#5489

Effects of Humidity and Rainfall on Radon Levels in a Residential Dwelling

by: Albert Montague, Ph.D., P.E.
William E. Belanger, P.E.
U.S. EPA, Region III
Philadelphia, PA, 19107
Francis J. Haughey, Ph.D.
Rutgers University
New Brunswick, N.J. 08903

Although the effects of precipitation and barometric pressure are not well defined with regard to radon entry into buildings, evidence continues to be collected showing that there appears to be some type of relationship between these factors. Nazaroff showed that on one day of heavy rain with a moderate drop in barometric pressure the radon concentration in a dwelling rose to a level more than five times higher than the average (Nazaroff, 1983). Another study from which this report draws showed a strikingly similar relationship of radon with rainfall, barometric pressure and radon levels, (Montague, 1990). It showed that the average radon level in the dwelling increased to over eight times its normal concentration during a heavy rainfall event. A drop in barometric pressure also occurred, but the minimum occurred after the radon peak, in at least one instance. Surface soils were not frozen during the rainfall event. Other factors not previously reported are the focus of this report. These appear to be contributing to the complexity of the radon transport and entry problem.

A residential dwelling located in a rural area near Media, Pennsylvania, was selected for a radon study that covered a five-month period from November 1988 to March 1989. Meteorological and radon data were collected continuously during this period. The home, a two-story colonial wood frame structure with a full basement, was five-years old at the time of the study. It was selected because prior short-term radon observations showed levels in the basement to range between 15 to 20 pCi/L., and because the homeowner was amenable to having instrumentation installation in the house.

The house was constructed on the south side of a hill, near the 250-foot contour line, with a southerly orientation that is unobstructed by trees. On a sunny day solar exposure was continuous. However, the area behind the house is shielded from the direct rays of the sun because of the dwelling's shadow. This setting decreases the probability of freezing surface soil except for the area directly behind the dwelling during extended periods of sub-zero temperature. The hill, with a maximum elevation of approximately 375 feet above sea level, shields the dwelling from northerly winds and has a surface incline of about 10 percent.

The steepness of the incline affects the rate and extent of water runoff during periods of precipitation and snowmelt. The topography simultaneously affects the rate, and quantity of surface water that can percolate into the soil. This ultimately affects subsurface radon kinetics (EPA 1987). The subsurface geology has the Glenarm Series, metamorphic formations mainly of schist and phyllite with some marble, and quartzite of Peters Creek, Wissahickon, Cockeysville, and Setters Formations (DOA, 1963). The local soil has been classified as the Glenelg Series, which is a moderately deep, well-drained soil of uplands. The surface layer is a silt loam. The subsoil is also silt loam, but it contains a little more clay than the surface layer. In some locations there are flat channery fragments, nearly two inches across, in the surface layer. Slightly larger fragments are in the subsoil. Beneath the subsoil there is a strong brown to reddish-brown loam that contains many bright fragments of mica.

The dwelling is conventional from both a design, and structural standpoint. It contains two fireplaces, power (exhaust) vents in the bathrooms, and an electric clothes dryer vented to the outdoors. When placed into operation each of these items discharge indoor air to the outside air. The forced air heating and air-conditioning system uses a conventional gas-fired furnace and heat pump. The inclusion of a heat pump makes the heating system more efficient; however, it is not the usual residential heating system configuration. The heat pump is automatically shut off when the outside temperature falls below 40 degrees Fahrenheit. It is this point that the gas-fired furnace automatically begins to supply heat to the house. The gas furnace was in operation for most of the study period.

All of the meteorological readings were continuously recorded on strip charts, and collected at the end of each week, except for the anemometer strip chart readings, which were retrieved once a month. Basement radon levels were recorded on hard copy printout every three hours, and collected at the end of each week. All of the meteorological values were manually transformed from analog to digital form, by visually estimating the average value that best represented the strip chart values for each three-hour interval. Lotus 1-2-3 was used to conduct the analysis, because it has the ability to process the appropriate amount of data, conduct statistical analyses, and permits the user to generate graphs with relative ease.

Examination of all the radon data revealed a number of sharp "spikes" in radon concentration, during which the radon concentration went to several times its "normal" concentration. A selective retrieval was performed, to examine potential causes for these events. Four separate events, each having rainfall amounts that exceeded one (1) inch, were identified within the five-month period of study. It should be noted that the four events that were selected all occurred when the dwelling was operating under the same experimental mode; specifically, when the furnace was drawing inside (house) air for combustion. The absence at these events during operation on outside air is not thought by the authors to be related to the outside air supply, since the events appeared to be related to rainfall. With the four events identified and their time frames established, data retrievals were made for relative humidity, basement radon, outside temperature, barometric pressure, and the wind speed and direction dwelling's differential air pressure (vacuum). (Figures 4 to 7). Wind speed was found to have no located inside the dwelling envelope. There is a two inch gap around the outside of the chimney which leads to the attic. This combustion system provides a conduit for the continuous release of indoor air to the outdoors, and keeps the house under a slight vacuum (~.02"wc) throughout the heating season. Several factors responsible for this phenomenon include: the buoyancy of the dwelling's indoor (warm) air relative to outside (cool) air, outside wind-speed (velocity) that creates a pressure drop at the mouth (top) of the chimney commonly known as the "Bernoulli effect"; and the combustion of fossil fuels, e.g., gas or oil, which increases the temperature differential between the combustion exhaust gases flowing through the furnace, and up the chimney, with the surrounding ambient (outside) air, when the furnace is operating (Figure 1). The furnace was not found to produce a measurable negative pressure in the house, while fireplace operation caused a marked difference.

