United States
Environmental Protection
Agency

Office of
Radiation Programs
Washingto

EPA 520/1-86-015
August 1986

Radiation

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Seasonal Variations Of Radon And Radon Decay Product Concentrations In Single Family Homes

SEASONAL VARIATIONS OF RADON AND RADON DECAY PRODUCT CONCENTRATIONS IN SINGLE FAMILY HOMES

by

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FOREWORD

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation and to promote development of controls necessary to protect the public health and safety.

Within the Office of Radiation Programs, the Las Vegas Facility conducts in-depth field studies of various radiation sources (e.g., nuclear facilities, uranium mill tailings, and phosphate mills) to provide technical data for environmental impact assessments as well as needed information on source characteristics, environmental transport, critical pathways for population exposure, and dose model validation. The Office of Radiation Programs-Las Vegas Facility also provides, upon request, technical assistance to Western States and to other Federal agencies. The Las Vegas Facility participated in a radiation survey in Butte, Montana. The primary purpose of the survey was to determine if radioactive materials distributed in the community affected radon concentration in the homes. This report presents observations and discussions concerning the seasonal variation of indoor radon and radon decay products.

The readers of this report are encouraged to send the authors any comments. Requests for further information are also invited.

Sheldon Meyers

Sheldon Meyers, Director
Office of Radiation Programs

ABSTRACT

Radon and radon decay product concentrations were measured weekly for a period of 1 year in 20 homes. A seasonal cycle was observed for the radon concentrations; with a low during the warmer months and a high during the cooler months of the year. Radon decay product concentrations were found to generally follow the radon cycle, as expected. The equilibrium ratio was observed, however, to vary inversely with the radon and radon decay product cycles. The indoor radon cycle for the 20 homes was also found to follow the inverse of the outdoor radon concentrations. Some speculation and supporting data are presented to explain the inverse indoor and outdoor relationships.

CONTENTS

LIST OF FIGURES

SUMMARY AND CONCLUSIONS

Indoor radon concentrations were observed to follow a seasonal cycle in 20 Butte, Montana, houses. A cycle low occurs during the warmer months of the year. This low is believed to be due to increased ventilation of the houses during the warmer months and, in part, to changes in the radon source. Increased ventilation results from opening doors and windows for cooling. Changes in the radon source are believed to be caused by ground freezing and, possibly, snow-cover. This causes an increase in radon soil gas concentrations, thereby increasing the quantity of radon gas available for entering houses.

The indoor working-level cycle, as expected, generally follows the yearly radon cycle; however, it departs from the radon cycle during the cold months of the year. This departure is generally believed to be caused by the heating systems, which tend to either remove or precipitate airborne particulate material or to enhance the removal of the first progeny of radon or both. A yearly cycle of the working level was observed that, when adjusted for radon variations, augments this assumption. Little differences are noted when comparing convection and forced-air heating systems, but there are significantly lower working levels during the heating season.

The foregoing differences in the radon and working-level cycles result in the cycling of the equilibrium ratio. The equilibrium ratio is lowest in its cycle during the cooler months and highest in its cycle during the warmer months. Its form is approximately the inverse of the radon cycle.

These apparent complex interactions of the outdoor and indoor environments as well as lifestyle influences on the indoor radon

concentrations and working levels, indicate the need for further work and studies to better understand their relationships. These relationships, when better understood, will afford an opportunity for better appraisals of the annual average working level in houses and, possibly, measures to better control both indoor radon concentrations and working levels.

ACKNOWLEDGEMENT

Well over 100,000 measurements of indoor and outdoor radon concentrations and indoor working levels were made over a period of 18 months during the Butte Study. The authors express their appreciation to the staff of the Montana Department of Health and Environmental Sciences for their commitment to excellence in conducting the field portion of this study and for their prompt evaluation of the radon source terms in Butte, Montana, which involved additional hundreds of measurements. We acknowledge the efforts of Dr. Miron Israeli, visiting scientist from the Israel Atomic Energy Commission, for his outstanding work in editing and organizing the data base into comprehensive working files. Our appreciation is extended to Mr. Allen Sparks, Computer Sciences Corporation, for his tireless efforts in extracting and presenting information from the files for preparation of this report.

INTRODUCTION

Gesell (Ge83) reported in his 1983 review that little or no data was available concerning seasonal variations of indoor radon background concentrations. Since then, several investigators have reported seasonal variations. George (Geo83) noted seasonal variations in structures around former Manhattan Engineering District sites in Lewiston, New York; Cannonsburg, Pennsylvania; and Middlesex, New Jersey. Fleischer (F183) noted seasonal differences in energy efficient homes in northeastern New York state, and Swedjemark (Sw83) noted seasonal differences in Sweden. Abu-Jarad (Ab84) conducted a survey to specifically address the existence of seasonal variations in England, and George (Geo84) adjusted an ongoing study in Pennsylvania homes to observe seasonal variations.

In general, the investigators noted that seasonal variations of indoor radon concentrations appear to be commonplace, with higher concentrations in the cooler months and lower concentrations in the warmer months. The winter-to-summer ratios of radon decay product concentrations observed by Jonsson (Jo84) appear to contradict the seasonal variations of radon concentrations about 50 percent of the time. This paper confirms the aforementioned authors' work and, where possible, extends it further.

The data presented and discussed in this report are from the Butte Study. This study developed as a result of an investigation by the Montana Department of Health and Environmental Sciences (DHES) staff concerning the use of phosphate slag for construction purposes in Butte, Montana. Structures containing phosphate slag products were sampled to determine if the products affected indoor working levels. Other structures, sampled for comparison, were found to have working levels well above those structures containing phosphate slag products.

The Environmental Protection Agency's Office of Radiation Programs (ORP) supported DHES by contract to expand the structure sampling program and to investigate and identify the sources of radon causing elevated working levels. The sources were evaluated by Lloyd (L183). New radon and radon decay product measurement equipment that showed some promise of reducing measurement costs was appearing in the marketplace. The contract with the DHES was amended to conduct a study to evaluate this equipment in home environments.

Radon and working-level measurements were made in 68 houses, which were divided into three groups. One group contained four houses designated as Super Intensive Level of Measurement (SILOM) houses. Another group contained 16 houses designated as Intensive Level of Measurement (ILOM) houses. The third group was designated Normal Level of Measurement (NLOM) houses. The principal difference between the house groups was the frequency of measurements. The SILOM houses had additional instrumentation to measure hourly radon concentrations and working levels. Houses selected for the study were not random samples. The SILOM houses were selected to provide a broad range of radon concentrations and working levels. The ILOM and NLOM houses were selected from those that had prior working-level measurements or upon the willingness of the occupants to participate in the study.

There are about 112,000 measurements in the data base, exclusive of an 18-month file of hourly meteorological parameters. Quality assurance for the radon and radon decay product measurements is addressed by Nyberg (Ny85). About 11,000 measurements of radon and radon decay product concentrations from the data base and 9,000 measurements from the meteorological file were used for the preparation of this report.

METHOD

Twenty of the 68 homes measured in the Butte Study were selected to observe seasonal variations. Measurements of radon concentrations and working levels were made continuously in these houses for at least 1 year and with a resolution adequate to determine seasonal variations. The distribution of their average annual radon concentrations covers a wide range of values from 3 to 70 pCi/l.

Data used in this report are derived from three types of measurement devices; the Passive Environmental Radon Monitor (PERM); the Radon Progeny Integrating Sampling Unit (RPISU); and the Radon Gas Monitor (RGM). The PERM's and RPISU's were used to measure, respectively, indoor concentrations of radon and radon decay products (e.g., working level) respectively, on a weekly basis. The RGM was used to measure outdoor radon concentrations continuously on an hourly basis.

Weekly measurements from PERM's and RPISU's for the 20 houses are presented graphically in the appendix. Radon concentrations and working levels are plotted for each house on the same graph for each study week. Study week 1 began during the week of October 5, 1981.

The yearly data, by month, for each house is normalized to present the data for all 20 houses as a group. Normalization was done by dividing the average monthly concentration in each house by the average yearly concentration for that house. The outdoor radon concentrations were normalized using the same method.

RESULTS AND DISCUSSION

Figure 1 contains plots of the normalized radon concentrations, working levels, and equilibrium ratios for the 20 houses. Each point on the plot represents the mean of the normalized values for 20 houses for each calendar month.

The plots for both normalized radon concentrations and working levels indicate a yearly cycle. The equilibrium ratio, derived from the foregoing measurements, also indicates a yearly cycle. Each plot is discussed separately.

RADON CONCENTRATION CYCLE

This plot exhibits a strong seasonal cycle having minimum values in the warmer months and maximum values during the cooler months. The maximum occurs in December gradually falling until May, and begins a steeper drop to its lowest level in August. A steep rise occurs from August to October, followed by a gradual rise to December. The cycle is believed to be caused by alteration of the houses' ventilation rates and changes in the source term. House cooling during the warmer months in Butte is usually accomplished by opening doors and windows during the daylight hours. This increases the ventilation rate and subsequently reduces the indoor radon concentrations. The effect of the increased ventilation rate on the daily radon cycle in Butte houses has been studied (Ha85). The period of increased ventilation is presumed to occur from June through September and to be proportional to the outdoor temperature (i.e., warmer days result in longer ventilation periods).

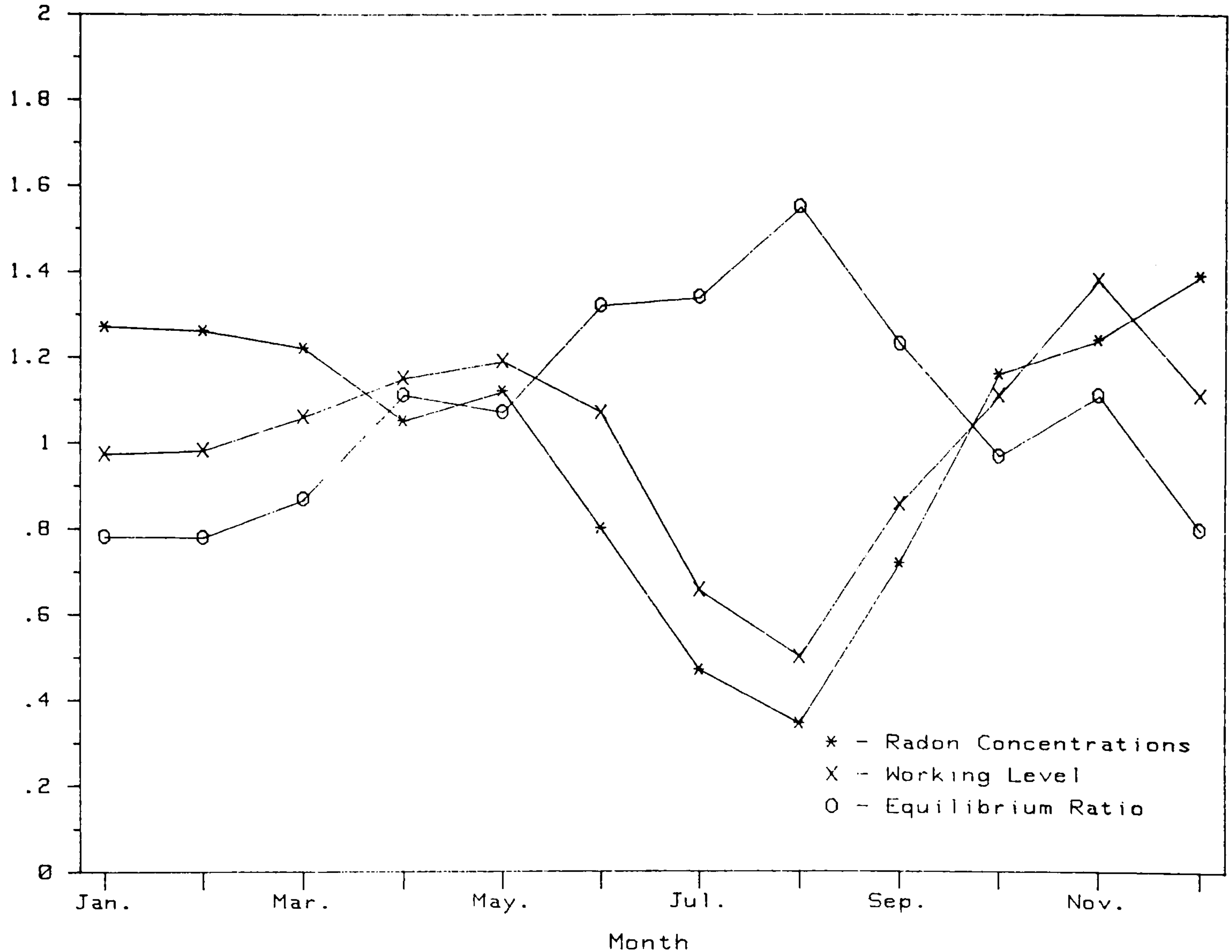

Figure 1. Normalized radon concentrations, working levels, and equlibrium ratios for 20 homes.

