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United States Atomic Energy Commission
For Delivery at the University of Washington, Seattle, Washington
Sponsored by Faculty of the College of Engineering
Faculties of the Departments of Chemistry and Physics
in the College of Arts and Sciences
and the University Office of Lectures and Concerts
March 13, 1959

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OPENNET ENTRY
☐ Authorized for Public Release
By: Date: 5/8/95
Entered In OpenNet
By: YES Date: NV0025805
☐ Not Authorized for Public Release
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DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
SINGLE REVIEW AUTHORIZED BY: 11-2-94
REVIEWER (ADD):
NAME:
DATE: 12-5-94
DETERMINATION (CIRCLE NUMBER(S))
1. CLASSIFICATION RETAINED
2. CLASSIFICATION CHANGED TO:
3. CONTAINS NO DOE CLASSIFIED INFO
4. COORDINATE WITH:
[✓ 5. CLASSIFICATION CANCELLED]
6. CLASSIFIED INFO BRACKETED
7. OTHER (SPECIFY):

I. INTRODUCTION

RADIOACTIVE FALLOUT

Radioactive fallout is the radioactivity produced by the detonation of nuclear weapons. It has been extensively studied and reported upon __/ - ___ and, in general, although certain questions remain unanswered, the broad characteristics of the behavior of radioactive fallout have been established. We might take a few minutes to review these.

The stratosphere, the top 1/4 of the atmosphere lying above about 40,000 feet, plays an extremely important role. In fact, the fallout from megaton yield weapons occurs very largely from it while the troposphere is the medium which disseminates the fallout from kiloton detonations; thus, speaking broadly, stratospheric debris is from H-bomb detonations and the tropospheric fallout is from A-bombs. It is not that the yield of the detonation is determinative, but rather the altitude to which the fireball rises that determines the fallout rates. The megaton yield fireballs are so enormous that they stabilize at levels only above the tropopause -- the imaginary boundary layer dividing the upper part of the atmosphere, the stratosphere, from

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the lower part, the troposphere -- while the kiloton yield fireballs stabilize below the tropopause. The tropopause normally occurs at something like 40,000 to 50,000 feet altitude, although it depends on season and location. In other words, low yield bombs fired in the stratosphere would be expected to give the same fallout rates as high yield weapons do when fired in the troposphere -- or on the surface. There is some small part of the fallout, even for megaton yield explosions, which does come down from the troposphere.

The stratospheric debris descends very slowly unless, of course, it is so large as to fall in the first few hours. This paper is concerned only with the world-wide fallout -- that is, the fallout which does not occur in the first few hours and excludes the local fallout which constitutes the famous elliptical pattern which is so hazardous because of its radiation intensity, but which, in test operations, is carefully restricted to test areas. It is worth mentioning in passing that the local fallout may be the principal hazard in the case of nuclear war. Most serious attention should be paid to it in civilian defense programs.

II. WORLD-WIDE FALLOUT MECHANISM

The world-wide fallout from the stratosphere occurs at a slow rate. The rate of descent of the tiny particles produced by the detonations is so small that something like five to ten

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years appears to be the average time they spend before descending to the ground, corresponding to an average annual rate of about ten to twenty percent of the amount in the stratosphere at any given time. It is not clear as to just how they do finally descend. It seems possible that the general mixing of the stratospheric air with the tropospheric air, which occurs as the tropopause shifts up and down with the season as well as what is brought about by the jet streams, constitute the main mechanisms. The descent of the stratospheric fallout apparently is never due to gravity but rather to the bulk mixing of stratospheric air with tropospheric air which brings the radioactive fallout particles down from the stratosphere into the troposphere where the weather finally takes over. This mechanism makes the percentage fallout rate the same for all particles too small to fall of their own weight -- and the same as would be expected for gases, providing some means of rapidly removing the gases from the troposphere exists, so the reverse process of troposphere to stratosphere transfer does not confuse the issue.

The world-wide fallout from the stratosphere descends very slowly and one of the questions unanswered at this time is just at what rate it does descend. There have been various estimates from 10% per year to 20% or even higher. But everyone is agreed that the stratosphere does hold its radioactive fallout for a

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much longer time than the lower part of the atmosphere. In fact, the stratospheric material has a residence time of something like several years and we shall estimate, in the course of the discussion, that this figure is something like six years, whereas the troposphere has a mean residence time of about one month with the lower 10,000 feet of it being washed clean on the average about every three days. Between 10,000 feet and the tropopause, which is at something like 40,000 to 50,000 feet, the residence time is perhaps 45 days for a mean time for the troposphere of about one month. Thus, we see that radioactive fallout which is injected into the troposphere is restricted to the general latitude of the detonations for the reason that the residence time is so short that it doesn't have time to mix appreciably latitudinally.

The principal mechanism for removal from the troposphere to the surface is rain. The tiny fallout particles hit cloud droplets and stick to them. Because the particles are so small (perhaps a few hundred atomic diameters) they are subject to a violent random jiggling motion due to collisions with air molecules. It is this motion which causes them to hit the cloud droplets. This motion is called the Brownian motion. In fact, for a particle one micron in diameter, Greenfield __/ calculates that the mean residence time in a typical cloud of water droplets of 20 microns diameter will lie between 50 and 300 hours,

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that for a particle of .04 micron diameter it will be between 30 to 60 hours, and that for a particle of .01 micron diameter it will be between 15 to 20 hours. The theory calculates the diffusion due to the Brownian motion and says that it is just this motion induced by the collisions with the air molecules which makes possible the contact between the fallout particles and the cloud drops. Since this theory is based on first principles with the single assumption that the fallout particle sticks to the water droplet on impact -- an assumption so plausible as to be almost beyond doubt -- it is no surprise to learn experimentally that the Greenfield theory appears to be correct.

There is essentially no world-wide fallout in the absence of rainfall; i.e., in desert regions -- except for a little that sticks to tree leaves, blades of grass, and general surfaces, by the same type of mechanism Greenfield describes in the case of clouds. Thus we see that it is the moisture in the troposphere which assures the short lifetime of the world-wide fallout particles and, that when the stratospheric air which contains essentially no moisture* and, therefore, has no cleansing

*Note: The total water in the stratosphere is about .01 gms/cm^2 while that in the troposphere is about 2 gms/cm^2, 200 times as much.

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mechanism, descends into the troposphere, the tropospheric moisture proceeds to clean it up. On this model, we see that for submicron fallout particles, weather phenomena are controlling and that the bombs which have insufficient energy to push their fireballs above the tropopause will have their world-wide fallout brought down in raindrops in a matter of about one month on the average, in extreme contrast with the stratospheric material which apparently stays aloft for years on the average.

The contrast between these two lifetimes means that the concentration of radioactive fallout in the stratospheric air in terms of equal densities of air is always much higher than in tropospheric air. This has been experimentally observed to be true.

Data from measurements made at the surface as given in Figs. 1 to 5 inclusive are calculated from surface air filter measurements made by the Naval Radiological Defense Laboratory __/. Figs. 1 and 2 present the mixed fission product data and Figs. 3, 4, and 5 give data obtained by analysis of the filters

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and calculated as rates of strontium-90 fallout. The calculation of fallout rates from the air filter data was made by assuming the mean residence time in the lower atmosphere to be three days. Ten thousand feet is estimated to be the average thickness of the air lying below the rain origin. The observed fallout rate in Pittsburgh for the same period of time checks very well with the calculated rate for Washington, D. C., from the air filter data.

Table I, and II give the results of similar calculations for both mixed fission products and air filter strontium-90 data for various latitudes. The theoretical values are those calculated from the model, assuming the average tropospheric residence time of one month and of the stratospheric material ten years.

The mean average concentration in the lower atmosphere during the last months of 1957 and the first few months of 1958 was about 1 disintegration per minute per 100 standard cubic meters or 0.26 per standard cubic foot in the Northern Hemisphere. At this time the content of the higher troposphere would have been expected to be about 15 times this or 3 to 4 disintegrations per minute per thousand standard cubic feet. This would be expected for air just below the tropopause in the higher levels of the troposphere.

We understand the broad problems of the residence time and the scavenging mechanism for the troposphere. In brief, fallout

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comes down from the troposphere mainly with rain; as a consequence of accretion in clouds by the rapid diffusive movements of the tiny particles causing them to hit the cloud droplets. By the same type of mechanism, contact with any surface such as grass, leaves, trees, etc., also will cause deposition. As a result of this the mean residence time in surface air up to about 10,000 feet is about three days and the average residence time for the whole troposphere is about one month. The residence time for the higher part, the top 20,000 to 30,000 feet, would be something like 45 days with an expected steady state concentration perhaps ten to fifteen times the value at the surface.

Now let us turn to the question of the residence time in the stratosphere. This is a very difficult one in the absence of reliable data on the actual quantity of bomb debris in the stratosphere. In the absence of firm direct measurements, one makes estimates of the stratospheric content by adding the amount of radioactivity which is injected, subtracting the fall-out and subtracting for the decay and thus calculating the difference. In this way numbers are derived which can be used to compare with the inadequate information that is available on stratospheric content. Now it isn't always clear just what fraction of a bomb falls out locally and what fraction goes into the stratosphere and troposphere. However, certain empirical rules have been used to estimate these numbers. These are:

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(1) the megaton bomb debris which does not fall out locally in the first few hours is assigned 99% to the stratosphere and 1% to the troposphere; (2) local fallout is assumed to be 80% for land surface shots and 20% for surface water shots and 100% for air shots; (3) all kiloton shots are assigned to the troposphere; (4) it is assumed that the latitudinal spread of tropospheric bomb clouds is only 10 degrees with a sharp step function rather than a normal error curve distribution and the residence time for this fallout is taken to be one month as described above. On the basis of these assumptions, knowing the yields and types of bombs which have been fired, we estimate the total stratospheric inventory and on the basis of various reasonable stratospheric residence time predict the stratospheric fallout over the earth's surface for an averaged intensity of rainfall. Figure 5 gives the stratospheric inventory for strontium-90 as deduced in this manner up to January 1, 1959, calculated on the basis of two assumed residence times -- 5 and 10 years.

It is interesting to note the tremendous rise in October of last year due to the Russian test series in the polar regions. About a 60% increase due to an estimated 15 megatons of fission injected into the stratosphere in that one month. This makes possible a searching test of all the theories of stratospheric

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storage, mixing and fallout and in particular of an interesting new one advanced recently by E. A. Martell __. Dr. Martell's theory is that whereas equatorial shots would have their radioactive debris distributed uniformly throughout the stratosphere and might well come down according to a residence time of 5 to 10 years, this is not true for shots made in the polar regions as for the Russian tests. He suggests that there may be a distinction to be drawn for these as compared to the U. S. - British tests carried out near the equator. For the polar shots he suggests a much shorter residence time - 1 year or less - and over the Northern Latitudes of the particular hemisphere involved. The Russian October series makes an immediate and definitive test possible. In Table II we display the strontium-90 fallout rate for northern latitudes expected now - on Dr. Martell's theory - of some 32 millicuries of strontium-90 per square mile per year with an average age such that the ratio of the 51 day strontium-89 to strontium-90 should be 120 in November decreasing to 46 in January as compared to expected rates on the older uniform distribution theory of 2.6 or 5.1 millicuries per square mile per year depending on whether the stratospheric residence time be taken as 10 or 5 years respectively and with the strontium-89 to strontium-90 at 55 for November, 41 for December and 32 for January 1959.

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In the table are given some on November for Pittsburgh, December for Westwood, New Jersey, and January for Washington, D.C.

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which, as you see, fall somewhat intermediate between the two theories, perhaps more closely fitting the old theory, particularly insofar as the strontium-89, strontium-90 values are concerned. At the present time it does not seem to be possible to decide definitely between the two alternatives, though the next few months should give us adequate data to distinguish between them.

In order to better delineate and understand the mechanism by which stratospheric fallout occurs the Atomic Energy Commission added the isotopes tungsten-185 and rhodium-102 to some of the nuclear devices exploded in the Hardtack Series last summer. Tungsten-185 with a half-life of 74 days was produced in a number of detonations over silica sand. Underlying the study of tungsten-185 is the hope that by determining the contribution of a single equatorial test series in all parts of the world it would become possible to distinguish among the different models which have been proposed: (1) the one by the author in which the stratospheric material is assumed to mix uniformly over the world and then fall out at a rate corresponding to a residence time of 5 to 10 years or something intermediate to be determined; (2) the one by Dr. Machta and Mr. Stewart which says that the mixing in the stratosphere is also uniform but that the fallout from the stratosphere occurs mainly at about 40°N Latitude where the polar tropopause meets the equatorial tropopause and for

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certain distance two tropopauses exist and the jet stream occurs. It is Dr. Machta's thought that this phenomenology is associated with a particularly high leakage rate from the stratosphere; (3) the theory of Dr. Martell that uniform mixing of the stratosphere vertically and horizontally similar to the first model occurs for equatorial shots but that for a polar shot this does not occur with a short residence time of one year or less.

The rhodium-102 having a life of 210 days was released only in the hydrogen bombs fired high in the stratosphere over Johnson Island in August. Thus this isotope will allow us to measure the stratospheric;mixing time from the data which will become available as a result of the sampling of rainfall over the world and the various programs for taking air filter samples, both of the stratosphere and in the troposphere. These data are not yet available but it might be interesting just to predict the order of magnitude one would expect in rainfall. By assuming perfect mixing in the stratosphere in a period of something like three months over the whole earth, then it works out that 100 megacuries of these isotopes would give something like 20 disintegrations per minute for 100 standard cubic meters of surface air, a readily detectable quantity.

There are preliminary data already indicating that as early as October 31 samples for the lower stratosphere near the equator at about 12°N showed the rhodium-102 isotope. In other

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words the vertical mixing in the stratosphere had occurred rapidly. This is one of the serious assumptions which all the models have in common. There appears to be a considerable speed with which the stratosphere mixes, particularly model one assumes essentially instantaneous mixing though, of course, as shown in the above remark one need not do this and perhaps three months time would be a reasonable figure to use.

