NTP TECHNICAL REPORT

ON THE

TOXICOLOGY AND CARCINOGENESIS

STUDIES OF

60-HZ MAGNETIC FIELDS

IN F344/N RATS AND B6C3F$_1$ MICE

(WHOLE-BODY EXPOSURE STUDIES)

NATIONAL TOXICOLOGY PROGRAM
P.O. Box 12233
Research Triangle Park, NC 27709

April 1999

NTP TR 488

NIH Publication No. 99-3978

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
National Institutes of Health

FOREWORD

The National Toxicology Program (NTP) is made up of four charter agencies of the U.S. Department of Health and Human Services (DHHS): the National Cancer Institute (NCI), National Institutes of Health; the National Institute of Environmental Health Sciences (NIEHS), National Institutes of Health; the National Center for Toxicological Research (NCTR), Food and Drug Administration; and the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control. In July 1981, the Carcinogenesis Bioassay Testing Program, NCI, was transferred to the NIEHS. The NTP coordinates the relevant programs, staff, and resources from these Public Health Service agencies relating to basic and applied research and to biological assay development and validation.

The NTP develops, evaluates, and disseminates scientific information about potentially toxic and hazardous chemicals. This knowledge is used for protecting the health of the American people and for the primary prevention of disease.

The studies described in this Technical Report were performed under the direction of the NIEHS and were conducted in compliance with NTP laboratory health and safety requirements and must meet or exceed all applicable federal, state, and local health and safety regulations. Animal care and use were in accordance with the Public Health Service Policy on Humane Care and Use of Animals. The prechronic and chronic studies were conducted in compliance with Food and Drug Administration (FDA) Good Laboratory Practice Regulations, and all aspects of the chronic studies were subjected to retrospective quality assurance audits before being presented for public review.

These studies are designed and conducted to characterize and evaluate the toxicologic potential, including carcinogenic activity, of selected chemicals or physical agents in laboratory animals (usually two species, rats and mice). The interpretive conclusions presented in this Technical Report are based only on the results of these NTP studies. Extrapolation of these results to other species and quantitative risk analyses for humans require wider analyses beyond the purview of these studies. Selection *per se* is not an indicator of carcinogenic potential.

Listings of all published NTP reports and ongoing studies are also available from NTP Central Data Management, NIEHS, P.O. Box 12233, MD E1-02, Research Triangle Park, NC 27709 (919-541-3419). The Abstracts and other study information for 2-year studies are available at the NTP's World Wide Web site: http://ntp-server.niehs.nih.gov.

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ABSTRACT

Electric and magnetic fields are associated with the production, transmission, and use of electricity; thus, the potential for human exposure is high. These electric and magnetic fields are predominantly of low frequency (60 Hz in the United States and 50 Hz in Europe) and generally of low intensity. Epidemiology studies have suggested a potential for increased breast cancer, brain cancer, and leukemia rates with increasing magnetic field exposure. However, these results are controversial and a National Research Council found no compelling evidence for an EMF effect on cancer. Because of the controversy and given the widespread exposure to low-intensity, 60-Hz magnetic fields in industrialized societies, standard toxicology studies and long-term carcinogenesis studies were conducted using traditional rodent models. Male and female F344/N rats and $B6C3F_1$ mice were exposed to 60-Hz magnetic fields by whole-body exposure for 2 years.

2-Year Study in Rats

Groups of 100 male and 100 female rats were exposed to 60-Hz magnetic fields at intensities of 0.02, 2, or 10 G for 18.5 hours per day, 7 days per week, for 106 weeks. Groups of 100 male and 100 female control rats were housed in the same exposure chambers without applied magnetic fields. Additional groups of 100 male and 100 female rats were intermittently exposed (1 hour on and 1 hour off) to a 10 G 60-Hz field 18.5 hours per day, 7 days per week, for 106 weeks. The highest field intensity (10 G) is approximately 5,000-fold greater than what was considered high intensity for homes in epidemiology studies in humans.

Survival and Body Weights

Survival and mean body weights of exposed groups of male and female rats were similar to those of the control groups.

Pathology Findings

The incidences of thyroid gland C-cell adenoma and carcinoma in 0.02 G male rats, adenoma in 2 G males, and adenoma or carcinoma (combined) in 0.02 and 2 G males were significantly greater than in the control group. The incidence of mononuclear cell leukemia in males in the 10 G intermittent group was significantly less than in the control group.

2-Year Study in Mice

Groups of 100 male and 100 female mice were exposed to 60-Hz magnetic fields at intensities of 0.02, 2, or 10 G for 18.5 hours per day, 7 days per week, for 106 weeks. Groups of 100 male and 100 female control mice were housed in the same exposure chambers without applied magnetic fields. Additional groups of 100 male and 100 female mice were intermittently exposed (1 hour on and 1 hour off) to a 10 G 60-Hz field 18.5 hours per day, 7 days per week, for 106 weeks.

Survival and Body Weights

Survival of male mice exposed to 10 G was significantly less than that of control mice after 2 years; survival of all other exposed groups of mice was similar to that of control mice. Mean body weights of exposed groups of male and female mice were similar to those of the control groups throughout the study.

Pathology Findings

The incidences of alveolar/bronchiolar adenoma were significantly decreased in 0.02 and 2 G male mice and 2 G female mice relative to the control groups; the incidences of alveolar/bronchiolar adenoma or carcinoma (combined) were significantly less in males and females exposed to 2 G than in the control groups. In female mice, the incidence of malignant lymphoma in the 10 G intermittent group was significantly less than in the controls.

CONCLUSIONS

Under the conditions of these 2-year whole-body exposure studies, there was *equivocal evidence of carcinogenic activity** of 60-Hz magnetic fields in male F344/N rats based on increased incidences of thyroid gland C-cell neoplasms in the 0.02 and 2 G groups. There was *no evidence of carcinogenic activity* in female F344/N rats or male or female $B6C3F_1$ mice exposed to 0.02, 2, or 10 G, or 10 G intermittent 60-Hz magnetic fields.

In exposed rats and mice, there were no increased incidences of neoplasms at sites for which epidemiology studies have suggested an association with magnetic fields (brain, mammary gland, leukemia).

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* Explanation of Levels of Evidence of Carcinogenic Activity is on page 8. A summary of the Technical Reports Review Subcommittee comments and the public discussion on this Technical Report appears on page 10.

Summary of the 2-Year Carcinogenesis Studies of 60-Hz Magnetic Fields

	Male F344/N Rats	Female F344/N Rats	Male $B6C3F_1$ Mice	Female $B6C3F_1$ Mice
Exposure field intensity	Control, 0.02, 2, or 10 G continuous, or 10 G intermittent	Control, 0.02, 2, or 10 G continuous, or 10 G intermittent	Control, 0.02, 2, or 10 G continuous, or 10 G intermittent	Control, 0.02, 2, or 10 G continuous, or 10 G intermittent
Body weights	Exposed groups similar to control group	Exposed groups similar to control group	Exposed groups similar to control group	Exposed groups similar to control group
Survival rates	57/100, 46/100, 47/100, 48/100, 59/100	59/100, 68/100, 60/100, 61/100, 58/100	76/100, 72/100, 84/100, 62/100, 74/100	70/100, 74/100, 79/100, 74/100, 77/100
Nonneoplastic effects	None	None	None	None
Neoplastic effects	None	None	None	None
Uncertain findings	Thyroid Gland (C-cell): adenoma (15/99, 25/100, 26/100, 23/100, 18/100); carcinoma (1/99, 7/100, 4/100, 2/100, 5/100); adenoma or carcinoma (16/99, 31/100, 30/100, 25/100, 22/100)	None	None	None
Level of evidence of carcinogenic activity	Equivocal evidence	No evidence	No evidence	No evidence

EXPLANATION OF LEVELS OF EVIDENCE OF CARCINOGENIC ACTIVITY

The National Toxicology Program describes the results of individual experiments on a chemical agent and notes the strength of the evidence for conclusions regarding each study. Negative results, in which the study animals do not have a greater incidence of neoplasia than control animals, do not necessarily mean that a chemical is not a carcinogen, inasmuch as the experiments are conducted under a limited set of conditions. Positive results demonstrate that a chemical is carcinogenic for laboratory animals under the conditions of the study and indicate that exposure to the chemical has the potential for hazard to humans. Other organizations, such as the International Agency for Research on Cancer, assign a strength of evidence for conclusions based on an examination of all available evidence, including animal studies such as those conducted by the NTP, epidemiologic studies, and estimates of exposure. Thus, the actual determination of risk to humans from chemicals found to be carcinogenic in laboratory animals requires a wider analysis that extends beyond the purview of these studies.

Five categories of evidence of carcinogenic activity are used in the Technical Report series to summarize the strength of the evidence observed in each experiment: two categories for positive results (**clear evidence** and **some evidence**); one category for uncertain findings (**equivocal evidence**); one category for no observable effects (**no evidence**); and one category for experiments that cannot be evaluated because of major flaws (**inadequate study**). These categories of interpretative conclusions were first adopted in June 1983 and then revised in March 1986 for use in the Technical Report series to incorporate more specifically the concept of actual weight of evidence of carcinogenic activity. For each separate experiment (male rats, female rats, male mice, female mice), one of the following five categories is selected to describe the findings. These categories refer to the strength of the experimental evidence and not to potency or mechanism.

- **Clear evidence** of carcinogenic activity is demonstrated by studies that are interpreted as showing a dose-related (I) increase of malignant neoplasms, (ii) increase of a combination of malignant and benign neoplasms, or (iii) marked increase of benign neoplasms if there is an indication from this or other studies of the ability of such tumors to progress to malignancy.
- **Some evidence** of carcinogenic activity is demonstrated by studies that are interpreted as showing a chemical-related increased incidence of neoplasms (malignant, benign, or combined) in which the strength of the response is less than that required for clear evidence.
- **Equivocal evidence** of carcinogenic activity is demonstrated by studies that are interpreted as showing a marginal increase of neoplasms that may be chemical related.
- **No evidence** of carcinogenic activity is demonstrated by studies that are interpreted as showing no chemical-related increases in malignant or benign neoplasms.
- **Inadequate study** of carcinogenic activity is demonstrated by studies that, because of major qualitative or quantitative limitations, cannot be interpreted as valid for showing either the presence or absence of carcinogenic activity.

When a conclusion statement for a particular experiment is selected, consideration must be given to key factors that would extend the actual boundary of an individual category of evidence. Such consideration should allow for incorporation of scientific experience and current understanding of long-term carcinogenesis studies in laboratory animals, especially for those evaluations that may be on the borderline between two adjacent levels. These considerations should include:

- adequacy of the experimental design and conduct;
- occurrence of common versus uncommon neoplasia;
- progression (or lack thereof) from benign to malignant neoplasia as well as from preneoplastic to neoplastic lesions;
- some benign neoplasms have the capacity to regress but others (of the same morphologic type) progress. At present, it is impossible to identify the difference. Therefore, where progression is known to be a possibility, the most prudent course is to assume that benign neoplasms of those types have the potential to become malignant;
- combining benign and malignant tumor incidence known or thought to represent stages of progression in the same organ or tissue;
- latency in tumor induction;
- multiplicity in site-specific neoplasia;
- metastases;
- supporting information from proliferative lesions (hyperplasia) in the same site of neoplasia or in other experiments (same lesion in another sex or species);
- presence or absence of dose relationships;
- statistical significance of the observed tumor increase;
- concurrent control tumor incidence as well as the historical control rate and variability for a specific neoplasm;
- survival-adjusted analyses and false positive or false negative concerns;
- structure-activity correlations; and
- in some cases, genetic toxicology.

NATIONAL TOXICOLOGY PROGRAM BOARD OF SCIENTIFIC COUNSELORS
TECHNICAL REPORTS REVIEW SUBCOMMITTEE

The members of the Technical Reports Review Subcommittee who evaluated the draft NTP Technical Report on 60-Hz magnetic fields on 11 March 1998 are listed below. Subcommittee members serve as independent scientists, not as representatives of any institution, company, or governmental agency. In this capacity, subcommittee members have five major responsibilities in reviewing the NTP studies:

- to ascertain that all relevant literature data have been adequately cited and interpreted,
- to determine if the design and conditions of the NTP studies were appropriate,
- to ensure that the Technical Report presents the experimental results and conclusions fully and clearly,
- to judge the significance of the experimental results by scientific criteria, and
- to assess the evaluation of the evidence of carcinogenic activity and other observed toxic responses.

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SUMMARY OF TECHNICAL REPORTS REVIEW SUBCOMMITTEE COMMENTS

On 11 March 1998, the draft Technical Report on the toxicology and carcinogenesis studies of 60-Hz magnetic fields received public review by the National Toxicology Program's Board of Scientific Counselors' Technical Review Subcommittee. The review meeting was held at the National Institute of Environmental Health Sciences, Research Triangle Park, NC.

Dr. G.A. Boorman, NIEHS, introduced the toxicology and carcinogenesis studies of 60-Hz magnetic fields by discussing the uses of magnetic fields and the rationale for study, describing the experimental design, reporting on survival and body weight effects, and commenting on compound-related neoplastic and nonneoplastic lesions in rats and mice. The proposed conclusions for the 2-year studies were *equivocal evidence of carcinogenic activity* in male rats and *no evidence of carcinogenic activity* in female rats and male and female mice.

Dr. Cullen, a principal reviewer, agreed with the proposed conclusions. He thought the use of two or multiple sections of the thyroid gland along with the use of a new diet might impact on comparisons with the historical control database. Dr. Boorman said that because second cuts had to be made for some rats, second cuts were done on the thyroid glands of all rats to eliminate bias. He agreed that double sectioning along with the new diet lessened the usefulness of the historical controls for comparisons. Dr. Cullen asked what parameters were evaluated in the pineal gland since this organ is not routinely examined. Dr. Boorman said that the pineal gland examination centered on diagnoses of the presence of small lysosomal granules. Dr. Cullen suggested that the effect of the age differences between weaned animals of 6 to 8 weeks of age and human neonates in their sensitivity to EMF effects be discussed. Dr. Boorman noted the study by Dr. R. Mandeville, who looked at the effects of exposures from the 20th day of gestation through parturition and weaning in female rats.

Dr. Bus, the second principal reviewer, agreed in principle with the proposed conclusions. He suggested that since the unexpected thyroid gland neoplasm findings seem unlikely to be attributable to magnetic field exposure, the NTP should consider emphasizing this point in the conclusion. Dr. Boorman agreed to address this issue in the discussion. Dr. Bus commented that the discussion implied that the findings of the current study are not consistent with reported associations of magnetic field exposures and human childhood and adult leukemias. Because the study design did not include pre- or early postnatal exposures, he suggested the findings of this study may not be particularly relevant to reports of human childhood leukemias.

Dr. Bailer, the third principal reviewer, agreed in principle with the proposed conclusions. He noted other dose-related increased neoplasm incidences in male rats, in particular skin trichoepithelioma and basal cell adenoma, as well as skin squamous cell papilloma and keratoacanthoma, and asked whether these results might support *some evidence of carcinogenic activity*. Dr. J.R. Hailey, NIEHS, explained that the relevant analysis is a combined analysis of these skin neoplasms as they are all thought to be derived from basal epithelium. Dr. J.K. Haseman, NIEHS, said that if one looks at the combination of these basal epithelial neoplasms, there are more neoplasms overall in the control group than in the exposed groups.

Three *ad hoc* expert consultants (Drs. Grubbs, Misakian, and Stuchly) were present to assist with the reviews. Dr. Stuchly said the report comprehensively described the study design, results, and data analysis and the essential findings were properly addressed. She said that from her engineering viewpoint, the only limitation was poor quantification of the exposure conditions. Particularly, the maps of field uniformity within the space occupied by the animals were not provided, and the contract facility did have the capability to compute uniformity of exposure fields. Dr. Boorman agreed to add an appendix that detailed the exposure conditions. Dr. Stuchly noted that calculations of induced surface currents from alternating fields were considerably different for humans and rodents. Dr. Misakian responded to Dr. Stuchly's concerns about the field conditions, stating that during site visits by the National Institute of Standards and Technology, uniformity of exposure was characterized by measuring on each shelf where animals were located and also on a perimeter line that enclosed the area. Approximately 18 measurements were made on

the perimeter and compared with the field value at the center of each shelf. All measured field values were within 10% of the targeted field levels reported. Dr. Misakian discussed the differences between circularly polarized and linearly polarized magnetic fields, and both he and Dr. Stuchly agreed that people are primarily exposed to linearly polarized magnetic fields.

Dr. Cullen moved that the Technical Report on whole-body exposures to 60-Hz magnetic fields be accepted with the revisions discussed and the conclusions as written for male rats, *equivocal evidence of carcinogenic activity*, and for female rats and male and female mice, *no evidence of carcinogenic activity*. Dr. Bus seconded the motion. There was some discussion as to whether "slightly increased incidences of thyroid gland C-cell neoplasms" should be modified by deleting "slightly." Dr. J.R. Bucher, NIEHS, suggested "occurrence of" instead of "slightly increased incidences" as less directly associating the neoplasms with exposure. In response to a query by Dr. Cullen, Dr. Haseman said the P value for the 0.02 and 2 G groups under "adenoma or carcinoma" was less than 0.01. Dr. Bus said there needs to be wording that qualifies why the call is *equivocal*. Dr. Medinsky noted that the definition of "equivocal" in the report uses the word "marginal," so marginal defines equivocal. Dr. Bailer moved to amend the motion by deleting "slightly." Dr. Medinsky seconded the amendment, which was accepted by seven yes votes to one no vote (Dr. Bus) with one abstention (Dr. Goldsworthy). Dr. Bus stated that there still needed to be wording suggesting a non-exposure related increase in thyroid gland C-cell neoplasms. Dr. Haseman suggested identifying the specific groups in which the increase was seen. Dr. Bailer moved to further modify his original amendment to read "based on increased incidences of thyroid gland C-cell neoplasms in the 0.02 and 2 G groups." Dr. Russo seconded the amended motion, which was accepted by eight yes votes with one abstention (Dr. Goldsworthy).

INTRODUCTION

Electric and magnetic fields associated with the production, transmission, and use of electricity are ubiquitous in industrialized society. The electric and magnetic fields associated with alternating current are predominantly of low frequency (50 or 60 Hz) and generally of low intensity. Electric fields exist when there is electric potential (voltage) in a line, while magnetic fields exist only when there is current flow (Miller and Schroeer, 1987). Electric and magnetic fields are often referred to as electromagnetic fields, or EMFs. Electric fields are easily shielded by trees, walls, and other material, whereas magnetic fields usually penetrate nonferrous material. Thus, most exposure in the home is to magnetic fields, and recent research has focused on potential adverse biological effects of exposure to magnetic fields. Most residential exposure is to magnetic fields that are less than 2 milligauss (mG) although many commonly used household appliances generate fields that exceed this intensity (Gauger, 1985). In some industries, mean workplace magnetic field exposure may exceed 10 mG (Theriault *et al.*, 1994).

Electromagnetic radiation, such as X-rays, ultraviolet light, or other ionizing radiation, have sufficient energy to damage DNA. However, low-frequency (e.g., 60 Hz) fields are of very low energy and are not sufficient to alter DNA structure or directly cause genetic injury (Juutilainen and Liimatainen, 1986; Rosenthal and Obe, 1989). Further, the magnetic fields produced by 60-Hz alternating current are of much lower intensity than the earth's static magnetic fields, which are 300 to 500 mG, depending on the geographic location, presence of ferrous materials, and other factors. Thus, many had assumed that exposure to low-frequency, low-intensity magnetic fields could not pose a health hazard. This view was challenged by Wertheimer and Leeper (1979), who were supported by a second study by Savitz *et al.* (1988), reporting that children living in homes with potentially high magnetic fields had a greater incidence of childhood leukemia than children living in homes that would be expected to have lower 60-Hz magnetic field exposures. Other studies (Fulton *et al.*, 1980; Coleman *et al.*, 1989) failed to find an association between wire codes and the occurrence of childhood cancer.

TOXICITY

Experimental Animals

Experimental animal studies to evaluate the potential effects of magnetic fields are difficult to conduct, and the exposure variables are difficult to control. Most reports of animal studies on the effects of magnetic fields do not give sufficient details on the exposure parameters or the local static magnetic fields of the earth to permit assessment of results. Conflicting results have been reported from animal studies on the potential hazard of exposure to electric and magnetic fields (Kavet and Banks, 1986; Kavet, 1996). Laboratory studies have shown that animals can respond behaviorally to electric fields; the evidence for behavioral response to magnetic fields is more tenuous, but in either case, no general adverse behavioral effects have been observed. While neuroendocrinologic effects have been reported in animals, these effects have not been associated with adverse health effects (NRC, 1997). In the NTP studies, no evidence of toxicity was observed in male or female F344/N rats or $B6C3F_1$ mice continuously exposed to 0.02, 2, or 10 G for 18.5 hours per day, 7 days per week for 8 weeks or intermittently exposed (1 hour on, 1 hour off) to 10 G for the same period (NTP, 1996; Boorman *et al.*, 1997).

Humans

The literature on the potential toxicity of 60-Hz magnetic fields includes human (epidemiology) studies and clinical studies. Most of this literature is difficult to evaluate due to the complex nature of the fields and the lack of adequate descriptions of the exposures or the potential confounding factors. Epidemiology studies can provide only an estimate of the exposures, because exposure in the home varies according to the location in the house; the number and type of appliances in use; the current load on the outside lines, which varies with electrical demand; and development and changes within a community, which cause

variations in the magnetic fields over time. Ambient levels of 60-Hz magnetic fields in residences and most workplaces are typically in the range from 0.1 to 3 mG (NRC, 1997). Further, residential exposures account for only a portion of a person's total magnetic field exposure because exposures also occur in the school or workplace, during travel, and during outdoor activities (Feychting *et al.*, 1996; Friedman *et al.*, 1996; Kheifets *et al.*, 1997).

Studies of residential exposures suggest possible increased rates of childhood leukemia (Savitz *et al.*, 1988; Feychting and Ahlbom, 1993, 1995) and brain cancer (Wertheimer and Leeper, 1979; Savitz *et al.*, 1988) in homes expected to have higher magnetic field intensities. Studies of occupational exposure of electricians suggest possible increased risks of leukemia (Theriault *et al.*, 1994), brain cancer (Savitz and Loomis, 1995), and breast cancer (Matanoski *et al.*, 1991). However, the studies are not always consistent. Savitz and Loomis (1995) reported increased incidences of brain cancer but not leukemia in electricians, while Theriault *et al.* (1994) reported increased incidences of leukemia but not brain cancer. Other potential indicators of toxicity in humans include headaches, depression, impaired neuropsychologic performance, and suicide, but the results are inconsistent and the studies are of mixed quality (NRC, 1997). In a series of studies, no effects of 200 mG exposure on nocturnal melatonin concentrations were seen in volunteers (Graham *et al.*, 1996, 1997).

Reproductive Toxicity

A review of the literature concluded that laboratory and epidemiological studies have not yielded conclusive data to suggest that magnetic field exposures induce adverse reproductive effects under the conditions studied (Chernoff *et al.*, 1992). Maffeo *et al.* (1988) and Jauchem (1993) have also suggested that the evidence for any reproductive effects is very weak.

Experimental Animals

There have been over 70 experimental animal and *in vitro* studies that evaluated the effects of low-frequency (30- to 300-kHz) or very low-frequency (30-kHz or less) EMF exposure on some aspect of reproduction or teratology (Delgado *et al.*, 1982; Juutilainen and Saali, 1986; Beers, 1989; Eckert, 1992). Many embryology studies used the chicken embryo to evaluate teratogenesis after 48 to 52 hours of development (Martin, 1992; Brent *et al.*, 1993; Koch *et al.*, 1993). In chicken eggs exposed to magnetic fields, some embryos showed retarded development (Juutilainen and Saali, 1986; Martin, 1988), while in other studies, there were no differences in embryos from exposed or control eggs (Maffeo *et al.*, 1984). Medaka fish eggs exposed to a 1 G 60-Hz magnetic field showed no gross abnormalities, but embryonic growth was retarded (Cameron *et al.*, 1985). Magnetic field exposures inhibited proliferation of sea urchins (Cameron *et al.*, 1993). No reproductive or developmental effects were seen in Sprague-Dawley rats exposed to magnetic fields of up to 10 G, 18.5 hours per day for as long as 6 months (NTP, 1996; Ryan *et al.*, 1996).

Humans

Studies of the reproductive effects of EMF exposures in humans include studies of exposures to video display terminals, power lines, and household appliances. The video display terminal studies were generally negative for reproductive effects, while the reproductive risks of power lines and home appliances were less consistent (Brent *et al.*, 1993). The National Research Council (NRC, 1997) concluded that there was no substantial or conclusive evidence for adverse reproductive effects caused by residential exposure to electric and magnetic fields.

Neuroendocrinologic Toxicity in Experimental Animals

Several studies have suggested that exposure to electric or magnetic fields may suppress nocturnal melatonin concentrations in rodents (Wilson *et al.*, 1986, 1989; Lerchl *et al.*, 1991; Reiter, 1992; Stevens *et al.*, 1992; Anderson, 1993; Stevens, 1993). In one study, serum melatonin concentrations but not pineal gland melatonin synthesis were reduced in Sprague-Dawley rats, suggesting that degradation or tissue uptake of melatonin may be stimulated by exposure to electric fields (Grota *et al.*, 1994). Another study reported that serotonin-*N*-acetyltransferase, the rate-limiting enzyme for melatonin production, may be inhibited by magnetic field exposure (Olcese and Reuss, 1986). No alterations occurred in serum or pineal gland melatonin or pineal gland serotonin-*N*-acetyltransferase in male or female

F344/N rats or B6C3F$_1$ mice exposed to magnetic fields of up to 10 G for 8 weeks (NTP, 1996). In that study, the magnitude of the pineal gland response was evaluated at only one nocturnal time point; consequently, the duration of the melatonin secretion could not be determined. When this study was repeated in mice, with evaluation of pineal gland response at multiple nocturnal time points, no effect of magnetic field exposures was observed. The NTP studies employed linear magnetic fields, and it has been suggested that circularly polarized magnetic fields will cause decreased melatonin concentrations in rats even though linear fields will not (Kato *et al.*, 1994a,b). Melatonin has been reported to be oncostatic (Kerenyi *et al.*, 1990; Reiter, 1992, 1993). Exposure to extremely low-frequency magnetic fields has been shown to block melatonin's growth inhibition of MCF-7 breast cancer cells (Liburdy *et al.*, 1993), and melatonin suppression may be associated with breast cancer, one of the cancers hypothesized to be increased by magnetic field exposure (Stevens *et al.*, 1992). More recent studies have not shown consistent alterations in nocturnal melatonin concentrations in hamsters exposed to 60-Hz magnetic fields (Truong *et al.*, 1996), nor was there an effect on reproductive maturation (Yellon, 1996).

CARCINOGENICITY

Experimental Animals

Several short-term (180-day) rodent carcinogenesis studies of magnetic fields have been conducted (Anderson, 1993). Static magnetic fields did not enhance the development of spontaneous lymphoblastic leukemia in female AKR mice (Bellossi, 1986). In skin tumor promotion models, there has been either a marginal increase in the incidence of skin papillomas with magnetic field exposure (McLean *et al.*, 1991) or no increase in neoplasm rate (Rannug *et al.*, 1993a). In SENCAR mice, intermittent magnetic field exposure was associated with a marginal increase in the number of skin tumors per tumor-bearing animal (Rannug *et al.*, 1994). In three independent studies in SENCAR mice, the results were variable and did not support an effect of magnetic fields on skin tumor promotion in this model (McLean *et al.*, 1997). In Sprague-Dawley rats, there was no increase in the incidence of liver foci following magnetic field exposure (Rannug *et al.*, 1993b); following partial hepatectomy and treatment with the tumor initiator diethylnitrosamine, magnetic field exposure was associated with a slight reduction in size and number of liver foci compared to unexposed controls (Rannug *et al.*, 1993c).

Humans

The potential of magnetic field exposure to promote breast cancer has been suggested by several epidemiology studies, but the data are far from conclusive. Wertheimer and Leeper (1979) and Savitz *et al.* (1988) classified the residences of children by using wire codes as surrogates for predicted magnetic fields within the home (Barnes *et al.*, 1989). Some epidemiology studies of residential exposure showed little or no correlation between estimated home exposure to magnetic fields and incidence of childhood leukemia (Fulton *et al.*, 1980; Ahlbom, 1988; Coleman *et al.*, 1989; Myers *et al.*, 1990). Some epidemiology studies of workplace exposure to EMFs suggested a potential occupational risk for increased leukemia rates (Gilman *et al.*, 1985), while other studies were negative (Fulton *et al.*, 1980; Myers *et al.*, 1990). These studies have been questioned concerning matching controls and tumor groupings (ORAU, 1992). The electric and magnetic field exposures were highly variable in these occupational studies (Deadman *et al.*, 1988), and many other confounding factors have been identified (Greenberg and Shuster, 1985; Michaelson, 1987; Beers, 1989). Thus, neither epidemiology studies nor experimental animal studies have provided conclusive evidence that magnetic fields increase the incidence of cancer or alter the carcinogenic process.

GENETIC TOXICITY

The potential genotoxic effects of low-frequency EMFs have been investigated in a variety of studies covering a broad range of test types and endpoints; thorough reviews of these studies were presented by McCann *et al.* (1993) and Murphy *et al.* (1993). With few exceptions, the data from laboratory experiments support the conclusion that low-frequency EMFs, as well as electric and magnetic fields separately, present little if any risk of induced genetic damage under the conditions of investigation. It is generally accepted that the energy from low-frequency electromagnetic radiation is insufficient to produce direct DNA damage (Kavet, 1996). However, electric field exposures characterized by sparking, high-intensity pulsing, or corona effects may represent a greater genotoxic risk, although the information from studies that involved such exposures is not definitive

(McCann *et al.*, 1993; Murphy *et al.*, 1993). Reports of significantly increased chromosomal aberration frequencies in peripheral blood lymphocytes of switchyard workers exposed to 50-Hz sinusoidal EMFs, electric shocks, and other hazards of this workplace environment (Nordenson *et al.*, 1984, 1988) and of dose-related increases in micronuclei in bone marrow cells of mice exposed to 50-Hz sinusoidal electrical fields of varying intensities (170 to 290 kV/m) (El Nahas and Oraby, 1989) raised a concern about the genetic effects of these exposures. However, neither of these studies has been independently confirmed, and numerous *in vitro* investigations of chromosomal or mutational effects conducted under carefully controlled and defined laboratory conditions with human cells (Nordenson *et al.*, 1984; Cohen *et al.*, 1986a,b; Rosenthal and Obe, 1989; Livingston *et al.*, 1991; Scarfi *et al.*, 1991) and rodent cells (Wolff *et al.*, 1980; Livingston *et al.*, 1991; Fiorio *et al.*, 1993; Suri *et al.*, 1996) have not confirmed the potential for EMF-induced genetic damage. Also, results from DNA repair (Pino *et al.* 1985; Whitson *et al.*, 1986; Reese *et al.*, 1988; Frazier *et al.*, 1990) and DNA damage (Fairbairn and O'Neill, 1994; Antonopoulos *et al.*, 1995) studies with mammalian cells exposed to EMFs were negative, as were results from bacterial mutagenicity assays (Moore, 1979; Thomas and Morris, 1981; Juutilainen and Liimatainen, 1986; Shimizu *et al.*, 1989; Morandi *et al.*, 1996).

Effects of electric and magnetic fields on biological systems that might potentially be related to cancer induction may include enhancement of cell proliferation, and earlier studies have been reviewed (McCann *et al.*, 1993; Murphy *et al.*, 1993). Investigations of the effects of EMF exposure on cell cycle progression have yielded mixed results, and possible modes of action whereby EMFs might enhance cell proliferation have not been determined (Murphy *et al.*, 1993; Kavet, 1996). Livingston *et al.* (1991) and Miyakoshi *et al.* (1996) found no exposure-related changes in clonogenicity and/or cell cycle time of Chinese hamster ovary cells cultured for at least 96 hours in the presence of 60-Hz electromagnetic or magnetic fields, and Cridland *et al.* (1996) detected no effects on the rate of DNA synthesis, a measure of cell proliferation, in normal human fibroblasts exposed to 50-Hz magnetic fields for up to 30 hours. Other investigators have reported stimulation of human peripheral blood lymphocyte proliferation *in vitro* after exposure to 50-Hz, 50 G EMFs (Rosenthal and Obe, 1989; Antonopoulos *et al.*, 1995) or 50-Hz pulsed magnetic fields (Scarfi *et al.*, 1994).

The possible effects of EMF exposure on epigenetic endpoints, such as transcriptional activation or modulation of gene expression, have been investigated at a number of laboratories with conflicting results (Blank *et al.*, 1992; Goodman *et al.*, 1992, 1994a,b; Phillips, 1993; Gold *et al.*, 1994; Libertin *et al.*, 1994; Saffer and Thurston, 1995). For example, exposure to extremely low-frequency EMFs was reported to stimulate transcription of c-fos, c-jun, c-myc and/or protein kinase C genes in various cell types, including human HL60, mouse myeloma, and yeast cells (Wei *et al.*, 1990; Goodman *et al.*, 1992, 1994a,b; Phillips, 1993; Lin *et al.*, 1994). However, Lacy-Hulbert *et al.* (1995) were unable to duplicate the c-myc transcriptional stimulation in HL60 human leukemic cells, despite the use of carefully controlled experimental protocols and a variety of sophisticated analytical methods capable of detecting very small alterations in transcriptional activation. In addition, Saffer and Thurston (1995) used ribonuclease protection assays as another sensitive means of measuring transcriptional activation in HL60 cells exposed to extremely low-frequency EMFs and found no alterations in gene expression. Furthermore, Miyakoshi *et al.* (1996) reported that similar exposure of cultured Chinese hamster ovary cells to 60-Hz EMFs did not alter cell growth rate or expression of c-myc. Several reviews of the controversial reports of transcriptional modulation following EMF exposures are found in the literature (Adair, 1992; Florig, 1992; Phillips, 1993; Lacy-Hulbert *et al.*, 1995; Blank and Goodman, 1997), and the current consensus among investigators in the field is that observations of transcriptional stimulation resulted from unique experimental conditions that could not be duplicated in any of several independent laboratories under carefully monitored conditions.

In summary, although a number of well-designed and conducted genotoxicity experiments with EMFs have been published, not all types of exposures nor all of the commonly employed assays have been used, and many studies are deficient in design, conduct, or reporting format (McCann *et al.*, 1993; Murphy *et al.*, 1993). Accordingly, the accumulated evidence implies little risk of direct genetic damage from EMF exposure.

STUDY RATIONALE AND DESIGN

In 1988, in response to an epidemiology report by Savitz *et al.* (1988) that appeared to confirm an earlier study by Wertheimer and Leeper (1979), the Department of Energy and the Electric Power Research Institute (EPRI) nominated 60-Hz (power line frequency) electric and magnetic fields to the NIEHS to be considered for evaluation by the NTP. In 1990, the National Association of Regulatory Utility Commissioners (representing all 50 states; Washington, DC; Puerto Rico; and the Virgin Islands) and the Large Public Power Council (representing 17 of the largest publicly owned utilities in the United States) requested that the NIEHS undertake studies to evaluate the unresolved potential hazard of exposure to electric and magnetic fields. Therefore, given the widespread exposure to low intensity, 60-Hz magnetic fields in industrialized societies, standard toxicology studies and long-term carcinogenesis studies were conducted using the traditional rodent models.

Because several effects have been reported in the literature, a draft protocol was circulated to approximately 80 experts to solicit comments on appropriate studies for magnetic field evaluation. The toxicity, developmental, and reproductive studies preceded the carcinogenicity studies. The standard toxicity studies in F344/N rats and $B6C3F_1$ mice included evaluation of pineal gland function in addition to the standard histopathology, hematology, and clinical chemistry evaluations. Standard comprehensive protocols for the assessment of developmental toxicology in female Sprague-Dawley rats and for a continuous breeding study in Sprague-Dawley rats (the usual strain and species for NTP assessment of developmental and reproductive effects) were included. The few existing animal studies were generally short-term promotion studies and not long-term studies that would address the potential carcinogenic hazard of magnetic fields, such as the studies that have traditionally been conducted by the NTP. There was no indication of magnetic field toxicity in any of these studies (NTP, 1996; Ryan *et al.*, 1996; Boorman *et al.*, 1997).

Because electric and magnetic field exposures are very complex and a vast combination of field parameters could be evaluated, the circulated draft protocol solicited comments on appropriate field parameters for evaluation. A workshop was held at NIEHS to assist in determining the field parameters for study. While there are different frequencies of exposure in homes with different appliances, and 50 Hz is the predominant field frequency in western Europe and Japan, the predominant frequency in United States homes is 60 Hz; therefore, it was decided that all exposures would use a 60-Hz frequency.

The field intensities were limited by design considerations. The creation of magnetic fields for animal exposure requires large coils. As field intensities increase, noise, heat, vibration, and stray fields become a problem for technicians and control animals. A manageable maximum field intensity of 10 G was selected for the present studies; this is approximately 5,000-fold greater than what was considered high intensity for homes in the epidemiology studies. Because it was possible that on-and-off changes in the magnetic field, and not necessarily the field intensity itself, were important, a second high-intensity group was included, with 1-hour-on and 1-hour-off exposures. Because current density within a body is related to the body volume and shape, the exposure levels for rodents needs to be increased to obtain similar current densities (Xi *et al.*, 1994); thus, the lowest field intensity used in the present studies (0.02 G) gives rodents an exposure that may be slightly higher than residential exposures for humans. A third field intensity, 2 G, intermediate between the other two field intensities, was also used.

While power line magnetic field exposures are predominantly sine-wave fields, residential and occupational exposures may include square waves, sawtooth waves, and other wave forms. Harmonics (120 Hz, 180 Hz, etc.) may also be found. Further, as appliances are switched on and off, spikes or transients in fields may occur. It is not feasible to evaluate all possible variables in large animal studies. Therefore, this study used linearly polarized, pure sine-wave exposures at 60 Hz, with the fields turned on when the sine wave was at zero amplitude and gradually increased over seven to nine cycles (between 0.11 and 0.15 seconds) to full intensity, and similarly gradually decreased to avoid transients. The NIEHS studies evaluate the predominant component (60-Hz sine-wave magnetic fields) without all the complexities of the exposures that occur in residential and occupational settings.

To increase the statistical power for detecting potential carcinogenic effects, sample sizes in the 2-year studies

were increased from the usual 50 animals per group to 100 per group. The gain in power achieved by these additional animals depends upon the background neoplasm rate and the magnitude of the response. For example, for a site with a background incidence of 20%, the likelihood that a doubling of neoplasm incidence would be significant at a P value less than 0.05 is approximately 64% for groups of 50 animals, whereas with groups of 100 the likelihood of detection increases to 91%.

According to a National Research Council report (NRC, 1997), there is no conclusive and consistent evidence that exposure to residential electric and magnetic fields produces cancer, adverse neurobehavioral effects, or reproductive and developmental effects. The report failed to make conclusions relative to evidence of occupational exposure, but noted an association between residential wiring configurations and childhood leukemia. However, the contradictory report of Linet *et al.* (1997) found no association between childhood leukemia and wiring codes, although a small increased risk for childhood leukemia was associated with residential exposures of about 3 mG. Many scientists still consider the question of an association of increased risk for cancer with residential or occupational exposure to magnetic fields unresolved.

Funds authorized by the Energy Policy Act of 1992 supported additional animal studies to evaluate initiation/promotion in rats using a breast cancer model (Mevissen *et al.*, 1993) and pineal gland function and ornithine decarboxylase activity in rats exposed to harmonic fields, 60-Hz fields with transients, and intermittent fields. The initiation/promotion breast carcinogenicity studies, which have obvious implications for the interpretation of the 2-year carcinogenicity studies, are reported in NTP Technical Report 489 (NTP, 1999).

MATERIALS AND METHODS

MAGNETIC FIELD PRODUCTION AND MONITORING

The magnetic field exposure facility consisted of five animal exposure rooms, storage rooms, cage washing facilities, a necropsy facility, an engineering control room for the generation and monitoring of fields and room conditions, access corridors, and showers and changing rooms for laboratory technicians (Figure E1). Offset coils in the exposure rooms and in storage rooms between the exposure rooms were used to minimize stray fields. The engineering control room contained the generator that produced the current that supplied the coils in each exposure room and monitors for induced and stray 60-Hz magnetic fields and for the collection of humidity, temperature, sound, vibration, ventilation, and light data. The engineering control room was outside the range of stray magnetic fields above 1 mG.

Each coil set consisted of seven pairs of rectangular, vertically oriented coils connected in series and spaced uniformly through the room. The coil sets were stacked one above the other; the bottom coils produced a linear 60-Hz magnetic field in one direction while the top coils produced a similar field in the opposite direction (Figure E2). The coil position in each room protected against field overlap between rooms. The opposing fields produced by the coil sets largely canceled each other outside the area of the exposure room. Additional field cancellation was provided by horizontally positioned steering coils located at the ends of each coil set. Compensating capacitors were located between each coil to cancel the inductive reactance at 60 Hz and to control the voltage differential between adjacent coils.

Coils were held in place by fiberglass supports and were protected from moisture by Plexiglas™ enclosures. Durometer™ neoprene pads between the coils and supports isolated coil vibrations. Each coil set was controlled from the engineering control room. The fields in three rooms had intensities of 0.02, 2, and 10 G, and the field in a fourth room was manipulated to produce an intermittent 10-G field (1 hour on and 1 hour off). Harmonic distortion was less than 3%. A fifth room with an identical coil apparatus that was not operating served as the control animal exposure room. Fiberglass cage racks were constructed to prevent disruption of the induced magnetic fields. The stainless steel automatic watering system was designed and configured to eliminate possible current loops. Fiberglass guides and floor plates were located in each room to provide precise alignment of racks and cages within the magnetic field. Racks held equal numbers of polycarbonate cages in either the top or the bottom field of the coil sets (Figure E2). Cages were alternated between the top and bottom linear horizontal fields on a weekly basis. The field uniformity within the cage area was within $\pm$ 10% of the targeted field intensity (Appendix E). Measurements of field intensities showed that the maximum deviations from the target field levels occurred at the extreme corners of the cages.

Induced alternating 60-Hz magnetic fields were monitored by a MultiWave™ Monitoring System (Electric Research and Management, Inc., Pittsburgh, PA), which consisted of a microcomputer, an external tie-in, and data multiplexors that were located in the control room. In animal exposure rooms, monitoring system components included a series of three-axis alternating-current magnetic field probes (two per room), alternating-current voltage probes, and environmental sensor probes (to measure rack vibration, noise, light intensity, temperature, and humidity). The magnetic probes, which were located at the end of each exposure module in the center of the steering coils to detect faults in the coils, allowed monitoring of the ambient magnetic fields during the "off" periods of intermittent exposure and during daily field shutdowns. The computer program (WAVE-C) continuously monitored and collected sensor data. Data samples were electronically stored every 30 minutes, and data were off-loaded from the system on a daily basis. The system was equipped with alarms to alert project personnel in the event that measured parameters deviated from set ranges.

Average field intensities measured during the 2-year studies are given in Table E1. All daily mean intensities were within 10% of the target; the maximum magnetic field intensity in the control animal exposure room did not exceed 1.3 mG. There was some variation in the mean magnetic field strengths since the field controllers did not tightly regulate line voltage from the commercial power grid. These variations were on the order of a few percent or less and may be similar to what would occur in a residence. The field controllers did reduce harmonics and provide protection from over-voltage and brown-outs. The sham exposure field intensities were due to field sources outside the facility such as distribution lines buried in adjacent streets and street lighting circuits. While these background fields were variable, the sham exposure fields were nearly always less than 1 mG. The groups of animals were rotated from room to room every 10 weeks, so each of the five animal exposure rooms served as the control exposure room twice during the 2-year study (a final rotation was not carried out for the last 4 weeks). This served to minimize environmental effects of each room and the variation between the earth's static magnetic fields with different exposure regimens.

FACILITY VALIDATION

During a preliminary study, an animal rack equipped with eight thermocouples was placed in each animal room to record cage temperatures when fields were on and off. No differences in temperature were found with magnetic field exposures. In addition, the exposure system was validated by a representative of the National Institute of Standards and Technology (NIST), who found that the intensities and spatial uniformity of the earth's static magnetic fields within the animal exposure area were consistent with the expected intensities in the Chicago area (approximately 300 to 400 mG) (Table E2). Using a NIST fluxgate magnetometer, measurements were made of the direct-current magnetic field component that was parallel to the direction of the alternating-current magnetic field in each exposure room in a north-south direction. The measurements were performed in the top and bottom coil systems at the level of the rat and mouse enclosures in each exposure bay. The results are presented in Table E3. The calibration uncertainty of the fluxgate magnetometer was estimated to be less than 2%; however, the measurements are sensitive to probe alignment because of the nonuniformity of the field and the presence of a significant vertical magnetic field component. The full NIST validation report is presented in Appendix F.

2-YEAR STUDIES

Study Design

Groups of 100 male and 100 female rats and mice were exposed to 60-Hz magnetic fields at intensities of 0.02, 2, or 10 G for 18.5 hours per day, 7 days per week, for 106 weeks. The exposure was continuous for 4 hours (11 a.m. to 3 p.m.), discontinued for 1.5 hours (3 p.m. to 4:30 p.m.), continuous for 14.5 hours (4:30 p.m. to 7 a.m.), and then discontinued for an additional 4 hours (7 a.m. to 11 a.m.). Gaps in exposure allowed for animal husbandry and observation. Groups of 100 male and 100 female control rats and mice were housed in the same exposure chambers without applied magnetic fields. Groups of 100 male and female rats and mice were intermittently exposed (1 hour on and 1 hour off, starting at 11 a.m.) to a 10 G 60-Hz field for 18.5 hours per day, 7 days per week, for 106 weeks, with similar 1.5- and 4-hour gaps in exposure.

Source and Specification of Animals

Male and female F344/N rats and $B6C3F_1$ mice were obtained from Taconic Farms (Germantown, NY). Rats were quarantined for 11 or 12 days before the beginning of the studies; mice were quarantined for 13 or 14 days. Five male and five female rats and mice were randomly selected for parasite evaluation and gross observation of disease. Rats and mice were 6 to 7 weeks old at the beginning of the studies. The health of the animals was monitored during the studies according to the protocols of the NTP Sentinel Animal Program (Appendix H).

Animal Maintenance

Rats and female mice were housed five per cage; male mice were housed individually. Feed and water were available *ad libitum*. Further details of animal maintenance are given in Table 1. Information on feed composition and contaminants is provided in Appendix G.

Clinical Examinations and Pathology

All animals were observed twice daily. Animals were weighed on the first exposure day, weekly through week 12, monthly until week 93, and then every 2 weeks until the end of the study. Clinical observations were recorded monthly.

A complete necropsy and microscopic examination were performed on all rats and mice. At necropsy, all organs and tissues were examined for grossly visible lesions, and all major tissues were fixed and preserved in 10% neutral buffered formalin, processed and trimmed, embedded in paraffin, sectioned to a thickness of 4 to 6 μm, and stained with hematoxylin and eosin for microscopic examination. For all paired organs (e.g., adrenal gland, kidney, ovary), samples from each organ were examined. Recuts of tissue are routinely taken if the original section contains an inadequate amount or altered tissue (e.g., folds) that may interfere with adequate microscopic assessment and interpretation. In this study, the number of tissue recuts that included thyroid gland C-cell tissue was higher in some groups than others. This small sample bias was corrected by getting recuts of thyroid gland C-cell tissue from all male rats for which recuts were not originally taken. As a result, there were two sections (rarely three) of thyroid gland C-cell tissue for each male rat. Tissues examined microscopically are listed in Table 1.

Microscopic evaluations were completed by the study laboratory pathologist, and the pathology data were entered into the Toxicology Data Management System. The slides, paraffin blocks, and residual wet tissues were sent to the NTP Archives for inventory, slide/block match, and wet tissue audit. The slides, individual animal data records, and pathology tables were evaluated by an independent quality assessment laboratory. The individual animal records and tables were compared for accuracy, the slide and tissue counts were verified, and the histotechnique was evaluated.

