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RADON MEASUREMENTS AND ANALYSIS FOR CENTRAL PENNSYLVANIA COUNTIES HAVING ELEVATED RADON LEVELS

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ABSTRACT:

The USEPA, identified South Central Pennsylvania as a region having elevated radon levels. The thrust of this paper is to examine in some detail the TCS Industries Inc., TCS, data base for eight Central Pennsylvania counties having a combined population of about 1.7 million people, which is 14% of the state population.

TCS has been making and analyzing radon measurements since 1986. During the period 1986 to 1999 more than 125 thousand measurements were recorded in the TCS data base. The data consisted of analyzed results from four subsets. Results were from mail order charcoal canisters, bulk orders from RMP certified companies for their placement, wholesales to retail vendors, and also direct home placement of canisters, track detectors, and continuous radon monitors. The data base for the eight South Central Pennsylvania counties for the thirteen year period consists of more than 23,000 screening measurements from non-duplicated addresses.

The results were assembled into three interesting studies. The locations of the measurements were converted into individual latitude and longitude values. The data were divided into four blocks of concentrations from 20 picocuries per liter, pCi/l, (.74 kBq/ m^3) to over 120 pCi/l (4.44 kBq/m_3). The data were plotted on computer generated maps for South Central Pennsylvania. The plots indicated both hot spots and regions of relatively uniform chronic levels of 20 to 40 pCi/l (.74 to 1.48 kBq/m^3).

An average value of the basement to first floor concentrations ratio was constructed from measurements made by TCS for real estate purposes. The ratio represents 1608 sets of simultaneous measurements of basements and first floor radon values above 1 pCi/l (37 Bq/m^3). The measurements were made by trained personnel performed under the EPA protocol for closed house conditions. The ratio was 2.3 at one standard deviation of 0.05 of the mean.

A third study assembled all of the data into First floor radon concentrations, and separately for addresses with only basement values. The average concentration data within each of the eight counties, were converted into dosimetry values and compared with occupational values for nuclear power plant workers. This study illustrates the importance of a continuing strong measurement and remediation program in South Central Pennsylvania .

INTRODUCTION:

Any environmental radiation safety program consists of four parts. The first is the development of a measurement program. Second is a data base to record measurement results. Third, the radiation environment is transformed into population radiation exposure which is directly related to potential human risk, and the last is remediation or the means to reduce the risk. This paper addresses the first three parts for South Central Pennsylvania, an eight county region centered on the capital city of Harrisburg.

TCS Industries was founded in 1978 to manufacture radio-iodide air sampling and dosimetry assessment systems for the nuclear power industry as well as the nuclear navy. Becoming aware of the high potential radon exposures in Central Pennsylvania, TCS added radon air sampling to their capabilities. In 1985 TCS built a radon test chamber, and developed two different open face activated charcoal detectors based on the work of George, (George 1984). The TCS detector characteristics were outlined by Distenfeld, (Distenfeld 1995). After being listed by the USEPA by satisfying the RMP program for the two TCS styles of charcoal detectors, TCS started commercial service in 1986.

TCS provides activated charcoal detectors and associated laboratory services to mail order customers, to other firms including those certified by Pennsylvania for radon measurements, to retail outlets, and to a national mail order firm. TCS personnel also have placed activated charcoal, continuous radon, alpha track, and radon water test devices in private homes, commercial buildings, and county offices. All of the above comprise a data base of more than 125 thousand US wide measurements.

On Nov. 22, 1995 The US EPA Region III published a radon potential chart by zip code for the percentages of radon readings above 4 picocuries per liter (pCi/l). Perusal of the EPA data suggested 70 to 80% of central Pennsylvania dwellings contained radon concentrations above the US EPA action level for remediation of 4 pCi/l. The purpose of this paper was to explore the risk potential to the inhabitants of part of central Pennsylvania within an eight county region centered on the capital city of Harrisburg, Pennsylvania. Finally risk comparisons to nuclear radiation workers are offered .

DATA BASE:

All radon screening data were entered into a dBase IV version 2, (dBase IV 1994). This DOS based data base program was able to accept all of the information in a flexible, addressable form, but also allowed discard of measurements from duplicated addresses.

