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STUDIES ON THE TECHNICAL ARMS CONTROL ASPECTS  
OF CHEMICAL AND BIOLOGICAL WARFARE

THE HISTORY OF CHEMICAL WARFARE PLANTS  
AND FACILITIES IN THE UNITED STATES

ACDA/ST-197  
Volume IV

by

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I. INTRODUCTION

At the end of World War II, the United States Army discovered that Germany had been producing a series of chemical warfare agents more toxic than any previously known man-made military chemical agent. As much information as possible was collected from the Germans about these new "nerve agents," and research on them was started in the United States in 1946.

In the period of demobilization following World War II, the War Department placed little emphasis on chemical and biological warfare agents. But beginning in 1948, more attention began to be paid to these systems. The Secretary of Defense appointed committees of civilian and military experts to study and make recommendations in these areas. One of these groups was headed by Dr. Earl Stevenson, President of Arthur D. Little Company. This committee made its report to the Secretary of Defense in June of 1950.

The recommendations of the Stevenson Committee, which coincided with the views of the Chief Chemical Officer, were to improve U.S. posture in chemical and biological warfare. One result of this increased emphasis was the decision of the Defense Department to build facilities as soon as possible for the manufacture of "nerve gas." The Chemical Corps, with Defense Department approval, drew up plans to carry out the nerve gas manufacturing process on a three step basis. Under these plans, a plant at the Tennessee Valley Authority's Wilson Dam in Alabama would carry out the first step, the manufacture of a chemical intermediate. This material would then be shipped by rail tank car to Rocky Mountain Arsenal where the next two steps of the process would be completed.

In August 1950, the Under Secretary of the Army approved the request of the Chief Chemical Officer, MG Anthony C. McAuliffe, to negotiate a contract with the Kellogg Corporation (later known as the Vitro Corporation of America), and Universal Oil Products for design of a plant at Muscle Shoals, Alabama, to produce the GB intermediate, (b)(2) (b)(2) HIGH (Dichlor), and a plant at Rocky Mountain Arsenal in Denver, Colorado, to produce the final product, the nerve agent isopropyl methylphosphonofluoridate (GB).

b(2)  
high

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The design, development, and construction of these plants were undertaken in November of 1950. The Dichlor facility at Muscle Shoals was designated "Site A," or the "Muscle Shoals Phosphate Development Works," and the GB facility was referred to as "Site B," or the "Incendiary Oil Plant."

In January 1951, the government negotiated other contracts with the Monsanto Chemical Company of St. Louis as prime contractor and with the Leonard Construction Company of Chicago as sub-contractor to build a chlorine plant adjacent to the Site A plant at Muscle Shoals. This plant was required to furnish much needed chlorine to the PDW plant. The Corps of Engineers supervised construction of both plants and Site B in Colorado. The Chief Chemical Officer maintained a staff under COL Graydon C. Essman to coordinate technical matters relative to the construction of the plants.

Much later, in 1956, a third nerve agent facility was planned and discussed by the Chemical Corps' Engineering Command and Materiel Command at the Army Chemical Center, Edgewood, Maryland. The Chemical warfare laboratories had been doing research for some time on a new nerve agent which was more toxic and more persistent than agent GB. It was planned in 1956 to review the possibility of producing the new nerve agent, known as V-agent or VX or V-1701, on a pilot-plant scale first, and from there to a final production facility.

In 1957, the Chief Chemical Officer appointed a committee to study the production problem and select a site at which to produce a V-agent. The site selected was the AEC Heavy Water Plant at Dana, Indiana--which became known as the "Newport Chemical Plant." A development contract was awarded to the M. W. Kellogg Company, and initial pilot-plant operations were carried out at the Army Chemical Warfare Laboratories.

Sections II, III, and IV of this volume deal with the various problems, failures, and successes experienced by each of the three nerve-agent plants: Site A, Site B, and Newport. Section V contains the conclusions of this study.

## II. MUSCLE SHOALS PHOSPHATE DEVELOPMENT WORKS

### A. Historical Background

The earliest records obtained from the various offices at the U.S. Army's Edgewood Arsenal and the U.S. Army Munitions Command Historical Office reveal that firm plans for the selection of a process and a site for the production of the GB nerve-agent intermediate, (b)(2) b(a) (b)(2) HIGH (Dichlor) were developed in 1947.<sup>1/</sup> At that time huafn it was decided by the U.S. Army Chemical Corps Materiel Command, the U.S. Army Chemical Corps Research and Engineering Command, the Chemical Corps Advisory Council, and, ultimately, the U.S. Army Chief Chemical Officer (with Department of the Army approval) that the German five-step Dimethyl Hydrogen Phosphite (DMHP) process would be used for GB production, and that the first three steps of this process (leading to the production of Dichlor) would be carried out in a commercially designed, constructed and operated facility in the Wilson Dam area at Muscle Shoals, Alabama.

During the late 1940's, a number of conferences and plant visits were held with selected chemical-process and chemical-construction companies to discuss the problems of plant design, development, construction, and operation, and to outline management procedures, personnel requirements, and costs.

The plant at Muscle Shoals, designated as "Site A" or the "Muscle Shoals Phosphate Development Works (MSPDW), was designed by the Vitro Corporation of America (VITRO) and constructed by them under the overall management of the U.S. Army Corps of Engineers. Upon completion of construction, the U.S. Army Chemical Corps Materiel Command assumed initial responsibility for the plant. It was operated by the Tennessee Valley Authority (TVA) and a Chemical Corps technical and administrative staff.

In November 1948, the Office of the Chief Chemical Officer (OCCMO) issued a directive for the development of a plant design for Site A, which was supplemented by Instructions for writing a plan for a unit plant design.<sup>2/</sup> The actual design work began in November 1950, and

January 1951, a Memorandum of Agreement was executed by the Department of the Army for construction, maintenance and operation of the PDW by TVA.<sup>3/</sup> Based on this Agreement, and the amendments or modifications thereto,<sup>4,5/</sup> an Administrative Manual was prepared by TVA and the Office of the Chief Chemical Officer (OCCml O).

In the spring of 1951 the construction phase of the MSPDW began, and it was planned (and officially scheduled) that the DMHP plant would be in production in the fall of 1951. At the same time, construction began on a chlorine plant adjacent to the PDW site to serve as a feeder plant. The chlorine plant was designed and operated by the Monsanto Company. The rationale for building a separate chlorine plant is discussed in Section B.

In September 1951, VITRO was directed to provide a plant design report, and in November 1951, submitted an estimate of the cost of preparing the requested report and an outline of the format.<sup>6/</sup> These are discussed in Sections B and C below.