For the 2-year rat studies, a quality assessment pathologist reviewed the adrenal medulla (males only) and mammary gland (females only) for all diagnoses. The following were reviewed by a quality assessment pathologist for all diagnoses of proliferative lesions specific to the site: adrenal cortex, brain, liver, thyroid gland C-cell, and pancreatic islets (males only). The pineal gland was reviewed for degeneration, and the spleen for hematopoietic cell proliferation (females only). The liver and spleen were reviewed for all diagnoses of lymphoproliferative neoplasms (including histiocytic sarcoma). The following were reviewed by a quality assessment pathologist only when the specific diagnoses had been made: kidney necrosis, mammary gland fibroadenoma, preputial gland adenoma, carcinoma, and focal hyperplasia, and seminal vesicle adenoma in male rats; all skin neoplasms in male and female rats; and uterus deciduoma in female rats.

For the 2-year mouse studies, the following were reviewed by a quality assessment pathologist for all diagnoses of proliferative lesions specific to the site: brain, lung, and uterus (females only). The following were reviewed for all diagnoses of hematopoietic proliferative neoplasms (including histiocytic sarcoma): liver, spleen, thymus, and mesenteric and mandibular lymph nodes. The prostate was reviewed for cysts. The following were reviewed by a quality assessment pathologist only when the specific diagnoses had been made: kidney carcinoma, nose sarcoma, prostate adenoma and carcinoma, and seminal vesicle adenoma and carcinoma in male mice; and nose rhabdomyosarcoma, liver adenoma, and hemangiosarcoma of the bone, skeletal muscle, and liver in female mice.

The quality assessment report and the reviewed slides were submitted to the NTP Pathology Working Group (PWG) chairperson, who reviewed selected tissues and addressed any inconsistencies in the diagnoses made by the laboratory and quality assessment pathologists. Representative histopathology slides containing examples of lesions related to chemical administration, examples of disagreements in diagnoses between the laboratory and quality assessment pathologists, or lesions of general interest were presented by the chairperson to the PWG for review. The PWG consisted of the quality assessment pathologist and other pathologists experienced in rodent toxicologic pathology. This group examined the tissues without any knowledge of dose groups or previously rendered diagnoses. When the PWG consensus differed from the opinion of the laboratory pathologist, the diagnosis was changed. Final diagnoses for reviewed lesions represent a consensus between laboratory pathologists, reviewing pathologist(s), and the PWG. Details of these review procedures have been described, in part,

by Maronpot and Boorman (1982) and Boorman *et al*. (1985). For subsequent analyses of the pathology data, the decision of whether to evaluate the diagnosed lesions for each tissue type separately or combined was generally based on the guidelines of McConnell *et al*. (1986).

TABLE 1
Experimental Design and Materials and Methods in the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

Study Laboratory
IIT Research Institute (Chicago, IL)

Strain and Species
Rats: F344/N
Mice: $B6C3F_1$

Animal Source
Taconic Farms (Germantown, NY)

Time Held Before Studies
Rats: 11-12 days
Mice: 13-14 days

Average Age When Studies Began
6-7 weeks

Date of First Exposure
Because of the size of study groups, there were two cohorts each for male and female rats and mice.
Rats: 26 September or 17 October 1994 (males)
27 September or 18 October 1994 (females)
Mice: 5 or 26 October 1994 (males)
6 or 27 October 1994 (females)

Duration of Exposure
18.5 hours per day, 7 days per week, for 106 weeks

Date of Last Exposure
Rats: 1 or 23 October 1996 (males)
4 or 25 October 1996 (females)
Mice: 9 or 30 October 1996 (males)
11 October 1996 or 1 November 1996 (females)

Necropsy Dates
Rats: 30 September and 1 October 1996 or 21-23 October 1996 (males)
2-4 October 1996 or 23-25 October 1996 (females)
Mice: 7-9 October 1996 or 28-30 October 1996 (males)
9-11 October 1996 or 30 October-1 November 1996 (females)

Average Age at Necropsy
112-113 weeks

Size of Study Groups
100 males and 100 females

Method of Distribution
Animals were distributed randomly into groups of approximately equal initial mean body weights.

TABLE 1
Experimental Design and Materials and Methods in the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

Animals per Cage
5 (rats and female mice)
1 (male mice)

Method of Animal Identification
Tail tattoo

Diet
NTP-2000 open formula pelleted diet (Zeigler Brothers, Inc., Gardners, PA), available *ad libitum*, changed daily

Water
Tap water (Chicago municipal supply) via automatic watering system (SE Lab group, Cincinnati, OH), available *ad libitum*

Cages
Polycarbonate (Lab Products Inc., Maywood, NJ), changed twice weekly (rats and female mice) or once weekly (male mice)

Bedding
Beta-Chips® (Northeastern Products Corp., Warrensburg, NY), changed twice weekly (rats and female mice) or once weekly (male mice)

Cage Filters
Flat non-woven sheets (Lab Products Inc., Maywood, NJ), changed every 2 weeks

Racks
Fiberglass (fabricated on site), cages rotated in racks twice weekly, racks rotated within room once weekly, and exposure groups rotated between exposure rooms every 10 weeks, except before the final 4 weeks

Animal Room Environment
Temperature: 21.5°-23.4° C
Relative humidity: 37%-61%
Room fluorescent light: 12 hours/day
Room air changes: 10/hour

Exposure Levels
Continuous exposure: 0, 0.02, 2, or 10 G, 18.5 hours per day, 7 days per week
Intermittent exposure: 10 G (1 hour on and 1 hour off), 18.5 hours per day, 7 days per week

Type and Frequency of Observation
Observed twice daily; animals were weighed on the first exposure day, weekly through week 12, monthly until week 93, and then every 2 weeks until the end of the study; clinical observations were recorded monthly.

Method of Sacrifice
CO_2 asphyxiation

Necropsy
Necropsy was performed on all animals.

Histopathology
Complete histopathologic examinations were performed on all rats and mice. In addition to gross lesions and tissue masses, the tissues examined included: adrenal gland, bone with marrow, brain, clitoral gland, esophagus, gallbladder (mice), harderian gland, heart with aorta, large intestine (cecum, colon, and rectum), small intestine (duodenum, jejunum, and ileum), kidney, liver, lung, lymph nodes (mandibular and mesenteric), mammary gland (except male mice), nose, ovary, pancreas, parathyroid gland, pineal gland, pituitary gland, preputial gland, prostate gland, salivary gland, spleen, stomach (forestomach and glandular), testis with epididymis and seminal vesicle, thymus, thyroid gland, trachea, urinary bladder, and uterus.

STATISTICAL METHODS

Survival Analyses

The probability of survival was estimated by the product-limit procedure of Kaplan and Meier (1958) and is presented in the form of graphs. Animals found dead of other than natural causes or removed from the study for other reasons were censored from the survival analyses; animals dying from natural causes were not censored. Statistical analyses for possible dose-related effects on survival used Cox's (1972) method for testing two groups for equality and Tarone's (1975) life table test to identify dose-related trends. All reported P values for the survival analyses are two sided.

Calculation of Incidence

The incidences of neoplasms or nonneoplastic lesions are presented in Tables A1, A3, B1, B3, C1, C3, D1, and D3 as the numbers of animals bearing such lesions at a specific anatomic site and the numbers of animals with that site examined microscopically. For calculation of statistical significance, the incidences of most neoplasms (Tables A2, B2, C2, and D2) and all nonneoplastic lesions are given as the numbers of animals affected at each site examined microscopically. However, when macroscopic examination was required to detect neoplasms in certain tissues (e.g., harderian gland, intestine, mammary gland, and skin) before microscopic evaluation, or when neoplasms had multiple potential sites of occurrence (e.g., leukemia or lymphoma), the denominators consist of the number of animals on which a necropsy was performed. Tables A2, B2, C2, and D2 also give the survival-adjusted neoplasm rate for each group and each site-specific neoplasm. This survival-adjusted rate (based on the Poly-3 method described below) accounts for differential mortality by assigning a reduced risk of neoplasm, proportional to the third power of the fraction of time on study, to animals that do not reach terminal sacrifice.

Analysis of Neoplasm and Nonneoplastic Lesion Incidences

The Poly-k test (Bailer and Portier, 1988; Portier and Bailer, 1989; Piegorsch and Bailer, 1997) was used to assess neoplasm and nonneoplastic lesion prevalence. This test is a survival-adjusted quantal-response procedure that modifies the Cochran-Armitage linear trend test to take survival differences into account. More specifically, this method modifies the denominator in the quantal estimate of lesion incidence to approximate more closely the total number of animal years at risk. For analysis of a given site, each animal is assigned a risk weight. This value is one if the animal had a lesion at that site or if it survived until terminal sacrifice; if the animal died prior to terminal sacrifice and did not have a lesion at that site, its risk weight is the fraction of the entire study time that it survived, raised to the kth power.

This method yields a lesion prevalence rate that depends only upon the choice of a shape parameter for a Weibull hazard function describing cumulative lesion incidence over time (Bailer and Portier, 1988). Unless otherwise specified, a value of $k=3$ was used in the analysis of site-specific lesions. This value was recommended by Bailer and Portier (1988) following an evaluation of neoplasm onset time distributions for a variety of site-specific neoplasms in control F344 rats and $B6C3F_1$ mice (Portier *et al.*, 1986). Bailer and Portier (1988) showed that the Poly-3 test gave valid results if the true value of k was anywhere in the range from 1 to 5. A further advantage of the Poly-3 method is that it does not require lesion lethality assumptions. Variation introduced by the use of risk weights, which reflect differential mortality, was accommodated by adjusting the variance of the Poly-3 statistic as recommended by Bieler and Williams (1993).

Tests of significance included pairwise comparisons of each exposed group with controls and a test for an overall exposure-related trend. Continuity-corrected tests were used in the analysis of lesion incidence, and reported P values are one sided. Values of P greater than 0.5 are presented as 1–P with the letter N added to indicate a lower incidence or negative trend in neoplasm occurrence relative to the control group (e.g., P=0.99 is presented as P=0.01N).

QUALITY ASSURANCE METHODS

The 2-year studies were conducted in compliance with Food and Drug Administration Good Laboratory Practice Regulations (21 CFR, Part 58). In addition, as records from the 2-year studies were submitted to the NTP Archives, these studies were audited

retrospectively by an independent quality assurance contractor. Separate audits covered completeness and accuracy of the pathology data, pathology specimens, final pathology tables, and a draft of this NTP Technical Report. Audit procedures and findings are presented in the reports and are on file at the National Institute of Environmental Health Sciences. The audit findings were reviewed and assessed by NTP staff, and all comments were resolved or addressed during the preparation of this Technical Report.

RESULTS

RATS

2-YEAR STUDY

Survival

Estimates of 2-year survival probabilities for male and female rats are shown in Table 2 and in the Kaplan-Meier survival curves (Figure 1). Survival of exposed rats was similar to that of control rats.

Body Weights and Clinical Findings

Mean body weights of exposed groups of male and female rats were similar to those of the control groups throughout the study (Figure 2; Tables 3 and 4). There were no exposure-related clinical findings.

TABLE 2
Survival of Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Male					
Animals initially in study	100	100	100	100	100
Other[a]	0	1	0	0	1
Moribund	29	32	32	36	33
Natural deaths	14	21	21	16	7
Animals surviving to study termination	57	46	47	48	59
Percent probability of survival at end of study[b]	57	47	47	48	60
Mean survival (days)[c]	692	678	684	675	688
Survival analysis[d]	P=0.583[e]	P=0.197	P=0.282	P=0.244	P=0.923N
Female					
Animals initially in study	100	100	100	100	100
Other[a]	1	0	0	1	0
Moribund	22	15	22	19	23
Natural deaths	18	17	18	19	19
Animals surviving to study termination	59[f]	68[g]	60	61[g]	58
Percent probability of survival at end of study	60	68	60	62	58
Mean survival (days)	692	705	697	686	684
Survival analysis	P=0.988	P=0.244N	P=0.884N	P=0.719N	P=0.877

[a] Censored from survival analyses
[b] Kaplan-Meier determinations
[c] Mean of all deaths (uncensored, censored, and terminal sacrifice)
[d] The result of the life table trend test (Tarone, 1975) is in the control column, and the results of the life table pairwise comparisons (Cox, 1972) with the controls are in the exposed group columns. A lower mortality in an exposure group is indicated by **N**.
[e] Intermittent group not included in trend test analysis
[f] Includes one animal that died during the last week of the study
[g] Includes two animals that died or were sacrificed moribund during the last week of the study

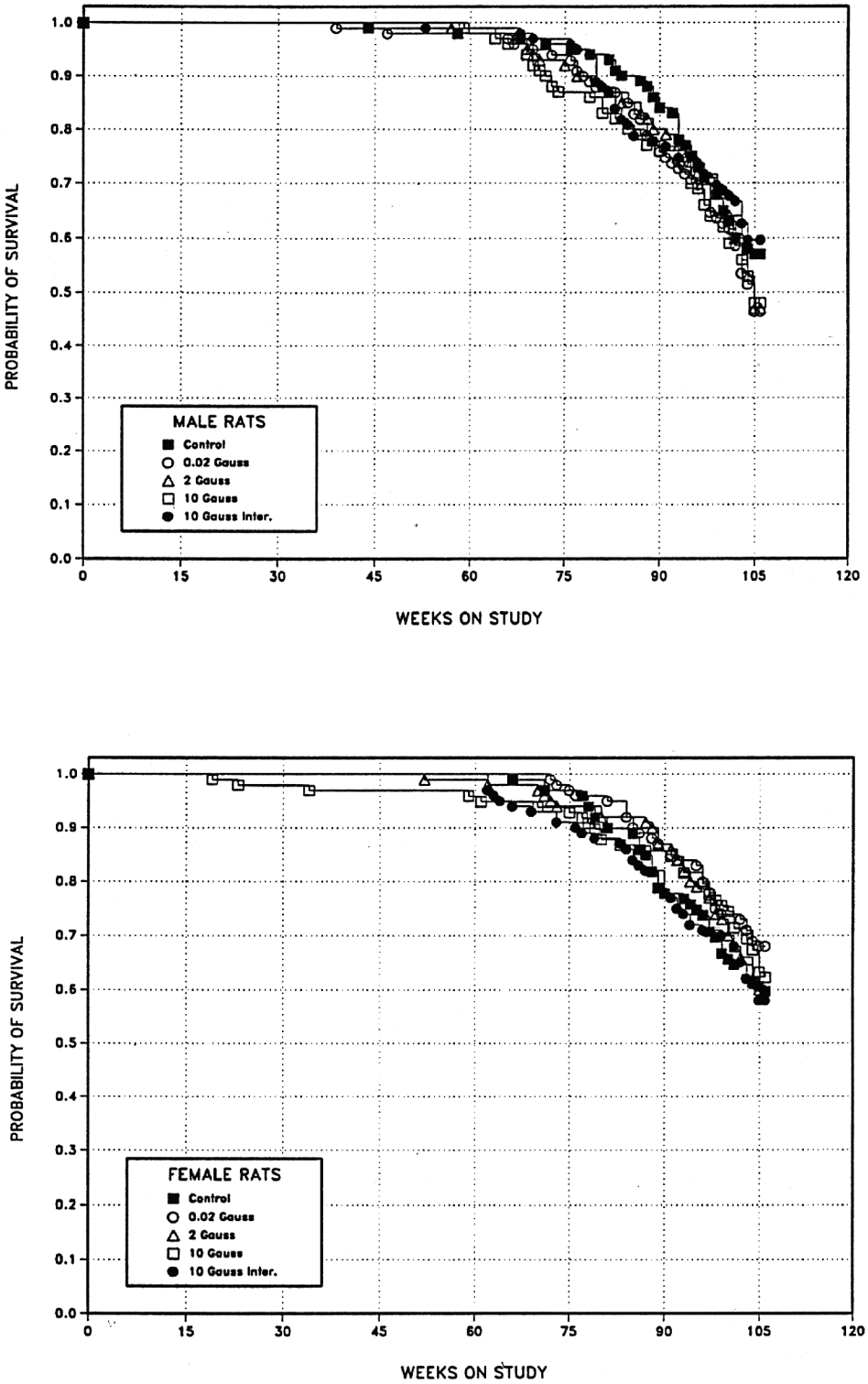


FIGURE 1
Kaplan-Meier Survival Curves for Male and Female Rats Exposed to 60-HZ Magnetic Fields for 2 Years

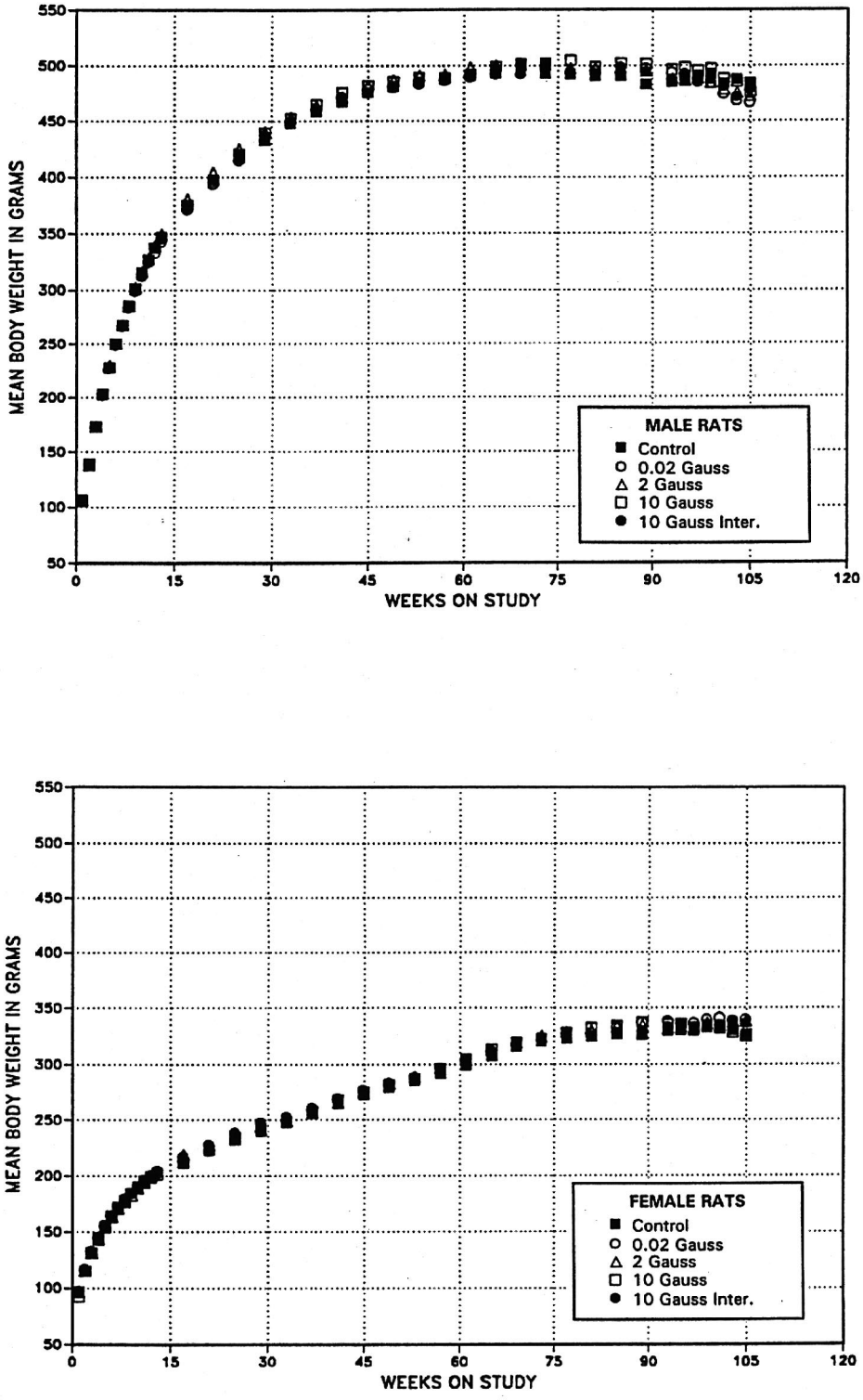


FIGURE 2
Growth Curves for Male and Female Rats Exposed to 60-HZ Magnetic Fields for 2 Years

TABLE 3
Mean Body Weights and Survival of Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	Control		0.02 G			2 G		
	Av. Wt. (g)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	107	100	106	99	100	106	99	100
2	138	100	138	100	100	138	100	100
3	173	100	173	100	100	173	100	100
4	202	100	202	100	100	203	101	100
5	228	100	227	100	100	230	101	100
6	250	100	249	100	100	250	100	100
7	267	100	267	100	100	268	100	100
8	286	100	284	99	100	285	100	100
9	301	100	299	100	100	302	101	100
10	315	100	312	99	100	316	100	100
11	327	100	324	99	100	328	100	100
12	337	100	333	99	100	339	101	100
13	347	100	343	99	100	349	101	100
17	375	100	371	99	100	380	101	100
21	398	100	394	99	100	404	102	100
25	417	100	415	100	100	425	102	100
29	433	100	433	100	100	440	102	100
33	448	100	448	100	100	454	101	100
37	459	100	461	101	100	464	101	100
41	467	100	472	101	99	472	101	100
45	476	99	479	101	99	482	101	100
49	482	99	482	100	98	487	101	100
53	485	99	485	100	98	491	101	100
57	488	99	487	100	98	492	101	100
61	491	98	490	100	97	498	102	98
65	494	98	493	100	97	500	101	98
69	495	97	493	100	95	501	101	97
73	493	96	496	101	94	501	102	93
77	492	95	494	100	92	498	101	92
81	491	94	496	101	87	498	101	89
85	491	90	494	101	86	498	102	85
89	483	88	498	103	78	496	103	82
93	485	82	494	102	73	488	101	79
95	486	77	493	101	71	487	100	75
97	491	73	488	99	69	489	100	72
99	493	71	485	98	64	485	98	71
101	484	65	475	98	62	479	99	65
103	488	60	469	96	58	476	98	64
105	484	58	467	96	51	473	98	53
Mean for weeks								
1-13	252		251	100		253	100	
14-52	439		439	100		445	101	
53-105	489		488	100		491	100	

TABLE 3
Mean Body Weights and Survival of Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	10 G			10 G Intermittent		
	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	105	99	100	106	99	100
2	139	101	100	139	101	100
3	173	100	100	172	100	100
4	203	101	100	202	100	100
5	228	100	100	227	100	100
6	250	100	100	249	100	100
7	268	100	100	266	100	100
8	285	100	100	285	100	100
9	301	100	100	300	100	100
10	316	100	100	313	99	100
11	327	100	100	326	100	100
12	338	100	100	337	100	100
13	347	100	100	345	100	100
17	375	100	100	373	99	100
21	397	100	100	396	100	100
25	420	101	100	420	101	100
29	439	102	100	437	101	100
33	452	101	100	450	101	100
37	465	101	100	462	101	100
41	476	102	100	470	101	100
45	482	101	100	475	100	99
49	486	101	100	480	100	99
53	489	101	100	483	100	99
57	489	100	100	488	100	98
61	492	100	99	492	100	98
65	499	101	97	497	101	98
69	502	101	96	502	101	97
73	502	102	90	501	102	96
77	505	103	87	495	101	95
81	499	102	86	493	101	88
85	502	102	82	499	102	81
89	502	104	77	495	102	78
93	497	102	76	488	101	76
95	498	102	73	492	101	74
97	496	101	68	485	99	73
99	498	101	64	487	99	70
101	488	101	62	481	100	68
103	486	100	59	472	97	66
105	476	98	53	478	99	59
Mean for weeks						
1-13	252	100		251	100	
14-52	444	101		440	100	
53-105	495	101		489	100	

TABLE 4
Mean Body Weights and Survival of Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	Control		0.02 G			2 G		
	Av. Wt. (g)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	97	100	97	100	100	97	100	100
2	116	100	116	101	100	115	100	100
3	131	100	133	101	100	131	100	100
4	144	100	145	101	100	144	100	100
5	154	100	155	101	100	155	100	100
6	164	100	165	100	100	163	100	100
7	172	100	172	100	100	171	99	100
8	178	100	178	100	100	177	100	100
9	184	100	184	100	100	182	99	100
10	190	100	190	100	100	189	99	100
11	195	100	194	99	100	194	99	100
12	199	100	199	100	100	200	100	100
13	203	100	202	99	100	204	100	100
17	213	100	213	100	100	219	103	100
21	223	100	222	100	100	227	102	100
25	232	100	233	100	100	234	101	100
29	240	100	240	100	100	242	101	100
33	248	100	249	101	100	249	101	100
37	255	100	259	102	100	256	100	100
41	264	100	268	102	100	266	101	100
45	272	100	276	101	100	275	101	100
49	279	100	282	101	100	282	101	100
53	285	100	289	101	100	289	101	99
57	292	100	297	102	100	296	102	99
61	299	100	303	102	100	304	102	99
65	307	100	311	101	100	313	102	98
69	315	99	317	101	100	319	101	98
73	320	97	322	101	99	325	102	95
77	323	96	327	101	96	329	102	94
81	324	92	328	101	96	330	102	92
85	327	90	333	102	92	333	102	92
89	326	82	337	103	88	334	103	90
93	330	78	338	103	84	332	101	84
95	330	76	336	102	84	334	101	80
97	330	74	337	102	80	333	101	78
99	332	70	340	102	75	336	101	73
101	331	66	341	103	74	334	101	70
103	330	64	339	103	73	338	102	66
105	326	61	340	104	69	338	104	62
Mean for weeks								
1-13	164		164	100		163	99	
14-52	247		249	101		250	101	
53-105	319		326	102		325	102	

TABLE 4
Mean Body Weights and Survival of Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	10 G			10 G Intermittent		
	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	93	96	100	97	100	100
2	115	100	100	117	101	100
3	132	100	100	132	101	100
4	144	100	100	145	101	100
5	154	100	100	156	101	100
6	163	99	100	164	100	100
7	171	99	100	172	100	100
8	177	99	100	179	101	100
9	182	99	100	185	100	100
10	189	99	100	191	100	100
11	194	99	100	196	101	100
12	198	99	100	201	101	100
13	201	99	100	204	100	100
17	212	100	100	217	102	100
21	223	100	99	228	102	100
25	234	101	98	239	103	100
29	242	101	98	247	103	100
33	249	101	98	253	102	100
37	258	101	97	261	102	100
41	268	102	97	269	102	100
45	275	101	97	276	102	100
49	282	101	97	283	102	100
53	287	101	97	288	101	100
57	296	102	96	296	102	100
61	304	102	94	303	101	100
65	313	102	93	312	102	95
69	319	101	93	319	101	94
73	323	101	92	324	101	93
77	328	102	91	326	101	90
81	332	102	86	326	100	88
85	334	102	85	328	101	86
89	338	104	84	330	101	82
93	335	102	83	333	101	75
95	336	102	80	335	101	72
97	333	101	78	333	101	71
99	335	101	75	334	101	71
101	333	101	73	335	101	70
103	329	100	70	336	102	64
105	325	100	66	337	103	61
Mean for weeks						
1-13	163	99		165	101	
14-52	249	101		253	102	
53-105	324	102		323	101	

Pathology and Statistical Analyses

This section describes the incidences of neoplasms and/or nonneoplastic lesions of the thyroid gland, skin, mammary gland, and brain and incidences of mononuclear cell leukemia. Summaries of the incidences of neoplasms and nonneoplastic lesions and statistical analyses of primary neoplasms that occurred with an incidence of at least 5% in at least one animal group are presented in Appendix A for male rats and Appendix B for female rats.

Thyroid Gland (C-cell): Incidences of adenoma and carcinoma in male rats exposed to 0.02 G and of adenoma in 2 G male rats were significantly greater than in the control group (Tables 5 and A2). The incidences of adenoma or carcinoma (combined) were significantly greater in males exposed to 0.02 or 2 G than in the controls. Incidences of hyperplasia in exposed groups of male rats were similar to that in controls (Tables 5 and A3). Incidences of neoplasms in exposed groups of female rats were similar to those in controls (adenoma: control, 15/100; 0.02 G, 20/100; 2 G, 19/100; 10 G, 20/100; 10 G intermittent, 16/100; carcinoma: 5/100, 3/100, 3/100, 3/100, 6/100; Table B2).

C-cells (calcitonin-producing cells) are located between the follicular epithelium and the basement membrane of the thyroid follicle. As rats age, there is an increase in the number of these pale-staining C-cells which may be diffuse throughout the thyroid gland, but often there is focal proliferation of C-cells which may distort and eventually fill the thyroid follicle. Because essentially all aging rats have some increase in the number of C-cells, C-cell hyperplasia was diagnosed when this was a prominent feature in the thyroid gland. Focal C-cell hyperplasia is difficult to distinguish from C-cell adenoma. Because the lesion can progress from diffuse and focal hyperplasia to obvious neoplasia, the criteria used to separate hyperplasia from adenoma are subjective. Sometimes hyperplasia and adenoma differ only in the relative size of the lesion. Focal proliferative lesions smaller than five follicles in diameter are designated as focal C-cell hyperplasia, and masses larger than this are considered to be neoplasms. Cellular atypia, when present, can help distinguish C-cell hyperplasia from C-cell adenoma. In this study, a reviewing pathologist reviewed all proliferative C-cell lesions to provide consistency in applying the criteria. The C-cell adenomas in this study were often small, but a few C-cell adenomas filled nearly an entire lobe, and occasional C-cell adenomas were bilateral (occurring in both lobes of the gland). Because of the microscopic nature of C-cell hyperplasia and C-cell adenoma, they are often found in one histologic section but may not be seen on a subsequent section of the same gland. C-cell carcinomas consist of solid to irregular groups of neoplastic cells similar to those found in the C-cell adenoma. Size and invasion are important criteria. C-cell carcinomas usually involved the entire lobe of the thyroid gland. C-cell carcinomas often showed invasion of the thyroid capsule and in two cases had metastasized to the lung. The larger C-cell carcinomas show more cellular atypia. In contrast to C-cell neoplasms in humans, amyloid is rarely found in the rat and was not seen in this study. Because of their size, C-cell carcinomas are less subject to sectioning and usually appear on all sections of the thyroid gland.

TABLE 5
Incidences of Neoplasms and Nonneoplastic Lesions of the Thyroid Gland (C-Cells) in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Number Examined Microscopically	99	100	100	100	100
Hyperplasia (includes bilateral)[a]	33 (1.9)[b]	23 (2.3)	27 (2.2)	26 (1.9)	33 (2.1)
Adenoma					
Overall rate[c]	15/99 (15%)	25/100 (25%)	26/100 (26%)	23/100 (23%)	18/100 (18%)
Adjusted rate[d]	17.2%	30.0%	30.5%	27.4%	21.5%
Terminal rate[e]	7/57 (12%)	15/46 (33%)	16/47 (34%)	13/48 (27%)	16/59 (27%)
First incidence (days)	583	589	604	561	725
Poly-3 test[f]	P=0.326	P=0.035	P=0.028	P=0.075	P=0.305
Carcinoma					
Overall rate	1/99 (1%)	7/100 (7%)	4/100 (4%)	2/100 (2%)	5/100 (5%)
Adjusted rate	1.2%	8.5%	4.8%	2.5%	5.9%
Terminal rate	1/57 (2%)	2/46 (4%)	2/47 (4%)	2/48 (4%)	4/59 (7%)
First incidence (days)	736 (T)	619	687	736 (T)	666
Poly-3 test	P=0.280N	P=0.030	P=0.177	P=0.483	P=0.103
Adenoma or Carcinoma					
Overall rate	16/99 (16%)	31/100 (31%)	30/100 (30%)	25/100 (25%)	22/100 (22%)
Adjusted rate	18.4%	36.8%	35.1%	29.8%	26.1%
Terminal rate	8/57 (14%)	17/46 (37%)	18/47 (38%)	15/48 (31%)	19/59 (32%)
First incidence (days)	583	589	604	561	666
Poly-3 test	P=0.438	P=0.005	P=0.009	P=0.055	P=0.147

(T)Terminal sacrifice
[a] Number of animals with lesion
[b] Average severity grade of lesions in affected animals: 1=minimal, 2=mild, 3=moderate, 4=marked
[c] Number of animals with neoplasm per number of animals with thyroid gland examined microscopically
[d] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[e] Observed incidence at terminal kill
[f] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend is indicated by **N**.

Skin: The incidence of trichoepithelioma was increased in the 10 G male group (0/100, 1/100, 0/100, 5/100, 0/100; Table A2). This increase was not seen for other neoplasms of basal cell origin such as basal cell adenoma, keratoacanthoma, or the group of all skin neoplasms (combined) (Tables A1 and A2).

Mammary Gland: The incidences of fibroadenoma and carcinoma in exposed groups of male and female rats were similar to those in the control groups (Tables 6, A1, and B1). The incidences of epithelial hyperplasia in males occurred with a negative trend (Tables 6 and A3). Incidences of epithelial hyperplasia in exposed groups of female rats were similar to that in the control group (Tables 6 and B3).

TABLE 6
Incidences of Neoplasms and Nonneoplastic Lesions of the Mammary Gland in Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control		0.02 G		2 G		10 G		10 G Intermittent	
Male										
Number Examined Microscopically	99		97		100		98		95	
Epithelial Hyperplasia[a]	9	(1.4)[b]	1*	(2.0)	4	(2.3)	3	(1.7)	4	(1.8)
Fibroadenoma	6		6		11		9		8	
Carcinoma	0		1		0		0		0	
Female										
Number Examined Microscopically	100		100		100		100		100	
Epithelial Hyperplasia	1	(3.0)	4	(2.5)	3	(1.7)	2	(2.0)	3	(2.0)
Fibroadenoma	56		62		54		64		51	
Carcinoma	2		7		5		2		2	

* Significantly different ($P \leq 0.05$) from the control group by the Poly-3 test
[a] Number of animals with lesion
[b] Average severity grade of lesions in affected animals: 1=minimal, 2=mild, 3=moderate, 4=marked

Brain: Astrocytoma was observed in one male and one female in the control groups and in two females exposed to 10 G (Tables A1 and B1). Oligodendroglioma was observed in one control male rat and one male rat in the 10 G intermittent group (Table A1). In female rats, glioma was observed in one control rat (Table B1), and focal gliosis was observed in one rat in the 10 G intermittent group (Table B3). The incidence of brain neoplasms was not affected by exposure to magnetic fields.

Mononuclear Cell Leukemia: The incidence of mononuclear cell leukemia in males in the 10 G intermittent group was significantly less ($P=0.045$) than that in the control group (50/100, 44/100, 47/100, 50/100, 36/100; Table A2). Incidences of mononuclear cell leukemia in exposed groups of female rats were similar to that in the control group (20/100, 18/100, 24/100, 25/100, 22/100; Table B2).

MICE

2-YEAR STUDY

Survival

Estimates of 2-year survival probabilities for male and female mice are shown in Table 7 and in the Kaplan-Meier survival curves (Figure 3). Survival of male mice exposed to 10 G was significantly less than that of control mice; survival of all other exposed groups of mice was similar to that of control mice.

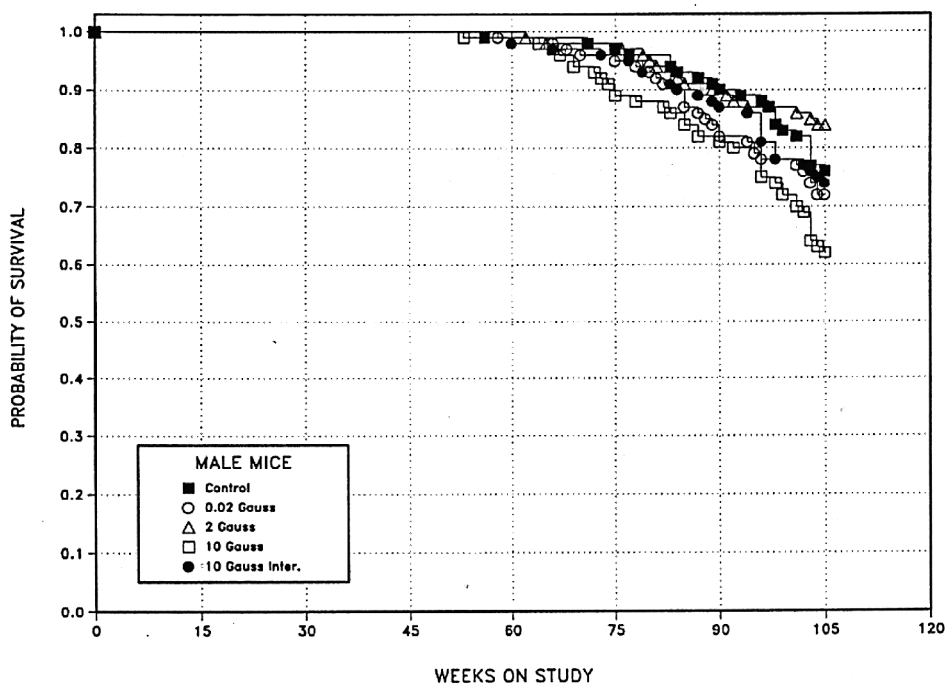
Body Weights and Clinical Findings

Mean body weights of exposed groups of male and female mice were similar to those of the control groups throughout the study (Figure 4; Tables 8 and 9). There were no exposure-related clinical findings.

TABLE 7
Survival of Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Male					
Animals initially in study	100	100	100	100	100
Moribund	11	13	6	15	8
Natural deaths	13	15	10	23	18
Animals surviving to study termination	76	72	84	62	74[d]
Percent probability of survival at end of study[a]	76	72	84	62	74
Mean survival (days)[b]	711	698	712	687	703
Survival analysis[c]	P=0.011[e]	P=0.540	P=0.248N	P=0.037	P=0.783
Female					
Animals initially in study	100	100	100	100	100
Accidental deaths[f]	1	1	2	1	0
Moribund	6	7	6	7	8
Natural deaths	23	18	13	18	15
Animals surviving to study termination	70[d]	74	79	74	77
Percent probability of survival at end of study	71	75	81	75	77
Mean survival (days)	702	700	700	696	704
Survival analysis	P=0.967N	P=0.674N	P=0.185N	P=0.676N	P=0.490N

[a] Kaplan-Meier determinations
[b] Mean of all deaths (uncensored, censored, and terminal sacrifice)
[c] The result of the life table trend test (Tarone, 1975) is in the control column, and the results of the life table pairwise comparisons (Cox, 1972) with the controls are in the exposed group columns. A negative trend or lower mortality in an exposure group is indicated by **N**.
[d] Includes one animal that died during the last week of the study
[e] Intermittent group not included in trend test analysis
[f] Censored from survival analysis



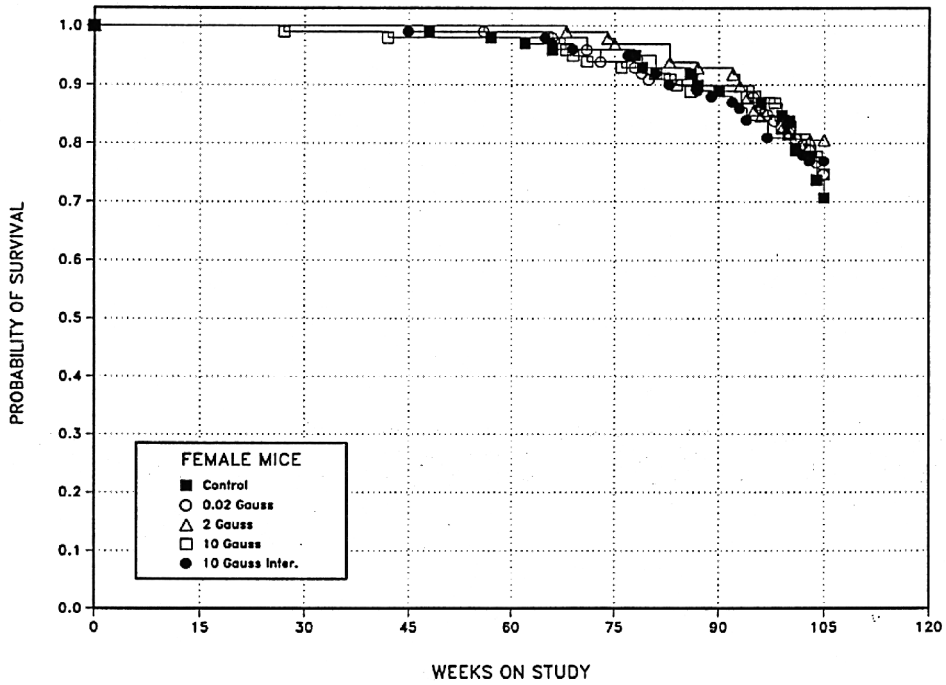


FIGURE 3
Kaplan-Meier Survival Curves for Male and Female Mice Exposed to 60-HZ Magnetic Fields for 2 Years

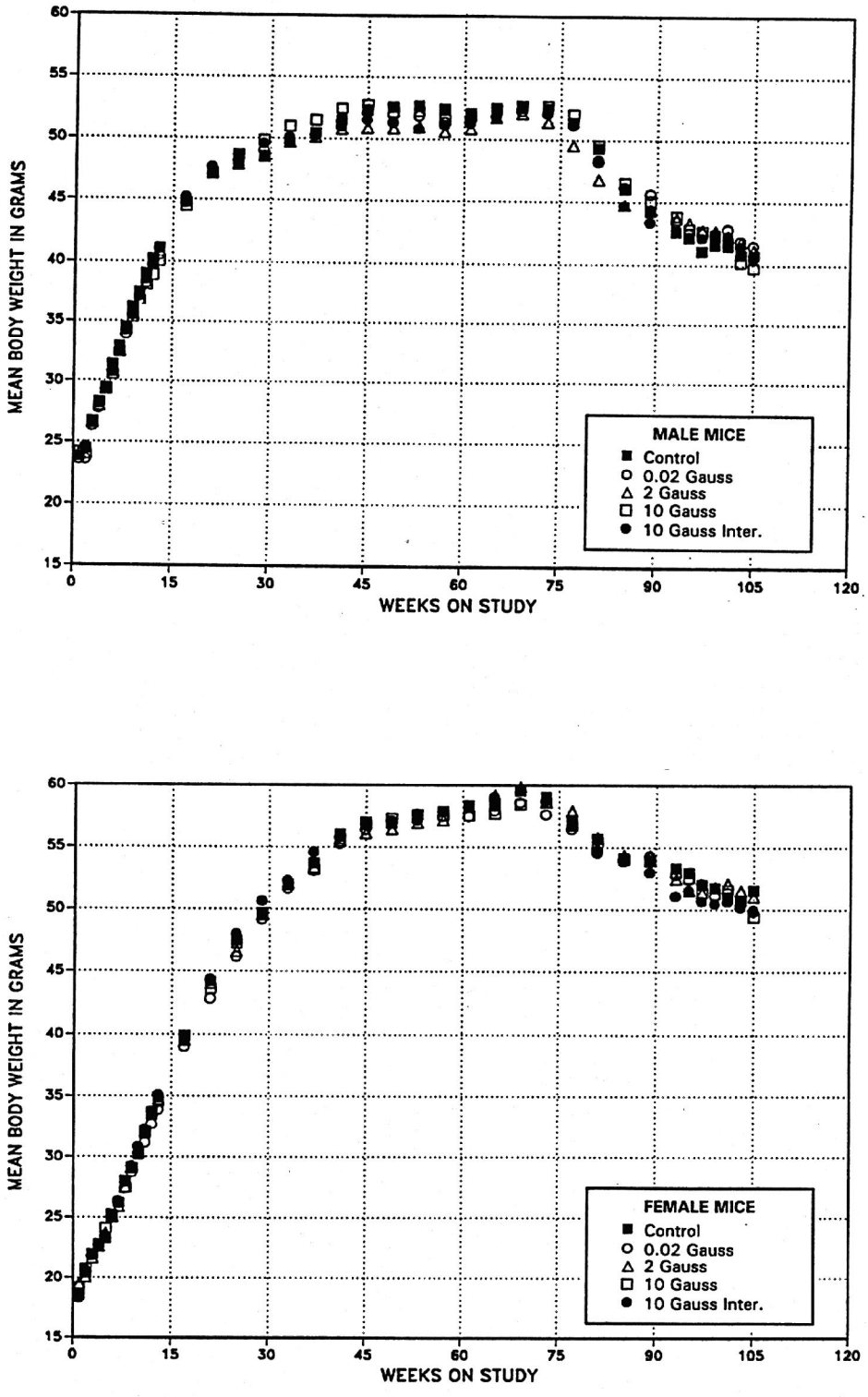


FIGURE 4
Growth Curves for Male and Female Mice Exposed to 60-HZ Magnetic Fields for 2 Years

TABLE 8
Mean Body Weights and Survival of Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	Control		0.02 G			2 G		
	Av. Wt. (g)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	23.8	100	23.6	99	100	24.1	101	100
2	24.4	100	23.6	97	100	24.5	100	100
3	26.6	100	26.3	99	100	26.6	100	100
4	28.1	100	27.8	99	100	28.0	100	100
5	29.5	100	29.3	99	100	29.3	99	100
6	31.4	100	30.8	98	100	30.8	98	100
7	32.9	100	32.4	99	100	32.5	99	100
8	34.5	100	33.9	98	100	34.3	99	100
9	36.2	100	35.5	98	100	35.5	98	100
10	37.5	100	37.0	99	100	36.8	98	100
11	39.0	100	38.2	98	100	38.3	98	100
12	40.2	100	39.7	99	100	39.7	99	100
13	41.0	100	40.5	99	100	40.8	100	100
17	44.7	100	44.7	100	100	45.0	101	100
21	47.2	100	47.1	100	100	47.2	100	100
25	47.8	100	48.2	101	100	47.9	100	100
29	48.5	100	49.0	101	100	48.6	100	100
33	49.7	100	49.7	100	100	49.7	100	100
37	50.5	100	50.3	100	100	50.1	99	100
41	51.5	100	51.4	100	100	50.8	99	100
45	52.3	100	52.1	100	100	50.9	97	100
49	52.5	100	52.0	99	100	50.9	97	100
53	52.7	100	51.9	99	100	51.0	97	100
57	52.4	99	51.4	98	100	50.6	97	100
61	52.1	99	51.7	99	99	50.9	98	100
65	52.5	99	51.9	99	99	51.8	99	99
69	52.7	99	52.3	99	97	52.1	99	98
73	52.5	98	52.1	99	96	51.4	98	98
77	51.4	97	51.2	100	95	49.6	97	97
81	49.3	96	48.3	98	93	46.8	95	95
85	46.0	93	46.2	100	90	44.8	97	92
89	44.2	92	45.7	103	85	44.4	101	91
93	42.6	90	43.5	102	82	43.7	103	88
95	42.2	89	42.5	101	81	43.3	103	87
97	41.1	88	42.5	103	78	42.8	104	87
99	41.6	84	42.4	102	78	42.7	103	87
101	41.5	83	42.8	103	78	42.3	102	86
103	40.8	82	41.9	103	76	41.9	103	86
105	40.8	77	41.5	102	72	41.2	101	84
Mean for weeks								
1-13	32.7		32.2	98		32.4	99	
14-52	49.4		49.4	100		49.0	99	
53-105	46.8		47.0	100		46.5	99	

TABLE 8
Mean Body Weights and Survival of Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	10 G			10 G Intermittent		
	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	24.2	102	100	23.8	100	100
2	24.0	98	100	24.6	101	100
3	26.7	100	100	26.5	100	100
4	28.3	101	100	28.1	100	100
5	29.4	100	100	29.3	99	100
6	30.5	97	100	30.7	98	100
7	32.4	99	100	32.5	99	100
8	34.3	99	100	34.2	99	100
9	35.3	98	100	35.6	98	100
10	36.8	98	100	37.1	99	100
11	38.0	97	100	38.4	99	100
12	38.9	97	100	39.8	99	100
13	40.0	98	100	41.0	100	100
17	44.4	99	100	45.2	101	100
21	47.1	100	100	47.6	101	100
25	48.7	102	100	48.6	102	100
29	49.9	103	100	49.6	102	100
33	51.0	103	100	50.1	101	100
37	51.5	102	100	50.2	99	100
41	52.5	102	100	51.0	99	100
45	52.7	101	100	51.6	99	100
49	52.2	99	100	51.3	98	100
53	52.2	99	100	50.8	96	100
57	51.6	99	99	51.1	98	100
61	51.8	99	99	51.3	99	98
65	52.4	100	98	51.8	99	98
69	52.7	100	96	52.5	100	97
73	52.7	100	93	52.1	99	97
77	52.0	101	89	51.3	100	96
81	49.5	100	88	48.4	98	93
85	46.6	101	86	44.7	97	90
89	45.1	102	82	43.4	98	89
93	43.9	103	80	42.6	100	87
95	42.8	101	80	42.3	100	86
97	42.7	104	75	42.2	103	81
99	42.4	102	74	42.5	102	78
101	41.8	101	72	42.3	102	78
103	40.2	99	68	41.5	102	76
105	39.7	97	63	40.5	99	75
Mean for weeks						
1-13	32.2	98		32.4	99	
14-52	50.0	101		49.5	100	
53-105	47.1	101		46.5	99	

TABLE 9
Mean Body Weights and Survival of Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	Control		0.02 G			2 G		
	Av. Wt. (g)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	18.5	100	18.7	101	100	19.5	105	100
2	20.4	100	20.6	101	100	20.1	99	100
3	21.9	100	21.8	100	100	21.7	99	100
4	22.7	100	22.7	100	100	22.6	100	99
5	23.3	100	23.4	100	100	23.7	102	99
6	25.2	100	25.0	99	100	25.0	99	99
7	26.2	100	26.2	100	100	25.9	99	99
8	28.0	100	27.4	98	100	27.5	98	99
9	29.1	100	28.7	99	100	29.3	101	98
10	30.2	100	30.3	100	100	30.3	100	98
11	31.9	100	31.2	98	99	32.1	101	98
12	33.4	100	32.7	98	99	33.7	101	98
13	34.8	100	33.9	97	99	34.8	100	98
17	39.6	100	39.0	99	99	39.6	100	98
21	44.2	100	42.8	97	99	44.1	100	98
25	47.4	100	46.2	98	99	46.6	98	98
29	49.7	100	49.2	99	99	49.5	100	98
33	52.0	100	51.7	99	99	52.1	100	98
37	53.7	100	53.1	99	99	53.4	99	98
41	56.0	100	55.3	99	99	55.5	99	98
45	56.9	99	56.4	99	99	56.1	99	98
49	56.8	98	57.1	101	99	56.4	99	98
53	57.4	98	57.6	100	99	56.9	99	98
57	57.9	98	57.5	99	98	57.2	99	98
61	58.3	97	57.4	99	98	58.3	100	98
65	58.3	96	57.9	99	98	59.2	102	98
69	59.5	95	58.6	99	97	59.9	101	97
73	59.1	95	57.6	98	95	58.6	99	97
77	57.2	95	56.5	99	93	57.9	101	95
81	55.7	92	54.8	98	90	55.7	100	95
85	54.1	92	54.1	100	90	54.4	101	92
89	53.9	89	54.3	101	89	54.3	101	91
93	53.3	88	52.9	99	89	52.5	99	90
95	53.0	88	52.4	99	89	51.6	97	86
97	52.0	86	52.1	100	84	51.4	99	83
99	51.8	86	51.1	99	83	51.8	100	83
101	51.0	82	51.4	101	81	52.1	102	80
103	50.8	78	50.4	99	79	51.5	101	80
105	51.5	73	49.8	97	76	51.1	99	79
Mean for weeks								
1-13	26.6		26.4	99		26.6	100	
14-52	50.7		50.1	99		50.4	99	
53-105	55.0		54.5	99		55.0	100	

TABLE 9
Mean Body Weights and Survival of Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

Weeks on Study	10 G			10 G Intermittent		
	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors	Av. Wt. (g)	Wt. (% of controls)	No. of Survivors
1	19.1	103	100	18.3	99	100
2	20.7	102	100	20.7	102	100
3	22.0	101	100	21.8	100	100
4	22.8	100	100	22.5	99	100
5	24.1	103	100	23.5	101	100
6	25.1	100	100	25.1	100	100
7	26.2	100	100	26.4	101	100
8	27.5	98	100	27.9	100	100
9	29.1	100	100	29.2	100	100
10	30.4	101	100	30.8	102	100
11	32.1	101	100	32.3	101	100
12	33.7	101	100	33.7	101	100
13	34.6	99	100	35.1	101	100
17	39.9	101	99	39.9	101	100
21	43.6	99	99	44.4	101	100
25	47.3	100	99	48.0	101	100
29	49.6	100	98	50.6	102	100
33	51.9	100	98	52.3	101	100
37	53.2	99	98	54.6	102	100
41	55.6	99	98	55.7	100	100
45	56.8	100	97	56.8	100	99
49	57.2	101	97	57.0	100	99
53	57.6	100	97	57.1	100	99
57	57.6	100	97	57.8	100	99
61	57.5	99	97	58.2	100	99
65	57.6	99	97	59.0	101	99
69	58.4	98	95	59.5	100	97
73	58.6	99	93	58.7	99	96
77	56.7	99	92	56.7	99	96
81	55.4	100	92	54.5	98	95
85	54.0	100	89	53.9	100	90
89	54.0	100	88	53.0	98	89
93	53.0	99	88	51.1	96	87
95	52.6	99	87	51.5	97	84
97	51.4	99	87	50.7	98	84
99	51.3	99	85	50.5	98	81
101	51.6	101	81	50.7	99	81
103	50.7	100	80	50.2	99	78
105	49.4	96	77	50.0	97	77
Mean for weeks						
1-13	26.7	100		26.7	100	
14-52	50.6	100		51.0	101	
53-105	54.6	99		54.3	99	

Pathology and Statistical Analyses

This section describes the incidences of neoplasms and/or nonneoplastic lesions of the lung and mammary gland and incidences of malignant lymphoma. Summaries of the incidences of neoplasms and nonneoplastic lesions and statistical analyses of primary neoplasms that occurred with an incidence of at least 5% in at least one animal group are presented in Appendix C for male mice and Appendix D for female mice.