There was another tracer added in the Johnson Island shots by virtue of the fact these were the first hydrogen bombs ever fired in the stratosphere. As has been remarked previously, all of the hydrogen bombs release a considerable amount of tritium ____, - ____, but because the devices previously have always been fired in the troposphere where a large quantity of water is incorporated in the fireball with the result that when it rises into the stratosphere and cools making the familiar white cloud which consists of rather large ice crystals which fall rather quickly and thus carry the tritium back to earth again. This did not happen for the two devices fired over Johnson Island in the stratosphere, and therefore, we can expect that for the first time the stratosphere has its tritium content of its water raised appreciably above the level it had previously due to the cosmic rays. The stratosphere is so low in moisture (a fair extimate seems to be about 10 milligrams per square centimeter of the earth's surface for the entire stratosphere as compared to something like 2 to 3 grams per square centimeter for the [redacted]

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troposphere) that the concentration of the cosmic ray tritium in the stratospheric moisture will be very high, something like in the inverse ratio of the water concentrations, together with an additional factor for the 5 to 10 year storage time of the cosmic ray-produced tritium. Well, in substance, the hydrogen bombs fired over Johnson Island made tritium water in large quantities in the stratosphere and so it is to be expected if the simple uniform model is correct that the rains all over the world will show a stratospheric tritium drip as well as the well known stratospheric strontium-90 and cesium-137 fission product drips which have been occurring for years. But this stratospheric tritium drip from Johnson Island had its zero time in August of 1958 just as the rhodium-102 isotope did . The tritium, however, with a 12.26 year half-life and its presence as natural water and following the hydrological cycle of the atmosphere will, in some ways, be more enlightening. So it is with real interest we look forward to the next few months to determine the mechanism by which the top part of the world's atmosphere mixes in itself and with the lower atmosphere. This will be an important contribution to meteorology and geophysics if it develops as expected.

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The apparent age of the fallout is measured by the Sr^{89}/Sr^{90} and Ba^{140}/Sr^{90} ratios. Strontium-89 with a 54 day half-life and barium-140 with a 13 day half-life give independent measures of the age. In Figure 7 the results of extensive

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measurements on the strontium-89/strontium-90 ratio, as shown by rain samples collected monthly at various places all over the world, are plotted together with the values predicted by the simple uniform theory for 40°N Latitude and for pure stratospheric fallout. According to the model, stratospheric fallout is the principle type occurring throughout most of the Southern Hemisphere and in certain parts of the Northern Hemisphere which happen not to have been in the paths of tropospheric debris. The theoretical calculation is made by taking the various contributions to the stratospheric reservoir and multiplying by their calculated strontium-89 to strontium-90 ratios (new debris is taken as having a ratio of 180 and the half-life of strontium-89 is taken as being 54 days with, of course, strontium-90's half-life being 28 years). In this manner the expected Sr^{89}/Sr^{90} ratio of fallout from the stratosphere is calculated. It has a fluctuating value due to injections from weapons tests but it rapidly settles down at all times prior to October 1958 to something like 5 to 10 units.

The tropospheric debris on the other hand having a mean residence time of only one month has a much higher strontium-89 to strontium-90 ratio. In making the calculation for the total expected fallout at any given position the amount of tropospheric debris is calculated by the rules given previously and the average taken. Similar calculations are done with barium-140

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which has a half-life of 12.8 days. It being a much shorter lived fission product affords a possibility of revealing details which the longer lived strontium-89 cannot show. Figure 8 gives detailed data for the Sr^{89}, Sr^{90} ratio for our most concerted and carefully conducted rain fallout study, the Pittsburgh study. In the figure is shown the theoretical curve and again the agreement seems to be satisfactory. Figure 9 shows the analogous data for the barium-140 - strontium-90 ratio in the Pittsburgh rain, and Figure 10 shows recent fallout data for the cities of Pittsburgh and Westwood, New Jersey, together with the strontium-89 to strontium-90 ratios in Westwood. Finally, Figure 11 shows the world-wide rain pot data for monthly collections in various places over the world. These data correspond to the strontium-89 to strontium-90 ratio data given in Figures 6 and 7. All of these data are given in the reference, HASL-42 report ___/.

It is clear from Figures 7 through 11 that there is a strong correlation between the strontium-89 to strontium-90 ratio and the occurrence of test series as shown on the bottom of the figures, and the success of the simple theory in predicting and accounting for the strontium-89 to strontium-90 ratios indicates that it is quite likely that a good part of the extra fallout in latitudes in which testing occurs, such as the middle northern latitudes is due to tropospheric fallout and

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may not be due to Dr. Machta's mechanism of preferential stratospheric drip in these middle latitudes.

In order to alleviate the abruptness of the step function-type of assumption in the model proposed by the author, calculations were done assuming that after the first month, tropospheric debris spread out to cover a band much wider than in the first month and, in fact, would cover an entire hemisphere. In this way, theoretical fallout curves were obtained which show the total predicted fallout at various latitudes assuming the average annual rainfall. It is always necessary to remember that particularly arid places will necessarily have low fallout and one should realize that this leads to other places having normal rainfall having higher fallout. This broad band theoretical model may fit the observations somewhat better than the narrow band model presented earlier.

Figure 13 gives the latitudinal profile of total fallout from the narrow band step function calculation and Figure 14 the broad band fallout curve. The important question is whether these predictions agree with observations. A first and most important point is that the data must be valid and not due to local fallout. Most are for the United States and the question is whether fallout is somewhat high because of the proximity of the Nevada test site. In Table III we compare United States and foreign soil strontium-90 content for the year 1955, the

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foreign soil samples having been taken in the same latitude band and at the same time. It is clear that the difference is large and amounts to about 11.4 millicuries per square mile which corresponds to some 340 kilotons of local fission fallout over the area of the United States, a reasonable figure. In other words the sharp division between local and world-wide fallout is probably somewhat artificial and the United States test site being close to many of the sampling stations in the United States has caused the United States data to be high as compared to the world-wide average. Therefore, in comparing the theoretically predicted fallout with observation we choose to use only foreign soil data. For rainfall, however, it is not necessary to do this at times when no firing is going on in Nevada and the Nevada test tropospheric material has been removed from the atmosphere. So, the data which are of principal use in measuring the total integrated fallout, are the foreign soil samples. This does not mean to say that the soil data in the United States should not correlate with the rain fallout data and, in fact they do, as Figure 15 shows, which presents the complete series of Pittsburgh rainfall data, together with the United States average soil data as a function of time together with the theoretical for the overlap of the two bands at 30° to 40° from the United States tests in Nevada and 50° to 60° from the Russian mid-latitude test site.

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However, to check the theory carefully, it is necessary to choose foreign soil samples which are widely selected over the world and which are carefully analyzed by the HCl extraction technique which removes all of the contained strontium-90. The only complete series of data available is for samples collected in the year 1956. They are presented in Figure 16 together with the theoretical predicted curve for that same period. The total observed fallout was 8 megatons of fission and the 10 year residence time theory would predict somewhat less than that, perhaps the average of 5.3 and 8.1 megatons, these being the figures for the two dates, January 1, 1956 and January 1, 1957. The foreign soil samples were collected throughout 1956 and represent something like an average for that period of time. Corresponding figures for the shorter stratospheric residence time of 5 years are 8.08 and 12.44. It would seem from these numbers that a residence time in the stratosphere of between 5 and 10 years is indicated. We shall see later that this agrees with other information as well. A series of soil samples taken in the spring of 1955 and the 1956 samples divided into two parts for the spring of 1956 and the rest of the year, together with some samples taken in the spring of 1958, for which preliminary analyses are available are presented in Table IV. Focusing on the latitudes in the Southern Hemisphere so that

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tropospheric fallout will be minimal and taking the spring 1956 data we obtain an average of 2.8 millicuries per square mile at that time. Doing the same thing in 1958 we obtain 6.5 millicuries per square mile for a difference of 3.7 millicuries per square mile or an average fallout rate of 1.8 millicuries per square mile per year. Taking the mean stratospheric inventory from Figure 6 for the year 1957 of about 24 megatons or 12 millicuries per square mile we calculate the stratospheric residence time which agrees with this. The result is 6.5 years which number will obviously agree well with the data shown in Figure 15.

The difference between the United States and foreign collections in the given latitude are well illustrated by the monthly rain data for July, August and September, 1957. ___. The average of United States stations for those three months was 2.4 ± .25 millicuries per square mile while the average for foreign stations in the same latitude was 1.3 ± 0.2, again agreeing with the soil data shown in Table III. It is to be hoped that we will soon have analyses of the 1958 soil collections because it is clear that these data are of extreme importance in deciding about the mechanism of stratospheric fallout.

The Ashcan Project, the project for sampling the stratosphere by means of balloons and filters continues but analytical difficulties have cast some doubt on the validity of the data.

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It is to be recalled that a rough average figure for the stratospheric inventory is 50 disintegrations per minute per 1000 standard cubic foot of air, and various evidence indicates that the filter efficiency may be 25%. Taking these rough numbers one then would deduce that the strontium-90 content of the stratosphere averages about200 disintegrations per minute per 1000 standard cubic feet in the early part of 1958 and late 1957. This number which agrees very well with the theoretically calculated stratospheric inventory given in Figure 6. Turning now, again, to the surface air concentration data taken by the Naval Radiological Defence Laboratory and quoted earlier in Table I which gave a mean surface concentration of about .3 disintegrations per minute per 1000 cubic feet we make a direct comparison between the observed mean residence time of about three days and the stratospheric time. Multiplying three days by the ratio of 200 to .3 the mean value at the surface gives the stratospheric residence time. This result is 5.5 years, agreeing with the two previous values.

Taking all of these different lines of evidence into account and noting the general agreement with observation, we conclude that the simple model proposed earlier still is likely to be correct in many respects. To recount, it says that material introduced into the stratosphere is mixed rapidly vertically

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and horizontally and leaks down uniformly over the world at a rate of about 16% per year (this would correspond to a mean residence time of six years) into the troposphere where it is removed in about one month by normal weather processes and by impinging on the surface of trees, grass and other features of the earth. Its main time is spent in the top 30,000 feet of the troposphere for it spends only about three days on the average in the bottom 10,000 feet. In this lower layer the possibility of being brought down by rainfall and surface impact is at a maximum. We have considerable evidence which is in the formative stages and we can expect that during the next weeks and months, the particular type of measurements displayed in Table II which bear on the fate of the Russian October 1958 debris will be most revealing. These data, together with measurements on the rhodium-102 and the tritium from the high stratosphere August shots over Johnson Island should very nearly settle most of the major points about the stratospheric mixing mechanism.

III. THE ASSIMILATION INTO THE BIOSPHERE

The great question arises as to whether and at what rate the fallout is taken into the biosphere. During Operation Hardtack, a considerable effort was made to introduce tonnages of silica sand into the firing barges on the thought that strontium-90 might thus be incorporated into glass-type insoluble beads which would thus be of reduced solubility and the probability of its being assimilated by plants and animals would thus be reduced. Measurements are now being made on the fallout with this point in mind but of course it is extremely difficult to distinguish the Hardtack fallout, particularly if the author's simple model is correct, from the previous earlier shots, many of which were done in coral sand or in plain sea water and which have no insoluble components. It does indicate, however, the type of effort that might be made to reduce the assimilability of strontium-90 in the biosphere. Such an approach seems reasonable from a consideration of the nature of the fireball and the probable chemical processes occurring there.

Direct study of the assimilation of radioactive fallout into the human body is restricted very largely to a few isotopes, particularly strontium-90, cesium-137 and iodine-131. Cesium-137 has been studied particularly carefully by Langham and Anderson at the Los Alamos Scientific Laboratory. ___, ___, ___, ___, ___ and Figure 17 presents their data for the cesium-137 content of people in the United States in the year 1957 versus the milk content. It clearly shows that milk is not the only source of cesium as one would expect, a part of it comes from vegetables, even though milk is a major source. This figure shows also that the discrimination factor against

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cesium, relative to potassium in the milk, is about two-fold, not too dissimilar from the discrimination factor against strontium, relative to calcium in milk. ___/, ___/, ___/, ___/, ___/

They found, however, that the human content of cesium-137 did not rise appreciably from the value of 41 ± 1.3 micromicrocuries per gram of potassium in 1956 to the 1957 value of 44 ± 1.1. This small change, together with the fact that cesium is an isotope which should come into rapid equilibrium with the human body because its mean residence time is only some 120 days as compared to many years for strontium-90. Therefore, the human body is obviously very nearly in equilibrium with the food chain in the case of cesium in sharp contrast to strontium-90 and we can therefore deduce from the cesium content something about the possible ways in which fallout enters the biosphere. First, the fact that there was no large rise between 1956 and 1957, together with the fact that certain observations on the strontium-90 content of milk and cheeses over the years indicates that they too do not rise as rapidly as the total fallout observed in the soil, suggests that possibly a large part of the fallout which enters the biosphere does so by virtue of the pickup directly on the leaves of grass and vegetables which are eaten directly, either by cows or by people with the result that an entirely different approach to the question of the fallout hazard is made. Of course, it is absolutely certain that

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there is pickup of the radioactive fallout through the roots. What may be the situation, however, is that this pickup is not nearly so serious as we have been supposing and a good part of the pickup we have observed has come from the leaves. If the latter is true then in a period of minimum fallout, the milk level and the vegetable level will fall correspondingly to a value somewhat closer to the amount that would come solely from the root pickup, and we would expect, therefore, that the steady state concentration in the human body of the fallout isotopes would be considerably lower than we have been calculating in the past. It is not clear at this time as to whether this conclusion is justified but further observation and study will make it clear and we should be alert to the importance and likelihood of this development.

