MARSHALL ISLANDS FILE TRACKING DOCUMENT

Record Number: 373

File Name (TITLE): A Meteorological Analysis of the Transport of Debris . . .

Document Number (ID): N40-4555 (DEL)

DATE: 8/1953

Previous Location (FROM): EML

AUTHOR: L. Hubert

Addditional Information:

OrMIbox: 20

CyMIbox:

UNITED STATES ATOMIC ENERGY COMMISSION

NYO-4555 (Del.)

A METEOROLOGICAL ANALYSIS OF THE TRANSPORT OF DEBRIS FROM OPERATION IVY

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Photostat Price $ 24.30
Microfilm Price $ 7.50

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

October 30, 1953

Weather Bureau

Technical Information Service Extension, Oak Ridge, Tenn.

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ABSTRACT

The purpose of this report is to present analysis of the meteorological aspects of Operation IVY, to document the radiological data, and to interpret the analysis and data for guidance in future Pacific tests.

Fallout data was collected by the Atomic Energy Commission on a world-wide network of gummed paper stations, supplemented by a few air filters, the radiological analysis being carried out by the New York Operations Office of the Atomic Energy Commission. Documentation of this data is in the form of maps showing the daily collections of beta activity at every sampling station used during this operation.

Meteorological analysis of the world-wide dispersion of debris from the MIKE and KING tests is best presented by dividing each cloud into three separate layers - the trade wind layer (surface to about 30,000 feet), the upper troposphere layer (30,000 feet to 55,000 feet) and the stratosphere layer (55,000 feet to cloud top). Schematic diagrams showing daily outlines of these layers as well as maps of daily radioactive surface deposition are presented and discussed. The trade wind layer of both clouds moved away from the test site toward the west, a southern portion continuing westward while a segment from the northern edge split off to curve toward the north and then eastward toward North America. Direction of transport of the upper troposphere and stratosphere layers of the debris was variable although movement was essentially zonal (east and west).

The effects of transport and diffusion are discussed and it is concluded that no data positively requires fallout of particles from debris that initially stabilized in the stratosphere.

Average activity of surface deposition is increased by precipitation, but the increase in the United States for this operation is

less than the increase found for continental tests (a factor of 3 compared to a factor of 8), an effect, perhaps, of smaller particles reaching North America from the Pacific tests.

In general, the program has not advanced meteorological knowledge in the field of trajectory computation or turbulent diffusion because of the many uncontrolled and unmeaurable variables.

CHAPTER 1

BASIC DATA

1.1 INTRODUCTION

Operation IVY, the fourth series of nuclear tests by the Atomic Energy Commission to be conducted at the proving grounds in the Marshall Islands of the Pacific Ocean consisted of two high yield nuclear devices. The first, MIKE, was detonated at 1915 GCT, 31 October 1952 and the second, KING, at 2330 GCT, 15 November 1952, both at the Eniwetok Proving Grounds. The fallout from these tests was of particular interest because of several unique conditions. First, the extremely high yield of the tests posed new questions as to possible health or industrial hazard, second, there had never been any extensive ground monitoring system for previous Pacific tests, and third, no previous atomic cloud had reached the altitudes estimated for the MIKE cloud, 120,000-140,000 feet above sea level.

The purpose of this report is to integrate the radiological and meteorological observations and achieve the following objectives:

1. Full documentation of the fallout data.

2. Meteorological interpretation of the fallout data, including a reconstruction of the most probable paths followed by the debris.

3. Use of IVY data to predict fallout for future tests.

4. Evaluation of atomic debris as a tracer for meteorological research.

1.2 BASIC METEOROLOGICAL DATA

Although the network of upper-air observing stations in the vicinity of the Eniwetok Proving Grounds was increased for the IVY test period, it was still pitifully small in comparison with that in the United States. (It would correspond roughly to stations in Texas, Montana, and Mexico if transferred to the Nevada Proving Grounds!) Analysis of air flow patterns in the tropics is further hampered by the breakdown of the geostrophic approximation, a theoretical relationship between the wind field and the pressure field which is extremely useful at higher latitudes, so that reliance on wind observations alone is necessary and little further assistance is derived from observations of the pressure field.

The wind structure over the Marshall Islands area during the test period can be considered in three broad layers: the trade wind layer of steady eastnortheast winds extending from the surface to about 25,000 feet; the upper troposphere, from 25,000 to about 55,000 feet, which consists of a series of moving large-scale vortices; and the lower stratosphere, from 55,000 to 130,000 feet, containing variable east or west winds with speeds decreasing from values as high as 50 knots near the base of the layer to light (and uncertain) values above.

Unfortunately, wind data over the Pacific is almost completely lacking at heights above 100,000 feet and only sporadic soundings are available in the remainder of the lower stratosphere. Even climatological mean winds are not available at these great heights. The paucity of data is critical in view of the great height reached by the MIKE cloud and the fact that the bulk of the airborne debris is probably contained in the mushroom. The relatively small number of observations make it necessary to place special emphasis on the analysis of flow patterns that can only be achieved under research conditions, paying particular attention to time continuity. Figure 1.1 illustrates the 30,000-foot flow patterns for 0300 GCT and 1500 GCT, 1 November 1953, and shows the number of observations typically available at this level. Meteorological data for the Marshall Islands area was obtained from a publication by the Joint Task Force (6), the remaining data from conventional weather teletypewriter sources.

Maps of the airflow patterns at several elevations are used to prepare trajectories of the various portions of the atomic cloud. In general, the average error of the trajectories over the United States has been found to be about 20% of the path length at 30,000 feet. The lesser amounts of data will undoubtedly increase this error over the Pacific, except in trade wind layer, where the regularity of the winds increases the accuracy.

Another meteorological feature of most of the tropical Pacific region, which differs from conditions in the United States, is the precipitation regime. Rainfall in tropical areas occurs in frequent showers (rather than large areas of steady rain) derived, in general, from clouds embedded in the trade wind layers, although thunderstorms in disturbed situations do extend to 55,000 or 60,000 feet.

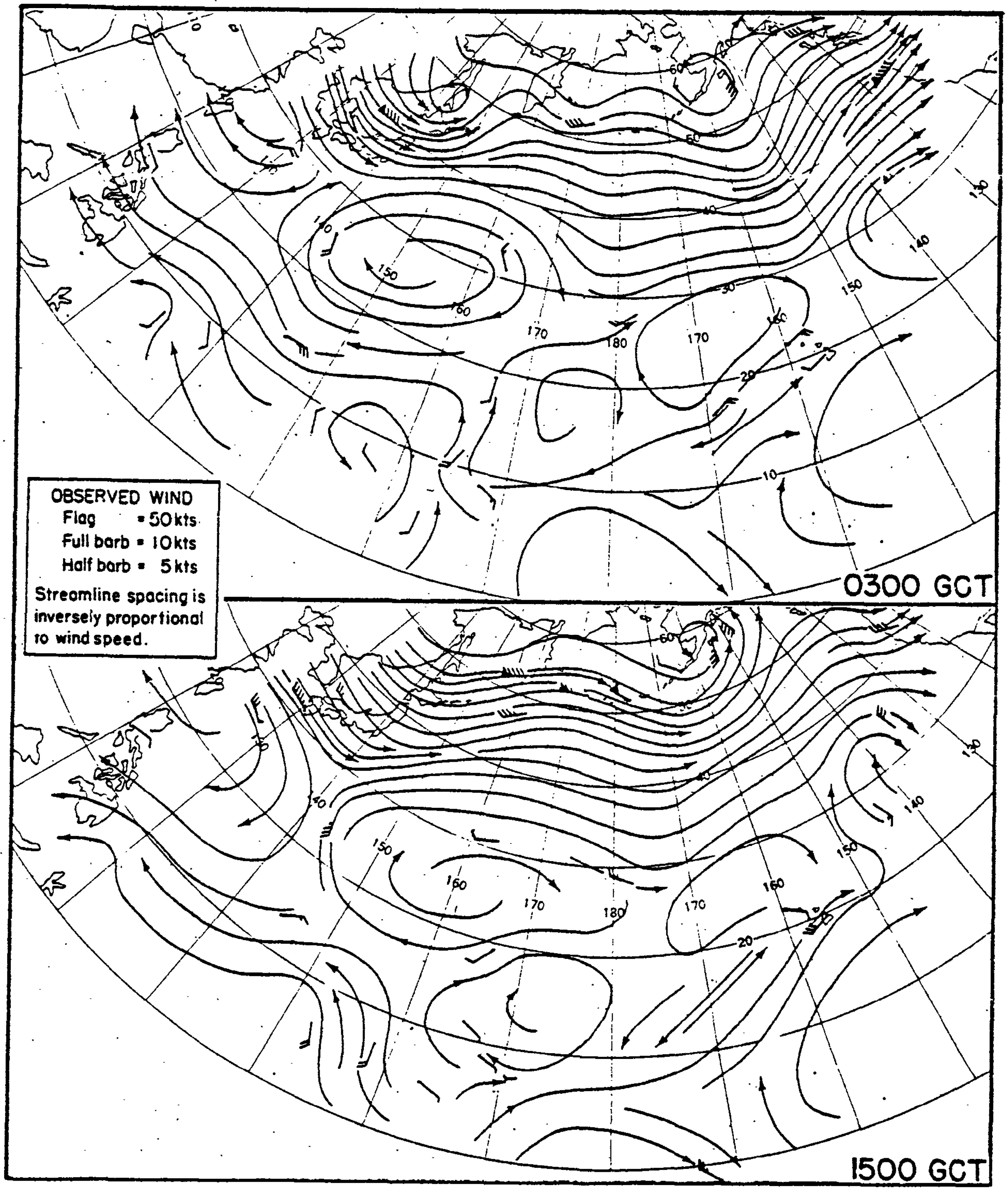

Figure 1.1 30,000-foot streamline analyses for 1 Nov 1952

1.3 BASIC RADIOLOGICAL DATA

The monitoring network set up by the New York Operations Office for the IVY tests represents the first systematic, world-wide radiological monitoring program for an atomic test series. Various military and AEC establishments performed some sampling during earlier tests, but no standardized collecting or counting techniques were employed nor was the network of stations dense enough to delineate fallout patterns.

The only previous health and property hazard monitoring in the United States for a Pacific test occurred during the GREENHOUSE series and interest in future tests was stimulated when a peak value of 1100 $d/m/ft^2$ on a gummed paper exposed for 24 hours was measured at Rochester, New York (2).

The basic instrumentation for the monitoring network was gummed paper and high-volume air filter measurements which had proved adequate for the previous continental tests (7, 9, 10). In addition, supplementary short-term measurements were made with air filters, automatically operated equipment, and by special aerial surveys (8).

Figures 1.2 and 1.3 show the location of stations in the basic network. Special air filter observations were made at Guam, Kwajalein, Midway, and Barber's Pt., T.H.

All observations from the basic network consisted of 24-hour sampling periods beginning at 1830 GCT each day. Gummed paper observations were made in duplicate on stands located about six feet apart except for a few stations in the United States where two different Weather Bureau stations (airport and city offices) in the same vicinity were used.

A large part of the field operation was performed by weather observers of the Weather Bureau or the Air Force, but in addition some sampling was done by personnel of the Navy. the Coast Guard.

All samples were mailed to the New York Operations Office of the Atomic Energy Commission, together with a data card showing the sampling period and relevant weather information. The gummed paper and filters were ashed and counted by automatic beta counters. Since radioactivity was measured several days to a few weeks after the sample was collected, a growth correction (time extrapolation) must be applied to obtain the activity that was present on the sampling date. The value of the growth correction depends on the

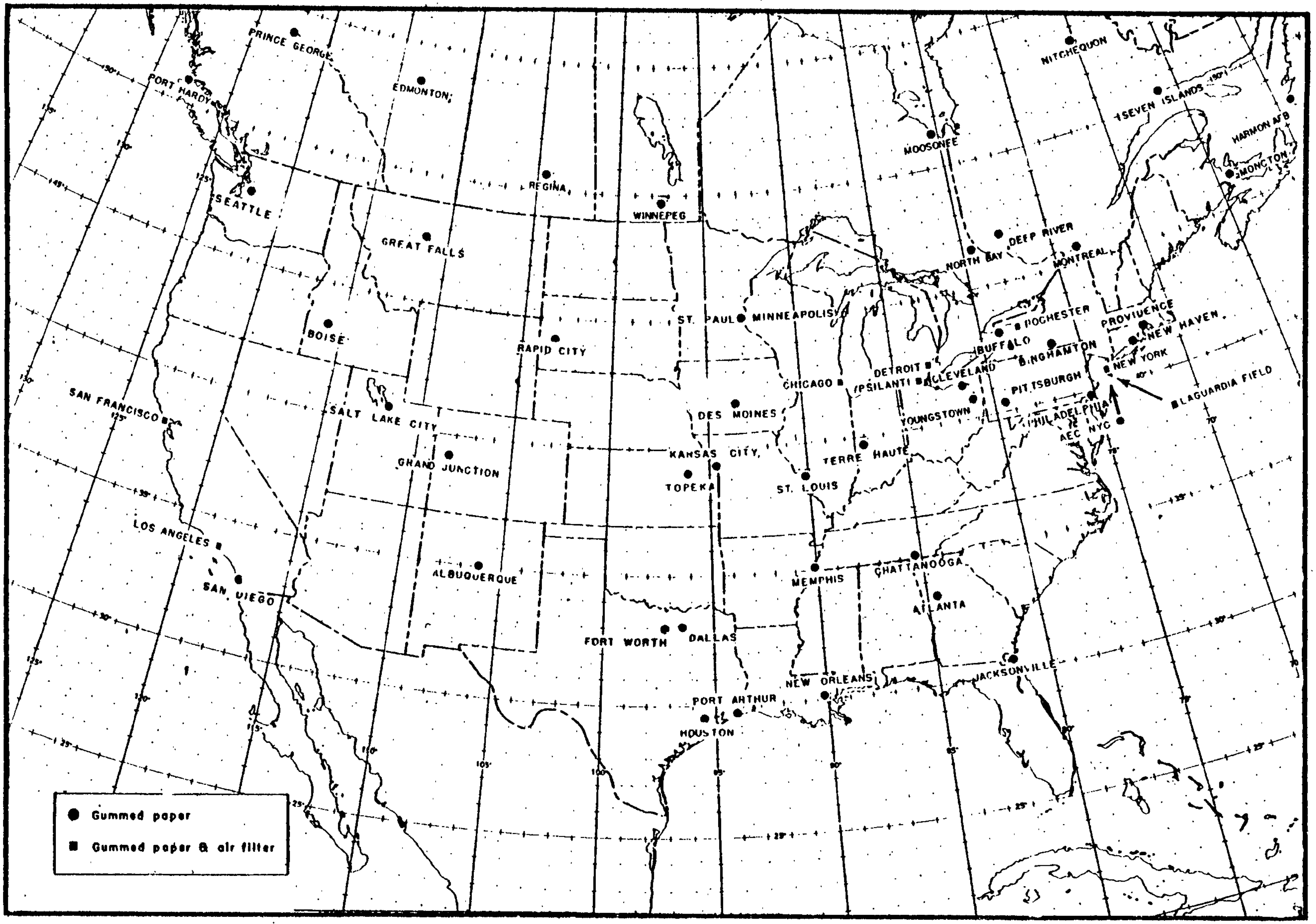

Figure 1.2 Location of fallout stations in the United States

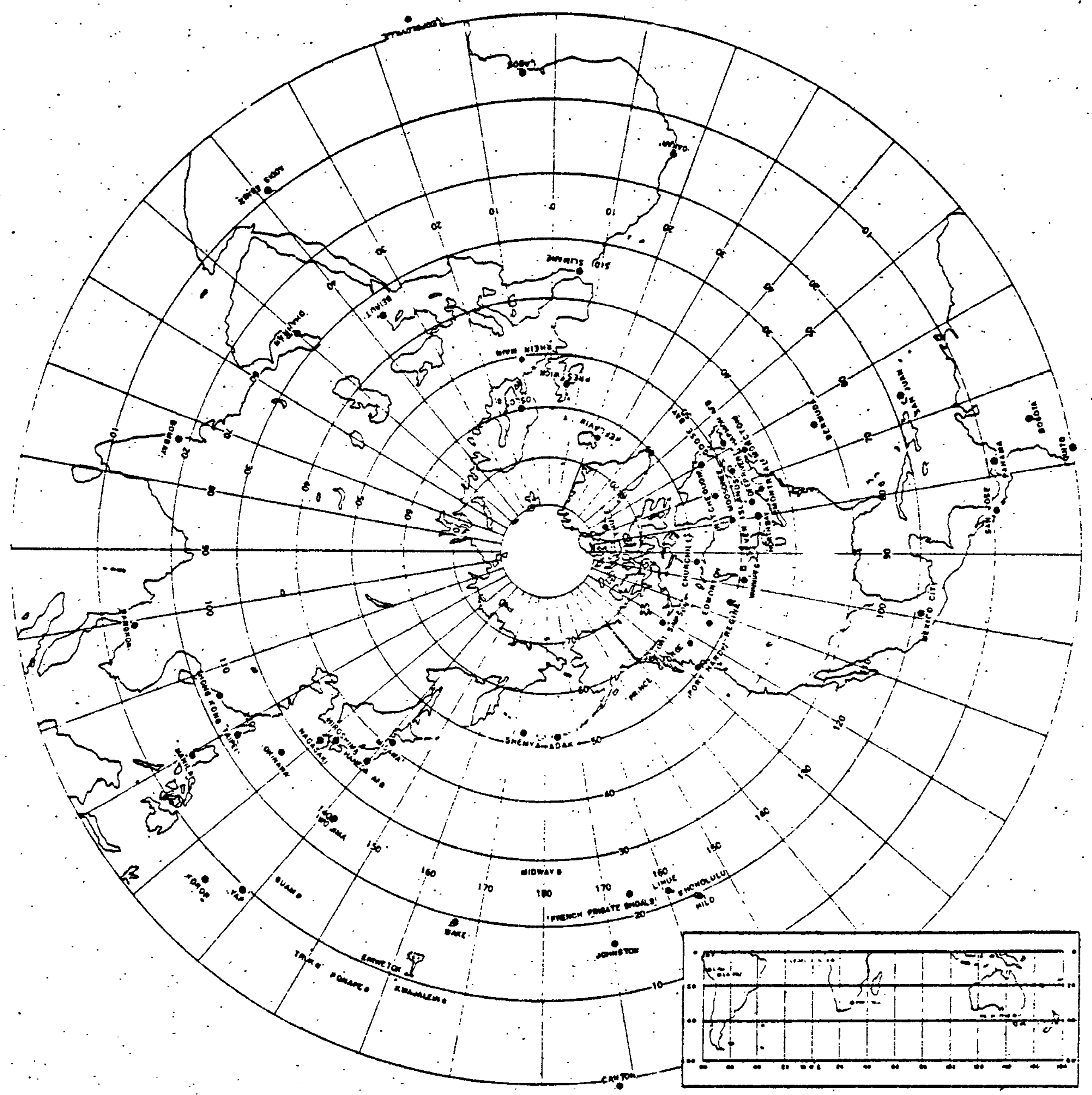

Figure 1.3 Location of fallout stations in the Northern and Southern Hemisphere

form of the decay law, the time interval between the explosion and collection dates, and the time interval between collection and counting.

Radioactivities on the gummed papers given in this report are corrected to the date of sampling, and recorded in the units "disintegration per minute per square foot per day", referred to hereafter as "d/m". Air filter activity, also corrected to the date of sampling, is expressed in "disintegration per minute per cubic meter of filtered air" and is abbreviated "d/m/m³".

1.4 SOURCES OF ERROR IN RADIOLOGICAL DATA

In order to interpret the radiological measurements, sources of error must be appraised. Any series of measurements of this nature must include inaccuracies, some inherent in the methods, others the result of human error.

The sources of error and limitations of the data can be considered in two categories: errors in the radiological data, and the representativeness of the gummed paper samples as a measure of the ground contamination.

1.4.1 Observers' Errors

The most frequent error appears to be misdating the data cards. It is also possible that on some occasions gummed papers were mailed with the wrong card. Errors originating at the collection station cannot, in general, be corrected.

1.4.2 Tabulation Errors

Mistakes are known to occur in punching the IBM cards which were used for computing and tabulating the data. A recheck of questionable observations resulted in the correction of a large number of such errors. Tabulation error undoubtedly remain, but they comprise a very small fraction of the data.

1.4.3 Contamination of Samples in Processing

In processing such a large number of samples by routine procedures, cross-contamination is possible, especially if a very active sample is present. Evidence that such errors exist can be seen from an examination of samples processed on 14 November 1952, the date on which a very active gummed paper was processed (viz., Iwo Jima - 1,260,000 d/m). For example, papers from Leopoldville, Belgium Congo, and Wellington, New Zealand exposed the day before the first burst had 2442 d/m and 432 d/m respectively. Many other samples processed on this day as well as other days when "hot" papers were processed, indicated activity in areas not believed to have been affected by the IVY clouds at the time.

1.4.4 Counting Accuracy

Counting errors are believed to be unimportant in comparison with other sources of error. For the purposes of this analysis the absolute magnitude of the few very large collections is not important.

1.4.5 Growth Correction

The growth correction is computed from the Way-Wigner law, which assumes that the decay of activity in the fission products is proportional to $t^{-1.2}$, where t is the time since the burst. Measurements of IVY debris by the New York Operations Office (8) indicate that for this series of tests the exponent in the Way-Wigner law is closer to -1.4, however, the error so introduced would make the reported activity no more than 20% too low, which is not significant in comparison with other uncertainties in the data.

1.4.6 Burst Assignment

Many inconsistencies remain in the data because their origin cannot be traced or the erroneous item cannot be discarded on the basis of available evidence. For example, there are numerous cases of more than two gummed papers from one station on a given day where it was not possible to have made more than two

24-hour samples per day. Similarly, isolated collections of activity appear in areas distant from those affected by airborne debris. Such errors indicate the caution which should be exercised in examining individual values. The emphasis, rather, should be on the broader aspects where the presence of corroborating information lends credence to the individual samples.

1.5 REPRESENTATIVENESS OF THE GUMMED PAPER AS A MEASURE OF GROUND DEPOSITION

1.5.1 Dry Fallout

It is likely that the gummed paper collects more activity than remains on the ground in periods of dry weather when the wind can pick up debris which has already fallen out. This is especially true in dusty locations.

1.5.2 Rainout

The effect of rain running or splattering off the gummed paper and carrying with it some debris and soluble radioactive material, must be important, but no information is available on this subject. It is believed that more debris will be lost in the heavy tropical showers than in lighter steady rains of the temperate latitudes.

1.5.3 Effect of the Particulate Nature of Debris

If activity is concentrated on a relatively small number of large particles, it is possible that the small area sampled by the gummed paper may not be a statistically significant sample. The duplicate papers, exposed within six feet of one another frequently showed large differences, which are discussed in Section 6.2.

1.5.4 Other Factors

The effect of elevation of gummed papers some three feet above the ground is unknown, as are the effects of temperature, dust, humidity and water on the adhesive properties of the gummed papers. These factors may be significant but cannot be evaluated here.

CHAPTER 2

MECHANISM OF TRANSPORT

The detonation of a nuclear device releases a tremendous quantity of heat which serves to vaporize the bomb casing and other nearby material and to heat the surrounding air to very high temperatures. The bouyant forces of the heated gas causes the cloud to rise, sucking up quantities of dust and debris. The ascending cloud cools by radiation, entrainment of outside air and adiabatic expansion until it reaches equilibrium with its environment, at which time it is said to be stabilized. In the continental tests, a short period of hovering at the level of detonation is usually observed, but it is likely that the explosion itself produced an upward impulse, at least for the MIKE shot, since the initial rate of rise to about 90,000 feet was reported to approach the speed of sound.

Both the MIKE and KING clouds developed the stem and mushroom so characteristic of the atomic explosion, but in the case of MIKE, the dimensions were very much larger than any previous burst. Since the bursts both occurred close to the ground the amount of debris carried upward was very large.

In previous reports of fallout from the continental tests, a relatively complete discussion of the factors governing the transport and deposition has been given. Briefly, the movement of the cloud is the result of the horizontal winds, the spread of the cloud the result of vertical and horizontal diffusion aided by wind shear, and the downward transport the result of scavenging by precipitation, vertical diffusion and gravitational settling. Gravitational settling is undoubtedly an important factor within the first several hours after the burst when the very large particles fall out, but afterwards it is likely that the main descent of the debris outside of rain areas is produced by vertical diffusion rather than gravitational settling.

A comparison of certain phases of transport and deposition of the IVY clouds with those of domestic tests may be informative in the light of the different locale and the fact that the IVY clouds penetrated into the stratosphere.

Considering first the locale, two essential characteristics differentiate the tropics from the mid-latitudes. First the trade winds will almost always carry material westward. The upper level tropical winds from 20,000 feet or 30,000 feet up to the tropopause at 55,000 feet are highly variable, but over a period of several days carry material to the east or west, but at a different speed than the underlying layer. The result is large shear between these layers - an important effect because it causes great horizontal stretching which in turn exposes large areas to the diffusive action of atmospheric turbulence. The rate of dilution by diffusion, therefore, proceeds much faster than would be the case with no stretching. An elongation of the clouds originating from the continental tests also occurs since there is a change of wind speed with elevation but the effect is not as dramatic as in the Pacific. In some of the earlier Pacific tests there was evidence that the cloud extended from North America to Asia within a few days after the burst.

Second, the tropical precipitation is in the form of showers instead of large areas of continuous rain more typical of the United States. It would be very instructive to determine the effect of the showery type of rainfall on the gummed paper collections.

The height of atomic debris affects the resulting deposition pattern. Tests at the Nevada Proving Grounds rarely penetrate appreciably into the stratosphere whereas both the MIKE and KING tests did and the mushroom from MIKE is believed to have been entirely within the stratosphere. It is believed by most meteorologists that vertical diffusion in the stratosphere is appreciably slower than in the troposphere although no quantitative data is available. If that is true and if the important vertical transport is the consequence of vertical diffusion, then the vertical transport within the stratosphere would be considerably slower than the transport through the troposphere. The consequence of the great height of the IVY clouds, therefore, might be to deposit their debris later than previous atomic clouds and thus produce more uniform fallout, since there is more time for horizontal diffusion to operate.

CHAPTER 3

THE MIKE TEST

3.1 INTRODUCTION

The most powerful man-made explosion known to have taken place was detonated at 1915 GCT, 31 October 1952. The entire atoll on which the experiment was conducted disappeared and is part of the debris. The stem was many miles wide while the mushroom was reported to be 60 miles in diameter at stabilization.

Despite elaborate efforts to ascertain the cloud height, there is still considerable doubt in some circles concerning the maximum elevation reached by the bulk of the cloud. The report issued by Dr. Palmer, a noted meteorologist who observed the test from a ship thirty miles south of the ground zero, stated that the maximum height of the bulk of the debris was only a few thousand feet above the tropopause. Theodolite measurements from that same ship and from adjacent naval vessels indicate much higher elevations. It appears, however, that the most reliable estimates of the cloud height resulted from sextant observations taken from aircraft, which placed the base of the huge mushroom between 70,000 and 80,000 feet and the top between 120,000 and 130,000 feet.

3.2 UPPER WINDS AT TIME OF MIKE

Figure 3.1 shows the upper wind observations made at Eniwetok before and after the MIKE test, along with the estimated winds at burst time derived from meteorological analysis. The trade winds extended to about 25,000 feet at detonation, but were from the eastsoutheast instead of the normal eastnortheast, due to a meteorological disturbance in the Marshall Island area. In the upper troposphere winds were from the south while at the base of the stratosphere (about 56,000 feet) the direction was again easterly with increased speed. The speeds diminish with increasing elevation in the stratosphere with evidence suggesting the winds at the top of the mushroom were from a westerly quadrant.

3.3 DISPERSION OF THE MIKE CLOUD

The motion of MIKE atomic cloud has been reconstructed on the basis of all available radiological data and meteorological analyses.

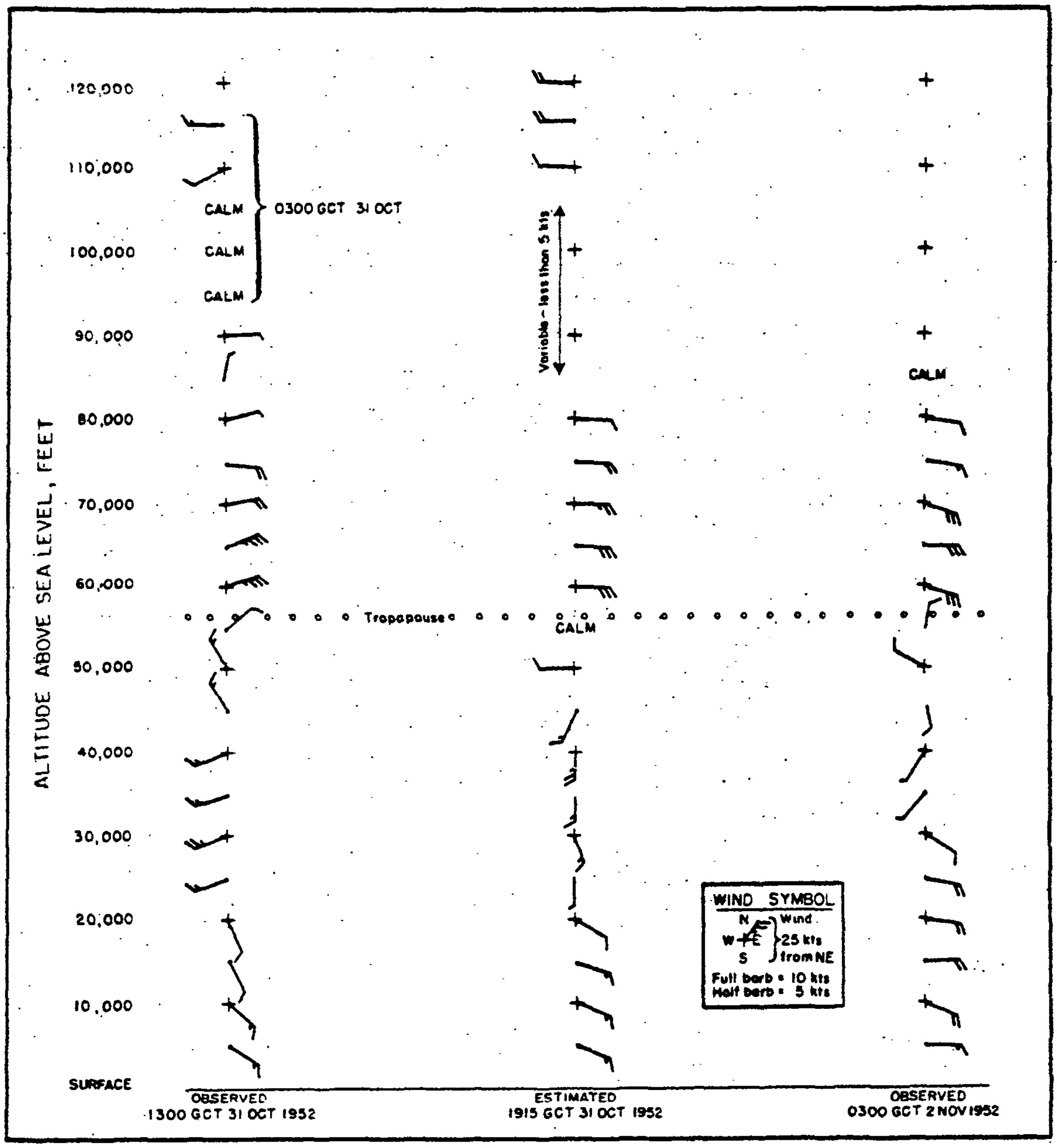

Figure 3.1 Winds aloft — MIKE burst

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It is worth repeating here that the uncertainty in meteorological trajectories increases with height. The discussion of cloud motion is conveniently treated under three headings; the trade wind portion (surface to about 30,000 feet), the upper tropospheric portion (30,000 feet to about 55,000) and the stratospheric portion (55,000 feet to 130,000 feet). Figures 3.2, 3.3 and 3.4 are schematic pictures of the outlines of MIKE debris which was initially located in each particular layer and remained in that layer. It should be noted that the areas shown do not include the material which was transported vertically from layer to layer. For example, by 10 November the trade wind layer was contaminated by fallout and diffusion from above so that almost the entire Pacific area probably contained debris in the lower levels rather than just the northeastern part.

3.3.1 Trade Wind Portion

The lowest 25,000 feet of the cloud shown in Figure 3.1 moved westward for three days then split into two segments, one proceeding northward around the west limb of the Pacific high pressure cell (clockwise circulation) and the other continued across the Philippine Islands and into southeast Asia. Because of more numerous meteorological data, we can be more certain of the trajectory that curved northward and are able to trace this portion across the Pacific and onto the United States west coast on 10 November.

3.3.2 Upper Tropospheric Portion

Figure 3.3 shows the motion of this layer of the cloud, initially northward and then gradually turning clockwise around the anticyclonic circulation just east of Eniwetok (See Fig. 1.1). After the third day, different levels within this layer commenced to diverge appreciable, the stratum near 30,000 feet curved toward the northeast to carry debris over the Hawaiian Islands (first detected there on 5 November) while the upper stratum (45,000 to 50,000 feet) curved south and then westward near the equator.

No detailed estimates of the cloud movement, beyond those shown in Figure 3.3 have been made because there are no upper air reports in the broad area of the Pacific between Central America and the Hawaiian Islands or along the equator west of the Marshall Islands. There is meteorological evidence to suggest the cloud curved toward the southeast after passing Hawaii. Such a

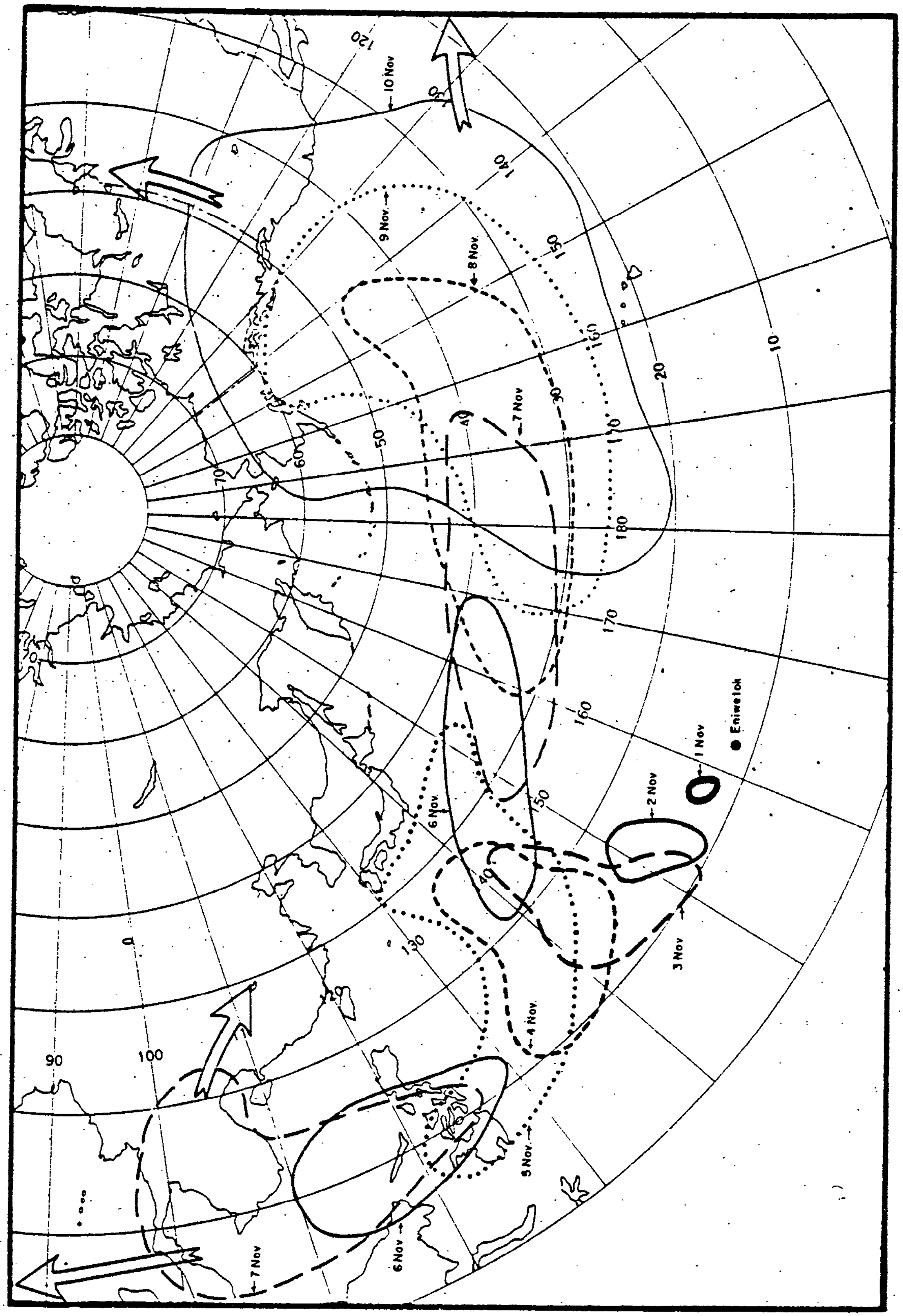


Figure 3.2 Schematic outlines, daily at 1500 GCT, trade wind portion of the MIKE cloud

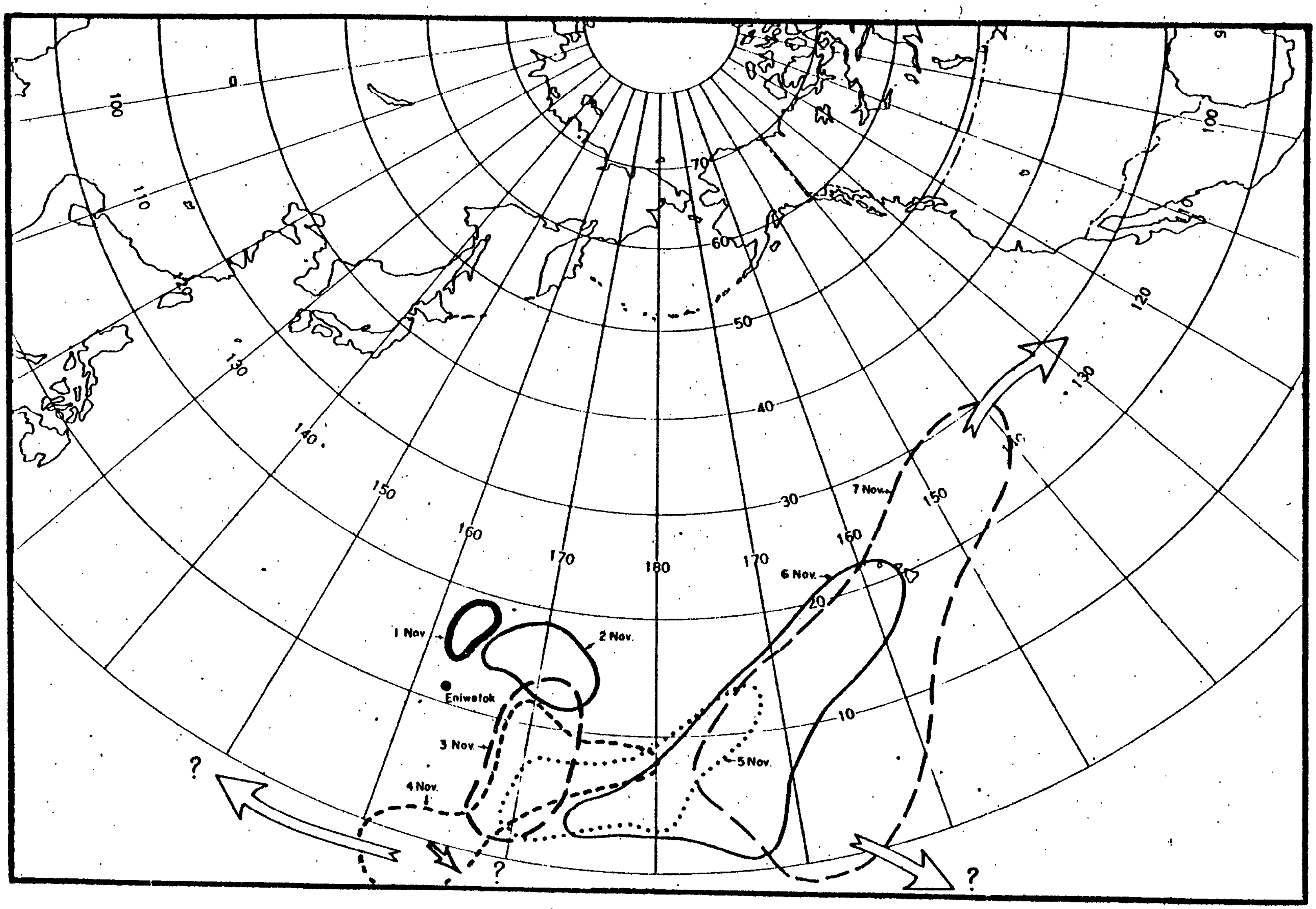


Figure 3.3 Schematic outlines, daily at 1500 GCT, upper troposphere portion of the [redacted]

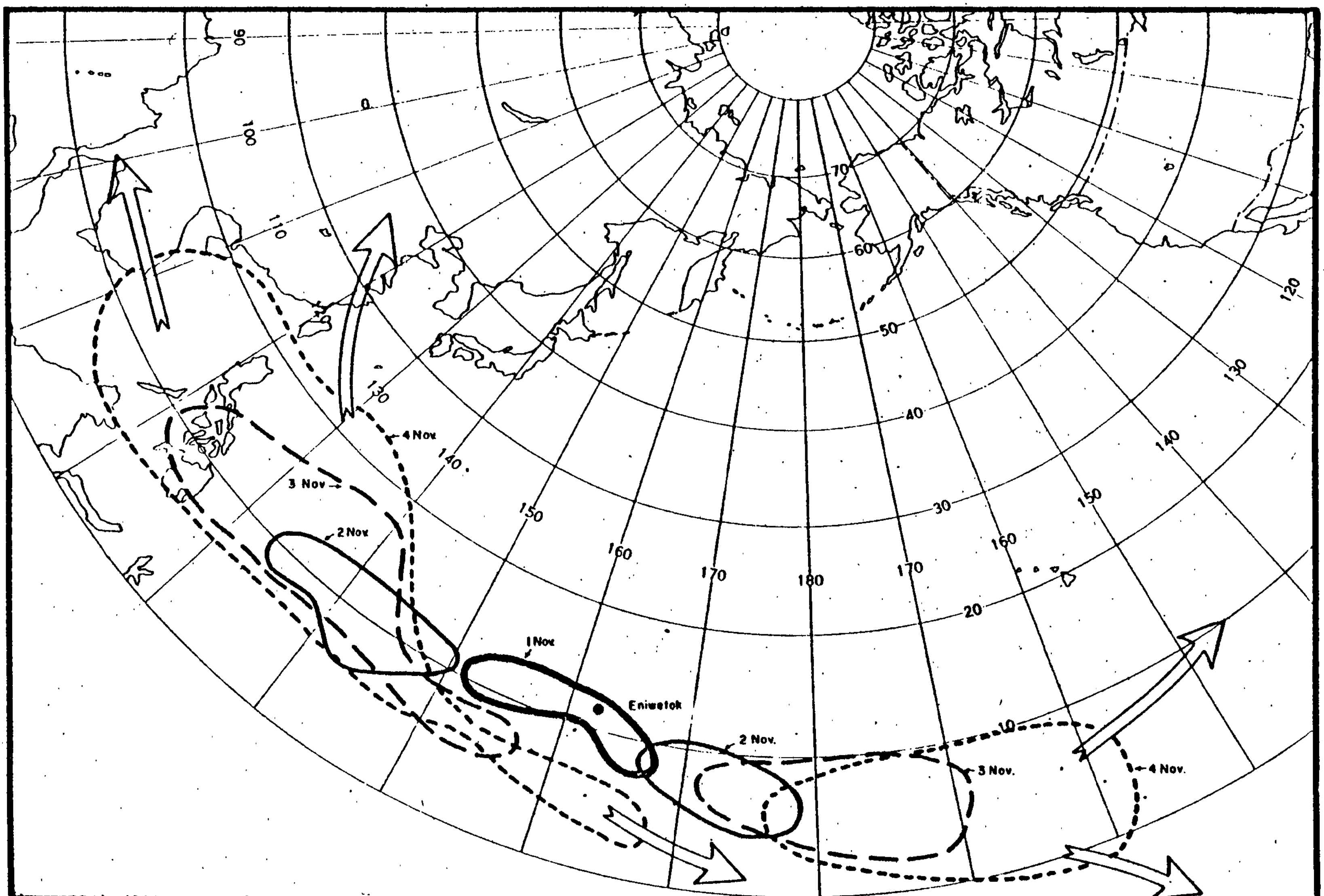


Figure 3.4 Schematic outlines, daily at 1500 GCT, stratosphere portion of the MIKE cloud

path would account for the failure of debris to enter the United States on 9 November as might be expected from an extrapolation of the previous movement. It is not possible to estimate the path of this cloud toward the United States, but undoubtedly part of the material from this section of the cloud moved eastward while at the same time other parts descended into the trade winds and moved back toward the west, depositing radioactivity from Hawaii to Asia for many days after the test.

3.3.3 Stratospheric Portion

The evidence provided by winds above the tropopause indicates that this part of the atomic cloud moved initially very slowly, and as shown in Figure 3.4, some layers eastward, but most of the cloud toward the west. The few wind observations at these elevations suggests a zonal extension of the cloud with only small north-south excursions. Beyond this, little more concerning the history of the mushroom cloud can be added by the meteorologist.

It is tempting to attribute the activity deposited at many stations far from the Marshall Islands a few days after the explosion to transport of debris initially in the stratosphere, since there is no positive proof that the stratospheric (and most highly radioactive) part of the cloud could not have moved in unexpected paths and at very high speeds. Such explanations have been avoided because they require unreasonable or impossible winds. Further, most of these cases of apparent arrival of fallout which one might ascribe to the stratospheric cloud are isolated in time and space. This is contrary to that which might be expected from fallout of debris initially in the stratosphere. The present analysis has led to the conclusion that there is no credited report of fission products collected in this operation which positively requires transport of debris initially in the mushroom. The debris in the mushroom spread both to the east and to the west so if there were any distant fallout, it would have been masked by fallout from lower levels.

3.3.4 Areas of MIKE Fallout

Combination of the radiological with the meteorological data provides an adequate basis for estimating areas of the earth's surface that received radioactive material. Figure 3.5 shows these estimates for the first week following the MIKE test and includes areas believed to have received fallout and rainout from all levels of the cloud. That is, experience with fallout in connection with continental tests has been used as the basis for

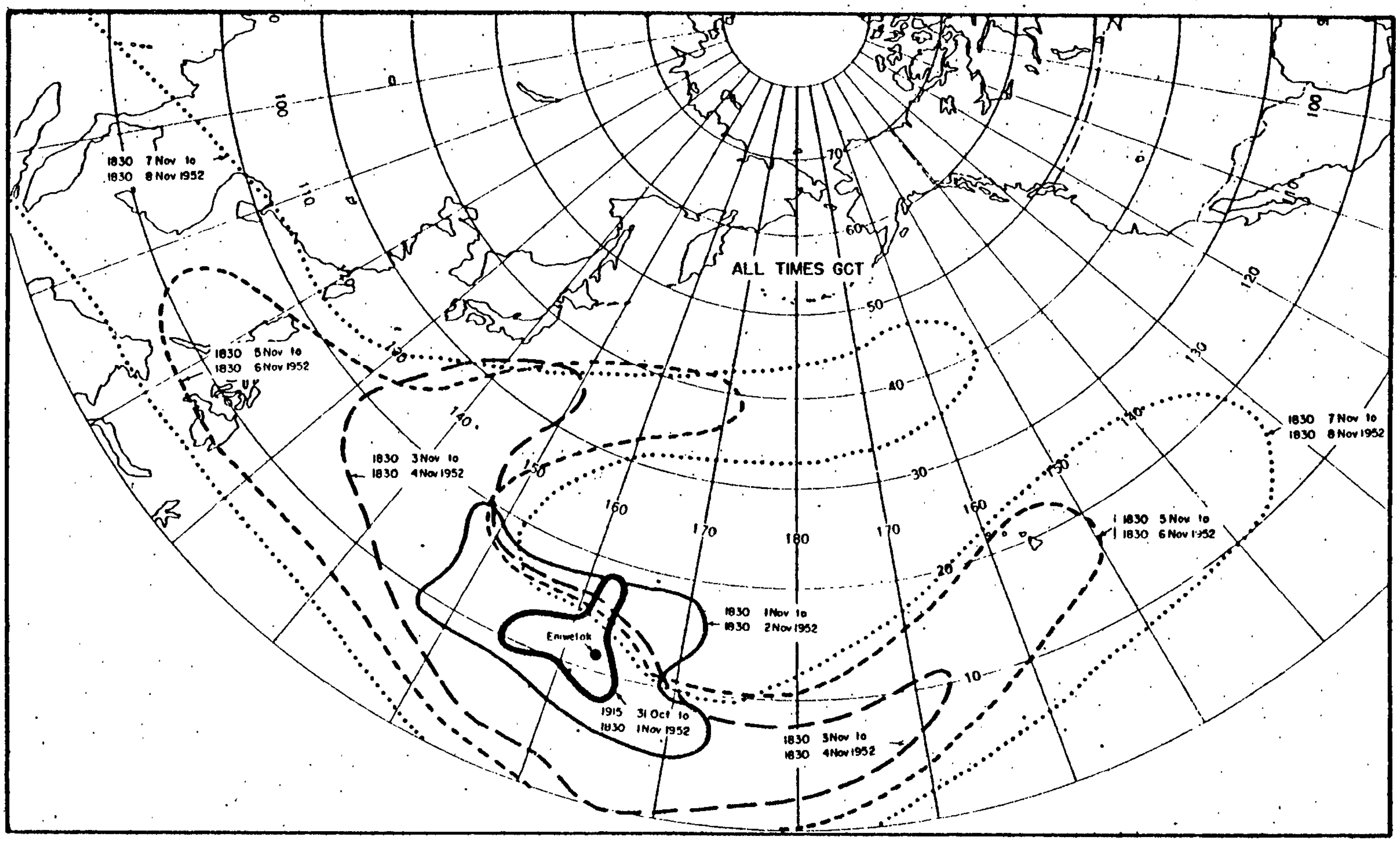


Figure 3.5 Estimated areas—surface deposition of debris from the MIKE cloud

estimating the total effect of diffusion, rainout and deposition of debris from the various levels.

While the radiological data form a basis for the analysis, not all of the observations necessarily fit into the picture shown. For example, it was felt that Guam should have received fallout a day earlier than reported and the area of fallout is drawn according to meteorological expectations. Similarly, it was believed Hilo, Hawaii and Johnston Islands should have received activity a day earlier than was recorded. On the other hand, the areas do not include Hong Kong, Formosa, the Aleutian Islands, or Japan, all of which reported small amounts of fission products. These probably represent minor offshoots from the main cloud. It is evident, therefore, that the areas are not intended to delineate all of the detail but rather to present the broader aspects of fallout and rainout.

The area of Figure 3.5 that extends west of Eniwetok is primarily the result of deposition from the trade wind portion of the atomic cloud while the areas east of the test site is contaminated by fallout from the upper tropospheric cloud which was transported downward through the trade winds after first moving eastward at higher levels.

CHAPTER 4

THE KING TEST

4.1 INTRODUCTION

The KING nuclear device was detonated at 2330 GCT, 15 November 1952.

The top of the cloud was estimated to be 75,000 feet with the base of the mushroom at approximately 40,000 feet.

4.2 UPPER WINDS AT TIME OF KING

Figure 4.1 shows the observed winds at Eniwetok before and after the detonation of KING and the estimated winds at the time of the test. The trade winds extended to just under 30,000 feet with westerly winds in the upper troposphere. At about 50,000 feet, a second reversal occurred so that in the lower stratosphere the directions again were from the east. A third reversal occurs between 70,000 and 75,000 feet and it is likely that the bulk of the KING mushroom, or perhaps all of it, lay below the west winds based at about 75,000 feet.

4.3 DISPERSION OF THE KING CLOUD

Figures 4.2, 4.3, and 4.4 show the successive positions of the various parts of the KING cloud for the first several days after the explosion. As with the MIKE cloud, the outlines have been prepared for three layers designated as the trade wind portion (surface to about 30,000 feet), upper tropospheric portion (30,000 feet to 55,000 feet) and the stratospheric portion (55,000 feet to 75,000 feet).

