Environmental Monitoring Near A Multi-Stack Uranium Plant

Roger D. Caldwell and Ronald F. Crosby
Nuclear Materials and Equipment Corporation
Apollo, Pennsylvania

Introduction

Every nuclear plant must demonstrate permissible radioactivity concentrations beyond its site boundaries. The nuclear industry almost traditionally limits stack discharges below permissible concentrations.(1) Because it is unequivocal, the Atomic Energy Commission encourages this approach. If the stack concentration is permissible, then certainly the concentration anywhere else will be less.

Evaluating off site concentrations at NUMEC's uranium plant proved difficult, but also quite necessary. You can appreciate the problem by examining Figure 1 which shows the plant setting. The NUMEC building, located inside the town of Apollo, shares three common walls with a steel truss fabricator. The whole complex of buildings was once the old Apollo Steel Plant. Houses crowd in as close as 200 feet and several hundred people live within a thousand yard half circle of the plant. Since the Kiskiminetas River runs close by, the whole town sets down in one of those typical, steep sided Appalachian river valleys. We're located about 30 miles northeast of Pittsburgh.

Stack Sampling

Figure 2 shows our stack sampling problem. There are 124 filtered stacks on our plant roof. You can also see the housings for six large unfiltered exhaust fans which provide comfort ventilation for the plant. About 10^5 CFM of filtered air is exhausted via the stacks and an equal amount of unfiltered air by the roof fans.

It is obviously impractical to monitor all stacks continuously. We have been sampling each stack four hours once a month. Even this minimal sampling keeps one full time technician busy.

Our stack sampling technique is standard: We insert an isokinetic probe into the center line of the stack and draw air at 40 l/min through an inline Whatman 41 filter paper. Recently we have successfully used Gelman Type E glass fiber filters. Where the stack discharge is corrosive or has high water vapor content, we bubble the sample through cascaded impingers. Several models of Gelman and Gast pumps have given us good service.

This intermittent stack sampling has not given us assurance that off site concentrations are acceptable. In the first place, the measured stack concentration frequently exceeds permissible levels. (^{234}U is the major isotope; its $MPC_a = 4 \times 10^{-12}$ μCi/ml or 8.8 $d/m/M^3 \approx .08$ $\mu gm/M^3$).[2] Occasionally this is caused by a deficiency in air cleaning such as a poor filter seal. But more often the leakage is through the filter itself. So called "absolute" filters are merely highly efficient, allowing a small ($< .03\%$)[3] but measurable quantity of aerosol to penetrate through the filter. Adding a second stage of absolute filtration would solve the problem, but is too costly.

Secondly, only 8 of the stacks are sampled on a given day. It is not reasonable to guess what the other 116 are discharging on that day.

Even total continuous sampling of all stacks would not guarantee permissible off site concentrations. For example, the off site concentration might exceed MPC_a because of the summed contributions from several stacks, each of which was discharging concentrations below MPC_a.

We could not apply the commonly used stack gas dispersion formulas(4), because our local topography is grossly unfavorable. The steel plant next door is twice as high as our plant. Rain hats cover many stacks. Figure 3 pictures graphically what rain hats do to exhaust plumes. The effective stack height of the capped stacks is easily half that of the uncapped stack. Most of our stacks do not reach above the peak of our roof; all are well below the recommended(5) 2-1/2 times the building height. A better set up for downwash cannot be imagined.

Off Site Sampling Methods

Our stack sampling experience forced us to begin monitoring the neighborhood for radioactivity. When we started, we were afraid we might find excessive levels. But, as we will show later, we had underestimated the dispersion capability of the atmosphere.

Since exposure of people was our controlling concern, we chose air sampling as the best monitoring technique. If our building had been surrounded with farm land, perhaps deposition on crops would be more important.

Continuous air sampling in the neighborhood posed several practical problems. Battery powered high volume air samplers are not commercially available. Even where there were electrical outlets, air sampling equipment could not be left unattended very long. Children cannot leave gadgets alone. Finally cost dictated a limit on the number of continuous samplers.

We decided to supplement whatever air samplers we could manage with fallout collectors. We thought that they would at least enable us to extrapolate reasonably between air sampling locations.

Figure 4 shows our continuous environmental sampling network. There are seven fixed station air samplers, four of which are at stack height on the plant roof. The three off site continuous air samplers were placed north, east and south of the plant. Our industrial neighbors, Raychord and Nuclear Decontamination Corporation, kindly permitted us to locate samplers at their sites. Filters are changed daily and counted for alpha radioactivity.

We distributed 26 fallout collectors around the plant. After some study we settled on two types of dust fall collectors: Vertical gummed paper and 9 inch aluminum low wall pans (pie pans). The fallout collectors are assayed weekly for alpha radioactivity in an Eberline PC-4 large area proportional counter. Counts are scaled on an NCA RC-3 scaler-ratemeter.

To understand the plant effluent dispersion better, we air sampled at points between and beyond the fixed stations. We took two approaches to this supplementary sampling. First, many individual short period samples were grabbed whenever the wind behaved in an unusual way. One example is during downwash in the lee of a high wind. Second, we carried out sampling campaigns under typical wind conditions. After determining wind speed and direction, we set out high volume air samplers downwind at different distances from the plant. At the furtherest distance we also set out samplers crosswind. Most of these sampling studies were run for four hours.

Figure 5 depicts some of our equipment. One of us is cranking up a gasoline powered Richmond Sampler. It draws about 2.5 CFM through 4 inch Whatman 41 or glass fiber filters. On the hand truck you see the 8 x 10 inch sample head of a Gelman Hurricane sampler. We carried several hundred feet of electrical cord to power our A/C samplers. The can-like object on the hand truck is an Anderson Cascade impactor. It has its own 12 volt battery powered D/C pump. Our assistant is changing one of the low wall pie pan fallout collectors. If you look carefully, you can see, on the telephone pole behind the car, one of our 4" x 8" vertical gummed paper dust collectors.

Local Wind Conditions

The Kiski valley is narrow, steep sided and prone to frequent inversions. At Apollo it runs north and south, across the prevailing westerlies. Since such valleys tend to distort wind flow(6), we felt it was necessary to measure local wind parameters. Consequently, we purchased a Taylor Instrument Co. Windscope, a combination potentiometer wind vane and generator anemometer. The windscope was mounted on the plant roof at stack height, about 40 feet high, and the readout located in the Plant Health and Safety Laboratory. Readings of wind speed and direction are taken every four hours, seven days a week.

The annual windrose for 1966, Figure 6, clearly demonstrates the valley's perturbation of the upper wind flow. Almost all wind flow in the valley is north and south, while the general wind direction, recorded at the Greater Pittsburgh Airport, is out of the west.

An inordinate proportion of wind speeds below 1 MPH worried us a great deal. We thought perhaps that the anemometer wasn't properly calibrated, so we ran several smoke drift and velometer tests, all of which confirmed the anemometer readings. A possible explanation is our observation of frequent nocturnal calms. A lid goes on the valley at night and most of the low wind speeds are recorded then. Even at low wind speeds, the wind vane functioned, so we have added the wind direction during these calms to the windrose.

Because of the dramatic variation, we have plotted a Seasonal Windrose, Figure 7. The relative turbulence in winter and fall is much greater than during the spring and summer seasons. Most valley inversions occur in late spring, summer and early fall.

