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PROGRESS REPORT

ON THE

HIGH ALTITUDE SAMPLING PROGRAM

by

MAJ. ALBERT K. STEBBINS, III

RADIATION DIVISION

1 JULY 1959

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TECHNICAL ANALYSIS REPORT

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PROGRESS REPORT on the HIGH ALTITUDE SAMPLING PROGRAM

by

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RADIATION DIVISION

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HEADQUARTERS, DEFENSE ATOMIC SUPPORT AGENCY
WASHINGTON 25, D. C.

ABSTRACT

The High Altitude Sampling Program was initiated by the Joint Chiefs of Staff in 1954 to determine the spread of weapon produced fission products through the stratosphere. U-2 aircraft operated by the Strategic Air Command have been sampling stratospheric air at various altitudes along North-South paths from 66° North to 57° South at 70° West since 1957. Isotopes Incorporated, the principle contractor in this program, has analyzed over 1500 samples to date. Further metrological correlation has evolved a model of the stratosphere which accounts for the non-uniform deposition of fission products. The total stratospheric inventory of Sr^{90} as of the Fall of 1958 was found to be 1 megacurie. The half-residence time of polar injections and equatorial injections into the stratosphere was found to be six months and twelve months respectively. The major portion of the stratospheric debris moves into the troposphere through the mid-latitude tropopause break. Predictions of Sr^{90} levels to be found in equilibrium bone have been made through 1972.

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Chapter I

INTRODUCTION

Historical Background

With the advent of thermonuclear weapons in 1952, weapons testing and their employment entered a new dimension. With the magnitudes larger yields came concomitant magnitudes larger problems. Fallout of radioactive debris was a consequence which could no longer be ignored.

Most certainly all news media have done their share to focus widespread recognition and attention on the potential hazard associated with radioactive fallout. The Joint Chiefs of Staff, realizing the seriousness and complexity of this problem, requested in the early fall of 1954 that the Defense Atomic Support Agency (DASA), formerly the Armed Forces Special Weapons Project (AFSWP), study and evaluate this problem on a continuing basis. After considerable study of the problem within DASA during 1955, it was determined that the largest uncertainty in the prediction of the distribution and concentration of world-wide fallout debris on the surface of the earth is the quantity of fission products in the stratospheric reservoir and the rate and mode of their transfer. Therefore, DASA, early in 1956, initiated a research program to define and delineate the stratospheric reservoir of fission debris. This program became known as the High Altitude Sampling Program or "Project HASP."

Objectives of HASP

Briefly, the HASP Project has the following objectives:

a. Determine the total content of fission products in the stratospheric reservoir.

b. Define the variation of their concentration with latitude, altitude, and time.

c. Determine the rates of lateral and vertical mixing and the mean residence time of the debris in the stratosphere.

d. Deduce the mechanism of transfer of the radioactive debris from the stratosphere to the troposphere.

Method of Achieving the Objectives

In order to sample the stratosphere adequately, a system had to be devised which could cover a wide band of latitude, obtain samples through an altitude range extending from the troposphere well into the stratosphere, permit frequent sampling intervals, and collect enough material for accurate radiochemical analysis. Sampling with manned aircraft proved to be the most attrative approach because of the integrated nature of the sample obtained, the tremendous potential coverage, the control of the sample path, and the potential coverage per unit cost.

The development and availability to DASA of the Lockheed U-2, using a new filter medium of low resistance to air flow at high velocities, yet with high collection efficiency under flight conditions, plus experimental and theoretical aerodynamic investigations showing that a volume of air sampled under flight conditions could be accurately determined, all made Project HASP a real possibility.

In light of these developments, certain operational considerations, and the need for establishing scientific facilities and contacts to support the Project, the following four-phase concept was conceived:

a. Phase I

1. Development of an atmospheric sampling mechanism.

2. Flight operation planning and training.

3. Establishment of scientific facilities and contacts.

b. Phase II

1. Establishment of a meridional sampling net in the Northern Hemisphere.

2. Flight profiles to measure precision of sampling.

3. Calibration of the AEC Balloon Sampler.

c. Phase III

1. Extension of the meridional sampling net to the Southern Hemisphere.

2. Study rates of lateral mixing of HARDTACK (1958 Pacific Test) debris.

d. Phase IV

1. Continue the meridional sampling net in the Northern Hemisphere.

2. Detailed study of mixing and transfer processes.

3. Conduct atmospheric sampling to the North Pole.

Operationally it was planned that Project HASP would maintain a meridional sampling net at about 60 to 70 degrees West Longitude, through which most of the atmosphere passes every month or two. It was also planned that the net would have sufficient vertical cross-section to

sample most of the radioactive debris in the atmosphere. Extrapolation to the higher stratosphere would be made by use of the Atomic Energy Commission Project ASHCAN Balloon Data.

Scientific Program

A contract was let in September 1956 with The Institute of Paper Chemistry (IPC), Appleton, Wisconsin, for further development and calibration of a filtering medium. The filter medium being used in the HASP is IPC filter paper No. 1478, consisting of cotton fibers with gauze backing. The fibers are impregnated with di-butoxylethyl phthalate, a sticky, oily substance which assists the retention of particulate.

