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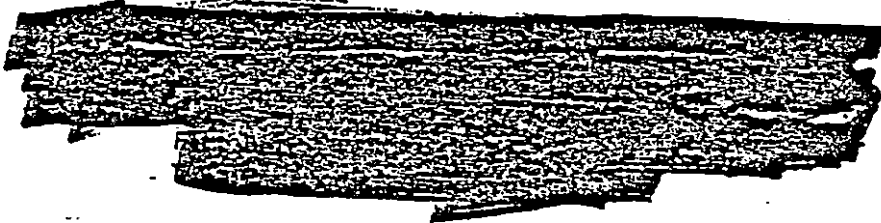
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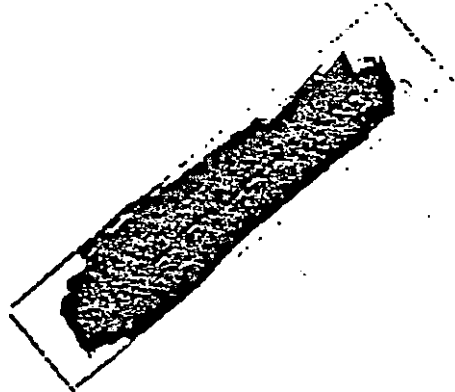
MISCELLANEOUS PUBLICATION 37

HISTORY OF CROPS DIVISION—PLANT SCIENCES LABORATORIES,
STATEMENT #2 (CLASSIFIED) 1943-1968



Vesta Z. Mattie

November 1970



Office of Director
PLANT SCIENCES LABORATORIES



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(U) ABSTRACT

(U) The activities and accomplishments of personnel in Crops Division—Plant Sciences Laboratories, headed by Division Chief and Director, Dr. Charles E. Minarik, are narrated from the time Crops Division was established in October 1943 through 1969. The history narrates the development of chemicals for military use in vegetation and crop control and the development of systems for crop destruction by pathogens. Research of personnel published in open literature and as government reports is documented in detail throughout the report. The Author Index includes more than 400 literature citations and references.

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CROPS DIVISION			
Oct 1943- Sep 1945	Chief, Dr. A. G. Norman (Civilian) (Military Organization)	Biological Chemical	LT. Axel L. Andersen CAPT. William Epps CAPT. W. W. Dorrell Chief, Pilot Plant Branch LT. R. M. Page Dr. A. G. Norman
Sep 1945- Sep 1946	Chief, Dr. C. E. Minarik (Civilian Organization)	Biological Branch Chemical Branch	Chief, Dr. Berch W. Henry Chief, Dr. C. E. Minarik
Sep 1946- Jul 1952	Chief, Dr. A. G. Norman Deputy Chief, Dr. C. E. Minarik	Biological Branch Chemical Branch	Chief, Dr. Berch W. Henry Chief, Dr. Ian W. Tervet Chief, Dr. John E. Mitchell Chief, Dr. C. E. Minarik
Jul 1952- Jul 1955	Chief, Dr. C. E. Minarik	Biological Branch Chemical Branch	Chief, Dr. J. E. Mitchell Dr. R. L. Weintraub
Jul 1955- 31 Dec 1957	Chief, Dr. C. E. Minarik	Biological Branch Chemical Branch	Bio. I Chief, Dr. John E. Mitchell Chief, Dr. Chris G. Schmitt Bio. II Chief, Dr. C. H. Kingsolver Physiology Branch Chief, R. L. Weintraub Chemistry Branch Chief, Dr. A. S. Newman Operational Requirements Branch, Chief, Mr. R. M. Acker
1 Jan 1958- Sep 1959	Chief, Dr. C. E. Minarik	Crops RAD program discontinued. Small staff retained for possible reactivation.	
Sep 1959- 30 Sep 1967	Chief, Dr. C. E. Minarik	Biological Branch Chemical Branch	Chief, Dr. C. H. Kingsolver Chief, Dr. R. A. Darrow

1946-Sep 1947
Oct 1947-Jul 1951
Jul 1951-Jul 1952

Jul 1955-Aug 1956
Aug 1956-Dec 1957

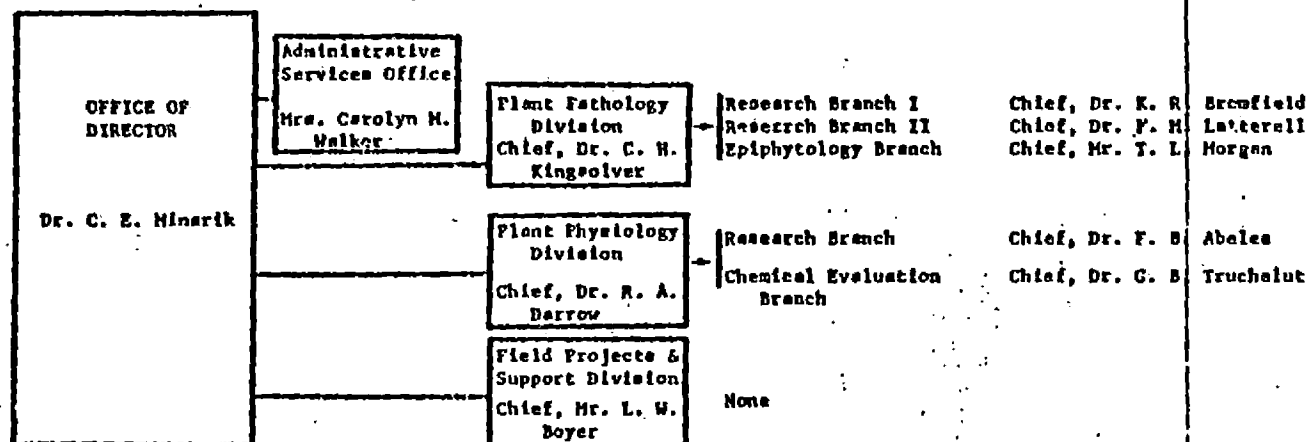
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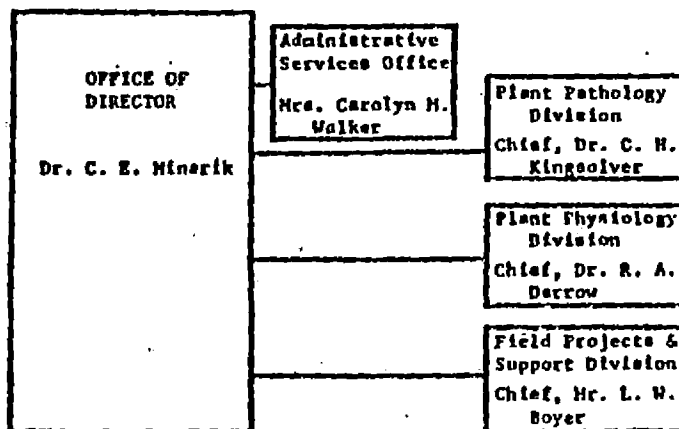
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PLANT SCIENCES LABORATORIES

1 Oct 1967-
31 May 1968



1 June 1968
to present date.



(U) Organization, Crops Division—Plant Sciences Laboratories, 1943 to Present. (U)

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(U) Dr. Charles E. Minarik,
Chief, Crops Division—Director, Plant Sciences Laboratories,
1952 to Present. (U)

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7.

(U) FOREWORD

(U) Dr. Charles E. Minarik, an internationally recognized authority on plant physiology and chemistry, organized Crops Division as a civilian organization in 1946, and since 1952 he has directed its activities (now Plant Sciences Laboratories). In 1959 he reestablished the anticrop and defoliation research and development programs of the Department of Defense that were phased out in 1957 because of limited funds and a lack of clear indication of military utility. Through his foresight and the dedicated efforts of his research group that he led and is leading, the United States military forces in Southeast Asia are equipped with defoliation and anti-crop weapons that are materially assisting them in combating the enemy. Dr. Minarik has visited Vietnam and other parts of Southeast Asia numerous times as a consultant to the USAF, the Advance Research Projects Agency (ARPA), the Military Assistance Command Vietnam (MACV), and the U.S. Embassy on matters relating to defoliation and antiplant activities. Some of his more important accomplishments from 1954 through 1969 include: (i) serving as editor of Weeds (now Weed Science), a quarterly journal issued by Weed Society of America (now Weed Science Society of America) in 1954 and 1955; (ii) becoming in 1962 a member of the original 203 Committee that coordinates defoliation and anticrop operations in Vietnam, and recognition by the 202 Committee of the Vietnamese Joint General Staff for his contributions to the defense of the Republic of Vietnam; (iii) serving on a committee of the National Academy of Sciences, National Research Council, from 1961 through 1966; (iv) serving as consultant to the U.S. Ambassador to Bolivia, who requested his on-site consultation on vegetation control matters in that country in December 1965; (v) becoming an honorary member of the Staff and Faculty, U.S. Army Chemical Center and School, Fort McClellan, Alabama, on 25 May 1966 and serving as a guest lecturer on defoliation; (vi) investigating alleged damage to rubber in Vietnam in 1967 by invitation of the U.S. Embassy, Saigon; (vii) assisting Headquarters MACV from 17 March through 8 April 1968 in conducting the Herbicide Policy Review; (viii) serving as a member of the Subcommittee on Defoliants/Anticrop Systems of the Joint Technical Coordinating Group for Chemical/Biological (JTCC/CS) since 1967; (ix) serving as Chairman of the Standing Subpanel E-2.5 on Plant Sciences, The Technical Coordination Program (TTCP) since 1968; (x) evaluating the alleged damage to rubber and other crops in Cambodia in June and July 1969 as a member of a team of scientists at the request of the State Department; and (xi) presenting invitational papers throughout the years before various professional societies.