Alteration of the radon source terms is believed to be caused by ground freezing. Ground freezing lowers the radon exhalation rate. This causes increased radon concentrations below the ground surface and subsequently higher radon concentrations available for transport and diffusion into the houses. This assumption is based on summer and winter measurements of radon soil gas concentrations and the behavior of outdoor radon concentrations. Radon concentrations in soil were measured by Lloyd (L183) over deep alluvium in the southern part of Butte, Montana, at a depth of 30 inches at 30 locations on a half-mile grid. A warm weather measurement and a cold weather measurement were made at each location. The mean radon concentration for the warm weather measurements was 300 pCi/l, and the mean of the cold weather measurements was 500 pCi/l. The warm-to-cold weather ratio was about 0.6, indicating increased below-grade concentrations during colder months. Figure 2 contains plots of monthly averages for outdoor concentrations radon and temperature. Outdoor radon concentrations exhibit a yearly cycle similar to the temperature cycle. The concentrations are lower in the cooler months and higher in the warmer months, possibly due, in large part, to the alteration of the soil's exhalation rate (i.e., from freezing and thawing of the ground).

Figure 3 contains a plot of the means of the normalized radon concentrations in 17 houses, a plot of the means of the normalized radon concentrations in three houses, and a plot of the normalized outdoor radon concentrations. The three houses do not exhibit a clear seasonal cycle of indoor radon concentrations (appendix figures A-4, A-5, and A-12). Their plot indicates below normal radon concentrations during the winter and late summer, with above normal concentrations in the late spring and fall. The cause of this cycle is presented as pure speculation. House 4 was the office for the DHES staff and was unoccupied about 14 hours per day and on weekends. It was kept closed most of the time. It is suspected that houses 5 and 12 were kept closed during the summer months because of the low number and high ages of the occupants. The low amplitude cycle is probably due to lower ventilation rates.

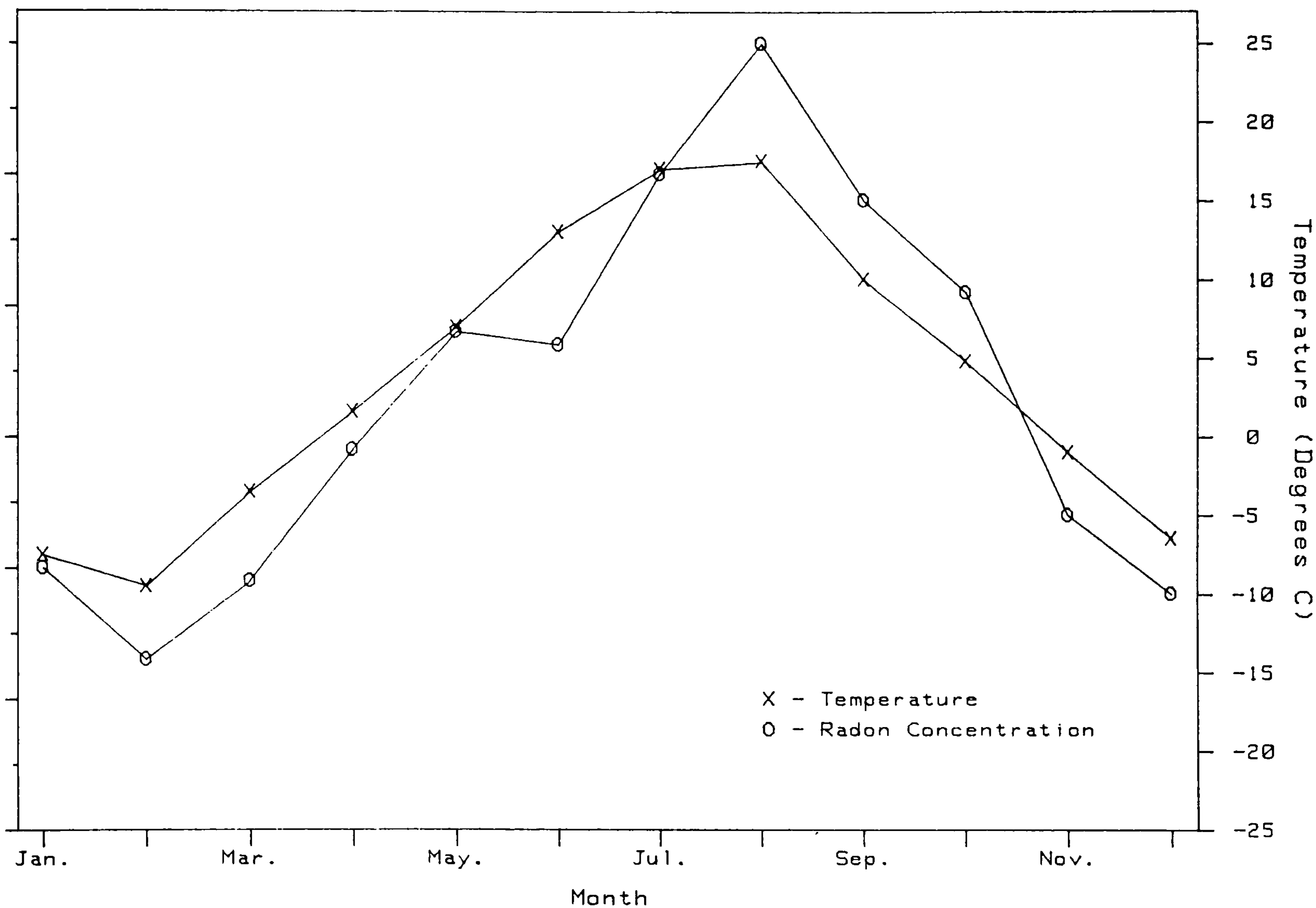

Figure 2. Average outdoor radon concentrations and temperatures.

The plot of the normalized outdoor radon concentrations is inverted to show its relationship to the plot for the normalized radon concentrations for the remaining 17 houses. Both cycles generally follow each other in time and magnitude, indicating a possible relationship between indoor and outdoor radon. These observations and relationships are currently under study at our facility.

WORKING-LEVEL CYCLE

The normalized working levels generally follow the normalized radon cycle, except for colder months of December through March (figure 1). It is speculated that the lower values (i.e., below the norm) of the working levels during this time period is due to air cleaning by the heating systems. Windham (Wi78) and Rundo (Ru78) noted the effect of air conditioning and a central fan on the reduction of radon concentrations, working levels, and equilibrium ratios.

Figure 4 shows the observed normalized working level and the working level without the effect of the radon cycle. The effect of the radon cycle is removed by adjusting the observed working level up or down opposite the displacement of the radon cycle from its norm. If the normalized radon value is 10 percent above its norm for a particular month, the observed working level is reduced by 10 percent for that month. The resulting working-level plot essentially represents the yearly variation of the working level with radon variations minimized. The cycle is generally a smooth curve, gradually peaking in the summer months and reaching lows in the winter months. This augments the premise that this cycling is due, in large part, to the air cleaning action of the heating systems.

Figure 5 compares the effects of two types of heating systems on the working level. Four houses were selected that have forced air heating with filters in the ductwork, and four houses were selected having convective heating systems. The plots for each group of four houses are the mean

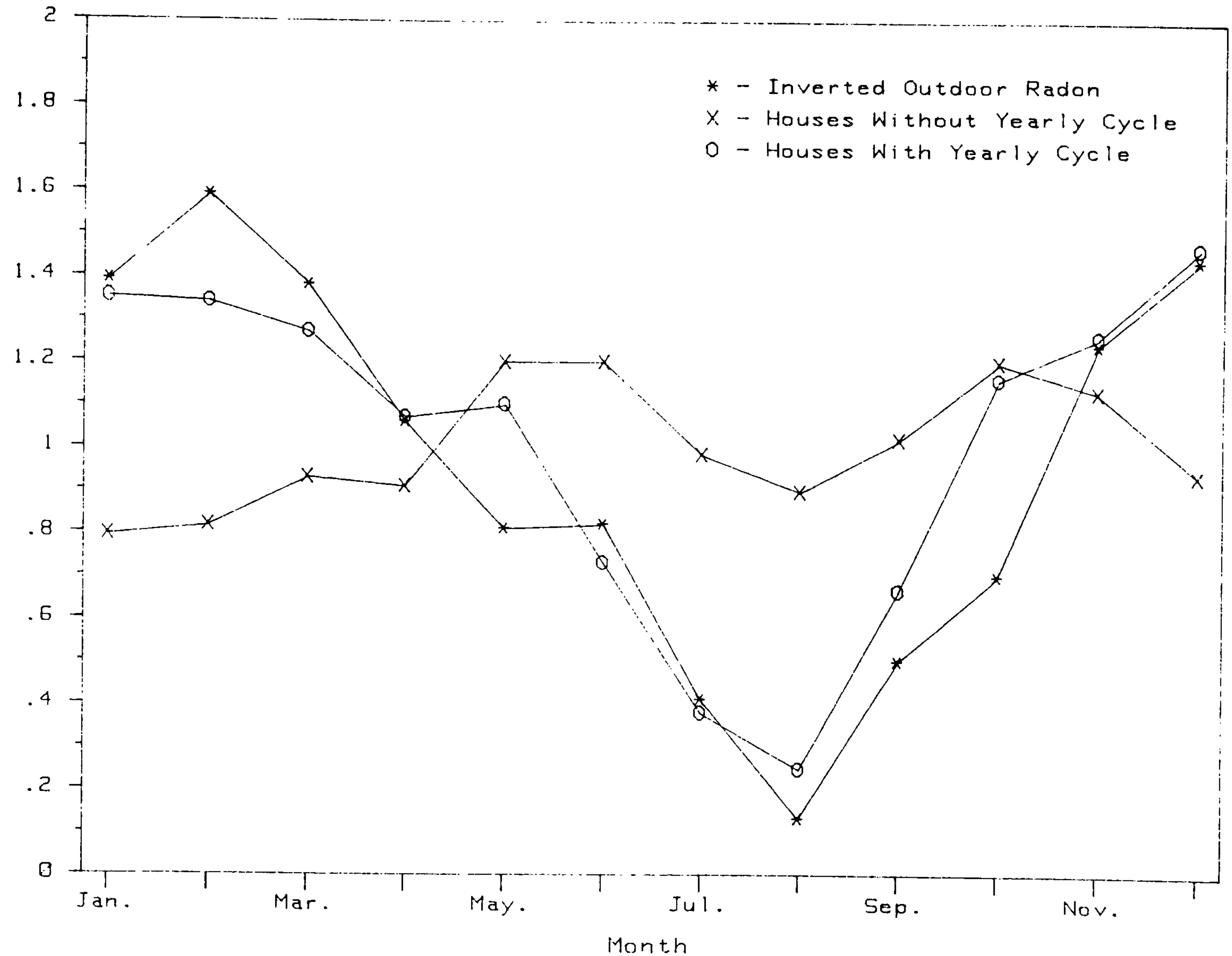

Figure 3. Comparison of normalized radon concentrations for houses with and without yearly cycles and normalized inverted outdoor radon concentrations.

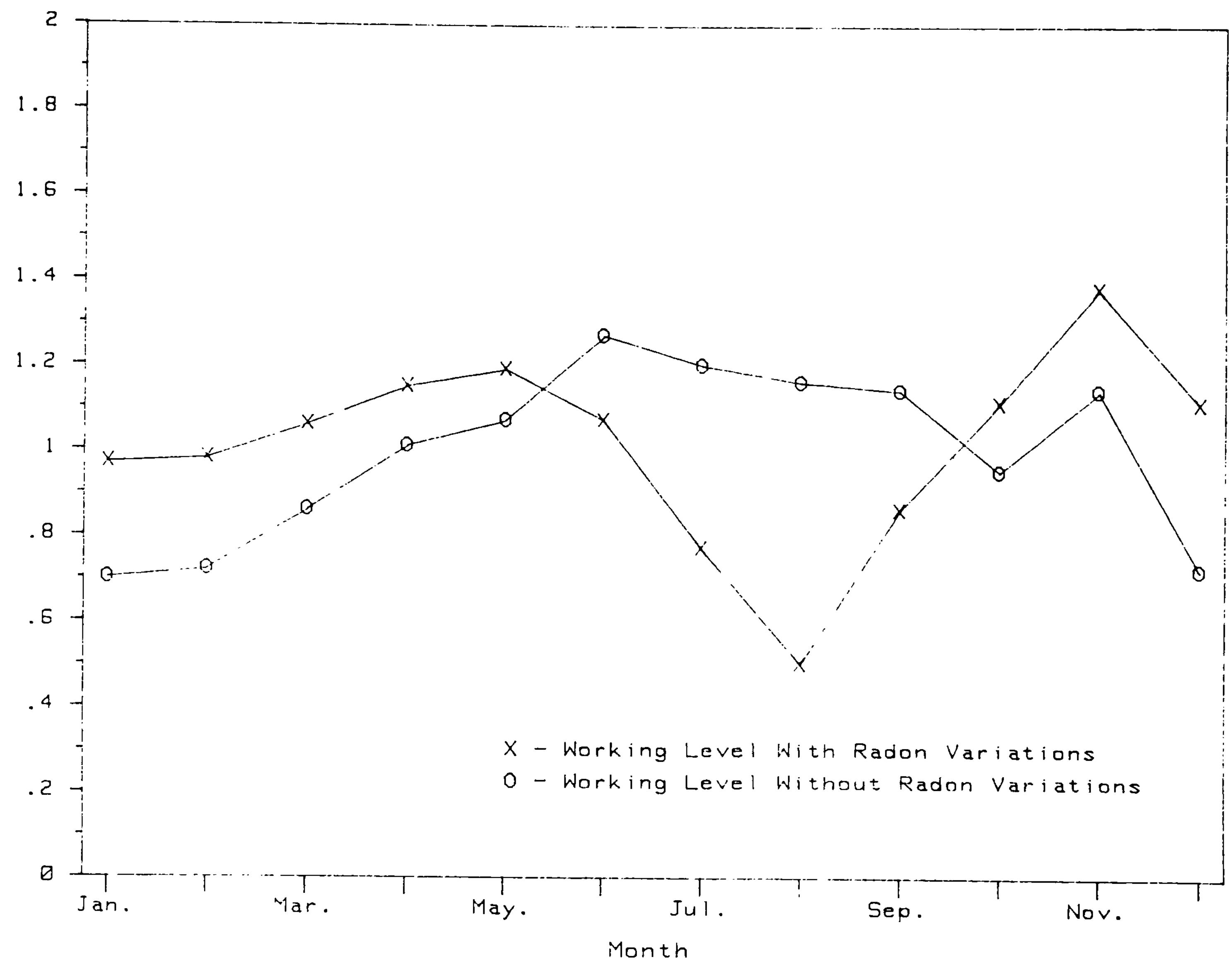

Figure 4. Comparison of the normalized working level and the normalized working level with radon variations subtracted.

monthly normalized working levels with radon variations subtracted. They represent a seasonal working level cycle independent of the seasonal radon cycle. There are no apparent gross differences between the two types of heating systems. Although small differences occur between the two plots, they follow a general yearly cycle with lows in the cooler months and highs during the warmer months.

