sity gradient centrifugation, only the nuclear fraction was able to synthesize viral RNA. Other published evidence has suggested that the nuclei are the site of viral RNA synthesis (*5*).

We have also found that the effectiveness of the nuclear fraction in synthesizing viral RNA can be greatly enhanced if the nuclear membranes are ruptured by ultrasonic treatments. In one experiment synthesis jumped from 10 percent to 116 percent above that of the control when the membranes were ruptured.

Preliminary reports on the biosynthesis of viral RNA described in this report have been published elsewhere (*6*). Our conclusions regarding such biosynthesis in a cell-free medium have been confirmed in experiments reported by Kim and Wildman (*7*).

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24 September 1962

## Tritium and Helium-3 in Solar Flares and Loss of Helium from the Earth's Atmosphere

*Abstract*. Analysis of the data gathered by the Discoverer XVII satellite on the constituents of solar flares leads to results that have broad implications in geophysics and solar physics.

It has recently been suggested that $H^3$ and $He^3$ may be produced in solar flares as well as the surfaces of magnetic stars by bombardment of $He^4$ with accelerated protons (*1*). At present, the only direct evidence of such stellar processes is the discovery of $H^3$ and $He^3$ in the casing of the earth satellite Discoverer XVII which was flown following the solar flare of 12 November 1960 (*2, 3*). The amounts of $H^3$ and $He^3$ recovered from the satellite are two orders of magnitude too large to be accounted for by spallation of the casing material. It was concluded that the solar flare radiation intercepted by the satellite consisted of 0.4 percent $H^3$, 10 percent $He^3$, and 90 percent $H^1 + He^4$ with errors of at least a factor of three (*2, 3*). Despite these large errors, the composition of the radiation detected by Discoverer XVII has broad implications in geophysics and in solar physics: (i) The greater part of the $He^3$ and a significant fraction of the $H^3$ in the earth's atmosphere probably is accreted from the sun. (ii) Escape of helium from the atmosphere most probably is thermally controlled. (iii) Cross sections for $H^3$ and $He^3$ production by $He^4(p,2p)H^3$, $He^4(p,pn)He^3$, and $He^4(p,d)He^3$ reactions near the threshold energies are consistent with the ratio of the two nuclides in the flare radiation, indicating that $H^3$ and $He^3$ were indeed produced by these reactions rather than by fusion or by spallation of heavier nuclei in the sun. (iv) The overall composition of the radiation can be reproduced by the solar flare model of Gold and Hoyle (*4*).

Table 1. Threshold energies and total cross sections for production of $H^3$ and $He^3$ by 28-Mev protons on $He^4$.

| Reaction | Energy (Mev) | Cross section (mbarn) |
|---|---|---|
| $He^4(p,2p)H^3$ | 25.0 | 8.9 + 1.0 |
| $He^4(p,pn)He^3$ | 25.5 | 4.8 + 1.3 |
| $He^4(p,d)He^3$ | 23 | 50 |

1) Measurements of the flux of solar flare particles of energy above 30 Mev at the top of the earth's atmosphere appear to be converging on a global average annual value of the order of 100 per $cm^2$-sec (*5, 6*). If we assume the composition of the 12 November radiation to be typical of solar flares, we obtain a global average annual influx of 10 $He^3$ atoms and 0.4 $H^3$ atoms per $cm^2$-sec. Spallation of air molecules by the solar protons or interactions of secondary neutrons with nitrogen (*6, 7*) produce $H^3$ at a rate comparable to the rate of accretion. The only other significant source of $H^3$ is the production by galactic cosmic rays, estimated at 0.1 to 1.0 atom per $cm^2$-sec (*7, 8*). Since the rate of $He^3$ production by spallation is comparable to the rate of $H^3$ production (*9*), we have about 2 $He^3$ atoms per $cm^2$-sec produced in the earth's atmosphere as compared to 10 atoms per $cm^2$-sec accreted from the sun.

