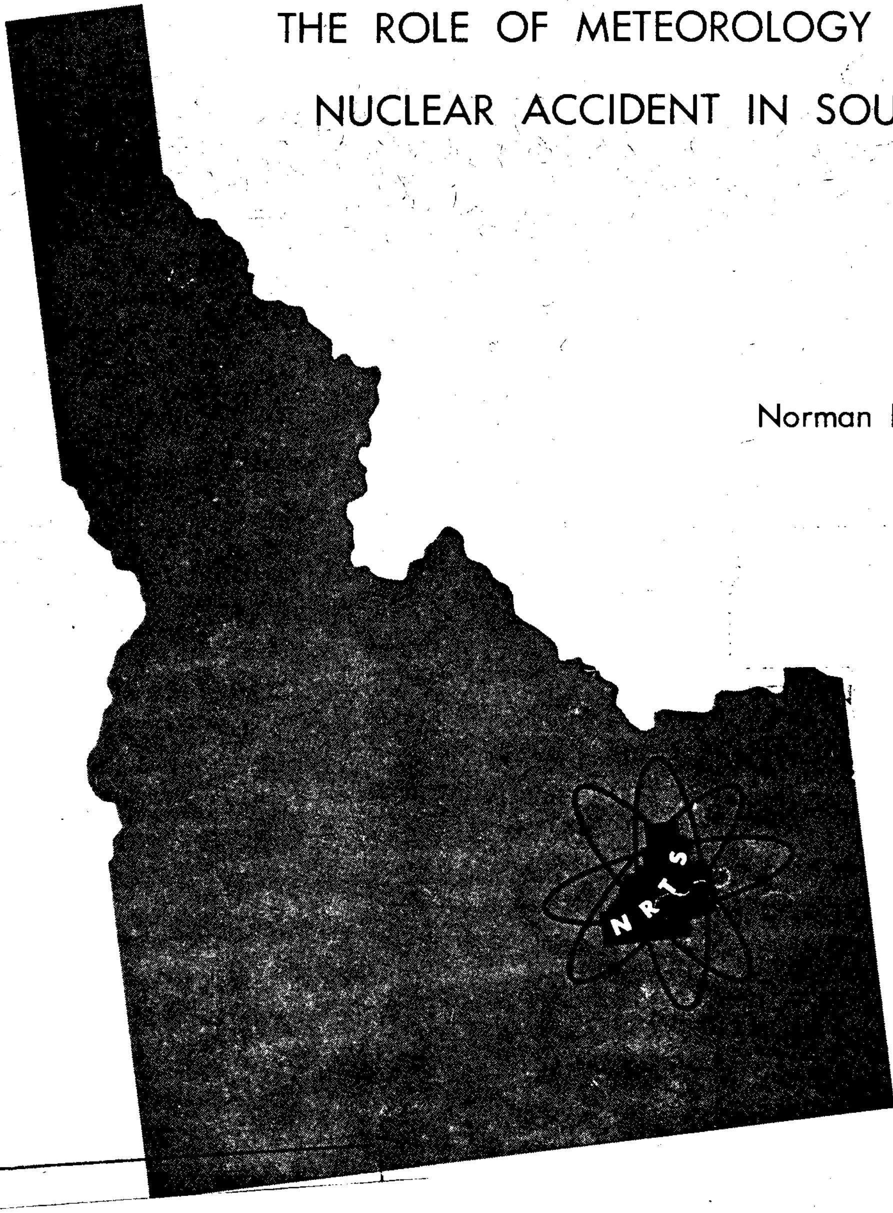
IDO-19310

THE ROLE OF METEOROLOGY FOLLOWING THE NUCLEAR ACCIDENT IN SOUTHEAST IDAHO



Norman F. Islitzer

nited States Weather Bureau
National Reactor Testing Station
Idaho Falls, Idaho
May, 1962

THE ROLE OF METEOROLOGY FOLLOWING THE NUCLEAR ACCIDENT IN SOUTHEAST IDAHO

Norman F. Islitzer

United States Weather Bureau
National Reactor Testing Station
Idaho Falls, Idaho

May, 1962

ABSTRACT

The nuclear accident at the Stationary Low Power Reactor No 1 (SL-1) on January 3, 1961 presented the most severe test to date of meteorological support capabilities for such an occurrence at the National Reactor Testing Station. The activities of the Weather Bureau in providing responsible officials with the necessary meteorological information and interpretations during the emergency are discussed. The stagnant weather conditions following the accident provided a maximum potential air pollution episode. Meteorological evaluations of air concentrations and deposits of iodine 131 on the vegetation are presented. A deposition velocity for iodine 131 of 0.2 cm sec^{-1} over desert-type vegetation was computed. Computed dispersion patterns and emission rates of this isotope from the SL-1 are presented. The computed long-period average air concentrations, based on wind speed and direction statistics, are considerably less than measured values at greater distances from the source. This is apparently due to the confinement of the mountains forming the outline of the Snake River Plain. A volumetric-type calculation of air concentration appears to be more satisfactory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The work described in this report was supported by the Reactor Development Division, United States Atomic Energy Commission. This report could not have been completed without the assistance and cooperation of the personnel at the Weather Bureau, National Reactor Testing Station, Idaho Falls, Idaho. In particular the contributions of George R. Yanskey, who computed the dispersion of iodine 131 from meteorological measurements, and of James A. Speidel, who drafted the many figures, are gratefully acknowledged.

I. INTRODUCTION

On Tuesday, January 3, 1961, at 9:01 p.m. a nuclear accident occurred at the Stationary Low Power Reactor No. 1, known as the SL-1, located at the National Reactor Testing Station (NRTS), Idaho. This nuclear accident resulted in three fatalities and extensive damage to the reactor core. The SL-1 Reactor was designed by Argonne National Laboratory as the prototype for a power plant to provide power and heat for a remote radar installation and its support facilities. Originally designated as the Argonne Low Power Reactor (ALPR), the SL-1 was a direct cycle, boiling water moderated and cooled, natural circulation reactor.

II. WEATHER BUREAU ACTIVITIES FOLLOWING THE ACCIDENT

The Weather Bureau was called upon to provide considerable meteorological information and interpretation of radiation measurements at the various monitoring stations following the nuclear accident at SL-1. This support can be classified essentially into two phases: 1) the emergency-type action taken in the immediate hours following the accident for the protection of personnel and 2) the continuous evaluation of meteorological and radiation data in the weeks that followed for obtaining the maximum information to assist in salvage operations and future reactor hazards analyses. Upon being notified by the Office of the Director, Health and Safety Division of the occurrence of the accident, Weather Bureau personnel made a rapid preliminary analysis of weather conditions in the SL-1 region from observations taken by security personnel on duty at the National Reactor Testing Station. Security personnel have been trained to read wind records accurately and relay this information by telephone or radio during emergencies.

The particular weather type that prevailed during the accident was quickly recognized as the type usually associated with strong anti-cyclonic conditions in the winter night in this region. Generally steady north to northeast wind directions are experienced with an extremely strong inversion under clear skies and very light surface winds. Any released material would have been accurately prognosticated to travel fairly slowly to the south or southwest and thus not endanger any of the other reactor populations, since the SL-1 is on the southern perimeter of the NRTS (see fig. 8); likewise, no major off-site populated area was in any immediate danger. Immediate preliminary trajectory information was given to the ground monitoring teams. Their first information showing low levels of radioactivity, along with the unlikely interception of any major inhabited area by the radioactive plume due to the observed wind conditions, were factors considered by the Idaho Operations Office, Atomic Energy Commission in their actions following the accident [1].

Weather Bureau personnel then drove rapidly from Idaho Falls to the weather central in Central Facilities for more detailed analyses. Trajectories and areas of maximum surface-level radioactivity were computed for releases at several assumed heights, since the exact height of release of any radioactive material was not known.

Mobile monitoring teams were advised as to optimum sampling areas for radioactive material released at or near ground-level. The aerial monitoring team was dispatched at daybreak of January 4, the morning after the accident, down the Snake River Plain to the most likely interception point of any radioactive material released at the time of the accident at about the 200-ft level or above. Continuous surveillance and analysis of weather conditions were made thereafter to direct the aerial and mobile surface monitoring operations until emergency conditions had passed and the mobile sampling crews were replaced by a fixed grid of high volume air samplers around the SL-1. An estimate of the release of iodine 131 which was the principal isotope detected on both the vegetation and in the air, was then made by working backward from the radiation measurements in the field to the source with the usual atmospheric diffusion equations.

The second phase of the meteorological support was conducted in close cooperation between meteorologists of the Weather Bureau and health physicists, ecologists, and chemists of the Health and Safety Division. Since it was obvious that there was a slow but continuous discharge of iodine 131 from the SL-1 area, an extensive sampling and analysis program was initiated. A number of high volume air samplers were installed around the SL-1 region to supplement the environmental monitoring network (see fig. 12). The filters were collected daily, analyzed for iodine 131, and then the air concentrations were used with the observed meteorological conditions to determine a daily release of iodine 131 from the SL-1 area.

