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Rhodium-102 High-Altitude Tracer Experiment

The tracer gives clues to the transport and distribution of materials in the stratosphere.

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A considerable amount of knowledge about atmospheric circulation has been gained through the study of the distribution of bomb debris from atmospheric nuclear weapon tests (*1–6*). One of the major difficulties in these studies is that most of the radioactive products that one might sample and measure are the results of many weapon tests conducted under differing conditions with regard to time, place, and altitude of injection into the atmosphere. To some degree it is possible to unravel the sources of a given sample of bomb debris by measuring several of the radioactive products and determining their relative ratios. Obviously, it would be desirable to have a unique tag for a given study.

With this in mind, a large amount of the rhodium-102 isotope was made as a tracer in the Orange shot of the U.S. Hardtack series on 11 August 1958 at 2330 hours. This shot was an air burst about 43 kilometers above Johnston Island at about 16° north latitude and 170° west longitude (*7*). There are few accurate data concerning the final altitude of the bulk of the debris. It is estimated that the debris almost certainly rose to above 100 km and probably went at least as high as 150 km. Two isomers of Rh^{102} were produced; one with a half-life of 210 days, and one with a half-life of roughly 4 years (*8*). Both isomers decay mainly by electron capture and have a prominent 475-kev gamma ray. The estimated total Rh^{102} produced was about 3 megacuries. The most likely method of production for Rh^{102} would be a Rh^{103} (n, 2n) Rh^{102} reaction.

It has also been reported that the isotope W^{185} (75d) was produced during the Hardtack series in the spring and early summer of 1958 (*9, 10*). The W^{185} would most likely have been produced by W^{184} (n, γ) W^{185} and W^{186} (n, 2n) W^{185} reactions. Libby has reported a total production of 250 megacuries of W^{185} (corrected to 1 August 1958), mostly in high-yield shots (*10*) which should have placed an appreciable portion into the stratospheric reservoir. Since natural tungsten also contains W^{180} (0.14 percent) and W^{182} (26.2 percent), significant quantities of W^{181} (120d) were also produced. In addition, a small amount of W^{188} (70d) would have been produced by the W^{186} (n, γ) W^{187} (n, γ) W^{188} reactions.

The tungsten isotopes can be considered as representing low stratosphere equatorial debris, while the rhodium isotope can be considered as representing high stratosphere equatorial debris, although some Rh^{102} (about 0.3 megacurie) was produced in other tests contributing to the low stratospheric debris. In addition, stratospheric samples collected at northerly latitudes in the fall of 1958 suggest that there may have been some Soviet production of Rh^{102}.

Stratospheric filter samples have been obtained by U-2 aircraft up to an altitude of 21.3 km and by balloon flights from 1958 to the present. The aircraft samples were obtained with the assistance of the Defense Atomic Support Agency (DASA). Most of the balloon samples were supplied to us by the U.S. Atomic Energy Commission. Some were flown for us under a contract with General Mills, Inc.

Volumes for the samples collected by aircraft have been determined from calibration curves reported by DASA (*11*). These volumes are considered to be correct to within 25 percent. Volumes for the samples collected by balloons have been estimated by a number of methods, but unfortunately large inconsistencies still occur. Recent techniques should allow more accurate estimation of the volumes of balloon samples.

Up to June 1959 most of the aircraft samples were collected on orbiting flights made at a fixed location. Most of the later ones were collected over a range of 5 to 10 degrees of latitude. The balloon samples were all taken at fixed locations.

The most serious limitation with regard to the high-altitude samples is that it was not possible to specify exactly where and when samples were to be collected. As a result, there are a number of gaps in the data with respect to certain periods of time and location, where it would have been quite enlightening to have had additional information.

Radiochemical Procedures

Rhodium. Filter samples are ashed and dissolved in perchloric acid. The amount of rhodium carrier added is kept to 2 to 4 mg so that relatively thin samples can be mounted on a very small area (approximately 0.6 cm in diam-