Dispersion From A Multi-Stack Source

Air sampling has demonstrated effective dispersion of the plant effluent. When averaged over eight hours, we have never measured off-site concentration above permissible limits. Ten minute grab samples, taken in the lee of the building, have occasionally given concentrations up to 25 d/m/M^3. However, another 10 minute sample, taken a short time later, might give a result a 1000 times lower. Since preventing accumulation of long term body burdens is the criterion for uranium health protection, averaging concentrations is completely justified.

The off site fixed station air samplers have consistently averaged below 10% of the MPC_a. The roof edge samplers, averaged over the year, show permissible concentrations. We have found the roof samplers very useful in detecting problem stacks. When we were sampling stacks monthly, it was possible to have a leaky stack go undetected for several weeks. The present arrangement allows us to find our problems much faster.

We intended our separate air sampling surveys to confirm an alternate diffusion model to common formulas such as Sutton's continuous point source equation.[7] Since such formulas are for point sources, large errors can result in calculating ground level concentrations downwind from a multi-stack source. We proposed, Figure 8, treating all of the stacks as one large volume source.

Holland[8] has suggested that a volume source could be represented by postulating a "virtual point source" just far enough upwind to produce a gaussian distribution of material within the volume source. This postulation's value is permitting point source calculations to predict dispersion from a volume source.

The calculation of the distance to this virtual point source may be accomplished simply by taking advantage of a surprising observation: The magnitude of the cross wind spread at short range from a point source is independent of wind speed over a large range of wind speeds. Experimental results[9] show that an average cross wind spread of 20 degrees is observed for wind speeds of 2-12 meters/sec for distances up to one kilometer. This amazing fact can be better understood by considering the x^{2-n} term in Sutton's equation. At high turbulence the concentration varies almost as the inverse square of the distance downwind, at low turbulence at somewhat less than the inverse square. This means that at higher wind speeds, when a narrower plume is expected, higher turbulence tends to spread the plume. At longer distances the turbulence factor is not as important and the angle of spread does vary with wind speed. We found that 66 meters represented the distance to our virtual point source for most conditions.

Figure 9 shows why it's important to choose diffusion formulas carefully. Curve A represents the conventional form of Sutton's equation for a 12 meter stack. B & C are volume source curves where the height of the virtual point source, h', is 12 and 24 meters respectively. The significant difference between point and volume sources is immediately apparent: Volume sources yield higher concentrations closer to the point of discharge. The point source formula predicts undetectable concentration 15 meters away. The fact is that concentrations measured here were the greatest.

The measured data do not really follow the volume source formula well. The different data points were gathered under widely separated times. We were lucky to get the data to stay on the graph. The data seems to follow an inverse power function rather than a product of power and exponential functions. It's as if there was no effective stack height at all. This is not surprising, considering the adverse topography and short stacks.

However, atmospheric dispersion is still effective. For a conservative wind speed of 1 meter/sec and a maximum discharge, Q, of 10^3 d/m/sec, the predicted averaged concentration will never exceed 1.6 $d/m/M^3$; this is less than 0.2 MPC_a.

Surface Deposition

Fallout collection is an elusive monitoring technique to interpret. Simple correlations between concentrations measured above a surface and the amount deposited per unit surface area with time do not exist.

Our luck was no better than others at finding a simple factor by which to multiply surface collection to obtain air concentration. So we chose to represent fallout collection separately. Figure 10 shows a typical weekly fallout contour. The contours are multiples of picocuries per square foot per week. The contours account for 25% of the released activity; the rest is dispersed at a distance. There are several interesting features of the fallout contour. Fallout generally follows the wind pattern, the direction and extent being dependent on the direction and speed of the wind. The fallout collectors are useful for detecting otherwise unknown releases. For instance, the local contours around NDC resulted one week from unwittingly burning contaminated scrap clothing. No excessive levels resulted, but the fallout network enabled us to warn NDC and the error was corrected before it got out of hand.

We experimented considerably with gummed paper. Cylindrical collectors(10) were recommended to us, but we found the directionality benefit was lost. Apparently due to small particle size (AMAD≈0.3-3 microns), the collection on the back of the cylinder was as great as in front. This led us however to use vertical collectors. It is very simple to staple gummed paper to a telephone pole.

One of the surprising things to us was the prevailing presence of alpha activity in the environment. Fallout collectors, located many miles away, often showed activity levels as high as 20 pCi/ft^2/week. Thus the effect of uranium plant fallout is lost within a few hundred yards of the plant.

Another interesting feature of the remote fallout collectors illustrated something about the mechanism of fallout collection. Collectors located near well-traveled roads always give higher results than those away from roads. We think this happens because radioactive dust doesn't settle out; it impacts onto surfaces. The more turbulence in an area the higher the collection rate of the available radioactivity. This is why vertical gummed paper works as well as horizontal adhesive. Of course, the reason stems from the small particle size and resultant low settling velocities.

Kiskiminetas River Survey

An appreciation of the magnitude of natural radioactivity levels can be gained from a survey we made in May, 1966. For several years we have sampled the Kiskiminetas River at three bridges, one above our uranium plant, one below the uranium plant and above our plutonium plant and another below the plutonium plant. The 1966 average is given in the following table:

Table 1

Alpha Activity Levels
Kiskiminetas River - 1966

Location	Averaged Concentration pCi/liter	Concentration Range, pCi/l
Apollo	13.14	.3 - 102.7
Vandergrift	13.36	.45 - 101.0
Leechburg	10.77	.9 - 46.0

Since the average flow in the Kiski River is 3080 cubic feet per second, the Apollo concentration represents about a curie per day. The mystery of all this radioactivity upstream proved irresistable to us, so in May, 1966, we took a two day survey by canoe of the Kiski watershed. Figure 11 show the sample locations. The results are in Table 2.

The Kiski area contains a number of coal mines, whose drainage creates a high acid content (pH = 2-5) in the Kiskiminetas River. Several geological publications[11,12,13] have described the association of uranium and coal in Western Pennsylvania. Estimates of uranium in coal ranged from

10-140 ppm. Consequently, we also surveyed water from several mines. The term, boney pile, refers to the overcover removed from coal.

We found striking increases in radioactivity from coal mine drainage. The levels are appreciable, considering that the MPC_W for unidentified radionuclides is 10 pCi/l. We subjected several samples to radiochemical analysis and found the activity predominantly from $^{234,238}U$; less than 10% was from ^{226}Ra. Thus the mines do exceed the MPC_a, but not so much that a truly dangerous circumstance exists.

Conclusion

We have demonstrated that the NUMEC uranium plant effluent produces permissible off-site radioactivity concentrations. Even with adverse topography, cramped site boundaries, short stacks and unfavorable winds, the lower atmosphere dilutes our stack concentrations by factors of 100-1000. Restricting stack effluents to MPC_a is unnecessary.

We have also shown that nature's radioactivity can be appreciable. Our natural radiation environment must be understood if we are to have reasonable and realistic regulation of radioactive waste discharge.