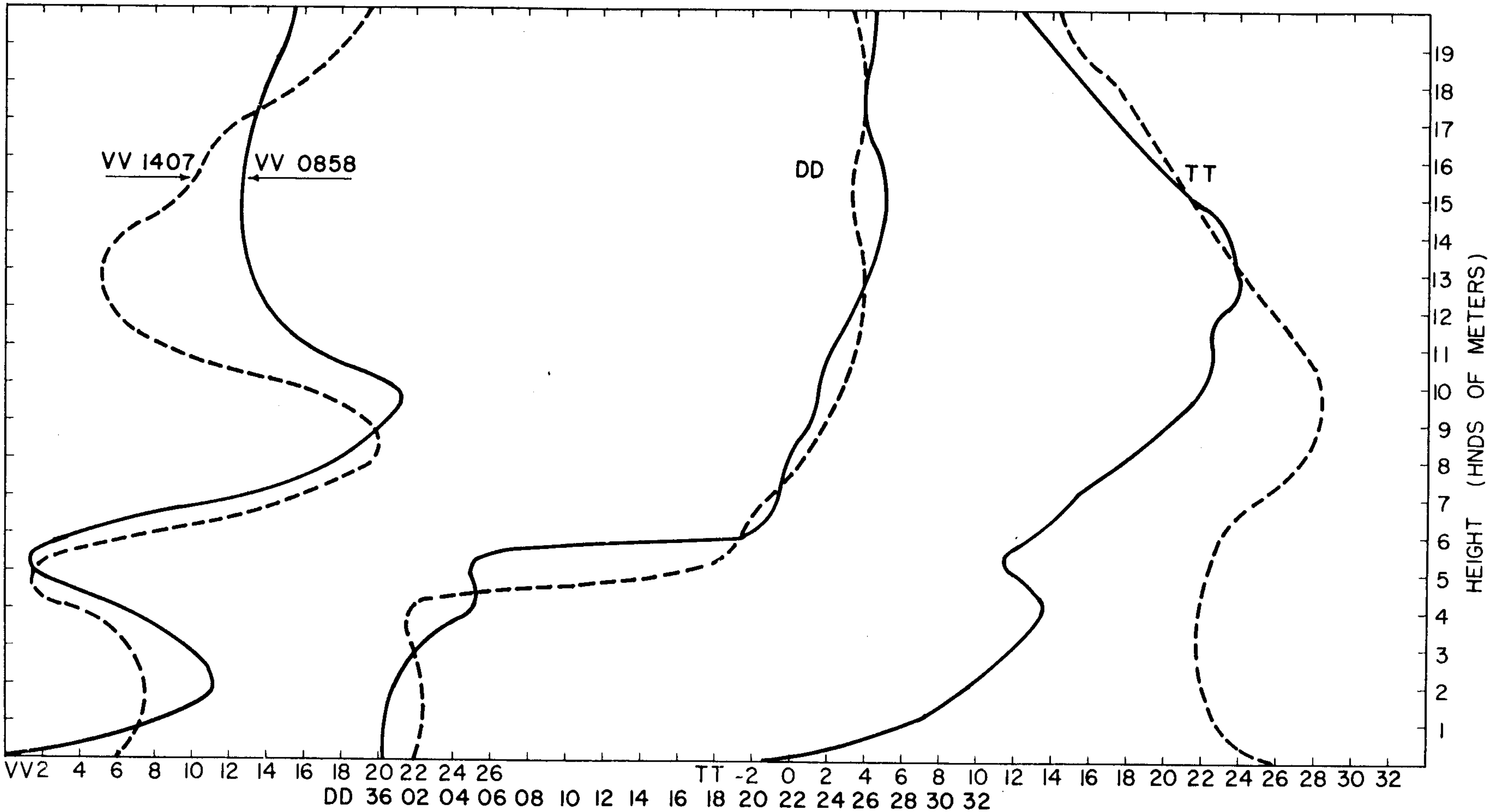
There appeared to be no other method of determining this effluent discharge from the SL-1, since re-entry was prohibited because of the high radiation levels encountered in the reactor building. Vegetation samples were collected near many of the high-volume air sampling stations and compared to measured air concentrations in order to determine an appropriate deposition velocity. Snow and soil samples were also used to compute deposition velocities.

A wind station was installed in the SL-1 area with wire telemetry to the main Weather Bureau office at Central Facilities, some 5 mi away, for operational and research purposes. At the time of the accident the nearest weather station to SL-1 was at Central Facilities. This station, along with the other stations normally in operation in the region, plus vertical soundings of wind and temperature to 7000 ft above the surface furnished the meteorological data for a thorough evaluation of the transport and dispersion of the airborne iodine 131. From this observational program, the daily operational weather forecasts that were made to cover the salvage operations in the SL-1 were monitored.

In the following sections, a discussion of the meteorological conditions during and after the accident is presented. The estimates of iodine 131 release, correlations of air concentration and surface deposition of iodine 131, and the relation between observed radiation patterns and meteorological information are described in the following sections.

III. METEOROLOGICAL CONDITIONS FOLLOWING THE ACCIDENT

A general anticyclonic weather regime, with its customary clear skies, light winds, and strong nocturnal cooling permitting strong, deep inversions was in existence during the period Jan. 3 to Jan. 29. The minor synoptic weather changes experienced during this stagnant period were largely masked out by the normal diurnal changes of the winter season. Because of the high elevation, near 5,000 ft above sea level, and generally dry air masses, a regular and pronounced change in the diffusive capacity of the atmosphere is measured with the time of the day. This is shown in fig. 1, which portrays the typical temperature and wind variation with height following the accident in the morning and afternoon near the times when the effects of nocturnal cooling or solar heating are the maximum. A strong nocturnal inversion usually formed to greater than 3000 ft above the ground with a temperature increase in excess of 20 F from the ground to the top of the inversion by sunrise. The slight amount of solar heating during this season in the daylight hours permitted a weak temperature lapse to form to between 1500-2000 ft above the ground in the afternoon, with a capping inversion persisting aloft throughout the entire day. The inversion would then quickly reform in the lower-most layers shortly after sunset from nocturnal radiational cooling. The daily maximum inversion height and intensity, the latter being defined as the temperature difference between the warmest part of the temperature sounding and the surface temperature, are given in table 1 for this period. It can be seen that inversion heights to 5400 feet above the surface were



VV = KNOTS PER HOUR
DD = 000°- 360°
TT = °F

FIG. I TYPICAL MORNING AND AFTERNOON TEMPERATURE AND WIND VARIATIONS WITH HEIGHT FOLLOWING THE SL-I ACCIDENT. SOUNDING MADE ON JAN. 5, 1961

Table 1

SL-1 Inversion Summary*

Date	Maximum Inversion Height (ft)	Inversion Intensity (F)
1/5/61	3100	30
1/6/61	3000	26
1/9/61	690	7
1/11/61	5400	17
1/12/61	5400	10
1/17/61	2600	30
1/18/61	1400	18
1/19/61	2460	20
1/20/61	3280	24
1/24/61	1870	23
1/25/61	1800	6
1/26/61	1770	10
1/27/61	2460	15
2/3/61	400	2

*Data obtained from T-Sonde flights shortly after sunrise.

measured with 30 F temperature increases from the surface to the inversion top. The inversion broke each day at about 1000 MST to the 250-ft level and reformed at near 1700 MST so that 17 hrs out of each day experienced inversion conditions in the lower layers of the atmosphere.

The prevailing winds in the lower levels over the NRTS during such stability conditions are steady north to northeast winds of light to moderate speeds. Surface wind speeds are essentially near calm with the direction strongly influenced by local topographic features. One would anticipate an airborne effluent very near the surface to move slowly in an erratic course down the elevation contours much as water flows down hill under the influence of gravity. The streamlines of flow at the time of the accident and six hours later as could best be constructed from the wind observations in the region are shown in fig. 2. These show that any airborne material released in the hours following the accident would have moved off to the south or southwest down the Snake River Plain. In the 100-hr period following the accident, there were 98 hours with north-northeast wind directions with a mean speed of 7.5 mph as observed on the 250-ft level of the meteorological tower at Central Facilities. This consistent wind was a fortunate result, of course, with respect to the measurement and interpretation of radiation measurements in the field. The northeasterly winds continued to prevail during the month of January, as shown by the January wind rose in fig. 3 for the SL-1 surface wind station, with 60 per cent of the winds blowing from the northeast quadrant.