Further studies of the retention of IPC filter paper No. 1478 for small particles, carried out under the direction of Dr. J. A. Van den Akker at the Institute of Paper Chemistry, lend support to the belief that the filter medium has approximately 100 percent retention efficiency for stratospheric particulates under flight conditions.

Dr. Elliott G. Reid of Stanford University, one of this country's leading authorities on the application of aerodynamic theory to atmospheric sampling mechanisms, was consulted regarding the design and application of a filter-type sampler for the HASP. Based on Dr. Reid's theoretical work in this field, Lockheed Aircraft Corporation designed and built a sampler having a capability of exposing four filter papers, consecutively. This sampler was installed in the nose position as an integral part of each of the six U-2 aircraft assigned to DASA for carrying out the HASP.

An experimental flight test calibration program, under the direction of Dr. Reid, was conducted at Laughlin Air Force Base, Texas during September 1958. Preliminary results verify Dr. Reid's theoretical calculations of the

volume of air sampled with the nose sampler using IPC filter paper No. 1478. These calculations have been used as a basis for determining the volume of air represented by each HASP sample.

A contract was let in February 1957 with Isotopes, Incorporated, Westwood, New Jersey, to provide scientific direction and interpretation, and to perform the radiochemical analysis.

Isotopes, Incorporated effort, under the scientific direction of Dr. J. Laurence Kulp, has been devoted to:

a. Planning, in coordination with DASA, flight profiles for the sampling missions which weave the strands of the meridional sampling net.

b. Performing radiochemical analysis.

c. Research and correlation of fallout information bearing on the objectives of the HASP.

d. Interpretation of results and drawing conclusions. All data are reduced to disintegrations per minute per 1,000 standard cubic feet prior to interpretation.

e. Report writing.

The radiochemical procedures used to analyze HASP samples have been revised from time to time to increase the efficiency and accuracy of the analysis. A sequential analysis capable of yielding a maximum amount of information from a minimum amount of sample has been adopted. All samples are analyzed for total beta activity, for strontium^{90}, strontium ^{89}, and tungsten^{185} content. In addition, one out of every four samples collected is analyzed for barium^{140} and zirconium^{95}. A number of samples are also analyzed for cesium^{137}, plutonium and cerium^{144}. Analytical schemes for

the measurement of molybdenum^{99} and rhodium^{102} have been worked out and will be used where appropriate.

A mission was flown in which a HASP aircraft collected four samples while orbiting a balloon which was collecting a sample for Project ASHCAN. Intercomparison of the radiochemical data permits calibration of the ASHCAN sampler at one altitude.

Preliminary results from studies of the particulate matter in HASP samples indicate that the radioactivity is carried almost entirely by particles smaller than 0.5 microns in diameter.

Operational Program

The operational responsibility for carrying out Project HASP was assigned to the Strategic Air Command (SAC).

The Project got underway when six Lockheed U-2 aircraft were made available to SAC for assignment to the 4080th Strategic Reconnaissance Wing (4080th SRW) in August and September 1957. The U-2 is an unarmed, single engine jet aircraft with a crew of one. The range and altitude performance are consistent with the requirements of a research program of this nature. It has tandem landing gear and outrigger wheeled struts, sometimes referred to as "pogo sticks." These struts drop off when the aircraft becomes airborne. Landing is accomplished with the aid of a drag chute and, after the landing roll, wing tip skids prevent damage to the aircraft.

Following an initial training and testing phase in August - October, 1957, at Laughlin Air Force Base, Texas, the sampling aircraft were based

at Plattsburg Air Force Base, New York and Ramey Air Force Base, Puerto Rico. From these two bases a north-south sampling corridor along 70° West Longitude, and extending from 66° North to 6° South Latitude, was monitored systematically from November, 1957 through May, 1958. During June and July, 1958, sampling was conducted only in the vicinity of Puerto Rico. Since September, 1958, the aircraft have operated from Ramey Air Force Base and Ezeiza Airport, Buenos Aires, Argentina, in order to sample the Southern Hemisphere more completely. A corridor along 63° West Longitude, and extending from 38° North to 57° South Latitude has been monitored. The Ramey aircraft have made occasional deployments to Plattsburg to check the northern reaches of the sampling corridor. Since these sampling missions are flown over terrain which includes sub-arctic - water - and tropical areas having a minimum of emergency landing fields and navigation aids, Air Rescue support is provided for each mission by the 64th Air Rescue Squadron. SC-54 type aircraft are used for this support. It is planned to discontinue sampling in August 1959 from the Ramey and Ezeiza bases and resume sampling in a corridor along 100° West Longitude during September, 1959, from Laughlin Air Force Base, Texas, and a north-central U. S. base. It is also planned to make occasional deployments from Laughlin to Ramey Air Force Base, Puerto Rico to check on the stratospheric inventory of fission debris across the equator. It is believed that the air sampled along a meridional corridor will be representative of the entire atmosphere as long as sampling is carried out over a sufficiently long period of time. Eventually the whole atmosphere will be carried through the corridor by normal zonal circulation.