The original study focused on the effects of depressuriza-tion in a dwelling, differential air pressure, and the kinetics of radon entry. This study focused on the operation of a residential fossil fuel central heating appliance that is located within the living space. The furnace combustion system was completely isolated from the air within the dwelling envelope during predetermined intervals and returned to its normal configuration for the remainder of the time as a control. This was accomplished by mechanically providing only outside air to the appliance (Figure 2). The investigators took care to assure that no unsafe condition would result from the outside air supply to the furnace. The device used has been tested and approved by Underwriters Laboratories. Provisions were also incorporated in the modified furnace combustion air supply system, to allow for switching easily from internal house air.

A five-month cold season monitoring period was selected to minimize the effect of perturbations associated with the prolonged opening of windows and doors, to minimize seasonal variations, and to collect a sufficient amount of data to obtain a valid result. Within the period of study, a two-week "outside air" followed by a two-week "inside air" interval was selected. This cycle was repeated throughout the entire investigation.

Several calibrated radon monitors were used in all floors at the house in the original study; however, only the Pylon model AB-5 with passive call that was placed in the basement will be the monitor of interest in this report. It was programed to provide three-hour radon averages or eight readings each day. Data generated by the Pylon monitor was collected every two weeks to coincide with intervals selected to switch the furnace system from indoor air to outdoor air.

Since the primary driving force moving radon into the dwelling is the soil-gas pressure relative to the interior air pressure. A methodology developed by Belanger was selected to gather meaningful indoor/outdoor air pressure data (Figure 3). The approach requires that two outdoor air pressure measurements be made. A differential outdoor air pressure reading is obtained between the upwind-side, and the downwind-side of the dwelling. Second, a differential air pressure reading is also simultaneously obtained between the interior and exterior of the dwelling. The second reading is taken only when the differential air pressure in the first observation indicates very close to zero. This approach removes the effect of wind on the differential pressure value observed between the inside and outside wall of the dwelling.

Two Magnahelic gauges were used to measure differential air pressure. One Magnahelic having a zero center, i.e., -.25 to 0 to .25 inches water column (0 to 62 Pascals) was used to measure the air pressure difference caused by winds blowing across the exterior of the dwelling. The second gauge, with .25 inches water column full scale, was used to measure the interior building pressure relative to the air pressure outside the dwelling. Air diffusers normally used in a domestic aquarium were attached to the tip of the outside probes, to prevent wind velocity (pitot) effects on the exposed end of the pressure tube. With the diffusers connected to the tubing pitot effects disappeared.

A tee fitting was inserted in one of the lines and connected to the pressure port of the 0 to .25 inch pressure Magnahelic. The vacuum port was left open to the interior building air pressure so a vacuum in the building would give a positive deflection on the meter. The Magnahelics were then read twice each day, at approximately 7:00am in the morning and again at 7:00pm in the evening.

A meteorological station was set up at an adjacent dwelling, approximately 200 feet from the test house. It continuously measured wind speed and direction, outside temperature, humidity, and barometric pressure.

systematic relationship with these radon perks. It was excluded from subsequent analysis because the relationship with the other parameters was quite striking.

Visual examination of the graphed data presented in Figure 4, Event 1, provides some valuable insight into various actions that occurred during the "Event." First, it shows that it was preceded by a rise in relative humidity, which also represents concurrent rain period. Second, barometric pressure readings, which were multiplied by a constant so that they could also be plotted on the same graph, show an inverse relationship with respect to the dwelling's basement radon levels and relative humidity. The latter observation is well-known, but may not imply cause-and-effect. Last, the static values representing the dwelling's differential air pressure (vacuum) decreased, i.e., became less negative while the basement radon level surged upward, and then increased again as the event proceeded until basement radon levels returned to their normal values.

The fact that the differential pressure in the dwelling decreased and then started to recover increase in negativity during the course of the event, can be explained and attributed to the buoyancy of the dwelling's indoor air, its temperature and and relative humidity which remained almost constant throughout the event. However, the differential density between the inside air decreased relative to the outside air, because the outside air became less dense as its relative humidity increased. As the event progressed the relative humidity of the outside air declined, its density increased, causing the buoyancy of the dwelling air, hence the dwelling's vacuum, to increase relative to the ambient air outside the dwelling. This decrease in the vacuum appears to be related in time to the measured outdoor humidity rather than the radon concentration.