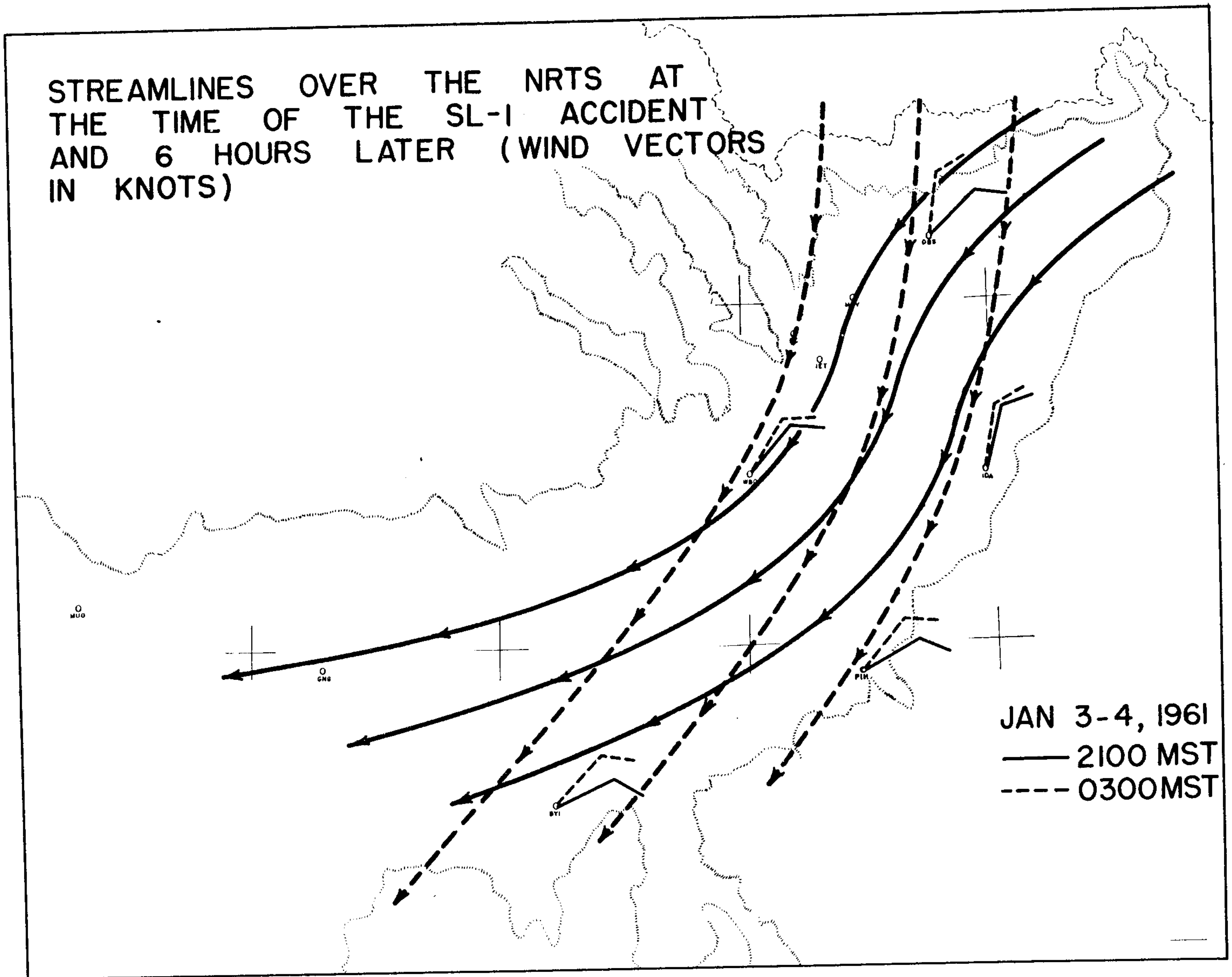

STREAMLINES OVER THE NRTS AT THE TIME OF THE SL-1 ACCIDENT AND 6 HOURS LATER (WIND VECTORS IN KNOTS)
JAN 3-4, 1961
2100 MST
0300MST

FIG. 2

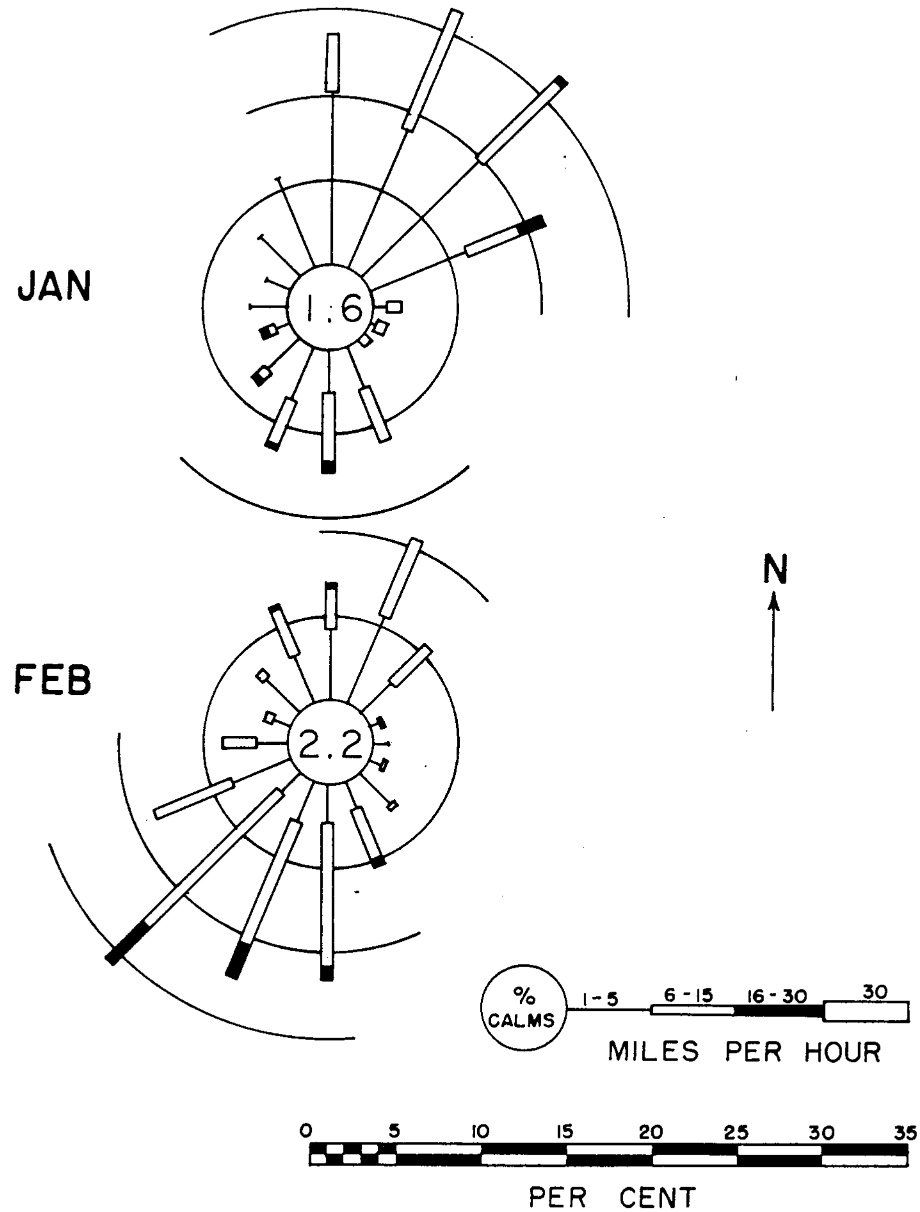


FIG. 3 WIND ROSES FOR MONTHS OF JANUARY AND FEBRUARY, 1961 AT SL-1

The typical variation of wind with height from pilot balloon observations during January is shown in fig. 1 with the temperature sounding. The layer of northeast winds extends to about 1500 ft, near the top of the steepest part of the inversion, and then the winds veer rapidly to assume the westerly gradient winds at about the 700 mb level. During the first several days after the accident, the gradient winds at the 700 mb level were westerly to northwesterly. The stability of the air was so strong that the westerly gradient winds were not able to work down to the surface even during the period of maximum solar heating in the afternoon. Any radioactive material reaching the 700 mb level, about 5000 ft above the surface, would have moved off to the southeast or east. However, because of the strong capping inversion, it is unlikely that any significant amount of iodine 131 would penetrate to that height and the most likely motion of effluent would be down the Snake River Plain with north to northeast winds. The dispersion of the iodine 131 was undoubtedly limited in the horizontal by the mountains rising to several thousand feet above the surface along the confines of the Snake River Plain as shown in fig. 2, whereas, the capping inversion would tend to limit the vertical dispersion to below about 2,000 ft. Due to the light but persistent winds and strong stability with minimum dilution down the plain, long range travel of any pollutant towards the western end of the Snake River Plain would have been likely.

The limitation of vertical dispersion as well as the nature of variable, light surface winds during the strong inversion of the accident is shown in fig. 4. The photograph, a time exposure of a smoke release near the SL-1 shortly after sunrise two days after the accident, shows the smoke staying near the ground and traveling in a zig-zag path down the plain. The meteorological conditions during the accident were similar to that when the photograph was taken, so that similar transport and dispersion features were likely. The camera was facing approximately east on Highway 20 (see fig. 7) for the photograph.

After January 29, the anticyclonic high pressure system weakened with a change in wind and diffusion regimes. The month of February was marked by frequent frontal passages with their attendant strong southwest winds, precipitation, and reduction of inversion hours. A six inch snow-fall on February 2 was the first significant precipitation recorded for the year. The change of prevailing winds is shown in fig. 3 by the wind rose for the SL-1 area for February in which 60 per cent of the winds were from the southwest quadrant. The contrast between January and February in the prevailing flow is also shown in figs. 5 and 6, which show the wind roses at several stations along the Snake River Plain for these two months. The predominance of down valley winds in January along the entire plain is in sharp contrast with the predominance of westerly or southerly winds in February, with a general increase in speeds in the latter month.

The strong, deep inversions of January were largely absent in February with many nights showing no inversion hours near the surface. Dilution of any radioactive material would have been considerably

FIG. 4 A SMOKE PHOTOGRAPH SHOWING THE LIMITED VERTICAL DISPERSION AND EXTREME WIND MEANDER FOLLOWING THE SL-1 ACCIDENT.