Lung: The incidences of alveolar/bronchiolar adenoma were significantly decreased in 0.02 and 2 G male mice and 2 G female mice relative to the control groups (Tables 10, C2, and D2); the incidences of alveolar/bronchiolar adenoma or carcinoma (combined) were significantly less in males and females exposed to 2 G than in the control groups. Incidences of hyperplasia in exposed groups of male and female mice were similar to those in the control groups (Tables 10, C3, and D3).

Mammary Gland: No mammary gland neoplasms were observed in male mice. Incidences of adenoma or carcinoma in exposed groups of females were similar to those in the control group (adenoma: control, 0/94; 0.02 G, 0/98; 2 G, 1/99; 10 G, 2/99; 10 G intermittent, 1/98; carcinoma: 1/94, 0/98, 0/99, 0/99, 1/98; Table D1). Incidences of hyperplasia in exposed groups of male and female mice were similar to those in the control groups (Tables C3 and D3).

Malignant Lymphoma: The incidences of malignant lymphoma in all exposed groups of male mice were similar to that in the control group (8/100, 7/100, 4/100, 7/100, 6/100; Table C2). In female mice, the incidence of malignant lymphoma in the 10 G intermittent group was significantly less ($P=0.035$) than in the controls (32/100, 31/100, 22/100, 26/100, 20/100; Table D2).

TABLE 10
Incidences of Neoplasms and Nonneoplastic Lesions of the Lung in Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Male					
Number Examined Microscopically	100	99	100	99	99
Alveolar Epithelium, Hyperplasia, Focal[a]	2 (1.5)[b]	2 (1.5)	0	3 (2.3)	2 (2.5)
Alveolar/bronchiolar Adenoma					
Overall rate[c]	26/100 (26%)	11/99 (11%)	9/100 (9%)	16/99 (16%)	16/99 (16%)
Adjusted rate[d]	28.0%	12.5%	9.6%	18.0%	17.9%
Terminal rate[e]	22/76 (29%)	10/72 (14%)	7/84 (8%)	7/62 (11%)	15/74 (20%)
First incidence (days)	683	722	585	518	672
Poly-3 test[f]	P=0.470N	P=0.007N	P<0.001N	P=0.077N	P=0.073N
Alveolar/bronchiolar Carcinoma	8	11	12	10	10
Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	30/100 (30%)	21/99 (21%)	19/100 (19%)	25/99 (25%)	23/99 (23%)
Adjusted rate	32.2%	23.7%	20.1%	27.7%	25.6%
Terminal rate	25/76 (33%)	19/72 (26%)	16/84 (19%)	11/62 (18%)	21/74 (28%)
First incidence (days)	683	612	430	448	668
Poly-3 test	P=0.495	P=0.130N	P=0.041N	P=0.302N	P=0.203N
Female					
Number Examined Microscopically	95	100	99	99	100
Alveolar Epithelium, Hyperplasia, Focal	4 (1.8)	1 (1.0)	2 (2.0)	0	1 (2.0)
Alveolar/bronchiolar Adenoma					
Overall rate	9/95 (9%)	6/100 (6%)	0/99 (0%)	5/99 (5%)	6/100 (6%)
Adjusted rate	10.2%	6.6%	0.0%	5.6%	6.6%
Terminal rate	7/70 (10%)	4/74 (5%)	0/79 (0%)	4/74 (5%)	6/77 (8%)
First incidence (days)	551	603	—[g]	566	735 (T)
Poly-3 test	P=0.363N	P=0.271N	P=0.002N	P=0.190N	P=0.275N
Alveolar/bronchiolar Carcinoma	2	6	2	2	1
Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	11/95 (12%)	11/100 (11%)	2/99 (2%)	7/99 (7%)	7/100 (7%)
Adjusted rate	12.5%	11.9%	2.2%	7.8%	7.7%
Terminal rate	7/70 (10%)	7/74 (10%)	2/79 (3%)	5/74 (7%)	6/77 (8%)
First incidence (days)	551	496	735 (T)	566	656
Poly-3 test	P=0.246N	P=0.544N	P=0.008N	P=0.213N	P=0.208N

(T)Terminal sacrifice
[a] Number of animals with lesion
[b] Average severity grade of lesions in affected animals: 1=minimal, 2=mild, 3=moderate, 4=marked
[c] Number of animals with neoplasm per number of animals with lung examined microscopically
[d] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[e] Observed incidence at terminal kill
[f] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend or a lower incidence in an exposure group is indicated by **N**.
[g] Not applicable; no neoplasms in animal group

DISCUSSION AND CONCLUSIONS

The NTP evaluated 60-Hz magnetic field exposures in rodent studies after two epidemiology studies suggested that children living in homes expected to have higher magnetic field intensities were at increased risk for childhood leukemia (Wertheimer and Leeper, 1979; Savitz *et al.*, 1988). Both the Department of Energy and the Electric Power Research Institute supported the concept of carefully controlled long-term rodent studies to determine if the normal pattern or incidence of cancer that occurs in aging rodents would be affected by exposure to 60-Hz (power line frequency) magnetic fields.

At the time of the NTP protocol design, extensive characterization of the electric and magnetic fields occurring in the home was lacking. The epidemiology studies had classified the childhood residences using wiring codes as surrogates for predicted magnetic fields within the home (Barnes *et al.*, 1989). Because electric fields can be easily shielded, and several animal studies showed little toxicity with electric fields (Leung *et al.*, 1990; Rommereim *et al.*, 1990), the greatest concern was with magnetic field exposure. However, residential magnetic fields are quite complex; they include not only the 60-Hz frequency but also harmonics of the 60-Hz frequency (120 Hz, 180 Hz, etc.), transients, and other frequencies from household appliances. Furthermore, it was not known what might be the important exposure parameter: frequency, field intensity, change in field intensity, time above a certain intensity, or even the wave form. Thus, the challenge was to develop a protocol to evaluate a complex physical agent for which little was known.

The NTP developed a protocol which was then circulated for comment to more than 80 scientists familiar with toxicology studies and magnetic field exposure. It was apparent during study development that only a limited number of exposure parameters could be evaluated. Because the predominant residential exposure in the United States is to 60-Hz fields, only this frequency was included. Given the complexity of transients and different wave forms, it was decided to evaluate 60-Hz sine-wave magnetic fields without transients. The maximum feasible field intensity that could be evaluated was 10 G, above which vibrations, sound, and heat could become confounding factors. Because 10-G magnetic fields were nearly 5,000-fold greater than most residential exposures, this was considered an adequate challenge. The two lower magnetic field intensities, 0.02 and 2 G, were chosen because the induced currents in rats are about 10 times less than in human models (Anderson, 1991; Miller, 1991). This suggested that the lowest field intensity used in rodents might mimic high human residential exposures. To explore the possibility that a change in field intensity might be more important than continuous magnetic field exposure, another group of animals was exposed to magnetic fields that were switched on and off at 1-hour intervals. To enhance sensitivity for detecting small changes in neoplasm incidences, 100 animals were used in each group rather than the usual 50. The final protocol was reviewed by more than a dozen scientists at a meeting at the NIEHS prior to the start of the studies.

The studies were preceded by 8-week whole-body exposure studies in F344/N rats and $B6C3F_1$ mice. There was no evidence of toxicity or clinical findings with exposures up to 10 G (NTP, 1996; Boorman *et al.*, 1997), or of developmental toxicity in a subsequent study in female Sprague-Dawley rats (Ryan *et al.*, 1996). Further, as part of a Congressional mandate for accelerated electromagnetic field (EMF) research (EMF *RAPID* Program), $B6C3F_1$ mice were evaluated for evidence of immunotoxicity at the same field intensities as in the 8-week studies. In these studies, there was no evidence of cellular alterations or host immune response (House *et al.*, 1996), or of alterations in reproductive parameters in a 6-month continuous breeding study in Sprague-Dawley rats (Ryan *et al.*, 1999).

Care was taken to ensure that the groups were as free from confounding factors as possible during exposure. This treatment included randomization of the animals, housing the animals in five rooms with identical magnetic field exposure capabilities, weekly cage and rack rotations, and room rotation every 10 weeks.

Room rotation assured that each group spent 10 weeks in each of the five rooms during the first 50 weeks and again for the second 50 weeks. The rooms were continuously monitored for sound, light, humidity, temperature, vibration, and magnetic fields. The magnetic fields were characterized by the National Institute for Standards and Technology (NIST; Appendix F) prior to the beginning of the studies, after 1 year, and at the completion of the 2-year studies. The earth's static magnetic fields in the rooms were also measured by the study contractor and verified by NIST.

Despite many physiologic differences between rodents and humans, there is good correlation between known or suspected human carcinogens and test results in rodent studies, often with the same organ system being affected in rodents as in humans (Wilbourn *et al.*, 1986). In the results section of this Technical Report, emphasis is placed on the analysis of cancers that have been reported to be associated with magnetic field exposure in humans.

Childhood leukemia has been considered a potential consequence of EMF exposure because of the initial reports of magnetic field-associated leukemia (Wertheimer and Leeper, 1979; Savitz *et al.*, 1988), but associations with childhood leukemia have also been reported more recently (London *et al.*, 1991; Feychting and Ahlbom, 1993). In addition, adult occupational exposures associated with increased incidences of leukemia have been reported (Floderus *et al.*, 1994; London *et al.*, 1994). However, Linet *et al.* (1997) failed to find an association between increased childhood leukemia and residential wire codes or measured magnetic fields. In another report, static magnetic fields did not enhance the development of spontaneous lymphoblastic leukemia in female AKR mice (Bellosi, 1986). In the present rodent study, mice exposed to up to 10 G for 2 years showed no increase in the incidences of malignant lymphoma or leukemia. In fact, in female mice there was a significant decrease in the incidence of malignant lymphoma.

In the present study, there was no exposure-related increase in the incidence of mononuclear cell leukemia in male or female rats. The intermittent exposure group of male rats actually had a significant decrease in the incidence of mononuclear cell leukemia. Another study also found that exposure to 60-Hz magnetic fields did not alter the clinical progression of transplanted mononuclear cell leukemia in Fischer rats (Sasser *et al.*, 1996). A study in female F344 rats exposed to 60-Hz magnetic fields from 0.02 to 20 G from day 20 of gestation with the female offspring continuously exposed for up to 2 years also failed to show increased incidences of mononuclear cell leukemia (Mandeville *et al.*, 1997). Male and female F344 rats exposed to 0, 5, or 50 G 50-Hz magnetic fields for up to 2 years also failed to show any exposure-related alteration in the incidences of mononuclear cell leukemia (Yasui *et al.*, 1997). Thus, in the long-term rodent studies to date, neither F344 rats nor $B6C3F_1$ mice showed increased leukemia or lymphoma rates when exposed to sine-wave magnetic fields for up to 2 years.

The lack of evidence for an increased incidence of leukemia associated with magnetic field exposure in rodent studies must still be viewed with caution. The most common childhood leukemia, with peak occurrence between 3 and 5 years of age, is acute lymphoblastic leukemia (Robison and Ross, 1995). Acute lymphoblastic leukemia is a heterogeneous disease including both T-cell and B-cell leukemia. It would appear that the F344/N rat mononuclear cell leukemia, which is characterized by a large granular lymphocyte (Stromberg *et al.*, 1983), may not be a good model for predicting the occurrence of acute lymphoblastic leukemia in humans. The mouse is considered a good rodent model for human leukemias (Pattengale, 1994), but most magnetic field studies in the mouse do not include prenatal magnetic field exposures. One study that included exposures from the day before parturition to 2 years of age was conducted in the female F344/N rat (Mandeville *et al.*, 1997).

Some studies have reported an association between exposure to magnetic fields and increased risk for brain cancer (Savitz and Loomis, 1995; Guénel *et al.*, 1996), while other studies failed to find a significant association (Miller *et al.*, 1996; Preston-Martin *et al.*, 1996). In the present study, brain cancer was rare. No glial neoplasms were diagnosed in male or female mice in any exposure group. In male rats, three glial neoplasms were found, two in the control group and one in the intermittent exposure group. In female rats, four glial neoplasms were found, two in the control group and two in the 10 G group. Glial tumors were also rare in the study by Yasui *et al.* (1997), one

being found in the 50 G male rat group and one in the female 5 G group. There was also no increase in the number of glial tumors in rats exposed during the prenatal period for up to 2 years (Mandeville *et al.*, 1997). Thus, long-term rodent studies have failed to provide support for an association between magnetic field exposure and increased incidences of brain cancer.

Several studies have suggested an association between the incidence of breast cancer and occupational exposure to magnetic fields (Matanoski *et al.*, 1991; Stevens, 1993; Coogan *et al.*, 1996). Alternating fields have also been reported to enhance the development of chemically induced mammary gland cancer in rats (Beniashvili *et al.*, 1991; Mevissen *et al.*, 1993; Löscher *et al.*, 1993, 1994; Löscher and Mevissen, 1994). Therefore, long-term rodent studies were examined for even minimal increases in breast cancer incidences. In the present study, no mammary gland carcinomas were diagnosed in mice. In male rats, one carcinoma was diagnosed in the 0.02 G group. In female rats, two carcinomas were found in the controls, seven in the 0.02 G group, five in the 2 G group, and two each in the 10 G intermittent and continuous exposure groups. The incidence in the 0.02 G group was not statistically significant. In the study by Mandeville *et al.* (1997), three carcinomas of the mammary gland were found in the 0.02 G group compared to two carcinomas in the controls, which provides no support for a low field intensity effect. As in the present study, there was no increase in the incidences of mammary gland carcinoma at the higher exposure intensities. In a companion series of studies, no effect of magnetic fields on chemically induced breast cancer was observed in female Sprague-Dawley rats (NTP, 1999).

Electric or magnetic field exposures have been hypothesized to depress nocturnal melatonin concentrations in rodents (Wilson *et al.*, 1986, 1989; Lerchl *et al.*, 1991; Reiter, 1992; Stevens *et al.*, 1992; Anderson, 1993; Stevens, 1993), possibly leading to increased rates of breast cancer. However, more recent studies cast some doubt on the effect of alternating magnetic field exposures on nocturnal melatonin levels (Truong *et al.*, 1996; Yellon, 1996). Melatonin suppression is an attractive hypothesis because melatonin is reported to be oncostatic (Reiter, 1992, 1993; Stevens *et al.*, 1992; Liburdy *et al.*, 1993). In one study in rats, serum melatonin concentrations, but not pineal gland melatonin synthesis, were reduced; this suggests the possibility that degradation or tissue uptake of melatonin is stimulated by exposure to electric fields (Grota *et al.*, 1994). Other studies have reported that serotonin-*N*-acetyltransferase, the rate-limiting enzyme for melatonin production, may be depressed by magnetic field exposure (Olcese and Reuss, 1986). In the 8-week NTP studies with 60-Hz magnetic field exposures at up to 10 G, no alterations in serum or pineal gland melatonin or pineal serotonin-*N*-acetyltransferase were found (NTP, 1996). That study had the limitation that only one nocturnal time point was evaluated; thus, the magnitude of the pineal gland response but not the duration of the melatonin secretion could be evaluated. Further, the NTP studies used linearly polarized magnetic fields, and it has been suggested that linearly polarized or vertical fields do not affect melatonin concentrations while circularly polarized fields will depress melatonin concentrations in rats (Kato *et al.*, 1994a,b).

The increase in incidences of thyroid gland C-cell adenoma and carcinoma (combined) in male rats was considered an equivocal finding for several reasons. First, the increase in thyroid gland C-cell neoplasm incidence was not related to field intensity. The highest incidence was observed at 0.02 G, and there was no significant increase in thyroid gland C-cell neoplasm incidence at 10 G.

Second, there is no supporting evidence from preneoplastic lesions. Generally, agents that cause neoplasia also increase incidences of preneoplastic lesions (in this case thyroid gland C-cell hyperplasia), but the highest incidence of thyroid gland C-cell hyperplasia was observed in the controls. C-cell adenomas do not differ morphologically from hyperplasia except for size (Boorman *et al.*, 1972, 1974), and the combined incidences of adenoma or hyperplasia did not differ between groups. On the other hand, more thyroid gland C-cell adenomas were bilateral in the exposed animals than in the controls. It is unlikely that any variability between groups resulted from diagnostic differences. C-cell lesions represent a spectrum from small focal increases in C-cells to clusters of cells that fill thyroid follicles and eventually spread outside of the thyroid gland. Small focal lesions are diagnosed as C-cell hyperplasia, larger lesions as C-cell adenoma, and invasive lesions as C-cell carcinoma (Hardisty and Boorman, 1990).

Thus, moderate differences in diagnostic criteria can lead to different incidences in various studies and exposure groups. To control for possible diagnostic differences in this study, the reviewing pathologist evaluated all thyroid glands for the presence of proliferative lesions, and a Pathology Working Group resolved diagnostic differences between the study pathologists. This procedure helps reduce diagnostic inconsistencies, and the NTP believes that diagnostic differences can be ruled out as a possible source of variability between groups.

Third, thyroid gland C-cell neoplasm incidences tend to be variable in NTP studies. In 18 recent NTP feed studies, the incidences of combined C-cell adenoma or carcinoma varied from 4% to 24%. Similarly, in 18 recent inhalation studies, the incidences of combined C-cell adenoma or carcinoma varied from 4% to 19%. The thyroid gland C-cell neoplasm incidences in this study cannot be directly compared to historical control incidences because rats in the present study were fed the NTP-2000 diet whereas historical studies used the NIH-07 diet. Further, two sections were taken of each thyroid gland in this study, whereas in previous studies, usually one section was taken. Thompson and Hunt (1963) determined that the numbers of microscopic C-cell adenomas detected are subject to sampling technique, with an 8% incidence found with single sections of the thyroid gland compared to a 33% incidence with serial sections.

Fourth, the thyroid gland C-cell is an infrequent site for a carcinogenic response. In an evaluation of 194 NTP 2-year studies in male F344/N rats, Haseman and Elwell (1996) found only one chemical (Ziram) that produced an increased incidence of thyroid gland C-cell neoplasms judged to be chemically related (4/50, 9/49, and 12/49 for control, low-dose, and high-dose groups, respectively). Conversely, it may be argued that an increased neoplasm incidence at a site that is rarely increased by chemical exposure is more important.

Fifth, 60-Hz magnetic fields were not expected to increase thyroid gland C-cell cancer incidences. None of the epidemiology studies to date suggest an association between thyroid gland C-cell neoplasms and magnetic field exposure (Savitz, 1993; Theriault *et al.*, 1994). As detailed above, mononuclear cell leukemia, mammary gland cancer, and brain cancer were considered the most likely neoplasms to arise in the present study, but no increases in the incidences of these neoplasms were found. Magnetic fields are reported to alter calcium flux in thymocytes *in vitro* (Walleczek and Liburdy, 1990), and C-cells are sensitive to and respond to changes in calcium concentrations (Black *et al.*, 1973; Boorman *et al.*, 1974). However, there are no reports that subtle changes in intracellular calcium alter cancer rates in animals.

Sixth, there is no other support for a carcinogenic effect on thyroid gland C-cells in these studies or in other studies. In many cases of a chemically induced effect in rodents, increased incidences of cancers are seen in both genders and in other species. The combined incidences of thyroid gland C-cell adenoma or carcinoma were similar in all groups of female rats in this study, as were the incidences of C-cell hyperplasia. Thyroid gland C-cell neoplasms were not diagnosed in exposed mice in these studies. Thus, other gender and species combinations do not provide any support for the increased incidences of thyroid gland C-cell neoplasms found in male rats. This lack of an effect in other gender and species combinations, however, cannot be used to argue that the effect in males may not be a carcinogenic response. The studies of Mandeville *et al.* (1997) and of Yasui *et al.* (1997) in F344 rats reported no increases in the incidences of thyroid gland C-cell neoplasms in groups exposed to similar or higher magnetic field intensities.

Finally, these studies involved approximately 40 tissue sites, four gender-species groups, four EMF exposure regimens, and 100 animals per group. Under these conditions, statistically significant differences in neoplasm incidence may arise by chance. Thyroid gland C-cell in male rats was the only tissue site showing a significant ($P<0.01$) EMF-related increase in neoplasm incidence, and this increase was seen in both the 0.02 and 2 G groups. The likelihood of finding at least one statistically significant ($P<0.01$) pairwise increase in neoplasm incidence arising by chance in the present studies is estimated to be approximately 50%. The corresponding likelihood of observing two or more exposure groups with a significantly ($P<0.01$) increased neoplasm incidence at the same site is approximately 9% to 10%. These calculations suggest that random variability cannot be ruled out as the source of the apparent increased

incidences of thyroid gland C-cell neoplasms observed in these studies.

For these reasons, NTP considers the evidence that the increased incidences of thyroid gland C-cell neoplasms in male rats are related to magnetic field exposure to be equivocal.

CONCLUSIONS

Under the conditions of these 2-year whole-body exposure studies, there was *equivocal evidence of carcinogenic activity** of 60-Hz magnetic fields in male F344/N rats based on increased incidences of thyroid gland C-cell neoplasms in the 0.02 and 2 G groups. There was *no evidence of carcinogenic activity* in female F344/N rats or male or female $B6C3F_1$ mice exposed to 0.02, 2, or 10 G, or 10 G intermittent 60-Hz magnetic fields.

In exposed rats and mice, there were no increased incidences of neoplasms at sites for which epidemiology studies have suggested an association with magnetic fields (brain, mammary gland, leukemia).

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* Explanation of Levels of Evidence of Carcinogenic Activity is on page 8. A summary of the Technical Reports Review Subcommittee comments and the public discussion on this Technical Report appears on page 10.

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APPENDIX A
SUMMARY OF LESIONS IN MALE RATS IN THE 2-YEAR WHOLE-BODY EXPOSURE STUDY OF 60-HZ MAGNETIC FIELDS

TABLE A1 Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 64

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TABLE A1
Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	29	32	32	36	33
Natural deaths	14	21	21	16	7
Other		1			1
Survivors					
Terminal sacrifice	57	46	47	48	59
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Intestine large, colon	(100)	(99)	(99)	(100)	(99)
Intestine large, rectum	(99)	(100)	(100)	(99)	(100)
Polyp adenomatous			1 (1%)		
Intestine large, cecum	(98)	(99)	(97)	(100)	(99)
Sarcoma				1 (1%)	
Intestine small, duodenum	(99)	(94)	(100)	(100)	(98)
Intestine small, jejunum	(91)	(90)	(95)	(98)	(98)
Intestine small, ileum	(94)	(92)	(97)	(96)	(97)
Sarcoma					1 (1%)
Liver	(100)	(100)	(100)	(100)	(100)
Hepatocellular adenoma	1 (1%)	1 (1%)	2 (2%)		2 (2%)
Hepatocellular adenoma, multiple		1 (1%)	1 (1%)		
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Osteosarcoma, metastatic, bone				1 (1%)	
Mesentery	(17)	(22)	(27)	(21)	(16)
Leiomyosarcoma, metastatic, spleen				1 (5%)	
Lipoma				1 (5%)	
Osteosarcoma, metastatic, kidney			1 (4%)		
Oral mucosa					(1)
Squamous cell carcinoma					1 (100%)
Pancreas	(98)	(99)	(99)	(99)	(100)
Mixed tumor benign		1 (1%)			
Acinus, adenoma	3 (3%)	5 (5%)	6 (6%)	5 (5%)	2 (2%)
Salivary glands	(99)	(99)	(100)	(100)	(100)
Schwannoma malignant, metastatic, skin					1 (1%)
Stomach, forestomach	(100)	(100)	(100)	(100)	(100)
Squamous cell papilloma	1 (1%)				
Stomach, glandular	(100)	(100)	(100)	(100)	(100)
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Tooth	(2)	(1)	(1)	(1)	(6)
Odontoma		1 (100%)			
Cardiovascular System					
Heart	(100)	(100)	(100)	(100)	(100)
Osteosarcoma, metastatic, bone				1 (1%)	
Schwannoma malignant	2 (2%)	1 (1%)	1 (1%)	1 (1%)	

TABLE A1
Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System					
Adrenal cortex	(99)	(100)	(100)	(100)	(100)
Adenoma		3 (3%)	1 (1%)	1 (1%)	1 (1%)
Adrenal medulla	(98)	(93)	(100)	(100)	(95)
Pheochromocytoma malignant	2 (2%)	2 (2%)			2 (2%)
Pheochromocytoma complex			1 (1%)		
Pheochromocytoma benign	19 (19%)	19 (20%)	15 (15%)	17 (17%)	25 (26%)
Bilateral, pheochromocytoma benign	5 (5%)	3 (3%)	6 (6%)	6 (6%)	8 (8%)
Islets, pancreatic	(99)	(99)	(99)	(99)	(100)
Adenoma	3 (3%)	2 (2%)	5 (5%)	3 (3%)	2 (2%)
Adenoma, multiple		1 (1%)	1 (1%)		
Carcinoma	1 (1%)	2 (2%)		1 (1%)	3 (3%)
Parathyroid gland	(85)	(87)	(93)	(81)	(89)
Adenoma		1 (1%)	2 (2%)	2 (2%)	
Carcinoma, metastatic, skin		1 (1%)			
Carcinoma, metastatic, thyroid gland		1 (1%)			
Pineal gland	(81)	(84)	(81)	(79)	(91)
Pituitary gland	(98)	(95)	(97)	(100)	(98)
Pars distalis, adenoma	34 (35%)	34 (36%)	28 (29%)	35 (35%)	40 (41%)
Pars distalis, adenoma, multiple		1 (1%)			
Pars distalis, carcinoma		1 (1%)	2 (2%)		3 (3%)
Pars intermedia, adenoma		1 (1%)	1 (1%)	1 (1%)	
Pars nervosa, schwannoma malignant				1 (1%)	
Thyroid gland	(99)	(100)	(100)	(100)	(100)
Bilateral, C-cell, adenoma		2 (2%)	4 (4%)	1 (1%)	3 (3%)
Bilateral, C-cell, carcinoma		1 (1%)			
C-cell, adenoma	15 (15%)	23 (23%)	22 (22%)	22 (22%)	15 (15%)
C-cell, carcinoma	1 (1%)	6 (6%)	4 (4%)	2 (2%)	5 (5%)
Follicular cell, adenoma	1 (1%)				
General Body System					
Peritoneum	(1)	(1)		(1)	
Tissue NOS	(3)	(2)		(1)	(2)
Abdominal, carcinoma		1 (50%)			
Abdominal, sarcoma	1 (33%)				
Mediastinum, schwannoma malignant	1 (33%)				
Thoracic, squamous cell carcinoma, metastatic, lung				1 (100%)	
Genital System					
Epididymis	(100)	(100)	(100)	(100)	(100)
Fibrosarcoma		1 (1%)			
Preputial gland	(100)	(99)	(100)	(99)	(100)
Adenoma	10 (10%)	8 (8%)	10 (10%)	12 (12%)	9 (9%)
Carcinoma			5 (5%)		2 (2%)
Fibroma			1 (1%)		
Bilateral, adenoma	3 (3%)	1 (1%)		1 (1%)	1 (1%)
Prostate	(100)	(99)	(100)	(99)	(100)
Adenoma				1 (1%)	
Leiomyosarcoma, metastatic, spleen				1 (1%)	

TABLE A1
Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Seminal vesicle	(100)	(99)	(100)	(99)	(100)
Adenoma			2 (2%)		1 (1%)
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Testes	(100)	(100)	(100)	(100)	(100)
Bilateral, interstitial cell, adenoma	82 (82%)	73 (73%)	72 (72%)	71 (71%)	67 (67%)
Interstitial cell, adenoma	11 (11%)	17 (17%)	19 (19%)	20 (20%)	22 (22%)
Interstitial cell, carcinoma	1 (1%)				
Hematopoietic System					
Bone marrow	(100)	(100)	(100)	(99)	(100)
Lymph node	(15)	(7)	(7)	(13)	(8)
Lymph node, mandibular	(99)	(99)	(100)	(100)	(100)
Schwannoma malignant, metastatic, skin					1 (1%)
Lymph node, mesenteric	(100)	(99)	(100)	(100)	(100)
Spleen	(100)	(100)	(100)	(100)	(100)
Fibroma			1 (1%)		1 (1%)
Hemangiosarcoma			1 (1%)		1 (1%)
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Sarcoma			1 (1%)		
Thymus	(97)	(94)	(95)	(90)	(95)
Thymoma benign	2 (2%)	1 (1%)	1 (1%)		
Thymoma malignant		2 (2%)			
Integumentary System					
Mammary gland	(99)	(97)	(100)	(98)	(95)
Carcinoma		1 (1%)			
Fibroadenoma	6 (6%)	5 (5%)	11 (11%)	8 (8%)	8 (8%)
Fibroadenoma, multiple		1 (1%)		1 (1%)	
Skin	(99)	(100)	(100)	(100)	(100)
Basal cell adenoma	3 (3%)		3 (3%)	3 (3%)	2 (2%)
Keratoacanthoma	10 (10%)	4 (4%)	11 (11%)	10 (10%)	8 (8%)
Keratoacanthoma, multiple		1 (1%)		1 (1%)	
Melanoma malignant					1 (1%)
Squamous cell carcinoma					1 (1%)
Squamous cell papilloma	1 (1%)	2 (2%)	1 (1%)		
Trichoepithelioma		1 (1%)		5 (5%)	
Dermis, fibroma	3 (3%)	2 (2%)	4 (4%)	5 (5%)	4 (4%)
Dermis, fibroma, multiple		1 (1%)			
Lip, basal cell adenoma					1 (1%)
Lip, squamous cell papilloma				1 (1%)	
Pinna, melanoma malignant				1 (1%)	1 (1%)
Prepuce, keratoacanthoma				1 (1%)	1 (1%)
Prepuce, squamous cell carcinoma					1 (1%)
Sebaceous gland, adenoma		1 (1%)	2 (2%)	1 (1%)	1 (1%)
Sebaceous gland, carcinoma	1 (1%)				
Subcutaneous tissue, fibroma	9 (9%)	6 (6%)	6 (6%)	10 (10%)	8 (8%)
Subcutaneous tissue, fibrosarcoma	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Subcutaneous tissue, leiomyosarcoma, metastatic, spleen				1 (1%)	
Subcutaneous tissue, lipoma	1 (1%)			2 (2%)	1 (1%)
Subcutaneous tissue, melanoma malignant		1 (1%)			
Subcutaneous tissue, sarcoma		1 (1%)	1 (1%)	3 (3%)	1 (1%)
Subcutaneous tissue, schwannoma malignant				1 (1%)	1 (1%)

TABLE A1
Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Musculoskeletal System					
Bone	(100)	(100)	(100)	(100)	(100)
Osteosarcoma				1 (1%)	
Femur, osteosarcoma, metastatic, bone			1 (1%)		
Maxilla, osteosarcoma			1 (1%)		
Skeletal muscle	(10)	(6)	(11)	(4)	(7)
Sarcoma			1 (9%)		
Nervous System					
Brain	(100)	(100)	(100)	(100)	(100)
Cerebellum, schwannoma malignant, metastatic, skin					1 (1%)
Cerebrum, astrocytoma malignant	1 (1%)				
Cerebrum, oligodendroglioma malignant	1 (1%)				1 (1%)
Cranial nerve, schwannoma malignant				1 (1%)	
Spinal cord	(11)	(6)	(9)	(4)	(6)
Respiratory System					
Lung	(100)	(100)	(100)	(100)	(100)
Alveolar/bronchiolar adenoma	3 (3%)	5 (5%)	5 (5%)	4 (4%)	
Alveolar/bronchiolar carcinoma		2 (2%)			
Carcinoma				1 (1%)	
Carcinoma, metastatic, thyroid gland		1 (1%)			
Chordoma, metastatic, uncertain primary site					1 (1%)
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Melanoma malignant, metastatic, skin		1 (1%)		1 (1%)	
Osteosarcoma, metastatic, bone			1 (1%)	1 (1%)	
Osteosarcoma, metastatic, uncertain primary site	1 (1%)				
Pheochromocytoma malignant, metastatic, adrenal medulla		1 (1%)			
Bronchus, adenoma	1 (1%)				
Bronchus, squamous cell carcinoma				1 (1%)	
Nose	(100)	(98)	(100)	(100)	(100)
Squamous cell carcinoma					1 (1%)
Trachea	(100)	(100)	(100)	(100)	(100)
Special Senses System					
Harderian gland	(100)	(100)	(100)	(100)	(100)
Adenoma		1 (1%)	1 (1%)		
Squamous cell carcinoma, metastatic, skin			1	(1%)	
Zymbal's gland	(1)	(2)	(1)	(1)	(1)
Adenoma		1 (50%)			
Carcinoma	1 (100%)	1 (50%)		1 (100%)	1 (100%)

TABLE A1
Summary of the Incidence of Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Urinary System					
Kidney	(100)	(100)	(100)	(100)	(100)
Fibroma	1 (1%)				
Leiomyosarcoma, metastatic, spleen				1 (1%)	
Nephroblastoma					1 (1%)
Osteosarcoma, metastatic, bone			1 (1%)		
Sarcoma			1 (1%)		
Capsule, sarcoma	1 (1%)				
Pelvis, transitional epithelium, carcinoma				1 (1%)	
Renal tubule, adenoma				1 (1%)	
Renal tubule, carcinoma				1 (1%)	
Urinary bladder	(99)	(96)	(100)	(100)	(99)
Transitional epithelium, papilloma	1 (1%)			1 (1%)	
Systemic Lesions					
Multiple organs[b]	(100)	(100)	(100)	(100)	(100)
Leukemia mononuclear	50 (50%)	44 (44%)	47 (47%)	50 (50%)	36 (36%)
Lymphoma malignant					1 (1%)
Mesothelioma malignant	4 (4%)	6 (6%)	5 (5%)	6 (6%)	4 (4%)
Neoplasm Summary					
Total animals with primary neoplasms[c]	100	98	98	100	98
Total primary neoplasms	298	304	317	327	303
Total animals with benign neoplasms	99	97	97	98	94
Total benign neoplasms	229	230	245	253	233
Total animals with malignant neoplasms	65	59	61	65	58
Total malignant neoplasms	69	74	72	74	70
Total animals with metastatic neoplasms	1	5	2	4	2
Total metastatic neoplasms	1	5	4	15	4
Total animals with malignant neoplasms of uncertain primary site	1				1

[a] Number of animals examined microscopically at the site and the number of animals with neoplasm
[b] Number of animals with any tissue examined microscopically
[c] Primary neoplasms: all neoplasms except metastatic neoplasms

TABLE A2
Statistical Analysis of Primary Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Adrenal Medulla: Benign Pheochromocytoma					
Overall rate[a]	24/98 (24%)	22/93 (24%)	21/100 (21%)	23/100 (23%)	33/95 (35%)
Adjusted rate[b]	27.8%	28.3%	24.5%	27.8%	39.9%
Terminal rate[c]	17/57 (30%)	9/43 (21%)	10/47 (21%)	14/48 (29%)	19/56 (34%)
First incidence (days)	619	505	617	488	552
Poly-3 test[d]	P=0.529	P=0.538	P=0.379N	P=0.567	P=0.063
Adrenal Medulla: Benign, Complex, or Malignant Pheochromocytoma					
Overall rate	26/98 (27%)	23/93 (25%)	21/100 (21%)	23/100 (23%)	35/95 (37%)
Adjusted rate	30.1%	29.6%	24.5%	27.8%	42.2%
Terminal rate	19/57 (33%)	10/43 (23%)	10/47 (21%)	14/48 (29%)	20/56 (36%)
First incidence (days)	619	505	617	488	552
Poly-3 test	P=0.457N	P=0.542N	P=0.258N	P=0.436N	P=0.066
Lung: Alveolar/bronchiolar Adenoma					
Overall rate	3/100 (3%)	5/100 (5%)	5/100 (5%)	4/100 (4%)	0/100 (0%)
Adjusted rate	3.5%	6.1%	6.0%	4.9%	0.0%
Terminal rate	3/57 (5%)	4/46 (9%)	5/47 (11%)	3/48 (6%)	0/59 (0%)
First incidence (days)	736 (T)	647	736 (T)	673	—[e]
Poly-3 test	P=0.593	P=0.333	P=0.345	P=0.471	P=0.127N
Lung: Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	3/100 (3%)	7/100 (7%)	5/100 (5%)	5/100 (5%)	0/100 (0%)
Adjusted rate	3.5%	8.6%	6.0%	6.2%	0.0%
Terminal rate	3/57 (5%)	6/46 (13%)	5/47 (11%)	4/48 (8%)	0/59 (0%)
First incidence (days)	736 (T)	647	736 (T)	673	—
Poly-3 test	P=0.558	P=0.145	P=0.345	P=0.330	P=0.127N
Mammary Gland: Fibroadenoma					
Overall rate	6/100 (6%)	6/100 (6%)	11/100 (11%)	9/100 (9%)	8/100 (8%)
Adjusted rate	7.0%	7.4%	13.1%	11.0%	9.5%
Terminal rate	6/57 (11%)	4/46 (9%)	6/47 (13%)	6/48 (13%)	5/59 (9%)
First incidence (days)	736 (T)	712	672	673	600
Poly-3 test	P=0.269	P=0.583	P=0.142	P=0.259	P=0.380
Mammary Gland: Fibroadenoma or Carcinoma					
Overall rate	6/100 (6%)	7/100 (7%)	11/100 (11%)	9/100 (9%)	8/100 (8%)
Adjusted rate	7.0%	8.6%	13.1%	11.0%	9.5%
Terminal rate	6/57 (11%)	5/46 (11%)	6/47 (13%)	6/48 (13%)	5/59 (9%)
First incidence (days)	736 (T)	712	672	673	600
Poly-3 test	P=0.316	P=0.462	P=0.142	P=0.259	P=0.380
Pancreas: Adenoma					
Overall rate	3/98 (3%)	5/99 (5%)	6/99 (6%)	5/99 (5%)	2/100 (2%)
Adjusted rate	3.5%	6.1%	7.2%	6.2%	2.4%
Terminal rate	2/57 (4%)	4/46 (9%)	5/47 (11%)	2/48 (4%)	1/59 (2%)
First incidence (days)	658	329	729	565	621
Poly-3 test	P=0.449	P=0.335	P=0.238	P=0.332	P=0.505N

TABLE A2
Statistical Analysis of Primary Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Pancreatic Islets: Adenoma					
Overall rate	3/99 (3%)	3/99 (3%)	6/99 (6%)	3/99 (3%)	2/100 (2%)
Adjusted rate	3.5%	3.7%	7.2%	3.7%	2.4%
Terminal rate	2/57 (4%)	2/46 (4%)	6/47 (13%)	3/48 (6%)	0/59 (0%)
First incidence (days)	714	659	736 (T)	736 (T)	675
Poly-3 test	P=0.551N	P=0.636	P=0.237	P=0.633	P=0.506N
Pancreatic Islets: Adenoma or Carcinoma					
Overall rate	4/99 (4%)	5/99 (5%)	6/99 (6%)	4/99 (4%)	5/100 (5%)
Adjusted rate	4.7%	6.2%	7.2%	5.0%	5.9%
Terminal rate	3/57 (5%)	2/46 (4%)	6/47 (13%)	3/48 (6%)	2/59 (3%)
First incidence (days)	714	659	736 (T)	702	675
Poly-3 test	P=0.505N	P=0.467	P=0.360	P=0.609	P=0.494
Pituitary Gland (Pars Distalis): Adenoma					
Overall rate	34/98 (35%)	35/95 (37%)	28/97 (29%)	35/100 (35%)	40/98 (41%)
Adjusted rate	38.8%	42.9%	33.5%	40.4%	46.0%
Terminal rate	23/57 (40%)	20/45 (44%)	18/46 (39%)	16/48 (33%)	28/58 (48%)
First incidence (days)	579	533	489	442	470
Poly-3 test	P=0.500	P=0.349	P=0.281N	P=0.479	P=0.206
Pituitary Gland (Pars Distalis): Adenoma or Carcinoma					
Overall rate	34/98 (35%)	36/95 (38%)	30/97 (31%)	35/100 (35%)	43/98 (44%)
Adjusted rate	38.8%	44.0%	35.8%	40.4%	49.2%
Terminal rate	23/57 (40%)	20/45 (44%)	19/46 (41%)	16/48 (33%)	29/58 (50%)
First incidence (days)	579	533	489	442	470
Poly-3 test	P=0.534N	P=0.295	P=0.401N	P=0.479	P=0.103
Preputial Gland: Adenoma					
Overall rate	13/100 (13%)	9/99 (9%)	10/100 (10%)	13/99 (13%)	10/100 (10%)
Adjusted rate	15.0%	10.8%	11.6%	15.8%	11.8%
Terminal rate	7/57 (12%)	4/45 (9%)	2/47 (4%)	7/47 (15%)	7/59 (12%)
First incidence (days)	649	396	489	445	586
Poly-3 test	P=0.301	P=0.281N	P=0.335N	P=0.527	P=0.348N
Preputial Gland: Carcinoma					
Overall rate	0/100 (0%)	0/99 (0%)	5/100 (5%)	0/99 (0%)	2/100 (2%)
Adjusted rate	0.0%	0.0%	5.9%	0.0%	2.4%
Terminal rate	0/57 (0%)	0/45 (0%)	2/47 (4%)	0/47 (0%)	0/59 (0%)
First incidence (days)	—	—	477	—	558
Poly-3 test	P=0.475N	—[f]	P=0.032	—	P=0.237
Preputial Gland: Adenoma or Carcinoma					
Overall rate	13/100 (13%)	9/99 (9%)	13/100 (13%)	13/99 (13%)	12/100 (12%)
Adjusted rate	15.0%	10.8%	15.0%	15.8%	14.0%
Terminal rate	7/57 (12%)	4/45 (9%)	4/47 (9%)	7/47 (15%)	7/59 (12%)
First incidence (days)	649	396	477	445	558
Poly-3 test	P=0.343	P=0.281N	P=0.584N	P=0.527	P=0.510N

