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EFFECTS OF SUPERWEAPONS

UPON THE CLIMATE OF THE WORLD

A SECOND STUDY

NOVEMBER 1952

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Per M. Pautratz, TSM, OS-6 - 5/13/94
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I. GENERAL

A. In September 1952 a preliminary report was prepared on this subject. When the preliminary study was made there was considerable doubt whether the cloud from thermonuclear weapons could pierce the tropopause and rise significantly against the isothermal or inversion lapse rate of the stratosphere. Since practically all of the mushroom of the IVY-MIKE shot penetrated the tropopause and the maximum height reached was 134,000 ft. msl for the plume and 125,000 ft. for the top of the mushroom, there is no longer any doubt that man made explosions can carry aloft to the required heights a considerable quantity of soil debris. The preliminary report used the Rayleigh equations for diffuse reflection and random scatter of radiation by dust particles. Upon further analysis of the problem it is now realized that since a majority of the dust particles under consideration are in the size range as the wave length of visible light, the simple inverse fourth power of the wave length function developed by Rayleigh for radiation scatter must be discarded for the more complete theory developed by Mie (5). In the preliminary report the amount of dust required aloft was divided by the fourth power of the ratio of the wave lengths of terrestrial to solar radiation. It is now realized that such a procedure was not justified. Much of the data contained in the preliminary report will be included in this second study. This may be repetitious, but it will have the advantage of putting the required information in one report.

B. 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 solar radiation (10 to 20%) due to a dust layer aloft. Humphreys (1) calculated that if 1.734×10^{24} spherical particles of 1.85 micron diameter are uniformly distributed throughout the isothermal region of the atmosphere, there would be a significant reduction in solar radiation. If this is continued over a period of time, the surface temperature of the earth would be reduced by several degrees centigrade and this would lead to a general cooling of the earth's climate. Humphreys also maintained that if major volcanic eruptions occur once a year, or even once every two years over a period of time, the snow line may be depressed significantly possibly leading to a moderate ice age. In a recent article Dr. H. Wexler of the U. S. Weather Bureau (3) states that Humphreys volcanic Theory of Climates has considerable merit as compared to the other climatic variation theories.

II. PURPOSE

Determine whether it is possible for superweapons exploded on the surface or underground to eject a sufficient quantity of dust into the stratosphere so as to reduce insolation by 10% to 20%.

III. THE TOTAL QUANTITY OF SOIL EJECTED ALOFT BY SUPERWEAPONS

If a simple comparison is made between the amount of material ejected from the major volcanoes and that from atomic bombs or even from thermonuclear bombs it is at once evident that volcanoes eject far more total 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 were ejected from the Katmai Volcano in 1912. Some of these volcanic eruptions 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, since even megaton weapons could not eject more than a small fraction of one cubic mile of material high into the atmosphere. 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 any persistent lowering of the intensity of solar radiation reaching the surface of the earth, volcanoes must throw out high into the atmosphere (20 to 30 miles high) fine volcanic ash particles that will not settle out over a period of several years. Hence a comparison of the total mass ejected by volcanoes as compared to that ejected by Super-weapons may not be significant. It is more important to determine the heights reached by such particles, and if possible, the particle size distribution of the dust reaching such heights. There is practically no information concerning the amount of dust that may be ejected aloft as a result of exploding superweapons on the surface or underground. According to references (8) and (8a), the cloud produced by 320,000 lbs. of TNT explosion weighed approximately 46,000 lbs. and had a volume of 1×10^{10} cubic feet. This gives the cloud density as 4.6×10^{-6} lbs/cu.ft. However, when a particle size analysis was made, it was determined that there were very few if any particles greater than 3 microns in the cloud sampled and 40% to 70% of the particles collected were below 0.8 micron in size. This means that the 46,000 lb. weight refers to the stabilized cloud and it certainly refers to the weight of very small particles in the cloud. Actually very little reliable data exists on the problem and the whole method of measuring particle sizes is dependent upon the methods used to collect the samples and also upon the method of analysis. For example, in studying the particle size distribution during Operation Jangle (2) it was found that the median particle diameter for gross samples was 0.22 micron when measured under the electron microscope whose limit of resolution is probably two orders of magnitude greater than the 0.5 micron resolving power of the optical microscope, and the median particle diameter of radioactive samples as measured by the optical microscope was 1.4 microns. Reference (8) gives the particle concentrations for the cloud from 1.0, 0.5 and 0.2 scale TNT shots as 2300 particles/cm^3, 6700/cm^3 and 2565/cm^3 respectively. It is assumed from this information that particle concentration in TNT explosion clouds is a function of the total amount of explosive used at scaled depths. It should be noted that 1.0 scale refers to 320,000 lbs. of TNT exploded 35 ft. underground, 0.5 scale refers to 40,000 lbs. TNT exploded 17 ft. underground and 0.2 scale refers to 2560 lbs. exploded 7 ft. underground. These charges and depths of explosion are scaled so that for the three different charges are the same where $\gamma = \frac{d}{W^{1/3}}$, and d= depth of burial of charge in feet, W = weight of TNT in lbs. If explosion cloud density is some function of the amount of high explosive used, then it may be that cloud density is also a function of the equivalent energy yield of atomic or thermonuclear weapons. Of course there is no method of determining the magnitude of such a function except to say that probably cloud density increases with energy yield of the bomb by some factor.