Two sampling missions, each of which collects 16 samples from the corridor, are scheduled per week. To date, over 1500 samples have been collected. These samples, with all accompanying data, have been forwarded to Isotopes, Incorporated for radiochemical analysis and interpretation.

Chapter II

SAMPLE COLLECTION AND ANALYSIS

General Procedures

Samples are collected by means of a filter sampler located in the nose of the plane. Four samples are collected by each plane during a mission. A single sample usually consists of the particulate matter filtered from between 5,000 and 20,000 standard cubic feet of air. Two missions, each of which collects 16 samples, are scheduled per week. The filters are shipped to Isotopes, Incorporated where they are analyzed for their total beta activity and for their content of selected radioactive nuclides.

The true air distance of each flight path is multiplied by the effective filter area to give the volume of air under ambient conditions. The effective filter area is a function of altitude and true air speed. This ambient volume is then converted to volume under standard conditions by means of pressure and temperature corrections. It has been estimated that the error in the use of these data is about $\pm$ 15 percent.

Collection Efficiency of the Filters

The work done by Professor J. A. Van den Akker at the Institute of Paper Chemistry during the past year has borne out the fact that the efficiency of IPC filter paper No. 1478, used to collect HASP samples, is effectively 100 percent for high velocity filtration of stratospheric particulate matter of sizes down to 0.005 microns in diameter. Electrostatic precipitators, located upstream and downstream from the filter paper in wind tunnel tests, have demonstrated this high efficiency. Electron microscope studies of the precipitated particles have been used

to determine the size range of the particles. Studies carried out at General Mills in connection with Project ASHCAN have also given results which suggest that, at the airflow rates which prevail during collection of HASP samples, the efficiency of IPC filter paper No. 1478 for submicron particles should approach 100 percent. In the calculations of stratospheric activity from HASP data the 100 percent filter efficiency has been used.

Particle Size Measurements

A unique opportunity for the study of the physical and chemical nature of stratospheric particulate matter is offered by the HASP filter samples. Very little is known about stratosphere particulates because of the difficulty of obtaining representative samples. Although the matrix of the HASP filters constitutes a barrier to the study of the contained particles, the information which might be obtained from these samples makes a thorough attempt at their analysis worthwhile.

Numerous autoradiograms of HASP filters have been made. Samples of recent and of older, background debris have been included. These autoradiograms have been studied in detail and "hot spots" on the filters have been cut out, impregnated with a plastic, microtomed, and the slices have been studied with the optical microscope, and, in a few cases, with an electron microscope. Autoradiograms have been made of some slices and they have been compared microscopically with the slices themselves in an attempt to associate high activity with specific particles. Further studies, including separation of particles from the paper, collection of impactor samples in conjunction with the filter samples and chemical microscopy of separated particles are being pursued.

Only preliminary results are available thus far. It is rather evident, however, that the radioactivity in the samples is associated with submicron particles. Microscopic comparison of filter slices with autoradiographs of the slices have shown no correlation of darkened film with particles visible to the optical microscope, i.e., particles larger than 0.5 microns. Rather, the spots of darkened film are associated with the filter fibers which contain no visible particles. Evidently the radioactivity is contained in particles too small to be resolved by the microscope.

Chapter III

DISTRIBUTION OF Sr^{90} IN THE STRATOSPHERE

Review of Atmospheric Structure

The troposphere is characterized by a decrease of temperature with altitude (in the mean). This lowest layer of the atmosphere extends from the ground up to altitudes which vary with season and with latitude. In the tropics the depth of the troposphere is approximately 55,000 feet, while in the polar regions it decreases to 30,000 feet or less. It is deeper in summer than in winter, and, except for a seasonal oscillation, is roughly symmetrical about the equator.

Vertical and horizontal mixing in the troposphere by turbulent and convective processes tends to produce a homogeneous distribution of airborne material. (The atmospheric gaseous constituents themselves are found in almost the same proportions everywhere.) The concentration of gaseous and small particulate radioactive debris is therefore quickly diluted by turbulent diffusion following its injection into the troposphere. Particulate material in the troposphere becomes attached to cloud droplets, ice crystals, snow flakes, and raindrops, and is removed from the atmosphere by precipitation. Thus the troposphere is a region in which the concentration of radioactive material is low, due to turbulent mixing, and from which radioactive debris is constantly being removed by precipitation. (It has been estimated that the particulate radioactivity in the troposphere is reduced to half its initial value in about one month by precipitation scavenging.) The background level of Sr^{90} in the upper troposphere, within

a few months after weapons testing, is about 1 dpm/1000 SCF* or less, while in the lower troposphere the level is about 0.3 dpm/1000 SCF. It is easily shown that the entire tropospheric reservoir of Sr^{90} is less than 3 percent of the total amount of bomb-produced radioactivity in the atmosphere. (The remainder resides in the stratosphere.)