EQUILIBRIUM RATIO CYCLE

The normalized equilibrium ratio plotted on figure 1 also indicates a yearly cycle, with a high occurring during the warmer months and lows occurring during the cooler months. Its form is approximately the inverse of the normalized radon cycle. The cycling is probably caused by a disproportionate reduction of radon concentrations and/or working levels by the heating systems.

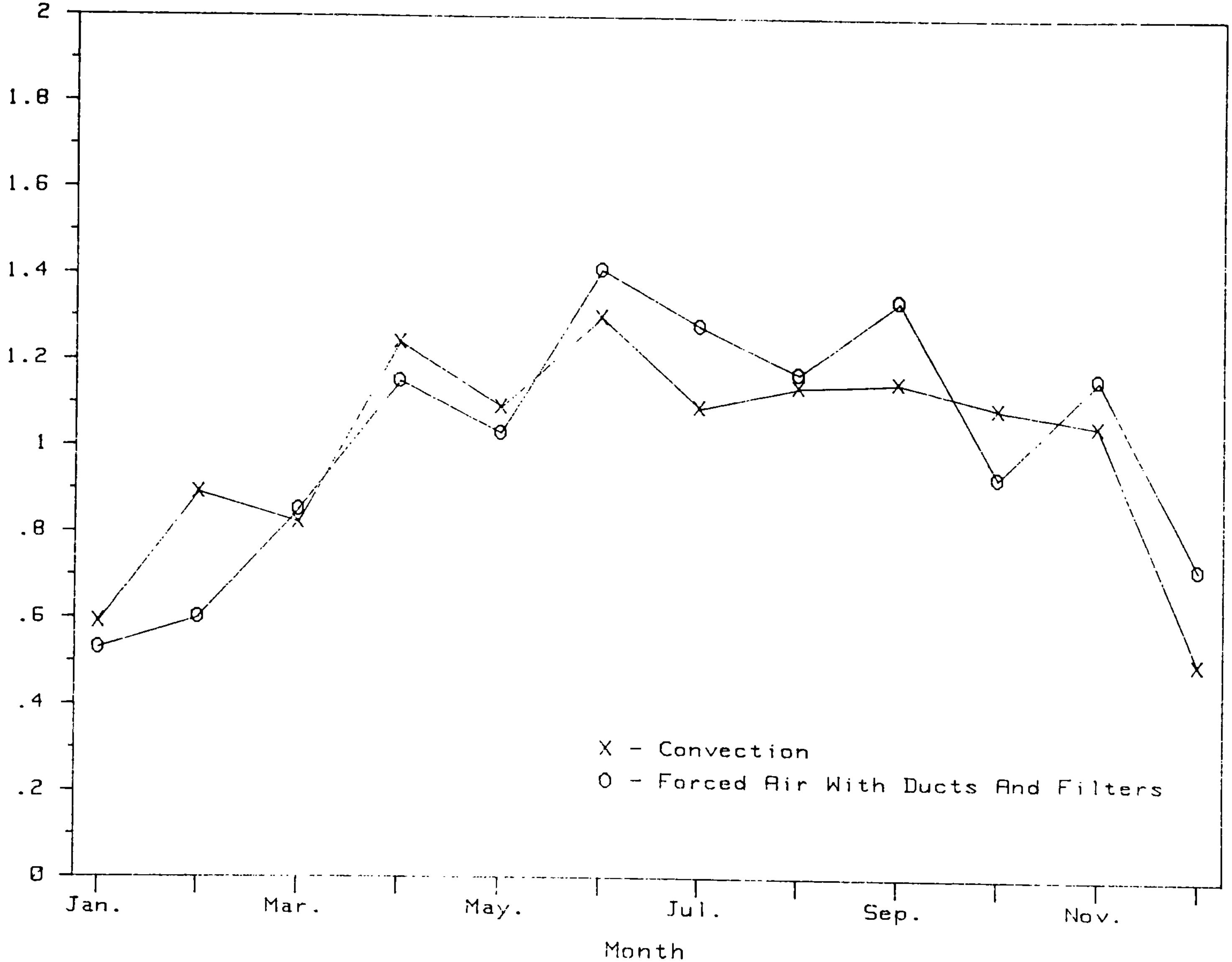

Figure 5. Normalized working levels for houses with different heating systems adjusted for radon variations.

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APPENDIX

RADON CONCENTRATIONS AND WORKING LEVEL PLOTS FOR 20 HOUSES.

PERM and RPISU - House 2

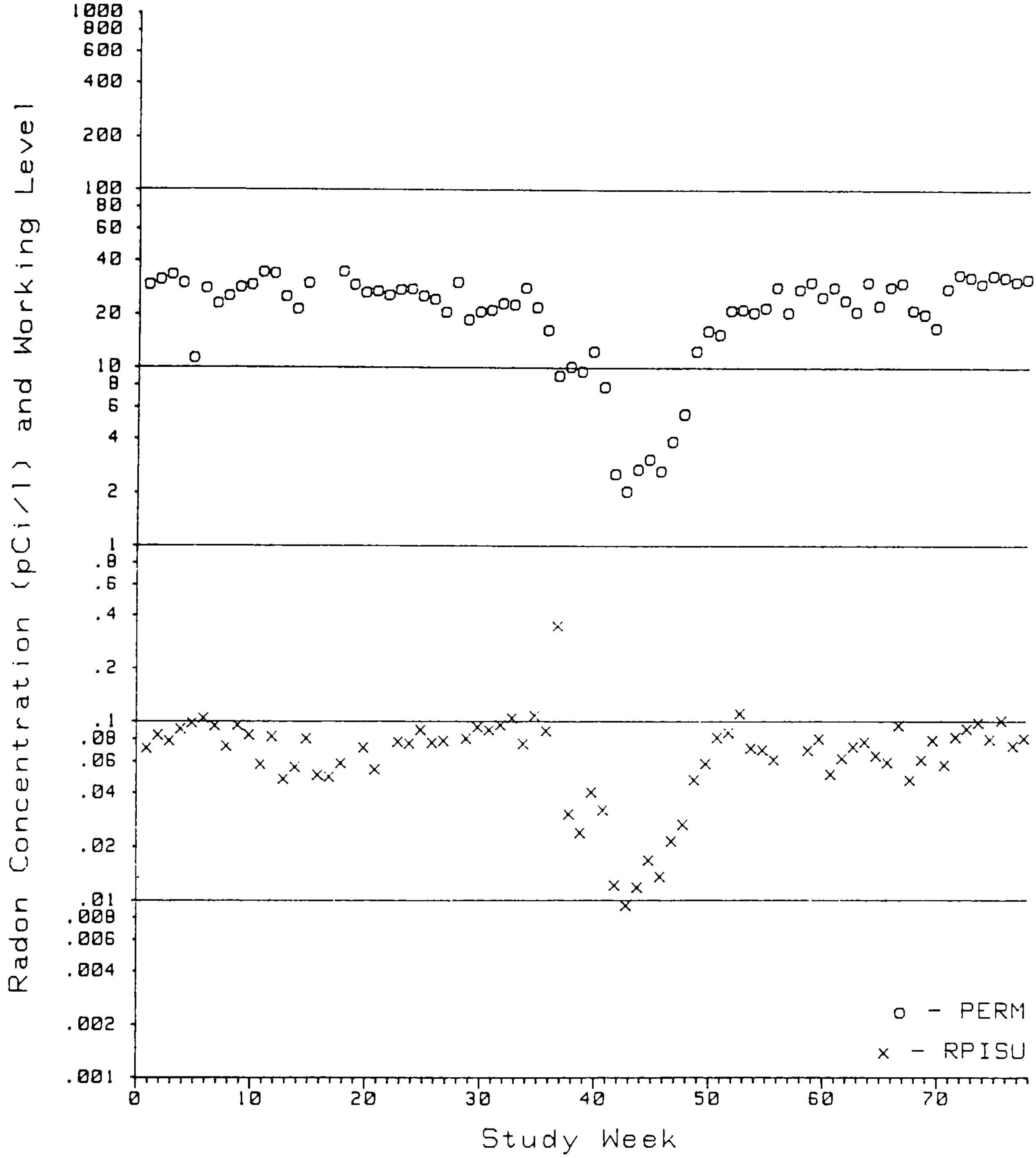

Figure A-2. Radon and working level vs. time.

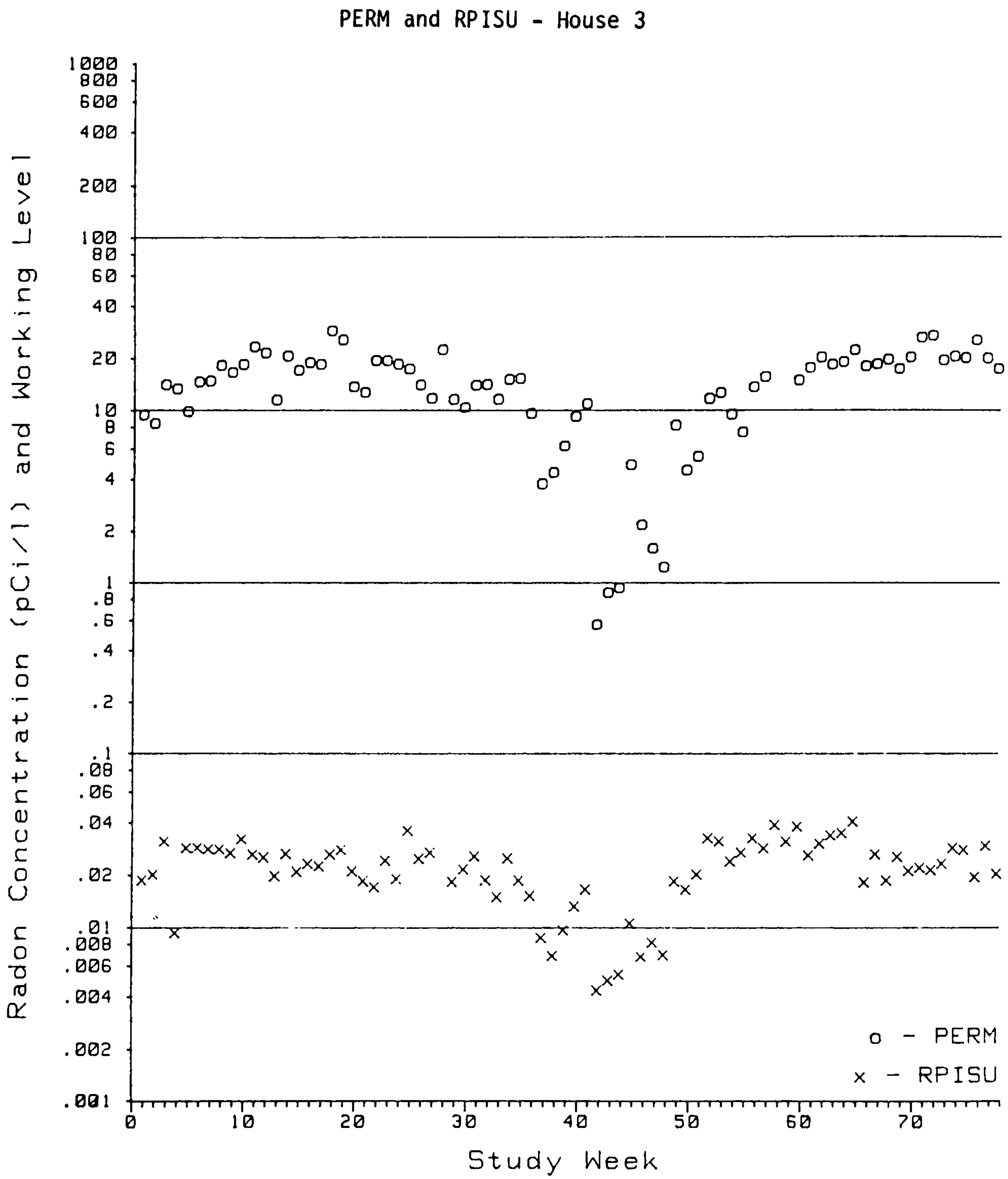

Figure A-3. Radon and working level vs. time.