Although construction was not completed until 1953,<sup>7,8/</sup> limited operations (i.e., plant start-up) at MSPDW began in June 1952; however, the planned sustained production rate was never achieved. Various sections or trains of the plant became operative, but the entire three-step process was never totally in full-scale operation. The many operational and administrative problems which arose during the early development, construction and operation of the Muscle Shoals plant, and the circumstances which led to shutdown of the Muscle Shoals project and its ultimate lay-away in 1958, are discussed in Sections B, C, D and E below.

#### B. Development, Construction and Operations

Three of the early major decisions in the development, construction and operation of the Phosphate Development Works were the determination of which production process to use, where to locate the plant, and whether to carry out the process in-house or contract with industry to provide the required GB intermediate.

b (2) high

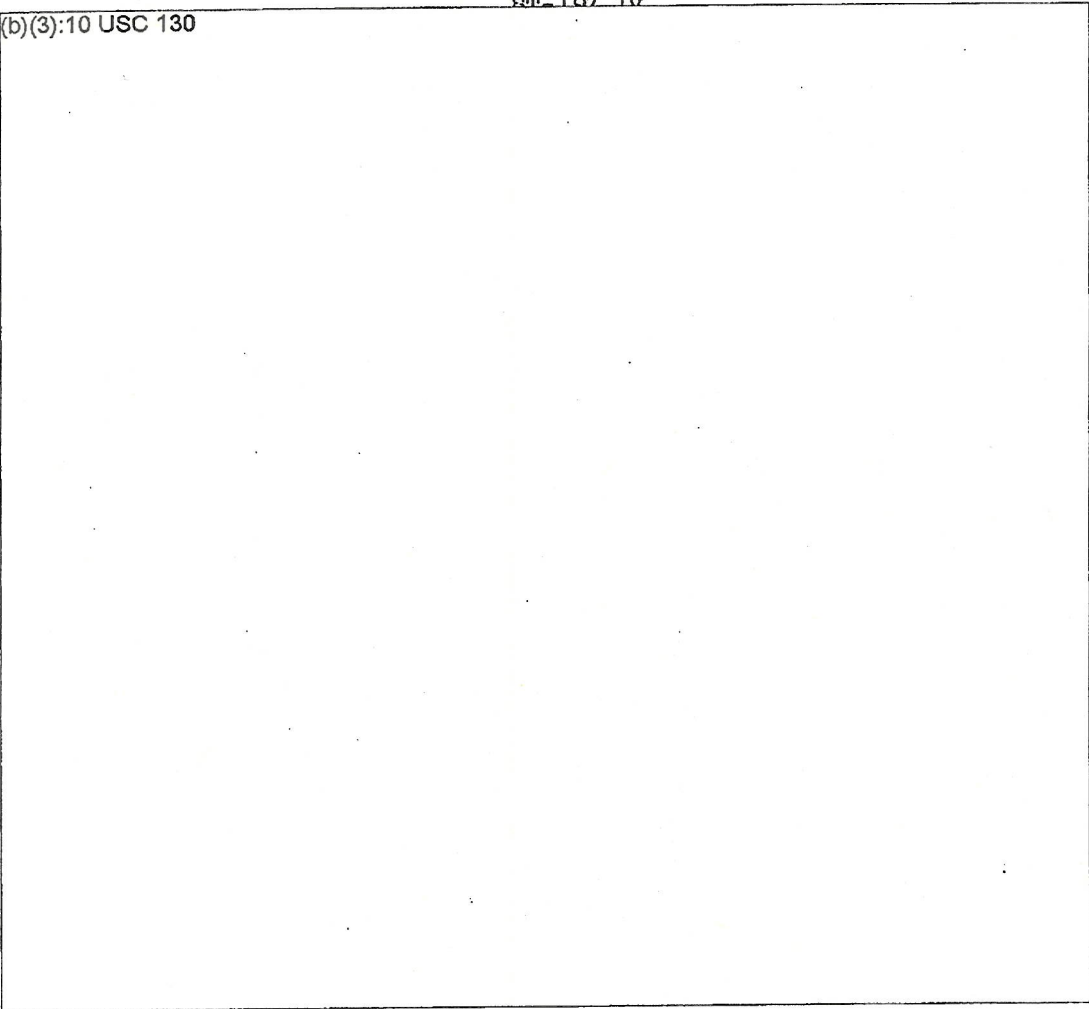
For the production of the GB intermediate, (b)(2) HIGH  
 (b)(2) HIGH (Dichlor), the production process selected was the German  
 Dimethyl Hydrogen Phosphite (DMHP) process. This method was selected  
 over others because more was known about the DMHP process than any  
 other method, the likelihood of success appeared to be greater, and it  
 seemed to be the most economical method at the time. (b)(3):10 USC 130

(b)(3):10 USC 130

(3)  
usc 130

In the planning stages it was thought, initially, that the entire GB production process from elemental phosphorus to agent might be carried out at a single location, but as planning progressed, it became apparent that two separate facilities would be required. The final production process involving GB itself was to be accomplished at the Rocky Mountain Arsenal (Site B) where adequate security, storage, handling, and safety facilities would be made available. The decision to locate the front end of the process (elemental phosphorus to agent intermediate) separately at Muscle Shoals (Site A) was based on the fact that there already existed at Muscle Shoals a phosphorus plant, ample electrical power, and a pool of potentially trained operating personnel from TVA. Additionally, this site offered the advantages of being dispersed from other chemical corps facilities, having adequate space, transportation and an ample water supply, and being located on government-owned property. And, since it was determined that the necessary operations would not be carried out in-house, i.e., by Chemical Corps or other Army personnel exclusively, the TVA facility at Muscle Shoals was an obvious location for the new plant.<sup>9/</sup> It was also decided that the large amounts of chlorine required could best be supplied by actually building a chlorine plant at Site A, rather than by purchasing and shipping the quantities needed from plants already in existence (surveys indicated that existing chlorine plants could not meet the demands).<sup>9/</sup> So rather than paying the cost of expanding one or more chlorine manufacturing facilities plus the costs of shipment, it was decided to negotiate a contract with the Monsanto Chemical Company and the Leonard Construction Company to build and operate a chlorine plant at MSPDW. This facility was designed to provide both chlorine and caustic soda to the Dichlor plant.