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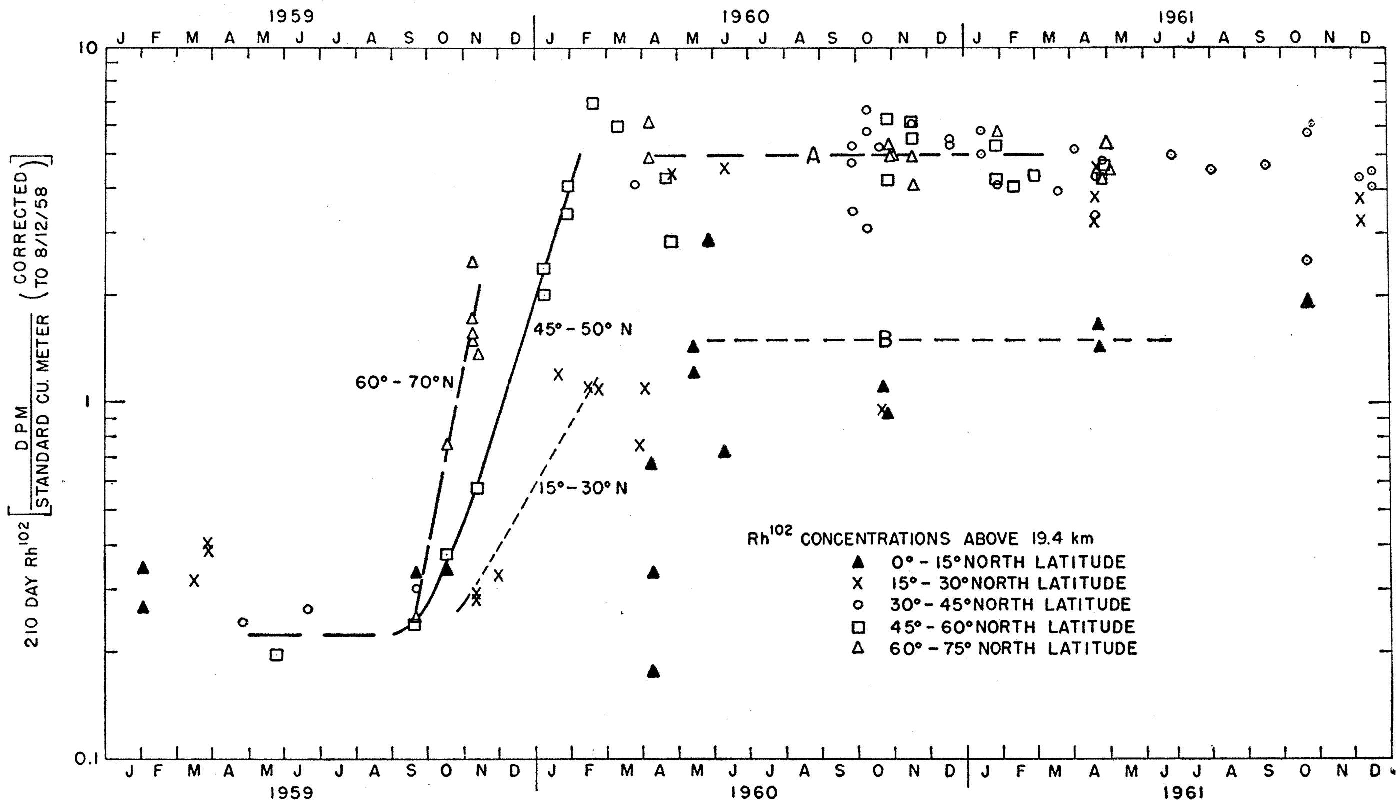

Fig. 1. Rhodium-102 concentrations above 19.4 km in the Northern Hemisphere. Line A (— — —) is intended only as a guide for high-latitude concentrations. Line B (- - - - -) is intended only as a guide for low-latitude concentrations. The latitude ranges given for the three ascending lines encompass the mid-latitudes for all the samples represented on these lines.