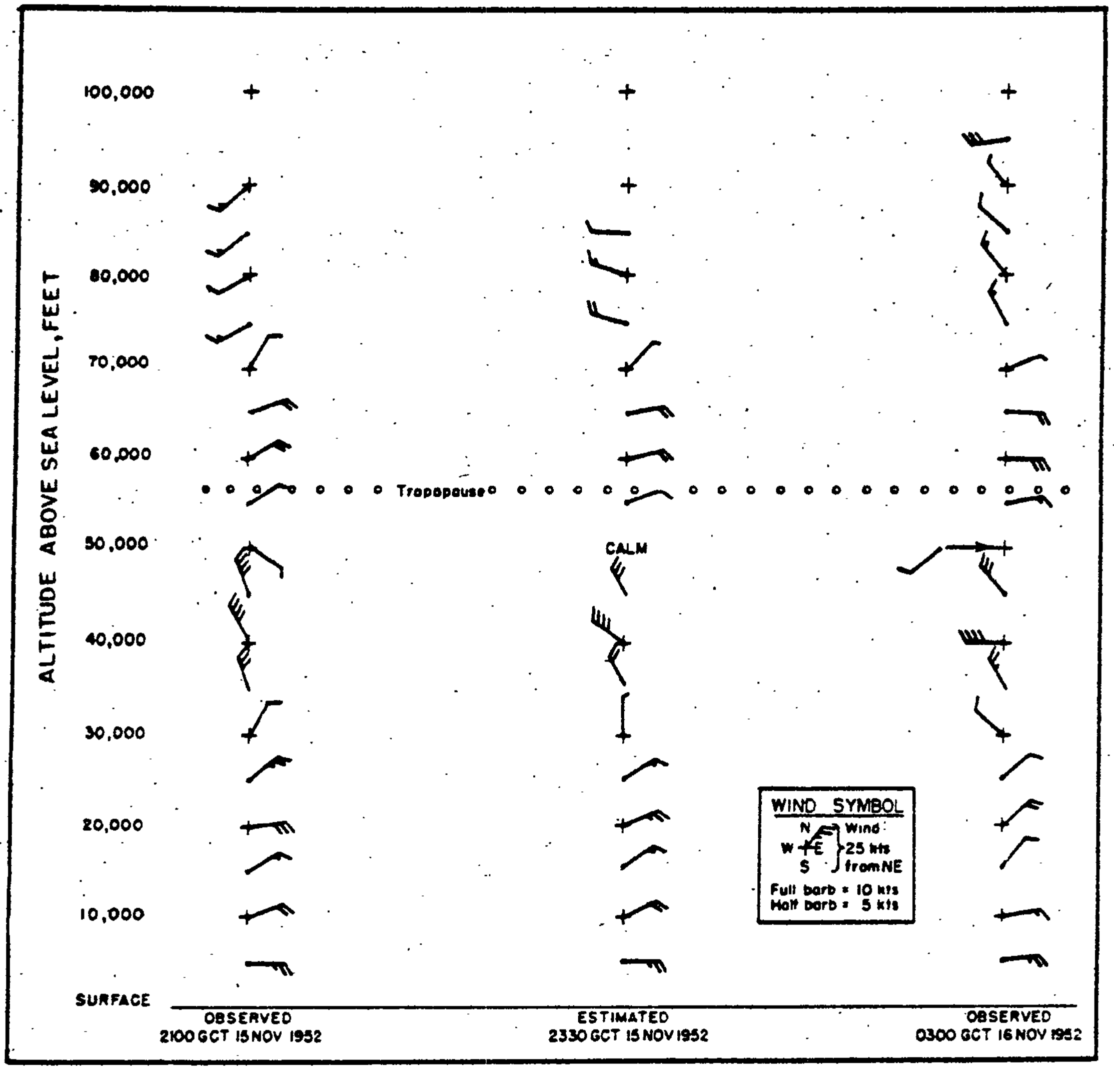


Figure 4.1 Winds aloft — KING burst

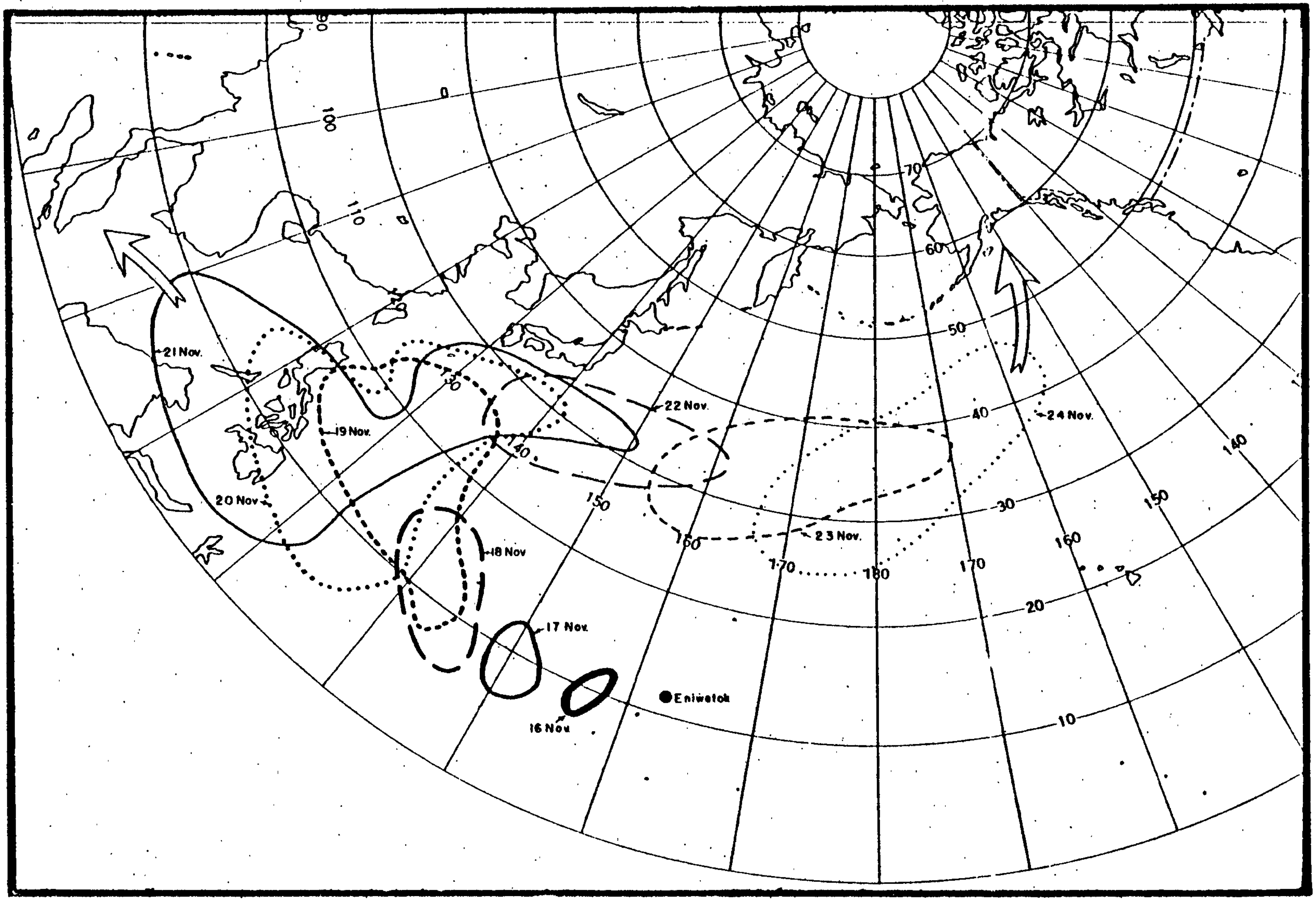


Figure 4.2 Schematic outlines, daily at 1500 GCT, trade wind portion of the KING cloud

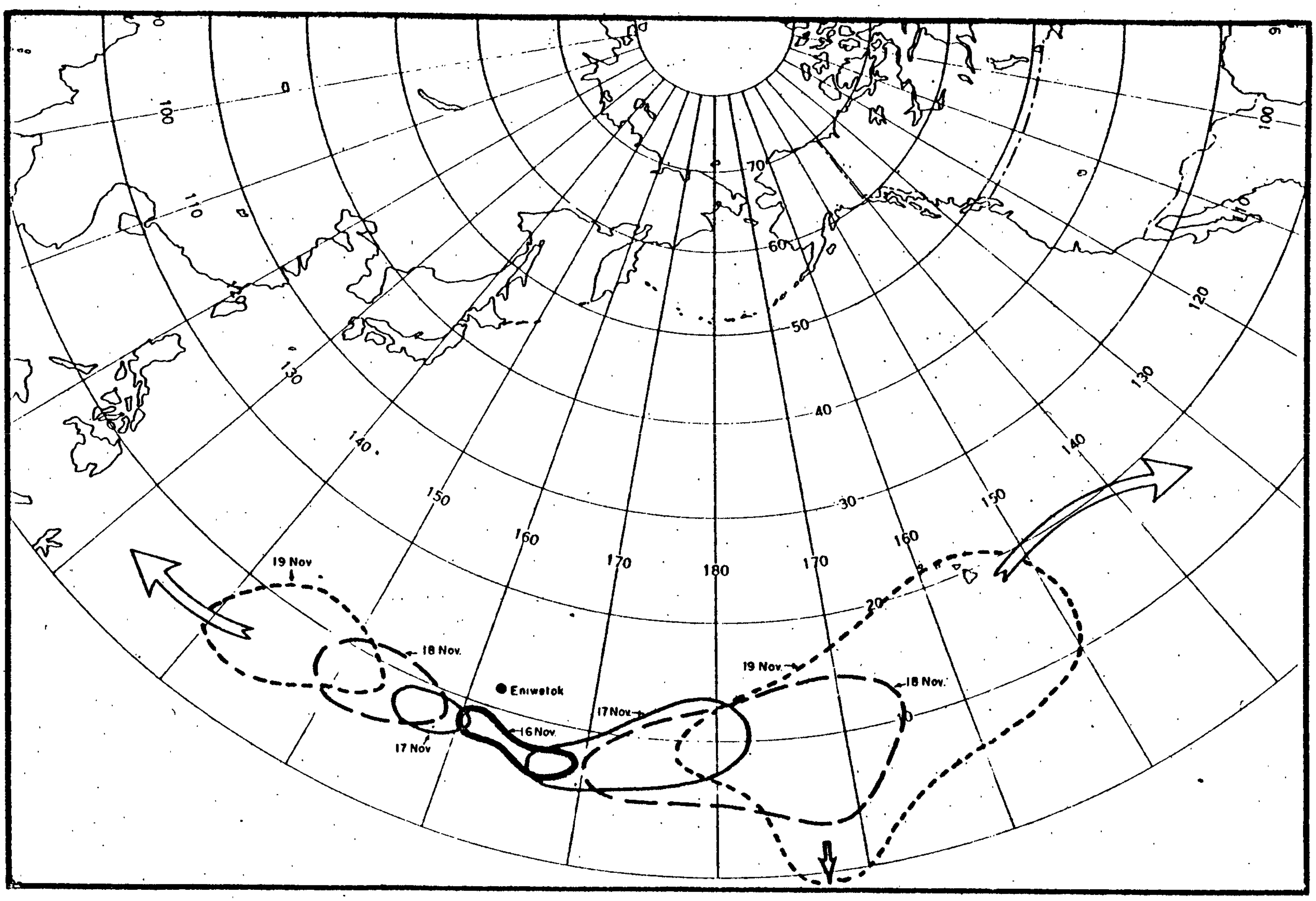


Figure 4.3 Schematic outlines, daily at 1500 GCT, upper troposphere portion of the KING cloud

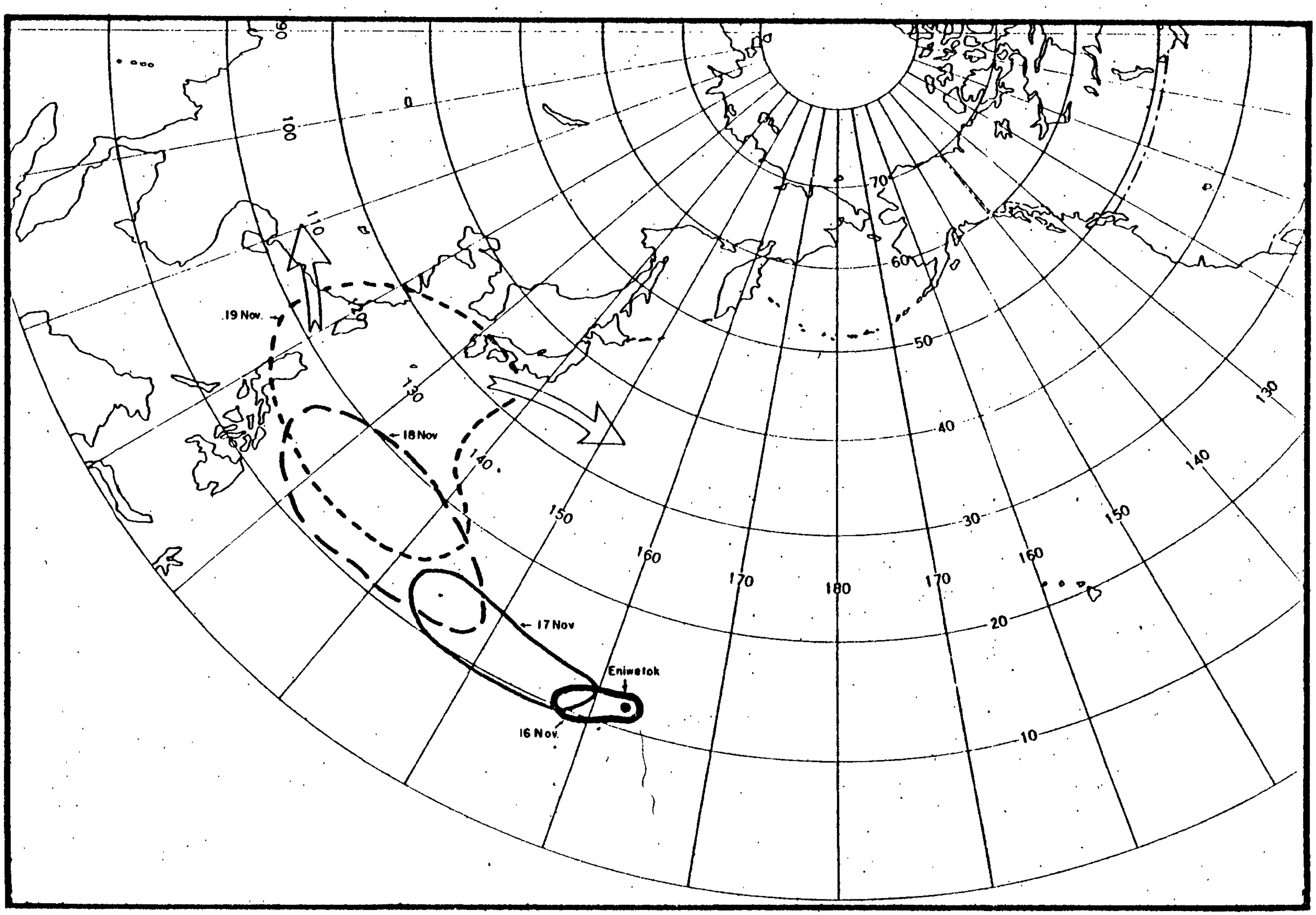


Figure 4.4 Schematic outlines, daily at 1500 GCT, stratosphere portion of the KING cloud

4.3.1 Trade Wind Portion

The path of the trade wind portion of the KING cloud (Figure 4.2) is similar to that of the MIKE cloud, moving westward and splitting east of the Philippine Islands with one part continuing westward and the other moving around the west limb of the Pacific anticyclonic cell. The main difference between the two IVY clouds in this layer lies in the more southerly track of the KING material which is located, on the average, almost five degrees farther south than the MIKE cloud.

4.3.2 Upper Tropospheric Portion

This portion of the cloud, as seen in Figure 4.3, is carried both toward the east and west, the upper and lower layers diverging more quickly than did the corresponding parts of the MIKE cloud. The layer between 30,000 feet and 40,000 feet, approximately, quickly curved toward the west into an area where the east winds extended from the surface up to about 40,000 feet. The upper part (40,000 to 55,000 feet) of the high tropospheric cloud moved eastward, passing the longitude of the Hawaiian Islands within four days after burst time, which was two days less than the time required by the MIKE cloud. The first fallout on the Hawaiian Islands, however, was detected five to six days after each burst (in rain), apparently because the KING cloud initially reached the longitude of the Islands a little further south than did the MIKE cloud.

4.3.3 Stratospheric Portion

The highest portions of the cloud (Figure 4.4) were carried westward at 20 to 40 knots, curving northward, after four days, near the Asiatic mainland. The portion of the KING cloud, if any, which may have reached above the base of the westerlies at 75,000 feet at burst time would have a path quite different than that shown. Instead of moving westward, it would have drifted slowly southeastward during four days following the KING burst.

4.3.4 Areas of KING Fallout

The estimated areas in which there was debris deposited during the first six days following the KING shot are shown in Figure 4.5. The method of preparation and the meaning of the lines in this figure are similar to those of Figure 3.5 for the MIKE shot.

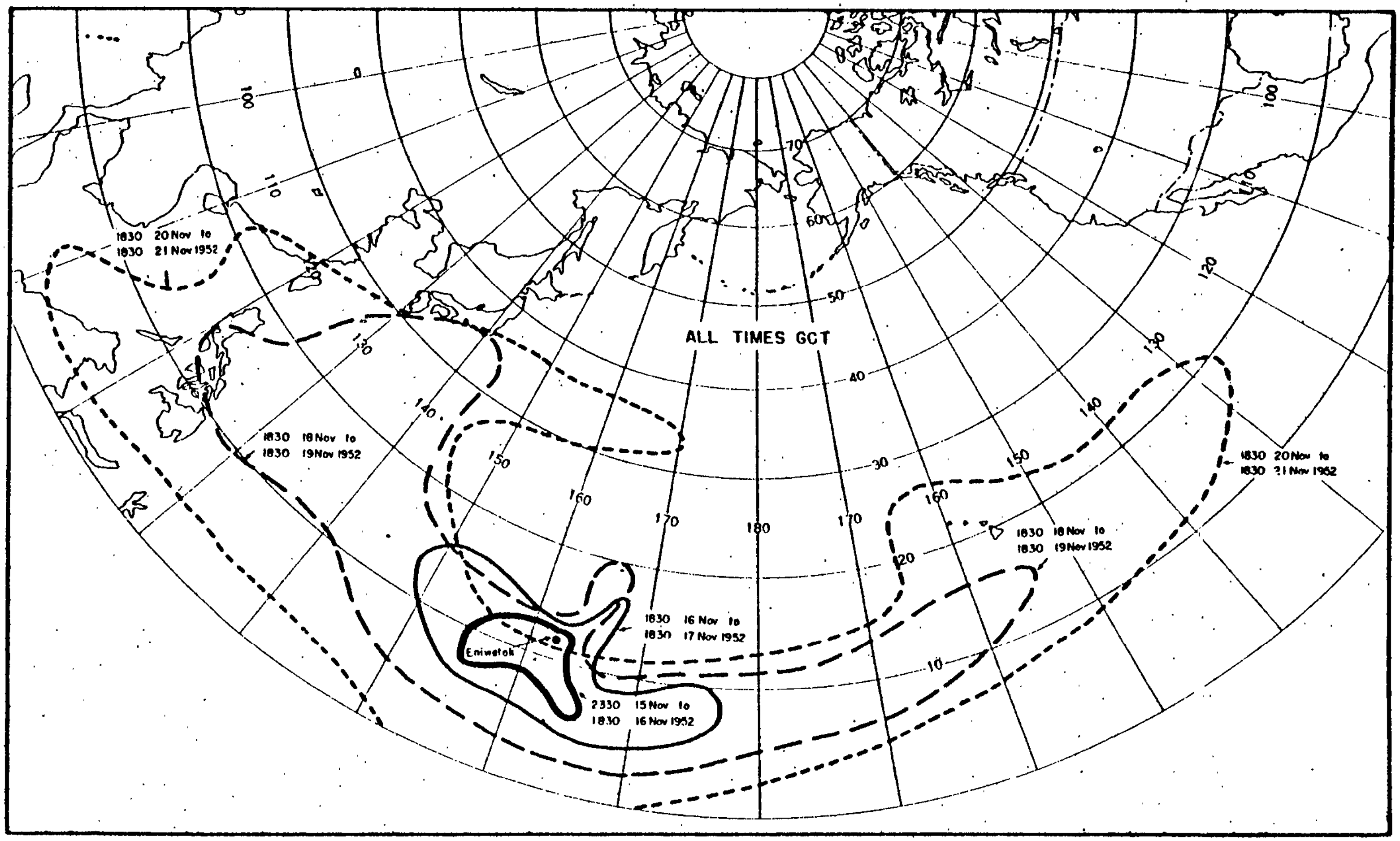


Figure 4.5 Estimated areas—surface deposition of debris from the KING cloud

The arrival of KING debris at each station is not as clear-cut as it was for the MIKE test since residual radioactivity from the first test was present over the entire northern Pacific Ocean at the time of first arrival of KING material. Fresh debris is usually indicated quite clearly, however, by an abrupt rise in activity from one day to the next. Such indications are consistent with the analysis shown, with two exceptions. Johnston Island, according to the broad meteorological features was again several days late in showing the first arrival of radioactivity. Yap showed an abrupt rise the day following the KING burst, but it is not included in the area outlined for 16 November. The reasons for not including Yap in the fallout area estimated up to 1830 GCT, 16 November are based on both radiological and meteorological data. Material from KING would have had to move faster than 35 knots in order to arrive before 1830 GCT, 16 November - a speed significantly higher than any observed in the area. Furthermore, if the debris was present late on the 16th, it would have contributed significant activity to the following day's sample, yet the paper exposed 17 to 18 November showed a sharp decrease to a level consistent with residual radioactivity from MIKE. The argument based on radiological considerations concerns the magnitude of the activity. The distance of Yap from the test site as well as its latitude would not lead one to expect it to receive more radioactivity than stations closer to Eniwetok. If the basic data were entirely correct, however, application of the growth factor appropriate to KING debris, would result in a figure of about 200,000 d/m which would be the highest value observed in the entire network for the KING burst!

The fallout appearing to the west of Eniwetok is essentially from the trade wind portion of the cloud and from the lower portion of the material initially in the upper troposphere. The areas of fallout east of Eniwetok are derived from the remainder of the upper tropospheric portion of the KING cloud. The areas covered by the KING fallout differ slightly from the areas associated with the MIKE test. The second test spread debris further south into the equatorial regions and slightly closer to Japan. The fallout from the segments of the cloud which were carried eastward arrived sooner after the KING test and probably extended a little further south. It should be noted that the estimated outlines do not indicate the magnitude of the activity inside the areas. Evidence suggests that while the total area of fallout from the KING shot may have exceeded that from the MIKE shot for the first few days, the total radioactivity deposited on the surface was greater for the MIKE detonation.

CHAPTER 5

FALLOUT IN SPECIFIC AREAS

5.1 INTRODUCTION

The objective of this section is to investigate the meteorological and radiological conditions which resulted in large surface deposition of radioactive debris in specific areas and attempt to estimate the maximum fallout to be expected from future Pacific tests of yields similar to IVY but under different weather conditions. The results of the fallout monitoring program for Operation IVY are contained in Appendix A and a summary of pertinent items of this data are tabulated in Appendix B.

5.2 WESTERN NORTH PACIFIC OCEAN

The highest individual gummed paper activity of the entire network was 3,600,000 d/m reported at Iwo Jima five to six days after the MIKE test and was collected during no precipitation. The highest activity from KING, 150,000 d/m was collected at Truk in rain, two to three days after detonation.

In general, the area west of the Marshall Islands reported the highest activity after each test, an order of magnitude or more greater than other areas. For the most part, these high values were obtained from portions of the atomic cloud which were in the trade winds at the time of stabilization. It is not believed that the trade wind layer of the cloud contained more radioactivity than did any other portion of the cloud, on the contrary, if past experience is any criterion, the mushroom contained much more radioactivity. Debris from the high troposphere and the stratosphere, however, is collected only after it has settled or diffused downward through relatively large vertical distances and consequently is widely dispersed. The normal precipitation of the tropics falls from clouds embedded entirely in the trade winds layer so that scavenging of the upper tropospheric debris is not common. On the other hand, there were no stations at low latitudes east of the test site, consequently there was no positive evidence that the fallout from the upper tropospheric segment of the cloud which moved eastward, contributed only low radioactivity at the surface.

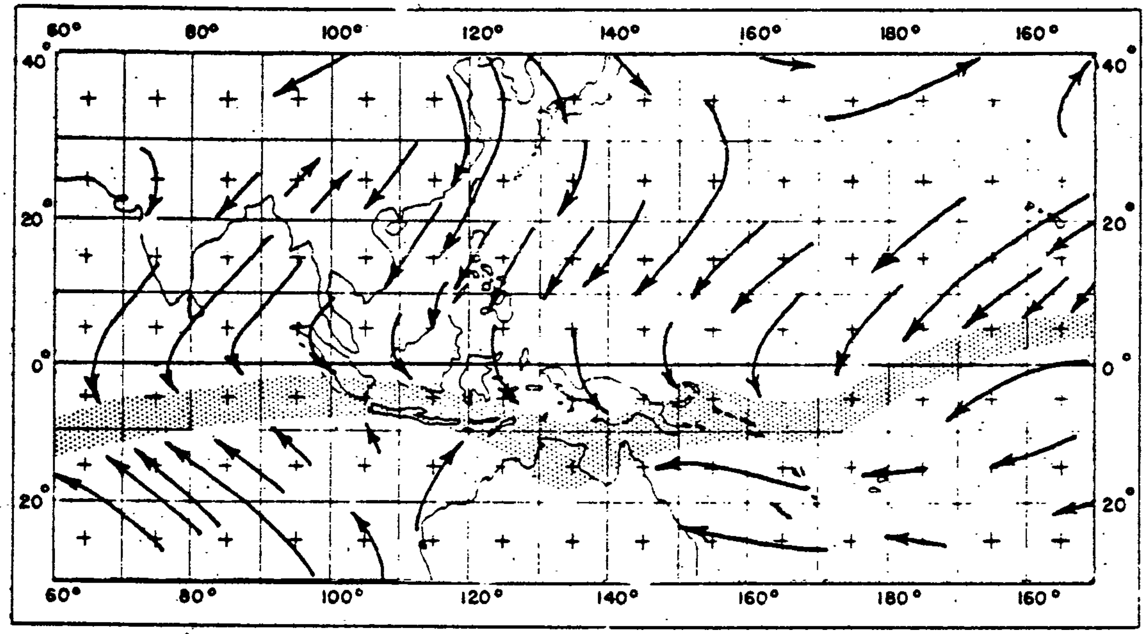
Trade winds being a dependable feature of the tropical circulation will always cause a westward drift of the lower layers of an atomic cloud. Disturbances in the trade winds modify the prevailing eastnortheast flow for periods of a few days but the effect is to enlarge the trade wind cloud* rather than alter the general westward drift. It is possible, however, to reduce the probability of contamination in some areas affected by the IVY debris by scheduling future tests in different months.

Figure 5.1, 5.2, and 5.3 show the monthly average trade wind flow at the surface as of the first of January, March, May, July, September, and November. The shaded portions mark the areas of mixing between the trade winds of northern and southern hemispheres - areas of increased precipitation and generally disturbed weather. Disturbed weather does not affect the entire shaded area simultaneously, for the storminess is, generally, confined to narrow and intermittent bands (often two east-west bands roughly parallel) perhaps only 100 miles wide. The areas indicated on the figures include the normal north-south range of this intermittent band of storminess and seasonal variation of rainfall is the result of the seasonal movement of this disturbed weather zone.

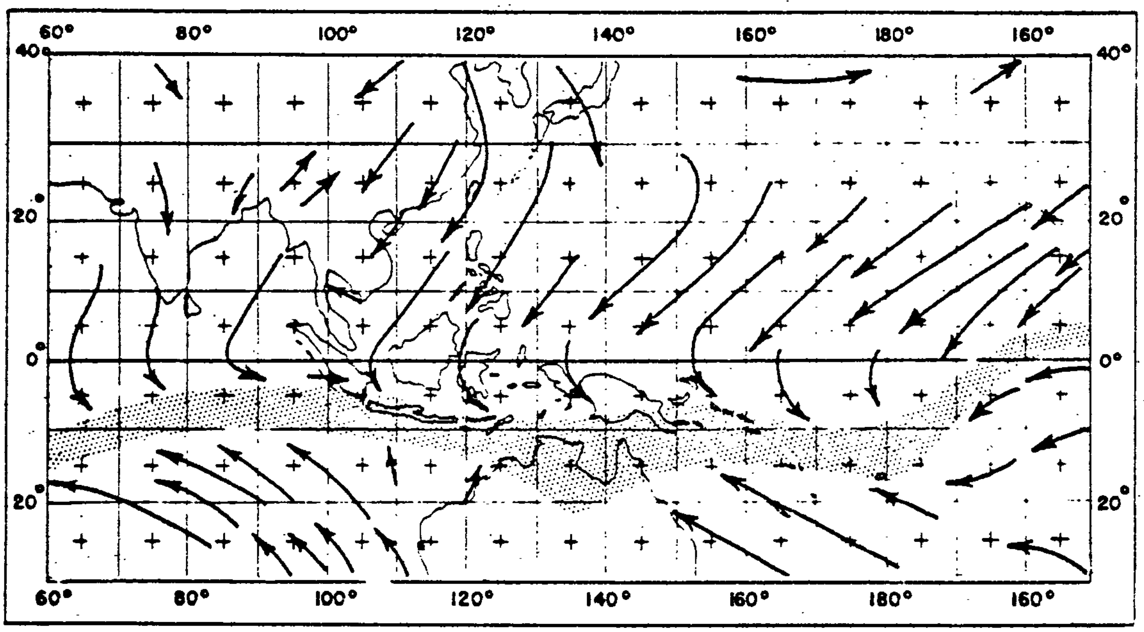
These figures present climatology that might be useful for general planning. For example, the probability of rainout hazard is maximized in the shaded areas. The second map of Figure 5.3 corresponds to the time of Operation IVY and illustrates the prevailing flow from Eniwetok to southern Asia. This was corroborated by the radiological data. The second map of Figure 5.2 on the other hand, illustrates the fact that the fallout and rainout at Guam, the Philippine Islands and southeastern Asia would be minimized in late summer.

In addition to fallout from the trade wind layer, the total activity could be greatly increased by superimposing material from the upper troposphere. Such superposition might be caused by a current of "deep easterlies". Occasionally, the winds at Eniwetok blow from the east throughout the troposphere - from the surface to 55,000 feet. Bomb debris that stabilized in the troposphere in such a situation would move toward the west with little stretching so that the amount of radioactivity available for fallout and rainout would be relatively large. Showers are more frequent over islands so it would be possible for a long column of this concentrated debris to move over an island such as Guam and be scavenged by rain. The meteorological conditions necessary for the

*Vertical shear in disturbances is more pronounced than in the undisturbed trades, producing a greater than normal cross-stream stretching of the atomic cloud.

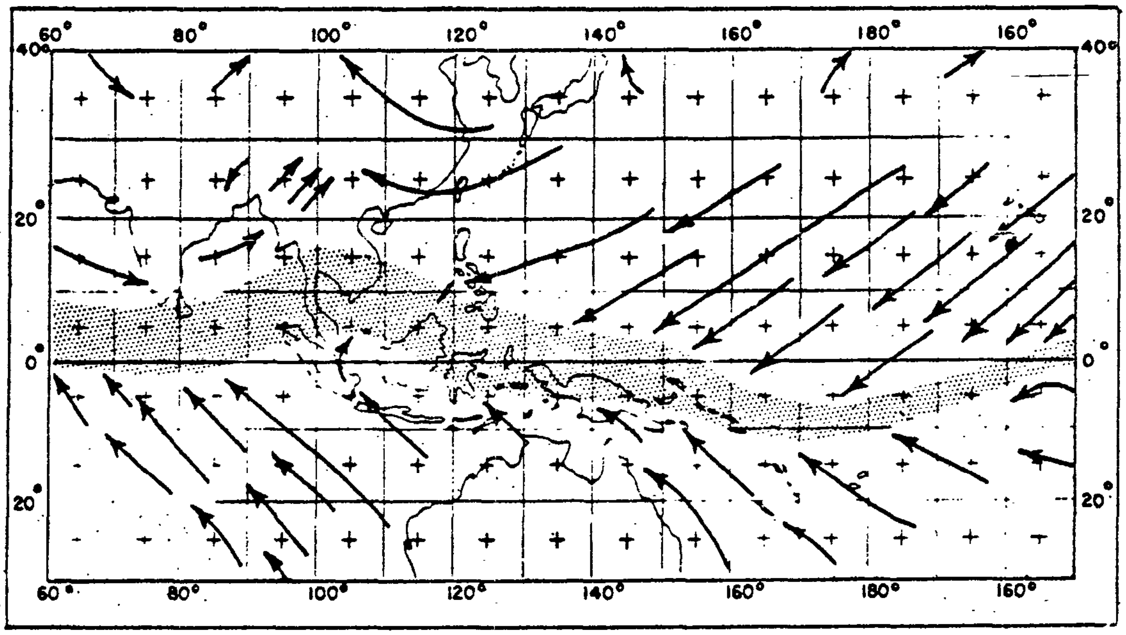


15 Dec to 15 Jan

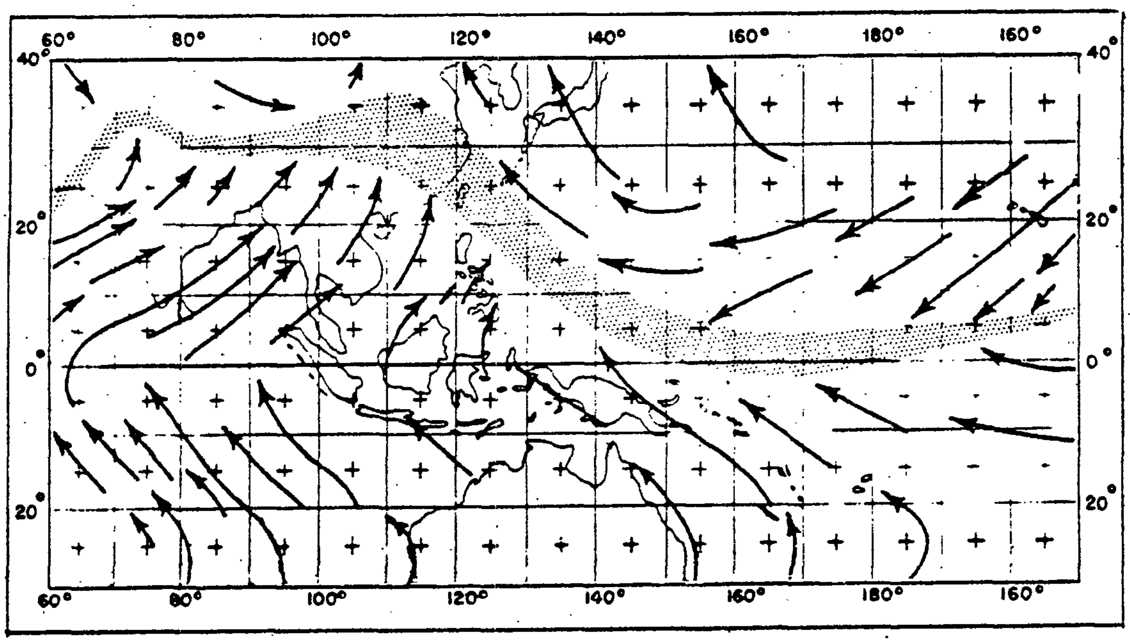


15 Feb to 15 Mar

Figure 5.1 Prevailing winds of the Western Pacific monthly mean around 1 Jan and 1 Mar

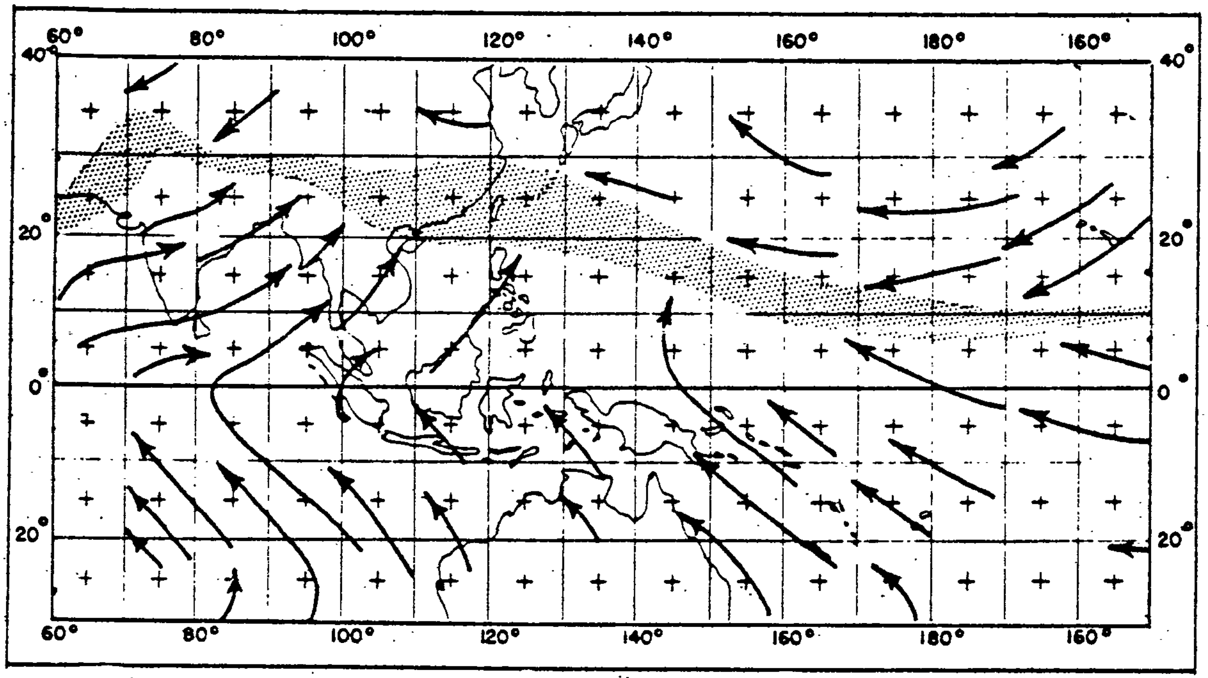


15 Apr to 15 May

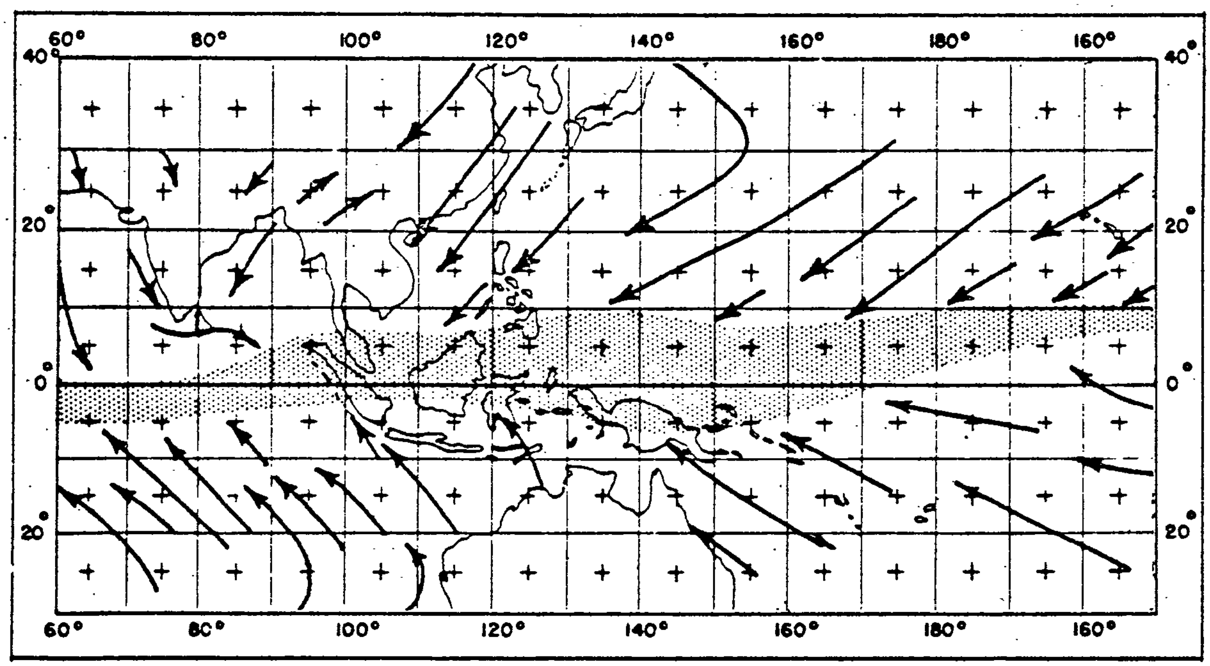


15 June to 15 July

Figure 5.2 Prevailing winds of the Western Pacific monthly mean around 1 May and 1 July



15 Aug to 15 Sept



15 Oct to 15 Nov

Figure 5.3 Prevailing winds of the Western Pacific monthly mean around 1 Sept and 1 Nov initial conditions as well as the maintenance of "deep easterlies" from the Marshall Islands to Guam would probably occur no more than a few times a year, however, so the probability of any one test being so affected is small.

5.2.1 Air Filter Observations in the Western Pacific

The highest air filter activity for the IVY operations was collected at Kwajalein four to five days after MIKE (700 d/m/m^3) and at Truk two to three days after KING (100 d/m/m^3). No data was obtained at Kwajalein following KING, however, so it is possible that the highest air concentration would have again been reported there.

Much higher air filter samples were reported from the continental tests, but these invariably were observed within 48 hours of the burst. Furthermore, the denser network within the United States increases the chances of sampling within the peak concentration. The Pacific network of air filters was not located along the core of the low-level cloud of either MIKE or KING. The samples obtained at Kwajalein were not from trade wind material, but from debris that had initially moved in the high troposphere. In general, the air filter samples of the western Pacific did not fit the pattern suggested by either the gummed paper network or the meteorology. The correlation between the two types of collections appears to be very low. If air concentrations are considered to be important, then steps should be taken to augment the air filter network for future Pacific tests and to determine the effects of rain on the air concentration.

5.3 HAWAIIAN ISLANDS

The Hawaiian Islands, lying about 2400 nautical miles from Eniwetok, are the nearest concentration of population, industry and agriculture east of the Pacific Proving Ground. The Hawaiian Islands are a few hundred miles further from the Pacific test site than are the cities of northeastern United States from the Nevada Proving Ground. Were it not for the prevailing circulation, the Hawaiian Islands might receive radioactive contamination in their copious rains that would create health hazards. The trade winds are a predominant feature of the atmospheric circulation in the vicinity of the Islands as well as near the test site so that debris which is gradually brought to earth must be carried toward the Hawaiian Islands from the east. The typical fallout, therefore, is derived from the fraction of the upper tropospheric cloud which diffuses or falls into the lower layers, east of the Islands. The core of the upper tropospheric clouds from MIKE and KING, as well as from most other atomic clouds detonated in the Marshall Islands, passed well to the south of the Hawaiian Islands. This characteristic trajectory, it is believed, is a further cause of the low level of activity deposited on the Hawaiian Islands.

The first material from MIKE detected in the Hawaiian Islands was collected five to six days after burst and was evident on both gummed paper and air filter samples. The maximum air filter activity (14 d/m/m^3) was collected seven to eight days after MIKE, the maximum gummed paper activity (6500 d/m) was collected eleven to twelve days after burst. Debris continued to fall but with diminished intensity until the arrival of the KING cloud on 20 to 21 November, again five to six days after burst. Activity on the first gummed paper sample was about the same as the maximum (slightly over 5000 d/m) that occurred three days later while the maximum air filter sample (10 d/m/m^3) was not collected until the tenth to eleventh day after KING.

The highest air concentration of 14 d/m/m^3 is small compared to the 570 d/m/m^3 found at Cincinnati, Ohio, two days after a Buster-Jangle test, but it should be noted that no value as high as 14 d/m/m^3 was ever observed in the United States as long as seven days following an atomic test.

5.3.1 Potential Maximum in the Hawaiian Islands

It is easy to find weather patterns which would result in passage of an atomic cloud over the Hawaiian Islands sooner after burst than did the MIKE or KING clouds; the GREENHOUSE DOG and the SANDSTONE YOKE were samples of such rapid movement. It is also possible for the clouds to pass more directly over the Islands than did the IVY clouds. It is difficult, however, to assign an upper bound to the activity which might be deposited because there is no data which can be used as a basis of reference.

The situation potentially most dangerous is one in which shower clouds build up to great heights and penetrate the upper tropospheric westerlies at the time a fast-moving cloud of debris passes overhead. Conditions favorable to this situation are present in both winter and summer, although the summer frequency is low.

During the months of November through March systems of disturbed weather with tall shower clouds, pass the Islands on the average of about twice a month - these are the "Kona Storms" that bring one to three days of rain. They represent a situation potentially dangerous from the radiological point of view because they combine clouds of great vertical extent with very fast winds in the upper troposphere.

During the warmer half of the year, precipitating clouds build up into the high troposphere only infrequently. The Kona storm is a rare phenomenon in the warmer seasons and shower clouds would reach into the high troposphere on the average of little more than once a month during the months April through October.

A rough estimate of the maximum radioactivity that would be scavenged under the optimal conditions might be made by use of the large rainout at Albany and Troy, N. Y., on 26 April 1953 during the UPSHOT-KNOTHOLE test series (4 - p. 52). It was reported that Albany received about 15,000,000 d/m on a day during which a thunderstorm penetrated a fresh atomic cloud. Troy was monitored and found to have received a dose of 0.1 roentgen integrated over thirteen weeks. If one merely scales up these figures by the ratio of the yields, then the Hawaiian Islands might receive a peak activity of the order of 10^9 d/m or a thirteen week integrated dose of 10 roentgens.

In summary, it appears that under typical weather conditions, the Hawaiian Islands would receive fallout and rainout of the same order as observed during IVY if the total amount of radioactivity initially in the high troposphere were similar to that of MIKE and KING. It should be recognized, however, that a potential hazard exists both from the standpoint of anamolous weather patterns and from the fact that a different type test - say an underwater burst - might stabilize greater quantities of debris in the high troposphere. Considerably more study would be required to determine the probability of the maximum rainout and the possibility of utilizing meteorological forecasts to avoid this situation.

5.4 THE UNITED STATES

The highest radioactivity collected on gummed papers and air filters during Operation IVY were much lower than during tests at the Nevada Proving Ground. The IVY clouds were not particularly fast-moving so it is not surprising that the great distance and time involved overcompensated the tremendous yield of MIKE.

The peak air concentration recorded was 3 $d/m/m^3$ and most of the values were 1 $d/m/m^3$ or less. Because so few stations obtained air filter data and because so little correlation between gummed paper and air filters can be found, no analysis of this data is attempted.

There were significant areas of surface deposition in the United States with activity greater than 500 d/m from 10 through 28 November 1952 and the fallout occurred in isolated patches up to 4 December. The maximum value reported was from MIKE debris; 10,000 d/m at Boise, Idaho on 10 and 11 November. The second highest value was 9,800 d/m at Ft. Worth, Texas, on 23 and 24 November, probably due to KING debris. It is believed that all fallout in the United States up to 22 November was due to MIKE material and most of the deposition after that date was due to KING. Greater deposition in rain, compared to deposition in no rain, is evident in the IVY data, in agreement with data from previous tests (see Section 6.2).

It is possible to trace four separate patches of fallout passing over the United States from west to east, at speeds slower than the winds aloft. The first entered northwestern United States on 10 November moved across the northern tier of states and southern Canada and left the east coast about 18 November, being found both in and out of precipitation. Apparently, the origin of this material was the portion of the cloud initially in the trade winds that moved northward around the west limb of the Pacific high cell (see Figure 3.2).

A second patch entered California on 14 November with deposition occurring both in and out of rain. The history of this patch is uncertain but probably represents part of the upper tropospheric MIKE cloud which moved eastward over the Hawaiian Islands (see Figure 3.3).

The third patch entered northwestern United States and southern Canada on 19 November. This merged with the second patch which was depositing material further south. The activity from this fragment of the MIKE cloud was generally below 1000 d/m.

On 22 November, the activity suddenly rose to 2900 d/m in rain at Ft. Worth, Texas. The following day, also with rain, the same station reported 10,000 d/m and during the following days many stations in the midwest and east began reporting activity in the thousands of d/m. It was not possible to carry trajectories of the KING cloud to the United States, but it is likely that the abrupt increase in activity 22 to 23 November represents the upper tropospheric cloud from KING which was shown over the Hawaiian Islands on 19 November (See Figure 4.3) because reasonable winds (about 50 knots) would have carried the debris from Hawaii to Ft. Worth on the twenty-second.

5.4.1 Potential Maximum in the USA

The MIKE debris took about ten days to reach gummed papers exposed in the United States and the KING material took about six days. In order to estimate the maximum activity that could be deposited in the United States from future Pacific tests of megaton yields, it is necessary to postulate the fastest possible transport. A review of previous Pacific tests indicates that the case of most rapid transport to the United States occurred with GREENHOUSE DOG, detonated 7 April 1951. Rochester, N. Y. and Washington, D. C. both reported approximately 1000 d/m in rain four to five days after burst (2).

Computation of high-level trajectories suggests that the core of the GREENHOUSE DOG bomb passed well south of Washington, so it is possible that the maximum rainout was also south of Washington and perhaps an order of magnitude greater than the activity reported.

it is reasonable to assume that under similar meteorological conditions radioactive from rainout on the west coast would be higher than on the east coast because decay and dilution would have been operating over a shorter period. The increase would probably be less than an order of magnitude, however, probably a factor of two or three.

Summarizing, it is estimated that the maximum possible rainout over the United States from megaton-yield tests in the Pacific would lie in the range 10^5 to 10^6 d/m. This crude estimate is based on the assumption that radioactivity from rainout, under similar meteorological conditions, is directly proportional to the bomb yield. The meteorological conditions necessary for maximum rainout are fast westerly winds in the upper troposphere and rainout from high levels over the United States. These conditions would be expected in winter and spring rather than during summer and fall.

5.5 SOUTHEAST AND EAST ASIA

Southeastern and eastern Asia is the only area outside of the Western Pacific which received activity of the order of 10^4 d/m. Furthermore, it is an area where even greater radioactivity might be expected. The highest radioactivity collected at Clark Field, P. I. from MIKE debris was about 200,000 d/m (with no rain) and 3,000 d/m after KING.

In view of the fact that a portion of the trade wind segment of MIKE passed directly over the Philippines, it is likely that some parts of those islands received rainout radioactivity at least an order of magnitude greater than that reported. Bangkok collected a peak value of 100,000 d/m from MIKE in no rain. Undoubtedly, some of southeastern Asia received larger amounts of radioactivity in rain - at least an order of magnitude greater than did Bangkok.

The highest value reported in Japan was 45,000 d/m from MIKE and only a few hundred d/m from KING. This relatively low activity was due to the fact that only the edge of the trade wind cloud touched Japan. Only during the warmer months of the summer could any significant portion of the low-level cloud affect the Japanese Islands because the cold monsoon from Siberia dominates the circulation during the winter. In the summer half of the year, Japan might receive levels of activity similar to that deposited on Iwo Jima during MIKE (10^6 d/m). During the winter, with strong winds off the continent, it is not likely that any low-level debris would reach Japan.

5.6 CENTRAL AMERICA AND NORTHERN SOUTH AMERICA

The radiological stations in Central and South America received practically no fission products from the MIKE burst; no sample prior to 15 November contained activity above a few hundred d/m. It was impossible to compute trajectories from the Hawaiian area to the Americas, but in the absence of contradictory evidence one can conclude that the upper tropospheric portion of the MIKE cloud passed north of Mexico City the first time around the world.

The high tropospheric portion of the KING cloud apparently moved much further south than did the MIKE cloud and deposited activity of about 800 d/m in Central America and 1800 d/m in northern South America. Had the MIKE cloud moved along this more southerly path, the fallout would undoubtedly have been much greater.

Trade winds are a feature of tropical America and as in the Pacific, the showers are commonly contained entirely within that current. Had the MIKE cloud followed the path described by the KING debris, rainout from the trade wind showers easily could have amounted to 10,000 d/m. During periods of weak winds when thunderclouds build up to the tropopause, it is reasonable to expect maximum activity of the order of 10^5 d/m.

5.7 SOUTHERN HEMISPHERE

Despite the fact that the Marshall Islands are very near the southern hemisphere (only 11 degrees north of the equator), the only reports of activity in excess of 300 d/m in the southern hemisphere came from stations essentially on the equator; namely Canton Island and Quito, Equador. The activity collected in the southern hemisphere is probably biased toward low values because the practical restrictions imposed on organizing a radiological network placed the gummed papers in dry areas. Stations selected on the basis of a high precipitation frequency would collect samples more representative of southern hemisphere maxima. The IVY network, however, does provide acceptable evidence that the fallout in the southern hemisphere is relatively insignificant. The interesting question of cross-equator flow is best considered in two sections - the trade wind layer and the levels above the trades.

The northern hemisphere trade winds have a component toward the south, the southern hemisphere trades a component toward the north (see figures 5.1, 5.2, and 5.3) so that low-level debris approaching the southern hemisphere from Eniwetok could not, on the average, penetrate very far into the southern hemisphere. Rising currents in the convergence zone might carry material aloft and spew it into the southern hemisphere a few degrees south latitude above the trades, but as the debris returned to earth it would enter the southeast trades and be carried northward. In addition to dilution associated with such a complex path, the depletion by rainout would be large because the mixing zone between the trade winds is likewise the zone of great rainfall. It is, therefore, difficult to conceive of the trade wind portion of any atomic cloud being a significant source of fallout in the southern hemisphere.

Radioactivity initially in the upper troposphere and the stratosphere is transported zonally, that is, to the east or west rather than north-south. There are, to be sure, appreciable north and south components, but these are the consequences of waves on a zonal current that rarely have an amplitude, insofar as is known, greater than fifteen degrees of latitude, the trajectory returning to its original latitude more frequently than not. The intensity of the north-south motions, and thereby their effectiveness in transporting debris poleward, increases with increasing latitude because of the storminess of temperate latitudes. For this reason, more debris is transported to Canada than to Australia, despite the closer proximity of the latter to the test site. High-level data and analyses for the tropics are meager, but there is evidence* that on some occasions a large amount of debris initially in the upper levels, could be carried into the southern hemisphere. This situation is not believed common, however.

*As an example, see figures 2 through 7 of High Tropospheric Westerlies of the Equatorial West Pacific Ocean, by Hubert, Jl. of Met., Vol. 6, No. 3, June 1949.

CHAPTER 6

SPECIAL STUDIES

6.1 VARIABILITY OF SIMULTANEOUS GUMMED PAPERS

The current state of knowledge on collection characteristics of gummed paper leaves much to be desired. An important problem in connection with gummed paper samples concerns the representativeness of individual collections. Data for investigation of one phase of this problem was obtained by exposing pairs and triplets of gummed papers simultaneously about six feet apart during some of the test operations.

The basic data, unfortunately, are not amenable to standard statistical tools available to test the significance of differences between simultaneous samples.* Analysis of the problem indicates that we must make additional assumptions about the average radioactivity per particle as well as the constancy of that average, or abandon the attempt to obtain absolute results and be satisfied with comparisons. Only the second alternative appears justified at this time.

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*A straight-forward approach could be based on two assumptions; a) fallout on papers exposed six feet apart is from a homogeneous cloud of radioactive particles, i.e., no gradient of particles over a distance of six feet, and b) collection efficiency of simultaneous paper is identical. As a consequence of the assumptions one would expect identical collections and the observed departures from equal collections could be examined for significance.

A serious difficulty arises, however, because the tests of significance depends upon the number of particles collected on each paper, <u>not</u> on some quantity proportional to that number. For example, suppose the average radioactivity collected on two given pairs is such that 40% of the total activity is on one paper. Were this activity caused by 10 particles per pair, a division as different from 5-5 as is 4-6 has approximately a 0.5 probability of occurring by chance. On the other hand, if the activity were due to an average of 1000 particles per pair, an average division as different from 500-500 as is 400-600 has a probability of less than 0.01 of being equalled or exceeded purely by chance.

Data from IVY gummed paper duplicate samples were compared to a selection of pairs from UPSHOT-KNOTHOLE. Data for each operation were also divided according to area; that is, duplicates for North America were compared to duplicates outside of North America for the IVY tests while the UPSHOT-KNOTHOLE data (which was available for North America only) was divided according to location west or east of the Mississippi River. Duplicate samples were used in this study only if each paper had at least 100 d/m on counting day.

