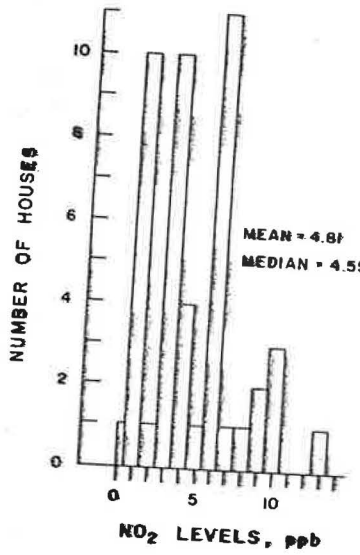


Figure 9. Nitrogen dioxide readings, 1983 study.

OBJECTIVES AND RESULTS OF RADON SURVEYS IN SASKATCHEWAN

R.R. Sentis, Director, Saskatchewan Environment, Mines Pollution Control Branch, Box 3003, Prince Albert, Saskatchewan, Canada

E.P. Wagner, Manager, Radiation Division, Saskatchewan Environment, Mines Pollution Control Branch, Box 3003, Prince Albert, Saskatchewan, Canada

ABSTRACT

Radon surveys were carried out by Saskatchewan Environment since 1980 with the objectives firstly; to assess the radon daughter concentrations in the existing houses and secondly; to identify the geographic boundaries of potential radon problem areas for future housing.

The first objective was reached in the region north of the 54° parallel by a process of successive elimination through the following phases: reconnaissance sampling in 16 communities; continuous monitoring at suspect locations and finally, intensive investigation in the neighbourhood of confirmed problem locations. As a result, two basements were identified for limited occupancy and/or remedial measures. In the coal bearing Southern region the first phase was completed involving 35 communities. This study plus the air sampling carried out in Regina and Saskatoon by the Cross Canada Survey (reference 3), may be now considered to add up to a fairly comprehensive reconnaissance survey coverage across the Province.

Reaching the second objective in the North was facilitated by the airborne gamma-ray spectrometric surveys of the Geological Surveys of Canada which now covers much of the region. These surveys were designed to estimate ground concentration of potassium, thorium, and uranium to aid geological mapping and uranium exploration. Counts recorded in the "uranium channel" are available in the interpreted form of contour maps showing the near surface concentration of "equivalent uranium" (eU) in parts per million (ppm). The theory of statistical correlation between the "eU" measurements and the observed indoor radon daughter concentration (WL) is outlined in some detail. It was found that the combined geometric mean WL in eight communities on either side of the 1.0 ppm contour differ by a factor greater than four.

There is a discussion on the general existence as well as on the highly "site specific" nature and other limitations of the proposed "eU-WL" correlation.

INTRODUCTION

One of the main lessons derived during the Uranium City radiation clean-up operations was that in the majority of the 100 cases investigated, the source of radon contamination were radionuclides of the uranium series naturally contained in the ground rather than man-made sources originally assumed due to proximity of uranium mines.

Following up on this finding, the Saskatchewan Department of Environment in 1980 launched a province-wide radon survey program with the objectives of assessing the existing radon levels of the non-uranium mining communities of the Province and to identify potential radon problem areas where control of construction techniques may be advisable for new housing.

At the time of this writing, the Department is in the process of publishing an updated Progress Report containing the results of this survey in considerable detail. We shall therefore, confine ourselves in this paper to a brief summary of these results and to expand on some statistical considerations not contained in that report.

SURVEY DESIGN

Indoor concentration of radon is known to vary considerably both with place and time, and in an essentially unpredictable manner. The task of detecting the highest occurrences over large areas within reasonable budget and time called for a process of successive eliminations through the following phases:

- Reconnsissance survey consisting of single measurements at a maximum number of locations, favouring the most likely places of high radon concentrations, such as unventilated basements.
- Confirmation of high spot sample results by the use of time integrating monitoring devices.
- Intensive survey at confirmed problem locations with the aim to determine the maximum rates of exposure to radon daughters in the neighbourhood.

Since there was good reason to believe that in the populated central part of the Province radon concentrations would be within the range of national averages as established by the Radiation Protection Bureau's surveys (Reference 3), the two target areas were defined as the Precambrian North and the coal-bearing South. (Figures 1 and 2).