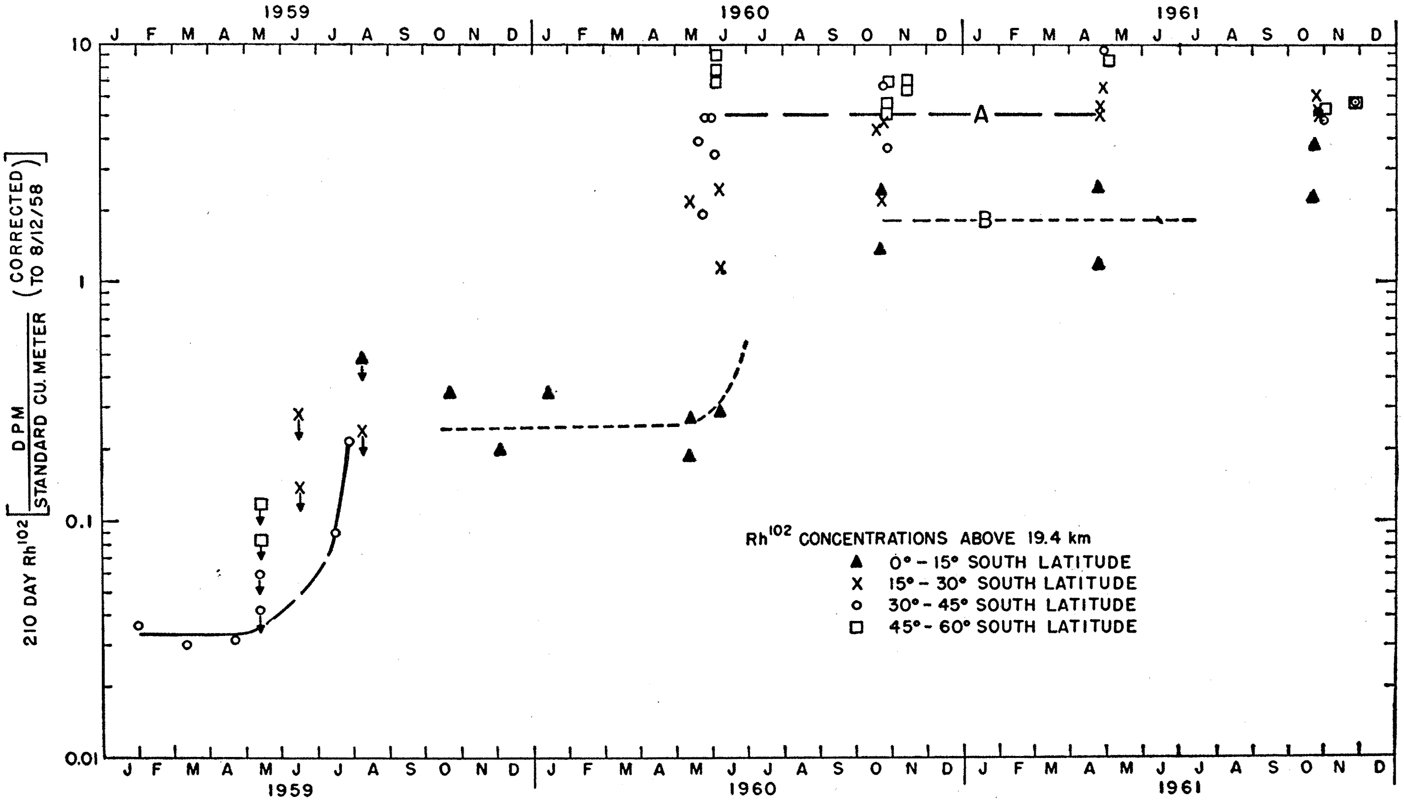

Fig. 2. Rhodium-102 concentrations above 19.4 km in the Southern Hemisphere. Line A (— — —) is intended only as a guide for high-latitude concentrations. Line B (- - - - -) is intended only as a guide for low-latitude concentrations.

eter). The rhodium separation and purification method includes rhodium iodide and potassium rhodium nitrite precipitations, ion-exchange column purification (Dowex 1-X10, 200–400 mesh), and electroplating from a dilute sulfuric acid solution. The chemical yields average about 50 to 60 percent.

Tungsten. Tungsten is precipitated as the oxide before the rhodium separation is made. It is purified by subsequent oxide precipitations under various conditions and finally precipitated as the 8-hydroxyquinolate. The chemical yields range from about 30 to 60 percent.

Counting Methods

Rhodium. Since the decay of Rh^{102} is mainly by electron capture, positive identification of the activity as being due to Rh^{102}, high counting efficiency, and low background are achieved by measuring the ruthenium K x-rays (about 20-kev energy) with a small, thin scintillation detector and a pulse-height analyzer. The detector used for these measurements was a square thallium-activated sodium iodide crystal 1 inch on the diagonal and 0.025 inch thick. The background, with 4 inches of lead shielding, under the whole x-ray peak is of the order of a few tenths of a count per minute.

The conversion of the counting data to disintegrations per minute of Rh^{102} has become complicated recently because of the finding of a new longer-lived isomer of Rh^{102} and also the long-lived isomer of Rh^{101} in the Orange debris (*8*). Originally, intercalibrations between this laboratory and the Los Alamos Scientific Laboratory and work done at the Livermore Radiation Laboratory led to our adopting a value of 71 percent for the portion of the decays of 210-day Rh^{102} that go by electron capture. The existence of the longer-lived isomer will affect this value, but it is not expected that the effect on the results reported here will be very great. In any case, it will only be in the absolute values of the 210-day Rh^{102} concentrations where this could be very important. Relative concentrations should be affected very little. [Recent data comparing beta-ray and x-ray measurements on a Rh^{102} sample suggest that the amount of electron capture for the 210-day isomer may be closer to 60 percent.] The counts per minute in the x-ray peak are converted to counts per minute of 210-day Rh^{102} with the help of a decay curve for several samples of Orange-debris rhodium that have been normalized and plotted as a function of time (*12*). In converting x-ray counts per minute to disintegrations per minute, an L/K ratio of 0.1, a K fluorescence yield of 0.8, and a geometry of 0.4 are used.

Since several laboratories involved in studies of a similar nature have measured their rhodium samples by counting the beta rays emitted, it should be noted that curves for the beta decay of Rh^{102} show predominantly a 210-day half-life after subtraction of the x-ray contribution to the beta-ray count (*13*). Thus, data based on the beta ray activity need not be corrected for the longer-lived isomer.

Tungsten. Tungsten-181 decays by electron capture, predominantly to the ground state. The detection of the W^{181} activity is achieved by counting the tantalum K x-rays (about 57-kev energy) with a sodium iodide crystal 1½ inches in diameter by 1 inch high. An L/K ratio of 0.23 is used in calculating the W^{181} disintegrations per minute (*14*).

Tungsten-185 decays by beta emission and is counted by low-level beta-counting techniques.

Results

Rhodium. The results for the stratospheric samples are given in Tables 1 and 2 and are shown in Figs. 1–3. Statistical errors are not included with the results since the counting errors are quite small compared to uncertainties in the sample volumes and the decay scheme corrections. For those results where upper limits are given, the upper limits can be considered as being correct to within 30 percent.

The most attention is given to samples collected by aircraft at altitudes about 19.4 km. This seems to be a relatively stable and interesting region on the basis of these results and investigations of stratospheric aerosols (*15*) and radioactive particles (*16*). A complete tabulation of results for this altitude region and also for lower altitudes has been published (*12*).

