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(WE-48)

Effects of A.W.

EFFECT OF SUPERWEAPONS

UPON THE

CLIMATE OF THE WORLD

A PRELIMINARY STUDY

Classification changed to Unclassified
by authority of the U.S.D.O.E.,

Per M. Pautrat, TSM, OS-6 5/13/94
(Sig. of person authorizing change, title, org., date)

E M Sandoval, TSM, OS-6, 5-13-94
(Sig. of second reviewer, title, organization, date)

Air Force concurrence contained in memo from Col. J.C. Butler to M. Pautrat, 3 May 94.

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I. GENERAL:

From a study of the reddish-brown corona observed around the sun for two or three years after the volcanic eruptions of Krakatoa in 1883, Mont Pelee' and Santa Maria in 1902, and Katmai in 1912, astronomers observed a significant reduction in the solar radiation. Humphreys (1) calculated that if 1.734×10^{24} particles of 1.85 micron diameter are distributed throughout the isothermal region of the atmosphere, there would be a 10 to 20% reduction in the solar radiation, and that if this is continued over a period of time, it would reduce the surface temperature of the earth by several degrees, thus producing a general cooling of the earth's climate. It was calculated that if major volcanic eruptions occur once every year, or even once every two years over a period of time, the snow line may be depressed significantly and produce a moderate ice age.

II. PURPOSE:

A. Investigate validity of Volcanic Climate Theory.

B. Determine whether Superweapons can effect the climate of the world.

III. VALIDITY OF VOLCANIC CLIMATE THEORY:

There are many theories which try to explain climatic changes of the world. Some of these will be mentioned in brief in order to explain why the volcanic theory of climate is preferred. First, there is the Carbon Dioxide Theory which states that climate changes according to the amount of carbon dioxide in the atmosphere. It is true that CO_2 absorbs more terrestrial than solar radiation, but absorption is very selective and if the amount of CO_2 in the atmosphere be doubled or halved, there would be only a slight alteration in the surface temperature (approximately one degree Centigrade). Second, we have the Topographic Theory of climates preferred by some geologists who say that long-range climatic fluctuations are due to geological revolutions that altered the topography of the earth. Dr. Harry Wexler (2.2a) of the U. S. Weather Bureau, in a recent article, points out that the main objection to this idea is that there have been large climatic changes during the last few thousand years in regions of the earth where the topography has been stable. Third, there are those who believe that climatic changes may be due to fluctuations in the sun's energy output, but as Wexler points out the observed energy output of the sun has never varied by the required amount of 10 or 20%. The Volcanic Theory of climate states that the low temperature required for glaciation found in the ice ages was caused by the absorption of solar radiation by volcanic dust distributed uniformly at high levels in the atmosphere. As early as 1784, Benjamin Franklin mentioned the presence of volcanic dust in the atmosphere and related it to the cold winter of 1783-1784. The Sarasins of Switzerland suggested that low temperatures were due to absorption of solar radiation by volcanic dust. Humphreys showed that fine dust particles at high levels shut out solar radiation effectively by diffuse reflection, but that this dust does not hold in as well the longer heat waves radiated back from the ground, thus creating a net loss of radiation. This phenomena is of sufficient importance to warrant a closer study. Three quarters of solar radiation has wave lengths less than 1 micron, and at point of maximum intensity the wave length is less than 0.5 micron. Terrestrial radiation has a wave length of approximately 12 microns at its point of maximum intensity. The cube of solar wave length is small compared to the volume occupied by a volcanic dust particle which has a diameter of 1.85 micron, but the cube of terrestrial wave length is large compared to the same dust particle. Then, as Lord Rayleigh has shown, solar radiation will be diffusely reflected by the volcanic dust, but terrestrial radiation will be randomly scattered. The following relations apply:

$$I_x = I e^{-2 n p r^2 x} \qquad \text{(for reflection)..........Eqn 1}$$

$$E_y = E e^{-11 p^3 n y V^2 / a^4} \qquad \text{(for scatter).............Eqn 2}$$

Where x and y are distances of uniformly dusty regions. I and E are initial intensities of solar and terrestrial radiation respectively.

