

AN ASSESSMENT OF POTENTIAL HEALTH RISKS FROM EXPOSURES TO PAVE PAWS LOW-LEVEL PHASED-ARRAY RADIOFREQUENCY ENERGY

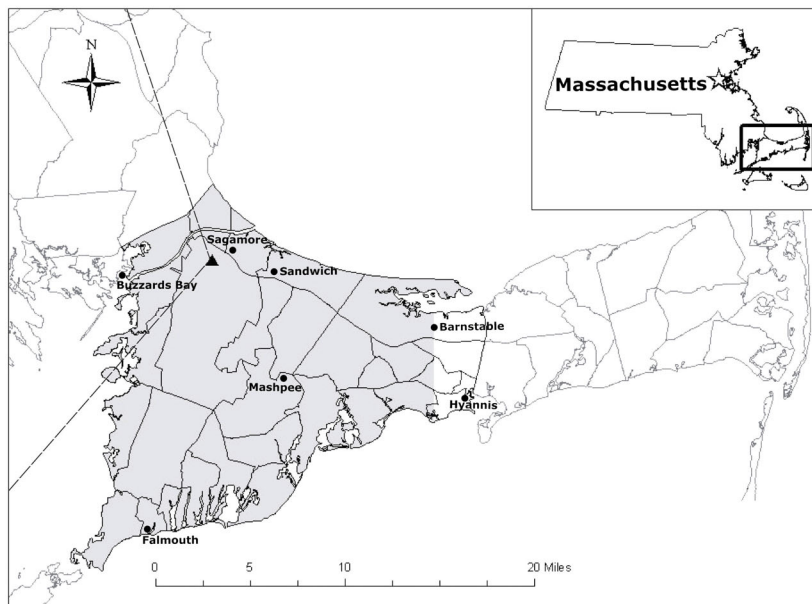
This report examines the potential biological and human-health effects from exposure to PAVE PAWS low-level phased-array radiofrequency energy. The PAVE PAWS radar system, part of the U.S. Air Force Space Command, is located at the Cape Cod Air Force Station in Cape Cod, Massachusetts (see Figure 1). The facility has been in continuous operation since 1979. “PAVE” is an Air Force program name and “PAWS” stands for Phased Array Warning System. The primary purpose of the facility is to detect and track sea-launched and intercontinental ballistic missiles. The system’s secondary function is to track earth satellites and identify other space objects.



The PAVE PAWS radar. Photo courtesy U.S. Air Force.

Even before the facility began operation, there had been concerns expressed by at least some members of the public regarding its safety and whether or not the facility had the potential to cause adverse health impacts. In 1979, concerns voiced by the public included the possibility of thermal effects, disruption to implanted medical devices (such as pacemakers), and secondary radiation effects from improperly-grounded structures exposed to the radar. Those concerns in part led to a

Figure 1. Map of Cape Cod in Massachusetts shows the “Upper Cape” (shaded area), which is the area of concern. The location of the PAVE PAWS radar is indicated by the solid triangle near the town of Sagamore. The dashed lines extending from the radar indicate the approximate boundaries of the main beam when the radar is scanning (beam scans to the east within the dashed lines).



1979 National Research Council (NRC) report on exposure levels and potential biological effects of the PAVE PAWS radar. That committee found that: "...the PAVE PAWS radar may be anticipated to expose a limited number of members of the general public intermittently to low intensities of pulse-modulated microwave fields with maximal intensities of 100 $\mu\text{W}/\text{cm}^2$ or less and time-averaged intensities lower by two orders of magnitude. There are no known irreversible effects of such exposure on either morbidity and mortality in humans or other species."

That committee also recommended that the Air Force conduct additional research and surveillance to evaluate the potential exposure effects of PAVE PAWS. Specifically, the 1979 report recommended:

- "Additional research is recommended to clarify further the possible effects of long-term exposure to microwave radiation at low power densities," and
- "In view of the known sensitivity of the mammalian central nervous system to electromagnetic fields, especially those modulated at brainwave frequencies, the possibility cannot be ruled out that exposure to PAVE PAWS radiation may have some effects on exposed people. Because these effects are still hypothetical, it is not feasible to assess their health implications. Such assessment will require additional research and surveillance and must be addressed in future evaluations of the potential exposure effects of PAVE PAWS and other high-power-output radar systems."

The present NRC committee found no evidence that the Air Force or others followed up substantially on the above two recommendations.

