DIOXIN REGISTRY REPORT
PREPARED BY REVIEW
OF DOCUMENTS RECEIVED FROM:

THOMPSON-HAYWARD CHEMICAL COMPANY
Kansas City, Kansas

DATES OF SITE VISITS:
April 28-May 1, 1981
May 11-12, 1982
May 9, 1985

REPORT WRITTEN BY:
David A. Marlow
Marilyn Fingerhut
Leo M. Blade
Susan Hearn

DATE OF REPORT:
June 1990

REPORT NUMBER:
117.12

Industrial Hygiene Section
Industrywide Studies Branch
Division of Surveillance, Hazard Evaluations and Field Studies
National Institute for Occupational Safety and Health
Centers for Disease Control
Cincinnati, Ohio

Disclaimer

Table of Contents

PURPOSE: To gather personnel, medical and process information and data for the Dioxin Registry.

EMPLOYER REPRESENTATIVES CONTACTED:

Harold Howard, President
Ray Fitzgerald, Senior Vice President of Marketing and Planning
Willis Hart, Vice President of Engineering
Jim Nye, Vice President of Employee Relations
E.K. Herndon, Director, Risk Management
John Sigler, Safety Director
Kim LeFever, Assistant General Counsel, North American Phillips Company
Rex Wood, Audit Section
Thomas Hogard, Coordinator-Litigation, T.H. Agricultural and Nutrition Company, Incorporated
Edward E. Chapman, Manager of Compliance Regulated Products
D.W. Fuhlhage, Director, Laboratory
William A. Lynch, Attorney-at-Law, Blackwell, Sanders, Matheny, Weary and Lombardi
John Noonan, Attorney-at-Law, Stinson, Mag, and Fizzell

EMPLOYEE REPRESENTATIVES CONTACTED: C.B. Conder, Teamsters, Local 41

STANDARD INDUSTRIAL CLASSIFICATION: 2869 - Industrial Organic Chemicals

Abstract

The National Institute for Occupational Safety and Health (NIOSH) Dioxin Registry is a compilation of demographic and work histories information for all U.S. production workers who have synthesized products known to be contaminated with 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and/or hexachlorodibenzo-p-dioxins (HxCDD). Currently, there are fourteen production sites and approximately 7000 workers included in the Registry. The first use of this information will be for a retrospective cohort mortality study for which the comparison group is the U.S. male population. This study will evaluate the causes of death among the workers exposed to products contaminated with 2,3,7,8-TCDD and/or HxCDD.

The Thompson-Hayward Chemical Company, in Kansas City, Kansas, is a site included in the Registry. Esters of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and 2-(2,4,5-trichlorophenoxy)propionic acid (silvex) and some sodium 2,4,5-trichlorophenate (Na 2,4,5-TCP) were produced at this site from 1948 to 1959 and 1963 to 1977. 2,4,5-T formulation occurred from 1948 to 1978 with only limit formulation occurring from 1959 to 1963. Presented in this report is a description and history of the facilities, workforce, processes, past exposures and personnel record systems taken from company documents, and collected during site visits in 1981, 1982, and 1985.

Introduction

The National Institute for Occupational Safety and Health (NIOSH), Division of Surveillance, Hazard Evaluations, and Field Studies (DSHEFS), Industrywide Studies Branch (IWSB) is conducting an investigation of health effects resulting from occupational exposure to polychlorinated dibenzo-p-dioxins, and in particular 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and hexachlorodibenzo-p-dioxins (HxCDD). This study, referred to as the Dioxin Registry, is a compilation of demographic and work history information for all U.S. production workers who have synthesized products known to be contaminated with 2,3,7,8-TCDD and/or HxCDD. The Registry, initiated in 1979, was prompted by animal studies showing 2,3,7,8-TCDD to be acutely toxic and a chloracnegen, as well as a carcinogen and teratogen.[1-7] 2,3,7,8-TCDD is a contaminant found in 2,4,5-trichlorophenol (2,4,5-TCP) and/or its sodium salt (Na 2,4,5-TCP) which are raw materials used to produce chemical compounds such as 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Currently, there are fourteen production sites and approximately 7000 workers included in the Registry. The first use of this information will be a retrospective cohort mortality study for which the comparison group will be the U.S. male population. This study will evaluate the causes of death among workers exposed to products contaminated with 2,3,7,8-TCDD and/or HxCDD.

Thompson-Hayward Chemical Company began esterifying purchased 2,4,5-T in 1948 at Plant 5, 27 Greystone Avenue, Kansas City, Kansas. The facility located on 400,000 square feet site. The Plant 5 building contained approximately 40,000 square feet of floor space in a main room and balcony-type construction arrangement and was partitioned three ways, one a processing area, another a packaging area and a third a warehouse area. 2,4-Dichlorophenoxyacetic acid (2,4-D) and 2,4-D esters were also produced in Plant 5, using the same equipment used to produce 2,4,5-T products. The major products of Plant 5 were 2,4-D products and occupied most of the equipment time. From 1957 to April 23, 1959, isooctyl ester of 2,4,5-T was synthesized directly from the raw material 2,4,5-TCP. Most of the 2,4,5-TCP was purchased; however several batches of 2,4,5-TCP were synthesized for use in the 2,4,5-T direct esterification process. On April 23, 1959, at 6:47 a.m., a runaway reaction occurred during the process of hydrolyzing 1,2,4,5-tetrachlorobenzene to produce 2,4,5-TCP, occurred, causing a rapid pressure increase, an explosion, and subsequently a fire. There were three workers killed and 7 injured in this accident. The cleanup of the explosion-damaged site was performed by plant employees and lasted approximately 45 days. After Plant 5 was destroyed, a new facility was constructed at 5200 Speaker Road, Kansas City, Kansas.

From April 1959 until the new plant began operations in January 1963, 2,4,5-T, 2,4-D and custom-blended formulations were purchased by Thompson-Hayward for distribution. No synthesis and very little formulation of 2,4,5-T esters occurred in a Thompson-Hayward facility.

Once the new plant opened, the Weed Killer Synthesis Plant (Cost Center 565), 2,4,5-TCP was purchased, synthesized into its sodium salt (Na 2,4,5-TCP) and used to synthesize 2,4,5-T isooctyl ester. 2,4-D isooctyl ester and 2-(2,4,5-trichlorophenoxy) propionic acid (Silvex) isooctyl ester (beginning in 1965) were also synthesized in the Weed Killer Synthesis Plant. The Weed Killer Synthesis Plant was located in a central area of the Speaker Road property. All the products synthesized in the Weed Killer Synthesis Plant were produced in a 6000 square feet building containing one floor with a balcony. There was no separation of any of the processes within the building except there was a control room on one end of the building. The operation of the three processes was alternated. Equipment was removed and the building was decontaminated and sealed by 1984.

Formulation of 2,4,5-T isooctyl esters at the Speaker Road facility also began in January 1963 in the Weed Killer Formulation Plant (Cost Center 566). Also formulated in the Weed Killer Formulation Plant were 2,4-D isooctyl esters, Silvex esters, 2,6-dichlorobenzonitrile (Casoron) and Catacarb®, a proprietary chemical which is alkaline nature and is used to separate carbon dioxide from ammonia. The Weed Killer Formulation Plant is located approximately 75-100 feet from the Weed Killer Synthesis Plant and consists of outdoor formulating tanks, and packaging facilities. The packaging lines for the 2,4,5-T and 2,4-D isooctyl esters were located in a large common area of the building. Two smaller separate rooms housed the Casoron® and Catacarb® operations. The locations of all of these operations remained the same from the beginning of formulation at the Speaker Road facility until the phase-out of formulations by December 1978 (or, in the case of Catacarb®, until the present). Currently, the Weed Killer Formulation Plant is used for different purposes. Some of the equipment used in these operations was cut for scrap metal and some of the pipelines were put to different uses.

Other Plants/Cost Centers located at the Speaker Road facility were 568 plant, which produced a variety chemicals; 567 plant, which produced animal feed additives; 560 plant, which produced mineral and acetic acids; 561 plant, which produced blended emulsifiers and wetting agents; and 684 plant, the boiler plant. Table 1 lists the compounds produced along with years of production at each of these plants/cost center as well as the Weed Killer Synthesis and Formulation Plants.

Description of the Workforce

In the old facility, Plant 5 on Greystone Avenue, 2,4,5-T ester synthesis, formulation and packaging occurred in one building. Three operators per shift were responsible for the 2,4,5-T operations as well as 2,4-D operations. These operations were ran 3 shifts per day and six days per week.

In the new facility, Weed Killer Synthesis Plant on Speaker Road, the 2,4,5-T and silvex isooctyl ester process operated seven days per week and three shifts per day. Nine synthesis workers were involved in total. There were at least two synthesis workers per shift, a class "A" and a class "B" synthesis worker. Usually there was a class "C" or trainee synthesis worker in addition to the "A" and "B" synthesis workers on the day shift. One shift supervisor was present on each shift except on weekends. His responsibilities required him to spend 30% of his time on the 2,4,5-T/silvex process and 70% on other processes. A unit supervisor was present on the day shift and on call 24 hours per day. He was assigned only to this unit, and spent approximately 50% of his time in the 2,4,5-T/silvex process area, although his office was not located in the production area. Because samples were collected by the synthesis worker (usually class "A" synthesis worker), lab technicians were not present in the plant. The "loaning out" of workers to another plant or process was not a common practice. Table 2 lists the job titles along with a list tasks for those job titles associated with the 2,4,5-T isooctyl ester and silvex isooctyl ester production processes.