TABLE A2
Statistical Analysis of Primary Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Skin: Keratoacanthoma					
Overall rate	10/100 (10%)	5/100 (5%)	11/100 (11%)	12/100 (12%)	8/100 (8%)
Adjusted rate	11.6%	6.1%	13.0%	14.8%	9.5%
Terminal rate	7/57 (12%)	3/46 (7%)	6/47 (13%)	8/48 (17%)	6/59 (10%)
First incidence (days)	627	713	535	702	557
Poly-3 test	P=0.139	P=0.167N	P=0.481	P=0.351	P=0.423N
Skin: Squamous Cell Papilloma or Keratoacanthoma					
Overall rate	11/100 (11%)	7/100 (7%)	12/100 (12%)	13/100 (13%)	8/100 (8%)
Adjusted rate	12.7%	8.6%	14.2%	16.0%	9.5%
Terminal rate	8/57 (14%)	3/46 (7%)	7/47 (15%)	9/48 (19%)	6/59 (10%)
First incidence (days)	627	688	535	702	557
Poly-3 test	P=0.177	P=0.266N	P=0.480	P=0.351	P=0.333N
Skin: Trichoepithelioma					
Overall rate	0/100 (0%)	1/100 (1%)	0/100 (0%)	5/100 (5%)	0/100 (0%)
Adjusted rate	0.0%	1.2%	0.0%	6.2%	0.0%
Terminal rate	0/57 (0%)	1/46 (2%)	0/47 (0%)	4/48 (8%)	0/59 (0%)
First incidence (days)	—	736 (T)	—	703	—
Poly-3 test	P=0.002	P=0.490	—	P=0.029	—
Skin: Trichoepithelioma or Basal Cell Adenoma					
Overall rate	3/100 (3%)	1/100 (1%)	3/100 (3%)	8/100 (8%)	3/100 (3%)
Adjusted rate	3.5%	1.2%	3.6%	9.8%	3.6%
Terminal rate	2/57 (4%)	1/46 (2%)	2/47 (4%)	5/48 (10%)	2/59 (3%)
First incidence (days)	659	736 (T)	586	656	582
Poly-3 test	P=0.008	P=0.327N	P=0.650	P=0.089	P=0.653
Skin: Squamous Cell Papilloma, Keratoacanthoma, or Squamous Cell Carcinoma					
Overall rate	11/100 (11%)	7/100 (7%)	12/100 (12%)	13/100 (13%)	10/100 (10%)
Adjusted rate	12.7%	8.6%	14.2%	16.0%	11.7%
Terminal rate	8/57 (14%)	3/46 (7%)	7/47 (15%)	9/48 (19%)	7/59 (12%)
First incidence (days)	627	688	535	702	470
Poly-3 test	P=0.177	P=0.266N	P=0.480	P=0.351	P=0.514N
Skin: Squamous Cell Papilloma, Keratoacanthoma, Trichoepithelioma, Basal Cell Adenoma, or Squamous Cell Carcinoma					
Overall rate	14/100 (14%)	8/100 (8%)	14/100 (14%)	20/100 (20%)	12/100 (12%)
Adjusted rate	16.1%	9.8%	16.4%	24.5%	14.0%
Terminal rate	10/57 (18%)	4/46 (9%)	8/47 (17%)	14/48 (29%)	8/59 (14%)
First incidence (days)	627	688	535	656	470
Poly-3 test	P=0.018	P=0.159N	P=0.563	P=0.122	P=0.428N
Skin (Dermis or Subcutaneous Tissue): Fibroma					
Overall rate	12/100 (12%)	8/100 (8%)	9/100 (9%)	13/100 (13%)	12/100 (12%)
Adjusted rate	13.9%	9.8%	10.6%	15.9%	14.2%
Terminal rate	9/57 (16%)	4/46 (9%)	4/47 (9%)	9/48 (19%)	8/59 (14%)
First incidence (days)	617	619	635	614	586
Poly-3 test	P=0.211	P=0.278N	P=0.339N	P=0.438	P=0.568

TABLE A2
Statistical Analysis of Primary Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Skin (Dermis or Subcutaneous Tissue): Fibroma, Fibrosarcoma, or Sarcoma					
Overall rate	13/100 (13%)	10/100 (10%)	11/100 (11%)	16/100 (16%)	14/100 (14%)
Adjusted rate	15.0%	12.1%	13.0%	19.2%	16.5%
Terminal rate	9/57 (16%)	5/46 (11%)	6/47 (13%)	9/48 (19%)	10/59 (17%)
First incidence (days)	617	619	635	442	586
Poly-3 test	P=0.141	P=0.374N	P=0.435N	P=0.303	P=0.477
Testes: Adenoma					
Overall rate	93/100 (93%)	90/100 (90%)	91/100 (91%)	91/100 (91%)	89/100 (89%)
Adjusted rate	95.1%	94.8%	94.4%	95.8%	93.8%
Terminal rate	54/57 (95%)	45/46 (98%)	43/47 (92%)	47/48 (98%)	57/59 (97%)
First incidence (days)	476	461	463	410	489
Poly-3 test	P=0.450	P=0.600N	P=0.544N	P=0.556	P=0.460N
Thyroid Gland (C-cell): Adenoma					
Overall rate	15/99 (15%)	25/100 (25%)	26/100 (26%)	23/100 (23%)	18/100 (18%)
Adjusted rate	17.2%	30.0%	30.5%	27.4%	21.5%
Terminal rate	7/57 (12%)	15/46 (33%)	16/47 (34%)	13/48 (27%)	16/59 (27%)
First incidence (days)	583	589	604	561	725
Poly-3 test	P=0.326	P=0.035	P=0.028	P=0.075	P=0.305
Thyroid Gland (C-cell): Carcinoma					
Overall rate	1/99 (1%)	7/100 (7%)	4/100 (4%)	2/100 (2%)	5/100 (5%)
Adjusted rate	1.2%	8.5%	4.8%	2.5%	5.9%
Terminal rate	1/57 (2%)	2/46 (4%)	2/47 (4%)	2/48 (4%)	4/59 (7%)
First incidence (days)	736 (T)	619	687	736 (T)	666
Poly-3 test	P=0.280N	P=0.030	P=0.177	P=0.483	P=0.103
Thyroid Gland (C-cell): Adenoma or Carcinoma					
Overall rate	16/99 (16%)	31/100 (31%)	30/100 (30%)	25/100 (25%)	22/100 (22%)
Adjusted rate	18.4%	36.8%	35.1%	29.8%	26.1%
Terminal rate	8/57 (14%)	17/46 (37%)	18/47 (38%)	15/48 (31%)	19/59 (32%)
First incidence (days)	583	589	604	561	666
Poly-3 test	P=0.438	P=0.005	P=0.009	P=0.055	P=0.147
All Organs: Mononuclear Cell Leukemia					
Overall rate	50/100 (50%)	44/100 (44%)	47/100 (47%)	50/100 (50%)	36/100 (36%)
Adjusted rate	53.1%	50.0%	52.0%	56.2%	39.7%
Terminal rate	24/57 (42%)	18/46 (39%)	17/47 (36%)	22/48 (46%)	15/59 (25%)
First incidence (days)	303	533	479	410	527
Poly-3 test	P=0.265	P=0.393N	P=0.502N	P=0.390	P=0.045N
All Organs: Malignant Mesothelioma					
Overall rate	4/100 (4%)	6/100 (6%)	5/100 (5%)	6/100 (6%)	4/100 (4%)
Adjusted rate	4.6%	7.2%	5.9%	7.2%	4.7%
Terminal rate	2/57 (4%)	1/46 (2%)	1/47 (2%)	2/48 (4%)	2/59 (3%)
First incidence (days)	658	581	568	488	576
Poly-3 test	P=0.415	P=0.350	P=0.492	P=0.349	P=0.632

TABLE A2
Statistical Analysis of Primary Neoplasms in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
All Organs: Benign Neoplasms					
Overall rate	99/100 (99%)	97/100 (97%)	97/100 (97%)	98/100 (98%)	94/100 (94%)
Adjusted rate	99.8%	99.4%	99.4%	99.5%	96.7%
Terminal rate	57/57 (100%)	46/46 (100%)	47/47 (100%)	48/48 (100%)	58/59 (98%)
First incidence (days)	303	329	463	410	470
Poly-3 test	P=0.876N	P=0.906N	P=0.926N	P=0.941N	P=0.092N
All Organs: Malignant Neoplasms					
Overall rate	66/100 (66%)	59/100 (59%)	61/100 (61%)	66/100 (66%)	58/100 (58%)
Adjusted rate	68.1%	64.7%	65.0%	69.4%	60.7%
Terminal rate	32/57 (56%)	23/46 (50%)	23/47 (49%)	26/48 (54%)	26/59 (44%)
First incidence (days)	303	466	477	410	365
Poly-3 test	P=0.325	P=0.365N	P=0.380N	P=0.483	P=0.173N
All Organs: Benign or Malignant Neoplasms					
Overall rate	100/100 (100%)	98/100 (98%)	98/100 (98%)	100/100 (100%)	98/100 (98%)
Adjusted rate	100.0%	99.7%	99.7%	100.0%	98.9%
Terminal rate	57/57 (100%)	46/46 (100%)	47/47 (100%)	48/48 (100%)	58/59 (98%)
First incidence (days)	303	329	463	410	365
Poly-3 test	P=0.957	P=0.985N	P=0.999N	—	P=0.471N

(T)Terminal sacrifice
[a] Number of neoplasm-bearing animals/number of animals examined. Denominator is number of animals examined microscopically for adrenal gland, lung, pancreas, pancreatic islets, pituitary gland, preputial gland, testis, and thyroid gland; for other tissues, denominator is number of animals necropsied.
[b] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[c] Observed incidence at terminal kill
[d] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend or a lower incidence in an exposure group is indicated by **N**.
[e] Not applicable; no neoplasms in animal group
[f] Value of statistic cannot be computed.

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	29	32	32	36	33
Natural deaths	14	21	21	16	7
Other		1			1
Survivors					
Terminal sacrifice	57	46	47	48	59
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Intestine large, colon	(100)	(99)	(99)	(100)	(99)
Inflammation, chronic			1 (1%)		
Parasite metazoan				1 (1%)	
Intestine large, rectum	(99)	(100)	(100)	(99)	(100)
Edema			1 (1%)		
Ulcer			1 (1%)		
Intestine large, cecum	(98)	(99)	(97)	(100)	(99)
Edema	1 (1%)		1 (1%)		1 (1%)
Inflammation, chronic active	1 (1%)				
Parasite metazoan				1 (1%)	
Intestine small, duodenum	(99)	(94)	(100)	(100)	(98)
Inflammation, acute			1 (1%)		
Intestine small, ileum	(94)	(92)	(97)	(96)	(97)
Inflammation, chronic	1 (1%)			1 (1%)	
Peyer's patch, hyperplasia, lymphoid				2 (2%)	1 (1%)
Liver	(100)	(100)	(100)	(100)	(100)
Angiectasis, focal		1 (1%)	3 (3%)		1 (1%)
Atrophy					1 (1%)
Atypia cellular, focal		1 (1%)			
Basophilic focus	35 (35%)	35 (35%)	47 (47%)	37 (37%)	36 (36%)
Clear cell focus	44 (44%)	37 (37%)	38 (38%)	35 (35%)	41 (41%)
Degeneration, cystic, focal	8 (8%)	2 (2%)	11 (11%)	13 (13%)	5 (5%)
Eosinophilic focus	21 (21%)	19 (19%)	26 (26%)	17 (17%)	17 (17%)
Hematopoietic cell proliferation	5 (5%)	4 (4%)	6 (6%)	3 (3%)	2 (2%)
Hepatodiaphragmatic nodule	2 (2%)	5 (5%)	7 (7%)		1 (1%)
Infiltration cellular, lymphocyte	1 (1%)				2 (2%)
Infiltration cellular, mixed cell	11 (11%)	15 (15%)	9 (9%)	14 (14%)	26 (26%)
Inflammation, chronic	2 (2%)	1 (1%)		1 (1%)	3 (3%)
Inflammation, chronic active		1 (1%)			
Mixed cell focus	25 (25%)	28 (28%)	25 (25%)	23 (23%)	18 (18%)
Necrosis	8 (8%)	6 (6%)	6 (6%)	4 (4%)	2 (2%)
Pigmentation			1 (1%)	1 (1%)	2 (2%)
Tension lipidosis	1 (1%)				
Artery, inflammation, chronic	1 (1%)				
Bile duct, hyperplasia	79 (79%)	88 (88%)	88 (88%)	74 (74%)	79 (79%)
Centrilobular, necrosis					1 (1%)
Hepatocyte, degeneration	1 (1%)				
Hepatocyte, hypertrophy	1 (1%)				
Hepatocyte, vacuolization cytoplasmic	14 (14%)	13 (13%)	19 (19%)	19 (19%)	20 (20%)
Hepatocyte, vacuolization cytoplasmic, focal		1 (1%)	1 (1%)		

[a] Number of animals examined microscopically at the site and the number of animals with lesion

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Mesentery	(17)	(22)	(27)	(21)	(16)
Accessory spleen					2 (13%)
Inflammation, chronic			1 (4%)		
Artery, hemorrhage		1 (5%)			
Artery, inflammation, chronic					1 (6%)
Fat, necrosis	14 (82%)	15 (68%)	23 (85%)	15 (71%)	13 (81%)
Pancreas	(98)	(99)	(99)	(99)	(100)
Cyst	3 (3%)		1 (1%)	1 (1%)	1 (1%)
Fibrosis, focal				1 (1%)	
Hemorrhage			1 (1%)		
Infiltration cellular, lymphocyte	5 (5%)	14 (14%)	13 (13%)	9 (9%)	3 (3%)
Acinus, atrophy, diffuse		3 (3%)	1 (1%)	1 (1%)	1 (1%)
Acinus, atrophy, focal	33 (34%)	26 (26%)	40 (40%)	27 (27%)	41 (41%)
Acinus, basophilic focus	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Acinus, hyperplasia, focal	20 (20%)	21 (21%)	23 (23%)	20 (20%)	18 (18%)
Acinus, inflammation, chronic		1 (1%)		1 (1%)	
Artery, inflammation, chronic	1 (1%)	2 (2%)		2 (2%)	1 (1%)
Salivary glands	(99)	(99)	(100)	(100)	(100)
Mineralization		1 (1%)			
Bilateral, pigmentation		1 (1%)			
Parotid gland, atrophy		2 (2%)		2 (2%)	
Parotid gland, fibrosis, focal				1 (1%)	
Parotid gland, hyperplasia, focal		1 (1%)		1 (1%)	
Parotid gland, inflammation, chronic				1 (1%)	
Parotid gland, vacuolization cytoplasmic, diffuse		1 (1%)			
Sublingual gland, atrophy				1 (1%)	1 (1%)
Sublingual gland, infiltration cellular, lymphocyte		1 (1%)			
Sublingual gland, inflammation, chronic		1 (1%)			
Submandibular gland, atrophy					1 (1%)
Stomach, forestomach	(100)	(100)	(100)	(100)	(100)
Edema	3 (3%)	3 (3%)	5 (5%)	3 (3%)	6 (6%)
Erosion, focal	1 (1%)	1 (1%)		1 (1%)	
Inflammation, acute		1 (1%)	1 (1%)		1 (1%)
Inflammation, chronic	1 (1%)	1 (1%)			3 (3%)
Inflammation, chronic active	2 (2%)	1 (1%)	4 (4%)	4 (4%)	1 (1%)
Ulcer	1 (1%)	2 (2%)	2 (2%)	3 (3%)	7 (7%)
Epithelium, hyperplasia	6 (6%)	5 (5%)	9 (9%)	2 (2%)	7 (7%)
Stomach, glandular	(100)	(100)	(100)	(100)	(100)
Atrophy	3 (3%)				
Edema	2 (2%)		1 (1%)		
Erosion, focal	9 (9%)	3 (3%)	9 (9%)	8 (8%)	11 (11%)
Hyperplasia, focal				1 (1%)	1 (1%)
Inflammation, acute				1 (1%)	1 (1%)
Inflammation, chronic					1 (1%)
Inflammation, chronic active		1 (1%)	1 (1%)		1 (1%)
Mineralization	1 (1%)				1 (1%)
Ulcer			1 (1%)		
Artery, inflammation, chronic	1 (1%)	1 (1%)			
Epithelium, cyst				1 (1%)	
Glands, cyst	4 (4%)	6 (6%)	1 (1%)	3 (3%)	2 (2%)
Muscularis, mineralization		1 (1%)			

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Tooth	(2)	(1)	(1)	(1)	(6)
Malformation					5 (83%)
Gingiva, inflammation, chronic active	2 (100%)		1 (100%)		1 (17%)
Gingiva, malformation	1 (50%)				
Peridontal tissue, inflammation, chronic active				1 (100%)	
Cardiovascular System					
Blood vessel	(99)	(99)	(99)	(100)	(100)
Aneurysm	1 (1%)				
Inflammation, chronic	1 (1%)				
Mineralization		1 (1%)			1 (1%)
Heart	(100)	(100)	(100)	(100)	(100)
Cardiomyopathy	88 (88%)	87 (87%)	88 (88%)	87 (87%)	87 (87%)
Metaplasia, focal, osseous				1 (1%)	
Pigmentation					2 (2%)
Artery, inflammation, chronic	1 (1%)				
Artery, mineralization		1 (1%)			1 (1%)
Atrium, mineralization					1 (1%)
Atrium, thrombosis	6 (6%)	6 (6%)	6 (6%)	9 (9%)	4 (4%)
Epicardium, inflammation, chronic	1 (1%)				
Myocardium, necrosis			1 (1%)		
Pericardium, inflammation, chronic					1 (1%)
Valve, inflammation, chronic		1 (1%)		2 (2%)	
Endocrine System					
Adrenal cortex	(99)	(100)	(100)	(100)	(100)
Accessory adrenal cortical nodule	1 (1%)		2 (2%)		3 (3%)
Angiectasis		4 (4%)		1 (1%)	
Degeneration, focal			1 (1%)		
Hematopoietic cell proliferation	1 (1%)	4 (4%)	3 (3%)	2 (2%)	6 (6%)
Hemorrhage	1 (1%)	1 (1%)			
Hyperplasia, focal	11 (11%)	15 (15%)	9 (9%)	11 (11%)	9 (9%)
Hypertrophy, focal	3 (3%)	3 (3%)	6 (6%)	3 (3%)	
Necrosis, focal	2 (2%)				
Pigmentation					1 (1%)
Vacuolization cytoplasmic, focal	14 (14%)	19 (19%)	19 (19%)	20 (20%)	19 (19%)
Bilateral, angiectasis	5 (5%)	8 (8%)	2 (2%)	2 (2%)	2 (2%)
Bilateral, hematopoietic cell proliferation	2 (2%)	3 (3%)	2 (2%)		3 (3%)
Bilateral, hyperplasia, focal	1 (1%)				
Bilateral, infiltration cellular, mixed cell			1 (1%)		
Bilateral, necrosis		1 (1%)			
Bilateral, pigmentation	1 (1%)		1 (1%)		1 (1%)
Bilateral, vacuolization cytoplasmic, diffuse		1 (1%)	2 (2%)	4 (4%)	3 (3%)
Bilateral, vacuolization cytoplasmic, focal	6 (6%)	5 (5%)	4 (4%)	5 (5%)	1 (1%)
Adrenal medulla	(98)	(93)	(100)	(100)	(95)
Degeneration, cystic		1 (1%)			
Hyperplasia, focal	14 (14%)	11 (12%)	9 (9%)	16 (16%)	13 (14%)
Infiltration cellular, lymphocyte		1 (1%)		1 (1%)	
Thrombosis			1 (1%)		
Bilateral, hyperplasia, focal	3 (3%)	5 (5%)	2 (2%)	2 (2%)	1 (1%)
Bilateral, infiltration cellular, lymphocyte				1 (1%)	

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Islets, pancreatic	(99)	(99)	(99)	(99)	(100)
Hyperplasia, focal	1 (1%)	1 (1%)	9 (9%)	2 (2%)	7 (7%)
Inflammation, chronic, focal				1 (1%)	
Metaplasia, focal			1 (1%)		
Parathyroid gland	(85)	(87)	(93)	(81)	(89)
Hyperplasia, focal	1 (1%)	1 (1%)		1 (1%)	
Pineal gland	(81)	(84)	(81)	(79)	(91)
Fibrosis				1 (1%)	
Hyperplasia, focal		1 (1%)			
Infiltration cellular, lymphocyte	1 (1%)	1 (1%)	2 (2%)		
Mineralization	42 (52%)	52 (62%)	54 (67%)	39 (49%)	57 (63%)
Pituitary gland	(98)	(95)	(97)	(100)	(98)
Inflammation, granulomatous		1 (1%)			
Pars distalis, angiectasis, focal	3 (3%)	2 (2%)	4 (4%)	2 (2%)	2 (2%)
Pars distalis, atrophy, focal	1 (1%)				
Pars distalis, cyst	8 (8%)	6 (6%)	6 (6%)	16 (16%)	7 (7%)
Pars distalis, hemorrhage			1 (1%)		
Pars distalis, hyperplasia, focal	11 (11%)	15 (16%)	9 (9%)	14 (14%)	16 (16%)
Pars distalis, hypertrophy, focal	2 (2%)	2 (2%)	3 (3%)		2 (2%)
Pars distalis, pigmentation, focal	1 (1%)				
Pars distalis, vacuolization cytoplasmic		2 (2%)		1 (1%)	1 (1%)
Pars distalis, vacuolization cytoplasmic, focal		1 (1%)			
Pars intermedia, atypia cellular		1 (1%)			
Pars intermedia, cyst	3 (3%)		1 (1%)		2 (2%)
Pars intermedia, hyperplasia, focal		1 (1%)			
Pars nervosa, atypia cellular		1 (1%)			
Pars nervosa, cyst				1 (1%)	
Pars nervosa, degeneration, focal			1 (1%)		
Rathke's cleft, cyst		1 (1%)	1 (1%)		1 (1%)
Thyroid gland	(99)	(100)	(100)	(100)	(100)
Hemorrhage					1 (1%)
Inflammation, chronic	2 (2%)			2 (2%)	
Mineralization		1 (1%)			
Ultimobranchial cyst	1 (1%)	1 (1%)	4 (4%)	7 (7%)	3 (3%)
Bilateral, C-cell, hyperplasia, focal	1 (1%)		1 (1%)		
C-cell, hyperplasia		1 (1%)	3 (3%)	1 (1%)	2 (2%)
C-cell, hyperplasia, diffuse	4 (4%)			1 (1%)	
C-cell, hyperplasia, focal	28 (28%)	22 (22%)	23 (23%)	24 (24%)	31 (31%)
Follicle, cyst	3 (3%)	2 (2%)	5 (5%)	2 (2%)	3 (3%)
Follicular cell, hyperplasia, focal	1 (1%)		2 (2%)	1 (1%)	
General Body System					
Tissue NOS	(3)	(2)		(1)	(2)
Necrosis	1 (33%)				
Genital System					
Epididymis	(100)	(100)	(100)	(100)	(100)
Atrophy	1 (1%)				
Granuloma sperm	2 (2%)			3 (3%)	
Infiltration cellular, lymphocyte		1 (1%)		1 (1%)	

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Epididymis (continued)	(100)	(100)	(100)	(100)	(100)
Inflammation, acute				1 (1%)	
Inflammation, chronic	3 (3%)	4 (4%)	4 (4%)	5 (5%)	2 (2%)
Inflammation, chronic active		1 (1%)	1 (1%)	1 (1%)	1 (1%)
Inflammation, granulomatous		1 (1%)			
Artery, inflammation, chronic	1 (1%)				
Bilateral, inflammation, acute			1 (1%)		
Bilateral, inflammation, chronic		1 (1%)			
Bilateral, epithelium, degeneration, mucoid	58 (58%)	61 (61%)	54 (54%)	60 (60%)	54 (54%)
Epithelium, degeneration, mucoid	24 (24%)	15 (15%)	29 (29%)	12 (12%)	25 (25%)
Preputial gland	(100)	(99)	(100)	(99)	(100)
Cyst			1 (1%)		
Hyperplasia, focal	4 (4%)	8 (8%)	2 (2%)	4 (4%)	1 (1%)
Inflammation, acute		1 (1%)		1 (1%)	
Inflammation, chronic	18 (18%)	19 (19%)	25 (25%)	31 (31%)	35 (35%)
Inflammation, chronic active	4 (4%)	3 (3%)	2 (2%)	7 (7%)	4 (4%)
Inflammation, granulomatous		1 (1%)			
Bilateral, atrophy	1 (1%)	1 (1%)		2 (2%)	
Bilateral, inflammation, chronic	47 (47%)	48 (48%)	44 (44%)	33 (33%)	34 (34%)
Bilateral, inflammation, chronic active	11 (11%)	6 (6%)	5 (5%)	4 (4%)	11 (11%)
Prostate	(100)	(99)	(100)	(99)	(100)
Atrophy	48 (48%)	57 (58%)	34 (34%)	47 (47%)	52 (52%)
Cyst					1 (1%)
Hypertrophy					1 (1%)
Infiltration cellular, lymphocyte					2 (2%)
Inflammation, acute	4 (4%)	7 (7%)	15 (15%)	7 (7%)	14 (14%)
Inflammation, chronic	6 (6%)	6 (6%)	14 (14%)	6 (6%)	7 (7%)
Inflammation, chronic active	36 (36%)	44 (44%)	36 (36%)	35 (35%)	39 (39%)
Artery, inflammation, chronic	1 (1%)				
Bilateral, inflammation, chronic		1 (1%)			
Bilateral, inflammation, chronic active					1 (1%)
Epithelium, hyperplasia, focal	10 (10%)	7 (7%)	5 (5%)	9 (9%)	12 (12%)
Seminal vesicle	(100)	(99)	(100)	(99)	(100)
Atrophy	30 (30%)	48 (48%)	50 (50%)	38 (38%)	30 (30%)
Dilatation					2 (2%)
Inflammation, acute		1 (1%)	1 (1%)		
Inflammation, chronic active			1 (1%)		1 (1%)
Bilateral, atrophy	54 (54%)	31 (31%)	36 (36%)	40 (40%)	49 (49%)
Bilateral, dilatation		1 (1%)			2 (2%)
Testes	(100)	(100)	(100)	(100)	(100)
Mineralization	1 (1%)	1 (1%)	4 (4%)		1 (1%)
Necrosis				1 (1%)	
Bilateral, inflammation, chronic		1 (1%)			
Bilateral, mineralization	2 (2%)				
Bilateral, necrosis		1 (1%)			
Bilateral, artery, inflammation, chronic	1 (1%)				
Bilateral, interstitial cell, hyperplasia, diffuse			1 (1%)		
Bilateral, interstitial cell, hyperplasia, focal	3 (3%)	1 (1%)	5 (5%)	5 (5%)	3 (3%)
Bilateral, germinal epithelium, atrophy	4 (4%)	3 (3%)	3 (3%)	2 (2%)	4 (4%)
Germinal epithelium, atrophy	6 (6%)	11 (11%)	11 (11%)	10 (10%)	9 (9%)
Germinal epithelium, hyperplasia, focal				1 (1%)	
Interstitial cell, hyperplasia, focal	8 (8%)	8 (8%)	12 (12%)	17 (17%)	21 (21%)

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System					
Bone marrow	(100)	(100)	(100)	(99)	(100)
Depletion cellular	3 (3%)	2 (2%)	3 (3%)	2 (2%)	6 (6%)
Hemorrhage				2 (2%)	1 (1%)
Hyperplasia	14 (14%)	18 (18%)	15 (15%)	12 (12%)	12 (12%)
Myelofibrosis		1 (1%)			
Necrosis			4 (4%)		
Lymph node	(15)	(7)	(7)	(13)	(8)
Hyperplasia, lymphoid	1 (7%)				1 (13%)
Mediastinal, hemorrhage	2 (13%)	1 (14%)	1 (14%)	2 (15%)	1 (13%)
Mediastinal, hyperplasia, lymphoid			1 (14%)		
Mediastinal, pigmentation	1 (7%)			1 (8%)	
Lymph node, mandibular	(99)	(99)	(100)	(100)	(100)
Atrophy		1 (1%)			
Degeneration, cystic	15 (15%)	10 (10%)	11 (11%)	12 (12%)	11 (11%)
Fibrosis	1 (1%)		1 (1%)		
Hemorrhage	2 (2%)	1 (1%)		7 (7%)	1 (1%)
Hyperplasia, lymphoid	17 (17%)	15 (15%)	14 (14%)	13 (13%)	14 (14%)
Infiltration cellular, histiocyte		3 (3%)	4 (4%)	2 (2%)	
Pigmentation	1 (1%)	1 (1%)		1 (1%)	2 (2%)
Lymph node, mesenteric	(100)	(99)	(100)	(100)	(100)
Angiectasis			1 (1%)		
Atrophy		1 (1%)		1 (1%)	
Degeneration, cystic	1 (1%)	2 (2%)	2 (2%)	1 (1%)	1 (1%)
Hematopoietic cell proliferation				1 (1%)	
Hemorrhage	2 (2%)	2 (2%)	2 (2%)	2 (2%)	1 (1%)
Hyperplasia, lymphoid		1 (1%)	1 (1%)	2 (2%)	3 (3%)
Infiltration cellular, histiocyte	65 (65%)	70 (71%)	73 (73%)	70 (70%)	80 (80%)
Inflammation, chronic		2 (2%)			
Pigmentation	1 (1%)				
Artery, inflammation, chronic active				1 (1%)	
Spleen	(100)	(100)	(100)	(100)	(100)
Accessory spleen	1 (1%)		1 (1%)		1 (1%)
Congestion		3 (3%)	5 (5%)	1 (1%)	1 (1%)
Depletion cellular, focal		1 (1%)			1 (1%)
Fibrosis	1 (1%)	6 (6%)	4 (4%)	1 (1%)	1 (1%)
Hematopoietic cell proliferation	14 (14%)	12 (12%)	13 (13%)	15 (15%)	16 (16%)
Hemorrhage	1 (1%)				
Necrosis, focal	1 (1%)				
Pigmentation	12 (12%)	11 (11%)	17 (17%)	15 (15%)	19 (19%)
Capsule, inflammation, chronic		3 (3%)	1 (1%)		
Capsule, pigmentation, focal		1 (1%)			
Lymphoid follicle, atrophy	1 (1%)	4 (4%)	3 (3%)	3 (3%)	3 (3%)
Lymphoid follicle, hyperplasia				1 (1%)	
Thymus	(97)	(94)	(95)	(90)	(95)
Atrophy	58 (60%)	46 (49%)	63 (66%)	62 (69%)	44 (46%)
Cyst	1 (1%)	2 (2%)	1 (1%)		2 (2%)
Hemorrhage	2 (2%)	3 (3%)	2 (2%)	2 (2%)	
Hyperplasia, lymphoid		1 (1%)	1 (1%)		1 (1%)
Epithelial cell, hyperplasia	2 (2%)	3 (3%)	3 (3%)	6 (7%)	2 (2%)

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Integumentary System					
Mammary gland	(99)	(97)	(100)	(98)	(95)
Cyst	18 (18%)	15 (15%)	10 (10%)	14 (14%)	14 (15%)
Fibrosis		2 (2%)	1 (1%)	2 (2%)	
Galactocele		2 (2%)	5 (5%)	1 (1%)	5 (5%)
Inflammation, chronic	1 (1%)		3 (3%)	1 (1%)	1 (1%)
Inflammation, chronic active	1 (1%)				
Mineralization	2 (2%)	1 (1%)	1 (1%)		1 (1%)
Pigmentation	2 (2%)				4 (4%)
Epithelium, hyperplasia	9 (9%)	1 (1%)	4 (4%)	3 (3%)	4 (4%)
Skin	(99)	(100)	(100)	(100)	(100)
Congestion			1 (1%)		
Cyst epithelial inclusion		4 (4%)	3 (3%)	3 (3%)	3 (3%)
Hyperkeratosis		1 (1%)			
Inflammation, acute					1 (1%)
Inflammation, chronic active			1 (1%)		
Dermis, fibrosis, focal		2 (2%)	1 (1%)		
Epidermis, hyperplasia		1 (1%)			
Hair follicle, hyperplasia, focal			1 (1%)	1 (1%)	
Lip, hemorrhage					1 (1%)
Subcutaneous tissue, fibrosis				2 (2%)	1 (1%)
Subcutaneous tissue, hemorrhage			1 (1%)		
Subcutaneous tissue, inflammation, chronic		1 (1%)			
Subcutaneous tissue, necrosis	1 (1%)				
Musculoskeletal System					
Bone	(100)	(100)	(100)	(100)	(100)
Cranium, hyperostosis	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Femur, hyperostosis	1 (1%)	2 (2%)	5 (5%)	2 (2%)	1 (1%)
Femur, hypertrophy			1 (1%)		
Maxilla, osteomalacia		1 (1%)			
Turbinate, hyperostosis		1 (1%)			
Skeletal muscle	(10)	(6)	(11)	(4)	(7)
Infiltration cellular, lymphocyte		1 (17%)			
Inflammation, chronic, focal					1 (14%)
Mineralization		1 (17%)			
Nervous System					
Brain	(100)	(100)	(100)	(100)	(100)
Artery, thrombosis			1 (1%)		
Cerebrum, hemorrhage				1 (1%)	
Cerebrum, hydrocephalus					1 (1%)
Cerebrum, infiltration cellular, lymphocyte					1 (1%)
Cerebrum, necrosis			2 (2%)	1 (1%)	
Choroid plexus, hyperplasia					1 (1%)
Choroid plexus, mineralization			1 (1%)	1 (1%)	
Choroid plexus, cerebrum, infiltration cellular, lymphocyte	1 (1%)				
Hypothalamus, compression	5 (5%)	8 (8%)	1 (1%)	9 (9%)	8 (8%)
Hypothalamus, necrosis, focal				1 (1%)	
Meninges, hyperplasia			1 (1%)		
Pons, compression					1 (1%)
Thalamus, necrosis, focal	1 (1%)				
Spinal cord	(11)	(6)	(9)	(4)	(6)
Meninges, cyst epithelial inclusion	1 (9%)				

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Respiratory System					
Lung	(100)	(100)	(100)	(100)	(100)
Congestion	5 (5%)	5 (5%)	2 (2%)	4 (4%)	3 (3%)
Edema					1 (1%)
Fibrosis, focal				1 (1%)	
Foreign body					1 (1%)
Hemorrhage	1 (1%)				
Infiltration cellular, lymphocyte		11 (11%)	5 (5%)	2 (2%)	3 (3%)
Infiltration cellular, histiocyte	8 (8%)	18 (18%)	12 (12%)	6 (6%)	5 (5%)
Inflammation, acute					1 (1%)
Inflammation, chronic, focal		1 (1%)			
Metaplasia, focal, osseous		1 (1%)		4 (4%)	1 (1%)
Alveolar epithelium, hyperplasia, focal	6 (6%)	3 (3%)	7 (7%)	5 (5%)	4 (4%)
Artery, inflammation, chronic	1 (1%)				
Bronchus, inflammation, acute				1 (1%)	1 (1%)
Bronchus, inflammation, chronic					2 (2%)
Bronchus, inflammation, chronic active			1 (1%)		
Interstitium, inflammation, acute					1 (1%)
Interstitium, inflammation, chronic	5 (5%)	5 (5%)	3 (3%)	2 (2%)	3 (3%)
Interstitium, inflammation, chronic active	1 (1%)			2 (2%)	
Serosa, inflammation, chronic			1 (1%)		
Nose	(100)	(98)	(100)	(100)	(100)
Congestion				1 (1%)	
Foreign body	1 (1%)	1 (1%)	1 (1%)	1 (1%)	
Inflammation, acute	1 (1%)				2 (2%)
Inflammation, chronic	5 (5%)	3 (3%)	5 (5%)	4 (4%)	3 (3%)
Inflammation, chronic active	22 (22%)	25 (26%)	35 (35%)	25 (25%)	31 (31%)
Metaplasia, squamous		2 (2%)			
Mineralization, focal	1 (1%)				
Glands, cyst	1 (1%)				
Nasolacrimal duct, inflammation, acute	1 (1%)		1 (1%)	1 (1%)	
Nasolacrimal duct, inflammation, chronic	6 (6%)	8 (8%)	12 (12%)	7 (7%)	4 (4%)
Nasolacrimal duct, inflammation, chronic active	1 (1%)		1 (1%)	3 (3%)	4 (4%)
Olfactory epithelium, cyst			1 (1%)		
Olfactory epithelium, cytoplasmic alteration	36 (36%)	32 (33%)	48 (48%)	41 (41%)	29 (29%)
Olfactory epithelium, mineralization			1 (1%)		
Respiratory epithelium, cyst			1 (1%)	1 (1%)	
Respiratory epithelium, cytoplasmic alteration	3 (3%)	1 (1%)	1 (1%)		1 (1%)
Respiratory epithelium, hyperplasia, focal				1 (1%)	
Trachea	(100)	(100)	(100)	(100)	(100)
Inflammation, chronic	10 (10%)	12 (12%)	15 (15%)	3 (3%)	12 (12%)
Inflammation, chronic active	1 (1%)	1 (1%)			
Glands, cyst	1 (1%)		1 (1%)		1 (1%)
Special Senses System					
Eye		(3)	(2)	(7)	(1)
Bilateral, lens, cataract				1 (14%)	
Bilateral, retina, atrophy				3 (43%)	
Iris, inflammation, chronic			1 (50%)		
Iris, synechia				1 (14%)	1 (100%)
Lens, cataract		3 (100%)	1 (50%)	5 (71%)	1 (100%)
Retina, atrophy		3 (100%)	2 (100%)	4 (57%)	1 (100%)

TABLE A3
Summary of the Incidence of Nonneoplastic Lesions in Male Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Special Senses System (continued)					
Harderian gland	(100)	(100)	(100)	(100)	(100)
Atrophy, diffuse					1 (1%)
Atrophy, focal	2 (2%)	1 (1%)	8 (8%)	2 (2%)	1 (1%)
Hyperplasia, focal	2 (2%)	2 (2%)	4 (4%)		2 (2%)
Infiltration cellular, lymphocyte	26 (26%)	30 (30%)	23 (23%)	25 (25%)	44 (44%)
Inflammation, acute					1 (1%)
Inflammation, chronic	3 (3%)	4 (4%)	6 (6%)	2 (2%)	1 (1%)
Inflammation, chronic active	1 (1%)				
Pigmentation	1 (1%)				
Bilateral, atrophy, diffuse			1 (1%)		
Bilateral, atrophy, focal					1 (1%)
Bilateral, infiltration cellular, lymphocyte	17 (17%)	19 (19%)	21 (21%)	21 (21%)	16 (16%)
Bilateral, inflammation, chronic	5 (5%)	8 (8%)	5 (5%)	2 (2%)	5 (5%)
Bilateral, inflammation, chronic active	1 (1%)			1 (1%)	
Bilateral, pigmentation					1 (1%)
Urinary System					
Kidney	(100)	(100)	(100)	(100)	(100)
Cyst	1 (1%)	3 (3%)	1 (1%)	2 (2%)	1 (1%)
Fibrosis, focal				2 (2%)	
Infarct	1 (1%)		1 (1%)		
Mineralization	16 (16%)	18 (18%)	14 (14%)	17 (17%)	16 (16%)
Nephropathy	1 (1%)	1 (1%)	2 (2%)	1 (1%)	2 (2%)
Artery, inflammation, chronic	1 (1%)				
Bilateral, hydronephrosis		1 (1%)			
Bilateral, mineralization	23 (23%)	10 (10%)	19 (19%)	14 (14%)	25 (25%)
Bilateral, nephropathy	91 (91%)	84 (84%)	87 (87%)	85 (85%)	87 (87%)
Bilateral, pigmentation			2 (2%)	1 (1%)	
Bilateral, artery, mineralization					1 (1%)
Bilateral, papilla, necrosis		1 (1%)			1 (1%)
Bilateral, pelvis, inflammation, acute					1 (1%)
Bilateral, pelvis, inflammation, chronic	1 (1%)				
Bilateral, pelvis, inflammation, chronic active	1 (1%)				
Bilateral, renal tubule, crystals		1 (1%)			
Bilateral, renal tubule, degeneration	2 (2%)	2 (2%)	2 (2%)	1 (1%)	
Bilateral, renal tubule, pigmentation	29 (29%)	20 (20%)	26 (26%)	23 (23%)	35 (35%)
Papilla, necrosis		1 (1%)			
Pelvis, inflammation, acute					1 (1%)
Pelvis, inflammation, chronic		1 (1%)			
Pelvis, transitional epithelium, hyperplasia	2 (2%)	1 (1%)			
Renal tubule, hyperplasia, focal			1 (1%)		1 (1%)
Urinary bladder	(99)	(96)	(100)	(100)	(99)
Edema	2 (2%)		1 (1%)		
Hemorrhage					1 (1%)
Infiltration cellular, lymphocyte	4 (4%)	6 (6%)	3 (3%)	6 (6%)	7 (7%)
Inflammation, acute			3 (3%)		
Inflammation, chronic	2 (2%)	1 (1%)		1 (1%)	
Ulcer		1 (1%)			
Transitional epithelium, hyperplasia	1 (1%)		1 (1%)		2 (2%)

APPENDIX B
SUMMARY OF LESIONS IN FEMALE RATS IN THE 2-YEAR WHOLE-BODY EXPOSURE STUDY OF 60-HZ MAGNETIC FIELDS

TABLE B1 Summary of the Incidence of Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 84

TABLE B2 Statistical Analysis of Primary Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 88

TABLE B3 Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 92

TABLE B1
Summary of the Incidence of Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	22	15	22	19	23
Natural deaths	18	17	18	19	19
Other	1			1	
Survivors					
Died last week of study	1	2		2	
Terminal sacrifice	58	66	60	59	58
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Intestine large, colon	(100)	(100)	(100)	(100)	(97)
Polyp adenomatous			1 (1%)		
Intestine large, rectum	(99)	(100)	(100)	(99)	(100)
Sarcoma	1 (1%)				
Schwannoma malignant, metastatic, uterus	1 (1%)				
Intestine large, cecum	(100)	(98)	(99)	(100)	(96)
Intestine small, duodenum	(97)	(97)	(96)	(100)	(96)
Intestine small, ileum	(94)	(91)	(93)	(97)	(91)
Liver	(100)	(100)	(100)	(100)	(100)
Hemangiosarcoma, metastatic, spleen					1 (1%)
Hepatocellular adenoma				1 (1%)	1 (1%)
Schwannoma malignant, metastatic, uterus	1 (1%)				
Mesentery	(11)	(6)	(5)	(13)	(16)
Histiocytic sarcoma, metastatic, skin		1 (17%)			
Leiomyoma				1 (8%)	
Schwannoma malignant, metastatic, uterus	1 (9%)				
Pancreas	(100)	(100)	(99)	(100)	(99)
Acinus, adenoma		1 (1%)		1 (1%)	
Salivary glands	(100)	(99)	(100)	(100)	(100)
Stomach, forestomach	(100)	(99)	(99)	(100)	(100)
Squamous cell papilloma				1 (1%)	
Stomach, glandular	(100)	(100)	(99)	(100)	(100)
Tooth	(2)	(1)	(1)	(1)	(1)
Odontoma, multiple		1 (100%)			
Cardiovascular System					
Heart	(100)	(100)	(100)	(100)	(100)
Carcinosarcoma, metastatic, lung	1 (1%)				
Schwannoma malignant		1 (1%)	2 (2%)		2 (2%)
Endocrine System					
Adrenal cortex	(100)	(100)	(100)	(100)	(100)
Adenoma	6 (6%)	2 (2%)	3 (3%)	1 (1%)	
Carcinoma	1 (1%)		1 (1%)		
Adrenal medulla	(96)	(94)	(94)	(98)	(97)
Pheochromocytoma malignant		1 (1%)	1 (1%)		
Pheochromocytoma complex					2 (2%)
Pheochromocytoma benign	7 (7%)	8 (9%)	3 (3%)	2 (2%)	3 (3%)
Bilateral, pheochromocytoma benign			1 (1%)		

TABLE B1
Summary of the Incidence of Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Islets, pancreatic	(100)	(100)	(99)	(100)	(99)
Adenoma	1 (1%)		3 (3%)	1 (1%)	1 (1%)
Carcinoma	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)
Parathyroid gland	(88)	(94)	(91)	(88)	(92)
Adenoma	1 (1%)		1 (1%)		
Pituitary gland	(99)	(99)	(98)	(98)	(98)
Pars distalis, adenoma	61 (62%)	59 (60%)	68 (69%)	51 (52%)	62 (63%)
Pars distalis, carcinoma	3 (3%)	1 (1%)	4 (4%)	2 (2%)	2 (2%)
Pars intermedia, adenoma		3 (3%)	1 (1%)		
Thyroid gland	(100)	(100)	(100)	(100)	(100)
Bilateral, C-cell, adenoma	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)
C-cell, adenoma	14 (14%)	19 (19%)	18 (18%)	19 (19%)	15 (15%)
C-cell, carcinoma	5 (5%)	3 (3%)	3 (3%)	3 (3%)	6 (6%)
Follicular cell, adenoma		1 (1%)			
General Body System					
Tissue NOS				(2)	
Abdominal, chemodectoma benign				1 (50%)	
Nasal, schwannoma malignant				1 (50%)	
Genital System					
Clitoral gland	(90)	(96)	(97)	(96)	(94)
Adenoma	9 (10%)	13 (14%)	10 (10%)	15 (16%)	11 (12%)
Hemangiosarcoma			1 (1%)		
Bilateral, adenoma	2 (2%)	2 (2%)	1 (1%)	1 (1%)	
Ovary	(100)	(100)	(100)	(100)	(99)
Granulosa cell tumor malignant					1 (1%)
Granulosa cell tumor benign			1 (1%)		
Granulosa-theca tumor benign		1 (1%)			
Luteoma	1 (1%)				
Tubulostromal adenoma	3 (3%)	1 (1%)	2 (2%)	1 (1%)	1 (1%)
Bilateral, granulosa cell tumor benign		1 (1%)			1 (1%)
Bilateral, tubulostromal adenoma		1 (1%)			1 (1%)
Uterus	(100)	(100)	(100)	(100)	(99)
Fibroma		1 (1%)			
Leiomyosarcoma	2 (2%)	1 (1%)			
Schwannoma malignant	2 (2%)				
Cervix, polyp stromal		1 (1%)			
Cervix, schwannoma malignant	1 (1%)				
Endometrium, adenoma					2 (2%)
Endometrium, deciduoma malignant		1 (1%)			
Endometrium, polyp stromal	13 (13%)	10 (10%)	13 (13%)	13 (13%)	10 (10%)
Endometrium, polyp stromal, multiple		1 (1%)			2 (2%)
Endometrium, sarcoma stromal		2 (2%)			
Vagina		(1)	(1)	(2)	(2)
Leiomyoma				1 (50%)	
Polyp					1 (50%)