(U) Dr. Minarik's activities in research and development have included visits in 22 foreign countries, and because of his distinguished service to the National Defense of the United States, Major General Frank G. White, Commanding General, U.S. Army Munitions Command, awarded him the Major General Amos A. Fries Gold Medal of the American Ordnance Association on 2 November 1967.

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I. 4 BACKGROUND, 1943-1965

A. (U) ACTIVATION

(U) In 1942 the War Research Service was established in the Federal Security Agency and assigned the task of initiating research and development on biological warfare in the United States. As a result, Camp Detrick was activated by the Chemical Warfare Service (CWS) on 10 April 1943.

(U) Crops Division was established in October 1943 to conduct research and development on chemical and biological anticrop agent systems. Dr. A. Geoffrey Norman, presently vice-president for research at the University of Michigan, was taken from another assignment at Camp Detrick and appointed the first Chief of Crops Division.

B. 4 EARLY RESEARCH WITH FOUR PLANT PATHOGENS

4 Several conferences were held among biologists of the National Research Council, War Research Service, and the United States Department of Agriculture, and as a result of these meetings, four plant pathogens, Sclerotium rolfsii, Phytophthora infestans, Helminthosporium oryzae, and Piricularia oryzae, were considered as possible biological anticrop agents.

(U) Sclerotium rolfsii was approved for investigation at Camp Detrick in September 1943, but the first experiment was not initiated until 22 October 1943 when Captain William M. Epps,* Plant Pathologist—Plant Breeder, undertook the investigation.¹ He initiated another experiment on 16 December 1943 using P. infestans.² Work was being carried out on both of these pathogens before Crops Division was established. Sclerotium rolfsii was being investigated in early 1943 by Dr. Freeman Weiss, Dr. E.B. Lambert, and Dr. Dorothy B. Vaughn at Beltsville, Maryland, under a War Research Service project. At the same time another War Research Service project with P. infestans was being carried out by Dr. Bonde and Dr. Stanley Snieszko at the Maine Agricultural Experiment Station and by Dr. Weiss at the New Jersey Agricultural Experiment Station. Later Dr. Weiss used P. infestans in an experiment at Beltsville, Maryland.

(U) In November 1943, Lt. Axel L. Andersen,** assigned to Crops Division at Camp Detrick, was sent to Beaumont, Texas, to begin preliminary work on H. oryzae and P. oryzae with Dr. Edgar Tullis of the USDA.

* Presently Professor and Head, Department of Botany & Bacteriology, Clemson University, Clemson, South Carolina 29631. Home address: 211 Wyatt Avenue, Clemson, South Carolina 29631.

** Presently Department of Botany and Plant Pathology, Michigan State University, East Lansing, Michigan 48823.

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(U) The first experiments with H. oryzae³ and P. oryzae⁴ were started at Camp Detrick on 23 February 1944 by Lt. Robert Meredith Page. Page, Assistant Professor, then Professor of Biology, Department of Biological Sciences, had been affiliated with Stanford University for 20 years (1948 to 1968) until his death 17 May 1968.* Because Lt. Andersen had worked on these pathogens prior to this date, he returned to Camp Detrick and began full-scale work.

(U) Preliminary work on all four pathogens during late 1943 and most of 1944 consisted mainly of laboratory tests to determine environmental conditions necessary for growth, data collection on adaptability to large-scale production, selection of media and substrates, and literature reviews. All work was preliminary because the planning committee had failed to provide for research in plant sciences, and sufficient personnel, facilities, and equipment were lacking. Therefore, early in 1944 the laboratory facilities in Building 201 of Fort Detrick were made available to Crops Division for work on plant pathogens.

(U) At this time, the facilities of Crops Division consisted of a 5-acre test field located near the present parking lot near Building 350 and a small 12- by 25-foot laboratory in Building 201 that had been designated as a wash room when the building was remodeled. Later it was expanded to include half of another larger laboratory in which personnel of another Division were working on human pathogens. Because all research and services at Camp Detrick were carried on in Building 201, personnel of Crops Division were required to conform to all safety regulations, making research on plant pathogens difficult. Under these circumstances, Captain Epps conducted the first greenhouse test with S. rolfsii on 5 May 1944; then on 30 June he conducted the first field test with this pathogen.

(U) When the laboratory in Building 201 was made available to Crops Division, three officers and two enlisted men constituted the Biological Section, an increase of one officer and one enlisted man since the latter part of 1943. From February 1944, the strength of the Division had increased to the point that shift work was initiated so that the meager facilities could be used more advantageously. One group of researchers worked from 0800 to 1600 hours and another used the same facilities from 1600 to 2400 hours. This setup continued until August 1944 when Crops Division moved into Buildings 321 and 325, the latter becoming Crops Division's Pilot Plant.

(U) With the occupancy of both buildings and additional personnel, intensive laboratory, greenhouse, field, and pilot-plant experiments were

* Raper, John R.; Briggs, Winslow R. November 1968. Robert Meredith Page - 1919-1968. In Plant Science Bulletin 14:3:6-7.

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conducted on all four pathogens. Branch Chief Captain William Dorrell* and Dr. Edwin P. Lowe** worked closely with laboratory personnel in adapting these pathogens to pilot-plant production. Under their supervision, Captain Epps set up the first experiment in the pilot plant for the growth of S. rolfsii on 23 December 1944.⁵ Sufficient quantities of all four pathogens were produced for additional laboratory and field testing.

(U) On 9 June 1945, in cooperation with Captain Tatlock of PC Division, experiments on the use of plant viruses as simulants for human viruses were performed in the testing of gas mask canisters and protective clothing.

C. (U) CROPS DIVISION, MILITARY TO CIVILIAN

(U) By late 1945, Crops Division consisted of 26 officers and 16 enlisted men under a civilian chief, Dr. A.G. Norman (Fig. 1). Dr. Charles E. Minarik, Plant Physiologist,*** joined Crops Division in May 1945 and was among the 26 officers assigned to the Division. He and 11 other officers and 10 enlisted men constituted the Chemical Branch, and 14 officers and 6 enlisted men including T/3 Sgt. Thomas L. Morgan (February 1944) constituted the Biological Branch. To date, Dr. Minarik and Mr. Morgan are the only wartime members left in Plant Sciences Laboratories.

(U) Dr. Norman resigned in September 1945, and Dr. Minarik became Chief, Crops Division. At the end of World War II and during the early part of 1946, Dr. Minarik organized Crops Division as a civilian organization. At that time 11 professionals composed the Division Staff. During early 1946 and until the end of 1947, the number of personnel increased gradually. Dr. Norman returned in September 1946, again to assume his role as Chief, Crops Division, with Dr. Minarik as his Deputy. Dr. Minarik was also Chief of the Chemical Branch. In December 1947 the Division strength numbered 32 people, including some military personnel either serving as technicians or working in the administrative branch.

D. (U) PIONEER DEVELOPMENT OF 2,4-D AND 2,4,5-T

1. (U) Early History

(U) Research in Crops Division has resulted in a number of developments that have been significant to the military and/or the United States

- * Presently Technical Coordinator (B), Directorate of Chemical and Nuclear Operations, Office of Assistant Chief of Staff for Force Development, Department of the Army, Washington, D.C.
- ** Presently Special Studies Branch, Special Operations Division, Fort Detrick.
- *** Presently Director of Plant Sciences Laboratories, Fort Detrick.

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Back Row Standing

1. Lt. F.W. Leaver (Dr.)
2. T/4 Landry
3. PhM2/c Jack Hyatt (Navy)
4. Capt. H. Robert DeRose (Dr.) (Deceased)
5. Lt. John C. Carpenter (Dr.)
6. Capt. Stanley F. Snieszko (Dr.)
7. Lt. Arden F. Sherf (Dr.) (Navy)
8. PhM1/c Fred Owings (Navy)
9. Ensign R.W. Allard (Dr.) (Navy)

Front Row Standing

1. Capt. Daniel Ready
2. PhM1/c John G. Jakob
3. Lt. Axel Andersen (Dr.)
4. YJ/c Wolfe (Waves) (Secretary)
5. Lt. Berch W. Henry (Dr.) (Navy)
6. PhM3/c Givens (Navy)
7. Sgt. Houston G. Adams
8. PhM3/c Ivy Freeman (Navy)

First Row Seated

1. Capt. Robert Weaver (Dr.)
2. Lt. Carl P. Swanson (Dr.)
3. Capt. David L. Taylor (Dr.) (Deceased)
4. Major John R. Taylor (Dr.)
5. Dr. A. Geoffrey Norman, Chief

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10. T/5 Edward Smith
11. Lt. Arthur Newman (Dr.)
12. Lt. Howard E. Thompson (Dr.) (Navy)
13. PhM2/c Bennett M. Goodloe (Navy)
14. Lt. John Patterson
15. Lt. Roy M. Acker
16. T/3 Thomas L. Morgan
17. Capt. Edward Cherry (Deceased)
18. Lt. Edwin P. Lowe

9. Lt. Robert M. Page (Dr.) (Deceased)
10. Sgt. Virgil E. Farmer
11. T/5 Robert G. Smith
12. T/4 Walter Pregler
13. Capt. Charles E. Minarik (Dr.)
14. PhM3/c Edwards (Navy)
15. Capt. William W. Dorrell (Dr.)