Recent Public Concerns

Public concerns over the possibility for adverse effects from the PAVE PAWS facility have continued over the years since the time of the 1979 NRC report. In recent years, public concerns have shifted away from thermal effects of the radiofrequency (RF). Concerns instead have focused on:

- the possible biological relevance of the waveform itself;
- the inherent time delay of the phased-array radar including the secondary beams or sidelobes that are below the main beam; and
- the possible implications for health arising from the propagation of the RF energy in tissue. Some members of the public have questioned whether radiation from the PAVE PAWS system is unique such that existing safety measures may not adequately protect the public. Others have stated that the system—in spite of its unique configuration—is not that dissimilar from the other sources of RF energy to which the public is constantly exposed such as FM radio stations, TV stations, or continuous-wave radar systems.

In an effort to try to address the questions that have been raised regarding the safety and uniqueness of the system, in January 2001, Senator Edward M. Kennedy asked the U.S. Air Force to fund an independent study through the National Research Council of the National Academies "to examine the health effects of the PAVE PAWS system" and to address in a follow-on report to the 1979 NRC report, the effects if any, of the PAVE PAWS radar over its two-plus decades of operation.

What the Committee Did

The committee undertook an extensive data- and information-gathering effort. That effort included 4 sessions at which members of the public were invited to attend and where researchers whose work was referenced as important by members of the public, or considered important by the committee, were invited to provide the committee with information. An additional meeting of the committee was held as a public forum in which interested members of the public were encouraged to present their viewpoints to the committee. In addition, there were several members of the public, who, on a number of occasions, requested that the committee review specific information they wished to be made available to the committee. Over 200 submissions of information were made to the committee by interested parties. Because there have been no studies of a phased-array system similar to PAVE PAWS in the public domain, we reviewed all the relevant available data (i.e., peer reviewed and scientifically available) in the radiofrequency range most applicable to the PAVE PAWS system (see appendix A). Further, in response to concerns raised by some members of the public that classified data might exist showing effects of a phased-array radar, a number of committee members with sufficient scientific expertise and security clearances also examined and assessed whether there was any classified research done by the U.S. Air Force that might show any evidence of biological effects with potential relevance to human health effects of radiation similar in characteristics to PAVE PAWS.

The committee found no evidence of any classified, phased-array experiments that were either relevant to the PAVE PAWS exposure conditions or indicated a potential for PAVE PAWS human-health effects. Thus, we do not believe there is any classified data showing potential harm from the PAVE PAWS system.

Results and Conclusions

The committee's conclusions address three primary areas: the implications of the PAVE PAWS waveform, the potential for biological effects, and the potential for human-health effects.

The PAVE PAWS Waveform

Recently collected waveform-characterization data that the committee reviewed has answered many questions. Based on that review and some additional statistical analyses we performed, we reached the following conclusions:

1. The PAVE PAWS narrow-band radiation is in fact similar to that of continuous narrow-band reflectors or so-called "dish" antennas. Those large parabolic reflector (dish) antennas are widely used for satellite earth terminals, and for radars. Both reflectors and phased arrays have time delays, and comparable size reflector antennas also have comparable delays.
2. The large number of PAVE PAWS active elements (1,792) and their irregular spacing make the discrete beam formation almost indistinguishable from a continuous formation.
3. The existence and possible biological significance of precursors (additions to a signal waveform that may occur before, during, or after the signal waveform) forming would be extremely small and probably not measurable for the narrow-band PAVE PAWS system.

Potential for Biological Effects

The committee concluded:

4. Relevant data exist from experiments with animals and cells exposed under certain RF conditions that contribute to an understanding of RF biological effects and to an understanding of the potential for human-health effects from PAVE PAWS.
5. There is no risk of cancer, reproductive or developmental effects, or neurobehaviorial effects based on a comprehensive review of animal studies or studies in other biological systems. A few statistically significant biological changes have been reported from RF exposures, but the relevance of those biological changes is not known and may or may not have any impact on human health.

Potential Public-Health Effects

The committee recognizes the concerns of some of the members of the public regarding the ongoing operation of the facility, especially in light of the increase in cancers for colorectal, breast, prostate, and lung that have been reported in the upper Cape over time. To date, those observed elevated cancer-incidence rates among residents of upper Cape Cod have not been adequately explained through previous investigations exploring a variety of environmental factors including PAVE PAWS. The inability of investigators to explore the possibility of health effects from the PAVE PAWS radar was due principally to the lack of PAVE PAWS RF power-density information at that time.

