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WSEG REPORT NO. 8

AN EVALUATION OF OFFENSIVE BIOLOGICAL WARFARE WEAPONS SYSTEMS EMPLOYING MANNED AIRCRAFT

ENCLOSURE "E"

CHARACTERISTICS OF ANTICROP AGENTS, MUNITIONS, AND WEAPONS SYSTEMS

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ENCLOSURE "E"

CHARACTERISTICS OF ANTICROP AGENTS, MUNITIONS, AND WEAPONS SYSTEMS

CHAPTER I

ANTICROP AGENTS

AGENTS - EXTENT, PRECISION AND SIGNIFICANCE OF EXISTING INFORMATION

Introductory notes

1. The agents being developed for use in attacking growing crops fall into two major categories: (a) chemical (plant growth regulators) and (b) biological (plant pathogens). The chemical agents are stable organic compounds of high potency, not known to be normally present in plants. Applications to plants may result in death, inhibition of growth, or growth modifications and aberrations that cause yield reductions. Broadleaved plants are in general more responsive than cereals or grasses, but chemical agents specifically inducing inhibitory responses in the latter are known. The chemical anticrop agents, or plant inhibitors, affect only those plants with which they come in contact. The biological agents are living organisms capable of invading plant tissues and causing the development of disease symptoms. Those of significance in anticrop weapons possess high potentialities of spread to adjacent healthy plants. Their effective use involves establishment of an epidemic or epiphytotic. Both categories will receive attention in this study. There are several agents now under research and development, which, although they will not be available by 1954, appear to have sufficient promise to warrant mention at this time. Among chemical anticrop agents, maleic hydrazide and certain fluorine substituted phenoxyacetic acids and derivatives are promising for spray application to reduce yield of cereals, including rice, sorghum, kaoliang, etc. Among the biological anticrop agents under development are several plant viruses, the agent causing late blight of potatoes, and the fungus which causes rice blast. These agents will be treated briefly in the appropriate sections of this study.

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Chemical Anticrop BW Agent Properties

2. Chemical anticrop agents are stable synthetic organic compounds which, if brought into contact with plants in very small amounts are active in producing inhibition of growth or modification. From data obtained in a large number of replicated plot experiments, it is clear that for many broadleaved crops several agents are known which will cause early death or substantial yield reduction at rates of 0.05 - 0.25 pounds per acre appropriately applied. For cereals, other agents are known to be effective at 0.5 - 2 pounds per acre.

3. Variously substituted halogen derivatives of short chain aryloxy acids possess broad inhibitory activity against crop plants. Species differences in responsiveness are well-recognized, but the differences are ordinarily only differences in degree, and may be overcome by increasing the dosage.

4. Some substituted phenyl carbamates have been found particularly effective in inhibiting growth of young cereals. Much of the development work has centered around three agents: (a) 2,4-dichlorophenoxyacetic acid (2,4-D) and esters thereof of which the butyl ester is best known; (b) 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and its esters, of which the butyl ester again is typical; (c) isopropyl-N-phenylcarbamate (IPC) and a halogen derivative, isopropyl-N-(3 chlorophenyl) carbamate (Chloro-IPC).

CHEMICAL AGENTS MOST USEFUL AGAINST BROADLEAF CROPS

5. Butyl 2,4-dichlorophenoxyacetate (butyl 2,4,-D)

a. General characteristics. This is the principal anticrop agent which has been tested so far. Undiluted technical grade butyl 2,4-dichlorophenoxyacetate is commercially available in large quantities at less than $1.00 per lb. It is a liquid of low volatility, with density 1.205, low viscosity (23.3 centipoises at 28°C) and low freezing point (-30°C).

b. Yield reduction.

TABLE I

CROPS SPRAYED WITH BUTYL 2,4-D
(Spray applied as 5% oil emulsion)

Crop	Stage Sprayed	Pounds Agent Per Acre	Gallons Spray Per Acre	% Reduction in Yield
Garden beets	0.9" roots	0.1	6.4	68
	1.6" "	0.1	6.4	53
Mangel	1.1" "	0.1	6.4	85
	2.2" "	0.1	6.4	50
Rutabaga (Swedes)	1.1" "	0.1	6.4	100
	2.5" "	0.1	6.4	95
Rutabaga (purple top)	0.8" "	0.1	6.4	100
	2.0" "	0.1	6.4	70
Sugar beets	0.9" "	0.1	6.4	68
	1.6" "	0.1	6.4	53
Onions	0.5" bulb	0.1	6.4	58
	1.0" bulb	0.1	6.4	55
Kale	9 leaf	0.1	6.4	100
	14 leaf	0.1	6.4	83
Cabbage	2" head	0.1	6.4	98
	2.5" head	0.1	6.4	69

The table above gives the results of tests in which 2,4-D was applied to various broadleafed plants. It shows the per cent reduction in crop yield for the various plants at two stages of growth. The data in Table I were obtained in comparable spray experiments in which the volume rate was relatively high. Many subsequent experiments showed, however, that per cent yield reduction is not a function of volume rate of spray until the latter becomes so low that the statistical chance of an adequate dosage reaching each plant in the droplets intercepted is reduced. In aerosol spray trials responsive plants have been killed or severely inhibited at mean volume rates of $\frac{1}{100}$ gallon per acre, according to Camp Detrick.

6. Butyl 2,4,5-trichlorophenoxyacetate (Butyl 2,4,5-T)

a. General characteristics. The butyl ester of 2,4,5-trichlorophenoxyacetic acid is the second most important chemical anticrop agent. Being a homolog of butyl 2,4-D, it possesses similar physical characteristics. It is non-volatile, with density 1.283, low viscosity (57.9 centipoises at 28°C) and low freezing point.

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b. Yield reduction.

TABLE II

CROPS SPRAYED WITH BUTYL 2,4,5-T

Crop	Stage Sprayed	Pounds Agent Per Acre	Volume Spray Per Acre	% Reduction in Yield
Soy beans 1/	9" tall	0.25	6.4 gal.	97
	18" tall	0.25	6.4 "	92
	Late blossom	0.25	6.4 "	99
	Early pod	0.25	6.4 "	98
Soy beans 2/	All stages to early pod	0.12	48 ml.	76-80
		0.25	96 "	99
Flax (fiber) 3/	Early bud	0.1	2.6 gal.	68
	Late blossom	0.1	2.6 "	46
Flax (oil) 3/	Early bud	0.1	2.6 gal.	84
	Late blossom	0.1	2.6 "	94
Flax 4/	All stages to blossom	0.13	48 ml.	86
Peanut 3/	Blossom	0.25	6.4 gal.	81
Sunflower 3/	Early bud	0.1	2.6 gal.	100
	Early flower	0.1	2.6 "	65
Irish potato 3/ 4/	Late bud	0.15	6.4 gal.	70
	0.5" tubers	0.25	121 ml.	92
	2.2" "	0.25	121 ml.	57

1/ Diesel oil carrier - agent dissolved in tributyl phosphate.
2/ 90% butyl 2,4,5-T.
3/ Diesel oil carrier
4/ 96% butyl 2,4,5-T

The table above gives the results of tests in which 2,4,5-T was applied to various broadleafed plants. It shows the per cent reduction in crop yield for the various plants at various stages of growth. As indicated above for butyl 2,4-D, equal yield reductions can be obtained with sprays at low volume rates. For example, the yield of soybeans, treated with 90% butyl 2,4,5-T at a rate equivalent to 48 ml/acre, was reduced over 75%.

7. Performance characteristics common to chemical agents most useful against broadleaf crops.

a. Factors affecting plant response. With very low volume sprays, the effect on plant yield reduction is markedly greater when sprays consist of small droplets the mean diameters of which are below 0.1 millimeter (mm) than with larger droplets, say 0.35 to 0.50 mm in diameter. The number of droplets into which a given volume of liquid is divided in spraying determines directly the number of points of spray contact with the vegetation and increases the probability of a given quantity of the agent contacting the plant. In general, plants become less responsive with increasing age, and particularly is this true of the lethal response. However, the flowering stage is again a very sensitive period in plants, the yield of which is determined by pollination and seed development (pods, grains, fruits). Environmental factors are not of great significance in determining the magnitude of response to anti-crop chemicals; if the conditions are such that the plant is actively growing the response will follow. If the application is made to plants at a dormant stage, abnormalities may develop when growth is resumed.

b. Entry and Transport. The stomata are not important as portals of entry for these agents. Plant responses to anti-crop chemical agents are slower and less severe in cloudy, cool weather than in bright sunny weather. When photosynthesis proceeds actively as in bright sunlight, the transport of the agent to those tissues where the responses develop is most rapid. If no photosynthetic products are being produced, as in darkness, transport does not occur. However, agents applied to plants in darkness, as would occur in night spray operations, will enter, and transport will occur when the flow of photosynthesised products from the leaves recommences. There is evidence to indicate that under good conditions for entry and transport, the maximum ultimate response will occur

from 2,4-D entering the leaf within 6 hours of application. Rainfall occurring relatively soon after spray application of chemical anticrop agents in oil carriers, or as undiluted esters of agents such as 2,4-D or 2,4,5-T does not reduce the yield reduction capabilities. Oil formulations and undiluted esters rapidly penetrate the leaf tissues. One experiment on sugar beets in which undiluted butyl 2,4-D was employed, following rain, indicated that the effects on yield depended on the rate of application and size of droplets. The agent applied in small droplets (0.060-0.070 mm diameter) and at a low rate (0.01 ml/sq yd) was rendered some 20 per cent less capable of normal yield reduction by a 0.07 inch rain immediately following agent application. However, rainfall actually increased the effectiveness of the larger (0.41-0.534 mm diameter) droplets applied at a rate of 0.05 ml per sq. yd. This was explained as being due to greater absorption by the leaf of the large droplets of the compound which had been spread into oil blotches 1/4 to 1/2 inch in diameter. Other factors such as temperature, humidity, and soil fertility have been investigated with respect to their influence on the inhibitory activity of anticrop chemical agents. None of these within the limits normal for plant growth was found to cause any deviation from the normal inhibitory response.

c. Responses Induced in Plants.

(1) The effects of a spray attack in which these agents are employed can be detected within a matter of hours in the case of certain plants such as sweet potatoes and sugar beets. The effect on these plants is observed as a marked curvature of the stem and shoot and drooping of the leaves within a few hours. This is followed by partial or complete inhibition of subsequent shoot growth. When harvested, the beets present a corky appearance.

(2) Soybean plants sprayed with butyl 2,4,5-T develop enlarged and woody stems, the axillary buds are abortive,

the pods remain small and do not develop fully, and the leaf fall which occurs normally on maturation is markedly delayed. The reaction of tuber plants, particularly the Irish potato, is manifested in an altering of the tuber shape accompanied frequently by the development of fissures. The harvested tuber is scabby. Affected tubers have poor edible and storage qualities. The degree of injury and possible storage qualities of tubers from treated plants require further investigation for the data to be complete. Tubers and pods which have already been formed may be harvested and the edible portions consumed in the normal manner without harm since the agent is nontoxic for man and the plant products themselves will not have been rendered toxic by the internal action of the agent.

(3) No effective bonus in the form of soil contamination can be expected when employing these agents at the low dosage rate of 0.1 lb. per acre. At much higher dosage rates (2-5 lbs. per acre) soil contamination effects may persist for weeks to months during which time seeds will not germinate or seedlings develop normally. Using the emergence of soybean seedlings as a criteria, it was found that 5 lbs. per acre of 2,4-d persisted more than 20 days in warm moist soil; at the same rate of application 2,4,5-T persisted for 93 days.

d. Mode of action. The mechanism of action of exogenous growth-regulators such as 2,4-D is not understood, nor indeed is it known whether the multiple responses induced in plants are the resultant of interference with a single master biochemical reaction. Some workers believe that competitive effects on the endogenous hormone system of plants may be involved. At Camp Detrick the metabolism of 2,4-D in plants is being followed by the use of radioactive C^{14}. It has been estimated that this compound is metabolized and that the aliphatic side chain is readily removed. Plant specificities may well arise from differences in ability to metabolize this compound in the various tissues and organs.