6. Major William Epps (Dr.)
7. Lt. William Ennis (Dr.) (Navy)
8. T/4 Rebecca Boorstein (WAC) (Secretary)
9. Capt. R. Marek
10. Ensign Margaret Mills (Navy)

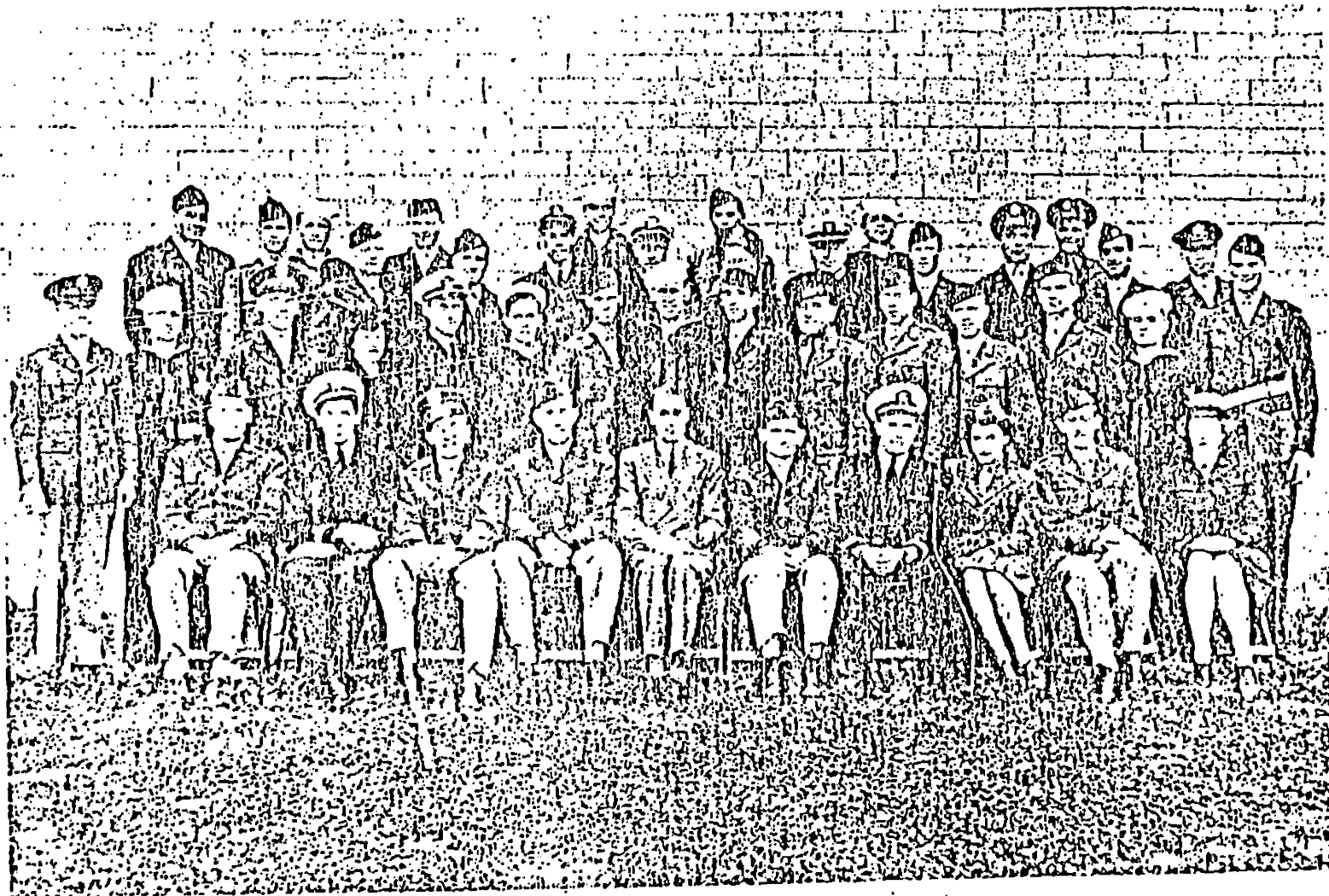


FIGURE 1. (U) Wartime Staff of Crops Division. (U)

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economy. The earliest, and possibly the most outstanding, contribution was the pioneering work on synthetic plant hormones as herbicides that led to the selection and development of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Early data on these compounds were developed during World War II and were publicized in the open literature after the war had ended.^{6-13, 13a-13f, 14-38} The high potency (physiological and morphological) of 2,4-D and 2,4,5-T was first discovered by Zimmerman and Hitchcock in 1942.³⁸ Dr. E.J. Kraus, who worked concurrently at the University of Chicago as Head of the Botany Department and at the U.S. Plant Industry Station, Beltsville, Maryland, obtained samples from Dr. Zimmerman, and in January 1943 performed successful preliminary experiments at the University of Chicago, then investigated the growth regulators more extensively at the Plant Industry Station.²⁷ After Crops Division was established in 1943, it sponsored this research.

(U) Early in 1944, Captain H. Robert DeRose and Captain David L. Taylor were detailed from Crops Division to the Plant Industry Station at Beltsville to carry out field experiments with 2,4-D and 2,4,5-T. Because the U.S. Army was considering the feasibility of using these growth regulators for the destruction of enemy crops, the work conducted by these men at the Station, and their subsequent research on growth regulators at Camp Detrick was not published.

(U) Dr. Kraus continued to have access to the work at Camp Detrick. He was also editor of the Botanical Gazette. Dr. Kraus was concerned when he received a paper for publication on these growth regulators in 1944 from Drs. Charles L. Hamner and H.B. Tukey (the latter Head of the Horticulture Department at Michigan State). He also was aware of a paper of Drs. John W. Mitchell and Hamner on work done while Hamner was still at Beltsville, one that Dr. Mitchell was holding for later publication. Dr. Hamner had already left the Plant Industry Station, and after assisting Kraus and Mitchell with their experiment with 2,4-D and 2,4,5-T, he understood the objectives.²⁸ Dr. Kraus released this paper²⁹ because he could think of no valid reason to withhold publication without breaking security. Therefore, he released the paper by Mitchell and Hamner.³⁰

(U) In September 1944, Dr. James W. Brown transferred at the Bureau of Plant Industry to work with Dr. Mitchell and conduct the testing of chemicals for growth-regulating activity in conjunction with the work at Camp Detrick.^{31, 32} In February 1947, Dr. Brown transferred to Camp Detrick to further the research in this area.³³⁻⁴³

(U) During the period February 1944 through 1945, Camp Detrick personnel intensively synthesized and screened a broad array of synthetic plant hormones. Lt.(jg) Howard E. Thompson, USNR, a keen and resourceful chemist, with a dedicated assistant, PhM/c Fred J. Owings, USNR, synthesized more than 1,000 chemicals during this period. Lt.(jg) Thompson devoted most of the day and night to his research, his time out for sleeping consisting mostly of naps on laboratory benches or foot lockers. A

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synthesis contract with Ohio State University supplemented the Camp Detrick synthesis effort. New growth regulators were tested and evaluated in Crops Division and the USDA (cross-service agreement).

(U) As a result of the synthesis and screening of many chemicals, the phenoxys, 2,4-D and 2,4,5-T, were identified as outstanding herbicides, and a mass of basic and applied data^{6-25,33-89} on their activities was developed under the guidance of Dr. Norman and Dr. Minarik until 1952, when Dr. Norman resigned, then under Dr. Minarik throughout the history of Crops Division.

(U) In the postwar period, the Camp Detrick group that was studying plant-growth-regulator-type herbicides was the foremost group in the world engaged in this type of activity. Release of information to the public after World War II^{16-25,31-37,87} caused revolutionary changes in weed control practices throughout the world and resulted in the development of many new industries and a new body of scientific literature. It has been estimated that during 1960 (prior to military use in Vietnam) the United States produced 50 million pounds of these chemicals annually for agricultural use. Since 1961, military requirements have caused expansion of the United States production capability.

2. (U) Contributors Toward Early Development

(U) The principal investigators at Camp Detrick who contributed to the early developments of defoliants and chemical anticrop agents were:

Dr. A.G. Norman (presently Vice-President for Research, University of Michigan, Ann Arbor, Michigan). Directed the program and maintained liaison with the using agencies and higher headquarters.^{5,7,8,45-47,50,55,68,72-74, 87,88}

Dr. C.E. Minarik (presently Director of Plant Sciences Laboratories, Fort Detrick, Frederick, Maryland). Worked on spray applications, effects of rainfall subsequent to spray applications, and root absorption by plants grown in nutrient culture.^{13-13f,50,51-52,56,57,70,72-75}

Dr. A.S. Newman (presently with Cooperative Research Service, U.S. Department of Agriculture, Washington, D.C. 20250). Lt. Newman joined Crops Division staff (Dr. Norman's first graduate student) as an Army Air Corps aerial photographer. From 18 February 1946 through 4 October 1957, Newman, civilian research agronomist, studied the effects of soil microflora on the persistence and decomposition of 2,4-D and other herbicides when applied to various types of soils.^{47,49,53,71-74,76-78,81,82}

Dr. W.B. Ennis, Jr. (presently Chief, Crops Protection Research Branch, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland). Developed the first invert emulsions, devised spray techniques, and studied droplet size.^{6,15,17,18,21,46,52,57,71,75-78,81}

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Dr. H.R. DeRose (Deceased 2 February 1969). Screened plant growth regulators for activity on various agricultural crops and studied the persistence of herbicides in soils until his retirement from Crops Division 31 August 1965.^{10,19-21,78-78,81,82}

Dr. H.E. Thompson (presently Dugway Proving Ground, Utah). Headed a synthesis group that synthesized more than 1,000 compounds.^{8,8,78}

Dr. C.P. Swanson (presently Associate Dean for Undergraduate Studies, Johns Hopkins University, Baltimore, Maryland 21218).^{8,9,11,16-19,70}

Dr. R.J. Weaver (presently Department of Viticulture, University of California, Davis, California 95616).^{10,12,13,17,21}

Dr. F.T. Boyd (presently, Agronomist, Florida Experiment Station).^{13,15,17,18}

Dr. H.H. Smith (presently Geneticist, Department of Biology, Brookhaven National Laboratories, Upton, New York 11973).^{8,14}

Dr. R.W. Allard (presently University of California, Davis, Calif.).^{18,19,21}

Dr. D.L. Tavior (Deceased).²²⁻²⁵

Mr. Daniel C. Ready (Retired—Ridge Road, Braddock Heights, Maryland).^{44,59}

Mr. Roy M. Acker (presently Manager, Market Planning, Allison Division, General Motors Corporation, Indianapolis, Indiana 46206). Laid the ground work for the defoliation systems currently in use in Vietnam.*

Dr. R.L. Weintraub (presently Professor of Botany, Department of Biology, George Washington University, Washington, D.C.; also Plant Physiologist, Radiation Biology Laboratory, Smithsonian Institution, Rockville, Maryland). Conducted extensive research on the mechanism of action of plant-growth-regulating chemicals.^{34-39,42,43,48,50,54,55,58,65-67,67-69}

(U) The USDA scientists who worked on Army contracts were:

Dr. J.W. Mitchell (presently Plant Physiologist, Bureau of Plant Industry, U.S. Department of Agriculture, Beltsville, Maryland).