IV. CONCLUSION

The future course of the fallout investigation is well set and is now proceeding on an international scale so that without doubt within the foreseeable future the major questions about the fallout mechanism will be answered. Remaining, however, will be the tremendous problems of the biological consequences of fallout radiation. We shall make no attempt here to consider these. It is, however, an area of uncertainty so large that only the most conservative treatment of the

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permissible body burdens of fallout isotopes is tolerable and this conservative treatment indicates that care and caution must be taken about the matter of additional radioactive contamination. The United States Atomic Energy Commission has consistently tried to reduce the magnitude of the fallout from atomic testing and it is clear that the new technique of testing underground can further greatly reduce world-wide fallout. It is to be hoped that other nations will adopt this procedure, even though it is sometimes difficult and more trouble. It does have one advantage, however, in addition to eliminating fallout; it makes the test schedule independent of weather. With further development of procedures it ought to be possible to obtain most of the results on weapons design with this technique. Of course, the proof testing of weapons in their carriers might not be possible underground, the critical question of whether the weapons operate and give the yields and behave as they should, can be answered by this method which is fallout free. No one who has studied radioactive fallout has any desire to, in any way, increase the amount of it. It is a risk and hazard which is limited and which can be considered relative to the advantages gained, but it is necessary to watch it and to control it as carefully as possible.

[redacted]

[redacted]

TABLE Ia.

DEPOSITION FROM TROPOSPHERIC FALLOUT FROM SURFACE AIR FILTER DATA

DATE	Fission Product Data*	Strontium-90 Data
1957		
July	.07 MT	.09 MT
August	.06	.08
September	.13	--
October	.11	.14
November	.05	.07
December	.05	.09
1958		
January	.07	.13
February	.07	.18
March	.10	.23
April	.32	.15
May	.16	--
June	.16	--
July	.13 Southern Hemisphere	--
	.12 Northern Hemisphere	--
August	.10 Northern Hemisphere	--
	.08 Southern Hemisphere	--
September	.06 Northern Hemisphere	--
	.04 Southern Hemisphere	--

Filter Efficiency 100% (assumed)
Lower 10,000 feet 50% atmospheric residence time 3 days
Troposphere (80% atmospheric) 30 day residence time

* (20 KT = 25 dpm/CuM at equator)

[redacted]

TABLE Ib.

THEORETICAL TOTAL TROPOSPHERIC FALLOUT (MT)

	1957						1958									Total
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Theo.	.19	.19	.26	.17	.08	.03	.02	.01	.29	.14	.10	.38	.81	.44	.45	2.9
Obs.	.08	.07	.13	.12	.06	.07	.10	.12	.21	.23	.16	.16	.25	.18	.10	1.9

[redacted]

[redacted]

[redacted]

TABLE IIa.

1959 FALLOUT DATA AND THEIR SIGNIFICANCE FOR STRATOSPHERIC FALLOUT MODELS

A. Polar Fallout Theory __/

For shots at or near the Poles, the stratospheric fallout occurs more rapidly than for shots elsewhere, expecially the equatorial region for which a longer residence time of perhaps 5 to 10 years is appropriate. Take $\tau = 1$ year for the October USSR tests which amounted to about 15 MT of fission added and assume uniform fallout as far south as 30°N (this means 1 MT of fission is equivalent to 2 mcs Sr^{90}/mi^2) then the increase in stratospheric fallout should be 30 $mc/mi^2/yr$.

On this basis the present fallout rate in these latitudes
should be 1.6 $mc/mi^2/yr$ for world-wide stratospheric if $\tau = 10$ years
or 3.2 $mc/mi^2/yr$ for world-wide stratospheric if $\tau = 5$ years
plus 30 $mc/mi^2/yr$ at an average age of 3 months for totals of 32 or 33 $mc/mi^2/yr$

The Sr^{89}/Sr^{90} ratios should be 115 for November
77 for December
51 for January
32 for February

[redacted]

[redacted]

TABLE IIb.

B. Uniform World-Wide Theory

Every addition is assumed to be mixed instantaneously and uniformly to all latitudes, longitudes, and altitudes. Then since the October additions amounted to a 60% increase, the fallout rates expected would be 1.6 times the previous values or 2.6 mc/mi^2/yr for a 10 year residence time and 5.1 mc/mi^2/yr for 5 years. The Sr^{89}/Sr^{90} ratios expected would be 5 for November, 36 for December, 26 for January and 18 for February.

C. Experimental Data

I. Pittsburgh Rain Data for November (Nuclear Science and Engineering Corporation)

Dates	Rainfall (inches)	Sr^{90} Fallout mc/mi^2	Sr^{89}/Sr^{90}
Oct. 28 to Nov. 2	0.02	.020	33
Nov. 2 to 3	.31	.084	62
" 3 to 6	.02	.004	97
" 6 to 9	.13	.073	43
" 9 to 10	.30	.070	46
" 10 to 15	.25	.103	35
" 15 to 16	--	.013	29
" 16 to 17	.03	.013	48
" 17 to 18	.04	.020	44
" 18 to 19	.19	.059	48
" 19 to 24	.02	.044	27
" 24 to 26	.02	.030	28
" 26 to 29	.19	.079	42
Total	2.21	.632	

Versus 2.7 from Polar theory and .42 from uniform theory with τ 5

[redacted]

[redacted]

TABLE IIc.

II. Westwood, New Jersey for December (Isotopes, Inc.)

Dates	Rainfall (inches)	Sr^{90} Fallout (mc/mi^2)	Sr^{89}/Sr^{90}
Nov. 19 to Nov. 26	0.12	.129	32
Nov. 26 to Dec. 1	2.30	.542	35
Dec. 1 to 4	0.68	.153	34
" 4 to 8	0.16	.091	35
" 8 to 10	0.20	.080	37
" 10 to 15	0.02	.035	32
" 15 to 23	Dry	$<$ .002	--
" 23 to 30	0.22	.107	33
Total	3.70	1.139	

= 1.00 mc/mi^2/mo
vs 2.7 expected by Martell
or 0.4 expected by uniform theory

III. Washington, D. C. for January, 1959 (author)

Dates	Rainfall (inches)	Sr^{90} Fallout (mc/mi^2)	Sr^{89}/Sr^{90}
Jan. 1	1.84	.350	23 ± 3
" 14 to 15	0.17	.098	29 ± 1

D. Comparison With Previous Years

Pittsburgh - Average rate for last year	1.00 mc/mi^2/mo
Pittsburgh - Average rate for 1955-1956	.80 mc/mi^2/mo
Pittsburgh - Average rate for Nov. Jan. in 1955-1957	.24 mc/mi^2/mo

[redacted]

[redacted]

TABLE III

U. S. AND FOREIGN SOIL SR^{90} CONTENT

1956

	Average	mc/mi^2
United States		17.7
Foreign	20° - 30°N	5.6
	30° - 40°N	6.3
	40° - 50°N	7.1
Average	20° - 50°N	6.3
Difference (U. S. - Foreign)		11.4

NOTE:
This corresponds to 340 KT fallout versus a total of 688 KT fired of which 308 KT was estimated to be local.

[redacted]

[redacted]

TABLE IVa.

SUMMARY SOIL DATA FOR FOREIGN SAMPLES

Latitude	Spring 1955	Spring 1956	Spring 1958
90°S - 70°S			
70°S - 60°S			
60°S - 50°S			
50°S - 40°S	1.8	2.5	8.6
40°S - 30°S	3.0	3.6	7.8
30°S - 20°S		2.7	6.2
20°S - 10°S			
10°S - Equator	0.5	2.3	3.5
Equator - 10°N		3.4	6.4
10°N - 20°N	1.2	6.3	6.4
20°N - 30°N	3		20
30°N - 40°N	4.3 ±2.5	4.2	23 ±4
40°N - 50°N	3.90 ±2.0		
50°N- 60°N			
60°N - 70°N			
70°N - 90°N			

[redacted]

[redacted]

TABLE IVb.

Southern average Spring 1956	2.8
Southern average Spring 1958	6.5

D = 3.7 mc/mi^2

Average Fallout rate = 1.85 $mc/mi^2/yr$

Mean Stratospheric Inventory = 12 mc/mi^2

$\bar{\tau}$ = 6.5 years

[redacted]

[redacted]

REFERENCES

1. Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, "The Nature of Radioactive Fallout and Its Effects on Man," May 27-29, June 3-7, 1957, Parts 1 and 2. U. S. Government Printing Office, Washington, 1957.

2. The Biological Effects of Atomic Radiation, National Academy of Sciences (1956)

3. "The Hazards to Man of Nuclear and Allied Radiations." British Medical Research Council (1956)

4. "Environmental Contamination from Weapons Tests." Hardy, Edward P., Jr. Harley, John H., Lough, S. Allan. HASL-42, June 16, 1958. U. S. Data Summarized.

5. "An Approach to a General Method of Computing Doses and Effects From Fallout." (Document A/3858) Prepared by Secretariat of U. N. With Experts of U. N. Scientific Committee on the Effects of Atomic Radiation. Has all standard problems worked out theoretically but neglects effect of foliar uptake on body burden.

6. Report of U. N. Scientific Committee on the Effects of Atomic Radiation. Gen. Assembly, Official Records 13th Session, Supplement #17 (A/3838).

7. "Strontium-90 in Food." Kulp, J. L., Slakter, R., Schulert, A. R. Paper read before the Div. of Ind. & Eng. Chem. of the Am. Chem. Society, Sept. 11, 1958, and Science 128, 85 - (1958).

8. Radioactivity of People and Foods. Anderson, E. C., Schuch, Robert L., Fisher, W. R. and Langham, Wright. Science, 125, p. 1273, 6/28/57.

9. "Radioactivity of People and Milk." Anderson, E. C., Science 128, 882-6 (1958) General presentation of cesium-137 content of people and milk content is roughly proportional to rainfall. The internal cesium-137 dosage in 1957 was .19 mr/yr and the external cesium-137 dosage in 1957 was about .84 mr/yr for an average of 44 micromicrocuries of cesium-137 per gram of potassium and 41 in 1956. A discrimination factor of 1.8 favorable to potassium relative to cesium was found in the body uptake of cesium-137 in milk and about half of the cesium-137 was found to come from milk and half from other foods. The fact that the body content in 1957 is not appreciably higher than it was in 1956 strongly suggests that the principal pickup is from foliar assimilation and not from the soil because this would be proportional to the rate rather than the total fallout.

[redacted]

[redacted]

REFERENCES CONT'D.

10. "Accumulation and Movement of Fission Products in Soils and Plants." Quarterly Reports of Soil and Water Conservation Research Division U. S. Department of Agriculture. Dr. R. F. Reitemeier, et al. January - March 1958; April - June 1958; July - September 1959. These studies show the existence of chemical fixation up to as much as 30% in some soils and many fine points about run-off and degree of absorption in mulch and plant cover.

11. "Strontium-90 in Man II." Kulp, J. L., Eckelmann, Walter R., and Schulert, A. R. Science 127, 266-74 (1958).

12. "Entry of Radioactive Fallout into the Biosphere and Man." Langham, Wright, and Anderson, E. C.

13. "World-Wide Distribution of Strontium-90 and Its Uptake in Man." Kulp, J. L.

14. "Barium-140 Radioactivity in Foods." Anderson, E. C., Schuch, R. L., Fisher, W. R., Van Dilla, M. A. Science 127, 3293, p. 283, Feb. 7, 1958.

15. "Note on the Entry of Strontium-90 Into Plants Under Normal Conditions." Russell, R. Scott (Private Communication)

16. "Discrimination Between Strontium and Calcium in Plants and Soils." Martin, R. P., Newbould, P., Russell, R. Scott. Paper presented at UNESCO Conf. on Radioisotopes in Scientific Research. (1957). This paper speaks convincingly of the importance of folial and stem pick up as contrasted with root assimilation. It shows that the former is much more important for plants growing at the line fallout occurs.

17. "Levels of Strontium-90 in Canada Up to December 1956." Grummitt, W. E., Carruthers, E. W. AECL-659, February 1957.

18. "Comparative Metabolism of Strontium and Calcium in Man." Schulert, S. R., Peets, E. A., Laszlo, D., Spencer, H., Charles, M., and Samachson, J. International Journal of Applied Radiation and Isotopes (to be published). Trace strontium and calcium were administered to terminal cancer patients intravenously and the distribution in bone and major organs determined. The ratio of strontium in bone to soft tissue increases until at four months 99.5% of the retained strontium is in bone. The retention of calcium is about 60% and of strontium 25%.

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[redacted]

[redacted]

REFERENCES CONT"D.

20. "Stratospheric Data and Meteorological Interpretation." Machta, L., and List, R. J. Paper presented at AEC Meeting on Collection and Classification of Atmospheric Particulate. October 8-9, 1958. Discusses the stratospheric filter data. Concludes they probably show a peak in strontium-90 concentration in middle stratospheric altitudes and using Dr. Holland's estimates of the filter efficiencies concludes that they show only 5 MT stored in the stratosphere. Cautions about the uncertainties of this conclusion.

21. "Evaluation of the Ground Level Sampling Program." Machta, L. Paper presented at meeting of participants in fallout meeting held by AEC in Washington, D. C., December 5, 1958.

22. "Atmospheric History of Strontium-90 Fallout." Martell, E. A., Cambridge Research Center. (In Preparation). Dr. Martell suggests that the increases in rate of fallout which have occurred in the spring of each of the last several years are due to largely Russian tests of intermediate and high yield weapons which have injected debris into the lower and intermediate levels of the stratosphere and for which the debris exhibits relatively short residence times of the order of 6 months. Mention that the stratospheric data are so uncertain it is unwise to use them yet. Point out that the latitudinal profile for tropospheric fallout is probably considerably wider than corresponds to a 10° step function.

23. "World-Wide Effects of Atomic Weapons, Project Sunshine." August 6, 1953, R-251-AEC (amended). It was this study conducted at the Rand Corporation in Santa Monica, California, in the summer of 1953 which launched the Sunshine Project on radioactive fallout.