Tungsten and rhodium-to-tungsten ratios. Comparison between the W^{185} beta disintegration rate and the W^{181} electron capture disintegration rate in a sample corrected to 1 August 1958 showed roughly 40 percent as much W^{181} activity as W^{185} at that time. This would correspond to roughly 100 megacuries of W^{181} on 1 August 1958. It might be expected that perhaps between 30 and 60 percent of the rhodium and tungsten produced in surface detonations was injected into the stratosphere. About 40 percent stratospheric retention was assumed for the analysis of the activity ratios. If we assume that the Rh^{102} produced in Hardtack tests other than the high-altitude test has the same stratospheric mixing history as the W^{181}, a constant 210-day Rh^{102}/W^{181} activity ratio of approximately 1/300 (corrected to 12 August 1958) would be expected.

The W^{181} concentrations observed through 1959 show much less variation with hemisphere than the Rh^{102} concentrations (*12*). The measured 210-day Rh^{102}/W^{181} activity ratios (*12*) indicate that a large fraction of the Rh^{102} for most of the samples follows a different mixing history. This would be expected to be true for the Rh^{102} tracer produced at high altitude.

Tungsten-181 concentrations for samples collected later than 1959 were not measured. However, it seems apparent from the Rh^{102} concentrations that later samples derive most of their rhodium from the Orange shot debris.

Table 1. Results for the first half of 1959 for aircraft samples collected at altitudes above 19.4 km.

Collection date	210-day Rh^{102} (disintegrations per minute per standard cubic meter) (12 Aug. 1958)
Latitude 34°–35° South	
30 Jan.	0.0360
10 Mar.	0.0293
21 Apr.	0.0311
Latitude 14°–19° North	
30 Jan.	0.340
30 Jan.	0.262
11 Mar.	0.313
25 Mar.	0.401
25 Mar.	0.381
25 Mar.	0.382
Latitude 43°–46° North	
24 Apr.	0.238
22 May	0.194
19 June	0.260

Table 2. Balloon sample concentrations for collections made at latitude 32°N, longitude 100°W during the first week of April 1960.

Collection altitude (km)	210-day Rh^{102} (disintegrations per minute per standard cubic meter) (12 Aug. 1958)
28.4	4.91
24.5	5.51
22.3	6.99
20.5	4.45

Discussion of Results

Early distribution. Results for the first half of 1959 are given in Table 1. It is apparent that in the stratosphere mixing between hemispheres across the tropical region and into regions of higher latitude is slow, at least on the time scale and for the altitude region (about 20 km) represented by these values. This is also supported by the latitude profiles shown in Fig. 3.

Comparison of the early concentrations with later values indicates that the early rhodium in the low stratosphere is equal to only a few percent of the Orange rhodium. Although the earlier assumption was made that the distribution of rhodium produced in Hardtack tests other than Orange and tungsten would be the same, the possibility remains that this is not so since their distribution in individual shots may have been different. However, it would not be unreasonable to suggest that the early rhodium concentrations represent a few percent of the Orange shot that did not rise with the main cloud of the debris. Rhodium from Soviet tests can be reasonably ruled out on the basis of the higher concentrations in the region of 14° to 19°N as compared with those in the region of 43° to 46°N, particularly in view of the expected distribution for debris introduced into the stratosphere at high latitudes. (This will be discussed later.)

In any case, regardless of the actual source or sources of the rhodium in early observations, the conclusion that mixing between hemispheres is slow at lower levels in the stratosphere seems valid.

Northern Hemisphere increase. As is shown in Fig. 1, there was a sharp increase in Rh^{102} concentrations beginning in the late fall of 1959 and continuing through the early winter. This coincides well with the time one would expect downward mixing associated with the development of disturbances in the polar vortex region (a band of strong circumpolar westerly circulation centered about 60°N at 30 km). These disturbances begin about November and continue throughout the winter, being strongest around January (*17*). The increase in rhodium concentrations began in late October, reaching maximum values around January. The effect also seemed to be strongest at or north of about 60°N, where one would expect the maximum vertical flux. The data presented in Fig. 1 are consistent with a picture of great downward mixing at high latitude in the winter followed by horizontal movement in the low stratosphere. If the results for the balloon profile given in Table 2 can be considered meaningful, they too would support the idea that the increase at the middle latitudes is due to horizontal movement from higher latitudes rather than vertical downward mixing at these middle latitudes. These results also suggest that this horizontal flux is strongest in the altitude range of about 20 km and above, again consistent with other observations such as the maximum of sulfate particle concentration (*15*) and radioactive particles (*16*) in this altitude region.

Southern Hemisphere increase. Unfortunately, our picture of the changes that took place in the Southern Hemisphere is nowhere near as full as the picture for the Northern Hemisphere. The program of regular flights at mid-latitudes in the Southern Hemisphere was terminated in August 1959, and no further samples were collected there until May 1960. Since then, collections have been made twice a year covering a period of about a month each time.

A sample collected 15 July 1959 gave the first indication of a rise in concentrations in the Southern Hemisphere. This phase of the collecting program was terminated soon thereafter, so that the only checks that could be made on this increase were by analysis of samples in the HASP inventory (*18*). Nine samples were analyzed, but the volumes were generally too small to give much worthwhile information. The results for these are shown in Fig. 2 by the upper limit values indicated between May and August 1959 and by the value shown in June 1959. The fact that this increase occurred during the Southern Hemisphere winter again suggests that downward mixing at high latitudes in the winter is the mechanism. However, the concentrations for this period were generally as low as, or lower than, the concentrations at low latitudes in the Northern Hemisphere, so that the possibility of transport across the equator in the 20- to 30-km altitude range cannot be completely excluded as an explanation. Subsequent data on latitude variations, to be discussed later, tend to reinforce the first explanation.