I_x and E_y are intensities after radiation has passed through a uniformly dusty region.

n = number of particles in the dusty layer

r = radius of particles

V = volume of a single particle

a = wave length

p = 3.1416

From Equations one and two we get:

$$y/x = 2\, a^4\, r^2 / 11\, p^2\, V^2 = 30 \quad \text{approximately}$$

This means that a layer of volcanic dust of 1.85 micron diameter in the atmosphere is thirty fold more effective in shutting solar radiation out than it is in keeping terrestrial radiation in. This is in reality an inverse Greenhouse effect which would ultimately lower the equilibrium temperature of the surface of the earth if the dusty layer is maintained aloft indefinitely. Particles with diameters in the order of one half of sun's wave length or less shut out the solar radiation very much more effectively. This is because in the case of particles with such small diameters (0.2 micron or less) both solar and terrestrial radiation is randomly scattered and as Lord Rayleigh has shown, such scatter is proportional to the inverse fourth power of the wave length of radiation concerned (see Equation 2). Theoretically this would shut out the solar radiation approximately 332,000 times as effectively as it would shut out terrestrial radiation, since $12^4/0.5^4 = 3.32 \times 10^5$. The usefulness of this factor will be discussed in other parts of this report. Wexler is of the opinion that Humphreys' Volcanic Climate Theory is the correct one because of the striking fact that since 1912 no major volcanic explosion has occurred in the Northern Hemisphere and during this period the winters have been warmer. No other theory of climate can explain this marked warming, and since this trend marched on through three full sunspot cycles, the warming cannot be attributed to changes in the sun. Wexler also points out that volcanic dust particles may reduce the "sunfall" by acting as nuclei for the formation of ice clouds. This hypothesis is based upon the recent discovery that dust particles can act as nuclei to form ice crystals in subfreezing air saturated with water vapor. Astronomers measured a maximum reduction of 20% in the radiation of the sun due to the Katmai volcanic eruption in 1912. From a study of the reddish-brown corona around the sun the diameter of the dust particles was calculated to be 1.85 micron and the total number of particles was calculated to be 1.734×10^{24}. If it is assumed that all these particles are apherical and their density is 3 gm/cm^3 then total weight of these particles required aloft is 1.7×10^{13} gm. It should be noted that if the particles are 1.85 micron in diameter it would take approximately two years (1.8 years) for such particles to reach the ground from 100,000 ft. This is based upon Stokes' Law as altered by the Cunningham correction factor. According to the latest estimates, clouds from megaton yield weapons are expected to reach heights of from 70,000 to 150,000 ft. with some people speculating on the possibility of venting the atmosphere if hundreds of megatons of yield are obtained. If the average particle size is 0.25 micron then Stokes' Law does not apply since this dust would not settle out even in one century, but dust of such small size will be subjected to Brownian motion and of course to atmospheric turbulence. It may be assumed therefore that any dust of 0.2 micron diameter in the isothermal region of the atmosphere will probably remain there except as effected by atmospheric circulation.

IV. EFFECT OF SUPERWEAPONS UPON THE CLIMATE OF THE WORLD:

If a simple comparison is made between the amount of material ejected from the major volcanoes and that from atomic bombs (even of megaton yields) it is at once evident that volcanoes eject far more material into the atmosphere. Although no accurate figures exist it has been variously estimated that 13 cubic miles disappeared during Krakatoa, and from 1 to 5 cubic miles of material was ejected from Katmai volcano in 1912. Some of these volcanoes lasted over a period of days or weeks with variations in the intensity of explosions. There is no doubt that large volcanoes eject much more total mass into the atmosphere as compared to any man made explosion. However, it may be that volcanoes are not efficient in this matter, in that they waste a very large amount of their total output in the lower layers of the atmosphere. It should be noted that to produce major effects on climate the volcano must throw high into the atmosphere (100,000 ft.) fine material (average diameter of 2 microns or less) that will stay aloft for long periods of time.