Dr. J.W. Brown (Plant Physiologist, also Deputy to Dr. C.E. Minarik, Office of the Director, Plant Sciences Laboratories, Fort Detrick, Frederick, Maryland, until his retirement 28 February 1969. Transferred to Camp Detrick February 1947).

* Events discussed in text.

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E. (U) FIRST AERIAL SPRAYS WITH DILUTED CHEMICALS

(U) The crash program of synthesizing and screening chemicals was the result of a request from the U.S. Army to investigate chemicals that were available in large quantities in the United States that would defoliate trees, shrubs, ground covers, and vines. At that time, there was a great deal of interest in destroying vegetation in the South Pacific Theater, and the principal means available was high explosives. Millions of tons of high explosives were required to destroy vegetation on these Pacific Islands.⁹⁰

1. (U) B-25 Aircraft—Fort Knox, Kentucky

(U) The screening program yielded two chemicals of promise, ammonium thiocyanate and zinc chloride. In cooperation with the Armored Medical Research Laboratory, personnel sprayed temperate zone vegetation at Fort Knox with these two chemicals and with other chemicals with excellent results. The spray treatment was followed with incendiaries that were dropped from B-25 aircraft.⁹⁰

2. (U) B-25 Aircraft with Standard M-10 Smoke Tanks—Florida Everglades

(U) In another program that dealt with subtropical vegetation in the Florida Everglades, Captains Weaver and Taylor and Lts. Page, Carpenter, and Newman under Dr. Norman's leadership conducted successful aerial sprays in March and April 1944 and in August and September 1944 at two locations in Florida, at Marathon and at Orlando (the latter site 90 miles west of Orlando—a forested area that included part of the Chassahowitzka Swamp). Aqueous solutions of ammonium thiocyanate and zinc chloride were sprayed from B-25 aircraft with standard M-10 airplane smoke tanks with excellent results. The vegetation changed color in 2 or 3 days and defoliation occurred in 4 or 5 days, resulting in effective target marking.⁹¹

(U) Because the United States might be accused of conducting poison gas warfare (the word thiocyanate sounded very much like cyanide), these chemicals were not used in the Pacific Theater. The war ended before another defoliant could be developed.⁹⁰

3. (U) B-26 Aircraft with Standard and Modified M-10 Smoke Tanks—Bushnell Army Air Field, Bushnell, Florida

(U) After working with the phenoxys and other growth regulators in the greenhouse and field at Camp Detrick, personnel from Camp Detrick tested some of the agents at Bushnell Army Air Field, Bushnell, Florida, with the cooperation of personnel from Dugway Proving Ground Mobile CWS Unit and AFTAC personnel at Orlando Army Air Base. From February through April 1945 Lts. R.M. Acker, J.B. Carpenter, A.S. Newman, and Harold H. Smith (USNR), with Major H. Hall, Capt. D.L. Taylor, and T/4 C.G. Wyckoff tested the practicability of destroying crops with diluted 2,4-D and its ammonium salt sprayed from standard M-10 chemical smoke tanks mounted on

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tactical aircraft, A-26 B airplanes (attack bombers). Preliminary tests also were carried out with a modified M-10 tank with reduced orifice plate and venturi tailpipe, and with the E-2 bomb bay chemical spray tank installed in a TB-25J airplane. Both agents sprayed from standard M-10 chemical smoke tanks caused severe injury or destruction of crops (potted plants were used as indicators). Less than 1 pound per acre of 2,4-D in oil destroyed crops (other than cereals).⁶⁸

(U) Natural vegetation primarily affected by spray drift (2,4-D in oil and its ammonium salt in water) incidental to other trials showed characteristic symptoms of injury in the younger growth.⁶⁹

4. (U) A-20-G (Now B-26 Aircraft) Attack Bomber with Modified M-10 Smoke Tank—Vigo Plant, Terre Haute, Indiana

(U) Further extensive research in destroying crops by aerial spray operations was carried out at Vigo Plant CWS, Terre Haute, Indiana, and at Beaumont, Texas (limited operations on commercially planted irrigated rice at the latter). From April through October 1945, nine officers and one enlisted man (T/4 C.G. Wyckoff, CWS) from Crops Division, aided by some enlisted personnel for field work and ground operations from the Technical Department, Vigo Plant, conducted 104 missions in the area. There were 81 missions over grid areas (where potted plants and indicator cards were set up) or over weed fields and 23 missions over a variety of field crops (planted in strips) in different stages of development.⁷⁰

(U) At the Vigo Plant, Capt. C.E. Minarik, Cav; 1st Lt. R.M. Acker, CWS; Lt. W.B. Ennis, USNR; Major H. Hall, AC; 1st Lt. A.S. Newman, AC; Lt. H.H. Smith, USNR; Lt. C. Swanson, USNR; Capt. D.L. Taylor, CWS; and Capt. H.W. Wheeler, CWS, intensively investigated and modified equipment, solutions, agents, and related droplet distributions to plant responses. They confirmed and extended the results of tests carried out at Bushnell Army Air Field and further demonstrated that by installing a reduced orifice adapter (recommended 3¼-inch opening) on the M-10 airplane smoke tank mounted on a A-20-G (now B-26 aircraft) attack bomber, the swath length would be increased 25%, with no apparent reduction in effective width. They tested the suitability of an alternative large-volume spray tank (550-gallon bomb-bay installation for the B-25 airplane) for disseminating crop-destroying agents and reduced the lag period between beginning of discharge and attainment of full flow rate by adding an air collector scoop attached to the air inlet, placing the contents under small positive pressure. The preferred discharge rate was 3.5 to 4.0 gallons per second at an altitude of about 100 feet and a speed of 200 mph.⁷⁰

(U) The officers thoroughly investigated solutions and agents. They tested such items as 2,4-D and 2,4,5-T and their various esters and studied spray volumes in relation to agent concentration; compared agents; determined the most satisfactory oil-type carriers for agent dissemination; and also tested spray solutions after adding a coagent or a wetting agent.⁷⁰

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(U) Twelve missions were reserved for comparing agents (phenoxyacetic acid type) that were as good as, or better than, 2,4-D as inhibitory or herbicidal agents. One was easier to manufacture. Four other agents were directly miscible in oil and therefore required no cosolvent such as tributylphosphate. Dr. Minarik et al. made valid comparisons between spray density as revealed on the indicator cards at any one station and plant responses at the same station as judged by the degree of inhibition of new growth.⁷⁰

(U) Additional agents that showed inhibitory action comparable to 2,4-D in static trials proved to be at least as effective in the field. The oil sprays were more effective than water sprays at similar spray densities and agent concentration. The investigators recommended that the production of ethyl ester of 2,4-D be considered for direct incorporation into oil for crop destruction.⁷⁰

(U) The following year (12 to 14 August 1946) Newman and Ennis returned to the Vigo Plant to determine the enduring effects of such sprays upon annual and perennial vegetation. They found that insufficient chemical was present in the soil to affect the growth of soybeans or corn that was planted the next year. There was no noticeable reduction in the weedy plant population in areas treated the preceding year with aerial sprays of plant inhibitors, ranging in concentration from 1 to 15%.⁷¹

F. ⁴ AERIAL SPRAYS WITH UNDILUTED CHEMICAL

1. (U) C-47 Aircraft—Avon Park, Florida

(U) After demonstrating the feasibility of releasing diluted agent from aircraft at Vigo, Indiana, field tests were set up at Avon Park, Florida, to demonstrate the feasibility of releasing undiluted agent from aircraft. The tests at Avon Park were conducted by Mr. Roy M. Acker, project leader, who contributed significantly to the program. His work on aerial spray systems for military aircraft and his dissemination trials at Avon Park Air Force Base, Florida, and Edgewood Arsenal, Maryland, laid the ground work for the defoliation systems currently in use in Vietnam. The agent used in Vietnam was one that he selected—mixed butyl esters of 2,4-D and 2,4,5-T.*

(U) Acker conducted the first aircraft releases (crosswind and upwind) of undiluted agent from a C-47 aircraft (furnished by Commanding General, Tactical Air Command, Langley Air Force Base, Virginia) at Avon Park during the spring of 1951. He and Roger W. Hartmeyer** et al.

* Personal letter from Dr. Minarik to Mr. Acker on 3 March 1959.