The number of workers in the Weed Killer Formulation Plant totaled between 35 to 40 during the first quarter of each year when the herbicide mixtures were being prepared for heavy seasonal use. The lowest formulation months were July to October. From July to December each year, between 15 to 20 workers staffed the formulation plant. Usually, two shifts worked five or six days per week. The formulation workers were responsible for both formulation and packaging, with the products usually formulated by the night shift and packaged by the workers on the day shift. The same workers formulated and packaged 2,4-D, 2,4,5-T and silvex products. The company encouraged rotation of jobs in the various formulating and packaging steps. When cleanout of the kettles and lines was necessary, the formulation workers performed these tasks. Casoron was made in separate equipment in a separate room during one season of a year. This product was made in small volumes, usually by the same one or two workers since special training was required to perform the tasks required for its formulation. Catacarb® was made occasionally each year in another separate room in vessels unique to the Catacarb® process. As with Casoron formulating, Catacarb® formulating required special techniques for which only two or three formulators were trained; normally they were the only workers assigned to the process. However, since both the Catacarb® and Casoron formulations were produced only intermittently, the Catacarb® and Casoron formulators spent most of their time working in 2,4-D, 2,4,5-T, and silvex formulation and packaging operations. Table 2 lists the job titles and descriptions for those workers who worked in the Weed Killer Formulations Plant.

Maintenance personnel were drawn from a central pool which performed jobs throughout the entire facility as needed. The maintenance personnel, as a whole, spent approximately 40 to 50% of their time working on 2,4,5-T and silvex related operations. Maintenance work was usually done on the day shift, but occasionally performed on second shift also. Table 2 lists the job titles with descriptions for the maintenance personnel.

Description of Record Systems

NIOSH first visited Thompson-Hayward in conjunction with this study in July, 1979. Company representatives explained the company card file system, which was initiated in 1962 and includes service cards for all employees, both hourly and salaried. Shortly after the initial visit, NIOSH returned to microfilm the service cards for all current and terminated Thompson-Hayward employees. This card file was used to identify employees who have ever worked in cost center "565", the 2,4,5-T isooctyl ester synthesis operation at the Speaker Road facility. From the microfilmed service cards, a list of names was developed of all workers with work histories including "565" or "Weed Killer Synthesis Plant". Additionally, names of maintenance workers were abstracted from the microfilmed card file under the maintenance cost center code "683". These names were forwarded to Thompson-Hayward prior to the return visit in April 1981. Personnel records for all workers requested by NIOSH were obtained from the Inland Storage Center and microfilmed on the visit. These records contain the employee's application (including relevant demographic data), Workers' Compensation reports of injuries and illness, and the work history which had been consolidated on the card file.

No personnel records exist for workers who worked in Plant 5 at the Greystone Avenue facility and who were terminated before 1962. These records were destroyed after shipment to the Inland Storage Center. However, an effort is being made to identify workers employed at Plant 5 using Social Security 941 forms. The company did identify the employees who cleaned up after the 1959 explosion.

The Weed Killer Formulation Plant (Cost Center 566) began formulating the phenoxyalkanoic acid in 1963 at the Speaker Road location at the same time that the Weed Killer Synthesis Plant (Cost Center 565) initiated synthesis. Evaluation by NIOSH of information received from the company resulted in the recognition that Thompson-Hayward employees who worked in the Weed Killer Formulations Plant were also appropriate for inclusion in the Dioxin Registry. NIOSH identified the formulation workers from a NIOSH microfilm copy of the company service card system and the company obtained the personnel files for these individuals from the Inland Storage Center. In May 1982 these files were microfilmed in the same manner as the Weed Killer Synthesis worker files previously microfilmed in April 1981.

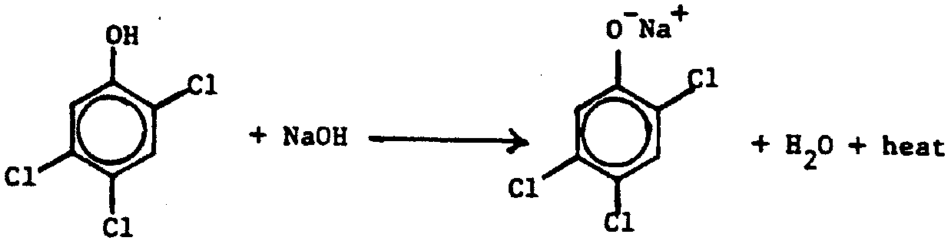
Description of Processes

The following sections contain detailed process descriptions for 2,4,5-T and silvex isooctyl ester synthesis processes as well as the formulation operations for 2,4,5-T and silvex products for the Speaker Road facility. In less detail, the processes to produce Na 2,4,5-TCP and 2,4,5-T ester in Plant 5 at Greystone Avenue are described.

A. Description of the Synthesis of 2,4,5-T Isooctyl Ester at the Speaker Road Facility

Thompson-Hayward Chemical Company manufactured and marketed the isooctyl ester of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T isooctyl ester) using caustic soda (NaOH), 2,4,5-trichlorophenol (2,4,5-TCP), monochloroacetic acid (MCA), and isooctyl alcohol (a mixture of isomers of the general formula $C_8H_{17}OH$) as the raw materials. Isooctyl alcohol was also used as a solvent during processing, and sulfuric acid (H_2SO_4) was used as a catalyst. A flow diagram of the process is included in Figure 1; subsequently mentioned equipment numbers refer to this figure. The process steps have remained the same since the opening of the new plant in January 1963, but operating conditions presented here are as they existed when the process was shut down in 1977, unless otherwise noted.

In the first step of the process, NaOH, 2,4,5-TCP purchased from Dow Chemical, and isooctyl alcohol flow into a batch reactor (R-3). NaOH and TCP react to form the sodium salt of TCP (known as "phenate") in the presence of the isooctyl alcohol solvent by the following mildly exothermic reaction:

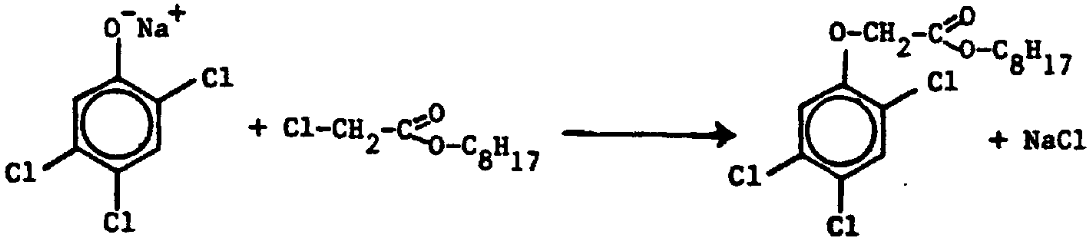


(2,4,5-TCP)

(Na 2,4,5-TCP)

This reaction occurs at atmospheric pressure and slightly elevated temperature. The mixture of phenate, water, and isooctyl alcohol, known as wet phenate, enters a vacuum distillation column (C-2) for removal of the water from the stream. This high vacuum column operates at an absolute pressure of 25 mm Hg (although in earlier years it was operated at as high as 150 mm Hg absolute pressure), and has a normal bottom temperature between 275° and 285°F (135 and 141°C), with a specified maximum of 290°F (143°C). Steam pressure to the reboiler is a maximum of 90 pounds per square inch (psi) gauge (105 psi absolute), and the normal temperature range at the top of the column is between 125°F (52°C) and 155°F (68°C). The overhead product, mostly water, is disposed of as waste or sent to a holding tank (T-6, not shown) to be recycled; the bottoms product, known as dry phenate and consisting of phenate in isooctyl alcohol, continues to the next step in the process.