In this report it will be assumed that the cloud density for high yield atomic or thermonuclear bombs in the order of 10 megatons of energy yield, exploded at scaled depths underground would be approximately forty times the cloud density for 1.0 scale TNT explosion mentioned above, and the cloud density for surface explosions would be approximately thirty times the cloud density of the above-mentioned TNT explosion. It will be assumed that the clouds from JANGLE-underground and JANGLE-surface shots have the same cloud density as that for the 1.0 scale TNT shot mentioned above. Under this assumption the stabilized cloud from 1.2 KT JANGLE-underground shot would weigh approximately 4×10^5 lbs., and the JANGLE-surface cloud would weigh approximately 3×10^5 lbs. This means that for a 10 megaton weapon exploded at scaled depth underground, the cloud would weigh approximately 1.6×10^{11} lbs. and for a surface burst the total cloud weight would be approximately 9×10^{10} lbs. It will be further assumed that the numerical median particle diameter in the cloud is 0.6 micron.

IV. REDUCTION OF SOLAR RADIATION BY THE LAYER OF DUST ALOFT

In the Preliminary Report, Rayleigh's Equations for diffuse reflection and random scatter were used. These equations will be mentioned here again so that a ready comparison could be made with the more rigorous treatment of the subject by Mie. Also a computational error was made by Humphreys (1), and this will also be discussed below.

A. Rayleigh's Equations

1. Equation for Random Scatter

If dust particles are smaller than the wave length of visible light then according to Humphreys' text the following equation applies:

$$E_y = E e^{-hy} \quad \text{- - - - - - - - - - - - - - - -Equation 1}$$

Where

$$h = 24\pi^3 \frac{(K' - K)^2}{(K' + 2K)^2} \frac{n V^2}{\lambda^4} \quad \text{- - - -Equation 2}$$

K' = dielectric constant dust particles
K = dielectric constant of medium
V = volume of each particle

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n = concentration of particles in air
E = original intensity of radiation
E_y = intensity after radiation has passed through y cm. of the dusty layer
λ = wave length of radiation
y = distance traversed by radiation in the dusty layer and in a path normal to it

Humphreys assumed that the dielectric constant of the volcanic ash particles was 7. This means that the index of refraction of the particles would be $\sqrt{7}$ which is considered to be quite high. In this study it has been assumed that the dust particles have an index of refraction of 1.55. For index of refraction equal to $\sqrt{7}$, the value of h is as follows:

$$h = 11\pi^3 \frac{V^2}{\lambda^4} n \text{ - - - - - - - - - - - - - Equation 3}$$

For an index of 1.55, h' has the value of

$$h' = 2.1\pi^3 \frac{V^2}{\lambda^4} n \text{ - - - - - - - - - -Equation 4}$$

Humphreys, using the value for h given by Equation 3, calculated that for dust particles of 1.85 micron diameter the solar radiation is shut out 30 times more efficiently than terrestrial radiation, but if the value for h' is substituted it is seen that solar radiation is shut out approximately 160 times more efficiently.

2. Equation for Diffuse Reflection

According to Rayleigh, if the particles are large compared to the wave length of solar radiation, the following equation applies:

$$I_x = I e^{-2\pi r^2 nx} \text{ - - - - - - - - - - - - - -Equation 5}$$

Humphreys used Equation 5 to determine that the total amount of 1.85 micron volcanic dust required aloft is 1.734×10^{24} to reduce solar radiation by 10% when the sun is at the zenith. In checking Humphreys calculations it seems obvious that he must have made a mistake, because if the necessary values are substituted in Equation 5 it turns out that 1.1×10^{25} particles are required aloft.