Table 2

Kiskiminetas River Radioactivity Survey
May, 1966

Sampling Point	Concentration pCi/liter	Remarks
River 1	2.7	Allegheny River
" 2	18.9	
" 3	26.9	
" 4	45.2	
" 5	25.5	
" 6	28.2	
" 7	142.7	Old mine drainage
" 8	16.8	
" 9	33.6	
" 10	17.3	
" 11	46.4	Downstream of principal mine drainage
" 12	119.1	" " " " "
" 13	81.8	" " " " "
" 14	11.8	
" 15	3.6	
" 16	14.5	
" 17	16.4	
" 18	17.3	
" 19	12.7	
" 20	1.8	Upstream of all mines
Stream A	32.7	Mine drainage
" B	30.5	" "
" C	21.6	
" D	29.3	
" E	20.5	
" F	12.7	
" G	1.0	
" H	2.9	
" I	1.0	
" J	163.6	Downstream of Boney Pile
" K	1.0	
" L	10.0	
" M	15.5	
" N	4.5	Upstream of all mines
" O	3.4	" " " "
" P	17.3	Reservoir, some mine drainage
Mine #1	174.1	
Mine #2	120.0	
Boney Pile	180.0	Shale overcover of coal

References

1. A. J. Breslin, Toward More Realistic Systems for the Discharge of Radioactive Airborne Wastes, Health Physics, Vol. 12, No. 10, pp. (1496)-(1501), October 1966.

2. Code of Federal Regulations, Title 10, Part 20, Appendix B.

3. W. J. Smith, N. F. Surprenant, Properties of Various Filtering Media, Third AEC Air Cleaning Conference, LASL (1953).

4. Meteorology and Atomic Energy, U.S. Government Printing Office, Washington, D.C. (July 1955).

5. Industrial Ventilation, A Manual of Recommend Practice, American Conference of Governmental Industrial Hygienists, Ninth Edition, 1966.

6. Air Pollution Control Manual, Part 1 - Evaluation, 1960, American Industrial Hygiene Association.

7. M. Eisenbud, Environmental Radioactivity, p. 76, McGraw-Hill, 1963.

8. J. Z. Holland, AEC Report ORO-99, 1955.

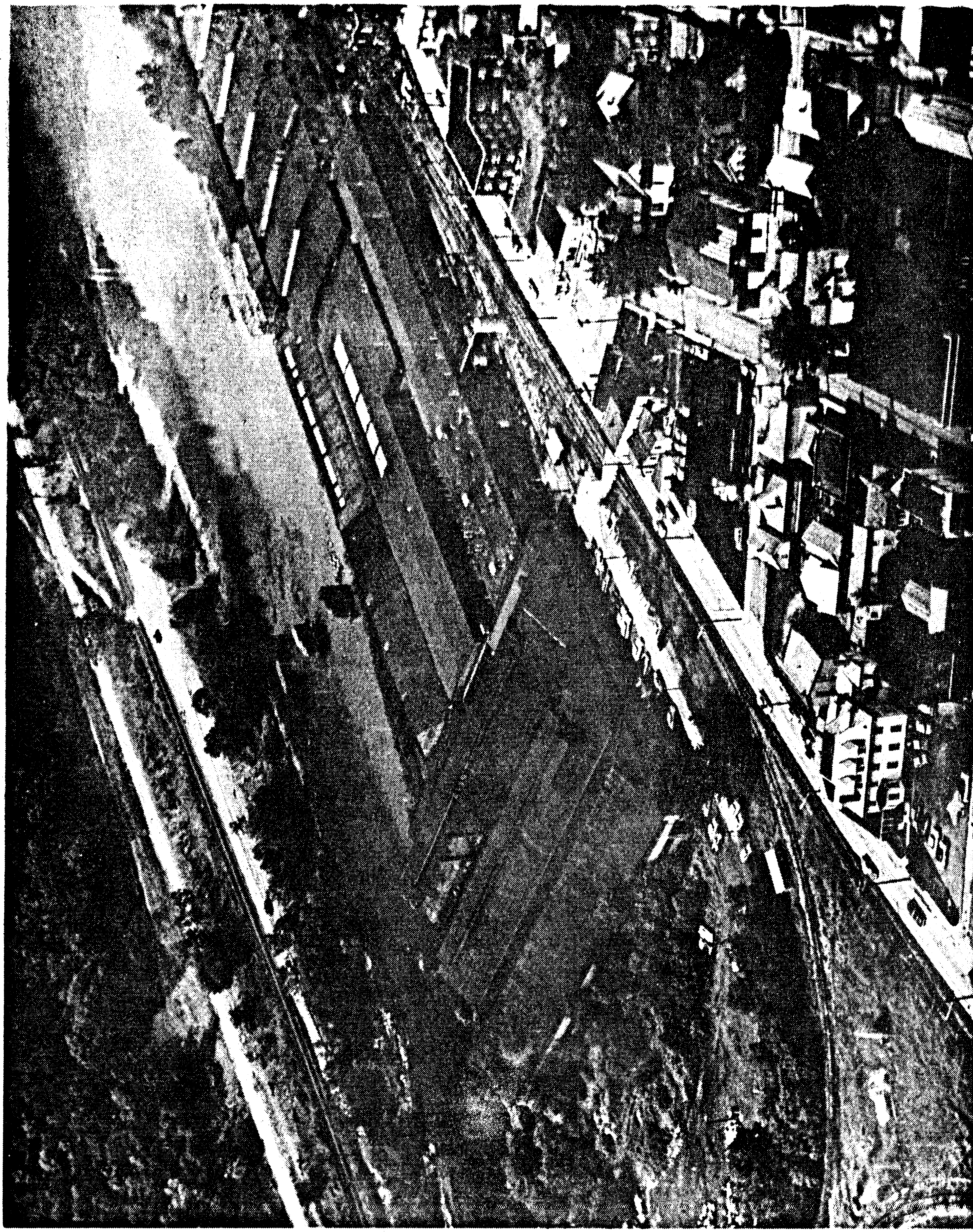
9. F. Pasquill, Atmospheric Diffusion, p. 134, Van Nostrand, 1962.