TABLE B1
Summary of the Incidence of Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System					
Bone marrow	(100)	(100)	(100)	(100)	(100)
Lymph node	(16)	(5)	(5)	(10)	(18)
Deep cervical, sarcoma, metastatic, skin	1 (6%)				
Lymph node, mandibular	(100)	(99)	(100)	(100)	(100)
Lymph node, mesenteric	(100)	(99)	(99)	(99)	(99)
Hemangiosarcoma		1 (1%)			
Spleen	(100)	(100)	(100)	(100)	(99)
Hemangiosarcoma					1 (1%)
Thymus	(95)	(95)	(92)	(91)	(92)
Thymoma benign			1 (1%)	1 (1%)	1 (1%)
Integumentary System					
Mammary gland	(100)	(100)	(100)	(100)	(100)
Adenoma	1 (1%)	2 (2%)	1 (1%)	1 (1%)	2 (2%)
Carcinoma	2 (2%)	7 (7%)	5 (5%)	1 (1%)	2 (2%)
Carcinoma, multiple				1 (1%)	
Fibroadenoma	36 (36%)	42 (42%)	32 (32%)	40 (40%)	27 (27%)
Fibroadenoma, multiple	20 (20%)	20 (20%)	22 (22%)	24 (24%)	24 (24%)
Skin	(100)	(100)	(100)	(100)	(100)
Basal cell adenoma		1 (1%)			1 (1%)
Hemangiopericytoma		1 (1%)			
Keratoacanthoma	1 (1%)	1 (1%)	2 (2%)	1 (1%)	
Squamous cell papilloma					1 (1%)
Trichoepithelioma			2 (2%)		
Lip, basal cell adenoma			1 (1%)		
Lip, squamous cell papilloma			1 (1%)		
Subcutaneous tissue, fibroma	4 (4%)	5 (5%)	4 (4%)		1 (1%)
Subcutaneous tissue, fibrosarcoma	1 (1%)			2 (2%)	1 (1%)
Subcutaneous tissue, hemangiosarcoma		1 (1%)			
Subcutaneous tissue, histiocytic sarcoma		1 (1%)			
Subcutaneous tissue, lipoma			1 (1%)		
Subcutaneous tissue, sarcoma	1 (1%)				
Subcutaneous tissue, schwannoma malignant		1 (1%)		1 (1%)	
Musculoskeletal System					
Bone	(100)	(100)	(100)	(100)	(100)
Vertebra, osteosarcoma		1 (1%)			
Nervous System					
Brain	(100)	(100)	(100)	(100)	(100)
Cerebellum, meningioma malignant				1 (1%)	
Cerebellum, meninges, granular cell tumor malignant			1 (1%)		
Cerebrum, astrocytoma malignant	1 (1%)			2 (2%)	
Cerebrum, glioma malignant	1 (1%)				
Meninges, granular cell tumor benign		2 (2%)			
Spinal cord	(3)	(4)	(4)	(1)	(2)

TABLE B1
Summary of the Incidence of Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Respiratory System					
Lung	(100)	(100)	(100)	(100)	(100)
Alveolar/bronchiolar adenoma	3 (3%)	5 (5%)	5 (5%)	1 (1%)	
Alveolar/bronchiolar carcinoma				1 (1%)	
Carcinoma, metastatic, Zymbal's gland				1 (1%)	
Carcinosarcoma	1 (1%)				
Chordoma, metastatic, uncertain primary site			1 (1%)		
Osteosarcoma, metastatic, bone		1 (1%)			
Pheochromocytoma malignant, metastatic, adrenal medulla		1 (1%)			
Nose	(100)	(100)	(100)	(100)	(100)
Special Senses System					
Harderian gland	(100)	(100)	(100)	(100)	(100)
Zymbal's gland				(1)	(1)
Carcinoma				1 (100%)	1 (100%)
Urinary System					
Kidney	(100)	(100)	(100)	(100)	(100)
Nephroblastoma					1 (1%)
Schwannoma malignant, metastatic, uterus	1 (1%)				
Renal tubule, adenoma				1 (1%)	
Urinary bladder	(99)	(97)	(99)	(99)	(96)
Transitional epithelium, carcinoma			1 (1%)	1 (1%)	
Systemic Lesions					
Multiple organs[b]	(100)	(100)	(100)	(100)	(100)
Histiocytic sarcoma		1 (1%)			
Leukemia granulocytic				1 (1%)	
Leukemia mononuclear	20 (20%)	18 (18%)	24 (24%)	25 (25%)	22 (22%)
Lymphoma malignant					1 (1%)
Mesothelioma malignant			1 (1%)		
Neoplasm Summary					
Total animals with primary neoplasms[c]	98	97	95	91	94
Total primary neoplasms	227	247	244	224	212
Total animals with benign neoplasms	92	94	87	85	86
Total benign neoplasms	184	206	199	180	169
Total animals with malignant neoplasms	40	41	38	39	40
Total malignant neoplasms	43	41	45	44	43
Total animals with metastatic neoplasms	3	3	2	1	1
Total metastatic neoplasms	6	3	2	1	1
Total animals with malignant neoplasms of uncertain primary site			1		

[a] Number of animals examined microscopically at the site and the number of animals with neoplasm
[b] Number of animals with any tissue examined microscopically
[c] Primary neoplasms: all neoplasms except metastatic neoplasms

TABLE B2
Statistical Analysis of Primary Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Adrenal Cortex: Adenoma					
Overall rate[a]	6/100 (6%)	2/100 (2%)	3/100 (3%)	1/100 (1%)	0/100 (0%)
Adjusted rate[b]	7.0%	2.2%	3.4%	1.2%	0.0%
Terminal rate[c]	4/59 (7%)	2/68 (3%)	3/60 (5%)	1/61 (2%)	0/58 (0%)
First incidence (days)	597	737 (T)	737 (T)	737 (T)	—[e]
Poly-3 test[d]	P=0.139N	P=0.127N	P=0.240N	P=0.062N	P=0.020N
Adrenal Cortex: Adenoma or Carcinoma					
Overall rate	7/100 (7%)	2/100 (2%)	4/100 (4%)	1/100 (1%)	0/100 (0%)
Adjusted rate	8.1%	2.2%	4.6%	1.2%	0.0%
Terminal rate	4/59 (7%)	2/68 (3%)	4/60 (7%)	1/61 (2%)	0/58 (0%)
First incidence (days)	597	737 (T)	737 (T)	737 (T)	—
Poly-3 test	P=0.103N	P=0.077N	P=0.260N	P=0.036N	P=0.011N
Adrenal Medulla: Benign Pheochromocytoma					
Overall rate	7/96 (7%)	8/94 (9%)	4/94 (4%)	2/98 (2%)	3/97 (3%)
Adjusted rate	8.5%	9.5%	4.8%	2.4%	3.7%
Terminal rate	6/56 (11%)	6/63 (10%)	0/56 (0%)	1/60 (2%)	2/58 (3%)
First incidence (days)	655	590	648	715	727
Poly-3 test	P=0.045N	P=0.521	P=0.263N	P=0.081N	P=0.164N
Adrenal Medulla: Benign, Complex, or Malignant Pheochromocytoma					
Overall rate	7/96 (7%)	9/94 (10%)	5/94 (5%)	2/98 (2%)	5/97 (5%)
Adjusted rate	8.5%	10.6%	6.0%	2.4%	6.1%
Terminal rate	6/56 (11%)	6/63 (10%)	0/56 (0%)	1/60 (2%)	3/58 (5%)
First incidence (days)	655	583	647	715	645
Poly-3 test	P=0.033N	P=0.423	P=0.376N	P=0.081N	P=0.381N
Clitoral Gland: Adenoma					
Overall rate	11/90 (12%)	15/96 (16%)	11/97 (11%)	16/96 (17%)	11/94 (12%)
Adjusted rate	14.1%	17.5%	13.0%	19.5%	13.5%
Terminal rate	7/56 (13%)	15/65 (23%)	10/58 (17%)	14/59 (24%)	8/56 (14%)
First incidence (days)	597	737 (T)	647	651	430
Poly-3 test	P=0.242	P=0.350	P=0.507N	P=0.239	P=0.547N
Lung: Alveolar/bronchiolar Adenoma					
Overall rate	3/100 (3%)	5/100 (5%)	5/100 (5%)	1/100 (1%)	0/100 (0%)
Adjusted rate	3.5%	5.5%	5.7%	1.2%	0.0%
Terminal rate	3/59 (5%)	2/68 (3%)	3/60 (5%)	1/61 (2%)	0/58 (0%)
First incidence (days)	737 (T)	598	687	737 (T)	—
Poly-3 test	P=0.126N	P=0.389	P=0.373	P=0.309N	P=0.126N
Lung: Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	4/100 (4%)	5/100 (5%)	5/100 (5%)	2/100 (2%)	0/100 (0%)
Adjusted rate	4.7%	5.5%	5.7%	2.4%	0.0%
Terminal rate	3/59 (5%)	2/68 (3%)	3/60 (5%)	2/61 (3%)	0/58 (0%)
First incidence (days)	610	598	687	737 (T)	—
Poly-3 test	P=0.209N	P=0.530	P=0.513	P=0.344N	P=0.068N

TABLE B2
Statistical Analysis of Primary Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Mammary Gland: Fibroadenoma					
Overall rate	56/100 (56%)	62/100 (62%)	54/100 (54%)	64/100 (64%)	51/100 (51%)
Adjusted rate	62.5%	67.0%	59.8%	71.8%	57.8%
Terminal rate	39/59 (66%)	49/68 (72%)	40/60 (67%)	45/61 (74%)	36/58 (62%)
First incidence (days)	543	522	557	522	430
Poly-3 test	P=0.109	P=0.305	P=0.409N	P=0.111	P=0.306N
Mammary Gland: Fibroadenoma or Adenoma					
Overall rate	56/100 (56%)	63/100 (63%)	55/100 (55%)	64/100 (64%)	52/100 (52%)
Adjusted rate	62.5%	67.9%	60.6%	71.8%	58.9%
Terminal rate	39/59 (66%)	49/68 (72%)	40/60 (67%)	45/61 (74%)	37/58 (64%)
First incidence (days)	543	522	557	522	430
Poly-3 test	P=0.127	P=0.260	P=0.457N	P=0.111	P=0.364N
Mammary Gland: Carcinoma					
Overall rate	2/100 (2%)	7/100 (7%)	5/100 (5%)	2/100 (2%)	2/100 (2%)
Adjusted rate	2.3%	7.8%	5.7%	2.4%	2.4%
Terminal rate	2/59 (3%)	4/68 (6%)	3/60 (5%)	2/61 (3%)	1/58 (2%)
First incidence (days)	737 (T)	589	656	737 (T)	591
Poly-3 test	P=0.202N	P=0.098	P=0.231	P=0.691	P=0.689
Mammary Gland: Adenoma or Carcinoma					
Overall rate	3/100 (3%)	8/100 (8%)	6/100 (6%)	3/100 (3%)	4/100 (4%)
Adjusted rate	3.5%	8.9%	6.8%	3.5%	4.8%
Terminal rate	3/59 (5%)	4/68 (6%)	3/60 (5%)	2/61 (3%)	3/58 (5%)
First incidence (days)	737 (T)	589	637	704	591
Poly-3 test	P=0.231N	P=0.125	P=0.263	P=0.659	P=0.493
Mammary Gland: Fibroadenoma, Adenoma, or Carcinoma					
Overall rate	58/100 (58%)	67/100 (67%)	55/100 (55%)	65/100 (65%)	54/100 (54%)
Adjusted rate	64.7%	71.7%	60.6%	72.9%	60.8%
Terminal rate	41/59 (70%)	51/68 (75%)	40/60 (67%)	46/61 (75%)	38/58 (66%)
First incidence (days)	543	522	557	522	430
Poly-3 test	P=0.187	P=0.184	P=0.333N	P=0.141	P=0.346N
Pituitary Gland (Pars Distalis): Adenoma					
Overall rate	61/99 (62%)	59/99 (60%)	68/98 (69%)	51/98 (52%)	62/98 (63%)
Adjusted rate	65.8%	62.5%	73.4%	58.4%	68.1%
Terminal rate	40/59 (68%)	36/67 (54%)	45/60 (75%)	34/61 (56%)	37/58 (64%)
First incidence (days)	533	563	429	522	430
Poly-3 test	P=0.143N	P=0.371N	P=0.159	P=0.183N	P=0.429
Pituitary Gland (Pars Distalis): Adenoma or Carcinoma					
Overall rate	64/99 (65%)	60/99 (61%)	72/98 (73%)	53/98 (54%)	64/98 (65%)
Adjusted rate	68.8%	63.5%	77.4%	60.6%	70.1%
Terminal rate	42/59 (71%)	37/67 (55%)	47/60 (78%)	36/61 (59%)	38/58 (66%)
First incidence (days)	533	563	429	522	430
Poly-3 test	P=0.138N	P=0.266N	P=0.114	P=0.153	P=0.492

TABLE B2
Statistical Analysis of Primary Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Skin: Squamous Cell Papilloma, Keratoacanthoma, Trichoepithelioma, or Basal Cell Adenoma					
Overall rate	1/100 (1%)	2/100 (2%)	6/100 (6%)	1/100 (1%)	2/100 (2%)
Adjusted rate	1.2%	2.2%	6.9%	1.2%	2.4%
Terminal rate	1/59 (2%)	2/68 (3%)	5/60 (8%)	1/61 (2%)	2/58 (3%)
First incidence (days)	737 (T)	737 (T)	710	737 (T)	737 (T)
Poly-3 test	P=0.393N	P=0.516	P=0.064	P=0.759	P=0.495
Skin (Subcutaneous Tissue): Fibroma					
Overall rate	4/100 (4%)	5/100 (5%)	4/100 (4%)	0/100 (0%)	1/100 (1%)
Adjusted rate	4.7%	5.6%	4.6%	0.0%	1.2%
Terminal rate	2/59 (3%)	4/68 (6%)	1/60 (2%)	0/61 (0%)	1/58 (2%)
First incidence (days)	660	711	652	—	737 (T)
Poly-3 test	P=0.035N	P=0.525	P=0.629N	P=0.065N	P=0.192N
Skin (Subcutaneous Tissue): Fibroma, Fibrosarcoma, or Sarcoma					
Overall rate	6/100 (6%)	5/100 (5%)	4/100 (4%)	2/100 (2%)	2/100 (2%)
Adjusted rate	6.9%	5.6%	4.6%	2.4%	2.4%
Terminal rate	2/59 (3%)	4/68 (6%)	1/60 (2%)	2/61 (3%)	1/58 (2%)
First incidence (days)	613	711	652	737 (T)	602
Poly-3 test	P=0.140N	P=0.477N	P=0.362N	P=0.144N	P=0.148N
Thyroid Gland (C-cell): Adenoma					
Overall rate	15/100 (15%)	20/100 (20%)	19/100 (19%)	20/100 (20%)	16/100 (16%)
Adjusted rate	17.3%	22.0%	21.4%	23.5%	19.0%
Terminal rate	12/59 (20%)	16/68 (24%)	14/60 (23%)	17/61 (28%)	14/58 (24%)
First incidence (days)	561	522	497	673	632
Poly-3 test	P=0.292	P=0.271	P=0.311	P=0.205	P=0.463
Thyroid Gland (C-cell): Carcinoma					
Overall rate	5/100 (5%)	3/100 (3%)	3/100 (3%)	3/100 (3%)	6/100 (6%)
Adjusted rate	5.9%	3.4%	3.4%	3.5%	7.1%
Terminal rate	4/59 (7%)	3/68 (4%)	1/60 (2%)	1/61 (2%)	5/58 (9%)
First incidence (days)	710	737 (T)	665	557	627
Poly-3 test	P=0.463N	P=0.335N	P=0.344N	P=0.357N	P=0.489
Thyroid Gland (C-cell): Adenoma or Carcinoma					
Overall rate	19/100 (19%)	22/100 (22%)	22/100 (22%)	23/100 (23%)	22/100 (22%)
Adjusted rate	21.9%	24.3%	24.6%	26.8%	26.1%
Terminal rate	15/59 (25%)	18/68 (27%)	15/60 (25%)	18/61 (30%)	19/58 (33%)
First incidence (days)	561	522	497	557	627
Poly-3 test	P=0.305	P=0.422	P=0.401	P=0.283	P=0.322
Uterus: Stromal Polyp					
Overall rate	13/100 (13%)	11/100 (11%)	13/100 (13%)	13/100 (13%)	12/100 (12%)
Adjusted rate	15.1%	12.2%	14.6%	14.9%	14.2%
Terminal rate	9/59 (15%)	7/68 (10%)	6/60 (10%)	6/61 (10%)	10/58 (17%)
First incidence (days)	620	669	557	485	480
Poly-3 test	P=0.457	P=0.370N	P=0.548N	P=0.569N	P=0.525N

TABLE B2
Statistical Analysis of Primary Neoplasms in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Uterus: Stromal Polyp or Stromal Sarcoma					
Overall rate	13/100 (13%)	12/100 (12%)	13/100 (13%)	13/100 (13%)	12/100 (12%)
Adjusted rate	15.1%	13.3%	14.6%	14.9%	14.2%
Terminal rate	9/59 (15%)	8/68 (12%)	6/60 (10%)	6/61 (10%)	10/58 (17%)
First incidence (days)	620	669	557	485	480
Poly-3 test	P=0.501	P=0.455N	P=0.548N	P=0.569N	P=0.525N
All Organs: Mononuclear Cell Leukemia					
Overall rate	20/100 (20%)	18/100 (18%)	24/100 (24%)	25/100 (25%)	22/100 (22%)
Adjusted rate	22.7%	19.6%	26.4%	28.8%	25.5%
Terminal rate	11/59 (19%)	11/68 (16%)	11/60 (18%)	16/61 (26%)	12/58 (21%)
First incidence (days)	495	498	488	579	526
Poly-3 test	P=0.121	P=0.375N	P=0.342	P=0.223	P=0.398
All Organs: Benign Neoplasms					
Overall rate	92/100 (92%)	94/100 (94%)	87/100 (87%)	85/100 (85%)	86/100 (86%)
Adjusted rate	95.6%	96.2%	90.8%	91.6%	91.3%
Terminal rate	58/59 (98%)	66/68 (97%)	57/60 (95%)	57/61 (93%)	55/58 (95%)
First incidence (days)	533	508	429	485	430
Poly-3 test	P=0.131N	P=0.564	P=0.124N	P=0.182N	P=0.145N
All Organs: Malignant Neoplasms					
Overall rate	40/100 (40%)	41/100 (41%)	38/100 (38%)	39/100 (39%)	40/100 (40%)
Adjusted rate	43.4%	43.4%	41.3%	44.1%	44.7%
Terminal rate	22/59 (37%)	25/68 (37%)	19/60 (32%)	24/61 (39%)	22/58 (38%)
First incidence (days)	462	498	488	409	480
Poly-3 test	P=0.477	P=0.555N	P=0.443N	P=0.523	P=0.490
All Organs: Benign or Malignant Neoplasms					
Overall rate	98/100 (98%)	97/100 (97%)	95/100 (95%)	91/100 (91%)	94/100 (94%)
Adjusted rate	99.1%	97.6%	97.6%	96.9%	96.5%
Terminal rate	59/59 (100%)	66/68 (97%)	60/60 (100%)	59/61 (97%)	56/58 (97%)
First incidence (days)	462	498	429	409	430
Poly-3 test	P=0.305N	P=0.371N	P=0.349N	P=0.234N	P=0.179N

(T)Terminal sacrifice
[a] Number of neoplasm-bearing animals/number of animals examined. Denominator is number of animals examined microscopically for adrenal gland, clitoral gland, lung, pituitary gland, and thyroid gland; for other tissues, denominator is number of animals necropsied.
[b] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[c] Observed incidence at terminal kill
[d] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend or a lower incidence in an exposure group is indicated by **N**.
[e] Not applicable; no neoplasms in animal group

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	22	15	22	19	23
Natural deaths	18	17	18	19	19
Other	1			1	
Survivors					
Died last week of study	1	2		2	
Terminal sacrifice	58	66	60	59	58
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Intestine large, colon	(100)	(100)	(100)	(100)	(97)
Inflammation, chronic active				1 (1%)	
Intestine large, rectum	(99)	(100)	(100)	(99)	(100)
Inflammation, chronic					1 (1%)
Inflammation, chronic active				1 (1%)	
Intestine large, cecum	(100)	(98)	(99)	(100)	(96)
Epithelium, hyperplasia					1 (1%)
Intestine small, duodenum	(97)	(97)	(96)	(100)	(96)
Diverticulum					1 (1%)
Ectopic tissue			1 (1%)	1 (1%)	
Intestine small, ileum	(94)	(91)	(93)	(97)	(91)
Ulcer					1 (1%)
Peyer's patch, hyperplasia, lymphoid				2 (2%)	
Serosa, inflammation, chronic	1 (1%)				
Liver	(100)	(100)	(100)	(100)	(100)
Angiectasis, focal	1 (1%)	1 (1%)	2 (2%)	3 (3%)	
Basophilic focus	66 (66%)	82 (82%)	77 (77%)	66 (66%)	78 (78%)
Clear cell focus	6 (6%)	13 (13%)	18 (18%)	13 (13%)	18 (18%)
Congestion					1 (1%)
Eosinophilic focus	18 (18%)	24 (24%)	30 (30%)	24 (24%)	31 (31%)
Fibrosis	2 (2%)		1 (1%)	1 (1%)	1 (1%)
Hematopoietic cell proliferation	6 (6%)	3 (3%)	2 (2%)	4 (4%)	2 (2%)
Hepatodiaphragmatic nodule	8 (8%)	4 (4%)	4 (4%)	5 (5%)	6 (6%)
Infiltration cellular, lymphocyte	1 (1%)	1 (1%)	4 (4%)		2 (2%)
Infiltration cellular, histiocyte				2 (2%)	1 (1%)
Infiltration cellular, mixed cell	32 (32%)	40 (40%)	37 (37%)	28 (28%)	27 (27%)
Inflammation, chronic	1 (1%)	1 (1%)	2 (2%)	2 (2%)	2 (2%)
Inflammation, chronic active			1 (1%)		
Inflammation, granulomatous					2 (2%)
Mixed cell focus	39 (39%)	45 (45%)	49 (49%)	42 (42%)	37 (37%)
Necrosis	3 (3%)	4 (4%)	7 (7%)	4 (4%)	4 (4%)
Pigmentation			1 (1%)		
Tension lipidosis, focal			1 (1%)	1 (1%)	1 (1%)
Bile duct, hyperplasia	28 (28%)	20 (20%)	31 (31%)	21 (21%)	24 (24%)
Hepatocyte, hypertrophy			1 (1%)		
Hepatocyte, vacuolization cytoplasmic	11 (11%)	12 (12%)	9 (9%)	11 (11%)	9 (9%)
Mesentery	(11)	(6)	(5)	(13)	(16)
Accessory spleen	1 (9%)			1 (8%)	
Fat, necrosis	9 (82%)	4 (67%)	4 (80%)	10 (77%)	15 (94%)

[a] Number of animals examined microscopically at the site and the number of animals with lesion

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Pancreas	(100)	(100)	(99)	(100)	(99)
Infiltration cellular, lymphocyte	14 (14%)	10 (10%)	9 (9%)	9 (9%)	7 (7%)
Metaplasia, hepatocyte			2 (2%)		
Acinus, atrophy, diffuse		3 (3%)	1 (1%)	2 (2%)	
Acinus, atrophy, focal	15 (15%)	18 (18%)	26 (26%)	16 (16%)	20 (20%)
Acinus, basophilic focus			2 (2%)		
Acinus, hyperplasia, focal	3 (3%)	5 (5%)	5 (5%)	1 (1%)	2 (2%)
Artery, inflammation, chronic			1 (1%)		
Duct, hyperplasia			1 (1%)	1 (1%)	
Salivary glands	(100)	(99)	(100)	(100)	(100)
Pigmentation		1 (1%)			
Duct, parotid gland, hyperplasia			1 (1%)		
Duct, parotid gland, mineralization	1 (1%)				
Duct, sublingual gland, metaplasia, squamous		1 (1%)			2 (2%)
Parotid gland, atrophy	3 (3%)	2 (2%)	3 (3%)	2 (2%)	2 (2%)
Parotid gland, hyperplasia	1 (1%)	1 (1%)			
Parotid gland, inflammation, acute			1 (1%)		
Parotid gland, inflammation, chronic				1 (1%)	
Sublingual gland, atrophy	1 (1%)		1 (1%)	1 (1%)	1 (1%)
Sublingual gland, infiltration cellular, lymphocyte		1 (1%)			
Sublingual gland, metaplasia, squamous		1 (1%)			
Submandibular gland, infiltration cellular, lymphocyte				1 (1%)	
Stomach, forestomach	(100)	(99)	(99)	(100)	(100)
Edema	3 (3%)		1 (1%)	3 (3%)	
Erosion, focal					1 (1%)
Inflammation, acute	1 (1%)		1 (1%)		1 (1%)
Inflammation, chronic		1 (1%)	1 (1%)		
Inflammation, chronic active	1 (1%)				2 (2%)
Ulcer	3 (3%)	1 (1%)		3 (3%)	1 (1%)
Epithelium, hyperplasia	7 (7%)	2 (2%)		3 (3%)	10 (10%)
Stomach, glandular	(100)	(100)	(99)	(100)	(100)
Edema			1 (1%)	1 (1%)	
Erosion, focal	5 (5%)	2 (2%)	2 (2%)	5 (5%)	3 (3%)
Fibrosis				1 (1%)	
Inflammation, chronic active					1 (1%)
Metaplasia, focal, squamous	1 (1%)				
Necrosis, focal	1 (1%)				
Glands, congestion			1 (1%)		
Glands, cyst	12 (12%)	20 (20%)	26 (26%)	12 (12%)	12 (12%)
Muscularis, mineralization			1 (1%)		
Tongue		(1)	(1)	(2)	(1)
Epithelium, hyperplasia, focal		1 (100%)	1 (100%)	1 (50%)	1 (100%)
Tooth	(2)	(1)	(1)	(1)	(1)
Inflammation, chronic			1 (100%)		
Malformation	1 (50%)		1 (100%)		
Necrosis					1 (100%)
Gingiva, inflammation, chronic active				1 (100%)	
Peridontal tissue, inflammation, chronic active	1 (50%)				

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Cardiovascular System					
Blood vessel	(99)	(100)	(100)	(100)	(100)
Inflammation, chronic			1 (1%)		
Heart	(100)	(100)	(100)	(100)	(100)
Cardiomyopathy	53 (53%)	71 (71%)	64 (64%)	61 (61%)	60 (60%)
Artery, inflammation, chronic			1 (1%)		
Atrium, mineralization					1 (1%)
Atrium, thrombosis	1 (1%)		2 (2%)		
Endocardium, inflammation, chronic	1 (1%)				
Myocardium, fibrosis, focal	1 (1%)				
Endocrine System					
Adrenal cortex	(100)	(100)	(100)	(100)	(100)
Angiectasis	1 (1%)	4 (4%)	4 (4%)	1 (1%)	5 (5%)
Degeneration	1 (1%)		1 (1%)		
Hematopoietic cell proliferation		1 (1%)	2 (2%)	4 (4%)	2 (2%)
Hemorrhage		1 (1%)			
Hyperplasia, focal	11 (11%)	23 (23%)	12 (12%)	8 (8%)	15 (15%)
Hypertrophy, focal	3 (3%)		1 (1%)	5 (5%)	1 (1%)
Infiltration cellular, lymphocyte	1 (1%)				
Inflammation, chronic	1 (1%)				
Mineralization			1 (1%)		1 (1%)
Necrosis	1 (1%)	2 (2%)		1 (1%)	1 (1%)
Vacuolization cytoplasmic, diffuse		1 (1%)		2 (2%)	1 (1%)
Vacuolization cytoplasmic, focal	27 (27%)	27 (27%)	24 (24%)	31 (31%)	24 (24%)
Bilateral, angiectasis	57 (57%)	51 (51%)	46 (46%)	58 (58%)	57 (57%)
Bilateral, hematopoietic cell proliferation	2 (2%)	3 (3%)	4 (4%)		2 (2%)
Bilateral, hyperplasia, focal		1 (1%)		2 (2%)	1 (1%)
Bilateral, infiltration cellular, lymphocyte		1 (1%)			
Bilateral, infiltration cellular, mixed cell		1 (1%)	1 (1%)		
Bilateral, inflammation, chronic		1 (1%)	1 (1%)		
Bilateral, necrosis		1 (1%)			1 (1%)
Bilateral, pigmentation	2 (2%)		2 (2%)		
Bilateral, vacuolization cytoplasmic, diffuse			1 (1%)		
Bilateral, vacuolization cytoplasmic, focal	2 (2%)	3 (3%)	2 (2%)	3 (3%)	3 (3%)
Adrenal medulla	(96)	(94)	(94)	(98)	(97)
Hyperplasia, focal	6 (6%)	6 (6%)	4 (4%)	7 (7%)	4 (4%)
Bilateral, hyperplasia, focal					1 (1%)
Bilateral, infiltration cellular, lymphocyte		1 (1%)		1 (1%)	
Bilateral, necrosis					1 (1%)
Islets, pancreatic	(100)	(100)	(99)	(100)	(99)
Hyperplasia, focal		1 (1%)			1 (1%)
Parathyroid gland	(88)	(94)	(91)	(88)	(92)
Cyst				1 (1%)	1 (1%)
Degeneration					1 (1%)
Hyperplasia, focal				1 (1%)	
Pineal gland	(85)	(90)	(85)	(90)	(89)
Fibrosis	1 (1%)				
Infiltration cellular, lymphocyte					1 (1%)
Mineralization	56 (66%)	54 (60%)	57 (67%)	54 (60%)	40 (45%)

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Pituitary gland	(99)	(99)	(98)	(98)	(98)
Pars distalis, angiectasis	1 (1%)		1 (1%)		
Pars distalis, angiectasis, focal	1 (1%)	9 (9%)	5 (5%)	3 (3%)	2 (2%)
Pars distalis, cyst	21 (21%)	21 (21%)	19 (19%)	28 (29%)	25 (26%)
Pars distalis, degeneration, focal					1 (1%)
Pars distalis, hyperplasia, diffuse	1 (1%)				
Pars distalis, hyperplasia, focal	10 (10%)	9 (9%)	6 (6%)	6 (6%)	7 (7%)
Pars distalis, hypertrophy, focal				1 (1%)	1 (1%)
Pars distalis, inflammation, chronic		2 (2%)		1 (1%)	1 (1%)
Pars distalis, pigmentation	2 (2%)	1 (1%)		2 (2%)	1 (1%)
Pars intermedia, hyperplasia, focal	1 (1%)	1 (1%)		1 (1%)	
Rathke's cleft, cyst	2 (2%)			2 (2%)	
Rathke's cleft, hemorrhage		1 (1%)			
Rathke's cleft, pigmentation	1 (1%)			1 (1%)	1 (1%)
Thyroid gland	(100)	(100)	(100)	(100)	(100)
Infiltration cellular, lymphocyte	1 (1%)				
Ultimobranchial cyst	2 (2%)	4 (4%)	7 (7%)	3 (3%)	3 (3%)
C-cell, hyperplasia	18 (18%)			5 (5%)	
C-cell, hyperplasia, diffuse	2 (2%)	1 (1%)		3 (3%)	2 (2%)
C-cell, hyperplasia, focal	20 (20%)	39 (39%)	52 (52%)	24 (24%)	30 (30%)
Follicle, cyst	1 (1%)		1 (1%)	1 (1%)	1 (1%)
Follicular cell, hyperplasia, focal	1 (1%)			1 (1%)	
General Body System					
None					
Genital System					
Clitoral gland	(90)	(96)	(97)	(96)	(94)
Cyst	1 (1%)		7 (7%)	1 (1%)	3 (3%)
Hyperplasia, focal	6 (7%)	4 (4%)	3 (3%)	5 (5%)	5 (5%)
Inflammation, acute	1 (1%)				1 (1%)
Inflammation, chronic	15 (17%)	9 (9%)	13 (13%)	23 (24%)	12 (13%)
Inflammation, chronic active		7 (7%)	2 (2%)	5 (5%)	1 (1%)
Bilateral, atrophy	1 (1%)				
Bilateral, inflammation, chronic	8 (9%)	2 (2%)	4 (4%)	2 (2%)	7 (7%)
Bilateral, inflammation, chronic active	2 (2%)	2 (2%)			
Ovary	(100)	(100)	(100)	(100)	(99)
Inflammation, chronic	1 (1%)	1 (1%)	1 (1%)		2 (2%)
Mineralization			1 (1%)		
Bilateral, atrophy	1 (1%)	2 (2%)	1 (1%)		
Bilateral, inflammation, chronic	3 (3%)	2 (2%)	3 (3%)	1 (1%)	2 (2%)
Bilateral, pigmentation			2 (2%)		
Bilateral, periovarian tissue, cyst		2 (2%)			
Bilateral, follicle, cyst			1 (1%)		
Bilateral, rete ovarii, hyperplasia	3 (3%)	2 (2%)	3 (3%)	1 (1%)	3 (3%)
Follicle, cyst	3 (3%)	5 (5%)	1 (1%)	4 (4%)	2 (2%)
Interstitial cell, hyperplasia		1 (1%)			
Periovarian tissue, cyst	6 (6%)	6 (6%)	12 (12%)	8 (8%)	11 (11%)
Rete ovarii, hyperplasia	5 (5%)	14 (14%)	5 (5%)	14 (14%)	13 (13%)

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Uterus	(100)	(100)	(100)	(100)	(99)
Hemorrhage		1 (1%)		2 (2%)	
Hydrometra	9 (9%)	10 (10%)	8 (8%)	7 (7%)	6 (6%)
Pigmentation	2 (2%)		1 (1%)	1 (1%)	1 (1%)
Cervix, cyst					2 (2%)
Cervix, inflammation, chronic active	2 (2%)		1 (1%)	1 (1%)	1 (1%)
Cervix, epithelium, vacuolization cytoplasmic					1 (1%)
Endometrium, angiectasis, focal				1 (1%)	
Endometrium, cyst	3 (3%)	3 (3%)	4 (4%)	1 (1%)	9 (9%)
Endometrium, cytoplasmic alteration	1 (1%)				
Endometrium, fibrosis	1 (1%)	1 (1%)		2 (2%)	
Endometrium, hyperplasia				1 (1%)	
Endometrium, inflammation, acute			1 (1%)		
Endometrium, inflammation, chronic	1 (1%)	3 (3%)	3 (3%)		1 (1%)
Endometrium, inflammation, chronic active				2 (2%)	
Endometrium, pigmentation			2 (2%)		1 (1%)
Endometrium, epithelium, hyperplasia		1 (1%)			1 (1%)
Serosa, fibrosis	1 (1%)				
Vagina		(1)	(1)	(2)	(2)
Cyst					1 (50%)
Hematopoietic System					
Bone marrow	(100)	(100)	(100)	(100)	(100)
Depletion cellular	9 (9%)	5 (5%)	6 (6%)	4 (4%)	11 (11%)
Hyperplasia	13 (13%)	19 (19%)	13 (13%)	12 (12%)	17 (17%)
Inflammation, chronic	1 (1%)				
Myelofibrosis	1 (1%)	1 (1%)			
Lymph node	(16)	(5)	(5)	(10)	(18)
Pigmentation	2 (13%)				
Inguinal, degeneration, cystic		1 (20%)			
Inguinal, hyperplasia, lymphoid	1 (6%)	1 (20%)			
Mediastinal, hemorrhage	1 (6%)	1 (20%)		1 (10%)	3 (17%)
Mediastinal, pigmentation	1 (6%)		1 (20%)		
Pancreatic, infiltration cellular, histiocyte			1 (20%)		
Lymph node, mandibular	(100)	(99)	(100)	(100)	(100)
Atrophy		1 (1%)			
Congestion				2 (2%)	
Degeneration, cystic	11 (11%)	19 (19%)	4 (4%)	8 (8%)	15 (15%)
Hemorrhage	1 (1%)	2 (2%)	3 (3%)	2 (2%)	3 (3%)
Hyperplasia, lymphoid	13 (13%)	21 (21%)	11 (11%)	7 (7%)	7 (7%)
Infiltration cellular, histiocyte	3 (3%)	1 (1%)	2 (2%)	1 (1%)	
Pigmentation			2 (2%)	2 (2%)	3 (3%)
Lymph node, mesenteric	(100)	(99)	(99)	(99)	(99)
Angiectasis				1 (1%)	
Degeneration, cystic	2 (2%)	1 (1%)	1 (1%)		
Hemorrhage	3 (3%)	3 (3%)	2 (2%)	4 (4%)	4 (4%)
Hyperplasia, lymphoid	1 (1%)		2 (2%)		
Infiltration cellular, histiocyte	85 (85%)	92 (93%)	86 (87%)	87 (88%)	86 (87%)
Spleen	(100)	(100)	(100)	(100)	(99)
Congestion		1 (1%)	1 (1%)		
Depletion cellular, focal	1 (1%)	1 (1%)	2 (2%)		
Fibrosis			1 (1%)		2 (2%)
Hematopoietic cell proliferation	15 (15%)	15 (15%)	20 (20%)	13 (13%)	28 (28%)
Infiltration cellular, histiocyte	2 (2%)				

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System (continued)					
Spleen (continued)	(100)	(100)	(100)	(100)	(99)
Pigmentation	54 (54%)	48 (48%)	56 (56%)	57 (57%)	46 (46%)
Capsule, fibrosis				1 (1%)	
Lymphoid follicle, atrophy	6 (6%)	3 (3%)	3 (3%)	4 (4%)	6 (6%)
Lymphoid follicle, hyperplasia	1 (1%)	1 (1%)			
Thymus	(95)	(95)	(92)	(91)	(92)
Atrophy	51 (54%)	48 (51%)	47 (51%)	48 (53%)	43 (47%)
Cyst	1 (1%)	3 (3%)	5 (5%)	2 (2%)	2 (2%)
Ectopic parathyroid gland			1 (1%)		
Hemorrhage	2 (2%)	1 (1%)	3 (3%)	6 (7%)	5 (5%)
Hyperplasia, lymphoid			1 (1%)		
Epithelial cell, hyperplasia	3 (3%)	1 (1%)	3 (3%)	4 (4%)	2 (2%)
Integumentary System					
Mammary gland	(100)	(100)	(100)	(100)	(100)
Cyst	47 (47%)	54 (54%)	56 (56%)	61 (61%)	53 (53%)
Fibrosis		2 (2%)			
Galactocele	10 (10%)	7 (7%)	14 (14%)	7 (7%)	10 (10%)
Inflammation, chronic		1 (1%)	2 (2%)	2 (2%)	2 (2%)
Mineralization					2 (2%)
Epithelium, hyperplasia	1 (1%)	4 (4%)	3 (3%)	2 (2%)	3 (3%)
Skin	(100)	(100)	(100)	(100)	(100)
Cyst epithelial inclusion			1 (1%)		1 (1%)
Hyperkeratosis	1 (1%)		1 (1%)		
Hyperkeratosis, focal			1 (1%)		
Inflammation, chronic	1 (1%)		1 (1%)	1 (1%)	
Inflammation, chronic active			1 (1%)		1 (1%)
Inflammation, chronic active, focal		1 (1%)			
Dermis, fibrosis, focal				1 (1%)	
Epidermis, hyperplasia, diffuse	1 (1%)				
Epidermis, lip, hyperplasia, focal				1 (1%)	
Nipple, hyperkeratosis			1 (1%)		
Subcutaneous tissue, inflammation, chronic			1 (1%)		
Subcutaneous tissue, necrosis		1 (1%)			
Musculoskeletal System					
Bone	(100)	(100)	(100)	(100)	(100)
Cranium, hyperostosis	7 (7%)	1 (1%)	5 (5%)	5 (5%)	2 (2%)
Femur, hyperostosis	20 (20%)	10 (10%)	20 (20%)	18 (18%)	13 (13%)
Intervertebral disc, degeneration		1 (1%)			
Maxilla, hyperostosis	1 (1%)		1 (1%)		
Turbinate, hyperostosis	7 (7%)	3 (3%)	9 (9%)	11 (11%)	6 (6%)
Nervous System					
Brain	(100)	(100)	(100)	(100)	(100)
Mineralization					1 (1%)
Cerebellum, gliosis, focal					1 (1%)
Cerebellum, hemorrhage					2 (2%)
Cerebrum, infiltration cellular, lymphocyte				1 (1%)	
Cerebrum, mineralization		2 (2%)			
Hypothalamus, compression	16 (16%)	9 (9%)	16 (16%)	15 (15%)	19 (19%)
Pons, compression			2 (2%)		

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Respiratory System					
Larynx	(1)	(1)	(1)	(1)	(1)
Inflammation, chronic			1 (100%)		
Lung	(100)	(100)	(100)	(100)	(100)
Congestion	5 (5%)	7 (7%)	4 (4%)	6 (6%)	7 (7%)
Emphysema				1 (1%)	
Hemorrhage	1 (1%)		2 (2%)	1 (1%)	1 (1%)
Infiltration cellular, lymphocyte	1 (1%)	6 (6%)	4 (4%)	7 (7%)	3 (3%)
Infiltration cellular, histiocyte	31 (31%)	42 (42%)	34 (34%)	46 (46%)	35 (35%)
Infiltration cellular, mixed cell	2 (2%)	5 (5%)			
Metaplasia, focal, osseous	1 (1%)				
Mineralization		1 (1%)			
Pigmentation	1 (1%)	1 (1%)	1 (1%)		
Alveolar epithelium, hyperplasia, focal	4 (4%)	3 (3%)	4 (4%)	1 (1%)	3 (3%)
Interstitium, inflammation, chronic	10 (10%)	20 (20%)	13 (13%)	4 (4%)	7 (7%)
Serosa, inflammation, chronic	1 (1%)				1 (1%)
Nose	(100)	(100)	(100)	(100)	(100)
Inflammation, acute	1 (1%)				2 (2%)
Inflammation, chronic	1 (1%)	2 (2%)	4 (4%)	1 (1%)	3 (3%)
Inflammation, chronic active	8 (8%)	8 (8%)	7 (7%)	5 (5%)	7 (7%)
Glands, cyst	1 (1%)				
Nasolacrimal duct, inflammation, acute			1 (1%)	2 (2%)	
Nasolacrimal duct, inflammation, chronic	2 (2%)	6 (6%)	4 (4%)	1 (1%)	7 (7%)
Nasolacrimal duct, inflammation, chronic active		3 (3%)	2 (2%)		1 (1%)
Olfactory epithelium, cytoplasmic alteration	69 (69%)	83 (83%)	87 (87%)	74 (74%)	77 (77%)
Olfactory epithelium, mineralization, focal		1	(1%)		
Respiratory epithelium, cytoplasmic alteration	4 (4%)	1 (1%)	3 (3%)	5 (5%)	1 (1%)
Trachea	(100)	(100)	(100)	(100)	(100)
Inflammation, chronic	6 (6%)	1 (1%)	7 (7%)	7 (7%)	5 (5%)
Inflammation, chronic active			1 (1%)		
Glands, cyst		2 (2%)			
Special Senses System					
Eye	(6)	(4)	(7)	(6)	(3)
Atrophy			2 (29%)	1 (17%)	
Bilateral, cornea, mineralization					1 (33%)
Bilateral, iris, synechia	1 (17%)				
Bilateral, lens, cataract	1 (17%)		1 (14%)	1 (17%)	
Bilateral, retina, atrophy	1 (17%)		1 (14%)	1 (17%)	
Cornea, inflammation, acute			1 (14%)		
Cornea, inflammation, chronic active				1 (17%)	
Iris, synechia	1 (17%)				
Lens, cataract	5 (83%)	4 (100%)	4 (57%)	3 (50%)	2 (67%)
Retina, atrophy	5 (83%)	4 (100%)	4 (57%)	3 (50%)	2 (67%)

TABLE B3
Summary of the Incidence of Nonneoplastic Lesions in Female Rats in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Special Senses System (continued)					
Harderian gland	(100)	(100)	(100)	(100)	(100)
Atrophy, focal	1 (1%)	2 (2%)	2 (2%)	3 (3%)	
Cyst			1 (1%)		
Hyperplasia, focal		1 (1%)		2 (2%)	2 (2%)
Infiltration cellular, lymphocyte	34 (34%)	33 (33%)	33 (33%)	28 (28%)	27 (27%)
Inflammation, chronic	4 (4%)	3 (3%)	5 (5%)	6 (6%)	2 (2%)
Mineralization	1 (1%)				
Pigmentation	1 (1%)				
Bilateral, infiltration cellular, lymphocyte	35 (35%)	40 (40%)	32 (32%)	28 (28%)	39 (39%)
Bilateral, inflammation, chronic	6 (6%)	6 (6%)	11 (11%)	9 (9%)	12 (12%)
Bilateral, inflammation, chronic active					1 (1%)
Lacrimal gland	(2)	(1)	(1)	(4)	
Inflammation, chronic				1 (25%)	
Urinary System					
Kidney	(100)	(100)	(100)	(100)	(100)
Hydronephrosis			1 (1%)		
Infarct	1 (1%)	1 (1%)	1 (1%)	1 (1%)	
Infiltration cellular, lymphocyte	2 (2%)				1 (1%)
Inflammation, chronic active		1 (1%)			
Mineralization	13 (13%)	12 (12%)	18 (18%)	11 (11%)	23 (23%)
Bilateral, infiltration cellular, lymphocyte	1 (1%)				
Bilateral, mineralization	10 (10%)	12 (12%)	11 (11%)	6 (6%)	16 (16%)
Bilateral, necrosis, chronic					1 (1%)
Bilateral, nephropathy	54 (54%)	46 (46%)	69 (69%)	46 (46%)	51 (51%)
Bilateral, pigmentation			2 (2%)		1 (1%)
Bilateral, artery, hypertrophy				1 (1%)	
Bilateral, medulla, inflammation, chronic	1 (1%)				
Bilateral, pelvis, inflammation, acute	1 (1%)				
Bilateral, pelvis, inflammation, chronic	2 (2%)				1 (1%)
Bilateral, pelvis, inflammation, chronic active					1 (1%)
Bilateral, pelvis, transitional epithelium, hyperplasia		2 (2%)			
Bilateral, renal tubule, accumulation, hyaline droplet	5 (5%)	2 (2%)	3 (3%)	3 (3%)	
Bilateral, renal tubule, degeneration	2 (2%)	2 (2%)	1 (1%)	2 (2%)	3 (3%)
Bilateral, renal tubule, dilatation				1 (1%)	
Bilateral, renal tubule, pigmentation	26 (26%)	11 (11%)	13 (13%)	30 (30%)	11 (11%)
Capsule, fibrosis, focal			1 (1%)		
Pelvis, dilatation	1 (1%)	1 (1%)			
Pelvis, inflammation, acute	1 (1%)				
Pelvis, inflammation, chronic		2 (2%)	1 (1%)		2 (2%)
Pelvis, inflammation, chronic active		3 (3%)		1 (1%)	
Pelvis, transitional epithelium, hyperplasia	2 (2%)	1 (1%)	1 (1%)		1 (1%)
Renal tubule, hyperplasia, focal			1 (1%)	1 (1%)	
Renal tubule, necrosis			1 (1%)		
Urinary bladder	(99)	(97)	(99)	(99)	(96)
Calculus, microscopic observation only			1 (1%)		
Edema	1 (1%)			1 (1%)	
Infiltration cellular, lymphocyte	10 (10%)	9 (9%)	9 (9%)	5 (5%)	10 (10%)
Inflammation, chronic	1 (1%)	2 (2%)	1 (1%)	1 (1%)	
Transitional epithelium, hyperplasia	2 (2%)	1 (1%)			

APPENDIX C
SUMMARY OF LESIONS IN MALE MICE IN THE 2-YEAR WHOLE-BODY EXPOSURE STUDY OF 60-HZ MAGNETIC FIELDS

TABLE C1 Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 102

TABLE C2 Statistical Analysis of Primary Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 108