Because insufficient data are available for the period from May 1959–May 1960, it is difficult to discuss the relative amount of the debris brought down during the first winter. However, Fig. 2 and a comparison between July 1959 in the Southern Hemisphere and January 1960 in the Northern Hemisphere suggest that a relatively small fraction appeared in the first winter and a much larger fraction appeared in the second. (This is also considered later.)

Latitude variations. Figure 3 shows rhodium concentrations as a function of latitude during a number of relatively short time periods. These figures appear to be qualitatively quite similar, suggesting that this distribution pattern (and the mechanism by which it is arrived at) is persistent with time.

The most obvious features of this distribution pattern are the relatively uniform and equal, high concentrations at the high latitudes in both hemispheres with a rather sharp drop to low concentration at the low latitudes. This drop in concentration is quite pronounced and seems to occur at roughly 30°. It would indicate that there is a large difference in the mixing pattern in the two regions (high latitude and low latitude). The stratosphere at the low latitudes is generally characterized by steady zonal flow (predominantly easterly), uninterrupted by transient disturbances, and a very stable temperature structure as evidenced by the greatest increase of temperature with altitude in this region. This then leads to a situation with very little north-south and vertical mixing. Observations of tungsten concentrations following the Hardtack series show that the highest concentrations persist at the low latitudes where injected, offering further support of this picture (*5*). At higher latitudes, there is planetary wave development which is strongest in the winter (*17*), leading to strong north-south and vertical mixing particularly in the winter.

There are some differences in the latitude distribution with time. As is shown in Fig. 3, the concentrations at low latitudes increase slowly. This is to be expected since, in addition to any vertical mixing that may occur, there is some horizontal mixing between the high and low latitude regions, particularly in the winter (*5*). Samples collected from 21 April to 1 May 1961 (Fig. 3, bottom left) show higher concentrations at the high latitudes in the Southern Hemisphere than at high latitudes in the Northern Hemisphere. Since the magnitude of the disturbance in the polar vortex region can vary from winter to winter, it is to be expected that the amount of downward mixing associated with these disturbances will vary. It