FIG. 5 WIND ROSES FOR STATIONS ON THE SNAKE RIVER PLAIN — JAN, 1961

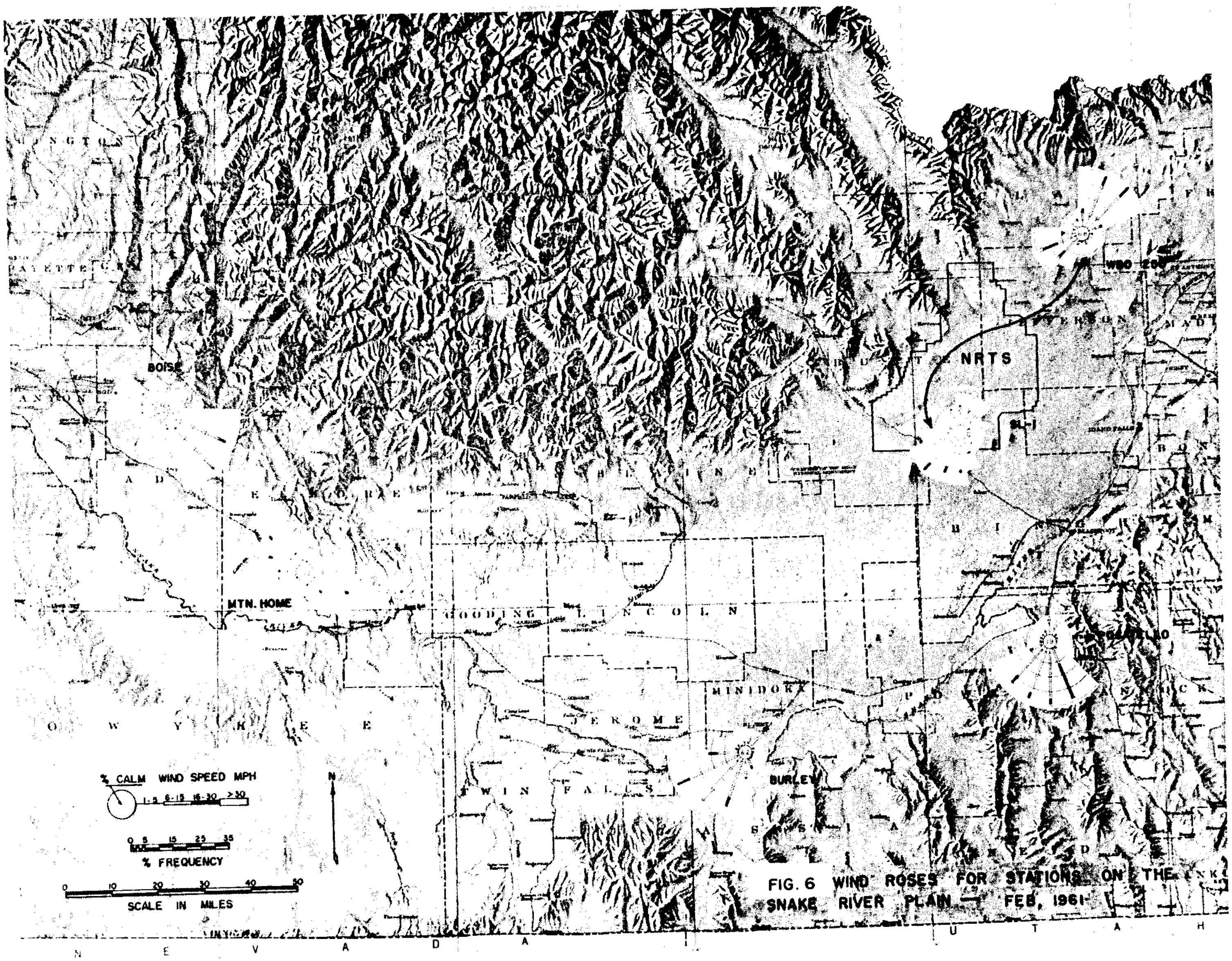


FIG. 6 WIND ROSES FOR STATIONS ON THE SNAKE RIVER PLAIN — FEB, 1961

increased over that of the previous month.

IV. METEOROLOGICAL INTERPRETATION OF RADIATION DATA

As discussed in section II, aerial and ground monitoring teams were guided to areas that were expected to be in the path of the effluent discharge. The aerial survey did not report any significant readings, probably because the iodine 131 stayed near the surface, so that only ground level data were available. Samples of vegetation were collected at easily accessible points along two principal cross-wind surveys at about 6 and 12 mi downwind on the first and second days after the accident respectively. From these initial surveys, the estimated release of iodine 131 during the first few days after the accident was made. The general areas of effluent deposition are shown in figs. 7 and 8, with what appeared to be the main part of the plume shown by the heavy line. The data from which fig. 7 was constructed were collected within 48 hours of the time of the accident, whereas, the more remote surveys of fig. 8 were completed by Jan. 9. The wide deposition pattern is typical of a steady release over a long period of time during extremely time-and spatial-variable winds. It appeared that the main part of the plume initially traveled somewhat east of the direction indicated by the winds as shown in fig. 2, before curving to the west along the axis of the Snake River Plain. This appeared to be due to some channeling effect of nearby terrain elevations.