The data included radon concentration, dwelling street address, county, 5 digit postal ZIP code, and measurement location information. The data were comprised of results from exposures made by property owners, Pennsylvania individuals certified for measurements , and real estate transaction tests by TCS personnel. The latter includes simultaneously exposed charcoal canisters in the basement as well as in the first and usually the second floor of a dwelling. The multi-location program allowed a determination of the basement to first floor ratio as a case controlled study. For radon values above 1 pCi/l, the ratio was 2.29 with a one sigma standard deviation of the mean of 0.05 for 1608 measured ratios. This may be contrasted to an environmental study of basement and first floor values of different addresses. This ratio was 2.69 for 25,731 basement and 14,928 individual first floor readings from the TCS data base. For dosimetry purposes, (radon risk), the former value of 2.3 should be used.

MAPPING PROGRAM:

To assess the potential risk to the inhabitants, it was important to map the radon concentration data to search for HOT SPOTS, and to test for extent and uniformity of the radon concentration. A commercial mapping program was used to plot location information, (3-D TopoQuads 1999). This WINDOWS 95/98 program was based on 7.5 minute US Geological Survey topographical charts. DeLorme repackaged the chart data in a more convenient form. Nearly four thousand data points were plotted by entering latitude and longitude for each point. Different plotting symbols in different colors allowed radon concentration information to be added to the location markers. The mapping program was not limited to the 4,000 points plotted, and was continuous for the 8 South Central Pennsylvania Counties, with any part or all accessible by varying the scale.

The US Postal Service has assembled latitude and longitude data for 9 digit ZIP codes for the US. These data were available as TIGER ZIP for each state, (TIGER ZIP 1999). The TCS data base containing 5 digit ZIP codes was amended to 9 digit Zip codes. The TCS and TIGER ZIP data bases were compared. Latitude and longitudes were copied to the TCS data base for each matched 9 digit ZIP code in TIGER ZIP. According to the US Postal Department, the resulting latitude and longitude would be within one half of a city block of the exact location. One half block uncertainty did not invalidate analysis drawn from the plotted information, but the location uncertainty was desirable to protect the privacy of individual homeowners. Pennsylvania regulations required all certified radon measurement firms transfer data to the Radon Division of the Pennsylvania Department of Environmental Protection. Exact addresses were required.

The TCS eight county data base consists of about 18803 non-duplicated short term screening basement values which varied from <1 to >120 pCi/l. Only values above 20 pCi/l were plotted. This reduced the available data points to about 4294 locations. Not all of the TCS 9 digit ZIP code data were included in TIGER ZIP. Post office box addresses, rural delivery boxes, new construction, and invalid addresses amounted to about 26% of the TCS eight county data base for radon values above 20 pCi/l.. Street Atlas, was used to derive latitude and longitudes for new construction, and other addresses that could be found in Street Atlas, (Street Atlas 1999). This recovered an additional 89% of the omissions in TIGER ZIP for a total of about 97% of the total available data points plotted as shown on Table 1.

As can be seen from Table 1, the fraction of unidentified locations varied with radon concentration; the higher the radon concentration, the greater the location uncertainty. For values above 120 pCi/l only about 3/4 could be located. Higher values may have reflected new construction in the more distant suburbs with locations not yet included in TIGER ZIP or in the 1999 version 7 of Street Atlas.

Figure 1, depicts the basement radon concentration data plotted in the greater Harrisburg metro region. The map scale was 1 in 56,200. Each flag represents a location with concentration between 20 and 40 pCi/l. Inspection of Figure 1 suggests a pervasive dispersion of radon with clustering in certain locations. Clustering, or regions containing greater concentration of 20 to 40 pCi/l locations, are observed in a few locations For examples, high concentrations of measurement points were found along a horizontal center line through Fig. 1; two West of center and two others East along the line. Figure 1 represents about 2% of the 8 county area, and was intended as a sample of the all of the plotted data.

Figure 2 is similar to Figure 1 except the radon results for concentrations above 40 pCi/l are shown for a lower map scale. The 3-D TopoQuad program allowed good control of image scale and color. Inspection of the data with a color computer monitor or a color printout of showed the same kind of detail seen of Figure 1 for three additional bands of radon concentration. Concentrations >120 pCi/l were plotted as red discs, 80 to 120 were yellow filled red rimmed discs, and 40 to 80 pCi/l data were shown as blue filled red rimmed discs. Unfortunately the gray scale figure image is harder to interpret for concentration. Generally it was shown that radon readings above 40 pCi/l occur in many of the same locations as the under 40 pCi/l data shown on Figure 1. A paste-up was made of the radon concentration data. The 8 county data was contained on twenty-four 8.5 by 11 inch color sheets printed to a scale of 1:112,000. Figure 1 is above the center and somewhat to the west in the paste-up.