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AGENTS MOST USEFUL AGAINST CEREAL CROPS

8. Isopropyl N-phenyl carbamate (IPC) and Isopropyl N-(3-chlorophenyl) carbamate (Chloro IPC)

a. General characteristics. IPC is a stable organic compound of high melting point and quite low aqueous solubility. It is commercially available in substantial amounts.

b. Yield reduction. This compound is effective in reducing the yield of cereals if applied to the soil in a solid granular form when the plants are in the seedling stage, or if sprayed in an appropriate carrier onto the tops of cereals at the early-heading to flowering stage. Because of the availability of cereal rusts as anticrop agents to be applied in the spring or early summer, development work at Camp Detrick has largely been concentrated on soil applications of granular material to plants at an earlier stage. Fall-planted cereals are vulnerable to winter applications, the date of application not being critical. On-target quantities of 2 lbs. IPC per acre in a granular form applied during January would be expected to achieve at least 70 per cent reduction in the yield of fall-planted wheat, rye, and barley. Typical data are given in Table III.

TABLE III

IPC APPLICATIONS TO FALL-PLANTED CEREALS

Cereal	Pounds IPC per acre	Time of Application	Per cent yield reduction
Wheat (Thorne)	2.0	Mid-Feb.	62-76 1/
	2.0	End Dec.	67-90 1/
	2.0	End Jan.	50-70 1/
Barley (Wong)	2.0	Mid-Feb.	53 2/
	2.5	Jan.	78 2/
Rye (Abruzzi)	2.0	Jan.	43-82
	2.5	Jan.	60-90

1/ Different locations and years.
2/ Limited data

The granular preparations applied have contained 25-75 per cent IPC, the remainder consisting of binder, diluent, disintegration aids, and wetting agents. The 75 per cent products have achieved as much yield reduction as lower concentrations, which provide more granules per unit area.

(1) The closely related compound Chloro-IPC (isopropyl-N-(3-chlorophenyl) carbamate) persists longer in the soil than IPC and has approximately equal activity on cereals. It is likely to be preferred to IPC, because it can be sprayed in liquid form at relatively high concentration even when soil contamination is the objective. Its melting point is about 25°C; the crystalline form is apt to be soft. The addition of about 5 per cent of a miscible liquid to the melted form prevents recrystallization. Formulation into pellets or granules is difficult without substantial dilution with inert material.

(2) Although most attention has been directed towards the study of winter applications of IPC and Chloro IPC to fall-planted cereals, spring-planted cereals are also vulnerable, but the length of the period during which application must be made to effect maximum yield reduction is much shorter. Oats treated at the fourth-fifth leaf stage with 2 lbs. per acre IPC or Chloro IPC have suffered 58-70 per cent reduction in yield.

(3) The yield of both fall and spring planted cereals can be reduced by spray applications of IPC or Chloro IPC to the tops at the time of heading and flowering. The agent rates required per acre for this type of application are lower than for soil contamination at the seedling stage, but the period for maximum responsiveness is no more than 7-10 days. Typical results are given in Table IV.

TABLE IV

SPRAY APPLICATIONS OF IPC AND CHLORO IPC TO CEREALS

Cereal	Stage	Agent pound per acre	Per cent yield reduction
Barley	Flowering	Cl-IPC 0.5	46
	"	Cl-IPC 1.0	78
Wheat	Heading	IPC 0.75	43
	"	IPC 1.5	67
		Cl-IPC 0.75	59
		Cl-IPC 1.5	93

The injury is primarily due to droplets intercepted by the developing heads; if the heads are shielded, yield reductions are slight.

9. Entry, response and mode of action. IPC and Chloro IPC do not enter the tissues of cereal plants as readily as 2,4-D and 2,4,5-T enter and are transported within broadleaved plants. They are effective, however, if taken up by the roots and result in cytological and histological changes in the growing points of the roots and shoots. There is some evidence that mitosis is interfered with so that normal cell division in these organs does not proceed. Instead, enlarged multinucleated cells develop. Spray applications to the foliage seem to be effective in yield reduction only if carried out in such a manner and at such a stage that the compounds fall on the shoot or developing head. At the flowering stage cereals are particularly susceptible since the normal processes of cell division that accompany pollination are disturbed.

PERFORMANCE CHARACTERISTICS COMMON TO CHEMICAL AGENTS FOR CEREAL CROPS

10. It has been pointed out above that mid-winter is generally the optimum time for target application of IPC and Chloro IPC in granular or pelleted form. The crop is not necessarily highly susceptible at this time. The extruded particles of the growth regulators do not have an effect on plant growth until the particles have been

broken up by action of rain, the chemical agent dissolved in the rain water and the resulting solution brought into contact with the root system. IPC and Chloro IPC are decomposed by soil microorganisms. The lower the soil temperature the slower will be the decomposition of the agent, due to the reduced activity of the soil population. When the dormant plant again recommences growth, as may occur on warmer days in the late winter, the chemical is present in the vicinity of the roots and when taken up causes injury to the shoot initials. Drought conditions in the winter would tend to reduce the effectiveness of the agent in that the granules would not disintegrate. However, under winter drought conditions, plant growth also would be halted, only to resume with the onset of warmer weather and rains. The case for winter application is primarily the latitude possible in selection of time of attack, which may be 4-6 weeks. Applications to spring planted cereals, to be effective would have to be made within a much shorter period (10-14 days), as is also even more sharply the case with spray applications to the tops of either fall or spring planted cereals which for maximum effectiveness would have to be made at or near to flowering (or another emergence).

BIOLOGICAL ANTICROP BW AGENT PROPERTIES

14. The term biological agent, as used here, does not include all possible organisms that might kill or severely injure crops. For example, insects are not now considered to be a suitable biological anticrop agent. The biological agents to be discussed are those the potentialities of which have suggested their use against an enemy in time of war and which are now in various stages of development: stem rust of wheat has been standardized and is in production, stem rust of rye is still in the research stage and judging from the present knowledge of the pathogen and the many problems attendant in its development, it is questionable whether it will be available in operational quantities by 1954. Previous work on stem rust of oats has been suspended but if required, stem rust of oats might be made

available in operational quantities by 1954. No work has been carried out on barley rusts. The organisms causing late blight of potatoes and head "blast" of rice are similarly under development and could be available in operational quantities by 1954.

12. The requirements of a plant pathogen for employment in anticrop warfare are that it shall be capable of being produced in quantity in a virulent and relatively stable form, be capable of being disseminated from a munition without loss of these properties, be capable then of establishing a damaging disease which spreads from plant to plant and field to field, to give an epidemic (or epiphytotic) beyond the ability of the enemy to control.

13. Inasmuch as biological agents are self-propagating and are capable of causing epidemics, the logistics of their use are attractive. Certain elements of uncertainty are inherently present. Both primary infection and subsequent spread are dependent on the presence of susceptible host plants and a favorable combination of environmental conditions. Although these meterological factors are usually not too sharply circumscribed, they contribute directly to the difficulties of prediction of extent of crop losses that may be anticipated. The "generation time" on the host plant (time from application of infective cells to development of lesions from which the infective cells may be carried to adjacent plants) is frequently in the region of 7-10 days. To take full advantage of the epidemic potentialities of a plant pathogen, the initial application should be made as early in the growing season as is compatible with the expectation of optimum meteorological conditions. The later in the season the agent is initially applied, the less time remains for successive steps of infection, reproduction and spread. Extensive yield reductions are usually correlated with presence of the pathogen early in the growing cycle.

14. Plant pathogens in general are specific for particular crops, and especially is this true of those causing extensive yield reductions. When related or non-related crops are infected with the same agent, the extent of the injury accomplished is usually less than on the crop for which the agent was primarily intended. Different varieties of a crop may exhibit a range of responses to a particular pathogen, from complete susceptibility to complete resistance. Conversely, strains or races of a particular pathogen may be found with a wide range of pathogenicity or virulence. This greatly complicates the planning of anticrop attacks against an enemy since there must be available knowledge as to the varieties of the target crop and the susceptibility of those varieties to available strains or races.

CEREAL RUSTS

15. General. Stem rust, caused by the fungus *Puccinia graminis*, is the most destructive pathogen of the cereal crops. It is an obligate parasite; that is, it cannot grow and develop other than in the tissues of the plant it parasitizes. *Puccinia graminis* has five possible spore forms and requires two different kinds of host plants to complete its life cycle. Several varieties of *Puccinia graminis* exist, each primarily infecting different cereals or grasses.

a. Spore cycle. The primary hosts of stem rust are wheat, barley and rye; the alternate host is the barberry. The barberry itself and the spores produced upon it, are comparatively unimportant in the epidemiology of stem rust of wheat, except in isolated regions. It is somewhat more important in producing epidemic stem rust on rye and grasses. The stage that infects the barberry will overwinter in temperate climates. In the early spring, after the rust has overwintered, the barberry pustules are formed on the under surface of the barberry leaf. The spores formed in these pustules carry the disease to the graminaceous host (cereal). The sexual stage occurs only on the barberry; the

presence of barberries, therefore, is associated with the appearance of new combinations having different degrees of virulence and pathenogenicity.

(1) Infection of the graminaceous host takes place when the spore from the barberry germinates and produces a germ tube. This tube then enters through a leaf breathing pore (stoma) or may penetrate the cuticle and wall of the epidermis directly. Once within the host the rust mycelium spreads slowly or rapidly, depending upon the relative resistance of the variety of wheat or other grain to the particular race of infecting rust. In any case, in from 8 to 10 days pustules appear on the host leaves and another type of spore, the uredospore, makes its appearance. In stem rust the uredospore is capable of reinfecting the graminaceous host. It cannot infect the barberry. The uredospore is thick walled, yellow, red, or orange in color, 15-20 microns in size, and well adapted to wind distribution. It may be carried hundreds of miles by the wind and still retain its infective quality. The uredospores are not hardy enough to overwinter in cold climates, but where mild winters occur, they provide a threat in the spring to susceptible grains in the direction of the prevailing wind.

(2) During favorable growing conditions for the host, a single rust pustule may produce and release spores daily for a period of 10 days to two weeks. A single pustule may produce from half a million to a million new uredospores during this period. Unfavorable conditions such as high temperatures or approaching maturity may cause uredospore production to slow down or stop. Instead, teliospores are produced which are not capable of infecting other cereal plants but which are resistant and remain viable through the winter on the straw. In the spring the telia germinate and produce another spore from which it is capable of reinfecting the barberry.

b. Mode of action. In the study of rust epidemiology the physiology of the uredospore is of chief interest. Although wheat is attacked by both the spores formed on the barberry and the uredospores formed during successive generations on the wheat, it is the uredo stage that gives rise to epidemics. As with the spores from the barberry, infection of the wheat plant by the uredospore takes place by the formation of a germ tube upon germination of the spore. This germ tube usually enters through a leaf breathing pore (stoma) but it may enter the cuticle and epidermis of the leaf or stem directly. Even under ideal conditions the percentage of spores which infect and cause the development of pustules is not high.

16. A heavy stem rust infection on the leaves and sheath greatly reduces the photosynthetic area of the plant, and on the neck may result in interference with transport to the head and therefore with the filling of the grain. It is reported that water loss is substantial through the pustular splits on leaves and sheath, and that diseased plants may therefore be in a condition of water stress in droughty periods.

17. Infection time is the period from the time that rust spores begin germinating on plant tissues to the time when the mycelium has penetrated the plant and established a successful nutritional relationship with the host. Under favorable conditions, this is a matter of no more than six hours. During this period, the rust fungus is very vulnerable to external environment. Low temperatures or dryness may delay or check the infection process, or destroy the chances for infection by spores. The studies of numerous workers indicate that the rust organism is incapable of infection and growth at temperatures lower than 50°F or greater than 90°F. The optimum temperatures lie between 65°F and 75°F. High humidities approximating 100 per cent are necessary to produce rapid infection of the plant. As temperature and relative humidity vary from these conditions

the length of infection time is prolonged. Under natural conditions, warm air heavily laden with moisture blanketing an area during the infection period would cause germination and subsequent invasion of the host tissue in a few hours, particularly if light rains or dews occurred during this time. Spores washed off the plant by heavy rains would be incapable of causing infection until picked up by the wind and again brought into contact with a plant. Short of freezing temperatures, uredospores are capable of withstanding comparatively drastic weather conditions while retaining viability. Once germination has commenced, however, the spore is much more vulnerable, particularly to desication.

18. Incubation time is the period which elapses between establishment of infection and development of an open lesion or pustule in which new uredospores are produced. This period varies considerably depending on environmental conditions. Under optimum conditions in the greenhouse, it is about 7 days and in the field 7-10 days. In the Amur and Rostov regions of the USSR the incubation period has been stated to be approximately 8 days. Low day or night temperatures lengthen the period of incubation.

