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1. In considering the efficiency of scavenging by rain-fall, this report introduces a line of reasoning about A-bomb cloud characteristics which is, so far as I know, entirely new, and which leads the authors to the important conclusion that rain will carry down nearly 100% of the activity in the rain cloud. The line of reasoning is quite convincing up to a certain point, after which it becomes rather unconvincing because of a number of uncertainties which are not mentioned. Since the problem is of considerable interest to us, I am here recording some order-of-magnitude calculations which seem to me to throw somewhat more light on the phenomena than is easily obtainable from a casual reading of subject report.

2. In brief, the reasoning on this topic in the AFSWP Report runs as follows: Since the cloud remains visible as it completes its rise, it must contain much condensed moisture, which will probably be condensed mainly on active particles, and which will be readily scavenged.

3. Harry Schulte and I have discussed the question of condensation, as supported by the visibility argument, and are satisfied that the evidence is very strong. Observed cloud volumes are roughly proportional to bomb yield, while the total mass of different models does not vary a great deal. Low yield bombs therefore should give higher concentrations of original material in the final observed cloud (near the end of its rise). For bombs with yields in the range 1 - 100 KT, one calculates final concentrations in the range 10^{-11} to 10^{-13} g/cc. Since a concentration on the order of 10^{-8} g/cc is needed to make a dust cloud visible, it is certain that what one sees finally is not the cloud of bomb debris.

4. If this argument is accepted, it is then easy to conclude that a cloud of condensed moisture forms an important part of what one observes, and it is easy to picture the formation of this cloud by the upsurge of warm moist air into the colder levels. (It is interesting to note that the thermal energy released by this condensation may be of about the same order of magnitude as the yield of the bomb, so that one might expect cloud height to depend on the humidity patterns in the atmosphere). This does not, however, explain the pinkish or brownish tinge of the cloud which, I think most observers would agree, persists at least until the cloud stops rising. The presence of this coloration, generally believed to be due to oxides of nitrogen, introduces considerable

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T. L. Shipman, H-DO 7 July 1953

uncertainty into the next stage of the reasoning in the AFSWP Report - the statement that most of the condensation will probably be on radioactive particles.

5. The following passages are excerpted from "The Microphysics of Clouds", by B. J. Mason and F. H. Ludlam, in Reports on Progress in Physics, Vol. XIV, 1951 (Ref. 27 in the AFSWP Report):

p. 158 "The evidence then, although by no means conclusive, suggests that the most important nuclei for atmospheric condensation are hygroscopic in nature and are of two main types - salt nuclei derived from sea spray and maybe from desert regions, and acid nuclei produced by combustion. - - - The larger and more efficient nuclei are almost certainly sea salt. - - - - Mean concentration of salt nuclei in country air remote from industrial areas is about 200/cc.

p. 157 "Large numbers of new (condensation) nuclei were produced whatever the source of heat - even when pure absolute alcohol was burned and when a clean platinum surface was heated electrically in air previously freed from nuclei and SO_2. - - - - Coste and Wright suggested that the nuclei so produced consisted of nitrous acid formed from the nitrogen, oxygen and water vapour of the air according to the following reactions:

$$N_2 + O_2 = 2NO \text{ (above } 620^\circ C)$$

$$2NO + O_2 = 2NO_2 \text{ (}620^\circ C \text{ to } 140^\circ C)$$

$$NO + NO_2 + H_2O = 2HNO_2$$

They were able to detect the presence of nitrous acid in their chamber after combustion had occurred, and from the simultaneous presence of the acid and the nuclei they suggested their identity. Further support comes from the fact that traces of nitrous acid have been detected in rain water - - - -

p. 158 - - - - Non-hygroscopic nuclei may be quite important if there are only a few hygroscopic ones available, and will have a higher probability of being activated in convective clouds in which higher peak super saturations are reached. - - - -

6. The mass of oxides of nitrogen formed by a nominal bomb is estimated in "The Effects of Atomic Weapons" as on the order of 100 tons. This gives a final cloud concentration on the order of 10^{-10} to 10^{-11} g/cc, which seems somewhat low for visibility in the presence of say 10^{-5} to 10^{-6} g/cc of condensed moisture. It seems fairly safe to conclude that the concentration of oxides of nitrogen is at least 10^2 to 10^4 times that of the bomb debris in the cloud.

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T. L. Shipman, H-DO 7 July 1953

7. One is then led to suspect that much of the condensation may occur on nuclei formed from the oxides of nitrogen rather than on bomb debris. How the authors arrive at an estimate of 20 - 30 microns droplet size is not clear. (It is from this size, coupled with other information, that they conclude that scavenging by rain may be quite efficient). If one takes one micron as the average particle size of bomb debris, and assumes that moisture condenses on this only, then a droplet size in the range 10 - 100 microns comes quite reasonably out of the preceding estimates. However, in the presence of competition from other condensation nuclei, it is not clear what one should expect. In the absence of competition, and within the range of stable growth, it appears that the growth of nuclei (expressed as proportional increase in radius) with increasing relative humidity does not depend very much on particle size (Compendium of Meteorology, p. 185). If one assumes that as the cloud rises, the increase in humidity is rapid enough so that all nuclei (not just the most efficient) will grow and that the same rule applies in the unstable region (if attained), then it follows that the mass of water condensed is partitioned in accordance with the total mass concentration of particles of each particular size. It then follows that at least 10^2 to 10^4 times as much moisture would condense on the nitrogen products as on bomb debris, leading to a droplet size for the active particles that would not be readily scavenged. This reasoning is certainly not convincing, but I think it is as plausible as that followed in the report.

8. I think that the authors have taken the only safe course in assuming 100% scavenging, but I also think that the validity of this assumption is considerably more doubtful than one would gather from reading the report.

9. I agree most heartily with the authors' conclusion that there is no need at this time for a full scale atomic weapons test in the rain.

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3