24. "Radioactive Strontium Fallout." Libby, W. F., Proceedings of the National Academy of Sciences. Vol. 42, No. 6, pp. 365-390. June 1956.

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26. "Radioactive Fallout." Libby, W. F., Proceedings of the National Academy of Sciences. Vol. 43, No. 8, pp. 758-775. August 1957.

27. "Radioactive Fallout."Libby, W. F. Proceedings of the National Academy of Sciences. Vol. 44, No. 8, pp. 800-820. August 1958.

[redacted]

[redacted]

RADIOACTIVITY PROFILE - 1957
FISSION PRODUCTS

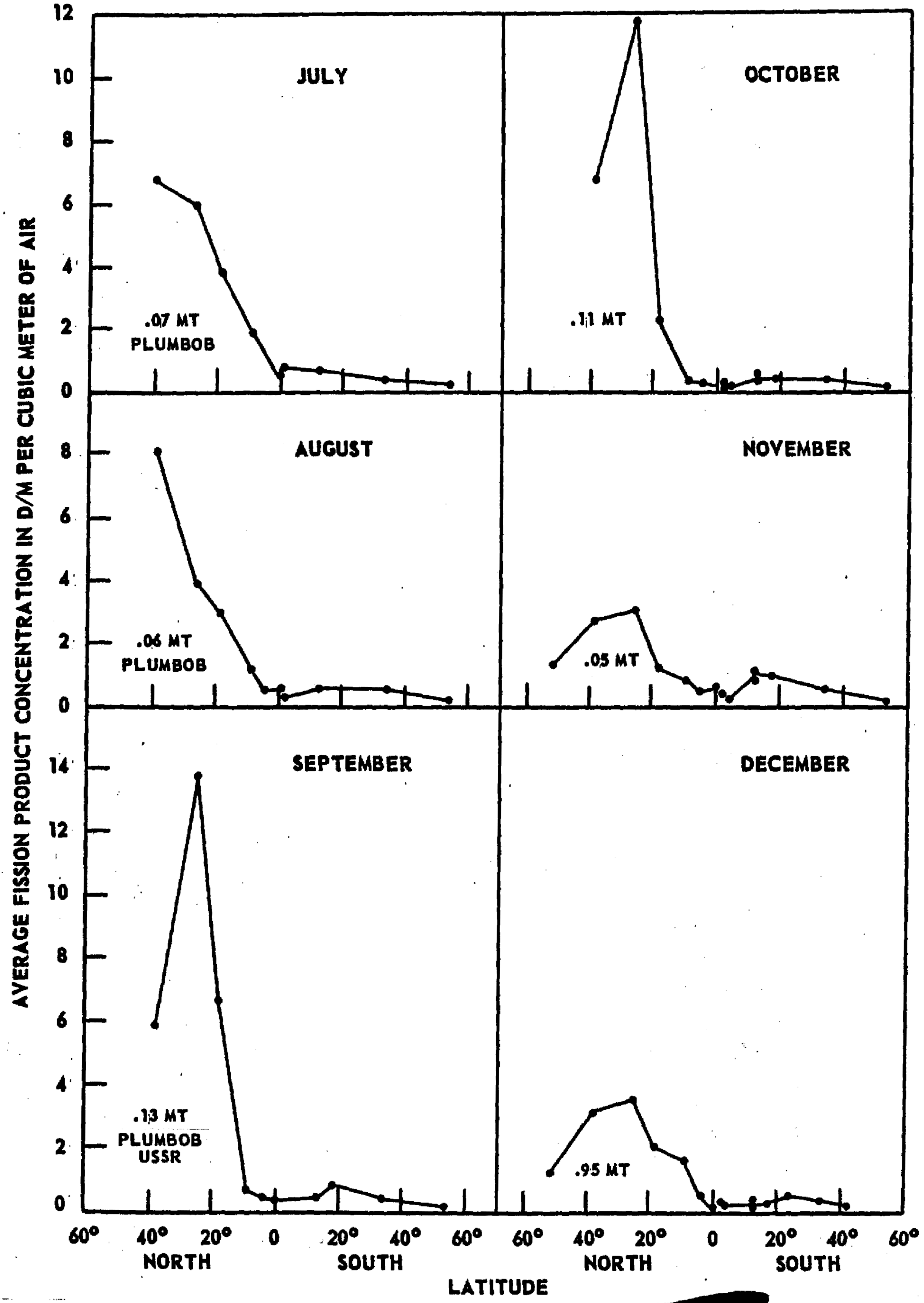


FIGURE 1

[redacted]

[redacted]

RADIOACTIVITY PROFILE - 1958
FISSION PRODUCTS

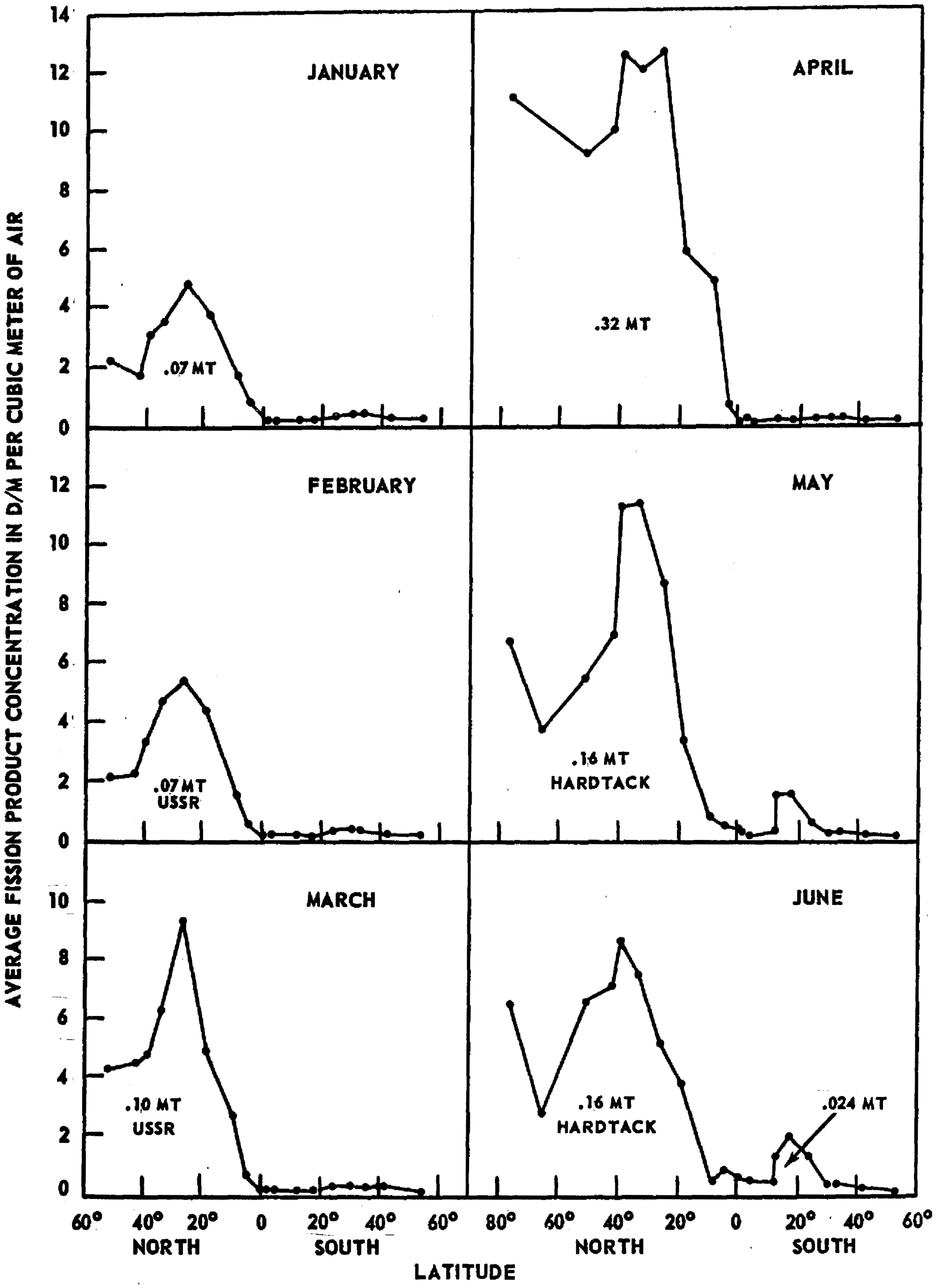
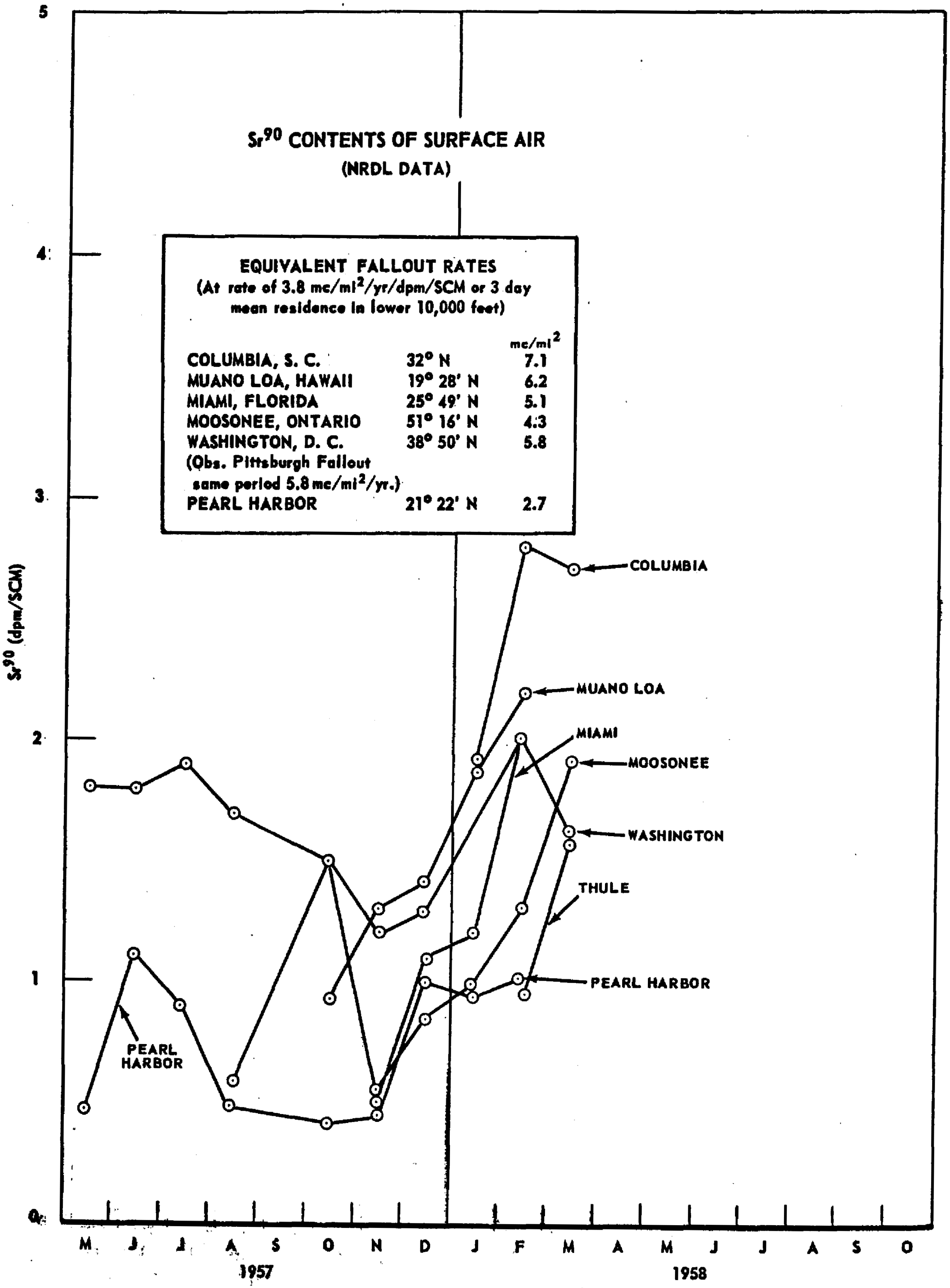


FIGURE 2

[redacted]

[redacted]