RADON DOSIMETRY AND RISK:

After several radioactive transformations, gaseous radon emerges from its naturally occurring solid Uranium 238 parent. Radon is a nonchemically reactive noble gas with an atomic weight of 222 and with a radioactive half life of a little less than 4 days. Radon decays sequentially into four dosimetrically important short half life solid daughter products, Polonium 218, Lead 214, and Bismuth 214 having respective half lives of about 3, 27, and 20 minutes. Bismuth 214 decays to Polonium 214 which in turn nearly instantaneously decays by emitting a 7.7 million electron volt alpha particle to much longer lived Lead 210. The solid daughters of radon are electrostatically charged and attract or are attracted to dust particles in the air. With time the charged dust particles attract additional dust particles and grow in size. Not all of the daughters have the same diameter. The concentration of the daughters relative to the radon concentration determines a value termed the equilibrium ratio. If the dust borne solid daughters of radon vary in size, different aerodynamic properties cause alpha energy to be transferred to different parts of the respiratory system and different factions to be exhaled. Generally, the less dusty the environment, the more damaging a given concentration of radon as the smaller particles can penetrate more deeply into the lung . The EPA adopted 50% equilibrium as appropriate for residential environments, (EPA 1992).

The act of breathing draws in radon gas and, more importantly, the radioactive daughters into the respiratory system. The daughters decay by ejecting alpha particles which potentially deposit 6 and 7.7 million electron volts of energy per decaying Polonium 218 and Polonium 214 atom to respiratory tissue. Radon gas is exhaled, and since radon has a relatively long half life, few decays take place in the respiratory tract between breaths. The irradiated tissue has some probability of developing lung cancer. This process is similar to the damage caused by radiation exposure to nuclear power plant workers, X-ray technicians, medical isotope workers, or anyone occupationally or otherwise exposed to ionizing radiation. Federal and state regulatory organizations limit the amount of radiation exposure to workers. The limits were selected to reduce the workers risk of developing observable short term bodily damage or later developing cancer at a rate greater than the natural rate that people expect working in a safe industry.

Most radiation workers are exposed to radiation over much of their whole body; whereas radon and daughters only expose the respiratory system. Standard dosimetry practice adjusts the energy deposited in a reference organ, such as the lung, to include radiosensitivity, organ size or cells at risk, and how vital the organ is to the life of the host. This item is termed the weighting factor which is used to balance risk for all parts of the body. The final value is expressed as the effective dose equivalent, and since it is risk related, is additive for different radiations affecting different organs, (NCRP 1993). When summed over all organs and body parts, the result is termed the total effective dose equivalent, TEDE. The U.S. Nuclear Regulatory Commission, NRC, collected and reported on all classes of radiation workers under their control, (NUREG 1998). For the year 1998, the NRC listed 65,070 persons with a measurable radiation exposure with an average total effective dose equivalent of 0.36 rem.

It is revealing to compare the fatal cancer risk acquired by radiation workers during employment to the risk of contracting lung cancer from radon and radon decay products in 8 South Central Pennsylvania Counties.

For illustration, the annual lung cancer risk due to an exposure of 1.24 pCi/l at home is:

<u>Assumptions:</u>

1, Over a 365 day year a person spends 18 hours a day at home with an average radon concentration of 1.24 pCi/l, (EPA 1992)

2, Remaining time is spent outdoors with a median radon concentration of 0.39 pCi/l, (EPA 1992).

Aver. Radon exposure is 1.03 pCi/l = 1.24 x 0.75 + 0.39 x 0.25

3, The number of working hours per month is defined as 170 hours, (EPA 1992).

4, For an equilibrium of 50% the working level is 0.02/ 4 = 0.005 WL/pCi/l, (EPA 1992).

5, In 1995 15,400 to 21,800 extra lung cancer deaths were projected due to radon exposure in US homes, BEIR VI 1999).

6, The 1995 U.S. population was 262,803,000, (Census 1990 to 1999).