A. Crater Size Produced by Superweapons

In order to make a start in evaluating whether superweapons can effect the climate, an estimate must be made of the amount of material they eject by studying the crater size. Preliminary Report of Operation Jangle (2) gives the apparent crater volume of the underground shot as 57,000 cubic yards and that for the surface shot as 2140 cubic yards. Engineering Research Associates (9) reported that the ratio of true crater depth to apparent crater depth is 1.282 for underground and 1.715 for surface when 320,000 lbs. of TNT was exploded on the surface or 35 ft. underground at Dugway Proving Ground. This indicates that the true crater volumes for the Jangle underground and surface shots should be approximately 73,000 and 3670 cubic yards respectively.

B. Percent of Crater Material Present in the Atomic Cloud

At the present time there is no adequate method of calculating the amount of dust that will be sucked up into the cloud when superweapons are exploded on the surface or underground. However, an attempt will be made to evaluate the order of magnitude of the material sucked up in an atomic cloud in order to determine whether there is a possibility of superweapons affecting the climate of the world.

(1) Percent of Material Deposited on Lip or Returned to Crater

It was thought that some information could be obtained by noting the amount of material returned to the crater and that deposited on the lip. 57% of the true crater volume was returned to the lip or crater in the underground Jangle Shot while the amount returned during Jangle Surface shot was 50%. An attempt was made to determine the total amount of fall-out beyond the lip of the crater, but the fall-out was found to be assymetric and the information available (5) was inadequate. It should be noted that when an attempt was made to calculate the amount of material thrown out during HE tests at Dugway (8) by subtracting from the true crater volume the volume of material that fell back into the crater and onto the lip, the volume came out negative even when allowance was made for density differences. This is apparently due to the fact that the lip consists of both fall-out and push-out material. In view of the unknown value of the push-out material, this approach to the problem was abandoned.

(2) Particle Size Distribution in the Throw-out

Soil Analysis of Jangle area at Nevada Proving Grounds (5) shows that approximately 5 to 10% of the soil has diameters of 2 microns or less. However when the soil was elutriated (8a) and collected on molecular filters, it was shown that 76% of the particles were 2 microns in diameter or less (see Table I for more detailed analysis of Particle Size Distribution). A study of the Particle Size in the cloud from TNT explosions at Dugway Proving Ground shows that 97% of Particles are less than 2 microns, 94% are less than 1 micron and approximately 25% are less than 0.2 microns. Bouton

(10) studied the dust at Frenchman's Flats, a dry lake at Nevada Proving Grounds. This dust was that generated by thermal radiation prior to the arrival of the shock wave from Tumbler/Able shot. Bouton reports that the particle size distribution at NPG is similar to that reported for Dugway Proving Grounds. Vincent Salmon (4) predicted in November 1951 that the throw-out from Jangle underground would be 30,000 tons of which 2000 tons would be below 1 micron diameter based on a laboratory analysis. This indicates that 6.5 percent by weight of the throw-out would be 1 micron or less in diameter. It is assumed that if 1.7×10^{24} particles of approximately 2 micron diameter are distributed in the atmosphere, the solar radiation will be reduced 10 to 20 per cent. If this is true, then from Rayleigh's relation it follows that only 1/330,000 of 1.7×10^{24} particles of 0.3 micron diameter are required to reduce solar radiation by the same amount (See equations 1 and 2).

(3) Estimates of Particle Concentration in the Atomic Cloud from Superweapons Exploded on the Surface or Underground