The question to be answered, "Is the nature of the fallout such that the differences between duplicate gummed papers varies from one part of the world to another, or from one test series to another?"

The difference between adjacent gummed papers is described, in this study, by a "variability characteristic"* and the differences

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*The "variability characteristic" is simply the arithmetic mean of the individual Chi-squared values ($\overline{\chi^2}$) for each comparison group, i.e., χ^2 was computed for each pair of gummed papers and then averaged with the other χ^2 of its particular group, e.g., UPSHOT-KNOTHOLE, east of the Mississippi River.

$$\chi^2 = \frac{d_1^2}{M} + \frac{d_2^2}{M}$$

where M = mean of two simultaneous papers

d_1 = departure of first paper of pair from M

d_2 = departure of second paper of pair from M

(Therefore, $+d_1 = -d_2$)

thus,

$$\overline{\chi_j^2} = \frac{1}{N} \sum_{i=1}^{N} (\chi^2)_i$$

where N = total number of pairs in the "j-th" group

$(\chi^2)_i$ = value of Chi-square for the i-th pair of the j-th group

The values of $\overline{\chi^2}$ are different from group to group and the significance of their difference is examined by use of the standard t-test for significance of difference of means.

50

between these "variability characteristics" (computed for two test series as well as for different geographical areas) are subjected to a standard statistical test. Table 6.1 shows the results of that test in terms of probability. The probabilities shown reflect the likelihood that the "variability characteristics" of gummed groups were computed from a single homogeneous population, i.e., a small probability infers that the groups were NOT drawn from a homogeneous population and are, therefore, different, while a probability in the vicinity of 0.5 infers that the apparent differences could have occurred by chance.

TABLE 6.1

Probability that "Variability Characteristic" for Compared Groups Was Computed from a Single Homogeneous Population

Duplicates Compared	Probability*
IVY - United States vs. remainder of world	0.30
UPSHOT-KNOTHOLE - East of Mississippi River vs. west of Mississippi River	0.55
IVY - United States vs. UPSHOT-KNOTHOLE, United States	0.10
IVY - all data vs. UPSHOT-KNOTHOLE, United States and Canada	<0.01

Table 6.1 indicates that the tendency of adjacent gummed papers to be different from one another depends upon the test series rather than the area in which they were exposed. This conclusion is interesting because it suggests possible causes. For example, the relative levels or radioactivity in the area comparisons of IVY data was quite different from the relative levels of activity involved in the UPSHOT-KNOTHOLE data yet the "variability characteristic" remained unchanged from area to area. This suggests that the level of activity has a minor effect on this statistic. On the other hand, one obvious difference between collections of

*Probabilities are result of "t-test" for significance of difference in means (5, Table 12, p. 138).

the IVY series and the collections of the UPSHOT-KNOTHOLE series is that the IVY samples were largely of material that stabilized in the stem of the cloud while many of the samples of the domestic test contained particles from the mushroom, therefore, the different distribution of activity and particles with height may be significant in the subsequent ground deposition. The complex of unknown variables appears to make further speculation unjustified at this time. The predominant factors may eventually be determined, but must await a complete analysis of the data.

6.2 INCREASED RADIOACTIVE DEPOSITION IN RAIN

Early in the fallout monitoring program of the Atomic Energy Commission it became evident that surface deposition was enhanced by precipitation. This section summarizes some results of studies of radioactivity deposited in rain.

A study was made for the Buster-Jangle tests (11) to determine the increase of radioactivity collected on trays during periods of rain compared to collections made during no rain. The results indicated about a tenfold increase of activity in rain. No gummed paper comparisons were made. A similar comparison was made with the gummed paper samples collected at a group of stations in the United States east of the Mississippi River, during the Tumbler-Snapper series (10). A 30-day period was chosen to include days when debris from one or more tests of the series was airborne over the eastern part of the United States. An increase of a factor of 8.3 was found when the average activity of collections in rain was compared with activity in no rain (trace of rain was excluded). A similar study was made for the entire United States for the IVY tests using a 15-day period when MIKE debris was airborne over the United States (13 to 26 November 1952), and the average increase of activity in rain was by a factor of 3.4.

These results suggest that the debris from domestic tests may consist of large particles that are more efficiently scavenged by rain, while only the smaller particles are airborne by the time the debris of the Pacific tests reached the United States - the smaller increase in rain reflecting the smaller collection efficiency for the small particles. If that were true, one would expect rain in the North Pacific area to bring about an order of magnitude increase of surface deposition. Unfortunately, this figure is not available because the averages are unduly biased by a few very high collections made within a few days following the IVY tests.

Further evidence that precipitation has an important effect on surface deposition is presented in Figure 6.1. These bar graphs illustrate the frequency of low activity (low activity defined here as less than 100 d/m on counting day) as a function of rainfall amounts during the TUMBLER-SNAPPER Operation and during the IVY Operation. The same tendency is evident in all three graphs although it is not as pronounced in the North Pacific. An important conclusion which can be drawn from the graphs is that when atomic debris is present in the atmosphere, even after considerable dilution, rain usually brings about deposition on the surface and the greater the rain the more likely is the deposition. The small decrease of frequency with greater rain amounts in the Pacific is probably a reflection of the fact that a great deal of material was airborne in the Pacific during IVY and the general level of dry fallout was large.

6.3 CUMULATIVE FALLOUT

The world-wide fallout monitoring network established for Operation IVY makes it possible to estimate the total beta activity deposited on the earth by the two tests. To this end all gummed paper activities were extrapolated to 1 January 1953. The sum of these extrapolated activities at each station, which is a measure of the cumulative fallout present on 1 January 1953, was used in a numerical integration of fallout for the entire surface of the earth.

Figure 6.2 shows the cumulative fallout at each station for the entire period of record and an analysis of the distribution, based on radiological and meteorological considerations. Total activity, in units of disintegrations per minute per square foot, was computed separately for the North Pacific (shaded area) and the balance of the world. A similar computation was made for the fallout assumed to be from the MIKE test only so that the analysis provided totals for MIKE and KING separately. Figure 6.2 shows the total fallout for the entire period of record at each station and the amount contributed by the KING shot.

Adjustments and additions to the basic data were necessary for this analysis. First, the collections assigned to KING on the fallout maps (see Appendix A, Figures A.33 through A.73) as well as other samples of doubtful origin but thought to be due to KING, were extrapolated to 1 January on the basis of 15 November 1952 burst date. Second, many station records were imcomplete so their totals had to be adjusted upward. Where the station record included radioactive samples before and after the missing period, the missing activity was estimated by linear interpolation.

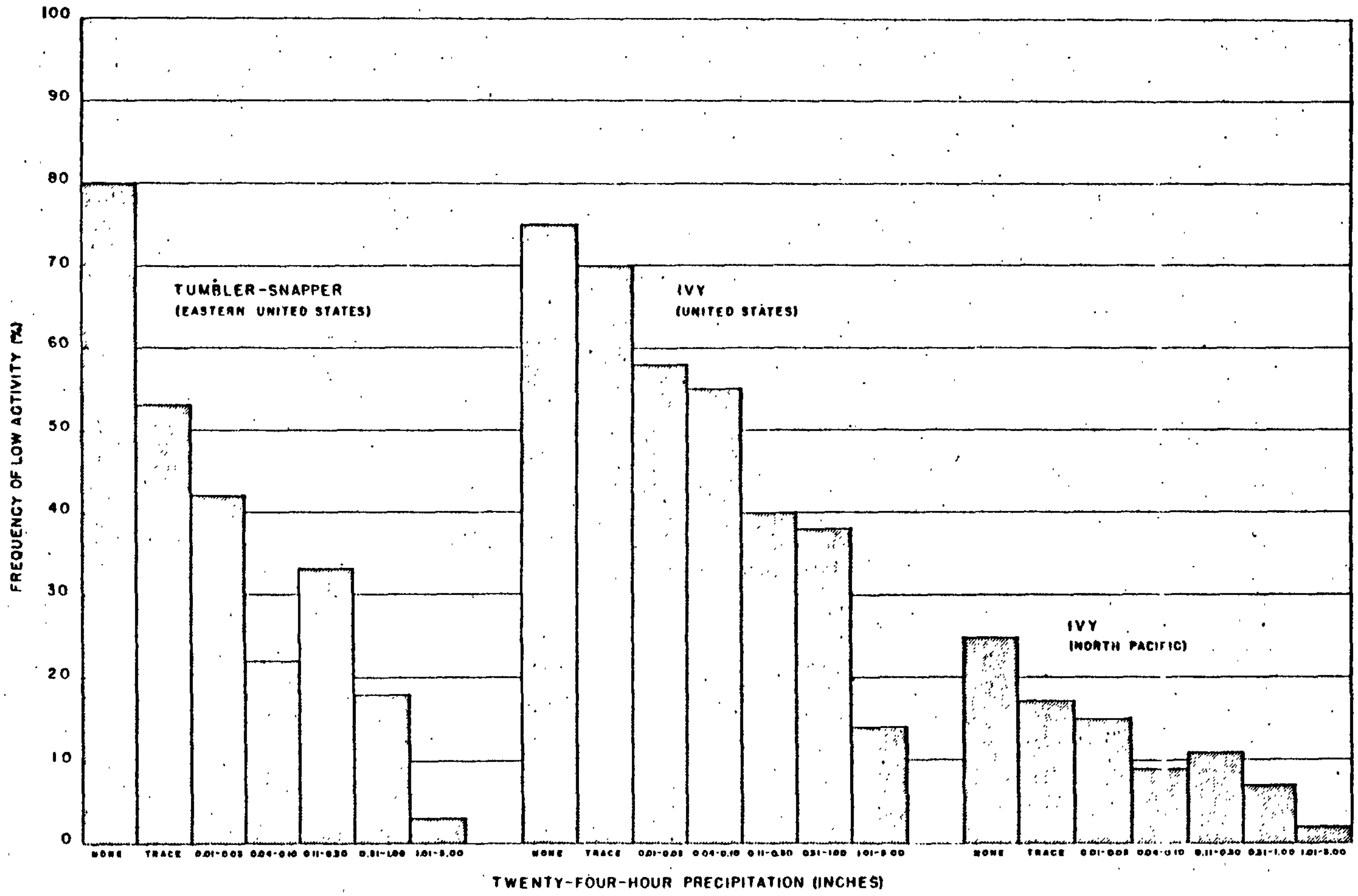

Figure 6.1 Frequency of low activity (less than 100 d/m counting day) versus precipitation amounts

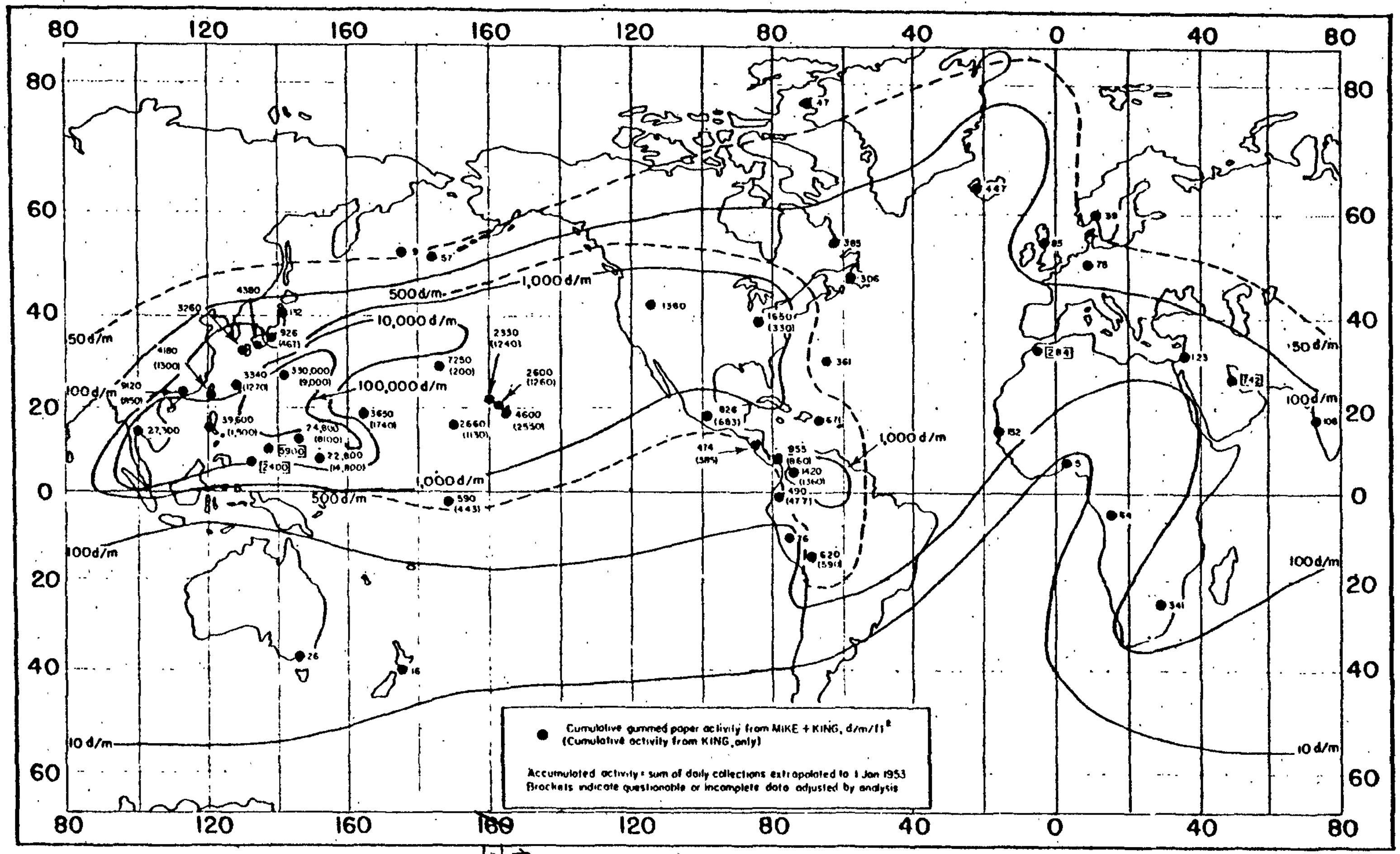

Figure 6.2 Total Beta activity deposited by IVY debris as of 1 Jan 1953

Where the station record started too late to detect the first arrival of material or ended too early to collect debris when debris was in the neighborhood, the station total is enclosed in brackets. Data thought to be questionable on other grounds is also bracketed and all such numbers are essentially ignored in the final analysis. United States and Canadian data are represented by two values plotted in Figure 6.2 in the western and the eastern United States. These numbers represent the average total for the two groups of stations. Table 6.2 shows the results of this analysis.

6.4 CLIMATOLOGY OF THE STRATOSPHERE

The special efforts expended in making extra meteorological observations during the various Pacific atomic tests have produced valuable and unusual data - especially at great elevations. A brief resumé of this information follows along with reference to the analysis of that data. While it is dangerous to assume that meteorological data of one location can be considered representative of any other location, this section is based on the only direct observations ever made in the equatorial stratosphere and as such is the best climatological data available for planning purposes. For example, it may be of interest to have some knowledge of the probable path of the middle stratospheric debris if high level sampling is contemplated.

The data above 55,000 feet obtained during Operation SANDSTONE and GREENHOUSE have been collected and analyzed by the group under Dr. C. E. Palmer. The results have not been published, but preliminary results are the subject of two reports (1) to the sponsoring agency.

Dependable wind observations were made in the Marshall Islands in the spring of 1951 and the fall of 1952 and the Navy made a total of 19 observations at Palmyra during April and May 1951. A scattering of data from other stations is also available. The sample is small and confined to short periods of time, but certain general conclusions appear justified and are quoted here from the reports just mentioned.

a. In spring, a band of very steady west winds lies on the equator from about 60,000 feet to 85,000 feet. The northern limit in the central Pacific is about 9°N, but there is no data to fix the southern limit. The steadiness compares to the low-level trade winds.

b. Long-wave disturbances probably affect the equatorial westerlies much in the manner of the waves in the high latitude free air westerlies.

c. Above and below the stream of steady westerlies the winds are about as variable as the winds of the high troposphere.

d. The general stratospheric pattern of winter westerlies reversing to summer easterlies observed in the mid-latitudes appears to extend down to about 10°N. with a narrow zone of transition to the steady equatorial westerlies, at least up to the end of July.

If the tentative conclusions quoted above are valid, one would expect a stratospheric cloud of debris to move almost due east in the colder half of the year. During the warmer half of the year the motion would still be zonal (more east or west than north or south) but would have almost equal probability of moving toward the east or the west.

6.5 ESTIMATED FALLOUT ALONG CORE OF THE MIKE TRADE WIND CLOUD

The greatest radioactivity on a gummed paper reported during Operation IVY was collected at Iwo Jima on 5 November 1952 during a period of no precipitation. It appears that the core of the MIKE trade wind cloud passed near Iwo Jima during the period this paper was exposed, thereby depositing the maximum fallout likely without rain. This fortuitous situation was used in connection with pertinent meteorological theory to estimate the activity expected to be collected along the core of this cloud, in the absence of precipitation.

The estimates are based on the postulate that the activity measured at Iwo Jima is absolutely correct and was actually collected during a period of no precipitation. In addition, it is assumed that the decrease of activity collected under the core of the cloud (with increasing time) is essentially the effect of turbulent diffusion and radioactive decay. The form of the Fickian diffusion law indicated that the peak concentration in a diffusing cloud initially decreases at a rate inversely proportion to the 1.5

power of time and meteorological arguments suggest this exponent soon increases to 2.0 to 2.5 because the rate of eddy diffusion increases with time. The radioactive decay is assumed to be proportional to the 1.2 power of time. Table 6.3 is computed under the assumption that the over-all change is proportional to $t^{-3.5}$ and shows the radioactivity expected to be collected under the core of the cloud, as a function of time. It should be borne in mind that the activity would be significantly higher in rain - perhaps a factor of ten or even 100.

TABLE 6.3

Estimated Maximum Dry Fallout Expected to be Collected
Under MIKE Trade Wind Cloud

Collection Period Days After Burst Start	End	Maximum β Radioactivity Expected Without Rain d/m/ft²/day	Range Estimated to Include Approximately 50% Likelihood of Occurrence d/m/ft²/day
1	2	4×10^8	10^8 to 10^9
2	3	6×10^7	2×10^7 to 10^8
3	4	2×10^7	10^7 to 4×10^7
4	5	7×10^6	$5 \times 10^6 \times 10^7$
5	6	4×10^6	No range - an absolute value by assumption.
11	12	3×10^5	10^4 to 10^6

The last item of the table is shown for comparison with the greatest radioactivity measured when this portion of the cloud entered the United States, name 10^4 d/m collected 11 to 12 November at Boise, Idaho.

It should be noted that the computation has not been extended to the first day after burst because it is probably invalidated by the fallout of large particles.

6.6 ASSISTANCE TO METEOROLOGY

In view of the paucity of weather data and the lack of an adequate knowledge of tropical meteorology and turbulent diffusion, it might be expected that the use of atomic debris as a tracer would shed considerable light on those problems. Specifically, it seems that the analysis of dispersion of atomic debris could be used a) to check atmospheric motion by a verification of computed trajectories, b) derive information relative to the collection efficiency (scavenging) of natural precipitation and c) evaluate turbulent diffusion on both a small and large scale. Since the MIKE cloud penetrated so far into the stratosphere there seemed to be hope of obtaining data on the diffusive exchange of matter between the stratosphere and troposphere.

Anticipation of important meteorological gains from this data, unfortunately, has been largely unfulfilled, because of the appalling number of uncontrolled and unmeasurable variables. Consider first the check on winds by studying the accuracy of computed trajectories. There were some cases in which the debris appeared to move more rapidly than estimated by computations based on wind observations, both during Pacific and during continental tests. Aside from errors introduced by uncertainties in the wind field, inaccuracies will occur for two reasons. First, meteorologically computed trajectories estimate the mean motion of the cloud, omitting any forward diffusion. Second, and more important, the first material to arrive at a point is often the result of complicated, unpredictable three-dimensional motion. The computed trajectories, in other words, do not always portray the most rapidly-moving segment of the cloud and the meteorologist faced with the accomplished fact of unexpectedly fast transport can seldom deduce the three-dimensional path for there are often numerous equally-probable solutions. There have also been cases studied where the computed trajectories overestimated the actual speed of debris, but this appears to be explained by the development of an undetected disturbance which moved the debris in an unexpected direction. In summary, then, there have been many cases of observed fallout which indicate that the computed trajectories were in error, but it has not yet been possible to improve the meteorological techniques through this experience.

The IVY data again demonstrated the fact that a greater quantity of debris is deposited on days of rain than on days with no rain. The increase in rain in the United States during the IVY tests, however, was not as great as was the increase noted during continental tests. It is believed that the difference results from the fact that only smaller and less readily scavenged particles remain airborne by the time the IVY clouds arrived in the United States. Since there is no data available to verify this hypothesis, however, it must be regarded as only speculation.

There has been no attempt to employ the spread of debris as observed at the surface of the earth to estimate the coefficients of eddy diffusion. The reasons are several. Most important is the fact that the presence or absence of debris at the ground has little quantitative relation to the amount of radioactive debris that is airborne. This is due to the fact that the surface deposition is largely a function of the precipitation and without precipitation a cloud might pass overhead undetected. Furthermore, the spread of debris is also a function of the wind shear and unless there is rather detailed wind data, it is difficult to separate the growth due to shear and that due to diffusion. It would be of great interest to determine the rate of turbulent exchange between the stratosphere and troposphere, but the effect of precipitation in addition to the fact that the initial vertical distribution of debris is unknown precludes solution of the problem with the present data. Of equal interest would be the computation of the gross diffusion between the northern and southern hemispheres, but adequate data is not available. While it is possible to estimate the fraction of the total debris in the southern hemisphere, this information is still insufficient to determine the coefficient of eddy diffusion across the equator.

It must be concluded that at present, the meteorological use of radioactive tracers from the Pacific tests has not yet appreciably improved the understanding of weather processes.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY OF RADIOLOGICAL ANALYSIS

The radiological data provided by Operation IVY reveals the following information:

a. The direction and speed of transport of the IVY atomic clouds appears to be reasonably typical of conditions during November.

b. The greatest radioactivity measured on a single gummed paper from the monitoring network was 3.6×10^6 d/m at Iwo Jima five to six days after the MIKE burst. The highest deposition in the Hawaiian Islands was about 6×10^3 d/m and the highest deposition in the United States and Canada was 1×10^4 d/m. While there have been higher values of radioactivity than 3.6×10^6 d/m reported from continental tests they have always occurred within two days after the explosion.

c. There appears to be little correlation between the fallout collected on gummed paper and the air concentration measured by the air filters. The latter measurements do not lend themselves to a satisfactory meteorological analysis.

7.2 SUMMARY OF POTENTIAL MAXIMA FALLOUT ESTIMATES

Different but reasonable conditions may well bring about greater surface radioactivity than was observed during this operation. The following estimates of potential radioactivity are based on possible meteorological conditions and on the assumption that the amount of radioactive debris available for surface deposition is directly proportional to the yield.

a. Fallout without precipitation near the core of the trade wind portion of the cloud after one day may be of the order of 1 x 10^8 d/m and perhaps 1 x 10^9 in rain. The period of deposition in each case is 24 hours.

b. Under very special weather conditions in the Hawaiian Islands, the rainout might be of the order of 1 x 10^9 d/m or a dose of 10 roentgens, integrated over thirteen weeks. This is based on the maximum rainout activity at Albany-Troy during Upshot-Knothole and a scaling factor (to 4 megatons).

c. Based on the rainout over Washington, D. C. and Rochester, N. Y., during GREENHOUSE DOG test and the appropriate scaling factor it is estimated the highest activity in rain expected for the United States from a test the size of MIKE is of the order of 10^6 d/m.

d. Radioactivity from fallout or rainout for almost any populated area of the earth, outside of the North Pacific, appears to be negligible. Eastern and southeastern Asia appears to be the only area in which the peak surface deposition for one day might be greater than 10^6 d/m.

7.3 SUMMARY OF METEOROLOGICAL ANALYSIS

Meteorological data and analysis were employed to explain the world-wide distribution of atomic debris. The limited success of this attempt leads to the following conclusions.

a. The radiological data, if correct, has indicated a few cases in which the meteorological estimates of speed were too low, due partly to complicated three-dimensional motion that cannot be deduced from the available data.

b. It is not possible to use meteorology at present adequately to track the atomic clouds from Pacific tests more than a few days or at elevations above about 40,000 feet.

c. There appears to be no way of determining whether any of the stratospheric debris has been transported to the ground. Such data would yield important information concerning the exchange of matter between the stratosphere and the troposphere.

d. No estimates of diffusion coefficients are yet possible. The analysis has shown the approximate fraction of material that was transported into the southern hemisphere, but this data is not sufficient to compute any exchange coefficients.

7.4 RECOMMENDATIONS

The difficulties encountered in the analysis discussed in this report have pointed up shortcomings that existed in some aspects of Operation IVY. The recommendations listed below are put forward in an effort to increase the usefulness of the monitoring program, and to enhance the phenomenology of the whole problem.

a. A larger number of close-in gummed paper stations than was used during IVY is necessary to locate the peak values of fallout and rainout a few days after the explosion. The use of ships should be explored.

b. A series of special observations is suggested for future tests. The experiments should be conducted in the Pacific area west of the test site to study the phenomenon of rainout in tropical showers.

c. The preliminary study of this report indicates that the potential maximum rainout in the Hawaiian Islands is significant. A more complete analysis should investigate the probability of this occurrence and the possibility of forecasting it.

d. Greater effort should be made to determine the height and dimensions of the atomic clouds from megaton weapons so that the vertical extent be known.

e. A sampling of the stratosphere be attempted, possibly by balloons, to determine the present stratospheric content of debris, as well as the content after future tests.

f. A system be devised which will minimize the number of errors that appear in the final data. Perhaps a long "shake down" period previous to scheduled tests would show up the most frequent type of error that occurs in the field and enable improvement of performance before the tests begin.

APPENDIX A

RADIOLOGICAL DATA MAPS

A.1 EXPLANATION OF PLOTTED DATA

Figures A.1 through A.74 show the data from the world-wide sampling network, plotted in accordance with the key shown on each map. Because of the greater density of reporting stations in the United States, that data is shown on separate larger scale maps.

In addition to the data from the fixed station, the maps also include the results of non-routine observations made at selected locations for a few days following each burst. Such observations are indicated as "Special Data" on the northern hemisphere maps. Ordinarily, these observations consist of a series of shorter period collections rather than the 24-hour samples taken by the routine network. Since the exact times of observation are unavailable, these data are listed in an arbitrary order on the appropriate day.

All activity has been extrapolated to collection date on the basis of the MIKE burst unless otherwise indicated. Where it was clearly evident that debris from the KING burst was present at a station on a given day, the activity for that day and all succeeding days was extrapolated on the basis of the second burst and indicated by "K".

On the United States maps, areas in which at least one gummed paper at a station had activity of 500 d/m or more are delineated by a solid line to show the movement of individual patches of debris across the country.

The data has been closely inspected for inconsistencies. Questionable data, which would be misleading if accepted as correct, have been enclosed in parentheses. In some cases, the data is doubtful because they require unreasonable (and in some cases impossible) wind speeds, others are questioned because they are isolated in time and space. A certain number of questionable data are not so indicated, however. For example, some stations show more than two gummed paper samples on one map, but none on the day before or after, no doubt the result of misdating the data card in the field. Obviously, a portion of the data is not correctly plotted, but the inconsistency is obvious without being so marked. In addition, many values of the order of 100 d/m remain without parentheses even though it was felt there was no significant cloud of debris in the vicinity. These items have remained unquestioned because they are actually of low activity (say 20 to 50 d/m on counting day) and have not been used in the analysis. Lastly, no attempt was made to evaluate the air filter data because the poor correlation between gummed papers and air filters provides little basis for judgement, therefore, no air filter data is questioned.