(b)(3):10 USC 130



b(3)  
10 USC 130

2. Operational Planning and Early Execution: Considerable difficulty was experienced in putting the Muscle Shoals plant into successful operation. It was originally planned, when the contract was let with VITRO in November of 1950, that Site A would be operative, i.e., producing Dichlor, by late 1951. However, in the fall of 1951, construction was still far from complete because of the necessity for equipment changes, process modifications, required laboratory and pilot plant programs, technical and administrative errors, and logistic and managerial problems (see Sections C, D, and E). So in August 1951, the Chief Chemical Officer directed the Corps of Engineers to submit a completion report for the MSPDW project. This requirement was placed on VITRO in November 1951, and VITRO responded that same month with an outline of the proposed report.<sup>6/</sup>

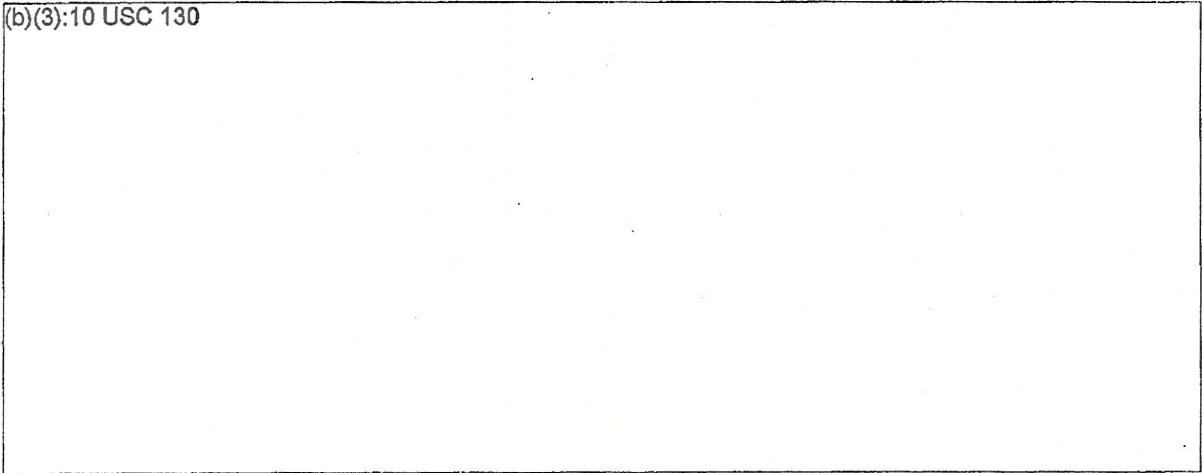
VITRO completed the construction phase in September 1953, and the Chemical Corps Materiel Command assumed responsibility for the plant-- which up to that time had produced no Dichlor.<sup>7/</sup> During this two-year period (1951-1953), TVA personnel assisted the Chemical Corps under a Memorandum of Agreement for plant operations executed in January 1951,<sup>8/</sup> and offered their services in operating the DMHP plant when construction was completed.

Prior to that time, TVA designed and built a small pilot-plant Aluminum Chloride Process for making (b)(2) [redacted]. The process uses (b)(2) [redacted] (b)(2) HIGH as a raw material, and since the DMHP process produced large quantities of by-product methyl chloride, it was thought that this material could be usefully recycled via the Aluminum Chloride Process to produce more Dichlor. Further, TVA believed, and the Chemical Corps concurred, that some of the other problems plaguing the Site A operations might be solved by exploring a process other than DMHP for producing Dichlor. See Section E for discussion of major problem areas.

b(2)  
high

The pilot-plant Aluminum Chloride Process produced about 3,100 lb of Dichlor, which was shipped to the Army Chemical Center at Edgewood, where analyses showed that the product was of high purity. Based on its demonstrated feasibility at Muscle Shoals, an Aluminum Chloride Process plant for the large-scale production of Dichlor was established in 1952 by the Julius Hyman Company of Denver, Colorado, to supply GB intermediate for the Site B operation at Rocky Mountain Arsenal.<sup>10/</sup>

(b)(3):10 USC 130



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The following mission was assigned to the Commanding General, Research and Engineering Command by the Chief Chemical Officer:

1. "Run the plant as much as possible to produce product, and, on the highest priority, make every effort to expedite operation of the plant with the objective of placing the facility on a sustained production basis...."
2. "Second in priority, effect the necessary modifications in the plant to the end of sustained operation at full design capacity."
3. "Concurrently with the above, but on the third priority, prepare plans, final designs, and cost estimates to increase the capacity of the intermediate product plant to support the final product plant on the basis of three complete production units operating at capacity."<sup>11/</sup>

The Chemical Corps Research and Engineering Command operated Step 0 (see paragraph 2, page 7) and Step I continuously until the latter part of June 1954. A sufficient quantity of (b)(2) HIGH was produced to provide for future operation of Steps II (paragraph 2, page 7) and III and to ship a substantial amount to the facilities at Rocky Mountain Arsenal. During this operation, design modifications were prepared for an enlarged off-gas system for Step I, and new equipment installed. Late in June the production facility was voluntarily shut down to allow for engineering changes wherever needed in preparation for a production run of the three basic steps (I, II, and III). Proof testing was scheduled for the winter and spring of 1954-1955. It was estimated in October 1954, that the plant would be "rounded out" by 1 February 1955.

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In September 1954, the TVA prepared a narrative summary of the operations at Site A which discussed in some detail each of the major processes. (b)(3):10 USC 130

(b)(3):10 USC 130

b(3)  
10 USC 130

At the beginning of 1955 a Dichlor production capability approximately one and one-half times the original design capability had been achieved. The major effort during that year was devoted to improving the phosphorus oxychloride reduction facility, and to process refinements on Steps I, II, and III. At the close of 1955, a Dichlor production capability of about three times the original design capability was in sight. This lowered the cost of Dichlor to about \$0.36 per lb.<sup>12/</sup>

Unfortunately, the phosphorus oxychloride reduction center still did not balance the Dichlor capability, even though substantial improvements had been achieved to permit closer balance. (b)(3):10 USC 130

(b)(3):10 USC 130

(b)(3):10 USC 130

b(3)  
10 USC 130

During 1955, the chlorine-caustic plant, built at Site A in 1952 at a cost of almost \$21 million,<sup>13/</sup> was sold to the Diamond Alakli Company. The plant continued to supply chlorine to the DMHP plant under contract.

The major operational problem in 1956 was getting the phosphorus oxychloride reduction facility to perform adequately. Early in the year, the Dichlor production capacity had been increased to 100 tons per day, so a major effort was directed at bringing the oxychloride reduction center into balance with the 100 ton per day Dichlor capability. An intensive testing and engineering program resulted in the establishment of appropriate furnace operating conditions for one of the two reduction trains\* by using a modified refractory lining. This permitted a predictable furnace run of 100 days at an average oxychloride reduction rate of 50 tons per day, and established an oxychloride reduction support for a Dichlor production rate of 100 tons per day without the necessity of any sale of oxychloride to

\* The POCl<sub>3</sub> reduction operation consisted of two independent lines or trains of process equipment, each designed for continuous operation.

b(3)  
10 USC 130

industry.<sup>14/</sup> Hence, for the first time, (b)(3):10 USC 130

(b)(3):10 USC 130

Another accomplishment in 1956 was the result of a program to determine the usability of salt made from by-product HCl in the hydrochloric acid neutralization facility. The results of this work showed that the Diamond Alkali chlorine-caustic plant at Muscle Shoals would be able to utilize the entire 90 tons per day of salt produced at Site A. This alleviated a major storage problem.