In most, but not all, of the stratosphere the temperature does not decrease with altitude. (The decrease of temperature with height is called the lapse rate.) Where the temperature does decrease with altitude in the stratosphere, the decrease is much smaller than in the troposphere. The intensity of vertical mixing is, other things being equal, closely related to the variation of temperature with altitude, and is greater where the decrease of temperature with height is large. Thus vertical mixing is generally strong in the troposphere and weak, although not entirely absent, in the stratosphere. The relative weakness of vertical mixing in the stratosphere accounts for the inhomogeneous distribution of radioactivity in the stratosphere compared with the troposphere, and also for the relatively long time of residence of radioactive debris in the stratosphere.

The stability of the stratosphere (i.e., its resistance to vertical mixing) is not uniform. At all seasons of the year the tropical stratosphere, between about 25°N and 25°S, exhibits an inversion, or increase of temperature with altitude. This represents a very stable stratification, which strongly inhibits vertical mixing. On the other hand, in arctic and sub-arctic

*One decay per minute per one thousand standard cubic feet of air.

latitudes the stratosphere tends to be more nearly isothermal. This represents a less stable stratification than that of the tropical stratosphere, although it is still far more stable than the troposphere. In winter the arctic stratosphere becomes quite cold at upper levels, with the result that the temperature decreases with altitude. Thus the stratosphere is least stable, and therefore most easily mixed in the vertical, in winter in the arctic regions.

The boundary between the troposphere and the stratosphere is a layer known as the tropopause. Often the transition from troposphere to stratosphere is so abrupt that the tropopause can be identified as a surface, with positive lapse rate below and an inversion above. But just as frequently the transition is gradual, so that one may only be able to identify as the tropopause a layer several thousand feet thick above which the lapse rate is clearly stratospheric and below which it is clearly tropospheric.

The tropopause is not a continuous surface, but rather consists of several partially overlapping layers. The tropical tropopause is a nearly horizontal layer at about 55,000 feet above sea level extending from about 35°N to 35°S. It extends farther from the equator and is higher in summer than in winter. (It is also higher over warm air masses in the troposphere than over cold air masses. But rarely, if ever, is it found lower than 40,000 feet.) The pressure at the mean altitude of the tropical tropopause is about 10 percent of sea level pressure, indicating that only 10 percent of the mass of the atmosphere lies above the tropopause in tropical latitudes. The polar tropopauses, on the other hand, slope upward from an altitude less than 30,000 feet in the polar regions of the

two hemispheres, to about 40,000 feet in the vicinity of 30°N and 30°S. The polar tropopauses are much more variable, exhibiting not only large seasonal variations (high in summer, low in winter), but also large fluctuations with the weather systems from day to day. The mean pressure at the polar tropopause is about 25 percent of sea level pressure, so that about 25 percent of the mass of the atmosphere poleward of latitude 30° is stratospheric.

In the gap between the two principal tropopause layers an intermediate tropopause is frequently observed. The gap is a transition zone between tropospheric air on the equatorial side and stratospheric air on the poleward side. Particularly in winter, a narrow band of strong westerly winds, the jet stream, is found meandering in a wave-like fashion around each hemisphere. On a north-south (meridional) cross-section the jet stream appears as a relatively small area of high velocity penetrating the vertical plane near the lower part of the gap. Turbulence is usually severe in the jet stream region, and indeed throughout the gap, despite the fact that the lapse rate in the gap is not large. The turbulence in this region is a consequence of the excessively large wind shear associated with the velocity maximum. The gap is a region of strong mixing, and undoubtedly represents a region of active mass exchange between the polar stratosphere and the tropical troposphere. The latitude of the gap varies with season, being found closer to the pole in summer and closer to the equator in winter. But there is an equally large variation from day to day associated with the migratory pressure systems.

The sampling conducted by Project HASP has been restricted (with a few exceptions) to a vertical, north-south cross section of the atmosphere

along approximately the 70° West Meridian. The meteorological analysis has also (with few expections) been restricted to the examination of the structure of the atmosphere in this narrow corridor, and is displayed in the form of meridional cross sections. The sampling program was designed on the assumption that east-west (zonal) variations of atmospheric structure and radioactivity are transient in nature, and are fully compensated for by sampling over a period of time long enough to permit the essentially zonal winds of the earth to transport all the air through the sampling net. This assumption of zonal symmetry over a long sampling period, which still appears to be inherently sound, is implicit in all the discussions, analyses, and calculations that follow, and must be accepted until data are available from another meridian.