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conducted tests to determine if low-volume highly concentrated anticrop agents could be sprayed from aircraft both effectively and practically. They also conducted tests to determine (i) droplet distribution obtained from various atomizing devices, (ii) rates (gal/acre) of undiluted agent that severely inhibited or killed young potted plants (arranged on sample lines of a grid), and (iii) lethal swath widths in crosswind flights at different altitudes and flow rates.⁷⁹

2. (U) Navy XBT 2D-1 with Navy Aero X 2A—Avon Park, Florida

(U) During these trials Acker et al. also tested the performance of the Navy Aero X 2A spraying device that they mounted on a Navy XBT 2D-1. This equipment was developed by the Navy to meet a requirement for insecticide sprayers that could be attached to and removed from combat aircraft. Therefore, they conducted flights to determine whether this general type of sprayer might be adapted for low-volume anticrop spray operations. Upwind flights were made primarily to obtain particle size and distribution data, and crosswind flights for determining maximum effective swath widths.⁷⁹

3. (U) USAF B-17, USAF B-26, USN AD Skyraider, USN F4U Corsair—Avon Park, Florida

In the fall of 1951 at Avon Park, Acker, Hartmeyer and others conducted low-volume anticrop aerial spray trials (49 missions) using the USAF B-17, USAF B-26, USN AD Skyraider, and a USN F4U Corsair to disseminate undiluted butyl 2,4-D (Agent 143), isopropyl 2,4-D (Agent 167), and butyl 2,4,5-T (Agent 974). The Commanding Generals of Warner Robins Air Force Base, Georgia, and MacDill Air Force Base, Florida, provided essential logistical support. The commanding Officer, 3210th Chemical and Ordnance Test Group, Aberdeen Proving Ground, Maryland, from the 110th Chemical Test Squadron, Army Chemical Center, Maryland, furnished the B-17 and B-26 aircraft and experienced test pilots and crews. The Malaria and Mosquito Control Unit No. 1, Jacksonville Naval Air Station, Florida, furnished the Navy AD Skyraider, the F4U Corsair, Navy dispersal equipment, and personnel who participated in the Navy phases of these trials. The dual spraying system that proved most valuable in the assessment trials was originally developed by the Forest Insects Laboratory of the Division of Forest Insects Investigation, USDA. The test director stressed the investigation of (i) behavior of agent when discharged from various atomizing devices, (ii) effects of airspeed on spray characteristics, (iii) effects of location of atomizing devices on distribution of the spray, and (iv) effects of altitude of release on swath characteristics. The location of the atomizing device greatly affected the behavior of the droplet cloud, a major finding in these tests. The chemical anticrop agents proved potent. It became known beyond question that 0.1 to 0.25 lb. per acre would cause killing of plants or severe yield reduction in many major economic crops. Recovery of sprays upon the ground was high for all three agents. From data obtained, personnel determined that an adequate installation for chemical anticrop spraying probably would be relatively simple in design and suited for placement in bomber-type aircraft without extensive modification.⁸⁰

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4. (U) Modifications Resulting in Development of Hourglass-MC-1--
Eglin Air Force Base, Florida

(U) The third series of chemical aerial spray trials was conducted in November and December, 1952 after the Division Chief, Dr. A. G. Norman, resigned and was replaced by Dr. C.E. Minarik who formerly was Chief, Chemical Branch. The trials were conducted jointly by Chemical Corps and Air Force personnel at Eglin Air Force Base, Florida, with R.M. Acker as Project Leader. The tests included an Air Force project—that of evaluating a large-capacity spraying system for installation in B-29, B-50, and C-119 aircraft. Optimal flow rate for maximum utilization of agent was determined (100 gal/min recommended for broadleaf crop attack), based on the finding of lethal swaths ranging from 8,000 to 20,500 feet as determined with potted test plants. Data collected at flow rates of 50, 100, 150, and 200 gal/min permitted recommendations for optimal flow rates to be used in effectively treating a given target area. The engineering data that Acker et al. collected with this prototype large-capacity spray system⁸³ subsequently led to the design of the "Hourglass-MC-1," the first system to be used in Vietnam. This system, standardized and built for the U.S. Air Force by Hayes Aircraft Corporation,⁸² has been adapted for use in the C-123 and has been the major spray system that has been used in Vietnam since 1962. In Dr. Minarik's letter to Acker on 3 March 1969 he states, "We made a few changes in flow rates and used wing booms, but we regard it as a modified 'Hourglass' system. With the sound background information that you developed, it was simple to make changes that would adapt the Hourglass for use in the C-123, with a three-gallon per acre deposit."

5. (U) Navy F3D Jet Fighter with Aero 14A Airborne Spray Tank

(U) In the spring of 1954, Acker, Hartmeyer and others dispersed standardized chemical anticrop agents, butyl 2,4-D, and butyl 2,4,5-T from the Navy F3D jet fighter at 100-, 300-, 500-, and 700-foot altitudes, with speeds of 360 knots, using two Aero 14A Airborne Spray Tanks. The results were highly satisfactory. Sprays that were released at 700 feet effectively treated a swath 7,000 feet wide and more than 8 miles long, representing an area coverage of 10 square miles per sortie. Sprays released at 300 feet produced areas highly overdosed, resulting in inefficient agent utilization.⁸⁵

6. (U) U.S. Navy F3D-1 Jet Aircraft with Navy Aero 14A Airborne Spray Tanks—Avon Park, Florida

(U) Additional trials were included for the fall of 1954 at Avon Park. Acker et al. conducted and completed the trials in January 1955, seeking further information on the dissemination of chemical anticrop agents. They used two Navy Aero 14A Airborne Spray Tanks (manufactured by Edco Corporation) mounted on the wings of a U.S. Navy F3D-1 jet aircraft and particularly studied the effect of altitude of spray release on swath characteristics and the effects of airspeed on spray atomization. Higher altitude spraying resulted in greater swath widths. Sprays released in crosswind missions at altitudes of 1,500 feet produced average effective swaths of

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17,425 feet in contrast to an average of 7,190 feet obtained from previous tests in which sprays were released at 700 feet. From data obtained, it was calculated that a single jet aircraft using two tanks could effectively treat about 20 square miles of susceptible broad-leaved crops per sortie in 51 seconds over the target under a variety of meteorological conditions. When they increased the airspeed from 180 to 360 knots, the mass median diameter of the droplets decreased from 273 to 170 microns. Because finer spray droplets were expected to produce a more uniform deposition with an increase in area coverage, higher airspeeds were suggested in future tests for possibly obtaining finer spray atomization. Further studies were recommended for establishing an optimum spray release altitude for maximum coverage.⁸⁶

G. (U) GREENHOUSE AND FIELD INVESTIGATIONS WITH CHEMICALS AT FORT DETRICK AND ELSEWHERE

(U) While the chemical aerial spray trials were conducted in the field and equipment was being perfected, the Chemical Branch at Camp Detrick was investigating other phases of research: Pre-emergence herbicides and their behavior;⁵¹ Influence of different carriers upon the inhibitory properties of growth regulatory sprays;⁵² New growth-regulating compounds;⁵³ Disappearance of 2,4-D and 2,4,5-T from soil;⁵³ Behavior of droplets impinging on leaves of different species;⁵⁴ Studies on the relation between molecular structure and physiological activity of plant growth-regulators: I. Abscission-inducing activity;³⁷ Metabolism of 2,4-D;^{38,54} A root elongation test for herbicide screening;⁴⁰ 2,4-D - Mechanisms of action;⁵⁵ Herbicides: Chemical weed control;⁵⁶ Halogenated phenyl alkyl ethers as plant growth-regulators;⁵⁵ Precision sprayer for small plots;⁵⁶ New growth-regulating compounds: IV. Selected toloxyacetic acids;⁵⁶ Species sensitivity to chemicals tested for herbicidal properties.⁵²

(U) Defoliant and desiccant chemicals were being screened and investigated intensively.⁵⁷⁻¹⁰⁴

(U) During 1954 and 1955, SP3 J.R. Whiteley, SP3 E.B. Minton, and SP3 B.C. Patten, Jr. conducted greenhouse and field defoliation investigations, including selection of active compounds, field testing, variation in response among species, and comparison of the effectiveness of two of the most promising compounds.⁹⁸ In field applications at Fort Detrick, plants were treated with a battery-operated portable sprayer.⁹⁸ This equipment permitted application of small volumes to small areas of foliage (approximately 2 ft²). It also was used in a forested area at Fort Ritchie (9 and 11 August 1955) to spray endothal on selected branches of various species. Previously (March and April 1955) chemicals had been applied to plants (in 16-ft² areas) (1 ml/16 ft² was equivalent to 0.75 gal/acre) at Avon Park with a 250-ml hand sprayer operated by carbon dioxide and equipped with a flat-spray Tee-jet nozzle. In all areas (Camp Detrick, Maryland; Avon Park Air Force Base, Florida; and Fort Ritchie, Maryland) disodium 3,6-endoxohexahydrophthalate and 2-butyne-1,4-diol were the most effective defoliants on woody vegetation.⁹⁸

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H. (U) INITIATION AND DEVELOPMENT OF THE DEFOLIATION PROGRAM

(U) From 1956 through 1964 approximately 12,000 chemicals were screened for herbicidal activity. Those that showed even the slightest defoliation or desiccation activity were put into the defoliant screening program that was initiated in 1962.⁹⁰

(U) Dr. Minarik implemented the present U.S. Army Biological Laboratories Defoliation Program with the establishment of a synthesis and screening contract with Penhsalt Chemicals Corporation in July 1962,¹⁰⁵ also an in-house screening for candidate defoliants. In April 1962¹⁰⁶ he had negotiated a seedling tree contract with Bio-Search and Development Company Inc. to screen more than 600 chemicals that had previously shown biological activity in Crops Division screening programs. In the fall he established a tree nursery (8,000 trees comprising 18 species) at Fort Detrick. The program expanded rapidly. Defoliation Conferences were held at Fort Detrick in 1963,^{90a} 1964,¹⁰⁷ and 1965¹⁰⁸ so that all contractors and government personnel who were working in support of the Defoliation Program could summarize their findings, discuss their problems, and exchange ideas.⁹⁰

(U) Dr. Robert A. Darrow had joined Crops Division in September 1962 after extensive experience in research in vegetation control at Texas A&M University. He assumed the role of Chief, Chemical Branch, when he joined the Division Staff and in 1963 and 1964 served as Project Officer for the defoliation test program conducted in Thailand under ARPA Order Number 423.