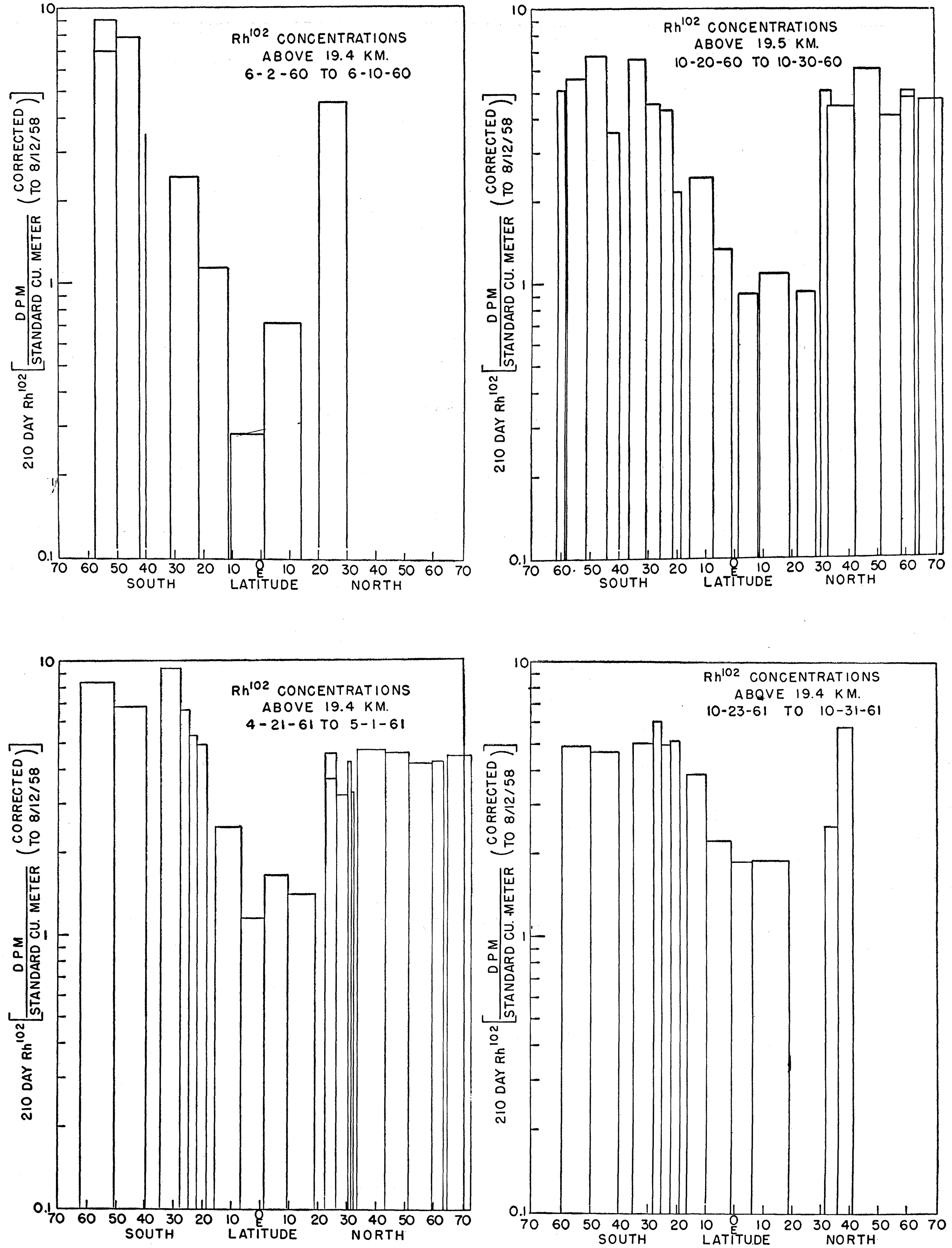

Fig. 3. Latitude variations of Rh^{102} concentrations above 19.4 km. (Top left) Period of 2 to 10 June 1960. (Top right) Period of 20 to 30 October 1960. (Bottom left) Period of 21 April to 1 May 1961. (Bottom right) Period of 23 to 31 October 1961.

seems, therefore, quite natural that there are variations in concentrations between the Northern and Southern Hemispheres.

Stratospheric storage. Although the concept of a stratospheric storage or residence time is not a very rigorous one (it is dependent on time, latitude, altitude of injection, and burst type [surface land, water, or air]), it remains a question with which many people seem most concerned. If one keeps in mind the fact that the specific case of high-altitude Rh^{102} is being considered here, the following discussion should have greater validity than more general considerations of this question.

It is possible to make some estimates of the amount of Rh^{102} being stored at high altitudes and the percentage that is observed at our sampling altitudes. There are approximately 5×10^{21} grams of air in the earth's atmosphere. This is equivalent to about 4×10^{18} standard cubic meters of air. One megacurie (2.2×10^{18} disintegrations per minute) of activity uniformly spread throughout the earth's atmosphere would thus be equivalent to about 0.55 disintegration per minute (dpm) per standard cubic meter of air. Three megacuries of activity would lead to a uniform distribution of about 1.7 dpm per standard cubic meter. From the results shown in Figs. 1–3 and those reported elsewhere (*12*), we can say that most of the activity is at latitudes higher than 30° and at altitudes above about 18 km (approximately 70 to 75 mb pressure). If we suppose that the Rh^{102} is essentially all confined to these regions, the uniform distribution of 3 megacuries of activity throughout this volume would be approximately 50 dpm per standard cubic meter. If one takes as the observed concentration a value of about 5 dpm per standard cubic meter, approximately 10 percent of the well-mixed concentration has been obtained. Assuming that steady-state conditions exist (as is somewhat indicated by the fact that concentrations in the Northern Hemisphere have remained relatively constant for the past 2 years), an estimate of the high-altitude Rh^{102} tracer "residence" time can now be attempted. A last assumption with regard to the turnover time for the region in which we are sampling must be made. (By the term "turnover time" is meant the time required for fairly complete removal regardless of the timing of the injection. In some sense, this can be construed as being an upper limit to the residence time.) One year as the turnover time for this region seems to be of the right order of magnitude, both on the basis of previous estimates for low stratospheric sources (*2, 4, 19*) and the fact that concentrations have remained fairly constant with the main mixing from the high altitudes occurring on a yearly basis. This leads to a "residence" time of roughly 10 years for the high-altitude Rh^{102} tracer. This value must be recognized as being a very rough one in view of the many assumptions explicitly stated in this section, as well as the uncertainties in the amount of Rh^{102} produced (possibly uncertain to 50 percent), in the counting efficiency due to