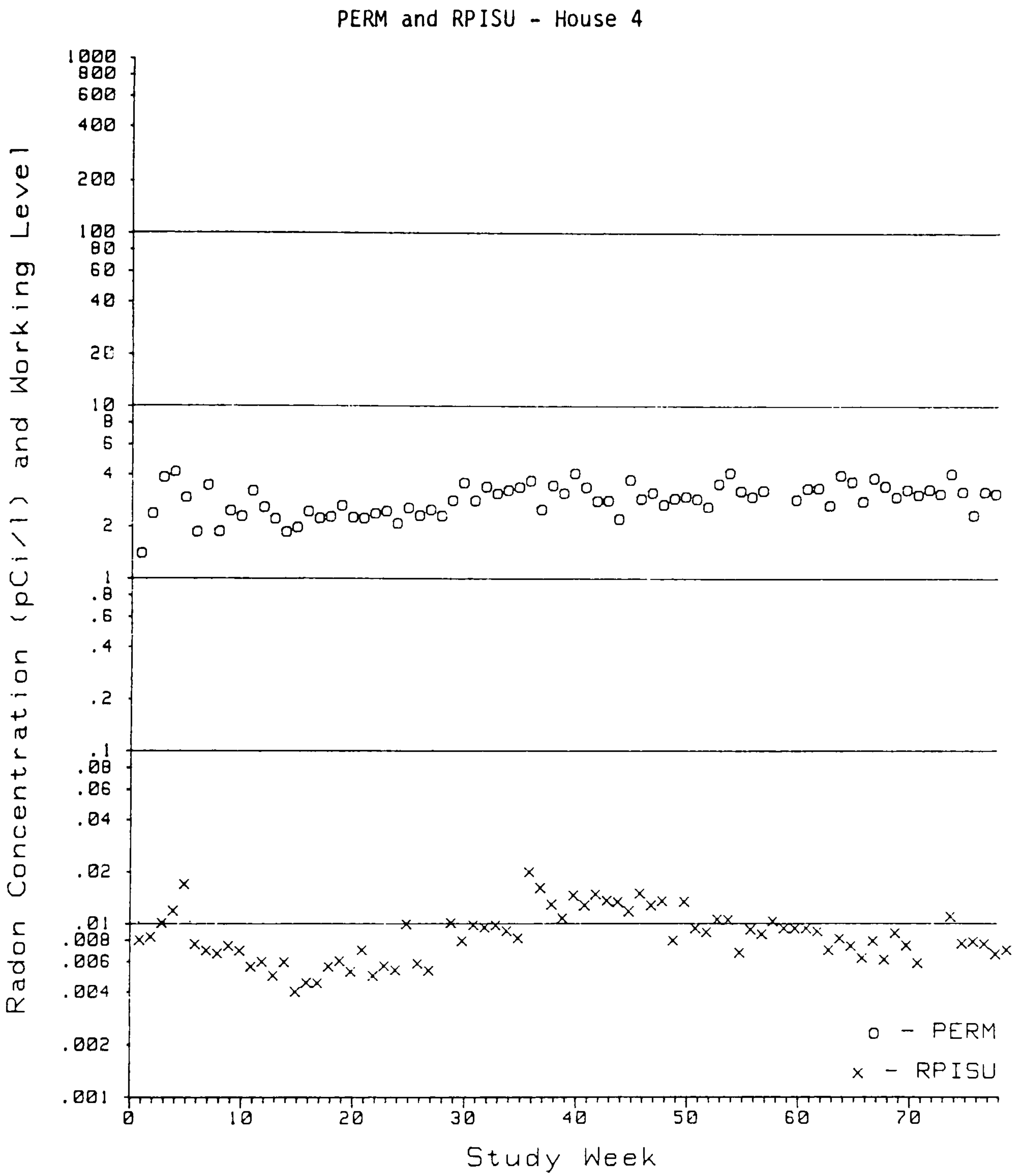

Figure A-4. Radon and working level vs. time.

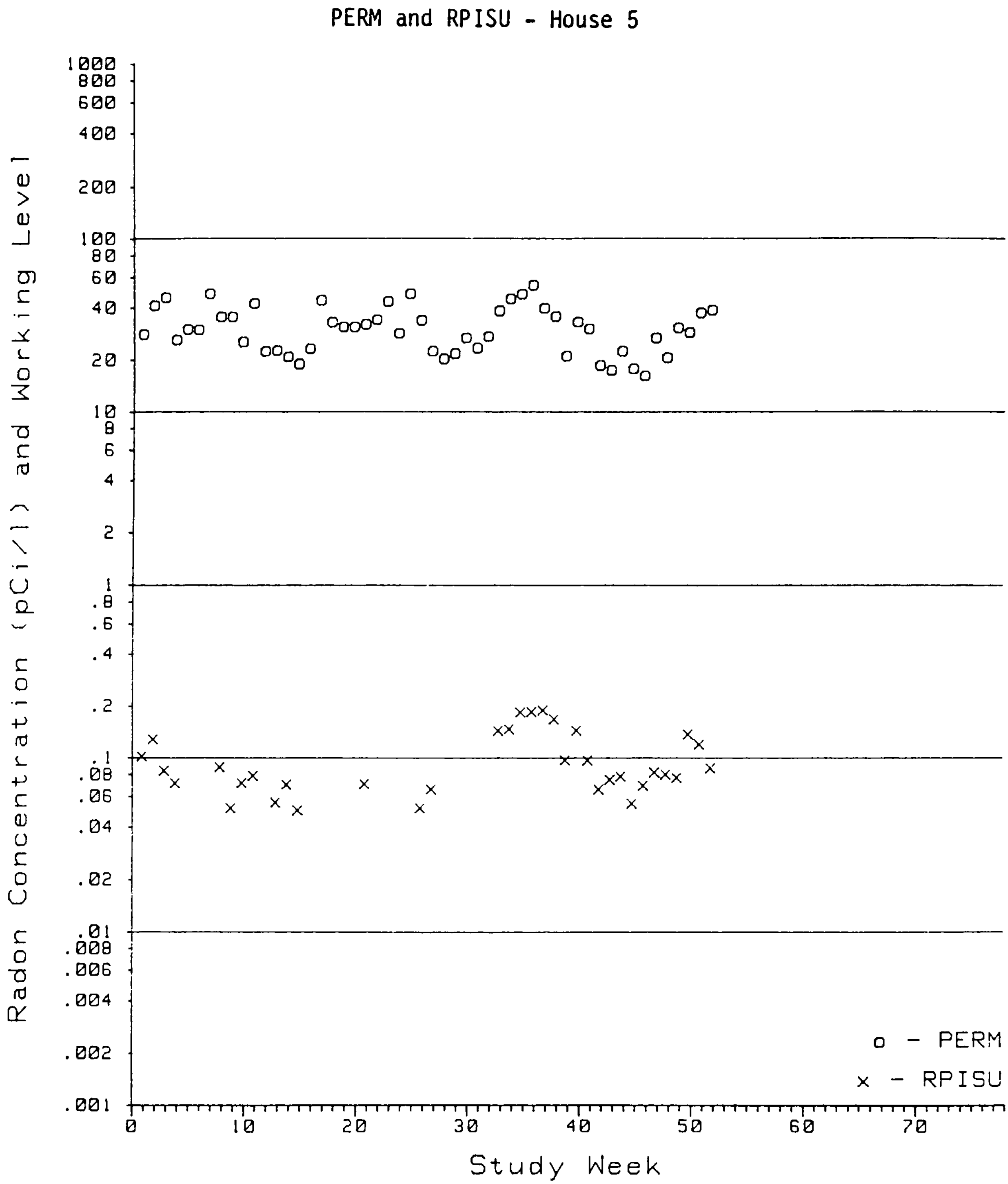

Figure A-5. Radon and working level vs. time.

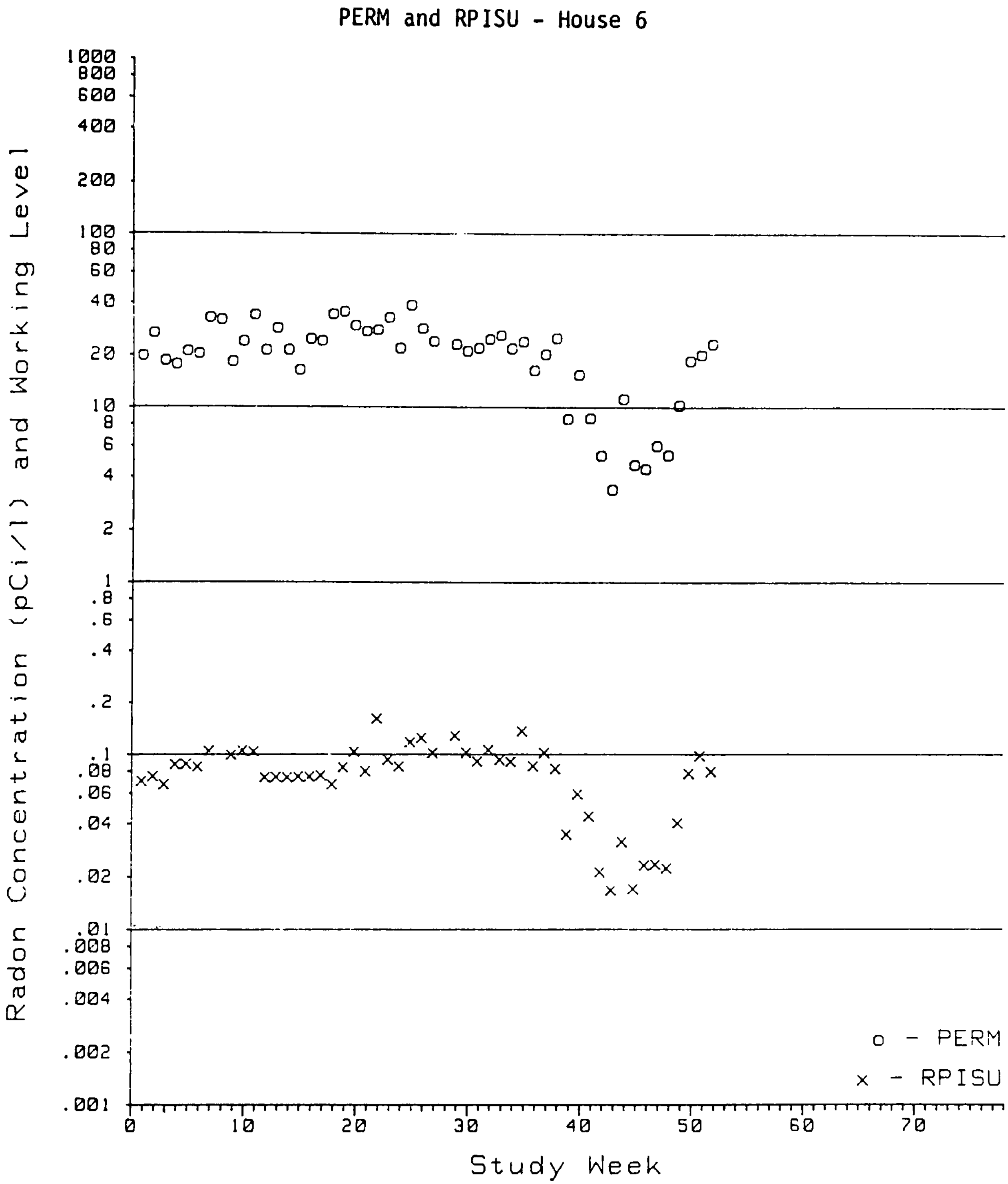

Figure A-6. Radon and working level vs. time.