19. Cereal rust infections are rarely so intense that the plant dies rapidly. Stunting due to reduction of leaf area and injury to the neck together result in a failure of the grain to fill. Shrivelled grain and empty heads are common; the reductions in yield arise primarily from this cause. The weakened stems and heads often break over rendering harvest more difficult.

EPIDEMIOLOGY AND PROBABLE CROP LOSSES

20. The effective employment of cereal rusts as anticrop agents depends on first, the initial establishment of infection and second, subsequent substantial spread of the disease to accomplish significant crop injury so that yields are reduced.

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The evaluation of these components is a matter of difficulty, it being borne in mind that although the second cannot happen without the first, it is by no means certain that first is inevitably followed by the second.

a. Infection.

(1) The initial establishment of infection depends on the retention of viable spores of a virulent race on the leaf and shoot surfaces of a susceptible plant, and the presence of sufficiently favorable micro-meterological conditions in the immediate vicinity of the spores so that germination proceeds and the germ-tubes enter the plant tissues. Uredospores are not particularly fragile or sensitive to conditions less than optimum. The definition of recommended conditions for spore processing and long storage has given rise to an impression of a lack of spore stability that is at variance with facts. In nature uredospores are exposed to wind transport and widely fluctuating temperatures and humidities in the normal diurnal cycles, yet many retain the ability to infect for days. Since it can be assumed that in an anticrop attack only spores of high to moderate viability and vigor would be distributed and that the distribution system would be such that these characteristics would not be impaired, the primary issue is the likelihood of obtaining infection. At the time when cereal crops would probably be subjected to attack the ground surface is largely covered by the seedling plants. In unpublished studies at Camp Detrick the per cent contact of chemical sprays by cereals at various stages has been determined and found to be much higher than anticipated (50-70% increasing with the development of the crop). However, the situation with spores is not entirely comparable, because a droplet once it contacts the plant is retained whereas a spore may well be later dislodged unless trapped by

leaf pubescence, deposited in the leaf axils or held by surface tension forces. Although a high percentage of the spores deposited on a crop may therefore initially come in contact with susceptible tissues, there is a considerable probability that many will later be dislodged by wind movement. Distribution onto wet or dew-laden plants might greatly enhance retention.

(2) Careful experimentation under optimum conditions has shown that only a small percentage (2-4%) of viable uredospores that alight and are retained on the leaf surfaces of susceptible plants finally cause the development of lesions. The germ tubes from many spores which germinate on the leaf surface do not penetrate the tissues. Germination and penetration take place with the greatest degree of probability if moisture is present and the temperature is in the vicinity of 70°F. At cooler temperatures growth of the germ tube is less rapid. Sufficient moisture must be present for several hours (circa 8) if infection is to be established. Ideal conditions in the field are therefore provided by warm still nights with light dew deposition. Viability of a spore is quickly lost once germination has commenced if moisture conditions then become adverse. This in nature probably accounts for the failure of most spores to infect.

(3) In summary, it can be concluded that only a very small fraction of the spores deposited on a target will germinate and form pustules, and that the most critical requirement is that of the onset of satisfactory meteorological conditions from time of destribution for germination and penetration within a few hours of at most a few days.

b. Spread.

(1) Once infection has successfully been established on a susceptible variety, a lesion can be expected to

develop, being manifest first in the form of a fleck of lighter color on the leaf or stem, this being followed by a splitting of the epidermis and the appearance of the characteristic reddish-brown pustule in which large numbers of uredospores are produced. Under optimum conditions of crop growth the pustule may develop in 6-8 days. Cool conditions may delay pustule development. Large numbers of uredospores are produced terminally on the fungal hyphae and may be carried by wind to adjacent or distant plants, there in turn to establish the disease. Each active pustule may be considered as a small "continuous generator" for a period of two weeks or so. Data are scanty but figures of the order of 50-60,000 spores per day to a total of 700,000-1,000,000 per pustule have been recorded. These represent spores which as produced are of high viability. Many are carried to plants in the immediate vicinity of the parent pustule; others may be carried great distances. It is common field experience, however, to be able to see centers of heavy infection, presumably surrounding the initial pustule. These centers are not ordinarily visible until the third generation.

(2) Inasmuch as uredospores are produced from pustules for a period of many days, the likelihood of establishment of secondary and tertiary infections is high. Sometime during the period of two weeks or so of pustule productivity the optimum-minimum permissible conditions for infection are likely to be encountered. It can therefore be concluded that the establishment of primary infection sites is much more critical than secondary sites in the development of an epidemic.

(3) Although there are many observations on outbreaks of cereal rust in the field there is no consistency of pattern that permits calculation of the probabilities of

spread, and the probable area of disease injury. Very little experimental epidemiology has been carried out, and recourse must therefore be had to observations on natural epidemics in the U.S. In some of these the appearance of the disease has been followed subsequent to a known spore "shower"; in others the disease has developed from the aeciospores originating on a barberry or a group of barberries.

(4) In the outbreaks in the Plains states and the Red River Valley the initial infections arise from uredospores airborne from the south. Estimates of density of spore deposition have been made from the numbers of spores adhering to coated slides. Such figures do not form any reliable index of the numbers which might be retained on cereal leaves in the vicinity, nor are all spores so trapped necessarily viable. Certainly there has been no consistent or dependable relationship between density of spore shower and intensity of outbreak of rust. Again the dominant factor is the presence of favorable meteorological conditions. In general, the primary infections, when detected, are quite light. Only occasional pustules are visible; only a low percentage of the plants bear pustules. From that point however, rapid build-up occurs if environmental conditions are favorable, and in as little as two weeks more all plants may be infected. Thereafter the intensity and severity rapidly increase so that in a further two weeks most of the leaf and much of the stem may be involved, without which yield reductions are not severe.[1/]

(5) The experiences in relation to spread from barberry bushes are very diverse. Generally speaking spread from such sources appears to have been local only (not in excess of one mile). In many cases however only one,

1/ In the Pine Camp trials using oats and oat stem rust, about 8 per cent of the plants had developed pustules in 14 days following a spore deposition which must have averaged less than 0.1g/acre. After a further week half the plants were involved, and at 4 weeks almost 100 per cent of the plants carried pustules.

or at best a few, small bushes were all that were involved. In a significant proportion of the epidemics traced to infected barberries the area of spread was much greater than one mile. It must also be pointed out that "small" rust outbreaks are far easier to trace back to the spore source than a large outbreak in which the chances of finding the source are remote, and that in some areas at least the barberry infections may be relatively late.

(6) Moreover, the barberry data have been compiled mainly in connection with a barberry eradication program and not as a part of studies on rust epidemiology. The barberry acts as a continuous generator of aeciospores, and provides a situation that is comparable to that present in a cereal field when a number of primary infections have been established in a small area. A single barberry bush or a small group of bushes cannot be considered as parallelling a feather bomb drop. Indeed the latter, if primary infection is established, would not be dissimilar to a heavy infestation of infected barberries over an area of several square miles.

(7) Whether the initial source of spores causing the appearance of pustules in a cereal crop be uredospores or aeciospores from barberry bushes, the epidemic must arise by build-up from those primary pustules. The earlier and the more widespread the initial infection, the greater is the number of rust spores produced, and the greater is the likelihood of massive infection and yield reduction. With a limited amount of inoculum to distribute, a system providing a broad diffuse, and very light deposition rate would be preferable to one which concentrated this material on relatively few foci. The time required for the spore generation, and the probabilities of injury both favor early establishment of infection.

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(8) As the existing data do not support any definitive factor for secondary spread of rust, and the corresponding radii for heavy yield reduction, WSEG asked the Operations Research Office, Department of the Army, and the Office of Scientific Intelligence, Central Intelligence Agency, to review these data and to prepare an estimate for the secondary spread factor. The conclusion of this group, based on an analysis of United States and Canadian cereal rust epidemics, was that the primary infection from one E-73 feather bomb could reasonably be expected to spread over 100 square miles and cause heavy yield reductions. This estimate takes account of delays due to short periods of weather unfavorable for infection, the anticipated discontinuity of plantings and stage differences in spring planted cereals caused by variations in planting dates. Evidence obtainable from American examples of rust spread indicates that if seasonal and other conditions are less favorable the spread of heavy damage may be less than one mile, while under more favorable circumstances the spread of heavy damage may be as much as 250 square miles. The estimate for 100 square miles does not take account of the fact that the growing environment in the USSR is much less favorable for the development of cereal grains (and hence of rusts) than is true in either the United States or Canada. No allowance has been made for this factor.

(c) Yield reduction.

(1) The cereal rusts and in particular the stem rusts are damaging diseases. Plants of susceptible varieties, heavily infected by virulent races, may never reach maturity and if infected early may indeed never head. A reduction of 100 per cent in yields of individual plants is therefore entirely possible.

Fully resistant varieties on the other hand may be almost unaffected. Predictions of yield reductions therefore can only be made with knowledge of the combinations of variety and race involved. However, many races are essentially similar, rather than dissimilar, and differ only with respect to their ability to infect one particular variety of those used to differentiate races (twelve for wheat stem rust). Combinations of races would be selected in any planned anticrop operation, based on available knowledge of varieties in the target area.

(2) In natural epidemics, even those regarded as severe, complete crop losses over any extensive area do not occur. The usual pattern is a complex of heavy to slight yield reductions, with a tendency for areas having similar planting dates and environmental conditions to be equally affected. In a few townships or a county the average losses may be heavy; in nearby townships or the adjacent county yields may be less affected. In calculating on the basis of larger political subdivisions "heavy" losses might be 50% of total anticipated production. As indicated earlier there may also be a substantial reduction in quality due to the presence of shrivelled and light kernels.

(3) It cannot be too strongly emphasized that "heavy" losses are correlated with early appearance of inoculum and establishment of primary infection, and with the prevalence of conditions generally favorable to the establishment of an epidemic during much of the subsequent period.

(4) In the U. S. yield losses in winter wheat in Kansas and Nebraska are rarely significant, because the rust inoculum if present comes in too late to establish an epidemic, but spores then increased are carried north

and into the Dakotas, there to catch the spring wheats at an earlier and more vulnerable stage.

(5) Based on the preceding discussion and for purposes of calculation, the following yield reduction ranges are employed for the 100 square mile areas covered by the spread factor specified above, it being presupposed that the operations are carried out with full knowledge of the nature of the missions and with adequate planning based on available information on planting and/or maturity dates, crop patterns, varieties, and weather forecasts.

Stem rust	- winter wheat	30 - 60%
	- spring wheat	30 - 60% *
	- barley	20 - 40% **
	- rye	20 - 40% ***
Stem and Crown rust	- oats	30 - 60%

* In an area in which both winter and spring wheats are present and in which an attack is made at the appropriate time for winter wheat, spring wheat losses may be expected to be high. Separate attack on spring wheat would not be necessary.

** The predicted range for barley is not based on spillover from wheat and can only be accomplished if specific races of wheat stem rust virulent for barleys are employed. The figures are lower than those given for wheat because barley matures more rapidly.

*** The predicted range for rye is based on the employment of rye rusts as virulent as can be obtained. The figures are lower than those given for wheat because rye matures more rapidly. There is evidence that some rye selections do not become fully susceptible until the time of flowering which leaves only a short period during which the severity of the disease can attain a level which results in yield reduction.

WHEAT STEM RUST ON BARLEY

21. Because of apparent inconsistencies in the information obtained and opinions expressed relative to probable "spill-over" of wheat stem rust into barley in the USSR and the extent of yield reduction in barley to be anticipated therefrom, the subject was reviewed with Dr. Karl Quisenberry (Assistant Chief, Bureau of Plant Industry, USDA) who consulted with Dr. H.A. Rodenhiser (Chief, Cereal Crop Division, USDA) and in turn with Dr. M.A. McCall (ORO).