At the present time there is practically no information on the concentration of soil in the atomic cloud from surface and sub-surface shots. However, some information exists on this matter with respect to clouds produced by TNT explosions at Dugway and NPG. This information is contained in Table II and is obtained from references 8 and 8a. According to Reference 8, if the cloud from 320,000 lbs. of TNT exploded 35 ft. underground at Dugway Proving Ground is assumed to be a cylinder which is 3000 ft. high and 2000 ft. in diameter, then total weight of particulate material in the cloud would be 46,000 lbs. provided the soil density is 3 gm/cm^3. This uses a particle concentration of 2300 particles/cm^3 air, hence it applies to the stabilized cloud. If we assume that the true crater dimensions are 252 ft. in diameter and 77 ft. in depth, then the true volume of the crater is 1.9×10^6 cubic feet if the crater is a paraboloid. The total contents of the crater would then weigh 3.6×10^8 lbs. Hence approximately 0.013% by wt. of the total crater material is present in the TNT cloud after it is stabilized. Further calculation shows that the particle size in the cloud is assumed to be from 0.6 micron to 0.7 micron if all particles are spherical, and the total number of particles in the cloud comes out to be 6×10^{18}. On the basis of information contained in Tables I and II and using the cube root scaling law and the Jangle cloud data it is possible to obtain an estimate of the number of particles in clouds of superweapons, and the values obtained are given in Tables III and IV. Inspection of Tables III and IV shows that the atomic cloud from a 2 to 3 Megaton Superweapon contains approximately 4×10^{22} soil particles if exploded on the surface and 3×10^{23} particles if exploded underground for particles which are 0.3 micron or less in diameter. However, it would be unrealistic to assume that all of the 0.3 micron particles in the stabilized atomic cloud would reach the isothermal region of the atmosphere. It will be assumed that only 10% of the 0.3 micron particles in the atomic cloud reach the necessary high altitudes.

This means that 4×10^{21} particles of 0.3 micron diameter from the surface and 3×10^{22} particles from the underground shot will reach the stratosphere. It has been assumed that 1.5×10^{20} particles of 0.3 micron size are required to reduce solar radiation by 10 to 20%. Even if this assumption is in error by a factor of 10 or even by a factor of 100, superweapons of 10 to 100 megatons still have the capability of reducing solar radiation significantly if exploded on the surface or underground. If superweapons are exploded in the air instead of on the surface or sub-surface, they will have no effect on the climate of the world as far as the dust factor is concerned. It is also assumed that the atomic cloud will rise up to heights of 70,000 to 100,000 ft. m.s.l.

V. SUMMARY AND CONCLUSIONS:

A. It is assumed that if approximately 2×10^{24} to 2×10^{26} volcanic ash particles of 2 micron diameter are distributed in the isothermal region of the atmosphere, solar radiation will be reduced by 10 to 20%. If the atmosphere is filled with such an amount of volcanic ash once every year or even once every two years over a long period of time, the surface temperature of the earth may be reduced by several degrees resulting in a general cooling of the hemisphere.

B. It is calculated that if superweapons of 10 to 100 megaton energy yield are exploded on the surface or underground in dry clay or sandy type of soil, a sufficient amount of 0.3 micron soil particles will be ejected into the isothermal region of the atmosphere to reduce the solar radiation by approximately 10 or 20%. If such superweapons are exploded once every six months over a period of time, it may be possible to reduce the surface temperature sufficiently to depress the snow line and to increase the general cloudiness. Thus it may be possible that a general cooling of the climate of the Northern Hemisphere is within the reach of man.

C. Since it is not possible at the present time to compare the soil of Eniwetok with that at Nevada Proving Ground or at Dugway, no statements can be made concerning the effect of superweapons exploded on the surface in the Pacific Islands.

D. If it is at all possible to lower the surface temperature of the earth, thus bringing on a general cooling, this effect probably cannot be confined to any one region or country.

E. It will be difficult to evaluate experimentally the amount of dust thrown out into the stratosphere from superweapons exploded on the surface or underground. This is because sample collecting methods at heights of 100,000 ft. have not yet been developed, and also because of the low order of collection efficiency for particles which have diameters less than one micron. However, it may be possible to make some indirect measurements. For instance, a change in sky brightness or a reduction in the solar radiation may be anticipated.

VI. RECOMMENDATIONS:

A. Every attempt should be made to determine the particle concentration in the atomic cloud produced by the Mike Shot of IVY in order to determine the validity of the calculations contained in Table III of this preliminary report. Program 5.4b of IVY may shed some light in this matter.