This last observation--a declining vacuum in the dwelling-- was unexpected, since it clearly conflicts with conventional wisdom. The radon spike, was presumed to be driven by the vacuum in the house. This is apparently not the case. The reduced differential air pressure (vacuum) in the dwelling should have produced a lower radon level in the basement. Instead an opposite outcome occurred, clearly indicating the some other overriding factor was causing the radon concentration in the dwelling to increase.

It is important to note and understand that throughout the study period there were numerous instances when the barometric pressure was low and it did not rain. However, these occurrences were never accompanied with radon spikes. Radon spikes were observed only during and after a rainfall event when the barometric pressure was low and the surface soil was not frozen. Furthermore, these spikes appeared to follow the rain event when the event was significant, i.e., precipitation was greater than 0.3 inches. Occasionally, the barometric pressure appeared to follow the radon spike. In light of these observations it is reasonable to conclude that rainfall, and not barometric pressure is the cause of the radon spikes. In addition, the height of the radon spike correlates with the amount of rainfall; a relationship that is presented in Figure 8.

Further examination of the three remaining events yielded similar findings. In light of these observations, it now appears that the rain percolating into the subsoil plays a far greater role in the dynamics of radon gas transport from the surrounding soil and into a dwelling that was previously believed. As surface water percolates vertically downward through the soil, it displaces the gas in the soil pores. This soil gas is compressed and forced laterally into the unsaturated soil pores immediately below the foot print of the dwelling since these soil pores are protected from the rain and associated percolate because of the dwelling's cover. This process, in effect, produces a gas surge of radon-222 spike that is pushed, rather than pulled into the dwelling during the rainfall event. However, additional studies should be done to corroborate this theory.

Reference

DOA (Department of Agriculture). May 1963. Soil Survey Series 1959, No. 19. Government Printing Office, Washington, DC., pp78-79.

EPA (Environmental Protection Agency). September 1987. Radon Reference Manual. EPA/520/1-87-20, Government Printing OFfice, Washington, DC. pp2-1 to 3-8.

Montague, A., W.E. Belanger, and F.J. Haughey, 1990. "An Analysis of the Parameters Influencing Radon Variations in a House.: In 1990 International Symposium on Measurements of Toxic and Related Air Pollutants. U.S. Environmental Protection Agency/Air & Waste Management Association, Raleigh, North Carolina.

Montague, A., 1990b. An Evaluation of the Quantitative Effects on Radon Gas from the Modification of a Home Heating and Air Conditioning Systems. PhD Thesis, Rutgers University, New Brunswick, NJ.

Nazaroff, W.W. and S.M. Doyle, Radon Entry Into Houses Having a Crawl Space. Lawrence Berkeley laboratory, Report LBL-16637, Berkelely, CA, 1983.