At batch reactor R-2, the dry phenate is reacted with the isooctyl ester of monochloroacetic acid (MCA ester). (MCA ester is produced in another part of the process which will be discussed near the end of this section.) In the first phase of the batch process, excess isooctyl alcohol is boiled off at a temperature in the range of 265°F (129°C) to a maximum of 275°F (135°C), and under vacuum at an absolute pressure of 70 mm Hg. This excess isooctyl alcohol is then recycled to be used in the reaction at R-3. The remaining mixture in R-2 is then cooked at a maximum temperature of 325°F (163°C) for approximately 3 hours and the reaction proceeds as follows to produce 2,4,5-T isooctyl ester and salt (NaCl):



(MCA isooctyl ester) (2,4,5-T isooctyl ester)

The remaining mixture of 2,4,5-T isooctyl ester, salt, and isooctyl alcohol is pumped to a tank (T-5) where it is washed twice with water to remove the salt. When the mixture enters the tank and is thoroughly mixed with a dilute salt water solution which is left behind from the second wash of the previous batch, most of the salt is removed from the isooctyl alcohol solvent and dissolves into the first aqueous solution. The multicomponent mixture is then allowed to separate; the aqueous phase, now concentrated with salt and relatively dense, forms at the bottom of the tank, while the organic phase of isooctyl alcohol and 2,4,5-T ester forms at the top. The first aqueous phase mixture is then drained from the bottom of the tank and sent to a brine tank where the salt settles out. The organic phase mixture remains in the tank for the second wash, which is accomplished by introducing fresh city water into the tank, followed by thorough mixing. The small amount of remaining salt is almost completely dissolved into the water, and the mixture is again allowed to separate. The second aqueous phase mixture, now dilute and relatively low in density, forms at the top, while the organic phase forms at the bottom. The organic phase mixture is drained from the bottom of the tank and sent to the next purification step, and the dilute second aqueous phase mix is left in the tank to serve as the initial wash for the next batch. The tank (T-5) is not heated externally because the residual heat from the incoming stream from batch reactor (R-2) is sufficient for this step.

The 2,4,5-T ester product and isooctyl alcohol solvent are contaminated with an appreciable quantity of water due to the slight miscibility of water and isooctyl alcohol, and the resultant incomplete phase separation in the wash tank (T-5) makes removal of the water in a column (C-4) necessary. This column is operated at nearly atmospheric pressure; the temperature at the bottom is normally between 390°F (199°C) and 410°F (210°C), while the temperature at the top is normally between 210°F (99°C) and 220°F (104°C). The feed stream for C-4 is heated with a steam heat exchanger. The water separated in this column from the product stream is sent to a holding tank (T-6, not shown).

The product stream is next sent to a fractionation column (C-5) to be further concentrated by removing excess isooctyl alcohol. The column is operated under a high vacuum; the absolute pressure is 50 mm Hg. It is also operated at a rather high temperature, with a normal temperature range between 225°F (107°C) and 250°F (121°C) at the top and between 380°F (193°C) 400°F (204°C) at the bottom. The isooctyl alcohol removed at this stage is recycled for use in the esterification of monochloroacetic acid (a step which is discussed later in this section). The product stream then proceeds to the final purification step, at a high-vacuum distillation column (C-6). Operating at between 10 and 20 mm Hg absolute pressure, with a temperature range between 260°F (127°C) and 280°F (138°C) at the top and between 365°F (185°C) and 385°F (196°C) at the bottom, this column removes the excess MCA ester used in reactor R-2, any unreacted trichlorophenol, and any glycolate by-products. These materials are sent to waste or to a holding tank (T-16, not shown) for later reprocessing. The finished and purified isooctyl ester of 2,4,5-T product in, an isooctyl alcohol solvent, leaves the synthesis area and proceeds to "formulation", where a marketable product is mixed and packaged.

The MCA isooctyl ester which is used at the batch reactor R-2 is produced in a continuous flow reaction from pure MCA and isooctyl alcohol. First, a small amount of sulfuric acid (H_2SO_4), a catalyst, is added to the isooctyl alcohol. Next, the crystalline MCA is liquified by heating to 145°F (63°C) and the MCA and isooctyl alcohol streams are mixed. The mixture then flows into a steam heat exchanger where MCA ester and water are produced by the following reaction:

$$Cl{-}CH_2{-}C\overset{O}{\underset{OH}{\lessgtr}} + C_8H_{17}OH \longrightarrow Cl{-}CH_2{-}C\overset{O}{\underset{O-C_8H_{17}}{\lessgtr}} + H_2O$$

(MCA) (isooctyl alcohol)

When the reaction is approximately 60% complete, the presence of excessive water inhibits its continuation. The mixture then moves into a high-vacuum distillation column (C-1) where water is removed and the reaction proceeds to virtual completion. This column operates at 50 mm Hg absolute pressure, with a temperature range between 300°F (149°C) and 315°F (157°C) at the bottom. The aqueous waste is sent to the sewer; the product stream, known as "dry MCA ester" and consisting of the isooctyl ester of MCA in isooctyl alcohol solvent, is pumped to reactor R-2 for reaction with "dry phenate", as described earlier in this section.

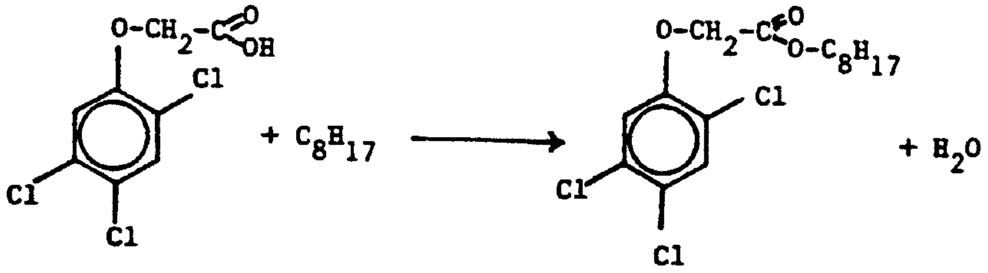
B. Overview of the Synthesis of the Isooctyl Ester of Silvex at the Speaker Road Facility

Thompson-Hayward Chemical Company manufactured and marketed the isooctyl ester of 2-(2,4,5-trichlorophenoxy)propionic acid (Silvex isooctyl ester) at the current facility using the same process used there to synthesize 2,4,5-T ester with very similar process temperatures and pressures. 2-Chloropropionic acid replaces monochloroacetic acid as the raw material (at T-3) for the esterification. With this change, less heat is required for liquefaction since the melting point of 2-chloropropionic acid is considerably lower than that of monochloroacetic acid. At all other stages in the process, an analogous propionic-substituted compound is found in place of the acetic-substituted compound.

C. Description of the Synthesis of TCP and 2,4,5-T Isooctyl Ester at the Greystone Avenue Facility

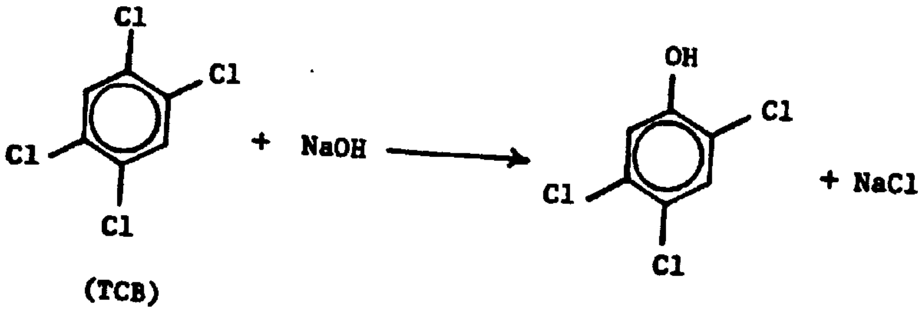
Thompson-Hayward Chemical Company marketed the isooctyl ester of 2,4,5-T which was produced at its old plant prior to an explosion at this operation on April 23, 1959. One method of producing this compound was by esterifying purchased 2,4,5-T; another method, utilizing purchased 2,4,5-TCP, was similar to the process used to synthesize 2,4,5-T ester at the current facility after 1962. On several occasions during 1957 through 1959, TCP was manufactured solely for use in the synthesis of 2,4,5-T ester.

To produce the isooctyl ester of 2,4,5-T from purchased 2,4,5-T, the 2,4,5-T was pumped into a batch reactor along with isooctyl alcohol and a small amount of sulfuric acid, a catalyst. The reaction to produce 2,4,5-T ester and water is:



(2,4,5-T)

This endothermic process was operated at atmospheric pressure and approximately 260°F (127°C). The water was removed as produced because a buildup of water inhibits the reaction; this problem is analogous to the inhibition of the production of MCA ester from MCA and octyl alcohol by water as presented in the "Description of the Synthesis of 2,4,5-T Isooctyl Ester at the Current Facility" section. 2,4,5-T ester was purified using batch "pot distillations" rather than the continuous flow columns found in the current plant. A batch process was used to produce 2,4,5-TCP from 1,2,4,5-tetrachlorobenzene (TCB) and caustic soda, via the following endothermic reaction:



The process was operated at atmospheric pressure and at temperatures between approximately 284°F (140°C) and 302°F (150°C). The reaction occurred in a solvent of propylene glycol; however, ethylene glycol may have occasionally been used. Purification of TCP for use in the 2,4,5-T ester production was also accomplished using batch "pot distillations."

The route of synthesis of 2,4,5-T ester from 2,4,5-TCP was the same at the old plant as in the current one: 2,4,5-TCP (purchased or produced on-site) was reacted with caustic soda to produce Na 2,4,5-TCP, while MCA and isooctyl alcohol were reacted to form MCA ester. The Na 2,4,5-TCP and MCA ester were then reacted to form 2,4,5-T isooctyl ester. However, the old plant contained batch processing equipment for steps such as "pot distillations" instead of the continuous flow columns and other continuous flow equipment found in the current plant.