In July of 1957, Dichlor production at MSPDW was terminated by order of the Chief Chemical Officer,<sup>15/</sup> and plant cleanup was concluded on 31 August. On 1 September the installation was placed in an "inactive status," and a layaway program was officially initiated. Although Dichlor production had been stopped, work continued on operational improvements. Emphasis was placed on improving the yields in Step I and solving the POCl<sub>3</sub> refractory problem.

A new Step I jet system was designed to support a production rate of 100 tons per day per train at approximately 90% quality. The cost of this additional capacity added less than \$1,000 to the cost of the jet system. The increased jet capacity was supposed to permit higher DMHP qualities at lower production rates. Unfortunately the relatively low Dichlor requirements for phasing out production orders permitted only one significant run. This run confirmed previous data that a stripper vacuum of 50 mm should be maintained at higher rates (75 tons per day per train) in order to maintain a minimum of 90% DMHP quality. Cessation of production precluded operational testing of the total Step I jet system.

The most important operational program during 1957, as in previous years, was the work associated with the phosphorus oxychloride reduction facility. As a result of laboratory tests on various refractories under simulated furnace conditions, it was determined that an electrocast Alundum type refractory (Norton RA 5190) appeared better than high density Zircon. Examination of a furnace test patch, using RA 5190 subsequent to the final field furnace run, corroborated experimental laboratory data. Although encouraging, considerably more field testing was required to properly evaluate its effect on prolonging furnace lining life. The results, however, supported previous estimates that the POCl<sub>3</sub> facility could be operated to process the 84,000 tons of by-product that would be generated annually at the designated Dichlor mobilization rate of 30,000 tons per year.<sup>16/</sup>

Unfortunately, the  $\text{POCl}_3$  facility was always a costly, difficult, and relatively unsafe operation, and represented a distinct impediment to the country's nerve gas mobilization capability. Therefore, a study was initiated in 1957 and completed in 1958 which recommended the installation of a high temperature methanation (HTM) Step I Unit at MSPDW at a cost of \$4.5 million.<sup>17</sup> The process was designed to eliminate the entire by-product  $\text{POCl}_3$  reduction facility and supposedly to effect a savings of approximately \$10 million per year at mobilization rates. The process was also designed to permit faster reactivation. Even though this HTM-Pyro unit was actually installed at Site A to replace the oxychloride reduction facility, it remained in a standby status and was never used. The  $\text{POCl}_3$  reduction unit was dismantled.

The complexity of the Site A plant always provided innumerable problems and challenges to the Chemical Corps - TVA team assigned to MSPDW. The peacetime production schedule was so low that its accomplishment had been relegated to merely an incidental objective. The guiding philosophy was to use the production runs as a means of improving the plant from the standpoint of capability, process simplification, ease of maintenance, economy and safe working conditions. By this approach, it was felt that the production potential would be developed to its maximum for mobilization purposes at which time the production objective would become paramount. Although mobilization objectives were based on a 300-day operating year, Site A objectives had always been predicated on the premise that the higher the daily production capability, the better the probability of attaining yearly objectives in the event of any major interruption of production due to enemy action, fire, explosion, etc.

As a result of the above philosophy, production capability runs equivalent to approximately 75 tons per day of Dichlor on a one train basis were successfully made at each of the basic process steps during 1956 and 1957. It was recognized, of course, that an overall production capability would never be positively established until the entire plant was operated as an integrated unit over a period of months. Peacetime limitations never permitted a run of this type. Determination of the adequacy of utilities was particularly difficult to extrapolate to maximum production conditions. The ability to operate the basic process steps considerably in excess of declared mobilization objectives greatly enhanced, however, the probability of meeting mobilization production schedules. Of course, the initiation of chemical warfare at some future time could undoubtedly result in a requirement for nerve gas far in excess of the thinking and budget limitations of the 1950's and 1960's.

d n, construction and preoperational trials, and TVA was responsible for to-day operations of the facility.

Since TVA wanted to make certain that the Site A plant was completely operational before they accepted operational responsibility, the TVA resident engineer conducted frequent and routine inspections of process equipment installed by VITRO and preoperational tests conducted by VITRO. In 1952 and 1953 weekly reports were submitted by TVA to the Chemical Corps Project Officer at Muscle Shoals (and from him to the OCCml O, Department of the Army) detailing the many construction errors, process and safety equipment flaws, test failures, and engineering design faults, which apparently occurred repeatedly. These reports are on file at the Edgewood Arsenal Historical Office, and some of them are discussed in Section II-E of this report (page 34) and in the Appendix (pp. 120-133).

The numerous delays during and after the construction phase at Site A were due in part to the deficiencies outlined by the inspection engineers and the many disagreements between VITRO and TVA personnel on what really needed modification or replacement and what did not. The delays, modifications and failures at Site A prevented that facility from providing the intermediates required for GB production operations at Site B (Rocky Mountain Arsenal), forcing the Chemical Corps to purchase these chemicals from other sources to keep Site B operative. Finally, the spiralling costs in time and money due to the many constructional and operational failures forced the Chief Chemical Officer, MG E. F. Bullene, to phase out the construction activities of VITRO and waive all further test operations by them.<sup>20/</sup>

Five months later, in December of 1953, the Chief Chemical Officer asked the Chemical Corps Advisory Council to study and recommend "what the future course of action of the Chemical Corps should be regarding the classified plant at Muscle Shoals."<sup>21/</sup> An Ad Hoc Committee of the Advisory Council met at Site A on 10-12 January 1954, and made the following recommendations.<sup>22/</sup>

1. The reasons discovered for the inoperability of the Muscle Shoals plant were:

- a. Unsatisfactory design of portions of the Site A facility.

b. Inadequate management at all stages of construction and operation.

c. Defects in valves, lines, instruments, etc.

2. On the subject of plant management the committee recommended that a "Site Commander be chosen and placed in authority at once," and that plant operations "be carried on by Chemical Corps personnel."

In February 1954, the Chief Chemical Officer transferred the operational and technical control of the MSPDW from the Chemical Corps Materiel Command (MATCOM) to the Chemical Corps Research and Engineering Command (RECOM).<sup>23/</sup> He then directed the Commanding General, RECOM (BG William Creasy), to establish a task force under the command of COL Adam Meetze with LTC Harvey Sheppard as Deputy Project Commander. Two key civilian engineers of the Chemical Corps, Mr. Louis Garono and Mr. William Harmon, were also transferred to Muscle Shoals. The Commanding Officer, MATCOM (COL H. M. Black) was directed to provide administrative support to RECOM, continue industrial mobilization preparedness responsibilities for MSPDW, and transfer all Chemical Corps personnel permanently stationed at Site A to RECOM.<sup>23/</sup> MAJ Trathen, Chemical Corps Project Officer, was to remain at MSPDW as COL Meetze's assistant.