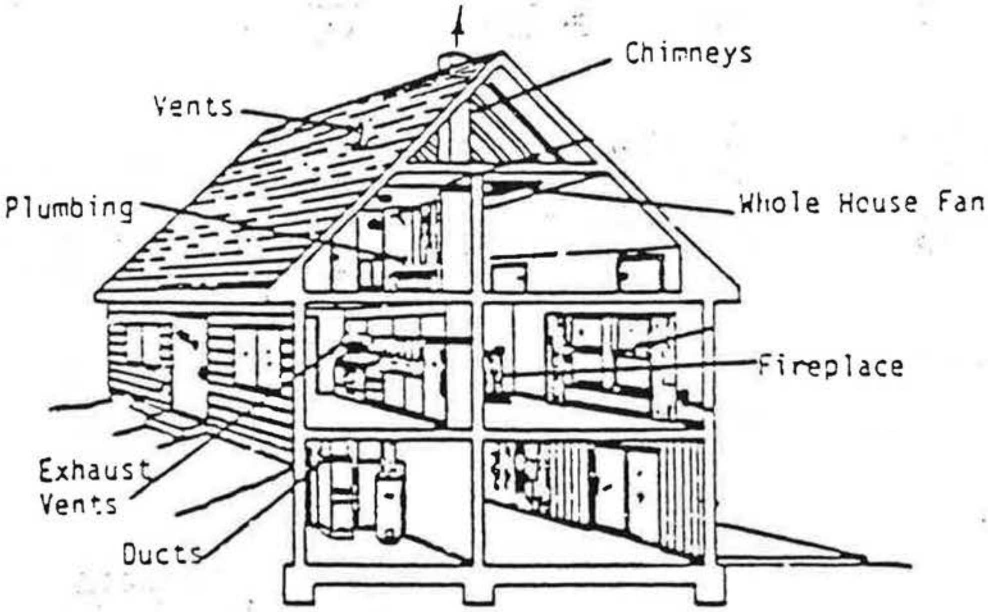

Figure 1. Sources of Negative Pressure

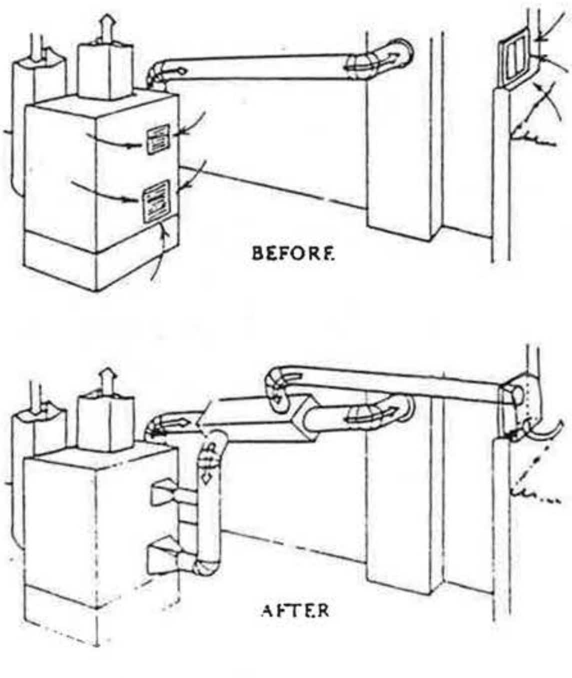

Figure 2. Furnace Modification

