Hodgkin's disease, and cancers whose nature was unspecified) and cirrhosis of the liver. The SMR was greatest for Hodgkin's disease. No excess was statistically significant. These two SMR analyses also provided limited evidence of no differential risk by two different periods of latency. The strong healthy worker effect observed limits the value of these SMR results, but they point to causes requiring further study.

Mortality was also lower for Rad Lab staff members than for physicians (Table 5). Rather than implicating nonionizing radiation (NIR) exposure, the study may have demonstrated a difference in survival and all-cause mortality between two professions, that is, physicians versus scientists, chiefly physicists and engineers. The physicians were internists, ophthalmologists, and otolaryngologists. For all causes combined, the staff members had a lower rate of mortality than physicians. The risks for deaths from diseases of the circulatory system and from external causes, e.g., accidents, were significantly lower for staff members than for physicians. The deficit of deaths from these two causes was probably responsible for better survival in the Rad Lab cohort. The rates for all malignant neoplasms were the same. The rates were also approximately the same for deaths from all other causes, considered together. But increased risks were seen for lymphomas, particularly Hodgkin's disease; cancers of the gall bladder and bile ducts; pancreatic cancer; cancers of the nervous system; and cirrhosis of the liver. Given these excesses, the Rad Lab deaths may have an infectious, immunological, and/or behavioral component.

Internal comparisons were made with three broad exposure groups (Table 6). No gradient in mortality on the basis of presumed exposure was seen. Age-adjusted death rates were greatest among the group with the lowest presumed exposure for all causes combined and in all major disease groupings; therefore, there was no evidence of dose response. But, the procedure used to identify and stratify exposure may have introduced confounding negative factors that would appear to be stronger than the influence of exposure differences, if such differences exist and affect outcome. Men in the low-exposure group mostly had management, administrative, or support jobs rather than scientific and technical jobs; the differences in mortality may thus reflect professional or socioeconomic differences among exposure groups. Despite this, the results do not necessarily mean that an exposure gradient does not exist. The two other exposure groups (medium and high) were more similar in profession and age. The risk of death from all causes combined and in major disease groupings was greater in the high-exposure group, but was not statistically significant. Numbers were small. The rates for all cancers combined were approximately the same. Excesses for Hodgkin's disease, nervous system cancers, and cirrhosis of the liver were greatest for the medium-exposure group. The reasons underlying the observations are not clear. The medium-exposure group contains subjects exposed to several frequencies of NIR; about 25% worked with low frequencies rather than microwaves.

In summary, the overall survivorship of Rad Lab staff members was better than U.S. white males and a group of physician specialists. The study did not demonstrate significantly increased risk for total mortality or mortality from specific causes to be associated with NIR exposure, primarily from microwave frequencies. However, deaths from certain diseases were elevated, e.g., Hodgkin's disease and digestive diseases, especially cirrhosis of the liver. Results for the cohort grouped by an exposure ranking scheme were equivocal. Paradoxically, the mortality rates were highest in the group with the lowest presumed exposure which may reflect some sort of socioeconomic bias. There is a slight gradient in the rates for major causes of death between the groups with intermediate and highest exposure potential; this may reflect frequency specificity. This study had a good tracing rate and a sufficient follow-up period to evaluate cancer, but the necessary censoring of the data set to permit comparisons to physicians reduced an already small study population. Statistical power was low for some cancers. Exposures for individuals could not be determined but were estimated by surrogates. There were no data on other risk factors. Lack of smoking information is probably not a problem, because low mortality for circulatory disease and lung cancer suggests smoking may not have been prevalent in the cohort.

Szmigielski et al. (1988) examined cancer incidence among Polish career military personnel. The authors stated that radar exposures predominated, but exposures to Extremely Low Frequencies (ELF) were also noted. Large and consistent differences in cancer rates in exposed versus unexposed personnel were found

**Table 5: Mortality of Rad Lab Staff and Physicians, Through December 31, 1974, for All Causes of Death and Cancers. Part A. Standardized Mortality Ratios (SMRs) for Staff Aged 25 Years or More at Entry, Expected Values Based on Rates in Physicians. Part B. Mortality Risk Ratios for Staff members vs. Physicians Using Cox's Proportional Hazards Model**

| Cause | Part A: Standardized Mortality Ratios | | | | Part B: Proportional Hazards Model | | |
|---|---|---|---|---|---|---|---|
| | Observed | Expected | SMR | 95% CI | Risk Ratio (Rad Lab: Physicians) | Maximum Likelihood Chi-Square | Maximum Likelihood (p-value) |
| ALL CAUSES | 213 | 246.01 | 0.87 | 0.78-1.02 | 0.6392 | 41.06 | (<0.0000)[b] |
| ALL MALIGNANT NEOPLASMS | 47 | 42.96 | 1.09 | 0.80-1.45 | 0.8385 | 1.43 | (0.8655) |
| Neoplasms, Lymphatic & Hematopoietic Tissues | — | — | — | — | 1.0646 | 0.03 | (0.8655) |
| Neoplasms/Lymphoid Tissue | — | — | — | — | 1.0646 | 0.86 | (0.3538) |
| Lymphomas | 4 | 1.89 | 2.12 | 0.59-5.42 | 1.3804 | 0.21 | (0.6463) |
| Lymphomas/Other Lymphoid | — | — | — | — | 1.0880 | 0.02 | (0.8989) |
| Leukemias | 2 | 3.14 | 0.64 | 0.08-2.30 | 0.7200 | 0.29 | (0.5920) |
| Hodgkin's Disease | 3 | 0.21 | 10.34 | 2.13-30.23[b] | 4.0186 | 2.17 | (0.1406) |
| Gall Bladder/Bile Ducts | 2 | 0.14 | 14.29 | 1.69-50.29[b] | 11.2728 | 4.08 | (0.0435)[b] |
| Pancreas | 5 | 3.12 | 1.60 | 0.52-3.74 | 1.169 | 0.11 | (0.7383) |
| Brain and Nervous System | 3 | 2.80 | 1.07 | 0.22-3.13 | 0.8449 | 0.09 | (0.7587) |
| Nervous System Neoplasms[a] | 3 | 0.89 | 4.26 | 0.70-9.85 | — | — | — |
| Malignant Melanoma/Skin | — | — | — | — | 3.7957 | 1.63 | (0.2013) |
| Prostate | — | — | — | — | 0.8583 | 0.12 | (0.7273) |

[a]Excluding brain tumors.
[b]Confidence intervals (CI) do not overlap 1.0; or $\leq$ 0.05.