2. Solving the Managerial Problem: As soon as GEN Bullene had received Department of the Army approval for the above changes, he wrote a letter to the Manager of Chemical Engineering for TVA, to outline the managerial shift and personnel changes. To assure TVA engineers that the Army did not put the blame for Site A failure on them and desired their continuing operational support, Bullene congratulated TVA on the contribution they had made to the project--especially in the development and refining of the Aluminum Chloride Process.<sup>24/</sup>

To implement the Chief Chemical Officer's desires, and to set-up a new administrative chain of command, BG Creasy outlined the procedures to be followed by RECOM personnel in a letter to his commanding officers in April 1954.<sup>25/</sup> The instructions read, in part, as follows:

"The RECOM installation commander at Site A will review the current list of research and engineering support tasks and will confirm in writing, with his priority listing, a request

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An aerial view of the Muscle Shoals facility as it looks today is shown on pages 16 and 69 of Volume II of this report. A current description of the facility is given on page 68 of Volume II.

A chronology of major developments at MSPDW during the period 1950-1957 is shown below:

A SUMMARY OF MAJOR DEVELOPMENTS AT MSPDW

<u>Year</u>	<u>Activity</u>
1950	Design work begun by Vitro Corporation of America (VITRO) and U.S. Army Chemical Corps
1951	VITRO starts construction of Dichlor plant
1951	Monsanto starts construction of chlorine plant
1952	TVA personnel prepare for plant operations
1952	Construction of chlorine plant completed
1953	Construction of Dichlor plant completed
1953	TVA takes over operational activities at Site A (Dichlor plant)
1953	POCl <sub>3</sub> -reduction center inoperative, many design and construction problems
1954	Chemical Corps Advisory Council recommends a TVA-Chemical Corps team with sound managerial experience to run MSPDW operations
1954	Chemical Corps Research and Engineering Command given control of MSPDW
1954	POCl <sub>3</sub> -reduction process fails again
1955	Dichlor production capability one and one-half times original design capability achieved (beginning of year)
1955	POCl <sub>3</sub> -reduction center still inoperative
1955	Dichlor production capability 2.7 times original capability achieved by end of year
1956	POCl <sub>3</sub> -reduction center still inoperative
1957	MSPDW shut down and prepared for layaway

III. ROCKY MOUNTAIN ARSENAL

A. Historical Background

In 1945, it was discovered that Germany had been making and had apparently planned to use a new type of war gas known as "nerve agents." A considerable quantity of data was collected at that time from German plants and from talking with German scientists. The potential of these new nerve agents was such that a research program was established in the United States which continued uninterrupted through 1950, when a decision was made by the Department of the Army to undertake production of one of these anticholinesterase agents. The agent selected was isopropyl methylphosphonofluoridate, better known as GB. At that time an extensive research program was established under contract with Universal Oil Products to provide data for construction of a GB manufacturing plant, and funds were provided to design and build such a plant with a GB production capability of several thousand tons per year.

The design, development and construction of this plant began in 1950 for the five-step DMHP process developed in Germany. The first three steps were to be carried out at Muscle Shoals, Alabama, designated "Site A" (see Section II-A and -B of this volume), and the last two steps at Rocky Mountain Arsenal in Denver, Colorado, designated "Site B." At Site A the GB intermediate, Dichlor, was to be produced and shipped to Site B for use in making the final product, GB.

In late 1952, Site B was ready for trial runs; however, a continuous series of construction, operational and managerial difficulties at the Muscle Shoals facility delayed operational tests at Site B (see Sections II-B, II-C, and II-E. As an emergency measure, the Tennessee Valley Authority (TVA), who were operating Site A under contract with



Department of the Army, developed the Aluminum Chloride Process for the manufacture of Dichlor. This alternate process was used by the Shell Chemical Company at Rocky Mountain Arsenal to produce Dichlor on a sufficient scale to test the GB facilities at Site B.

B. Development, Construction and Operations

The GB manufacturing plant at Site B was designed by the Vitro Corporation of America (VITRO) in 1950. By the spring of 1952, 80% of the pilot plant objectives had been completed.<sup>88</sup> The operational objectives accomplished were as follows:

1. Feasibility of the proposed manufacture of GB by a continuous process was confirmed.
2. The plant had provided 31 tons of product for large-scale field tests.
3. The process hazards from the viewpoint of plant operations had been assessed and the risk to the surrounding area eliminated.
4. Problems of effluent disposal had been overcome.
5. The best and safest methods of materials handling to date had been developed.
6. The extent of plant maintenance had been assessed and it was insured that this could be carried out.
7. The suitability of the materials of construction and the performance of any control instruments to be used in the unit plant had been checked out.
8. The type and quality of personnel required was assessed, and about 50 operators were trained to provide a small nucleus of labor and supervision.

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Operation of Step IV, which converts Dichlor to the dichloro-fluoro mixture, was satisfactory and kept abreast of Step V requirements. Operation of Step V could not be brought under sufficient control for statistical correlation until April of 1952 due to the extensive modifications necessary to place instruments and equipment in satisfactory operating conditions.

Investigation of the Aluminum Chloride Process (APC) progressed slowly due to deficiencies in equipment. Corrective measures were taken to the point where satisfactory reaction and hydrolysis operations had been obtained. The centrifugation and distillation continued to give trouble.

1. Early Plans, Modifications and Design Accomplishments: Plans in the summer of 1952 were to (1) continue experimental operations in both pilot plants, (2) determine optimum conditions for operation of various combinations of equipment, (3) obtain precise pilot-plant data that could be used in unit designs of Steps IV and V, and (4) investigate the feasibility of producing Dichlor by the Aluminum Chloride Process.

In early 1952, a 1-ton per day pilot plant for Steps IV and V of the DMHP process for manufacturing GB, and a pilot plant for development of the Aluminum Chloride Process for manufacturing Dichlor had been completed. In addition, the work accomplished through June of 1952 consisted of (1) modifications to the Step V (DMHP) process pilot plant, (2) design of a continuous, combined Steps IV-V (DMHP) process, (3) modification of the hydrolysis pilot plant, (4) preliminary studies of the ASP process and Steps IV and V of the SALT process,<sup>89/</sup> and (5) design work on Step V of the SALT process.<sup>89/</sup> Each of these five accomplishments is discussed below.

a. Step V, DMHP Pilot Plant - 1950 Design:

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b(3)  
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(b)(3):10 USC 130

5. Final Operational Steps and Proof-Testing: In 1953 and 1954, while the Muscle Shoals site was being prepared for operation, the final process steps at Site B were being conducted. Continuous improvement was made in equipment and methods at the Rocky Mountain Site throughout 1954, and by the end of the year it was reported that a cumulative total of 456,655 gal. of agent had been produced. Dichlor for this operation had been prepared by the Shell Chemical Company in a plant at Rocky Mountain Arsenal. The Shell Company designed this plant, employing mustard gas production equipment on hand, to use the Aluminum Chloride Process.<sup>91/</sup>

The overall "round-out" program on GB production was scheduled to begin after proof-testing had demonstrated the capacity of both intermediate product and final product facilities. In 1954, the performance data indicated that the design production figure for production of agent GB would be exceeded. Concurrently with the proof-testing, production facilities and methods were subjected to intensive analyses to determine relative merits of the existing processes and other processes. Meanwhile, research continued on new processes, and considerable attention was given to possible modifications of the DMIP process to eliminate the enormous quantities of (b)(2) HIGH which constituted a major problem. See Section II-B and II-E of this volume. b(2) w.gh

In 1955, a series of test programs were conducted to "round-out" the Site B project. The objective of the program was to increase

the plant capacity. A work outline was prepared by the Site B personnel outlining certain tests or trails which would indicate the desired production capability.