B. Experts in the field of atmospheric radiation should be asked to check Humphreys' calculations concerning the number of particles of 2 micron diameter required to reduce solar radiation by 10 to 20%. Humphreys calculated that approximately 2 X 10^{24} particles are required. In the present study, it has been assumed that the correct figure is between 2 X 10^{24} to 2 X 10^{26} particles. It is recommended that this range of values be checked.

C. Experiments should be made with scaled values of TNT. Such TNT explosions should be made on different types of soil and the particle size distribution, particle concentration and total number of particles in the cloud from TNT explosions should be determined. Such data should then be scaled to atomic explosions to determine the accuracy of calculations contained in Tables III and IV of this preliminary report.

D. In the event that it is possible to reduce the surface temperature, an attempt should be made to evaluate the effect of such a decrease in temperature upon the countries located in the more northerly latitudes as compared to those countries in the middle latitudes or in the tropics.

E. Different types of soil should be sent to V. Schaeffer or other experts in the field of nucleating agents to determine the relative nucleating properties of the dust that will be ejected aloft by superweapons. This recommendation is based on Dr. Wexler's statements concerning the nucleating properties of volcanic ash (see references 2 and 2a).

F. An attempt should be made to determine the circulation pattern in the level of from 70,000 ft. to 100,000 ft. m.s.l. during November in the latitude of Eniwetok. Once this circulation pattern is established, action should be taken to determine whether there are any visible evidences of dust aloft from the superweapon that will be exploded at IVY, provided the superweapon at IVY is to be detonated either on the surface or at a height not over 50 ft. from the ground.

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TABLE I

PERCENTAGE OF TOTAL PARTICLES IN EACH SIZE RANGE

PARTICLE DIAMETER IN MICRONS	DISPERSED NPG SOIL		DISPERSED DUGWAY SOIL		CLOUDS FROM TNT EXPLOSIONS AT DUGWAY 1.0 SCALE		0.5 SCALE		0.2 SCALE		AT NPG 0.2 SCALE SURFACE		UNDERGROUND	
	M.F.	IMP.	M.F.	IMP.	M.F.	IMP.	M.F.	IMP.	M.F.	IMP.	M.F.	IMP.	M.F.	IMP.
$<$ 0.05	-	1.4%	-	1.1%	-	20.1%	-	8.6%	-	15.3%	-	-	-	0
0.05-0.1	-	12.6	-	10.3	-	22.5	-	30.7	-	29.5	-	-	-	6.3
0.1-0.2	-	14	-	11.5	-	17.8	-	20.4	-	12.9	-	-	-	19.1
0.2-0.3	-	17.5	-	18.4	-	10.1	-	15	-	14.2	-	-	-	30.2
0.3-0.4	-	10.5	-	16.1	-	5.9	-	6.5	-	10.2	-	-	-	12.7
0.4-0.5	-	8.3	-	11.5	-	5.9	-	3.5	-	5.1	-	-	-	7.9
0.5-0.6	-	-	-	11.5	-	3.6	-	4.3	-	3.4	-	-	-	-
0.5-1.0	-	27.3	-	-	-	-	-	-	-	-	-	-	-	15.8
0.6-0.7	-	-	-	3.4	-	3.6	-	2.2	-	4.7	-	-	-	-
$<$ 0.77	-	-	-	-	78%	-	60	-	79	-	-	-	-	-
0.7-0.8	-	-	-	8.0	-	2.4	-	3.0	-	1.0	-	-	-	-
0.8-0.9	-	-	-	0	-	2.4	-	2.2	-	0.7	-	-	-	-
$<$ 1	60	-	-	-	-	-	-	-	-	-	93	-	83	-
0.9-1.0	-	-	-	2.3	-	1.8	-	1.3	-	0.7	-	-	-	-
0.77-1.54	-	-	-	-	15	-	28	-	13	-	-	-	-	-
1 - 2	16	7.6	-	3.4	-	4.8	-	2.6	-	1.7	3	-	13	7.9
1.54-3.08	-	-	-	-	5	-	10	-	6	-	-	-	-	-
2 - 3	-	0.8	-	1.1	-	0	-	1.7	-	0	-	-	-	0
3 - 4	-	-	-	-	-	0	-	0	-	0	-	-	-	-
2 - 4	14	-	-	-	-	-	-	-	-	-	3	-	4	-
3.08-6.16	-	-	-	-	1.5	-	1.5	-	1.5	-	-	-	-	-
4 - 8	7	0	-	-	-	-	-	-	-	-	3	-	0	-
6.16-9.24	-	-	-	-	0.3	-	0.5	-	0.5	-	-	-	-	-
8 - 12	2	0	-	-	-	-	-	-	-	-	0.5	-	0	-
9.24-12.32	-	-	-	-	0.2	-	0	-	0	-	-	-	-	-
12 - 20	1	0	-	-	-	-	-	-	-	-	0.5	-	0	-