A more detailed description of the operating conditions and procedures at each step of these processes is not available because the company does not have records of details of processes during that early period.

D. Description of the Process for the Formulation and Packaging of Products Containing the Isooctyl Ester of 2,4,5-T or the Isooctyl Ester of Silvex at the Speaker Road Facility

Thompson-Hayward Chemical Company formulated, packaged, and sold products containing 2,4,5-T isooctyl ester, most of which was synthesized by this company. Thompson-Hayward also formulated, packaged, and sold products containing Silvex isooctyl ester; most of which were also synthesized by the company. These formulations contained the following materials: one of the aforementioned phenoxyalkanoic esters; a solvent, which was either kerosene, heavy aromatic naphtha, or both; and an emulsifier. A block flow diagram of the ester formulation process is included in Figure 2. The procedure remained the same from the opening of the current facility in January 1963 until 2,4,5-T isooctyl ester formulation was discontinued in 1977.

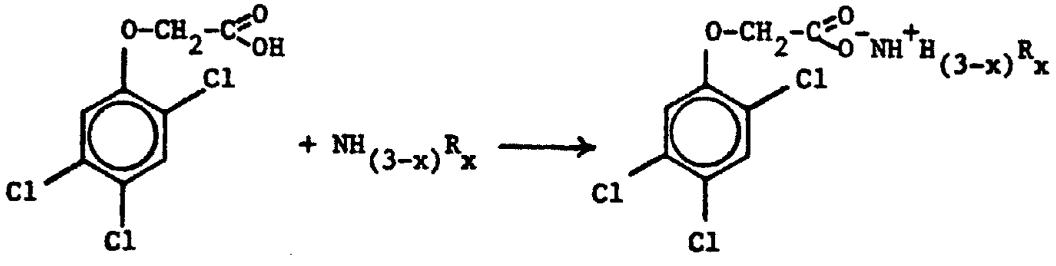
In the first step of the procedure, a measured amount of the isooctyl ester of 2,4,5-T or Silvex is pumped from a storage tank into a closed, agitated formulation tank. Then, the solvent is pumped into the tank, followed by the emulsifier. The contents are agitated to provide a homogeneous mixture. There is no reaction; therefore, no elevated pressure or temperature results.

The packaging step of the procedure follows the formulating step. The ester formulations are packaged in drums, 1-gallon and 5-gallon containers, and 1-pint and 1-quart containers. Ester formulations to be packaged in drums, or 1-gallon or 5-gallon containers, are pumped directly from the formulation tank through a metering device and into the appropriate container. A worker places the dispenser nozzle into the container and starts the pump; the meter stops the flow when the container is full. The worker is required to watch this process at all times so that if the container overflows, he can stop the flow. The small containers are filled on a packaging line which is fully atumated. The formulated product is pumped from the formulation tank to a reservior on the packaging line; containers are automatically positioned and filled with the product. The drums and containers of 2,4,5-T or Silvex isooctyl ester formulations are then ready for sale.

E. Description of the Process for the Formulation and Packaging of Products Containing the Amine Salt of 2,4,5-T at Speaker Road Facility

Thompson-Hayward Chemical Company formulated, packaged, and sold a product containing the amine salt of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T amine). The raw materials for this process were purchased 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and an aqueous amine solution. The formulation also included castor oil ethoxylate as a "crystal inhibitor," which prevents the salt from precipitating in the product. A block flow diagram of the amine formulation process is included in Figure 3. This process was not changed significantly during the years it was in operation.

In the first step in the formulation procedure, water is pumped into an agitated formulation tank; then the aqueous triethylamine solution is dumped from drums into the vessel. Workers dump 2,4,5-T from bags (which arrive at the site in box cars) into a bucket elevator which in turn dumps the material into the vessel. A reaction occurs between the 2,4,5-T and the amine to form the amine salt of 2,4,5-T via the following mechanism:



(2,4,5-T)

(2,4,5-T amine)

This reaction occurs at near-atmospheric pressure and at a temperature slightly above ambient. The "crystal inhibitor" is then added. The packaging of the aqueous product follows the formulating step. The procedure is very similar to that used for ester formulations. For a description, refer to the preceding section. After packaging, the product is ready for sale.

F. Supplemental Information about the Formulation and Packaging Operations at Speaker Road Facility

The formulation and packaging operations for 2,4,5-T ester and amine, 2,4-D esters and amine, and Silvex ester time-shared some equipment. Specifically, the materials were often stored in the same storage tanks prior to formulation, but the tanks were cleaned to remove the residues of one material before another material was introduced into them. Also, the packaging operations were all performed with the same equipment. The same mixing vessels were used to formulate the different products.

Dow Chemical Company was the source of the purchased 2,4,5-T isooctyl ester which was sometimes formulated by Thompson-Hayward when it was not synthesizing its own ester. Dow Chemical was also the main source of the purchased 2,4,5-T which was formulated into 2,4,5-T amine; some of the 2,4,5-T may have been purchased from the Diamond Shamrock Chemical Company, although Thompson-Hayward officials believe that this is unlikely. Some 2,4-D esters were purchased for formulation, and all of the 2,4-D acid formulated to 2,4-D dimethyl amine was purchased; Rhodia, Incorporated was the supplier of these products, although Thompson-Hayward officials believe that on occasion some of these materials may have been procured from both Dow Chemical and Diamond Shamrock Chemical.

The majority of the 2,4-D and 2,4,5-T esters which were synthesized were formulated and packaged, although significant amounts were sold to distributors and other firms for formulation. Some of the Silvex isooctyl ester which was synthesized also may have been sold to outside formulators, but most of it was formulated by Thompson-Hayward. The formulation operations at Thompson-Hayward operated during all the years when synthesis of these materials was performed, although there may have been some years when the phenoxyalkanoic esters were not sold to other firms for formulation.

Several measures were employed by Thompson-Hayward to assess and control workers' exposures to 2,4-D and 2,4,5-T at the dumping operation at the bucket elevator in the amine formulation process, and to all airborne contaminants in the packaging building. Ventilation was employed in the packaging building to provide approximately 20 complete air changes per hour. Also, workers at the bucket elevator were provided with disposable clothing, respirators, goggles, and shower facilities. A change of clothing after a work shift was recommended for all individuals.

The formulation and packaging operations at the Speaker Road facility have never been involved in an explosion or pressure release which resulted in occupational over-exposure to dioxin-contaminated materials. An incident of this type would not be expected in processes such as these, since no elevated temperatures or pressures are employed.

Description of Past Exposures

There was a limited industrial hygiene program at this facility although surface wipe samples in the Weed Killer synthesis and formulation plant may have been conducted by the company's insurance carrier.

Chloracne occurred occasionally in the synthesis plant and in the laboratory.

Beginning in 1970, Thompson-Hayward routinely analyzed process streams, products and wastes sample for 2,3,7,8-TCDD from the 2,4,5-T/Silvex isooctyl ester synthesis process. The method used to conduct these analyses involved the ester be saponified with methanolic NaOH. Water was then added and the dioxin was extracted with hexane. The hexane was evaporated to a small volume and other impurities were removed by concentrated sulfuric acid washes. Further separation of dioxin from other components was achieved by adsorption alumina column separation using an ether-hexane eluent. Finally, the dioxin was analyzed by electron capture gas chromatography.

Routine analyses to check for dioxin was done the Thompson-Hayward Control Laboratory for the following types samples: 1) technical 2,4,5-T isooctyl ester from T-18, T-1, formulating and/or storage tanks; 2) technical silvex isooctyl ester from T-18, T-1, formulating and/or storage tanks; 3) dry phenate from T-9A and T-9B; 4) inbound shipments of 2,4,5-TCP; 5) all outbound shipment of technical 2,4,5-T and silvex isooctyl esters; and 6) all formulations containing 2,4,5-T and silvex isooctyl esters. These analyses along with less routine analyses were recorded in the Dioxin Assay Lab notebook and NIOSH was provided with a copy. Table 4 is a summarization of these various types of sample analyses. The dioxin analyses are summarized by year and by type of sample, samples collected from various points in the processes as well as from other sources. A total of 3753 analyses were conducted, with 3199 of the analyses having dioxin concentrations below the limit of detection (LOD) and 554 of the analyses have detectable dioxin concentrations. The following summary statistics are included in Table 4: 1) the year of a given sample set; 2) a description of the type of samples and the source; 3) the number of samples included in a sample set; 4) the number of non-detectable (ND) sample results in a sample set; 5) the analytical LOD for the sample set; 6) the arithmetic mean value of a sample set if the ND results are treated as zero; 7) the standard deviation of a sample set when the ND results were treated as zero; 8) the arithmetic mean value of a sample set when the ND results were treated as equal to the LOD; 9) the standard deviation of a sample set when the ND results were treated as equal to the LOD; 10) the minimum detectable sample value for a sample set; 11) the maximum detectable sample value for a sample set; 12) the arithmetic mean value for the detectable sample results for a sample set; and 13) the standard deviation for the detectable sample results for a sample set. Dashed lines for a given entry in the summary table designate that this was not applicable for the sample set summary. Numbers in parenthesis following LOD values indicate the number of ND results reported at that LOD.