RESULTS

Northern (Precambrian) Region

Air sampling procedures were standardized to draw 72 litres of air through a glass fibre filter; to count and calculate the radon daughter (RD) concentration in Working Levels (WL) using the modified Kusnetz method. 313 homes were visited in 16 communities (Figure 1) uncovering 61 follow-up cases on basis of the 1980 criterion of 0.01 WL (Reference 2). Gamma measurements carried out concurrently did not show any significant results.

Continuous monitoring of these locations during the first half of 1981 by passive (track etch) detectors indicated that the year-around average WL's are generally lower than the grab samples obtained during the summer. The geometric mean of this reduction of 0.67 is applicable only to the present survey.

The monitoring results further showed that the annual average RD concentration in the surveyed communities, or in any part of the region, is not likely to exceed the interim criterion that is now in effect for further investigation (0.1 WL - Reference 1), with the notable exception of a small isolated area within La Ronge.

In the La Ronge intensive survey the extent of the anomaly was located within 4 city blocks containing 59 homes. Successive monitoring of these homes were carried out both at the point of highest anticipated radon concentration and at points of highest occupancy. As a result, two basements were identified as unfit for unlimited occupancy, but none of the living areas. Owners and occupants of these 59 homes were both notified of the survey results.

The knowledge that radon problems are of manageable proportions in this region, which contain some of the world's largest uranium deposits, was rather gratifying.

Southern (coal bearing) Region

Air sampling and gamma measurements were carried out as before in 613 homes of 35 communities (Figure 2). While the average R.D. concentration was higher than in the North (GM = 0.0097 v. 0.0047 WL) the number of follow-up cases, according to the "Interim Guidelines" Reference 1) only amounts to 10. Continuous monitoring of these 10 locations and of the 2 cases located by the RPD surveys in Regina will be the next step in the survey's progress.

IDENTIFICATION OF ZONES WITH ELEVATED RADON CONCENTRATION

Northern (Precambrian) Region

The second objective of the survey was to identify zones of above normal radon occurrence. Considering that the survey area extends to some 150,000 square kilometers, the task obviously required extrapolation of the survey results in some plausible manner.

Since 1967 the Geological Survey of Canada carried out a program of airborne gamma ray spectrometric surveys which by now covers most of Northern Saskatchewan. The program is designed for the estimation of ground concentration of potassium, uranium and thorium in order to aid geological mapping and uranium exploration. For the present purpose the most valuable part of the survey are the counts recorded in the "uranium channel" which, after corrections (stripping), represent the characteristic emissions from only one source: Bismuth 214, a radon daughter. By inference, as Bismuth 214 is a link in the U238 decay chain, it is the practice to express the records of the "uranium channel" in terms of "equivalent uranium" (eU) concentration in parts per million (ppm). There is therefore, a very good theoretical reason for interpreting such "eU" contour maps in terms of near-surface abundance of radon gas that is available for indoor contamination.

The theory of a correlation between the airborne "eU" values observed at some point and the geometric mean of WL's measured in the surface area just below that point has been tested both under ideal and normal conditions.

The wealth of unpublished airborne and ground survey data generated in the course of the remedial program at Uranium City and Elliot Lake provided the opportunity to put this theory to test under ideal conditions: The air surveys were carried out with a line interval of about 120 m, therefore producing near continuous airborne records in all directions. Also, in the course of ground survey each home was sampled once at least. Statistical analysis indicates that essentially the same quantitative linear relation exists between the geometric means of "eU" and Wl values with correlation coefficients of 0.95 for Uranium City and 0.97 for Elliot Lake.

Under the conditions that we are considering here, there are a number of uncertanties, mostly arising from the considerably increased flight line interval (120 v 5000 m) that preclude such quantitive correlations. It appeared logical, however, that if there is a proven valuable correlation between the regional distribution of Bi-214 and U-238 there should be a far more definite and perhaps equally valuable qualitative correlation between the distribution of Bi-214 and Rn-222 in nature.