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22. The following appear to be the facts to which all were prepared to subscribe. These are based, unless otherwise stated, on experience in the United States.

a. Both wheat and barley can be infected by the same variety (*Puccinia graminis tritici*) of stem rust. Varieties of both crops vary in relative susceptibility to races of this stem rust. One race may, or may not, be of equal virulence or produce equal losses on the two crops. In the field on widely planted varieties the usual experience is that one race is not of equal virulence on both crops. For example, the wheat stem rust race 15B which is highly virulent to many wheats and which caused serious losses of spring wheat in North Dakota in 1950 has been isolated from barley, but has not in the field caused significant yield reduction in commonly planted barleys. The wheat stem rust race 59 which is damaging to barley is of no consequence on the varieties of wheat grown widely.

b. By appropriate research, it may be possible to find a race or races of rust equally virulent on both wheat and barley varieties planted in the U. S. or in the USSR. Such a race might, or might not, be equal in virulence to those having the highest degree of virulence separately for the appropriate wheat and barley varieties. There has not yet been nearly so much effort to find and exploit in a breeding program sources of resistance to rust in barley as in wheats.

c. In years of bad wheat stem rust epidemics there has been some damage on barley at some locations, but there appears to be no certainty or high probability that this will be the case. In the severe 1935 epidemic of wheat stem rust, some fields of barley were reported as rusted. In the central plains states no close relationship between appearance of rust on wheat and barley has ever been apparent. In the United States, in general, barley varieties are earlier maturing than the wheat varieties in the same area. As a

result, barley is likely to escape damage from rust even when the crop becomes infected because little time remains for the disease to build-up to the level that would cause significant crop losses.

d. In plantings made in Puerto Rico, Florida and at several locations in the North Central States in 1951, a spring barley (Montcalm) though exposed to heavy inoculum of wheat stem rust races 56, 38 and 17, did not develop the disease, (Camp Detrick data) indicating perhaps more critical environmental requirements for establishment of infection in barley.

e. In some plantings made in South America certain barleys became heavily rusted as did many wheat varieties, the races involved being those indigenous to the areas concerned. It was not established that the wheats and barleys were in fact infected by identical or single races (USDA - Cml. Corps data).

23. In view of the above considerations, in calculations for 1954, "spill-over" of wheat stem rust to barley in the USSR is assumed negligible, and no figure for barley losses from an operation planned primarily for wheat are included in the evaluation. Stem rust races specifically damaging barleys are known and might be developed, therefore, separate calculations can be made employing barley rusts, on the assumption that these could be developed in from two to three years.

OTHER PLANT PATHOGENS

24. Certain other plant pathogens are under development and in the opinion of Camp Detrick, with appropriate emphasis could be ready in 1954. Greatest progress has been made with the organism Phytophthera infestans which causes the "late blight" disease in the Irish potato. This disease has high epidemic potentialities; plants heavily infected usually die. Unlike the cereal rusts the causal fungus can be grown in artificial substrates. Production therefore depends on the development of

suitable facilities. The major difficulty encountered in its employment is the provision of a form of the organism that is stable. The sporangia are fragile, and will not withstand drying or freezing. A mycelial (vegetative) form of the organism has therefore been preferred, grown in a pelletted matrix. These infested pellets retain viability on drying. When wetted, the organism grows more rapidly than superficial saprophytic contaminants from the soil or air, and sporangia are produced which are then windborne to the leaves of adjacent potato plants. The heavy canopy of foliage ordinarily present in well-established potatoes is an aid in maintaining moist conditions. Infection of the plants under the cool moist conditions of northerly latitudes is not expected to be limiting. The epidemiology of the disease is well understood. Fungicidal sprays at relatively high volumes can provide complete protection but massive area spraying is expensive in materials and labor.

25. For rice, certain leaf spot organisms, notably Piricularia oryzae which cause "blast" of rice are also under development. The problem of production in a stable infective form is not so difficult as with the late blight organism, because the conidia which are readily produced in artificial substrates, can be dried without loss of viability. This disease, which is the most damaging one known on rice, is serious in certain areas in the Orient. Resistant varieties of rice are known. It is not believed that this disease has the epidemic potentialities of the cereal rusts or late blight, but information as to precise conditions of infection and spread is scanty. Supplementing Piricularia is the organism Helminthosporium oryzae, somewhat similar in properties, but less damaging in probable yield reduction.

26. Although certain virus diseases of plants are under study by the developing agency it is by no means yet certain that viruses can be effectively employed as anticrop agents. With many plant viruses neither infection nor spread is assured without the participation of insect vectors.

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CHAPTER II

ANTICROP MUNITIONS

GENERAL DATA ON BW ANTICROP MUNITIONS

27. Consideration will be given in this portion of the discussion to the anticrop munitions that could possibly be made operationally available in 1954. Those munitions are the E-73 and E-86 comparable cluster type bombs, the E-95 three inch spherical bomb, the E-27 dry agent disseminator (modified 700 gallon fuel tank), and the 1,000 gallon capacity spray system. Some theoretical characteristics of these items are shown in Table V. Although not a part of the anticrop munition group for manned aircraft, the E-77 anticrop bomb for unmanned balloons is described briefly at the end of this section.

28. Two of the anticrop munitions, the E-73 and E-86 are designed for the dissemination of pathogenic agents such as rust spores dusted on feathers as carriers. Another type, the E-95, is designed to disseminate rust spores without benefit of a carrier. These three types are air burst bombs. The spray system, on the other hand, functions while remaining attached to the aircraft and is designed for the dissemination of liquid anticrop chemicals such as 2,4-D.

E-73 BOMB, BIOLOGICAL

29. The E-73 bomb, biological is a modification of the M16-type cluster adapter used for dissemination of fragmentation bombs and propaganda leaflets. Development has been done by the Chemical Corps at Camp Detrick. The E-73 consists of a fuze (M-146R1 or M-155) and a casing having four compartments. In current practice, each compartment is loaded with a plastic impregnated paper container (E2R3) filled with 2½ pounds of TX1. There are 10 pounds of TX1 per bomb. The E-73, filled, weighs 84 pounds. TX1, a standard anticrop agent fill, consists of 10 parts of agent carrier (M1) mixed with one part of the agent

Puccinia graminis tritici, a cereal rust (TX). This ratio may be changed if the viability of the rust spores has declined during storage. The agent carrier will retain up to its own weight of cereal rust spores. The M1 agent carrier is composed of dry, washed and fluffed feathers averaging 3½" long by 1 1/4" wide. Per bomb, there are at least 53,000 feathers impregnated with rust spores. The size of the feathers is less important than their spore retentive capacity. The E-73 bomb is designed so that the E2R3 containers are ruptured by an air burst at a selected altitude. Although the E-73 has been developed and tested for the agent TX1, it is equally suitable for spores of all cereal rusts or other similar plant pathogenic organisms that might be infective in a dry or "powdery" condition. Different pathogens may be placed in the same bomb by mixing them before packaging or by inserting packages of different kinds of cereal rusts within the bomb.

30. The E-73 is carried on a 500 pound bomb station in bombardment type aircraft. The number of bombs carried per plane is not limited by weight, but depends upon: (a) the number of 500 pound bomb stations in the aircraft, and (b) the number of these around which there is sufficient room to permit two bombs to be carried instead of one. For example, the B-29 and B-50 can accommodate 56 E-73's; they have forty 500 pound bomb stations, and double shackling is possible on 16 of these. The fuze, M146R1 or M-155, is a mechanical time fuze which functions by causing the two longitudinal halves of the bomb casing to burst open at a selected altitude. This in turn ruptures the E2R3 packages which spill the contents (TX1 or others) into the air. The spore-impregnated feathers fall to the ground individually. Bomb functioning does not affect the viability of the spores since blast and heat from the fuze mechanism is negligible. Area coverage and density of the agent TX1 on the ground is roughly a function of air burst altitude, wind velocity to the surface, and thermal conditions.

TABLE V

GENERAL CHARACTERISTICS OF ANTICROP MUNITIONS 5/

Munitions	Weight of Metal components (pounds)	Weight of carrier (pounds)	Weight of agent (pounds)	Weight of filled unit (pounds)	Estimated Cost of complete unit (dollars)		
					Metal Components	Agent plus carrier	Total
E-73, Biological Bomb (for stem rust)	73	10 1/	1 2/	84	165	100	265
E-86, Biological Bomb (for stem rust)	225	12	1.2	238	500	120	620
E-95, Biological Bomb (for stem rust)	0.75	-	0.16	0.91	10	16	26
E-27, Dry Agent Disseminator (for stem rust)	1400	Unknown	Unknown: max.600 pounds	Unknown max.2000 pounds	5000	Maximum 60,000	Maximum 65,000
Spray System (Anticrop chemicals)	1000	-	10,000	11,000	3,000 3/	6,000 4/	9,000

1/ Carrier consists of feathers.
2/ Agent is wheat stem rust. Estimated cost of 100.00 per pound.
3/ Cost may be reduced by repeated use.
4/ Assuming agent to be pure butyl 2,4-D esters.
5/ Taken from 1952 Technical Estimates, Committee on BW, RDB, 1 April 1952.

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31. The employment of this munition is based on the principle that a number of small foci of infection is sufficient to initiate an epidemic spread of a plant disease. Each of the M1 carriers when it reaches the ground retains many hundreds of the TX spores. Also many spores are released into the air as a kind of spore "shower." The M1 carrier literally brushes the spores onto the plants with which it comes in contact. In operation the bombs would not necessarily be aimed at a defined target (i.e., a field of grain). Bombing technique would require only that the individual bombs be dropped into areas of known target crop concentrations.

32. Because cereal rusts cannot withstand freezing, the E-73 will require bomb bay heating on many missions against the USSR. Such a heating unit is currently under development; it is a small, self-contained gas combustion type which does not depend upon the electrical circuit capacity of the aircraft.

33. A major disadvantage of the E-73 is its relatively low weight per volume. This results in very poor fall-away behavior from the upper rear shackles of both bomb bays on B-29 type aircraft causing erratic fuze functioning which results in unpredictable burst altitudes. However, it would appear that the ballistics of this bomb could be improved to overcome its present erratic fall-away. It is assumed that this modification could be made by 1954 if needed. Another disadvantage of the E-73 is the lack of temperature protection for the spores during airborne phases. Above freezing temperatures will be maintained, however, by the use of the bomb bay heater described elsewhere.

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34. Total cost of this munition filled with TX1 is estimated by the Chemical Corps at $265.00. Of this total, $165.00 is estimated for the components less TX1 and $100.00 for the TX1.

Development Testing.

35. The first test of the "prototype" E-73 was done at Pine Camp, N. Y. in August 1950. The munition was an M16A1 cluster adapter filled and assembled by hand without benefit of technical specifications. The target area consisted of sixteen ½ acre plots of Overland variety oats. The plots were located in a rectangular area approximately 11 miles long by 1½ miles wide. Three agent filled munitions were dropped from a B-26 aircraft on the same aiming point. The agent was Race 8 of oat stem rust (*Puccinia graminis avenae*). This is the only known race of oat stem rust that is infective to the Overland variety of oats. There were two major objectives in this test: (1) to observe the rust infection obtained in this manner; (2) to observe the functioning of the cluster.

Cluster Pattern.

36. Six (6) clusters were dropped to determine ground pattern of the M1 carriers. Results of the pattern tests are summarized as follows:

TABLE VI

RELATION OF OPENING ALTITUDE, WIND VELOCITY, AND COVERAGE USING THE E-73 FEATHER BOMB

Opening altitude 1/	Wind velocity 2/	Surface area covered 3/
1300 feet	25 mph	4.6 sq. mi.
1800 "	25 "	5.0 "
2000 "	23 "	4.6 "
2300 "	25 "	6.5 "
3000 "	23 "	8.2 "
4000 "	23 "	12.5 "

1/ Approximate
2/ Average from surface to opening altitude
3/ Determined by recovery of feathers.

The size of the pattern varied with altitude. In this particular test it ranged from 4.6 square miles from a 1300 foot opening altitude to 12.5 square miles from a 4,000 foot opening altitude. The shape of the pattern was roughly oblong. The length and width varied in no set fashion, but generally the length was 5 to 10 times the width.

37. Patterns of the size mentioned above would yield feather densitites in the order of 4,000 to 11,000 per square mile with an agent concentration of 34 to 93 grams per square mile.

Infections Observed.

38. Two weeks after the three munitions with agent were released, infection was found on 11 of the 16 plots. However, only five plots were hit with spore laden feathers from the cluster. It was concluded that the six other plots were infected by free

spores released from the feathers. The free spores were presumably windborne to a greater distance due to lesser specific gravity. Judging from the simultaneous appearance of primary infections on plots on which feathers did not fall, it was estimated that perhaps as much as 25 square miles might have been exposed to spores from the clusters dropped. However, it should be noted that the wind velocities were relatively high. Within four weeks after the attack all test plots were infected. This illustrated a secondary spread of the disease onto plots that were not exposed to spores from the munition.