**Table 6: Age-Adjusted Mortality Rates Per 1,000 Person-Years for All Causes of Death and Selected Cancers for Rad Lab White Male Staff Members by Exposure Ranking Group Based on Predominant Division of Work, Followed Through December 31, 1986**

| Cause of Death | Rank 1 Low | | Rank 2 Medium | | Rank 3 High | | Mortality Risk Ratios[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | # | Rate | # | Rate | # | Rate | Rank 2:1 | Rank 3:1 | Rank 3:2 |
| All Causes | | | | | | | | | |
| Crude | 150 | 11.97 | 66 | 5.26 | 90 | 6.87 | 0.44 | 0.57 | 1.31 |
| Adjusted | | 9.07 | | 6.76 | | 7.44 | 0.75 | 0.82 | 1.1 |
| All Malignant Neoplasms | 34 | 2.02 | 20 | 1.70 | 42 | 1.65 | 0.84 | 0.82 | 0.97 |
| All Lymphocytic Cancer | 4 | 0.25 | 4 | 0.31 | 5 | 0.19 | 1.24 | 0.76 | 0.61 |
| Lymphomas | 2 | | 2 | | 2 | | | | |
| Hodgkin's Disease | 1 | | 1 | | 1 | | | | |
| Leukemias | 2 | | 1 | | 2 | | | | |
| Multiple Myeloma | 0 | | 1 | | 1 | | | | |
| Brain/CNS Neoplasms | 1 | 0.06 | 3 | 0.26 | 1 | 0.04 | 4.33 | 0.67 | 0.15 |

[a]All the confidence intervals (not shown) overlap.
Source: Hill, 1988.

for all sites reported (Table 7). Most of the data is on cancer of the lymphatic and hematopoietic system, and not all cancer sites were discussed. Generally, rates in the exposed group were six times larger than rates in the unexposed group.

The study was described as retrospective, but the exact design employed is difficult to discern. In fact, the presentation of the procedures, results, and analyses is atypical. For example, only rates per 100,000 are given; the numbers forming the basis of computed rates are not given (Table 7). Furthermore, most rates are only graphically displayed in figures rather than listed in tables. The author noted that, due to limits, the number of cancer cases and the size of the population, overall and within age groups, could not be presented. Although not stated, it is possible these limits were governmentally-imposed restrictions.

In summary, mixed results are seen in epidemiological studies about exposures to RF radiation. Two early studies (Lilienfeld et al., 1978; Robinette et al., 1980) showed only a slight tendency, if any, for increased cancer risk. This tendency was slightly stronger for cancers of the hematopoietic system. These studies suffer from either very low-exposure levels, crude exposure estimators, and/or limited follow-up periods. The study of RF exposure and cancer, evaluated for census tracts in Hawaii (Environmental Epidemiology Program, State of Hawaii, 1986), found significant excess risk for leukemia if census tracts contained RF towers, but small numbers, the crude exposure proxy, and the ecological design limit this study's usefulness. The study by Hill (1988) found some excess risks for some cancer sites, specifically lymphomas, Hodgkin's disease, cancers of the nervous system (excluding brain cancer), and cancers of the digestive system (especially gall bladder), but overall, the results are generally nonpositive or, if positive, usually not statistically significant. Leukemias were not elevated. Misclassification with respect to exposure was possible. In contrast, Milham conducted several increasingly more analytical studies of ham radio operators are found positive and statistically increased mortality risks for acute myeloid leukemias (SMR=1.76) and, considered together, multiple myelomas and other neoplasms of the lymphoid system (SMR=1.62) among FCC-licensed amateur radio operators in California and Washington State. For leukemias, all SMRs were elevated, but only the SMR for acute myeloid leukemias was statistically significant. In follow-up analysis, Milham (1988) evaluated ham operator mortality by five FCC license classes which served as surrogates for possible higher and/or chronic exposure with increased experience and expertise. No clear gradient by license class was found. The study by Szmigielski et al. (1988) reported increased rates of cancer, especially for specific sites in the hematopoietic system, among Polish military personnel exposed to RF and microwave radiation. Yet restrictions on the degree of detail for reporting results limit evaluation and interpretation of this study.

A summary listing of the discussed studies is given in Table 8. In general, epidemiologic studies of cancer and RF radiation show only a slight tendency, if any, for excess risk, but they present several methodological difficulties. The studies by Milham are the most persuasive in demonstrating positive and significant associations. However, the exposures evaluated by Milham differ in frequency (lower end of the RF portion of the EM spectrum) from the other studies which chiefly examined microwave frequencies.

In addition to the above discussed studies on RF radiation, there have been many general occupational studies that have examined cancer risks among broad groupings of industries, occupations, jobs, or "electrical work." This body of literature is generally considered to relate to potential risk from exposure from Extremely Low Frequency (ELF) electric and magnetic fields (EMF) or 60-Hz power frequency EMF and has been reviewed elsewhere in great detail (Savitz and Calle, 1987; Ahlbom et al., 1988; California PUC and DHS, 1989; OTA 1989; U.S. EPA, 1990; Dennis, 1991; Texas PUC, 1992). Determination of exposure in these studies is very crude. It is estimated indirectly by, for example, job titles. Excesses have been reported for many types of jobs beyond electricians, e.g., radar technician, radio repairer, electronics engineer, telecommunications worker, etc. Frequency of exposure cannot be readily discerned for job titles or job classifications. Thus, these occupational studies can involve exposures to multiple frequencies of nonionizing radiation and exposure to 50 or 60 Hertz. The predominating exposures may be to ELF electric and magnetic fields, but jobs involving work with radio, TV, radar, and so forth also entail exposure to some extent to modulated RF radiation.