TABLE C3 Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields 111

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	11	13	6	15	8
Natural deaths	13	15	10	23	18
Survivors					
Died last week of study					1
Terminal sacrifice	76	72	84	62	73
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Esophagus	(97)	(97)	(98)	(96)	(99)
Periesophageal tissue, sarcoma, metastatic, uncertain primary site				1 (1%)	
Gallbladder	(84)	(83)	(84)	(75)	(82)
Adenoma		1 (1%)			
Carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Intestine large, colon	(93)	(94)	(92)	(83)	(85)
Intestine large, rectum	(93)	(90)	(93)	(81)	(87)
Intestine large, cecum	(90)	(89)	(92)	(81)	(85)
Intestine small, duodenum	(89)	(88)	(92)	(79)	(84)
Carcinoma		2 (2%)	1 (1%)		1 (1%)
Polyp adenomatous			2 (2%)		1 (1%)
Intestine small, jejunum	(89)	(94)	(93)	(80)	(85)
Carcinoma	1 (1%)	1 (1%)	3 (3%)	1 (1%)	
Intestine small, ileum	(91)	(89)	(92)	(81)	(84)
Carcinoma				1 (1%)	
Liver	(100)	(100)	(100)	(98)	(99)
Carcinoma, metastatic, islets, pancreatic			1 (1%)		
Carcinoma, metastatic, pancreas				1 (1%)	
Carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Hemangiosarcoma	4 (4%)	2 (2%)	3 (3%)	5 (5%)	4 (4%)
Hemangiosarcoma, metastatic, skin			1 (1%)		
Hemangiosarcoma, metastatic, spleen		1 (1%)		1 (1%)	
Hepatoblastoma	2 (2%)	2 (2%)	1 (1%)	4 (4%)	5 (5%)
Hepatocellular carcinoma	19 (19%)	14 (14%)	20 (20%)	15 (15%)	23 (23%)
Hepatocellular adenoma	28 (28%)	26 (26%)	32 (32%)	21 (21%)	30 (30%)
Hepatocellular adenoma, multiple	2 (2%)				2 (2%)
Hepatocholangiocarcinoma		1 (1%)			
Histiocytic sarcoma	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Rhabdomyosarcoma, metastatic, heart			1 (1%)		
Mesentery	(13)	(16)	(8)	(10)	(9)
Carcinoma, metastatic, islets, pancreatic			1 (13%)		
Carcinoma, metastatic, intestine small, duodenum		1 (6%)			
Hemangiosarcoma		1 (6%)	1 (13%)		
Hepatocellular carcinoma, metastatic, liver					1 (11%)
Rhabdomyosarcoma, metastatic, heart			1 (13%)		
Rhabdomyosarcoma, metastatic, skeletal muscle				1 (10%)	
Sarcoma, metastatic, uncertain primary site				1 (10%)	

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Oral mucosa		(2)			
Squamous cell carcinoma		1 (50%)			
Pancreas	(99)	(99)	(98)	(95)	(98)
Carcinoma				1 (1%)	
Carcinoma, metastatic, islets, pancreatic				1 (1%)	
Carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Rhabdomyosarcoma, metastatic, skeletal muscle				1 (1%)	
Sarcoma				1 (1%)	
Schwannoma malignant, metastatic, skin				1 (1%)	
Salivary glands	(99)	(99)	(98)	(96)	(99)
Stomach, forestomach	(99)	(98)	(97)	(96)	(99)
Sarcoma		1 (1%)			
Squamous cell carcinoma					1 (1%)
Squamous cell papilloma				1 (1%)	
Stomach, glandular	(94)	(93)	(97)	(87)	(93)
Serosa, hemangiosarcoma, metastatic, mesentery		1 (1%)			
Tongue					(1)
Squamous cell papilloma					1 (100%)
Cardiovascular System					
Blood vessel	(97)	(94)	(100)	(96)	(98)
Aorta, adventitia, rhabdomyosarcoma, metastatic, heart					1 (1%)
Aorta, adventitia, sarcoma, metastatic, uncertain primary site				1 (1%)	
Heart	(100)	(100)	(100)	(99)	(100)
Carcinoma, metastatic, kidney	1 (1%)				
Hemangiosarcoma		2 (2%)			
Hemangiosarcoma, metastatic, liver	1 (1%)		2 (2%)	2 (2%)	
Hemangiosarcoma, metastatic, spleen	1 (1%)			1 (1%)	1 (1%)
Rhabdomyosarcoma			1 (1%)		1 (1%)
Sarcoma, metastatic, uncertain primary site				1 (1%)	
Endocrine System					
Adrenal cortex	(99)	(96)	(99)	(94)	(97)
Adenoma	3 (3%)		1 (1%)	5 (5%)	
Bilateral, rhabdomyosarcoma, metastatic, skeletal muscle				1 (1%)	
Capsule, carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Adrenal medulla	(98)	(93)	(99)	(91)	(96)
Pheochromocytoma malignant	2 (2%)				
Pheochromocytoma benign	1 (1%)		1 (1%)		
Bilateral, rhabdomyosarcoma, metastatic, skeletal muscle				1 (1%)	
Islets, pancreatic	(99)	(99)	(98)	(97)	(98)
Adenoma	1 (1%)	3 (3%)	1 (1%)		1 (1%)
Carcinoma	2 (2%)		1 (1%)	1 (1%)	
Hemangiosarcoma, metastatic, mesentery		1 (1%)			

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Pineal gland	(55)	(58)	(62)	(45)	(57)
Pituitary gland	(83)	(84)	(82)	(84)	(86)
Pars distalis, adenoma		1 (1%)	1 (1%)		
Pars intermedia, adenoma			1 (1%)		
Thyroid gland	(99)	(98)	(98)	(97)	(98)
Adenoma	1 (1%)	1 (1%)		1 (1%)	
General Body System					
Tissue NOS	(2)	(4)	(1)	(1)	
Alveolar/bronchiolar carcinoma, metastatic, lung	1 (50%)				
Histiocytic sarcoma		1 (25%)			
Schwannoma malignant				1 (100%)	
Pelvic, sarcoma		1 (25%)			
Thoracic, fat, hemangioma			1 (100%)		
Genital System					
Epididymis	(98)	(99)	(99)	(96)	(98)
Carcinoma, metastatic, islets, pancreatic			1 (1%)		
Hemangiosarcoma, metastatic, skin			1 (1%)		
Histiocytic sarcoma		1 (1%)			
Bilateral, carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Bilateral, sarcoma, metastatic, pancreas				1 (1%)	
Preputial gland	(98)	(98)	(100)	(95)	(99)
Prostate	(98)	(92)	(94)	(94)	(92)
Adenoma					1 (1%)
Histiocytic sarcoma				1 (1%)	
Sarcoma, metastatic, pancreas				1 (1%)	
Seminal vesicle	(99)	(97)	(98)	(98)	(98)
Carcinoma		1 (1%)			
Carcinoma, metastatic, islets, pancreatic			1 (1%)		
Hemangiosarcoma, metastatic, mesentery		1 (1%)			
Bilateral, sarcoma, metastatic, pancreas				1 (1%)	
Testes	(99)	(98)	(100)	(96)	(98)
Adenoma	1 (1%)	1 (1%)	2 (2%)	1 (1%)	1 (1%)
Hemangiosarcoma			1 (1%)		
Hematopoietic System					
Bone marrow	(99)	(99)	(99)	(99)	(100)
Hemangiosarcoma, metastatic, liver				2 (2%)	
Hemangiosarcoma, metastatic, skin			1 (1%)		
Hemangiosarcoma, metastatic, spleen		1 (1%)		1 (1%)	1 (1%)
Mast cell tumor benign	1 (1%)				

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System (continued)					
Lymph node	(6)	(6)	(5)	(3)	(7)
Alveolar/bronchiolar carcinoma, metastatic, lung					1 (14%)
Hemangiosarcoma					1 (14%)
Hepatocellular carcinoma, metastatic, liver					1 (14%)
Histiocytic sarcoma	1 (17%)				
Plasma cell tumor malignant		1 (17%)			
Bronchial, alveolar/bronchiolar carcinoma, metastatic, lung			1 (20%)		
Lumbar, hemangiosarcoma, metastatic, mesentery		1 (17%)			
Lumbar, histiocytic sarcoma				1 (33%)	
Lymph node, mandibular	(92)	(92)	(92)	(89)	(90)
Histiocytic sarcoma			1 (1%)		
Lymph node, mesenteric	(87)	(90)	(96)	(85)	(92)
Carcinoma, metastatic, islets, pancreatic			1 (1%)		
Carcinoma, metastatic, intestine small, duodenum		1 (1%)			
Histiocytic sarcoma	1 (1%)		1 (1%)		
Plasma cell tumor malignant		1 (1%)			
Rhabdomyosarcoma, metastatic, heart			1 (1%)		1 (1%)
Sarcoma, metastatic, pancreas				1 (1%)	
Sarcoma, metastatic, uncertain primary site				1 (1%)	
Spleen	(99)	(98)	(98)	(93)	(98)
Hemangiosarcoma	2 (2%)	5 (5%)		3 (3%)	1 (1%)
Hemangiosarcoma, metastatic, skin			1 (1%)		
Histiocytic sarcoma		1 (1%)			1 (1%)
Thymus	(69)	(68)	(63)	(68)	(60)
Sarcoma, metastatic, uncertain primary site				1 (1%)	
Integumentary System					
Skin	(99)	(99)	(100)	(100)	(100)
Carcinoma, metastatic, harderian gland		1 (1%)			
Hemangiosarcoma			1 (1%)		
Histiocytic sarcoma			1 (1%)		
Rhabdomyosarcoma, metastatic, heart			1 (1%)		
Sarcoma					1 (1%)
Schwannoma benign		1 (1%)			
Schwannoma malignant			1 (1%)	1 (1%)	
Squamous cell papilloma		1 (1%)			1 (1%)
Musculoskeletal System					
Bone	(97)	(100)	(99)	(99)	(99)
Femur, hemangiosarcoma, metastatic, liver			1 (1%)		
Femur, hemangiosarcoma, metastatic, spleen					1 (1%)
Skeletal muscle	(8)	(7)	(2)	(7)	(4)
Hemangiosarcoma, metastatic, mesentery		1 (14%)			
Rhabdomyosarcoma				1 (14%)	

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Nervous System					
Brain	(100)	(99)	(100)	(99)	(100)
Meninges, sarcoma			1 (1%)		
Respiratory System					
Lung	(100)	(99)	(100)	(99)	(99)
Alveolar/bronchiolar adenoma	24 (24%)	11 (11%)	7 (7%)	14 (14%)	13 (13%)
Alveolar/bronchiolar adenoma, multiple	2 (2%)		2 (2%)	2 (2%)	3 (3%)
Alveolar/bronchiolar carcinoma	8 (8%)	11 (11%)	12 (12%)	10 (10%)	9 (9%)
Alveolar/bronchiolar carcinoma, multiple					1 (1%)
Carcinoma, metastatic, harderian gland		1 (1%)			
Carcinoma, metastatic, islets, pancreatic			1 (1%)		
Carcinoma, metastatic, kidney	1 (1%)				
Carcinoma, metastatic, pancreas				1 (1%)	
Hemangiosarcoma, metastatic, liver		1 (1%)			
Hemangiosarcoma, metastatic, mesentery		1 (1%)			
Hepatoblastoma, metastatic, liver					1 (1%)
Hepatocellular carcinoma, metastatic, liver	2 (2%)	5 (5%)	8 (8%)	5 (5%)	9 (9%)
Histiocytic sarcoma			1 (1%)	1 (1%)	
Pheochromocytoma malignant, metastatic, adrenal medulla	1 (1%)				
Rhabdomyosarcoma, metastatic, heart			1 (1%)		1 (1%)
Sarcoma, metastatic, uncertain primary site	1 (1%)			1 (1%)	
Schwannoma malignant, metastatic, skin				1 (1%)	
Arteriole, hepatoblastoma, metastatic, liver					1 (1%)
Nose	(99)	(99)	(100)	(97)	(100)
Sinus, sarcoma, metastatic, eye				1 (1%)	
Special Senses System					
Eye		(2)		(2)	(1)
Retrobulbar, sarcoma				1 (50%)	
Harderian gland	(99)	(99)	(100)	(96)	(99)
Adenoma	12 (12%)	14 (14%)	16 (16%)	10 (10%)	11 (11%)
Carcinoma		1 (1%)			3 (3%)
Sarcoma, metastatic, eye				1 (1%)	
Bilateral, adenoma		2 (2%)		2 (2%)	
Bilateral, carcinoma		1 (1%)			
Urinary System					
Kidney	(99)	(98)	(99)	(96)	(97)
Sarcoma, metastatic, pancreas				1 (1%)	
Bilateral, carcinoma	1 (1%)				
Bilateral, rhabdomyosarcoma, metastatic, heart			1 (1%)		
Capsule, rhabdomyosarcoma, metastatic, heart					1 (1%)
Cortex, rhabdomyosarcoma, metastatic, heart					1 (1%)
Renal tubule, adenoma	1 (1%)	2 (2%)			
Urinary bladder	(98)	(95)	(95)	(93)	(94)
Histiocytic sarcoma				1 (1%)	
Papilloma			1 (1%)		
Sarcoma, metastatic, pancreas				1 (1%)	

TABLE C1
Summary of the Incidence of Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Systemic Lesions					
Multiple organs[b]	(100)	(100)	(100)	(100)	(100)
Histiocytic sarcoma	1 (1%)	1 (1%)	3 (3%)	1 (1%)	1 (1%)
Leukemia granulocytic					1 (1%)
Lymphoma malignant	8 (8%)	7 (7%)	4 (4%)	7 (7%)	6 (6%)
Mesothelioma malignant		2 (2%)		1 (1%)	
Neoplasm Summary					
Total animals with primary neoplasms[c]	71	81	72	74	76
Total primary neoplasms	127	123	122	112	124
Total animals with benign neoplasms	54	50	54	47	52
Total benign neoplasms	77	64	68	57	65
Total animals with malignant neoplasms	40	49	45	49	48
Total malignant neoplasms	50	59	54	55	59
Total animals with metastatic neoplasms	8	11	15	17	13
Total metastatic neoplasms	9	23	28	36	22
Total animals with malignant neoplasms of uncertain primary site	1			1	

[a] Number of animals examined microscopically at the site and the number of animals with neoplasm
[b] Number of animals with any tissue examined microscopically
[c] Primary neoplasms: all neoplasms except metastatic neoplasms

TABLE C2
Statistical Analysis of Primary Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Adrenal Cortex: Adenoma					
Overall rate[a]	3/99 (3%)	0/96 (0%)	1/99 (1%)	5/94 (5%)	0/97 (0%)
Adjusted rate[b]	3.3%	0.0%	1.1%	6.1%	0.0%
Terminal rate[c]	3/76 (4%)	0/71 (0%)	1/84 (1%)	5/61 (8%)	0/73 (0%)
First incidence (days)	734 (T)	—[e]	734 (T)	734 (T)	—
Poly-3 test[d]	P=0.032	P=0.134N	P=0.305N	P=0.297	P=0.133N
Harderian Gland: Adenoma					
Overall rate	12/100 (12%)	16/100 (16%)	16/100 (16%)	12/100 (12%)	11/100 (11%)
Adjusted rate	13.0%	17.8%	16.9%	13.9%	12.0%
Terminal rate	11/76 (15%)	12/72 (17%)	11/84 (13%)	9/62 (15%)	8/74 (11%)
First incidence (days)	716	589	585	483	533
Poly-3 test	P=0.413N	P=0.240	P=0.290	P=0.517	P=0.511N
Harderian Gland: Adenoma or Carcinoma					
Overall rate	12/100 (12%)	18/100 (18%)	16/100 (16%)	12/100 (12%)	14/100 (14%)
Adjusted rate	13.0%	19.9%	16.9%	13.9%	15.3%
Terminal rate	11/76 (15%)	13/72 (18%)	11/84 (13%)	9/62 (15%)	11/74 (15%)
First incidence (days)	716	485	585	483	533
Poly-3 test	P=0.342N	P=0.142	P=0.290	P=0.517	P=0.405
Liver: Hemangiosarcoma					
Overall rate	4/100 (4%)	2/100 (2%)	3/100 (3%)	5/98 (5%)	4/99 (4%)
Adjusted rate	4.3%	2.2%	3.2%	5.9%	4.5%
Terminal rate	1/76 (1%)	1/72 (1%)	1/84 (1%)	3/62 (5%)	3/74 (4%)
First incidence (days)	582	624	585	518	666
Poly-3 test	P=0.222	P=0.361N	P=0.498N	P=0.446	P=0.622
Liver: Hepatocellular Adenoma					
Overall rate	30/100 (30%)	26/100 (26%)	32/100 (32%)	21/98 (21%)	32/99 (32%)
Adjusted rate	32.3%	28.9%	34.0%	24.4%	35.3%
Terminal rate	28/76 (37%)	22/72 (31%)	30/84 (36%)	15/62 (24%)	29/74 (39%)
First incidence (days)	646	560	562	500	415
Poly-3 test	P=0.148N	P=0.367N	P=0.460	P=0.156N	P=0.391
Liver: Hepatocellular Carcinoma					
Overall rate	19/100 (19%)	14/100 (14%)	20/100 (20%)	15/98 (15%)	23/99 (23%)
Adjusted rate	19.8%	15.3%	21.2%	17.1%	24.4%
Terminal rate	8/76 (11%)	6/72 (8%)	17/84 (20%)	9/62 (15%)	9/74 (12%)
First incidence (days)	520	542	527	480	456
Poly-3 test	P=0.472N	P=0.268N	P=0.477	P=0.392N	P=0.279
Liver: Hepatocellular Adenoma or Carcinoma					
Overall rate	46/100 (46%)	37/100 (37%)	45/100 (45%)	35/98 (36%)	52/99 (53%)
Adjusted rate	47.8%	39.9%	47.2%	39.5%	54.5%
Terminal rate	34/76 (45%)	26/72 (36%)	40/84 (48%)	24/62 (39%)	36/74 (49%)
First incidence (days)	520	542	527	480	415
Poly-3 test	P=0.242N	P=0.169N	P=0.522N	P=0.157N	P=0.215

TABLE C2
Statistical Analysis of Primary Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Liver: Hepatoblastoma					
Overall rate	2/100 (2%)	2/100 (2%)	1/100 (1%)	4/98 (4%)	5/99 (5%)
Adjusted rate	2.2%	2.3%	1.1%	4.7%	5.5%
Terminal rate	1/76 (1%)	2/72 (3%)	1/84 (1%)	3/62 (5%)	2/74 (3%)
First incidence (days)	731	734 (T)	734 (T)	716	666
Poly-3 test	P=0.160	P=0.678	P=0.498N	P=0.300	P=0.212
Liver: Hepatocellular Carcinoma or Hepatoblastoma					
Overall rate	21/100 (21%)	16/100 (16%)	21/100 (21%)	19/98 (19%)	27/99 (27%)
Adjusted rate	21.9%	17.5%	22.2%	21.7%	28.5%
Terminal rate	9/76 (12%)	8/72 (11%)	18/84 (21%)	12/62 (19%)	11/74 (15%)
First incidence (days)	520	542	527	480	456
Poly-3 test	P=0.428	P=0.283N	P=0.545	P=0.557N	P=0.189
Liver: Hepatocellular Adenoma, Hepatocellular Carcinoma, or Hepatoblastoma					
Overall rate	47/100 (47%)	38/100 (38%)	46/100 (46%)	38/98 (39%)	55/99 (53%)
Adjusted rate	48.8%	41.0%	48.2%	42.8%	57.4%
Terminal rate	34/76 (45%)	27/72 (38%)	41/84 (49%)	26/62 (42%)	37/74 (50%)
First incidence (days)	520	542	527	480	415
Poly-3 test	P=0.371N	P=0.171N	P=0.522N	P=0.247N	P=0.147
Lung: Alveolar/bronchiolar Adenoma					
Overall rate	26/100 (26%)	11/99 (11%)	9/100 (9%)	16/99 (16%)	16/99 (16%)
Adjusted rate	28.0%	12.5%	9.6%	18.0%	17.9%
Terminal rate	22/76 (29%)	10/72 (14%)	7/84 (8%)	7/62 (11%)	15/74 (20%)
First incidence (days)	683	722	585	518	672
Poly-3 test	P=0.470N	P=0.007N	P<0.001N	P=0.077N	P=0.073N
Lung: Alveolar/bronchiolar Carcinoma					
Overall rate	8/100 (8%)	11/99 (11%)	12/100 (12%)	10/99 (10%)	10/99 (10%)
Adjusted rate	8.6%	12.4%	12.8%	11.5%	11.2%
Terminal rate	7/76 (9%)	9/72 (13%)	11/84 (13%)	5/62 (8%)	9/74 (12%)
First incidence (days)	715	612	430	448	668
Poly-3 test	P=0.495	P=0.280	P=0.249	P=0.351	P=0.377
Lung: Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	30/100 (30%)	21/99 (21%)	19/100 (19%)	25/99 (25%)	23/99 (23%)
Adjusted rate	32.2%	23.7%	20.1%	27.7%	25.6%
Terminal rate	25/76 (33%)	19/72 (26%)	16/84 (19%)	11/62 (18%)	21/74 (28%)
First incidence (days)	683	612	430	448	668
Poly-3 test	P=0.495	P=0.130N	P=0.041N	P=0.302N	P=0.203N
Spleen: Hemangiosarcoma					
Overall rate	2/99 (2%)	5/98 (5%)	0/98 (0%)	3/93 (3%)	1/98 (1%)
Adjusted rate	2.2%	5.6%	0.0%	3.7%	1.1%
Terminal rate	2/76 (3%)	3/72 (4%)	0/84 (0%)	2/62 (3%)	1/74 (1%)
First incidence (days)	734 (T)	400	—	726	735 (T)
Poly-3 test	P=0.567	P=0.208	P=0.238N	P=0.445	P=0.513N

TABLE C2
Statistical Analysis of Primary Neoplasms in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
All Organs: Hemangiosarcoma					
Overall rate	6/100 (6%)	10/100 (10%)	6/100 (6%)	8/100 (8%)	5/100 (5%)
Adjusted rate	6.4%	11.0%	6.4%	9.2%	5.5%
Terminal rate	3/76 (4%)	6/72 (8%)	3/84 (4%)	5/62 (8%)	4/74 (5%)
First incidence (days)	582	400	585	518	666
Poly-3 test	P=0.473	P=0.199	P=0.611N	P=0.335	P=0.524N
All Organs: Hemangioma or Hemangiosarcoma					
Overall rate	6/100 (6%)	10/100 (10%)	7/100 (7%)	8/100 (8%)	5/100 (5%)
Adjusted rate	6.4%	11.0%	7.4%	9.2%	5.5%
Terminal rate	3/76 (4%)	6/72 (8%)	4/84 (5%)	5/62 (8%)	4/74 (5%)
First incidence (days)	582	400	585	518	666
Poly-3 test	P=0.488	P=0.199	P=0.506	P=0.335	P=0.524N
All Organs: Malignant Lymphoma					
Overall rate	8/100 (8%)	7/100 (7%)	4/100 (4%)	7/100 (7%)	6/100 (6%)
Adjusted rate	8.6%	7.8%	4.3%	8.0%	6.6%
Terminal rate	7/76 (9%)	4/72 (6%)	3/84 (4%)	3/62 (5%)	3/74 (4%)
First incidence (days)	691	562	701	510	579
Poly-3 test	P=0.536	P=0.522N	P=0.182N	P=0.550N	P=0.402N
All Organs: Benign Neoplasms					
Overall rate	54/100 (54%)	50/100 (50%)	54/100 (54%)	47/100 (47%)	52/100 (52%)
Adjusted rate	57.7%	54.8%	56.5%	51.3%	55.9%
Terminal rate	47/76 (62%)	42/72 (58%)	46/84 (55%)	30/62 (48%)	44/74 (60%)
First incidence (days)	646	542	562	483	415
Poly-3 test	P=0.234N	P=0.402N	P=0.490N	P=0.230N	P=0.458N
All Organs: Malignant Neoplasms					
Overall rate	40/100 (40%)	49/100 (49%)	45/100 (45%)	49/100 (49%)	48/100 (48%)
Adjusted rate	41.3%	50.3%	46.1%	51.4%	49.7%
Terminal rate	25/76 (33%)	27/72 (38%)	35/84 (42%)	23/62 (37%)	29/74 (39%)
First incidence (days)	520	400	430	448	456
Poly-3 test	P=0.205	P=0.134	P=0.302	P=0.103	P=0.153
All Organs: Benign or Malignant Neoplasms					
Overall rate	71/100 (71%)	81/100 (81%)	72/100 (72%)	74/100 (74%)	76/100 (76%)
Adjusted rate	73.0%	82.2%	73.3%	76.5%	77.9%
Terminal rate	53/76 (70%)	56/72 (78%)	60/84 (71%)	43/62 (69%)	54/74 (73%)
First incidence (days)	520	400	430	448	415
Poly-3 test	P=0.506N	P=0.081	P=0.547	P=0.343	P=0.266

(T)Terminal sacrifice
[a] Number of neoplasm-bearing animals/number of animals examined. Denominator is number of animals examined microscopically for adrenal gland, liver, lung, and spleen; for other tissues, denominator is number of animals necropsied.
[b] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[c] Observed incidence at terminal kill
[d] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend or a lower incidence in an exposure group is indicated by **N**.
[e] Not applicable; no neoplasms in animal group

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Moribund	11	13	6	15	8
Natural deaths	13	15	10	23	18
Survivors					
Died last week of study					1
Terminal sacrifice	76	72	84	62	73
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Gallbladder	(84)	(83)	(84)	(75)	(82)
Congestion			1 (1%)		
Inflammation, granulomatous		1 (1%)			
Epithelium, cyst		4 (5%)	2 (2%)	2 (3%)	2 (2%)
Epithelium, hyperplasia, focal	1 (1%)				
Intestine large, colon	(93)	(94)	(92)	(83)	(85)
Lymphoid tissue, hyperplasia				1 (1%)	
Muscularis, hypertrophy					1 (1%)
Intestine large, rectum	(93)	(90)	(93)	(81)	(87)
Lymphoid tissue, hyperplasia		1 (1%)			
Intestine large, cecum	(90)	(89)	(92)	(81)	(85)
Inflammation		1 (1%)		1 (1%)	
Lymphoid tissue, hyperplasia	41 (46%)	33 (37%)	37 (40%)	20 (25%)	46 (54%)
Serosa, fibrosis					1 (1%)
Intestine small, duodenum	(89)	(88)	(92)	(79)	(84)
Infiltration cellular, histiocyte		1 (1%)			
Muscularis, inflammation		1 (1%)			
Peyer's patch, hyperplasia	2 (2%)				1 (1%)
Intestine small, jejunum	(89)	(94)	(93)	(80)	(85)
Inflammation			1 (1%)		1 (1%)
Epithelium, hyperplasia, focal					1 (1%)
Muscularis, hypertrophy		3 (3%)	1 (1%)		2 (2%)
Peyer's patch, hyperplasia	1 (1%)	5 (5%)	1 (1%)		1 (1%)
Serosa, inflammation				1 (1%)	
Intestine small, ileum	(91)	(89)	(92)	(81)	(84)
Inflammation		1 (1%)			
Epithelium, degeneration					1 (1%)
Muscularis, hypertrophy		9 (10%)	8 (9%)		7 (8%)
Peyer's patch, hyperplasia		1 (1%)		1 (1%)	
Serosa, inflammation		1 (1%)			

[a] Number of animals examined microscopically at the site and the number of animals with lesion

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Liver	(100)	(100)	(100)	(98)	(99)
Basophilic focus		2 (2%)			2 (2%)
Clear cell focus	7 (7%)	9 (9%)	9 (9%)	7 (7%)	9 (9%)
Clear cell focus, multiple	7 (7%)	9 (9%)	6 (6%)	4 (4%)	5 (5%)
Congestion				1 (1%)	
Eosinophilic focus	10 (10%)	12 (12%)	11 (11%)	14 (14%)	15 (15%)
Eosinophilic focus, multiple	2 (2%)	1 (1%)	4 (4%)	1 (1%)	1 (1%)
Hematopoietic cell proliferation					1 (1%)
Hepatodiaphragmatic nodule				2 (2%)	
Infiltration cellular, focal, mixed cell	6 (6%)	10 (10%)	14 (14%)	10 (10%)	11 (11%)
Inflammation, focal				1 (1%)	
Inflammation, granulomatous		1 (1%)			
Metaplasia, focal, osseous					1 (1%)
Mixed cell focus	4 (4%)	1 (1%)	3 (3%)	4 (4%)	3 (3%)
Necrosis	7 (7%)	6 (6%)	4 (4%)	4 (4%)	3 (3%)
Pigmentation			1 (1%)		
Thrombosis, focal		1 (1%)			
Bile duct, cyst	2 (2%)				1 (1%)
Hepatocyte, vacuolization cytoplasmic	13 (13%)	9 (9%)	6 (6%)	6 (6%)	5 (5%)
Hepatocyte, centrilobular, hypertrophy					1 (1%)
Sinusoid, centrilobular, dilatation		1 (1%)			
Mesentery	(13)	(16)	(8)	(10)	(9)
Infiltration cellular, histiocyte	1 (8%)				
Inflammation		1 (6%)		1 (10%)	
Artery, inflammation	1 (8%)	1 (6%)	1 (13%)		
Fat, inflammation	1 (8%)	3 (19%)	2 (25%)		
Fat, necrosis	11 (85%)	11 (69%)	4 (50%)	6 (60%)	7 (78%)
Pancreas	(99)	(99)	(98)	(95)	(98)
Cytoplasmic alteration					1 (1%)
Infiltration cellular, focal, mixed cell	1 (1%)		1 (1%)	1 (1%)	
Infiltration cellular, lymphocyte	1 (1%)	4 (4%)	2 (2%)		5 (5%)
Inflammation			1 (1%)		
Lipomatosis	1 (1%)	11 (11%)	14 (14%)	1 (1%)	4 (4%)
Necrosis					1 (1%)
Vacuolization cytoplasmic	16 (16%)	31 (31%)	28 (29%)	5 (5%)	28 (29%)
Acinus, atrophy	1 (1%)		1 (1%)		2 (2%)
Acinus, cytoplasmic alteration		1 (1%)	3 (3%)		4 (4%)
Acinus, degeneration				1 (1%)	
Acinus, hypertrophy, focal		1 (1%)	1 (1%)		
Duct, cyst	2 (2%)	1 (1%)	1 (1%)	2 (2%)	
Salivary glands	(99)	(99)	(98)	(96)	(99)
Atrophy	1 (1%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)
Infiltration cellular, lymphocyte	66 (67%)	65 (66%)	72 (73%)	61 (64%)	69 (70%)
Vacuolization cytoplasmic		1 (1%)			
Stomach, forestomach	(99)	(98)	(97)	(96)	(99)
Diverticulum			1 (1%)		
Inflammation, focal				1 (1%)	1 (1%)
Epithelium, atrophy	9 (9%)	10 (10%)	8 (8%)	7 (7%)	8 (8%)
Epithelium, hyperplasia			3 (3%)		1 (1%)
Epithelium, hyperplasia, focal				1 (1%)	
Epithelium, vacuolization cytoplasmic					1 (1%)

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Stomach, glandular	(94)	(93)	(97)	(87)	(93)
Erosion, focal			1 (1%)		
Inflammation		3 (3%)	1 (1%)		1 (1%)
Epithelium, atrophy	8 (9%)	9 (10%)	8 (8%)	8 (9%)	10 (11%)
Epithelium, cyst, focal	6 (6%)	10 (11%)	10 (10%)	3 (3%)	11 (12%)
Epithelium, hyperplasia, focal				1 (1%)	
Epithelium, mineralization	1 (1%)		1 (1%)		
Serosa, inflammation		1 (1%)			
Cardiovascular System					
Blood vessel	(97)	(94)	(100)	(96)	(98)
Aorta, mineralization			1 (1%)	1 (1%)	
Heart	(100)	(100)	(100)	(99)	(100)
Inflammation, focal	2 (2%)	1 (1%)	5 (5%)	2 (2%)	2 (2%)
Arteriole, inflammation		1 (1%)			
Arteriole, mineralization			1 (1%)		
Artery, inflammation	1 (1%)				1 (1%)
Artery, mineralization	1 (1%)	1 (1%)			
Atrium, infiltration cellular				1 (1%)	
Atrium, thrombosis	1 (1%)				
Capillary, myocardium, infiltration cellular, focal		1 (1%)			
Epicardium, mineralization			1 (1%)	1 (1%)	
Myocardium, degeneration			2 (2%)		2 (2%)
Myocardium, mineralization					1 (1%)
Myocardium, necrosis, focal			1 (1%)		
Valve, thrombosis					2 (2%)
Endocrine System					
Adrenal cortex	(99)	(96)	(99)	(94)	(97)
Bilateral, mineralization					1 (1%)
Bilateral, capsule, hyperplasia	55 (56%)	52 (54%)	53 (54%)	50 (53%)	52 (54%)
Bilateral, capsule, mineralization	1 (1%)			1 (1%)	
Bilateral, zona fasciculata, hyperplasia, focal	1 (1%)	1 (1%)			
Bilateral, zona fasciculata, hypertrophy	1 (1%)		2 (2%)	2 (2%)	
Bilateral, zona fasciculata, hypertrophy, focal	2 (2%)	3 (3%)	6 (6%)	2 (2%)	3 (3%)
Capsule, hyperplasia	31 (31%)	31 (32%)	38 (38%)	31 (33%)	33 (34%)
Zona fasciculata, degeneration, focal			1 (1%)		
Zona fasciculata, hyperplasia, focal	3 (3%)	6 (6%)	7 (7%)	2 (2%)	5 (5%)
Zona fasciculata, hypertrophy	8 (8%)	14 (15%)	11 (11%)	7 (7%)	5 (5%)
Zona fasciculata, hypertrophy, focal	13 (13%)	17 (18%)	15 (15%)	10 (11%)	16 (16%)
Zona fasciculata, infiltration cellular, polymorphonuclear				1 (1%)	
Zona fasciculata, vacuolization cytoplasmic	2 (2%)				
Zona fasciculata, vacuolization cytoplasmic, focal	1 (1%)				
Zona glomerulosa, hyperplasia, focal	3 (3%)	7 (7%)	4 (4%)	2 (2%)	7 (7%)
Zona reticularis, degeneration, fatty	1 (1%)	1 (1%)			

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Adrenal medulla	(98)	(93)	(99)	(91)	(96)
Angiectasis		1 (1%)			
Hyperplasia		2 (2%)	3 (3%)	3 (3%)	5 (5%)
Islets, pancreatic	(99)	(99)	(98)	(97)	(98)
Hyperplasia	97 (98%)	88 (89%)	84 (86%)	84 (87%)	89 (91%)
Hypertrophy, focal				1 (1%)	
Infiltration cellular, lymphocyte					1 (1%)
Infiltration cellular, histiocyte				1 (1%)	1 (1%)
Parathyroid gland	(66)	(55)	(72)	(65)	(67)
Cyst		1 (2%)	1 (1%)	1 (2%)	2 (3%)
Hyperplasia	1 (2%)	2 (4%)	2 (3%)		1 (1%)
Infiltration cellular, lymphocyte					1 (1%)
Infiltration cellular, mixed cell	1 (2%)				
Pituitary gland	(83)	(84)	(82)	(84)	(86)
Pars distalis, cyst	9 (11%)	7 (8%)	6 (7%)	4 (5%)	14 (16%)
Pars distalis, hyperplasia, focal	1 (1%)	2 (2%)	1 (1%)	3 (4%)	1 (1%)
Pars nervosa, cyst					1 (1%)
Thyroid gland	(99)	(98)	(98)	(97)	(98)
Bilateral, follicle, cyst				1 (1%)	
Follicle, cyst	5 (5%)	13 (13%)	7 (7%)	7 (7%)	9 (9%)
General Body System					
Tissue NOS	(2)	(4)	(1)	(1)	
Inflammation, acute		1 (25%)			
Abdominal, fat, necrosis	1 (50%)				
Genital System					
Coagulating gland	(2)		(2)	(1)	
Cyst	1 (50%)		1 (50%)	1 (100%)	
Bilateral, cyst	1 (50%)				
Epididymis	(98)	(99)	(99)	(96)	(98)
Cyst				1 (1%)	
Granuloma sperm	2 (2%)	2 (2%)	1 (1%)	2 (2%)	
Hyperplasia			1 (1%)		
Infiltration cellular, lymphocyte	13 (13%)	9 (9%)	16 (16%)	14 (15%)	15 (15%)
Inflammation					2 (2%)
Inflammation, granulomatous		1 (1%)			
Spermatocele	2 (2%)		3 (3%)	7 (7%)	6 (6%)
Bilateral, atrophy		1 (1%)			
Bilateral, granuloma sperm		1 (1%)	1 (1%)		
Bilateral, infiltration cellular, lymphocyte	11 (11%)	2 (2%)	5 (5%)	4 (4%)	9 (9%)
Preputial gland	(98)	(98)	(100)	(95)	(99)
Atrophy	8 (8%)	22 (22%)	15 (15%)	10 (11%)	18 (18%)
Cyst	29 (30%)	13 (13%)	7 (7%)	23 (24%)	17 (17%)
Infiltration cellular, lymphocyte		1 (1%)		1 (1%)	
Inflammation	15 (15%)	18 (18%)	33 (33%)	27 (28%)	34 (34%)
Bilateral, atrophy	17 (17%)	34 (35%)	34 (34%)	27 (28%)	38 (38%)
Bilateral, cyst	55 (56%)	75 (77%)	86 (86%)	53 (56%)	72 (73%)
Bilateral, inflammation	31 (32%)	19 (19%)	23 (23%)	26 (27%)	27 (27%)
Bilateral, mineralization		1 (1%)			

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Prostate	(98)	(92)	(94)	(94)	(92)
Atrophy		1 (1%)			
Infiltration cellular, lymphocyte	2 (2%)	4 (4%)	4 (4%)	2 (2%)	6 (7%)
Inflammation		1 (1%)			1 (1%)
Epithelium, hyperplasia	49 (50%)	52 (57%)	56 (60%)	47 (50%)	45 (49%)
Seminal vesicle	(99)	(97)	(98)	(98)	(98)
Atrophy				2 (2%)	1 (1%)
Cyst	28 (28%)	22 (23%)	23 (23%)	19 (19%)	16 (16%)
Infiltration cellular, lymphocyte	1 (1%)				
Inflammation	2 (2%)		2 (2%)		
Bilateral, atrophy			1 (1%)	1 (1%)	
Bilateral, cyst	52 (53%)	41 (42%)	36 (37%)	49 (50%)	42 (43%)
Bilateral, inflammation		1 (1%)			
Testes	(99)	(98)	(100)	(96)	(98)
Atrophy	3 (3%)	3 (3%)	1 (1%)	2 (2%)	1 (1%)
Hemorrhage, focal					1 (1%)
Mineralization		1 (1%)	1 (1%)		1 (1%)
Necrosis			1 (1%)		
Bilateral, atrophy		2 (2%)		6 (6%)	1 (1%)
Interstitial cell, hyperplasia, focal				1 (1%)	
Tunic, inflammation					1 (1%)
Tunic, mineralization	1 (1%)	1 (1%)			1 (1%)
Tunic, mineralization, focal			1 (1%)		
Hematopoietic System					
Bone marrow	(99)	(99)	(99)	(99)	(100)
Atrophy		1 (1%)	1 (1%)		3 (3%)
Fibrosis					1 (1%)
Hyperplasia	33 (33%)	30 (30%)	28 (28%)	30 (30%)	25 (25%)
Infiltration cellular, focal, lymphocyte	3 (3%)	1 (1%)	2 (2%)		2 (2%)
Myelofibrosis		1 (1%)	2 (2%)		2 (2%)
Necrosis					1 (1%)
Thrombosis				1 (1%)	
Erythroid cell, atrophy	1 (1%)				
Myeloid cell, hyperplasia	2 (2%)	3 (3%)		5 (5%)	
Lymph node	(6)	(6)	(5)	(3)	(7)
Inflammation, focal	1 (17%)				
Inguinal, hemorrhage			1 (20%)		
Inguinal, hyperplasia			1 (20%)		
Inguinal, necrosis			1 (20%)		
Lumbar, hemorrhage	1 (17%)				
Lumbar, hyperplasia					1 (14%)
Lumbar, infiltration cellular, plasma cell		1 (17%)			
Lymph node, mandibular	(92)	(92)	(92)	(89)	(90)
Atrophy	4 (4%)	2 (2%)	3 (3%)	4 (4%)	1 (1%)
Hemorrhage				1 (1%)	1 (1%)
Hyperplasia	1 (1%)	4 (4%)	1 (1%)	1 (1%)	3 (3%)
Infiltration cellular, mast cell	1 (1%)		1 (1%)	7 (8%)	2 (2%)
Infiltration cellular, plasma cell		2 (2%)	3 (3%)	2 (2%)	1 (1%)
Infiltration cellular, polymorphonuclear				1 (1%)	
Infiltration cellular, histiocyte			1 (1%)		3 (3%)
Infiltration cellular, mixed cell	4 (4%)	2 (2%)		3 (3%)	1 (1%)
Necrosis		1 (1%)			
Pigmentation	2 (2%)	4 (4%)	3 (3%)	2 (2%)	4 (4%)

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System (continued)					
Lymph node, mesenteric	(87)	(90)	(96)	(85)	(92)
Atrophy	6 (7%)	12 (13%)	14 (15%)	7 (8%)	12 (13%)
Hematopoietic cell proliferation			1 (1%)		
Hemorrhage	3 (3%)	2 (2%)	3 (3%)	3 (4%)	5 (5%)
Hyperplasia		7 (8%)	5 (5%)	1 (1%)	3 (3%)
Infiltration cellular, plasma cell					1 (1%)
Infiltration cellular, lymphocyte		1 (1%)	1 (1%)		
Infiltration cellular, histiocyte	59 (68%)	67 (74%)	79 (82%)	56 (66%)	72 (78%)
Infiltration cellular, mixed cell	3 (3%)	5 (6%)	2 (2%)	3 (4%)	6 (7%)
Necrosis	1 (1%)				
Pigmentation					1 (1%)
Artery, inflammation	1 (1%)				
Spleen	(99)	(98)	(98)	(93)	(98)
Hematopoietic cell proliferation	37 (37%)	43 (44%)	52 (53%)	36 (39%)	48 (49%)
Pigmentation		1 (1%)			1 (1%)
Capsule, degeneration, focal				1 (1%)	
Lymphoid follicle, atrophy	11 (11%)	12 (12%)	8 (8%)	14 (15%)	8 (8%)
Lymphoid follicle, hyperplasia	21 (21%)	27 (28%)	17 (17%)	13 (14%)	19 (19%)
Red pulp, atrophy		4 (4%)	3 (3%)	4 (4%)	4 (4%)
Red pulp, pigmentation				1 (1%)	
Thymus	(69)	(68)	(63)	(68)	(60)
Atrophy	62 (90%)	50 (74%)	47 (75%)	64 (94%)	44 (73%)
Cyst, focal	4 (6%)	10 (15%)	9 (14%)	4 (6%)	5 (8%)
Hemorrhage	1 (1%)		1 (2%)		
Hyperplasia, lymphoid	3 (4%)	5 (7%)	9 (14%)		5 (8%)
Integumentary System					
Mammary gland	(2)	(1)	(3)	(4)	(1)
Hyperplasia			1 (33%)		
Duct, dilatation				1 (25%)	
Skin	(99)	(99)	(100)	(100)	(100)
Cyst			1 (1%)	1 (1%)	
Inflammation	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Ulcer, focal		1 (1%)		1 (1%)	1 (1%)
Musculoskeletal System					
Bone	(97)	(100)	(99)	(99)	(99)
Cartilage, epiphysis, femur, cyst			1 (1%)		
Cartilage, epiphysis, femur, cyst, multiple		1	(1%)		
Femur, fibrous osteodystrophy			1 (1%)		
Vertebra, inflammation			1 (1%)		
Nervous System					
Brain	(100)	(99)	(100)	(99)	(100)
Hydrocephalus		1 (1%)			
Cerebellum, developmental malformation					1 (1%)
Cerebellum, hemorrhage				1 (1%)	
Cerebrum, vacuolization cytoplasmic, focal		1 (1%)			
Thalamus, mineralization	70 (70%)	68 (69%)	60 (60%)	78 (79%)	63 (63%)
Thalamus, vacuolization cytoplasmic, focal					1 (1%)

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Nervous System (continued)					
Peripheral nerve	(7)	(8)	(2)	(6)	(3)
Sciatic, degeneration		1 (13%)			
Respiratory System					
Lung	(100)	(99)	(100)	(99)	(99)
Congestion		1 (1%)	2 (2%)		
Infiltration cellular, lymphocyte	21 (21%)	16 (16%)	22 (22%)	24 (24%)	16 (16%)
Inflammation, focal		3 (3%)	1 (1%)	3 (3%)	2 (2%)
Mineralization, focal					1 (1%)
Alveolar epithelium, hyperplasia, focal	2 (2%)	2 (2%)		3 (3%)	2 (2%)
Alveolus, infiltration cellular, histiocyte	3 (3%)	5 (5%)	4 (4%)	3 (3%)	9 (9%)
Arteriole, thrombosis	1 (1%)	1 (1%)			
Serosa, inflammation					1 (1%)
Nose	(99)	(99)	(100)	(97)	(100)
Inflammation	1 (1%)	2 (2%)	3 (3%)	2 (2%)	7 (7%)
Sinus, inflammation		1 (1%)			1 (1%)
Special Senses System					
Eye		(2)		(2)	(1)
Atrophy		1 (50%)			
Cornea, inflammation		1 (50%)			
Harderian gland	(99)	(99)	(100)	(96)	(99)
Atrophy, focal		1 (1%)	1 (1%)		
Infiltration cellular, lymphocyte	8 (8%)	11 (11%)	10 (10%)	4 (4%)	9 (9%)
Inflammation				1 (1%)	
Inflammation, focal	1 (1%)			1 (1%)	1 (1%)
Necrosis, focal				1 (1%)	
Bilateral, infiltration cellular, lymphocyte	3 (3%)	2 (2%)	6 (6%)	5 (5%)	5 (5%)
Epithelium, hypertrophy, focal	1 (1%)				
Urinary System					
Kidney	(99)	(98)	(99)	(96)	(97)
Hydronephrosis	1 (1%)		1 (1%)		
Infarct, focal	1 (1%)	3 (3%)	1 (1%)		1 (1%)
Infiltration cellular, lymphocyte	1 (1%)		1 (1%)		
Arteriole, inflammation	1 (1%)				
Artery, inflammation		1 (1%)			
Bilateral, hydronephrosis		1 (1%)	2 (2%)		
Bilateral, infarct, focal			1 (1%)		
Bilateral, artery, inflammation	1 (1%)	1 (1%)			
Bilateral, capsule, mineralization	1 (1%)				
Bilateral, cortex, congestion	2 (2%)		2 (2%)		
Bilateral, cortex, cyst	4 (4%)	7 (7%)	6 (6%)	6 (6%)	2 (2%)
Bilateral, cortex, infiltration cellular, lymphocyte	10 (10%)	8 (8%)	8 (8%)	10 (10%)	19 (20%)
Bilateral, cortex, inflammation					1 (1%)
Bilateral, cortex, mineralization	79 (80%)	78 (80%)	77 (78%)	66 (69%)	74 (76%)
Bilateral, cortex, renal tubule, degeneration	72 (73%)	75 (77%)	76 (77%)	57 (59%)	71 (73%)

TABLE C3
Summary of the Incidence of Nonneoplastic Lesions in Male Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Urinary System (continued)					
Kidney (continued)	(99)	(98)	(99)	(96)	(97)
Bilateral, cortex, renal tubule, dilatation	2 (2%)	1 (1%)	1 (1%)	5 (5%)	2 (2%)
Bilateral, cortex, renal tubule, pigmentation		1 (1%)	2 (2%)	2 (2%)	1 (1%)
Bilateral, medulla, infiltration cellular, lymphocyte	34 (34%)	26 (27%)	37 (37%)	26 (27%)	38 (39%)
Bilateral, medulla, inflammation	1 (1%)			1 (1%)	
Bilateral, medulla, mineralization	1 (1%)				1 (1%)
Bilateral, papilla, necrosis					1 (1%)
Cortex, cyst	19 (19%)	23 (23%)	21 (21%)	11 (11%)	20 (21%)
Cortex, degeneration, focal	1 (1%)				1 (1%)
Cortex, infiltration cellular, focal, mixed cell		1 (1%)			
Cortex, infiltration cellular, lymphocyte	9 (9%)	10 (10%)	13 (13%)	6 (6%)	18 (19%)
Cortex, inflammation		1 (1%)		2 (2%)	
Cortex, metaplasia, focal, osseous	4 (4%)	4 (4%)	8 (8%)	2 (2%)	4 (4%)
Cortex, mineralization			1 (1%)		3 (3%)
Cortex, renal tubule, degeneration	4 (4%)	2 (2%)	2 (2%)	1 (1%)	1 (1%)
Cortex, renal tubule, dilatation	1 (1%)		2 (2%)		
Glomerulus, inflammation, focal					1 (1%)
Medulla, infiltration cellular, lymphocyte	21 (21%)	14 (14%)	19 (19%)	15 (16%)	9 (9%)
Medulla, inflammation		1 (1%)	1 (1%)		
Medulla, mineralization					1 (1%)
Urethra					(1)
Cyst					1 (100%)
Urinary bladder	(98)	(95)	(95)	(93)	(94)
Hemorrhage					1 (1%)
Infiltration cellular, lymphocyte	4 (4%)	1 (1%)	1 (1%)		4 (4%)
Inflammation		1 (1%)		1 (1%)	
Artery, inflammation	1 (1%)				
Transitional epithelium, hyperplasia		1 (1%)			