39. Although this test was done with oat stem rust, it is presumed that wheat stem rust or any other similar disease would have given similar results.

40. At the time the test was terminated it was estimated that yield reduction on the 11 plots primarily infected would have amounted to at least 30 per cent. This test was done during the several weeks following the harvest of the local oat crop in order to avoid accidental contamination outside the test area. The test was started six weeks after seeding when the plants were in the late tillering to early boot stage. This would indicate that the plants were well established when first exposed. The first pustules appeared approximately two weeks after exposure. Observations on the prevalence (percentage of plants infected) and severity (percentage of leaf area infected with pustules) were continued for six weeks. The test was terminated because of the onset of inclement weather. The lateness in initiating the attack relative to crop development and the early terminatinn of the observations would indicate that the estimated 30 per cent yield reduction could

be increased under more favorable conditions. A greater reduction might be expected under conditions when the disease had a longer time to exert its effect.

41. It was concluded that a cereal rust epidemic could be initiated by disseminating the spores on feathers from a modified M16A1 cluster adapter (now the E-73). Due to the effects of shake-off of free spores, the area of primary infection was greater than the area covered by the spore-laden feathers--in this case 25 square miles or approximately 3 times the observed area covered by the feathers--from the three munitions. Inasmuch as a mean wind speed as high as 25 miles per hour is not to be generally anticipated between the point of opening and the ground, it is believed that for planning purposes a coverage of 10 square miles per E-73 should be used.

Operational Suitability Testing.

42. The USAF is currently engaged in studying the operational suitability of the E-73 at the Air Proving Ground, Eglin Air Force Base. At this date (30 April 1952), 62 drop tests have been made. Thirty-five remain to complete the drop schedule. Details of the test procedures are not discussed in this paper. The tests are intended to provide data on reliability of the opening mechanism, fuze functioning, and surface density and distribution of the M1 carriers when the bombs are dropped from various altitudes and fuzed to open at various altitudes. Meteorological conditions are recorded concurrently with the drop tests.

43. No official test data were available from these tests at the time of writing this report. However, an interview with

the project officer revealed that pattern sizes on the ground with burst altitudes of approximately 1600 feet and wind velocities of approximately 20 miles per hour were of the same order of magnitude as indicated by the Pine Camp tests discussed above.

44. B-29 and B-50 aircraft are being employed for operational suitability testing. It has been determined at the Air Proving Ground that the present version of the E-73 is unsatisfactory for bombing altitudes above 15,000 feet. This is largely due to the relatively low weight-volume ratio of the munition. At altitudes above 15,000 feet there is considerable buffeting of the munitions dropped from the top rear shackles of the bomb bays. This causes erratic fall-away characteristics and occasional tumbling in the free-fall phase which impairs or prevents proper fuze functioning. Four out of 62 fuzes (M155 type) failed to function for mechanical reasons. Three E2R3 packages out of an observed 100 failed to open for undetermined reasons.

45. Malfunctioning of bombs from the upper rear chackles might be obviated by adding nose weights or even by replacing the mose E2R3 package by a dummy of greater mass. Though the latter would reduce the usable space per bomb by 25 per cent, the effect would be less drastic than that imposed by the necessity of not using the upper rear shackles.

46. The estimated munition cost per aircraft is $14,840 using 56 E-73's per plane load.

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E-86, BOMB, BIOLOGICAL

47. This item is an improved version of the E-73. It will consist of a suitable fuze, a casing such as the E-48 adapter, and five plastic packages of agent. The packages are similar to the E2R3 containers mentioned in connection with the E-73. The bomb is designed for a capacity of 13.2 pounds of carrier plus agent. Assuming the same proportions of feathers (M1) to agent (TX) as described for the E-73, this bomb would contain 1.2 pounds of rust spores.

48. The E-86, filled, weighs 238 pounds and fits on the 500 lb. bomb station. The mechanics of operation and principles of employment are similar to those mentioned under the E-73 except that each plastic package will have its own individual opening mechanism. The mechanism is a time delay device armed at the time of cluster opening with a few seconds delay.

49. Heating and insulation are provided as integral parts of the E-86. This is an improvement over the E-73. If the temperature outside the bomb is -48° F. it will require a power of 100 watts, calculated per bomb, to maintain an inside temperature of 40 - 50° F. (best storage temperature). It appears that the present electrical circuits of bombardment aircraft can accommodate this additional load under combat conditions. For an outside temperature of -65° F. the requirement for electric power is calculated to be 140 watts to maintain the same internal temperature. Insulation inside the E-86 casing is provided by one inch of styrofoam. In the event of emergency shut-off of electrical power the styrofoam insulation is expected to provide sufficient protection to permit continuation of a mission. There are no data available on this point. The increased weight of the E-86 and its aerodynamic shape will also improve the ballistics characteristics and possibly eliminate such problems as buffeting occurring in bomb bays of B-29 and B-50 aircraft above 15,000 ft. altitude.

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50. The effective payload of the E-86 bomb is 20 per cent more than that of the E-73. The primary area coverage will be similar in size due to similarity of the content and construction.

51. Total cost of this munition filled with TX1 is estimated by the Chemical Corps at $620.00. Of this total, $500.00 is estimated for the components less TX1 and $120.00 for the TX1. The total munition cost per plane load is estimated at $24,800. The additional cost of the E-86 in comparison with the E-73 provides a more refined munition but no appreciable increase in mechanical effectiveness. The E-86 apparently offers two advantages over the E-73: (1) higher bombing altitude due to improved weight, and(2) 20 per cent agent per bomb. On the other hand, the addition of separate opening device on each of the packages in the bomb gives cause to expect some mechanical failures in package opening while seeming to offer no apparent advantage.

52. The E-86 is not expected to be operationally available until mid-1954. No field test data are available at this time, but as stated above, its performnance can be assumed to be almost identical to the E-73.

E-95, BOMB, BIOLOGICAL

53. This munition is designed primarily as a disseminator of free spores--that is to say, spores not contained on a carrier of some sort. Assuming that each item will contain 70 grams of spores, then 6.5 will contain the same quantity of spores as one E-73, and 364 E-95's would be equivalent in agent payload to one B-50 plane load of E-73's (assuming 56 E-73's maximum load). The 364 E-95 munitions would weigh roughly 328 pounds as compared with 4,704 pounds for 56 E-73's. However, the factor of importance on an aircraft payload basis is not the weight limitations as much as space limitations.

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54. This item is a small spherical bomb. It is three inches in diameter made out of plastic and designed for a barometric fuze. The E-95 is designed to weigh slightly less than one pound when filled. It will contain approximately 70 grams of rust spores.

55. The fuze will cause the two halves of the sphere to separate at a low altitude, thereby releasing free spores into the air. Spore viability should be unaffected by this method of release. Successful employment of these spheres, however, may well depend on the sensitivity and reliability of the fuze. Available knowledge of the ballistics of rust spores suggests that, in order to obtain an adequate ground density at low to moderate wind speeds, the altitude of release may well be under 200 feet and perhaps be under 100 feet. Using the same mean spore disposition rate as was achieved in the Pine Camp trials with E-73 bombs, the contents of one E-95 sphere should be distributed over 700 acres, or somewhat more than one square mile.

56. The developing agency (Chemical Corps) does not contemplate clustering the E-95 in a cluster adapter. Current plans indicate that the spheres will be released individually from a simple vat or hopper-like container in the aircraft. It is proposed that dissemination of small munitions can be done as well without clustering in an adapter suspended from bomb shackles. A large container suitable for ejecting the individual spheres poses no problem to the developing agency. Such a container could be developed for suspension in the bomb bay of bomber aircraft or mounted in the cargo compartment of transport aircraft. Development is estimated by the Chemical Corps to be complete by mid-1953 with operational availability by mid-1954. Total cost of the E-95 is now estimated by the Chemical Corps to be $26.00 of which $10.00 is estimated for the components less agent fill and $16.00 for the agent fill.

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57. For the purpose of drawing a rough comparison between the E-73 and E-95 on an aircraft load basis it will be necessary to estimate the total number of E-95's that a B-29 or B-50 could accommodate. As pointed out above it is planned to distribute the E-95 from a hopper type disseminator carried in the bomb bay. It is known from investigations on the design of the spray system (discussed later) that a unit measuring 120x60x51 inches suspended from special racks will fit in a B-29 bomb bay. A hopper of that size contains 367,200 cubic inches. Assuming one E-95 to occupy 27 cubic inches the maximum possible number of E-95's per bomb bay would be approximately 13,600. Assuming one E-95 to weigh 0.9 pounds the maximum weight of bombs alone would be 0.9 x 13,600 or 12,240 pounds. If one assumes that a hopper device would weight 750 pounds then the total combined weight per bomb bay would be 12,990 pounds. On the basis of 70 grams of rust spores per E-95 the total agent weight per bomb bay would be approximately 2,100 pounds. Using 0.1 gram of agent per acre as a desired ground density, one B-29 bomb bay load of E-95's could theoretically contain sufficient inoculum to infect 14,890 square miles.

58. A serious limitation exists in connection with the E-95. There is little or no knowledge at this time on the behavior of free spores released in the air in a target area. They would undoubtedly drift for much greater distances than when clinging to a heavier body such as the M1 carrier. Although infections occur from free spores under natural conditions, there is no basis for comparing the effectiveness of single spore infections with infections started by a mass of spores on a carrier. Therefore, conclusions on the relative on-target effectiveness of the E-73 or E-86 versus the E-95 would be conjectures at this point. Moreover, the E-95 does not lend itself so readily as does the E-73 to the solution of the problem posed by the availability of spores having reduced viability, as occurs in some stored batches of spores. A reduction in viability of 50 per cent would be

compensated for in the E-73 by doubling the quantity of agent applied to the feathers without changing the area covered per sortie; in the E-95 spheres no such compensation could be made so that the area covered per sortie would be greatly reduced from the theoretical maximum level, because more spheres would have to be distributed to approach the desired effective spore rate per acre. It is concluded that a meaningful comparative evaluation of the two munitions cannot now be made, and therefore the E-95 will not be used in making computation.

CHEMICAL SPRAY SYSTEM

59. The effectiveness of certain chemicals (i.e., 24-D and 2,4,5-T) against crops has been established. Continued research has made it more apparent that serial dissemination might be logistically feasible. The engineering design of a suitable spray system for operational aircraft is completed. The work is being done by the Wright Air Development Center with collaboration of the Chemical Corps.

60. Two prototypes of the system are planned for completion by August this year. Immediately following, it is planned to run practical field tests at Avon Park Bombing Range, Florida, where previous engineering and development tests had been done.

61. The system consists of a tank for the agent, pumping system, power unit, nozzles, and supporting structures having a total weight of 865 pounds when empty. The filled weight will be approximately 11,765 pounds. One complete unit can be contained in each bomb bay of a B-29 or B-50, or a C-119 cargo aircraft. In the B-29 type the unit will be suspended on bomb-bay shackles and will be jettisonable in flight. In the C-119 aircraft it will rest in a cradle on the cargo floor and could be manually jettisoned if necessary.

62. The unit will have four detachable fully castering wheels for towing up to 10 miles per hour on concrete surfaces. Final positioning under a bomb bay will be manual. Hoisting the tank

unit into the bomb bay will be done in a manner similar to the procedure for installing the in-flight refueling system in a B-29. Installation in a C-119 type aircraft will be done as prescribed for any similar cargo loading.

63. The tank is designed for a 1030 gallon capacity and a volume of 137 cubic feet. Fully loaded it will weigh 10,900 pounds. A filling port and splash proof vent will be provided in the top of the tank. Insulation is provided by suitable insulating board and material about one inch thick. The tank will be filled after installation by means of a modified F-1, F-2, or F-6 refueling trailer. The modification of the refueling trailer will be such as to enable reconversion with minimum time and effort. The agent will be pre-heated to a temperature of 90°F. during filling operations by passing it through a liquid combustion heater similar to that used on the E3R2 Incendiary Oil Mixing and Transfer Unit. Pre-heating of the agent plus insulation of the tank will maintain satisfactory viscosity for the duration of an eight hour mission under temperatures obtaining at operational altitudes.

64. A single-stage centrifugal pump feeds the nozzles at the rate of 150 gallons per minute under a pressure of 35 psi. The maximum pump capacity is 200 gallons per minute under 35 psi pressure with an input of 7 1/2 HP.