**Table 7: Incidence Rates Per 100,000 Per Year (1971-1980), for Polish Military Personnel Grouped by Work Exposure to Radiofrequency and Microwave Radiation and by Age**

| Type of Cancer | | E-Group[a] | NE Group | Total Population |
|---|---|---|---|---|
| All Neoplasms | All Ages | 192.2 | 64.2 | |
| | 40-49 | 350.0 | <50 | |
| Lung Cancer | All Ages | 33.2 | 23.6 | |
| Hematolymphatic | All Ages | 50.8 | 7.4 | 8.9 |
| | 20-29 | 26.3 | 2.7 | 3.6 |
| | 30-39 | 29.7 | 3.0 | 3.8 |
| | 40-49 | 81.3 | 9.9 | 11.8 |
| | 50-59 | 117.6 | 29.6 | 32.7 |
| LGR[a] | All Ages | 6.0 | 1.8 | |
| | 20-29 | 18.8 | 2.1 | |
| | 30-39 | — | 0.9 | |
| | 40-49 | 11.6 | 2.5 | |
| | 50-59 | — | 3.0 | |
| Ly Sa, Lymp[a] | All Ages | 18.3 | 2.2 | |
| | 20-29 | — | 0.3 | |
| | 30-39 | — | 0.3 | |
| | 40-49 | 46.5 | 4.2 | |
| | 50-59 | 58.8 | 8.9 | |
| CLL[a] | All Ages | 6.1 | 1.3 | |
| | 20-29 | — | | |
| | 30-39 | 9.9 | 0.3 | |
| | 40-49 | 11.6 | 1.4 | |
| | 50-59 | — | 8.9 | |
| ALL[a] | All Ages | 3.0 | 0.1 | |
| | 20-29 | 8.9 | 0.3 | |
| | 30-39 | — | | |
| | 40-49 | — | | |
| | 50-59 | — | | |
| CML[a] | All Ages | 12.2 | 0.5 | |
| | 20-29 | 8.8 | — | |
| | 30-39 | 19.8 | 1.2 | |
| | 40-49 | — | 0.3 | |
| | 50-59 | 29.4 | 1.1 | |
| AML[a] | All Ages | 6.1 | 1.1 | |
| | 20-29 | — | | |
| | 30-39 | — | 0.3 | |
| | 40-49 | 11.6 | 1.8 | |
| | 50-59 | 29.4 | 2.2 | |
| PL[a] | All Ages | — | 2.2 | |

Source: Szmigielski et al., 1987.

[a]E=exposed, NE=not exposed, LGR=malignant lymphogranulomatosis, Ly Sa, Lump=lymphosarcomas and other lymphomas, CLL=chronic lymphocytic leukemia, ALL=acute lymphoblastic leukemia, CML=chronic myelocytic leukemia, AML=acute myeloblastic leukemia, PL=plasmacytoma or plasma cell leukemia.

## Table 8: Studies of Radiofrequency Radiation and Cancer in Adults

| Author(s) (Yr.) | Study Design | Study Population | Comparison Group | Results | Highlights/ Deficiencies |
|---|---|---|---|---|---|
| Lilienfeld et al. (1978) | Cohort, SMRs | U.S. Nationals Abroad<br><br>U.S. Foreign Service employees (both of State Department and non-State Department) and dependents stationed at the Moscow Embassy in the Soviet Union. | Other similar employees serving at other East European posts. SMRs based on U.S. mortality rates. | Mortality in both groups generally lower than expected based on U.S. mortality. Some elevations for cancers, including leukemias. More excess cancers in females. | Good efforts to trace and locate populations. Low response rates for questionnaire. Relatively short follow-up dictated by study requirements. Very low exposures (max. 18$\mu$W/cm$^2$). |
| Robinette and Silverman (1977) Robinette et al. (1980) | Cohort, SMRs | U.S. Military<br><br>About 4,000 Navy Veterans (Korean War) from military occupational specialties that work with radar. | Divided into low and high exposure groups with further ranking of high group into a "hazard ranking system." Low exposure group estimated to have received < 1 mW/cm$^2$; high exposure group experienced higher RF exposures. Cohort mortality for subgroups compared to expected mortality based on group as a whole. | Mortality ratio of 1.64 (nonsignificant) for subgroup in high exposure group, based on 8 deaths. Also, elevated but nonsignificant leukemia mortality. | Large well-defined cohort. Attempted limited exposure measurements and applied an exposure ranking system. Mortality ratio biased down since included exposed groups in calculating expected cancers (could not exceed approximately 2). Longer follow-up would be useful. This group has a good potential for further follow-up with improvements in design and methods. |
| Milham (1985b) | Cohort, PMRs | U.S. (Washington & California)<br><br>Amateur radio operators who were members of the American Radio Relay League and died in Washington or California. | Expected values from 1976 U.S. age-specific white male death frequencies. | Significantly elevated PMRs for all leukemias and acute and chronic leukemia. For operators from Washington, PMR=2.64 if death certificate cited electrical work. If no such work, PMR=2.1. | Deaths identified from obituary listings in League's member magazine; an innovative approach but could introduce bias or under ascertainment. Amateurs also are exposed to lower frequencies, including 60 Hz, so probably cannot distinguish differential effects of RF vs. ELF radiation. |