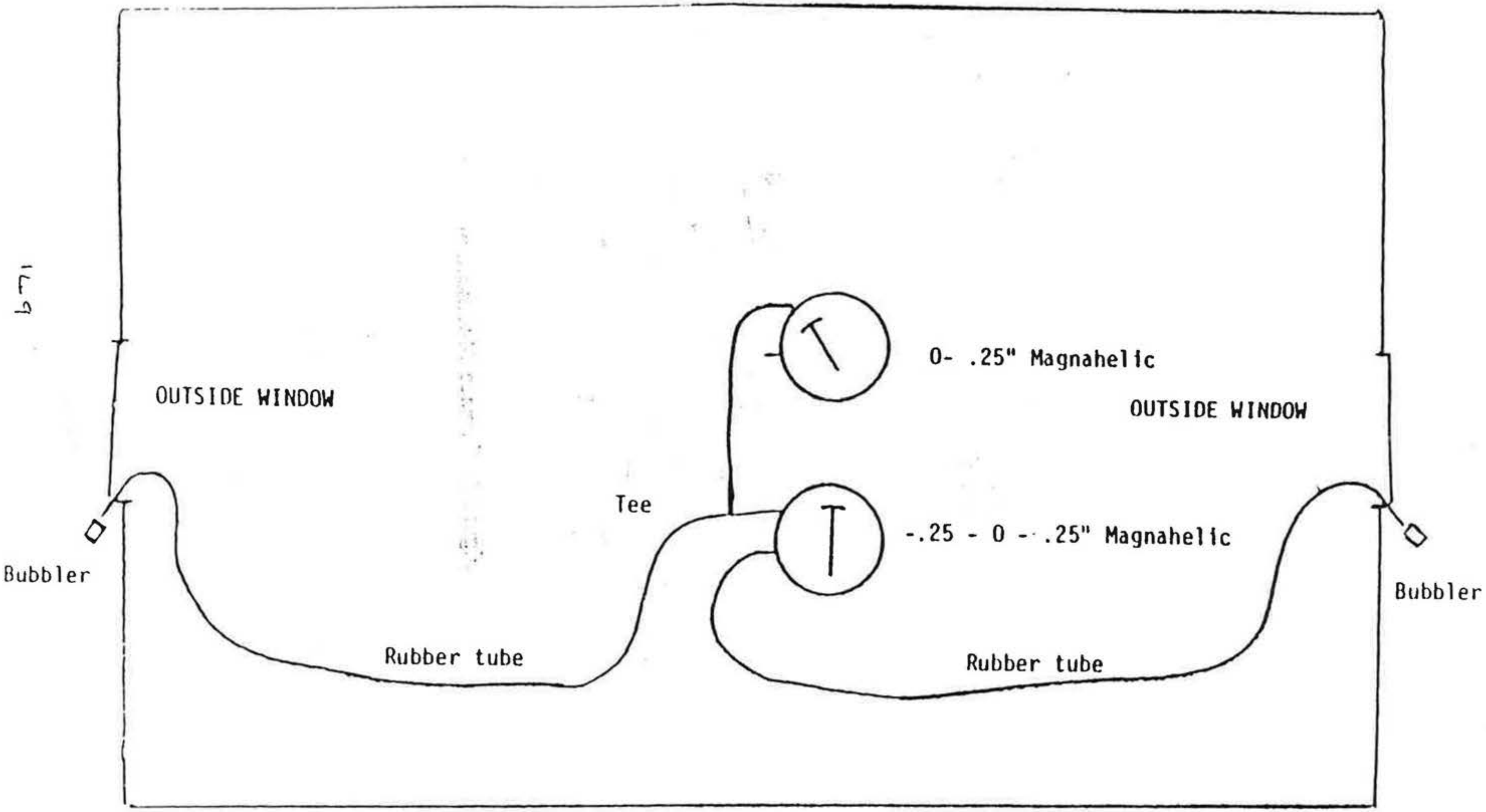

Figure 3. Installation of Magnahelic Pressure Gauges

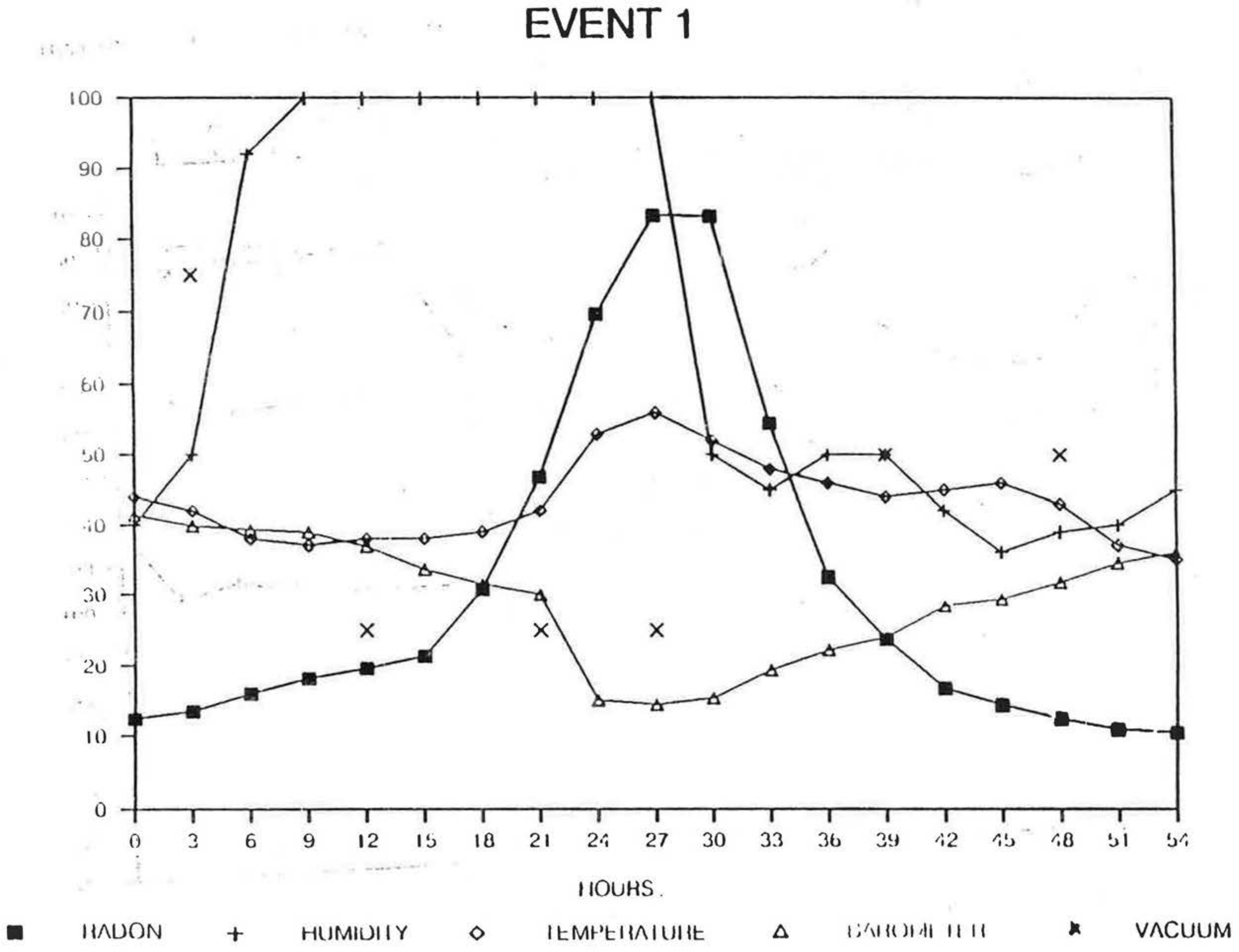