To test this idea in light of the collected field results, it was decided to use the 1 ppm "eU" contour to divide the survey area into zones of "normal" and "above normal" radon occurrence (Figure 1). The number of surveyed communities (16) are divided evenly in two groups associated with the two zones.

In comparing these two groups one interesting fact is that the collective Geometric Mean (GM) of WL's in communities located in the "low area" is well within the range of Canadian background variation, while those in the "high" zone average more than four times as much (Table 1).

The other points to consider is that individual GM values of one group of communities all exceed the 0.055 WL while none in the other group does. If there existed no eU-WL correlation on basis of which the 16

communities were divided, the distribution of their GM (WL) would be randomly spread across the map. Simple statistics tell us that the probability of such randomness, or the probability of non-existent eU-Wl correlation is at most $(0.5)^{16}$ or 0.002%.

These persuasive supporting facts for the existence of meaningful correlation between airborne and ground surveys do not necessarily apply outside of Northern Saskatchewan in the same manner.

Southern (coal bearing) Region

The task of delineating areas of higher than average radon levels from the Southern survey results was not assisted by related information from other sources. Geological maps did provide comprehensive and detail outline of the Ravenscrag Formation which is believed to contain the source of elevated radon levels, but due to extensive displacements by erosion and masking of these sources by overburden, correlation between geological data and survey results proved to be erratic. Consequently, the definition of high and low zones must be based on the survey results alone.

The scope of the survey conducted so far was not sufficient to identify the boundaries of areas higher than average radon level toward the more densely populated regions of the North (Figure 2).

CHANGING PRIORITIES

Originally the most pressing question was about the magnitude of radon daughter indoor concentration in the existing homes of non-uranium mining areas. This question has been answered to satisfaction in the North. In the South the survey is not yet complete, but by all indications the existing magnitude of radon problems right across the Province can be foreseen as readily manageable.

It is well to remember that the homes surveyed were all of the conventional type without controlled leakage and ventilation rates.

Differentiation between "areas of normal radon occurrence" and the "potential radon problem areas" becomes increasingly significant in connection with the new generation of energy efficient homes designed for controlled ventilation at reduced rates.

Analytical and experimental studies (References 7 and 8) concur about the disproportionate increase of radon daughter concentration with decreasing ventilation rates. Combining these studies with the statistical analysis of all radon surveys carried out in Saskatchewan leads to Figure 3 showing varying frequency of follow-up cases, i.e. those exceeding 0.10 WL, at various ventilation rates and in different parts of the Province. The year-around average air leakage rates of the existing conventional homes has never been established, but based on a consensus of expert opinions, a value of 1.0 air change per hour (ACH) is assumed.

The significance of the "Preliminary Index Map" derived in the Northern survey is clearly demonstrated in Figure 3: By subdividing the Northern Region into "Low" and "High" zones, corresponding to the white "Areas of Normal Radon Occurrences" and the shaded "Areas of Above Normal Radon Occurrence" of the "Preliminary Index Map" (Figure 1), we find that the average radon daughter concentration level in "Low" parts, comprising about 80% of the total area, is actually lower than the background level of the Central Region and therefore the radon problems commonly associated with the North, are largely confined to the relatively limited shaded areas shown in the Map. As a practical example, we learn from Figure 3 that if energy efficient houses designed for 0.5 ACH were built in the North, only about 1 out of 100 would require follow-up monitoring in the "Low" zones, while in the shaded "High" risk zones of the Map the ratio would be 1 out of every 5.

For the purpose of regional planning, public health or legislative control directed at energy efficient homes, such information should be of vital interest.

When the survey program started in 1980 energy efficient housing existed only in the form of pilot projects. By 1982, according to the Energy Mines and Resources Canada figures, 52% of all the new homes sold in the Province were of the energy efficient type. The trend is irreversible and it is accelerated by government support. In 1983 the Federal "Super Energy Efficient" program came into effect educating builders and building up to 27 demonstration units across Saskatchewan. Radon proofing of these homes is not part of the Federal program. The findings uncovered by these surveys must be considered in the administration of energy efficient housing programs.