BIOLOGICAL DATA MAPS

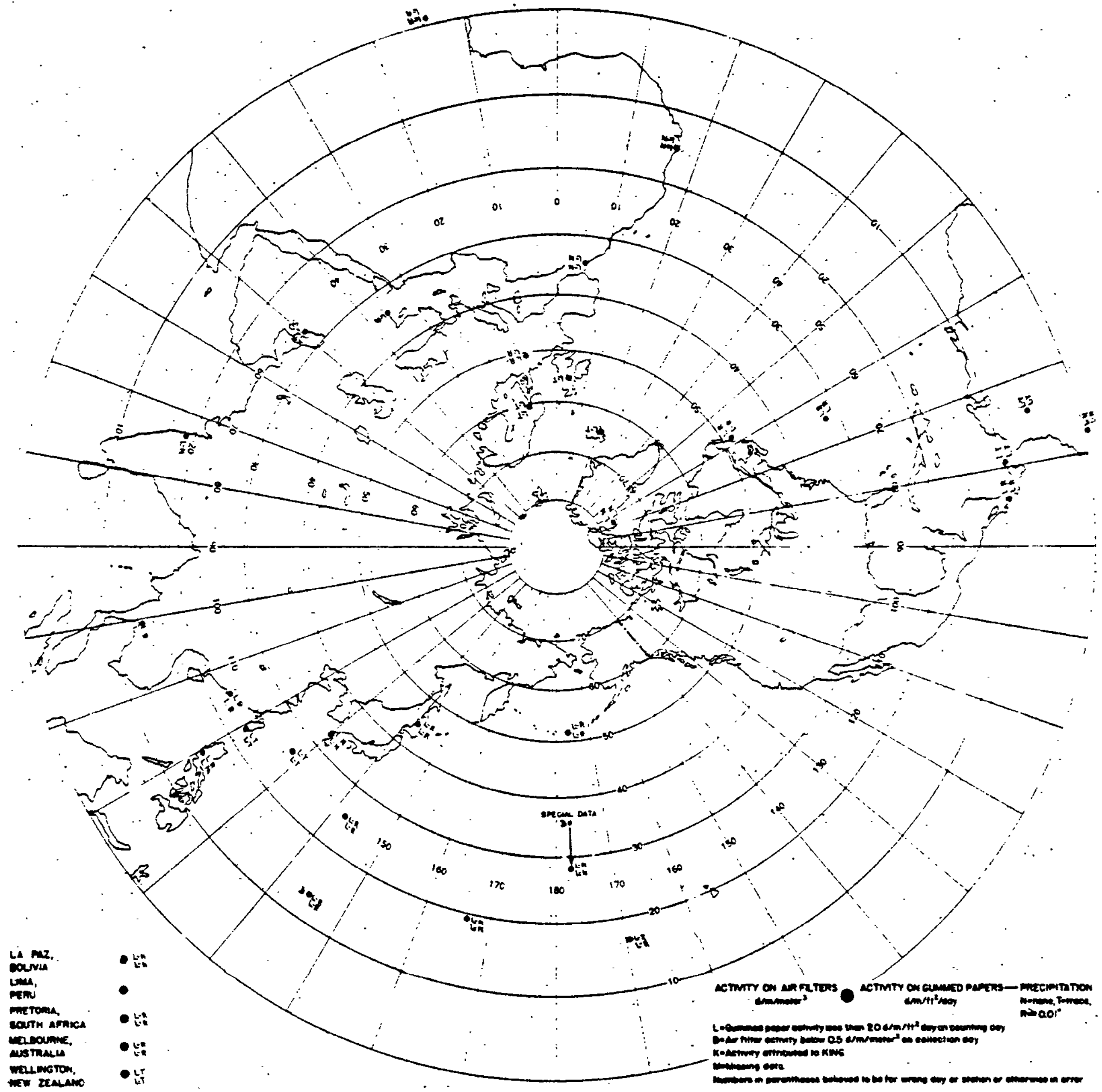

Figure A.1 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 1 Nov. 1952

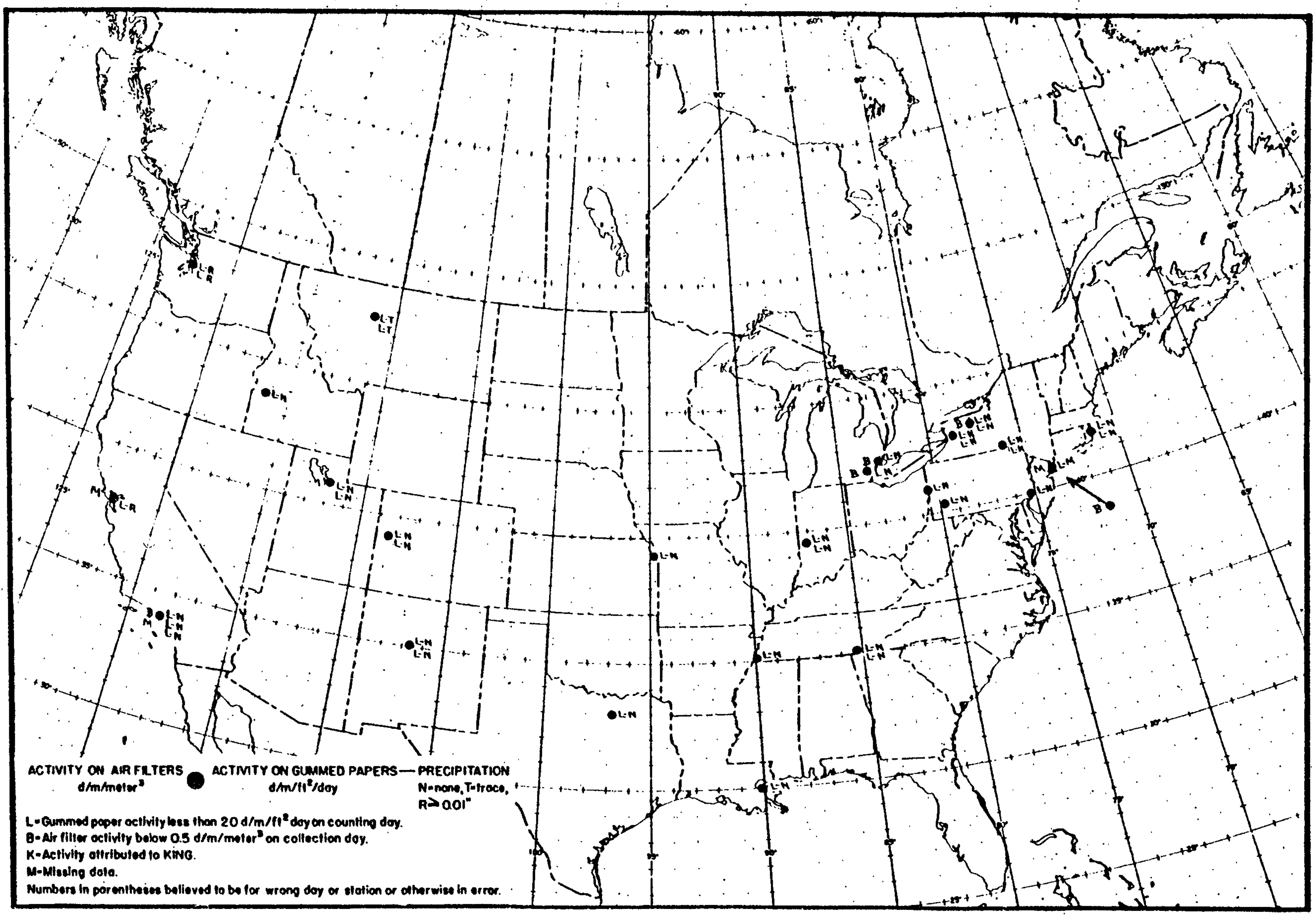

Figure A.2 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 1 Nov. 1952

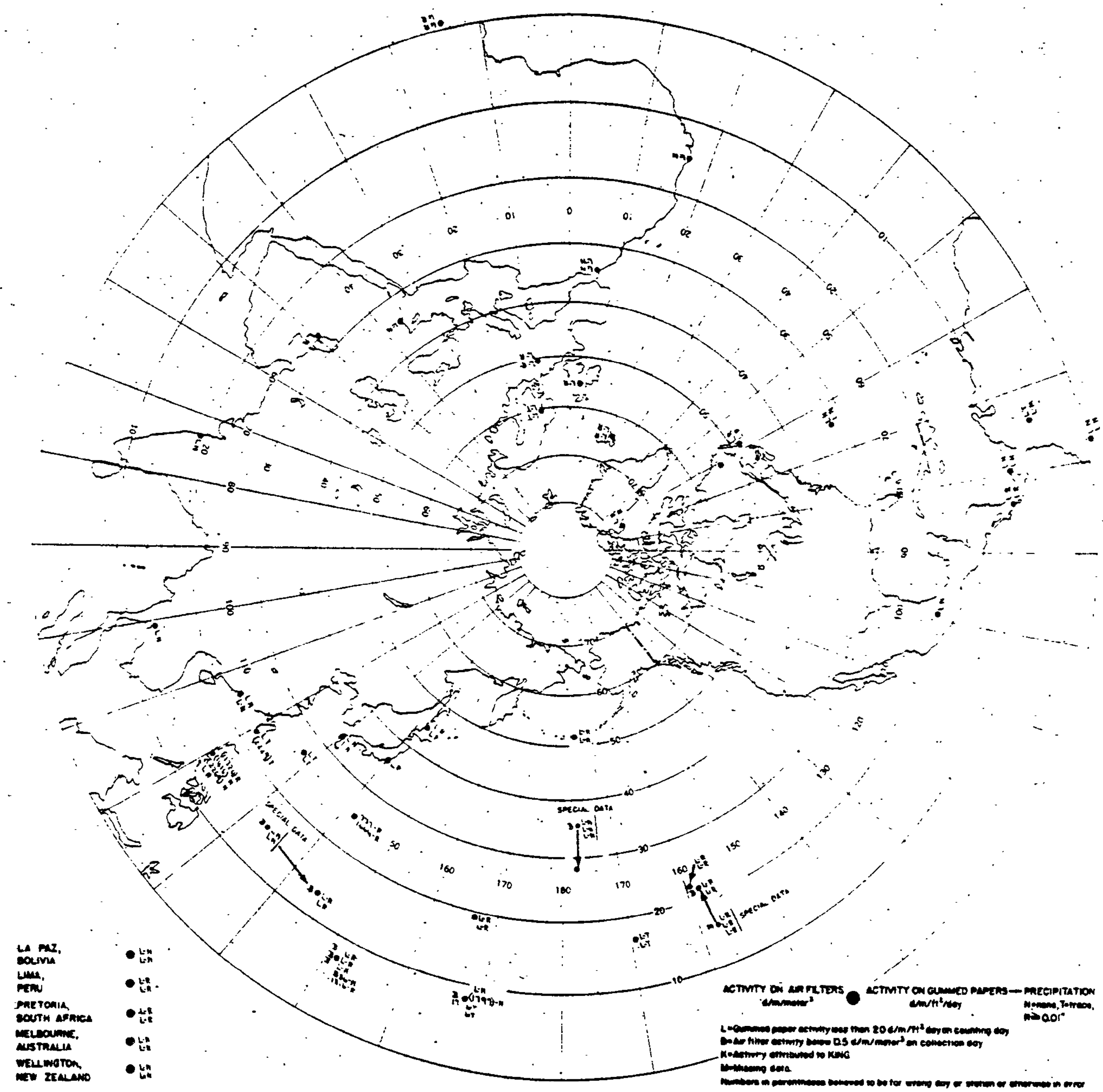

Figure A.3 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 2 Nov. 1952

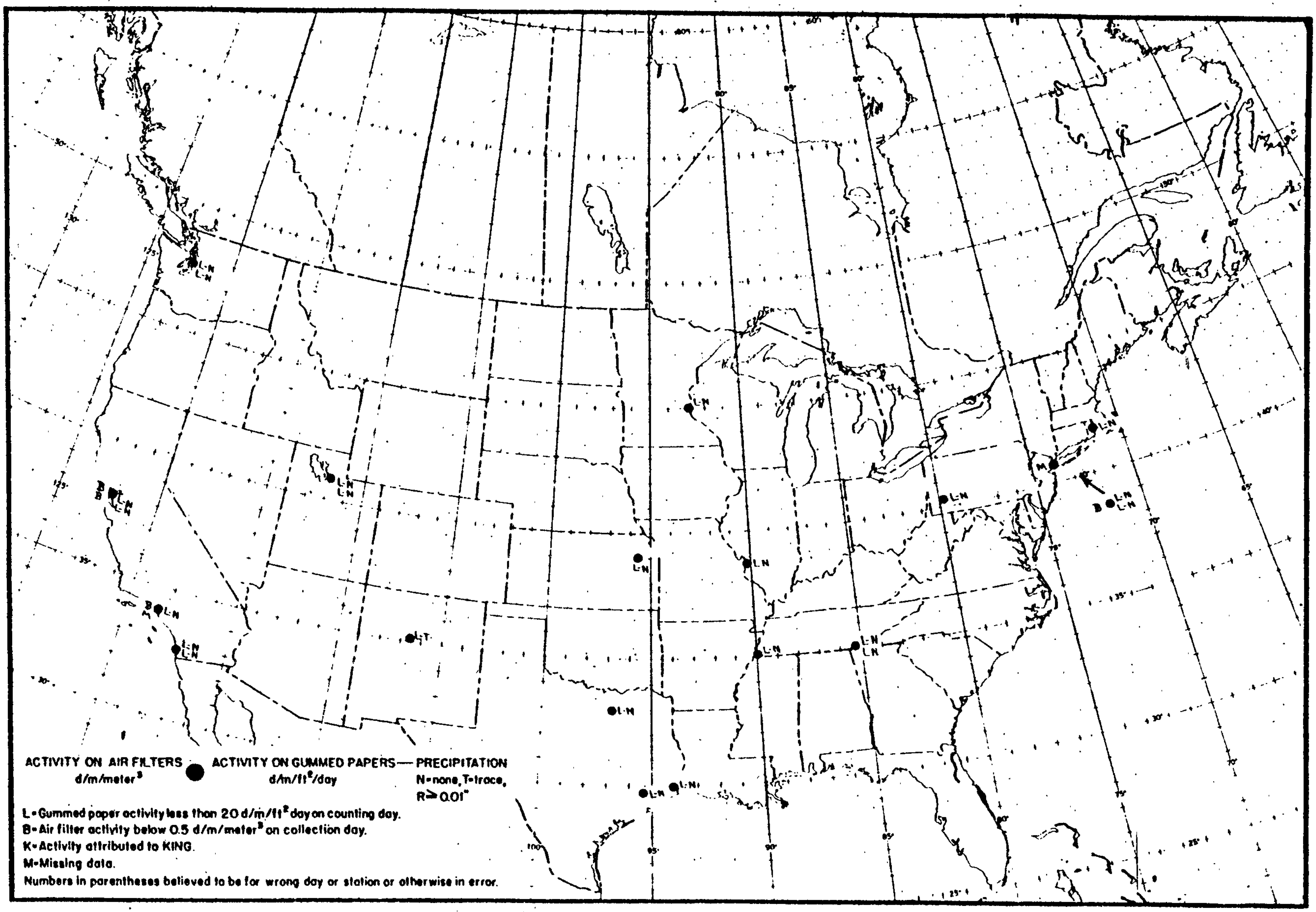

Figure A.4 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 2 Nov. 1952

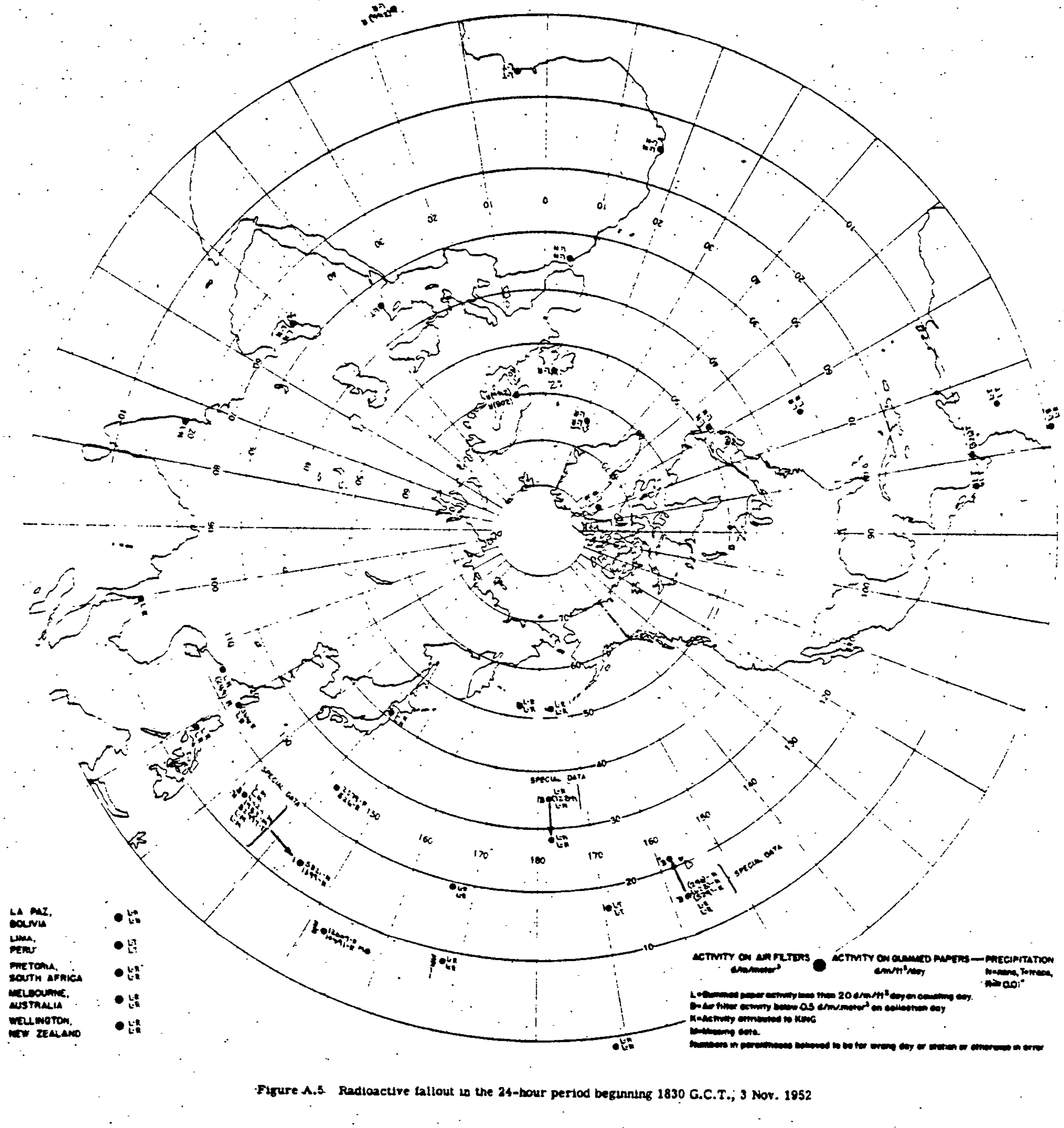

Figure A.5 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 3 Nov. 1952

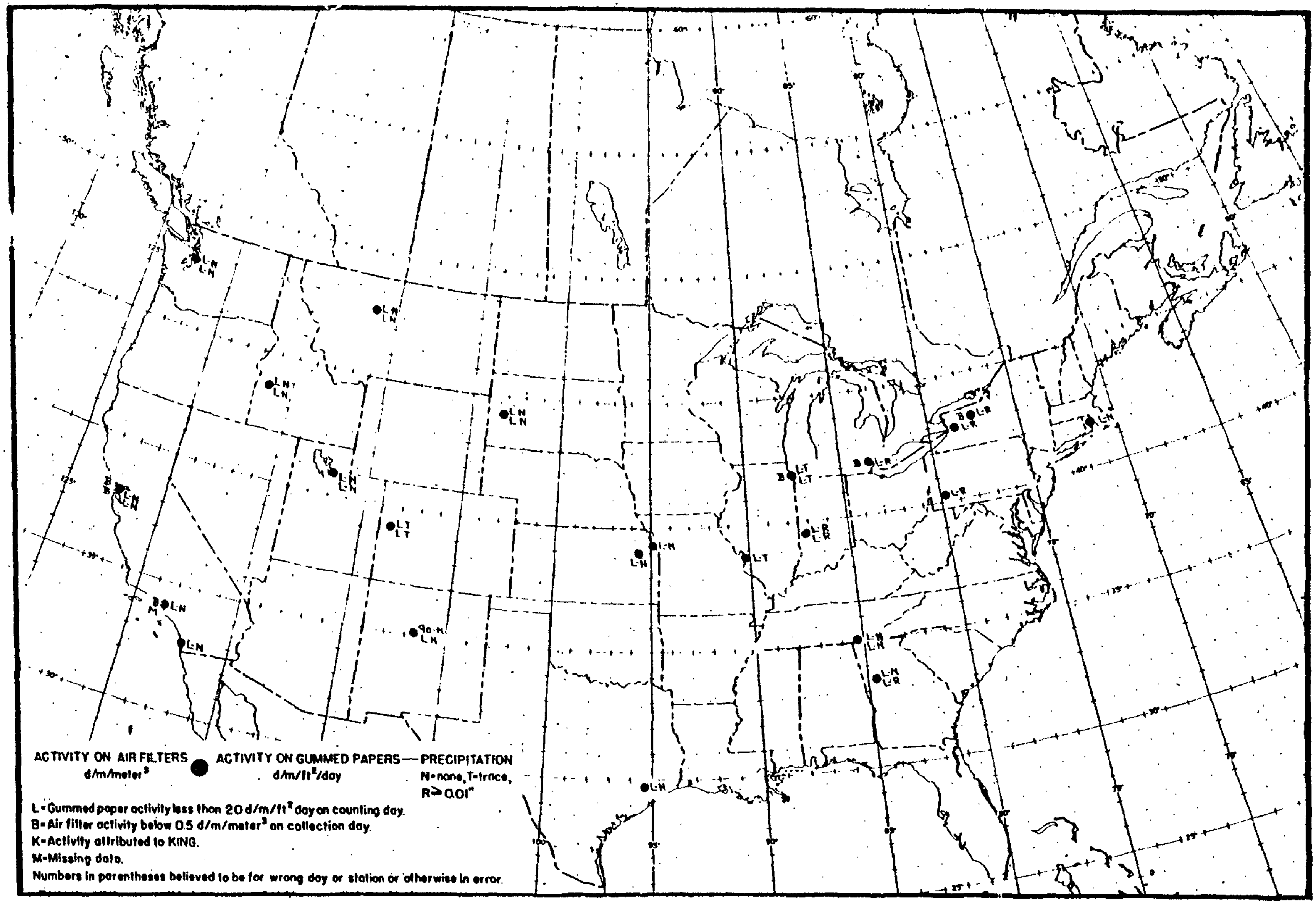

Figure A.6 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 3 Nov. 1952

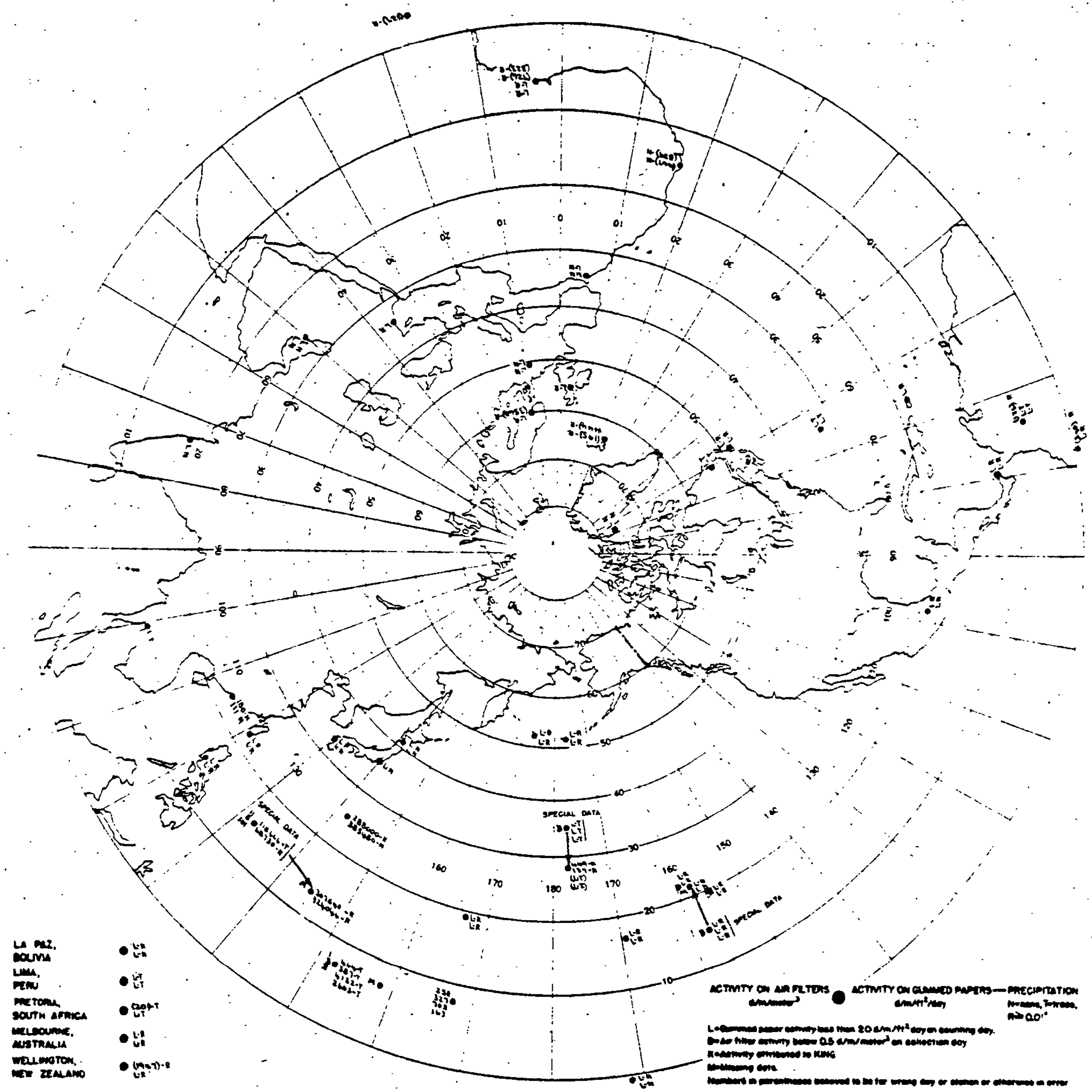

Figure A.7 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 4 Nov. 1952

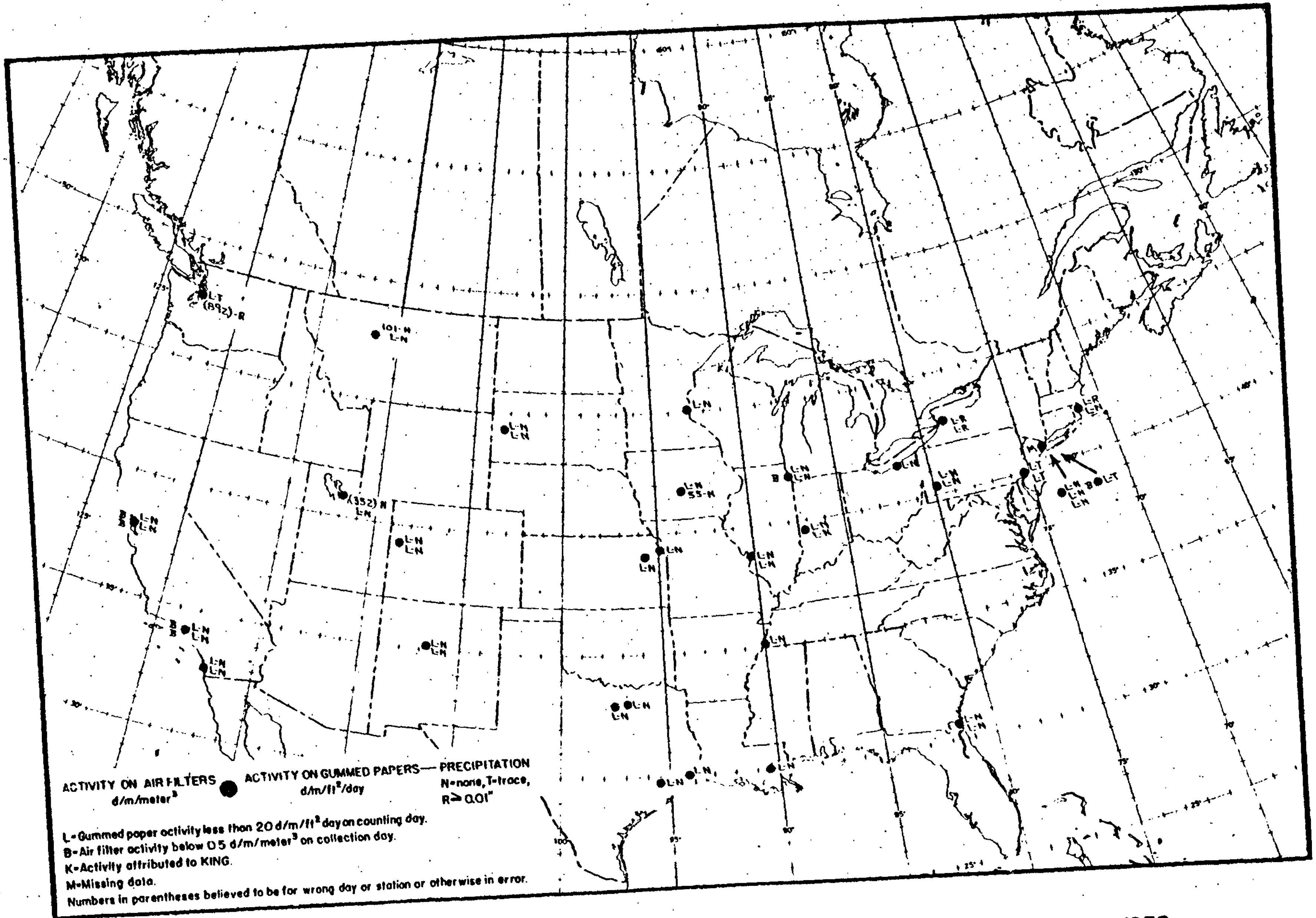

Figure A.8 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 4 Nov. 1952

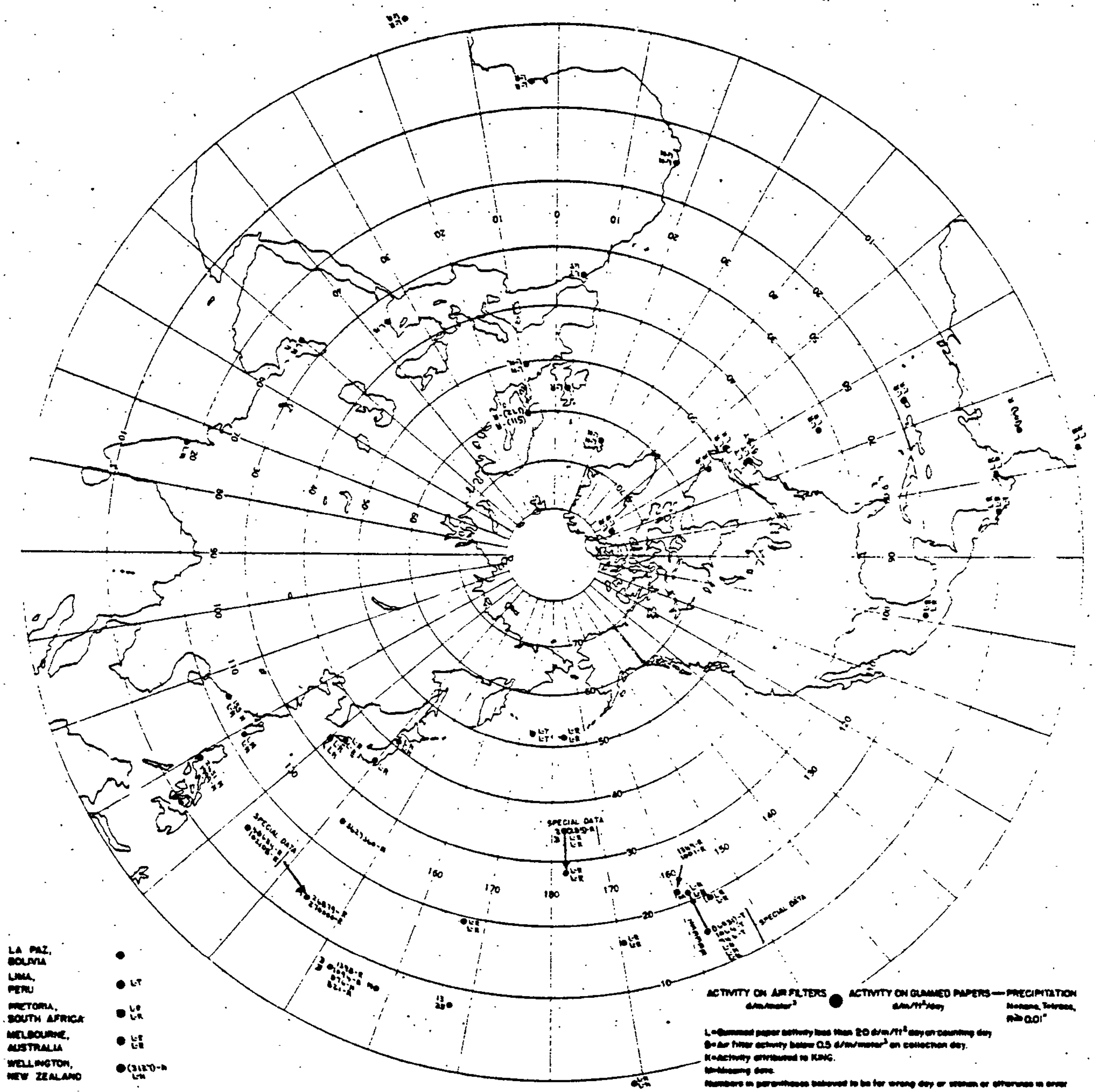

Figure A.9 · Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 5 Nov. 1952

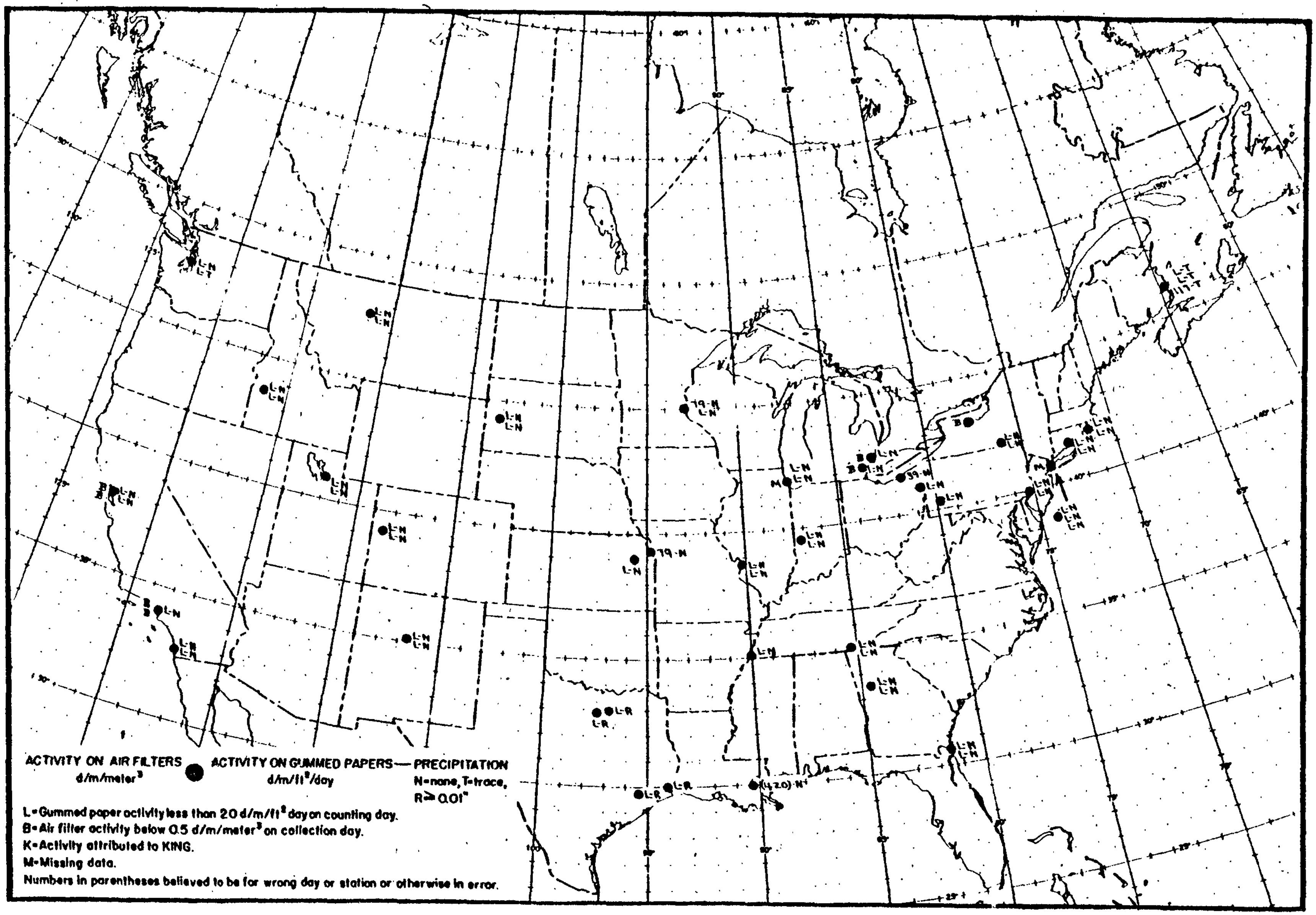

Figure A.10 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 5 Nov. 1952

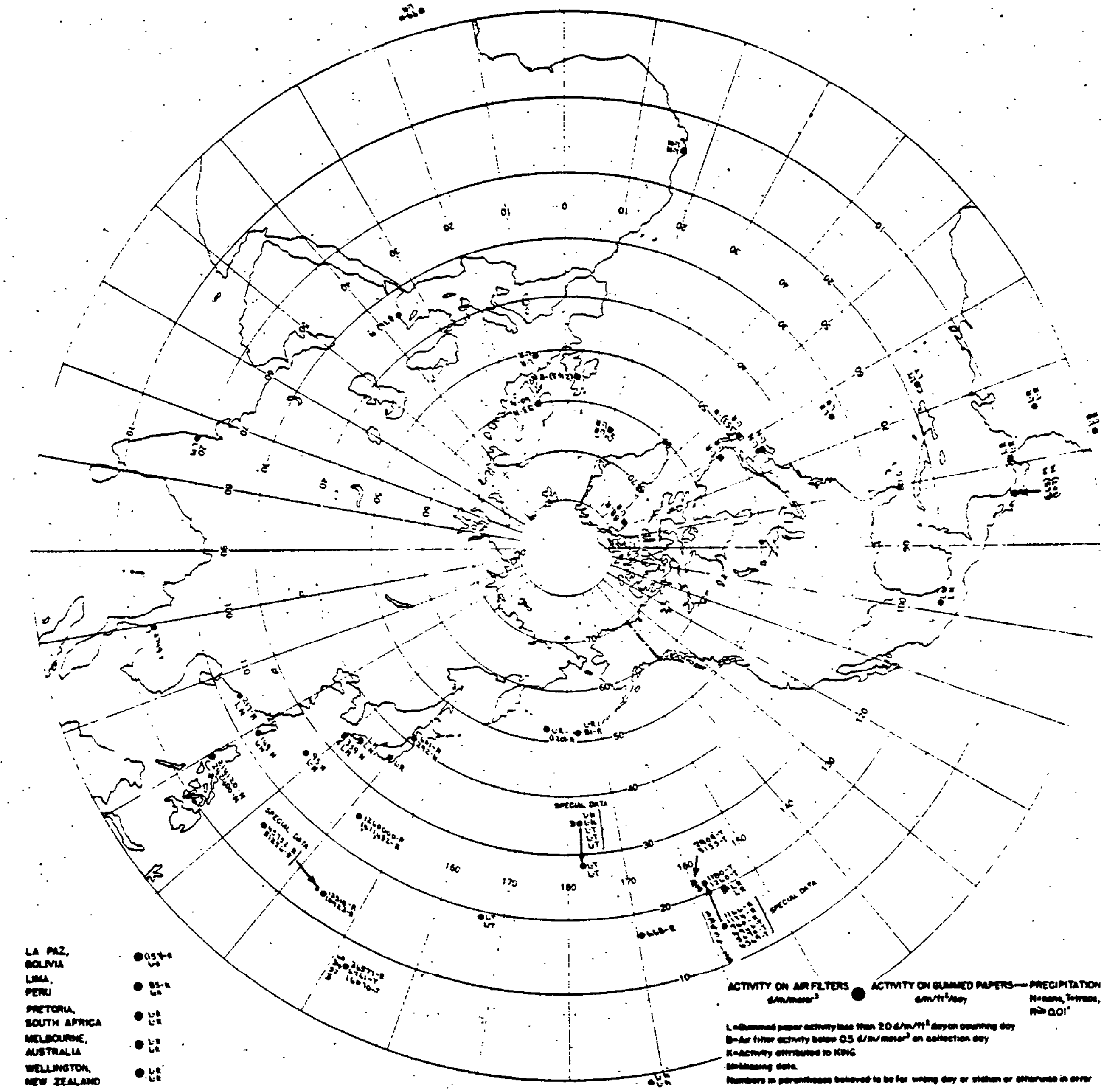

Figure A.11 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 6 Nov. 1952

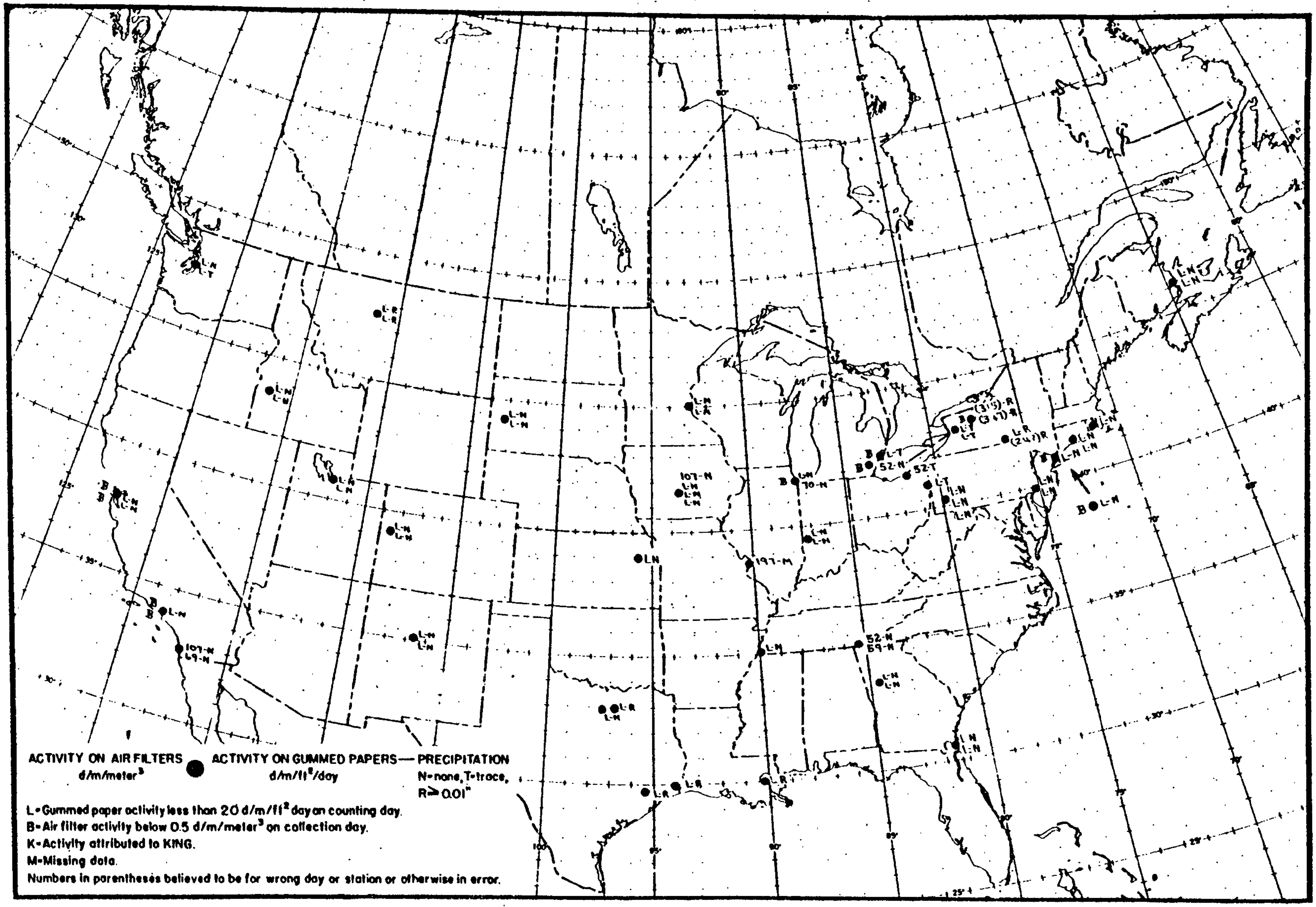

Figure A.12 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 6 Nov. 1952

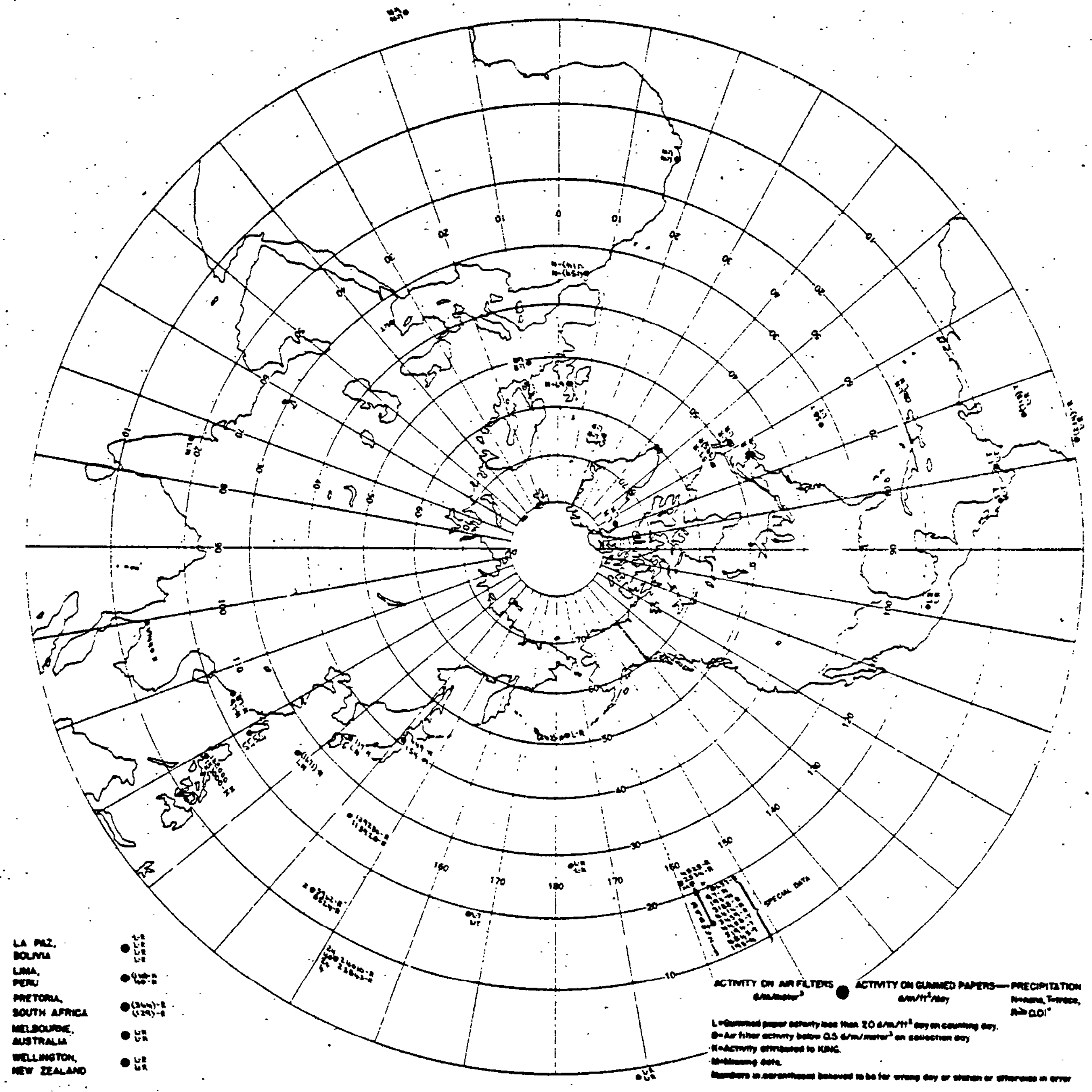

Figure A.13 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 7 Nov. 1952

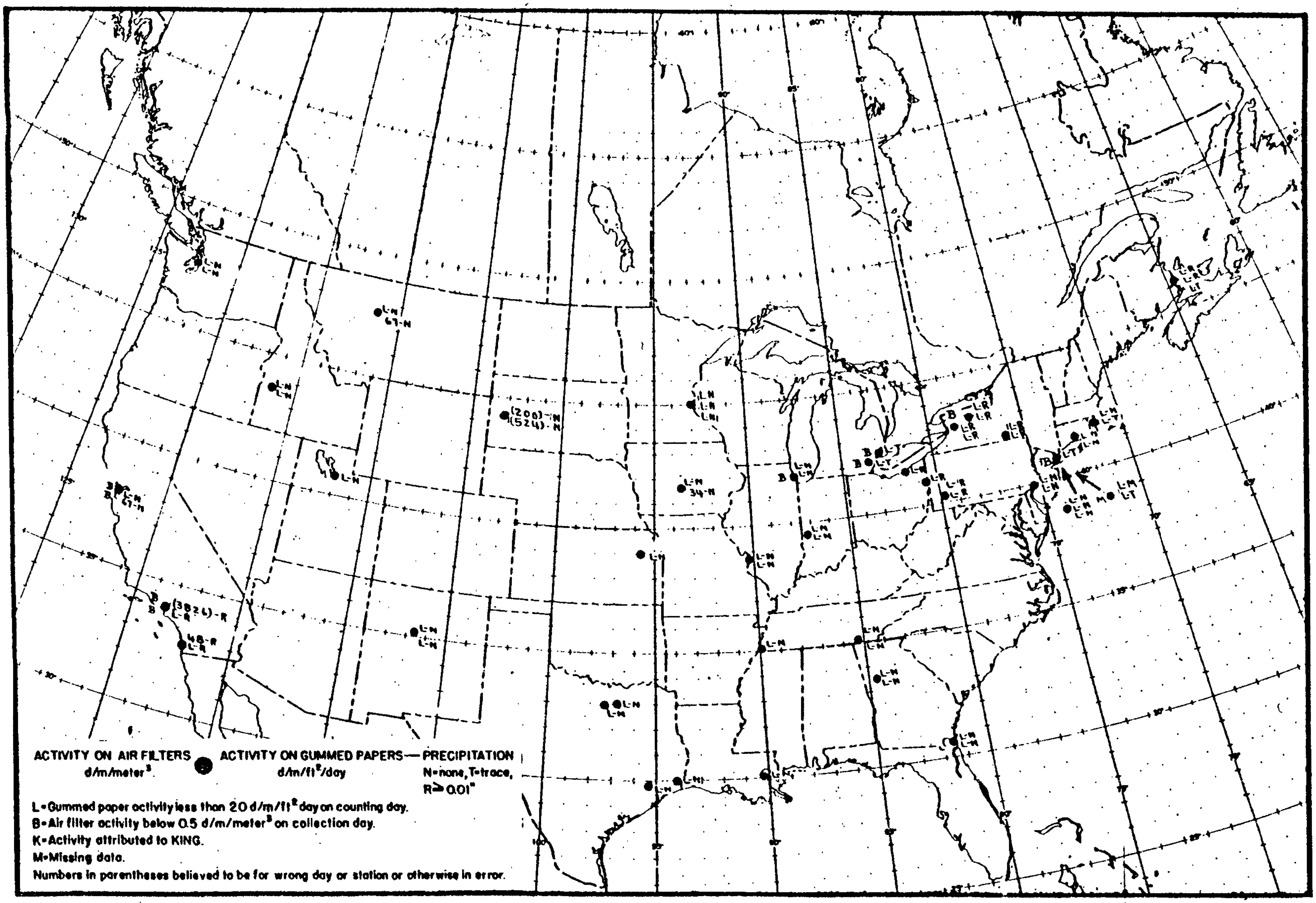

Figure A.14 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 7 Nov. 1952

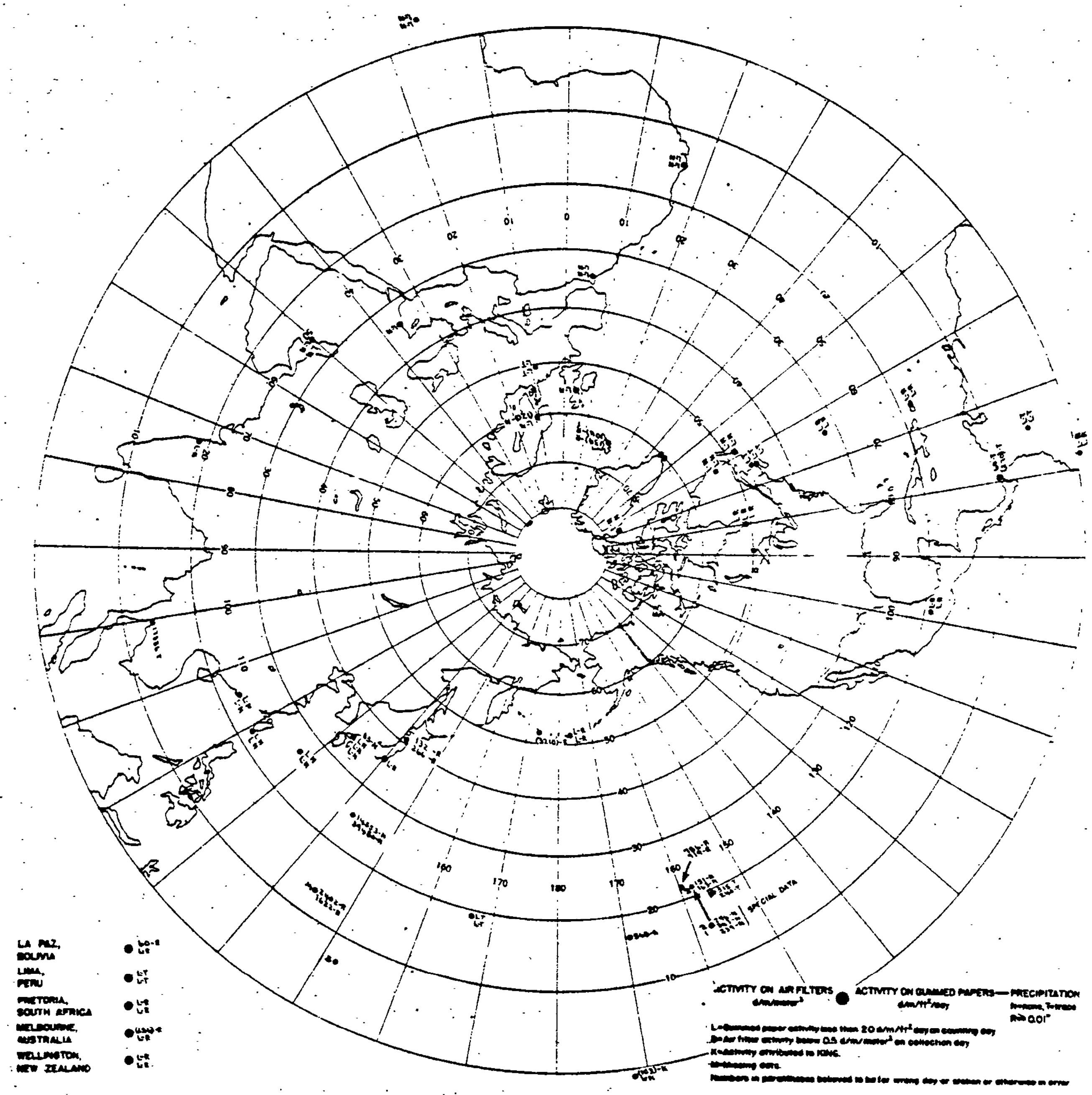

Figure A.15 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 8 Nov. 1952

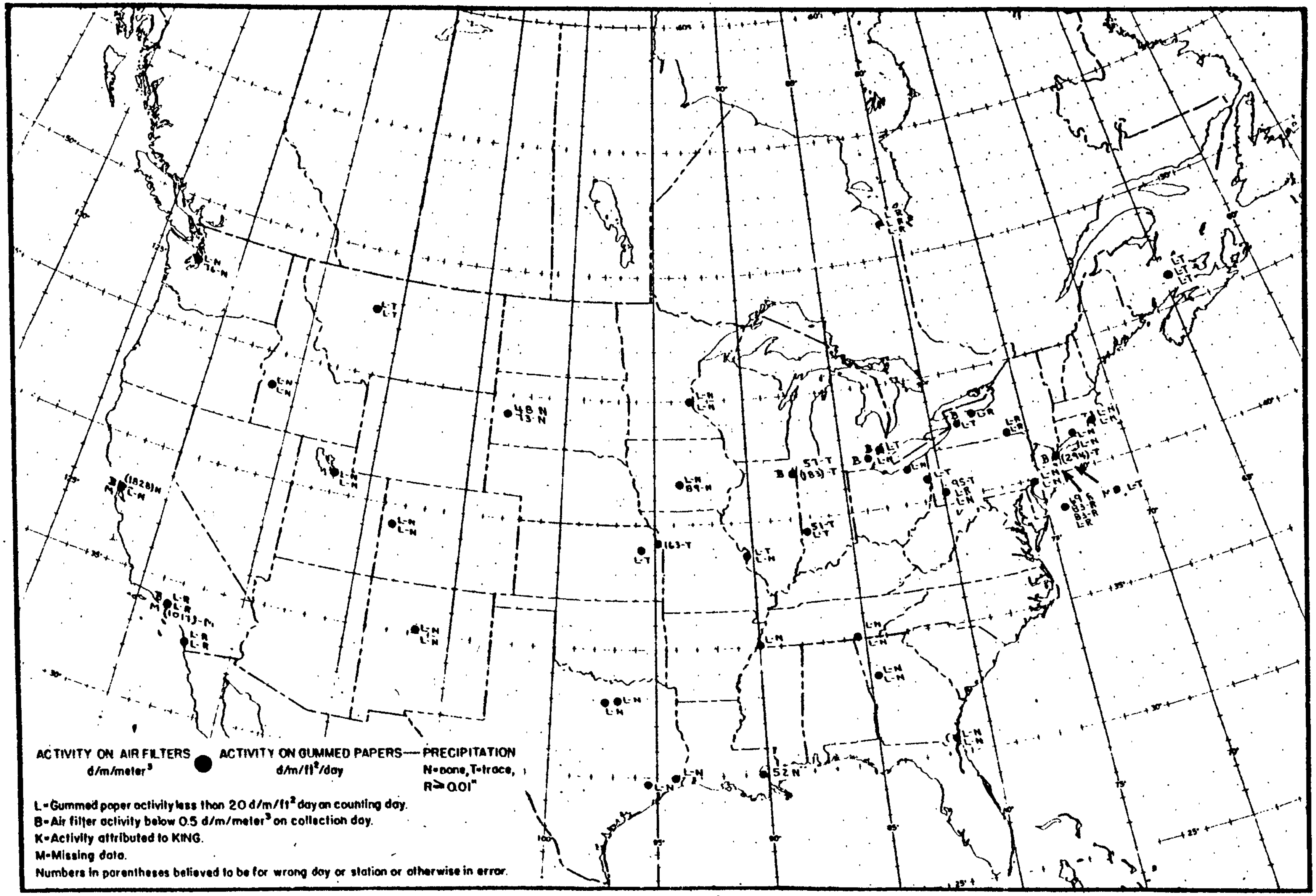

Figure A.16 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 8 Nov. 1952

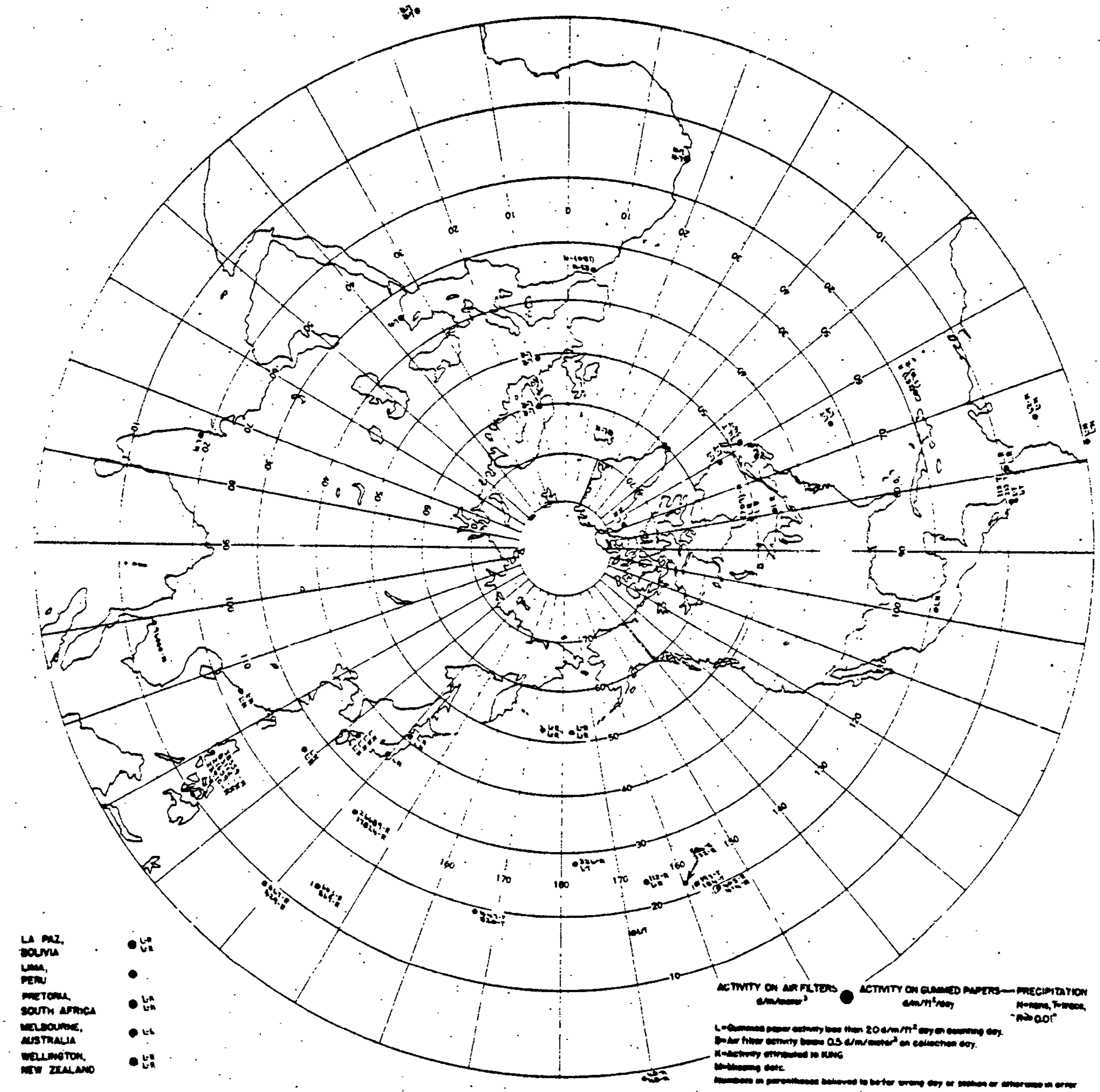

Figure A.17 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 9 Nov. 1952

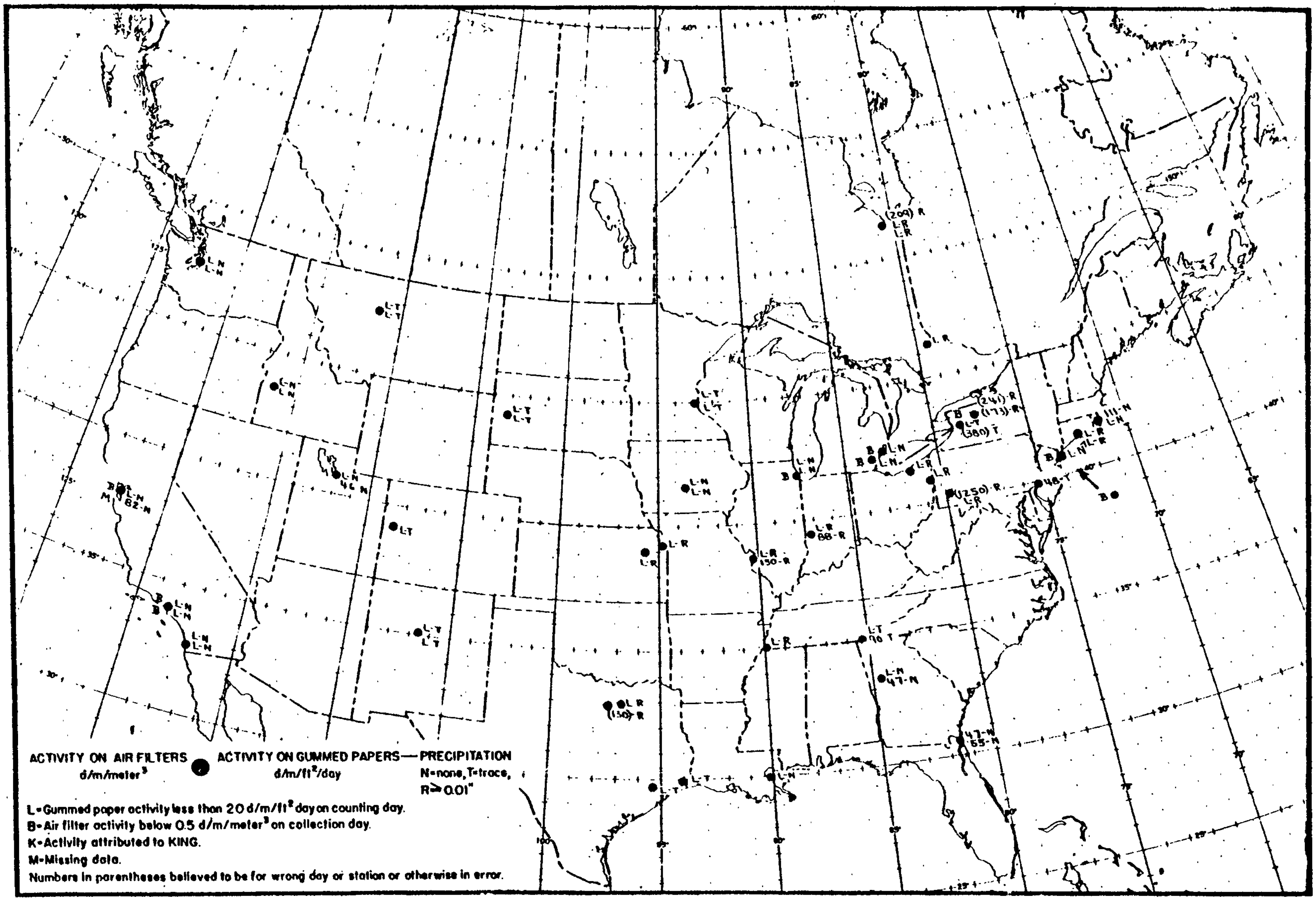

Figure A.18 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 9 Nov. 1952

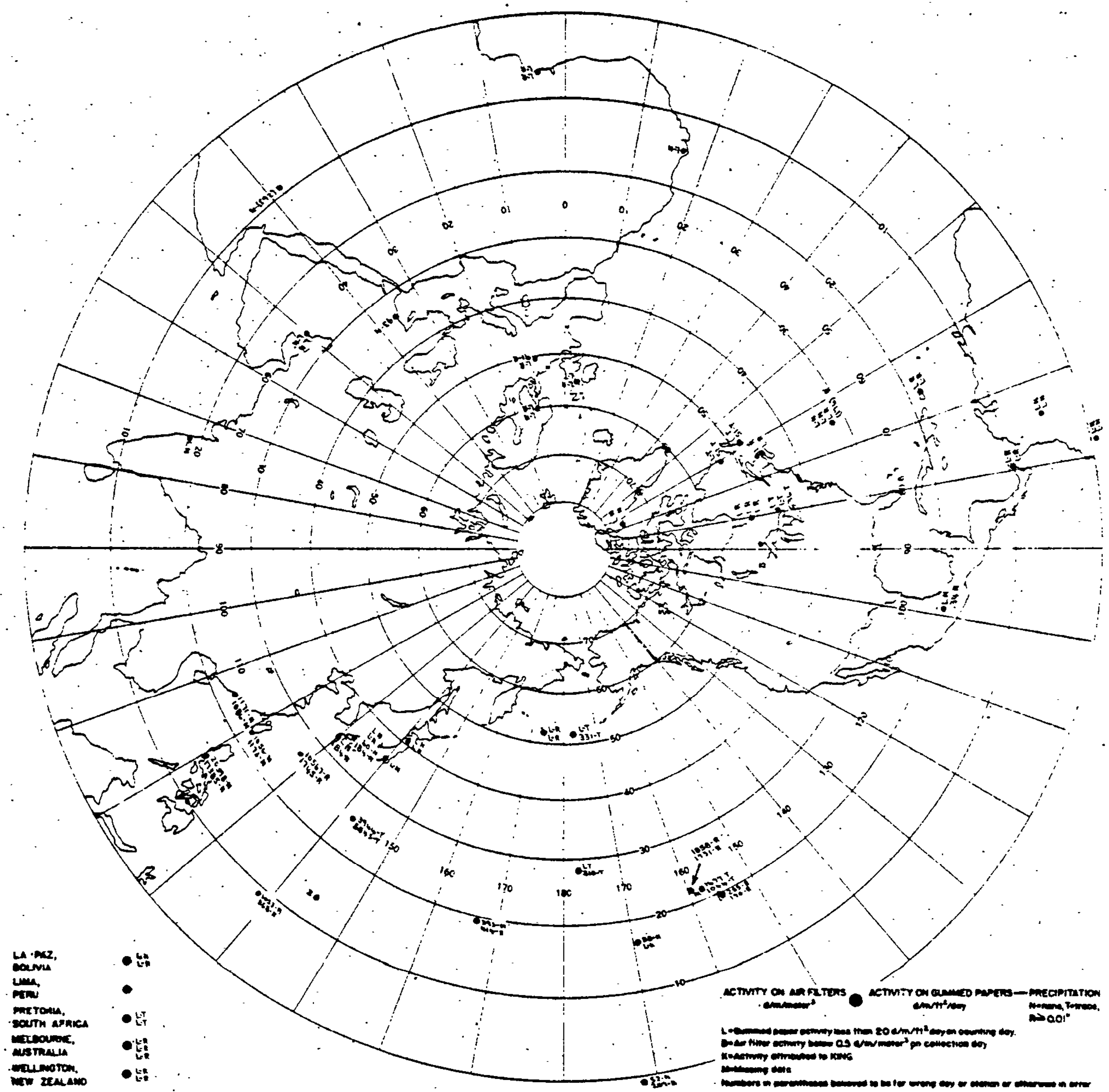

Figure A.19 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 10 Nov. 1952

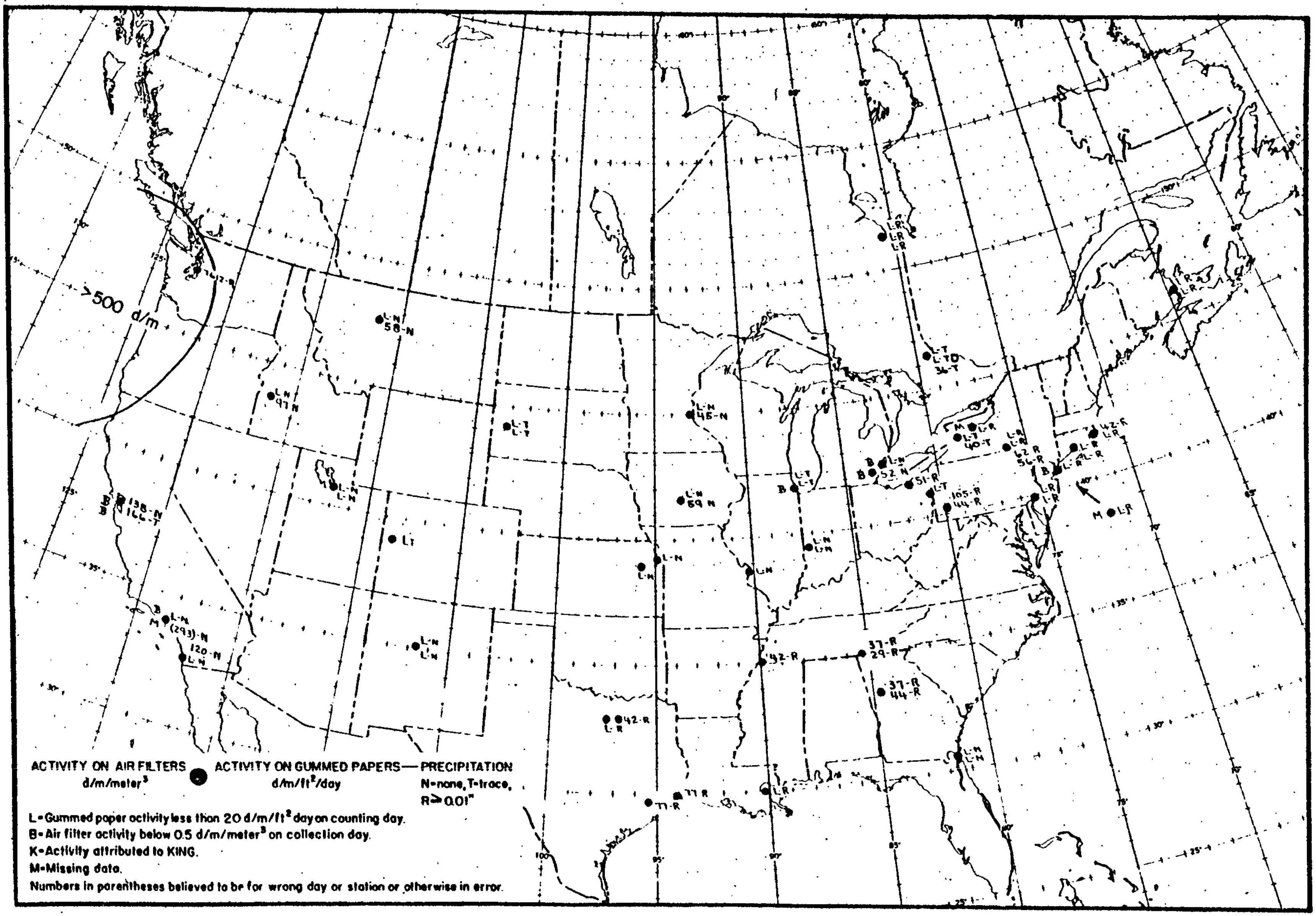

Figure A.20 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 10 Nov. 1952

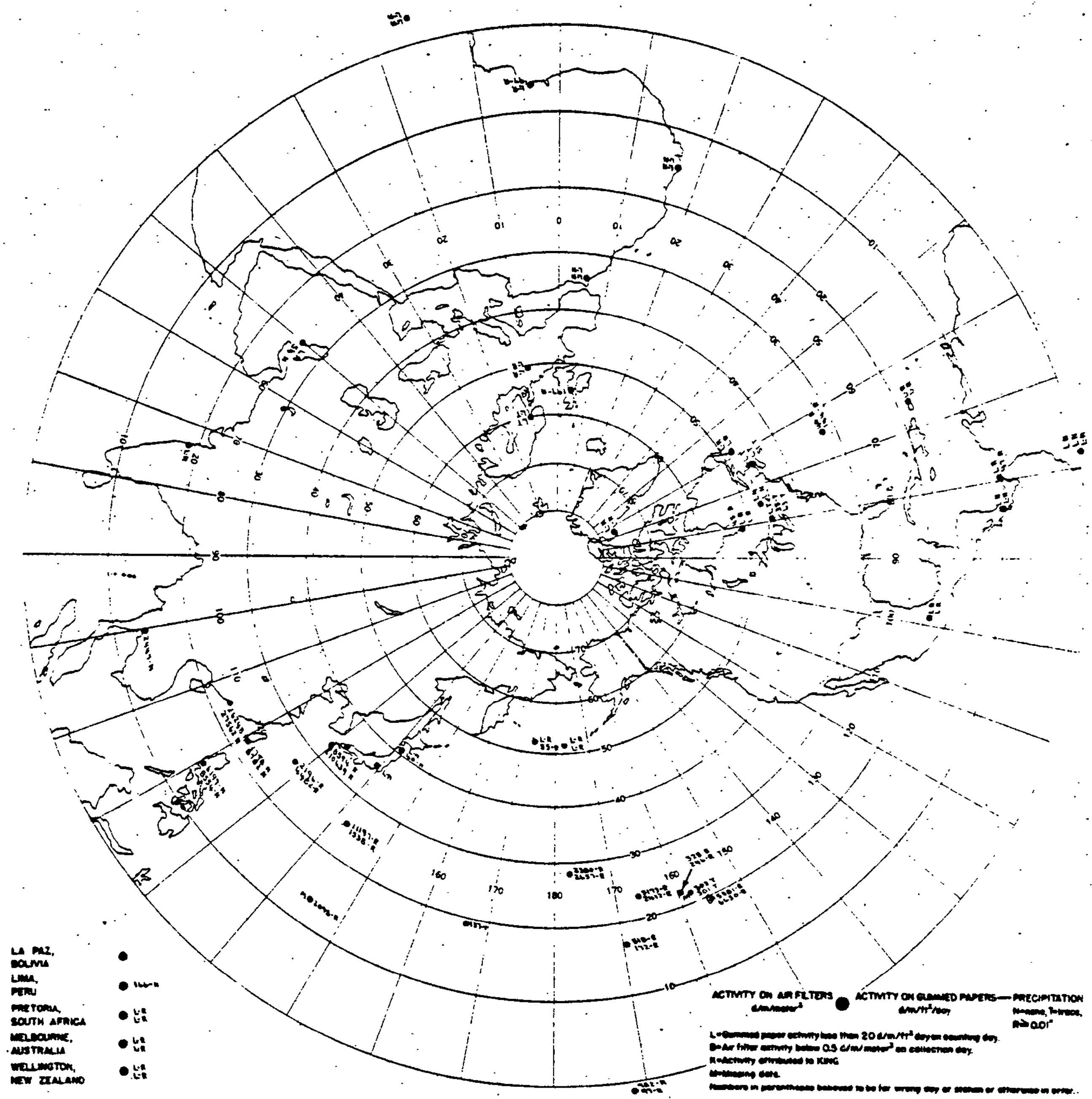

Figure A.21 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 11 Nov. 1952

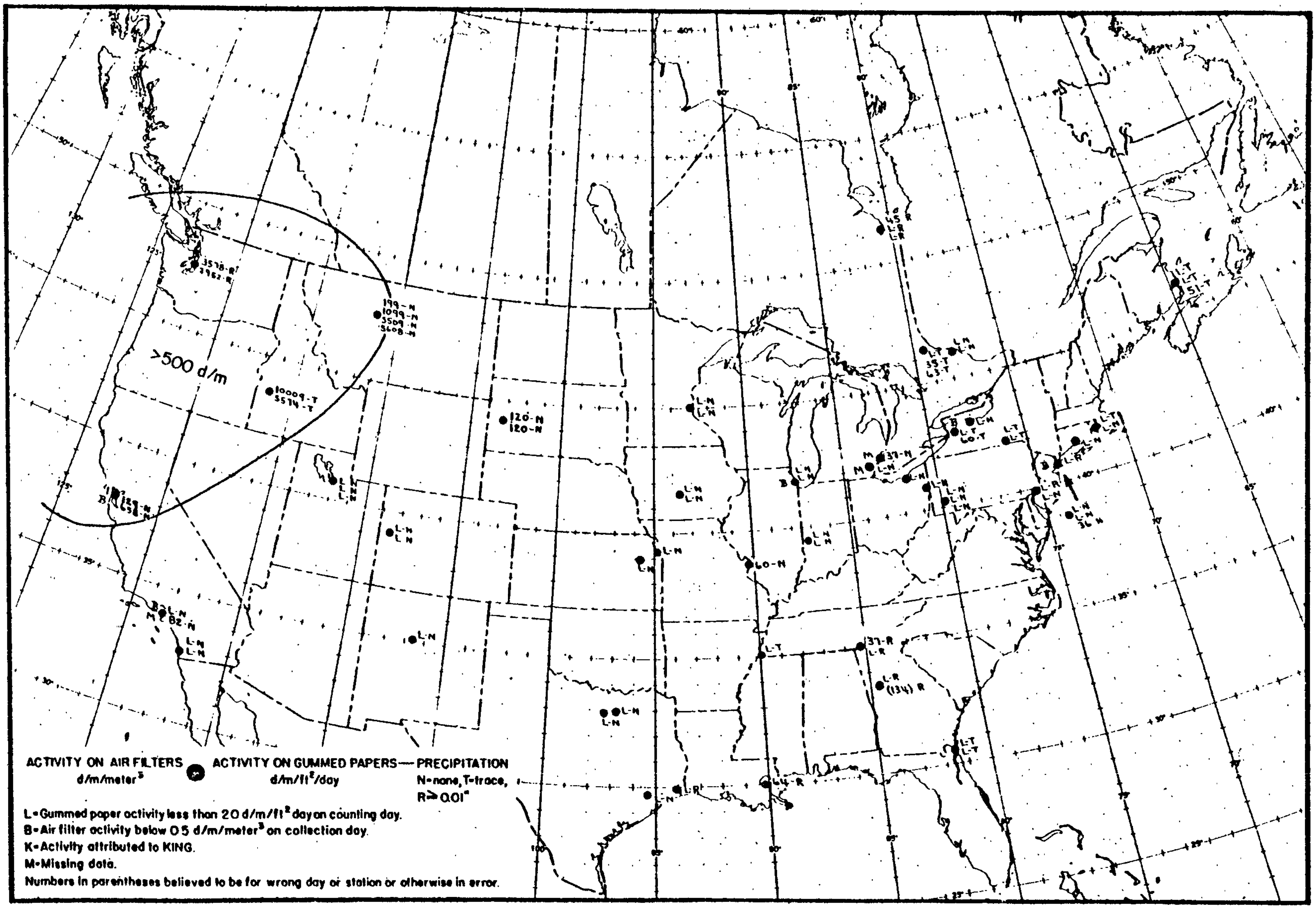

Figure A.22 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 11 Nov. 1952

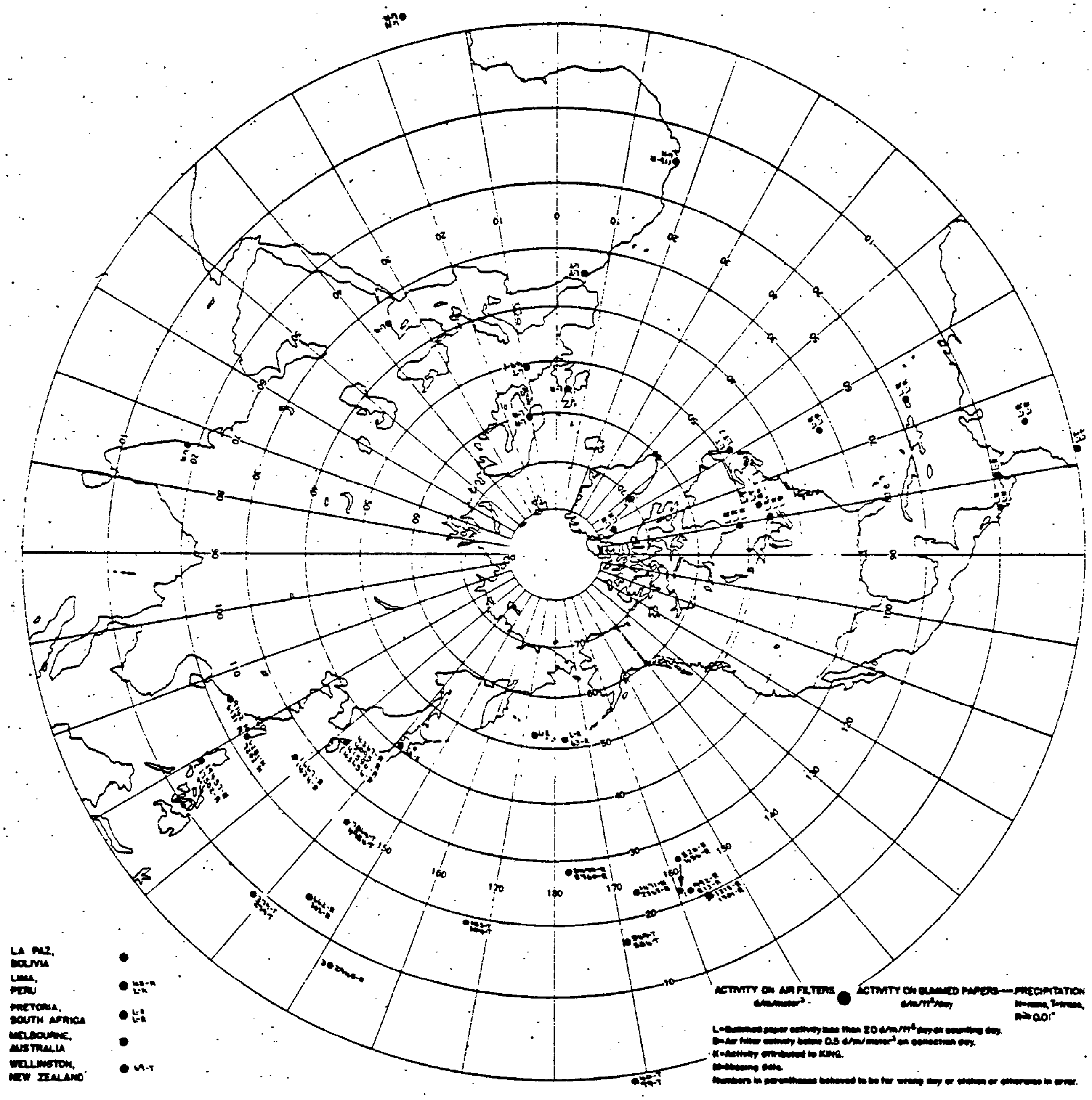

Figure A.23 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 12 Nov. 1952

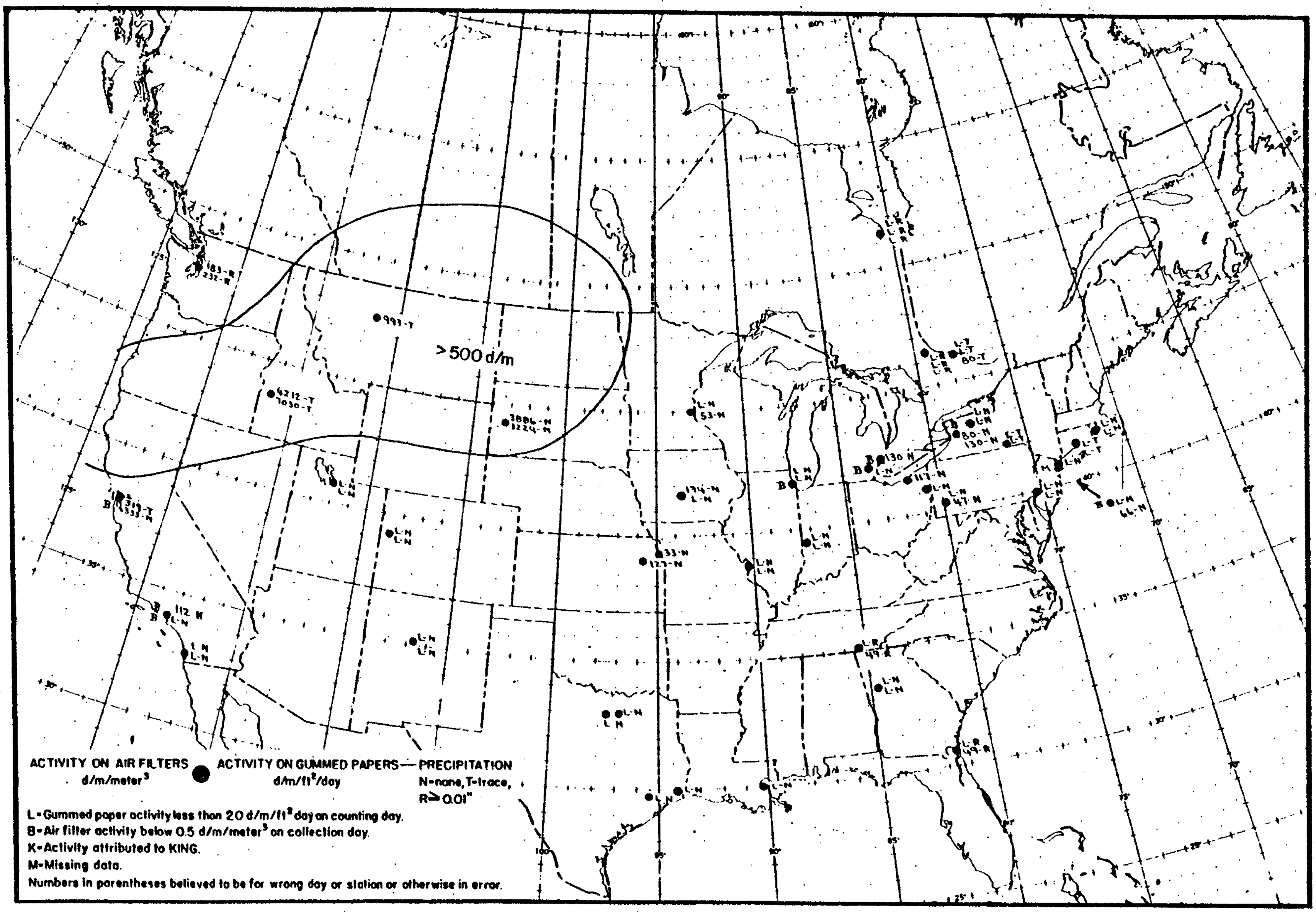

Figure A.24 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 12 Nov. 1952

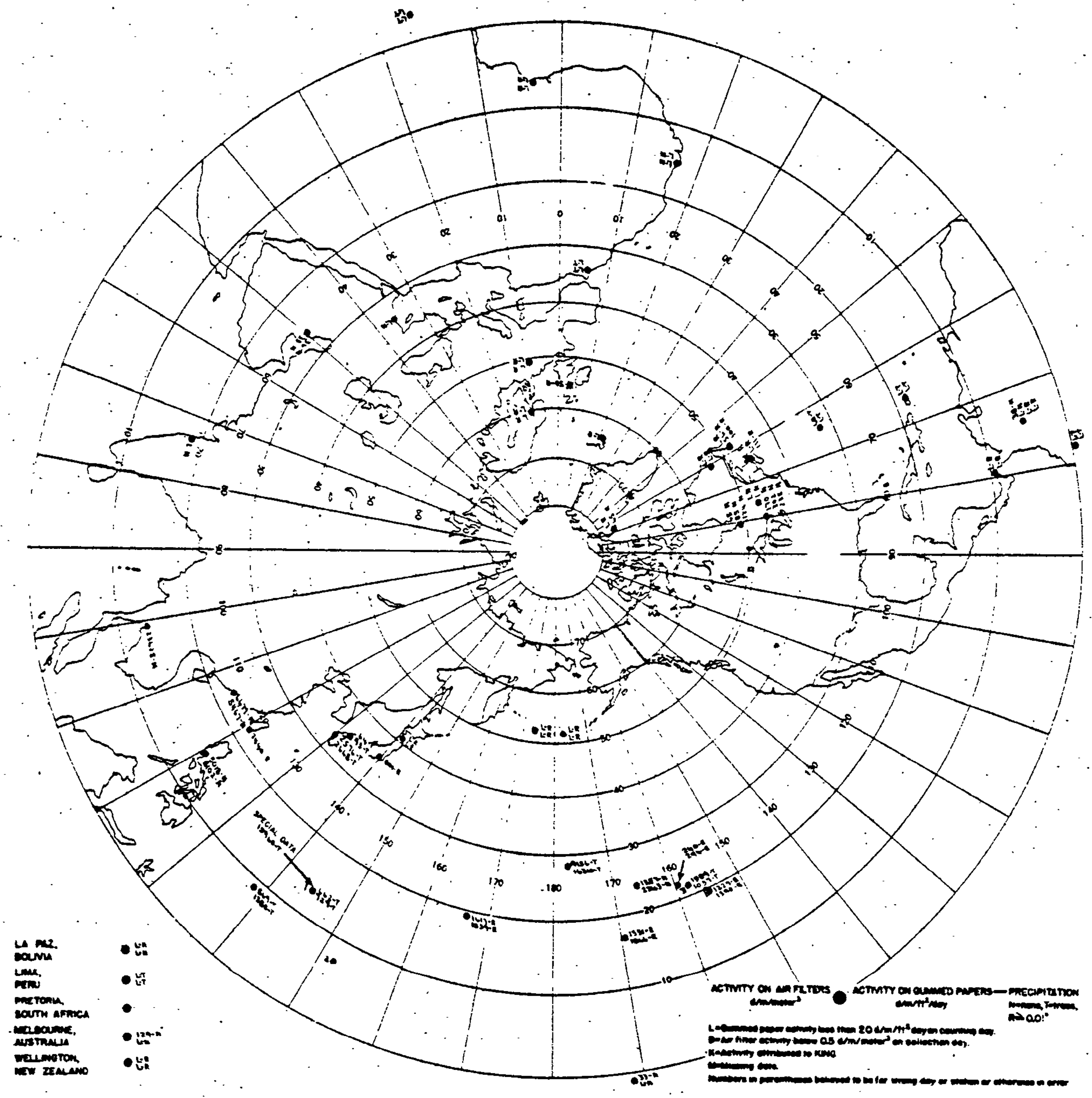

Figure A.25 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 13 Nov. 1952

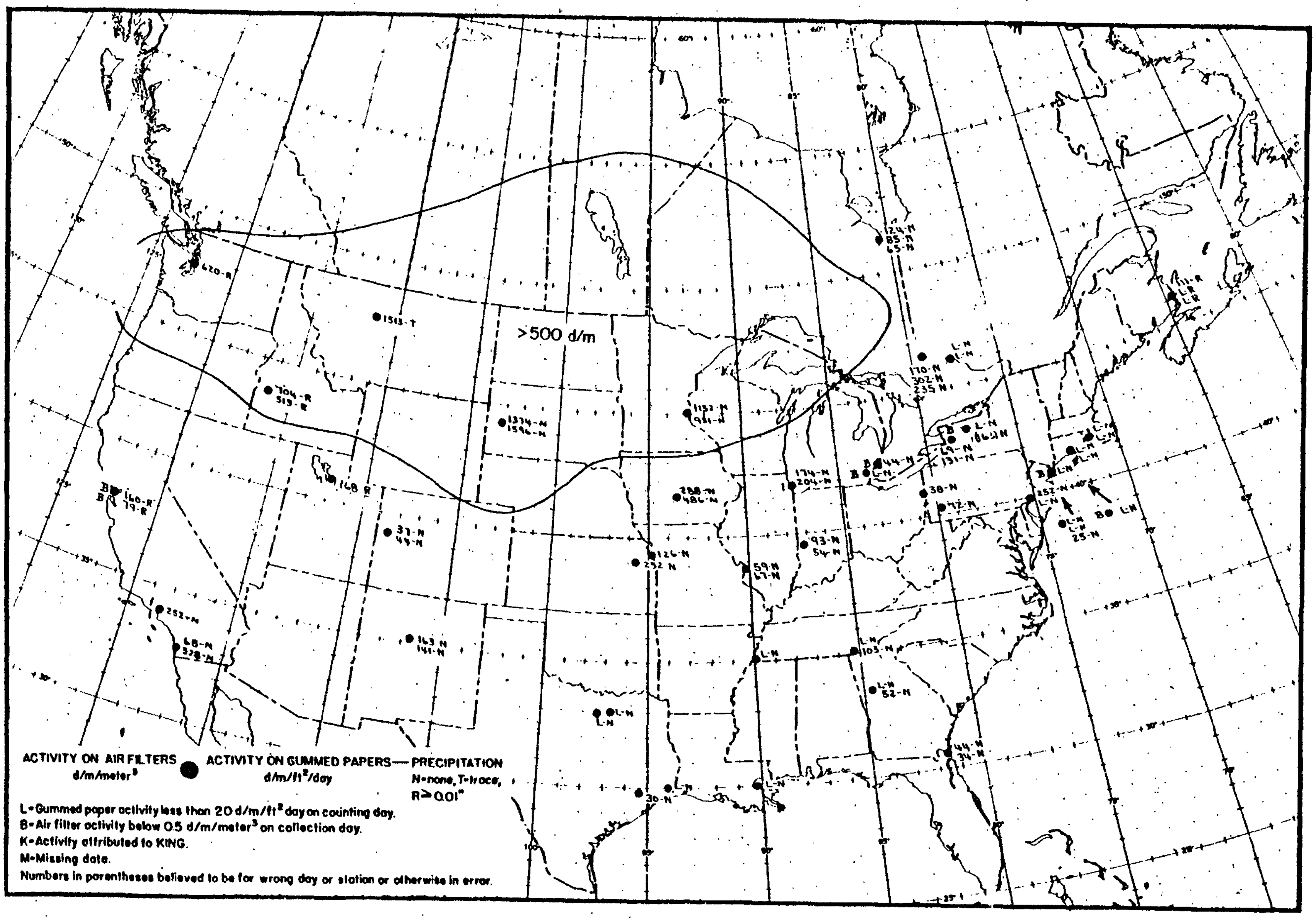

Figure A.26 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 13 Nov. 1952

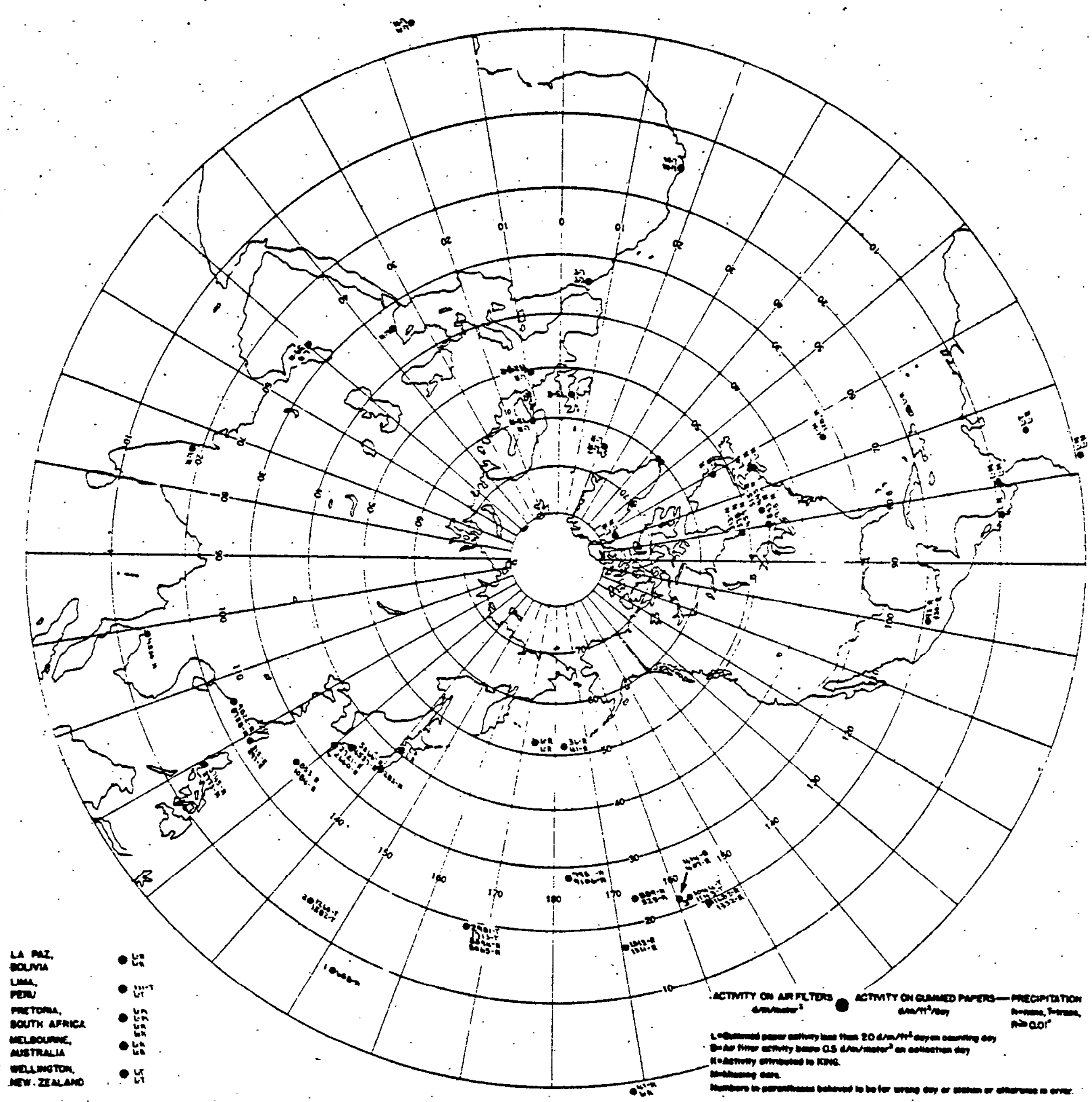

Figure A.27 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 14 Nov. 1957

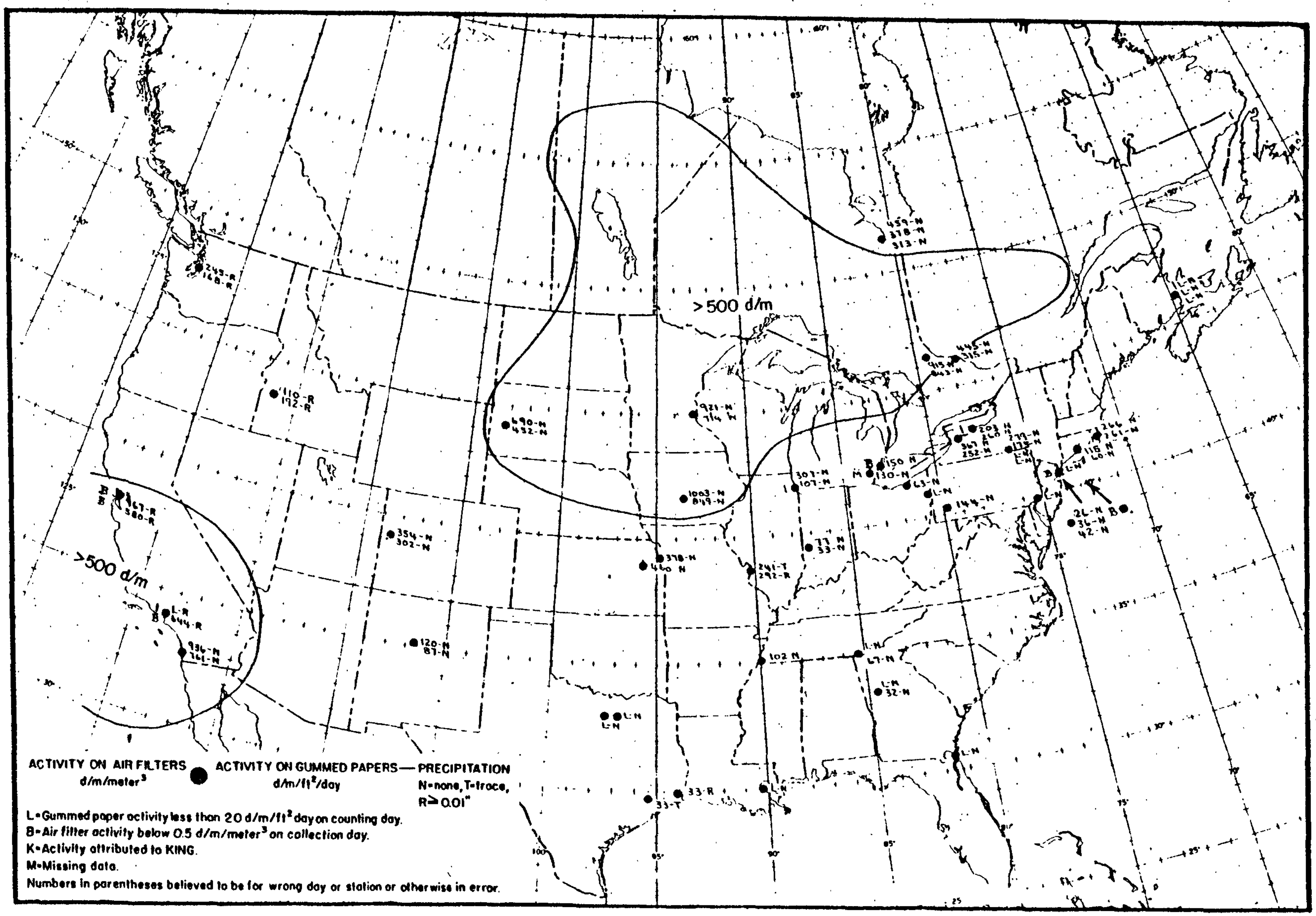

Figure A.28 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 14 Nov. 1952

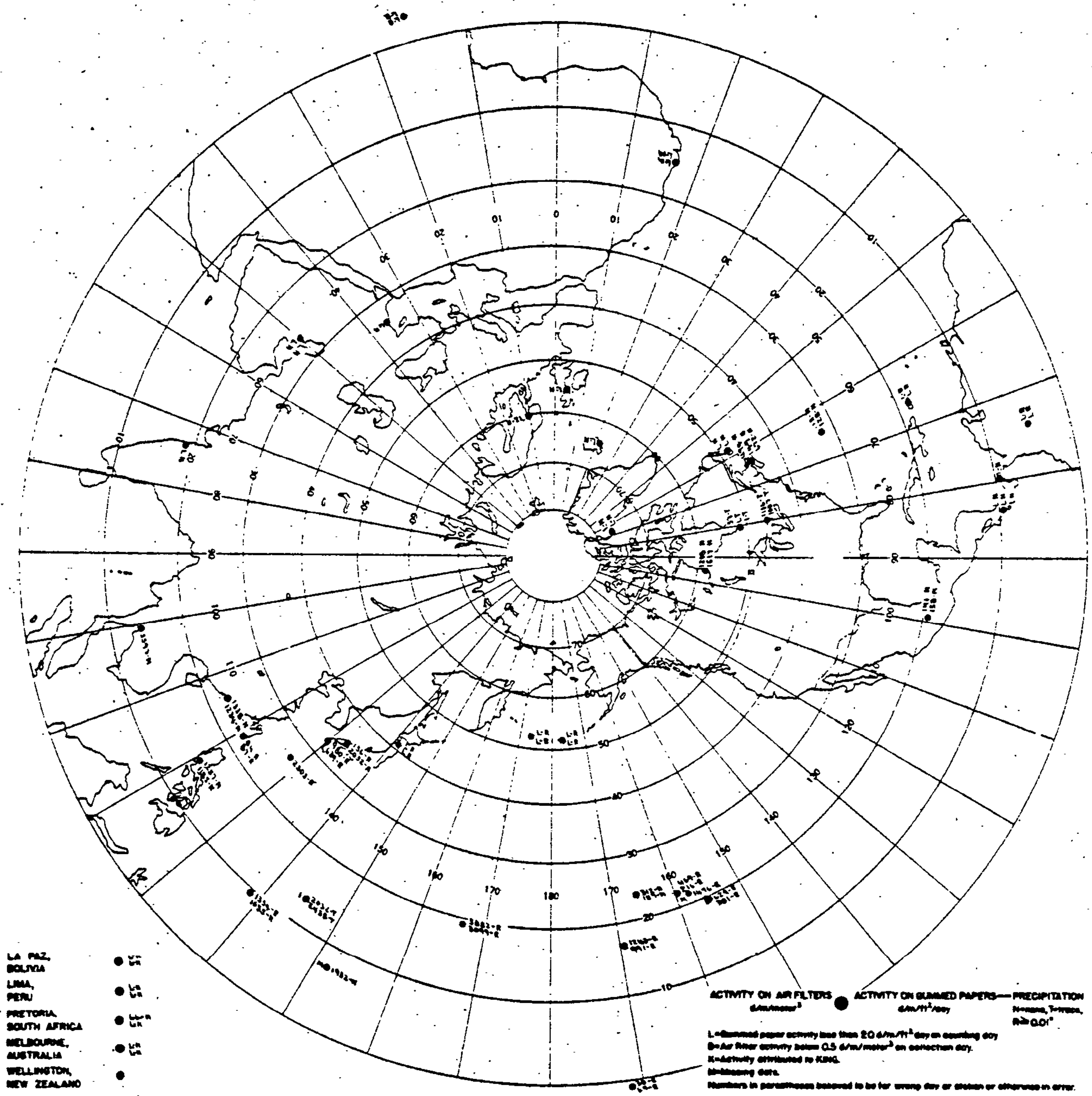

Figure A.29 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 15 Nov. 1952

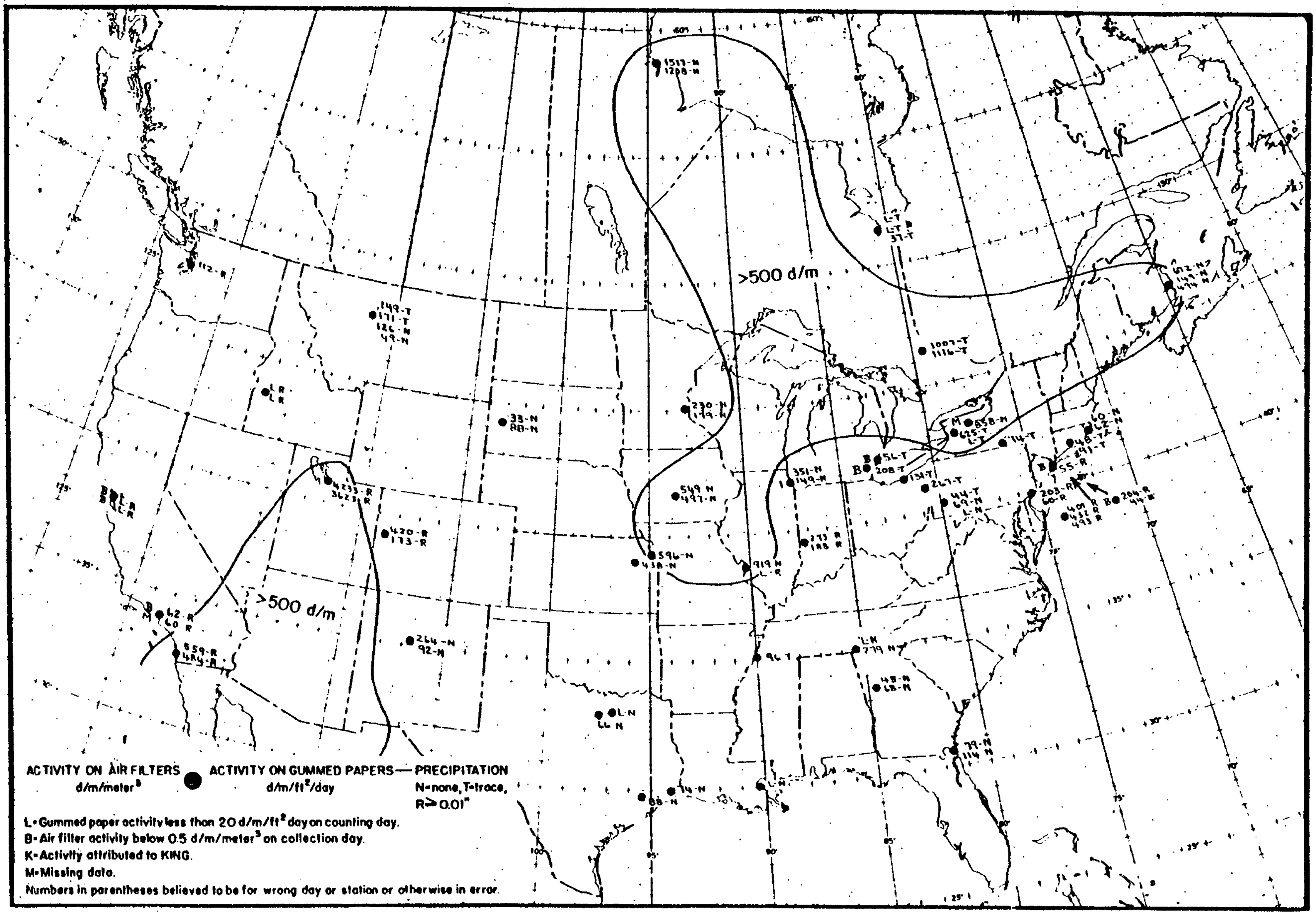

Figure A.30 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 15 Nov. 1952

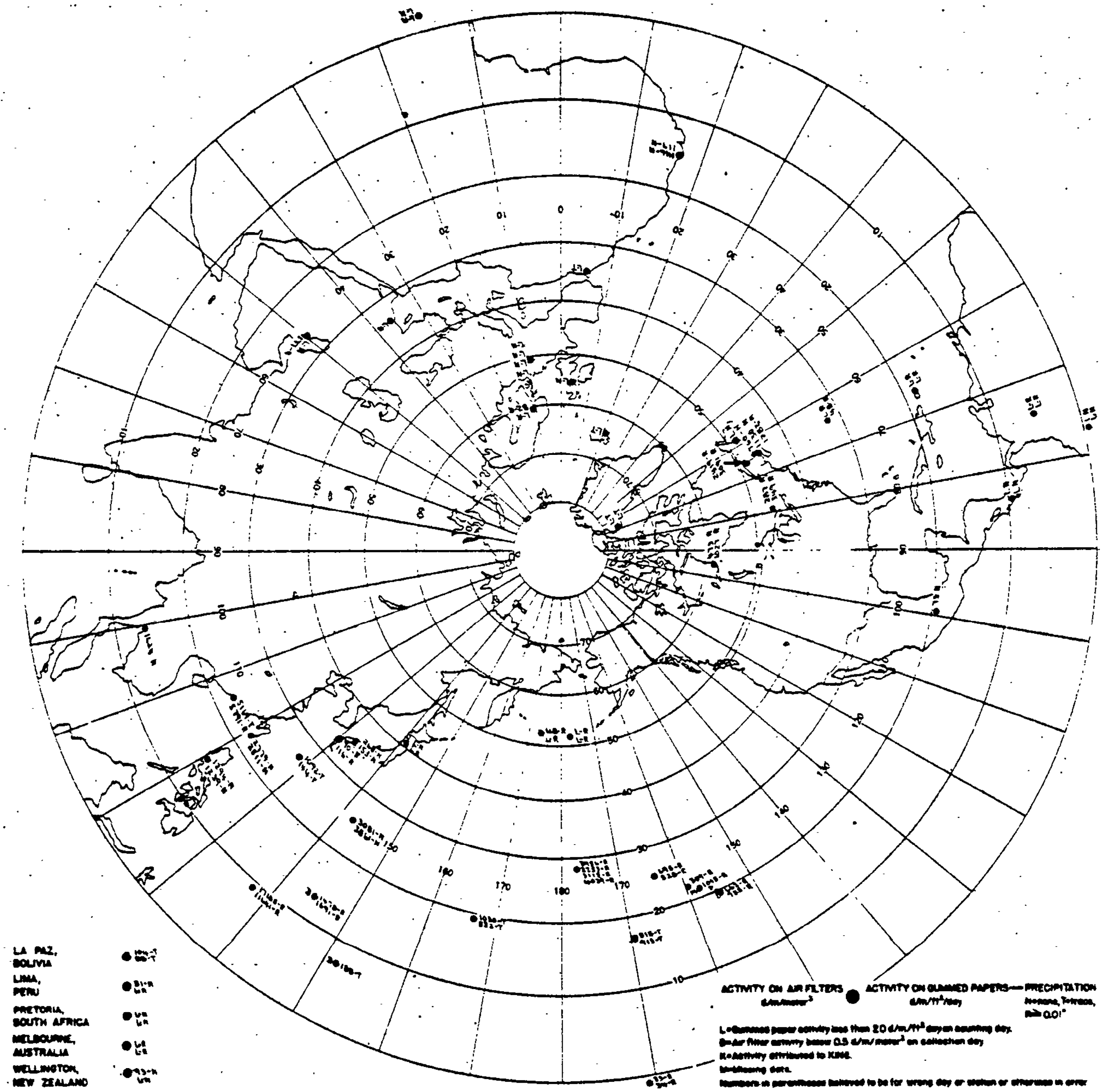

Figure A.31 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 16 Nov. 1952

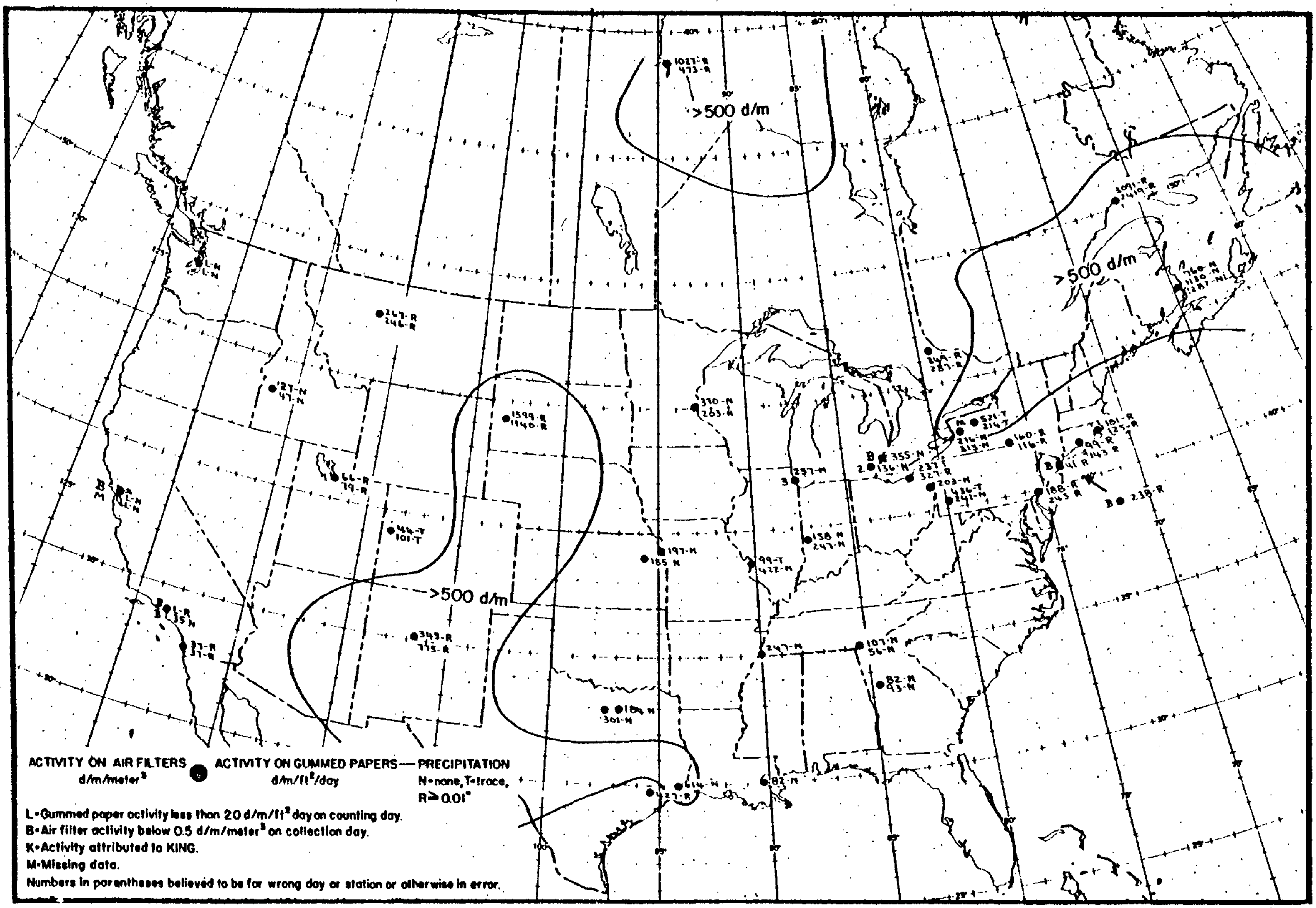

Figure A.32 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 16 Nov. 1952

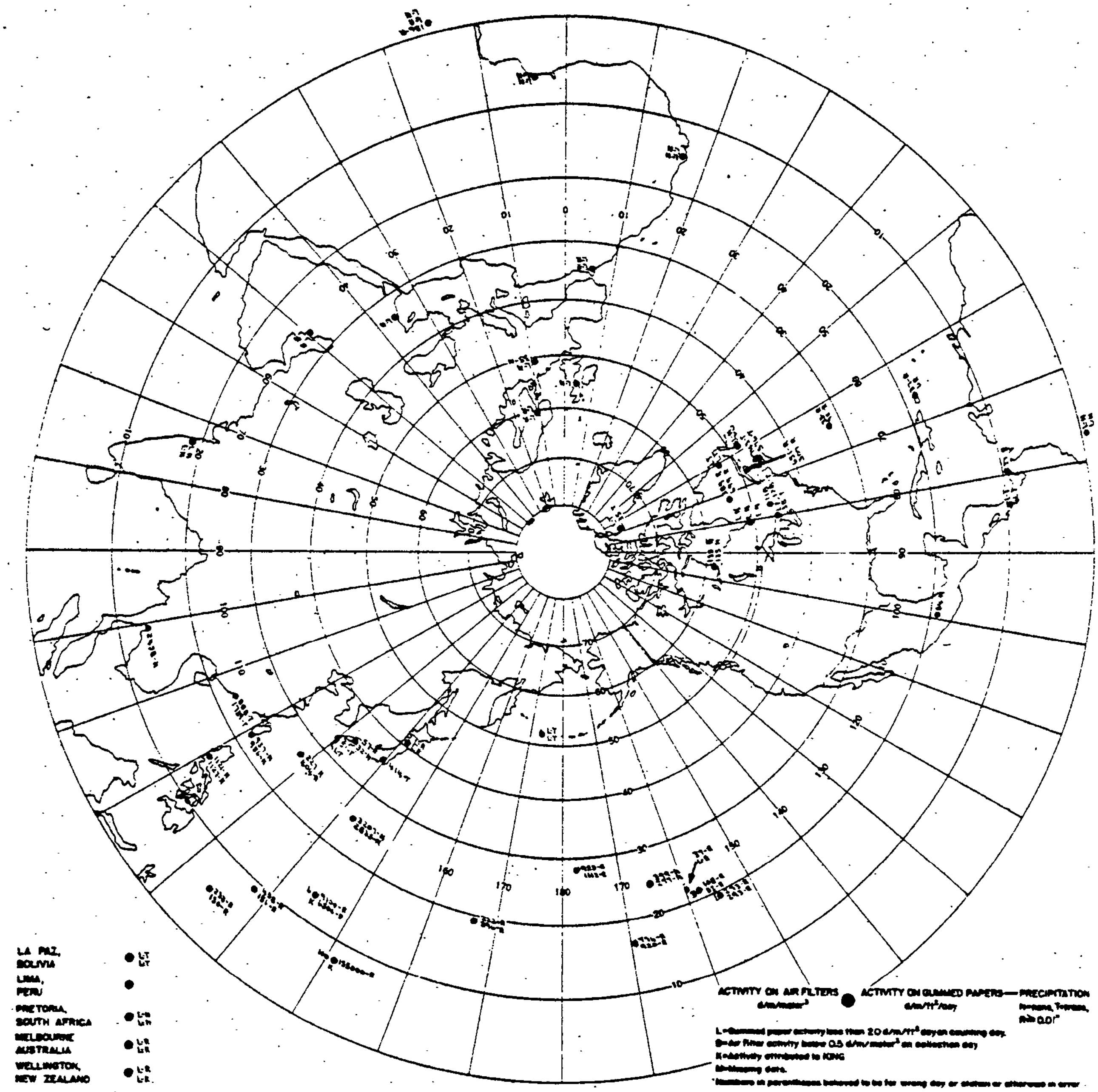

Figure A.33 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 17 Nov. 1952

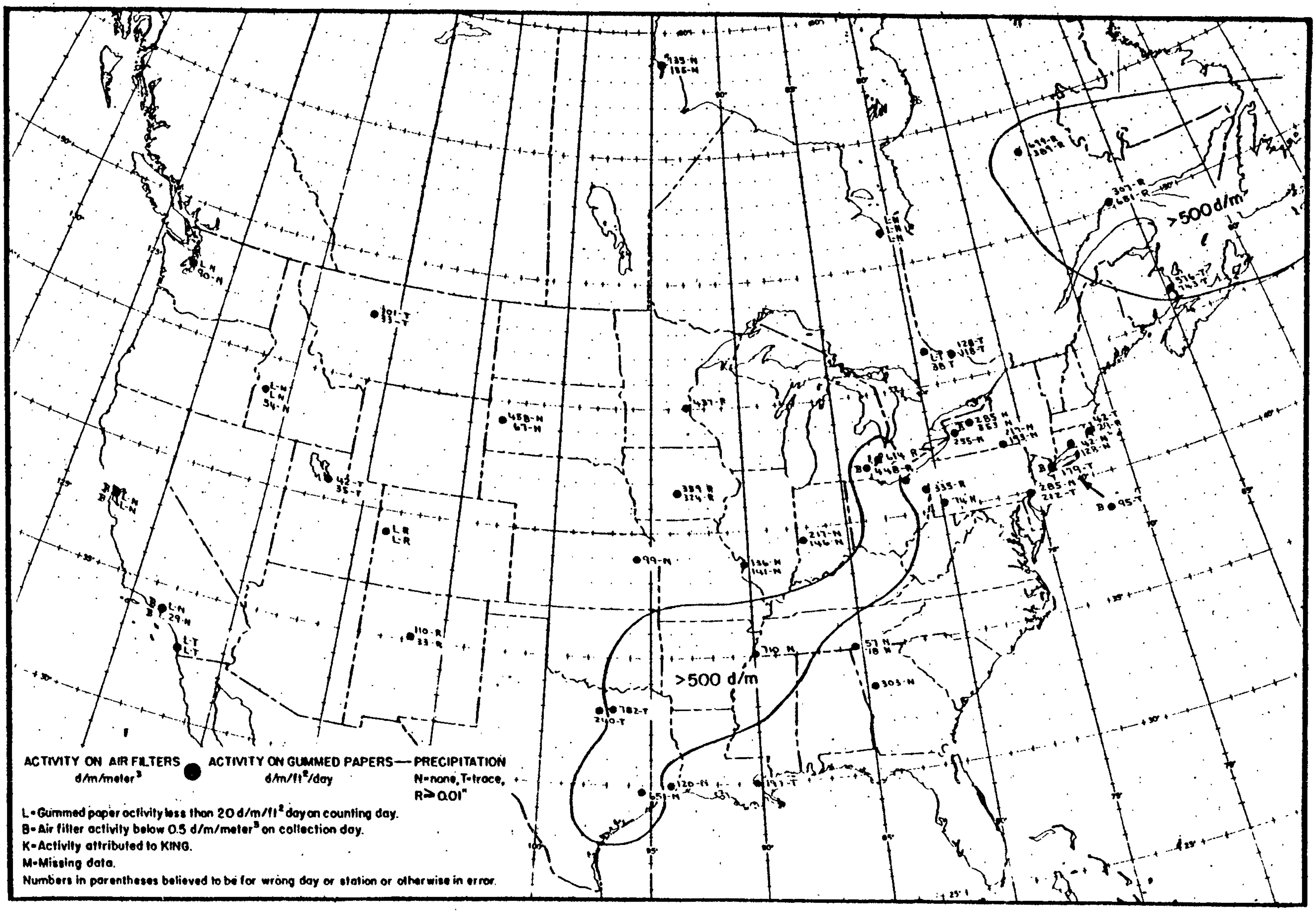

Figure A.34 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 17 Nov. 1952

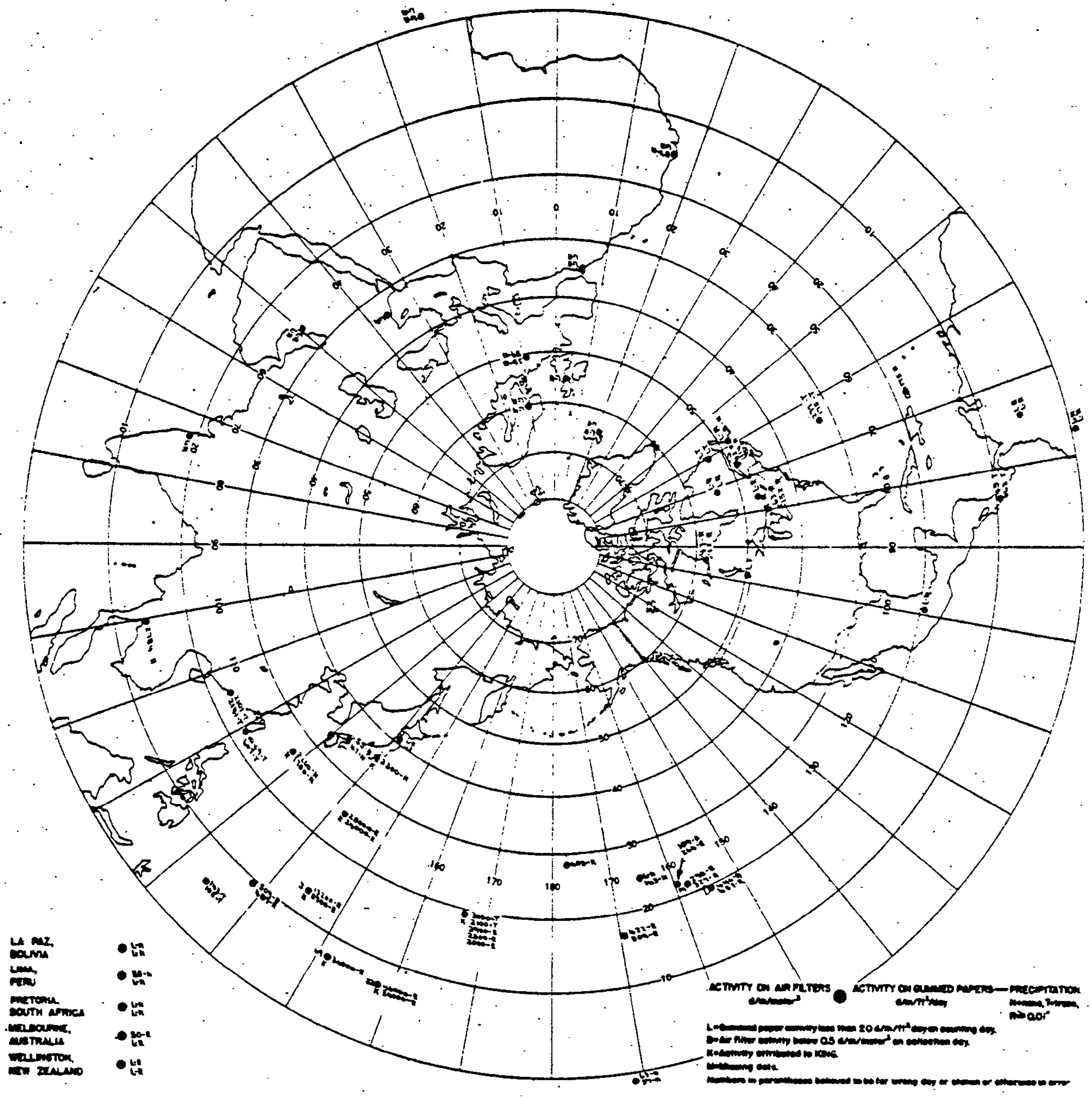

Figure A.35 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 18 Nov. 1952

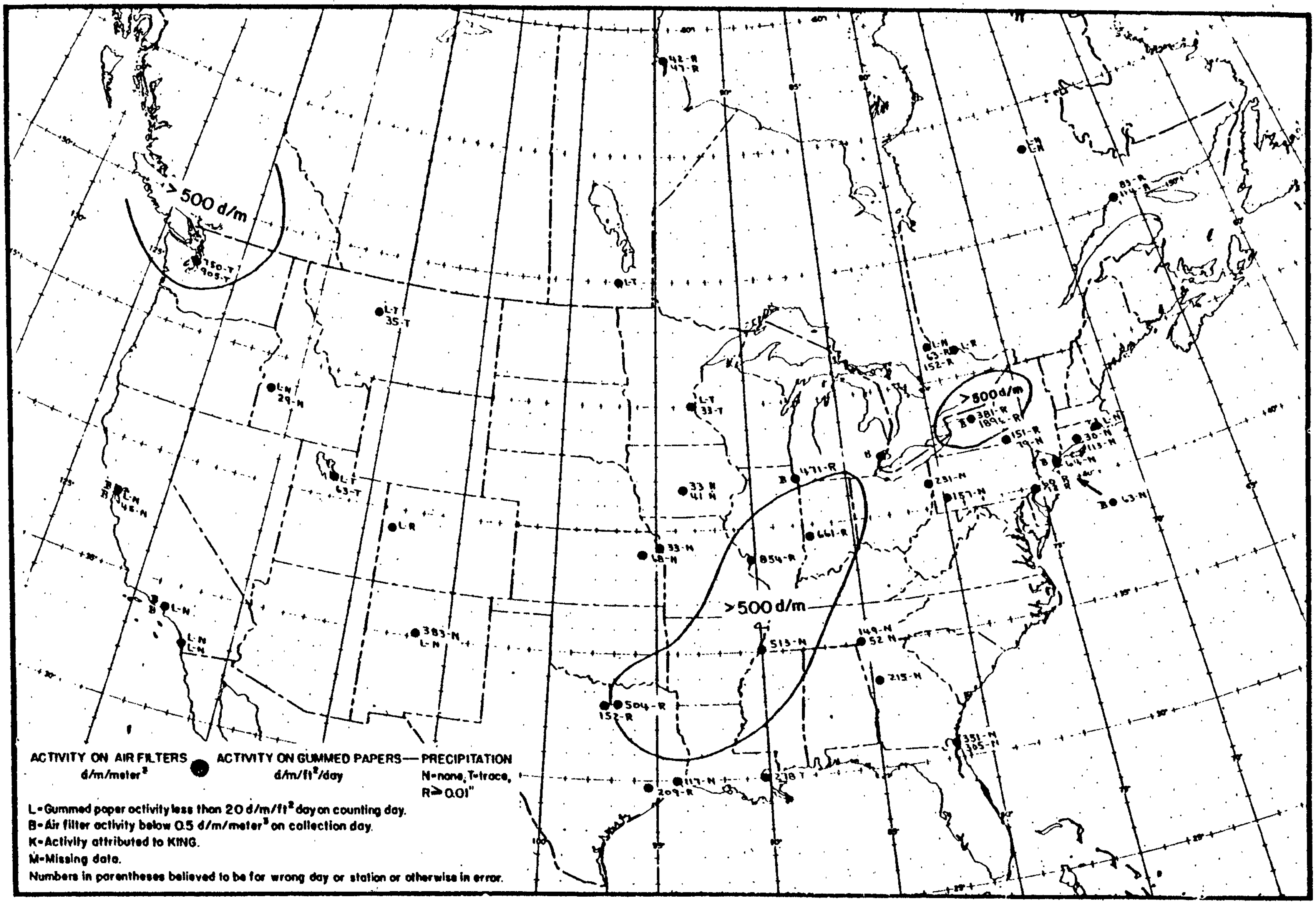

Figure A.36 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 18 Nov. 1952

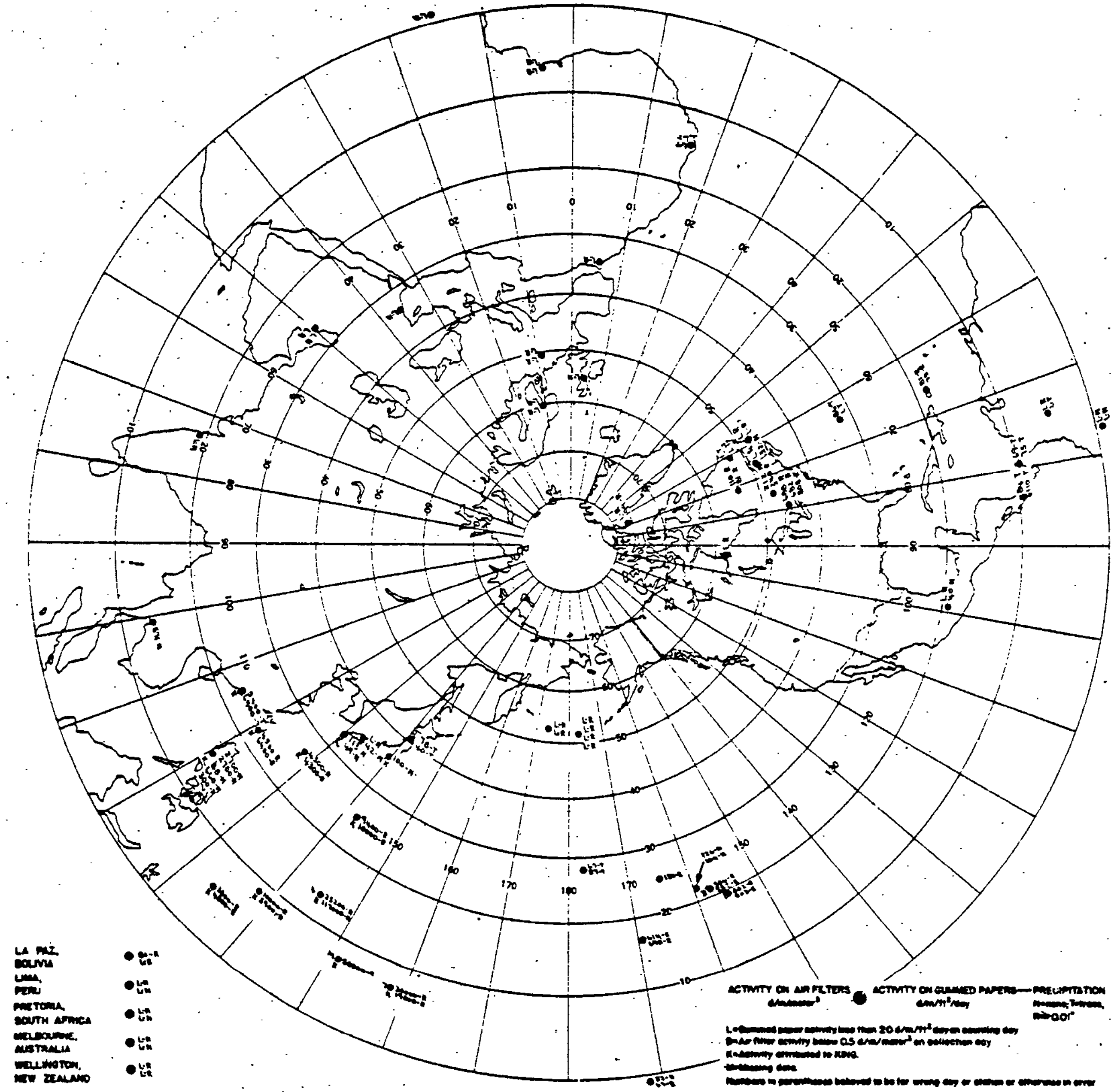

Figure A.37 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 19 Nov. 1952

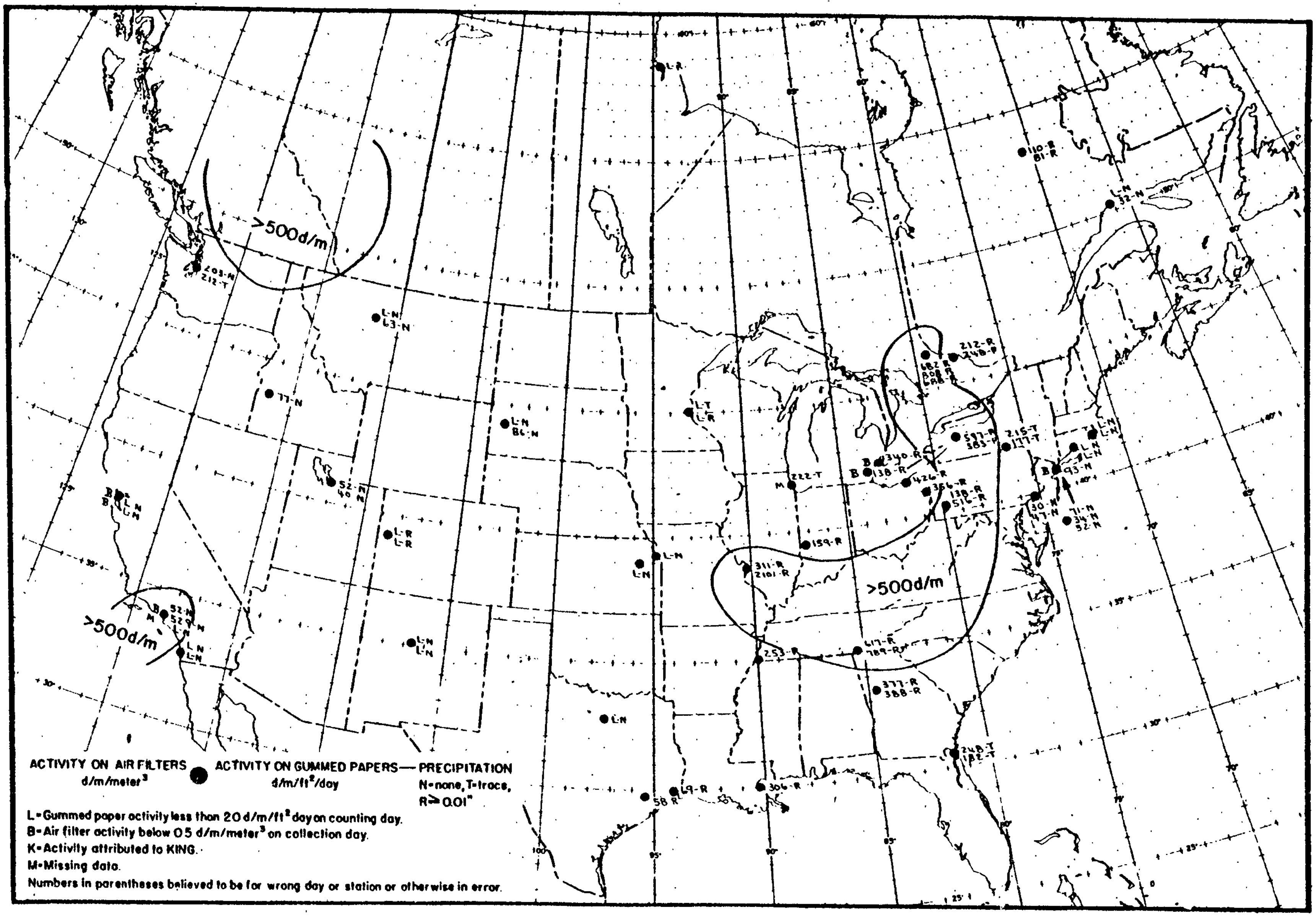

Figure A.38 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 19 Nov. 1952