Sr^{90} Inventory

The total stratospheric inventory of Sr^{90} has been calculated by integrating the specific activities over the entire stratosphere. Because of limitations in range and altitude accessible to the sampling aircraft, the HASP data must be extrapolated to the upper stratosphere and to the poles. Fortunately, the specific activity of the atmosphere is greatest in the lower layers of the stratosphere, most of which can be sampled by HASP aircraft. The extrapolation to the top of the atmosphere has been made by using Project ASHCAN data.[1/] Actually, only a small percentage of the mass of the atmosphere lies above the limits of HASP sampling and no reasonable assumption as to the exact distribution of activity within it will significantly affect the calculated total inventory. The stratosphere above the polar tropopause appears to be fairly well mixed so that extrapolation poleward beyond the range of HASP aircraft should introduce only

a small error into the calculation. One sampling mission to the North Pole has been accomplished. Data from it indicate that the concentration of nuclear debris in the polar stratosphere farther north than the limit of normal HASP sampling is roughly the same as the concentration in the part of the northern polar stratosphere regularly sampled. In Table 1 the total Sr^{90} concentration of the atmosphere averaged over the period November 1957 through November 1958 is given as a function of latitude. Sr^{90} data for samples collected during this period give a total concentration of Sr^{90} in the stratosphere for that period of about 1.0 megacurie.

Table 1

VARIATION OF STRATOSPHERIC Sr^{90} CONCENTRATION WITH LATITUDE

Latitude	mc/mi^2	megacuries
90° - 80° N	10.7	0.016
80° - 70° N	11.3	0.050
70° - 60° N	13.8	0.100
60° - 50° N	12.2	0.120
50° - 40° N	8.3	0.101
40° - 30° N	5.0	0.070
30° - 20° N	4.1	0.064
20° - 10° N	4.2	0.069
10° - 0° N	6.4	0.110
90° - 0° N		0.70
0° - 10° S	4.9	0.083
10° - 20° S	1.8	0.030
20° - 30° S	2.0	0.031
30° - 40° S	2.7	0.038
40° - 50° S	3.6	0.044
50° - 60° S	3.1	0.031
60° - 70° S	3.2	0.023
70° - 80° S	2.9	0.013
80° - 90° S	2.7	0.004
0° - 90° S		0.30

Total stratospheric concentration: 1.00 megacurie Sr^{90}

Chapter IV

MIXING AND TRANSFER OF RADIOACTIVE DEBRIS

Vertical and Horizontal Mixing of Fission Products in the Polar Stratosphere

Fission products introduced into the turbulent polar stratosphere by the USSR detonations results in fairly rapid vertical and latitudinal mixing of the fission products and these fission products pass out through the gaps in the tropopauses with a half residence time of about one year or less. For instance, about six weeks after the USSR detonated several large yield weapons in February 1958, the HASP program documented the relatively young fission debris in the polar stratosphere and found that the young fission debris was moving out through the gaps in the tropopauses into the troposphere where its residence time is short - about a month or so.

In contrast to this rapid lateral and vertical movement of USSR fission debris in the polar stratosphere, it is instructive to give some details of detonations in the equatorial region. (See Fig. 1.)

Horizontal Mixing of Fission Products in the Equatorial Stratosphere

Since a number of the U. S. detonations during Operation HARDTACK in 1958 contained tungsten, the HASP program was able to document the rate of mixing and spreading of this element in the equatorial stratosphere and the results are generally indicative of the effects of a typical U. S. test series on the stratospheric burden. Tungsten from the first shot of Operation HARDTACK that contained that element passed around the earth in the stratosphere and arrived at the longitude of the East Coast of the United States in about forty-four days after the shot. During the forty-four days the tungsten in the stratosphere had moved westward, it had spread a total of 45° in the north-south directions. About one degree