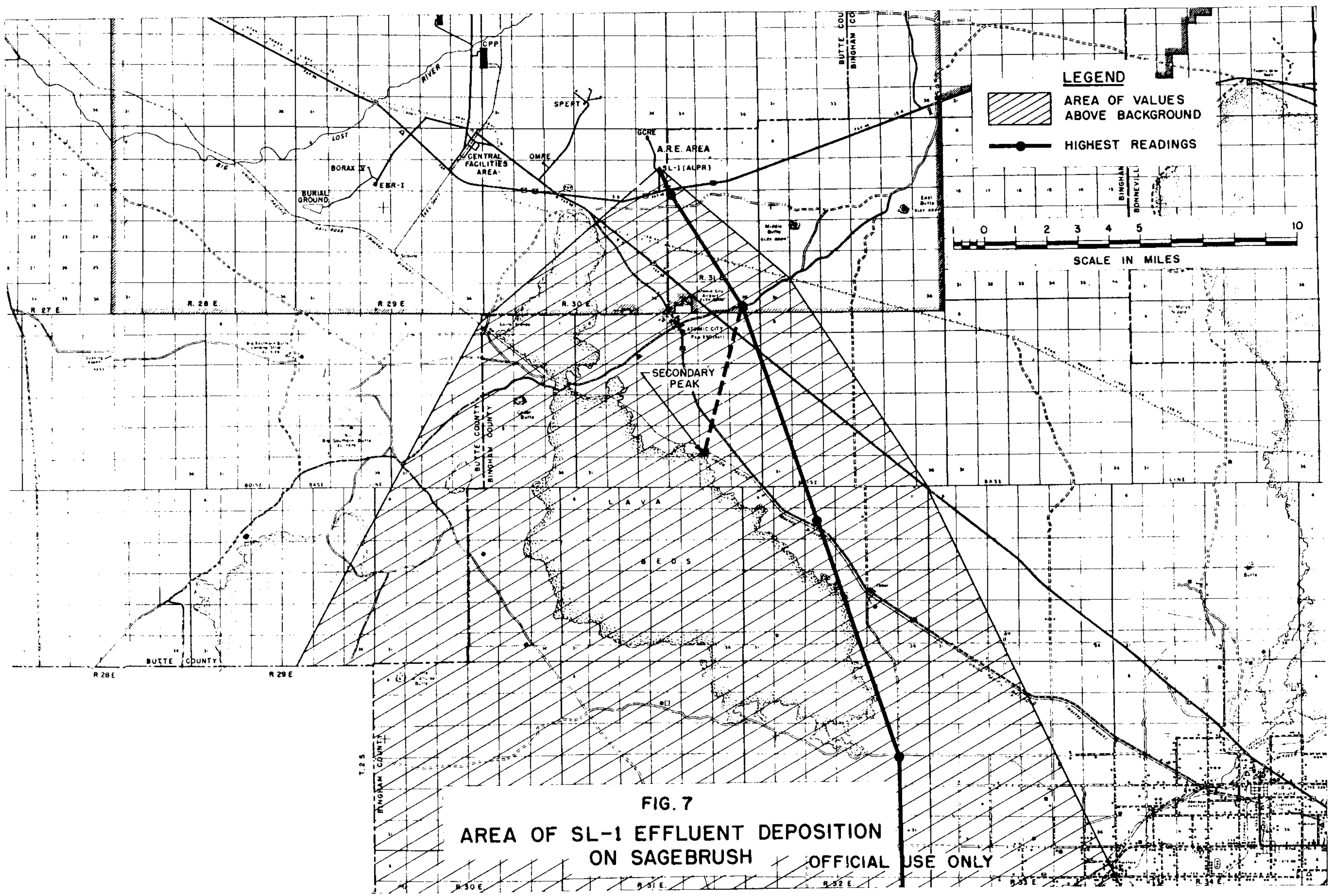


FIG. 7

AREA OF SL-1 EFFLUENT DEPOSITION ON SAGEBRUSH

OFFICIAL USE ONLY

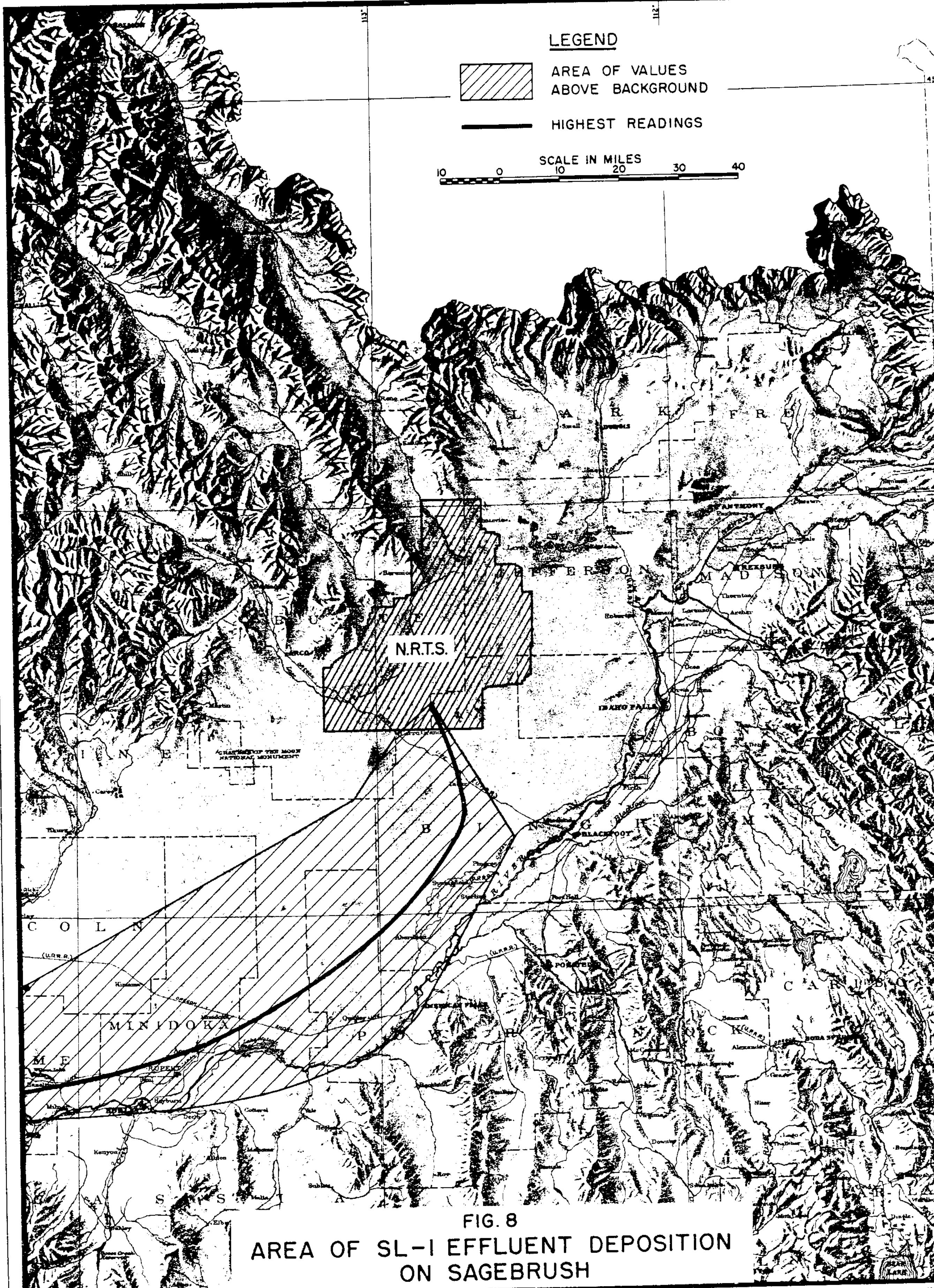


FIG. 8
AREA OF SL-I EFFLUENT DEPOSITION ON SAGEBRUSH

Because of the uncertainty of extrapolating surface winds very far from the point of measurement under the observed conditions, the observed air concentration from the environmental monitoring station at Atomic City, 5 mi south of SL-1, was not used to compute the emission rate of iodine 131. Instead the entire crosswind vegetation surveys, shown in figs. 9 and 10, were used. These figures show the radioactivity on the sagebrush in terms of counts/min/gm, which was determined to be largely iodine 131. The decrease of radioactivity on the sagebrush with distance downwind from the SL-1 is shown in fig. 11. The graph shows the measured activity in the main part of the plume, given by the solid line in fig. 7. The areas under the curves in figs. 9 and 10 give the crosswind integrated deposition of radioactivity, Dep, from the time of release for approximately the first day and the first two days respectively. This is related to the crosswind integrated air concentrations, CIC, along the survey arc by a deposition velocity, V_g, as

$$\text{Dep} = V_g \, \text{CIC} \qquad (1)$$

The source term, Q, can be computed from CIC by the usual diffusion equation

$$\text{CIC} = \frac{2Q}{\sqrt{\pi}\,\bar{U}\,C_z X^{\frac{2-n}{2}}} \qquad (2)$$

where $\bar{U}$ is the mean wind speed, C_z is the vertical diffusion coefficient, x is downwind distance, and n is a stability parameter. A slight correction should be made for radioactive decay, but this is not large