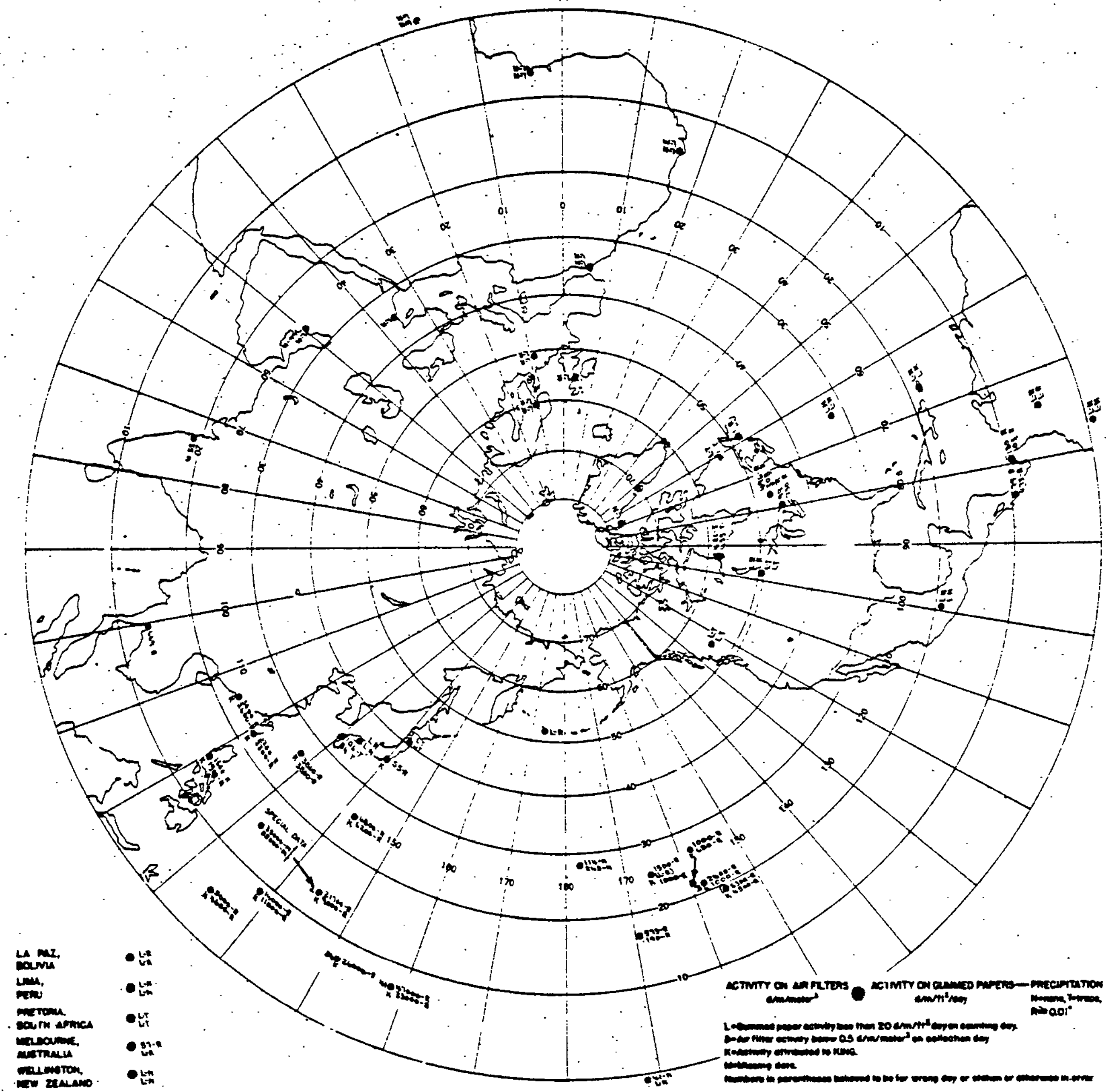

Figure A.39 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 20 Nov. 1952

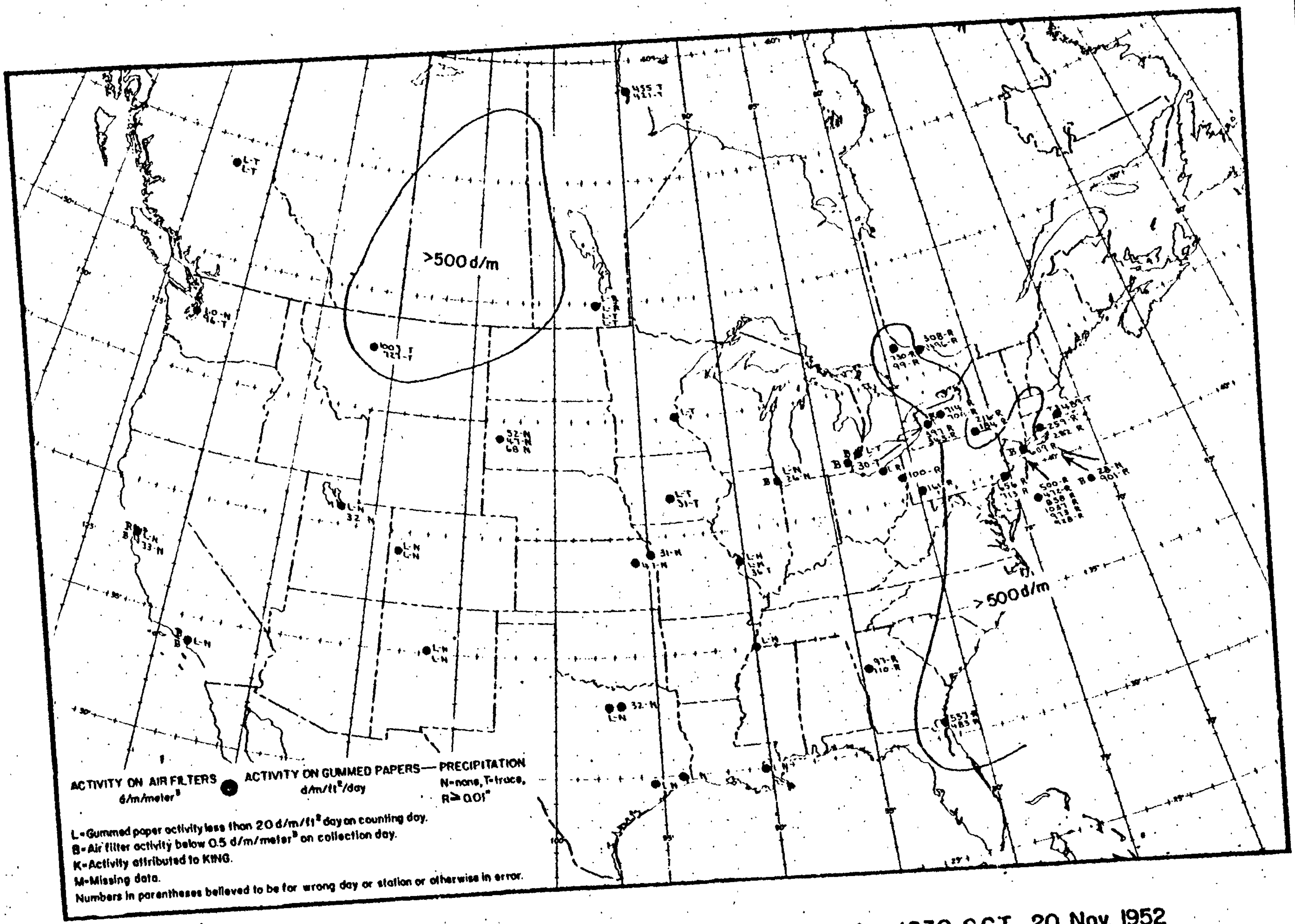

Figure A.40 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 20 Nov. 1952

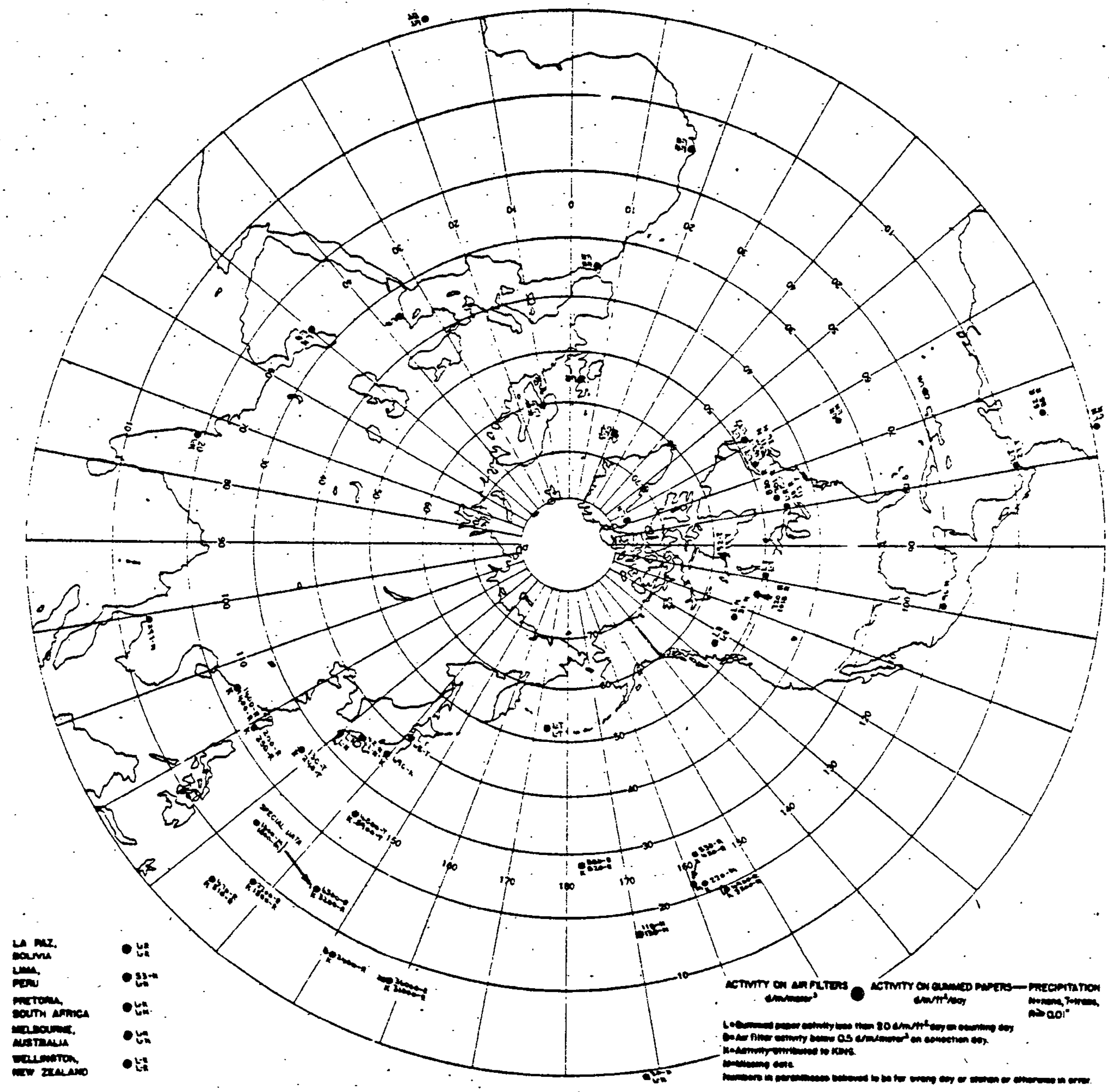

Figure A.41 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 21 Nov. 1952

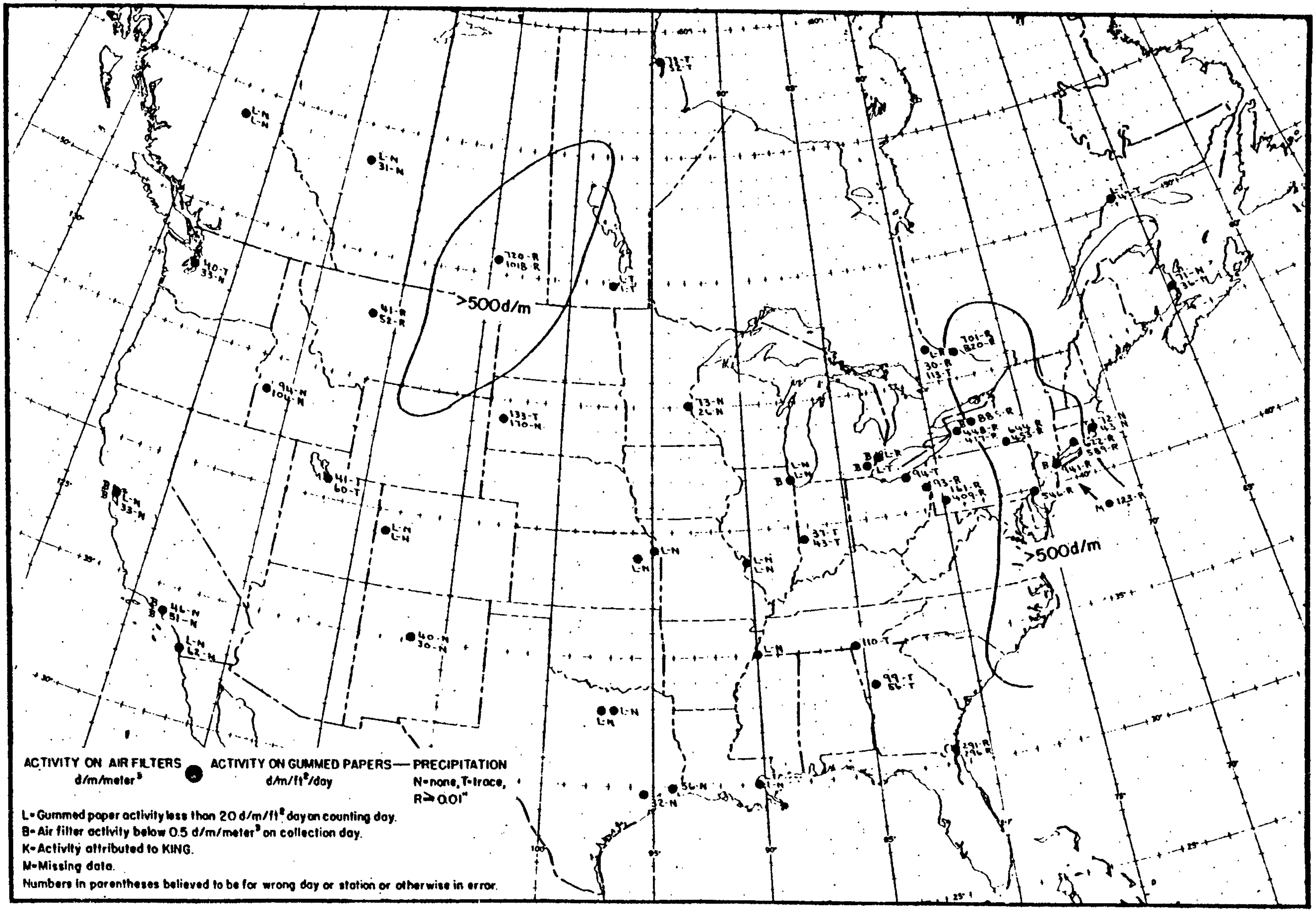

Figure A.42 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 21 Nov. 1952

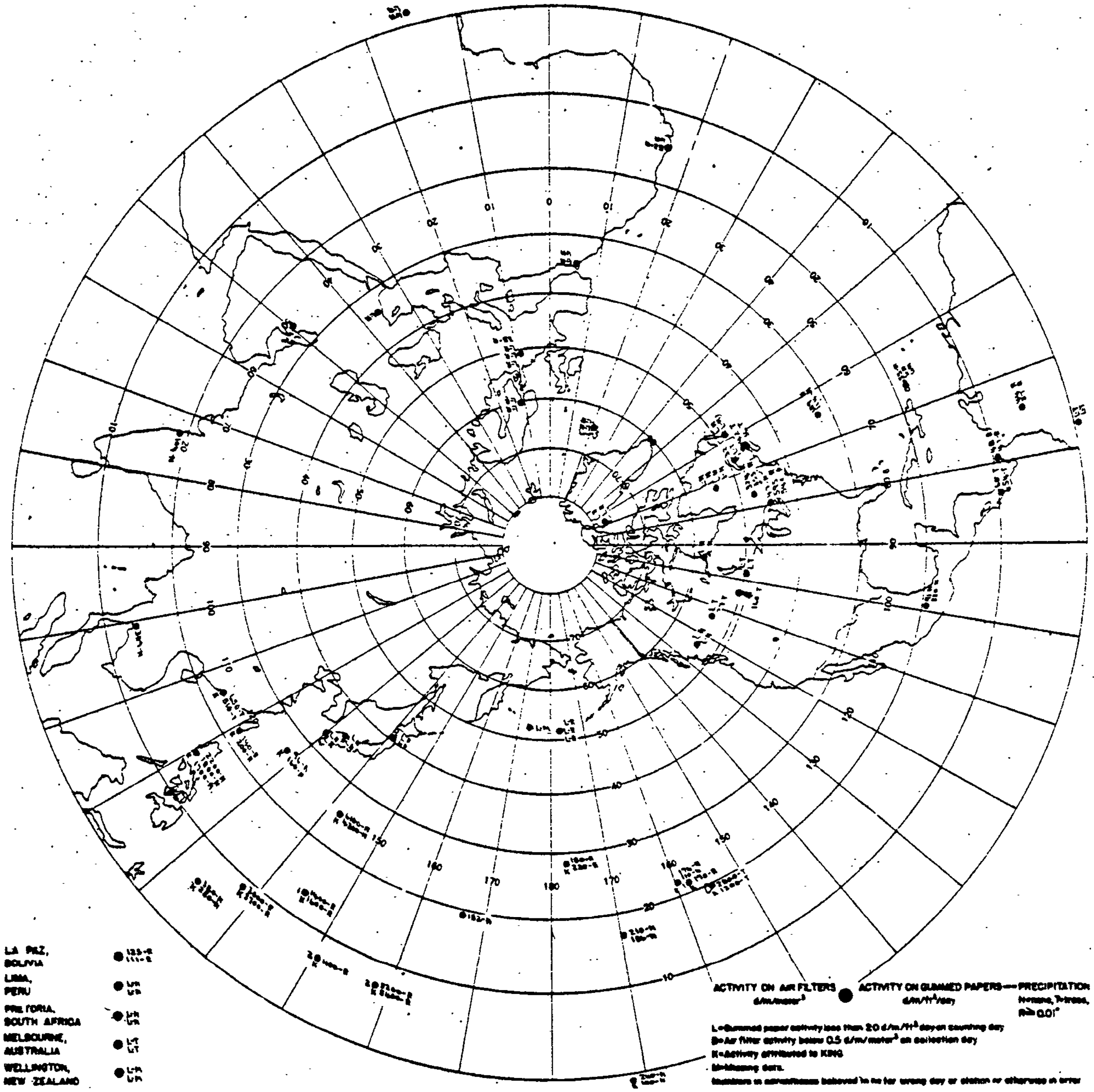

Figure A.43 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 22 Nov. 1952

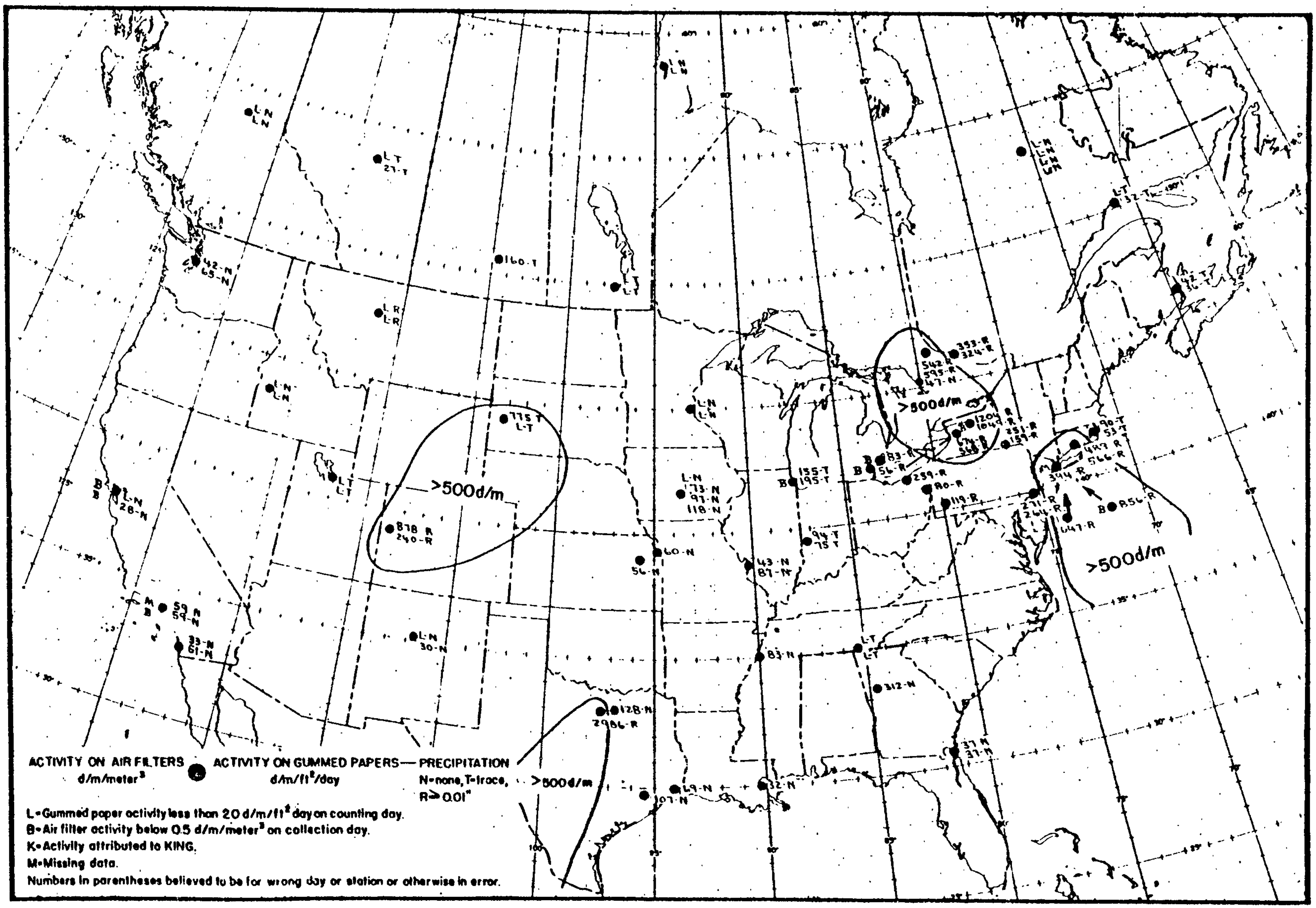

Figure A.44 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 22 Nov. 1952

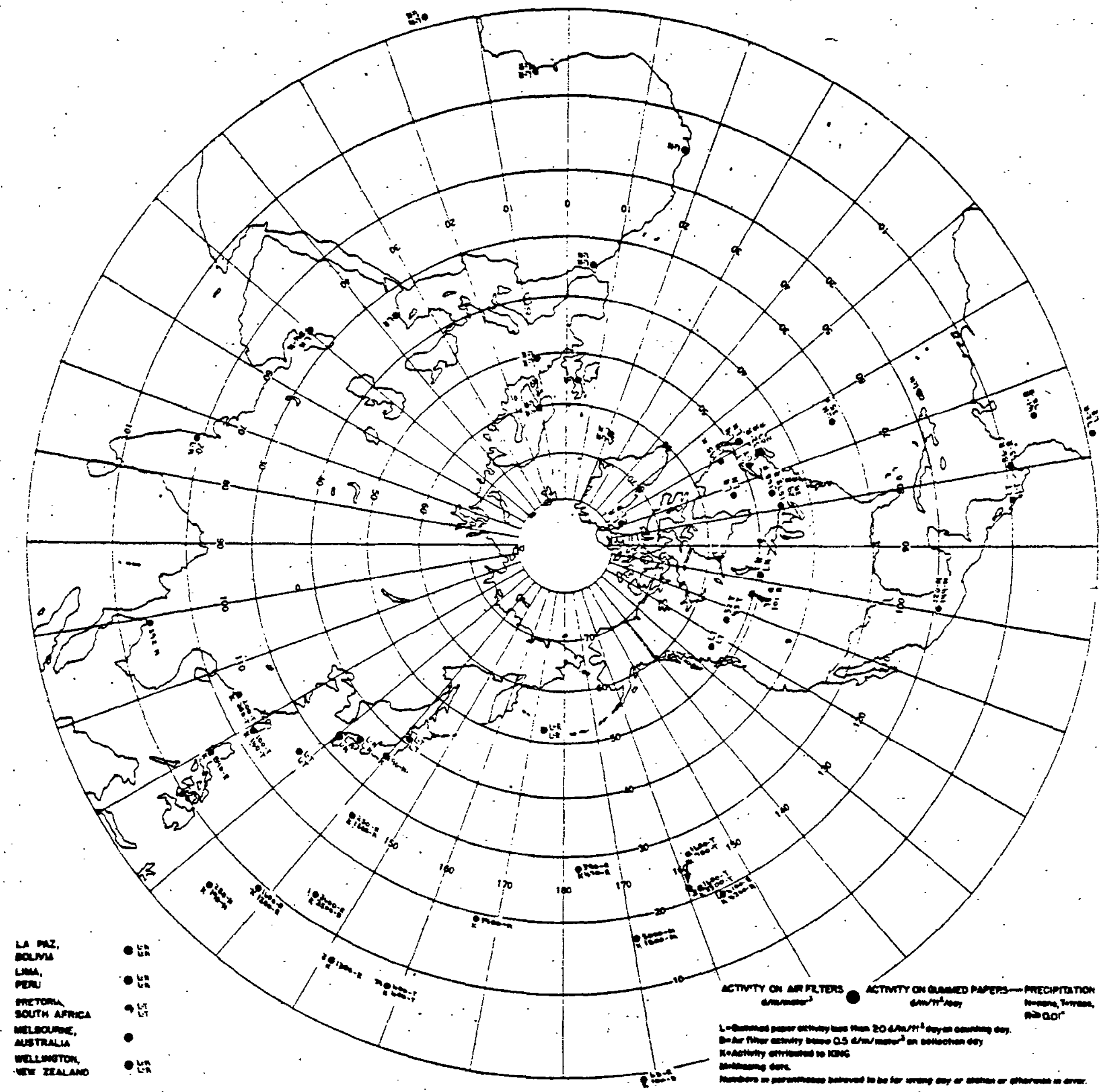

Figure A.45 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 23 Nov. 1952

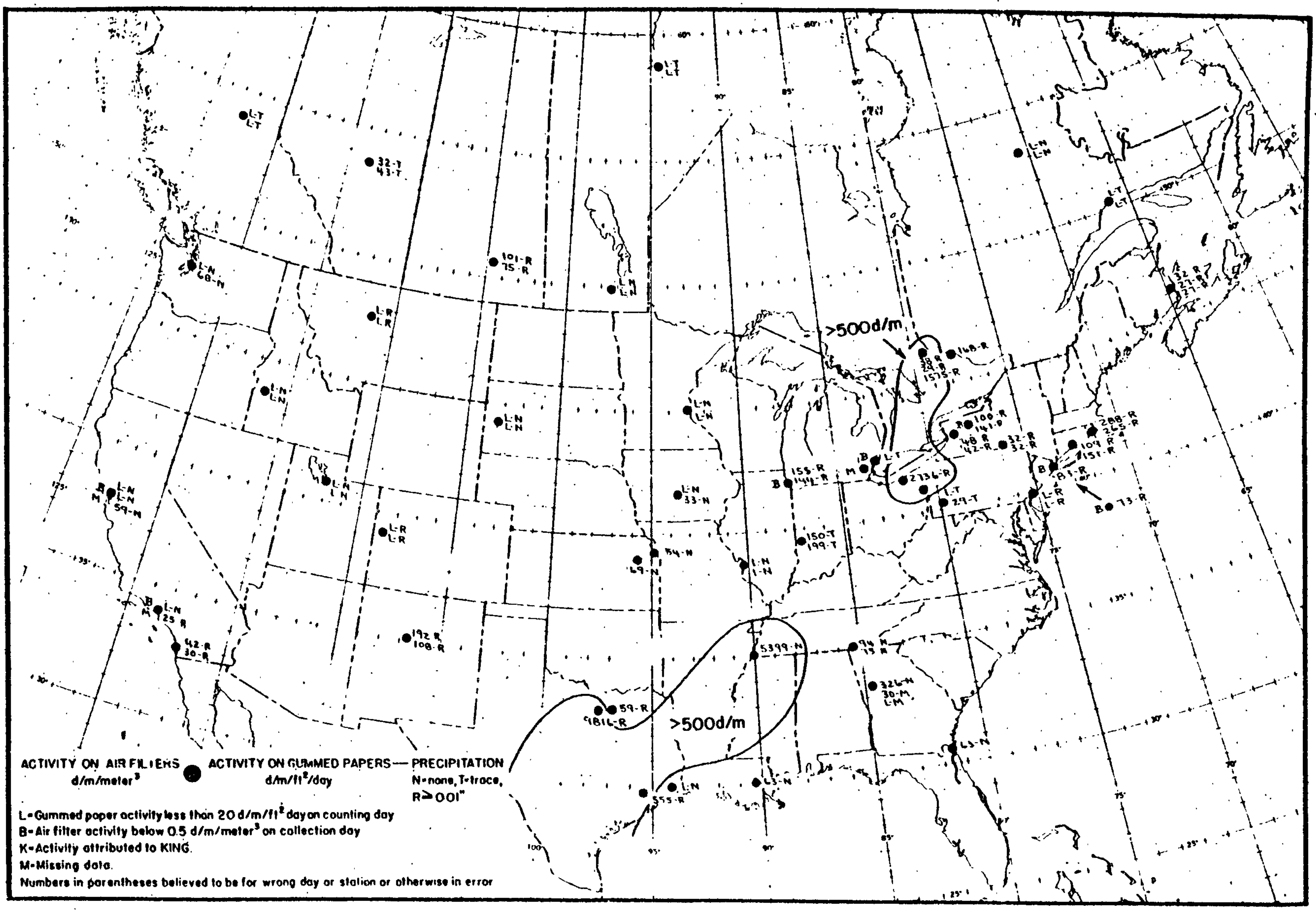

Figure A.46 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 23 Nov. 1952

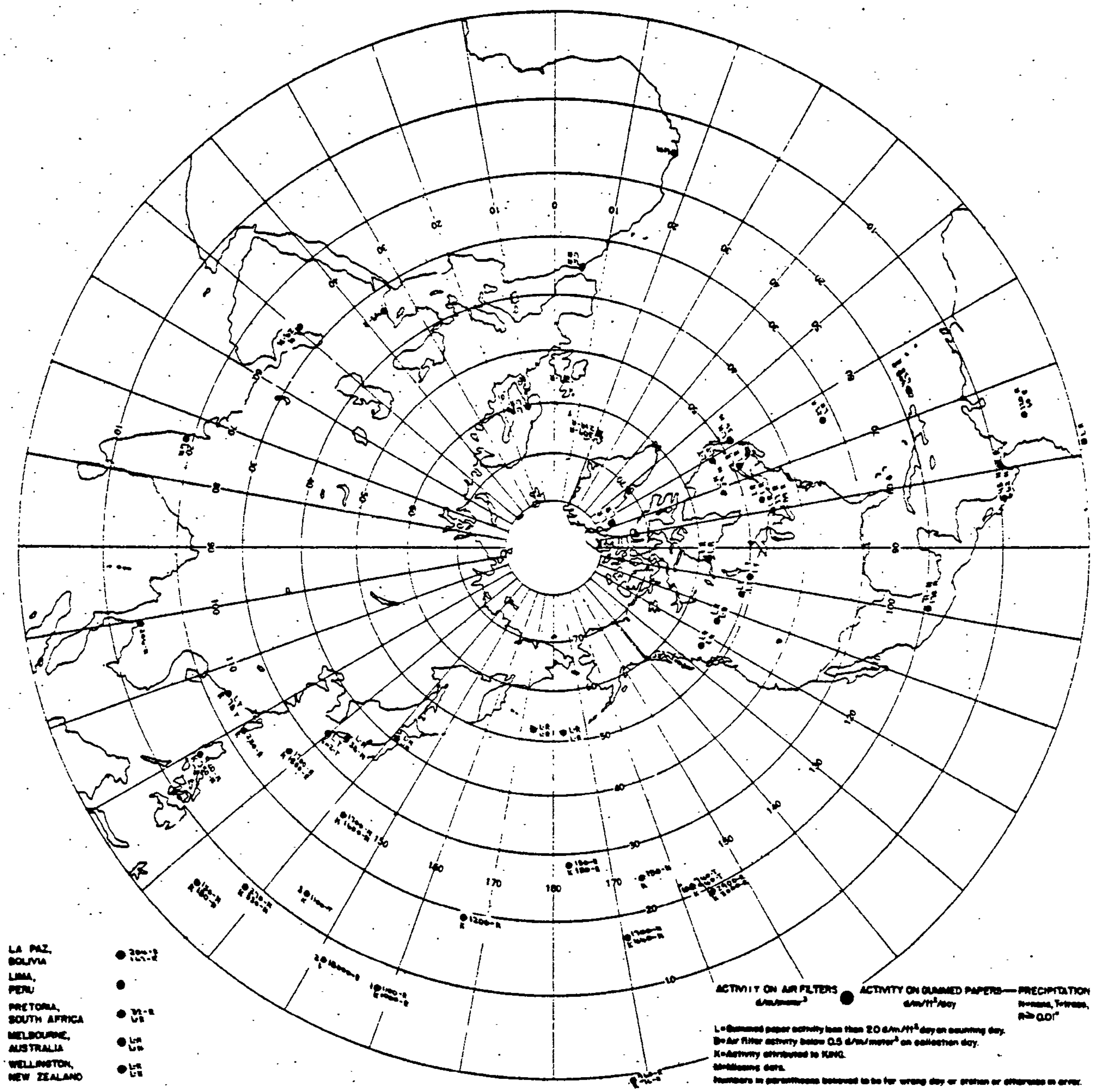

Figure A.47 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 24 Nov. 1952

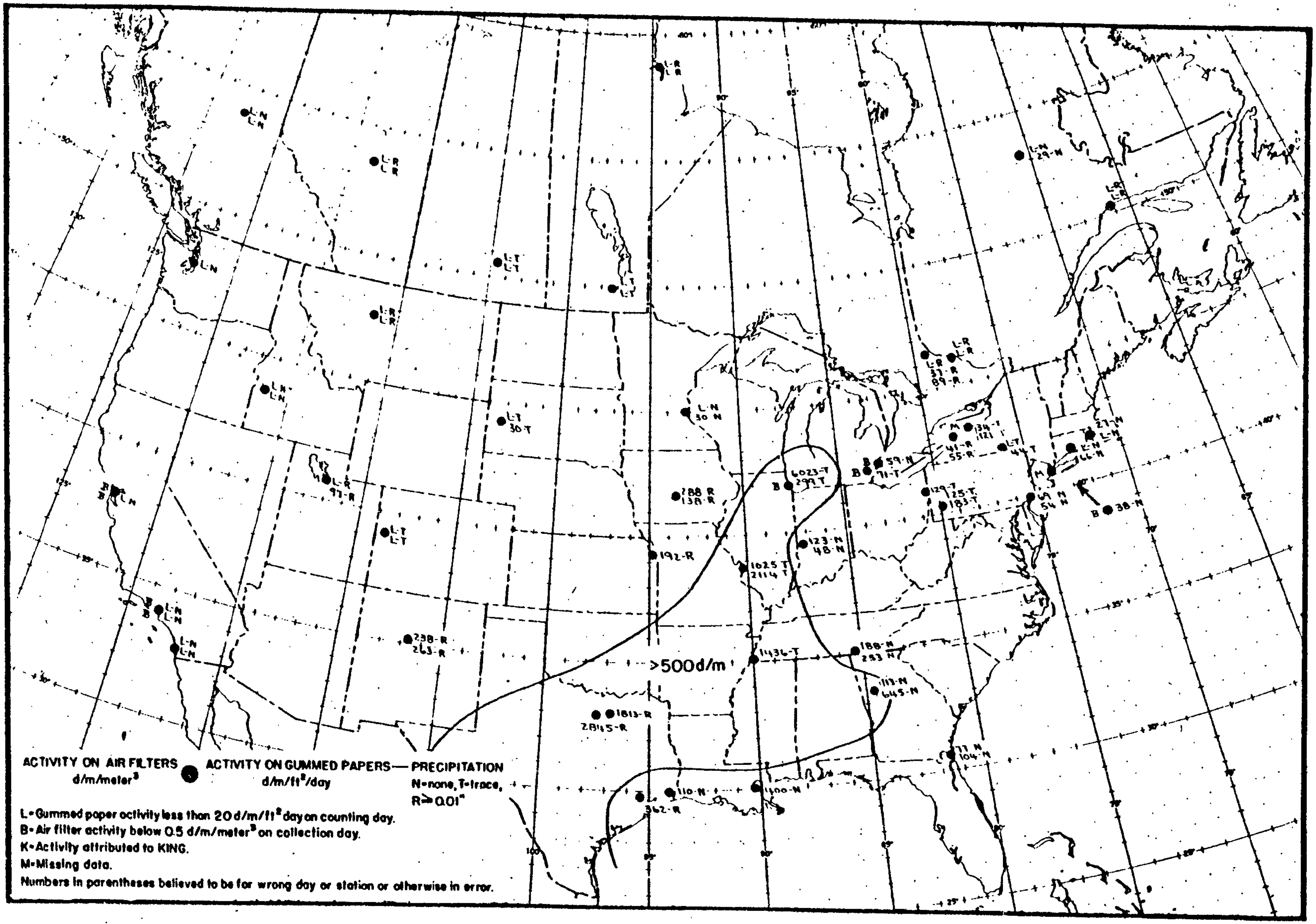

Figure A.48 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 24 Nov. 1952

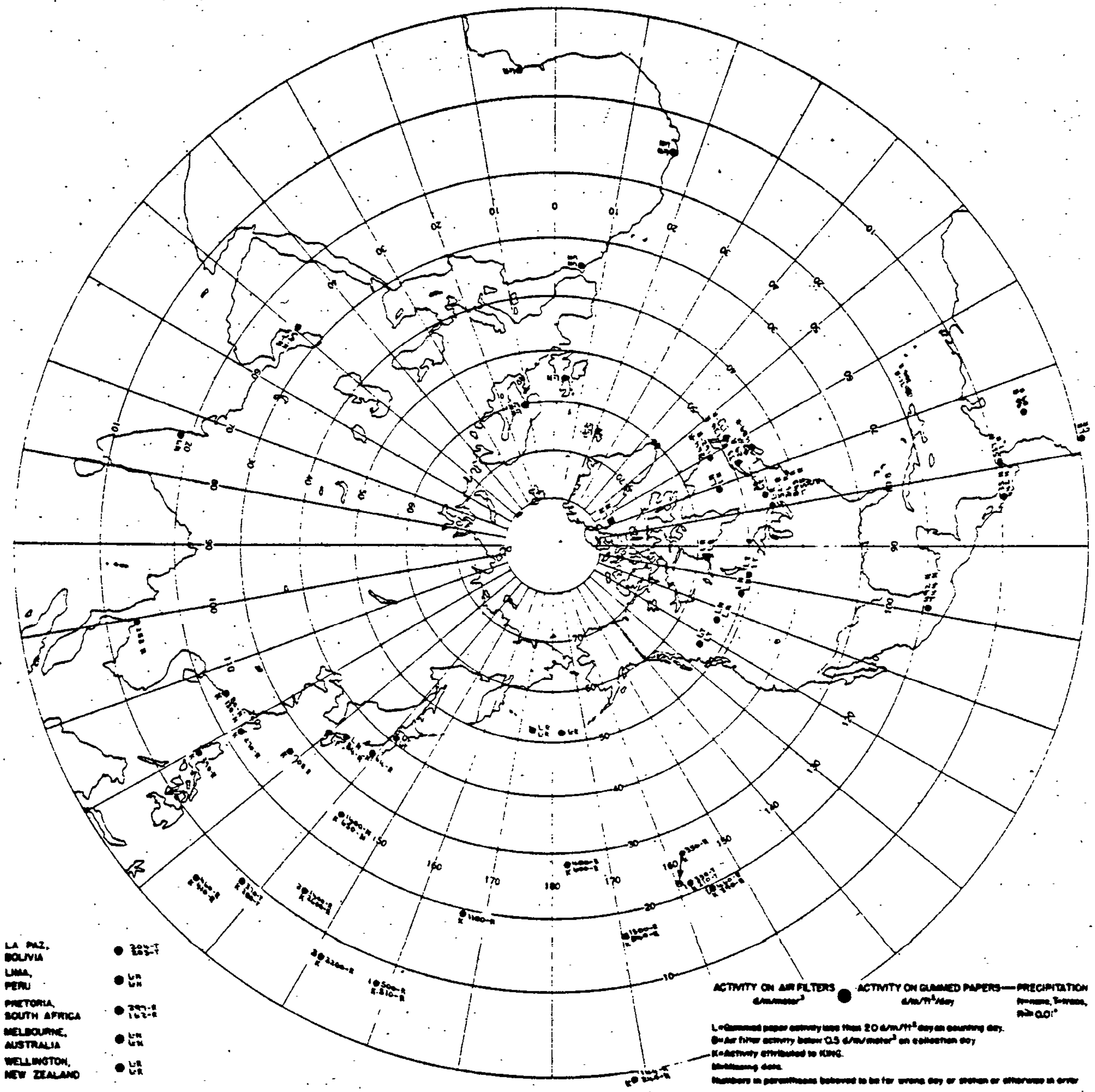

Figure A.49 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 25 Nov. 1952

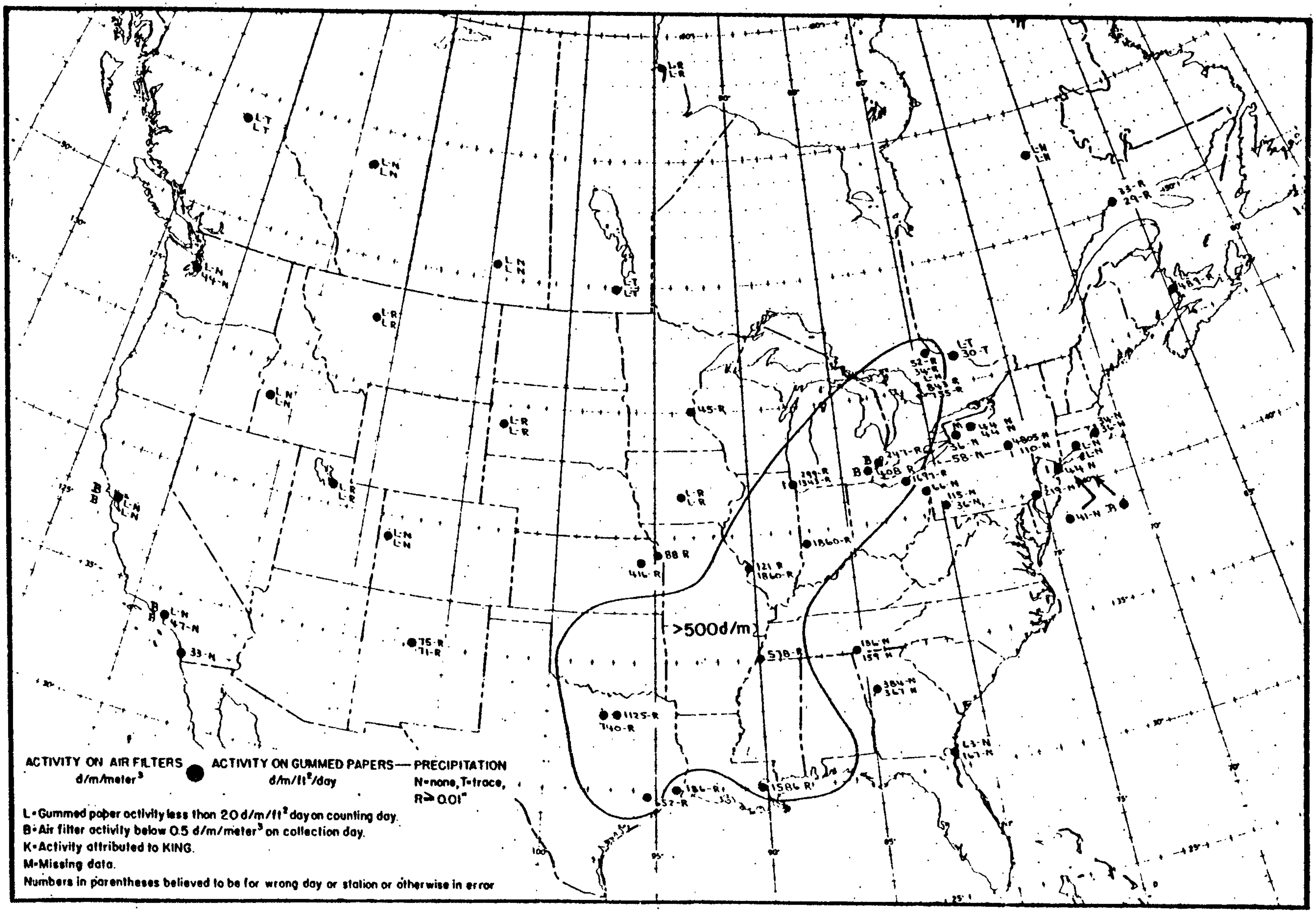

Figure A.50 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 25 Nov. 1952

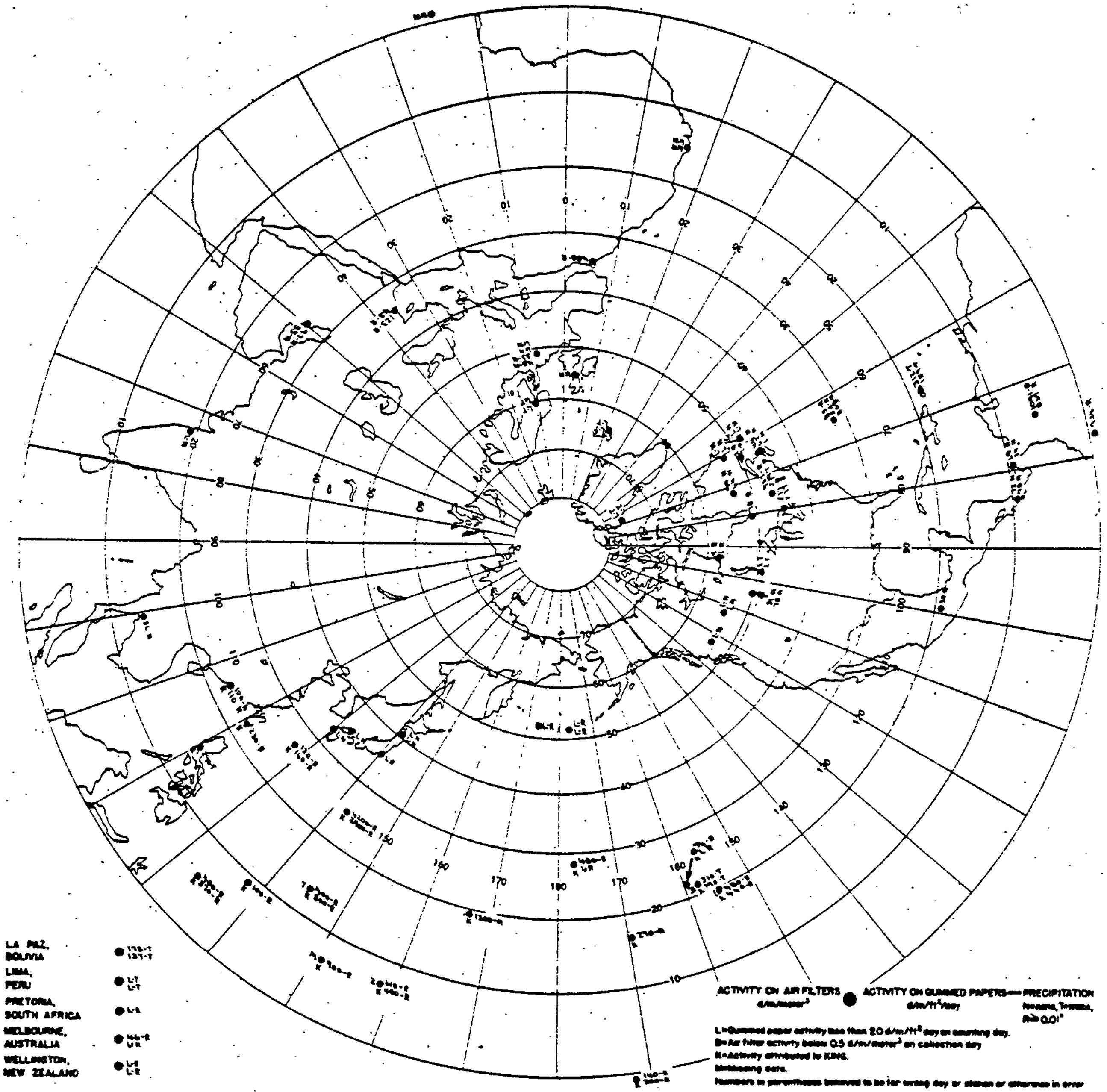

Figure A.51 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 26 Nov. 1952

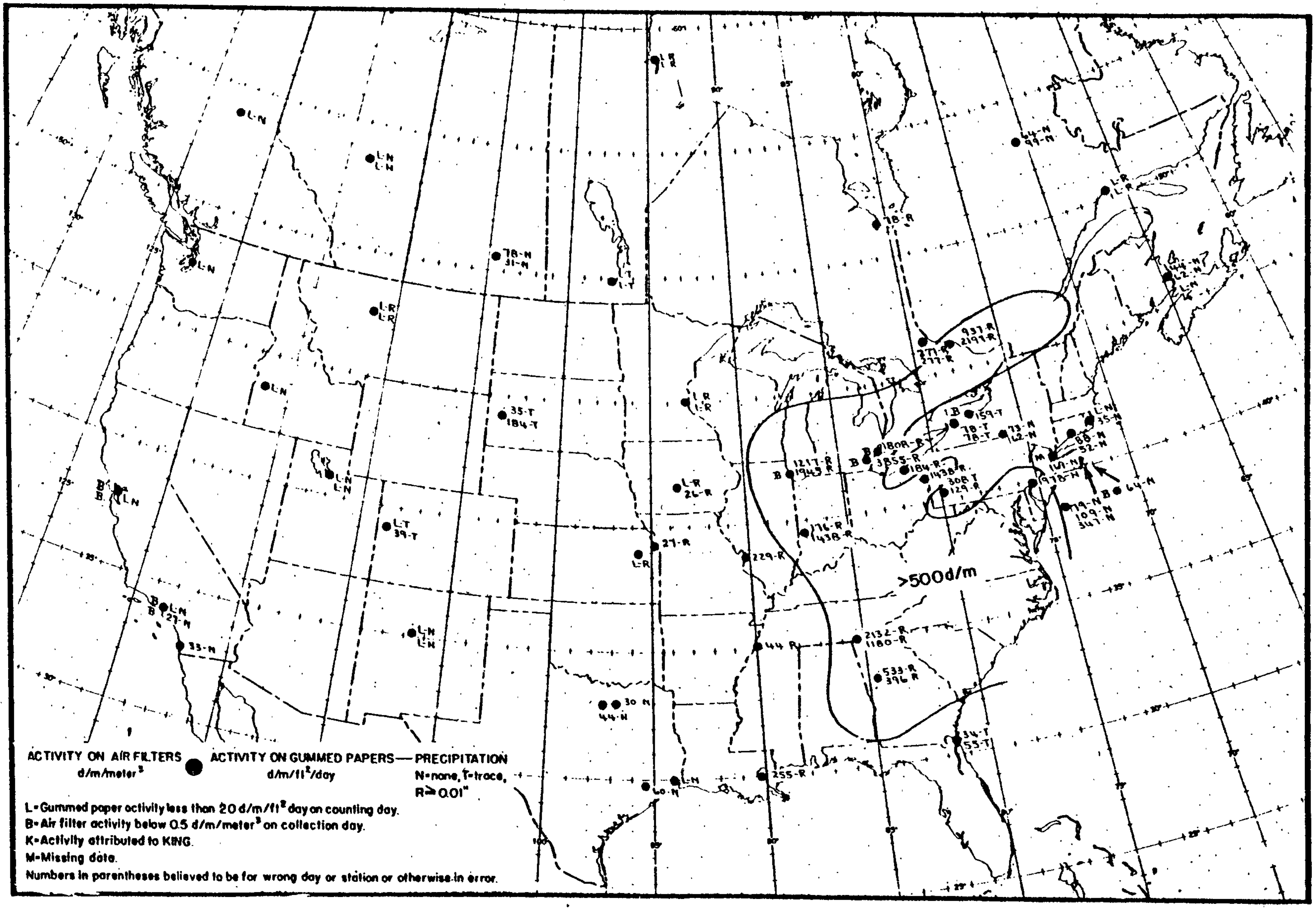

Figure A.52 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 26 Nov. 1952

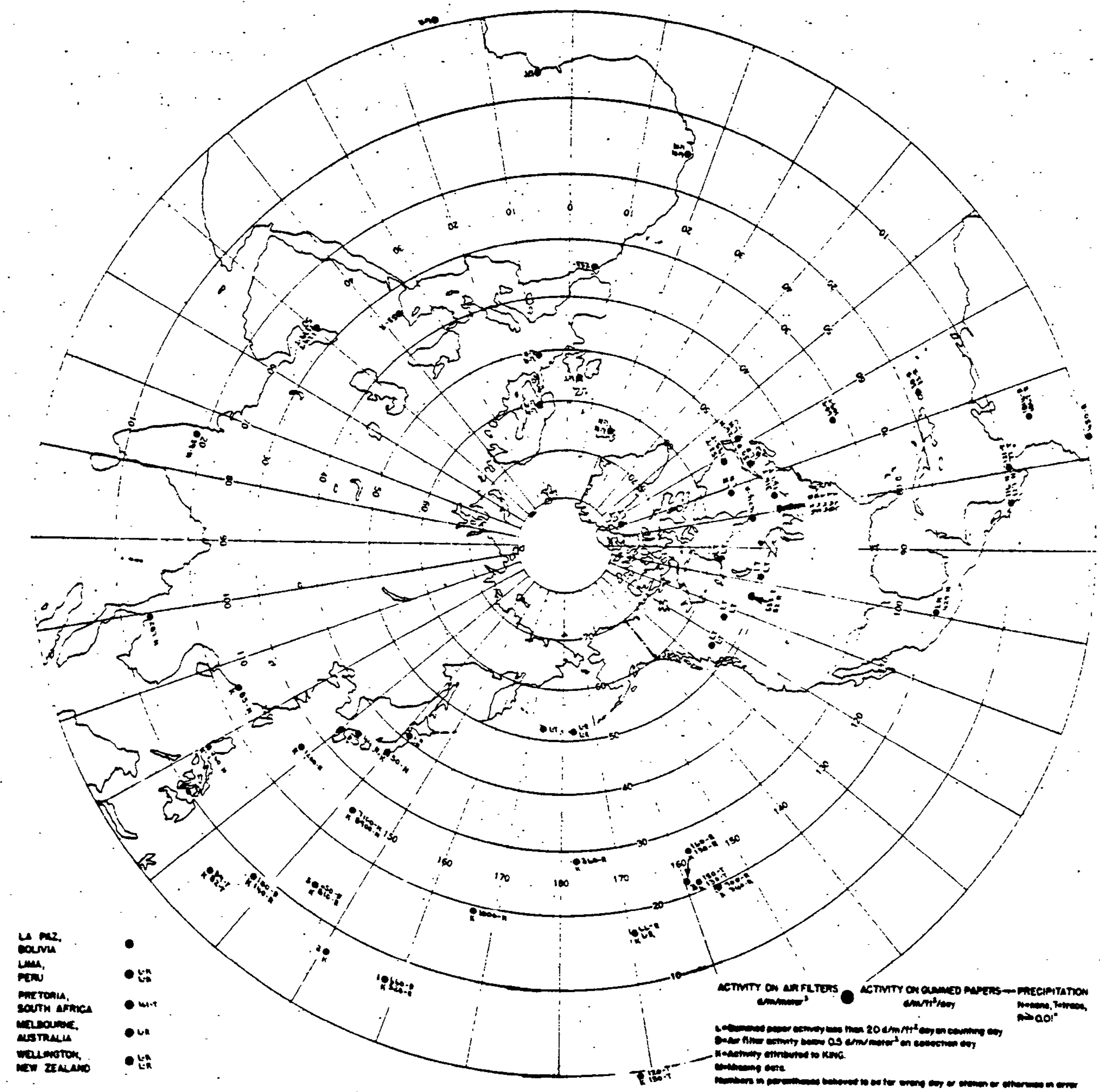

Figure A.53 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 27 Nov. 1952

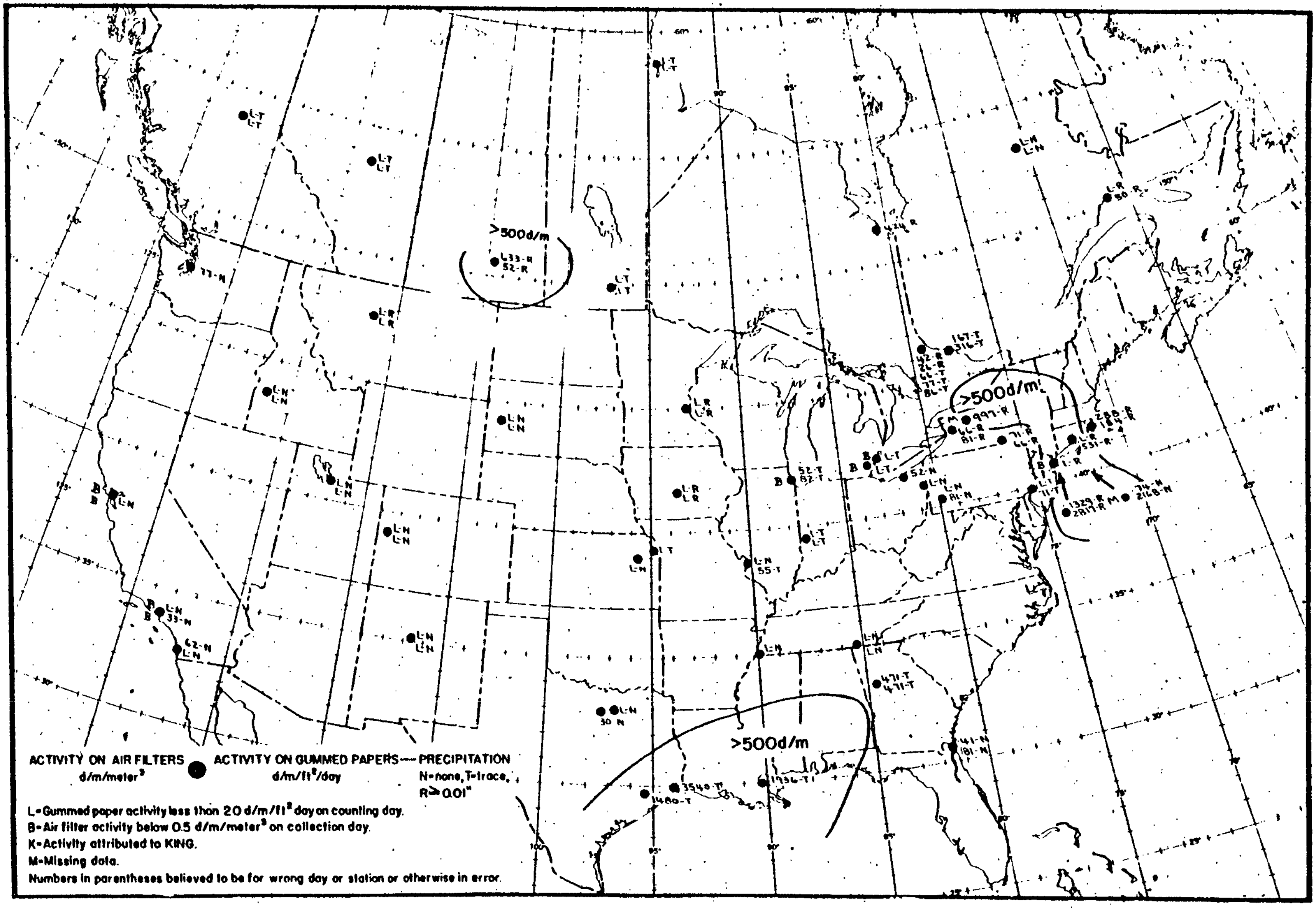

Figure A.54 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 27 Nov. 1952

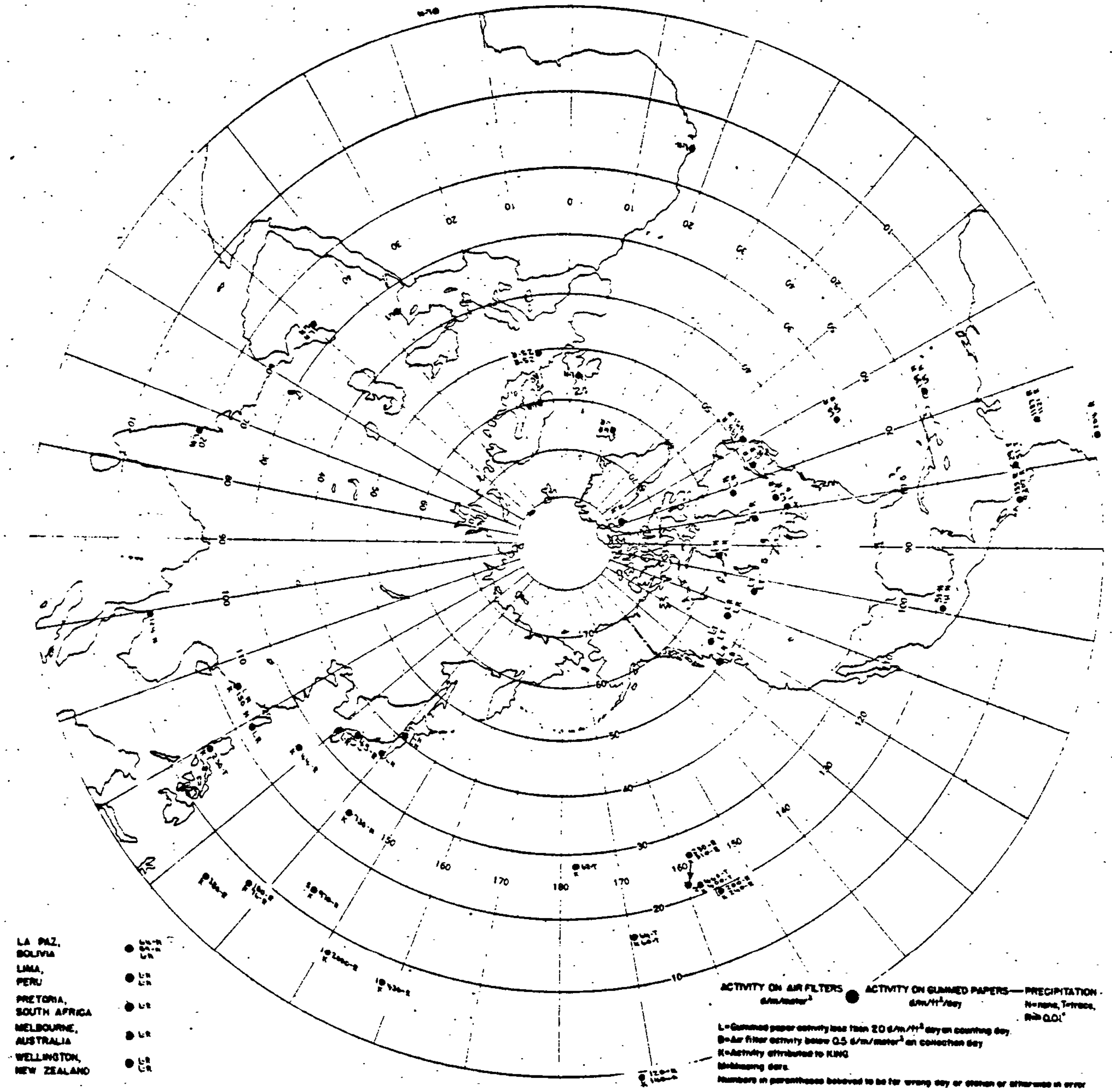

Figure A.55 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 28 Nov. 1952

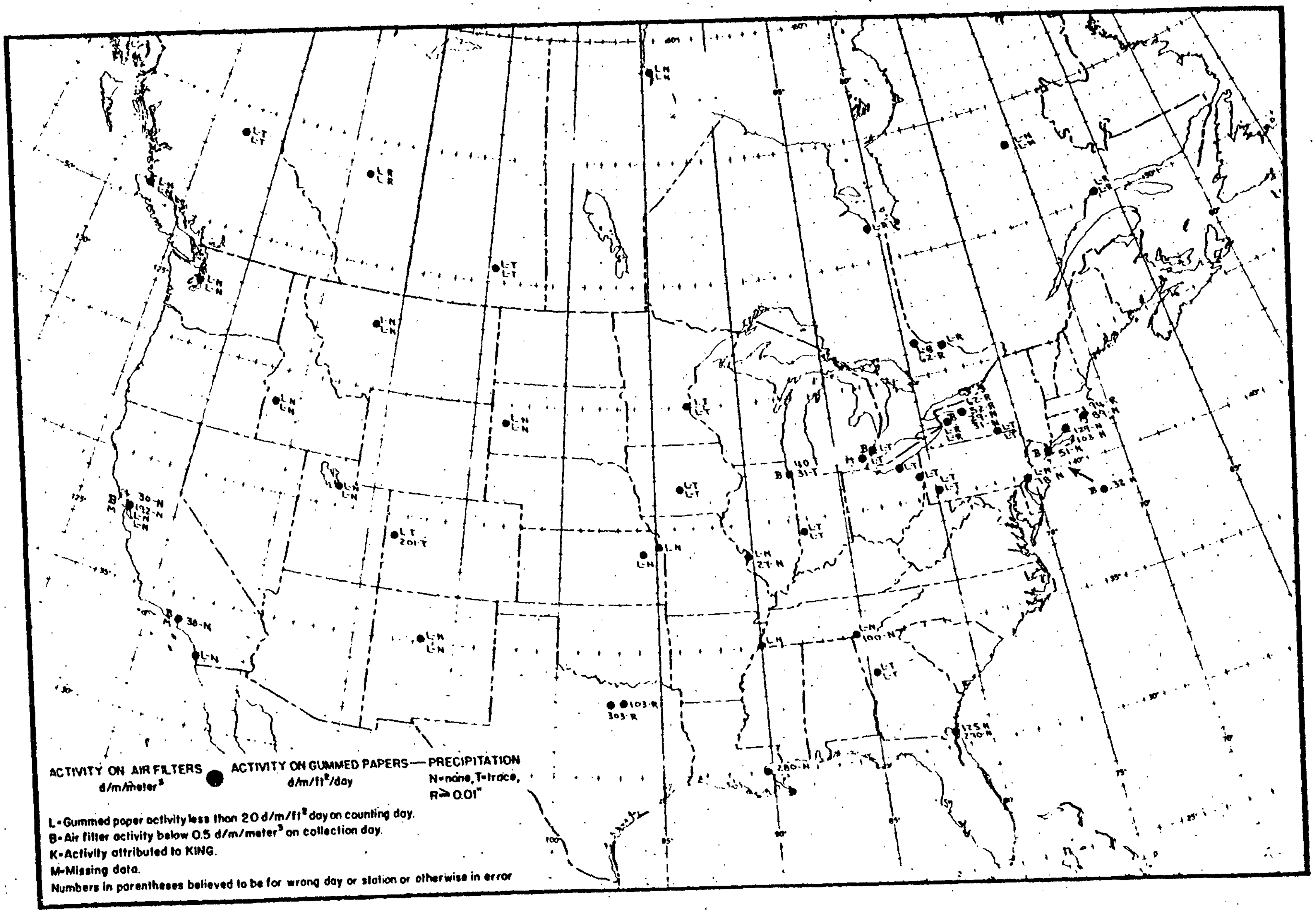

Figure A.56 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 28 Nov. 1952

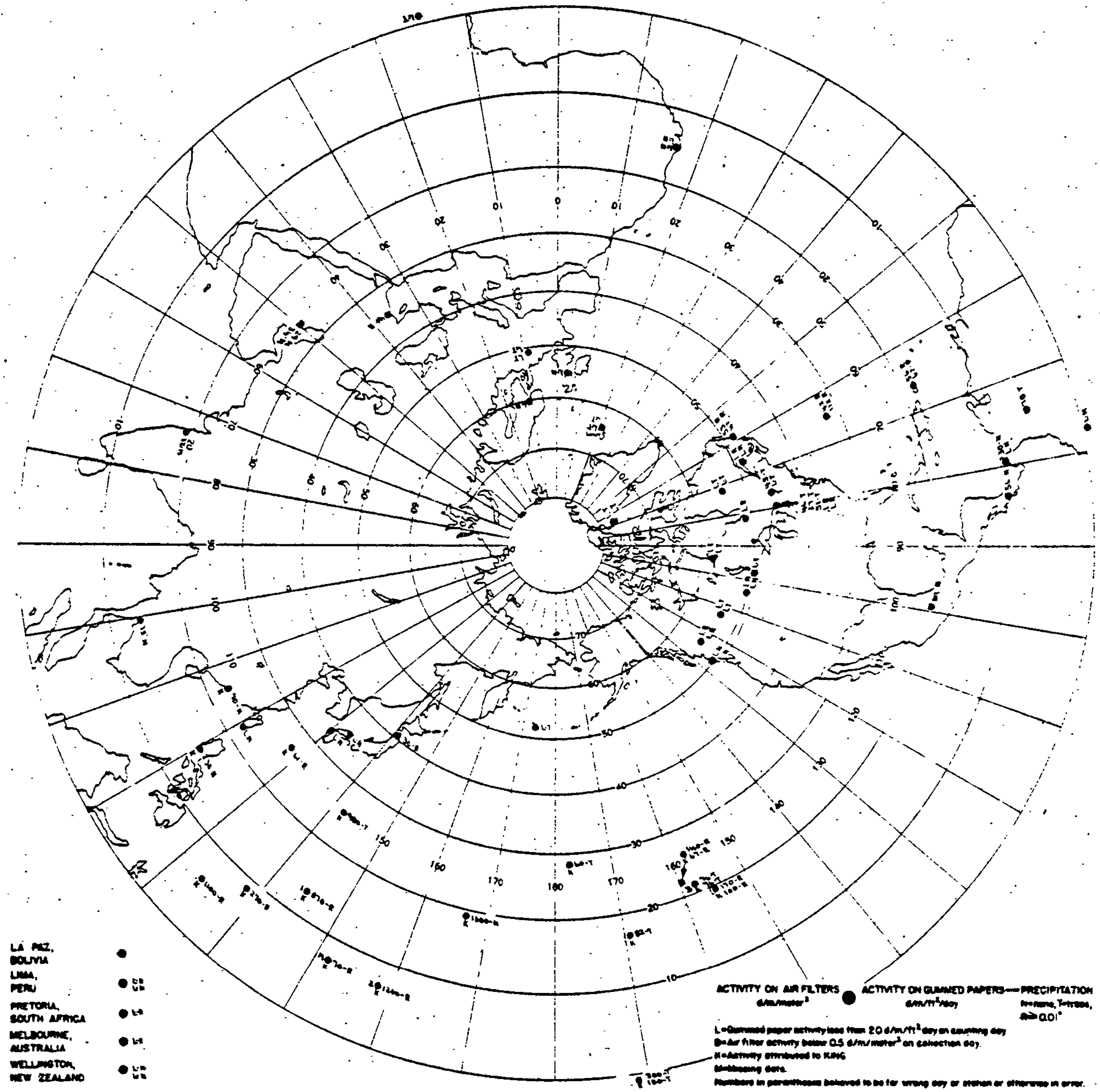

Figure A.57 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 29 Nov. 1952

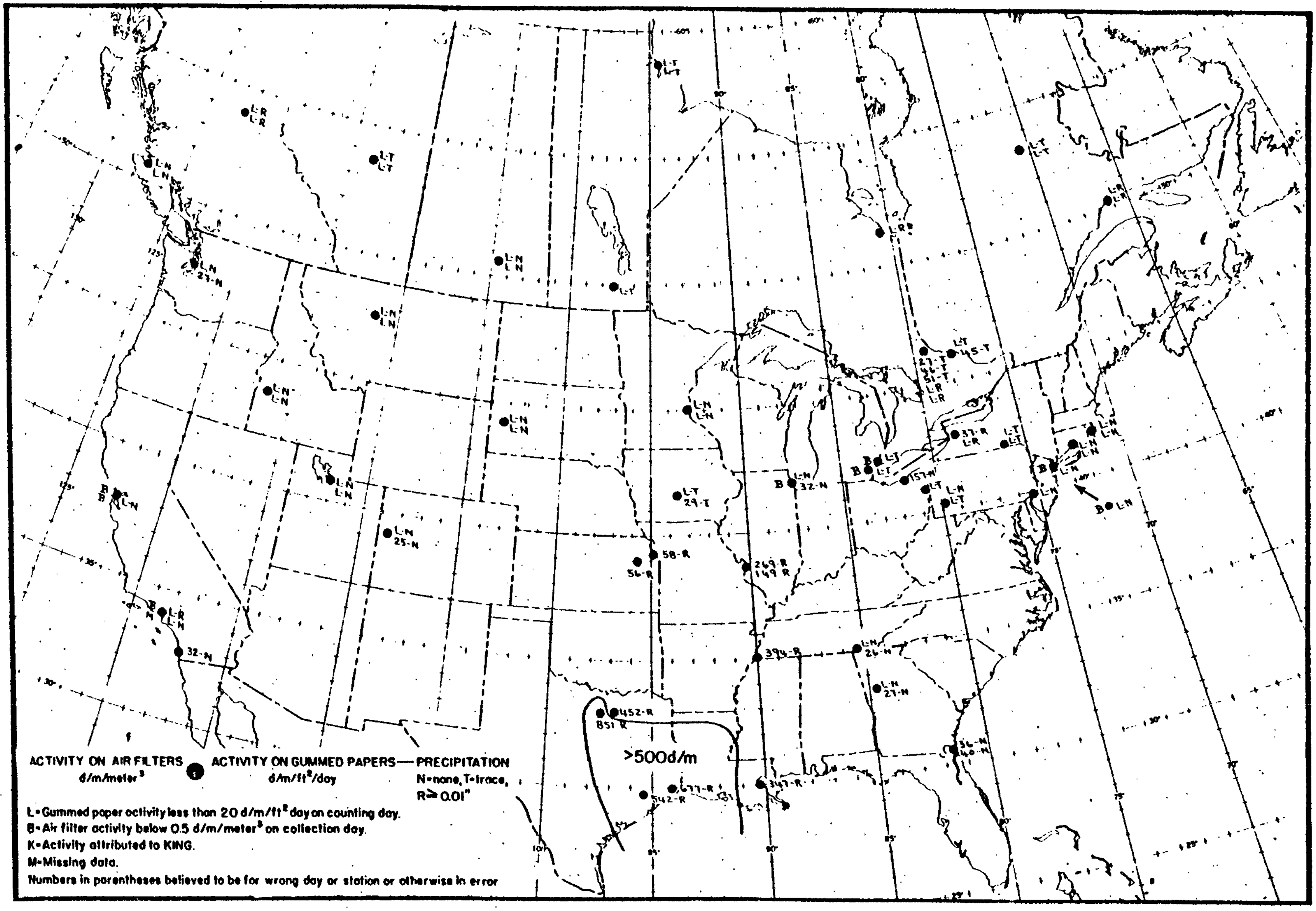

Figure A.58 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 29 Nov. 1952

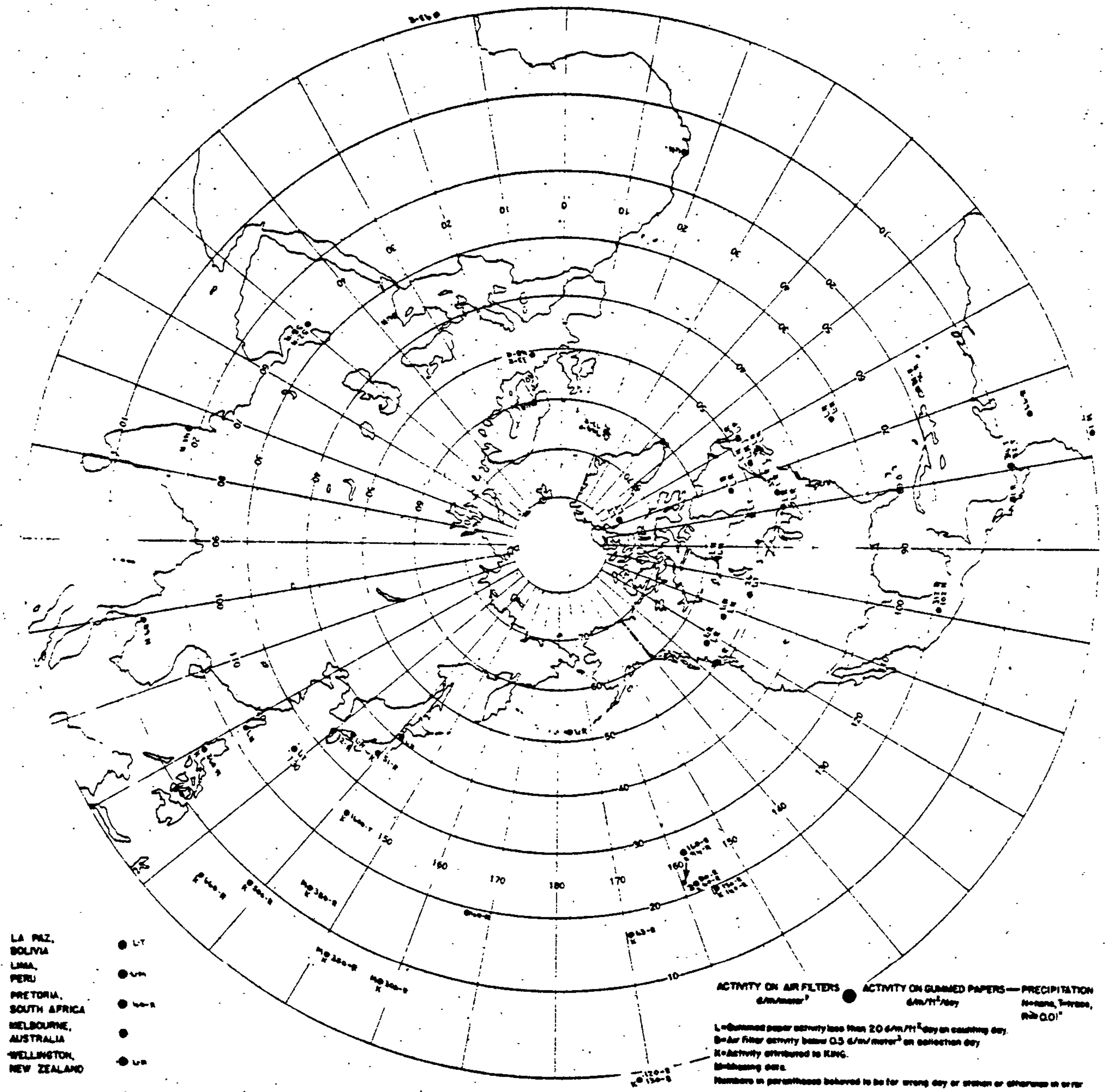

Figure A.59 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 30 Nov. 1952

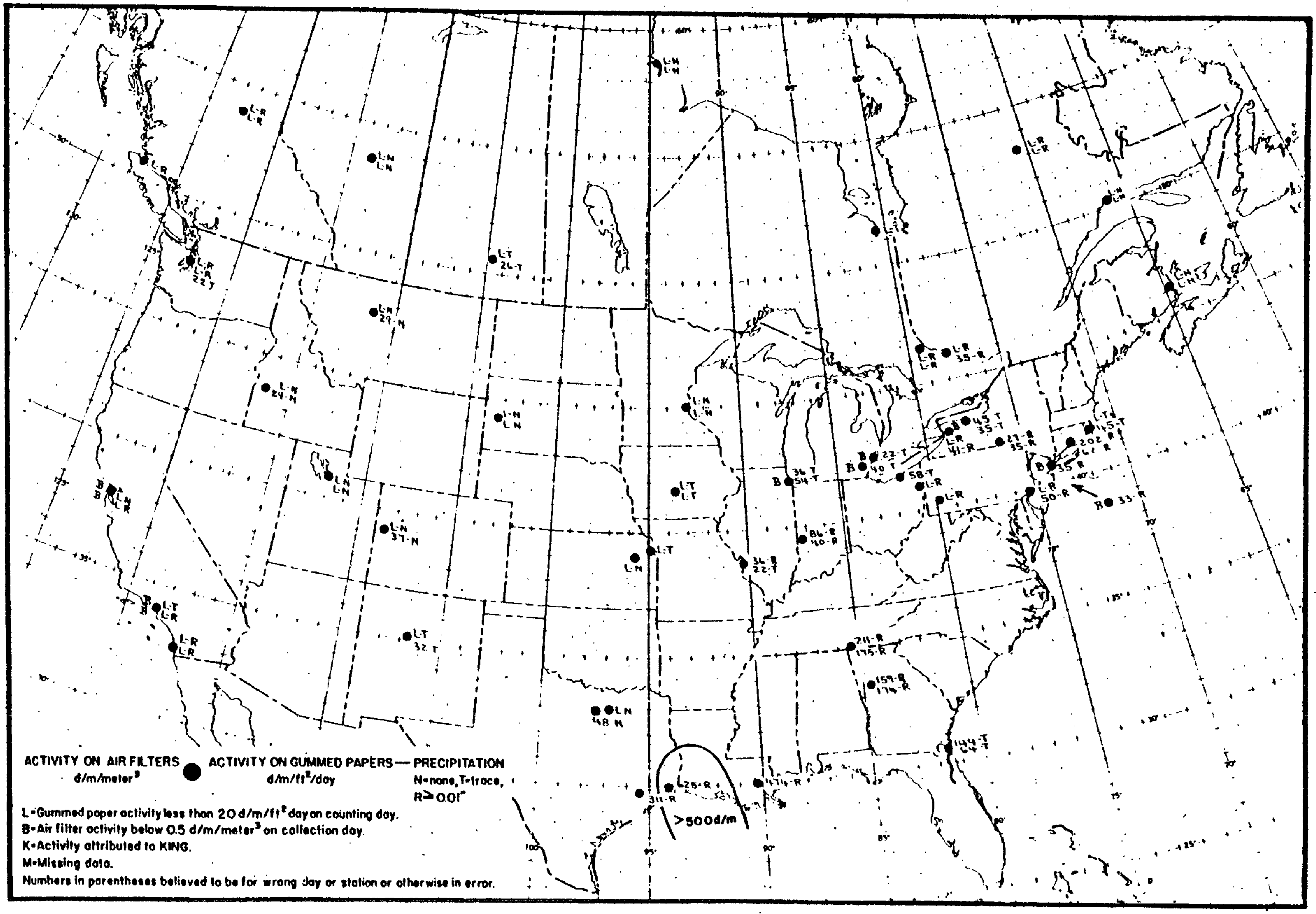

Figure A.60 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 30 Nov. 1952

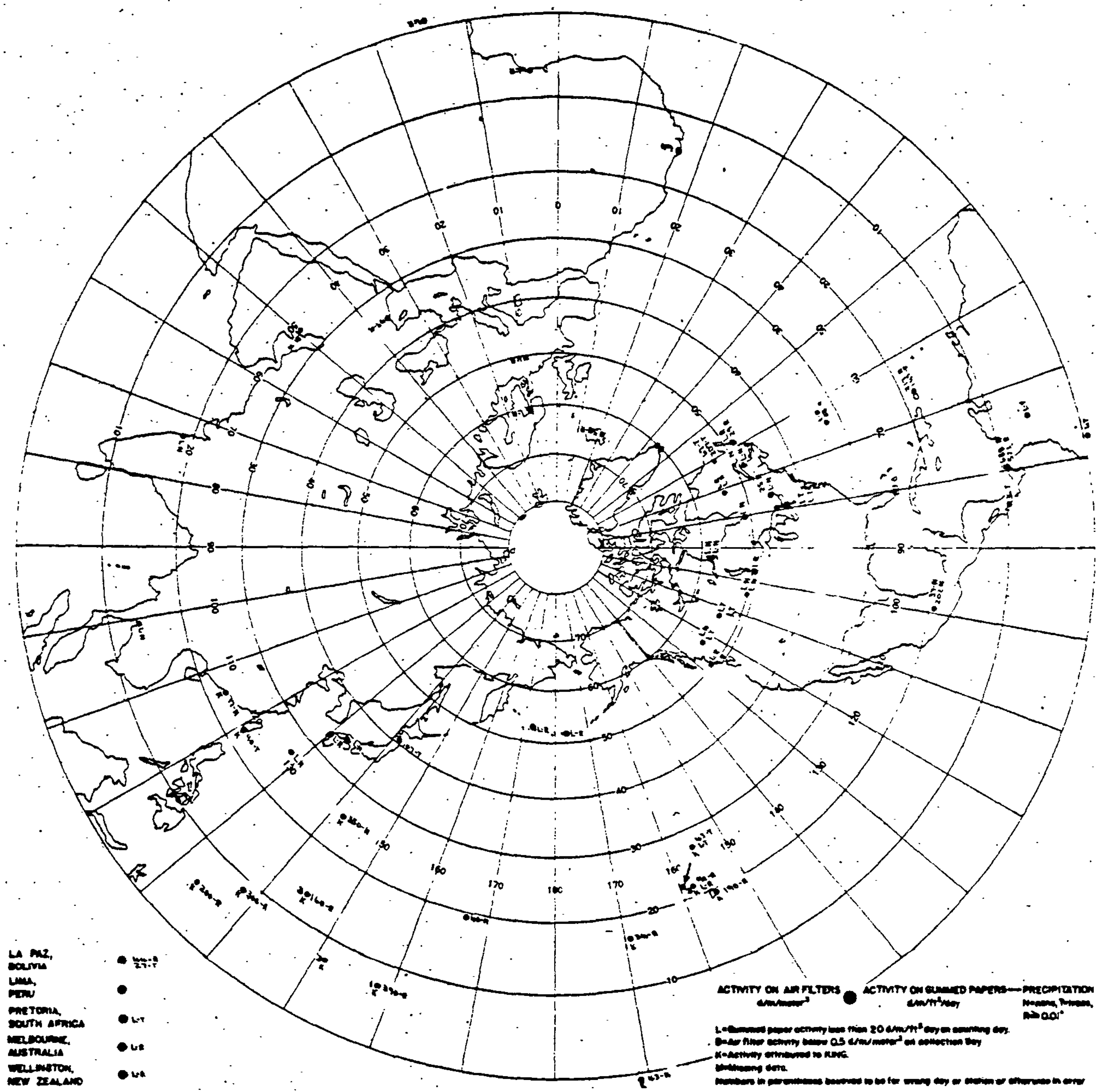

Figure A.61 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 1 Dec. 1952

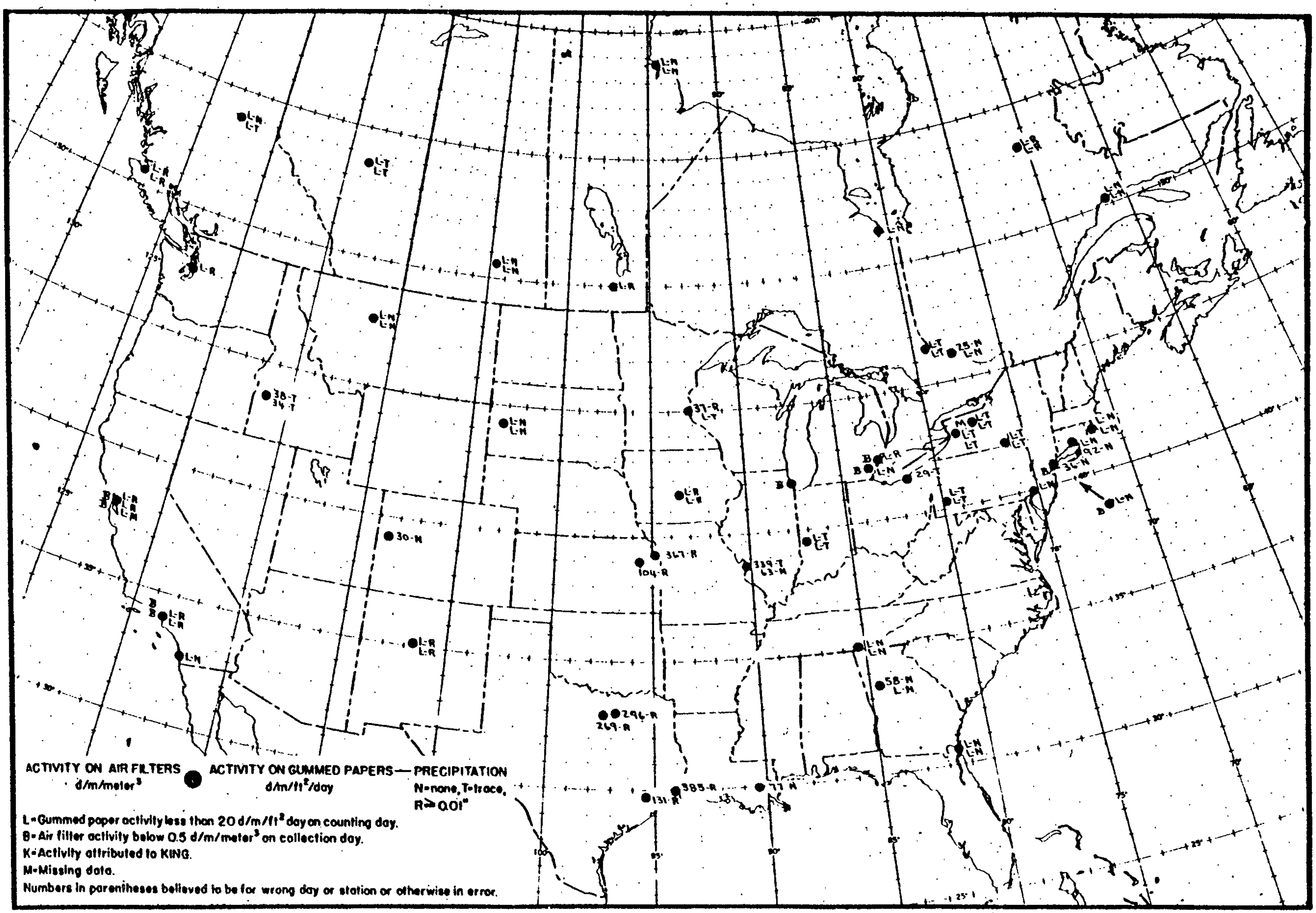

Figure A.62 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 1 Dec. 1952

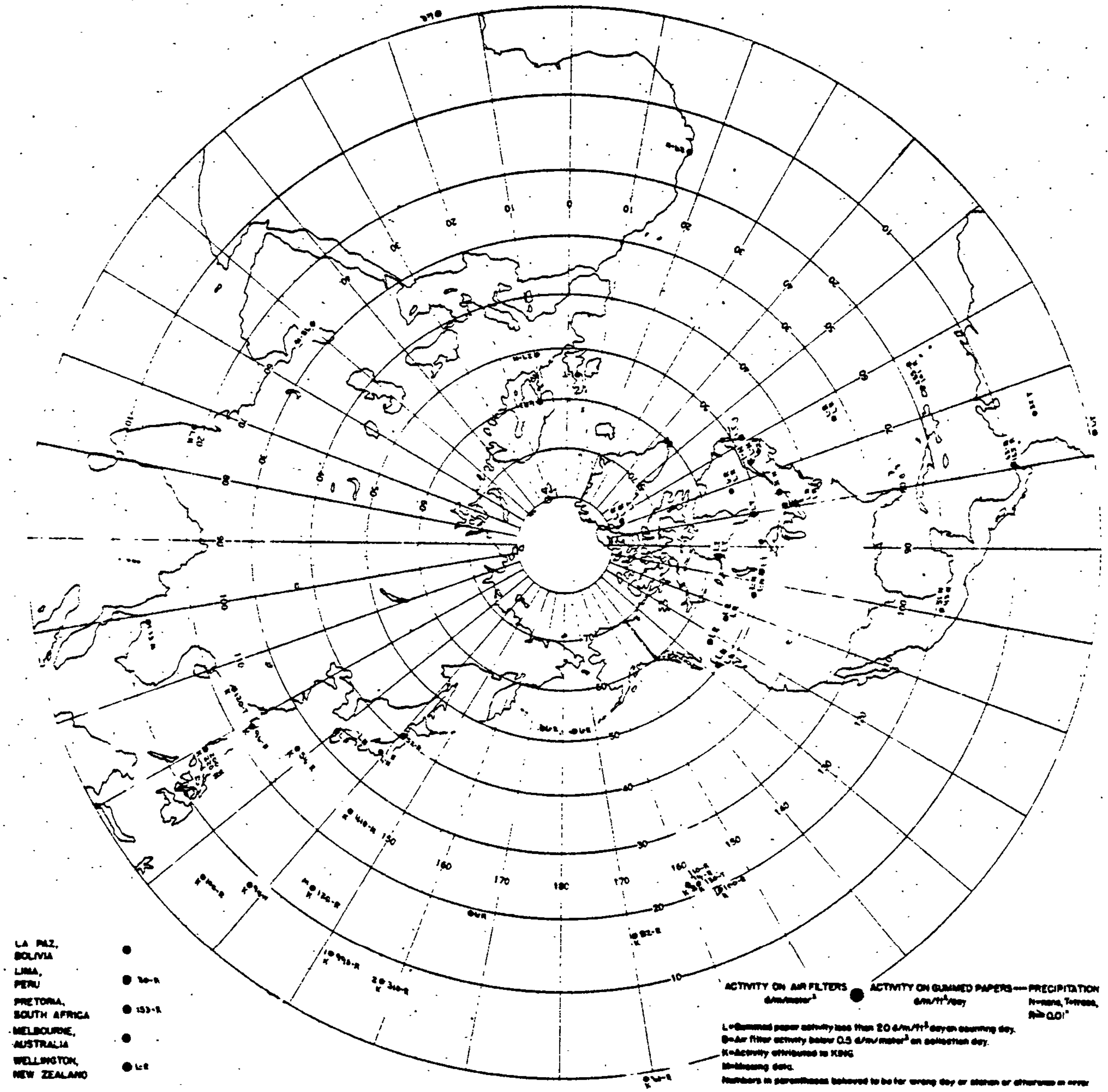

Figure A.63 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 2 Dec. 1952

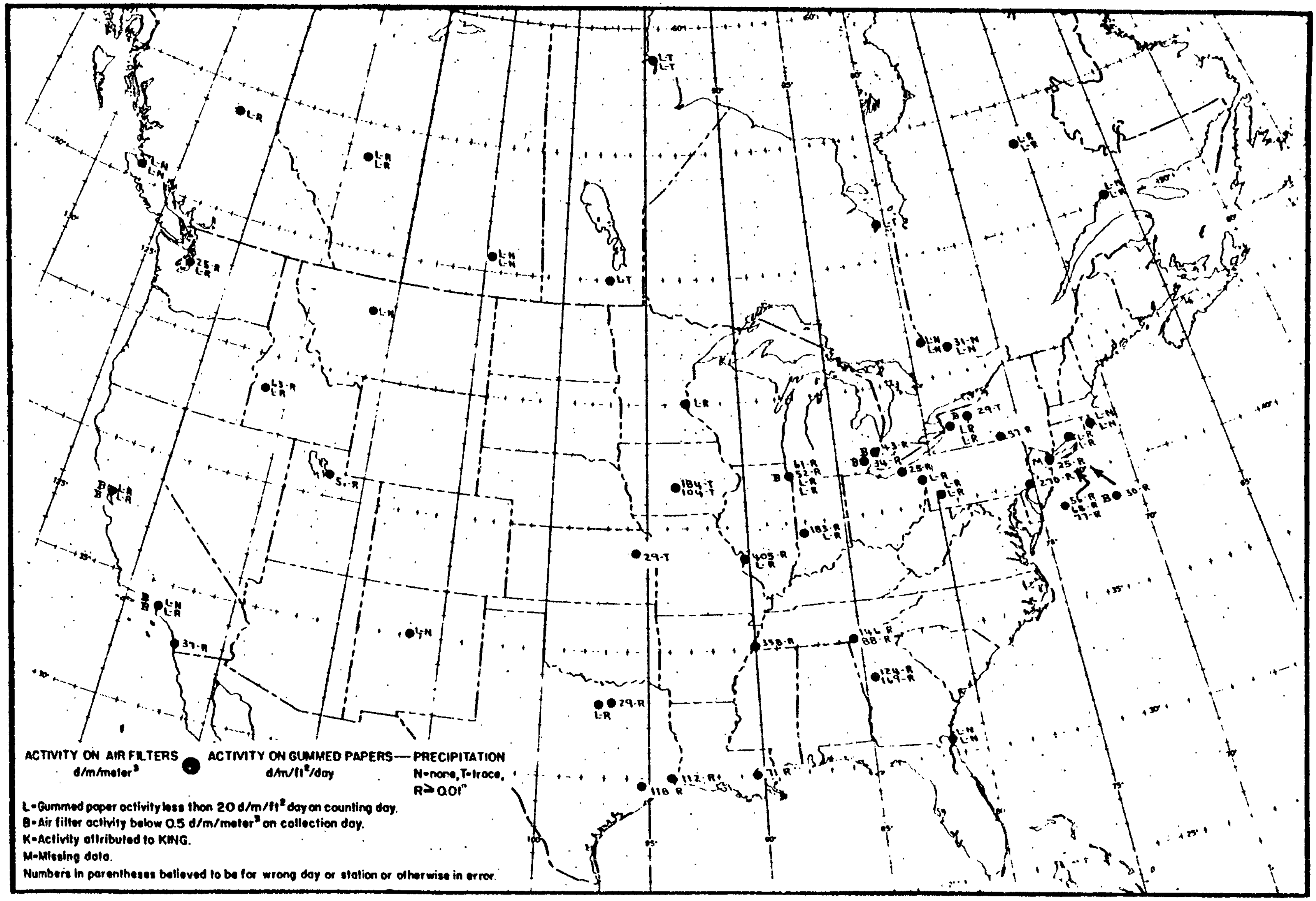

Figure A.64 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 2 Dec. 1952

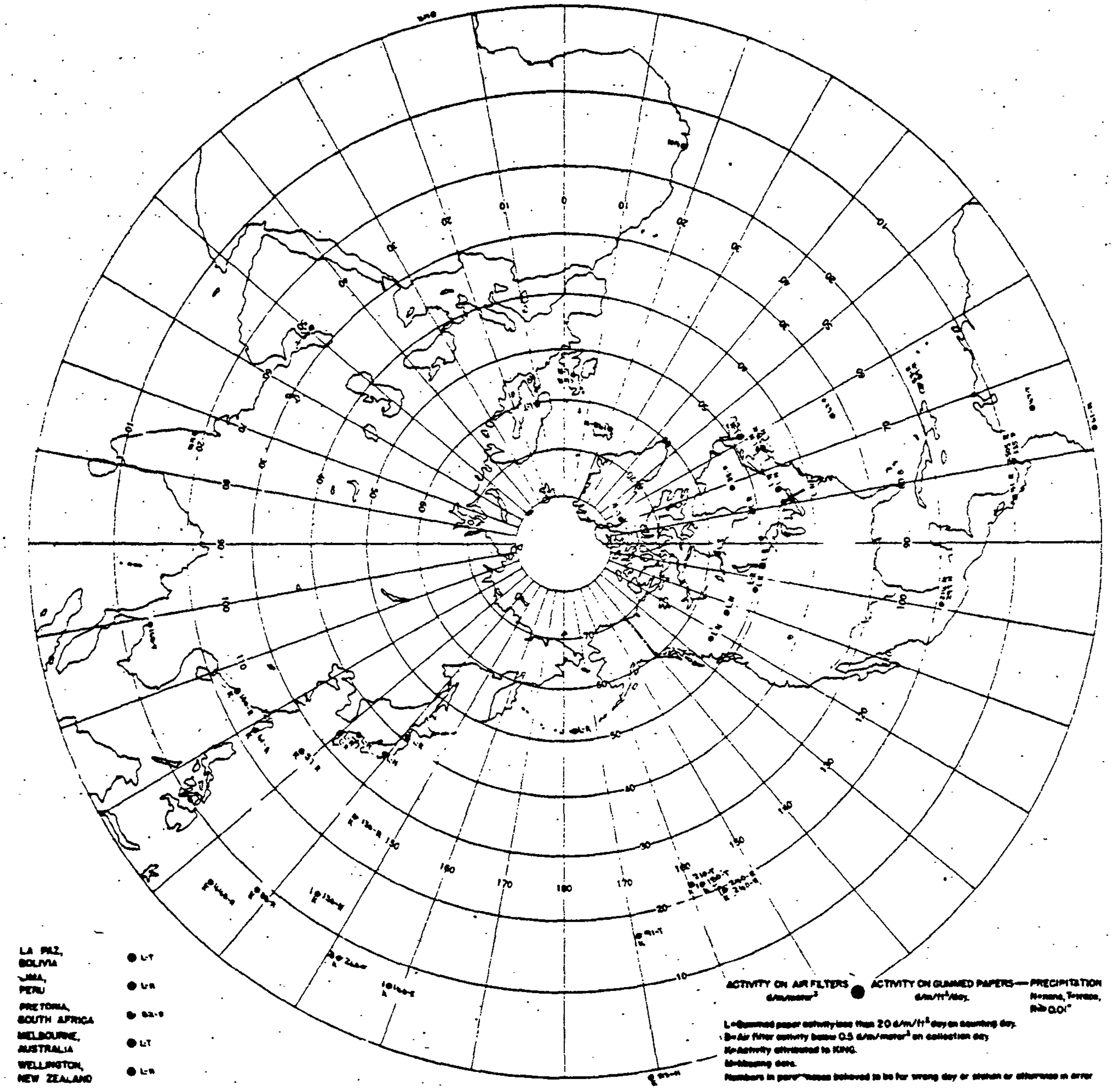

Figure A.65 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 3 Dec. 1952

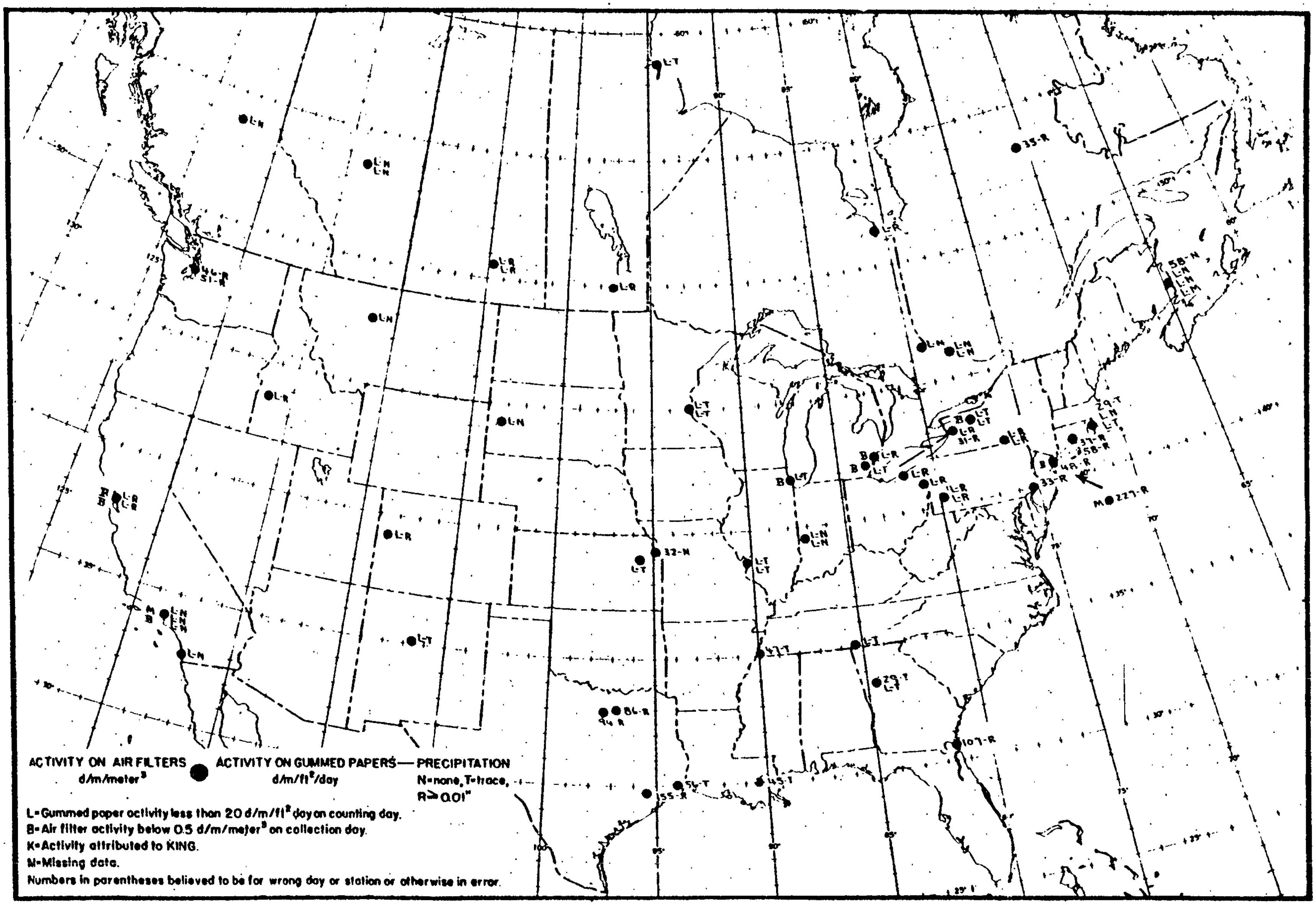

Figure A.66 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 3 Dec. 1952

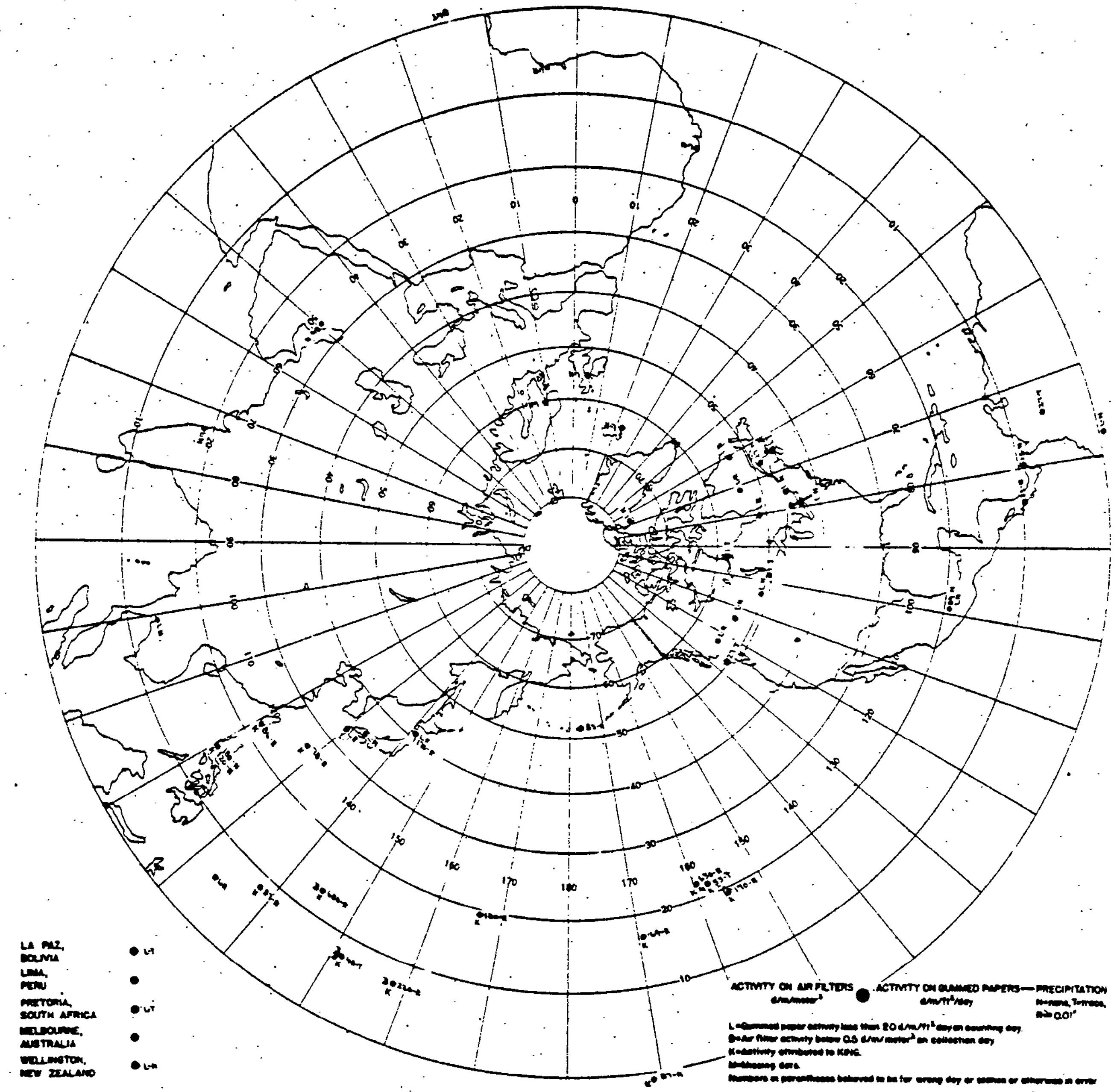

Figure A.67 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 4 Dec. 1952

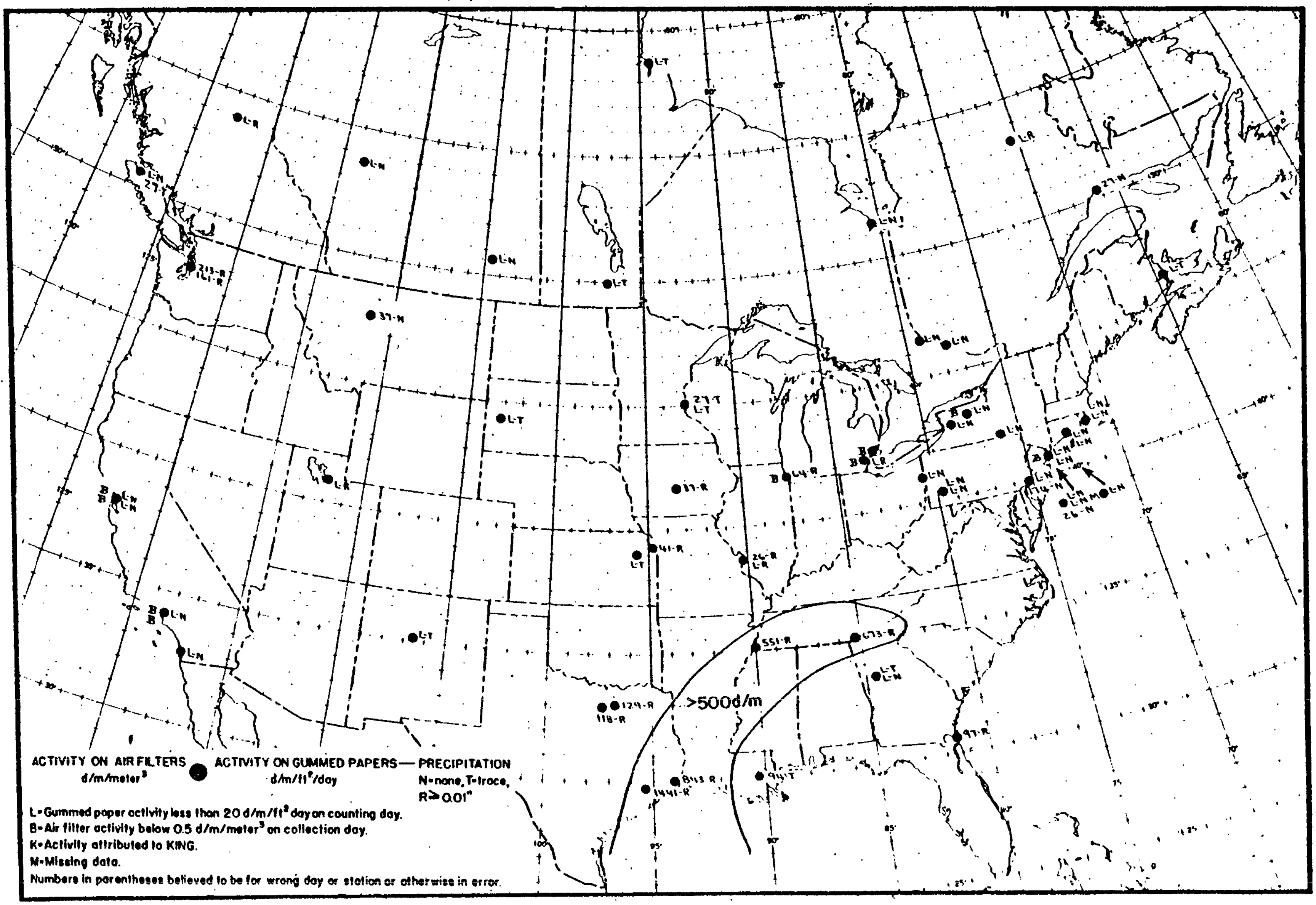

Figure A.68 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 4 Dec. 1952

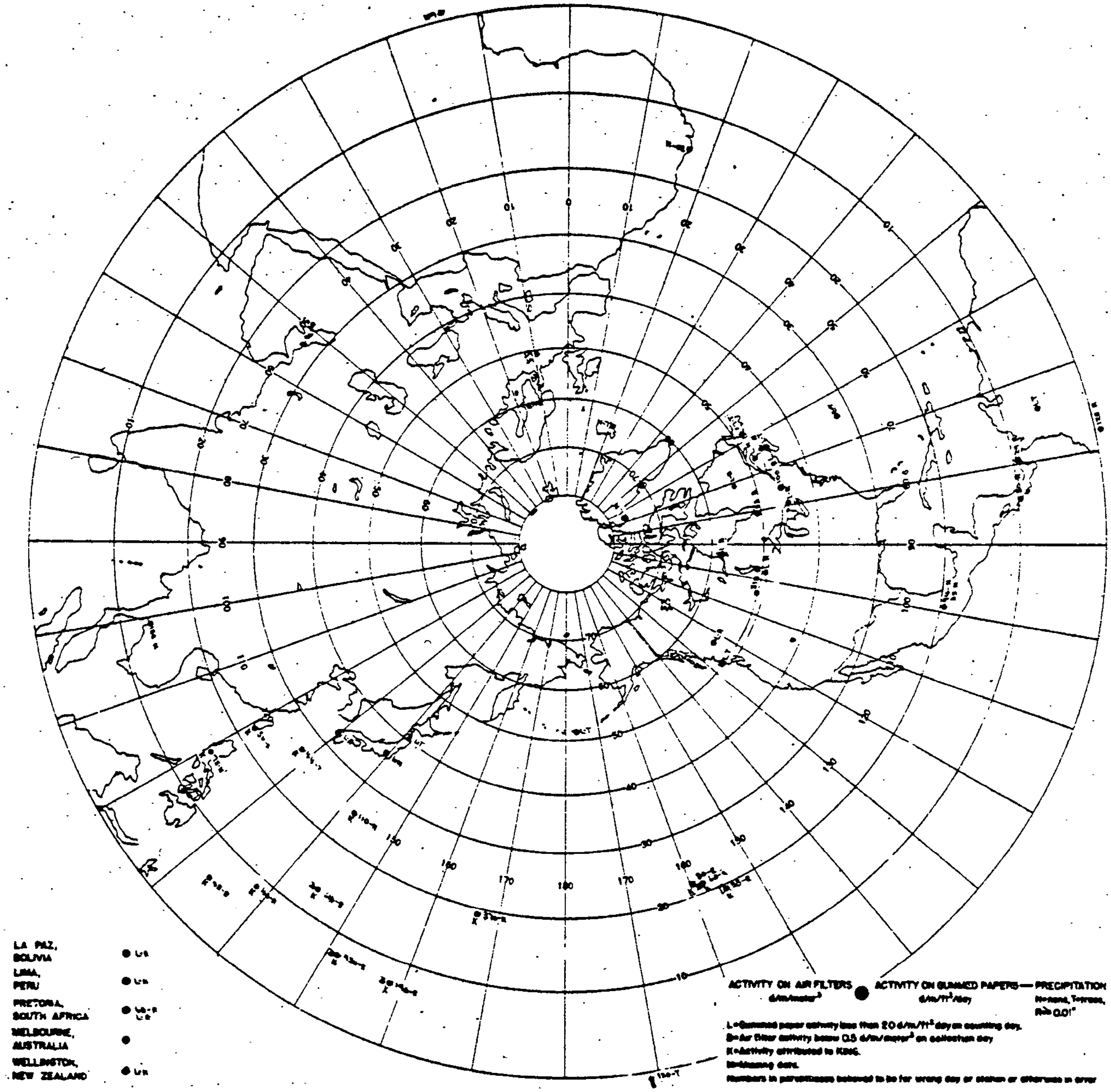

Figure A.69 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 5 Dec. 1952

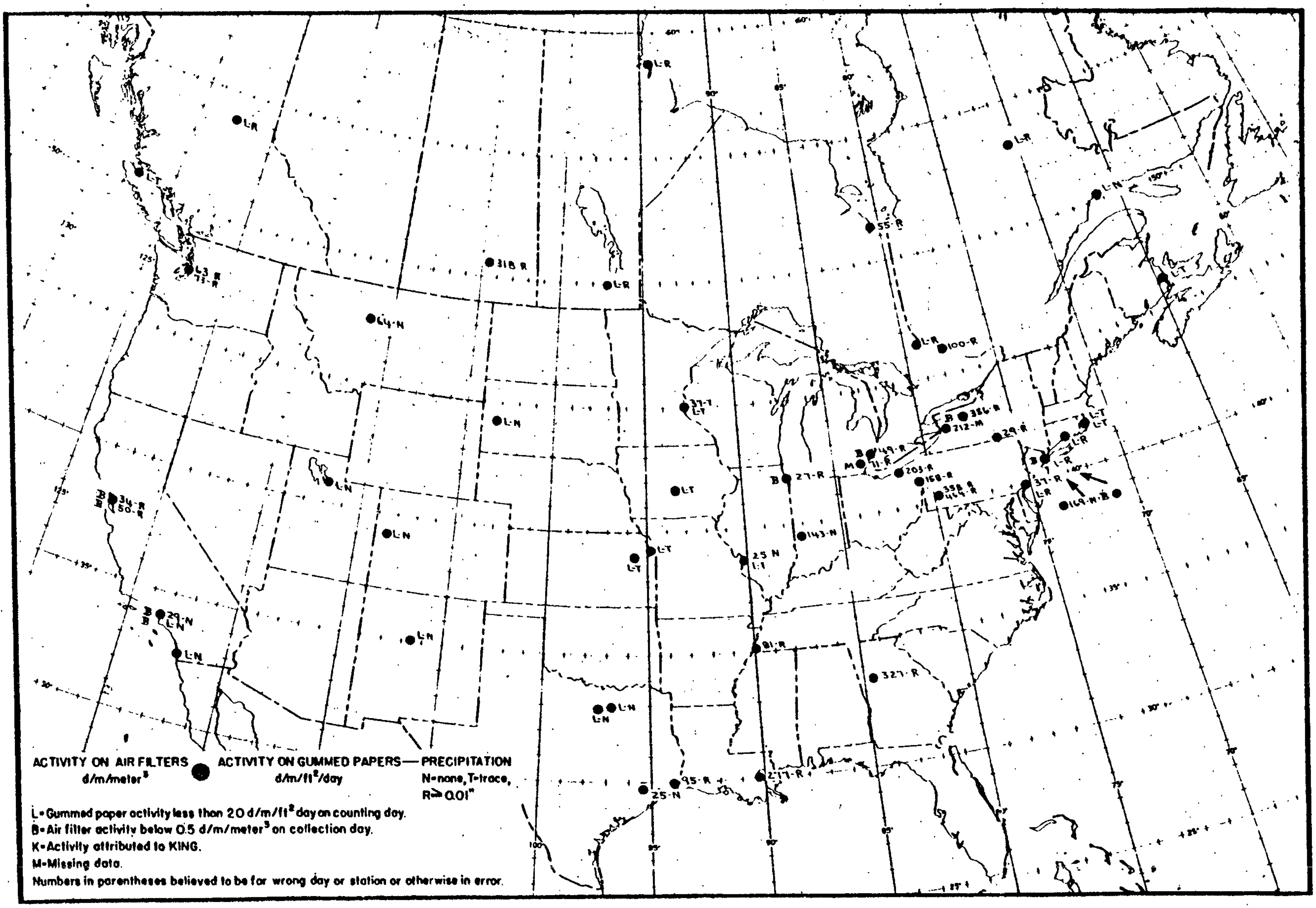

Figure A.70 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 5 Dec. 1952

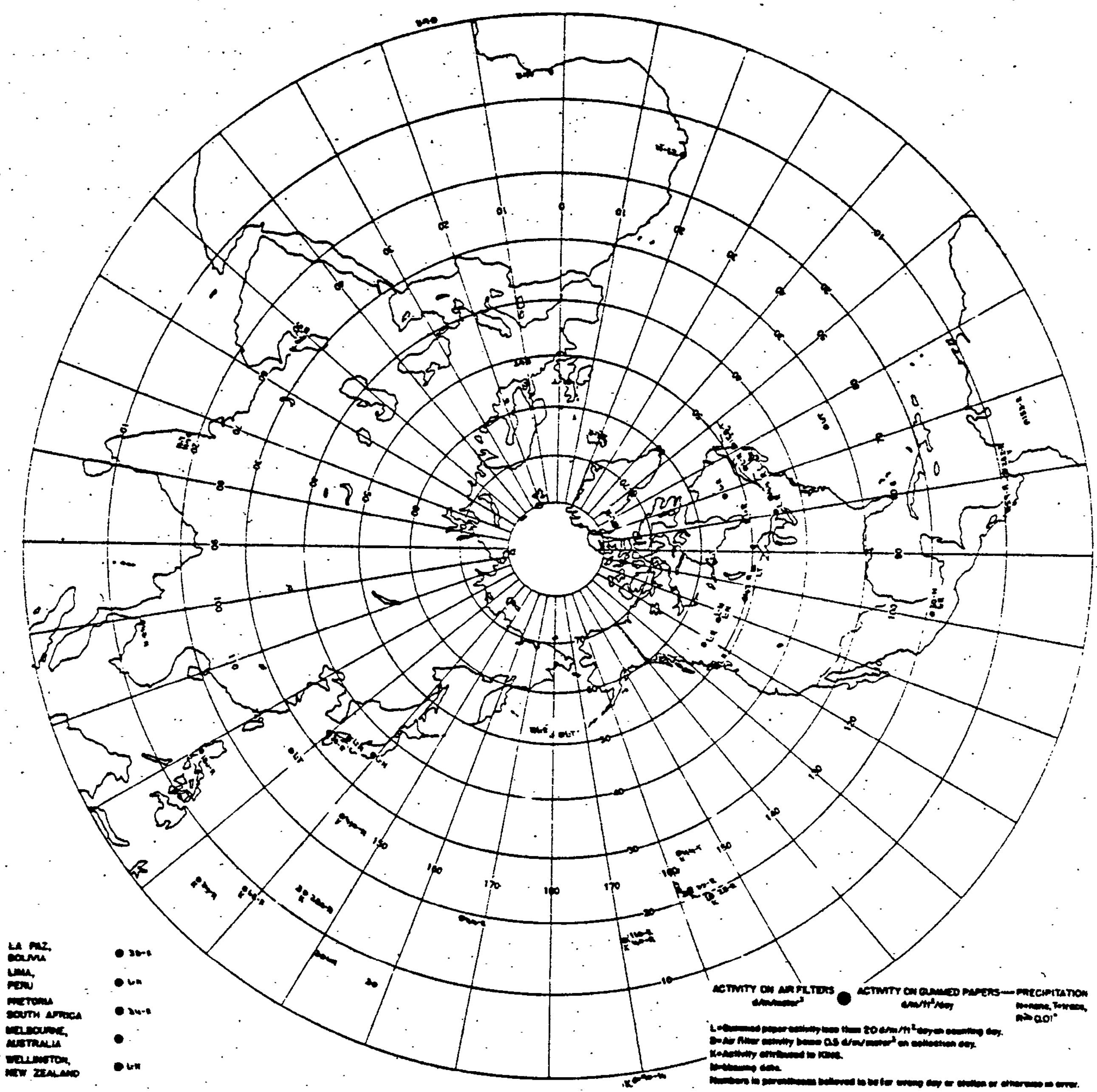

Figure A.71 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 6 Dec. 1952

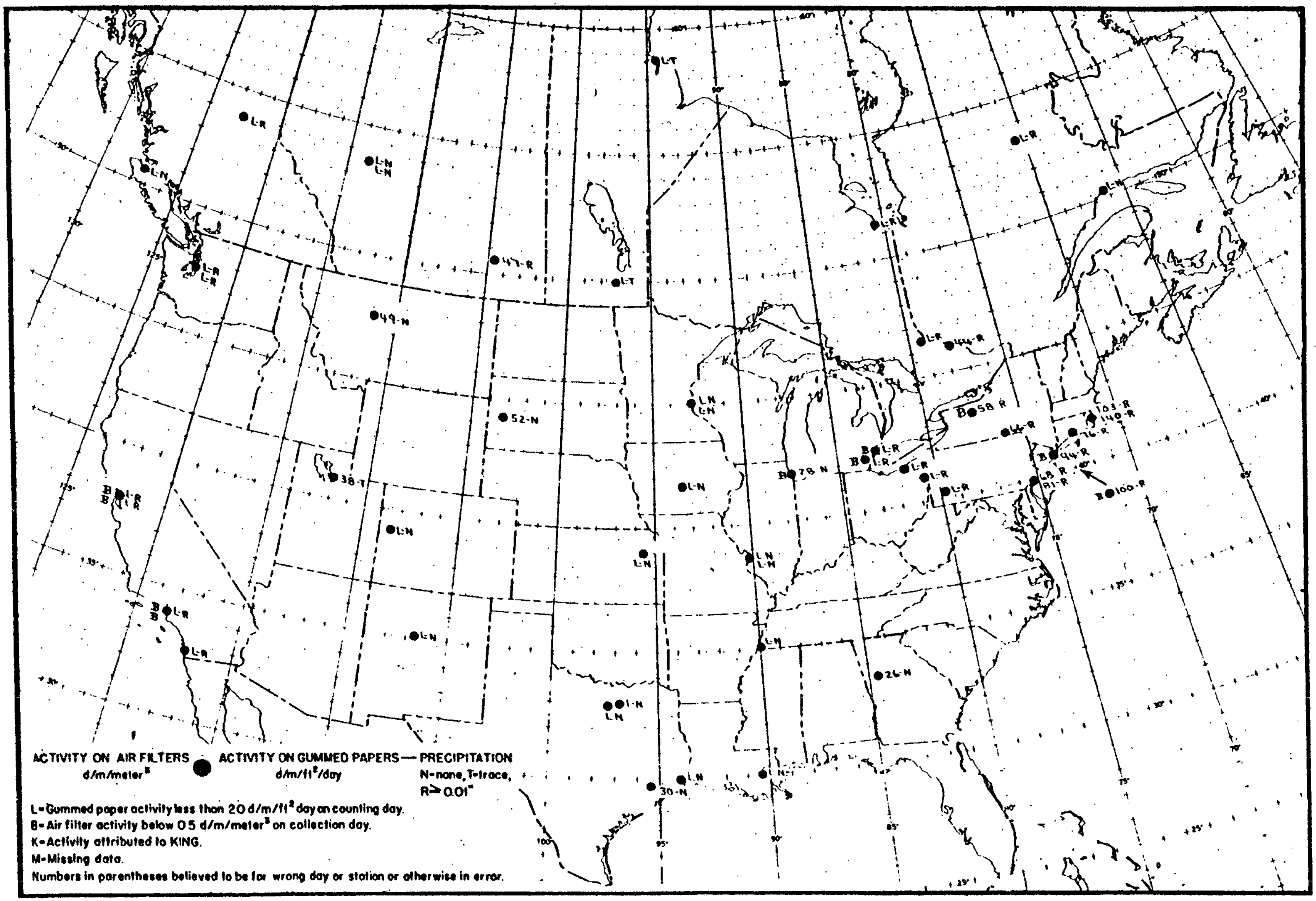

Figure A.72 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 6 Dec. 1952

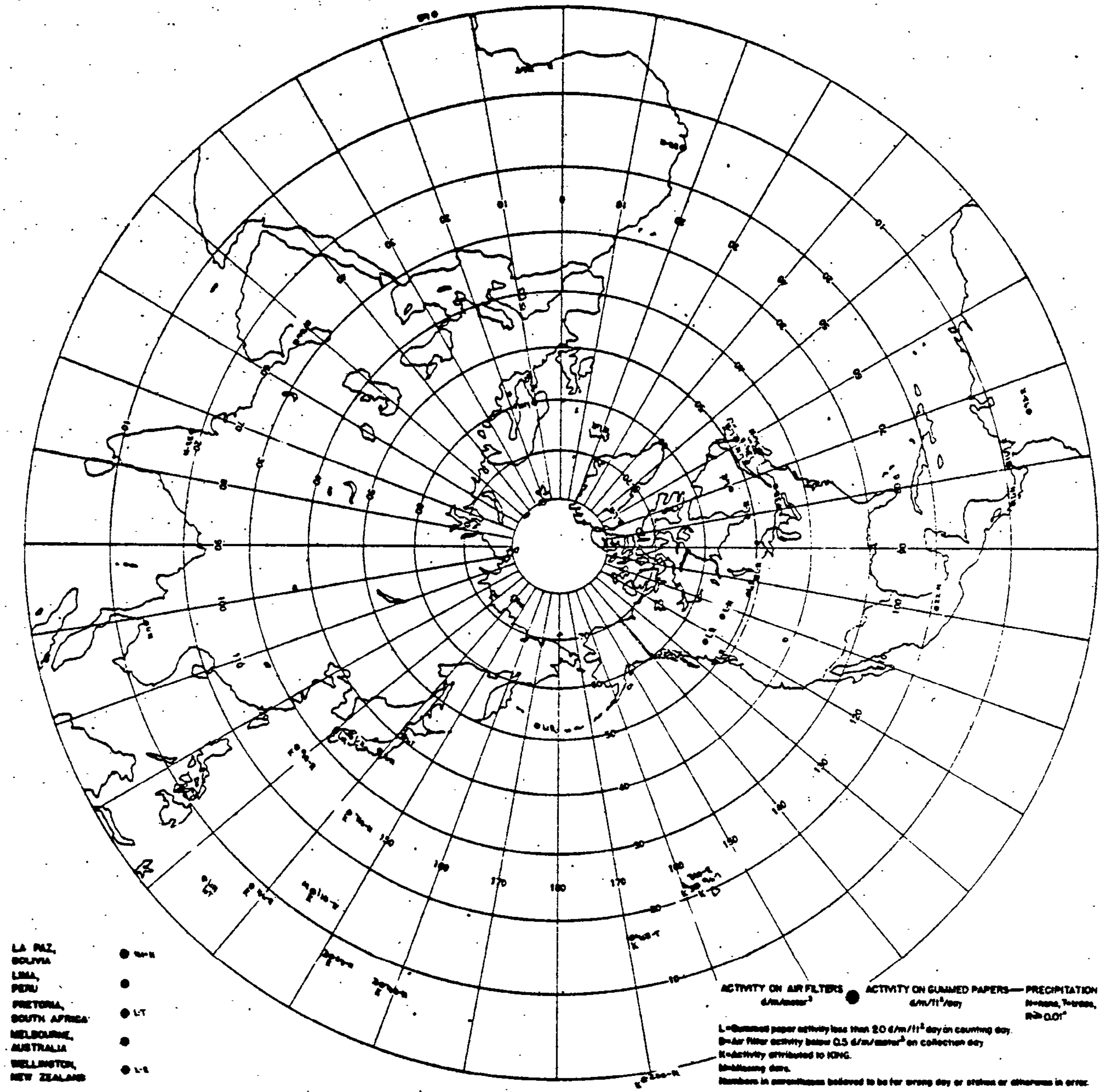

Figure A.73 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 7 Dec. 1952

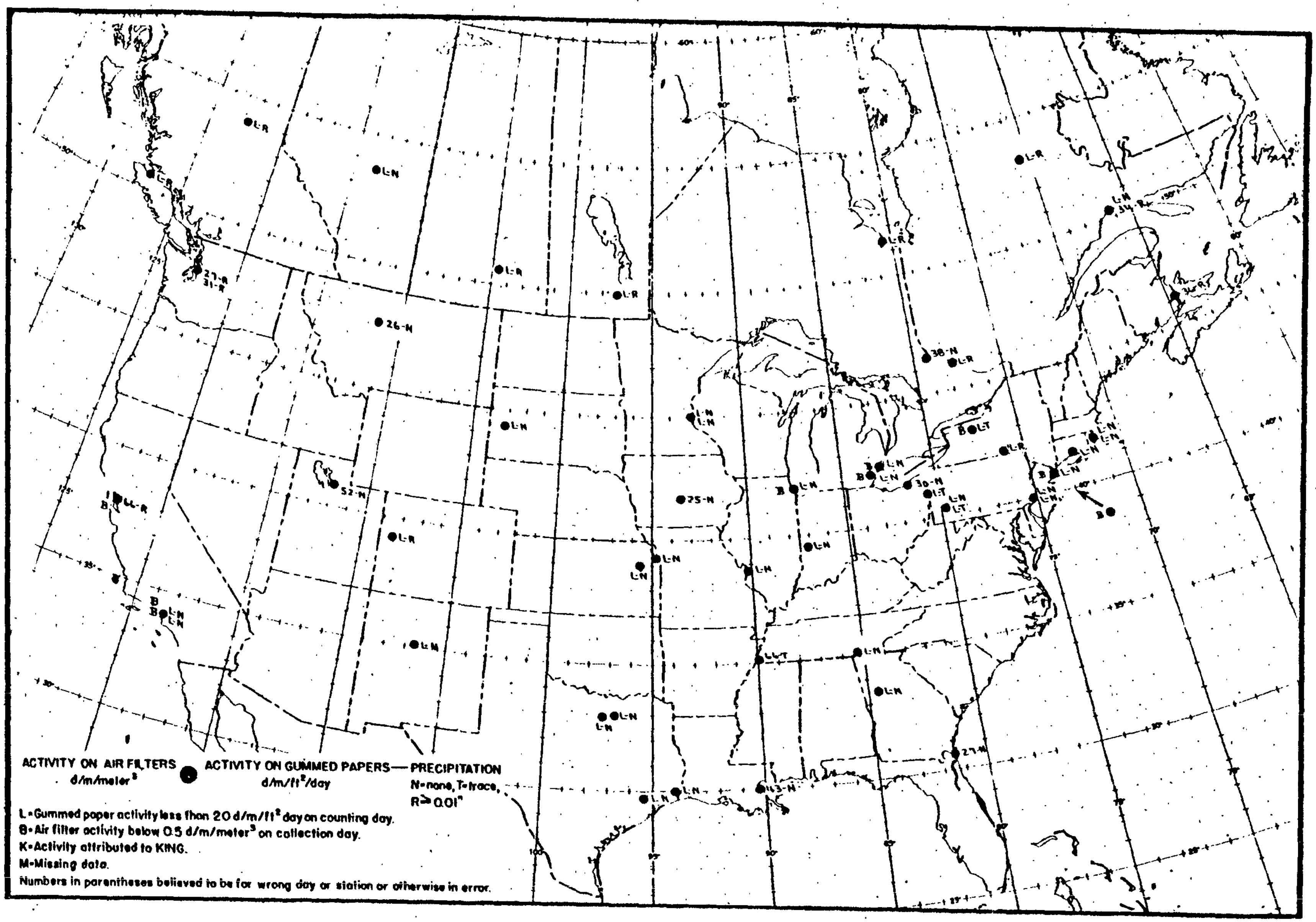

Figure A.74 Radioactive fallout in the 24-hour period beginning 1830 G.C.T., 7 Dec. 1952

APPENDIX B

DATA SUMMARY

B.1 EXPLANATION OF TABULATION

Table B.1 consists of a summary of data from all stations that comprised the routine gummed paper network for Operation IVY, under the following column headings.