CONCLUSION

The results of the Federal and Provincial surveys in Saskatchewan provide in combination a fairly comprehensive view of the regionally varying radon daughter concentrations in conventional homes right across the province. Although the survey is not yet complete, it is safe to conclude that any apprehension about the need for costly provincial remedial work may be laid to rest. Bringing this sensitive question into the open with a firm reassuring answer is one of the survey's benefits.

The other benefit of the survey is that it provides a rational basis on which to differentiate between areas of normal and above normal radon occurrence. This would allow the selective use of radon proofing techniques on basis on geographic location. As a result, the new dimension of radon problems introduced by the emergence of tight, energy efficient housing can be dealt with cost-effectively in a preventive rather than remedial context.

TABLE 1

REGIONAL DISTRIBUTION OF RADON DAUGHTER CONCENTRATION IN SASKATCHEWAN

REGIONS	SAMPLE NO.	BELOW 0.010	0.011 to 0.020 WL	0.021 to 0.050 WL	0.050 to 0.100 WL	ABOVE 0.100 WL	GEOMETRIC MEAN OF WL	GEOMETRIC STANDARD DEVIATION
Central-Total[1]	1730	79%	14%	6%	0.9%	0.1%	0.0039	3.1
Regina	961	75%	15%	8%	1.7%	0.3%	0.0044	2.9
Saskatoon	769	84%	12%	4%	0.0%	0.0%	0.0034	2.5
North-Total[2]	229	70%	14%	10%	3.7%	2.2%	0.0049	3.3
Areas of Normal Radon Occurrence (below 1 ppm eU)	155	85%	9%	5%	0.0%	1.6%	0.0031	3.1
Areas of Above Normal Radon Occurrence (above 1 ppm eU)	74	29%	23%	21%	11.8%	6.7%	0.0128	3.9
South-Total[2]	613	46%	27%	20%	5.7%	1.6%	0.0097	3.1

(1) Survey performed by the Radiation Protection Bureau, National Health & Welfare