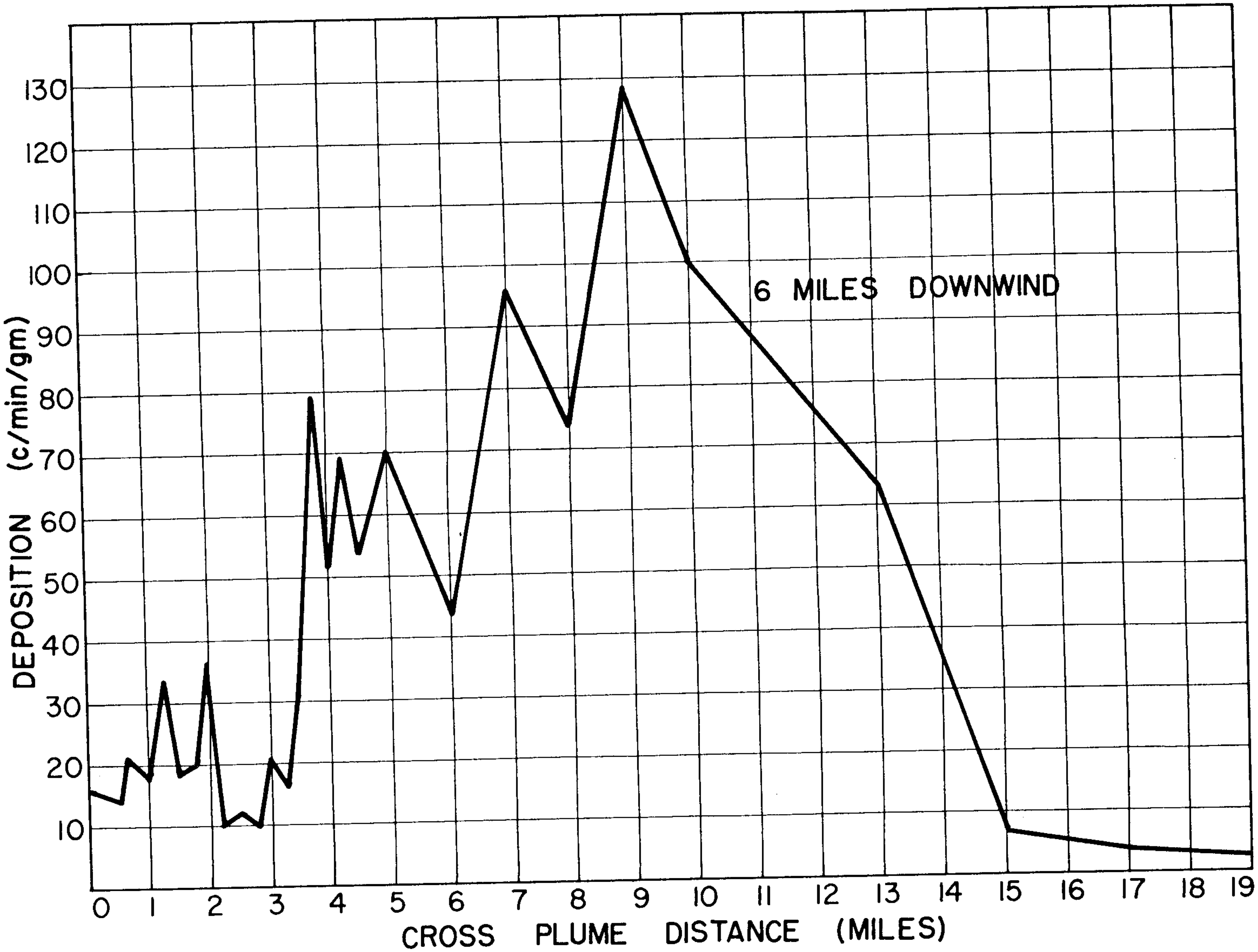


FIG. 9 DEPOSITION SURVEY ALONG HIGHWAY 26

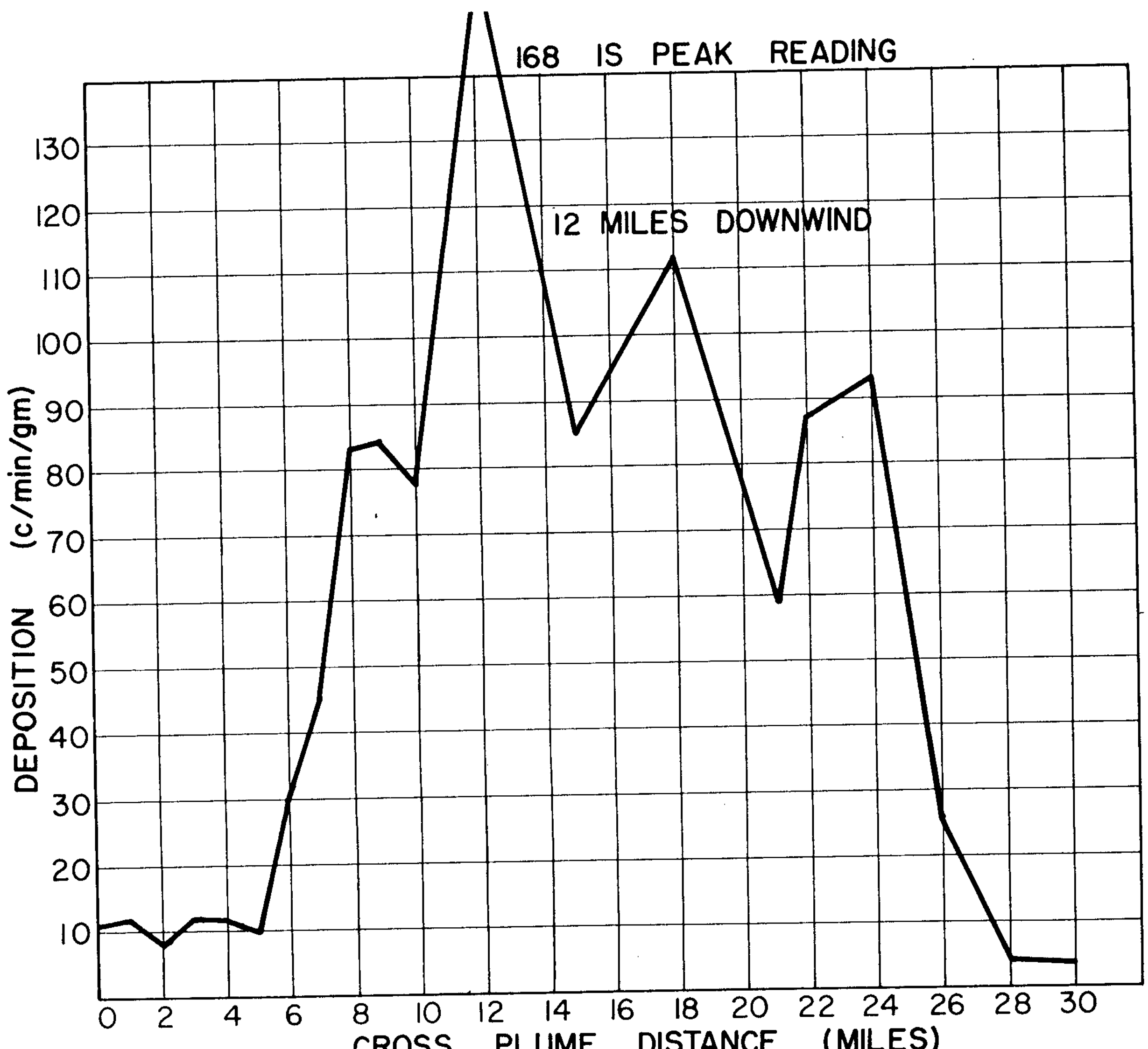


FIG. 10 DEPOSITION SURVEY ALONG RAILROAD TRACKS

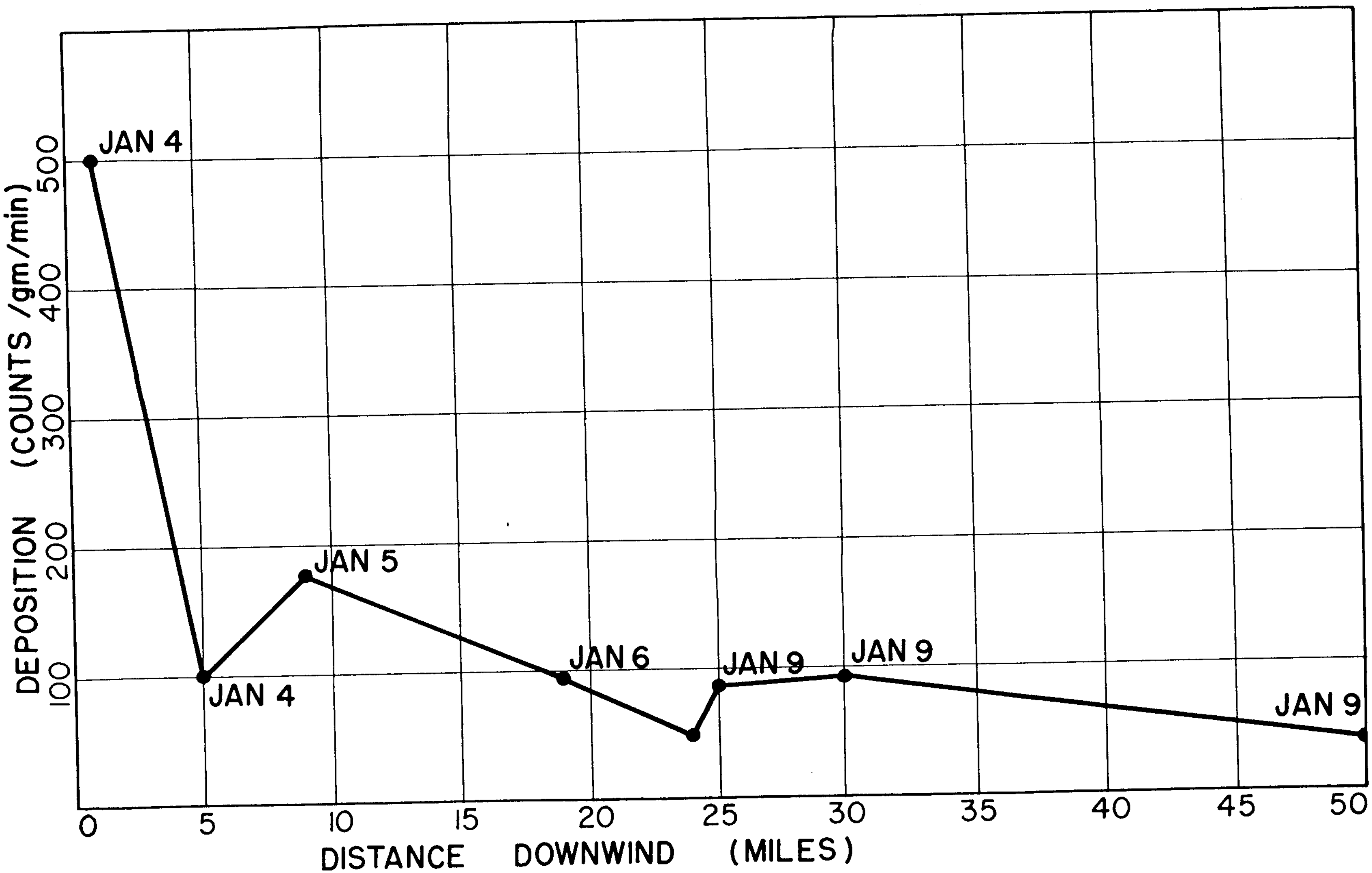


FIG. 11 DECREASE OF DEPOSITION ON SAGEBRUSH IN PLUME PEAK (HIGHEST READING) WITH DISTANCE

since iodine 131 has an eight-day half-life. A deposition velocity of 0.2 cm sec^{-1} was assumed to be appropriate as a result of some field experiments over similar terrain at the NRTS by General Electric Company [2]. Since the deposition is measured in terms of radioactivity per unit mass of vegetation whereas the deposition velocity is used to compute radioactivity per unit area, the density of vegetation is required to compare computed and observed deposition. The density of vegetation at this site was found to be 50 gm m^{-2} from ecological studies, and this value was used for deposition velocity calculations. It is of interest to note that the deposition velocity found for the iodine 131 deposition from the accident at Windscale, England [3], was similar to the value assumed above. Results of the calculations, shown in Appendix A, give an estimate of the total release of iodine 131 from the SL-1 area of 10 curies by the first day and 30 by the second day after the accident. Later deposition surveys gave additional estimates of the average daily discharge of iodine 131 for the period Jan. 6-11. All the calculations assumed that the release was at a constant rate through the day.

Completion of an extensive network of high volume air samplers around the SL-1 by Jan. 11 gave detailed air concentration data for source calculations. This included an arc of samplers 2 mi wide on Highway 20, about 3/4 mi. south of the SL-1, and several more samplers north of the SL-1. The filters were collected and analyzed on a daily basis and, using the diffusion equation (2) with observed meteorological conditions, source calculations were made. These calculations from air concentration data are shown in Appendix A. The estimated daily iodine 131 discharge to the atmosphere from the SL-1 area and cumulative total are shown in table 2. The results indicate a tapering off from a peak discharge of 20 curies/day on Jan. 4-5 to near 0.2 curies/day by the end of January with a total release of 84 curies by Feb. 12.

Since vegetation samples have been useful as an indication of trajectories of unexpected releases of radioactive material at the NRTS,

Table 2

Iodine 131 Release

Date	Rate (curies/day)	Cumulative Total (curies)
Jan. 4	10	10
Jan. 5	20	30
Jan. 6-11	5	60
Jan. 12-17	2	72
Jan. 18-23	1	78
Jan. 23-29	0.5	81
Jan. 30-Feb. 12	0.2	84

its potential use as an indication of the discharge rate of iodine 131 from a reactor is worthy of exploration. Samples of vegetation were taken near some of the air sampling stations and compared to air concentration data for the week Jan. 23-28 to obtain estimates of deposition velocities. This proved unrewarding since the deposition rates were too low by this time to provide the necessary precision. In some cases the decrease of radioactivity on the sagebrush from day to day exceeded that which would be predicted from radioactive decay alone. Apparently, the imperfections of the sampling techniques gave errors on the same order of magnitude as the daily decay, which is 8 per cent of the initial amount of radioactivity. However, several good samples were obtained near Atomic City, 5 miles south of SL-1, in the first few days after the accident, where an environmental monitoring air sampler is in continuous operation. The reported iodine 131 air concentration in microcuries per cubic centimeter (μc/cc) from this station was 36×10^{-12} μc/cc, whereas the adjacent vegetation 20 hrs after the accident showed a deposition of 80 counts/min/gm. Ignoring the slight bit of radioactive decay this gives

$$V_g = \frac{(80 \text{ counts/min/gm})(1.4 \times 10^{-6} \mu\text{c/counts/min})(50 \text{ gm/m}^2)}{(36 \times 10^{-12} \mu\text{c/cc})(10^6 \text{ cc/m}^3)(20 \text{ hrs})(3600 \text{ sec/hr})} = 0.2 \text{ cm sec}^{-1}$$

This is the value assumed in performing the iodine 131 release calculation. Similar estimates of deposition velocity were made from vegetation samples collected on Jan. 9, in the Springfield-Aberdeen area about 40 miles south of SL-1, and the mean air concentration for that period from the environmental monitoring station located there. The reported values of air concentration of iodine 131 and sagebrush radioactivity were 4×10^{-12} μc/cc and 50 counts/min/gm respectively which yield a similar value of deposition velocity as computed above.