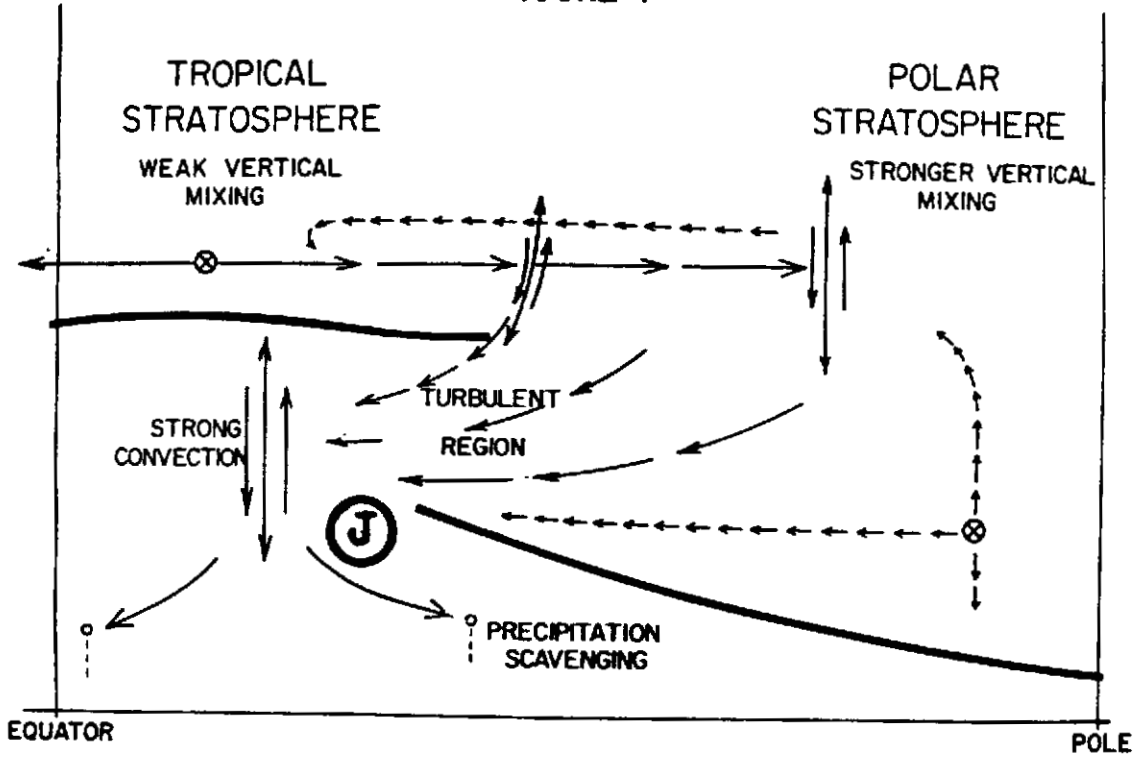
per day spread in the latitudinal direction as the fission products pass around the earth in the stratosphere is typical for U. S. detonations at the Eniwetok Proving Grounds and Great Britain detonations at Christmas Island. The fission debris is very strongly stratified in the equatorial stratosphere with its concentration dropping rapidly with respect to altitude in the stratosphere, which indicates weak vertical mixing. Since the U. S. detonations at the Eniwetok Proving Grounds are at about 10° North Latitude, the fission products placed in the stratosphere from these shots spreads preferentially to the northern hemisphere. Thus, the U. S. detonations at 10° North Latitude do bias the northern hemisphere stratospheric fission product burden along with the USSR polar detonations. This results in there being a larger amount of fission debris in the northern hemisphere than the southern hemisphere. The HASP program has shown conclusively that there is <u>not</u> a uniform distribution of fission products in the stratospheres of the northern and southern hemispheres. Secondly, the HASP program has shown conclusively that there is <u>not</u> a uniform distribution of fission products in the stratosphere with respect to standard cubic feet of air. The concentrations of fission products are largest near the bottom of the stratosphere and decrease relative to standard cubic feet of air with increasing altitude.

<u>Residence Half-Time</u>

A residence half time of nuclear debris in the stratosphere may be calculated by comparing the measured stratospheric inventory of Sr^{90} with estimates of the total quantity which has been injected into the stratosphere since the testing of nuclear weapons began. It is assumed, for the purposes of this calculation, that the "drip" of debris out of the stratosphere can

be approximated by first order kinetics. According to data on nuclear bomb yields published by the Atomic Energy Commission[2], the total fission yield for air bursts during 1945 through 1958 was 37.8 megatons. Presumably about 15 megatons of this was produced by the Soviet test series during the fall of 1958.[3] Similarly, the total fission yields for ground surface and water surface bursts during the same period were 21.5 and 32.6 megatons. Assuming that 100%, 20%, and 30% of the debris from air, land surface, and water surface tests respectively stabilizes in the stratosphere, about 37 megatons of fission products had been introduced into the stratosphere by October, 1958 when the fall Russian test series began. To explain the presence of only 1.0 megacuries of Sr^{90}, taken to be equivalent to 10 megatons of fission products, by mid-1958 requires a residence half time in the stratosphere of less than one year. If it is assumed that debris introduced into the polar stratosphere by Russian tests has a different residence time than debris introduced into the tropical stratosphere by United States and British tests, residence half times of 4 to 9 months for Russian debris and 9 to 15 months for United States and British debris may be calculated.

FIGURE 1



MODEL OF STRATOSPHERIC-TROPOSPHERIC TRANSFER MECHANISM

Chapter V

SURFACE DISTRIBUTION OF Sr^{90} FALLOUT

The distribution of fission products over the surface of the earth provides an important boundary condition for theories which endeavor to explain the mechanisms by which stratospheric fallout passes into the troposphere and thence to the ground. Estimation of the total quantity of Sr^{90} which has been deposited on the surface is needed in order to make a material balance calculation. The time rate of change of the quantity of Sr^{90} which has fallen out, combined with the time rate of change of the quantity of Sr^{90} still in the stratosphere provides a measure of the rate of leakage of debris from the stratosphere into the troposphere.

The total ground inventory of Sr^{90} was calculated using Alexander's[4] soil data. The average value for each ten degree latitude band, expressed as millicuries per square mile per inch of annual precipitation, was multiplied by an average annual rainfall value for that latitude and by the surface area, expressed in square miles, for that latitude band. These data are given in Table 2. The ground inventory in July, 1958 was 2.1 megacuries.

The estimates of yields give a stratospheric injection of 37 megatons of fission or about 3.6 megacuries of Sr^{90} by July 1958. The stratospheric burden of 1.0 megacurie and the ground burden of 2.1 megacuries agree reasonably well with this total injection considering the uncertainties in these estimates.