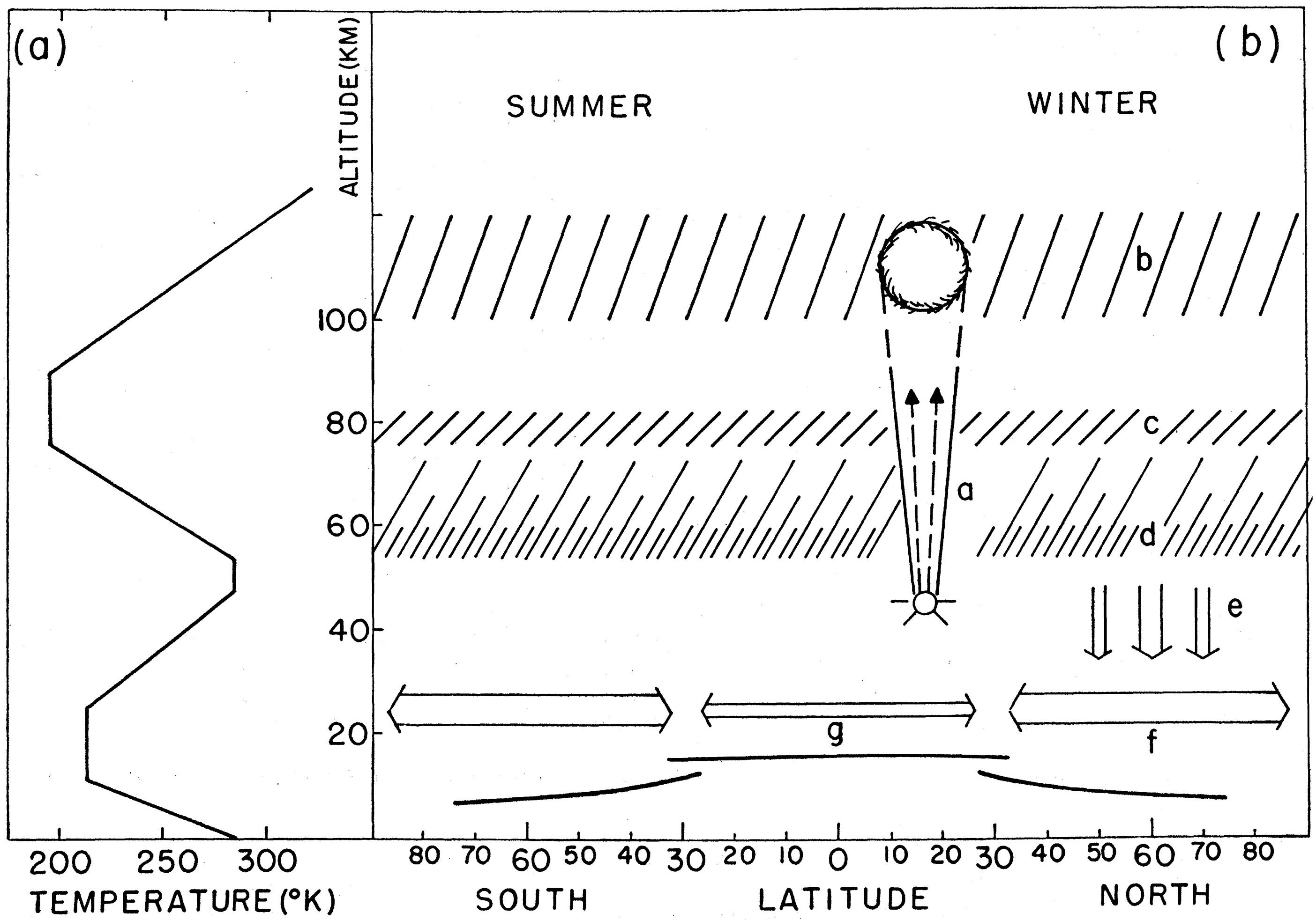

Fig. 4. (*a*) Schematic diagram of the variation of temperature with altitude. (*b*) Schematic representation of a possible history of Rh^{102} transport.

uncertainties in the decay scheme, and in sampling volumes. In addition, the magnitude of the winter temperature changes and the associated fluxes may vary considerably from year to year so that the values used here may not be truly representative. A further reservation, due to the difficulty of integrating for the whole atmosphere on the basis of a very limited number of observations, should be noted. It would probably be safest to say that, to the extent that a "residence" time for this material is meaningful, it is somewhere between 5 and 20 years.

Material transport. Assuming that the bulk of the debris from the Orange shot rose to above 100 km, we can now speculate on its subsequent history. Initially we can expect the rhodium to be in atomic or molecular form. At altitudes above 100 km, horizontal molecular diffusion should be relatively rapid. In addition, high-altitude observations have indicated that rather high-velocity winds, leading to considerable eddy diffusion, exist in this region (*20*). One can, therefore, expect that above 100 km debris will be distributed fairly uniformly soon after injection on a world-wide basis.

The next step to be considered is the vertical motion of the material to lower altitudes. Both molecular diffusion and gravitational sedimentation occur, with sedimentation playing the greater role in getting the material to altitudes below 100 km. On the basis of settling rates calculated by Junge (*21*) and the timing of the appearance of the high-altitude Rh^{102} in the lower stratosphere, an upper limit of the order of 0.01 micron radius can be set for the size of this material. Data of Drevinsky and Martell (*16*) for particle size distribution as a function of altitude suggest that the assumption of molecular sizes for the material at 100 km may not be unreasonable for considering sedimentation rates. Calculations indicate that the time for molecular (and near molecular) material to settle from above 100 km down to about 80 km is of the order of months (*22*). Even relatively large aggregates of molecules would still require times in this order of magnitude range. Any contribution due to mass motion of the air will tend to reduce this time.

Once material reaches about 80 km, we expect circulation processes to take over. Sedimentation rates become very slow below this altitude. As is indicated in Fig. 4*a*, the temperature profile between about 55 km and 80 km is very similar to that in the troposphere. It is to be expected that vertical mixing and also horizontal mixing throughout this region should be good.

It is not unreasonable that the time for the Orange debris to have reached about 55 km was such that it was too late to be brought further down in the first winter subsequent to injection in the Northern Hemisphere, but such that at least some of it was present to be brought down in the first winter in the Southern Hemisphere.