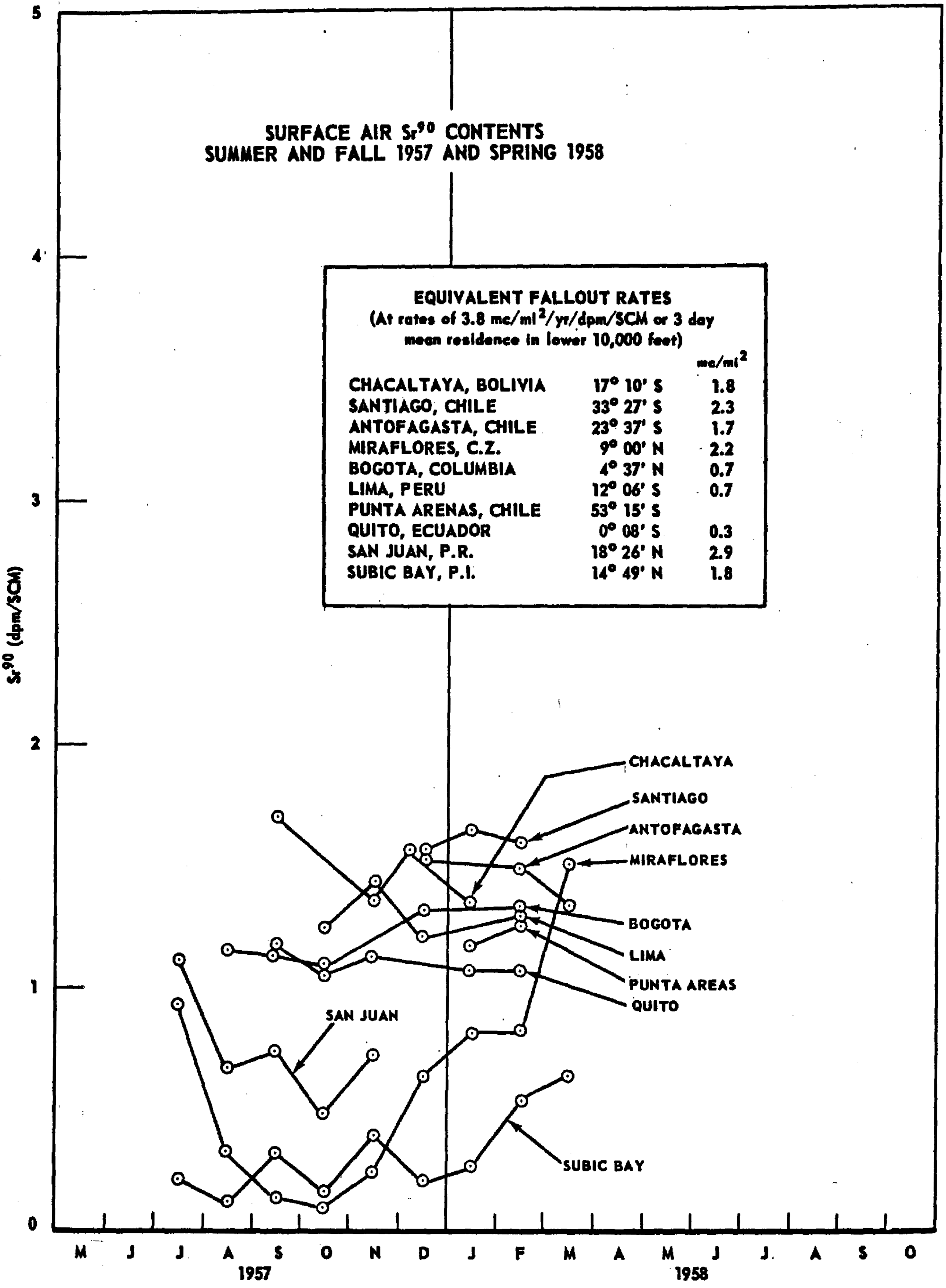
Sr^{90} CONTENTS OF SURFACE AIR
(NRDL DATA)

EQUIVALENT FALLOUT RATES
(At rate of 3.8 mc/mi^2/yr/dpm/SCM or 3 day mean residence in lower 10,000 feet)

		mc/mi^2
COLUMBIA, S. C.	32° N	7.1
MUANO LOA, HAWAII	19° 28' N	6.2
MIAMI, FLORIDA	25° 49' N	5.1
MOOSONEE, ONTARIO	51° 16' N	4.3
WASHINGTON, D. C. (Obs. Pittsburgh Fallout same period 5.8 mc/mi^2/yr.)	38° 50' N	5.8
PEARL HARBOR	21° 22' N	2.7

FIGURE 3

[redacted]



SURFACE AIR Sr^{90} CONTENTS
SUMMER AND FALL 1957 AND SPRING 1958

EQUIVALENT FALLOUT RATES
(At rates of 3.8 mc/mi²/yr/dpm/SCM or 3 day mean residence in lower 10,000 feet)

		mc/mi²
CHACALTAYA, BOLIVIA	17° 10' S	1.8
SANTIAGO, CHILE	33° 27' S	2.3
ANTOFAGASTA, CHILE	23° 37' S	1.7
MIRAFLORES, C.Z.	9° 00' N	2.2
BOGOTA, COLUMBIA	4° 37' N	0.7
LIMA, PERU	12° 06' S	0.7
PUNTA ARENAS, CHILE	53° 15' S	
QUITO, ECUADOR	0° 08' S	0.3
SAN JUAN, P.R.	18° 26' N	2.9
SUBIC BAY, P.I.	14° 49' N	1.8

FIGURE 4

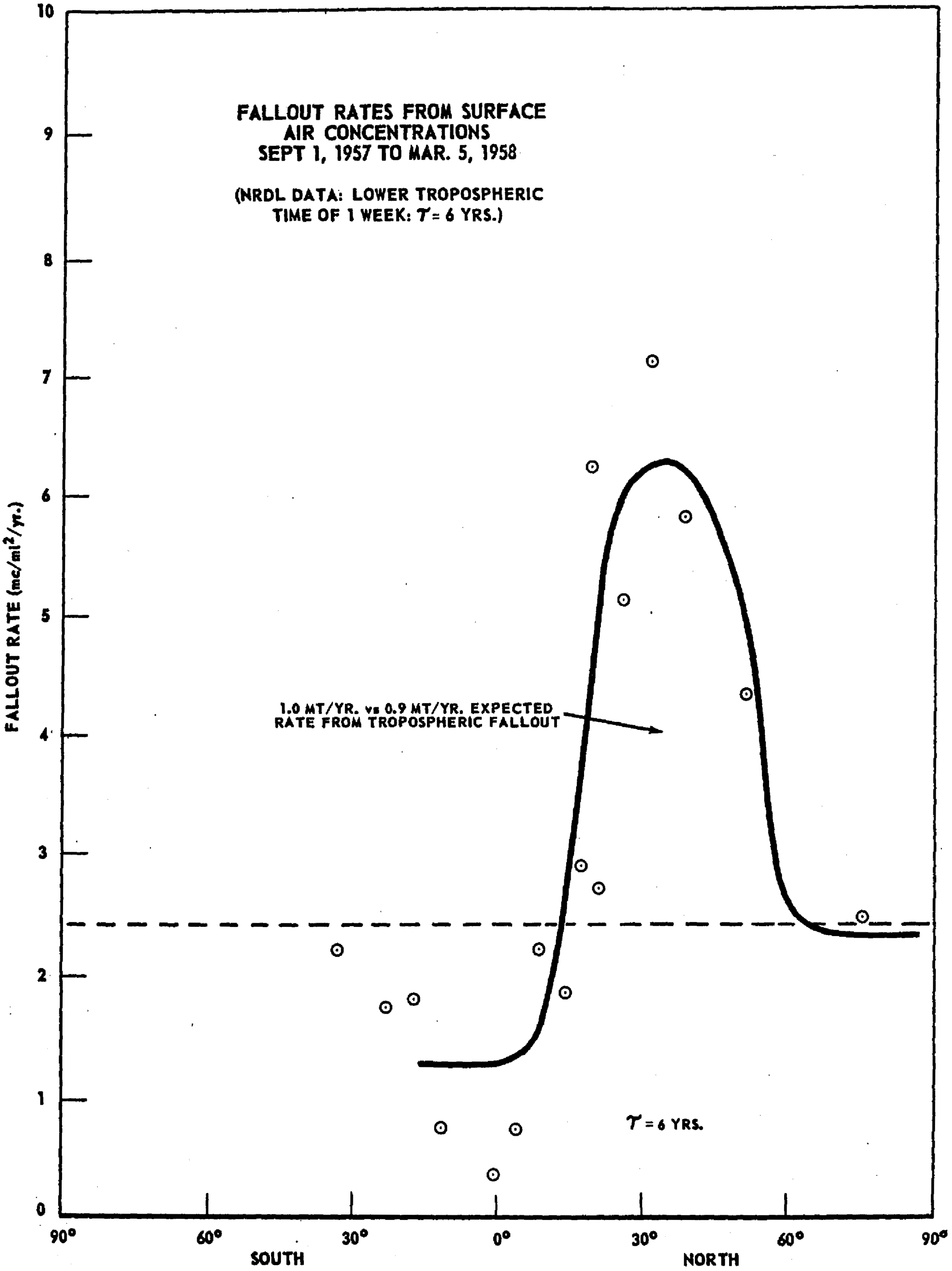

FALLOUT RATES FROM SURFACE
AIR CONCENTRATIONS
SEPT 1, 1957 TO MAR. 5, 1958
(NRDL DATA: LOWER TROPOSPHERIC
TIME OF 1 WEEK: τ = 6 YRS.)
1.0 MT/YR. vs 0.9 MT/YR. EXPECTED
RATE FROM TROPOSPHERIC FALLOUT
τ = 6 YRS.
FALLOUT RATE (mc/mi²/yr.)
10
9
8
7
6
5
4
3
2
1
0
90°
60°
30°
0°
30°
60°
90°
SOUTH
NORTH

FIGURE 5

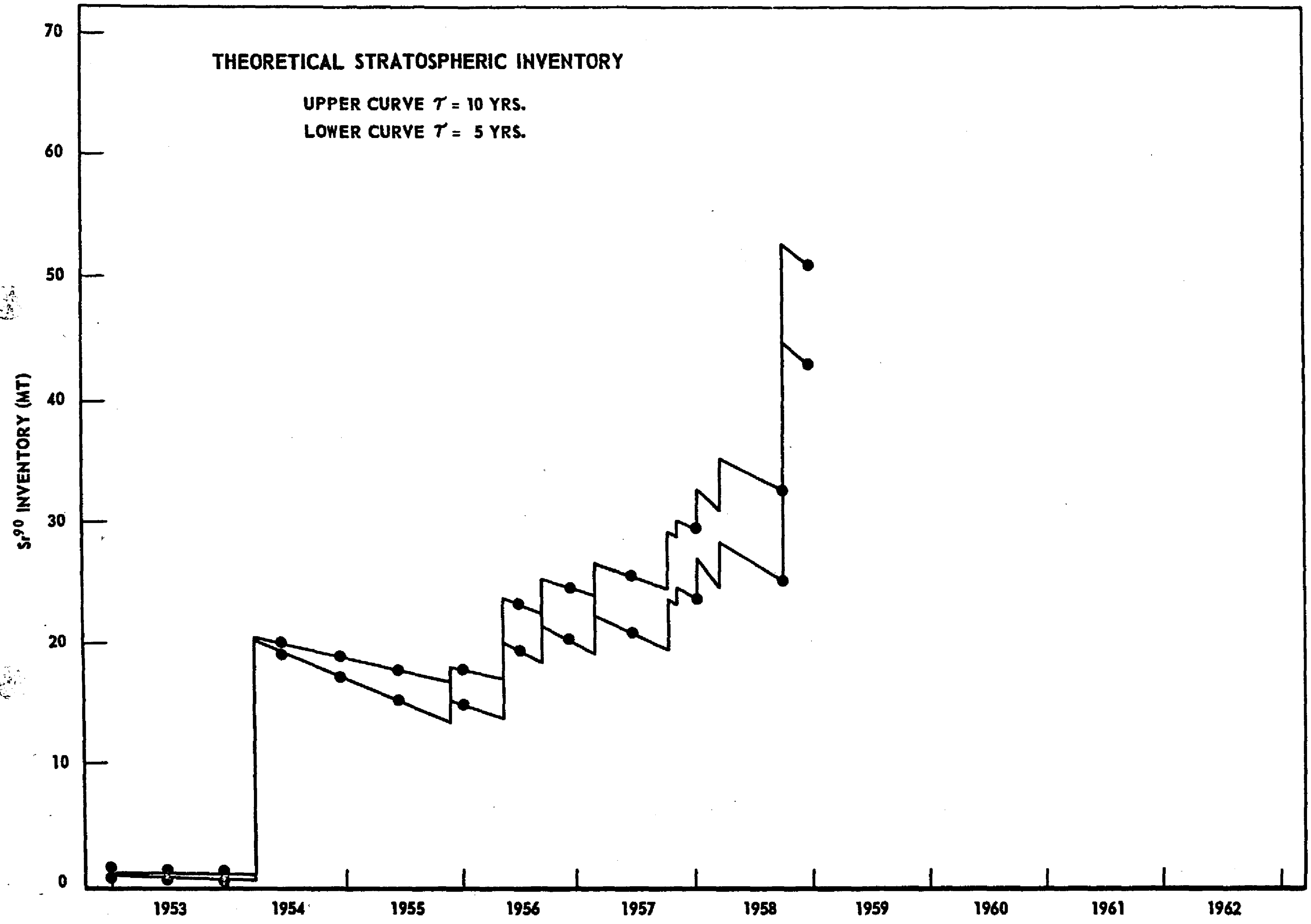

THEORETICAL STRATOSPHERIC INVENTORY
UPPER CURVE τ = 10 YRS.
LOWER CURVE τ = 5 YRS.
Sr^{90} INVENTORY (MT)
70
60
50
40
30
20
10
0
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962