Table 2

CALCULATION OF TOTAL WORLD GROUND FALLOUT*

Latitude	$\frac{mc/mi^2}{in.}$	Precip. (in.)	10^6 mi^2	MC
90° - 80° N	(0.80)	4	1.6	.005
80° - 70° N	(1.05)	6	4.3	.027
70° - 60° N	0.72	14	7.3	.074
60° - 50° N	1.16	26	9.8	.296
50° - 40° N	0.88	30	12.2	.322
40° - 30° N	0.70	28	14.0	.274
30° - 20° N	0.47	25	15.5	.182
20° - 10° N	0.33	34	16.5	.185
10° - 0° N	0.08	61	17.1	.084
90° - 0° N				1.45
0° - 10° S	0.15	46	17.1	.115
10° - 20° S	(0.15)	37	16.5	.092
20° - 30° S	0.18	26	15.5	.071
30° - 40° S	0.29	31	14.0	.123
40° - 50° S	0.29	44	12.2	.156
50° - 60° S	0.24	38	9.8	.089
60° - 70° S	(0.22)	16	7.3	.026
70° - 80° S	(0.20)	3	4.3	.003
80° - 90° S	(0.18)	1	1.6	.000
0° - 90° S				0.68

Total world ground fallout: 2.1 megacuries Sr^{90}

*The ground fallout concentrations, here expressed as millicuries per square mile/in. of annual precipitation, are based on Alexander's data.[4] Where these data were modified or extrapolated, parentheses are placed around the fallout concentration. Values of precipitation per ten degree latitude band are based on Moller's data.[5]

Chapter VI

RADIATION HAZARD FROM FALLOUT OF Sr^{90}

The Nature of the Hazard

Several factors must be considered in evaluating the potential hazard to the human population from the radioactive components of world-wide fallout. Basically, however, the extent of the hazard from a nuclide depends upon (1) the amount of radiation received from that nuclide by the human body and (2) the effect of that radiation on the body. The High Altitude Sampling Program is contributing information which permits a better estimation of the first of these.

The amount of radiation that a human will receive from a particular radioactive nuclide that enters his environment in world-wide fallout depends upon (1) the amount of fallout deposited in the region in which he lives, (2) the concentration of that nuclide in this fallout, (3) the amount and strength of the radiation emitted by that nuclide, (4) the amount of that nuclide which he ingests or inhales into his body, (5) the length of time during which the nuclide remains in his body, (6) any concentration of the nuclide in a critical tissue. The fourth factor, the amount of the nuclide taken into the body, is in itself a function of several variables. For nuclides such as Sr^{90} which may be dangerous when ingested, the concentration of the nuclide in soil, the discrimination in favor of or against the nuclide during its incorporation into plants or animals which will serve as human food and the relative amounts of such foods eaten by an individual will influence the danger of the nuclide to him. Because of the complexity of the processes by which fallout affects man, the hazard must be evaluated in terms of entire

populations to make allowance for fluctuations in concentrations and in susceptibilities. Sr^{90}, because of its long half-life, high absorption rate, concentration in bone, long biological half-life and low MPC (maximum permissible concentration), appears to be the most hazardous beta emitter. It is a potential source of bone cancer and leukemia.

The Hazard from Sr^{90}

Extensive research has been performed on the movement of Sr^{90} from the troposphere into the soil and through plants and animals into man. As a result, not only is the present concentration of Sr^{90} in soil, food and in human bone fairly well known, but, with the aid of data such as that provided by HASP, future concentrations in these materials may be predicted.

Because the residence time of nuclear debris in the stratosphere is so short, the radioactive decay during its storage there is negligible and cannot appreciably lessen the ultimate dietary and skeletal contamination of the human population. The introduction of about 1.5 megacuries of Sr^{90} by the Russians in late 1958[3], added to the 1.0 megacurie already present in mid-1958, gave a stratospheric burden of close to 2.5 megacuries by fall 1958. If it is assumed that there will be no further bomb testing, it may be calculated that the Sr^{90} concentration in newly formed bone, about 1.5 micromicrocuries per gram of calcium in the north temperate zone in January 1958[6], will continue to rise for two or three years, passing through a maximum of about 5 micromicrocuries per gram of calcium by 1962. Table 3 presents calculated stratospheric, surface and bone concentrations for the next few years. After the maximum is reached the concentration may be expected to decrease at a rate close to the half-life

of Sr^{90}. Thus no great increase in skeletal burden can be expected as a result of future stratospheric fallout from the bomb tests conducted through the end of 1958.

The present maximum permissible concentration for the public at large, as recommended by the International Committee on Radiation Protection is 66 micromicrocuries/gr calcium for the whole skeleton. For workers in the radioisotope industry it is 1,000 micromicrocurie/gr calcium. These concentrations have activities which are considerably less than the amount of natural background radioactivity from cosmic rays and rocks to which all individuals are constantly exposed.