## Table 8: Studies of Radiofrequency Radiation and Cancer in Adults

| Author(s) (Yr.) | Study Design | Study Population | Comparison Group | Results | Highlights/ Deficiencies |
|---|---|---|---|---|---|
| Milham (1988a,b) | Cohort, SMRs | U.S. (Washington & California)<br><br>Amateur radio operators licensed with the Federal Communications Commission (FCC) who lived in California or Washington and died between January 1, 1979 - December 31, 1984. Identified from FCC operator licensee lists. | a: Expected values based on U.S. male death rates.<br><br>b: Expected rates from U.S. male population. Internal comparisons by FCC license class. License category explored as potential measure of exposure and duration. | a and b: SMRs elevated for several cancer sites and statistically significant for acute myeloid leukemia (SMR=1.76) and multiple myelomas and miscellaneous neoplasms of the lymphoid tissues (SMR=1.62). Hodgkin's Disease elevated (SMR=1.23) but not statistically significant. Significantly lower SMRs for several diseases including all causes combined and all malignant neoplasms combined.<br><br>b: Lowest FCC license category (presumably shortest term operators) showed lowest risks. No trend across other categories. | a and b: Large well-defined cohort (n=68,000 men, PY=233,000). Level of exposure unclear. Deaths only sought in California and Washington. Amateurs also are exposed to lower frequencies, including 60 Hz, so probably cannot distinguish differential effects of RF vs. ELF radiation.<br><br>b: Extension of earlier study to attempt to identify possible exposure or duration groupings. Link between exposure level and license category not clear. |
| Environmental Epidemiology Program, State of Hawaii (1986) | SIRs, "Ecological," Incidence | U.S. (Hawaii)<br><br>Residents of Honolulu living in census tracts with RF radiation towers (TV, FM, AM). | Residents in Oahu living in census tracts without RF towers. Expected values based on State rates. | Significantly elevated total cancer in "exposed group." Leukemia in excess but not significantly. | Small numbers precluded concurrent age, sex, race adjustments. Exposures only broadly defined in census tracts. Urban/rural differences possible. |
| Hill (1986) | Cohort | U.S.<br><br>MIT scientists and engineers in radar R&D facility in World War II. | U.S. white males and cohort of physician specialists (to reduce socioeconomic differences). Internal controls grouped by work assignment to estimate exposure. | Overall survival better than expected. In comparison with physicians, increased risk for lymphomas, particularly Hodgkin's Disease (SMR=10.3, Risk ratios proportional hazards model=4.0). Differential risks not seen across exposure categories that ranked potential exposure. | Typical exposures for time period developed, i.e., 2-5 mW/cm$^2$, or SAR of about 0.4 W/kg. General follow-up over 40 years but had to be censored to compare to physicians to 1974. For the latter, further follow-up would be an improvement. |
| Szmigielski et al. (1987) | Cohort | Poland<br><br>Military personnel with RF and microwave exposure, primarily from radars. | Internal controls. Divided into exposed and unexposed subgroups. | Numerical striking excesses for hymphatic and hematopoietic neoplasms (6 times more) and most all sites in exposed group vs. unexposed group. | Information lacking to describe methods, exposures, population size and make-up, etc. that limits interpretability. Potentially important and further information should be obtained. |

## III. Reproductive and Developmental Effects

There have been few studies on reproductive or developmental effects from RF radiation exposure. Sigler et al. (1965) found an increase in Down's Syndrome among children whose fathers were military radar operators. But, the effect disappeared in a follow-up study by Cohen et al. (1977). Kallen (1982) found an increase in dead and malformed infants born to Swedish mothers who worked as physiotherapists using short wave treatments. Overall, however, this group had a better than expected delivery outcome. Lancranjan (1975) examined spermatic fluids and hormones in 31 men who worked with microwaves at low levels of exposure. Ketosteroids and gonadotropin were normal, but he did find statistically significant differences in the number of sperm per milliliter of semen, percent of motile sperm in ejaculate and percent of normal sperm. Buiatti (1984) reported azoospermia and oligospermia in a case-control study of men with a history of radio electronics work. There have also been several studies concerning central nervous system tumors (especially neuroblastoma) in children of fathers in electrical and electronics occupations.

While there does not seem to be evidence implying reproductive or developmental effects in humans exposed to RF radiation, research has been very limited. The reported results are mixed. Replication studies have not been conducted.

## IV. Ocular Effects

The occurrence of ocular effects, especially cataracts, had been a concern, based on effects in animals directly exposed to high levels of RF radiation. All studies on ocular effects involve military personnel and exposures to military sources or at military installations. These are generally clinical or cross-sectional studies in which ophthalmology examinations to discern minor lens changes, if any, were performed on study subjects at a given point in time while actively employed. These studies have largely been negative. Only one case-control study on cataract formation has been conducted; it was negative (Cleary, Pasternack, and Beebe 1965).

These studies have been carefully conducted, using standard protocols for detailed clinical examination. However, subject selection bias is possible and no long-term follow-up studies have been conducted to assess the risk of future cataract development in the exposed populations.

## V. Summary of Studies

Among studies of radiofrequency radiation exposure and cancer in adults, some cohort studies reported statistically significant risks

- of lymphatic and hematopoietic neoplasms, especially acute myeloid leukemia, in amateur radio operators based on proportional mortality ratios and standardized mortality ratios
- of total cancers in Hawaii residents living in close proximity to RF towers based on standardized incidence ratios
- of hematopoietic system cancer, including leukemia, lymphoma and lymphosarcoma, as well as melanoma from exposure to RF radiation, primarily from radar, in Polish military officers.

For the Hawaiian study, leukemias were nonsignificantly elevated, but small numbers made the leukemia estimates unstable. Two studies (of U.S. Embassy employees in Moscow exposed to microwave radiation and of U.S. Naval personnel exposed to radar) suggested a slight tendency toward an increased risk of cancer in general and the hematopoietic system specifically. Excesses were, however, not statistically significant in either study. The remaining cohort study of participants in a radar research and development project at the Massachusetts Institute of Technology, where the subjects were exposed to RF radiation estimated to be about 2 to 5 mW/cm2, produced few significant findings of mortality in the subjects. Some elevated risks of certain site-specific cancers, most notably Hodgkin's disease, were found.

These studies, although suggestive of an elevated risk, suffer from design and methodological problems, which preclude any definitive statement regarding causal relationships with RF exposures. However, the statistically significant excess risks of leukemia in amateur radio operators requires further examination.

There is little epidemiological evidence to suggest exposure to RF radiation leads to an increased risk of developing other diseases (non-cancer) and conditions, except possibly cataracts at extremely high levels of exposure. Yet there has been little research on human populations working or living near RF radiation sources.

## VI. Methodological Issues

There are some general issues surrounding the use and applicability of epidemiological research methods to study the effects of environmental agents, including RF radiation. Examples of such issues include the ability of epidemiological studies to detect low-level risks, to separate the effects of multiple causes, and to identify and control confounding factors. Moreover, specific problems are common in the current epidemiologic literature on RF radiation that limit the ability to draw inferences from this body of data and its usefulness in establishing exposure limits for the general population. These problems are briefly discussed below.

### Exposure Assessment

It is difficult to determine actual exposure and dose for individuals, and even for groups; that is perhaps the largest single problem in epidemiological studies on RF radiation. In general, there are no continuous surveillance programs in the workplace that could yield data for use in epidemiological studies. It is difficult to reconstruct RF-radiation exposure data for health studies that are begun after exposure has taken place. The study by Robinette and Silverman (1980) is a good example of attempts to deal with the difficulties of retrospective exposure assessment, e.g., two approaches (job type versus Hazard Number) were used, and an exposure gradient was obtained with the Hazard Number which simultaneously considered the RF sources and the length of service assignment. Despite these efforts, the estimates remain those of potential rather than actual exposures. In many of the other studies, the levels and frequencies of exposure are not known, not estimated, or not reported. Also, in studies of military populations, information relevant to exposure conditions might be classified. When well-developed exposure data are not available, it is difficult to analyze possible dose-response relationships, to interpret the significance of the findings, and to use the data in establishing protective exposure limits.