FIGURE 6

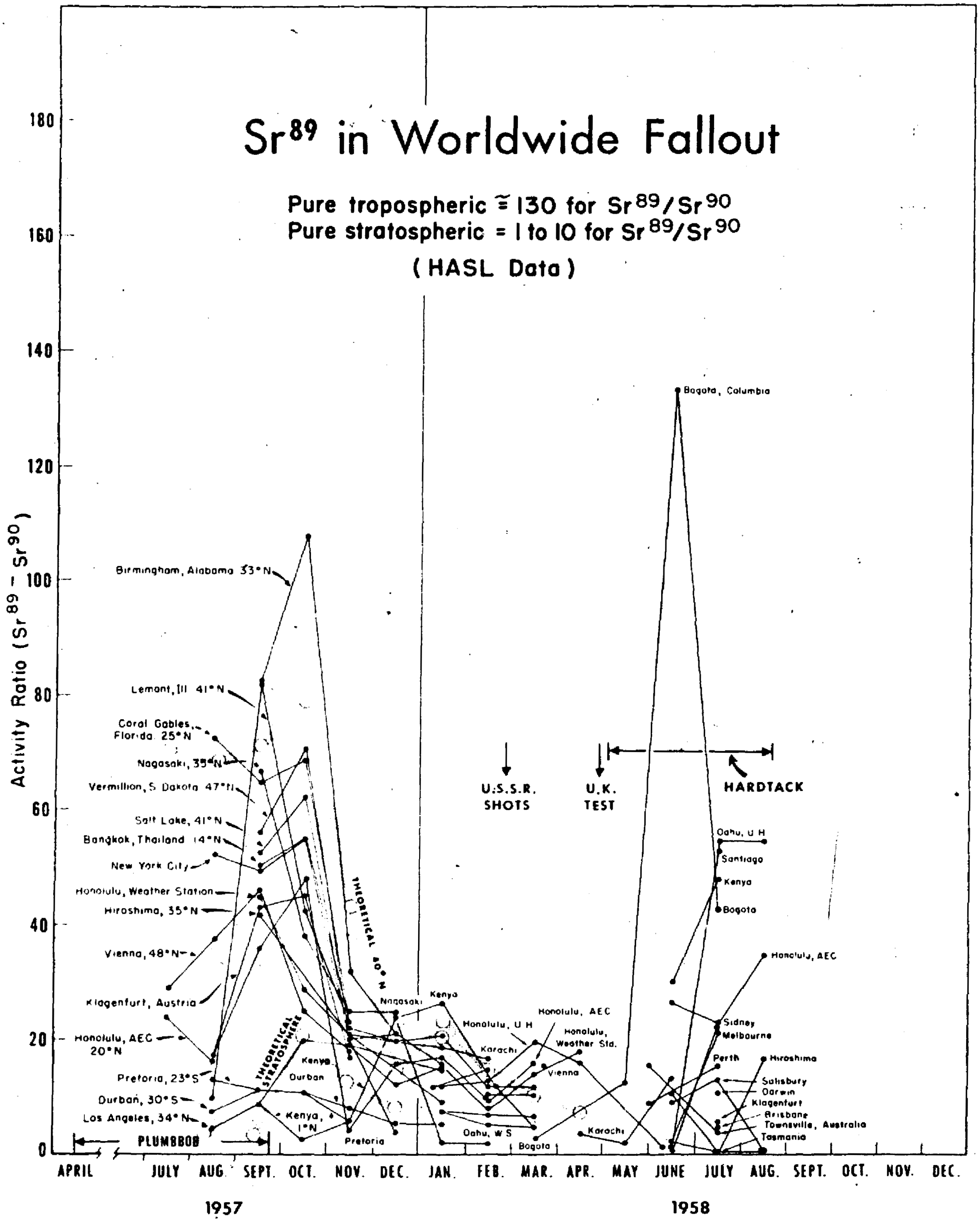

Sr89 in Worldwide Fallout
Pure tropospheric ≅ 130 for Sr89/Sr90
Pure stratospheric = 1 to 10 for Sr89/Sr90
(HASL Data)
Activity Ratio (Sr89 - Sr90)
180
160
140
120
100
80
60
40
20
0
Birmingham, Alabama 33°N
Lemont, Ill 41°N
Coral Gables, Florida 25°N
Nagasaki, 33°N
Vermillion, S Dakota 47°N
Salt Lake, 41°N
Bangkok, Thailand 14°N
New York City
Honolulu, Weather Station
Hiroshima, 35°N
Vienna, 48°N
Klagenfurt, Austria
Honolulu, AEC 20°N
Pretoria, 23°S
Durban, 30°S
Los Angeles, 34°N
PLUMBBOB
THEORETICAL STRATOSPHERE
THEORETICAL 40°N
Kenya
Durban
Kenya, 1°N
Pretoria
Nagasaki
Kenya
Honolulu, U H
Karachi
Honolulu, AEC
Honolulu, Weather Std.
Vienna
Oahu, W S
Bogota
Karachi
U.S.S.R. SHOTS
U.K. TEST
HARDTACK
Bogota, Columbia
Oahu, U H
Santiago
Kenya
Bogota
Honolulu, AEC
Sidney
Melbourne
Perth
Hiroshima
Salisbury
Darwin
Klagenfurt
Brisbane
Townsville, Australia
Tasmania
APRIL
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
1957
1958

Figure 7

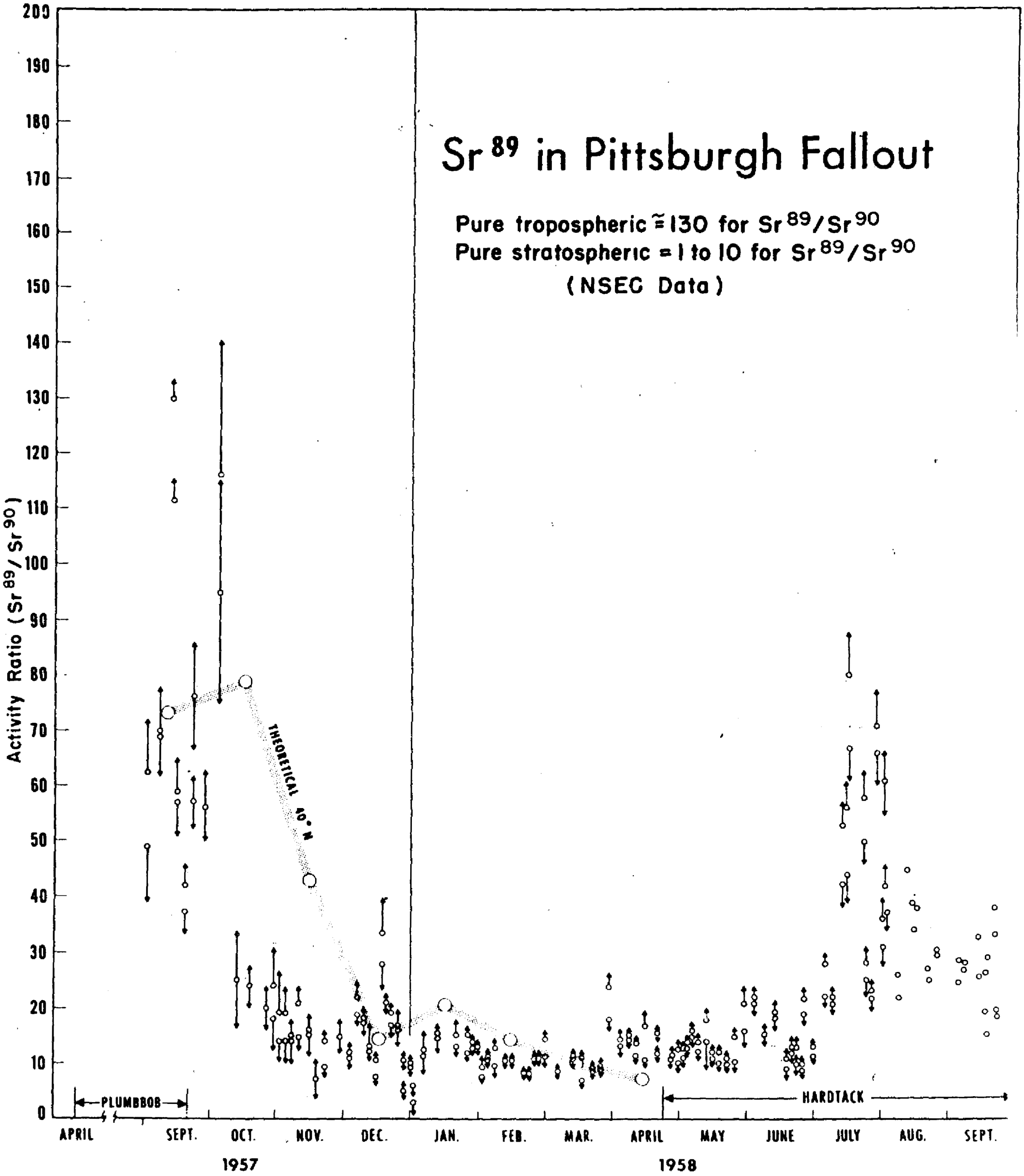

Sr^{89} in Pittsburgh Fallout
Pure tropospheric ≅ 130 for Sr^{89}/Sr^{90}
Pure stratospheric = 1 to 10 for Sr^{89}/Sr^{90}
(NSEC Data)
Activity Ratio (Sr^{89}/Sr^{90})
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
THEORETICAL 40° N
PLUMBBOB
HARDTACK
APRIL
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
1957
1958

Figure 8

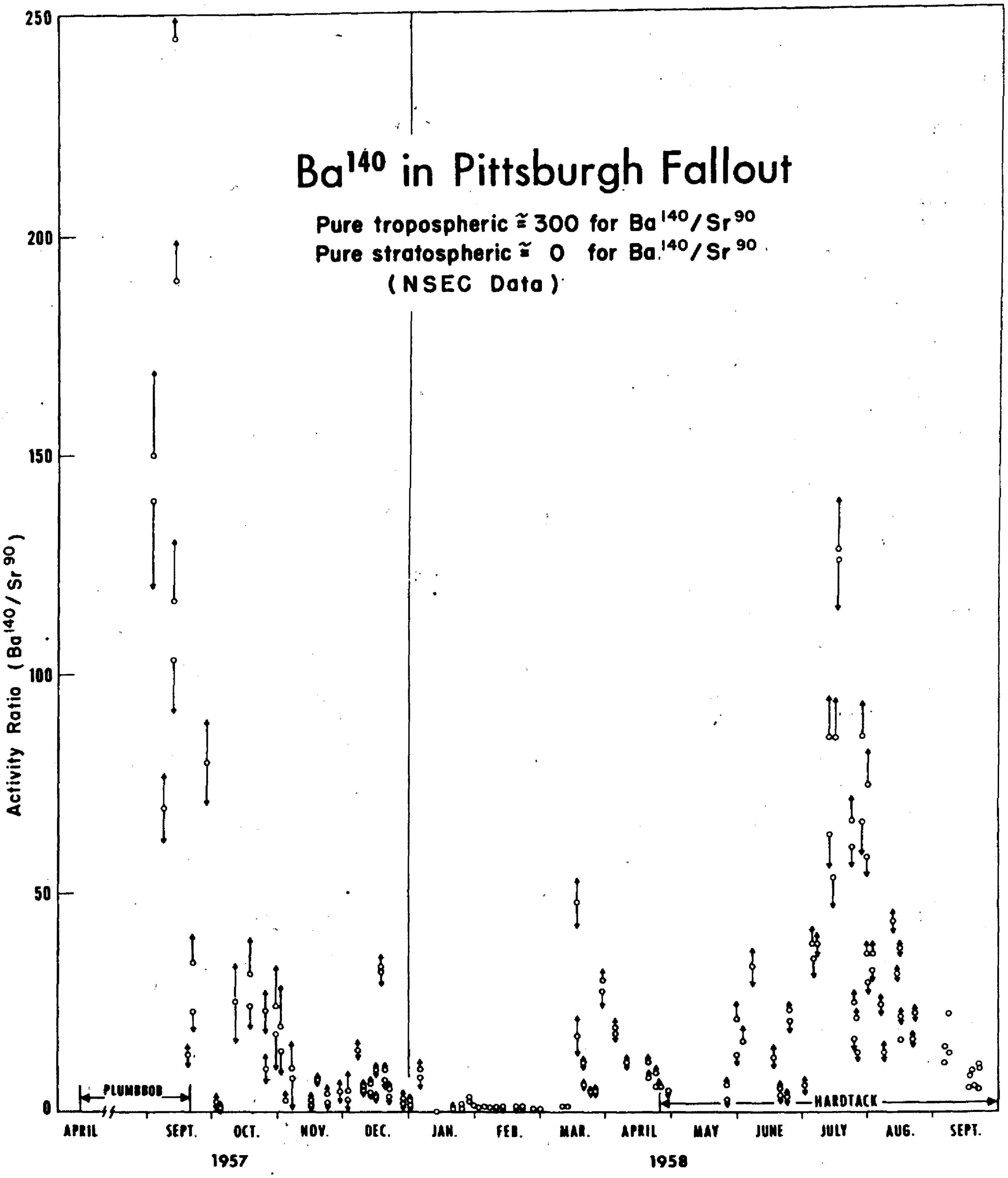
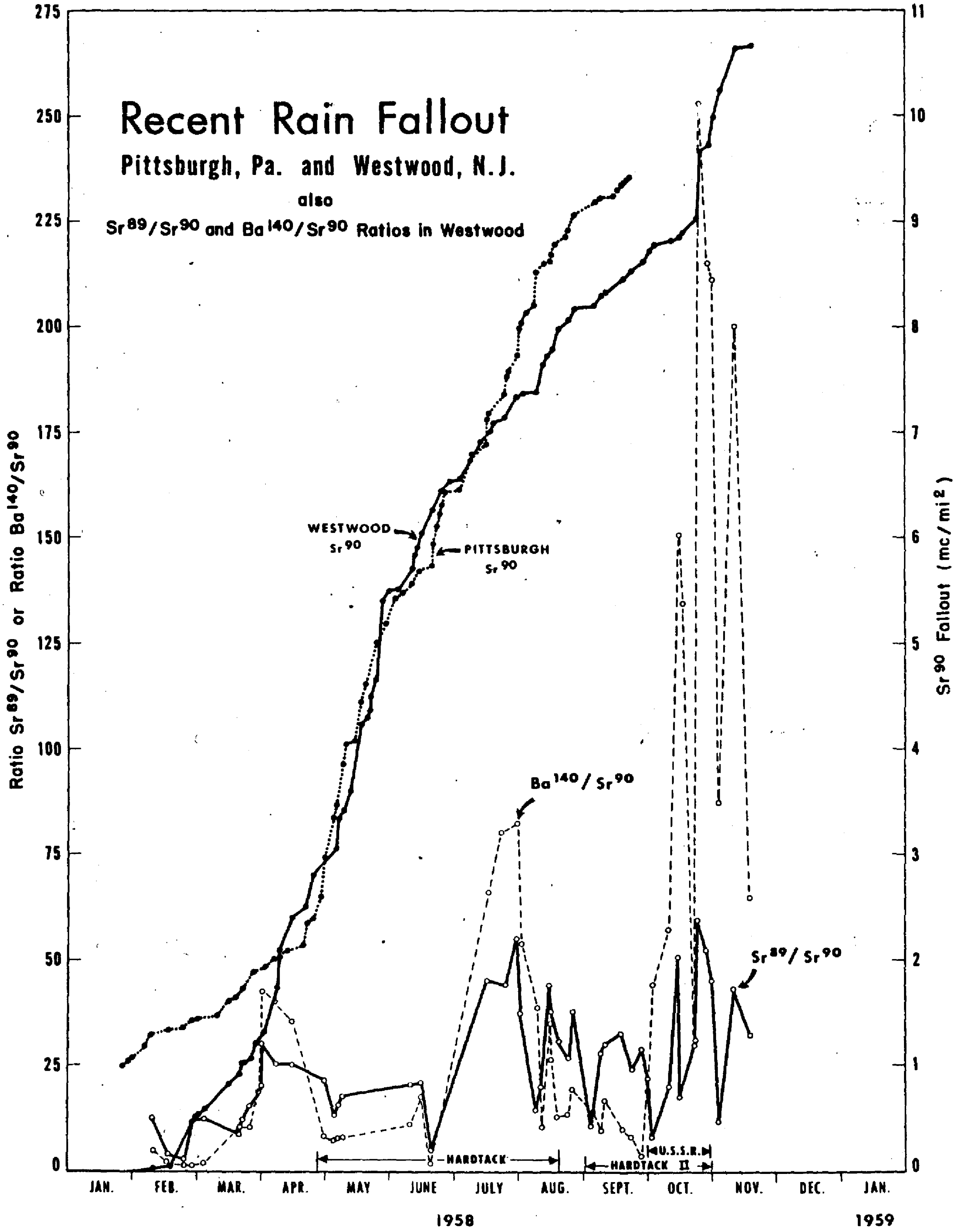