From 1971 through 1977, 54 analyses were conducted on purchased 2,4,5-TCP. Fifty-two of the 54 analyses yielded analytical results below the 0.1 ppm LOD for 2,3,7,8-TCDD. The detectable sample results were 0.5 ppm. 1765 dry phenate sample (Na 2,4,5-TCP from vessels T-9A&B) were analyzed for 2,3,7,8-TCDD content for the years 1970 through 1977. Thirty of the 1767 samples analyzed had detectable 2,3,7,8-TCDD concentrations ranging from 0.10 to 3.0 ppm, with a mean detectable value of 0.48 ppm. Technical 2,4,5-T isooctyl ester was analyzed for 2,3,7,8-TCDD content for the years of 1970 through 1978. 791 samples were analyzed for 2,3,7,8-TCDD with 153 samples having detectable levels of 2,3,7,8-TCDD ranging from 0.02 to 7.4 ppm with a mean detectable value 1.5 ppm. For silvex isooctyl ester, 196 of 444 samples analyzed had detectable levels of 2,3,7,8-TCDDD ranging from 0.1 to 24.4 ppm with a mean detectable value of 1.2 ppm.

Thompson-Hayward was one of the companies that provided the Defense Department with defoliant Agent Orange II. When use of this herbicide in Vietnam was discontinued, large quantities of this material were left over. Samples of Agent Orange II inventory from a United States Air Force Base in Gulfport, Mississippi were analyzed for 2,3,7,8-TCDD in 1972.[8] The samples of Agent Orange II were produced by Thompson-Hayward prior to or in 1969, the last year of their contract with the Defense Department. Six of the samples analyzed were from Thompson-Hayward Agent Orange II. The results of the analyses were 0.3, 0.3, 0.3, 0.3, 0.3, and 0.4 ppm with a mean value of 0.3 ± 0.04 ppm.

Conclusions

The workers employed in 2,4,5-T/silvex isooctyl ester synthesis and formulation are suitable for inclusion in the Dioxin Registry. Most of these workers were also exposed to 2,4-D products as well, particularly the formulators and to a lesser extent the synthesis operators. Recognition should be given to concurrent exposure of a small percentage of the formulators who also worked formulating Casoron®.

The 2,4,5-T/silvex isooctyl ester synthesis process at the Speaker Road facility was basically a closed process with limited points where synthesis workers could potentially come in contact with dioxin contaminated substances. Given the fact that analyses for dioxin in various process streams and products were relatively low (most analyses were below the LOD of 0.1 ppm) and given the closed process, the synthesis workers from 1963-1977 would have had relatively low exposures to dioxin.

Like the synthesis processes, the formulation and packaging processes were closed systems with the notable exception of the jobs of manually filling 55 gallon drums with 2,4,5-T and/or silvex isooctyl ester formulations and the dumping of 2,4,5-T into formulation kettles during the aminezation of 2,4,5-T acid. In all cases the dioxin concentrations in process streams and/or products were low, even lower than those associated with the synthesis processes. Therefore the formulations workers also would have had relatively low exposures to dioxin from 1963-1978.

The 2,4,5-T isooctyl ester process at Plant 5 in the Greystone Avenue facility was a batch type of process with points in the process were materials were isolated and which workers potentially could have come in contact. No dioxin analyses are available for this time period (1948 through 1959), but given the nature of the process, the dioxin content in process streams and products were probably equal to or higher than those values measured in process streams and products from 2,4,5-T isooctyl ester process at the Speaker Road facility. Therefore the workers involved in the process in Plant 5 would have had exposures equal to or more likely greater than those workers involve in 2,4,5-T isooctyl ester process at the Speaker Road facility.

References

1. Esposito, M.P., Turnam, T.D. and Dryden, F. (1980) Dioxins, Environmental Protection Agency Publication EPA-600/2-80-197.

2. Kimbroughm R., ed. (1980) Halogenated Biphenyls, Terphenyls, Naphthalenes, Dibenzodioxins and Related Products. Elseviar, New York.

3. Kociba, R., Keyes, D., Beyer, J., Carreon, E., Wade, C., et al. (1978) Results of a Two Year Chronic Toxicity and Oncogenicity Study of 2,3,7,8-Tetrachlorodibenzo-p-dioxin in Rats. Toxicol. Appl. Pharmcol. 46, 279-303.

4. McConnell, E., Moore, J.A., Haseman, J. and Harris, M. (1978) The Comparative Toxicity of Chlorinated Dibenzo-p-dioxins in Mice and Guinea Pigs, Toxicol. Appl. Pharmacol. 44, 335-336.

5. National Cancer Institute (1980) DHHS Publication No. NIH 80-175.

6. Nicholson, W.J. and Morre, J.A., eds. (1979) Health effects of Halogenated Aromatic Hydrocarbons. Ann. N.Y. Sci. 320, 1-730.

7. Polant, A. and Knutson, J. (1982) 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Related Halogenated Hydrocarbons: Examination of the Mechanism of Toxicity. Am. Rev. Pharmacol. Toxicol. 22, 517-554.

8. Fee, D.C., B.M. Huges, M.L. Taylor and T.O. Tiernan (1975) Analytical Methods for Herbicide Orange, Vol. II: Determination of Origin of USAF Stock. USAF ARL 75-00110, Vol. II.

Table 1
Cost Centers/Plant Names, Products and Production Years
Thompson-Hayward Chemical Company
Kansas City, Kansas

Cost Center (Plant Name)	Products Produced	Years of Production
565	2,4,5-T isooctyl ester	
Jan. 63-Mar. 65		
(Weed Killer		Jan. 66-Dec. 66
Synthesis Plant)		Feb. 67-Oct. 77
	Silvex isooctyl ester	
Jan. 64-Dec. 74		
	2,4-D isooctyl ester	Jan. 66
		Jan. 75-May 78
566	2,4,5-T isooctyl ester formulation	
Jan. 63-Oct. 78		
(Weed Killer	Silvex isooctyl ester formulation	
Jan. 64-Oct. 78		
Formulation Plant)	2,4-D isooctyl ester formulation	
Jan. 63-Oct. 78		
	2,4,5-T amine formulation	
Jan. 63-Oct. 78		
	2,4-D amine formulation	
Jan. 63-Oct. 78		
	Casoron	Jan. 63-Sept. 78
	Catacarb	Jan. 66-present
567		
(Animal Feed	Vitamins and minerals	
1963-1980		
Additives Plant)		
568	Ethylene oxide condensates	
1966-present		
	Alkyl phenols	1966-present
	Castor oil	1966-present
	Long chain alcohols	1966-present
	Calcium salt	1966-present
	Dodecylbenzene	1966-present
	Choline chloride	1966-present
560	Mineral acids	1963-present
	Acetic acid	1963-present
	Sulfuric acid	1963-present

Table 1 (continued)
Cost Centers/Plant Names, Products and Production Years
Thompson-Hayward Chemical Company
Kansas City, Kansas

Cost Center (Plant Name)	Products Produced	Years of Production
561	Blended emulsifiers	1967-present
	Wetting agents	1967-present
684 (Boiler Plant)	684 plant is the boiler plant and used water treating chemicals such as phosphates and tannin alkalis	1963-present
Plant 5 (Greystone Avenue Facility)	2,4,5-T esters	Jan. 50-April 59
	2,4-D esters	Jan. 52-April 59
	Na 2,4,5-TCP	Jan. 57-April 59

Table 2
Job Titles and Descriptions
2,4,5-T/2,4-D/Silvex Operation
Thompson-Hayward
Kansas City, Kansas

Cost Center (Plant Name)	Job Title	Job Description
565 (Weed Killer Synthesis Plant)	Synthesis Worker "A"	With oral and/or written instructions, layed out work in Weed Killer Synthesis plant, scheduled work, requisitioned necessary material, operated and used necessary equipment, tool, etc. Operated processes mainly from control room. Opened and closed some valves. Performed routine upkeep of all equipment, tools, etc. and may have been required to perform minor preventive maintenance. Collected at least two samples per shift. Accountable for the quality of product. Provided aid in the instruction of workers in low classifications.
565 (Weed Killer Synthesis Plant)	Synthesis Worker "B"	Same responsibilities and tasks as those performed by Synthesis Worker "A" except "B" worker was not responsible for quality of finished product, only for his part of the work.
565 (Weed Killer Synthesis Plant)	Synthesis Worker "C"	The synthesis worker "C" classification was established as a part of the Layoff procedure to allow previously qualified "A" and/or "B" workers to remain in the Department. The "C" worker performed the of "B" or lower classification.