1. (U) In-House Screening of Chemicals in Earlier Years

(U) In the earlier years (1956 and 1957) William H. Preston, Charles R. Downing, and Charles E. Hess were involved with in-house screening of chemicals. They intensively screened 577 chemicals at Fort Detrick and Fort Ritchie, Maryland, for the best available defoliants, desiccants, and vegetation-control agents. After investigating environmental conditions, spray techniques, and formulations that increase the effectiveness of defoliants and desiccants, they found that 2-butyne-1,4-diol and tributyl phosphate were the most effective defoliant and desiccant.¹⁰¹ Dr. S.R. McLane and Edward W. Dean had previously reported (1955)⁹⁷ that tributyl phosphate produced a discernible mark on vegetation in less than 30 minutes, making it potentially useful in camouflage detection. McLane also found that an area marked with 3-amino-1,2,4-triazole could be detected more than 3 months after the spray application, indicating its potential usefulness in target marking.

(U) When Charles E. Hess investigated the potentialities of cacodylic acid as an anticrop agent,⁹⁹ he reported that cacodylic acid was an agent of choice.¹⁰² In 1959 and 1960 Ray Taylorson was involved in synthesizing various forms of this chemical.¹⁰⁴

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2. (U) Greenhouse Screening and Field Testing Programs

(U) After the Defoliation Program was established, J. Ray Frank (Horticulturist, assigned to Crops Division 14 April 1961) headed the screening phase. He with the assistance of Ralph E. Buschmann and Robert F. Morneweck¹⁰⁹ conducted coordinate screening tests on 14-day-old Black Valentine bean plants for defoliant, desiccant, or herbicidal activity of compounds shown to be active in the contractor screening program or in the six-plant primary screening program that Dr. DeRose conducted. In turn, compounds showing a moderate or higher level of activity as defoliants, desiccants, or herbicides in the 14-day bean test (1,410 compounds tested from August 1961 to June 1963) were subjected to secondary screening on woody plant seedlings (8,000 trees used each year) in greenhouse tests, which J. Ray Frank also headed.¹⁰⁸ Active compounds in this screening program on woody plant seedlings were carried into a field testing program that Kenneth Demaree, Horticulturist, directed.^{90a.110}

I. ~~H~~ EARLY HISTORY OF THE ACTIVITIES OF THE BIOLOGICAL BRANCH

(U) An intensive biological program had been initiated at the same time as the chemical program. In March 1944 a formal research program was instituted in the Biological Branch on Piricularia oryzae as a potential agent against rice,^{4.111} and in 1946 on Puccinia graminis tritici, the pathogen causing stem rust of wheat. Research continued on other pathogens.^{2.112.113.114} A.L. Andersen, B.W. Henry, and E.C. Tullis studied factors affecting infectivity, spread, and persistence of P. oryzae in greenhouse and field trials. Investigations on sporulation conducted by Andersen, Henry, W.W. Dorrell, and Edward Cherry led to the development of a process for producing spores of P. oryzae in mass quantities.^{4.111.112} Henry and Andersen also investigated the use of wetting and adhesive agents to increase the effectiveness of conidial suspensions for plant inoculations.¹¹⁵ S.F. Snieszko, E.P. Lowe, and J.B. Carpenter not only intensively investigated the development of Phytophthora infestans as a potential agent for biological warfare,² but they also submitted improved methods for the cultivation and storage of P. infestans.¹¹⁴ R.M. Page, A.F. Sherf, and T.L. Morgan reported the effect of temperature and relative humidity on the longevity of the conidia of Helminthosporium oryzae and studied the factors affecting its infectivity.^{112.113} With interest in the Orient waning after the end of the war with Japan, the rice blast (P. oryzae) work was terminated in December, 1947, and the progress on all aspects of the problem was summarized in a final report.⁴

~~H~~ In the latter part of 1947, Dr. Ian W. Tervet* joined Crops Division staff as Chief of the Biological Branch, replacing Dr. Berch W. Henry,** who resigned in September 1947. Dr. Tervet, with Dr. Robert Cassell as

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project leader, made notable progress during the period 1948 through the summer of 1951.¹¹⁸⁻¹²³ He and his colleagues developed and demonstrated methods for performing all critical steps such as culturing,¹²⁰ harvesting,^{118,121,122} processing, storing, and disseminating P. graminis tritici. Experiments were being carried out in the field and greenhouse, and stem rust production was under way in Crops Division's new Pilot Plant (Building 374). Col. Theodore Odland had taken leave of absence from the University of Rhode Island where he was Head of the Agronomy Department* to head this project.

After carrying out extensive research on P. graminis tritici at Camp Detrick, field tests were set up in Puerto Rico during the winter of 1950 to 1951 to demonstrate the feasibility of large-scale production.

Success with tests in Puerto Rico resulted in a requirement from the Air Force for the production and stockpiling of a substantial quantity of P. graminis tritici. This procurement was assigned to Special Projects Division, Edgewood Arsenal, who directed six production sites in the midwest in the summer of 1951. Personnel from the Biological Branch of Crops Division gave technical advice and aided in establishing a facility for this requirement.

(U) Dr. Tervet resigned in the summer of 1951 and was replaced by Dr. John E. Mitchell.**

J. (U) PIONEER RESEARCH ON GIBBERELLIN

(U) Before Dr. Mitchell joined Crops Division, Dr. Axel Andersen was working on Gibberella zeae as an agent for wheat and had acquired numerous cultures of related fungi.¹²⁴ One culture, Fusarium moniliforme (Gibberella fujikuroi), was known to cause bakanae (foolish seedling) disease of rice. Dr. Andersen cultured the organism and studied it while Dr. Minarik investigated the spent culture liquids for their ability to stimulate vegetative elongation of rice. It was believed that there were two materials in the spent culture liquids—a stimulator and a toxic material. When Dr. Mitchell joined the staff on 1 July 1948, the latter task (isolation of biologically active materials) was turned over to him as his primary responsibility.

(U) Crops Division was now carrying out the first research on gibberellin outside that in the Orient.¹²⁵ In 1912, Sawada, a Japanese plant pathologist, believed that the bakanae disease of rice was caused by a fungus. In 1926, Kurosawa, a co-worker of Sawada, published his now classical paper, "Experimental studies on the secretion of Fusarium heterosporium on rice plants." Dr. Kurosawa is credited with the "opening up of the fertile

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gibberellin field." In 1935, Dr. Yabuta named the growth factor "gibberellin" on the basis of the scientific name of the fungus, Gibberella fujikuroi (Saw.) Wt. Three years later he and Dr. Sumiki reported the isolation of crystalline gibberellin A and B.¹²⁶

(U) In March 1950, Dr. Mitchell gave a review of his work at the 7th Annual Meeting of the Potomac Division of the American Phytopathological Society held in the Plant Industry Station Auditorium, Beltsville, Maryland, March 9 and 10.¹²⁷ After developing procedures for large-scale production of gibberellin concentrates, Dr. Mitchell served as project officer on a contract (negotiated August 1951) with a USDA, Peoria, Illinois, facility (Northern Regional Research Laboratory) to produce gibberellin. Dr. Mitchell et al. had obtained a new gibberellin in crystalline form from a fermentation using Mitchell's organism (No. 624 = NRRL 2284) on glucose solution and designated the new product as gibberellin X. (This new product was temporarily designated gibberellin X to distinguish it from Sumiki's natural gibberellins A and B and from his gibberellin C, a derivative of gibberellin A.) In June 1952, a successful 160-gallon fermentation had been run and crude crystalline gibberellin was obtained. On 1 July 1952 work was begun on contract with the Chemical Corps, Camp Detrick, to develop suitable methods for the production, isolation, and characterization of the gibberellins, plant growth regulators produced by the fungus F. moniliforme (G. fujikuroi).¹²⁸ According to the Source Book on Gibberellin, 1828-1957, compiled by Dr. Frank Stodola of the U.S. Department of Agriculture,^{128a} Dr. J.E. Mitchell in this country and Dr. P.W. Brian in England were the first to point out the potentialities of the gibberellin compounds, leading to rapid and substantial progress on all aspects of the problem by workers in all parts of the world.

K. STEM RUST

After Dr. Mitchell became Chief of the Biological Branch in 1951, Dr. C.A. Kingsolver joined the staff as leader of the rust project. Further significant improvements were made in cereal rust spore production techniques,¹²⁹⁻¹⁴⁵ leading to the development of new agent-dissemination techniques. In cooperation with the USN Bureau of Aeronautics, Roy M. Acker and his assistants in Operational Requirements Branch demonstrated effectively the feasibility of the line-source delivery of dry agents with the Aero 1A and Aero 2A tanks.¹³⁶ As a result of these demonstrations, this concept of agent delivery was widely accepted for CSR agent employment and was adopted throughout DOD.