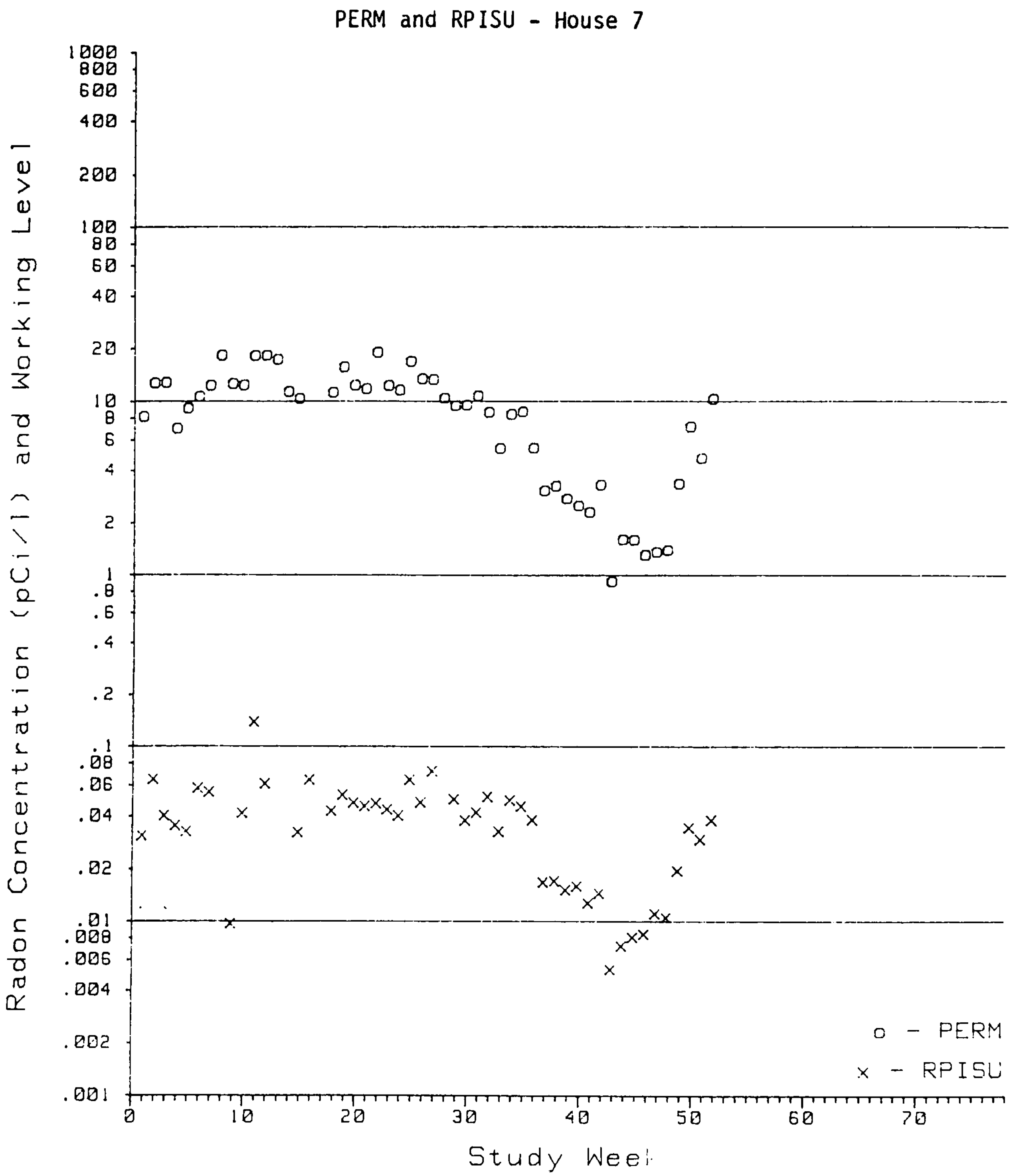

Figure A-7. Radon and working level vs. time.

PERM and RPISU - House 8

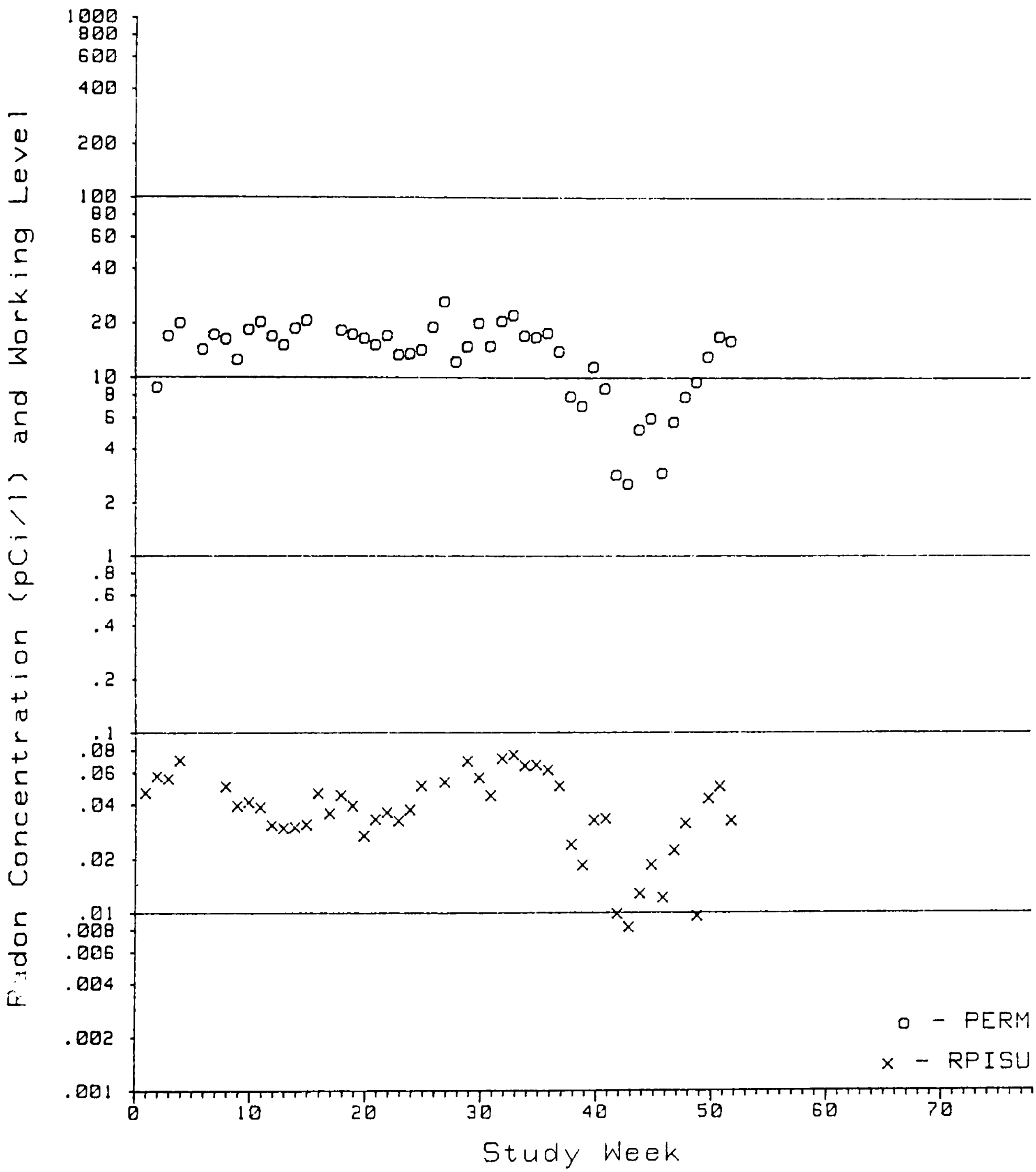

Figure A-8. Radon and working level vs. time.

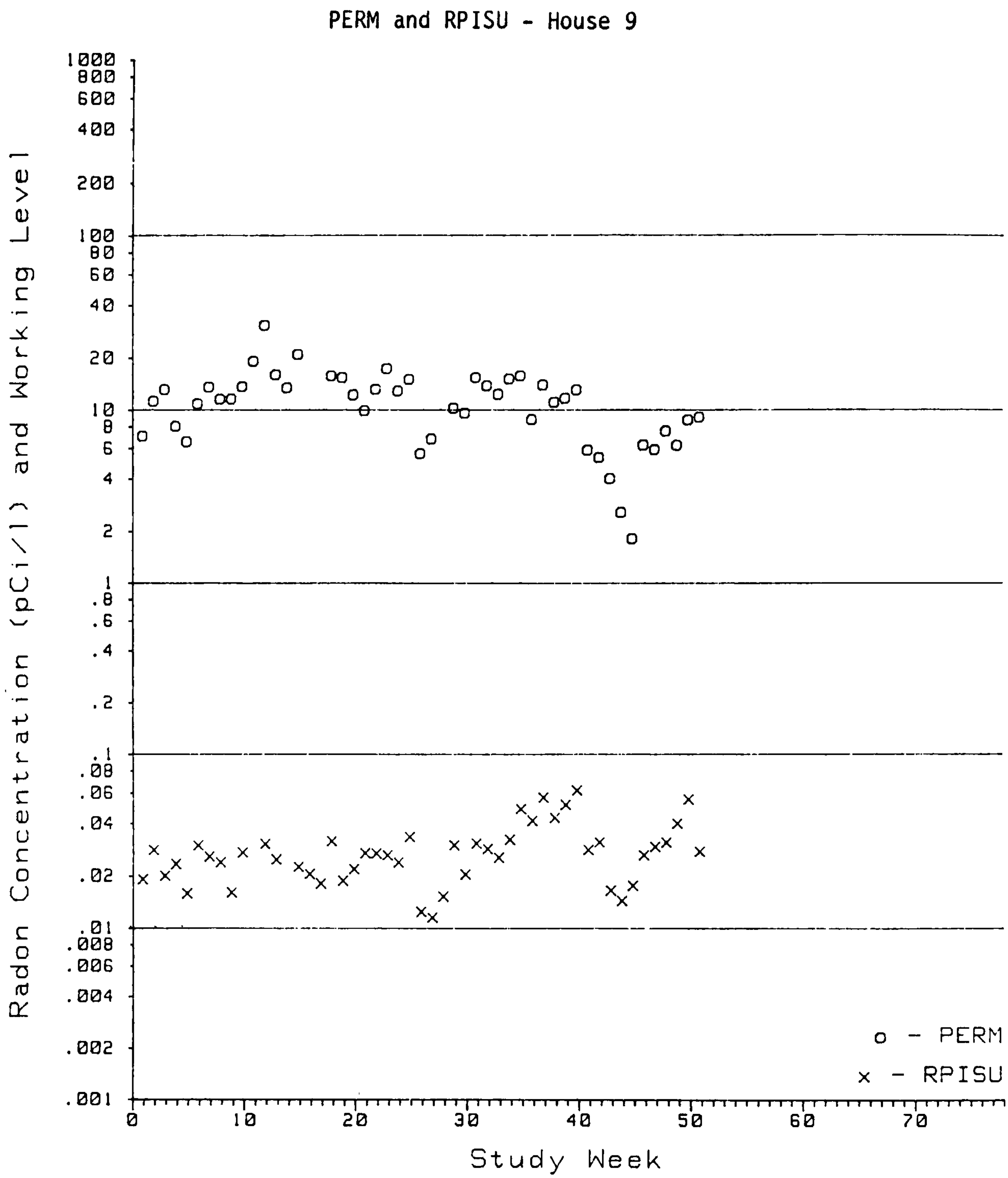

Figure A-9. Radon and working level vs. time.

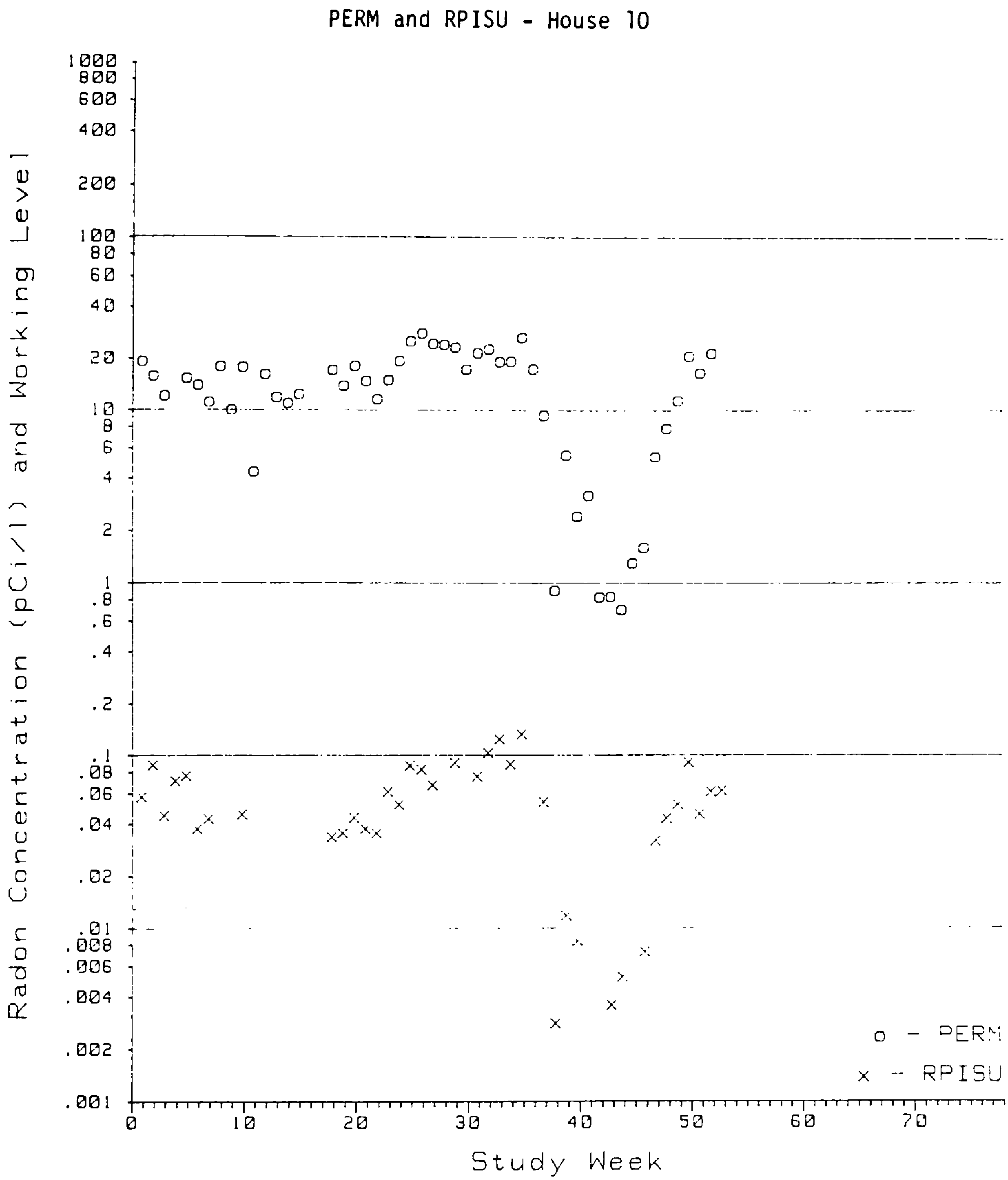

Figure A-10. Radon and working level vs. time.