Job Titles and Descriptions
2,4,5-T/2,4-D/Silvex Operation
Thompson-Hayward
Kansas City, Kansas

Cost Center (Plant Name)	Job Title	Job Description
565 (Weed Killer Synthesis Plant)	Synthesis Worker Trainee	Helped "A" and "B" workers operate the plant.
566 (Weed Killer Formulation Plant)	Formulation Worker "A"	With oral and/or written instructions, layed out work in the department, scheduled work, requisitioned necessary materials, operated and used necessary equipment, tools, etc. which included; loading and operating formulation kettles; collecting samples of finished products, 2 to 3 times per shift; cleaned out kettles and associated pipelines; and operated packaging equipment. Held accountable for the quality of products. Aid in the instruction of workers in lower classification.
566 (Weed Killer Formulation Plant)	Formulation Worker "B"	Same responsibilities and tasks as those performed by Formulation Worker "A" except "B" worker was not responsible for quality of finished product, only for his part of the work.
566 (Weed Killer Formulation Plant)	Formulation Worker "C"	The Formulation Worker "C" classification was establish as a part of the Lay-off procedure to allow previously qualified "A" and/or "B" workers to remain in the department. The "C"worker performed the work of "B" or lower classification.

Table 2 (continued)
Job Titles and Descriptions
2,4,5-T/2,4-D/Silvex Operation
Thompson-Hayward
Kansas City, Kansas

Cost Center (Plant Name)	Job Title	Job Description
566 (Weed Killer Formulation Plant)	Formulation Worker Trainee	Helped "A" and "B" workers operate the plant.
683 (Maintenance)	Maintenance Worker "A"	Skilled in at least two of the primary maintenance functions such as electrical, welding, instrumentation, pipefitting, brick, block and insulation work, carpentry, painting and general facility maintenance, equipment machinery overhaul, etc. Responsible for laying out work, scheduling work and aid in instruction of lower classified employees in his line of skill.
683 (Maintenance)	Maintenance Worker "B"	Same as Maintenance Worker "A" except had less responsibility for completing the job or workers.
683 (Maintenance)	Maintenance Worker "C"	Same as Maintenance Worker "B" except had less seniority than "B" worker.
683 (Maintenance)	Maintenance Worker Trainee	Helped "A" and "B" workers perform maintenance jobs.

Table 3
Vessel Numbers and Descriptions for 2,4,5-T and Silvex Isooctyl Esters Synthesis Process
Thompson-Hayward Chemical Company
Speaker Road Facility
Kansas City, Kansas

Vessel * Number	Vessel Description
C-1	Vacuum distillation column, water removal from MCA isooctyl ester
C-2	Vacuum distillation column, water removal
C-4	Distillation column, removal of water
C-5	Fractionation column, removal of isooctyl alcohol
C-6	Vacuum distillation column, removal of MCA isooctyl ester, 2,4,5-TCP, and glycolate by products
R-2A&B	Batch reactors, ester reactor
R-3	Batch Na 2,4,5-TCP reactor
R-4	Surge tank for in-process alcohol
T-1	Finished product holding tank
T-2A&3	Surge tanks for in-process alcohol
T-3	MCA storage tank
T-4A&B	Recovered isooctyl alcohol holding tanks
T-5A&B	Wash tanks, removal of salt
T-6	C-4 and C-2 water holding tank
T-7	Wet phenate holding tank
T-8	Recovered isooctyl alcohol holding tank
T-9A&B	Dry phenate holding tanks
T-11	Phenate waste water holding tank
T-12	High acid MCA ester holding tank
T-13	Recovered MCA ester holding tank
T-14	Surge tank for in-process alcohol
T-15A,B&C	Recovered alcohol holding tanks
T-16	Washed crude product holding tank
T-18	Finished product holding tank
T-21	Dry MCA ester holding tank
T-22	Surge tank for finished product
T-23	Surge tank for in-process alcohol
T-24&25	Isooctyl alcohol storage tank
T-27	2,4,5-TCP storage tank
T-28	Surge tank for finished product

* Vessel Numbers are associated with Figure 1: Flow Diagram for the Synthesis of 2,4,5-T and Silvex Isooctyl Esters.

Table 4
Summary of 2,3,7,8-TCDD Concentrations in Process Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1971	2,4,5-TCP	3	3	0.3(2) 0.1(1)	--	--	--	--	--	--	--	--
1972	2,4,5-TCP	5	3	0.1	0.20	0.27	0.26	0.22	0.50	0.50	0.50	--
1973	2,4,5-TCP	7	7	0.1	--	--	--	--	--	--	--	--
1974	2,4,5-TCP	10	10	0.1	--	--	--	--	--	--	--	--
1975	2,4,5-TCP	15	15	0.1	--	--	--	--	--	--	--	--
1976	2,4,5-TCP	9	9	0.1	--	--	--	--	--	--	--	--
1977	2,4,5-TCP	5	5	0.1	--	--	--	--	--	--	--	--
1970	Na 2,4,5-TCP (R-2A6B)	4	0	--	2.50	1.96	2.50	1.96	0.30	5.07	2.50	1.96
1971	Na 2,4,5-TCP (R-2A6B)	12	5	0.1(3) 0.3(1) 0.5(1)	0.77	0.96	0.86	0.89	0.30	2.20	1.31	0.92
1972	Na 2,4,5-TCP (R-2A6B)	55	49	0.1(44) 0.4(1) 0.2(2) 0.3(2)	0.02	0.08	0.13	0.08	0.10	0.50	0.22	0.15
1973	Na 2,4,5-TCP (R-2A6B)	9	5	0.1	0.04	0.24	0.21	0.17	0.16	0.55	0.36	0.18
1974	Na 2,4,5-TCP (R-2A6B)	5	4	0.1	0.50	1.12	0.58	0.76	2.50	2.50	2.50	--
1975	Na 2,4,5-TCP (R-2A6B)	1	1	0.1	--	--	--	--	--	--	--	--
1976	Na 2,4,5-TCP (R-2A6B)	1	1	0.1	--	--	--	--	--	--	--	--
1970	2,4,5-T ester	2	0	--	0.30	--	0.30	--	0.30	1.10	0.70	--
1971	2,4,5-T ester	185	70	0.1(44) 0.5(2) 0.2(10) 0.7(1) 0.3(2) 0.9(1) 0.4(1)	0.89	1.31	0.97	1.26	0.10	7.40	1.42	1.40

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process
Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1972	2,4,5-T ester	56	25	0.1(23) 0.5(1) 0.6(1)	1.08	1.68	1.14	1.65	0.05	7.50	1.96	1.84
1973	2,4,5-T ester	111	111	0.1	--	--	--	--	--	--	--	--
1974	2,4,5-T ester	115	115	0.1	--	--	--	--	--	--	--	--
1975	2,4,5-T ester	146	146	0.1	--	--	--	--	--	--	--	--
1976	2,4,5-T ester	110	109	0.1	0.001	0.001	0.10	0.003	0.13	0.13	0.13	--
1977	2,4,5-T ester	62	59	0.1	0.004	0.09	0.10	0.02	0.01	0.25	0.09	0.14
1978	2,4,5-T ester	4	3	0.1	0.005	0.02	0.08	0.04	0.02	0.02	0.02	--
1970	Silvex ester	12	0	--	2.86	1.81	2.86	1.81	0.76	5.30	2.86	1.81
1971	Silvex ester	152	33	0.1(9) 0.5(8) 0.2(10) 0.8(1) 0.3(5)	0.62	0.71	0.68	0.67	0.10	4.00	0.80	0.72
1972	Silvex ester	125	65	0.1(57) 0.5(1) 0.2(4) 1(1) 0.3(2)	0.75	2.49	0.82	2.46	0.10	24.4	1.56	3.42
1973	Silvex ester	62	57	0.1	0.08	0.34	0.17	0.34	0.10	2.40	0.95	0.99
1974	Silvex ester	32	32	0.1	--	--	--	--	--	--	--	--
1975	Silvex ester	34	34	0.1	--	--	--	--	--	--	--	--
1976	Silvex ester	24	24	0.1	--	--	--	--	--	--	--	--
1977	Silvex ester	3	3	0.1	--	--	--	--	--	--	--	--
1972	2,4,5-T amine	1	1	0.1	--	--	--	--	--	--	--	--
1976	2,4,5-T amine	1	1	0.1	--	--	--	--	--	--	--	--
1977	2,4,5-T amine	2	2	0.1	--	--	--	--	--	--	--	--