a. Station: Identification of station. Where samples were collected at two locations in one city, both locations are listed, e.g., airport and city offices of the Weather Bureau.

b. Period of daily record: Beginning and ending day of daily samples are listed. Some stations exposed a few papers at irregular intervals after cessation of daily operation, but those dates are not listed here.

c. No. of missing days: These are the number of days within the period of daily record on which no radiological data is available.

d. Frequency of precipitation %: This percentage is based on the number of days radiological reports were received and represents the fraction of days on which rain occurred (including a trace of rain).

e. Date of first arrival: The date of arrival of significant activity for this purpose is arbitrarily defined as the first day on which at least 100 d/m (extrapolated to collection day) was reported. Some stations never reported this level of radioactivity. In those cases, the first arrival is defined as the day of marked increase of activity above background. (See footnote (1), Table B.1)

f. Maximum activity, d/m-precip. date: The radioactivity extrapolated to collection day and the date of the highest single gummed paper at each station and the reported precipitation associated with that sample, "M" means precipitation data is missing. In a few instances the maximum was unreasonably early so the secondary maximum was chosen as the actual maximum.

g. Activity on last day of record: The activity (extrapolated to collection day) reported on the last day of the period of daily record. "L" means that the radioactivity was less than 20 d/m on counting day and no extrapolation to collection was made.

h. Remarks: Any unusual feature of the station record is noted in this column. In addition, debris that is thought to be from KING, but is not specifically assigned to the KING burst in Appendix A, is indicated.

Table B.1

Summary of daily gummed paper observations

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date		Activity on last day of record d/m	Remarks
United States								
Albuquerque, N. M.	1 Nov. 25 Dec.	3	31	13 Nov.	775-R	16 Nov.	L	
Atlanta, Ga.	3 Nov. 26 Dec.	3	39	17 Nov.	645-N	24 Nov.	L	
Binghamton, N. Y.	1 Nov. 27 Dec.	5	77	6 Nov.	4805-N	25 Nov.	L	
Boise, Idaho	1 Nov. 3 Dec.	3	26	11 Nov.	10009-R	11 Nov.	L	Highest U. S. value
Buffalo, N. Y.	1 Nov. 26 Dec.	11	73	9 Nov.	674-R	22 Nov.	L	
Chattanooga, Tenn.	1 Nov. 27 Dec.	8	39	15 Nov.	2132-R	26 Nov.	L	
Chicago, Ill.	3 Nov. 27 Dec.	3	62	8 Nov.	6023-R	24 Nov.	L	
Cleveland, Ohio	4 Nov. 28 Dec.	6	78	15 Nov.	2736-R	23 Nov.	L	
Dallas, Tex.	1 Nov. 27 Dec.	3	37	16 Nov.	1813-R	24 Nov.	L	
Des Moines, Iowa	4 Nov. 26 Dec.	7	43	13 Nov.	1003-N	14 Nov.	L	
Detroit, Mich.	1 Nov. 28 Dec.	5	68	14 Nov.	1808-R	26 Nov.	L	
Fort Worth, Tex.	4 Nov. 27 Dec.	5	33	16 Nov.	9816-R	23 Nov.	L	
Grand Junction, Colo.	1 Nov. 25 Dec.	6	43	14 Nov.	878-R	22 Nov.	L	
Great Falls, Mont.	1 Nov. 26 Dec.	8	37	11 Nov.	5608-N	11 Nov.	L	
Houston, Tex.	2 Nov. 26 Dec.	1	41	16 Nov.	1480-R	27 Nov.	L	
Jacksonville, Fla.	4 Nov. 26 Dec.	6	30	18 Nov.	557-R	20 Nov.	50	
Kansas City, Mo.	1 Nov. 27 Dec.	8	37	14 Nov.	596-N	15 Nov.	L	

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date		Activity on last day of record d/m	Remarks
Los Angeles, Calif.	1 Nov. 17 Dec.	8	31	7 Nov.	3826-R	7 Nov.	40	
Los Angeles, Calif. (Airport)	1 Nov. 26 Dec.	5	26	8 Nov.	1017-R	8 Nov.	L	
Memphis, Tenn.	1 Nov. 26 Dec.	11	40	16 Nov.	5399-N	23 Nov.	L	
Minneapolis, Minn.	4 Nov. 27 Dec.	6	40	13 Nov.	1132-N	13 Nov.	L	
New Haven, Conn.	5 Nov. 29 Dec.	3	42	16 Nov.	622-R	21 Nov.	L	
New Orleans, La.	1 Nov. 27 Dec.	6	43	5 Nov.	1936-N	27 Nov.	60	
New York, N. Y.	1 Nov. 29 Dec.	9	48	8 Nov.	941-R	21 Nov.	L	
New York, N. Y. (LaGuardia Field)	2 Nov. 21 Dec.	14	47	15 Nov.	2168-N	27 Nov.	L	
New York, N. Y. (AEC)	4 Nov. 5 Dec.	15	35	15 Nov.	2817-R	27 Nov.	169	
Philadelphia, Pa.	1 Nov. 27 Dec.	5	44	13 Nov.	1978-N	26 Nov.	L	
Philadelphia, Pa. (Airport)	5 Nov. 27 Dec.	12	46	16 Nov.	656-R	20 Nov.	L	
Pittsburgh, Pa.	1 Nov. 28 Dec.	6	64	9 Nov.	1250-R	9 Nov.	L	
Pittsburgh, Pa. (Airport)	2 Nov. 28 Dec.	12	62	16 Nov.	516-R	19 Nov.	L	
Port Arthur, Tex.	2 Nov. 26 Dec.	2	45	16 Nov.	3540-R	27 Nov.	L	
Providence, R. I.	1 Nov. 29 Dec.	3	32	14 Nov.	318-R	12 Dec.	L	
Providence, R. I. (Airport)	1 Nov. 28 Dec.	6	40	14 Nov.	489-R	20 Nov.	L	
Rapid City, S. D.	3 Nov. 27 Dec.	16	23	7 Nov.	3886-N	12 Nov.	L	
Rochester, N. Y.	1 Nov. 28 Dec.	7	74	6 Nov.	1896-R	18 Nov.	L	

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date		Activity on last day of record d/m	Remarks
St. Louis, Mo.	3 Nov. 28 Dec.	4	48	14 Nov.	1025-R	24 Nov.	L	