65. The pump is powered by an air-cooled internal combustion engine delivering a recommended maximum of 7.5 HP at 5,000 feet altitude. It will be self starting by means of a 12 volt starting battery. Fuel will be provided by a two-gallon capacity tank. Fuel consumption on a mission will be less than one gallon.

66. The pump and engine will be mounted on the tank frame and together will weigh an estimated 275 pounds. They will feed the agent to six Bete 32W Fog Nozzles suspended three feet below the fuselage on B-29 type aircraft. The nozzles will be spaced in

two rows two feet apart in both directions. On C-119 type aircraft the nozzles will extend through two small doors at the rear of the cargo compartment. It is planned that nozzles can be extended to the outside or withdrawn manually on the C-119 aircraft.

67. Provision is made for rapidly dumping the tank contents through a three-inch line in an emergency.

68. Minor aircraft modification will be necessary to install the system. Mounting racks must be bolted onto the aircraft frame; six semi-circular openings will be required in the edges of the bomb bay doors for nozzle extension; and a fuselage window less than one square foot in size is needed for the exhaust, air scoop, and vent line of the engine. In the cases where openings are cut in the fuselage a cover plate with zeuss fasteners will be provided.

69. It is proposed that all work, including aircraft modifications, can be done at wing level. No information is available on manhours required to prepare an aircraft for installation of the system or on readying the system for flight after installation.

DEVELOPMENTAL TESTING

70. In 1950, extensive trials were conducted at Avon Park, Florida, to determine the effectiveness of low volume spraying of pure or undiluted anticrop agents from aircraft. The flight tests were done with a USAF C-47 having a tailored experimental spray system installed and a Navy AD-1 equipped with an Aero X2A spray device. From the 1950 tests it was concluded that particle breakup was caused to a greater extent by the slipstream and to a lesser extent by the nozzle type. In terms of area coverage both surface winds and altitude of release were important.

TABLE VII

RESULTS OF 1950 DEVELOPMENTAL TESTING TO DETERMINE EFFECTIVENESS OF LOW VOLUME AIRCRAFT SPRAYING OF ANTICROP AGENT

Aircraft	Flow Rate (gpm)	Wind velocity above the surface in m.p.h. 3.3 ft.	26.7 ft.	Flight alt.	Swath Width(ft) Lethal*	Apparent**
C-47	15.9	6	11	100	4000	7100
"	16.1	3	9	100	4875	8650
"	14.2	4	8	100	3967	6200
"	16.0	2	8	100	3829	8700
"	12.6	8	19	100	5250	8250
"	14.8	0/5	6	100	2900	8000
"	21.4	2	9	200	7200	10000
"	17.8	2	6	200	6072	12672
AD-1	18.6	3	7	100	500	8000
"	18.6	12	27	100	3500	10560

* Death or 90% inhibition of test bean plants.
** Less than 90% inhibition of test bean plants.

Table VII shows that the installation in the C-47 aircraft yielded a lethal swath from 100 feet altitude averaging 4,137 feet wide at an average rate of 1208 acres per minute calculated from six flights. From two flights at 200 feet altitude the lethal swath averaged 6,636 feet wide at a rate of 1912 acres per minute. Due to the limitations of the sampling line, the effective area covered beyond the lethal and apparent swaths could not have been determined. It was determined by inspection that drift did occur beyond the distances recorded. The measured swath widths from the Navy AD-1 aircraft were less because of the larger particle sizes and downdraft effect.

71. It was concluded from the 1950 tests that 0.01 gallon (approximately 0.1 lb.) of pure 2,4-D per acre would kill plants having comparable sensitivity to red kidney beans.

72. In 1951, development tests on the aerial spray system were expanded somewhat and included utilization of a USAF B-17 and B-26, and a Navy AD (Skyraider) and F4U (Corsair) aircraft. Major objectives included studies on liquid chemical anticrop agent behavior when disseminated from various nozzles located at different places on the aircraft and discharged at various

altitudes and airspeeds. The most important results were obtained from the B-17 missions. The B-17 was equipped with two complete and independent systems that fed liquid to any one or a combination or right and left wing, fuselage (near wing roots) and tail locations. Data from the B-17 tests are shown in Table VIII.

TABLE VIII

EFFECTS OF RELEASE ALTITUDE AND WIND VELOCITY ON EFFECTIVE (LETHAL) AREA COVERAGE

Altitude	Flow Rate (gpm)	Nozzle Location	Lethal Swath width(ft)	Lethal coverage per min. Acres	Lethal coverage per min. Sq.miles	Wind Velocity 1/
350	100	Both wings	6,600	2662	4.2	9-12
350	100	Wing & fuselage	8,000	3219	5.0	10-34
500	100	" "	3,200	1280	2.0	4-18
500	100	Wing & tail	5,600	2259	3.5	6-20
500	54	Both wings	4,800	1937	3.0	Calm-8
500	100	" "	8,800	3539	5.5	2-20
500	100	" "	13,800	5568	8.7	6-20
750	100	Fuselage & tail	21,600	8717	13.6	5-22
750	100	" "	9,400	3840	6.0	4-16
1000	100	" "	5,200	2086	3.3	3-24
1000	100	" "	4,400	1772	2.8	2-18
1000	100	" "	3,400	1363	2.1	Calm-10
1000	50	Tail	5,400	2176	3.4	3-14

1/ Reported here as a range from surface to release altitude.

Of the various atomizing devices the Bete 32W fog nozzle was considered to be the most generally useful. It also had the advantages of simplicity, availability, small size, streamline contour, and adequate flow capacity. The agents that were proved to have satisfactory characteristics for aerial spraying against crops were butyl 2,4-dichlorophenoxyacetate, isopropyl 2,4-dichlorophenoxyacetate, and butyl 2,4,5-trichlorophenoxyacetate.

73. An examination of the data (Table VIII) shows no clear cut correlation from which one can draw firm conclusions. In fact, the Chemical Corps Biological Laboratories concluded "It was clearly apparent that no simple relationship exists between altitude of release and breadth of swath." However, it was pointed out that the test objectives at Avon Park did not include the

obtaining of data from which operational plans could be drawn. Location of the nozzles on the aircraft has a bearing on the distribution of aerial sprays. It was observed that the slipstream from along the fuselage projects downward for 100 - 200 feet, whereas, this does not occur from wing positions. At altitudes below 500 feet the downdraft tends to make fuselage positions for nozzles less desirable than wing mounted positions. At release altitudes from 500 - 1000 feet it was concluded that the fuselage and tail positions would be more desirable because of the downdraft effect. It should be pointed out that this may not be the case with operational aircraft such as the B-29.

74. On the basis of the satisfactory results obtained at Avon Park the construction of a prototype system described above is now underway. Examination of the data (Table VIII) indicates that one can expect a lethal swath 1 - 4 miles wide when the flow rate is 100 g.p.m., airspeed of 200 m.p.h., altitude 350 - 1000 feet, with the wind velocities at the surface and release altitude roughly 4 and 17 m.p.h., respectively. This area coverage corresponds to 3.3 - 13.2 sq. miles per minute of flight or per 100 gallons of agent. Under combat operations the B-29 would probably be equipped with only one tank having 1030 gallons capacity as described above. This would provide a coverage with lethal quantities of agent in the order of 34 - 136 square miles per B-29. The field test of the prototype system scheduled for August-September 1952, will yield some data to check the validity of the estimate of lethal area per aircraft. There is an additional effect from sub-lethal dosages which will enlarge the total effective area covered. Sub-lethal dosages cause inhibition of plant growth frequently resulting in little or no fruitfulness. This additional effective area may approximate the width of the lethal swath shown in Table VIII.

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E-27, AIRBORNE DRY AGENT DISSEMINATOR

75. This device is a modification of the 700 gallon droppable fuel tank for B-50 aircraft. (The B-29 is not equipped to utilize the tank). Development is based on the requirement from the USAF for a large capacity continuous disseminator for cereal grain rust spores.

76. The external configuration of the 700 gallon tank remains unchanged. The disseminating mechanism is a separate unit that fits inside the shell of the tank. This internal unit consists of an agent container and screw conveyer combination plus a gasoline burning heater. (The heater provides automatic temperature control.) A small electric motor drives the screw conveyer which feeds the agent to an outlet from the agent container into the slipstream of the aircraft. Preliminary flight tests in February and March, 1952, proved the mechanism to be satisfactory. Extensive flight tests to determine the effectiveness of the E-27 are scheduled for late 1952.

77. The degree to which the E-27 is effective is contingent, to a great extent, on the degree to which free spores in the air are effective in gaining a foothold on the host plant. The 1952 BW Technical Estimates state that one E-27 is capable of carrying 600 pounds of spores. It is further stated that 64 grams (.14 lbs.) of rust spores per square mile will give reasonable assurance of establishing sufficient foci of infection to start an epiphytotic. Assuming a maximum fill (600 lbs.) and uniform distribution one E-27 is theoretically capable of inoculating 4285 square miles with primary infection. Two E-27 (maximum B-50 load) would theoretically carry sufficient inoculum for 8570 square miles. However, the techniques of employing this device have not been developed. With an agent load of 600 pounds, a line source of enormous length could be established. The minimum night operational altitude of the B-50 may well be considerably above the

optimum altitude for release of free rust spores. Not enough is known about the cloud action of free spores at altitudes to make a conclusive statement on suitability of this munition. Recourse may have to be had to a mixture with some carrier to ensure deposition of the spores near the intended targets, which of course would reduce substantially the agent capacity of the device.

78. The total cost of the E-27 is estimated at maximum of $65,000 of which the cost of the agent is $60,000 and the munition components is $5,000.

E-77, BIOLOGICAL BOMB

79. Another development in the anticrop munition field is a device to be carried aloft by unmanned balloons. The bomb, E-77, weighs approximately 80 pounds when filled with 18 pounds of feathers impregnated with two pounds of rust spores. Tests have been conducted to prove the feasibility of the unmanned balloon system as a means of delivery to target areas up to 1500 miles from the launching site with a probability of hitting within a circle of 100 mile radius 75 per cent of the time. These tests have not been evaluated by WSEG.

80. The flight path of the balloon system and the time of arrival at a destination is predicated on fairly accurate knowledge of winds aloft. A timing mechanism will be utilized to release the E-77 from the balloon carriage within the target area. A separate fuzing mechanism on the E-77 will cause it to open at the proper altitude after fall-away from the balloon carriage. Spores on a carrier will then be released into the air and distributed on the target surface in a manner similar to the pattern from the E-73.

81. This item is estimated to be available by late 1954. It is mentioned in this report only to complete the picture of anticrop munitions that would conceivably be available in 1954, and is not considered further in this study.

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CHAPTER III

PRODUCTION, TRANSPORT, AND STORAGE ASPECTS OF ANTICROP AGENTS AND MUNITIONS

GENERAL DISCUSSION

82. Logistic considerations for use of anticrop BW agents vary according to the type of agent employed. Because none of the agents presently under development are harmful to humans, the factor of personnel safety which complicates the production, storage, handling and transport of antipersonnel BW agents is insignificant for anticrop agents. Chemical anticrop BW agents do not appear to present unusual logistic problems. On the other hand, the use of biological anticrop agents will involve some handling and storage precautions in common with other biological agents, primarily to insure the maintenance of viability. In the case of cereal rusts, and specifically with stem rust of wheat and rye, some unique logistic problems arise. Because their effective employment is limited to a short period in the early summer, production, storage and transport all have to be planned so that maximum capability is attained at that period. Furthermore, since the agents can only be produced by infecting a growing crop, no production plant in the ordinary sense is required. However, safety of commercial cereals in the ZI and in friendly areas must be a paramount consideration through all phases from production to operational use.

83. Present plans for anticrop BW weapons call for production and/or procurement of the agents and munitions by the Chemical Corps, U. S. Army. This organization will also be responsible for the storage, transport, and protective aspects of agents and munitions in the ZI until such time as they are delivered to the ZI port of embarkation where the United States Air Force will assume responsibility for storage and shipment to overseas facilities. The Air Force retains responsibility for overseas storage, handling, and operational delivery.