2) Setting the rate of escape of $He^3$ from the atmosphere equal to the rate of accumulation, and taking the number of $He^3$ atoms per square centimeter column of the atmosphere as $1.5 \times 10^{14}$, we arrive at a mean residence time:

$$\tau\,(He^3) = \frac{1.5 \times 10^{14}}{12 \times 3 \times 10^7} = 4 \times 10^5\ \text{yr}$$

The atmospheric residence time of $He^4$, calculated from the decay of uranium and thorium in rocks and the atmospheric concentration, is greater than $2 \times 10^6$ years and probably of the order of $10^7$ years (*10*). Such a marked difference between the $He^3$ and $He^4$ residence times gives an important clue to the mechanism by which helium escapes from the earth; a mechanism strongly dependent on mass is required. Of the various models proposed, those in which the escape rate is controlled by diffusion or by collision or photochemical processes fail to meet this requirement. Thermal escape processes (*11*), on the other hand, are controlled by a Boltzmann factor involving the gravitational energy exponentially, and consequently they discriminate strongly against heavier isotopes. We find, for several model atmospheres (*11, 12*) in which thermal control of the escape rate is assumed $\tau(He^3) = 4 \times 10^5$ years and $\tau(He^4) = 9 \times 10^6$ to $2 \times 10^7$ years at temperatures of 1900° to 2100°K. Temperatures as high as 2100°K have been calculated from satellite drag at high altitudes and latitudes during periods of high solar activity (*13*).

The apparent negative correlation between the sunspot cycle and the amount of $H^3$ deposited in Greenland snows (*14*) is not at variance with our conclusion that significant amounts of $H^3$ are contributed to the earth's atmosphere by solar flares. Tritons entering the atmosphere with energies below 500 Mev, as well as tritons produced in the atmosphere by solar protons (*15*), are stopped at altitudes well above the polar tropopause. On the other hand, some 20 percent of the $H^3$ produced in polar regions by galactic cosmic rays is formed in the troposphere (*7*). Studies of the distribution of radioactive fallout from

Soviet bomb tests in the Arctic (*16*) indicate that only $H^3$ deposited in the polar troposphere would be precipitated in polar snows of the same year. Atoms deposited in the lower stratosphere fall out primarily at middle latitudes, while those injected at greater altitudes may have an even wider meridional circulation (*17*). It thus appears that the $H^3$ content of Greenland snow reflects only the galactic cosmic-ray production rate. Since the galactic cosmic-ray intensity at the earth is negatively correlated with the solar cycle, an anticorrelation between the $H^3$ content of Greenland snow and solar activity is to be expected whether or not $H^3$ is accreted from the sun or produced in the atmosphere by flare-accelerated particles.

3) The threshold energies and total cross sections for production of $H^3$ and $He^3$ by 28-Mev protons on $He^4$ are shown in Table 1 (*18*). Integration of the differential cross section for the $He^4(p,d)He^3$ reaction at 31 Mev (*19*) likewise yields a total cross section of about 50 mbarn. Using the observed cross sections for the $He^3(d,p)He^4$ reaction (*20*), one calculates a cross section of 51 mbarn for the $He^4(p,d)He^3$ reaction at 28 to 33 Mev. The ratio of $H^3$ to $He^3$ production near threshold is then of the order of 0.1, a value in agreement with the ratio of the two nuclides detected after the 12 November flare. At high energies the $H^3$:$He^3$ production ratio is expected to approach unity. We note, however, that the integral spectrum of the flare-accelerated protons at the earth's orbit falls off roughly as $E^{-4}$ (*21*). Assuming a similar energy dependence of the flux in the flare material, the low-energy cross sections would largely determine the production ratio of $H^3$ to $He^3$. The production cross sections for accelerated alpha particles on hydrogen are of course the same as those for accelerated protons of the same velocity on $He^4$. Both processes must be considered here since the flare-accelerated radiation contains about 20 percent $He^4$ (*22*). Production of $H^3$ and $He^3$ by spallation of the less abundant heavier elements is an order of magnitude lower than the production by protons on $He^4$ and alpha particles on $H^1$. Fusion processes are ruled out as a significant source of $H^3$ and $He^3$ in flares by the relatively low densities of the flare material.