Ba140 in Pittsburgh Fallout
Pure tropospheric ≅ 300 for Ba140/Sr90
Pure stratospheric ≅ 0 for Ba140/Sr90
(NSEC Data)
Activity Ratio (Ba140/Sr90)
250
200
150
100
50
0
PLUMBBOB
HARDTACK
APRIL
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
1957
1958

Figure 9



Recent Rain Fallout
Pittsburgh, Pa. and Westwood, N.J.
also
Sr^{89}/Sr^{90} and Ba^{140}/Sr^{90} Ratios in Westwood

Figure 10

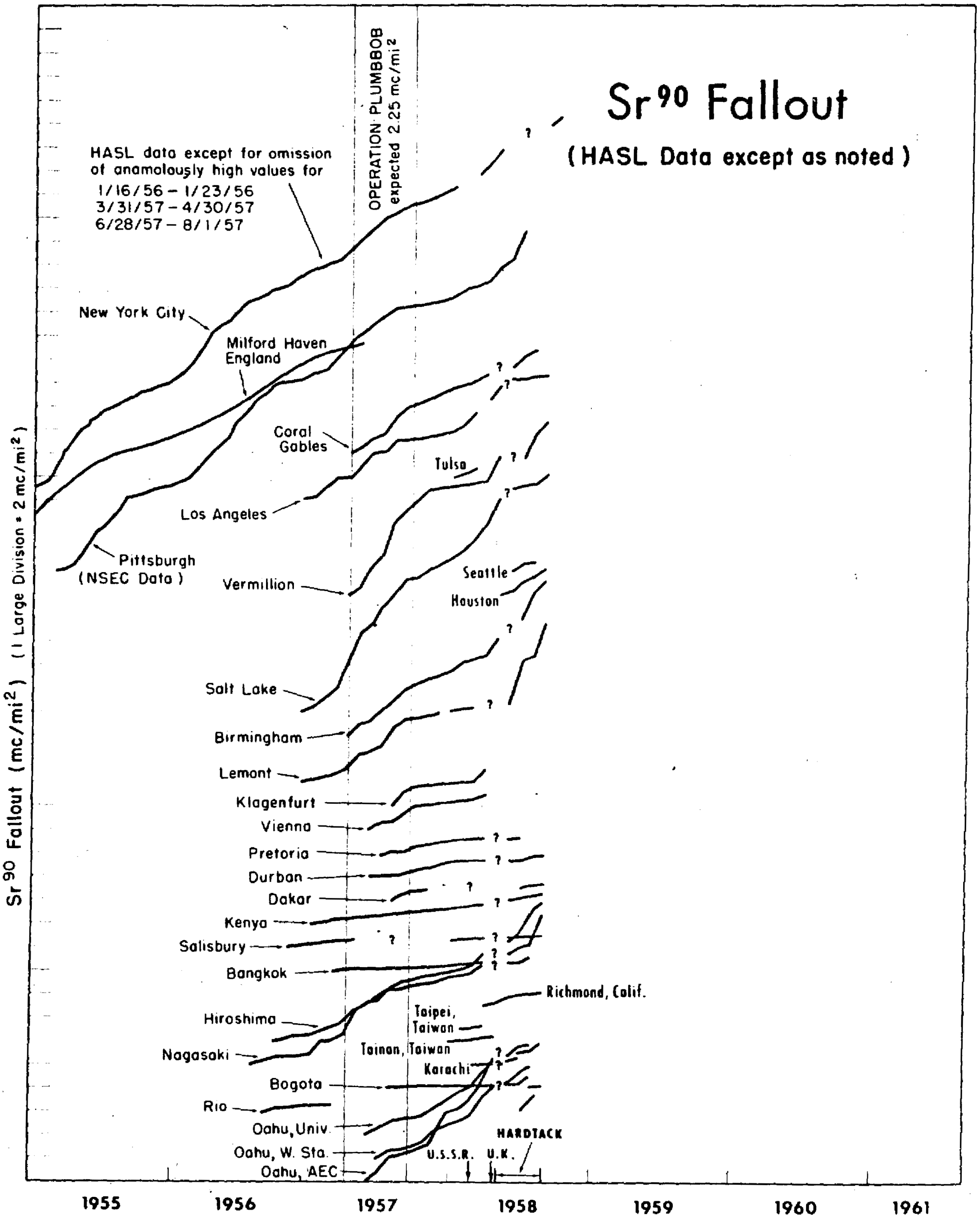
Sr⁹⁰ Fallout
(HASL Data except as noted)
Sr⁹⁰ Fallout (mc/mi²) (1 Large Division = 2 mc/mi²)
OPERATION PLUMBBOB
expected 2.25 mc/mi²
HASL data except for omission of anamolously high values for
1/16/56 – 1/23/56
3/31/57 – 4/30/57
6/28/57 – 8/1/57
New York City
Milford Haven England
Coral Gables
Tulsa
Los Angeles
Pittsburgh (NSEC Data)
Vermillion
Seattle
Houston
Salt Lake
Birmingham
Lemont
Klagenfurt
Vienna
Pretoria
Durban
Dakar
Kenya
Salisbury
Bangkok
Richmond, Calif.
Hiroshima
Taipei, Taiwan
Nagasaki
Tainan, Taiwan
Karachi
Bogota
Rio
Oahu, Univ.
Oahu, W. Sta.
Oahu, AEC
HARDTACK
U.S.S.R.
U.K.
?
1955
1956
1957
1958
1959
1960
1961

Figure 11

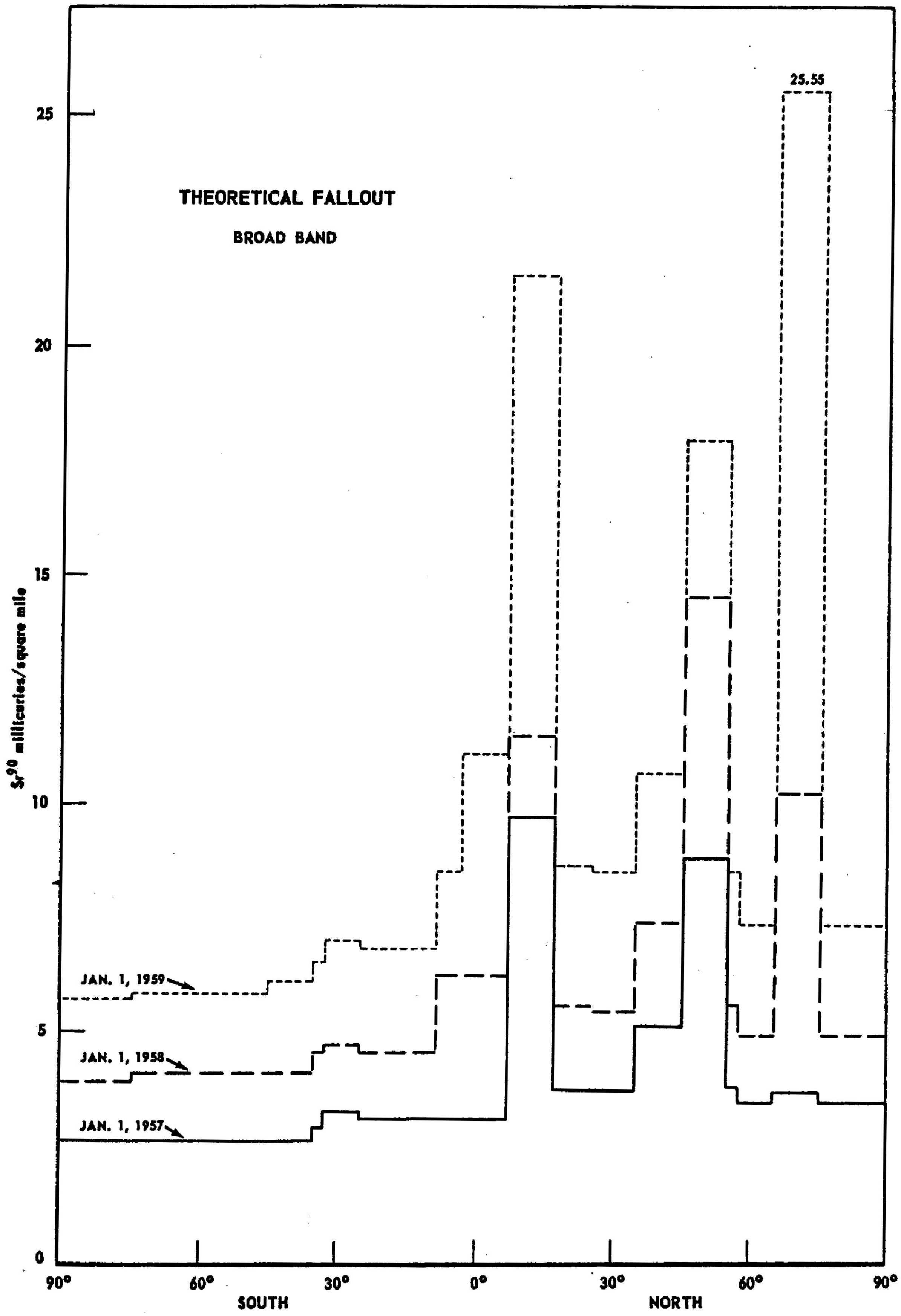

25.55
25
THEORETICAL FALLOUT
BROAD BAND
20
15
Sr90 millicuries/square mile
10
JAN. 1, 1959
5
JAN. 1, 1958
JAN. 1, 1957
0
90°
60°
30°
0°
30°
60°
90°
SOUTH
NORTH

FIGURE 12

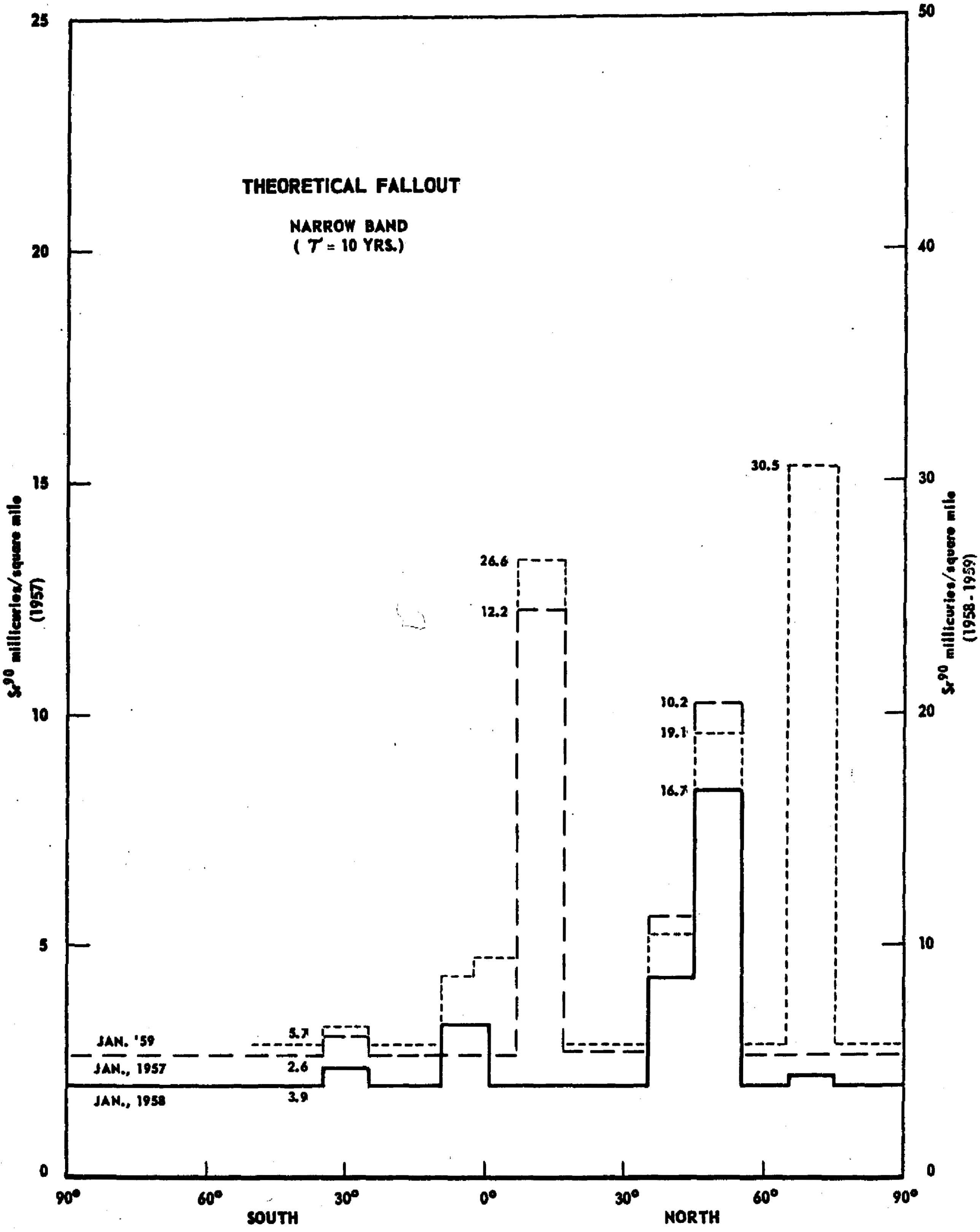

THEORETICAL FALLOUT
NARROW BAND
(τ = 10 YRS.)
25
20
15
10
5
0
50
40
30
20
10
0
Sr^{90} millicuries/square mile (1957)
Sr^{90} millicuries/square mile (1958-1959)
26.6
12.2
30.5
10.2
19.1
16.7
5.7
2.6
3.9
JAN. '59
JAN., 1957
JAN., 1958
90°
60°
30°
0°
30°
60°
90°
SOUTH
NORTH