At about 55 km, we arrive at a temperature maximum, as can be seen from Fig. 4*a*. Under normal conditions, there should be a very stable layer, with very little vertical motion, at about this altitude. Significant vertical motions are to be expected in the winter associated with the winter instability reported by Hare (*17*). The large increase of Rh^{102} observed in the winter of 1959–60 coincides in time with the period of large temperature fluctuations in the stratosphere at high latitudes. This allows the downward mixing of a fraction of the material, held at about 55 km, each winter. This mixing piles material up in the low stratosphere toward late winter and would thus probably help account for the spring peaks observed for fallout at the earth's surface.

Finally, we can consider horizontal transport in the low stratosphere. Here, as was mentioned earlier, mixing is fairly rapid at high latitudes, with relatively little mixing into and across the low latitudes.

Conclusions. A Generalized Model

On the basis of the discussions of the preceding sections, one can arrive at a crude and perhaps oversimplified model for the circulation of the high-altitude Rh^{102} tracer. It should be kept in mind that the purpose of this model is to trace the movement of the Rh^{102} tracer. It does not purport to say anything about equilibrium processes or balance of air motion.

The various features of this model can best be discussed by referring to Fig. 4*b*. The Orange shot was detonated at about 43 km altitude and 16°N latitude. The subsequent stages in its history are denoted in Fig. 4*b* by small letters. They are as follows:

a. Rather rapid rise of the bulk of the debris to high altitudes, finally stabilizing somewhere above 100 km. The possibility exists that a small fraction of the debris remained behind at relatively low altitudes.

b. Fairly rapid horizontal diffusion of material at altitude, probably involving both molecular and eddy diffusion (this step most likely requires a time of the order of weeks or less depending on the actual altitude at which it occurs).

c. Vertical diffusion down to an altitude of about 80 km, expected to proceed mainly by gravitational sedimentation (a time probably of the order of months for this step).

d. Vertical mixing due to turbulent mass motion between 80 km and about 55 km. There should also be a strong horizontal flux in this region to further assure a fairly uniform distribution with latitude at this point. Because of the exponential relation of density as a function of altitude, most of the material will be concentrated close to the bottom of this region or about 55 km (probably a time of the order of weeks to months to get good mixing throughout this region).

e. Large-scale downward mixing, associated with impulsive warming, during the winter months, which brings a portion of the material from high altitudes (about 55 km) down to the low stratosphere (20 to 30 km) at high latitudes. (This may be the main mechanism for introducing "new" material from high altitude into the low stratosphere.)

f. Fairly rapid horizontal mixing (above about 30°) between about 20 and 30 km at high latitudes (probably weeks to a few months for good mixing over these latitudes).

g. Much weaker mixing into and across the low latitude region (below about 30°).

A last point pertains to other high-altitude debris. There has been some talk about other possible experiments at even higher altitudes and also much concern about the operation of nuclear-powered rockets and nuclear-fueled auxiliary power units for orbiting satellites. A general conclusion suggested by the Rh^{102} results is that any material heavier than air remaining within the earth's gravitational field, or any heavy ions remaining within the earth's magnetic field even out to several earth radii, will very rapidly reach an altitude of the order of a few hundred kilometers and behave very much like the Rh^{102} thereafter.

Finally, inasmuch as the question has been raised with regard to possible

Soviet production and other U.S. production of Rh^{102}, it might be worth making a plea for greater coordination, preferably on an international basis, of possible future world-wide tracer experiments (*23*). Again, in view of the results for this experiment, it should be possible to plan in a better way the sampling program for future experiments. Certainly, the greatest value from future experiments will be obtained by increased coordination and participation of the world scientific community (*24*).

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Patterns and Populations

Basic problems of population biology transcend artificial disciplinary boundaries.

Paul R. Ehrlich and Richard W. Holm

An important and rapidly developing area of biological science is the study of aggregations of organisms. This field, which we call population biology, may be defined as including all aspects of groupings of organisms and organisms in groups. Often, however, it is considered to comprise only ecology in a relatively narrow sense, or even population genetics alone. We feel that there is much to be gained from taking a broad view in the study of populations, in which emphasis is on the many similarities in the phenomena studied by the taxonomist, the ecologist, the geneticist, the behaviorist, the economist, and perhaps the mathematician as well. Despite the apparent heterogeneity of this assemblage it seems to us that there are many basic problems common to these diverse disciplines. Often these areas of mutual interest have not been recognized, even though many workers have urged broad interdisciplinary approaches. Perhaps the time has come to dissolve disciplinary boundaries. Such a unification will require a careful study of techniques and procedures, in addition to an analysis of the language and the conceptual frameworks involved, with particular attention to the Whorfean hypothesis (*1*). Conceivably, a new mathematics must be developed in order to handle the problems of population biology. The mathematics of information theory (*2*) and game theory (*3*) already are being shown to have possible applications in this field, but so few biologists are versed in these mathematics that their importance and utility are only beginning to be investigated. A general mathematical theory of population biology may be formulated eventually, but a great deal of intellectual brush-clearing must necessarily precede even preliminary groping for overall principles. In the discussion which follows it may seem that we have restricted ourselves largely to destructive criticism, demonstrating the disadvantages of established procedures and modes of thought. But these must be pointed out before it is possible to develop improvements. Although we have not always discussed possible improvements in detail, these often are presented in the works cited. In science it frequently is necessary to criticize existing theoretical structures to clear the way for new ideas.

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