To determine the potential for health effects, it is important to have an estimate of exposure. One of the consistent problems in most epidemiologic studies is the lack of adequate exposure data. This was true in the relevant epidemiologic studies evaluated by the committee for other populations exposed to either pulsed or continuous radiofrequency energy. Unfortunately, there are too many limitations in those epidemiological studies to rely on them for making a determination of the potential impact of radar exposure on human health. With regard to PAVE PAWS exposures, the historic lack of waveform characterization data and exposure data (in the form of power-density measurements) at locations where exposure to the Cape Cod population occurs has made assessment of the potential for health effects difficult. Recent waveform and power-density models and measurements by the Air Force and Broadcast Signal Laboratories have enabled some analyses by this committee and enabled a forthcoming health study by the International Epidemiology Institute.

The committee concluded:

6. The available power-density measurements are generally consistent and show that the spatial distribution of the PAVE PAWS radiofrequency energy, and thus potential for exposure, is strongly influenced by site-specific local topography and intervening terrain at any given location. The measured data show that average power densities are consistently below $0.1 \mu\text{W}/\text{cm}^2$, and generally in the $0.001\text{-}0.01 \mu\text{W}/\text{cm}^2$ range at locations where the public would be expected to be exposed. Measured peak levels are generally less than $1 \mu\text{W}/\text{cm}^2$, although values as high as $15 \mu\text{W}/\text{cm}^2$ have been found at a few elevated locations near the radar where exposure might occur. The levels of exposure can be compared to EPA studies of FM and TV broadcast bands (54-900 MHz) in the 1970s. Those studies estimated that the median exposure in urban areas was $0.005 \mu\text{W}/\text{cm}^2$ and that 95% of the urban population was exposed to less than $0.1 \mu\text{W}/\text{cm}^2$ from FM and TV

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- broadcasts. Recent studies on cell-phone base stations in Great Britain, Canada, and Australia show RF frequencies in the vicinity of base stations ranging from 0.01 $\mu\text{W}/\text{cm}^2$ to a high reading of 2.6 $\mu\text{W}/\text{cm}^2$.
7. The potential for an individual's exposure over time is determined by how long they reside at any possible point(s) where exposure might occur, and the level of exposure at that particular point, which will vary with time and other factors. In spite of recent site-specific measurements and estimates of the PAVE PAWS waveforms and power densities that now exist for a number of geographic locations, there are still no data currently available to determine an individual's personal exposure to RF radiation from the PAVE PAWS radar.
 8. Using information on population density, topography, and direction of the PAVE PAWS radar beam, we estimated that, based on the 1990 census, 12,773 of the total resident population (11.8 % including children) of the upper Cape Cod were living in the line of sight¹ of the PAVE PAWS antenna and most likely receiving some exposure from the sidelobes of the PAVE PAWS radar beam (but not the primary beam, which is angled upward). Based on 2000 census data, the estimated number of population living in the area exposed to the PAVE PAWS radar-beam sidelobes was 16,403 (12.4%).
 9. Using power-density information from models provided by Mitre and recent power-density measurements and models provided by Broadcast Signal Laboratories, this committee also did its own statistical analysis. Based on our own statistical analyses, we did not identify any increase in cancer risk with exposure to the PAVE PAWS beam using peak and average power-density estimates. The analyses looked at the reported occurrences of all cancers combined on the upper Cape as well as specific cancers, including colorectal, breast (female), prostate, and lung. We are also aware of the epidemiologic investigation that is currently being conducted by the International Epidemiology Institute, but data from that study was not available to review as of the writing of this report.
 10. Socioeconomic status does not appear to influence results. We performed additional analyses to see whether some indicators of socioeconomic status might influence the results (an adjustment routinely made in health or epidemiologic studies). We found that adjusting for the proportion of the population below the poverty level did not influence the results.
 11. As another overall measure of health for the upper Cape Cod towns, the committee looked at premature mortality before age 75 as a useful indicator. Based on 2001 data, Barnstable, Falmouth, Mashpee, and Sandwich have lower mortality than the Massachusetts state average, while Bourne has elevated mortality.
 12. Further analysis by the committee indicates that increasing duration of exposure to the PAVE PAWS radiofrequency energy has not resulted in increased incidence of cancer over time. The committee compared the standard cancer-incidence rates, or SIRs, for 5 categories consisting of: total cancers, breast, colon, lung, and prostate cancer for the period of 1987-94 versus 1995-99 (which are the periods that the State of Massachusetts reports data) for the 5 towns in upper Cape Cod and found that there was no consistent pattern of increase. During those two time periods, a decrease in SIR was observed in 15 out of 25 SIRs, an increase in 6 out of 25 SIRs and, no change in 4 out of 25 SIRs. Again, the results indicate that increasing exposure to PAVE PAWS over time has not resulted in an increased incidence of cancer. PAVE PAWS over time has not resulted in an increased incidence of cancer.