The activity of iodine 131 on the vegetation along the sampling line on Highway 20 leveled off at about 3×10^{-3} μc/gm on Jan. 24 and then gradually declined. This value was at the sampling station showing the maximum vegetation reading, where the air concentration was reported as $6 \times 10^{-11} \mu c/cc$. One can compute the deposition rate which would equal the radioactive decay at this peaking period. These calculations are shown in Appendix B, which reveal a deposition rate of $2.6 \times 10^{-4} \mu c/gm/day$ and thus a deposition velocity of 0.25 cm sec^{-1}. The air concentration filters, consisting of a pre-filter to collect particulate iodine 131 and a charcoal cartridge to collect the gaseous material, were changed at daily or weekly intervals. About half of the iodine 131 was collected on the pre-filter, indicating that there was virtually an even division of the effluent into particulate and gaseous form by the time it reached the various sampling stations. The deposition velocities computed at several distances are summarized in table 3.

Table 3. Deposition Velocities of Iodine 131 from the SL-1 Accident

Distance (Kilometers)	Date	χ (curies m^{-3})	DEP (μ curies m^{-2} day^{-1})	V_g (cm sec^{-1})
1	Jan. 24	6.0×10^{-11}	1.3×10^{-2}	0.25
8.5	Jan. 4	3.6×10^{-11}	6.7×10^{-3}	0.20
67	Jan. 9	4.0×10^{-12}	7.8×10^{-4}	0.23

There appears to be little variation of V_g with distance, although the samples were not collected on the same days at the various distances. The V_g -values in table 3 are probably most appropriate for stable atmospheres since there were about 17 hrs. of strong inversion in the day during the period of these measurements.

A survey was made of the soil on Jan. 25 in the SL-1 region, showing the distribution of iodine 131 [1]. From these samples estimates of deposition velocity appropriate over soil cover could be made. These calculations, shown in Appendix B, give a value of 0.07 cm sec^{-1} for the deposition velocity over soil. Snow samples were taken along a 6 mi. arc about 10 mi. south of the SL-1 along with sagebrush samples at each point. The mean radioactivity of all samples was 2510 counts/min/m^2 and 204 counts/min/gm on the snow and sagebrush respectively. With a sagebrush density of 50 gm/m^2, this means about a 4 to 1 ratio in the deposition velocity over sagebrush as compared to snow. Although this figure is not surprising considering the nature of the two surfaces, the effect of snow melt or ablation is unknown and semi-quantitative conclusions only should be drawn. However, it appears that deposition rates over soil and snow are about 25 per cent of that over sagebrush.

All the estimates of deposition velocity over sagebrush made above are in fair agreement with one another. This may have been fortuitous considering the low levels of iodine 131 which had to be used, and the paucity of the data; however, it appears that 0.2 cm sec^{-1} is an appropriate figure to use for the deposition velocity of iodine 131 at the NRTS for operational-type calculations. The release estimates of iodine 131 from the SL-1 accident for the first few days made from deposition measurements on the vegetation are considered to be not gravely in error.

Measurements of air concentration [1] indicated that iodine 131 was eventually detected throughout the entire environmental monitoring network. This network extended to 100 mi. down the Snake River Plain to Shoshone, Idaho. The steady evolution of iodine 131 from the SL-1 resulted in a fairly even spatial distribution of radioactivity at greater distances. The levels of air concentration reported agreed quite well with a volumetric-type calculation of dilution. It can be assumed that iodine 131 was mixed rather uniformly to a height of 2000 ft (600 m), the limiting height due to the capping inversion. The horizontal width of the Snake River Plain across the prevailing winds is about 70 mi. (113 km). A mean wind speed of 7 mph (3 m sec^{-1}) through the layer is appropriate for the first two weeks, so that a relative concentration factor of

$$\chi/Q = \frac{1}{(1.13 \times 10^{5}\ m)(3\ m\ sec^{-1})(600\ m)} = 5 \times 10^{-9}\ sec/m^{3}$$

can be applied. For this dilution factor, the mean daily discharge of iodine 131 of about 10 curies day^{-1} (about 10^{-4} curies sec^{-1}) in the first several days would give an air concentration of about 5×10^{-13} curies m^{-3}, ignoring the slight radioactive decay. This was about the level measured in the outer-most stations of the environmental monitoring network.

A more sophisticated computation of the mean diffusion patterns as suggested by Culkowski [4], in which diffusion equations such as (2) are used with the wind rose and atmospheric stability measurements for the period, also was made and compared to measured air concentrations. In this technique the air concentrations are computed for the various wind speed and stability combinations, and then summed for each wind direction sector for the appropriate number of hours that a certain set of conditions occurred. The appropriate dispersion parameters are the same as those used in the calculations in Appendix A, and the source is given in table 2. The computed isopleths of average air concentration of iodine 131 for the period Jan. 3 to Feb. 12, 1961 are compared in figure 12 to measured average air concentrations for that period.

The agreement is good out to several miles, but predicted values are a factor of ten lower than measured values at distances beyond 25 mi. This probably is due to the recirculation of iodine 131 with the diurnal change of the wind and the containing effect of the mountains on three sides of the Upper Snake River Plain. A simple volumetric-type calculation appears more suitable than diffusion equations for long-period average air concentration calculations at greater distances under such conditions. Measured mean relative concentration factors can be computed from the source figures of table 2 and the measured air concentrations in figure 12.

There is evidence that the effluent reached Boise, Idaho in detectable amounts. The Atomic Energy Commission monitoring air sampler in Boise, analyzed weekly, showed a sudden jump from .08 to .34 $d/min/m^3$ of unidentified fission products on their filters on Jan. 7. The levels remained near the latter figure until Jan. 28, dropping suddenly to 0.07 $d/min/m^3$ on this date. The date of the rise of radioactivity coincided well with the expected arrival time of the iodine 131 from the SL-1, a distance of about 250 mi. Iodine 131 air concentrations of $10^{-13} \mu c/cc$, which are twice background, were measured by the U.S. Public Health Service [5] on Jan. 19, 1961. The date that the levels dropped at Boise, Jan. 28, coincides with the date of the major wind reversal from down-valley (east to west) wind directions to westerly winds. The inversion that dominated the weather situation in January weakened then, with a major change from the stable air mass conditions of January to the more diffusive conditions of February. This has been discussed in section 3. The change in the prevailing winds throughout the Snake River Plain from January to February is shown in figs. 5 and 6 by a comparison of respective wind roses for the two months.

V. CONCLUSIONS AND FUTURE RECOMMENDATIONS

Although large amounts of radioactive material were not released following the accident at SL-1, the situation did require meteorological support of the type necessary to cope with a major nuclear accident. It is felt, in reviewing the actions of the Weather Bureau, that the emergency disaster procedures originally devised for such an occurrence were successfully applied and vindicated. However, several results indicate that the following points should be emphasized:

1. Re-entry into the reactor following an accident may be impossible, so that release estimates can be made only from radiation measurements obtained in the field. These release estimates can have considerable significance, so that a capacity to rapidly supplement existing environmental monitoring networks, when necessary, with meteorological direction is required.
2. Even a fairly dense network of meteorological stations can fail to detect topographic influences on surface-level winds, particularly during strong inversions. Other devices such as visual

