RADIATIVE PROCESSES IN THE EARTH'S ATMOSPHERE RESULTING FROM COMET IMPACT; I.V.Nemchinov and V.V.Svetsov, Institute of Earth Physics, USSR Academy of Sciences, Moscow

The evolution of the Earth was accompanied by numerous impacts of massive cosmic bodies. The impact of comets seems to play an important role in these global catastrophes. The recent hypotheses about comet showers with periods of 30-32 million years are well known (1). But although the problem of crater formation has long attracted great attention, the phenomena occuring in the atmosphere after a high energy blow have not been much investigated.

Impact processes essentially depend on the ratio of the density of a cosmic body to the density of the Earth's surface materials. If the impacting body has a low density a wave will propagate into the Earth with rather low amplitude and only a small portion of the energy will be imparted to the Earth. The main part of the energy is partitioned into the vapour of the impactor. Indeed, if the body is initially porous with a density from 0.1 to 0.3 g/cm^3 (from estimates of the mean density of a comet nucleus (1)) the final density after shock compression will be in the range 0.4-1.5 g/cm^3, that is, lower than the density of a solid body without pores. Consequently, the elastic part of the energy in the compressed body is not great, and the major part of the internal energy is thermal. The movement of this substance can be regarded as a hydrodynamic flow.

The mass and temperature of the vapour injected into the atmosphere depend not only on the density of the impacting body, but also on its velocity. Exact determination of the parameters describing vaporization in the impact requires consideration of the vaporization along with the crater formation and ejecta dynamics. This was done in (2) where the internal energy of a 0.1 g/cm^3 icy cometary nucleus was found to exceed 70% of the initial kinetic energy for an impact velocity 15 km/s. Greater velocities of up to 45 km/s were considered but data on the temperature field wasn't presented. In calculations (3) the vapourized material possessed 10% of the energy of the cosmic body and its temperature was lower than 1 eV for velocities under 20 km/s and equal densities of the body and the target. Nevertheless, at higher speeds up to 70 km/s and lower impactor densities the temperature would be substantially greater.

We didn't consider here the impact itself and treated the parameters of the vaporized substance ejected into the atmosphere approximately. We consider the idealized process in which a certain small part of the body gives all of its energy to the Earth while the remaining part of the body is instantly vaporized, all of its kinetic energy being converted into internal energy of the plasma. The initial quantity of internal energy was taken to equal 2.5 MJ/g, corresponding to a velocity of the body of about 70 km/s.

Two values of vapour mass $0.8 \cdot 10^{12}$ kg and $0.8 \cdot 10^{10}$ kg have been taken into consideration. These amounts of plasma would occupy volumes restricted by hemispheres with radii equal to 1.1 km and 230 m if the density equals 0.3 g/cm^3. This can be imagined as an impact of a small comet or a comet fragment. The total internal energy of the plasma at this conditions reaches $2 \cdot 10^{21}$J and $2 \cdot 10^{19}$J, respectively. Evidently, a solution of this idealized problem weakly depends on the chosen initial vapour density, the initial temperature is the more important parameter.

As soon as the mass of the air in the motion is larger than the mass of the vapour, the whole problem can be reduced to the study of the explosion dynamics in non-uniform atmosphere. Explosions with energies of several orders smaller magnitude were investigated in detail sufficiently long time ago (4). The main features of this phenomenon will be conserved in the process of the comet plasma jet interaction with the atmosphere. But it is rather difficult to obtain a numerical solution of two-dimensional gas dynamics equations combined with the equation of radiation transfer. Indeed, optical thickness of the plasma volume alters from the black body limit to the limit of free emission at the late stage of expansion, and spectral dependences of opacities are complicated. A calculation procedure would be therefore too expensive for preliminary results.

At this first step of the problem solution we didn't try to achieve a very good accuracy and obtained numerical results in the so called sector approximation. This means that the flow region is mentally divided into sectors with vertices in the middle of the initial hemisphere, and the gas motion in each sector is regarded to be independent of all the others. Then a solution of the entire task can be reduced to the computation of separate one-dimensional spherically symmetric problems for a set of chosen directions with the appropriate atmospheric parameter change along these directions. This approach is evidently valid to a certain limit defined by the moment when the gas motion begins to differ critically from a spherically symmetric flow. It should be noted that the optical and thermodynamical properties of the comet plasma were taken to coincide with those of the air. Data on the air properties were taken from (5).