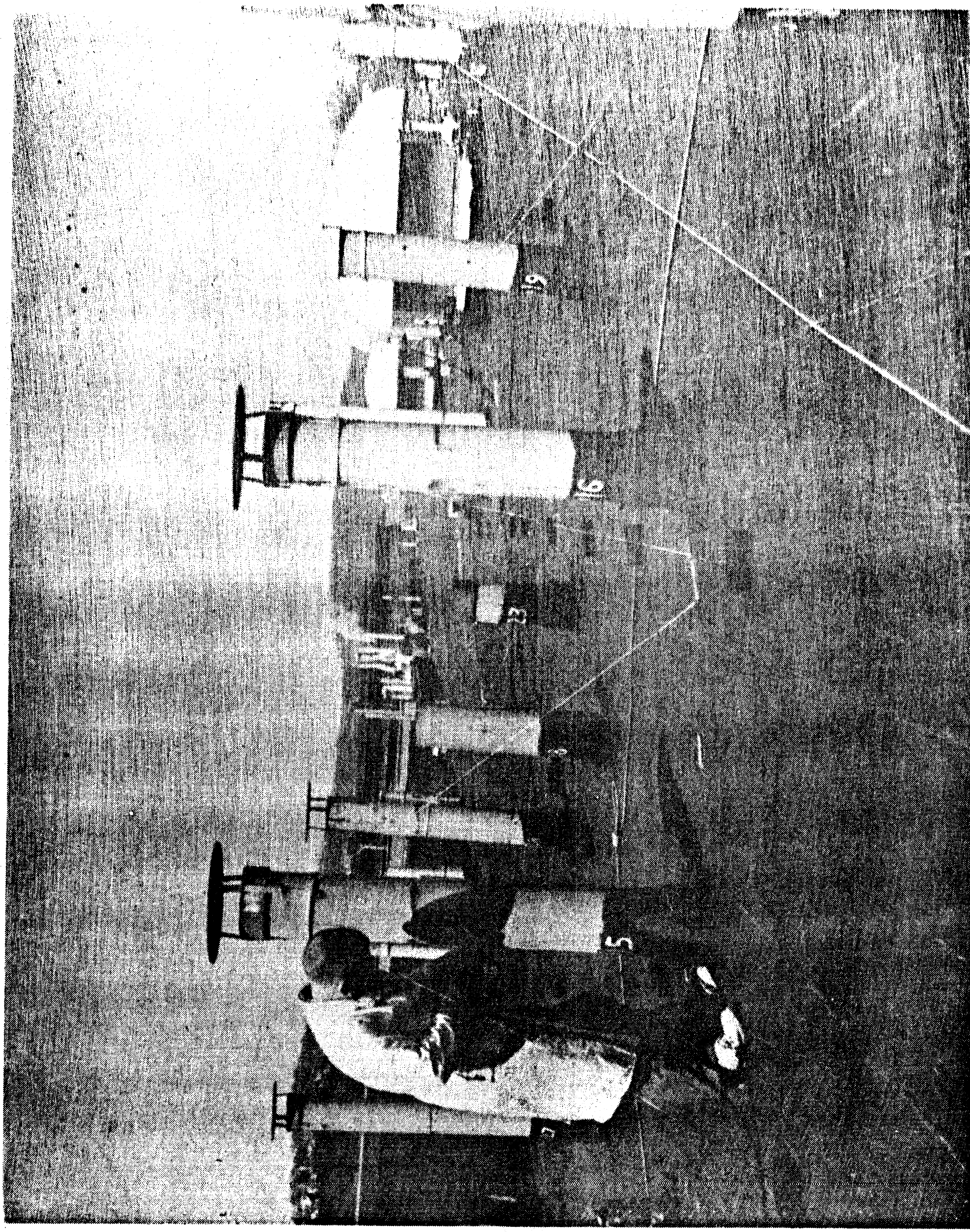
10. W. L. Pritchard, C. E. Schumann and C. W. Gruber, The Role of Surface Geometry in Particle Collection Upon Adhesive Materials, Presented at the 1966 American Industrial Hygiene Conference, Pittsburgh, Pa., May 1966.

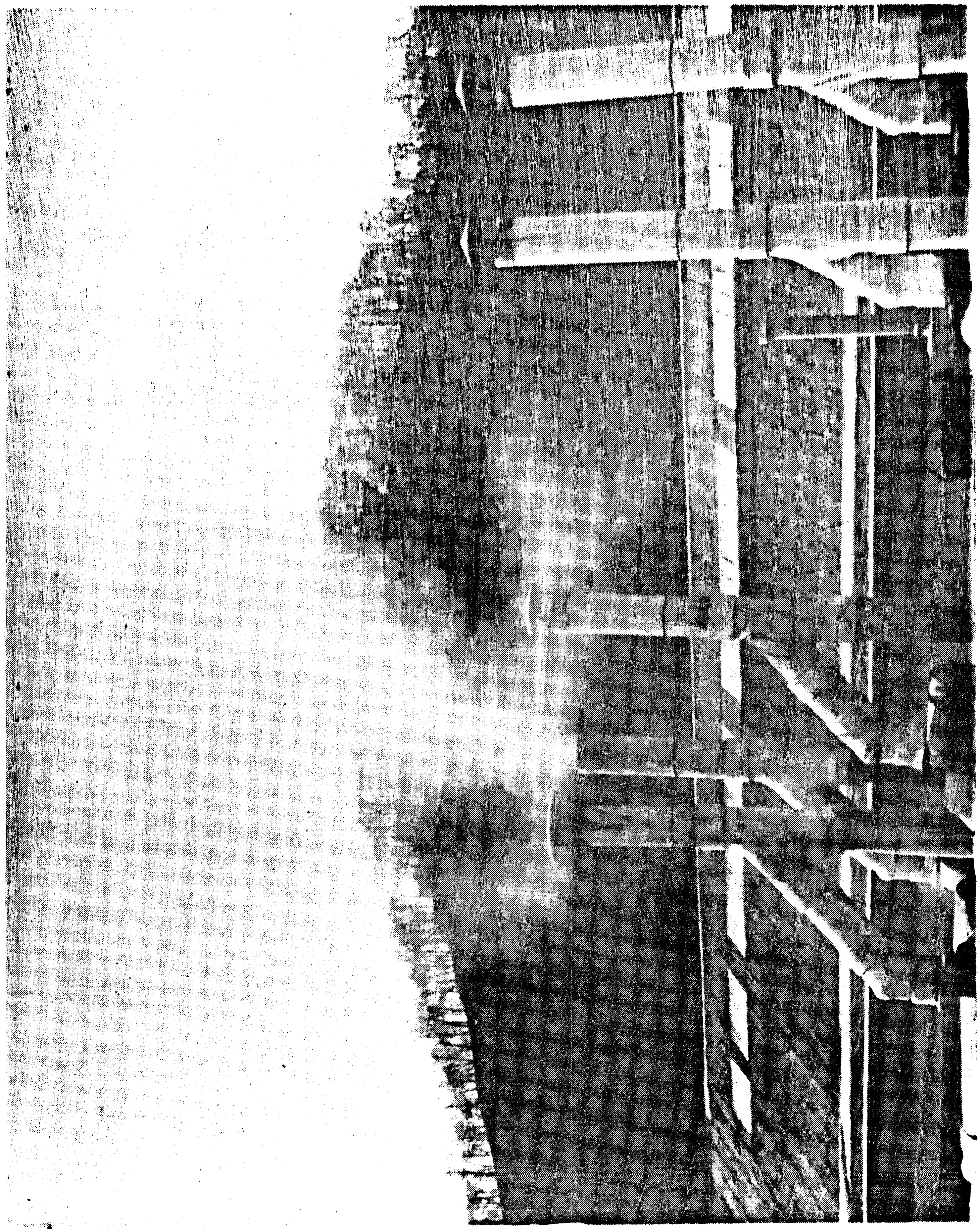
11. J. F. McCauley, Uranium in Pennsylvania, Pennsylvania Geological Survey, Bulletin M43, 1961.