St. Louis, Mo. (Airport)	2 Nov. 26 Dec.	12	53	14 Nov.	2114-R	24 Nov.	L	
St. Paul, Minn.	2 Nov. 27 Dec.	4	50	13 Nov.	931-N	13 Nov.	L	
Salt Lake City, Utah	1 Nov. 26 Dec.	3	38	13 Nov.	4233-R	15 Nov.	L	
San Diego, Calif.	2 Nov. 24 Dec.	2	29	13 Nov.	936-N	14 Nov.	L	
San Francisco, Calif.	1 Nov. 25 Dec.	3	37	8 Nov.	1828-N	8 Nov.	L	
San Francisco, Calif. (Airport)	2 Nov. 23 Dec.	1	37	11 Nov.	658-N	11 Nov.	L	
Seattle, Wash.	1 Nov. 23 Dec.	2	49	11 Nov.	3578-R	11 Nov.	L	
Seattle-Tacoma, Wash. (Airport)	1 Nov. 22 Dec.	7	64	11 Nov.	7612-R	10 Nov.	L	
Terre Haute, Ind.	1 Nov. 28 Dec.	10	54	15 Nov.	1860-R	25 Nov.	L	
Topeka, Kan.	2 Nov. 27 Dec.	5	31	13 Nov.	460-N	14 Nov.	L	
Youngstown, Ohio	1 Nov. 28 Dec.	7	69	15 Nov.	1438-R	26 Nov.	L	
Ypsilanti, Mich.	1 Nov. 28 Dec.	4	65	15 Nov.	3855-R	26 Nov.	L	
<u>Canada and Alaska</u>								
Adak, Alaska	1 Nov. 12 Dec.	8	100	10 Nov.	331-R	10 Nov.	L	
Churchill, Manitoba	15 Nov. 22 Dec.	2	63	15 Nov.	1517-N	15 Nov.	L	
Deep River, Ontario	11 Nov. 24 Dec.	6	71	14 Nov.	2197-R	26 Nov.	L	
Edmonton, Alberta	21 Nov. 24 Dec.	1	39	None	-		L	

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date	Activity on last day of record d/m	Remarks
Goose Bay, Labrador	2 Nov. 21 Dec.	30	75	23 Nov.	264-R 25 Nov.	L	
Harmon AFB, Newfoundland	1 Nov. 17 Dec.	3	60	28 Nov.	451-R 28 Nov.	L	
Moncton, New Brunswick	5 Nov. 19 Dec.	14	61	15 Nov.	1282-N 16 Nov.	L	
Moosoonee, Ontario	8 Nov. 21 Dec.	9	77	14 Nov.	459-N 14 Nov.	L	
Nitchequon, Quebec	17 Nov. 26 Dec.	3	62	17 Nov.	699-R 17 Nov.	L	
North Bay, Ontario	9 Nov. 27 Dec.	3	91	13 Nov.	1575-R 23 Nov.	L	
Port Hardy, British Columbia	28 Nov. 27 Dec.	2	32	-	-	L	
Prince George, British Columbia	20 Nov. 21 Dec.	2	60	-	-	L	
Regina, Saskatchewn	21 Nov. 26 Dec.	3	64	21 Nov.	1018-R 21 Nov.	L	
Seven Islands, Quebec	16 Nov. 26 Dec.	6	51	16 Nov.	3091-R 16 Nov.	L	
Shemya, Alaska	3 Nov. 10 Dec.	7	100	7 Nov.	242-R 7 Nov.	L	
Winnipeg, Manitoba	20 Nov. 23 Dec.	2	94	None	-	L	
Pacific Ocean							
Canton Island	3 Nov. 7 Dec.	0	34	11 Nov.	782-N 11 Nov.	169	Small and irregular activity after first arrival
French Frig. Shoals, T. H.	9 Nov. 24 Nov.	4	40	11 Nov.	5173-R 11 Nov.	72	Record for 10 Nov. missing, continuous activity 11-26 Nov.
Guam Island	1 Nov. 14 Dec.	1	95	3 Nov.	324,046-R 4 Nov.	L	Significant activity continuous after 5 Nov. with two sharp peaks corresponding to MIKE and KING tests.
Hilo, Hawaii, T. H.	4 Nov. 13 Dec.	2	100	7 Nov.	5266-R 20 Nov.	L	Significant activity 7 Nov. to 4 Dec.
Honolulu, Oahu. T. H.	2 Nov. 25 Dec.	3	80	6 Nov.	1505-R 20 Nov.	25	Activity continuous 6-28 Nov.

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date	Activity on last day of record d/m	Remarks
Iwo Jima Island	1 Nov. 16 Dec.	6	85	2 Nov.	3,627,360-N 5 Nov.	120	Significant activity nearly continuous 2 Nov. to 10 Dec., perhaps due to redeposited dust from ground. This station received greatest activity of entire gummed paper network.
Koror Island	17 Nov. 7 Dec.	0	81	17 Nov.	4450-R 21 Nov.	L	Sampling started too late for MIKE, debris mainly from KING.
Johnston Island	1 Nov. 12 Dec.	2	85	11 Nov.	3020-M 23 Nov.	101	Significant activity continuous 11-26 Nov.
Lihue, Kauai, T. H.	4 Nov. 12 Dec.	1	92	5 Nov.	4525-R 7 Nov.	22	Activity continuous 5-25 Nov.
Melbourne, Australia	1 Nov. 3 Dec.	3	66	13 Nov.	129-N 13 Nov.	L	See footnote (1) at end of table.
Midway Island	1 Nov. 29 Nov.	3	77	10 Nov.	16,310-R 13 Nov.	45	Significant activity continuous 10-16 Nov.
Ponape Island	18 Nov. 7 Dec.	1	97	18 Nov.	47,000-R 20 Nov.	38	Sampling started too late for MIKE, debris mainly from KING.
Truk Island	2 Nov. 7 Dec.	7	83	3 Nov.	154,816-R 17 Nov.	41	Irregular but high activity 3 Nov. to early Dec.
Wake Island	1 Nov. 6 Dec.	6	50	9 Nov.	8594-N 14 Nov.	44	Arrival on 9 Nov. questionable. More reasonable arrival day 13 Nov.
Wellington, New Zealand	1 Nov. 7 Dec.	1	70	16 Nov.	93-N 16 Nov.	L	See footnote (1) at end of table.
Yap Island	9 Nov. 7 Dec.	2	93	9 Nov.	17,185-R 16 Nov.	40	Sampling started too late for MIKE, debris mainly from KING.
<u>Asia</u>							
Bangkok, Thialand	1 Nov. 7 Dec.	3	26	6 Nov.	96,000-N 9 Nov.	L	All high activity 6-16 Nov.
Bombay, India	1 Nov. 7 Dec.	3	0	20 Nov.	104-N 22 Nov.	L	See footnote (1) at end of table
Haneda AFB, Japan	2 Nov. 9 Dec.	9	31	13 Nov.	944-R 18 Nov.	165	All activity during week of 13-20 Nov.

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip.	date	Activity on last day of record d/m	Remarks
Hiroshima, Japan	5 Nov. 21 Dec.	3	14	7 Nov.	43,656-R	12 Nov.	L	All high activity 12, 13, and 14 Nov.
Hong Kong, China	1 Nov. 3 Dec.	1	40	10 Nov.	27,562-N	11 Nov.	84	All high activity 11 - 18 Nov.
Manila, P. I.	1 Nov. 6 Dec.	5	29	5 Nov.	242,400-N	6 Nov.	155	All high activity 5-22 Nov., continuous in that period.