By mid-1955, the Chemical Corps decided to conduct a series of tests to determine (1) the degree to which the DMHP process (Step IV and V) could be simplified, and (2) the economical capability of the plant. This test program is given in detail in reference 92. Only a brief unclassified description is given in this report.

Test Run No. 1: During this run the equipment from Step V was simplified or eliminated, and operations of the Step IV process were revised. An engineering study was conducted to determine support needs for the revised systems. This work was carried out from April to September 1955.

Test Run No. 2: The chief goal here was to make operational improvements of the system after major changes had been effected. This work was done in October of 1955. One of the results of this run was that the Step IV capacity had been increased about 400 percent over design, and almost all excess equipment had been removed from the operating area.

Test Run No. 3: This run, in January-March 1956, was the first time the system had been operated as it was conceived the previous year. Hence, it was the first time the plant had been operated in accordance with the overall plan for Site B. The objective of this run was to increase production and to confirm or deny a number of operating concepts. The Step IV operation was operated at up to 300 percent of design rates. Use of a redesigned reactor and elimination of final product distillation (Step V) increased the overall plant yield very significantly.

Test Run No. 4: This run was conducted to determine maximum capabilities and the percent of on-stream time which could be expected for normal operations. In other words, this trial was the "proof test." It established the process as it exists today. This work, which was done in the Spring of 1956, permitted the elimination of all equipment intermediate between Steps IV and V. A high GB production rate was reached and maintained.

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r of steel lines and valves would have to be replaced, and all  
ets. Pumps needed to be reconditioned and all electric lines checked  
. It was proposed that a portion of the funds be made available as  
on as possible so that the few engineers who would be required for GB  
perations and the instrument people could be hired and trained in an  
orderly and efficient manner. With the balance of the startup funds  
available the following year, this work could progress so that by  
January 1965, the plant would be ready to operate with a nucleus of  
trained engineers and instrument and maintenance people.

3. Adequate lead time was needed for the purchase of nec-  
essary equipment and supplies.

4. Funds had to be made available immediately and a decision  
made to start the plant up in 1964 to avoid a crash program of trying  
to acquire a trained nucleus.

A chronology of major developments at Site B during the period  
1950-1957 is given below:

MAJOR DEVELOPMENTS AT SITE B

<u>Year</u>	<u>Activity</u>
1950	Design and construction of RMA begins by VITRO, Universal Oil Products, and U.S. Army Chemical Corps
1952	One ton per day pilot plant completed
1952	APC plant built by Julius Hyman Company to supply Dichlor for Site B operations
1952	Agent filling plant (munitions) 90% complete
1952	Site B ready for trial runs
1953	Final process steps conducted
1954	500,000 gal. of GB produced
1955	Site B "round-out" operation conducted
1955-1957	Site B placed in layaway

Today the Rocky Mountain Arsenal GB facility remains on a  
away or standby status.

IV. NEWPORT CHEMICAL PLANTA. Historical Background

In the 1950's firm plans were made to design, develop and construct a chemical plant for the production of the nerve agent, VX. By 1956, the Chemical Corps Engineering Command (Cml C ENCOM) had developed a pilot plant design and in December of that year a conference was held to discuss a proposed plant for the production of VX.<sup>97/</sup>

By June of 1957, the Chemical Corps Materiel Command (Cml C MATCOM) had held its first V-agent committee meeting, the purpose of which was to (1) review problem areas in the establishment of a V-agent capability, and (2) determine if V-agents could be produced entirely by industry.<sup>98/</sup> In September of that year the Chemical Corps and the Corps of Engineers laid down the scope of their proposed joint contract with industry. This contract was let in 1958 with the M. W. Kellogg Company for process and research and development studies.

While pilot plant studies were being conducted by M. W. Kellogg Company and the Army's Chemical Warfare Laboratories, discussions were held with a dozen other civilian organizations to determine where the V-agent production facility should be located and who would design, construct and operate it. Finally, in 1959, the AEC Heavy Water Plant at Dana, Indiana--later renamed the Newport Chemical Plant--was selected as the VX production site,<sup>99/</sup> and contracts were awarded the Lummus Company for design, and the Food Machinery and Chemical Corporation for construction and operation.<sup>100/</sup>

When the contracts were let, the Army estimated that it would be two years before a production plant was a reality--or about July 1961. This estimate was later revised to June 1961, and included both the chemical plant and the process and filling plant.<sup>101/</sup> Operational shakedown was to occur a year previous, and trial operations were to be completed by 1 March 1961.

Production at the Newport Chemical Plant (NCP) began in 1961 and was terminated in 1967. A discussion of the problems which occurred during the period is given in Sections B through D below.

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B. Development, Construction and Operations

Although the Army Chemical Center (ACC) Chemical Warfare Laboratories (CWL) at Edgewood, Maryland, had been carrying out research and performing bench-level production of V-agents for some time, it was not until about 1956 that steps were taken to develop and construct a pilot plant which would lead to a bona fide production facility for VX.

