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CORRELATION OF AIRBORNE RADIOMETRIC DATA AND GEOLOGIC SOURCES WITH ELEVATED INDOOR RADON IN NEW JERSEY

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ABSTRACT

The effectiveness of airborne gamma spectrometer surveys in predicting areas of elevated indoor radon has been evaluated in the New Jersey Statewide Scientific Scientific Study of Radon and through ancillary programs of confirmatory testing. National Uranium Resource Evaluation radiometric data collected by the US Department of Energy was reprocessed and portions were reflown. Data from ground sampling studies and in home radon testing show that the airborne systems reliably detect areas of elevated uranium and its daughter radionuclide radon. Areas with airborne anomalies of 6 ppm equivalent uranium or greater correlate well with clusters of homes where radon levels exceed 4 pCi/l and numerous homes exceed 200 pCi/l.

Numerous anomalies have been studied in a variety of geologic terranes including Precambrian granites, Cambro-Ordovician carbonates and Ordovician and Triassic black shales. All areas exhibit clusters of homes elevated in radon and controlled by specific source lithologies or structures elevated in uranium.

INTRODUCTION

Airborne gamma-ray spectrometer surveys have been used as a tool in geologic mapping, uranium exploration and background radiation determination for more than twenty years (1). Because spectrometer surveys are able to distinguish gamma radiation due to uranium from that due to other natural sources they are useful in radon hazard evaluations. In theory areas with greater measured radiation from the uranium decay series should correlate with higher indoor radon levels. This assumes that the isotope measured by the spectrometer (bismuth-214) is in equilibrium with its parent isotope (radon-220).

The correlation also depends on how well the measured near-surface concentrations represent the source region for radon around a house. Good correlations would be expected if the surface is rock, residual soil or thick transported over burden (e.g. glacial materials greater than 5 meters in thickness). A poor correlation might result in areas of thin (2 meters) glacial cover over a radioactive bedrock.

To test these theories and to quantify the levels of radon found in association with measured airborne radiometrics, radon data from a statewide study and from site specific localities has been compiled. The correlations developed are intended to provide a predictive input to a regional evaluation strategy for indoor radon.

RADON EVALUATION STRATEGY

Many of the strategies developed for uranium exploration in the 1970's are applicable to assessing radon hazards because radon is a decay product in the uranium decay series. A typical regional evaluation program for detecting anomalous concentrations of uranium might involve four aspects:

1) Geologic model development
2) Airborne geophysical survey
3) Reconnaissance geochemical survey
4) Random submittals

An effective radon evaluation program involves the same features worked in conjunction. Data from both regional and site specific studies are collected and used to modify the approach.

For radon hazard evaluations each aspect has its strengths and weaknesses when used alone. Geologic models allow one to predict problems and focus limited resources on the worst problems. However, in new areas, unknown or poorly understood occurrences will be missed.

A geophysical survey using airborne radiometrics is by far the quickest and most thorough method of regional radon screening. In the long run it is cost effective but requires a large initial expenditure to acquire data. If the data is already available, for example from prior uranium exploration programs then the cost effectiveness is unbeatable.

Reconnaissance geochemical sampling used in radon hazard evaluation has involved the measurement of indoor radon or radon in soil gas. Although there is an inherent security in collecting a direct measure of radon, these approaches are time and manpower intensive. Outside of an initial orientation survey most exploration programs have traditionally focused geochemical sampling on suspected anomalous areas.

Finally random submittals of information on homes elevated in radon has served to focus evaluations on anomalous regions. However, similar to exploration submittals by prospectors, this type of sampling is biased and non-uniform.

All of the above approaches have contributed to New Jersey's efforts to assess the scale and locations of radon hazards. The following sections focus on the airborne geophysical aspects of a statewide evaluation and the ground truth analysis of this geophysical data.