FIGURE 13

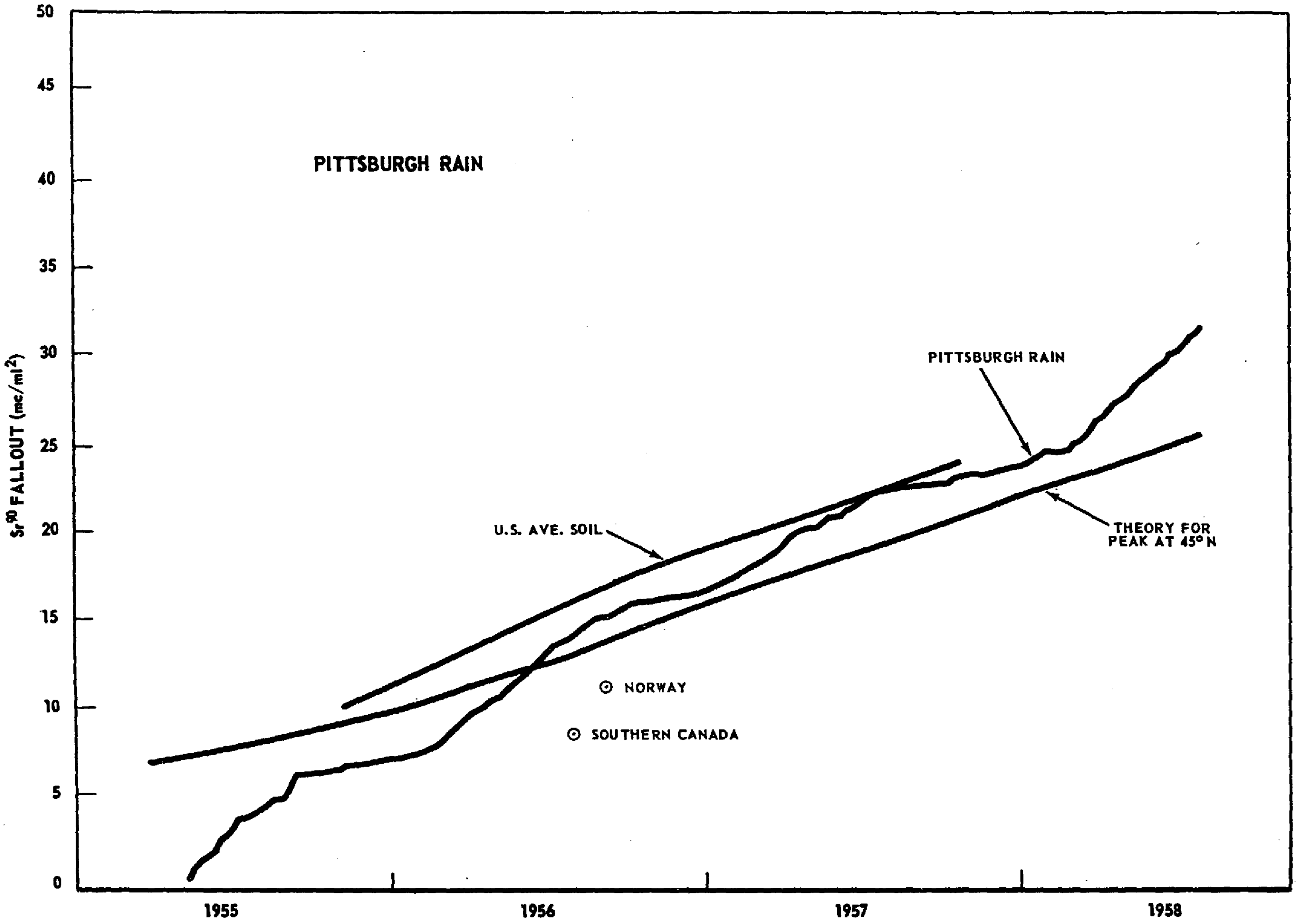
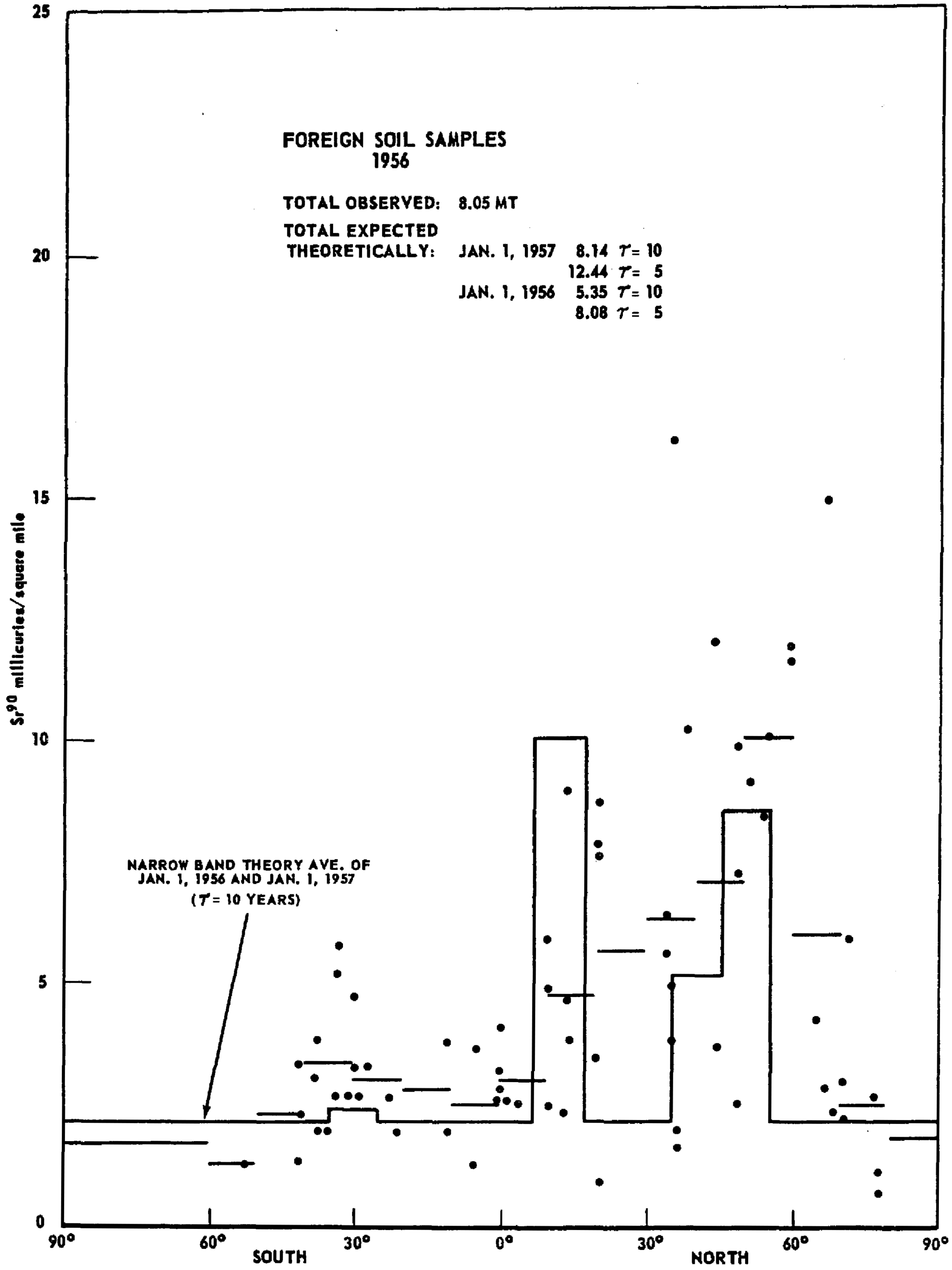

PITTSBURGH RAIN
Sr^{90} FALLOUT (mc/mi^2)
50
45
40
35
30
25
20
15
10
5
0
PITTSBURGH RAIN
U.S. AVE. SOIL
THEORY FOR PEAK AT 45° N
NORWAY
SOUTHERN CANADA
1955
1956
1957
1958

FIGURE 14



KT OBS.	113	620	414	407	745	452	490	670	675	885	790	853	693	395	131
KT THEORY	97	536	315	270	585	350	360	1720	370	324	685	965	189	104	98

FIGURE 15

COMPARISON OF Cs^{137} IN HUMANS
WITH Cs^{137} IN MILK

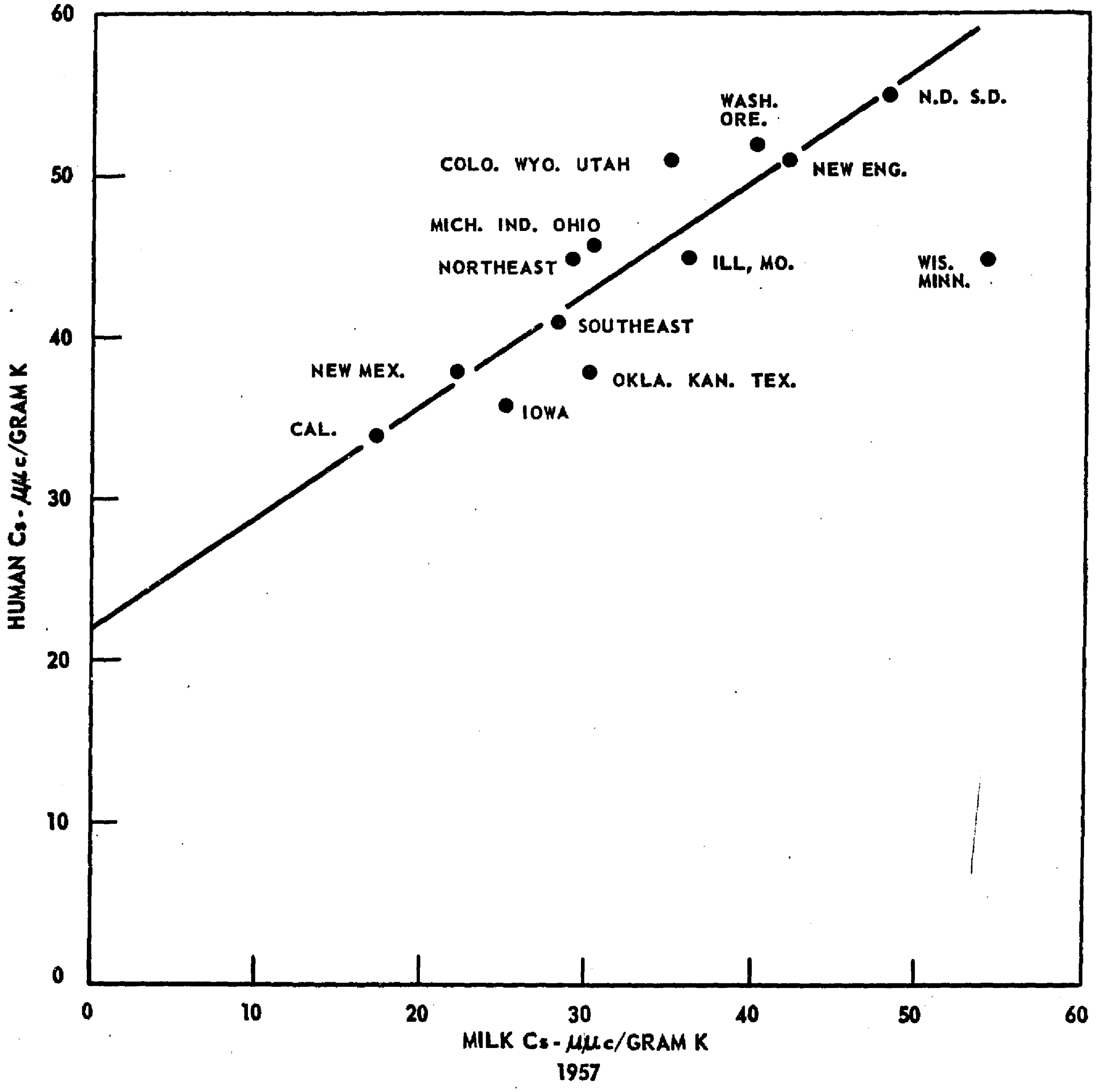


FIGURE 16