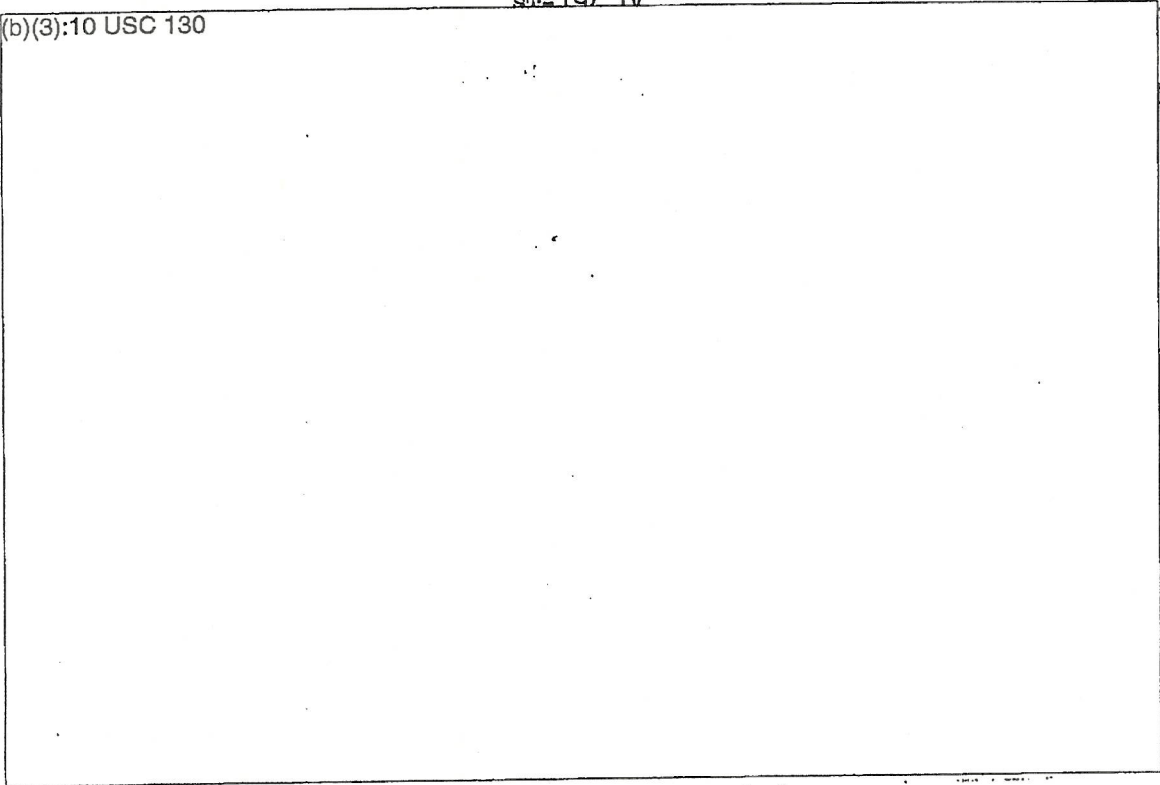
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3. Planning a V-Agent Capability: In May 1957 the first V-agent committee meeting was held, the purpose of which was to review and analyze the problems in establishing a V-agent capability.<sup>98/</sup> The following approach was developed in planning V-agent activities:

<u>Area</u>	<u>Time Frame</u>
Advanced Planning & Pilot Operation	1958-1961
Process Studies	1958-1960
Process Design	1959
Design & Batch Construction	1958
Continuous Construction	1960

Soon after that first meeting, bid proposals were sent to more than a dozen chemical manufacturing corporations, and a briefing was prepared for them outlining the nature of the work. The agenda for the program included the following:

\* See equation on page 78.



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1. Reviews of time schedule and funding
2. Project request status
3. Technical status
4. Corps of Engineers Participation
5. Legal Limitations
6. Site criteria
7. Safety requirements
8. Status of detectors and alarms
9. Extent of industry participation
10. Methods of waste disposal
11. Security requirements

A joint Chemical Corps-Corps of Engineers contract was prepared in September 1957<sup>101/</sup> outlining the contractor's responsibilities and eliminating from consideration as a possible VX production site any existing Cml C arsenal, including the Muscle Shoals facility. The requirements also directed that the V-agent facility should be located in a "non-strategic area." In the operations phase of the contract, it was stipulated that the contractor would agree and guarantee that each of the major steps of the process and supporting utilities would have adequate capacity to produce continuously the specified V-agent at the specified rate for a period of 30 days continuous operation. To meet this requirement, the contractor did not need to operate all steps simultaneously. However, in the area of utility support, he had to be prepared to prove that the demands on the utilities from each step when added together would meet total utility capacity. On completion of a test run meeting the three requirements, the design and construction of the plant would be considered acceptable.

The proposed contract was worded in such a way as to preclude the construction and testing fiascos which occurred on the Muscle Shoals Project. This is evidenced by the Statement of Work quoted from the proposed contract.<sup>101/</sup> (See pages 146 and 147 of the Appendix.)

In the meantime, ENCOM and CWL had worked out their differences of opinion on pilot and bench-scale studies to the point where a contract for additional development was feasible. This was let with the M. W. Kellogg Company in 1958, and in 1959 contracts were awarded to the Lummus Company and the Food Machinery and Chemical Corporation (FMC Corporation) for construction and operation of a V-agent plant at Dana, later named Newport, Indiana.<sup>100/</sup> The various companies competing for the contract had submitted proposals which were lower in cost than the Chemical Corps' original estimate made two years earlier.

The Department of Defense had insisted on using an existing government facility.<sup>100/</sup> The Newport Chemical Plant (NCP) was selected by the Army over Muscle Shoals, Rocky Mountain Arsenal, and other installations or areas because it met the following requirements:

1. The plant could not be located in densely populated areas of the U.S.

2. The plant could not be located near major defense installations or complexes, or in a "target" area.

3. The plant could not be located at Site A, Site B, or Pine Bluff Arsenal because other essential CB agents were being developed at those locations, and the strategic policy was to not "put all your eggs in one basket." A major catastrophe could wipe out a very significant portion of the Corps' capability.

4. The existing but inactivated Heavy Water Plant at Dana, Indiana, had considerable conversion value for a V-agent plant. It was not currently in use, but had much of its original equipment.

5. Adequate security would be no great problem, since the V-agent site was also the site of the Army's Wabash River Ordnance Works--not considered a strategic target--about 30 miles from the nearest community of any size.

The estimated time from awarding of the contract in June 1959 to completion of the construction and testing of operations was about two years, conducted entirely by the civilian contractor who had to design, construct and operate an agent filling facility in addition to the VX production plant. Transfer of the Newport plant to the Army and the beginning of construction were scheduled for fiscal year 1960.

The design of the filling facility for VX was started in San Jose, California, by FMC Corporation and the design of the plant per se was done in Newark, New Jersey, by the Lummus Company. By January of 1960, work was on schedule for a July 1961 completion. It was decided that FMC Corporation would actually operate the plant. Most of the existing equipment at Newport was in very good condition, and a large amount of it was used by FMC Corporation.

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By mid-1960 there were no particularly big technical problems. The Lummus Company's design work showed that the earlier work done at CWL and ENCOM required very few changes, and that most process conditions could be used as they were developed by the Chemical Corps a year or two earlier.