1. Development of Equipment for Cereal Rust System

An integral part of this development was the further design and fabrication of equipment and devices for all phases of the stem rust system. Dr. L.M. Massey, Jr., and Thomas L. Morgan developed methods for processing, packaging, and storing cereal rust spores.¹³⁷ (A search of the literature had produced no careful quantitative analysis of fungus

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spore longevity in storage prior to the initiation of their work.) Equipment (harvesters both for greenhouse and field) was fabricated as a joint activity of the Engineering Division and Crops Division. An historical account, with illustrations, of the various types of equipment used by Crops Division for harvesting cereal rust spores from host plants was written by Edward Cherry in Special Report 219-I.¹³¹ Field harvester development had progressed from a simple garden tractor (Field Harvester, Model 1) that collected 4 pounds of rust per acre in 1948 to a self-propelled machine harvester (Field Harvester, Model 4) that harvested as much as 73.7 pounds per acre in 1953.¹³¹

2. Cereal Rust Production at Various Sites

During the winter months of 1952 to 1953, C.R. Kingsolver, K.R. Brownfield, William E. Miller, Robert G. Emge, Edward Cherry, Louis Massey, and Thomas Morgan were involved in experiments on cereal rust production in the Southwestern United States.¹³² The following winter (1954 to 1955) some members of this team conducted tests at five sites in Puerto Rico and at one site in St. Croix, Virgin Islands. They recorded plant height, plant development, and plant susceptibility to stem rust for 13 varieties at the various sites throughout the testing period.^{135, 135a}

(U) During the winters of 1954 through 1957, Dr. Kingsolver, John F. Underwood, and Clyde Peet conducted a series of experiments in St. Croix to evaluate the intensification and spread of wheat stem rust both within field stands and over a 10-mile grid. These experiments resulted in the formulation of a mathematical model characterizing the spread potential of the stem rust organism. The exponential slope regression characterized the rate of rust intensification and, together with data on rust development prior to the exponential increase, could be used as a prediction system.^{135b, 135c}

3. (U) Development of Laboratory Assessment Techniques

(U) Concomitantly at Camp Detrick, laboratory assessment of stem rust was being studied intensively. To improve the accuracy of assay results, Massey and Morgan recommended certain modifications in methods of assessment.¹³³ Procedures for determining percentage total spores, percentage stem rust of total spores, spore viability, and moisture were adopted as standard.¹³⁴

(U) By February 1955, Drs. Kingsolver, C.G. Schmitt, and E.L. Sharp reported research on the influence of controlled environmental conditions on the infectivity of uredospores of cereal rusts. They found that hydration increased chances for rust establishment by increasing percentage of spore germination and by decreasing the time required for maximum germination and appressorium formation. The benefits of hydration for enhancing infection were proportionally greater with older spore lots than with younger and with

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shorter dew periods than with longer. Primary leaves were more susceptible to infection than were secondary or succeeding leaves. Uniform inoculations made on the adaxial leaf surface yielded more pustules than did those made on the abaxial surface. The minimum continuous moist-chamber temperature to initiate infection was near 55 F, the maximum near 85 F, and the optimum between 70 and 75 F. Minimum moist-chamber period for infection at optimum temperature was 6 hours for nonhydrated spores. Temperatures exceeding 90 F rapidly reduced infection potential of uredospores. Spores on plants that received a dew period of 15 to 120 minutes before interruption of dew at 60% RH and 70 F decreased directly in infection potential with period of dew prior to "drying" and resumption of dew period.¹³⁸

(U) Concurrently, Drs. Schmitt, Sharp, Ball, Miller, Bromfield, and Kingsolver were developing techniques for assessing infectivity of cereal rust spores. Relatively uniform spore distribution was attained by using a galvanized sheeting settling tower 4 feet high and 3 feet in diameter mounted over a plywood box with a rotating floor to facilitate loading and unloading and with a baffle to allow spore clumps to settle before exposing leaves to the spore shower. A CO₂ pistol provided somewhat better spore distribution than did air pressure between 15 and 50 psi instantaneously released by a solenoid-actuated mechanism. Leaves were exposed horizontally to the vertically falling spores by the expedient of fastening them to metal backboards. Regulation of temperature and humidity during the moist period was effected in specially constructed, thermostatically controlled dew chambers that provided a range of temperature from 55 to more than 95 F. Aniline blue and acid fuchsin alone or in mixture with either lactophenol or chloral hydrate were effective in rapid staining methods to demonstrate rust mycelium in host tissues.¹⁴⁰

L. (U) PRELIMINARY STUDIES ON LEAF RUST

(U) Complementary studies on leaf rust had been made previously (1950) to compare the behavior of this rust with the related stem rust. Kent Irish obtained significant information on the competition of races of the leaf rust organism. Preliminary studies indicated that competition was manifest between closely associated races growing in composite culture. Four important races of leaf rust, 9, 15, 58, and 126, were mixed in equal amounts and grown together on the uniformly susceptible host variety Cheyenne. A decline and/or disappearance of a race from the association was considered to be evidence of competition with one or all of the races in the mixture. Composite culture I was carried through seven generations and composite culture II was continued through 10 generations. The race populations in each generation were sampled by making a series of single-pustule isolations. The isolates were cultured and the races identified. One hundred and three isolations were made from the generations of culture I and 158 from those of culture II. Physiologic races 9 and 15 were the dominant competitors when grown with races 58 and 126.¹²³

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M. (U) EARLY WORK ON PLANT VIRUSES

(U) Investigations on the bud-blight disease of soybeans caused by the tobacco and tomato ring-spot viruses were conducted by Dr. Frances M. Latterell from 1950 to 1952.* Upon her reassignment to the rice project, virus studies were continued by Dr. P.R. Desjardins (llc.)** and Dr. Robert P. Kahn.*** Plant viruses considered as candidates for BW agents at this time were limited to mechanically transmitted viruses (as opposed to insect-transmitted) because of the anticipated problems in transporting viruliferous insects with retention of viability of both host and agent. Lt. R.C. Carter, an entomologist, spent his tour of duty (1954-1955) compiling a literature survey on the feasibility of using insect-transmitted plant viruses as BW agents.**** Dr. Kahn was assisted by Lt. Thomas C. Allen, Jr. and Pvt. O.J. Dickerson in his virus work.

(U) Dr. Mitchell continued as Chief of the Branch until July 1955, when it was divided into two branches, Biological Branch I and Biological Branch II. He headed Biological Branch I and directed research on rice and potato pathogens and plant viruses. Dr. Kingsolver became Chief of Biological Branch II, directing research on the cereal rusts.

N. (U) DEVELOPMENT OF A SYSTEM FOR RICE

1. (U) Field Studies

(U) In 1952, investigations on rice blast (Piricularia oryzae) and brown spot of rice (Helminthosporium oryzae) were reinstated in the Crops Division program under Dr. E.C. Tullis as Project Leader. Dr. T.W. Johnson, Jr., was assigned to study P. oryzae, and Dr. Latterell, H. oryzae. During that year, inocula of both rice pathogens were prepared by laboratory culture, and field tests were conducted in Texas, Arkansas, and Mississippi. The inoculations yielded minimal success for reasons relating to quality of inoculum, plant age, and weather. Inoculations of P. oryzae planned for plots in the new rice-growing areas in the Florida Everglade region in this first year were not completed because of the natural development of a severe epiphytotic of rice blast. Investigations on H. oryzae were terminated in the latter part of 1952 because the field trials and greenhouse tests showed that this agent could be effective only on pre-emerged or young seedlings, or on plants grown in poor soils having low nitrogen or unbalanced nutrition.***** The severity of the natural outbreak of blast

* Reference 67, page 141.

** References 62, 64, and 66, pages 140 and 141.

*** References 64, 66, and 67, pages 140 and 141.

**** Reference 15, page 136.

***** Johnson, T.W., Jr.; Latterell, F.M.; Tullis, E.C. 1952. Field tests of rice pathogens, (typewritten report). Crops Division, Camp Detrick, Frederick, Maryland.

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R. ~~6~~ ANALOGUE AREA STUDIES

(U) During this interim (1958), a state-of-the-art evaluation indicated a need for additional quantitative data on the effectiveness of the wheat stem rust agent in climatic analogues or possible targets. After Crops Division was reactivated and the mission was reinstated in 1959 (the Division was in process of staffing its operation from 1959 to 1962), an intensive test program was planned and initiated (in 1960) under the supervision of Kent R. Irish.¹⁸⁴ Because of the numerous uncontrollable variables, it was recommended that 5 years' testing be conducted to accumulate meaningful data.

~~6~~ The first tests that involved analogue areas had been conducted by Roger W. Hartmeyer, Kent R. Irish, Shosuke Goto, William B. Johnson, Wilton R. Tenney, and George N. Asai under the supervision of R.M. Acker at Rosemount Research Center, Rosemount, Minnesota, and at the adjoining Rosemount Agricultural Research Center. The USN Jet Fighter Cutlass F7U-3 was used in these experiments and results from 1955 to 1957 showed that cereal rust epidemics could be induced in analogue areas that would result in complete destruction of a cereal crop.¹⁸⁵

(U) After the reactivation of Crops Division, analogue tests were continued under an agreement with the USDA, who provided sites and crops at selected analogue areas. The first series of tests after reactivation were conducted in 1960 at Hays, Kansas, and Langdon, North Dakota,¹⁸⁴ where four 1-acre plots were inoculated with various amounts of stem rust spores. These tests were designed to delineate the major factors contributing to the development of destructive rust epidemics in the central United States. Extensive data were collected on rust increase and development, crop development, meteorology,* and effect of rust on crop yield.