¹Line of sight means that there are no hills between the resident and the radar that would block the radar emissions. The main beam is aimed above the population and residents in the line of sight are exposed to the sidelobes of the main beam.

Summary

In summary, based on the available scientific evidence, the committee concludes there are no adverse health effects to the population resulting from continuing or long-term exposure to the PAVE PAWS radiation. In particular, the committee concludes that there is no increase in total cancers or cancers of the prostate, breast, lung, or colon due to exposure to the PAVE PAWS radiation. Further, there are many studies and data that support the finding of no health or biological effects from RF exposures. There are a number of possible mechanisms and pathways by which electric and magnetic fields could lead to changes at higher power-density levels than the public is exposed to from the PAVE PAWS radar. However, at this time, the committee has not found evidence of a mechanism shown to change biologic processes at power levels that are associated with the PAVE PAWS radar. The recent waveform-characterization data collected for the PAVE PAWS radar has also shown that it is similar to exposures from “dish” radars to which the public are also continuously exposed.

It is extremely difficult, if not impossible, to prove ultimate safety. In the United States, various forms of safety or risk assessment are used along with regulatory guidelines to ensure that facilities, products, technologies, and other factors will not pose undue risk or harm to the public or environment. The scientific community, including medical professionals, is often reluctant to call something “safe” and so often speaks of having or not having some degree of evidence of harm or lack thereof. There is also growing interest in what is referred to as the “precautionary principle” which seeks to avoid taking actions that might have the potential for harm unless a relative degree of safety can be assured. Those decisions are policy or management decisions and not solely a matter of science. This committee has focused on the scientific evidence and carefully evaluated all the scientific evidence available to determine whether there is a reasonable degree of certainty regarding the presence or absence of harm from exposure to the PAVE PAWS phased-array radar. To those who live in the vicinity of that system, no less would be acceptable.

Recommendations Regarding Further Studies

The committee was also tasked to recommend further studies if warranted. The committee recognizes that while biological responses do not necessarily translate into human-health effects, studies on the biological effects of RF exposures should be done that build upon several existing studies demonstrating a statistically significant response to RF exposure, such as the effect of radars on studies of tree growth. Future studies should approximate the PAVE PAWS exposure characteristics as closely as possible. Specifically, we recommend that studies of tree growth in the vicinity of the PAVE PAWS facility should be done. A study of long-term exposures under similar conditions to human exposures might provide useful information as to any possible mechanisms for a biological response which currently does not exist. In addition, we recommend that a replication of a central nervous system endocrine function study be undertaken to confirm or refute previous Air Force-sponsored studies showing a significant and extended influence on brain dopamine levels during low-level RF exposures similar to that of PAVE PAWS.

The Toler and others study demonstrating a significant and long-lasting effect on serum dopamine levels does point to a biological effect that might result in a detrimental health effect. This study is one of the few studies we are aware of which utilized 435 MHz, and effects on brain activity were a major concern of the 1979 NRC review committee, so this study holds additional importance.

Moreover, the study utilized a 1 KHz modulation which would not be expected to have as profound an effect as a modulation frequency similar to that of PAVE PAWS which is in the 10-100 Hz range. For these reasons, it is recommended that this study be refined and repeated.

Finally, because of the limitations and uncertainties that exist in estimated exposure at the individual level and the number of health outcomes of interest, future health investigations or epidemiologic studies should look at exposures at both the census tract* and census-block level, and try to better estimate personal exposure and consider the types of factors known to complicate human-health investigations. Future or ongoing health studies should also specifically address possible early age-of-exposure and/or early age-at-onset of an adverse health effect. Finally, future epidemiologic studies should not be conducted unless they are expected to have sufficient statistical ability, or so-called power, to be able to detect any possible health effects in the Cape Cod population.

* For census reasons, states are divided into counties, which are in turn divided into census blocks, which are further subdivided into census tracts. Most census tracts have between 1500 and 8000 people and they average about 4000 inhabitants. Census blocks are subdivisions of a census tract and are the smallest area that the decennial census data are available to the public.

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For more information, contact the Board on Radiation Effects Research at 202-334-2840. *An Assessment of Potential Health Risks from Exposures to PAVE PAWS Low-level Phased-array Radiofrequency Energy* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); www.nap.edu.

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