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CHEMICAL ANTICROP WEAPONS

84. Production and Procurement.

a. Agents. Characteristics of chemical anticrop agents together with estimated production status are shown on Table IX. To date there has been no procurement of these agents. In the opinion of the Chemical Corps procurement in ~~the~~ amounts required from existing commercial facilities would not present any unusual problems. At present, the chemical industry has a production capacity for certain of these chemicals considerably in excess of sales.

b. Munitions. The munitions for dissemination of chemical anticrop agents are of the "fixed" type, i.e., they will remain attached to the aircraft during operations. Two such munitions are being developed; one, a bomb-bay spray tank to disseminate 2,4-D or 2,4,5-T in a concentrated liquid form; and the other, a hopper distributor for dissemination of IPC or other agents as extruded particles or granules with as high an agent content as is feasible.

c. The spray system for use in low-level spray operations from medium bombardment and cargo-type aircraft is presently under development at the Wright Air Development Center, in collaboration with the Chemical Corps, U.S. Army. The principles of this system were developed in extensive trials in 1951, and engineering studies have now been completed. In the opinion of the developing agency, the spray system could be operationally available by mid-1954, if a requirement for it exists. There are two prototypes in process of construction. These are designed to utilize standard equipment and stock items wherever possible (motors, pumps, nozzles, shackles, etc.) to reduce cost and minimize procurement and maintenance problems. The proposed basis of issue

TABLE IX

CHARACTERISTICS AND PRODUCTION STATUS OF CHEMICAL ANTICROP AGENTS

Agent	Susceptible Crops	Dosage per acre for maximum yield reduction	Storage, transportation and handling	Probable method of application to target	Production Estimates (1952)		Munitions
					Facilities	Daily capacity (pounds)	
2,4-D esters (butyl 2,4-dichlorophenoxyacetic acid and related esters of this acid.)	Broadleaf plants such as sugar beets, cotton, sweet potatoes, sunflowers, and turnips	0.1 lb.	Can be stored indefinitely under normal "dry storage" conditions. No special environmental conditions required. Delivered, stored and transported in 500 lb. steel drums.	Liquid spray from aircraft.	Commercial facilities exist.	80,000	Bomb spray tanks for B-29 or C-119 aircraft. Agent will be released at controlled rate through Bete fog nozzle 32W. Munition being developed by USAF and Chem. Corps, U.S. Army. Estimated operational availability is mid-1953.
2,4,5-T esters (butyl 2,4,5-trichlorophenoxyacetic acid)	Broadleaf plants such as flax, soy beans, peanuts, tobacco and Irish potatoes.	0.1 lb.	Can be stored indefinitely under normal "dry storage" conditions. No special environmental conditions required. Delivered, stored and transported in 500 lb. steel drums.	Liquid spray from aircraft.	Commercial facilities exist.	80,000	
Chloro IPC (Isopropyl 3-Chlorophenyl Carbamate) or IPC (Isopropyl phenyl carbamate.	Fall planted cereals such as wheat and rye.	2.0 lb.	Can be stored indefinitely under normal "dry storage" conditions. No special environmental conditions required. Delivered, stored and transported in 500 lb. steel drums.	Granules from aircraft hoppers, or sprayed in liquid form.	Commercial facilities exist.	1,400 (expanding rapidly)	Hopper distribution in early stage of development. Not expected to be operationally available by mid-1954.

Source:
(1) 1952 Technical Estimates, Department of Defense Research and Development Board, TOP SECRET
(2) Ltr. Office of the Chief Chemical Officer; Subject: Data on BW Readiness for Antipersonnel and Anticrop Agents, Mid-1954, dated 15 April 1952, TOP SECRET
(3) Ltr. USAF (AFOAT); Subject: BW Logistic Capabilities, dated 21 April 1952, TOP SECRET

will be one spray system per medium bomber or cargo aircraft assigned to the mission plus 20 per cent spares of basic components and 100 per cent spares for pumps and power units. Tentative USAF plans are to equip a maximum of two wings of B-29 or C-119 aircraft. This will require a total of 90 units plus replacement components as indicated above. In view of the comparative simplicity of the system together with the comparatively small numbers involved, production and/or procurement problems appear to be nominal even if larger quantities were required.

85. Storage, Stockpiling and Transport. The chemical anti-crop agents considered in this study can be stored indefinitely under conditions of ordinary "dry" storage. The agents are usually procured in steel drums containing approximately 500 pounds each and may be stored, stockpiled and transported without additional packaging. No extraordinary safety precautions are involved. The transport of the small numbers of spray systems and hopper distributors contemplated would have a negligible impact upon either rail or ship transport. No stockpiling of these items is planned.

86. Handling at Operational Bases. The liquid agents (2,4-D and 2,4,5-T esters or chloro IPC) will be delivered to operational bases in steel drums, transferred at the base to modified F1 or F2 fuel units for transport to the aircraft and filling of the munitions after they have been installed in the aircraft. Preheating to 90°F will be accomplished by passing the agent through a heating unit during the filling operation. The munitions are designed to be installed in the aircraft by personnel

at wing level. Neither the handling of the agent nor the installation of the munitions will require additional personnel or specialized training of the normal personnel complement of operational bases. No extraordinary safety precautions are involved.

BIOLOGICAL-ANTICROP WEAPONS

87. Production

a. The only plant pathogens currently in production are spores of stem rust of wheat (*Puccinia graminis tritici*, races 17, 38, and 56), standardized as TX, and spores of stem rust of rye (*Puccinia graminis secalis*). These are produced by Edgewood Arsenal, Chemical Corps, in acceptance of an Air Force requirement for 1,200 pounds of TX and 4,800 pounds of stem rust of rye. The developing agency had not proved the methods of production at the time when the requirement was established; essentially therefore the production operations to date have consisted of large-scale experimentation.

(1) The cereal rusts can be produced only infecting the appropriate host crop, establishing the disease, and by means of a special harvester, collecting repeatedly from the diseased plant the uredospores produced in pustules on the stem and leaves. Such a production process involves unique problems. Inasmuch as the cereal rusts are only employable offensively in the late spring and early summer, the production sequence has to be planned to meet the requirements at that time each year. Because the amounts required are far beyond the amounts which could be produced in greenhouses, two possible courses remain. Either the agent must be produced in a crop planted in the preceding winter in semi-tropical or southern hemisphere locations, or on a crop planted

in the normal cereal season in the previous year. The latter involves the maintenance of required viability and virulence for at least 10 months. Winter production would involve only three to four months storage, and might therefore have to be preferred unless satisfactory stability could be secured for longer term storage.

(2) The development agency has had two seasons experience in Puerto Rico, and one season's experience at sites in the north central states in the ZI. The latter is preferred if safety of domestic crops can be assured. The major problems center around the selection of a suitable variety of cereal on which to produce rusts. Commercially available varieties in general are quite unsuitable; they have been developed to be high yielding in a particular area, to yield grain of good quality and to be resistant to diseases including rust normally encountered in that area. For rust production, on the other hand, yield of grain is unimportant, but susceptibility to those races of rust which it is desired to produce is essential. A degree of susceptibility so high that the development of the infected plant might be halted would be undesirable. The selection, development, and increase of seed of such new varieties adapted to desired areas takes several years. In the interval, various compromises are necessary, which must be recognized as not providing ideal production conditions, both with respect to yields and purity.

(3) The 1951 production by the Chemical Corps was 672 pounds of stem rust of wheat and 224 pounds of stem rust of rye. As much as 50 pounds of rust (crown rust of oats) has been collected from a single acre by repeated

harvests in a 14 day period, and 15 pounds per acre is the planning figure upon which requirements for supporting equipment are based. The experience in 1951 was that the over-all average per acre yield of rust was under four pounds, but this included some areas from which no usable material was collected. The low yields in 1951, in the judgment of Camp Detrick, were due to the highly experimental nature of the operation and to the complete unavailability of seed of suitable quality. The bulk of the acceptable material was in fact collected from relatively few acres, at a yield in the neighborhood of 10 pounds per acre.

(4) Production operations require irrigation facilities in order that the diseased crop may be kept alive and productive of spores if subjected to moisture stress by a prolonged dry period. Suitable harvesters capable of covering about 15 acres per day have been developed and procured from the Minneapolis-Moline Company.

(5) Safety of domestic cereals can be assured only by producing races of rusts to which the commercially planted varieties have resistance, or by producing off season, which may introduce other agronomic problems in the selection of suitable varieties. Wheat stem rust races 17, 38, and 56 do not constitute a hazard to commercial wheats in the north central states and some intermountain areas. Stem rusts of rye can be safely produced in southern Florida in the winter and in most northern states in the summer because so little rye for grain is normally planted at these times. The production of stem rusts of oats and barley might involve greater difficulties; oat rust could perhaps be produced

off-season in the late summer and early fall, and barley rust in non-barley growing areas.

(6) The development agency might have difficulty in accepting and accomplishing immediately any substantial increase in requirements for stem rusts of wheat and rye or establishment of requirements for oats and barley rusts, not only because of unavailability of suitable seed in sufficient quantity but because of lack of precise knowledge and experience in the behavior of probable varieties on the areas selected. Fully airconditioned greenhouses adequate and suitable for the production of rust inoculum for such an expanded program will be completed at Camp Detrick in July 1952.

b. Munitions. The E73R1 bomb is the only available munition for disseminating cereal rust spores. USAF requirements call for 5,000 bombs by March 1953. Present stock is 4,037 stored in the ZI plus 400 at each of two overseas installations. The bombs and fuses are procurable through ordnance channels; seven months lead time is required. E2R3 packages made of polyethylene-coated kraft paper are standardized and procurably commercially; a lead time of seven months is required. M1 carrier (feathers) are procured commercially; lead time is three months. The E-86, Bomb, Biological, an improved version of the E73R1, is presently in process of development. Production and procurement is expected to be comparable to the E73R1 except that the cost less fill will be approximately $500 as compared to $165 for the E73R1. Lead time is estimated at six months.

88. Storage and Stockpiling.

a. Surveillance studies on the stability of cereal rust spores in storage have yielded conflicting results. Many

samples of spores variously processed have been stored for months under a variety of conditions, and have still been found viable, though the percentage germination may have fallen. No simple set of conditions can clearly be specified as being optimum. It is believed, however, that the following will in general apply: reduction of moisture content to 10 to 12 per cent relatively soon after collection, followed by bulk packaging under nitrogen and storage at a temperature of about 40° F. Present practice is to segregate the field collections on the basis of moisture content, and to hold under refrigeration until drying can be carried out where necessary. This is done in vacuum tray driers, following which the spores are packaged in one pound glass containers, evacuated and filled with dry nitrogen at atmospheric pressure. There is cumulative evidence that the initial purity of the product is a significant factor in stability. Samples that do not contain inorganic material (sand and clay), and are relatively free from other pathogens or from those saprophytic organisms that develop on the dying leaves of cereal plants in moist weather, retain viability much longer than contaminated products. Some of the better material produced in July 1951 declined relatively little in viability in eight months; other material had fallen to 25 per cent or below. It is believed that the purity of the spores collected will be much improved as properly selected varieties of cereals become available and that in consequence the storage behavior of the product will become more dependable and satisfactory.

b. Inasmuch as the cereal rust filled munitions can only be employed in the late spring or early summer, production and stockpiling must be programmed to meet the requirement at that time. Some provision must be made in planning for decline in viability between the time of collection and expected time of use; loss of viability could increase requirements by a factor of four. The stored agent will therefore be checked for viability in the late winter (by 15 February - 1 March), and the filling plan will be based on the percentage viability determined. The relative proportion of TX and carrier to be placed in the E2R3 packages can be increased to compensate for reduction in viability. Only material of high viability should be used in the E95 spheres.

c. Bomb casings and fuses are stored at the Eastern Chemical Depot, Edgewood, Maryland; 800 have been delivered to the USAF and are stored at two overseas bases; 4,037 are on hand in the ZI. Material for 6,000 shipping containers for TX1 is on hand (each container has a capacity of four filled E2R3 packages). Material for 24,000 packages has been procured. 22,000 pounds of M1 carrier (feathers) are stored at Edgewood, Maryland. Additional deliveries of 20,000 to 25,000 pounds are expected to be completed by 1 July 1952. No unusual storage difficulties are anticipated.