7, The fatal cancer risk due to radiation exposure to a nuclear industry worker was 0.04 per Sv (0.0004 per rem) where one Sievert, Sv is equivalent to 100 rem, TEDE, (BEIR V 1990).

<u>Then:</u>

Per year, working level months, WLM, = 1.03x 0.005x 365x24/170 = 0.265

The annual lung cancer risk due to exposure of 0.265 WLM is:

Lower limit; 15,400/(262,803,000*0.265)= 0.000221 lung cancer risk per person per WLM.

Equivalent risk is,

TEDE = 0.000221/0.0004= 0.553 rem/WLM

Upper limit: As above for 21,800 lung cancer deaths= 0.000313 per WLM

TEDE = 0.000313/0.0004 = 0.783 rem/WLM

Table 2, represents radon measurement data taken from nonzero, and non-duplicated addresses between 1986 and 1999. The radon concentration data was converted to WLM by assuming 75% indoor and 25% outdoor exposure. TEDE was calculated as the product of projected average working level months and the TEDE per WLM for each county considered and for the overall. It was apparent every value is greater than the average annual nuclear industry worker exposure.

Federal and state regulatory bodies require occupationally exposed workers to be exposed to a effective dose equivalent of less than 50 mSv (5 rem) per year. Many scientists began to believe exposures near the annual limit for many years would cause the cancer risk to exceed that of a safe industry. Partly for this reason the federal agencies adopted the principal of "As Low As Reasonable Achievable, ALARA", (ICRP 1977). ALARA is defined as:

1, No practice shall be adopted unless its introduction produces a net positive benefit;

2, all exposures shall be kept as low as reasonably achievable; economic, and social factors being taken into account; and

3, the dose equivalent to individuals shall not exceed limits recommended for the appropriate circumstances by the Commission.

Since 1975, the consequences of a vigorously applied ALARA program reduced the average annual occupational dose equivalent to a US radiation worker to an average of 0.36 rem(3.6 mSv) (NUGEG 1998).

DISCUSSION:

The work was performed to reveal the radon risk potential for South Central Pennsylvania. As such the data base was filtered to eliminate duplicate addresses. Thus lower values due to remediations of previous high values were filtered out. It was inappropriate to include values due to remediations when the data sets represent a very small fraction of all households; since the people that test are more likely to remediate and retest. Including all the data would force county average radon values down without significantly changing the actual average thereby creating false optimistic impressions of the radon risk.

A graphical presentation of radon concentration data illuminates hot spots, and reinforces the EPA recommendation that every household should test for radon. This is particularly true for South Central Pennsylvania. Based on an aggregate measurement of 4.2% of all the homes in the 8 county region, the average radiation exposure to adults occupying the first floor is more than 2 times greater than workers occupationally exposed to radiation. Many Central Pennsylvania families use their basements for living space. Based on inspection of homes during radon measurements, TCS estimates about a quarter of the homes built in the last 20 years have finished areas in the basements. Of older homes, possibly one in 10 to fifteen have bedrooms in the basement. Central Pennsylvania is experiencing a home building boom. Many of the larger new construction have high ceilings with walk out basements which may encourage owners to convert to family rooms. In time, this would trend toward more people using basements as living space and more radon exposure.

Adams County had the lowest first floor average radon exposure value. As seen the value was similar to the average national radiation worker exposure. It is useful to note about 3.3 pCi/l in a home is equivalent to the risk borne by the average US radiation worker exposure.

From Table 1 for basements, more than 433 first floors exceed 35 pCi/l. The first floor value was calculated by dividing the basement number by 2.3 which is the TCS measured basement to first floor ratio. The lower limit of 80 pCi/l in basements divided by 2.3 was about 35 pCi/l. Accounting for six daily hours spent outdoors, the minimum first floor exposure for the group was projected to be about 26 pCi/l averaged over a year. This corresponds to a TEDE of 3.5 to 5.0 rem per year. Some of the basements were also occupied. Assuming about 15% of basements contain child play areas, bedrooms and finished family rooms, and taking only the 40 to 80 pCi/l group, an additional 182 households project annual exposures of 4.3 to 6.1 rem per year, TEDE. Assuming 2.6 people per household, more than 1414 people living in 8 Central Pennsylvania counties may receive yearly exposures above the federal and international limit of 5.0 rem TEDE. None of the more than 57,339 nuclear power plant workers, which had measurable radiation exposures, received an over limit exposure for the five year period 1994 to 1998 inclusive, (NUREG 1998). The 1414 person group was based on measured households from only 4 % of households in 8 of 67 Pennsylvania Counties.