B. Mie's Theory of Scatter

The complete rigorous theory for the scattering of light by isotropic spherical particles was developed by Mie. The Mie theory leads to rather complex expressions involving infinite series of terms where the series converges more and more slowly as the ratio of the diameter of the spherical particle to the wave length of radiation increases. For spheres of any size the Mie general equations are as follows, given by Sinclair (5):

$$h = \frac{\lambda^2 n}{2\pi} \sum_{n=1}^{\infty} \left(\frac{A_n^2 = P_n^2}{2n+1} \right) \text{ - - - - - - - - - - Equation 6}$$

Where A and P are complex functions of α and m.
m = index of refraction of particles
h = scattering coefficient

For transparent (non-absorbing) spheres, m is real and Equation 6 yields the total amount of light that is taken out of the incident beam. For absorbing particles m is complex and equation 6 yields only that part of the light which is scattered by the spherical particle. For absorbing spherical particles the total amount of light abstracted from the beam (scattered and absorbed) is given by

$$h' = \frac{\lambda^2 n}{2\pi} \text{ REAL-}\left(\sum_{n=1}^{\infty} (-1)^n \, i \, (A_n + P_n) \right) \text{ - - Equation 7}$$

Where
h' = extinction coefficient (scatter and absorbtion coefficient).
"REAL" stands for the real part of the expression in brackets.

Houghton (7) has shown that for a given wave length of light Mie's Equation may be reduced to the following:

$$I = I_o \exp(-\pi x \sum n r^2 K_s) \text{ - - - - - - - - Equation 8}$$

Where
K_s = total area cross-section as calculated by Lowan and Houghton and others. K_s is given as a function of α, where

$$\alpha = \frac{2\pi r}{\lambda}.$$

Even for the relatively simple case under consideration (dielectric spheres) the computational problem of Mie's equations is formidable. Lowan (9) has computed Mie's Equations for α = 0.5 to α = 6.0. H. G. Houghton (7) has calculated the total scattering from non-absorbing water drops whose index of refraction is 4/3 for values of α = 6.0 to α = 24. A study of Mie's equations shows that for particles larger than air molecules the scattering coefficient does not follow such a simple law as the inverse fourth power of the wave length as indicated by Rayleigh (Eqns. 1 and 2), but rather that the scatter coefficient is a complicated function of the ratio of the particle diameter to the wave length of the radiation. As a matter of fact the scattering area coefficient, K_s, versus α curve shows at least two maxima and two minima and according to Houghton probably such maxima and minima continue to oscillate about the value of $K_s = 2$ with decreasing amplitudes. However, such variations of transmission with wave length will be evident only for small α and for monodisperse aerosols. In natural aerosols such as fog and clouds, α is so large and the drop size distribution is so broad that no variation of transmission with λ is expected to be evident. This conclusion is verified by the fact that the sun's disk appears white when viewed through fog or thin clouds. Stratton (6) was able to produce artificial fog in the laboratory using steam and natural nucleating agents found in the air. This fog was composed of water droplets which were considerably smaller than in natural fog. Stratton found a definite variation of transmission with wave length. At $\alpha = 11.2$ and using $\lambda = 0.49$ micron there was a maximum transmission. Hence the radius of the fog particles was calculated to be 0.875. This is a remarkable confirmation of Mie's theory of scatter and an experimental verification of the first minimum in the K_s versus α curve. Since Equation 8 applies only to a given wave length, to obtain the correct value for solar radiation the value of I should be integrated over the range of wave lengths in sunlight. In order to simplify the computational problem, it will be assumed that solar wave length is equal to 0.57 micron. And because it is known that the atomic cloud is not a monodisperse aerosol, probably the Jobst asymptotic curve of K_s versus α would produce more realistic results than the complex K_s versus α curves. If the particle size distribution in the atomic cloud were known with some accuracy, it may be worthwhile to determine I by the summation process indicated in Equation 8 and then to integrate I over the range of λ values. As it is, there is no merit in such a procedure until the particle size distribution in the atomic cloud is better known. It will be assumed that $m = 1.55$, and it will also be assumed that the particles are transparent since the absorbtivity of the dust particles is not known. Under these assumptions K_s may have a maximum value of approximately 4 when α has a value between 3 and 4, and it will be assumed that K_s reduces asymptotically from its maximum value to a value of 2 at $\alpha = 50$.