AERIAL RADIOMETRIC DATA

As part of The National Uranium Resource Evaluation (NURE) program abundant aerial radiometric data was collected over New Jersey by the U.S. Department of Energy in the late 1970's. The original purpose of the program was to define potential uranium resources and identify areas for further exploration. Data compiled during the airborne geophysical surveys included gamma spectrometer counts of bismuth-214, thallium-208 and potassium-40. Bismuth-214 is a decay product within the uranium-238 decay series and can be used to estimate concentrations of uranium or radon assuming radioactive equilibrium.

NURE flight line data in New Jersey is spaced at 3-mile intervals in the northern part of the State and 6-mile intervals in the southern part of the State (figure 1). In addition a 1/4 mile spaced survey was conducted over a large portion of the Reading Prong. As part of a statewide radon study these data sets were reprocessed and contoured. Areas of anomalous bismuth-214 gamma activity, defined as exceeding 3 standard deviations above the mean of 2.4 ppm equivalent uranium, were highlighted as having the greatest source potential for elevated radon (figure 2). Fifty of these 6 ppm anomalies were reflown to assure adequate delineation and to verify the reliability of the data.

Regional trends in the data have been assessed in regard to geologic associations. The data has also been compared to a 6000 home survey of radon levels collected as part of a statewide study (2).

The ground truth analysis of specific anomalies includes detailed geologic mapping, gamma radiometric traverses and geochemistry. Data on associated indoor radon levels is also available for many anomalies through a State program of confirmatory radon measurements.

REGIONAL TRENDS

New Jersey is broadly divided into six geologic regions or provinces for the purposes of assessing regional trends in radiometric signitures. Radon statistics for the 6000 home survey are summarized in table 1 along with the NURE equivalent uranium averages associated with the sampled homes. Provinces with mean equivalent uranium (eU) exceeding the Statewide mean (2.4 ppm eU) have associated average radon levels exceeding 4 p Ci/l. These provinces also contain most of the NURE anomalies which exceed the mean by 3 standard deviation in figure 2.

Conversely provinces with average equivalent uranium values less than the Statewide mean have associated radon averages less than 4 pCi/l and contain only a few NURE anomalies.

Cambro-Ordovican Sedimentary rocks in the Valley and Ridge Province and Precambrian crystalline rocks in the Highlands or Reading Prong are the source of the most severe radon problems in the State. Radon levels in more than 50% of the homes in these provinces exceed 4 pCi/l.