89. Handling, Filling, and Transport.

a. Present plans call for the shipment of bomb components less fill via rail to ZI port of embarkation and water to overseas bases where they will be held until operational needs arise. There appear to be no unusual handling or transport problems involved. Bombs will be filled by insertion of E2R3 packages at operational bases immediately prior to use.

b. The E2R3 packages will be filled at the Army Chemical Center on request from the Air Force. Inasmuch as the stability of the spores when mixed with carrier to produce the agent fill (TX1) declines more rapidly than when in bulk storage under nitrogen, mixing of agent and carrier will not ordinarily be carried out until a few days before shipment. The mixing operation is relatively simple, the Chemical Corps will have ready facilities and personnel to carry out mixing and filling at the appropriate time before the anticipated employment of the munition.

c. The mixing of agent and carrier will be carried out in rotating drums in proportions based on surveillance figures for viability determined about 15 February, each year. Mixing will be done under controlled environmental conditions of 43°F ± 5° and 50 per cent RH. Some relaxation of these requirements may be possible, inasmuch as the rate of moisture uptake by both feathers and spores is low. The chief requirement is to protect the material against high humidity, which would cause premature germination of the spores. At temperatures higher than 43° F. no harmful results would necessarily follow. The agent-carrier mixture will be weighed into E2R3 packages and sealed; these in turn will be packed in fours in sealed cylindrical shipping containers to be stored at a temperature of 43° F ± 5° until shipped.

d. Present plans call for air transportation of the TX1 to forward bases. During transport the temperature conditions in the aircraft must be controlled to prevent exposure to extremes of heat or cold. Temperatures below freezing must be particularly avoided, because spore viability will be lost. On receipt at the forward base, it will again be desirable to hold these containers at a temperature in the vicinity of 43° F until the E2R3 packages are inserted into

the bombs. Aerial transport of E2R3 packages may not be feasible if large scale operations are planned, because of the high volume/weight relationship of these packages. Two alternatives are possible. Either rail and water shipment would be adopted, which would call for refrigerated space, or the mixing and filling might be carried out at overseas bases, because there are no special skills, elaborate equipment or particular hazards involved. The carrier and E2R3 components could be shipped without special precautions; temperature control would be necessary for the agent, which would be transported in the same containers as prepared for storage. Insertion of the E2R3 package into the bombs, perhaps in mixtures determined by the operational plan, will be accomplished at the forward operational bases by the normal personnel complement. Some safety precautions may be necessary in the event that the filling operations were carried out in a friendly area in which cereal crops were grown.

CHAPTER IV

CHARACTERISTICS OF ANTICROP WEAPONS SYSTEMS

UNITED STATES AIR FORCE AIRCRAFT AVAILABLE IN 1954

90. The numbers, types, and characteristics of USAF combat units program for mid-1954 appears in Enclosure "C", Chapter II. Table X below summarizes the Air Force estimate of the total numbers of aircraft which should be on hand in operational units in mid-1954, and which could have an operational capability for the delivery of anticrop agents and munitions against the USSR.

TABLE X

ESTIMATED TYPES AND NUMBERS OF UNITED STATES AIR FORCE AIRCRAFT AVAILABLE FOR ANTICROP ATTACKS IN 1954

Type	No. of Wings	Estimated Number of Aircraft on Hand
B-36	7	204
B-50	5	190
B-47	12	593
B-29	10	350

Source: USAF Planning Budget Program, BPX-54-4, May 1952, Projected Aircraft Inventory, SECRET.

UNITS WITH AN ANTICROP BW DELIVERY CAPABILITY

91. The 20 June 1951 directive of the Vice Chief of Staff, United States Air Force, classified TOP SECRET, outlining the USAF approach toward attainment of a BW-CW delivery capability is discussed in detail in Enclosure "C", Chapter II. Relative to anticrop BW it was directed that appropriate action be taken to assure sustained combat capability in air force units phased as follows:

a. Phase II - 31 December 1953

(1) SAC - Three wings of medium bombers to be operationally capable of employing biological agents using "interim" and such preferred munitions as are available:

Anticrop

(a) TX-1

(b) Rye Rust

(c) Barley Rust

(2) TAC - No BW capability. One light bomber wing and three fighter-bomber wings with CW capability.

(3) FEAF - No BW capability. One light bomber wing and one fighter-bomber wing with CW capability.

(4) USAFE - No BW capability. One light bomber wing and one fighter-bomber wing with CW capability.

b. Phase III - 31 December 1954

(1) SAC - All units qualified as in Phase II

(2) TAC - " " " " " " "

(3) FEAF - " " " " " " "

(4) USAFE - " " " " " " "

92. The Air Force directive reflects a dependence upon the units of the Strategic Air Command for the delivery of anticrop BW agents specifying that by 31 Dec. 1954 all units of SAC be capable of delivering available anticrop munitions. It appears reasonable to assume, for the purposes of this problem, that all of the Strategic Air Command units will have the capability of delivering the E-73 and E-86 cluster munitions since this does not pose any unique problems for units trained in strategic bombing. The use of the E-27 dry agent disseminator for the delivery of BW attacks or the spray system for the dissemination of chemical anticrop agents will require an attack at low altitudes. The Air Force has been studying low altitude penetration tactics, and no unusual difficulties are foreseen if altitudes of 750 to 1,000 feet are maintained. However, such altitudes may be too high for the dry disseminator of rust spores without a carrier, although satisfactory for low volume CW anticrop spraying.

93. No munitions are programmed for the fighter-bomber delivery of anticrop BW or CW agents and the limited capacity of the available light bombers renders them impractical as a means of delivery. Some thought is being given to the use of the C-119 cargo type aircraft for delivery of chemical spray by

use of the spray system installed in the cargo compartment. No evaluation has been made of the practicality of using cargo type aircraft on long missions over enemy territory. Therefore, for the purposes of this study, no units of the Tactical Air Forces are considered to have a capability for the delivery of either BW or CW anticrop agents.

CAPACITY OF PROGRAMMED AIRCRAFT TYPES FOR ANTICROP MUNITIONS AVAILABLE IN 1954

94. Table XI lists the carrying capacity of programmed aircraft types for anticrop munitions expected to be available in mid-1954. The bomb capacity is given under two sets of conditions. The first condition considers the maximum load of the aircraft and is limited only by allowable weight or space requirements. This represents a sacrifice in fuel load in favor of the bomb load. The second set of conditions gives a sample mission in which the fuel load has been increased at a sacrifice in allowable bomb load as developed in the basic mission outlined in the Standard Aircraft Characteristics Handbook.

95. In the case of the B-50 the basic mission reflects the use of a bomb-bay fuel tank with the pay load restricted to the capacity of one bomb bay.

Aircraft Characteristics

96. The characteristics of those aircraft types considered available for the delivery of anticrop BW-CW munitions are discussed in detail in Enclosure "C", Chapter II.

TABLE XI

CARRYING CAPACITY OF AIRCRAFT TYPES FOR ANTICROP BW-CW MUNITIONS

A/C Type	Max. Bomb Load E-73	Max. Bomb Load E-86	Max. Bomb Load E-27	Max. Bomb Load Spray System	Basic Mission 1/ E-73	Basic Mission 1/ E-86	Basic Mission 1/ E-27	Basic Mission 1/ Spray System
Light Bombers								
B-26	6	6	0	0	6	6	0	0
B-45	27	27	0	0	16	16	0	0
B-57	6	6	0	0	6	6	0	0
Fighter-Bombers								
F-86F	0	0	0	0	0	0	0	0
F-84F	0	0	0	0	0	0	0	0
Strategic Bombers								
B-50D	40 2/	40 2/	2	2	20	20	2	1
B-47B	0	8	0	0	0	8	0	0
B-36F	132 3/	132 3/	0	0	132	132	0	0
Cargo								
C-119				1				1

1/ Basic Mission Reference WADC Report No. 2, Standard Aircraft Characteristics Handbook, Vol. 1, "Green Book", January 1952, SECRET. Bomb load determined by allowable weight and/or Bomb Bay space limitations.

2/ Maximum load can be increased to 56 clusters by loading two clusters on each of 16 bomb stations, according to the Armament Section, Wright Field.

3/ Maximum load can be increased to 248 clusters by loading two clusters on each of 116 bomb stations, according to the Armament Section, Wright Field.

DELIVERY OF CLUSTERED BW MUNITIONS

97. As indicated in Enclosure "C", Chapter II, the United States Air Force has placed the responsibility for the development of an anticrop BW delivery capability on the Strategic Air Command. The Tactical Air Forces have a potential for anticrop BW delivery but no munitions will be available for fighter-bomber delivery. Further, the limited capacity of the programmed light bomber aircraft prevents a significant contribution in the delivery of an anticrop campaign. In the Strategic Air Command the delivery capability is limited to those units equipped with the B-50, B-29 and B-36 aircraft, inasmuch as there is no known method of dropping the E-73 or the E-86 from the B-47 due to its high speed. The B-36 is capable of carrying a large payload of the clustered munitions; however, this is the only

bomber capable of attacking the USSR from North American bases without refueling, a degree of flexibility which may cause it to be reserved for missions where such a characteristic is essential. Based on present USAF plans, it appears reasonable to assume that the bulk of an anticrop campaign would be carried out by those units of SAC equipped with the B-50/B-29 type. Since the B-50 will be present in combat-ready units in much greater numbers than the older B-29, it is assumed for the purpose of this problem that the anticrop BW attack will be delivered by the B-50 units except for the strikes on the areas east of the Urals where the B-36 will be needed to meet the range requirements.

98. In accordance with existing base programs, the USAF will have medium bomber bases in the UK, North Africa and Saudi Arabia capable of supporting the anticrop BW campaign. The North African medium bomber bases include those in the French Moroccan complex, a base at Tripoli and a base at Cairo. From the UK bases the B-50 can reach, with minor exceptions, the target area west of the Urals with a full bomb load of fifty-six (56) E-73 bombs. Approximately 14 per cent of the B-50 sorties west of the Urals would require the use of bomb bay fuel, thereby reducing the bomb load by one-half. Should the base area in the vicinity of Cairo not be available, an additional 4 per cent of the B-50 sorties would require the use of one bomb bay for fuel. There are advantages in basing the medium bombers in the Cairo area apart from the decreased sortie requirements. The sortie requirements for the anticrop attack are computed under two sets of conditions; one assuming the availability of the Cairo base and the other assuming that the Cairo base is not available. The B-36 can attack the area east of the Urals with a full bomb load taking off from Alaska, Greenland, or Iceland and landing after the attack in the UK or North Africa.

99. In answer to the query from WSEG with respect to the tactics which would be used in the delivery of an anticrop BW attack, the Air Force opinion was stated as follows: 5/

> ". . . It is the intent of those responsible for USAF operations and development that BW munitions will not dictate any deviation from normal flight profiles."

100. The "normal flight profiles" in strategic bombing of the USSR call for high altitude penetration and attack; therefore, it is anticipated that an attempt would be made to penetrate and bomb at altitudes of 30,000 to 35,000 feet with the B-50 and 35,000 to 40,000 feet with the B-36. In cases where range requirements would not permit the entire course of flight over enemy territory to be flown at these altitudes, the penetration of perimeter defenses might be flown at minimum altitudes with the climb to bombing altitude conducted in areas away from organized air defense systems. It can be expected that steps would be taken to avoid the local defenses of those important Soviet targets that fall within the target areas.

101. The anticrop campaign developed in Encl. "D", Chap. V, would require one E-73 cluster per each 100 square miles of the target area. One possible method of obtaining this uniform coverage in an attack would be to break down the target area into 100 square mile grids. Flight paths of attacking aircraft could be planned ten miles apart with an E-73 cluster released at each ten mile interval along this flight path. For aircraft crews trained for the attack of strategic targets within the USSR the navigation involved in such a plan of attack should not present any unusual difficulties.

102. In accordance with accepted strategic bombing practices as many aircraft as possible would be scheduled to penetrate to the target area simultaneously so as to contribute to the saturation and confusion of enemy defenses. The nature of the

5/ Ltr., Deputy Chief of Staff, Operations, Subject: BW Logistic Capabilities. TOP SECRET.

mission would require that the aircraft attack individually; therefore, it is reasonable to expect that the attack would take place during hours of darkness. For the most part, the nights are of sufficient length at the time of the year when the crops are vulnerable to attack to permit the attack to be carried out during hours of darkness. However, in the White Russian region, latitude 57° to 52°, which is bombed about 5 May, there are 2 to 4 hours of darkness at 30,000 feet. In the area just south of Moscow, latitude 55° to 52° which is bombed 15 May, there are 0 to 2 hours of darkness at 30,000 feet. At Sea level in this region on this date, there are 3 to 4 hours of darkness. Since anti-aircraft artillery can be avoided in the anticrop campaign, there is no objection to flying low. It is therefore assumed that all operations involving B-50's can be carried out under cover of darkness, since there are at least 2 to 4 hours of darkness; the northern part of the region can be bombed and withdrawal made to the South.