Table 3

VARIATION WITH TIME OF THE BURDEN OF Sr^{90}
IN THE NORTHERN AND SOUTHERN HEMISPHERES*

Date	Stratospheric Burden (MC)		Surface Burden (MC)		Newly Deposited Bone ($\mu\mu c$/gm Calcium)	
	No. Hemi	So. Hemi	No. Hemi	So. Hemi	No. Hemi	So. Hemi
Jul 58	0.77	0.68	1.45	0.68	2.2	1.0
Jan 59	1.47	0.48	2.13	0.87	3.2	1.3
Jul 59	0.81	0.34	2.75	0.99	4.1	1.5
Jul 60	0.25	0.17	3.22	1.14	4.8	1.7
Jul 61	0.09	0.08	3.30	1.18	5.0	1.8
Jul 62	0.04	0.04	3.26	1.20	4.9	1.8
Jul 63	0.02	0.02	3.22	1.18	4.8	1.8
Jul 64	0.01	0.01	3.12	1.14	4.7	1.7
Jul 66	0.00	0.00	2.98	1.11	4.5	1.7
Jul 68	0.00	0.00	2.84	1.06	4.3	1.6
Jul 70	0.00	0.00	2.71	1.00	4.1	1.5
Jul 72	0.00	0.00	2.57	0.96	3.9	1.4

*It is assumed that (1) no further testing of nuclear weapons will be done in the atmosphere, (2) the stratospheric residence half time of Soviet debris is 6 months and that of U. S. - British debris is 12 months, (3) all debris from Soviet tests remains in the Northern Hemisphere, (4) the Sr^{90} concentration in bone is proportional to cumulative soil concentrations. The Sr^{90} burden of the stratosphere is derived from HASP data, the burden of the surface is based on Alexander's data[4], and the concentration in newly formed bone is based on the estimation by Kulp, et al[6] of the diet concentrations in the north temperate zone in July 1958 (8.7 $\mu\mu c$ Sr^{90}/gm Ca) and of the diet to bone discrimination factor of 0.25.

Chapter VII

CONCLUSIONS

The primary objective of HASP is the determination of the distribution of Sr^{90} in the stratosphere and the estimation of the total quantity of that nuclide held in this "reservoir." A cross-sectional picture of the atmosphere has been obtained giving the mean distribution of Sr^{90} during the sampling period November 1957 - November 1958. The distribution is characterized by a primary maximum, with activities of about 600 dpm/1000 SCF, in the lower equatorial stratosphere. The activity level diminishes sharply south of the maximum and is uniformly low, generally between 50 and 80 dpm/1000 SCF, from 15°S to at least as far south as 55°S. North of the equatorial maximum the Sr^{90} level is relatively uniform at about 150 to 200 dpm/1000 SCF, with a few centers of higher activity. The specific activity of stratospheric air is believed to decrease after reaching a maximum in the lower stratosphere. The low Sr^{90} activity (less than 10 dpm Sr^{90}/1000 SCF) below the mean tropopause level clearly distinguishes the troposphere from the stratosphere. There is a gradual decrease in activity across the tropopause gap from the polar stratosphere into the tropical troposphere but there is an almost discontinuous vertical transition in the activities across the tropical tropopause. The mean total Sr^{90} content of the stratosphere during the sampling interval is estimated to have been about 1.0 megacurie. (This mean value does not include the large quantity of debris injected by Soviet tests during the fall of 1958.) No reasonable assumptions as to the distribution of activity in the parts of the stratosphere beyond the reach of HASP sampling can possibly derive a stratospheric content greater than about 1.4 megacuries from the HASP data.

The residence half-time of debris in the stratosphere has been calculated assuming that first order kinetics can satisfactorily fit the actual

process of loss using estimated stratospheric yields from all nuclear weapons tests to date and the HASP stratospheric Sr^{90} inventory. If a single residence half-time is assumed for all debris, the half-time is less than one year. If different half-times are assigned to Soviet and to U. S. - U. K. debris, the data may be explained by a high latitude half-time of 3 to 9 months and a low latitude half-time of 9 to 24 months. Reasonable values appear to be 6 months for the half-time of Soviet debris and 1 year for the half-time of United States and British debris.

In the mixing-transfer model which has been developed, it is hypothesized that the tropopause gap is the main route for the migration of debris from the stratosphere into the troposphere. Because of the rapid rates of lateral migration and the fairly good vertical mixing in the polar stratosphere, debris injected at high latitudes has a short residence time. The slower rates of lateral migration and the virtual absence of vertical mixing in the tropical stratosphere cause debris introduced at low latitudes to have a longer residence time. Indeed such debris must spread into the polar stratosphere before encountering sufficient vertical mixing to bring it down to altitudes at which it can be carried out of the stratosphere.

Because of the short residence half-time of stratospheric debris the ground level fallout of Sr^{90} and, therefore, the burden of Sr^{90} in human bone will reach a maximum within the next two or three years. In the northern hemisphere the maximum bone burden will be about 5 micromicrocuries per gram of calcium in young children, compared to the present burden of about 3 micromicrocuries per gram of calcium. The southern hemisphere values are about one-third of these latter. Although the possible hazard

to the human population from Cs^{137} and from plutonium requires much more extensive investigation, it appears, on the basis of available information, to be less critical than that from Sr^{90}.

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