### Documentation and Methods

Another problem in the RF radiation literature on human beings relates to documentation of methods and procedures. Degree of detail in reporting seems to be a major difference between studies done in the U.S. and those conducted in other countries. The paper "Guidelines for Documentation of Epidemiologic Studies" (Epidemiology Work Group, 1981) suggests the types of topics that are useful to document when reporting an epidemiologic study, especially one used to support regulatory decisions. These major elements include a statement of background and objectives, methods of selection and characterization of study and comparison subjects, data collection procedures, and analysis. Few reports on human beings exposed to RF radiation adequately include such necessary information. It is frequently difficult to tell whether certain research methods were not applied or simply not reported. For example, the criteria for selecting controls are frequently not stated, but controls are often said to be comparable in all respects except exposure; analyses or data to support such statements may not be supplied. Also, common practices such as development of standardized rates or use of procedures to control confounding variables, e.g., age adjustment, are usually not reported. Statistical power is rarely evaluated or discussed, but it is difficult to estimate power if the underlying prevalence or incidence of the disease under study is not well known, especially for some of the conditions and symptoms, e.g., functional disturbances, studied in relation to RF radiation exposure.

Health End Points: Design and Populations

Another issue is the medical significance of any changes that may be induced by exposure to RF radiation. For example, the studies on ocular effects usually have examined a subclinical end point, e.g., lens opacities, which may not necessarily be an early marker or risk factor for cataractogenesis and visual problems (Silverman 1979). Further, most studies present only single measures at one point in time; the study populations have not been followed long enough to permit development of longitudinal data upon which to base a determination of whether symptoms and subtle changes lead to disability or disease. A similar concern surrounds the problematic information on functional changes and nervous system effects reported in some of the Eastern European literature. The potential for neurological or behavioral effects has not been thoroughly and rigorously evaluated, and standardized questionnaires and more objective medical measurements need to be used in studies on these effects.

Most studies concern occupational groups of relatively young healthy males. It cannot be presumed that sensitivity, or lack thereof, to RF radiation exposure would be the same in the general population as in working groups. The general population is more diverse, with the full range of ages, sexes, races, and other factors that could influence health status or the development of disease. To resolve this issue, specific exposed populations could be identified and evaluated if such research appeared feasible.

## VII. RF Epidemiological Data and Decision-Making

In using epidemiological data for making decisions about public health, one must ask what that data reveal about hazard and risk and whether it is useful in decision-making. In 1984, in its report on the biological effects of RF radiation, the EPA concluded:

> Human data are currently limited and incomplete but do not indicate any obvious relationship between prolonged low-level RF radiation exposure and increased mortality or morbidity, including cancer.

Since that time, there have been a few additional studies concerning cancer. These studies were either cohort studies or general broad occupational studies. Do they serve to change the conclusion drawn by EPA in 1984? The answer is no. The reasons are discussed below.

The cohort studies were described in detail in preceding sections of this report. Only one dealt with cancer among the general population. The cohort studies provide some evidence of increased risk of various cancers; however, they also present certain problems that limit their usefulness in determining hazard and risk. These problems include relatively small sample sizes, too short periods of follow-up, lack of critical exposure data, and so forth. On the other hand, the results from these studies call for caution and further research, but cannot help determine risk or be used to set standards.

The occupational studies are less analytical and, in general, focus on disease, primarily cancer, in various broad industrial, occupational, and job title categories. This approach, by its nature, provides limited information about exposures to individuals. As such, the results from these studies do not provide the type of data useful to standard-setting. However, since some of these studies have indicated a degree of excess cancer risk among certain types of jobs, it is important to point out that these sorts of data, albeit very weak, were previously unavailable. The results do not definitively implicate RF radiation or electric and magnetic fields as the causative agent, but they do point to potentially "risky" jobs that deserve more careful examination through further research.

The available studies have examined exposures to radio frequencies other than those used for cellular telephone transmission. If effects are frequency specific, the studies may, thus, not be relevant. However, this a major area of uncertainty. The body of studies that have investigated 60-Hz power frequency and Extremely Low Frequency (ELF) exposures pose the same uncertainties when one tries to consider their relevance to effects at the frequencies for cellular telephone transmission. ELF research is probably relevant to ELF-modulated RF effects. However, there is a need to sort out exposures to look for

consistencies and commonalities. Such research could include job exposure analyses, area measurements, cluster characterizations, and examination of various occupations.

The basic difficulty in determining the health risks posed by RF radiation exposure, including exposures from cellular telephone sources, is that there is little and limited data concerning low-level, long-term exposures and chronic disease. The epidemiological studies are few in number and present limitations for interpretation. While there is adequate data to provide the thermal effects basis in existing exposure guidelines, there is no clear-cut evidence for an "athermal" basis for setting standards. Because of the potential impacts on public health from risky or improperly used technology and the benefits to society from new useful technology (and the costs for its withdrawal or control), further -- more careful -- research on RF radiation is warranted.

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## Appendix 1: Some Terminology of Epidemiology*

**Association** (*Syn: correlation, [statistical] dependence, relationship*) Statistical dependence between two or more events, characteristics, or other variables. An association is present if the probability of occurrence of an event or characteristics, or the quantity of a variable, depends upon the occurrence of one or more other events, the presence of one or more other characteristic, or the quantity of one or more other variables...An association may be fortuitous or may be produced by various other circumstances; the presence of an association does not necessarily imply a causal relationship...The terms "association" and "relationship" are often used interchangeably.

**Case Control Study** (*Syn: case comparison study, case compeer study, case history study, case referent study, retrospective study*) A study that starts with the identification of persons with the disease (or other common variable) of interest, and a suitable control (comparison, reference) group of persons without the disease. The relationship of an attribute to the disease is examined by comparing the diseased and nondiseased with regard to how frequently the attribute is present or, if quantitative, the levels of the attribute, in each of the groups. Such a study can be called "retrospective" because it starts after the onset of disease and looks back to the postulated causal factors. Cases and controls in a case control study may be accumulated "prospectively;" that is, as each new case is diagnosed it is entered in the study. Nevertheless, such a study may still be called "retrospective" because it looks back from the outcome to its causes.