APPENDIX D
SUMMARY OF LESIONS IN FEMALE MICE
THE 2-YEAR WHOLE-BODY EXPOSURE STUDY
OF 60-HZ MAGNETIC FIELDS

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TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Accidental deaths	1	1	2	1	
Moribund	6	7	6	7	8
Natural deaths	23	18	13	18	15
Survivors					
Died last week of study	1				
Terminal sacrifice	69	74	79	74	77
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Esophagus	(97)	(100)	(99)	(98)	(100)
Gallbladder	(70)	(84)	(87)	(79)	(91)
Histiocytic sarcoma		1 (1%)			2 (2%)
Rhabdomyosarcoma, metastatic, intestine small, jejunum	1 (1%)				
Intestine large, colon	(82)	(88)	(90)	(90)	(93)
Histiocytic sarcoma					1 (1%)
Intestine large, cecum	(78)	(87)	(90)	(87)	(92)
Histiocytic sarcoma	1 (1%)				
Leiomyosarcoma					1 (1%)
Serosa, histiocytic sarcoma	1 (1%)				
Intestine small, duodenum	(77)	(85)	(90)	(87)	(91)
Histiocytic sarcoma					1 (1%)
Leiomyosarcoma			1 (1%)		
Polyp adenomatous	1 (1%)		1 (1%)		
Intestine small, jejunum	(79)	(86)	(89)	(91)	(92)
Histiocytic sarcoma					1 (1%)
Sarcoma, metastatic, skin			1 (1%)		
Serosa, rhabdomyosarcoma, metastatic, skeletal muscle	1 (1%)				
Intestine small, ileum	(78)	(85)	(90)	(87)	(93)
Histiocytic sarcoma	1 (1%)				1 (1%)
Liver	(98)	(97)	(98)	(99)	(100)
Hemangiosarcoma	1 (1%)	1 (1%)	1 (1%)		
Hemangiosarcoma, metastatic, spleen				1 (1%)	
Hepatocellular carcinoma	6 (6%)	5 (5%)	6 (6%)	6 (6%)	6 (6%)
Hepatocellular carcinoma, multiple			1 (1%)		
Hepatocellular adenoma	15 (15%)	8 (8%)	19 (19%)	17 (17%)	11 (11%)
Hepatocellular adenoma, multiple	2 (2%)	2 (2%)	1 (1%)	1 (1%)	2 (2%)
Hepatocholangiocarcinoma	1 (1%)				
Histiocytic sarcoma		2 (2%)	2 (2%)		6 (6%)
Plasma cell tumor malignant, metastatic, spleen	1 (1%)				
Plasma cell tumor malignant, metastatic, uncertain primary site			2 (2%)	1 (1%)	1 (1%)

TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Mesentery	(36)	(27)	(30)	(30)	(53)
Histiocytic sarcoma					4 (8%)
Leiomyosarcoma, metastatic, intestine small, duodenum			1 (3%)		
Liposarcoma		3 (11%)	1 (3%)		1 (2%)
Osteosarcoma, metastatic, uncertain primary site					1 (2%)
Plasma cell tumor malignant, metastatic, uncertain primary site					1 (2%)
Rhabdomyosarcoma, metastatic, skeletal muscle	2 (6%)				
Sarcoma	1 (3%)	2 (7%)			1 (2%)
Pancreas	(87)	(94)	(96)	(94)	(95)
Histiocytic sarcoma					3 (3%)
Rhabdomyosarcoma, metastatic, uncertain primary site				1 (1%)	
Rhabdomyosarcoma, metastatic, skeletal muscle	1 (1%)	1 (1%)			
Sarcoma, metastatic, mesentery		1 (1%)			
Sarcoma, metastatic, skin			1 (1%)		
Salivary glands	(94)	(98)	(97)	(98)	(99)
Carcinoma	1 (1%)				
Histiocytic sarcoma		1 (1%)			2 (2%)
Stomach, forestomach	(91)	(92)	(93)	(94)	(97)
Basal cell adenoma				1 (1%)	
Sarcoma			1 (1%)		
Squamous cell carcinoma					1 (1%)
Squamous cell papilloma	1 (1%)	1 (1%)		1 (1%)	
Stomach, glandular	(86)	(90)	(93)	(93)	(94)
Osteosarcoma, metastatic, uncertain primary site					1 (1%)
Cardiovascular System					
Blood vessel	(98)	(100)	(94)	(99)	(96)
Heart	(98)	(100)	(100)	(99)	(100)
Hemangiosarcoma					1 (1%)
Histiocytic sarcoma					2 (2%)
Osteosarcoma, metastatic, bone		1 (1%)			
Sarcoma, metastatic, skin					1 (1%)
Endocrine System					
Adrenal cortex	(92)	(98)	(99)	(99)	(99)
Histiocytic sarcoma					2 (2%)
Capsule, adenoma			2 (2%)		
Capsule, rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Capsule, sarcoma	1 (1%)				
Adrenal medulla	(90)	(95)	(97)	(97)	(98)
Pheochromocytoma benign		3 (3%)		2 (2%)	2 (2%)
Bilateral, histiocytic sarcoma					1 (1%)
Bilateral, pheochromocytoma benign			1 (1%)		

TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Islets, pancreatic	(87)	(95)	(94)	(94)	(94)
Adenoma	2 (2%)		7 (7%)	2 (2%)	3 (3%)
Histiocytic sarcoma					2 (2%)
Rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Parathyroid gland	(63)	(53)	(53)	(53)	(58)
Pineal gland	(52)	(37)	(67)	(61)	(61)
Histiocytic sarcoma					2 (3%)
Pituitary gland	(83)	(92)	(87)	(89)	(93)
Histiocytic sarcoma					1 (1%)
Pars distalis, adenoma	16 (19%)	17 (18%)	18 (21%)	21 (24%)	15 (16%)
Pars distalis, adenoma, multiple	1 (1%)		2 (2%)		1 (1%)
Pars distalis, histiocytic sarcoma					1 (1%)
Pars intermedia, adenoma	1 (1%)				1 (1%)
Thyroid gland	(92)	(99)	(98)	(98)	(98)
Adenoma	1 (1%)	1 (1%)	2 (2%)		1 (1%)
Adenoma, multiple	1 (1%)				
Histiocytic sarcoma					1 (1%)
Bilateral, adenoma				1 (1%)	
C-cell, adenoma					1 (1%)
General Body System					
Peritoneum			(1)		
Tissue NOS	(1)	(1)	(3)		
Leiomyosarcoma, metastatic, intestine small, duodenum			1 (33%)		
Rhabdomyosarcoma	1 (100%)				
Sarcoma		1 (100%)	1 (33%)		
Schwannoma benign			1 (33%)		
Genital System					
Clitoral gland	(89)	(84)	(85)	(84)	(82)
Bilateral, histiocytic sarcoma					1 (1%)
Bilateral, sarcoma			1 (1%)		
Ovary	(79)	(91)	(95)	(94)	(96)
Cystadenoma	3 (4%)	3 (3%)	2 (2%)	2 (2%)	
Granulosa cell tumor benign	2 (3%)	3 (3%)	1 (1%)		
Hemangioma		1 (1%)		1 (1%)	2 (2%)
Hemangiosarcoma	1 (1%)			1 (1%)	
Histiocytic sarcoma		1 (1%)			
Luteoma		1 (1%)	1 (1%)		
Rhabdomyosarcoma, metastatic, intestine small, jejunum	1 (1%)				
Bilateral, histiocytic sarcoma					1 (1%)
Bilateral, luteoma	1 (1%)				1 (1%)

TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Uterus	(92)	(97)	(98)	(99)	(100)
Hemangioma			1 (1%)		
Hemangiosarcoma		1 (1%)		1 (1%)	
Lymphangioma				1 (1%)	
Rhabdomyosarcoma, metastatic, skeletal muscle	1 (1%)				
Bilateral, histiocytic sarcoma					1 (1%)
Cervix, histiocytic sarcoma					1 (1%)
Endometrium, polyp stromal	1 (1%)	1 (1%)		1 (1%)	
Vagina				(1)	(1)
Hemangiosarcoma				1 (100%)	
Hematopoietic System					
Bone marrow	(96)	(99)	(97)	(99)	(100)
Histiocytic sarcoma	1 (1%)				1 (1%)
Sarcoma		1 (1%)			
Lymph node	(19)	(15)	(4)	(14)	(12)
Histiocytic sarcoma					1 (8%)
Sarcoma, metastatic, skin	1 (5%)	1 (7%)			
Schwannoma malignant, metastatic, skin	1 (5%)				
Bronchial, histiocytic sarcoma	1 (5%)				
Iliac, sarcoma, metastatic, skin		1 (7%)			
Inguinal, histiocytic sarcoma	1 (5%)				1 (8%)
Lumbar, histiocytic sarcoma		2 (13%)			2 (17%)
Mediastinal, histiocytic sarcoma	2 (11%)	1 (7%)			1 (8%)
Renal, histiocytic sarcoma	1 (5%)	2 (13%)			
Lymph node, mandibular	(84)	(94)	(89)	(91)	(92)
Histiocytic sarcoma	2 (2%)	1 (1%)			2 (2%)
Lymph node, mesenteric	(83)	(88)	(89)	(92)	(95)
Histiocytic sarcoma	2 (2%)	2 (2%)			4 (4%)
Plasma cell tumor malignant				1 (1%)	
Rhabdomyosarcoma, metastatic, tissue NOS	1 (1%)				
Rhabdomyosarcoma, metastatic, uncertain primary site				1 (1%)	
Rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Spleen	(91)	(93)	(95)	(93)	(99)
Hemangiosarcoma				1 (1%)	
Histiocytic sarcoma	2 (2%)	2 (2%)	2 (2%)		4 (4%)
Plasma cell tumor malignant	1 (1%)		1 (1%)	1 (1%)	
Thymus	(78)	(92)	(84)	(75)	(89)
Histiocytic sarcoma	1 (1%)	2 (2%)			3 (3%)
Rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Sarcoma, metastatic, skin		1 (1%)			
Thymoma benign	1 (1%)	1 (1%)			
Thymoma malignant		1 (1%)			

TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Integumentary System					
Mammary gland	(94)	(98)	(99)	(99)	(98)
Adenoma			1 (1%)	2 (2%)	1 (1%)
Carcinoma	1 (1%)				1 (1%)
Histiocytic sarcoma					1 (1%)
Skin	(99)	(100)	(100)	(100)	(100)
Basal cell carcinoma	1 (1%)				
Fibrosarcoma					1 (1%)
Hemangioma		1 (1%)		1 (1%)	
Hemangiosarcoma		1 (1%)		1 (1%)	2 (2%)
Rhabdomyosarcoma, metastatic, uncertain primary site				1 (1%)	
Sarcoma	4 (4%)	5 (5%)	2 (2%)	3 (3%)	4 (4%)
Schwannoma malignant	2 (2%)	1 (1%)	4 (4%)	1 (1%)	2 (2%)
Trichoepithelioma			1 (1%)		
Musculoskeletal System					
Bone	(100)	(100)	(99)	(99)	(99)
Femur, hemangiosarcoma, metastatic, spleen				1 (1%)	
Femur, osteosarcoma		1 (1%)			
Sternum, sarcoma, metastatic, mesentery		1 (1%)			
Vertebra, osteosarcoma	1 (1%)				
Skeletal muscle	(7)	(3)	(3)	(4)	(4)
Hemangiosarcoma, metastatic, heart					1 (25%)
Osteosarcoma, metastatic, uncertain primary site					1 (25%)
Rhabdomyosarcoma	3 (43%)	1 (33%)			1 (25%)
Nervous System					
Brain	(99)	(100)	(98)	(98)	(100)
Ventricle, hamartoma, lipomatous		1 (1%)	2 (2%)		1 (1%)
Respiratory System					
Lung	(95)	(100)	(99)	(99)	(100)
Alveolar/bronchiolar adenoma	9 (9%)	6 (6%)		5 (5%)	6 (6%)
Alveolar/bronchiolar carcinoma	2 (2%)	6 (6%)	2 (2%)	1 (1%)	1 (1%)
Alveolar/bronchiolar carcinoma, multiple				1 (1%)	
Basal cell carcinoma, metastatic, skin	1 (1%)				
Hepatocellular carcinoma, metastatic, liver		2 (2%)		1 (1%)	
Histiocytic sarcoma	1 (1%)	2 (2%)	2 (2%)		3 (3%)
Osteosarcoma, metastatic, bone	1 (1%)	1 (1%)			
Plasma cell tumor malignant, metastatic, uncertain primary site					1 (1%)
Rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Sarcoma, metastatic, mesentery					1 (1%)
Sarcoma, metastatic, skin	1 (1%)	1 (1%)	1 (1%)	1 (1%)	2 (2%)
Mediastinum, alveolar/bronchiolar carcinoma, metastatic, lung		1 (1%)			

TABLE D1
Summary of the Incidence of Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Respiratory System (continued)					
Lung (continued)	(95)	(100)	(99)	(99)	(100)
Mediastinum, histiocytic sarcoma			1 (1%)		
Mediastinum, osteosarcoma, metastatic, bone		1 (1%)			
Mediastinum, schwannoma malignant, metastatic, skin			1 (1%)		
Serosa, sarcoma, metastatic, mesentery		1 (1%)			
Nose	(99)	(100)	(99)	(100)	(99)
Trachea	(94)	(100)	(98)	(99)	(98)
Special Senses System					
Harderian gland	(98)	(97)	(99)	(96)	(97)
Adenoma	9 (9%)	7 (7%)	14 (14%)	12 (13%)	12 (12%)
Carcinoma	2 (2%)				
Histiocytic sarcoma					1 (1%)
Bilateral, adenoma	1 (1%)	1 (1%)			1 (1%)
Lacrimal gland				(1)	
Bilateral, sarcoma				1 (100%)	
Urinary System					
Kidney	(92)	(96)	(98)	(98)	(99)
Histiocytic sarcoma			1 (1%)		1 (1%)
Osteosarcoma, metastatic, bone		1 (1%)			
Plasma cell tumor malignant, metastatic, uncertain primary site					1 (1%)
Rhabdomyosarcoma, metastatic, skeletal muscle		1 (1%)			
Bilateral, histiocytic sarcoma		1 (1%)			3 (3%)
Urinary bladder	(79)	(87)	(94)	(89)	(92)
Carcinoma		1 (1%)			
Systemic Lesions					
Multiple organs[b]	(100)	(100)	(100)	(100)	(100)
Histiocytic sarcoma	2 (2%)	2 (2%)	2 (2%)		6 (6%)
Lymphoma malignant	32 (32%)	31 (31%)	22 (22%)	26 (26%)	20 (20%)
Mesothelioma malignant			1 (1%)		
Neoplasm Summary					
Total animals with primary neoplasms[c]	78	80	72	71	68
Total primary neoplasms	132	122	124	117	110
Total animals with benign neoplasms	52	49	54	49	44
Total benign neoplasms	68	58	77	71	61
Total animals with malignant neoplasms	55	58	38	38	44
Total malignant neoplasms	64	64	47	46	49
Total animals with metastatic neoplasms	9	8	5	5	6
Total metastatic neoplasms	14	21	8	8	12
Total animals with malignant neoplasms of uncertain primary site			2	2	2

[a] Number of animals examined microscopically at the site and the number of animals with neoplasm
[b] Number of animals with any tissue examined microscopically
[c] Primary neoplasms: all neoplasms except metastatic neoplasms

TABLE D2
Statistical Analysis of Primary Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Harderian Gland: Adenoma					
Overall rate[a]	10/100 (10%)	8/100 (8%)	14/100 (14%)	12/100 (12%)	13/100 (13%)
Adjusted rate[b]	11.0%	8.8%	15.3%	13.4%	14.4%
Terminal rate[c]	7/70 (10%)	6/74 (8%)	13/79 (17%)	12/74 (16%)	12/77 (16%)
First incidence (days)	625	692	692	735 (T)	715
Poly-3 test[d]	P=0.309	P=0.406N	P=0.258	P=0.399	P=0.323
Harderian Gland: Adenoma or Carcinoma					
Overall rate	12/100 (12%)	8/100 (8%)	14/100 (14%)	12/100 (12%)	13/100 (13%)
Adjusted rate	13.2%	8.8%	15.3%	13.4%	14.4%
Terminal rate	9/70 (13%)	6/74 (8%)	13/79 (17%)	12/74 (16%)	12/77 (16%)
First incidence (days)	625	692	692	735 (T)	715
Poly-3 test	P=0.398	P=0.242N	P=0.419	P=0.574	P=0.495
Liver: Hepatocellular Adenoma					
Overall rate	17/98 (17%)	10/97 (10%)	20/98 (20%)	18/99 (18%)	13/100 (13%)
Adjusted rate	19.0%	11.3%	22.0%	20.1%	14.3%
Terminal rate	16/70 (23%)	9/74 (12%)	19/79 (24%)	16/74 (22%)	11/77 (14%)
First incidence (days)	667	723	578	690	679
Poly-3 test	P=0.246	P=0.111N	P=0.371	P=0.498	P=0.262N
Liver: Hepatocellular Carcinoma					
Overall rate	6/98 (6%)	5/97 (5%)	7/98 (7%)	6/99 (6%)	6/100 (6%)
Adjusted rate	6.7%	5.6%	7.7%	6.6%	6.6%
Terminal rate	4/70 (6%)	2/74 (3%)	5/79 (6%)	4/74 (5%)	5/77 (7%)
First incidence (days)	691	545	578	183	679
Poly-3 test	P=0.554	P=0.502N	P=0.511	P=0.607N	P=0.610N
Liver: Hepatocellular Adenoma or Carcinoma					
Overall rate	22/98 (22%)	13/97 (13%)	24/98 (24%)	23/99 (23%)	18/100 (18%)
Adjusted rate	24.5%	14.5%	26.4%	25.2%	19.8%
Terminal rate	19/70 (27%)	10/74 (14%)	22/79 (28%)	19/74 (26%)	16/77 (21%)
First incidence (days)	667	545	578	183	679
Poly-3 test	P=0.217	P=0.067N	P=0.451	P=0.522	P=0.284N
Lung: Alveolar/bronchiolar Adenoma					
Overall rate	9/95 (9%)	6/100 (6%)	0/99 (0%)	5/99 (5%)	6/100 (6%)
Adjusted rate	10.2%	6.6%	0.0%	5.6%	6.6%
Terminal rate	7/70 (10%)	4/74 (5%)	0/79 (0%)	4/74 (5%)	6/77 (8%)
First incidence (days)	551	603	—[e]	566	735 (T)
Poly-3 test	P=0.363N	P=0.271N	P=0.002N	P=0.190N	P=0.275N
Lung: Alveolar/bronchiolar Carcinoma					
Overall rate	2/95 (2%)	6/100 (6%)	2/99 (2%)	2/99 (2%)	1/100 (1%)
Adjusted rate	2.3%	6.6%	2.2%	2.2%	1.1%
Terminal rate	0/70 (0%)	4/74 (5%)	2/79 (3%)	1/74 (1%)	0/77 (0%)
First incidence (days)	701	496	735 (T)	687	656
Poly-3 test	P=0.287N	P=0.154	P=0.678N	P=0.684N	P=0.483N

TABLE D2
Statistical Analysis of Primary Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Lung: Alveolar/bronchiolar Adenoma or Carcinoma					
Overall rate	11/95 (12%)	11/100 (11%)	2/99 (2%)	7/99 (7%)	7/100 (7%)
Adjusted rate	12.5%	11.9%	2.2%	7.8%	7.7%
Terminal rate	7/70 (10%)	7/74 (10%)	2/79 (3%)	5/74 (7%)	6/77 (8%)
First incidence (days)	551	496	735 (T)	566	656
Poly-3 test	P=0.246N	P=0.544N	P=0.008N	P=0.213N	P=0.208N
Pancreatic Islets: Adenoma					
Overall rate	2/87 (2%)	0/95 (0%)	7/94 (7%)	2/94 (2%)	3/94 (3%)
Adjusted rate	2.4%	0.0%	8.0%	2.3%	3.5%
Terminal rate	1/70 (1%)	0/74 (0%)	6/79 (8%)	2/74 (3%)	3/76 (4%)
First incidence (days)	542	—	694	735 (T)	735 (T)
Poly-3 test	P=0.609	P=0.228N	P=0.101	P=0.672N	P=0.518
Pituitary Gland (Pars Distalis): Adenoma					
Overall rate	17/83 (20%)	17/92 (18%)	20/87 (23%)	21/89 (24%)	16/93 (17%)
Adjusted rate	21.9%	20.1%	24.1%	25.8%	18.7%
Terminal rate	16/67 (24%)	15/71 (21%)	20/76 (26%)	20/71 (28%)	15/74 (20%)
First incidence (days)	625	698	735 (T)	730	710
Poly-3 test	P=0.258	P=0.465N	P=0.445	P=0.352	P=0.373N
Skin (Subcutaneous Tissue): Sarcoma					
Overall rate	4/100 (4%)	5/100 (5%)	2/100 (2%)	3/100 (3%)	4/100 (4%)
Adjusted rate	4.4%	5.4%	2.2%	3.3%	4.4%
Terminal rate	1/70 (1%)	2/74 (3%)	1/79 (1%)	0/74 (0%)	2/77 (3%)
First incidence (days)	625	461	513	684	580
Poly-3 test	P=0.404N	P=0.506	P=0.336N	P=0.504N	P=0.640N
Skin (Subcutaneous Tissue): Fibrosarcoma or Sarcoma					
Overall rate	4/100 (4%)	5/100 (5%)	2/100 (2%)	3/100 (3%)	5/100 (5%)
Adjusted rate	4.4%	5.4%	2.2%	3.3%	5.4%
Terminal rate	1/70 (1%)	2/74 (3%)	1/79 (1%)	0/74 (0%)	2/77 (3%)
First incidence (days)	625	461	513	684	481
Poly-3 test	P=0.404N	P=0.506	P=0.336N	P=0.504N	P=0.505
All Organs: Hemangiosarcoma					
Overall rate	2/100 (2%)	3/100 (3%)	1/100 (1%)	5/100 (5%)	3/100 (3%)
Adjusted rate	2.2%	3.3%	1.1%	5.5%	3.3%
Terminal rate	0/70 (0%)	3/74 (4%)	1/79 (1%)	2/74 (3%)	3/77 (4%)
First incidence (days)	707	735 (T)	735 (T)	699	735 (T)
Poly-3 test	P=0.131	P=0.499	P=0.498N	P=0.219	P=0.499
All Organs: Hemangioma or Hemangiosarcoma					
Overall rate	2/100 (2%)	5/100 (5%)	2/100 (2%)	7/100 (7%)	5/100 (5%)
Adjusted rate	2.2%	5.5%	2.2%	7.8%	5.5%
Terminal rate	0/70 (0%)	4/74 (5%)	2/79 (3%)	4/74 (5%)	5/77 (7%)
First incidence (days)	707	559	735 (T)	699	735 (T)
Poly-3 test	P=0.084	P=0.222	P=0.691N	P=0.084	P=0.220

TABLE D2
Statistical Analysis of Primary Neoplasms in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
All Organs: Histiocytic Sarcoma					
Overall rate	2/100 (2%)	2/100 (2%)	2/100 (2%)	0/100 (0%)	6/100 (6%)
Adjusted rate	2.2%	2.2%	2.2%	0.0%	6.5%
Terminal rate	2/70 (3%)	1/74 (1%)	0/79 (0%)	0/74 (0%)	1/77 (1%)
First incidence (days)	735 (T)	721	655	—	309
Poly-3 test	P=0.162N	P=0.693	P=0.688N	P=0.240N	P=0.146
All Organs: Malignant Lymphoma					
Overall rate	32/100 (32%)	31/100 (31%)	22/100 (22%)	26/100 (26%)	20/100 (20%)
Adjusted rate	34.7%	33.5%	24.0%	28.3%	21.7%
Terminal rate	23/70 (33%)	23/74 (31%)	20/79 (25%)	20/74 (27%)	15/77 (20%)
First incidence (days)	461	461	581	467	567
Poly-3 test	P=0.253N	P=0.494N	P=0.074N	P=0.219N	P=0.035N
All Organs: Benign Neoplasms					
Overall rate	52/100 (52%)	49/100 (49%)	54/100 (54%)	49/100 (49%)	44/100 (44%)
Adjusted rate	56.2%	52.2%	58.6%	54.1%	48.0%
Terminal rate	44/70 (63%)	38/74 (51%)	49/79 (62%)	46/74 (62%)	38/77 (49%)
First incidence (days)	542	64	578	566	576
Poly-3 test	P=0.496N	P=0.339N	P=0.431	P=0.442N	P=0.162N
All Organs: Malignant Neoplasms					
Overall rate	55/100 (55%)	58/100 (58%)	39/100 (39%)	40/100 (40%)	45/100 (45%)
Adjusted rate	57.6%	59.6%	41.1%	42.5%	46.2%
Terminal rate	34/70 (49%)	37/74 (50%)	29/79 (37%)	26/74 (35%)	27/77 (35%)
First incidence (days)	397	461	513	183	309
Poly-3 test	P=0.014N	P=0.448	P=0.015N	P=0.024N	P=0.071N
All Organs: Benign or Malignant Neoplasms					
Overall rate	78/100 (78%)	80/100 (80%)	72/100 (72%)	71/100 (71%)	68/100 (68%)
Adjusted rate	81.0%	81.2%	75.8%	74.9%	69.7%
Terminal rate	54/70 (77%)	56/74 (76%)	60/79 (76%)	55/74 (74%)	49/77 (64%)
First incidence (days)	397	64	513	183	309
Poly-3 test	P=0.158N	P=0.561	P=0.237N	P=0.193N	P=0.045N

(T)Terminal sacrifice
[a] Number of neoplasm-bearing animals/number of animals examined. Denominator is number of animals examined microscopically for liver, lung, pancreatic islets, and pituitary gland; for other tissues, denominator is number of animals necropsied.
[b] Poly-3 estimated neoplasm incidence after adjustment for intercurrent mortality
[c] Observed incidence at terminal kill
[d] Beneath the control incidence are the P values associated with the trend test; the trend does not include the 10 G intermittent group. Beneath the exposed group incidence are the P values corresponding to pairwise comparisons between the controls and that exposed group. The Poly-3 test accounts for differential mortality in animals that do not reach terminal sacrifice. A negative trend or a lower incidence in an exposure group is indicated by **N**.
[e] Not applicable; no neoplasms in animal group

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields[a]

	Control	0.02 G	2 G	10 G	10 G Intermittent
Disposition Summary					
Animals initially in study	100	100	100	100	100
Early deaths					
Accidental deaths	1	1	2	1	
Moribund	6	7	6	7	8
Natural deaths	23	18	13	18	15
Survivors					
Died last week of study	1				
Terminal sacrifice	69	74	79	74	77
Animals examined microscopically	100	100	100	100	100
Alimentary System					
Esophagus	(97)	(100)	(99)	(98)	(100)
Epithelium, hyperplasia, focal					1 (1%)
Gallbladder	(70)	(84)	(87)	(79)	(91)
Infiltration cellular, lymphocyte		1 (1%)		1 (1%)	
Infiltration cellular, mixed cell				1 (1%)	
Epithelium, cyst	5 (7%)	14 (17%)	2 (2%)	3 (4%)	11 (12%)
Epithelium, cytoplasmic alteration		1 (1%)			
Epithelium, vacuolization cytoplasmic			1 (1%)		
Intestine large, rectum	(82)	(90)	(90)	(88)	(94)
Lymphoid tissue, hyperplasia				1 (1%)	
Serosa, inflammation, chronic active			1 (1%)		
Intestine large, cecum	(78)	(87)	(90)	(87)	(92)
Lymphoid tissue, hyperplasia	25 (32%)	33 (38%)	35 (39%)	24 (28%)	32 (35%)
Lymphoid tissue, necrosis					1 (1%)
Intestine small, duodenum	(77)	(85)	(90)	(87)	(91)
Inflammation	1 (1%)				
Muscularis, hypertrophy	1 (1%)				
Peyer's patch, hyperplasia			1 (1%)	1 (1%)	2 (2%)
Intestine small, jejunum	(79)	(86)	(89)	(91)	(92)
Inflammation			1 (1%)		1 (1%)
Muscularis, hypertrophy	6 (8%)	8 (9%)	5 (6%)	3 (3%)	7 (8%)
Peyer's patch, hyperplasia	3 (4%)	6 (7%)	5 (6%)		7 (8%)
Peyer's patch, inflammation		1 (1%)			
Peyer's patch, necrosis, lymphoid					1 (1%)
Serosa, inflammation			1 (1%)	1 (1%)	
Intestine small, ileum	(78)	(85)	(90)	(87)	(93)
Inflammation	1 (1%)	1 (1%)			2 (2%)
Artery, inflammation					1 (1%)
Muscularis, hypertrophy	17 (22%)	16 (19%)	20 (22%)	17 (20%)	15 (16%)
Peyer's patch, hyperplasia	4 (5%)	2 (2%)	4 (4%)	4 (5%)	5 (5%)
Serosa, inflammation			1 (1%)		
Liver	(98)	(97)	(98)	(99)	(100)
Angiectasis	1 (1%)			2 (2%)	3 (3%)
Basophilic focus	2 (2%)	3 (3%)	4 (4%)	2 (2%)	
Basophilic focus, multiple			1 (1%)		1 (1%)
Clear cell focus	4 (4%)	3 (3%)	7 (7%)	5 (5%)	4 (4%)
Clear cell focus, multiple			1 (1%)	1 (1%)	1 (1%)
Developmental malformation		1 (1%)	2 (2%)		1 (1%)
Eosinophilic focus	5 (5%)	3 (3%)	10 (10%)	10 (10%)	9 (9%)
Eosinophilic focus, multiple	1 (1%)	1 (1%)		2 (2%)	

[a] Number of animals examined microscopically at the site and the number of animals with lesion

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Liver (continued)	(98)	(97)	(98)	(99)	(100)
Fibrosis	1 (1%)				
Hematopoietic cell proliferation			1 (1%)		1 (1%)
Hemorrhage			1 (1%)	1 (1%)	
Hepatodiaphragmatic nodule			1 (1%)		
Infiltration cellular, focal, mast cell		1 (1%)			
Infiltration cellular, focal, lymphocyte	1 (1%)			2 (2%)	1 (1%)
Infiltration cellular, focal, polymorphonuclear					1 (1%)
Infiltration cellular, focal, mixed cell	53 (54%)	58 (60%)	48 (49%)	48 (48%)	51 (51%)
Inflammation, focal		1 (1%)			
Mixed cell focus		1 (1%)	2 (2%)	1 (1%)	
Necrosis	4 (4%)	2 (2%)	4 (4%)		5 (5%)
Pigmentation					1 (1%)
Bile duct, cyst				1 (1%)	
Hepatocyte, vacuolization cytoplasmic	14 (14%)	15 (15%)	14 (14%)	17 (17%)	14 (14%)
Sinusoid, centrilobular, dilatation					1 (1%)
Mesentery	(36)	(27)	(30)	(30)	(53)
Hemorrhage	1 (3%)	1 (4%)	1 (3%)	1 (3%)	
Inflammation					1 (2%)
Arteriole, inflammation					1 (2%)
Artery, mineralization	1 (3%)				
Fat, inflammation	6 (17%)	4 (15%)	5 (17%)	4 (13%)	14 (26%)
Fat, necrosis	22 (61%)	16 (59%)	23 (77%)	22 (73%)	31 (58%)
Pancreas	(87)	(94)	(96)	(94)	(95)
Angiectasis, focal	1 (1%)				
Cytoplasmic alteration			1 (1%)		
Infiltration cellular, focal, mixed cell	7 (8%)	12 (13%)	7 (7%)	10 (11%)	12 (13%)
Infiltration cellular, lymphocyte	5 (6%)		1 (1%)	3 (3%)	5 (5%)
Inflammation			1 (1%)		1 (1%)
Lipomatosis	21 (24%)	16 (17%)	23 (24%)	29 (31%)	33 (35%)
Vacuolization cytoplasmic	12 (14%)	21 (22%)	18 (19%)	16 (17%)	15 (16%)
Acinus, cytoplasmic alteration	1 (1%)	3 (3%)	4 (4%)	2 (2%)	5 (5%)
Acinus, degeneration, focal		1 (1%)			
Acinus, hypertrophy, focal	1 (1%)		2 (2%)		1 (1%)
Artery, inflammation				1 (1%)	1 (1%)
Duct, cyst	1 (1%)	1 (1%)	3 (3%)	1 (1%)	2 (2%)
Salivary glands	(94)	(98)	(97)	(98)	(99)
Atrophy		1 (1%)		1 (1%)	
Fibrosis					1 (1%)
Infiltration cellular, lymphocyte	74 (79%)	83 (85%)	77 (79%)	75 (77%)	79 (80%)
Infiltration cellular, mixed cell					1 (1%)
Pigmentation				1 (1%)	
Arteriole, inflammation					1 (1%)
Duct, cyst		1 (1%)			
Duct, cytoplasmic alteration				1 (1%)	
Stomach, forestomach	(91)	(92)	(93)	(94)	(97)
Infiltration cellular, lymphocyte	1 (1%)				1 (1%)
Inflammation			3 (3%)	1 (1%)	1 (1%)
Ulcer, focal			1 (1%)		1 (1%)
Epithelium, atrophy	6 (7%)	11 (12%)	5 (5%)	10 (11%)	6 (6%)
Epithelium, cyst				1 (1%)	
Epithelium, hyperplasia	4 (4%)	5 (5%)	4 (4%)	5 (5%)	5 (5%)
Muscularis, mineralization, focal				1 (1%)	

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Alimentary System (continued)					
Stomach, glandular	(86)	(90)	(93)	(93)	(94)
Infiltration cellular, lymphocyte	7 (8%)	8 (9%)	3 (3%)		5 (5%)
Inflammation	1 (1%)	1 (1%)	1 (1%)	1 (1%)	
Ulcer, focal		1 (1%)			1 (1%)
Epithelium, atrophy	14 (16%)	24 (27%)	20 (22%)	18 (19%)	28 (30%)
Epithelium, cyst, focal	23 (27%)	19 (21%)	17 (18%)	12 (13%)	20 (21%)
Epithelium, mineralization	1 (1%)				
Serosa, hemorrhage					1 (1%)
Cardiovascular System					
Blood vessel	(98)	(100)	(94)	(99)	(96)
Aorta, mineralization	2 (2%)				
Aorta, adventitia, inflammation, chronic active			1 (1%)		
Heart	(98)	(100)	(100)	(99)	(100)
Inflammation	1 (1%)				
Artery, inflammation		1 (1%)		1 (1%)	1 (1%)
Artery, mineralization	1 (1%)				
Atrium, infiltration cellular, lymphocyte				1 (1%)	
Atrium, thrombosis	1 (1%)			1 (1%)	
Epicardium, inflammation, chronic active			1 (1%)		
Myocardium, degeneration	1 (1%)	4 (4%)		1 (1%)	1 (1%)
Myocardium, inflammation				1 (1%)	
Myocardium, mineralization	1 (1%)	3 (3%)	1 (1%)		
Myocardium, necrosis, focal			1 (1%)		
Valve, thrombosis			1 (1%)	1 (1%)	
Endocrine System					
Adrenal cortex	(92)	(98)	(99)	(99)	(99)
Cytoplasmic alteration, focal	1 (1%)				
Degeneration, fatty				1 (1%)	
Hematopoietic cell proliferation					2 (2%)
Infiltration cellular, lymphocyte			1 (1%)		
Inflammation	1 (1%)				
Bilateral, capsule, hyperplasia	88 (96%)	88 (90%)	85 (86%)	89 (90%)	94 (95%)
Bilateral, capsule, mineralization		1 (1%)			
Bilateral, zona fasciculata, hypertrophy, focal			1 (1%)		
Bilateral, zona glomerulosa, hyperplasia, focal			1 (1%)		
Bilateral, zona reticularis, degeneration, fatty	2 (2%)		4 (4%)		2 (2%)
Capsule, hyperplasia	3 (3%)	8 (8%)	12 (12%)	9 (9%)	5 (5%)
Zona fasciculata, hyperplasia, focal			1 (1%)		3 (3%)
Zona fasciculata, hypertrophy, diffuse		1 (1%)			
Zona fasciculata, hypertrophy, focal	2 (2%)		2 (2%)	5 (5%)	
Zona reticularis, degeneration, fatty	2 (2%)	2 (2%)	3 (3%)		1 (1%)
Adrenal medulla	(90)	(95)	(97)	(97)	(98)
Hyperplasia	3 (3%)	8 (8%)	2 (2%)		3 (3%)
Bilateral, amyloid deposition			1 (1%)		

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Endocrine System (continued)					
Islets, pancreatic	(87)	(95)	(94)	(94)	(94)
Degeneration		1 (1%)			
Hyperplasia	40 (46%)	60 (63%)	42 (45%)	48 (51%)	47 (50%)
Infiltration cellular, focal, mixed cell		2 (2%)	1 (1%)	3 (3%)	1 (1%)
Infiltration cellular, lymphocyte					1 (1%)
Inflammation, chronic active			1 (1%)		
Parathyroid gland	(63)	(53)	(53)	(53)	(58)
Cyst		1 (2%)	1 (2%)		
Degeneration				1 (2%)	
Hyperplasia	11 (17%)	8 (15%)	7 (13%)	6 (11%)	8 (14%)
Infiltration cellular, lymphocyte	2 (3%)	1 (2%)	2 (4%)	2 (4%)	
Infiltration cellular, mixed cell					1 (2%)
Inflammation, focal			2 (4%)		
Vacuolization cytoplasmic	1 (2%)				1 (2%)
Pineal gland	(52)	(37)	(67)	(61)	(61)
Hyperplasia					1 (2%)
Infiltration cellular, lymphocyte					1 (2%)
Inflammation				1 (2%)	
Pituitary gland	(83)	(92)	(87)	(89)	(93)
Hemorrhage				1 (1%)	
Pars distalis, cyst		2 (2%)	3 (3%)	1 (1%)	4 (4%)
Pars distalis, hyperplasia, diffuse				1 (1%)	
Pars distalis, hyperplasia, focal	37 (45%)	50 (54%)	33 (38%)	35 (39%)	35 (38%)
Pars distalis, hypertrophy, focal			3 (3%)	1 (1%)	1 (1%)
Rathke's cleft, cyst		1 (1%)			
Thyroid gland	(92)	(99)	(98)	(98)	(98)
Infiltration cellular, lymphocyte			3 (3%)		
Inflammation, focal	2 (2%)		3 (3%)	4 (4%)	2 (2%)
Bilateral, infiltration cellular, lymphocyte				1 (1%)	
Follicle, cyst	21 (23%)	21 (21%)	25 (26%)	22 (22%)	37 (38%)
Follicular cell, hyperplasia, focal	3 (3%)	5 (5%)	1 (1%)	1 (1%)	
Follicular cell, hypertrophy, diffuse	2 (2%)				
General Body System					
Tissue NOS	(1)	(1)	(3)		
Inflammation, chronic active			1 (33%)		
Genital System					
Clitoral gland	(89)	(84)	(85)	(84)	(82)
Atrophy	25 (28%)	19 (23%)	16 (19%)	21 (25%)	17 (21%)
Cyst	29 (33%)	26 (31%)	15 (18%)	18 (21%)	19 (23%)
Inflammation			1 (1%)		1 (1%)
Arteriole, inflammation				1 (1%)	
Bilateral, atrophy	55 (62%)	56 (67%)	61 (72%)	55 (65%)	57 (70%)
Bilateral, cyst	55 (62%)	56 (67%)	66 (78%)	58 (69%)	52 (63%)
Bilateral, inflammation	2 (2%)	1 (1%)			
Ovary	(79)	(91)	(95)	(94)	(96)
Amyloid deposition					1 (1%)
Angiectasis		2 (2%)	3 (3%)		3 (3%)
Atrophy	3 (4%)	1 (1%)	1 (1%)	2 (2%)	1 (1%)
Cyst	20 (25%)	23 (25%)	28 (29%)	32 (34%)	21 (22%)

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Genital System (continued)					
Ovary (continued)	(79)	(91)	(95)	(94)	(96)
Hemorrhage		1 (1%)		1 (1%)	1 (1%)
Infiltration cellular, mast cell	1 (1%)				
Infiltration cellular, mixed cell				1 (1%)	
Inflammation, chronic active			2 (2%)		
Mineralization	1 (1%)			1 (1%)	
Pigmentation		1 (1%)			
Thrombosis			1 (1%)		1 (1%)
Bilateral, amyloid deposition				1 (1%)	
Bilateral, atrophy	1 (1%)	2 (2%)	2 (2%)	3 (3%)	2 (2%)
Bilateral, cyst	2 (3%)		2 (2%)	1 (1%)	3 (3%)
Germinal epithelium, hyperplasia				1 (1%)	
Interstitial cell, hyperplasia					1 (1%)
Uterus	(92)	(97)	(98)	(99)	(100)
Amyloid deposition		1 (1%)			1 (1%)
Angiectasis	1 (1%)	3 (3%)	2 (2%)		3 (3%)
Hemorrhage	1 (1%)	1 (1%)			
Hydrometra	24 (26%)	18 (19%)	16 (16%)	20 (20%)	22 (22%)
Inflammation	2 (2%)				
Inflammation, chronic		1 (1%)			
Thrombosis		1 (1%)			
Bilateral, atrophy		1 (1%)			
Bilateral, hydrometra	24 (26%)	15 (15%)	24 (24%)	21 (21%)	26 (26%)
Bilateral, endometrium, amyloid deposition	1 (1%)				
Bilateral, endometrium, hyperplasia, cystic	32 (35%)	44 (45%)	41 (42%)	45 (45%)	38 (38%)
Cervix, angiectasis			1 (1%)		
Endometrium, angiectasis				1 (1%)	
Endometrium, hyperplasia, cystic	22 (24%)	27 (28%)	26 (27%)	21 (21%)	24 (24%)
Hematopoietic System					
Bone marrow	(96)	(99)	(97)	(99)	(100)
Angiectasis		1 (1%)			2 (2%)
Atrophy			1 (1%)		1 (1%)
Hyperplasia	23 (24%)	13 (13%)	13 (13%)	14 (14%)	19 (19%)
Infiltration cellular, focal, lymphocyte			1 (1%)		
Myelofibrosis	10 (10%)	18 (18%)	17 (18%)	10 (10%)	21 (21%)
Necrosis		1 (1%)			
Myeloid cell, hyperplasia	3 (3%)				
Lymph node	(19)	(15)	(4)	(14)	(12)
Ectasia	2 (11%)	2 (13%)	2 (50%)	1 (7%)	1 (8%)
Hemorrhage	1 (5%)	2 (13%)	1 (25%)	1 (7%)	1 (8%)
Hyperplasia, reticulum cell					1 (8%)
Infiltration cellular, mast cell			1 (25%)		
Infiltration cellular, histiocyte		1 (7%)			1 (8%)
Lumbar, ectasia	3 (16%)	1 (7%)	1 (25%)	2 (14%)	
Lumbar, hemorrhage	4 (21%)		1 (25%)	1 (7%)	
Lumbar, pigmentation	1 (5%)				
Mediastinal, hemorrhage				1 (7%)	
Mediastinal, infiltration cellular, mixed cell		1 (7%)			
Renal, ectasia		1 (7%)			

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Hematopoietic System (continued)					
Lymph node, mandibular	(84)	(94)	(89)	(91)	(92)
Atrophy	3 (4%)	7 (7%)	4 (4%)	4 (4%)	3 (3%)
Hemorrhage	2 (2%)	2 (2%)	1 (1%)	2 (2%)	3 (3%)
Hyperplasia	8 (10%)	10 (11%)	12 (13%)	4 (4%)	4 (4%)
Hyperplasia, reticulum cell		2 (2%)	1 (1%)	2 (2%)	2 (2%)
Infiltration cellular, plasma cell	2 (2%)	1 (1%)	2 (2%)	1 (1%)	1 (1%)
Infiltration cellular, histiocyte			1 (1%)	1 (1%)	
Infiltration cellular, mixed cell	2 (2%)	1 (1%)	2 (2%)	1 (1%)	1 (1%)
Pigmentation	22 (26%)	9 (10%)	18 (20%)	10 (11%)	18 (20%)
Lymph node, mesenteric	(83)	(88)	(89)	(92)	(95)
Angiectasis	1 (1%)	1 (1%)			
Atrophy	12 (14%)	10 (11%)	24 (27%)	21 (23%)	22 (23%)
Ectasia	3 (4%)		4 (4%)	2 (2%)	
Hemorrhage	3 (4%)	2 (2%)	4 (4%)	4 (4%)	2 (2%)
Hyperplasia	2 (2%)	1 (1%)	4 (4%)		2 (2%)
Hyperplasia, reticulum cell	3 (4%)	7 (8%)	13 (15%)	8 (9%)	15 (16%)
Infiltration cellular, plasma cell	5 (6%)	4 (5%)	2 (2%)	1 (1%)	6 (6%)
Infiltration cellular, histiocyte	50 (60%)	45 (51%)	47 (53%)	43 (47%)	41 (43%)
Infiltration cellular, mixed cell	4 (5%)	1 (1%)	2 (2%)	5 (5%)	5 (5%)
Inflammation, focal			1 (1%)		
Artery, inflammation				1 (1%)	
Spleen	(91)	(93)	(95)	(93)	(99)
Congestion	1 (1%)				
Fibrosis, focal		1 (1%)			
Hematopoietic cell proliferation	74 (81%)	77 (83%)	87 (92%)	83 (89%)	92 (93%)
Infarct		1 (1%)			1 (1%)
Infiltration cellular, mast cell		1 (1%)			
Infiltration cellular, plasma cell			1 (1%)		
Pigmentation	17 (19%)	6 (6%)	8 (8%)	12 (13%)	12 (12%)
Lymphoid follicle, atrophy	6 (7%)	4 (4%)	7 (7%)	3 (3%)	3 (3%)
Lymphoid follicle, hyperplasia	31 (34%)	31 (33%)	32 (34%)	34 (37%)	40 (40%)
Lymphoid follicle, necrosis			1 (1%)		1 (1%)
Red pulp, atrophy	2 (2%)	3 (3%)			
Thymus	(78)	(92)	(84)	(75)	(89)
Angiectasis	1 (1%)	2 (2%)	3 (4%)	3 (4%)	2 (2%)
Atrophy	22 (28%)	20 (22%)	24 (29%)	29 (39%)	27 (30%)
Cyst, focal	5 (6%)	2 (2%)	3 (4%)	9 (12%)	3 (3%)
Hemorrhage				1 (1%)	2 (2%)
Hyperplasia, lymphoid	31 (40%)	19 (21%)	20 (24%)	24 (32%)	25 (28%)
Artery, inflammation					1 (1%)
Thymocyte, necrosis			1 (1%)		3 (3%)
Integumentary System					
Mammary gland	(94)	(98)	(99)	(99)	(98)
Hyperplasia	3 (3%)	3 (3%)	5 (5%)	2 (2%)	3 (3%)
Infiltration cellular, lymphocyte		1 (1%)	1 (1%)		
Artery, inflammation		1 (1%)			
Duct, dilatation	10 (11%)	15 (15%)	16 (16%)	17 (17%)	12 (12%)
Skin	(99)	(100)	(100)	(100)	(100)
Hemorrhage			1 (1%)		
Ulcer, focal	2 (2%)				
Artery, inflammation	1 (1%)				

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Musculoskeletal System					
Skeletal muscle	(7)	(3)	(3)	(4)	(4)
Degeneration			1 (33%)		
Necrosis	1 (14%)				
Nervous System					
Brain	(99)	(100)	(98)	(98)	(100)
Infiltration cellular, focal, mixed cell					1 (1%)
Artery, inflammation					1 (1%)
Cerebellum, developmental malformation, focal			1 (1%)		
Choroid plexus, infiltration cellular, lymphocyte				1 (1%)	
Hypothalamus, compression		2 (2%)	3 (3%)	3 (3%)	
Hypothalamus, hemorrhage				1 (1%)	
Thalamus, infiltration cellular, lymphocyte		1 (1%)			
Thalamus, mineralization	47 (47%)	68 (68%)	55 (56%)	60 (61%)	72 (72%)
Ventricle, hydrocephalus		2 (2%)			
Ventricle, infiltration cellular, lymphocyte			1	(1%)	
Respiratory System					
Lung	(95)	(100)	(99)	(99)	(100)
Congestion	1 (1%)		1 (1%)		
Fibrosis					1 (1%)
Hemorrhage	2 (2%)		1 (1%)		1 (1%)
Infiltration cellular, lymphocyte	32 (34%)	37 (37%)	33 (33%)	34 (34%)	30 (30%)
Inflammation, focal	2 (2%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)
Metaplasia, focal, osseous		1 (1%)	1 (1%)		
Alveolar epithelium, hyperplasia, focal	4 (4%)	1 (1%)	2 (2%)		1 (1%)
Alveolus, infiltration cellular, histiocyte	1 (1%)	4 (4%)	1 (1%)	2 (2%)	
Artery, mineralization	2 (2%)				
Serosa, inflammation			2 (2%)		
Trachea	(94)	(100)	(98)	(99)	(98)
Artery, inflammation					1 (1%)
Special Senses System					
Eye	(2)	(2)	(1)	(1)	(2)
Cornea, inflammation	2 (100%)		1 (100%)		
Lens, degeneration		1 (50%)			
Lens, mineralization				1 (100%)	
Harderian gland	(98)	(97)	(99)	(96)	(97)
Infiltration cellular, lymphocyte	13 (13%)	12 (12%)	18 (18%)	16 (17%)	20 (21%)
Bilateral, infiltration cellular, lymphocyte	14 (14%)	11 (11%)	18 (18%)	16 (17%)	16 (16%)

TABLE D3
Summary of the Incidence of Nonneoplastic Lesions in Female Mice in the 2-Year Whole-Body Exposure Study of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Urinary System					
Kidney	(92)	(96)	(98)	(98)	(99)
Hydronephrosis		1 (1%)		1 (1%)	1 (1%)
Infarct, acute			1 (1%)		
Infiltration cellular, lymphocyte		1 (1%)			1 (1%)
Artery, inflammation			1 (1%)		
Bilateral, artery, inflammation				1 (1%)	
Bilateral, artery, mineralization	1 (1%)				
Bilateral, artery, cortex, inflammation					1 (1%)
Bilateral, cortex, cyst, multiple		1 (1%)			
Bilateral, cortex, infiltration cellular, lymphocyte	11 (12%)	8 (8%)	7 (7%)	7 (7%)	8 (8%)
Bilateral, cortex, inflammation	1 (1%)				
Bilateral, cortex, mineralization	1 (1%)	1 (1%)			
Bilateral, cortex, renal tubule, accumulation, hyaline droplet			2 (2%)		3 (3%)
Bilateral, cortex, renal tubule, degeneration	7 (8%)	11 (11%)	7 (7%)	8 (8%)	9 (9%)
Bilateral, cortex, renal tubule, dilatation	1 (1%)	1 (1%)	1 (1%)		1 (1%)
Bilateral, cortex, renal tubule, vacuolization cytoplasmic					2 (2%)
Bilateral, glomerulus, amyloid deposition	1 (1%)				
Bilateral, glomerulus, inflammation		1 (1%)			1 (1%)
Bilateral, medulla, infiltration cellular, lymphocyte	26 (28%)	29 (30%)	38 (39%)	31 (32%)	37 (37%)
Bilateral, medulla, mineralization	1 (1%)			1 (1%)	
Cortex, cyst				3 (3%)	
Cortex, infiltration cellular, plasma cell			1 (1%)		
Cortex, infiltration cellular, lymphocyte	13 (14%)	9 (9%)	14 (14%)	8 (8%)	8 (8%)
Cortex, infiltration cellular, mixed cell				1 (1%)	
Cortex, metaplasia, focal, osseous	4 (4%)	3 (3%)	3 (3%)	3 (3%)	3 (3%)
Cortex, necrosis					1 (1%)
Cortex, renal tubule, degeneration	3 (3%)	7 (7%)	4 (4%)	4 (4%)	4 (4%)
Cortex, renal tubule, dilatation				2 (2%)	
Medulla, cyst				1 (1%)	
Medulla, infiltration cellular, lymphocyte	21 (23%)	24 (25%)	18 (18%)	27 (28%)	20 (20%)
Medulla, inflammation	1 (1%)		1 (1%)		
Medulla, mineralization	2 (2%)	1 (1%)		1 (1%)	1 (1%)
Pelvis, calculus, microscopic observation only	3 (3%)	2 (2%)	2 (2%)	1 (1%)	2 (2%)
Urinary bladder	(79)	(87)	(94)	(89)	(92)
Infiltration cellular, plasma cell	1 (1%)				
Infiltration cellular, lymphocyte	8 (10%)	3 (3%)	4 (4%)	6 (7%)	5 (5%)
Arteriole, inflammation				1 (1%)	1 (1%)
Artery, inflammation			1 (1%)		
Serosa, inflammation, chronic active					1 (1%)

APPENDIX E
MAGNETIC FIELD PRODUCTION AND MONITORING

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MAGNETIC FIELD PRODUCTION AND MONITORING

METHODS

The magnetic field exposure facility consisted of five animal exposure rooms (one of these had coils that did not carry a current and served as a control animal exposure room), storage rooms, cage washing facilities, a necropsy facility, an engineering control room for the generation and monitoring of fields and room conditions, access corridors, and showers and changing rooms for laboratory technicians (Figure E1). Offset coils in the exposure rooms and in storage rooms between the exposure rooms were used to minimize stray fields. The engineering control room contained the generator that produced the current that supplied the coils in each exposure room and monitors for induced and stray 60-Hz magnetic fields and for the collection of humidity, temperature, sound, vibration, ventilation, and light data. The engineering control room was outside the range of stray magnetic fields above 1 mG.