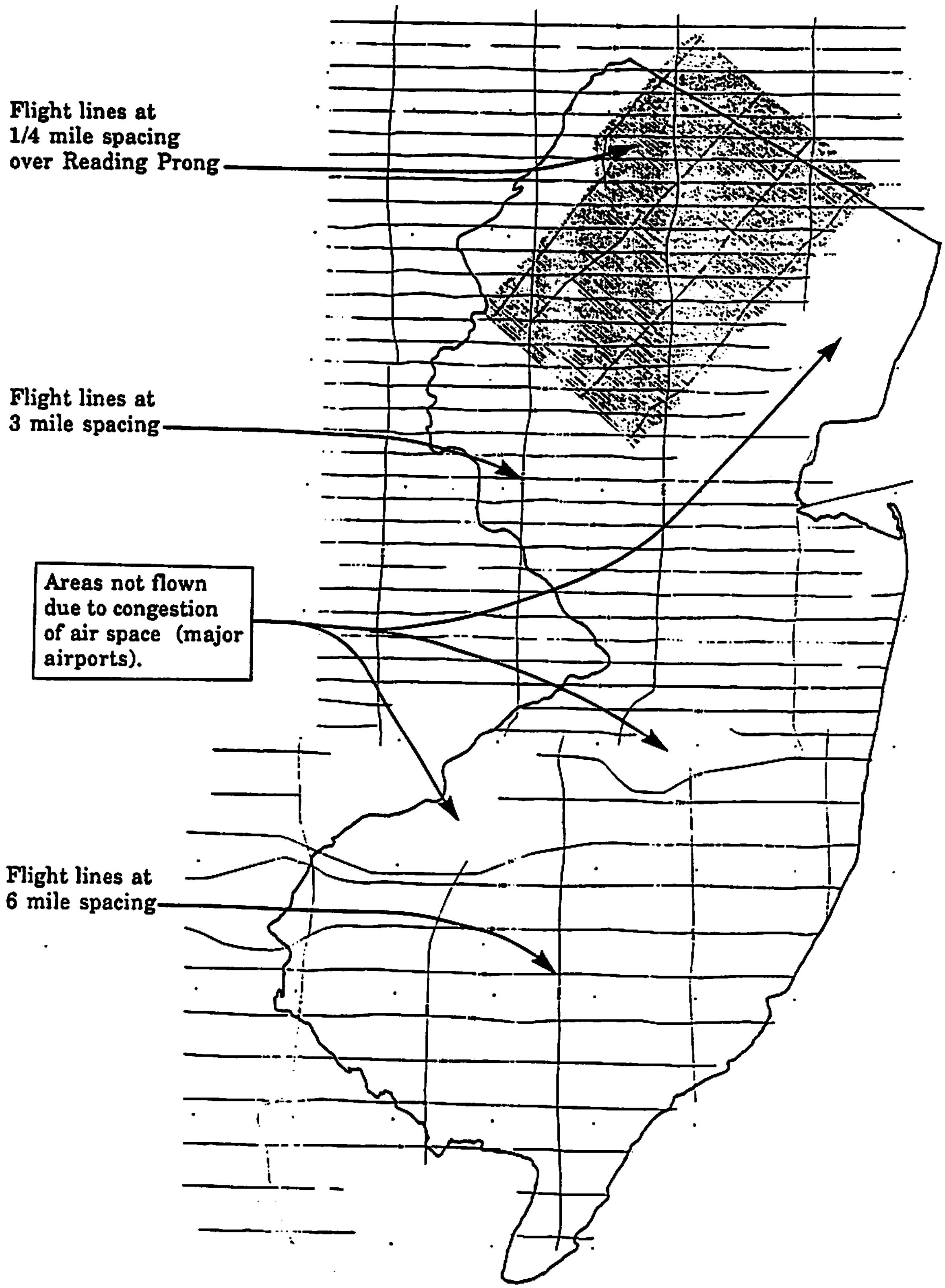

Figure 1. Flight line locations of NURE aerial radiometric data in New Jersey.