FIGURE 4. RADON AND METEROLOGICAL RELATIONSHIPS - EVENT #1

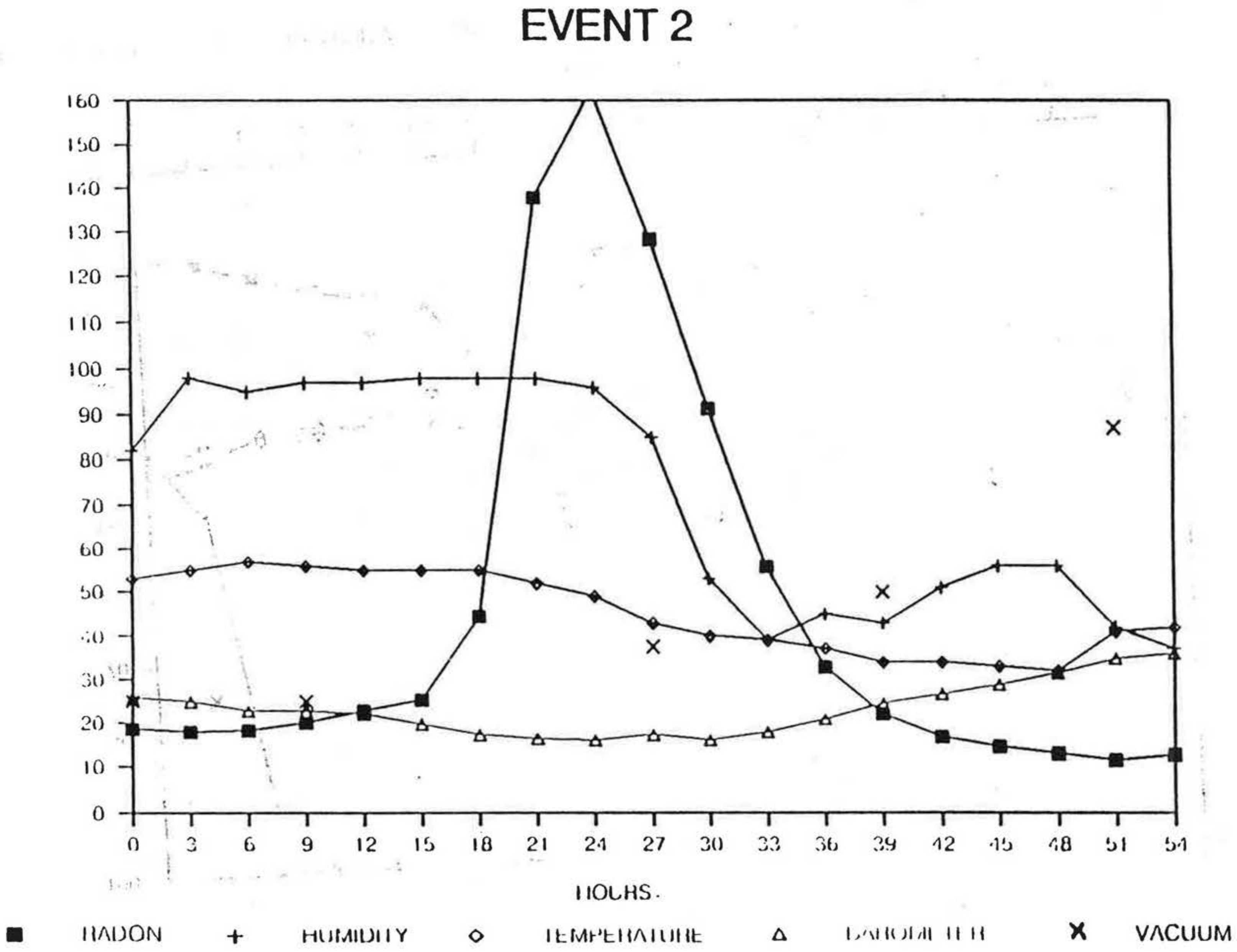

FIGURE 5. RADON AND METEROLOGICAL RELATIONSHIPS - EVENT #2