**Cohort Study** (*Syn: concurrent, follow-up, incidence, longitudinal, prospective study*) The method of epidemiologic study in which subsets of a defined population can be identified who are, have been, or in the future may be exposed or not exposed, or exposed in different degrees, to a factor or factors hypothesized to influence the probability of occurrence of a given disease or other outcome. The alternative terms for a cohort study, i.e., follow-up, longitudinal, and prospective study, describe an essential feature of the method, which is observation of the population for a sufficient number of person-years to generate reliable incidence or mortality rates in the population subsets. This generally implies study of a large population, study for a prolonged period (years), or both.

**Confounding** (*from the Latin confundere, to mix together*) 1. A situation in which the effects of two processes are not separated. The distortion of the apparent effect of an exposure on risk brought about by the association with other factors that influence the outcome. 2. A relationship between the effects of two or more causal factors as observed in a set of data, such that it is not logically possible to separate the contribution that any single causal factor has made to an effect. 3. A situation in which a measure of the effect of an exposure on risk is distorted because of the association of exposure with other factor(s) that influence the outcome under study.

**Confidence interval (CI) (limits)** A measure of the reliability of a risk estimate. A 90% confidence interval means that 9 times out of 10, the estimated risk would be within the specified interval.**

**Confounding variable** (*Syn: confounder*) A variable that can cause or prevent the outcome of interest, is not an intermediate variable, and is not associated with the factor under investigation. Such a variable must be controlled in order to obtain an undistorted estimate of the effect of the study factor on risk.

**Consistency** Close conformity between the findings in different samples, strata, or populations, or at different times or in different circumstances, or in studies conducted by different methods or different investigators. Consistency may be examined in order to study effect modification. Consistency of results on replication of studies in an important criterion in judgments of causality.

**Epidemiology** The study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to control of health problems. There have been many definitions of epidemiology. In the past 50 years or so, the definition has broadened from concern with communicable disease epidemics to take in all phenomena related to health in populations.

**Excess Risk** A term sometimes used to refer to the "population excess rate" and sometimes to "risk difference."

*Source: Last, J.M. *A Dictionary of Epidemiology*. Oxford University Press. New York, New York. 1988
**Source: National Research Council. *Health Effects of Exposure to Low Levels of Ionizing Radiation-BEIRV*. National Academy Press. Washington, D.C. 1990.

**Odds ratio (OR)** (*Syn: cross-product ratio, relative odds*) The ratio of two odds. The term "odds" is defined differently according to the situation under discussion. Consider the following notation for the distribution of a binary exposure and a disease in a population or a sample.

| | Exposed | Unexposed |
|---|---|---|
| Disease (case) | a | b |
| No disease (control) | c | d |

The odds ratio (cross-product ratio) is *ad/bc*. The exposure-odds ratio for a set of case control data is the ratio of the odds in favor of exposure among the cases (*a/b*) to the odds in favor of exposure among noncases (*c/d*). This reduces to *ad/bc*. With incident cases, unbiased subject selection, and a "rare" disease, *ad/bc* is an approximate estimate of the risk ratio...

**Null hypothesis** (*Syn: test hypothesis*) The statistical hypothesis that one variable has no association with another variable or set of variables, or that two or more population distributions do not differ from one another. In simplest terms, the null hypothesis states that the results observed in a study, experiment, or test are no different from what might have occurred as a result of the operation of chance alone.

**P, P (probability) value** The probability that a test statistic would be as extreme as or more extreme than observed if the null hypothesis were true. The letter P, followed by the abbreviation n.s. (not significant) or by the symbol < (less than) and a decimal notation such as 0.01, 0.05, is a statement of the probability that the difference observed could have occurred by chance, if the groups are really alike, i.e., under the null hypothesis.

**Population excess rate** A measure of the amount of disease associated with exposure to a putative cause of the disease in the population. It is the difference between the rates of disease in the entire population and among the nonexposed.

**Proportionate mortality (morbidity) rate, ratio (PMR)** Number of deaths from a given cause in a specified time period, per 100 or 1000 total deaths in the same time period. Can give rise to misleading conclusions if used to compare mortality experience of populations with different distributions of causes of death.

**Risk** The probability that an event will occur, e.g., that an individual will become ill or die within a stated period of time or age. Also, a nontechnical term encompassing a variety of measures of the probability of a (generally) unfavorable outcome.

**Risk factor** An aspect of personal behavior or lifestyle, an environmental exposure, or an inborn or inherited characteristic, which on the basis of epidemiological evidence is known to be associated with health-related condition(s) considered important to prevent.

**Risk difference** (*Syn: excess risk*) The absolute difference between two risks.

**Standardized mortality (morbidity) ratio (SMR)** The ratio of the number of events observed in the study group or population to the number that would be expected if the study population had the same specific rates as the standard population, multiplied by 100.

**Statistical significance** Statistical methods allow an estimate to be made of the probability of the observed or greater degree of association between independent and dependent variables under the null hypothesis. From this estimate, in a sample of given size, the statistical "significance" of a result can be stated. Usually the level of statistical significance is stated by the "p value."

# POTENTIAL PUBLIC HEALTH RISKS FROM WIRELESS TECHNOLOGY:

## Research Agenda for the Development of Data for Science-Based Decisionmaking

# POTENTIAL PUBLIC HEALTH RISKS FROM WIRELESS TECHNOLOGY: RESEARCH AGENDA FOR THE DEVELOPMENT OF DATA FOR SCIENCE-BASED DECISIONMAKING

Scientific Advisory Group

on

Cellular Telephone Research

*Prepared By:*

*Scientific Advisory Group on*
*Cellular Telephone Research*

*1711 N Street, NW*
*Washington, DC 20036*

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Scientific Advisory Group
on
Cellular Telephone Research

George L. Carlo, Ph.D., M.S., J.D. (Chairman)

Health & Environmental Sciences Group, Ltd.
and
George Washington University
School of Medicine and Health Sciences
Washington, DC

Ian Munro, Ph.D., F.R.C.Path.

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Arthur W. Guy, Ph.D.