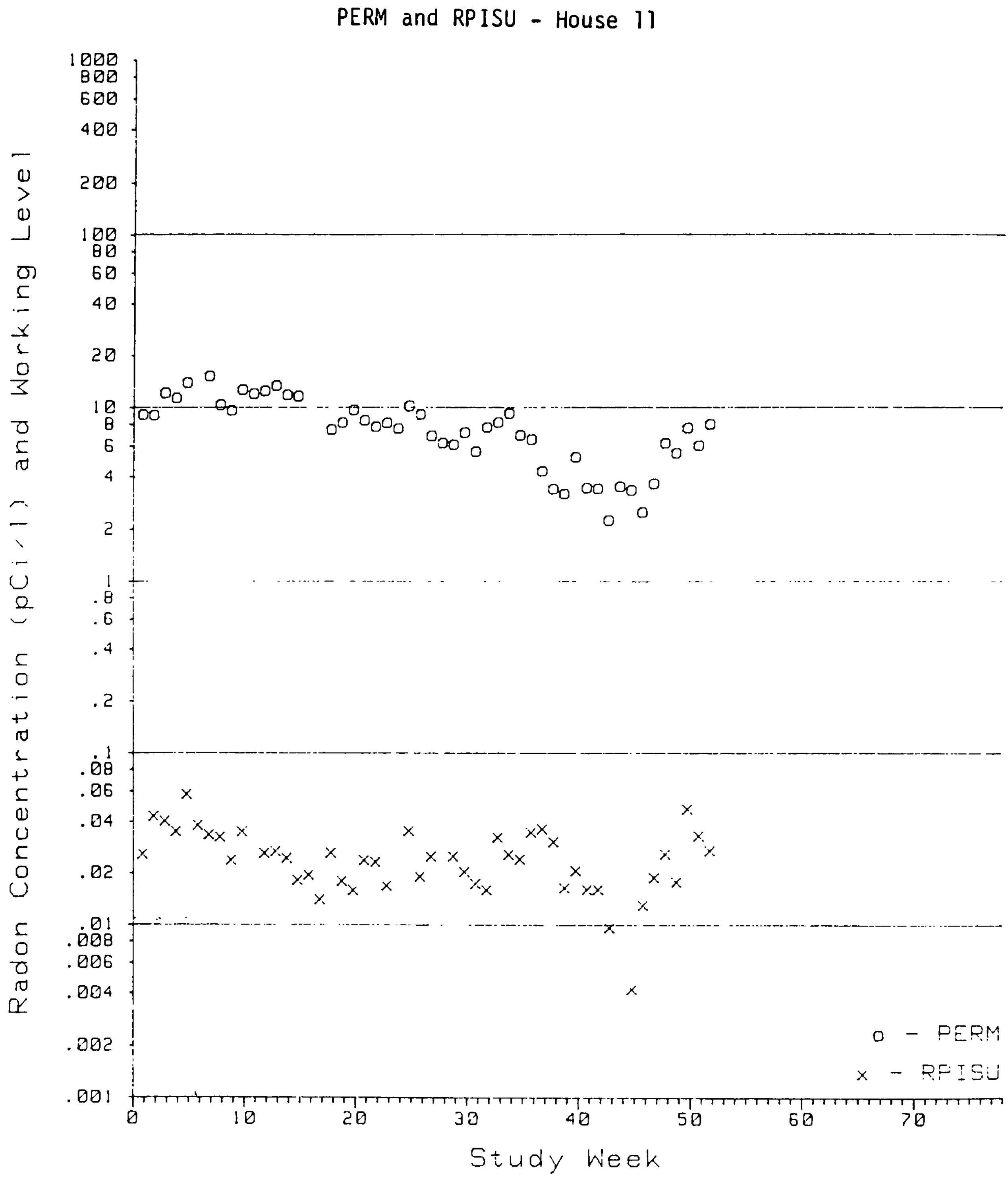

Figure A-11. Radon and working level vs. time.

PERM and RPISU - House 12

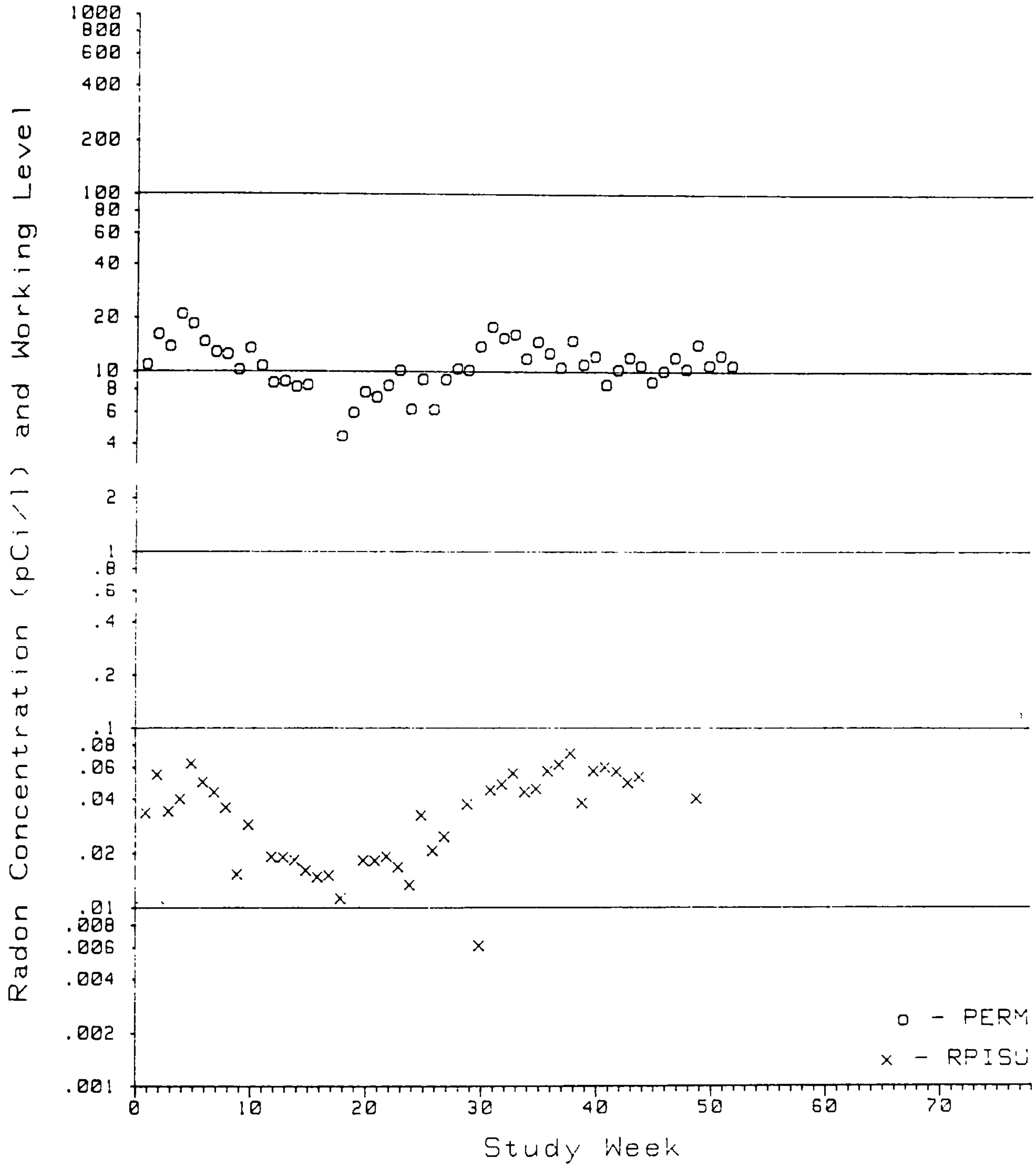

Figure A-12. Radon and working level vs. time.

PERM and RPISU - House 13

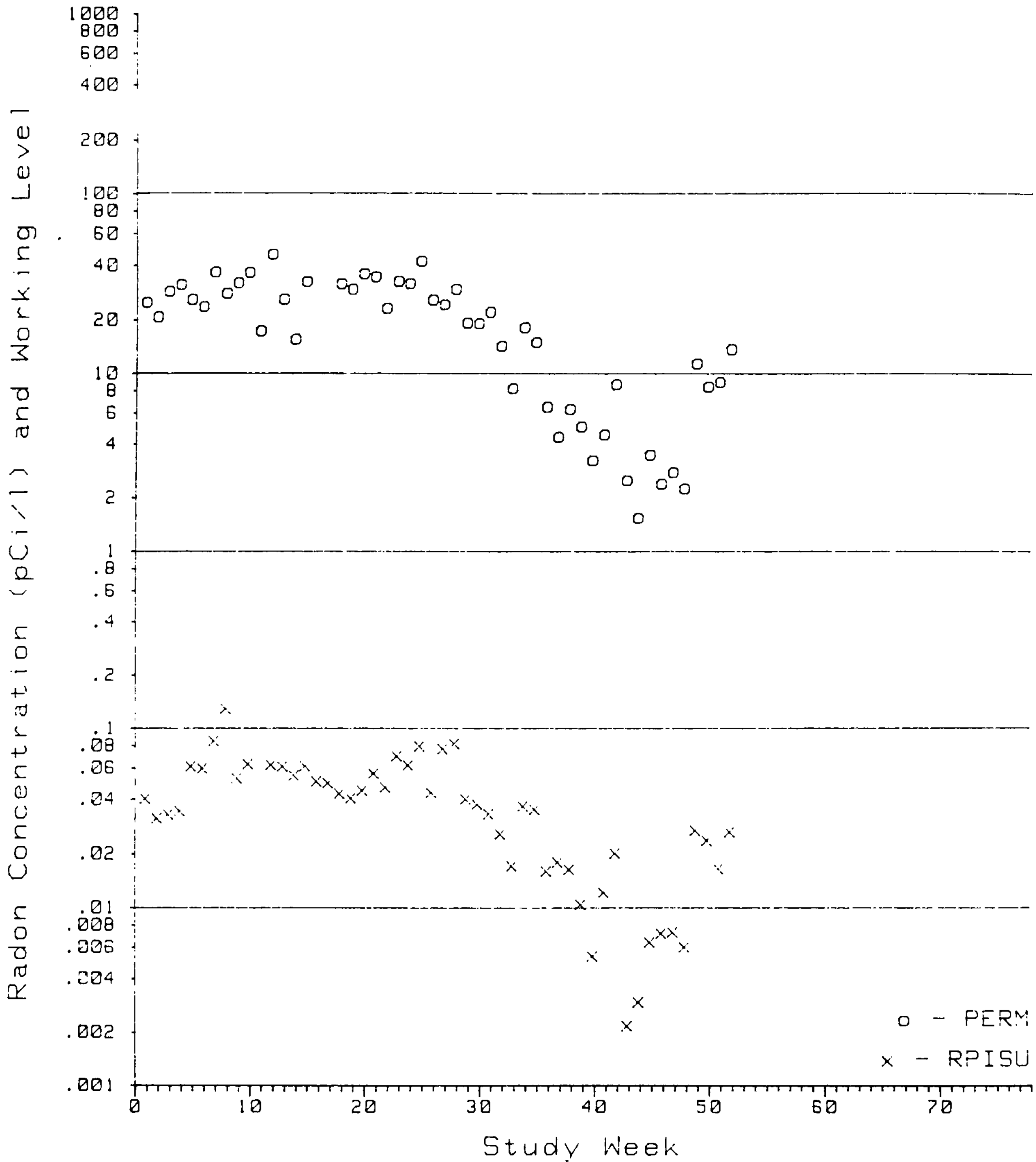

Figure A-13. Radon and working level vs. time.