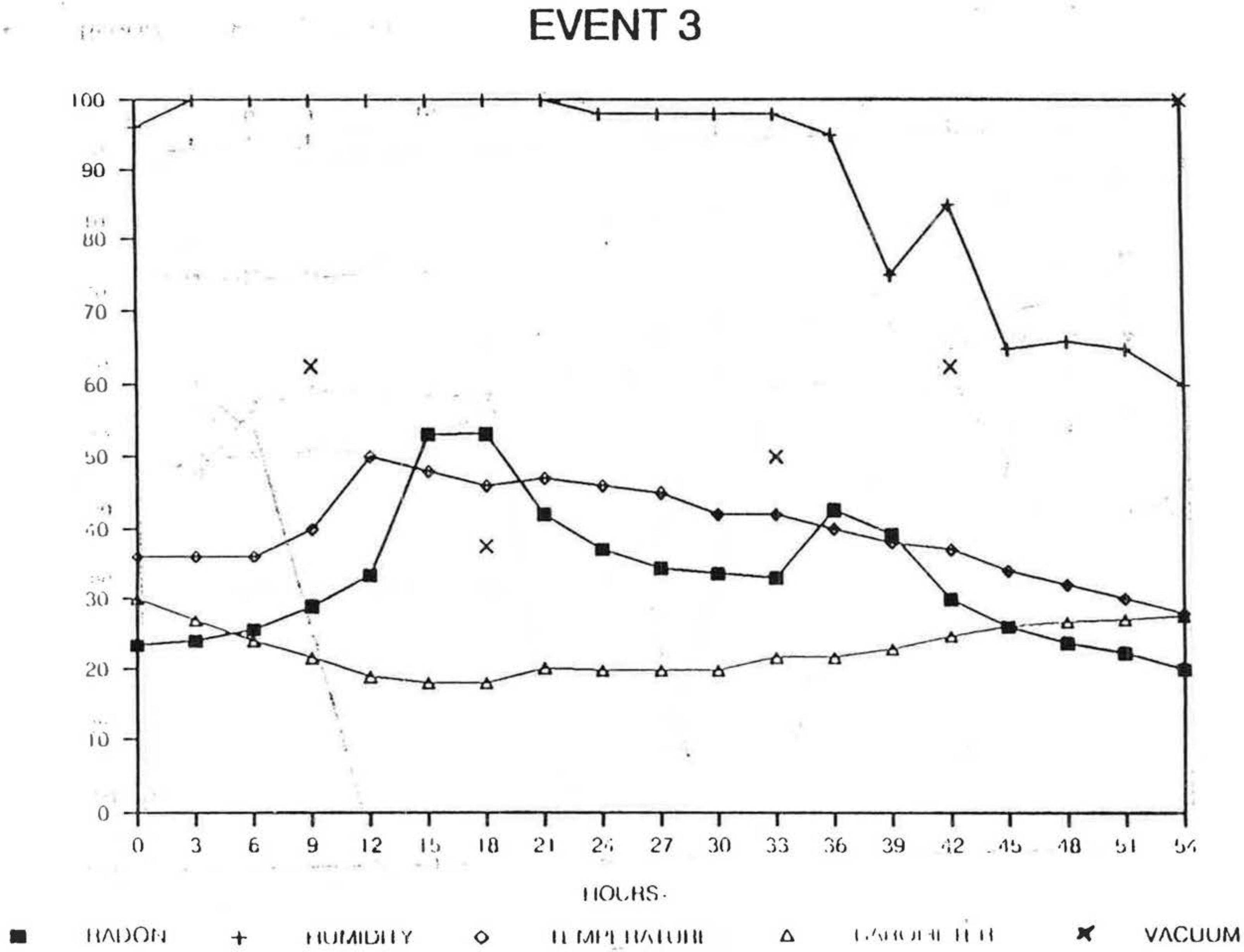
EVENT 3

FIGURE 6. RADON AND METEROLOGICAL RELATIONSHIPS - EVENT #3

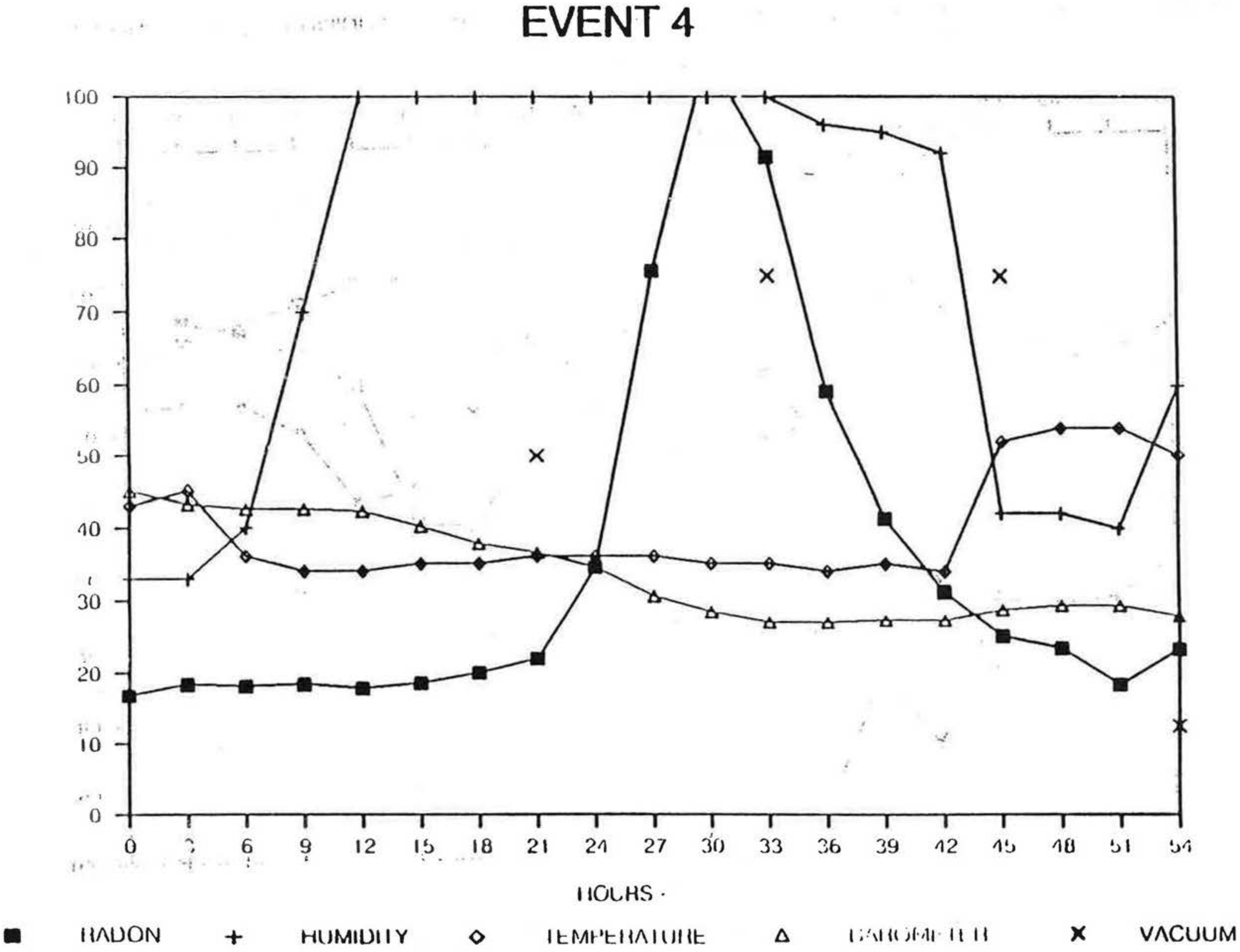