Misawa, Japan	1 Nov. 12 Dec.	0	67	11 Nov.	107-R	1 Dec.	L	See footnote (1) at end of table
Nagasaki, Japan	1 Nov. 18 Dec.	8	74	20 Nov.	10,639-R	11 Nov.	L	All high activity 11-16 Nov.
Okinawa Island	1 Nov. 11 Dec.	5	78	7 Nov.	10,567-R	10 Nov.	25	Significant activity continuous 10-25 Nov.
Taipei, Formosa	1 Nov. 4 Dec.	2	62	10 Nov.	7440-R	13 Nov.	68	All high activity 10-19 Nov.
Europe and North Atlantic								
Bermuda Island	1 Nov. 6 Dec.	2	64	18 Nov.	308-R	26 Nov.	L	Irregular activity
Keflavik, Iceland	1 Nov. 9 Dec.	9	82	24 Nov.	744-R	30 Nov.	L	Irregular activity
Oslo, Norway	1 Nov. 11 Dec.	1	63	8 Nov.	120-N	8 Nov.	L	Only significantly high activity is questionable. See footnote (1) at end of table.
Prestwick, Scotland	1 Nov. 9 Dec.	5	60	11 Nov.	197-N	11 Nov.	32	See footnote (1) at end of table.
Rhein-Main, Germany	1 Nov. 10 Dec.	11	80	10 Nov.	91-R	10 Nov.	L	Questionable data. See footnote (1) at end of table.
Thule, Greenland	1 Nov. 20 Dec.	4	37	19 Nov.	199-R	19 Nov.	L	Only active papers were pair on 19 Nov.
Central and South America								
Bogota, Columbia	1 Nov. 10 Dec.	2	90	26 Nov.	1862-R	27 Nov.	84	Nearly all activity collected on 26, 27, and 28 Nov., probably KING.
Lima, Peru	2 Nov. 23 Dec.	10	20	11 Nov.	166-N	11 Nov.	L	See footnote (1) at end of table.

Table B.1 (continued)

Station	Period of daily record	No. of missing days	Frequency of precipitation %	Date of first arrival	Maximum activity d/m-precip. date		Activity on last day of record d/m	Remarks
La Paz, Bolivia	1 Nov. 12 Dec.	8	40	24 Nov.	204-R	24 Nov.	53	Most activity in week after 24 Nov., probably all KING debris.
Mexico City, Mexico	4 Nov. 11 Dec.	2	17	22 Nov.	744-N	25 Nov.	30	Irregular activity after 22 Nov., probably mostly KING debris.
Panama, Canal Zone	1 Nov. 12 Dec.	3	90	25 Nov.	688-R	1 Dec.	38	Most activity early in Dec., presumably from KING.
Quito, Equador	1 Nov. 5 Dec.	2	50	26 Nov.	924-R	26 Nov.	125	All activity after 22 Nov., probably all KING debris.
San Jose, Costa Rica	1 Nov. 13 Dec.	5	65	28 Nov.	207-R	28 Nov.	34	See footnote (1) at end of table.
San Juan, Puerto Rico	4 Nov. 3 Dec.	0	85	18 Nov.	630-R	24 Nov.	75	Low levels of activity nearly continuous after 24 Nov.
<u>Africa and Middle East</u>								
Addis Ababa, Ethiopia			only one day of record - doubtful data					
Beirut, Lebanon	1 Nov. 1 Dec.	2	24	10 Nov.	123-R	26 Nov.	L	See footnote (1) at end of table.
Dakar, Nigeria	1 Nov. 12 Dec.	1	2	16 Nov.	146-N	16 Nov.	22	See footnote (1) at end of table.
Dhahran, Saudi, Arabia	1 Nov. 11 Dec.	3	2	16 Nov.	766-N	20 Nov.	67	Irregular and low activity
Lagos, Nigeria	3 Nov. 7 Dec.	15	73	11 Nov.	97-R	11 Nov.	L	See footnote (1) at end of table.
Leopoldville, Belgium Congo	1 Nov. 7 Dec.	3	50	17 Nov.	156-R	17 Nov.	L	See footnote (1) at end of table.
Pretoria, Union of South Africa	1 Nov. 16 Dec.	2	80	25 Nov.	297-R	25 Nov.	L	Very irregular activity, only two days with activity higher than 100 d/m on counting day.
Sidi Slimane, French Morocco	1 Nov. 27 Nov.	3	62	26 Nov.	458-R	26 Nov.	253	Only two active samples 26 and 27 Nov., most precip. in form of trace of rain.

(1) Maximum activity less than 100 d/m on counting day.

BIBLIOGRAPHY

1. Central Pacific Projects, Contract No. AF 19 (122) - 414. University of California, Inst. of Geophysics. Los Angeles, California. First Report October, 1951 and Final Report March 1953.

2. Dust and Precipitation Sampling Program, April thru June 1951, New York Operations Office of the Atomic Energy Commission, June 25, 1952.

3. Effects of Atomic Weapons, Los Alamos, New Mexico, June 1950.

4. Major Activities in the Atomic Energy Programs, January-June 1953, a semi-annual report of the Atomic Energy Commission. Washington, D. C., July 1953.

5. Mathematics of Statistics - Part two, J. F. Kenney, D. Van Nostrand Co., New York 1941.

6. Operation IVY Meteorological Data October - November 1952, issued by CJTF-132.

7. Radioactive Debris from Operation BUSTER and JANGLE, NYO-1576, New York Operations Office of the Atomic Energy Commission, January 28, 1952.

8. Radioactive Debris from Operation IVY, NYO-4522, New York Operations Office of the Atomic Energy Commission, April 28, 1953.

9. Radioactive Debris from Operation TUMBLER and SNAPPER, New York Operations Office of the Atomic Energy Commission. Part I-NYO-4505.

10. Radioactive Debris from Operation TUMBLER and SNAPPER, New York Operations Office of the Atomic Energy Commission. Part II-NYO-4512, February 25, 1953.

11. Transport of Radioactive Debris from Operations BUSTER and JANGLE, Hq. United States Air Force Project 7.1 Armed Forces Special, Washington, D. C., 15 March 1952.