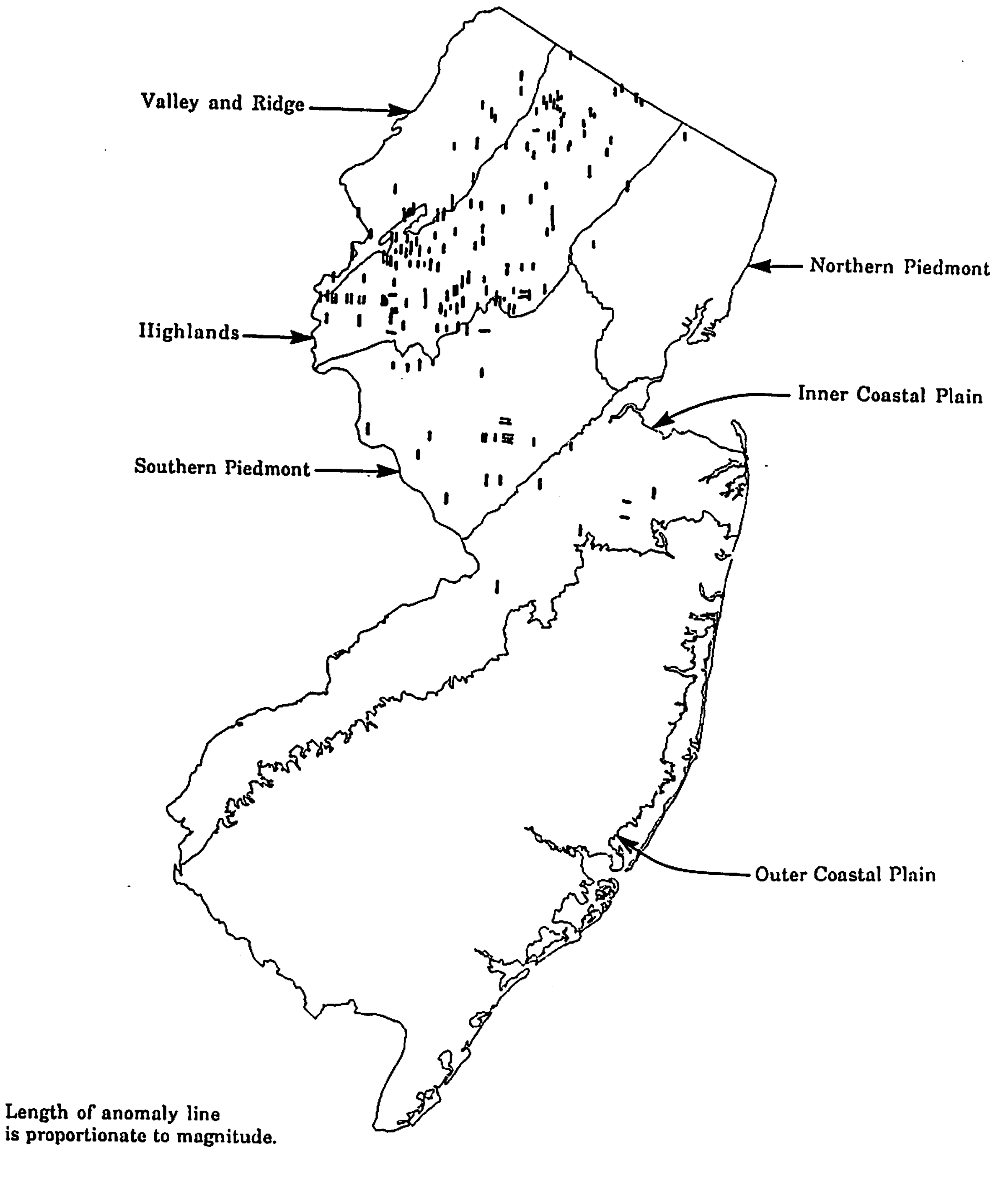

Figure 2. Locations of NURE gamma anomalies greater than 3 standard deviations above the mean (2.4 ppm equivalent uranium).

TABLE 1. INDOOR RADON STATISTICS AND NURE DATA FOR GEOLOGIC PROVINCES

Province	Arithmetic Average*	Geometric Mean*	% of Homes ≥4pCi/l	% of Homes ≥20pCi/l	NURE eU#
Valley & Ridge	7.6	4.5	57	8	2.5
Highlands (Reading Prong)	8.6	4.2	52	9	2.6
Southern Piedmont	4.9	2.5	32	4	2.7
Northern Piedmont	1.7	1.2	6	<1	2.1
Inner Coastal Plain	2.4	1.5	14	1	1.8
Outer Coastal Plain	1.4	1.0	5	<1	1.2
Statewide	5.2	2.4	33	5	2.4

* Average and mean indoor radon valves are in p Ci/l.
# Average equivalent uranium (eU) in ppm.

The Piedmont Province is comprised of Triassic-Jurassic sedimentary rocks of the Newark Basin. There is a dramatic difference between the portions of the province north and south of the terminal glacial moraine. The southern Piedmont has an elevated radiometric signature and moderate radon levels with 32% of the homes exceeding 4 pCi/l. In contrast the northern Piedmont has much lower radon and surfical radiometric levels due to a mitigating cover of glacial materials. Glacial cover is also a mitigating factor in the northern portions of the other high radon provinces discussed above.

The Coastal Plain province, covering the southern half of New Jersey, is comprised of Cretaceous through Tertiary age sediments. Significant differences in radon and aeroradioactivity are found between the inner (northern) and outer (southern) portions of the province. The Inner

Coastal Plain is dominantly immature marine clastics containing abundant glauconite and enriched in potassium and phosphorous. This area exhibits a more elevated radon and aeroradometric signiture (table 1) than the Outer Coastal Plain where clean quartz sands dominate.