(2) Only survey results from basements considered

FIGURE 1

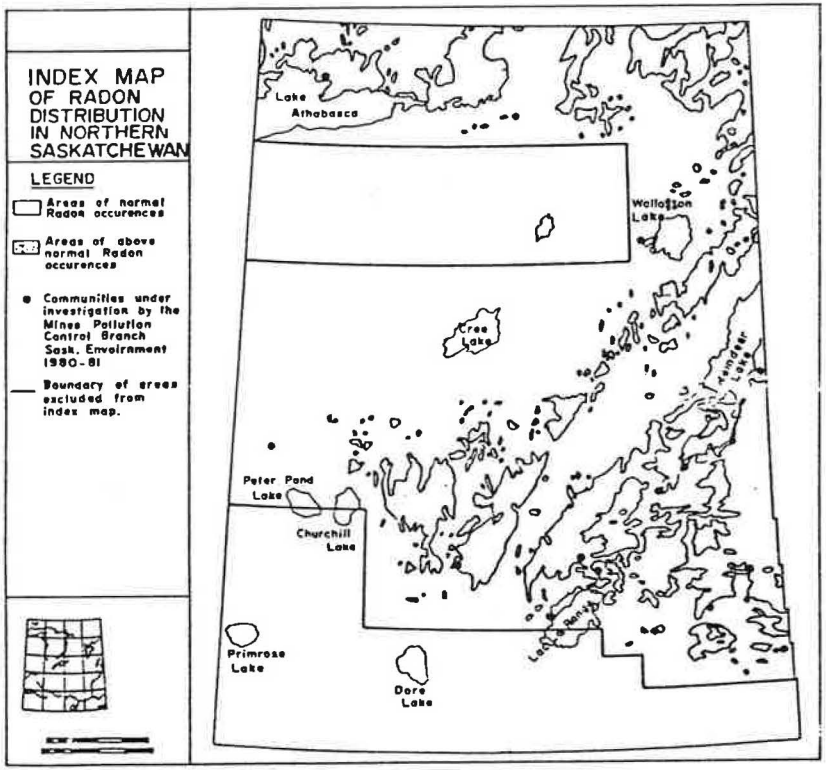


FIGURE 2

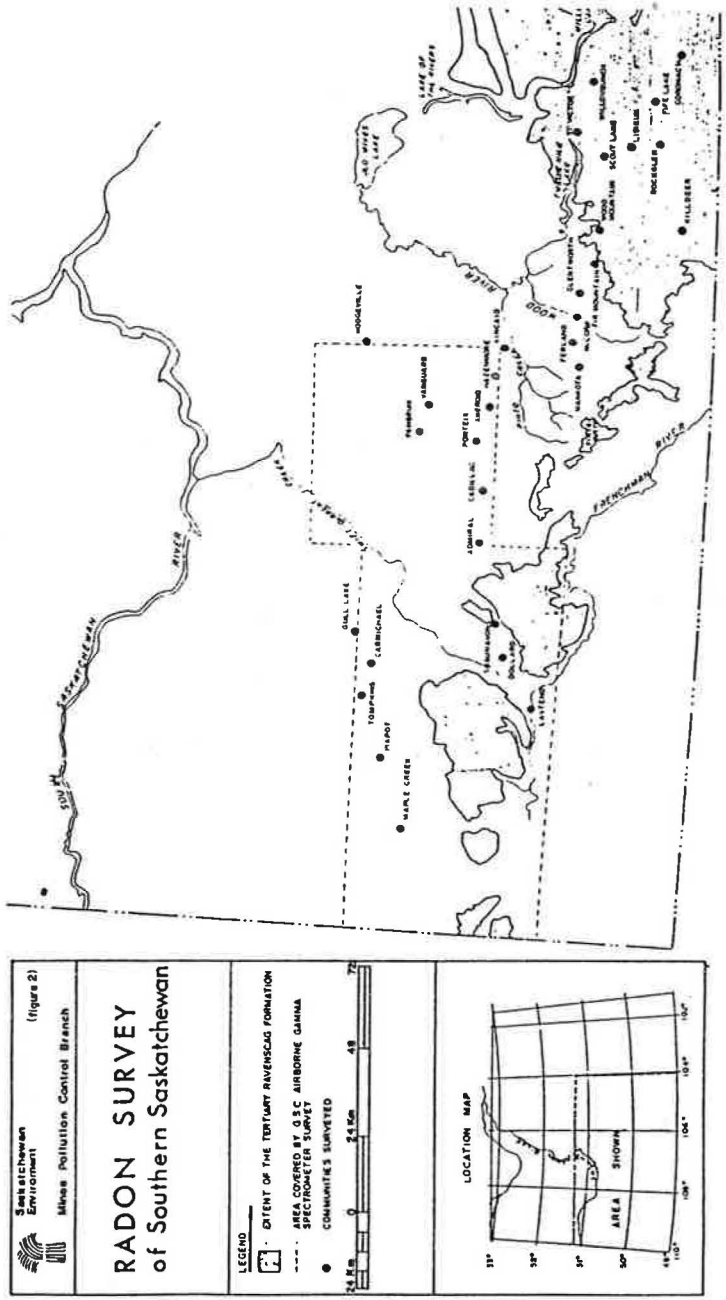
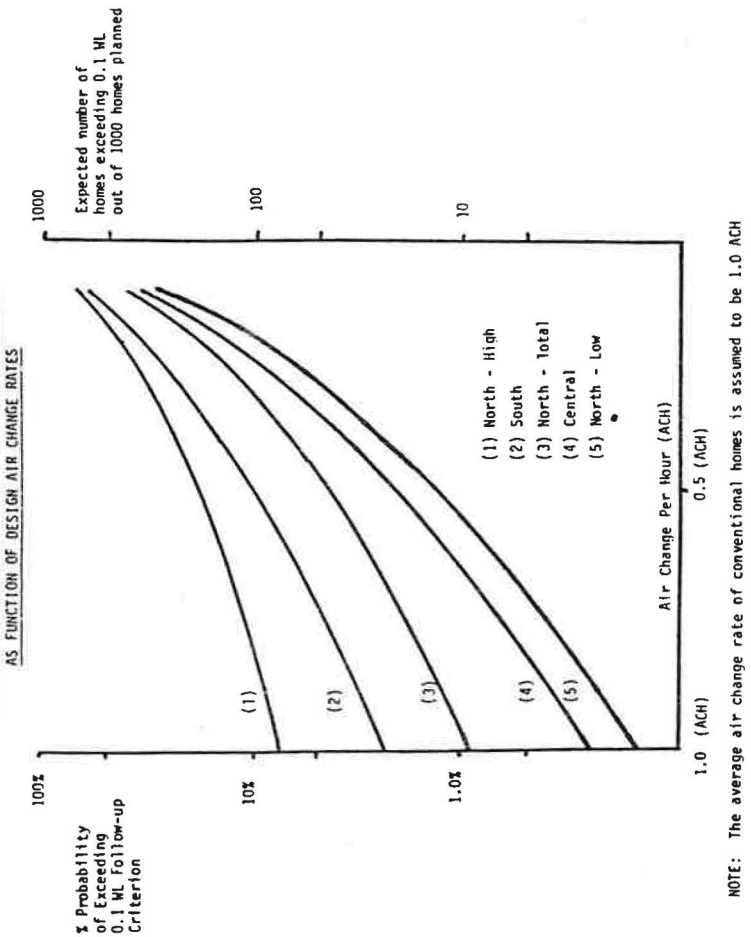