4) We present here an order of magnitude calculation of the yields of $H^3$ and $He^3$ in the 12 November solar flare, using the above cross sections and experimental observations on the flare region. The yield $Y_p$ of $He^3$ from irradiation of the flare material by protons is defined as the density of $He^3$ atoms produced in time $t$ divided by the density of accelerated protons with energy greater than the 23-Mev production threshold:

$$Y_p = \frac{\phi_p \sigma(He^3)\, N(He^4)\, t}{\phi_p / \bar{v}_p} = \sigma(He^3)\, N(He^4)\, \bar{v}_p\, t$$

where $\phi_p$ is the proton flux above 23 Mev, $\sigma(He^3)$ is the sum of the $He^4$(p,pn) and $He^4$(p,d) cross sections, $N(He^4)$ is the $He^4$ atom density, $t$ is the irradiation time, and $v_p$ is the average velocity of the accelerate protons, close to $10^{10}$ cm/sec. A similar equation can be written for the yield of $He^3$ from bombardment of hydrogen atoms by accelerated alpha particles. The total yield of $He^3$ is the sum of the yields from these two processes. The yield of $H^3$ may be calculated in a similar manner. Substituting 50 mbarn for the $He^3$ total cross section, 9 mbarn for the $H^3$ cross section, and using an $H^1$:$He^4$ ratio of 4 for the flare material, we obtain a composition of 1 percent $H^3$, 5 percent $He^3$, and 95 percent $H^1 + He^4$ when $N\bar{v}t$ is $3 \times 10^{24}$ atoms per square centimeter, where $N$ is now the total atom density. $N$ is not known for the 12 November event, but observations on other flares indicate densities considerably in excess of $10^{12}$ to $10^{13}$ atoms per cubic centimeter (*4, 23*). Assuming an average density of $3 \times 10^{14}$, amounts of $H^3$ and $He^3$ consistent with those observed in the 12 November radiation would then have been produced if the accelerated protons and alpha particles bombarded the flare material for an average of about 1 second.

In the Gold and Hoyle model (*4*), the source of the energy released in solar flares is a magnetic field of about 200 gauss extending upward from the photosphere. The dimensions of the flare region are $2 \times 10^8$ cm in diameter and $10^9$ to $10^{10}$ cm long. Annihilation of the magnetic field is assumed to take place over a period of the same order as the radio emissions from the flare region, roughly $10^3$ seconds for the 12 November event (*24*). During this period a small part of the energy released by the annihilation of the magnetic field is converted, via the resulting electric field, to kinetic energy of the flare particles. At a velocity of $10^{10}$ cm/sec, accelerated particles traveling radially outward along straight paths would leave the flare region in an average of $10^{-2}$ second, two orders of magnitude shorter than the time required to produce the observed amounts of $H^3$ and $He^3$. We are, however, dealing with charged particles in a magnetic field. One might expect such particles to spiral about the field lines, in which event their path lengths may well be orders of magnitude longer than the radial dimension of the flare region. Insofar as quantitative considerations are possible, it thus appears that the composition of the 12 November solar radiation can be accounted for within the framework of the Gold and Hoyle flare model (*25*).

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26 September 1962

## Moving Earth and Rock with a Nuclear Device

*Abstract.* A test in Nevada increases confidence that nuclear explosions can be used for large excavation projects.

Of all the potential peaceful applications of nuclear detonations perhaps the most obvious, certainly the best understood, and probably the most practical for realization in the near future is excavation. The test program for nuclear weapons has produced several craters, and well over 100 have been made with chemical high explosives in the Plowshare program. The data from both kinds of explosions have provided valuable new information concerning the feasibility and safety of nuclear earth-moving projects. Indications are that the use of nuclear explosives will bring substantial savings in cost and time on large-scale excavation projects. The experiments have been conducted for the most part in tuff, a cemented volcanic ash, and alluvium, an unconsolidated valley-fill material.

Detonations in other rock types remain to be investigated. The effects of arranging charges in a row and other variations have been studied with chemical high explosives, which have relatively low yield. The extension of these techniques into the range of yields obtainable with nuclear devices is desirable.