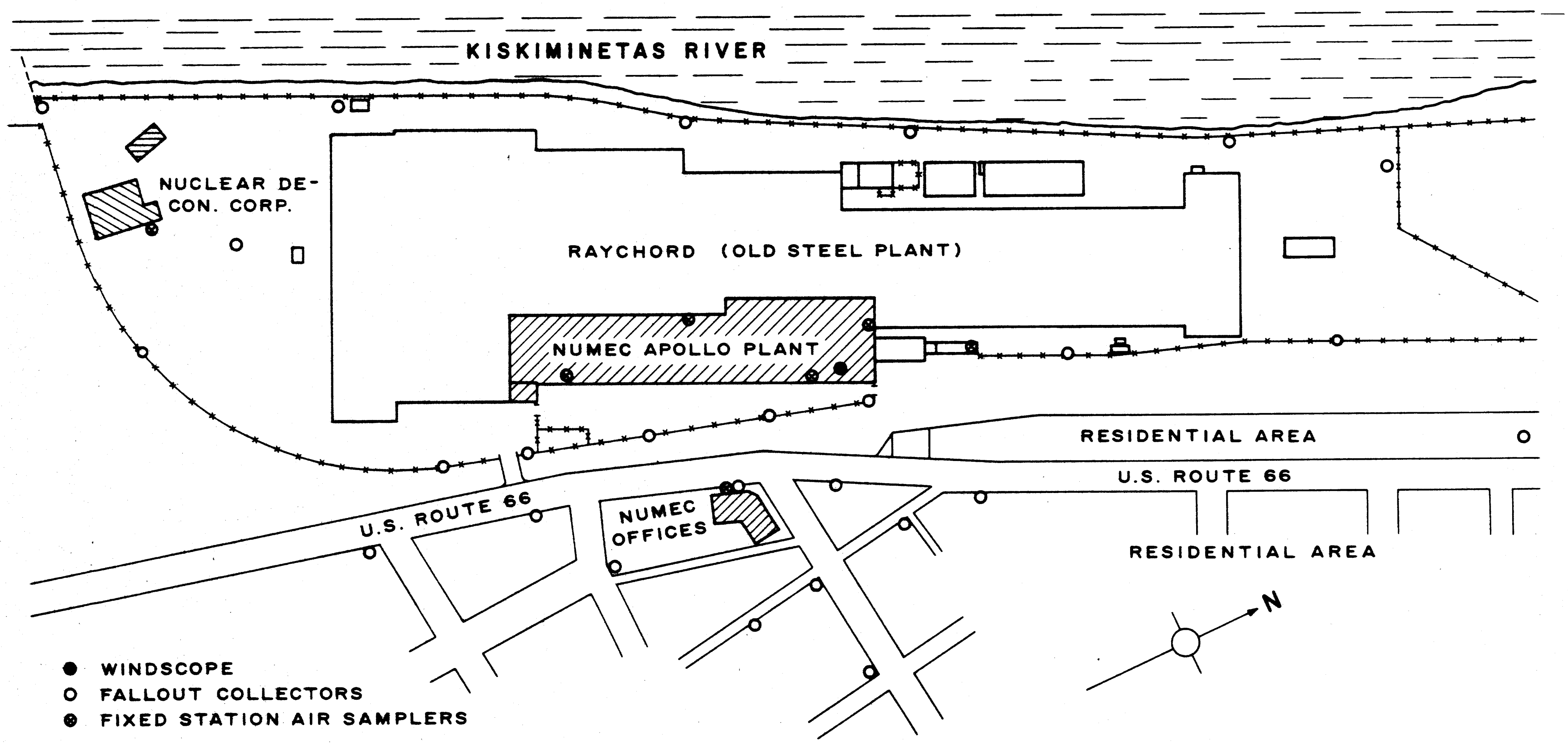
12. J. C. Ferm, Radioactivity of Coals and Associated Rocks in Beaver, Clearfield and Jefferson Counties, Pennsylvania, U.S. Geological Survey, TEI-468, January 1955.

13. E. D. Patterson, Radioactivity of Part of the Bituminous Coal Region of Pennsylvania, U. S. Geological Survey, TEI-49, November, 1954.

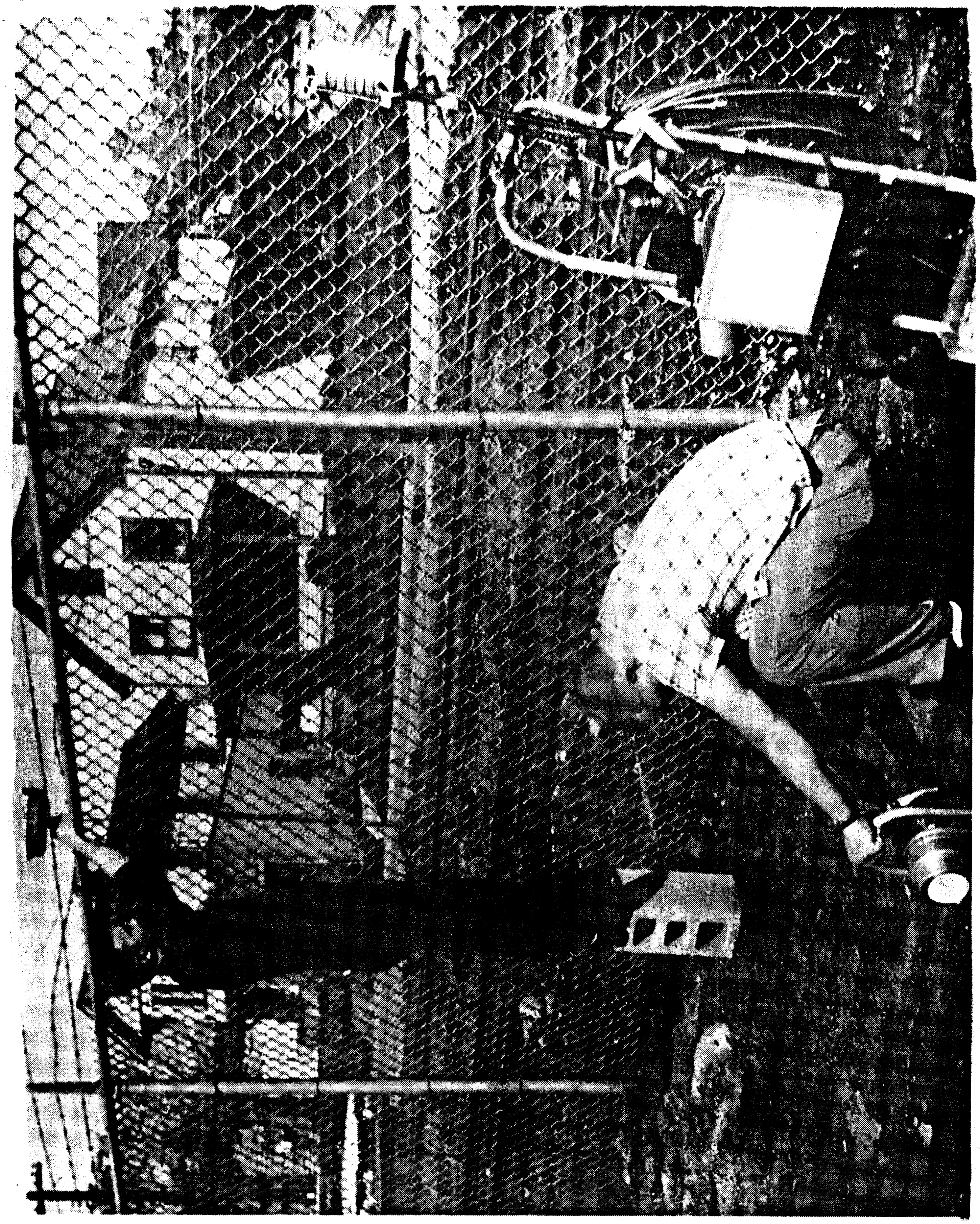








ENVIRONMENTAL MONITORING NETWORK
NUMEC APOLLO PLANT

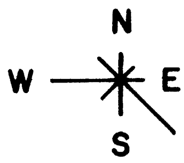


SEASONAL WIND ROSE - APOLLO, PENNSYLVANIA

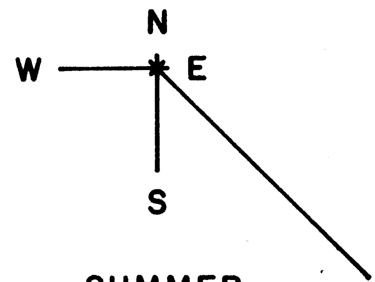
HEIGHT OF MEASUREMENT = 40 FEET   YEAR-1966