GROUND TRUTH ANALYSIS

The correlation of indoor radon levels with airborne radiometric data for nine anomalous areas is summarized in table 2. These areas have been ground checked by detailed geologic mapping, soil sampling and ground radiometric traverses. The indoor radon data was collected under a State program of confirmatory monitoring in areas of elevated radon.

TABLE 2: NURE VALUES FOR INDOOR RADON CLUSTER AREAS

LOCATION	NURE eU ppm*	%>4pCi/l	%>20pCi/l	%>200pCi/l
Clinton	10	96	80	35
Montgomery	9	67	27	7
Ewing	8	78	40	5
Princeton	9	75	28	2
Bethlehem	7	75	35	11
Hampton	11	100	64	14
Bernardsville	9	87	45	9
Mansfield	10	88	65	7
Washington	10	87	57	13

* Peak value for the anomaly in the NURE data.

All studied localities are located within or immediately adjacent to airborne radiometric anomalies which exceed 6 ppm eU. As might be expected the spatial correlation of anomalies with elevated indoor radon is improved with more closely spaced data. Anomalies in the 1/4-mile data are well-defined, detected on multiple flight lines and coincident with clusters of elevated radon homes (Bernardsville, Mansfield and Washington). Anomalies detected in the 3-mile data occur on one flight line, are frequently adjacent to areas where elevated radon has been detected and occur along continuations of a geologic unit which causes home radon problems.

To illustrate and quantify these correlations the following sections present data for each individual site.

CLINTON CLUSTER

Extreme levels of elevated indoor radon were discovered in homes near Clinton, New Jersey, in the spring of 1986. NURE flight lines in the Clinton area are situated approximately 1.5 miles north and west of the site with elevated radon. The flight data detected 10 ppm eU in the strike extension of the Beekmantown geologic unit on which the homes are built.

Additional data on surface radiation patterns is available from a 1963 airborne survey (3) of total gamma activity. This type of survey combines radiations due to uranium, thorium and potassium. Thus anomalies detected are not unambiguous guides to elevated uranium or radon. Nevertheless, an anomaly exceeding 950 c.p.s. gamma radiation was detected over the subdivision where 96% of the homes exceed 4 pCi/l. Few anomalies of this magnitude were recorded in the survey where the background radiation levels were approximately 600 c.p.s.

Subsequent to the discovery of elevated radon levels in homes, mapping revealed fractures in the Ordovician dolomites filled with hydrothermal, uranium-rich mineralization. In hindsight a careful scanning of the 1963 total gammma data would have highlighted the Clinton area as a site with a potential radon problem. Other regions of elevated radioactivity noted in the 1963 survey have recently been tested for radon. The initial results confirm the predicted high radon levels.

TRIASSIC CLUSTERS

The Montgomery, Ewing and Princeton clusters of elevated indoor radon are situated on Triassic rocks of the Piedmont Province. All of these sites are localized by uranium-rich black shales in the Lockatong Foramtion. In particular a unit near the basal contact of the Lockatong with the Stockton Formation causes consistently elevated indoor radon.

The NURE data in this region is spaced on lines 3-miles apart. Three sigma anomalies in equivalent uranium were detected along the contact zone about 1 mile along strike from homes at the Montgomery and Ewing sites and 1/2 mile away at the Princeton site. Helicopter and ground radiometric surveys in 1987 showed that this zone of uranium enrichment is continuous and stratigraphy controlled. Radon problems are predicted whenever homes are built along this zone. Recent sampling in two areas along the contact zone have confirmed the prediction of elevated indoor radon.

PRECAMBRIAN GRANITE CLUSTERS

The Bethlehem, Hampton and Bernardsville clusters of elevated indoor radon are situated on Precambrian granitic gneisses of the Reading Prong. Uranium-rich hornblende granites and alaskites are responsible for the elevated radon levels. Fault and shear zones that deform these granitic units enhance the radon levels found in homes.