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process
Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1968	2,4,5-T formulation	2	0	--	0.14	--	0.14	--	0.14	0.14	0.14	--
1971	2,4,5-T formulation	11	3	0.5	1.74	1.96	1.88	1.84	0.18	5.30	2.40	1.92
1972	2,4,5-T formulation	14	3	0.5	0.84	1.03	0.86	1.02	0.30	4.00	1.06	1.06
1974	2,4,5-T formulation	35	35	0.1	--	--	--	--	--	--	--	--
1975	2,4,5-T formulation	27	27	0.1	--	--	--	--	--	--	--	--
1976	2,4,5-T formulation	16	16	0.1	--	--	--	--	--	--	--	--
1977	2,4,5-T formulation	56	53	0.1	0.04	0.28	0.13	0.16	0.10	2.00	0.74	1.09
1978	2,4,5-T formulation	12	12	0.1	--	--	--	--	--	--	--	--
1973	2,4,5-T + Silvex formulation	11	6	0.1	0.25	0.41	0.30	0.37	0.08	1.20	0.54	0.46
1975	2,4,5-T + Silvex formulation	2	0	--	0.12	--	0.12	--	0.10	0.13	0.12	--
1977	2,4,5-T + Silvex formulation	6	1	0.1	3.02	2.92	3.06	2.07	0.04	9.00	4.53	5.16
1978	2,4,5-T + Silvex formulation	2	2	0.1	--	--	--	--	--	--	--	--
1977	2,4,5-T acid	3	1	0.1	0.07	0.06	0.10	0.00	0.10	0.10	0.10	--
1970	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	1	0	--	0.23	--	0.23	--	0.23	0.23	0.23	--
1971	Na 2,4,5-TCP (T-9A&B:R-4;R-1)	20	9	0.1(3) 0.2(1) 0.3(5)	0.58	0.78	0.68	0.71	0.10	3.00	1.13	0.78
1972	Na 2,4,5-TCP (T-9A&B:R-4;R-1)	348	336	0.1(331) 0.2(4) 0.5(1)	0.006	0.05	0.10	0.04	0.10	0.75	0.18	0.19
1973	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	434	429	0.1	0.004	0.05	0.10	0.04	0.10	0.78	0.37	0.27
1974	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	172	172	0.1	--	--	--	--	--	--	--	--
1975	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	395	395	0.1(394) 1.1(1)	--	--	--	--	--	--	--	--

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1976	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	285	285	0.1	0.0004	0.007	0.10	0.001	0.12	0.12	0.12	—
1977	Na 2,4,5-TCP (T-9A&B;R-4;R-1)	110	110	0.1	—	—	—	—	—	--	—	—
1971	Na 2,4,5-TCP (C-2)	131	122	0.1(31) 0.2(10) 0.3(81)	0.08	0.35	0.30	0.31	0.10	2.70	1.07	0.78
1972	Na 2,4,5-TCP (C-2)	8	8	0.1(6) 0.2(1) 0.3(1)	—	—	—	—	—	--	—	—
1973	Na 2,4,5-TCP (C-2)	4	1	0.1	0.47	0.46	0.50	0.42	0.20	1.00	0.63	0.40
1974	Na 2,4,5-TCP (C-2)	1	1	0.1	—	—	--	--	—	--	—	—
1976	Na 2,4,5-TCP (C-2)	1	1	0.1	--	--	--	--	--	--	—	—
1970	2,4,5-T ester (C-6;C-5;C-4)	2	0	--	1.16	--	1.16	—	0.89	1.42	1.16	--
1971	2,4,5-T ester (C-6;C-5;C-4)	8	3	0.5	0.51	0.70	0.70	0.59	0.23	2.00	0.81	0.75
1976	2,4,5-T ester (C-6;C-5;C-4)	1	1	0.1	—	--	—	—	--	--	—	--
1971	Wash Tank sample (T-5A&B)	4	2	0.5(1) 0.1(1)	0.25	0.44	0.40	0.38	0.10	0.90	0.50	—
1972	Wash Tank sample (T-5A&B)	15	11	0.1(10) 0.2(1)	0.39	0.70	0.47	0.66	1.20	2.10	1.48	0.43
1973	Wash Tank sample (T-5A&B)	3	2	0.1	0.13	0.23	0.20	0.17	0.40	0.40	0.40	—
1971	Reboiler sludge (C-2;C-5)	6	5	0.1(3) 0.2(1) 1(1)	0.58	1.43	0.83	1.35	3.50	3.50	3.50	—
1972	Reboiler sludge (C-2;C-5)	7	5	0.1(4) 0.3(1)	0.47	0.83	0.57	0.77	1.30	2.00	1.65	—

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process
Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1974	Reboiler sludge (C-2;C-5)	4	4	0.1	--	--	--	--	--	--	--	--
1976	Reboiler sludge (C-2;C-5)	2	2	0.1	--	--	--	--	--	--	--	--
1977	Wash butyl alcohol (R-4)	1	0	--	0.14	--	0.14	--	0.14	0.14	0.14	--
1966	Silvex formulation	2	0	--	1.00	--	1.00	--	1.00	1.00	1.00	--
1970	Silvex formulation	15	0	--	1.58	0.88	1.58	0.88	0.26	3.10	1.58	0.88
1971	Silvex formulation	12	0	--	0.94	0.42	0.94	0.42	0.37	1.79	0.94	0.42
1974	Silvex formulation	7	7	0.1	--	--	--	--	--	--	--	--
1975	Silvex formulation	5	5	0.1	--	--	--	--	--	--	--	--
1976	Silvex formulation	11	11	0.1	--	--	--	--	--	--	--	--
1977	Silvex formulation	15	13	0.1	0.02	0.04	0.10	0.01	0.10	0.15	0.12	--
1978	Silvex formulation	6	6	0.1	--	--	--	--	--	--	--	--
1973	Silvex ester (R-4;R-1)	34	18	0.1(13) 0.13(1) 0.3(3)	0.66	1.00	0.74	0.95	0.12	3.70	1.42	1.04
1972	Silvex reclaims (T-13)	2	2	0.1	--	--	--	--	--	--	--	--
1973	Silvex reclaims (T-13)	2	2	0.1	--	--	--	--	--	--	--	--
1972	2,4,5-T + silvex ester (R-4)	1	1	0.1	--	--	--	--	--	--	--	--
1973	2,4,5-T + silvex ester (R-4)	1	1	0.1	--	--	--	--	--	--	--	--
1972	Brine tank sample	9	5	0.1	1.08	2.06	1.14	2.03	0.35	6.30	2.44	2.64
1971	Alcohol flush (C-2)	3	3	0.1(1) 0.3(2)	--	--	--	--	--	--	--	--
1972	Alcohol flush (C-2)	3	3	0.1	--	--	--	--	--	--	--	--
1974	Alcohol flush (C-2)	1	1	0.1	--	--	--	--	--	--	--	--
1976	Alcohol flush (C-2)	1	1	0.1	--	--	--	--	--	--	--	--

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process
Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1972	Alcohol flush (C-4;C-5;C-6)	11	6	0.1	0.26	0.32	0.32	0.32	0.20	1.20	0.46	0.42
1973	Alcohol flush (C-4;C-5;C-6)	1	1	0.1	--	--	--	--	--	--	--	--
1972	Alcohol flush (R-2A&B)	4	3	0.1(2) 0.2(1)	0.02	0.05	0.12	0.05	0.10	0.10	0.10	--
1972	Alcohol flush (T-1;T-18)	8	4	0.1	0.20	0.22	0.25	0.17	0.30	0.50	0.40	0.08
1973	Alcohol flush (T-1;T-18)	3	2	0.1	0.05	0.08	0.12	0.03	0.15	0.15	0.15	--
1972	Alcohol flush (T-5A&B)	2	2	0.1	--	--	--	--	--	--	--	--
1971	Alcohol flush (T-9A&B)	2	1	0.1	1.00	--	1.15	--	2.00	2.00	2.00	--
1972	Alcohol flush (T-9A&B)	2	2	0.1	--	--	--	--	--	--	--	--
1972	Alcohol flush (T-16)	2	1	0.1	0.15	--	0.20	--	0.30	0.30	0.30	--
1970	Silvex ester (T-16)	2	0	--	2.76	--	2.76	--	2.02	3.50	2.76	--
1972	Silvex ester (T-16)	3	2	0.1 0.2	0.87	1.50	0.97	1.41	2.60	2.60	2.60	--
1970	Silvex ester (C-6)	1	0	--	2.89	--	2.89	--	2.89	2.89	2.89	--
1971	Silvex ester (C-6)	5	3	0.1(2) 0.2(1)	0.42	0.69	0.50	0.64	0.50	1.60	1.05	--
1972	Silvex ester (C-6)	1	0	--	5.10	--	5.10	--	5.10	5.10	5.10	--
1970	Silvex ester (R-2A&B)	4	0	--	2.17	2.74	2.17	2.74	0.62	6.27	2.17	2.74
1971	Silvex ester (R-2A&B)	1	1	0.1	--	--	--	--	--	--	--	--
1972	Silvex ester (R-2A&B)	2	1	0.1	0.10	--	0.15	--	0.20	0.20	0.20	--
1971	2,4,5-T ester (R-2A&B)	2	2	0.1	--	--	--	--	--	--	--	--

Table 4 (continued)
Summary of 2,3,7,8-TCDD Concentrations in Process
Streams, Products and Wastes
Thompson-Hayward Chemical Company
Kansas City, Kansas