SCALE = MILES PER HOUR x FREQUENCY

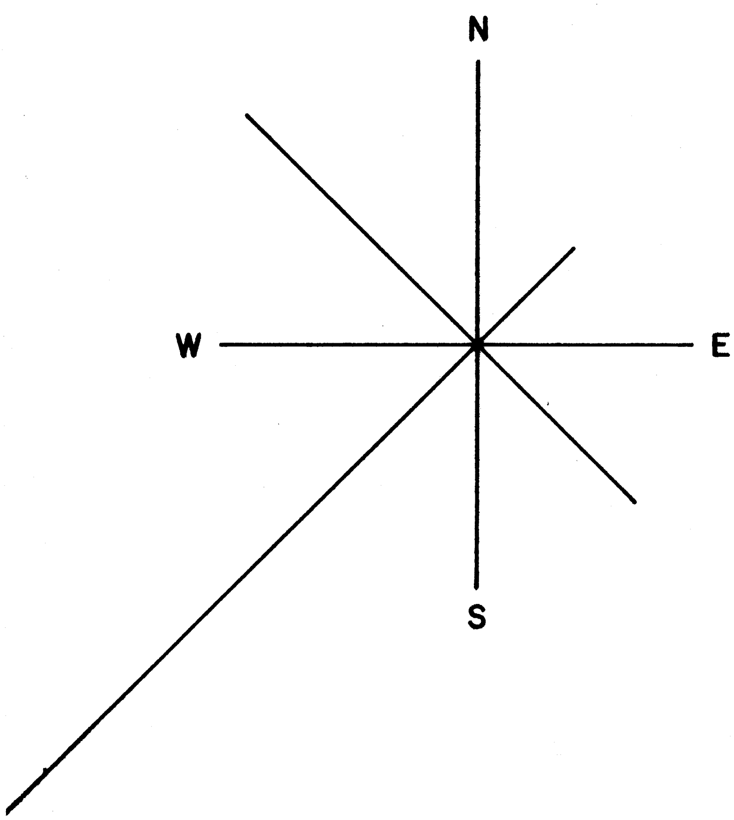
1.25 MILES PER READING



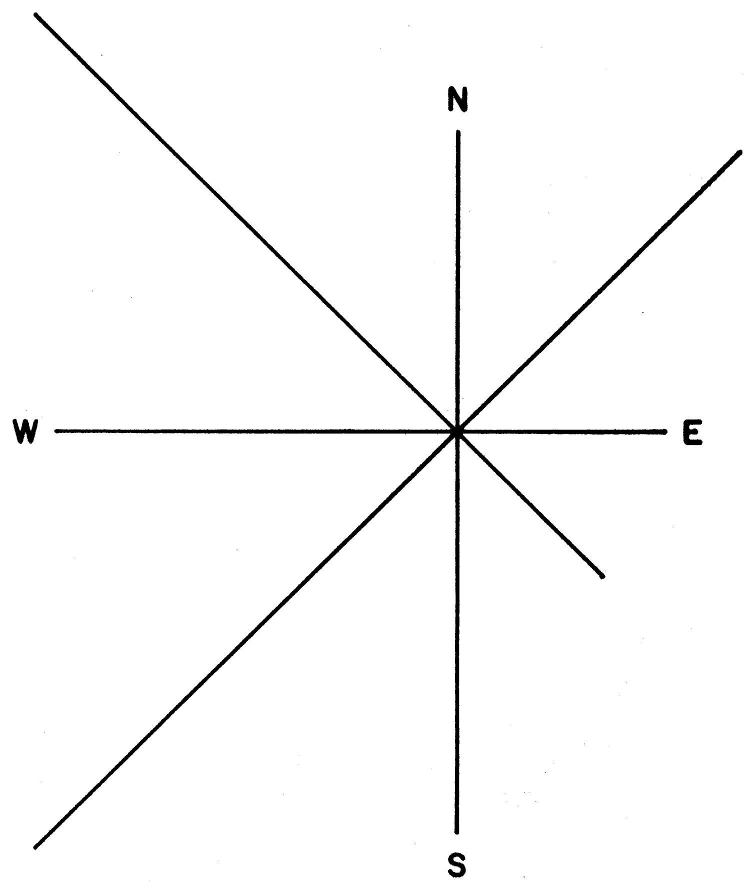
SPRING



SUMMER



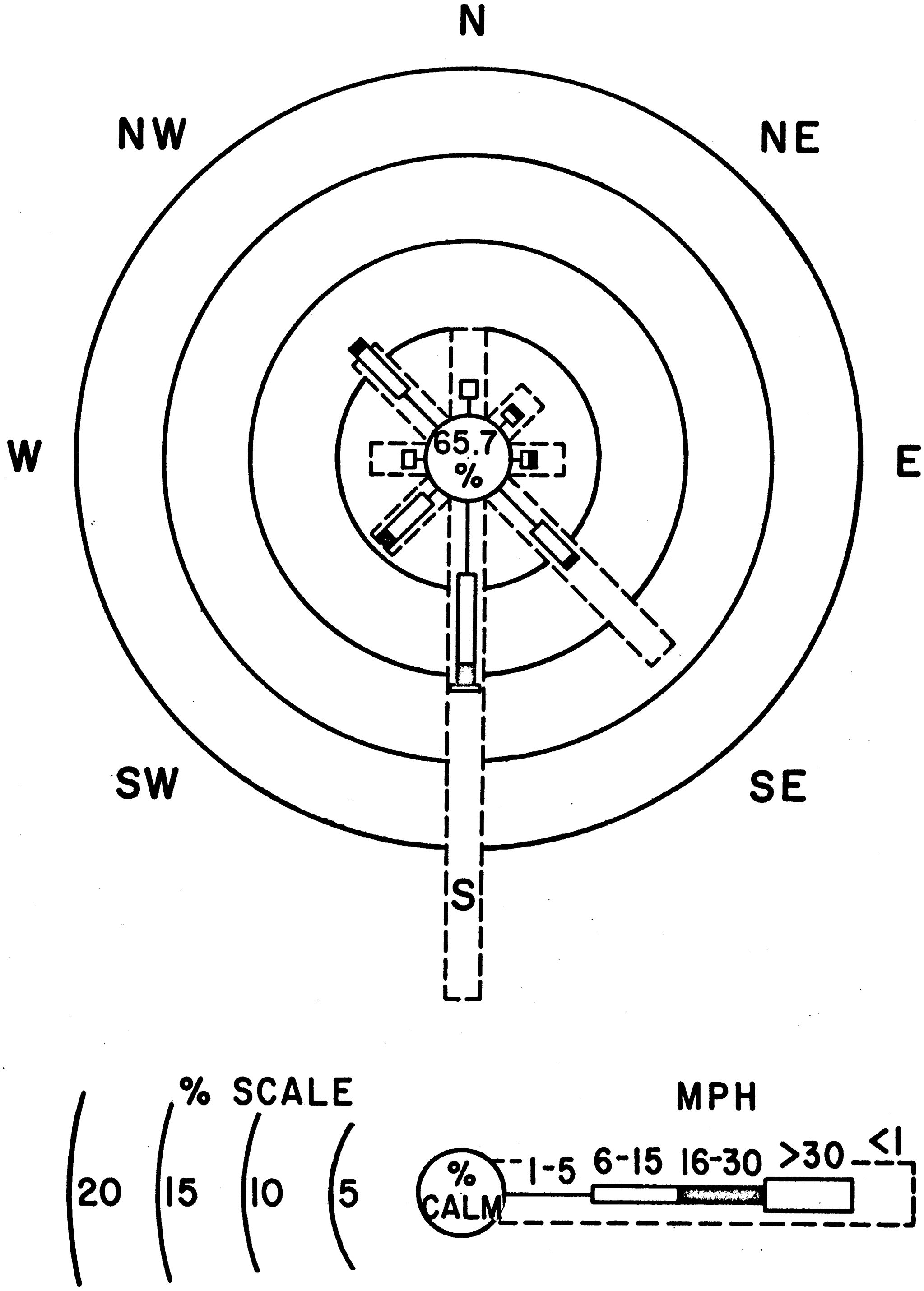
WINTER



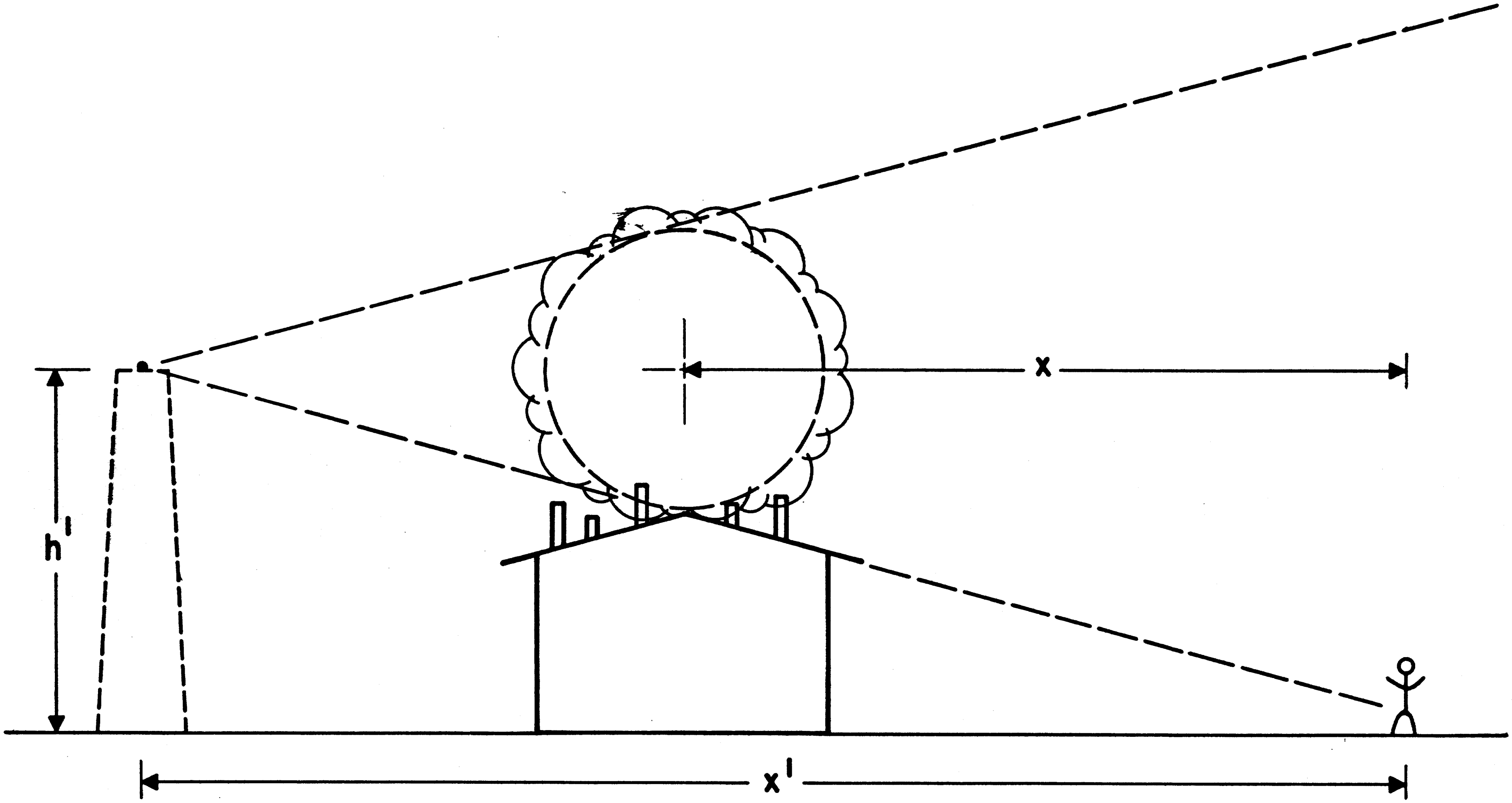
FALL