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Attachment A

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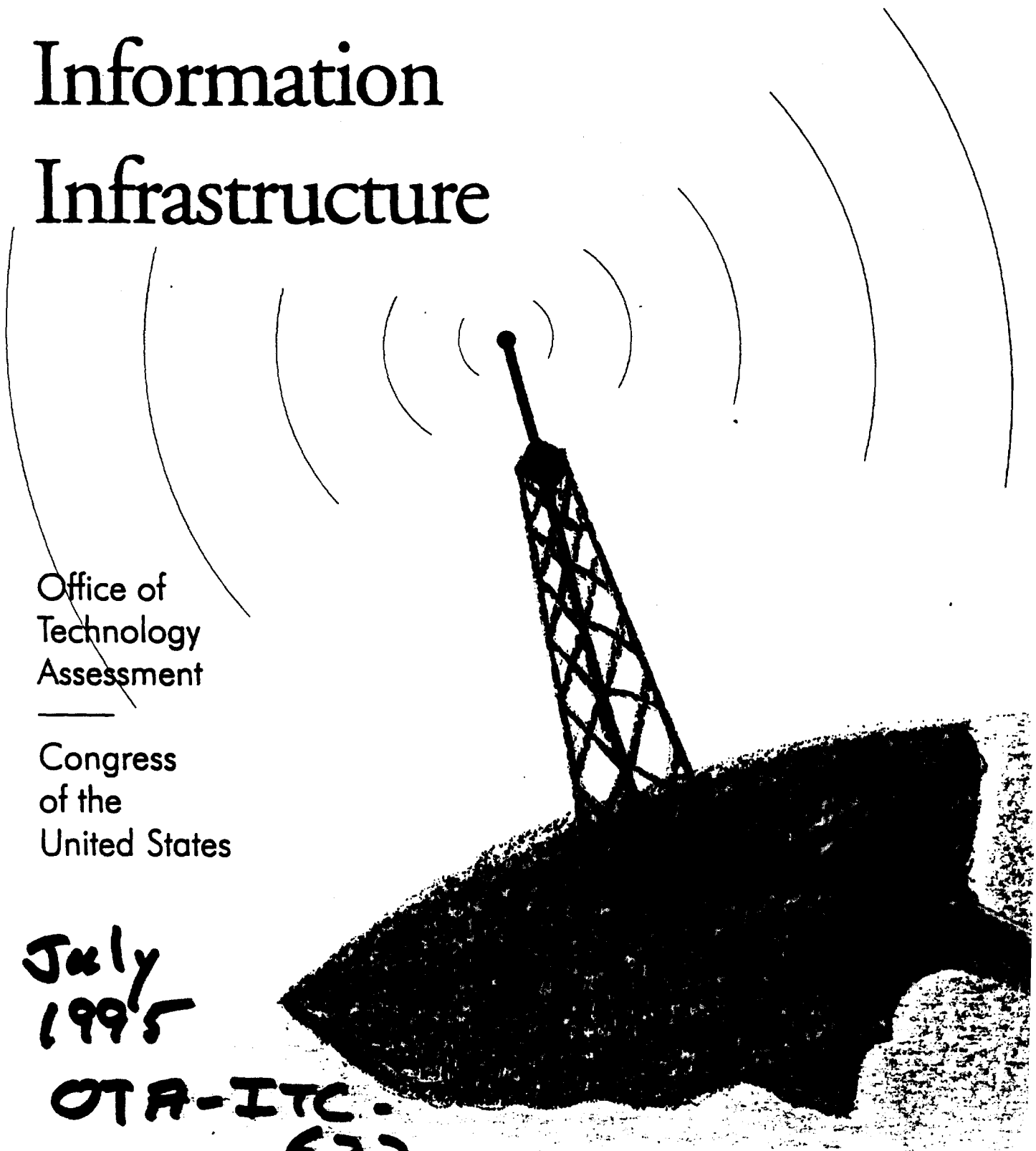
E193

# Wireless Technologies and the National Information Infrastructure



Office of Technology Assessment

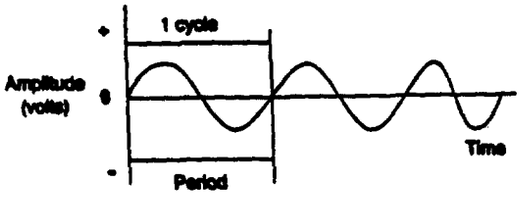
Congress of the United States

July 1995

OTA-ITC-622

①

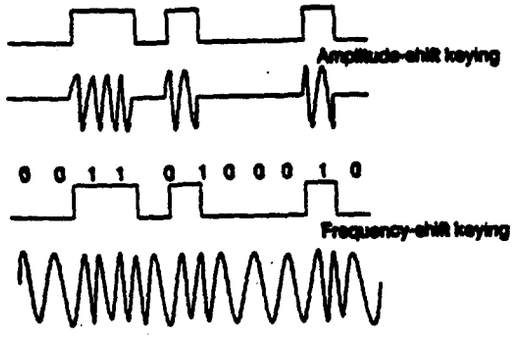
## FIGURE [illegible] The Pure Radio Wave




Each cycle of a pure radio wave is identical to every other cycle.

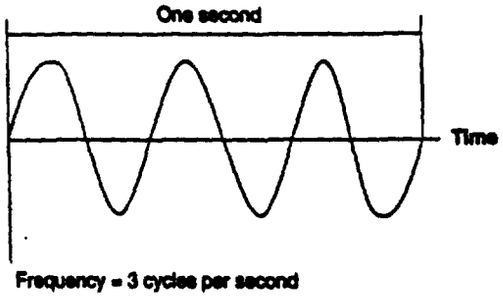
SOURCE: Office of Technology Assessment, based on Harry Mileaf (ed.), *Electronics One*, revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976) p. 1-10.

## [illegible]




SOURCE: U.S. Congress, Office of Technology Assessment, *The Big Picture: HDTV & High-Resolution Systems*, OTA-BP-CIT-84 (Washington, DC: U.S. Government Printing Office, June 1990), figure 3-3, p. 41.

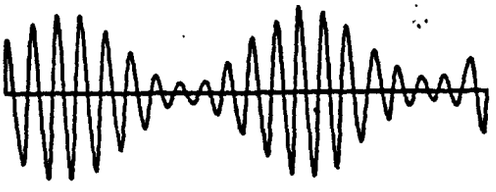
## FIGURE A-1: Frequency of a Continuous Wave




Frequency = 3 cycles per second

SOURCE: Harry Mileaf (ed.), *Electronics One*, revised 2d ed. (Rochelle Park, NJ: Hayden Book Co., 1976) p. 1-10.