C. Calculations of the Reduction of Insolation due to the Dust Layer Aloft

It will be assumed that the numerical median particle distribution in the atomic cloud is approximately 0.6 microns in diameter for large yield atomic bombs or thermonuclear weapons (10 megatons) exploded on the surface or underground. However, since the particle size distribution of the atomic bomb cloud is admittedly not known with any high degree of accuracy, calculations

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will be made assuming the numerical median diameter to be 1.85, 1.0, 0.6 and 0.3 microns. The total number of particles required aloft to reduce solar radiation by 10% when the sun is at the zenith is given by the following relations, where it is assumed that the mean solar radiation wave length is 0.57 microns:

$$nxA = \frac{\ln 10 - \ln 9}{\pi r^2 K_s} \quad \text{--------- Equation 9}$$

nx = Number of dust particles of radius, r, in a vertical column of 1 cm^2 cross section in the atmosphere.
A = Surface area of the earth = 5.1×10^{17} cm^2

TABLE I

PARTICLE DIAMETER IN MICRONS	TOTAL NUMBER OF PARTICLES REQUIRED ALOFT TO REDUCE SOLAR RADIATION BY 10%	VALUE OF K_s USED	VALUE OF α USED
1.85 μ	6.7×10^{24}	3	10
1.0	1.7×10^{25}	4	5.5
0.6	5.4×10^{25}	4	3.3
0.3	6.1×10^{26}	1.25	1.65

If it is assumed that the density of dust particles is 3 gm/cm^3, and that all particles are either spherical (a = b = c) or spheroids, where a = 2b = 3c, then the total number of particles in the atomic cloud from 10 megaton weapons exploded on the surface and subsurface is given in Table II below:

TABLE II

10 Megaton Bomb exploded on Surface or Subsurface — Total number of Particles in the atomic cloud assuming spherical and spheroidal particles for the different numerical median particle distribution of the atomic cloud indicated:

	SPHERICAL PARTICLES WHERE a = b = c				SPHEROIDAL PARTICLE WHERE a = 2b = 3c			
	1.85 μ	1.0 μ	0.6 μ	0.3 μ	1.85 μ	1.0 μ	0.6 μ	0.3 μ
Surface Detonation	4×10^{24}	2.6×10^{25}	1.2×10^{26}	9.6×10^{26}	2.5×10^{25}	1.6×10^{26}	7.2×10^{26}	5.8×10^{27}
Sub-Surface Detonation	6.6×10^{24}	4.2×10^{25}	1.9×10^{26}	1.6×10^{27}	4×10^{25}	2.5×10^{26}	1.2×10^{27}	9.3×10^{27}

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V. CONCLUSIONS

Table I indicates the total number of dust particles required aloft to reduce sol· ·adiation by 10% if the sun is at the zenith. Table II shows the est ·ed number of particles ej ·cted aloft by 10 megaton superweapons ·oded on the surface or sub-surface. Hence a comparison of the values obtained by the two tables for a given particle size would indicate whether 10 megaton weapons can have any effect on the world climate. However, the values shown in Table II are based on scaling the cloud density o· 320 000 lb. TNT shot with the cloud density that may be produced by a 20,000,000,000 lb. equivalent TNT shot (10 megaton Superweapon). Certainly scaling over such a large range of values could be in error by a factor of 10 or more. Therefore, although Table II indicates that a 10 megaton weapon is capable of reducing sol· radiation significantly, it would be more realistic to assume that fr· 10 to 100 megaton weapons are required to produce significant reduction of insolation. It should be noted that in the preliminary report it was concluded that Superweapons in the energy yield range of 10 to 100 megatons may be able to effect the climate of the world, and this conclusion remains essentially unaltered despite the more detailed analysis of the radiation scatter problem presented in this study. Since it would take several years for 0.6 micron particles to fall to the ground from 100,000 ft. then it is assumed that if 10 to 100 megaton weap· are exploded on the surface or underground once every few years, they ·y still be able to reduce solar radiation. In order to have any confider· in the assumed density of the explosion clouds an attempt should be m· to sample atomic clouds to obtain the total number of particles p· ·unit volume of the cloud. After such experimental data is available, i· will be possible to evaluate this report in more realistic terms. It is recommended that an attempt be made to determine the total particle concentration in a TNT explosion cloud using different amounts of high explosives at a given depth of charge burial or exploding the different amounts of TNT on the surface. This recommendation is made to determine the change in total particle concentration of an explosion cloud with different amounts of high explosives used. In order to simplify the problem of determining particle concentrations it is suggested that relatively large amounts of TNT be employed. For example, 160,000 lbs., 320,000 lbs. and 640,000 lbs. of TNT may be used at a given depth of burial, say 17 ft. underground, or all three of them may be exploded on the surface. If the cloud concentration increases perceptibly with increase in charge, then the assumptions made in this report may be justified. However, if there is no marked change in cloud ·oncentration from the three different charges of TNT menti· ·d above, then ·e estimates made in this study will have to be reduced b· factor of approximately 50 or 100.

~~Atomic Energy Act 1946~~

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