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Figure 1 shows the computational results obtained for explosion with energy $2\cdot10^{21}$J and mass $0.8\cdot10^{12}$kg. The explosion develops in the atmosphere in such a way that at the beginning of the expansion the vapour velocity exceeds the comet velocity before the impact. While the vapour acts as a piston, the air is heated in the shock and in the thermal radiative wave. Two seconds after the blow when the shock reaches the height of 50 km, a movement in the vertical direction becomes analogous to that of a jet exhausting into vacuum. Reduction of density and opacity of the expanding plasma causes a growth of the radiative flux. In 5 s the vertical dimension of the comet plasma plume is about 140 km. The vapour edge velocity in 10 s is about 10 km/s, that is, the comet material does not escape the Earth gravitation.

Effective radiation process from the air plasma and the comet material plasma comes into action 1 or 2 seconds after the blow when the temperature behind the air shock front is less than 1.5 eV, and in 10 s this process comes to an end. The part of the energy lost by the plasma in the form of radiation proved to be about 20% of the initial plasma energy adopted. For the smaller explosion energy $2\cdot10^{19}$J, and a respectively smaller vapour mass, the flow does not differ essentially. The dimensions of the plasma plume are correspondingly smaller, and the energy losses by radiation are equal to the same 20% of the initial plasma energy.

Since energy losses by radiation take place mainly from the regions where the temperature values are about 1 eV or less, the radiation spectra are in the the range of transparency for the cold atmosphere. Radiation flux appears to be so great that the energy absorbed by the unit area exceeds value of 100 J/cm^2 all over the surface of direct vision of the comet plasma plume. This value of 100 J/cm^2 can be adopted as a threshold for the fire starting.

As it can be seen from figure 1, the mean height of the plasma volume, throughout the time interval of intensive radiation, is about 100 km. For the less energy of the explosion $2\cdot10^{19}$J this mean height of the plasma plume is about 15 km. The magnitudes of direct vision radii proved to be equal to 1100 km and 440 km for the two explosion energies considered.

So, as a result of the high speed comet impact, fires can arise on the area with characteristic dimension of the order of 1000 km, that is, almost the size of a continent. If this is the case, the total mass of the burnt material and the released chemical energy on the area of the first ignition only would far exceed the mass and the energy of the comet. Hence, the quantity of smoke and soot aerosol ejected into the atmosphere would be essentially greater than it is proposed in the nuclear winter scenarios (6). These catastrophic phenomena connected with the global change of the climate could be a reason for the biological crises of the past.

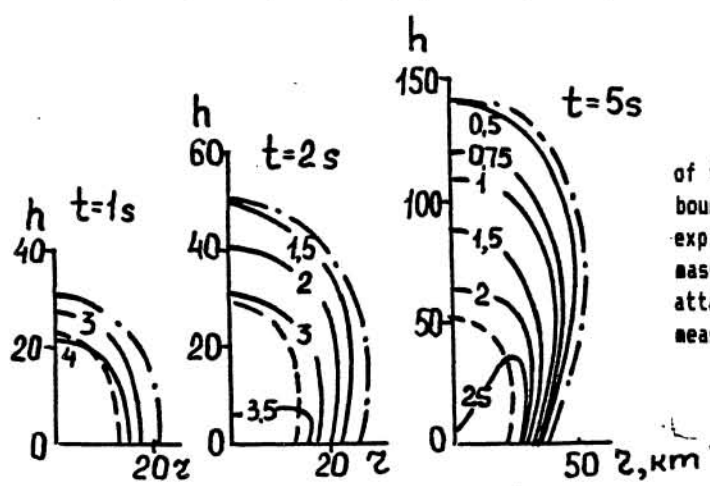

Figure 1. Isotems (solid lines), positions of the shock wave (dashed-dotted) and the vapour boundary (dashed curves) 1, 2 and 5 s after the explosion with the energy $2\cdot10^{21}$J, the initial mass of the comet plasma equals $0.8\cdot10^{12}$ kg. The attached numbers indicate the temperature values measured in eV.

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