(U) The program was accelerated in 1962 to include a greater number of locations and more detailed study of rust increase, micrometeorological factors, and yield reduction at each location.¹⁸⁷ Under Dr. Kingsolver's leadership (he resumed his role as Chief, Biological Branch, 17 September 1962), William B. Johnson and Dr. Roland F. Line conducted tests at Stillwater, Oklahoma, and Hays, Kansas, in 1963;¹⁸⁷ then in 1964 the tests were expanded to include six locations and two to 11 plots in each area. That

* Of special interest was the amount of dew and its duration that was measured by the Taylor dew meter, an instrument that records with high accuracy the starting time and the duration of dew deposits (application for patent filed by the Federal Government in May 1953 under title "Dew Meter").¹⁸⁸ Dr. Carlton F. Taylor had invented this device (an invaluable instrument used to date, 1970) in the course of research on potato diseases. Edward Cherry (deceased), Raymond Crum (deceased), and Dr. John Smoot (presently Research Plant Pathologist, Market Quality Research Division, Agricultural Research Service, United States Department of Agriculture, 2120 Camden Road, Orlando, Florida 32789) also participated in its development from the basic idea to the present model.¹⁸⁶

year Dr. Line and Clyde E. Peet conducted field tests at the following locations: Stillwater, Oklahoma;¹⁸⁸ Hays, Kansas;¹⁸⁸ Crookston, Minnesota;¹⁸⁹ and Casselton¹⁹⁰ and Langdon, North Dakota.¹⁹¹ The inoculum (mostly race 56 of wheat stem rust) was varied in dosage from plot to plot to produce a range of primary infections. Also portions of each plot were protected from disease by fungicides to serve as controls in assessing yield reduction.

(U) In Hays, Kansas, from 1960 to 1965, Line, Peet, and Kingsolver studied the epidemiology of stem rust in fields of Cheyenne wheat that had been inoculated with uredospores of race 56 when the plants were in tillering to boot stages of growth. Infection occurred in 6 consecutive years. Severities at soft dough were about 30, 25, 7, 2, 2, and 20%; yields for rusted plots were 20, 19, 25, 34, 22, and 18 bushels per acre; and yields for adjacent control areas were 46, 29, 45, 35, 29, and 62 bushels per acre, respectively. In 1965, a natural epidemic of stem rust caused severe damage to wheat in Kansas and Nebraska. In 1965, the crop ripened late in the season. In 5 of the 6 years, weather was favorable for rust epidemics. Late natural infection appeared to be the primary factor limiting severity of the rust epidemics.¹⁹²

(U) Further research in Crops Division—Plant Sciences Laboratories during FY 1965-1967, 1968, and 1969 is discussed in Sections II, III, and IV.

in Florida, on the other hand, encouraged greater emphasis on the study of blast. This outbreak occurred in plantings of varieties that had been considered resistant to blast on the basis of their reactions in Arkansas, and thus provided circumstantial evidence of physiological specialization in the rice blast pathogen.

(U) Another outbreak of blast occurred in commercial rice plantings in the Belle Glade area in 1953.¹⁴⁶ Dr. R.D. Schein (CPL), Dr. Tullis, and other members of the staff observed the progress of the disease from 15 June to 25 September. Severe damage occurred in all fields planted in muck soil, both upland and flooded. Severity of infection subsided during late tillering stages, but increased during panicle development in most fields. The occurrence of this epiphytotic afforded an opportunity for firsthand study of the potentialities of the pathogen as a BW agent and of the conditions requisite for disease development.¹⁴⁶ The following year (work completed October 1954), Dr. Schein and Dr. R.B. Corey (enlisted Specialist of the U.S. Army), with the cooperation of personnel of the Everglades Experiment Station, induced an epiphytotic of the blast disease in rice growing under highly atypical soil conditions. It was started from inoculations in plots 0.036 acre and spread over more than 10 acres in 4 weeks' time. The increase in disease resulting from application of nitrogen fertilizers to the sand land was indicative of the potential effect of this nutrient element on blast development. The marked surge in disease development, followed by a definite regression of intensity, illustrated the need for more adequate knowledge concerning the effect of meteorological conditions on disease development and the need for an experimental site with soil more typical of rice-growing land.¹⁴⁷

2. (U) Etiology of Rice Blast

(U) With the increased interest in rice blast following the severe epiphytotics in Florida, Dr. Latterell was reassigned to study the cultural and pathogenic characteristics of the causal fungus, P. oryzae. Dr. Kahn was detailed from the virus project to study the factors influencing infection by the blast pathogen. As noted above, the varieties of rice affected in the Florida fields indicated that there probably existed more than one pathogenic strain of P. oryzae. Experiments were undertaken to determine whether such was the case by inoculating four varieties of rice with two strains of the pathogen: one from the 1952 epiphytotic and a 1943 isolate from Arkansas. The two isolates caused opposite responses from each of the four varieties: the Florida isolate was pathogenic to Zenith and Rexoro, but not to Lacrosse and Caloro; the Arkansas isolate showed the reverse pattern. These patterns of reaction appeared to be characteristic and consistent for both isolates, and thus provided the first experimental evidence of the existence of at least two strains of P. oryzae.¹⁴⁸ In October, 1953, Dr. Latterell initiated a screening program with several general goals: (i) to determine to the extent possible the degree of pathogenic variation or "physiologic specialization" that occurs among isolates of P. oryzae to be collected from different hosts and many rice-growing areas of the world; (ii) to select through intensive testing

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a group of varieties that by their reactions would provide clear-cut differentiation among the various races encountered among the collections; and (iii) to determine the capability of the isolates acquired for attacking varieties known or likely to be grown in potential target areas by screening a large number of varieties to the most broadly pathogenic races. As isolates were collected from various parts of the world and tested for pathogenicity, it became apparent that this fungus was extremely variable, and that the species comprised a number of "races" that differed in their ability to attack certain varieties of rice.¹⁴⁹

(U) The data from 3 years' testing (1954 to 1957) involving more than 1,000 isolates of P. oryzae and several hundred varieties of rice were summarized in a report published in 1959.¹⁵⁰ Dr. Latterell had selected ten varieties of rice as best among all those tested for characterizing the 15 physiologic races that she had identified up until that time.¹⁵⁰ In a 1960 publication¹⁵¹ presenting evidence for the existence of physiologic races characterized by their ability to attack rice varieties differentially, a scale of lesion types was proposed to delineate the range of response encountered among the different varieties, and a chart presented showing the response of the 10 differential varieties to the 15 races.

(U) By February 1956, Dr. Robert P. Kahn completed a study, under controlled environmental conditions, of factors influencing the infection of rice by the blast fungus.¹⁵² He continued working with this pathogen under controlled conditions, investigating the effects of temperature, moisture, age, rice cultural conditions, and/or light on appressorial development, the relative susceptibility to infection of different varieties, lesion incubation period, rate of lesion elongation, and relative sporulation.¹⁵³ During the first phase of work, PFC Jack Collier, PFC John Libby, and 1LT James Kato assisted Kahn in the plant inoculations and lesion counts. During the second phase, LT Thomas C. Allen, Jr., and PVT O.J. Dickerson assisted in the research. Kahn submitted data on the third phase in April 1958, his final report of investigation on infectivity studies.¹⁵⁴

(U) Dr. Mitchell resigned in August 1956 and Dr. Chris G. Schmitt assumed responsibilities as Chief of Biological Branch II.

O. (U) DEVELOPMENT OF MOBILE UNITS FOR RUST SPORE ANALYZING, PROCESSING, AND PACKAGING

(U) In December 1955, a proposal was submitted to the U.S. Army Chemical Corps Materiel Command for improvements in processing, harvesting, and storage equipment in connection with an anticrop agent. One of the phases of the proposed program was the design and development of mobile units for analyzing, processing, and packaging the agent. That part of the Industrial Preparedness Measure (IPM) concerned with the mobile units was approved, and work was initiated on their development during 1956. The units were obtained from Ross Ordnance Depot and delivered 9 November 1956. With the

cooperation of Engineering Research Division, personnel fitted the two semitrailers (34-foot van-type) as mobile units, one a laboratory, the other a processing unit, for processing and packaging the anticrop agent at the production site. These units were completed and turned over to Crops Division for preliminary testing in August 1957. Thomas Morgan, project leader, tested each project item as it was developed. For his outstanding service during the development and testing of the mobile labs,¹³⁹ the large-capacity storage containers, and the X5A harvester, all of which contributed significantly to greater efficiency of agent production, the Department of the Army awarded him a "Special Act or Service Award" (21 March 1961).^{139a} Edward Cherry received a "Special Act or Service Award" on the same date for his contribution, the perfecting (with the cooperation of Engineering Research Division) of the X5A harvester. After Morgan's final testing and acceptance of the units in the summer of 1958,¹³⁹ the units were shipped to Puerto Rico for use during stem rust experiments that Edward Cherry and Lester Boyer headed from 1958 to 1961.¹⁵⁵

P. (U) INHIBITOR STUDIES

(U) Other phases of research on P. graminis tritici in the laboratory and greenhouse were: some physical and chemical properties of a volatile fraction from uredospores affecting their germination and development;¹⁵⁶ pelargonaldehyde as an endogenous germination stimulator of wheat rust spores;¹⁵⁷ interaction of aldehydes with uredospores of stem rust of wheat;¹⁵⁸ the effect of DDT on the rust reaction of several wheat varieties to wheat stem rust;¹⁵⁹ the use of controlled temperature and selected hosts to differentiate between two cultures of wheat stem rust;¹⁶⁰ some critical factors involved in establishment of P. graminis;¹⁶¹ and determination of effects of different temperatures on uredial infection with P. graminis tritici.¹⁶²

Q. (U) PHASE-OUT

(U) Most of the activities of Crops Division ceased when the Department of the Army terminated the primary function of the Division 31 December 1957. Eight professionals* (of 118 personnel) and three nonprofessionals** were retained to complete reports of work^{82, 89-103, 135, 139, 150, 153, 164, 169-183, 185} and carry on research at a token level. IFM funds were used to improve equipment such as the mobile units and type-classified agent systems.^{139a}

* Dr. Charles E. Minarik, Dr. Frances M. Latterell, Dr. William E. Miller, Mr. Kent R. Irish, Mr. Thomas L. Morgan, Mr. William B. Johnson, Mr. Lester W. Boyer, and Mr. Edward Cherry.

** Mrs. Carolyn M. Walker, Mr. Melvin E. Krantz, and Mr. Charles M. Bierly (deceased 17 August 1968).