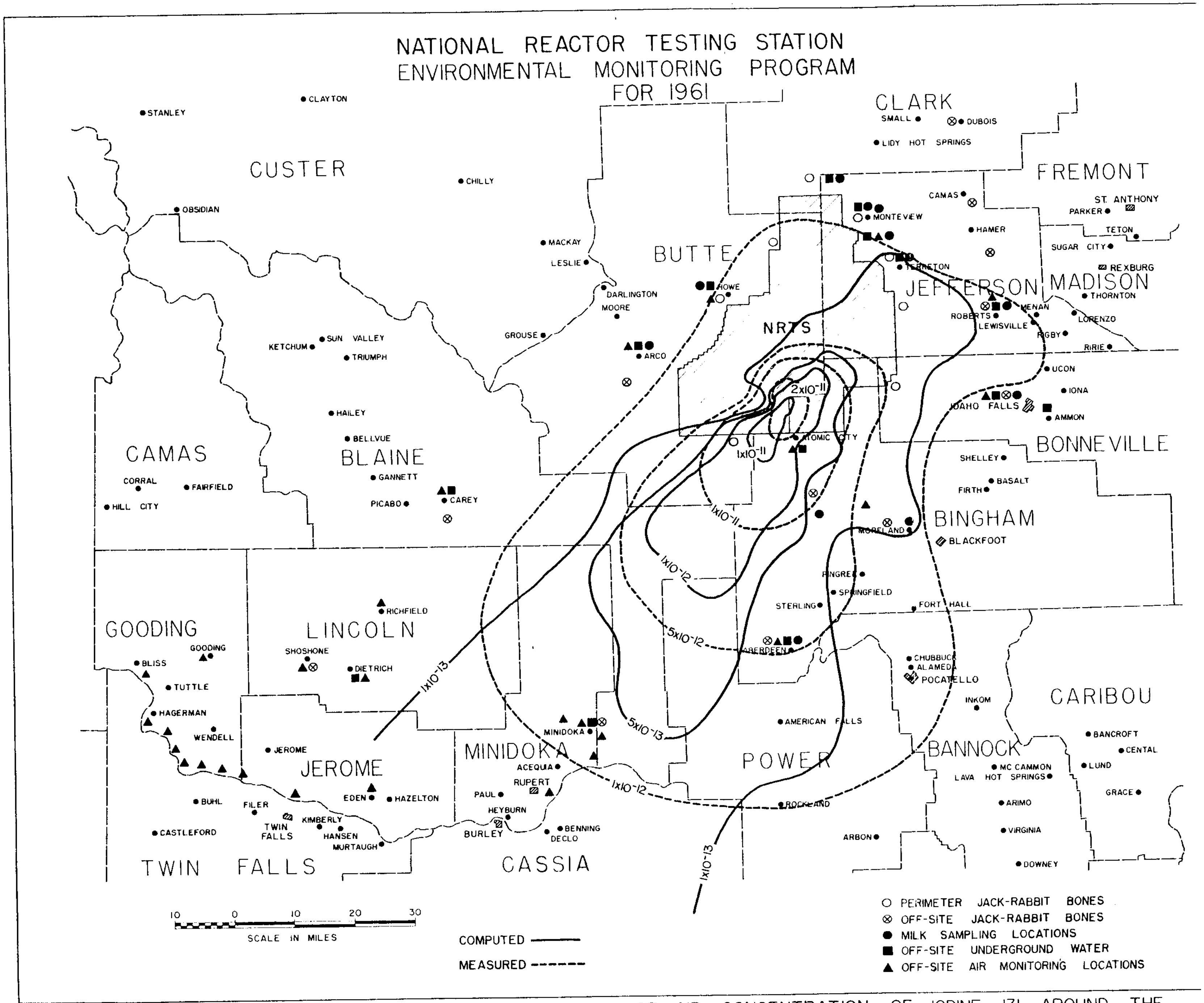


FIGURE 12. COMPUTED AND MEASURED ISOPLETHS OF AIR CONCENTRATION OF IODINE 131 AROUND THE SL-1 FOR JAN. 3 - FEB. 12, 1961

tracers and radar tracking of reflecting type targets can be quite useful. Smoke pots in reactor areas, available for immediate release are useful tools. As a result of the SL-1, both Weather Bureau vehicles, which are equipped with radio, have been supplied with smoke pots and compasses to obtain trajectory information at strategic locations.

3. Written detailed plans delineating the action to be taken by personnel within the branch should be available and memorized by branch personnel.

4. Non-interception of continuously-operated air samplers by the radioactive material may leave deposition measurements as the only means of determining initial cloud trajectory and release estimates. Some useful estimates of deposition rates-air concentration relationships were measured from the SL-1, but further research into this is required.

The meteorologist, in order to fulfill his mission during the tension of a nuclear accident, should endeavor to become thoroughly familiar with the manner of operation of the agencies to which he is attached during such times. The specific needs of responsible officials must be completely understood and information presented in a manner that will help, not confuse, the intended recipient.

References

1. Idaho Operations Office, Atomic Energy Commission, 1962: IDO report on the nuclear incident at the SL-1 reactor. IDO-19302, 197 pp. (Available from the Office of Technical Services, Dept. of Commerce, Washington 25, D. C. (Price $2.00)

2. General Electric Co., National Reactor Testing Station; 1960: Test results from D101-12E-4 LIME Experiment, IET 22, DC 60-10-720. Idaho Falls, Idaho.

3. Chamberlain, A. C. 1960: Aspects of the deposition of radioactive and other gases and particles. Int. J. of Air Poll., 3, 63-87.

4. Culkowski, Walter M., 1959: Estimates of accumulated exposures and environmental build-up of radioactivity. TID-7593, 6th AEC Air Cleaning Seminar, July 7-9, 1959, Idaho Falls, Idaho. (Available from Technical Information Service, Oak Ridge, Tennessee), 89-99.

5. Daniels, R. A., 1962: Personal communication. U.S. Public Health Service. Washington 25, D. C.

Appendix A

A-I. Method of computing iodine 131 release from SL-1 from deposition measurements

Crosswind integrated air concentration, CIC, times deposition velocity, V_g, equals crosswind integrated deposition, Dep.

V_g CIC = Dep , V_g = 0.2 cm sec^{-1}

From Sutton's equation for a source Q(curies):

$$CIC = \frac{2Q}{\sqrt{\pi}\,\bar{U}\,C_z X^{\frac{2-n}{2}}}$$

Parameter	Strong Inversion	Strong Lapse
$\bar{U}$(Wind speed)	2 m sec^{-1}	2 m sec^{-1}
C_z(vertical diffusion coefficient)	0.06	0.30
n(stability parameter)	0.50	0.20

Relative Concentration (CIC/Q)

stability case / distance	Inversion	Lapse	Daily Mean*
6 mi(9.65×10^3m)	9.8×10^{-3}	4.7×10^{-4}	7.1×10^{-3}
12 mi(1.93×10^4m)	5.9×10^{-3}	2.7×10^{-4}	4.3×10^{-3}

*Weighted for 17 hours of inversion and 7 hours of lapse

Jan. 4 - Deposition at 6 mi (fig. 9) = 1.35×10^6 counts-m/gm/min

$$Q = \frac{(1.35 \times 10^6 \text{ counts-m/gm/min})(1.4 \times 10^{-6}\ \mu c/\text{counts/min})(50\ \text{gm/m}^2)}{(2 \times 10^{-3}\ \text{m/sec})(7.1 \times 10^{-3})} = 6.65 \text{ curie}$$

Jan. 5 - Deposition at 12 mi (fig. 10) = 2.84×10^6 counts-m/gm/min

$$Q = \frac{(2.84 \times 10^6 \text{ counts-m/gm/min})(1.4 \times 10^{-6} \mu c/\text{counts/min})(50 \text{ gm/m}^2)}{(2 \times 10^{-3} \text{ m/sec})(4.3 \times 10^{-3})}$$

$$= 2.32 \times 10^7 \mu c = 23.2 \text{ curies}$$

These values are rounded off to 10 curies and 30 curies, which will compensate for radioactive decay.

A-II. Release estimates from air concentration data

Wind and field radiation measurements indicate that the effluent can be assumed to be evenly spread through a day over 60° for the first few miles downwind. Therefore, the average relative concentration out to Atomic City is given as

$$(\chi/Q)_a = \frac{3}{\pi x} \int_{-\infty}^{\infty} (\chi/Q)\, dy = \frac{6}{\pi^{3/2} \bar{U} C_z x^{\frac{4-n}{2}}}$$

where

$$\chi/Q = \frac{2}{\pi \bar{U} C_y C_z x^{2-n}} \exp - \left[\frac{y^2}{C_y^2 x^{2-n}} \right]$$

is the relative concentration expression assumed valid at Aberdeen. The following table shows a sample calculation.

Air Concentration Calculations

Jan. 14-16, 1961

Sampler Location	downwind distance (meters)	$(\chi/Q)_a$ Lapse (sec/m^3)	$(\chi/Q)_a$ Inversion (sec/m^3)	$(\chi/Q)_a$* Daily (sec/m^3)	χ ($curie/m^3$)	Q (curie/day)
Highway 20	1100	1.2×10^{-6}	3.9×10^{-5}	2.8×10^{-5}	5.7×10^{-10}	1.8
Atomic City	8500	2.5×10^{-8}	1.2×10^{-6}	8.5×10^{-7}	3.5×10^{-11}	3.5
Aberdeen	67,500	2.9×10^{-9}	1.0×10^{-6}	7.3×10^{-7}	4×10^{-12}	0.5

*Weighted for 17 hours of inversion and 7 hours of lapse.

Lapse parameters: $n = 0.2$, $C_y = 0.3$, $C_z = 0.3$, $\overline{U} = 5$ m sec^{-1}

Inversion parameters: $n = 0.5$, $C_y = 0.3$, $C_z = 0.06$, $\overline{U} = 2$ m sec^{-1}

The above calculations show that approximately two curies of iodine 131 per day were released for the period Jan. 14-16. Calculations for the following days were made in a similar manner.

Appendix B

B-I. Deposition velocity calculations

The differential equation for activity, $N(\mu c/gm)$, on the vegetation with a constant deposition rate, $D(\mu c/gm/day)$, for an isotope of decay constant, λ , can be written as

$$\frac{dN}{dt} = -\lambda N + D \quad ; \quad \lambda = \frac{.693}{T_{1/2}}$$

For the boundary condition that $N = N_o$, when $t = 0$, the solution is

$$N = N_o e^{-\lambda t} + \frac{D}{\lambda}(1 - e^{-\lambda t})$$

For equilibrium: $\lambda N = D$

λ (for iodine 131) = .085 day^{-1}

$D = (.085\ day^{-1})(3 \times 10^{-3}\ \mu c/gm) = 2.6 \times 10^{-4}\ \mu c/gm/day$

$$V_g = \frac{(2.6 \times 10^{-4}\ \mu c/gm/day)(50\ gm/m^2)}{(6 \times 10^{-11}\ \mu c/cc)(10^6\ cc/m^3)(8.65 \times 10^4\ sec/day)} = 0.25\ cm\ sec^{-1}$$

Deposition velocity over soil

Soil analysis near SL-1 on Jan. 25 showed a deposition of about $0.3\ \mu c/ft^2$ or about $3.0\ \mu c/m^2$. A mean air concentration on the order of 5×10^{-9} $\mu c/cc$ for Jan. 3-25 was computed by back extrapolation from measurements at more distant stations.

$$V_g = \frac{(0.3\ \mu c/m^2/day)(10^{-6}\ m^3/cc)}{(5 \times 10^{-9}\ \mu c/cc)(8.65 \times 10^4\ sec/day)} = 0.07\ cm\ sec^{-1}$$

The daily deposition rate used above, $0.3\ \mu c/m^2/day$, was computed from the decay equation with $N_o = 0$ and $t = 22$ days.