WIND ROSE - APOLLO, PENNSYLVANIA

HEIGHT OF MEASUREMENT-40 FEET　　YEAR-1966



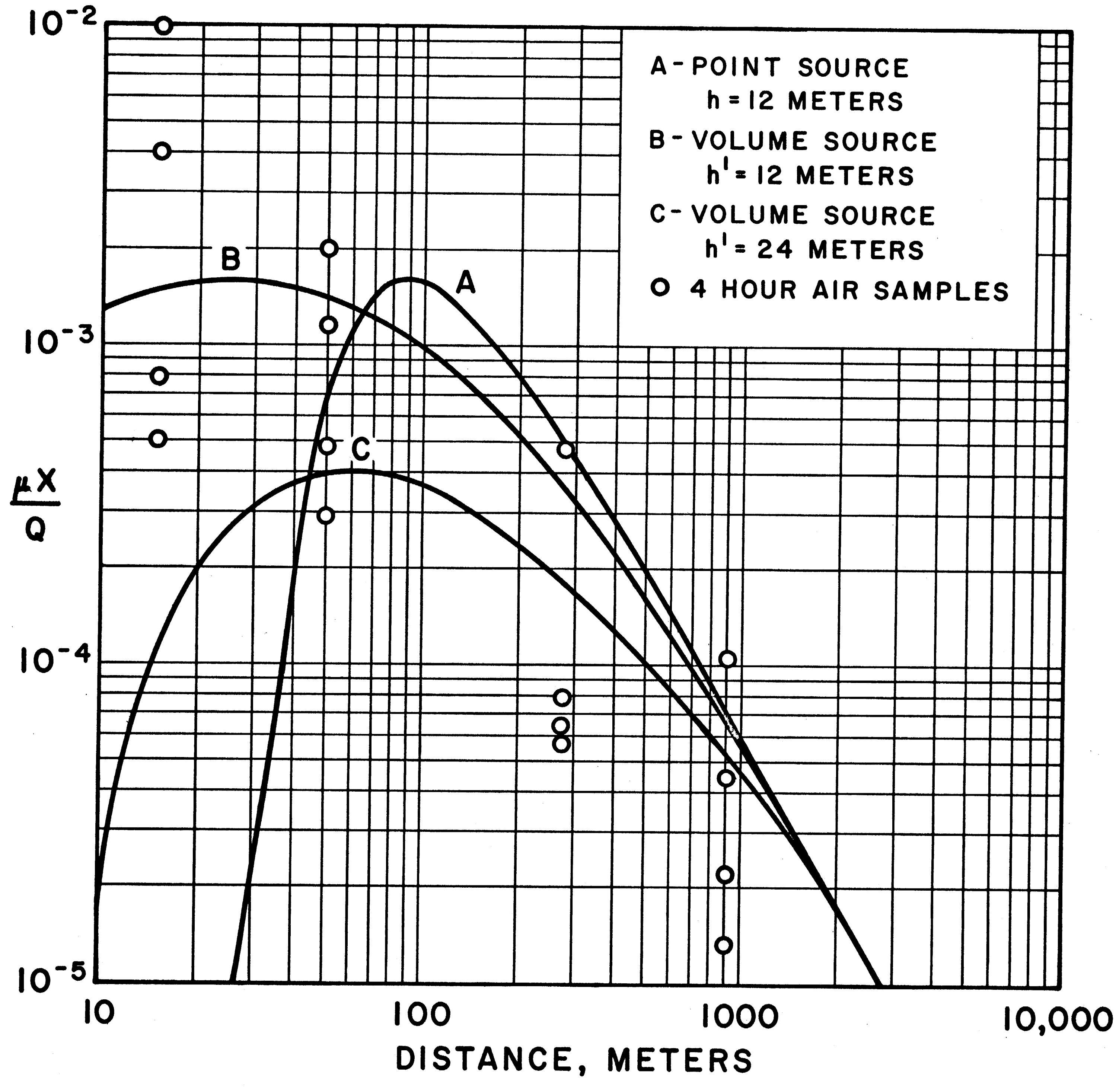
CONTINUOUS VOLUME SOURCE FORMULA FOR GROUND LEVEL CONCENTRATION AT DISTANCE x FROM A MULTI-STACK PLANT

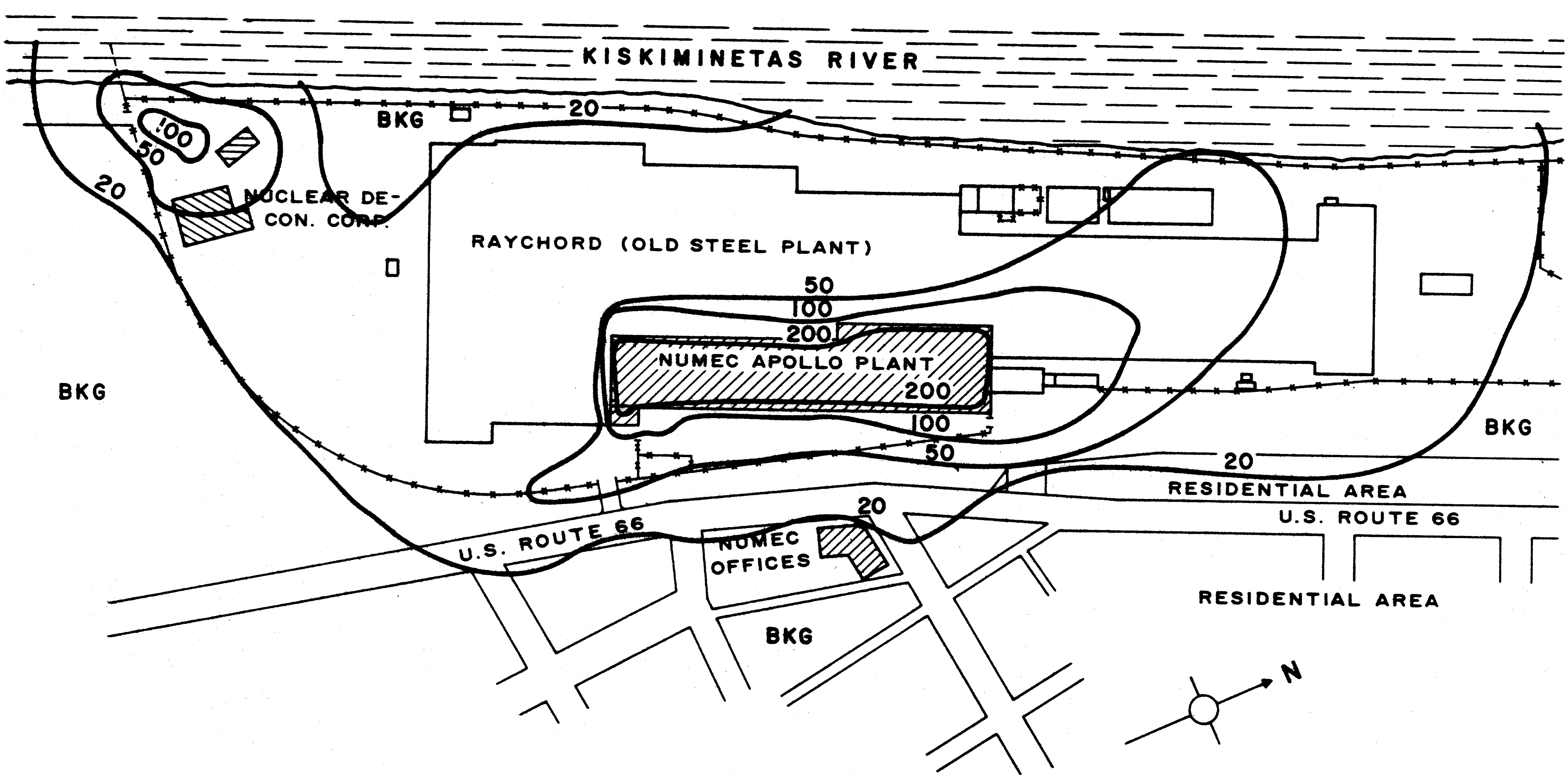


$$X = \frac{2Q}{\pi C_Y C_Z u x'^{(2-n)}} e^{-\frac{h'^2}{C_Z^2 x'^{(2-n)}}}$$

X = GROUND LEVEL CONCENTRATION

GROUND LEVEL DOWNWIND DIFFUSION
MULTI-STACK URANIUM PLANT





TYPICAL WEEKLY DEPOSITION - PICOCURIES / FOOT^2/ WEEK
NUMEC APOLLO PLANT

RADIOACTIVITY SURVEY - KISKIMINETAS RIVER