FIGURE 3

REGIONAL % PROBABILITY OF EXCEEDING 0.10 WL FOLLOW-UP CRITERION AS FUNCTION OF DESIGN AIR CHANGE RATES



NOTE: The average air change rate of conventional homes is assumed to be 1.0 ACH

REFERENCES

(1) Federal Provincial Subcommittee on Radiation Surveillance. "Interim Guideline for Radon Daughter Concentrations in Areas Other Than Uranium Mining Communities", (1981).

(2) Atomic Energy Control Board Information Bulletin 77-2. "Criteria for Radioactive Cleanup in Canada", (1977).

(3) McGregor, R.G., Vasudev, P., Letourneau, E.G., McCullough, R.S., Prantle, F.A., Taniguchi, H. "Background Concentrations of Radon and Radon Daughters in Canadian Homes", Health Physics, Vol. 39, August, 1980. pp 285-289.

(4) Letourneau, E.G., Wigle, D.T. "Mortality and Indoor Radon Daughter Concentrations in 13 Canadian Cities", Specialist Meeting on the Assessment of Radon and Daughter Exposures and Related Biological Effects, CNEN, 3rd to 7th March, 1980. Rome.

(5) Haywood, L.R., "Selection of a Radon Level Corresponding to 0.02 W.L.", "Seasonal Variation in f Factor", Proceedings of the 3rd Workshop on Radon and Radon Daughters in Urban Communities Associated with Uranium Mining and Processing, Port Hope, 12-14 March, 1980.

(6) Letourneau, E.G., Mayo, Y., McGregor, R.G., Semeciw, R., Smith, M.H., and Wigle, D.T. "Lung Cancer Mortality and Indoor Radon Concentrations in 18 Canadian Cities", Proceedings of the 16th Mid Year Topical Symposium-Epidemiology Applied to Health Physics, Health Physics Society, 10-14 January, 1983, Alberquerque N.M. pp 470-483.

(7) Kusunda, T., McNall, P.E., Silverstein, S., "Modelling of Radon and Its Daughter Concentrations in Ventilated Spaces", Journal of the Air Pollution Control Association, Vol, 30, No. 11, Nov. 1980. pp 1201-1207.

(8) Kliff, K.D., "Assessment of Airborne Radon Daughter Concentrations in Dwellings of Great Britain", Phys. Med. Biol., Vol. 23, No. 4, 1978. pp 696-711.

(9) United Nations Scientific Committee on the Effects of Atomic Radiation, "Exposures to radon and thoron and their decay product", UNSCEAR, Report to the U.N. General Assembly, Annex D. United Nations, 1982.

(10) Lindell, B., "A Radon Control Program in Theory and Practice", Radiation Protection Dosimetry, Vol, 7, No. 1-4, 1984. pp 417-425.

(11) Letourneau, E.G., McGregor, R.G., and Walker, W.B., "Design and Interpretation of Large Surveys for Indoor Exposure to Radon Daughters", Radiation Protection Dosimetry, Vol, 7, No. 1-4, 1984. pp 303-308.