GPU Nuclear operated two nuclear power plants in Dauphin County about 10 miles south of Harrisburg on an a tract of land named Three Mile Island, TMI. On March 29, 1979 an accident occurred that damaged Unit 2, and released radioactivity into the environment. Due to radioactive releases from the accident the US Department of Energy found an average individual exposure for people residing within one mile from the Unit 2 was 0.079 rem, (0.79 mSv), (Hull 1989). This was potentially delivered between March 29 to April 3, 1979. Both measurements and calculations showed the exposure rate on April 3 was about 1% of the initial value and this declined by another factor of 10 to 0.1% in another 7 days, (Hull 1989). The average exposure for residents within 1 mile of TMI Unit 2 was estimated to be less that 0.1 rem. (1.0 mSv) for the entire duration of the accident. Taking the first floor radon equivalent exposure for Dauphin County to be 0.71 rem per year (7.1 mSv/y), the TMI Unit 2 accident represented less that two months worth of equivalent risk of living at home with no release from TMI. In March 29, 2000, the incremental risk from TMI was less than 0.7% of the minimum accumulated household radon risk for the 21 year period.

The High-Radon Project run by the Lawrence Berkeley National Laboratory, United States Geological Survey posted on their WEB site a radon map for the 48 contiguous states, (Berkeley 2000). The color coded map indicates Iowa has the highest radon concentration which Berkeley expresses as a geometric mean of 2.72 pCi/l. Pennsylvania is posted as having a geometric mean of 1.83 pCi/l. Assuming a geometric standard deviation of 2.1, the Iowa arithmetic average radon concentration is about 3.5 pCi/l. This may be compared to the average derived from TCS first floor data of 6.7 pCi/l.

It is instructive to compare Central Pennsylvania to Iowa. Since radon reflects harm to people, any comparison must be people driven and not land area driven . In 1990 the population of the state of Iowa was 2.76 million people, (IOWA 2000). In 2000 with projected growth the total Iowa population should be about 2.97 million people. In July 1999, the eight South Central Pennsylvania Counties had a total population of 1.67 million people. Since lung cancer risk is taken to be directly proportional to the TEDE which is also directly proportional to the radon concentration, the 8 county region has about 1.08 times more radon related lung cancer risk than the state of Iowa. This analysis was based on projecting the average of 4.2% of the households to the whole population of the 8 counties. It must be remembered, South Central Pennsylvania is not the only high population, high radon risk area in the state. The state of Iowa reported a annual lung cancer rate of 54.0 fatalities per 100,000 population for 1996, and 53.6 for 1997 (IPH 1996). The corresponding rate for the 8 South Central Pennsylvania Counties was 56.9 fatalities per 100,000 for 1996, 54.2 for 1997, and 54.5 for 1999, (PBHS 2000). It is believed that only case controlled studies that take smoking and other items into account are useful to define the lung cancer risk due to radon. Regardless a higher radon related risk for the sub-set of Pennsylvania is not contra-indicated by the higher lung cancer fatality rate of the 8 South Central Pennsylvania Counties. A case controlled study may be indicated for Pennsylvania.

A degree of uncertainty is present in all of the published risk projections. For radon related risk, a meta-analysis of eight residential case-control studies found excessive lung cancer risk at an average indoor radon concentration of 4 pCi/l, (Lubin 1997). Thus semi-direct evidence existed for excess risk at or below average radon levels found in Central Pennsylvania. For radiation exposure of nuclear workers at or below occupational limit values, no direct evidence of risk was ever observed, (BEIR V 1990).

CONCLUSION:

The risk portion of this paper can be summarized in two thoughts. The radiation industry is extremely safe and the risk due to radon in South Central Pennsylvania is significant. The latter is supported by the latest results of four years of comprehensive study by a committee of the National Research Council. They found no reasons to significantly change the previous radon risk values, (BEIR VI 1999).