Date	Sample Description	Number of Samples	Number of Non-Detectable	Limit of Detection (ppm)	Mean if ND=0 (ppm)	SD if ND=0 (ppm)	Mean if ND=LOD (ppm)	SD if ND=LOD (ppm)	Min Detectable Value (ppm)	Maximum Detectable Value (ppm)	Mean Detectable Value (ppm)	SD Detectable Value (ppm)
1971	Wet Na 2,4,5-TCP (R-3;T-7)	10	6	0.3	1.68	4.70	1.86	4.62	0.30	15.00	4.20	7.21
1972	Wet Na 2,4,5-TCP (R-3;T-7)	1	1	0.1	--	--	--	--	--	--	--	--
1972	Alcohol feed (T-14;C-1)	1	1	0.1	--	--	--	--	--	--	--	--
1977	Silvex ester (Transvaal)	7	6	0.1	0.01	0.07	0.1	0.00	0.10	0.10	0.10	--
1978	Silvex ester (Transvaal)	6	4	0.1	0.03	0.03	0.08	0.04	0.02	0.03	0.02	--
1979	Silvex ester (Transvaal)	2	2	0.1	--	--	--	--	--	--	--	--

'Figure 1
Flow Diagram for Synthesis of
2,4,5-T and Silvex Isooctyl Esters
Speaker Road Facility
Thompson-Hayward Chemical Company
Kansas City, Kansas

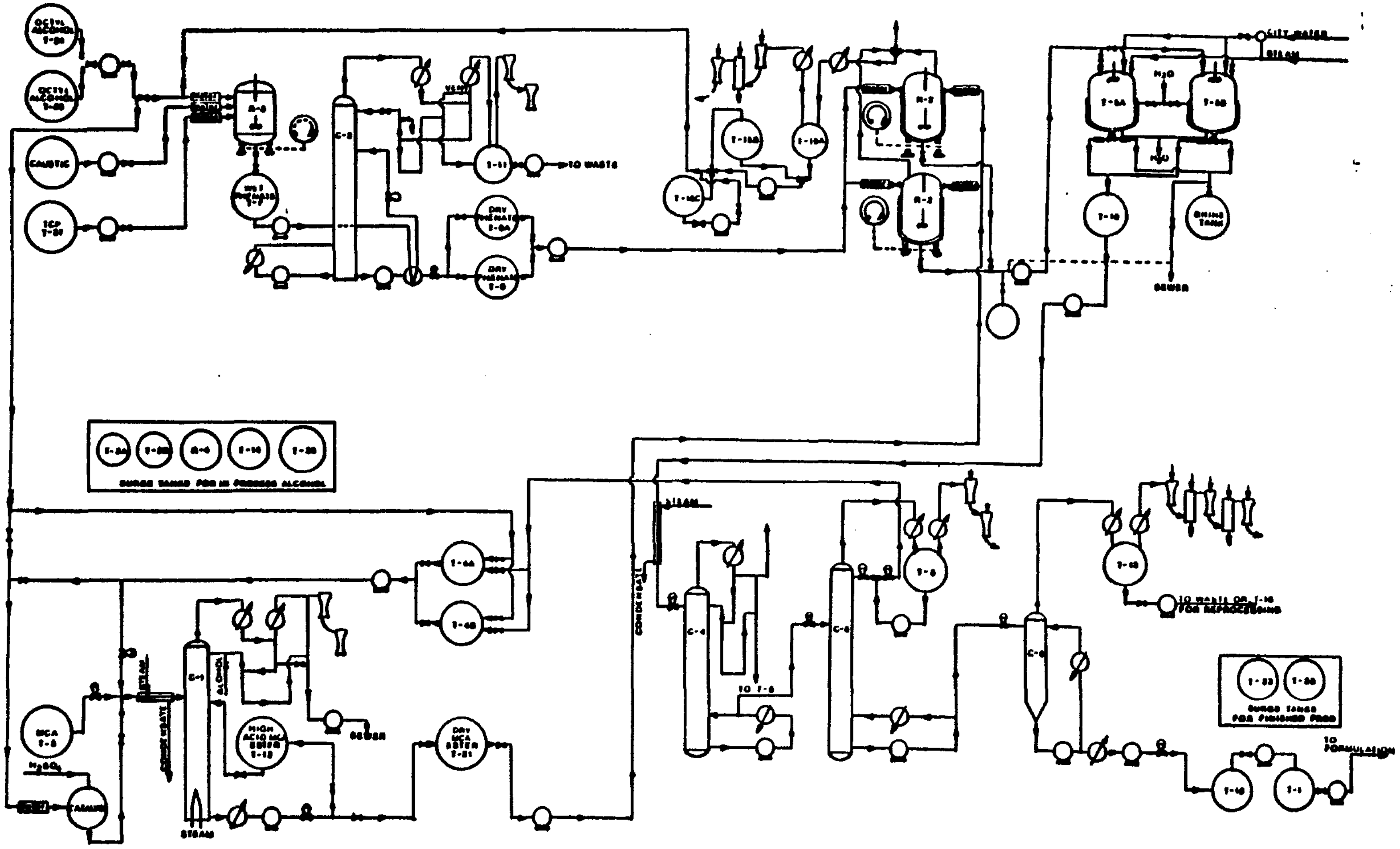


Figure 2
Flow Diagram for Formulation
and Packaging of 2,4,5-T, Silvex and 2,4-D Isooctyl Esters
Speaker Road Facility
Thompson-Hayward Chemical Company
Kansas City, Kansas

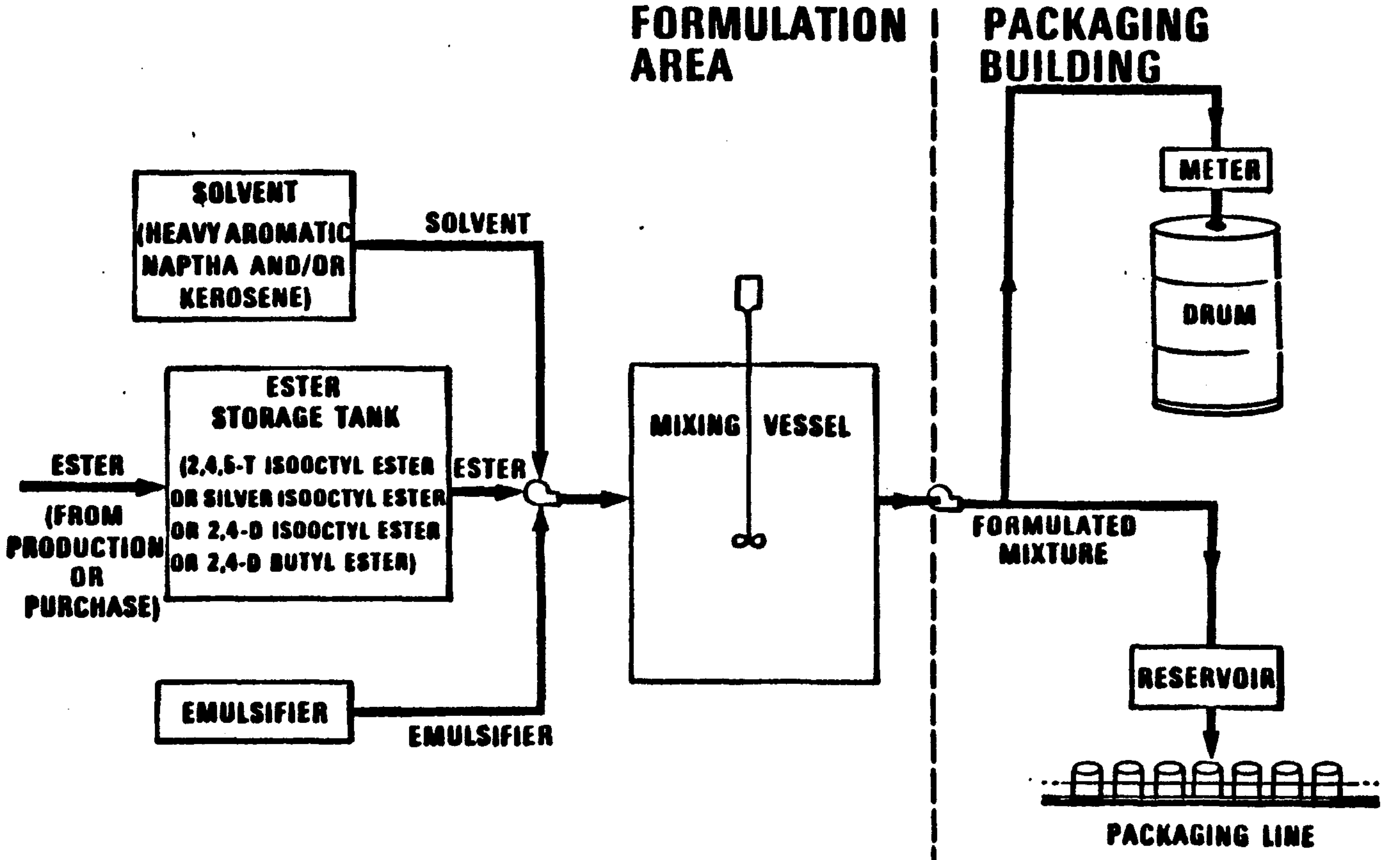


Figure 3
Flow Diagram of the Formulation and Packaging Operations from the Amine Salts of 2,4,5-T
Speaker Road Facility
Thompson-Hayward Chemical Company
Kansas City, Kansas