PERM and RPISU - House 14

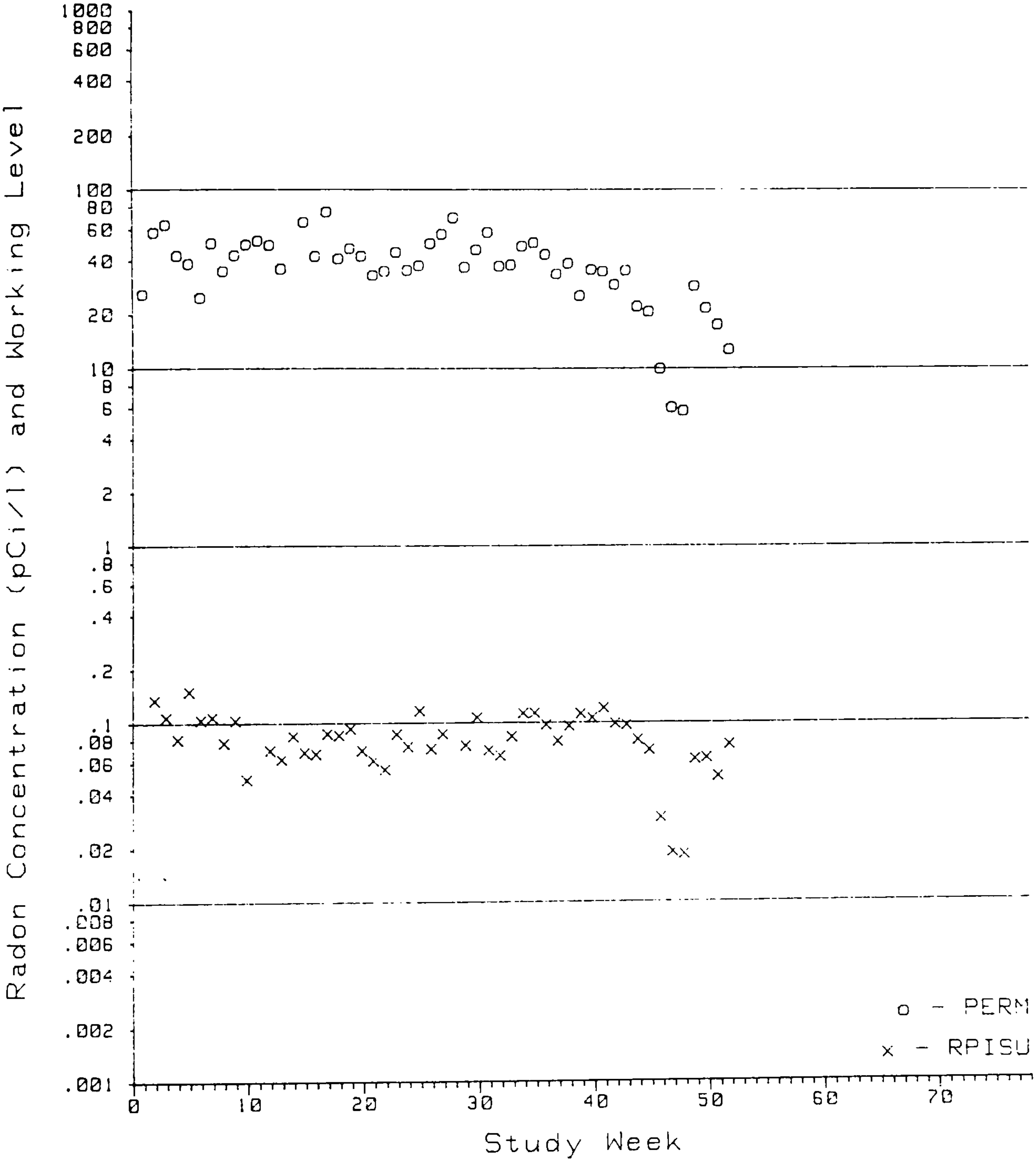

Figure A-14. Radon and working level vs. time.

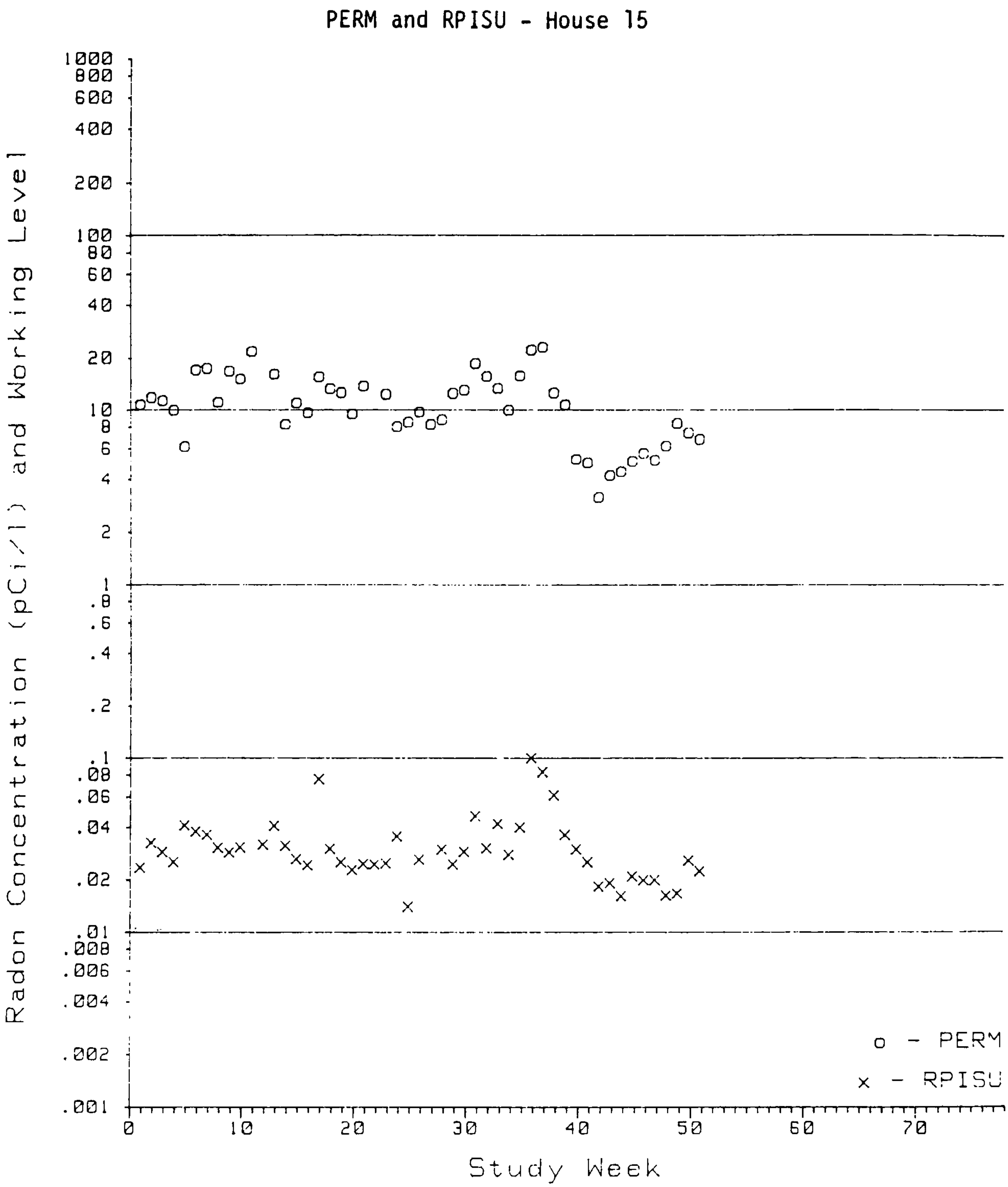

Figure A-15. Radon and working level vs. time.

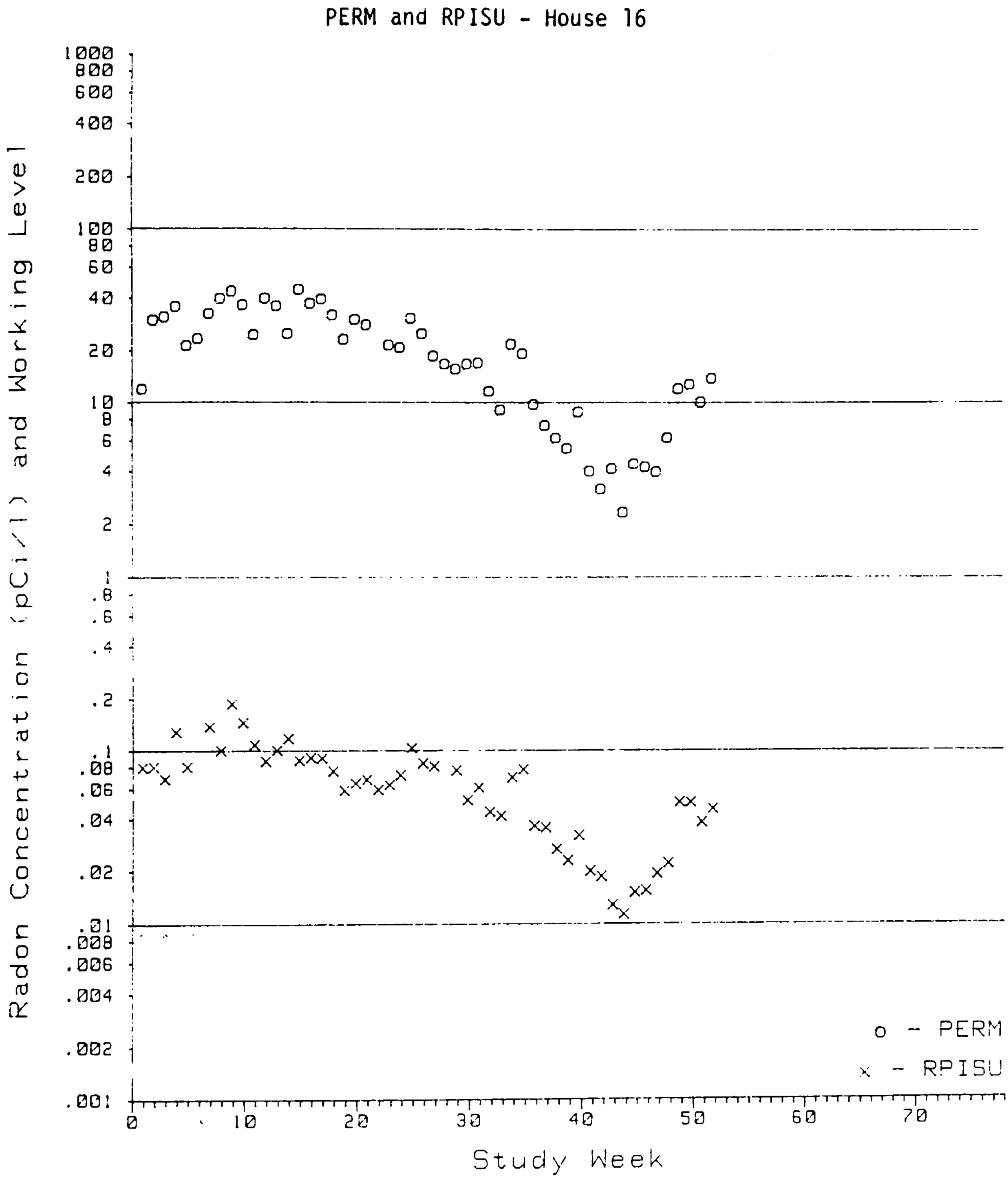

Figure A-16. Radon and working level vs. time.

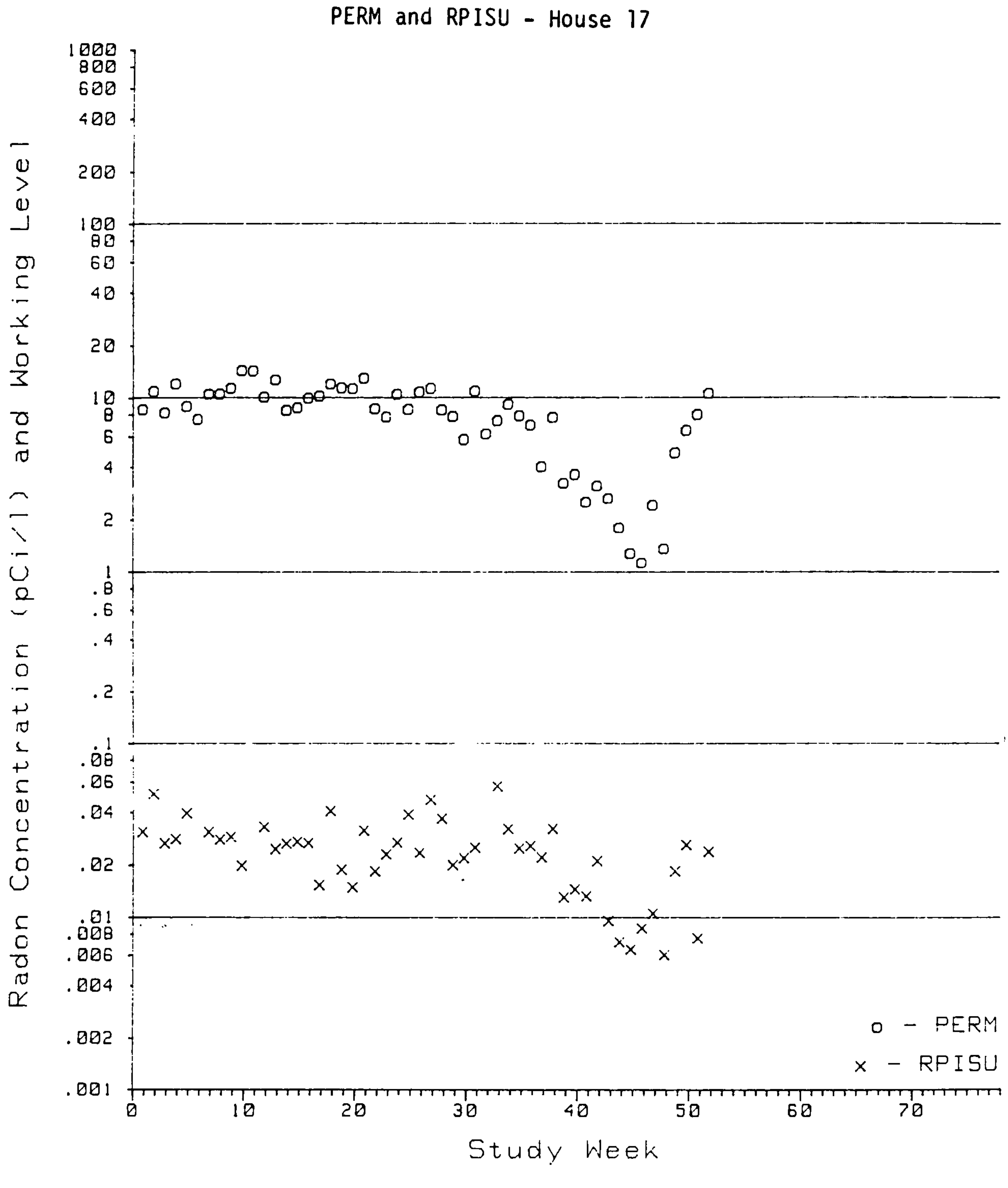

Figure A-17. Radon and working level vs. time.