A test program has been planned to acquire the techniques necessary to make nuclear excavation a reality. The first of the projected series of cratering experiments designed to develop these techniques was Project Sedan (*1*), which was conducted at the Atomic Energy Commission's Nevada test site. The experiment involved detonation of a device of about 100 kilotons' yield, buried at a depth of 635 feet in alluvium. This depth is greater than optimum depth if crater dimensions are proportional to the 0.3 power of the yield, as has been observed with devices of kiloton yield. By this scaling relation, it was predicted that Sedan would produce a crater about 1400 feet in diameter and 300 feet deep. But some theoretical considerations indicated that this scaling relation might not be applicable to devices of hundreds of kilotons' yield, and that the dimensions for these higher yields might be proportional to the 0.25 power of the yield. In this case, it was predicted that the crater would be about 1200 feet in diameter and 170 feet deep. With either law, it was predicted that less radioactivity would be released than the equivalent of 2 kilotons of fission.

Among other technical programs were measurement of air blast and seismic effects both on- and off-site. Photography from five camera stations was planned to determine surface motion and cloud dimensions.

Trays and collectors were positioned throughout the planned fallout sector, and bioenvironmental plots were laid out to study radiation effects caused by the explosion. Radioactive pellets were placed in holes near the shot point to study particle trajectories. Tarpaulins, trays, and measuring rods were distributed to measure and document the distribution of the throwout and dust.

A 100-kiloton thermonuclear device in which less than 30 percent of the energy released came from fission was used for the test. It was placed in a cased hole 36 inches in diameter and backfilled with dry sand. Measures were taken to reduce the radioactivity induced by the neutrons. Preliminary calculations indicate that the yield was probably within about 10 percent of the expected value.

Sedan was detonated at 10 A.M. Pacific Daylight time on 6 July 1962. A roughly hemispherical dome of earth 600 to 800 feet in diameter rose to a height of 290 feet in 3 seconds, when venting of burning gases resulted in a secondary explosion and flash. As this tremendous volume of earth fell back to the ground a base surge was formed that expanded radially to a distance of approximately 2.5 miles. The main cloud then rose to a height of 12,000 feet above the desert floor, where it was topped by inversion conditions.

The crater formed has a maximum apparent depth of about 320 feet and an average apparent diameter of about 1200 feet. The height of the crater lip ranges from about 20 to 100 feet. By comparison with pre-shot predictions (depth of 170 to 300 feet and diameter of 1200 to 1400 feet) it appears that in the 100-kiloton yield range the crater diameter scaling may approach the 0.25 power of the yield and the depth scales as the 0.3 power.

The dust cloud was carried downwind at a mean speed of about 19 knots from 185 degrees (slightly west of south). The heavier fallout was confined to within approximately 2 miles upwind and crosswind and 4 miles downwind of ground zero. The intensity of radioactivity deposited downwind was moderate considering the large amount of dust carried by the cloud. The radiation level on the crater lip 4 weeks after the detonation was less than 1 r/hr. The maximum total dose received by any person off the Nevada test site was 275 mr, which is well below the 500 mr/yr guide recommended by the Federal Radiation Council for peacetime uses of nuclear energy.

Analysis of data from the Atomic Energy Commission's off-site monitoring program (operated by the U.S. Public Health Service) and from the environmental monitoring network of the Public Health Service indicates that only a small part of the iodine-131 measured recently in milk produced in Utah is attributable to Sedan. Officials believe that Sedan is responsible for the initial increase measured on 13 July in the Salt Lake City area but attribute subsequent higher levels to two other nuclear weapon tests held at the Nevada test site—one at a shallow depth on 11 July and the other a few feet above ground on 14 July.

Ground shock intensities were much less than expected from previous experience in tuff and alluvium. Accelerations of only 0.1 grav were recorded at a distance of approximately 1.5 miles from ground zero. Air blast stations in the caustic range (80 to 150 miles) recorded peak pressures up to 0.83 mb at China Lake, Calif., some 137 miles southwest of ground zero.

The Sedan experiment was highly successful. Its displacement of 7.5 million cubic yards of earth and rock with-