Construction of the VX production plant and a complementary filling facility at Newport, Indiana, proceeded on schedule in FY 1960, and the Chemical Corps submitted a project request in FY 1960 to provide for a munitions assembly plant to be built in conjunction with the agent plant. By the end of FY 1960, the two contractors had nearly completed the design and engineering work and had completed 49% of the actual construction on the agent process and filling plants. The target dates set at the end of the year were as follows:<sup>102/</sup>

Step 0 Construction Complete	23 Jul 60
Operating Shakedown Commence	23 Jul 60
Step I Construction Complete	15 Aug 60
Waste Disposal Well Complete	15 Aug 60
Step II Construction Complete	30 Aug 60
Step III Construction Complete	1 Oct 60
Formal Trial Operation Commence between	1 Aug and 1 Oct 60
Machinery Installation Complete	31 Jan 61
Trial Operation Complete between	1 Jan and 1 Mar 61
Chemical Plant and Process Complete	23 Jun 61
Filling Plant Complete	23 Jun 61

The contractors reported no major technical problems in plant construction or process development. Minor problems and delays were attributed to bad weather, a brief labor dispute, shortage of equipment, a lack of instrumentation, and difficulties in coordinating process plans between Chemical Corps and contractor agencies. All of these problems were resolved by the end of FY 1960.<sup>102/</sup>

4. Summary of Operational Accomplishments: From 1961 to 1967, NCP was operative, producing varying amounts of Step III product on demand. The NCP operations were relatively troublefree, especially when compared to Site A. In 1967, Steps 0, I and II operations were terminated, and in 1968 Step III activities were shut down.<sup>103/</sup> The plant was placed in layaway in 1969.

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In regard to the estimated cost of the plant, even though the facility was being built on an existing plant site, the contractor was in fact designing and constructing a new plant--not just modifying an existing one. However, he was going to make use of salvageable materials and equipment as much as possible. ENCOM estimated the "as installed" value of the equipment that the Chemical Corps inherited from the AEC plant as about \$100 million.<sup>100/</sup> Not all of this, of course, was used or usable.

In early 1960 the estimated value of the plant was approximately \$23 million to \$25 million, which included furnishing the utilities. The estimated cost of VX was about \$2 per pound in late 1960. The labor cost per pound of agent was about \$0.40, and plant standby costs were estimated at \$12,000 per month.<sup>105/</sup>

To provide an estimate of later modification costs at Newport, a project conducted in 1965 to expand the Step III facilities<sup>106/</sup> is discussed below:

The project provided for the expansion of the toxic laboratory in the Step III building. The old laboratory contained equipment occupying approximately 150 sq ft which left only 112 sq ft in which the chemists had to operate. Standard operating procedures required the presence of two people (buddy system) whenever any toxic work was being performed in the laboratory. This safety procedure was mandatory. During production of chemical agent VX, a third person was required to be present to authenticate the contractor's analytical results in behalf of the Government. This resulted in an unsafe condition because of crowding and added confusion.

The proposed addition of 330 sq ft was required to substantially improve operational safety within the laboratory, even though providing somewhat less than the recommended minimum 400 sq ft per person. However, additional space over that proposed was not available.

The scope of work was to provide for the design, procurement, and installation of equipment and building modification to provide an extension to the existing laboratory. Modifications included a new wall, chemical drains, floors, painting, insulation and utilities. Equipment included hoods, fixtures, humidity control and a hood ventilation system.

The total cost of this project, which took about ten months to complete, was estimated at \$70,000.

CHRONOLOGY OF EVENTS AT NCP

<u>Year</u>	<u>Activity</u>
1958	Process and research and development studies started by M. W. Kellogg Company
1959	AEC's Heavy Water Plant at Dana, Indiana, selected as VX production site
1959	Design, construction, and operation contracts awarded to Lummus Company and FMC Corporation
1960	Construction of all four steps completed
1961	Final machinery installed, and chemical plant and filling plant complete
1961-1966	NCP operative; VX being produced on demand
1967-1968	Operation terminated and activities shut down
1969	NCP in layaway

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V. CONCLUSIONS

The following conclusions are based on an examination and evaluation of official documents and information on the research, design, development, construction and operations at the Muscle Shoals Dichlor plant, the Rocky Mountain GB plant, and the Newport VX facility. Where definitive data were not available, reasonable liberties were taken to fill in the gaps and develop meaningful assessments.

A. The Muscle Shoals Project

The data in Section II of this Volume clearly indicate the following factors:

1. Because of the apparent urgency of the situation, the Site A operation was entered into without sufficient bench-scale or pilot plant data and experience. The cart, indeed, was put before the horse.

Why it was essential to charge into the construction phase without adequate pilot plant back-up is not clear. But one can theorize that immediately following World War II military spending started to recede significantly. Previously, relatively unessential projects often had little difficulty in getting funded. But in the late 1940's this was no longer true. To get "big money" the purse holders had to be convinced that a program was absolutely essential to the preservation of democracy. The Chemical Corps convinced the War Department that (1) we had no adequate lethal CW capability, (2) we had to produce more agents quickly and in quantity, especially in view of the fact that the G-agent capability developed by Germany had been taken over by the Russians, (3) that mass casualty weapons such as CW agents were essential for our defense, and (4) that we had the technical know-how to produce G-agents.

When funds were allocated by Department of the Army, the Chief Chemical Officer was apparently convinced that the development of a G-agent plant would present no great problem. After all, the Germans did it, and we were using their method. But no one told, or at least convinced, the proper authorities that the U. S. did not have the technical

experience and pilot plant data to support, in 1950, a G-agent facility using the DMHP process. So our initial effort at Muscle Shoals was a thorn in the side of at least three Chief Chemical Officers (Gens. McAuliffe, Bullene and Creasy), and wasted hundreds of thousands of dollars.

2. Aside from technical problems, inadequate supervision and poor personnel management led to construction and operational delays. The lack of leadership caused many conflicts among contractor personnel. These problems were resolved when a strong technical and managerial team was established by the Chief Chemical Officer to supervise operations at Muscle Shoals.

3. The experience at Site A from 1954 to layaway in 1957 indicated that (a) the Chemical Corps-TVA team was capable of producing large amounts of GB intermediate on a reasonably continuous basis, and (b) that this could be done economically.

4. The phosphorus oxychloride reduction center was never properly operated--and was the weakest link in the U. S. G-agent capability.

#### B. The Rocky Mountain GB Plant

The data in Section III of this Volume reveal that the Site B operation was relatively smooth-running. The following facts are indicated:

1. There were no insurmountable problems.
2. Supervision during the construction and operational phases was accomplished by a Department of Army team of technically qualified managers. This precluded any significant personnel problems.
3. The process steps at Site B were relatively simple compared to those at Site A, and had been successfully researched and piloted or bench-scaled. This accounted in large part for the relatively trouble-free construction and testing phases.

C. The Newport VX Plant

The following facts are indicated from the discussions in Section IV of this Volume:

1. The Newport plant was completed on schedule.
2. Ample time was available for a thorough research and pilot-bench-scale evaluation of each of the steps in the VX production process. These were carried out by an army-contractor team.
3. No major problems or setbacks were encountered.
4. The successful operations at Newport can be attributed to adequate planning, timely and complete research and pilot studies, and proper management.