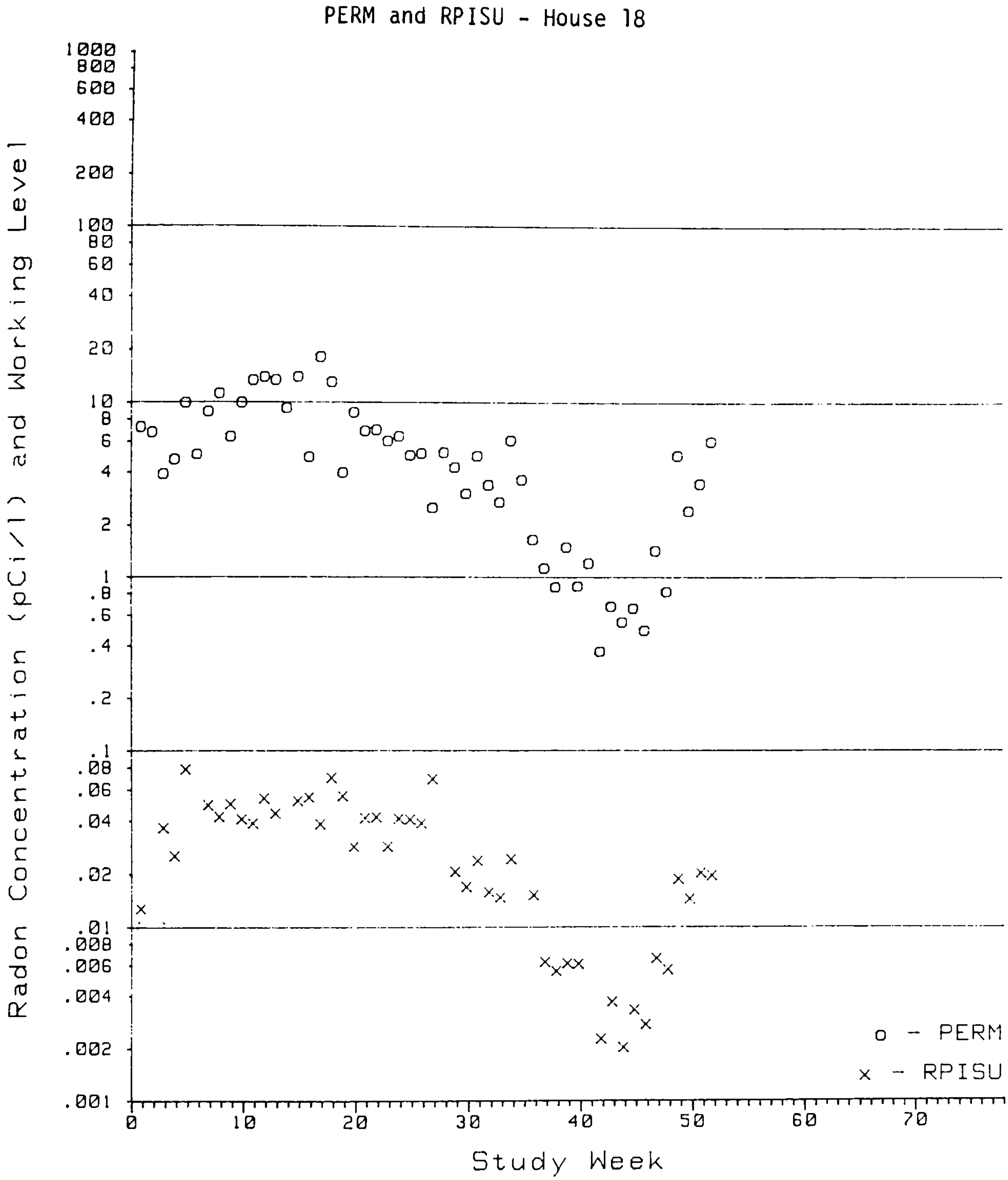

Figure A-18. Radon and working level vs. time.

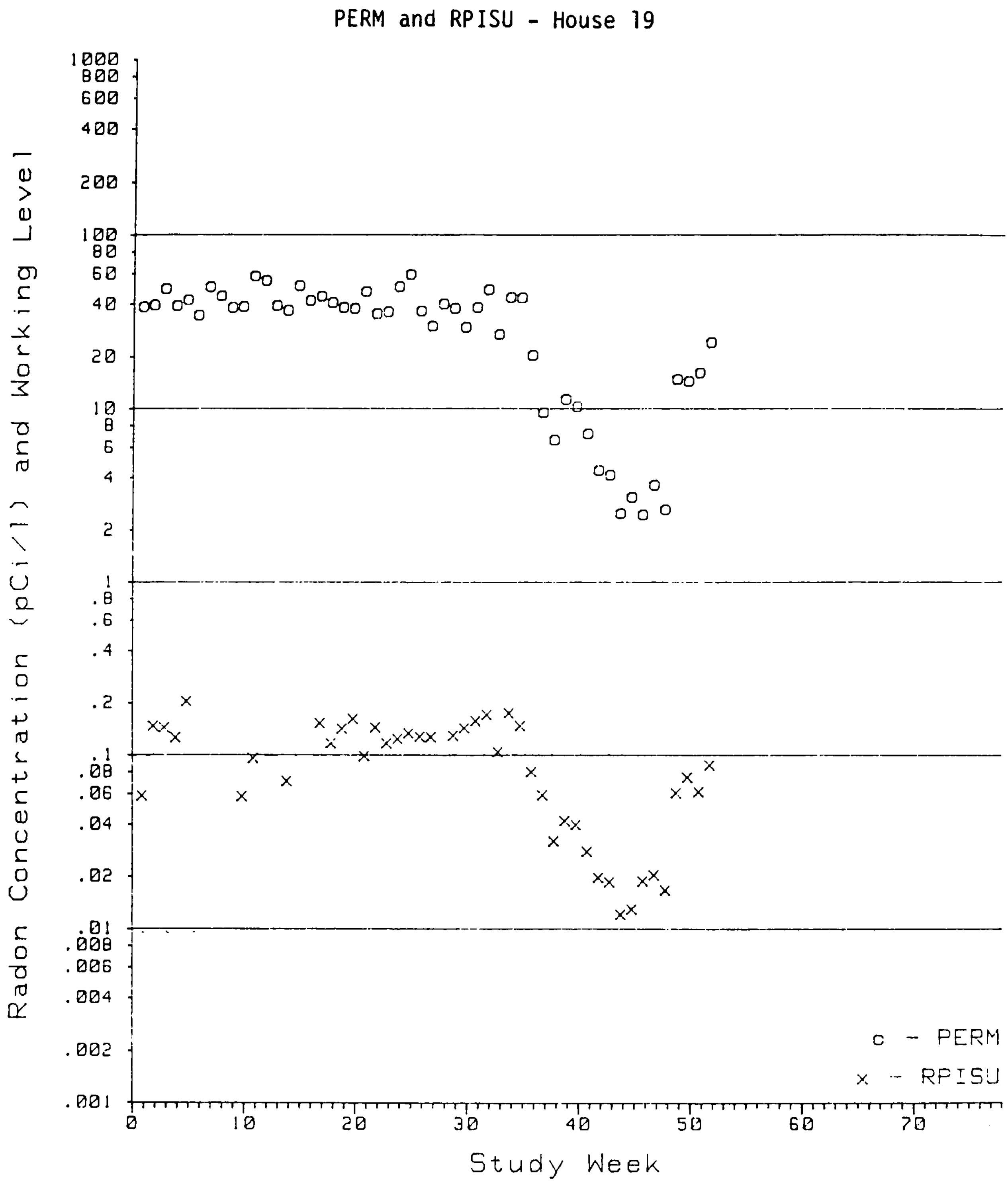

Figure A-19. Radon and working level vs. time.

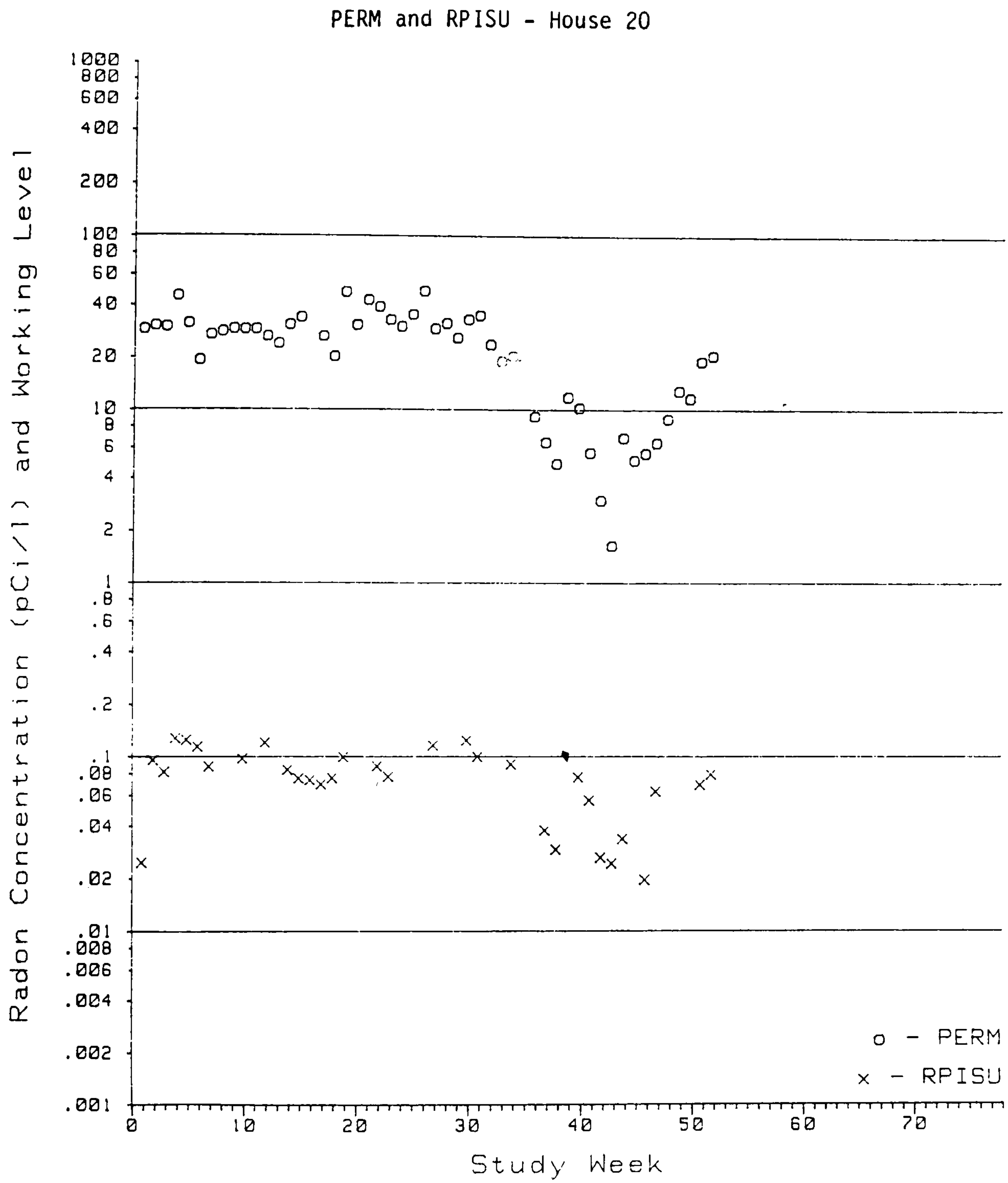

Figure A-20. Radon and working level vs. time.