FIGURE 7. RADON AND METEROLOGICAL RELATIONSHIPS - EVENT #4

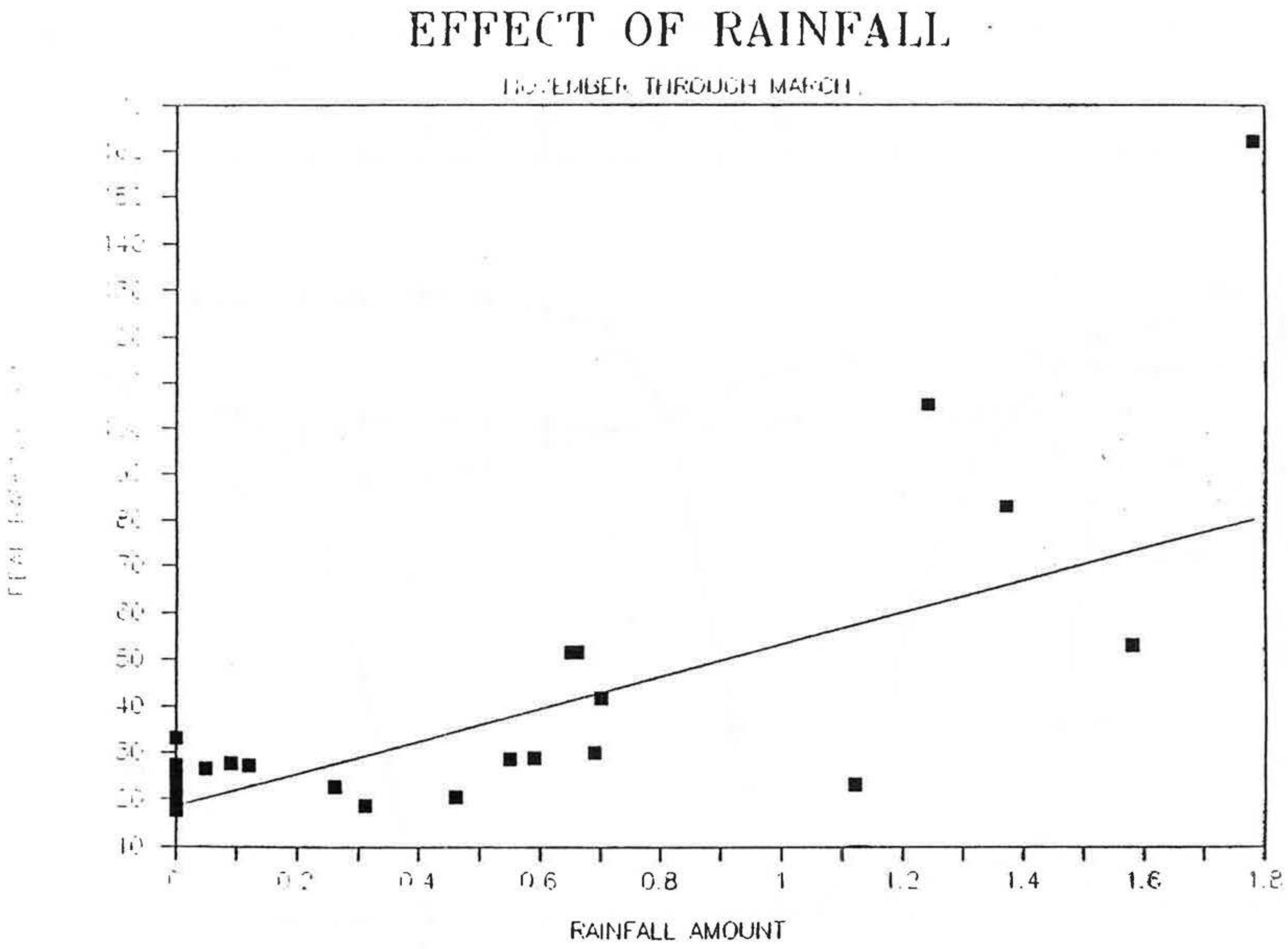

Figure 8 Effect of Rainfall