M.F. = Molecular Filter
IMP. = Impactors
1.0 Scale is 320,000 lbs. TNT exploded 35 ft. underground
0.5 Scale is 40,000 lbs. TNT exploded 17 ft. underground
0.2 Scale is 2,560 lbs. TNT exploded 7 ft. underground

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TABLE II

PARTICLE CONCENTRATION IN PARTICLES/CM^3 OF AIR FOR DIAMETERS GREATER THAN 0.3 MICRON

PASS NUMBER	DUGWAY UNDERGROUND SHOTS			N P G SHOTS	
	1.0 SCALE	0.5 SCALE	0.2 SCALE	SURFACE 0.2 SCALE	SUBSURFACE 0.2 SCALE
1	23000	6700	——	5667	——
2	4700	2300	——	1428	——
3	1700	2000	——	113	6992
4	4500	790	——	——	2916
5	3300	860	——	20*	2032
6	1100	740	——	——	1568
7	20	20	——	——	20*

*Blank

First pass was made at approximately two minutes after zero time, and each succeeding pass at intervals of two minutes.

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TABLE III

Atomic Cloud Parameters for Superweapons Exploded on the Surface of Dry Clay or Sandy Type of Soil, Based on Cube Root Scaling Law Using Jangle Surface Data:

JANGLE SURFACE DATA	DATA CALCULATED FOR SUPERWEAPONS EXPLODED ON THE SURFACE	
5500 Particles/cm^3	10,000 Particles/cm^3	Particle Density in cloud for particles greater than 0.3 micron diameter
12,800 Particles/cm^3	23,000 Particles/cm^3	Particle Density in cloud for particles with diameters ~~greater~~ less than 0.3 micron
7146 ft.	90,000 ft.	Height cloud top
2593 ft.	32,700 ft.	Height top stem
780 ft.	10,000	Width stem
1710 ft	21,500	Radius cloud mushroom
3×10^{10} cu. ft.	6×10^{13} cu. ft.	Total volume of cloud
1.3×10^{9} cu. ft.	3×10^{12} cu. ft.	Volume stem
2.75×10^{10} cu. ft.	5.7×10^{13} cu. ft.	Volume mushroom
8.5×10^{18} Particles	1.7×10^{22} Particles	Total number of particles greater than 0.3 micron
2×10^{19} Particles	4×10^{22} Particles	Total number of Particles less than 0.3 micron

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TABLE IV

Atomic Cloud Parameters for Superweapons Exploded Underground in Dry Clay or Sandy Type of Soil, Based on Cube Root Scaling Law Using Underground Data:

JANGLE UNDERGROUND DATA	DATA CALCULATED FOR SUPERWEAPONS EXPLODED UNDERGROUND	
23,000 Particles/cm^3	30,000 Particles/cm^3	Particle Density in Cloud for particles greater than 0.3 micron diameter
57,000 Particles/cm^3	70,000 Particles/cm^3	Particle density in cloud for particles ~~greater~~ less than 0.3 micron diameter
1.2	2.4×10^3	Yield in Kilotons
5000 ft.	60,000 ft.	Height cloud top
8×10^{10} cu. ft.	1.6×10^{14} cu. ft.	Total volume of cloud
5.3×10^{19} Particles	1.3×10^{23} Particles	Total number of particles greater than 0.3 micron
1.3×10^{20} Particles	3×10^{23} Particles	Total number of particles less than 0.3 micron

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