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Table 1, Numbers of Plotted Basement Locations *

Radon pCi/l	Total Locations	Plotted Locations	Recovered** Locations	Fraction Plotted
> 120	177	128	31	0.72
80 to 120	256	208	55	0.81
40 to 80	1212	1104	302	0.91
20 to 40	2649	2573	602	0.97
Total	4294	4013	990	

* Data for 8 Central Pennsylvania Counties

** Included in plotted locations

Table 2. PROJECTED HOME OWNER RADIATION EXPOSURE

County	Houses Total* No.	Measured Houses %	1 Floor Avg. pCi/l	1 floor TEDE rem/y	Basement Avg. pCi/l	Basement TEDE rem/y
Adams	33,730	1.5	2.5	0.28 - 0.39	6.8	0.74 - 1.04
Cumberland	81,024	10.1	6.6	0.72 - 1.01	14.4	1.55 - 2.19
Dauphin	94,452	8.4	6.5	0.71 - 1.00	14.2	1.53 - 2.17
Franklin	49,543	1.4	4.6	0.51 - 0.72	9.1	0.99 - 1.40
Lancaster	176,937	2.8	8.7	0.95 - 1.34	17.1	1.84 - 2.61
Lebanon	45,329	1.9	5.9	0.65 - 0.92	18.8	2.03 - 2.87
Perry	17,031	4.3	11.4	1.23 - 1.74	24.2	2.60 - 3.68
York	144,841	2.2	6.1	0.67 - 0.95	11.9	1.29 - 1.82
8 County Summary	642,887	4.2	** 6.7	0.76 - 1.04	** 14.4	1.56 - 2.21

* County households taken as 2.6 people per house from http://www.census.gov/population/estimates/county/co-99-1/99C1_42/txt
** average weighted over numbers of measurements

Fig. 1, Harrisburg, PA, 20 to 40 pCi/l

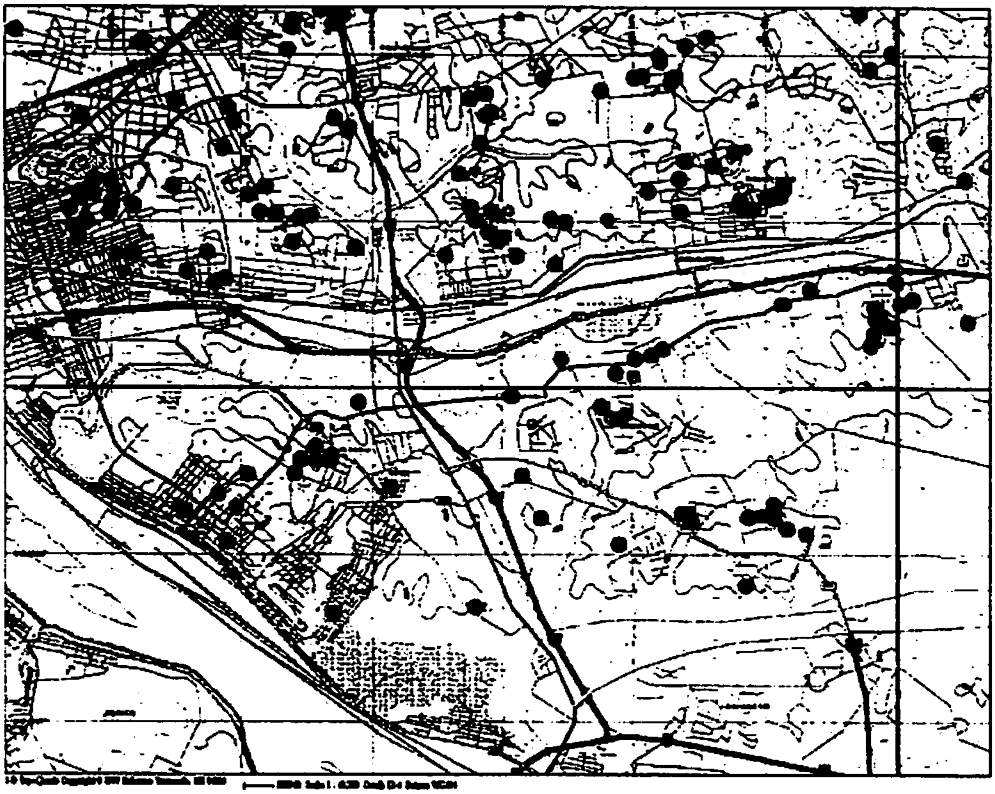

Fig. 2, Harrisburg, PA, 40 TO above 120 pCi/l