## [illegible]

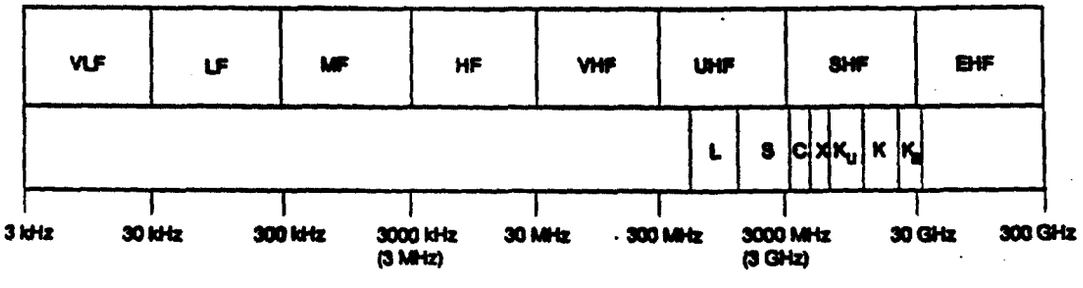


Amplitude-modulated wave

Frequency-modulated wave

SOURCE: U.S. Congress, Office of Technology Assessment, *The Big Picture: HDTV & High-Resolution Systems*, OTA-BP-CIT-84 (Washington, DC: U.S. Government Printing Office, June 1990), figure 3-1, p. 41.

## FIGURE [illegible] Radio Frequency [illegible]




SOURCE: Office of Technology Assessment, 1991, based on Richard G. Gould, "Allocation of the Radio Frequency Spectrum," OTA contractor report, Aug. 10, 1990.

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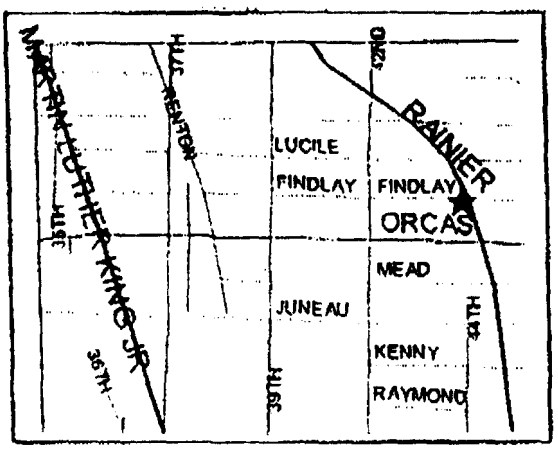


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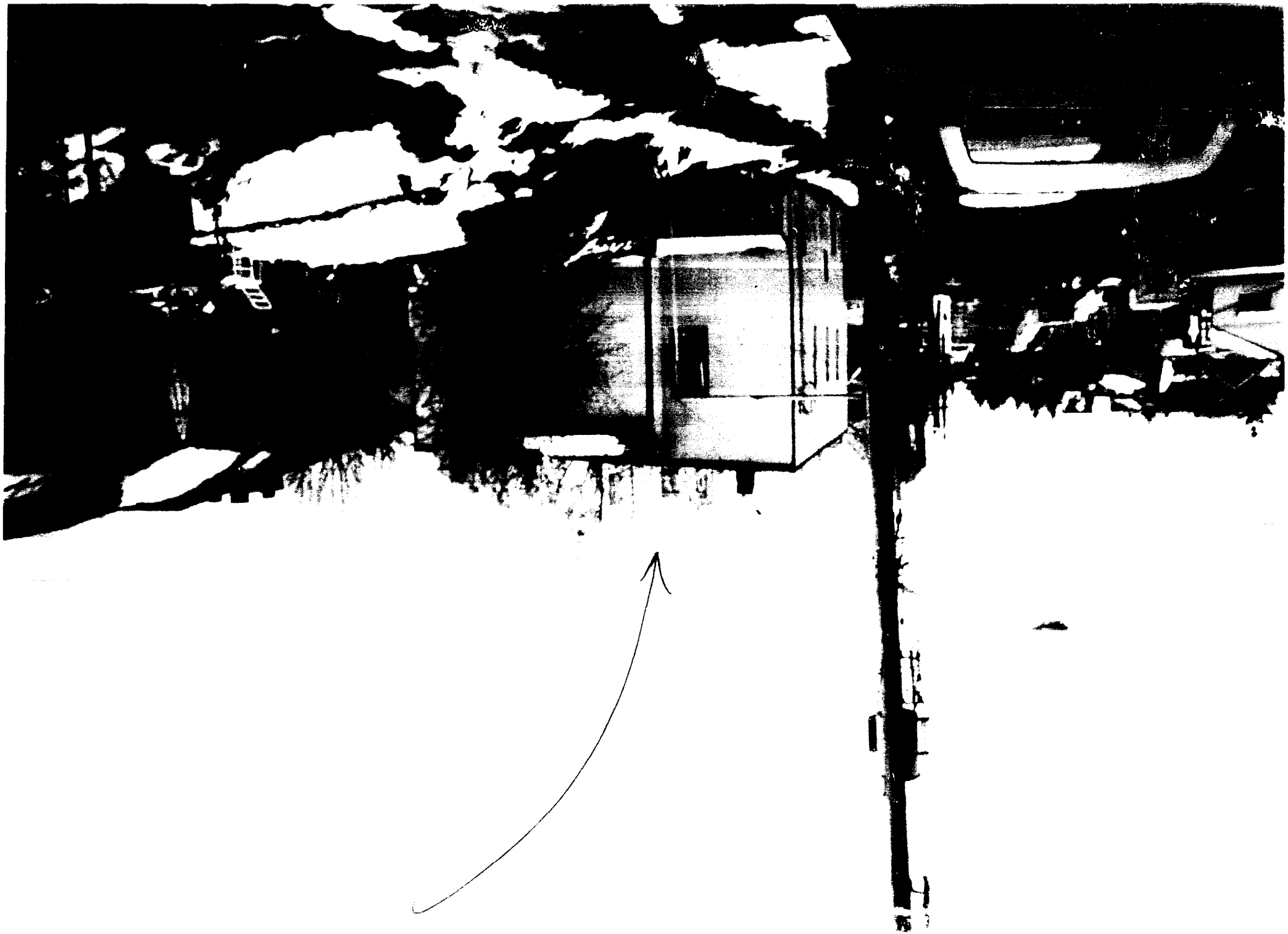
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