b. Uniform Annual Cost (without terminal value) | 11.98 |
| 11. Less Terminal Value (discounted) | 0.00 |
| 12a. Net Total Project Cost (discounted) | 77.28 |
| 12b. Uniform Annual Cost (with terminal value) | 4.29 |

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Current process - 2,000,000 lb/month class 5 HMX; manufacturing and recrystallization - OBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	16.34		17.34	.592	10.265
1982		32.69		32.69	.538	17.587
1983		32.69		32.69	.489	15.985
1984-1993 (10 year total)			189.84	189.84	3.003	57.009
9. Totals	10.0	81.72	189.84	281.56	8.605	107.848

10a. Total Project Cost (discounted)	<u>107.85</u>
10b. Uniform Annual Cost (without terminal value)	<u>15.64</u>
11. Less Terminal Value (discounted)	<u>0.00</u>
12a. Net Total Project Cost (discounted)	<u>107.85</u>
12b. Uniform Annual Cost (with terminal value)	<u>5.99</u>

**SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A**

1. Submitting DoD Component: U.S. Army Materiel Command
2. Date of Submission: _____
3. Project Title: ICP Application to HMX Nitrolysis and Recrystallization
4. Description of Project Objective: Production of HMX at reduced cost
5. Alternative: Bachmann/Improved Bachmann Process
6. Economic Life: Estimated 30 years

8. Program/Project Costs						
Optimized process - 2,000,000 lb/month class 5 HMX; manufacturing and recrystallization - OBL						
7. Project Year (FY)	a. Nonrecurring		b. Recurring Operations	c. Annual Cost	d. Discount Factor	e. Discounted Annual Cost
	R&D	Investment				
1976	1.0			1.0	.954	.954
1977	2.0			2.0	.867	1.734
1978	2.0			2.0	.778	1.576
1979	2.0			2.0	.717	1.434
1980	2.0			2.0	.652	1.304
1981	1.0	14.994		15.994	.592	9.468
1982		29.99		29.99	.538	16.135
1983		29.99		29.99	.489	14.665
1984-1993 (10 year total)			171.12	171.12	3.003	51.387
9. Totals	10.0	74.974	171.12	256.09	8.605	98.657

- | | | |
|---|-------|-------|
| 10a. Total Project Cost (discounted) | 98.66 | |
| 10b. Uniform Annual Cost (without terminal value) | | 14.23 |
| 11. Less Terminal Value (discounted) | 0.00 | |
| 12a. Net Total Project Cost (discounted) | 98.66 | |
| 12b. Uniform Annual Cost (with terminal value) | | 5.48 |