The Bethlehem and Hampton sites are located about 1 mile apart in an area of 3-mile spaced NURE data. Strong anomalies in equivalent uranium were detected on flight lines over unpopulated parts of the granitic unit. Residences with elevated radon levels (table 2) are situated within the same unit about 1/2 mile along strike from the flight line. Helicopter gamma spectrometer and ground radiometric surveys in 1987 confirmed the continuity of the units between the original NURE anomalies and radon cluster sites. The Hampton cluster site was predicted prior to testing from the NURE data.

The Bernardsville radon cluster is covered by 1/4-mile spaced NURE data. The peak anomaly in equivalent uranium is coincident with the highest radon levels exceeding 200 pCi/l. All homes with radon levels about 4 pCi/l occur within a uranium-rich hornblende granite whose equivalent uranium signature exceeds 3 ppm.

MANSFIELD CLUSTER

The Mansfield cluster of elevated indoor radon is situated over two distinctly different geological sources juxtaposed by a fault zone. Homes in the northern portion of the site are built on a granite alaskite unit similar to the previously described clusters in the Reading Prong. The southern part of the site occurs on black shales of the Ordovician Martinsburg Formation.

NURE coverage in the area is part of the 1/4-mile spaced survey. Anomalies over the northern granitics peak at 10 ppm eU and encompass the highest proportion of radon levels above 200 pCi/l. Ground radiometrics and geologic mapping indicate that the highest levels are associated with faults and fractures in the granite.

Anomalies over the southern shales indicate a widespread enrichment in uranium but with peak equivalent uranium anomalies at lower levels (4 to 7 ppm). A greater percentage of the associated radon values are distributed between 4 and 200 pCi/l in this part of the cluster.

WASHINGTON CLUSTER

The Washington indoor radon cluster is situated on a 6 mile long belt of Precambrian gneisses in the Reading Prong which are rich in monazite, a rare earth, thorium phosphate mineral. The belt is well defined in the 1/4-mile spaced NURE data where equivalent uranium valves peak at 10 ppm and uniformly exceed 4 ppm. This unit is even more dramatically defined in the NURE data for equivalent thorium where peak values reach 42 ppm. This occurrence of elevated indoor radon was predicted from the NURE data prior to testing.

CONCLUSIONS

Home testing data in New Jersey predicts that about a third of the residences have indoor radon levels exceeding 4 pCi/l. This equates with well over a million residences in a densely populated state. The scope of this radon problem dictates that an evaluation technique is required which is quicker and more efficient than simple home radon testing.

Our evaluation of existing airborne radiometric surveys using reflight data, ground checking and home testing proves that aeroradiometric data provides a method of focusing limited resources on the most serious health problems.

At site specific scales, the 1/4 to 1/2-mile spaced data is ideal for detecting clusters of homes elevated in radon and has shown an excellent correlation with radon testing results (table 2). The statistical population of radon levels is clearly more elevated at sites with elevated aeroradiometric signatures of equivalent uranium. However, house to house variations in radon within a site are dramatic and reflect the influence of house structure, weather conditions and soil permeability in addition to the variability of geologic sources of uranium.

Regional data at a 3-mile spacing has also proved to be a good predictor of elevated radon areas but requires a greater input of geologic knowledge on the extent and trends of rock units, structures and stratigraphy. Most of the radon clusters discovered with this data occur at distances of 1/2 mile or more away from the flight lines of aeroradiometric data. Flight line data spaced a 3-mile intervals frequently detects continuations of uranium anomalies which cause radon problems along strike.

Analysis to date of the 6-mile spaced NURE data is limited. No three sigma anomalies in equivalent uranium are present in this data and no homes exceeding 200 pCi/l radon in southern New Jersey have been reported. Nevertheless, higher levels of uranium and potassium were detected in the NURE data over the Cretaceous glauconite-rich sands of the Inner Coastal Plain. A regional potential for homes exceeding 4 pCi/l radon was predicted and subsequent testing has indicated that 15% of the homes in this province exceed 4 pCi/l. Additional ground studies are required and a more closely spaced airborne survey would help in defining sites with elevated radon levels.

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