Each coil set consisted of seven pairs of rectangular, vertically oriented coils connected in series with compensating capacitors between each coil. The compensating capacitors minimized the voltage required to circulate the necessary current through the coils by canceling the inductive reactance at 60 Hz. Capacitors also controlled the voltage differential between coils and thus minimized the electrical field produced. Coils were spaced uniformly through the room and were 4 feet tall and 8 feet wide, weighing approximately 80 kilograms. The coils in the five exposure room were driven individually by five source controllers located in the engineering control room. Coil sets were stacked one above the other; the bottom coils produced a linear 60-Hz magnetic field in one direction while the top coils produced a similar field in the opposite direction (Figure E2). The coil position in each room protected against field overlap between rooms. The opposing fields produced by the coil sets largely canceled each other outside the area of the exposure room. Additional field cancellation was provided by horizontally positioned steering coils located at the ends of each coil set.

Coils were held in place by fiberglass supports and were protected from moisture by Plexiglas™ enclosures. Durometer™ neoprene pads between the coils and supports isolated coil vibrations. Each coil set was controlled from the engineering control room. The fields in three rooms had intensities of 0.02, 2, and 10 G, and the field in a fourth room was manipulated to produce an intermittent 10-G field (1 hour on and 1 hour off). Harmonic distortion was less than 3%. A fifth room with an identical coil apparatus that was not operating served as the control animal exposure room. Fiberglass cage racks were constructed to prevent disruption of the induced magnetic fields. The stainless steel automatic watering system was designed and configured to eliminate possible current loops. Fiberglass guides and floor plates were located in each room to provide precise alignment of racks and cages within the magnetic field. Racks held equal numbers of polycarbonate cages in either the top or the bottom field of the coil sets (Figure E2). Cages were alternated between the top and bottom linear horizontal fields on a weekly basis.

Induced alternating 60-Hz magnetic fields were monitored by a MultiWave™ Monitoring System (Electric Research and Management, Inc., Pittsburgh, PA), which consisted of a microcomputer, an external tie-in, and data multiplexors that were located in the control room. In animal exposure rooms, monitoring system components included a series of three-axis alternating-current magnetic field probes (two per room), alternating-current voltage probes, and environmental sensor probes (to measure rack vibration, noise, light intensity, temperature, and humidity). The magnetic probes, which were located at the end of each exposure module in the center of the steering coils to detect faults in the coils, allowed monitoring of the ambient magnetic fields during the off periods of intermittent exposure and during daily field shutdowns. The computer program (WAVE-C) continuously monitored and collected sensor data. Data samples were electronically stored every 30 minutes, and data were off-loaded from the system on a daily basis. The

system was equipped with alarms to alert project personnel in the event that measured parameters deviated from set ranges.

Average field intensities measured during the 2-year studies are given in Table E1. All daily mean intensities were within 10% of the target; the maximum magnetic field intensity in the control animal exposure room did not exceed 1.3 mG. The background sound levels were uniform between exposure rooms and the vibrations caused by the force of the alternating fields on the metal components were damped almost completely. The groups of animals were rotated from room to room every 10 weeks, so each of the five animal exposure rooms served as the control exposure room twice during the 2-year studies (a final rotation was not carried out for the last 4 weeks). This served to minimize the environmental effect of each room and the variation between the earth's static magnetic fields with different exposure regimens.

FACILITY VALIDATION

Following installation of the exposure systems, measurements were made to verify that the systems were operating within specifications. These included measurements of magnetic field level, vibration, surface temperature rise, electric field levels, and sound levels; measurements of the effect of the transient suppression circuit were made on the prototype in Pittsburgh (Electric Research and Management, Inc., 1993). During a preliminary study, an animal rack equipped with eight thermocouples was placed in each animal room to record cage temperatures when fields were on and off. No differences in temperature were found with magnetic field exposures. In addition, the exposure system was validated by a representative of the National Institute of Standards and Technology (NIST), who found that the intensities and spatial uniformity of the earth's static magnetic fields within the animal exposure area were consistent with the expected intensities in the Chicago area (approximately 300 to 400 mG) (Table E2). Using an NIST fluxgate magnetometer, measurements were made of the direct-current magnetic field component that was parallel to the direction of the alternating-current magnetic field in each exposure room in a north-south direction. The measurements were performed in the top and bottom coil systems at the level of the rat and mouse enclosures in each exposure bay. The results are presented in Table E3. The calibration uncertainty of the fluxgate magnetometer was estimated to be less than 2%; however, the measurements are sensitive to probe alignment because of the nonuniformity of the field and the presence of a significant vertical magnetic field component. The full NIST validation report from the National Institute of Environmental Health Sciences appears in Appendix F.

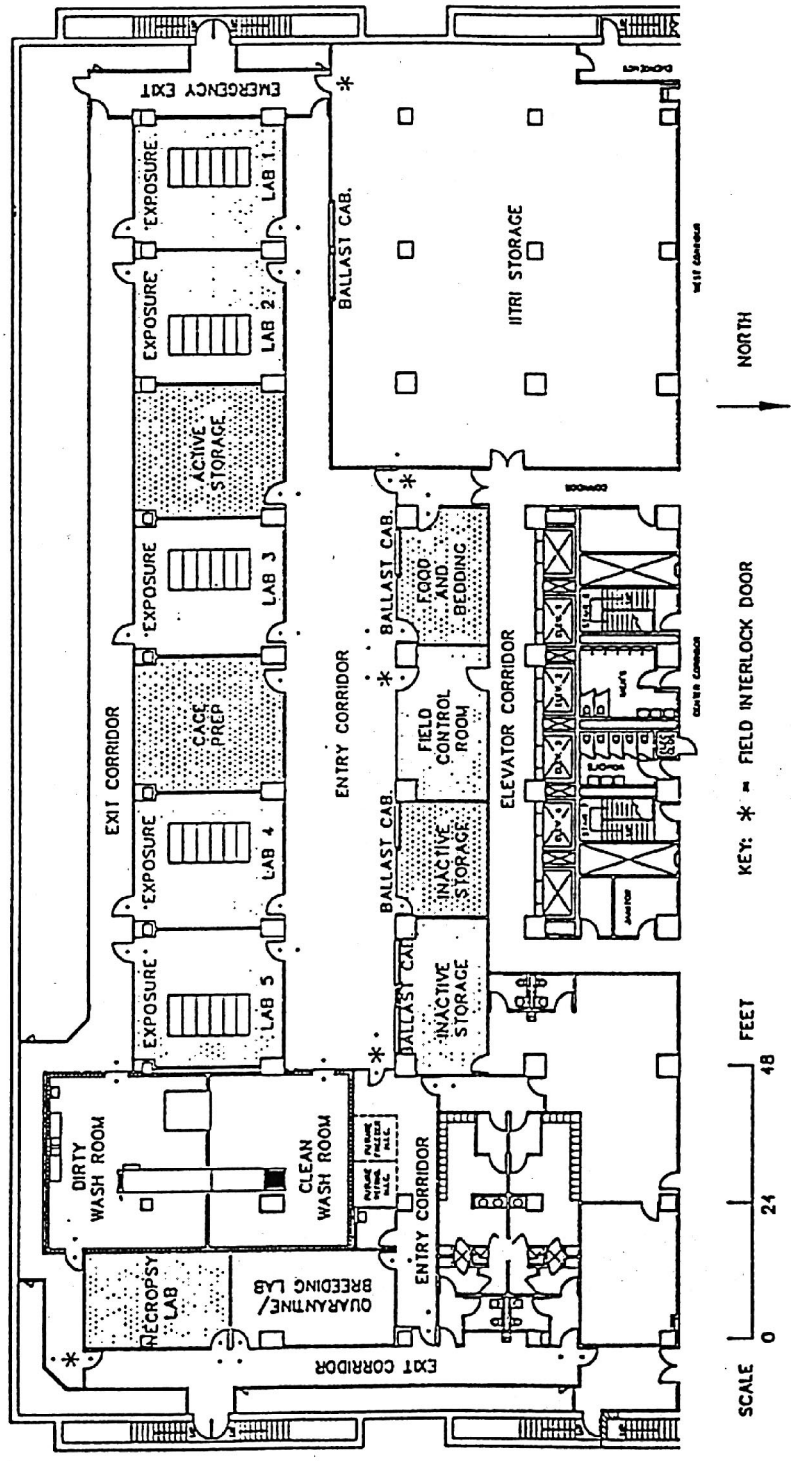

FIGURE E1
Exposure Facility Floor Plan

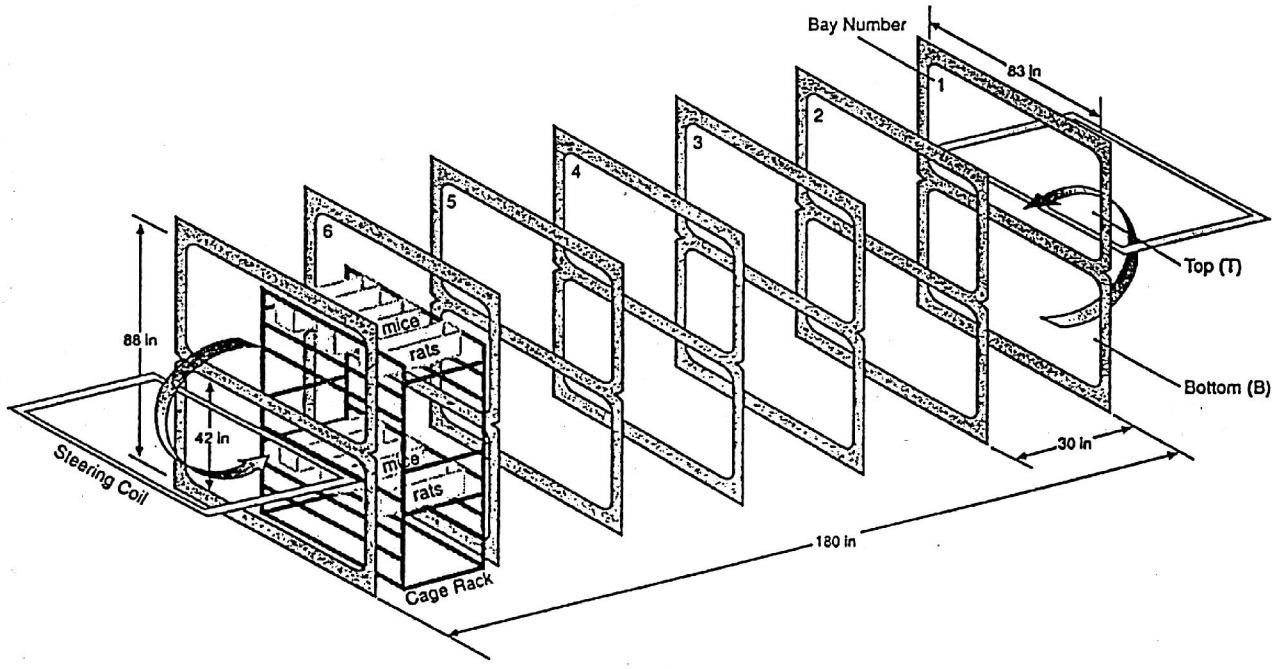

FIGURE E2
Magnetic Fields Unit

TABLE E1
Summary of Average Field Intensities and Exposure Conditions in the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Magnetic Field Intensity (mG)					
Fields on (North)					
Average	—[a]	20.05	2,002.92	10,047.49	10,019.79
Minimum	—	18.89	1,920.68	9,808.90	9,774.68
Maximum	—	21.05	2,076.51	10,272.18	10,397.20
Fields off (North)					
Average	0.39	0.36	0.35	0.62	0.51
Minimum	0.04	0.07	0.07	0.13	0.19
Maximum	0.96	0.92	0.74	1.70	1.04
Fields on (South)					
Average	—	20.01	2,007.93	10,056.70	10,023.40
Minimum	—	18.86	1,936.99	9,840.86	7,534.99
Maximum	—	22.04	2,078.27	10,313.29	10,382.35
Fields off (South)					
Average	0.62	0.66	0.64	0.68	0.72
Minimum	0.03	0.04	0.07	0.18	0.15
Maximum	1.26	1.35	1.34	1.64	1.44
Sound Levels (dB)					
Fields on					
Average	—	70.29	70.24	70.24	70.26
Minimum	—	60.00	60.00	60.00	60.00
Maximum	—	77.95	77.94	77.86	78.20
Fields off					
Average	70.01	70.07	70.14	70.16	70.16
Minimum	60.00	60.00	60.00	60.00	60.00
Maximum	78.20	78.20	78.20	78.20	78.20

TABLE E1
Summary of Average Field Intensities and Exposure Conditions in the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

	Control	0.02 G	2 G	10 G	10 G Intermittent
Vibrations[b]					
Fields on					
Average	—	0.00148	0.00105	0.00110	0.00143
Minimum	—	0.00000	0.00000	0.00000	0.00000
Maximum	—	0.01000	0.02500	0.02700	0.08900
Fields off					
Average	0.00148	0.00170	0.00125	0.00018	0.00156
Minimum	0.00000	0.00000	0.00000	0.00000	0.00000
Maximum	0.10600	0.09600	0.10800	0.17500	0.10700
Lights on/fields on					
Average	—	0.00152	0.00103	0.00107	0.00145
Minimum	—	0.00000	0.00000	0.00000	0.00000
Maximum	—	0.00800	0.02500	0.02400	0.08900
Lights on/fields off					
Average	0.00155	0.00171	0.00125	0.00123	0.00156
Minimum	0.00000	0.00000	0.00000	0.00000	0.00000
Maximum	0.10600	0.09600	0.10800	0.17500	0.10700
Lights off/fields on					
Average	—	0.00145	0.00105	0.00112	0.00142
Minimum	—	0.00000	0.00000	0.00000	0.00000
Maximum	—	0.01000	0.00800	0.02700	0.01600
Lights off/fields off					
Average	0.00141	0.00100	0.00107	0.00110	0.00103
Minimum	0.00000	0.00000	0.00000	0.00000	0.00000
Maximum	0.00900	0.00100	0.00200	0.14800	0.00200

[a] Not applicable
[b] Expressed as percent of gravity (9.8 m/s^2)

TABLE E2
Summary of Earth's Static Magnetic Field Intensities Measured Within Exposure Rooms Prior to the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

	Rack Bay	Field Intensity (G)	
		Top	Bottom
Room 1	1	0.118	0.008
	2	0.128	0.013
	3	0.148	0.129
	4	0.155	0.034
	5	0.159	0.191
	6	0.162	0.169
Room 2	1	0.113	0.023
	2	0.111	−0.035
	3	0.126	0.041
	4	0.177	0.271
	5	0.205	0.324
	6	0.206	0.328
Room 3	1	0.143	0.091
	2	0.148	0.104
	3	0.158	0.144
	4	0.162	0.183
	5	0.172	0.220
	6	0.175	0.217
Room 4	1	0.207	0.217
	2	0.199	0.168
	3	0.190	0.197
	4	0.169	0.179
	5	0.143	0.068
	6	0.125	0.002
Room 5	1	0.189	0.259
	2	0.205	0.243
	3	0.183	0.135
	4	0.148	−0.051
	5	0.111	−0.123
	6	0.094	−0.086

TABLE E3
Summary of Central Direct-Current Magnetic Fields Parallel to Alternating-Current Magnetic Fields in the 2-Year Whole-Body Exposure Studies of 60-Hz Magnetic Fields

	Rack Bay	Field Intensity (G)	
		Top	Bottom
Room 1	1	0.115	0.012
	2	0.126	−0.016
	3	0.144	0.136
	4	0.151	0.037
	5	0.157	0.175
	6	0.161	0.171
Room 2	1	0.117	0.050
	2	0.108	−0.050
	3	0.116	0.028
	4	0.162	0.160
	5	0.198	0.347
	6	0.210	0.379
Room 3	1	0.143	0.092
	2	0.145	0.110
	3	0.151	0.134
	4	0.161	0.186
	5	0.168	0.219
	6	0.170	0.214
Room 4	1	0.206	0.221
	2	0.197	0.174
	3	0.189	0.190
	4	0.169	0.187
	5	0.146	0.086
	6	0.126	0.013
Room 5	1	0.182	0.246
	2	0.205	0.257
	3	0.198	0.189
	4	0.167	0.028
	5	0.120	−0.114
	6	0.090	−0.127

APPENDIX F
MEASUREMENT OF 60-HZ MAGNETIC AND ELECTRIC FIELDS AT THE ILLINOIS INSTITUTE OF TECHNOLOGY RESEARCH INSTITUTE

(Reprinted with permission of the National Institute of Standards and Technology)

Measurement of 60-Hz Magnetic and Electric Fields at the Illinois Institute of Technology Research Institute Chicago, Illinois May 26-27, 1993

Applied Electrical Measurements
Report No. 811-3-96

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Measurements of 60-Hz Magnetic and Electric Fields at the Illinois Institute of Technology Research Institute

This report describes a visit to the Illinois Institute of Technology Research Institute (IITRI) in Chicago, Illinois during which 60-Hz magnetic fields were characterized in exposure systems that will be used to examine biological effects in rats and mice. Spot measurements of 60-Hz electric fields and dc magnetic fields were also performed. Briefly, there are five exposure systems located in separate rooms as shown in Figure 1 (provided by IITRI). Each exposure system consists of, in part, two sets of seven rectangular coils with a common axis for each set. The coils are stacked in a vertical configuration as indicated in the sketch shown in Figure 2, with the axis of each coil system in the north-south direction. The two coil systems are connected in series and the current is routed such that the direction of the axial magnetic field (the predominant field) in the top coil system is opposite to that in the lower coil system at any instant. Not shown in Figure 2 are two rectangular coils at the ends of the exposure system which bend the magnetic field lines and direct many of the field lines from the upper to lower set of coils at one end, and from the lower to upper set of coils at the opposite end (the direction of the field lines reverse as the direction of the current reverses).

The regions between the coils are labelled Bay 1 [top (T) or bottom (B)], Bay 2, etc., with Bay 1 being at the northern-most location. Mice and rats housed in plastic enclosures are introduced into the magnetic field on racks that roll into the individual bays. The mice occupy the upper levels in each coil system and the rats occupy the lower levels (Fig. 2). Present during the measurements were James Gauger, Louise Brousek, and Tim Johnson from IITRI and Martin Misakian from NIST. Louise Brousek participated in performing the measurements and Tim Johnson set the magnetic field levels in the different rooms according to an exposure scheme described below.

60-Hz Magnetic Field Uniformity and Magnitude

Table 1 shows the expected field levels in the different exposure systems according to room number and exposure scheme. The symbol I refers to an exposure system that is operated in an intermittent mode normally. During most of the measurements reported below, the field was left on continuously.

Table 1. Exposure Schemes

Exposure Scheme	Room				
	1	2	3	4	5
A	1 mT	1 mT(I)	0.2 mT	sham	2 μT
B	2 μT	1 mT	1 mT(I)	0.2 mT	sham

C	sham	2 μT	1 mT	1 mT(I)	0.2 mT
D	0.2 mT	sham	2 μT	1 mT	1 mT(I)
E	1 mT(I)	0.2 mT	sham	2 μT	1 mT

In order to characterize the field uniformity, measurements were made of the axial magnetic field at representative points in four exposure systems (Rooms 1, 3-5) when exposure scheme D was activated and in the remaining exposure system (Room 2) when exposure scheme A was activated. The measurements were made using a NIST magnetic field meter with an approximately 7 cm diameter probe. Thus, the measurements are average field values over the cross sectional area of the probe. In the top of each coil system, 18 measurements were made near a perimeter line which encloses the area occupied by the mice, and along a center line in the same area. The center of the probe was about 7 cm above the floor of the animal enclosure in each case. The uniformity was characterized by noting the measurements with the greatest negative and positive deviations, in percent, from the central value (points along center line in Bays 3 and 4). Thirty-six measurements were made in the lower coil system at the levels of the mice and rats--again along perimeter lines and center lines. Performing a larger number of measurements in the lower coil system did not make a significant difference in the largest deviations from the central values.

The magnitude of the central magnetic field was measured in each exposure system and compared with the expected value for all the exposure schemes. For the sham condition, the largest resultant magnetic field observed in all the bays (top and bottom) is reported. The resultant magnetic field, R, is given by

$$R = \sqrt{B_1^2 + B_2^2 + B_3^2},$$

where B_1, B_2, and B_3 are three spatially orthogonal field components. The resultant field values were obtained with a three-axis field meter. The uncertainty in the NIST measurements with the 7 cm probe is estimated to be less than ±2%. The three-axis meter has been compared with resultant field measurements obtained with the NIST field meter and agreement within 0.01 μT has been observed for measurements in the 0.1 to 0.2 μT range. The magnitude and uniformity results are given below according to room number.

Room 1

Uniformity. All magnetic field measurements in the top and bottom coil systems were within -4.8% to 0.3% (T) and -5.3% to 0.2% (B), respectively of their central values.

Magnitude. The departure of the central magnetic field from the expected field value is listed in Table 2 for the different exposure schemes.

Table 2. Departure of central field from expected value--Room 1

Departure (%)--Top/Bottom	Expected Value (Exp. Scheme)
1.8/1.8	1.0 mT (A)
8.9/7.9	2.0 μT (B)
largest $R \leq 0.05$ μT	sham (C)
5.0/6.4	0.2 mT (D)
3.1/3.0	1.0 mT(I) (E)

Room 2

Uniformity. All magnetic field measurements in the top and bottom coil systems were within -4.3% to 0.0% (T) and -3.4% to 1.6% (B), respectively of their central values.

Magnitude. The departure of the central magnetic field from the expected field value is listed in Table 3 for the different exposure schemes.

Table 3. Departure of central field from expected value--Room 2

Departure (%)--Top/Bottom	Expected Value (Exp. Scheme)
1.8/1.6	1.0 mT(I) (A)
3.6/3.1	1.0 mT (B)
6.2/10.9	2.0 μT (C)
largest $R \leq 0.04$ μT	sham (D)
5.1/4.8	0.2 mT (E)

Room 3

Uniformity. All magnetic field measurements in the top and bottom coil systems were within -5.2% to 0.2% (T) and -2.0% to 1.6% (B), respectively of their central values.

Magnitude. The departure of the central magnetic field from the expected field value is listed in Table 4 for the different exposure schemes.

Table 4. Departure of central field from expected value--Room 3

Departure (%)--Top/Bottom	Expected Value (Exp. Scheme)
4.5/5.1	0.2 mT (A)
2.7/2.8	1.0 mT(I) (B)
3.6/3.7	1.0 mT (C)
9.3/8.5	2.0 μT (D)
largest $R \leq 0.04$ μT	0.2 mT (E)

Room 4

Uniformity. All magnetic field measurements in the top and bottom coil systems were within -4.7% to 0.1% (T) and -4.1% to 0.8% (B), respectively of their central values.

Magnitude. The departure of the central magnetic field from the expected field value is listed in Table 5 for the different exposure schemes.

Table 5. Departure of central field from expected value--Room 4

Departure (%)--Top/Bottom	Expected Value (Exp. Scheme)
largest $R \leq 0.04$ μT	sham (A)
4.6/5.3	0.2 mT (B)
2.9/2.7	1.0 mT(I) (C)
3.3/3.0	1 mT (D)
9.0/8.0	2 μT (E)

Room 5

Uniformity. All magnetic field measurements in the top and bottom coil systems were within -4.8% to 0.3% (T) and -3.6% to 1.0% (B), respectively of their central values.

Magnitude. The departure of the central magnetic field from the expected field value is listed in Table 6 for the different exposure schemes.

Table 6. Departure of central field from expected value--Room 5

Departure (%)--Top/Bottom	Expected Value (Exp. Scheme)
8.7/10.2	2.0 μT (A)
largest $R \leq 0.04$ μT	sham (B)
5.1/4.8	0.2 mT (C)
2.0/2.6	1 mT(I) (D)
3.4/3.5	1 mT (E)

The data in Tables 2-6 indicate that with one exception, i.e., at the 2 μT level, the exposure fields are within 10% of the expected values at all the measurement points. The deviation from 2 μT can reach and exceed 10% by a small amount in the exposure systems located in Rooms 2, 3, and 5. The data also show that the sham field levels are well under 0.1 μT for all exposure schemes (see also **Stray Magnetic Fields** below).

Harmonic Content

The waveform of the 2 μT and 0.2 mT magnetic fields were checked for harmonics by examining the output signal from the NIST magnetic field meter, using an oscilloscope provided by IITRI. For the 1 mT and 1 mT(I) fields, the signal from the magnetic field probe, which is proportional to the time-derivative of the magnetic field, was examined directly with the oscilloscope. In no case, i.e, for all field levels (excluding sham) in all exposure systems and for all exposure schemes, was there discernible distortion of the magnetic field waveform or its time-derivative (It should be noted that the time-derivative observations are a more sensitive check for harmonic content *in the field*).

Prior to the waveform measurements, the linearity of the horizontal axis and the frequency response of the oscilloscope were checked by examining the waveforms of a square wave on the sweep settings used for the measurements. Nonlinearities as small as 1% of the full sweep would readily be seen with this check, but none were apparent. The rise and fall of the square waveform also indicated an adequate frequency response for observing 60-Hz waveforms and power frequency harmonics.

Stray Magnetic Fields

The largest resultant magnetic fields in each exposure system under sham conditions have been reported above. The effects of stray fields from the energized exposure systems on the sham system add up to well under 0.1 μT. Another situation for which stray fields are considered is during the "off period" for the 1 mT intermittent exposures. Two "worst case" conditions were checked. First, under exposure scheme A, the exposure system in Room 2 will have an intermittent 1 mT field. During the off period, stray fields can originate from the 1 mT exposure system in adjacent Room 1. Contributions from Room 3, which is not adjacent to Room 2, are not expected to be measurable (see Figure 1 and Table 1). The largest resultant magnetic field observed in all the bays in Room 2 during the off period was near 0.16 μT. Under exposure scheme D, similar measurements in Room 5 indicated that the largest resultant magnetic field in all the bays was near 0.13 μT.

60-Hz Electric Fields

Because voltages will occur between the rectangular loops of wire which produce the magnetic fields, electric fields will develop in a direction roughly parallel to the axial magnetic fields. Electric field shielding was reportedly provided by the contractor responsible for building the exposure systems. Using a NIST-owned free-body electric field meter, measurements were performed in all the bays of each exposure system under worst-case conditions, i.e., when the magnetic field was 1 mT. For this condition, the current through the magnetic field coils is a maximum and the associated voltage between the loops of wire will be the greatest.

The largest electric fields observed in exposure systems located in Rooms 1,3, and 5, in regions that would be occupied by test animals, were less than about 10 V/m.

In Room 2, electric fields as high as 100 V/m were observed in the bottom sections of Bays 1 and 2. Lesser values were observed in the other bays, but their values were not recorded.

In Room 4, electric fields as large as 39 V/m were observed in the bottom sections of Bays 3 and 4, and 55 V/m in the bottom section of Bay 5. All other regions had electric fields of about 11 V/m or less.

While the calibration uncertainty associated with the NIST free-body meter is estimated to be less than ±2%, some additional uncertainty is introduced during measurements because the analog display of the field meter is read from a distance, the fields are not uniform, and there is some movement of the field meter when the analog display is read. Thus, the electric field values reported here should be considered as being approximate.

DC Magnetic Field Measurements

Using a NIST-owned fluxgate magnetometer, measurements were made of the dc magnetic field component that was parallel to the direction of the ac magnetic field in each exposure system, i.e., along the horizontal north-south direction. The measurements were performed in the top and bottom coil systems at the level of the rat enclosures in each bay. The results are presented below in Table 7 according to room number.

The calibration uncertainty of the fluxgate magnetometer is estimated to be less than ±2%. However, the measurements are sensitive to probe alignment because of the nonuniformity of the fields (see below) and the presence of a significant vertical magnetic field component. Therefore, the measurement results should be considered approximate.

Table 7. Central dc magnetic field values parallel to ac field

Room	Bay	Magnetic Field (μT)--Top/Bottom
1	1	10.5/1.30
	2	14.5/7.77
	3	15.6/13.8
	4	15.4/4.8
	5	15.8/11.3
	6	16.9/13.7
2	1	11.3/0.44
	2	11.6/3.18
	3	13.6/3.17
	4	18.4/26.4
	5	21.5/38.5
	6	21.5/29.4

3	1	14.2/8.42
	2	14.2/9.67
	3	14.8/13.5
	4	15.8/19.4
	5	16.8/22.8
	6	17.0/23.3
4	1	20.1/21.3
	2	19.2/15.9
	3	18.3/18.2
	4	16.2/18.8
	5	14.0/9.78
	6	12.0/2.2
5	1	19.3/25.4
	2	20.7/23.2
	3	18.5/11.5
	4	15.5/-5.5
	5	12.4/-10.7
	6	10.8/-4.5

The results in the above table indicate a variable dc magnetic field aligned with the ac field direction. Differences exist between adjacent bays as well as between the top and bottom sections of each bay. The minus signs for the field values in Room 5 indicate reversals in field direction. When the magnetic field probe was removed from the top section of Bay 3 in Room 2, a field reversal was again seen. The perturbations of the dc magnetic field are apparently due to magnetized structural components in the building, e.g., magnetized metal beams. A preliminary investigation by James Gauger using a hand compass near a wall in Room 5 suggested the presence of a magnetized reinforcement bar in the wall which could be responsible for the dc field variations.

Other Items

Magnetic field Measurements in quarantine and breeding lab Measurements of the resultant magnetic field at representative points near floor level and at a height of about

1.8 m indicated that the ambient field did not exceed 0.1 μT.

Procedure for energizing magnetic field coils The possibility of transients being produced during the "turning on" and "turning off" operations was discussed. Provisions have been made in the power supplies to prevent this from happening. For example, a resistor is placed across the output of the power supply during the "off" operation, which results in a decaying oscillatory current waveform without transients.

Monitoring "on" condition of magnetic field The magnetic field is continuously monitored.

Blind operation of experiment Discussions with researchers at IITRI indicate that the biological endpoints will not be analyzed under blind conditions.

Vibrations The racks holding the animal enclosures will not be in mechanical contact with the magnetic field coils. No vibrations of the coils could be sensed by touch.

Mechanical scraping of rack on support structure of exposure facility One rack was used to support the magnetic field probes in the different bays of each exposure system. Occasionally, the top of the rack would scrape against part of the support frame for the water supply. It's not clear whether repeated scraping against the support frame could lead to mechanical failure of the frame.

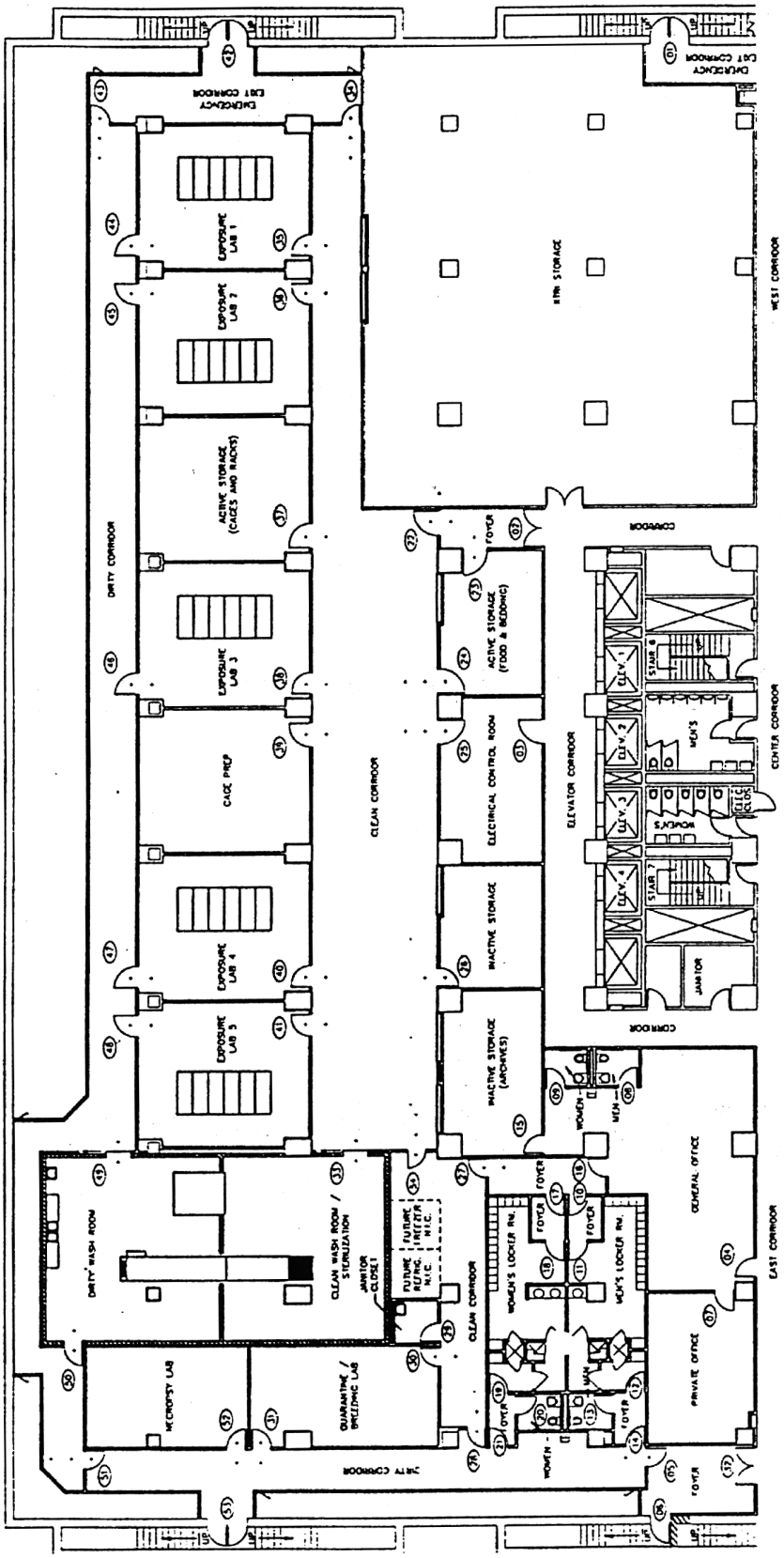

Figure 1

FIGURE F1

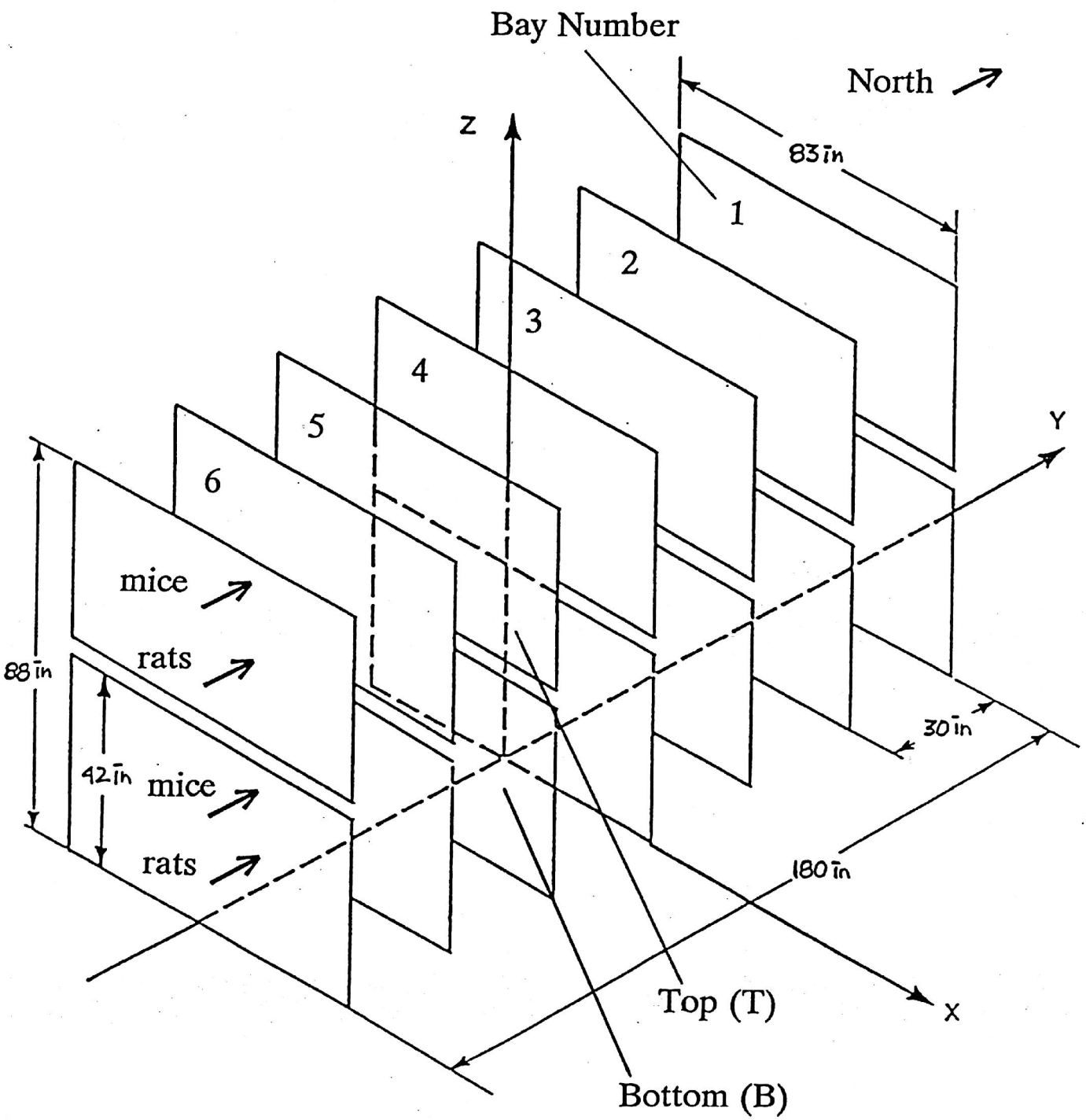

FIGURE F2
Two sets of rectangular coils of exposure systems with axes parallel to north-south direction.

APPENDIX G
INGREDIENTS, NUTRIENT COMPOSITION, AND CONTAMINANT LEVELS IN NTP-2000 RAT AND MOUSE RATION

TABLE G1 Ingredients of NTP-2000 Rat and Mouse Ration 162
TABLE G2 Vitamins and Minerals in NTP-2000 Rat and Mouse Ration 162
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TABLE G4 Contaminant Levels in NTP-2000 Rat and Mouse Ration 164

TABLE G1
Ingredients of NTP-2000 Rat and Mouse Ration

Ingredients	Percent by Weight
Ground hard winter wheat	22.26
Ground #2 yellow shelled corn	22.18
Wheat middlings	15.0
Oat hulls	8.5
Alfalfa meal (dehydrated, 17% protein)	7.5
Purified cellulose	5.5
Soybean meal (49% protein)	5.0
Fish meal (60% protein)	4.0
Corn oil (without perservatives)	3.0
Soy oil (without perservatives)	3.0
Dried brewer s yeast	1.0
Calcium carbonate (USP)	0.9
Vitamin premix[a]	0.5
Mineral premix[b]	0.5
Calcium phosphate, dibasic (USP)	0.4
Sodium chloride	0.3
Choline chloride (70% choline)	0.26
Methionine	0.2

[a] Wheat middlings as carrier
[b] Calcium carbonate as carrier

TABLE G2
Vitamins and Minerals in NTP-2000 Rat and Mouse Ration[a]

	Amount	Source
Vitamins		
A	4,000 IU	Stabilized vitamin A palmitate or acetate
D	1,000 IU	D-activated animal sterol
K	1.0 mg	Menadione sodium bisulfate complex
α-Tocopheryl acetate	100 IU	
Niacin	23 mg	
Folic acid	1.1 mg	
d-Pantothenic acid	10 mg	*d*-Calcium pantothenate
Riboflavin	3.3 mg	
Thiamine	4 mg	Thiamine mononitrate
B_{12}	52 μg	
Pyridoxine	6.3 mg	Pyridoxine hydrochloride
Biotin	0.2 mg	*d*-Biotin
Minerals		
Magnesium	514 mg	Magnesium oxide
Iron	35 mg	Iron sulfate
Zinc	12 mg	Zinc oxide
Manganese	10 mg	Manganese oxide
Copper	2.0 mg	Copper sulfate
Iodine	0.2 mg	Calcium iodate
Chromium	0.2 mg	Chromium acetate

[a] Per kg of finished product

TABLE G3
Nutrient Composition of NTP-2000 Rat and Mouse Ration

Nutrient	Mean ± Standard Deviation	Range	Number of Samples
Protein (% by weight)	14.16 ± 0.91	12.9 — 16.2	17
Crude fat (% by weight)	8.34 ± 0.40	7.50 — 8.80	17
Crude fiber (% by weight)	9.38 ± 0.73	7.80 — 10.3	17
Ash (% by weight)	4.95 ± 0.17	4.53 — 5.30	17
Amino Acids (% total diet)			
Arginine	0.752 ± 0.05	0.69 — 0.80	4
Cystine	0.22 ± 0.01	0.22 — 0.24	4
Glycine	0.712 ± 0.02	0.69 — 0.74	4
Histidine	0.345 ± 0.01	0.33 — 0.35	4
Isoleucine	0.548 ± 0.03	0.51 — 0.59	4
Leucine	1.107 ± 0.03	1.07 — 1.13	4
Lysine	0.728 ± 0.06	0.65 — 0.79	4
Methionine	0.425 ± 0.03	0.40 — 0.46	4
Phenylalanine	0.625 ± 0.02	0.60 — 0.64	4
Threonine	0.542 ± 0.03	0.52 — 0.59	4
Tryptophan	0.132 ± 0.01	0.12 — 0.15	4
Tyrosine	0.430 ± 0.02	0.40 — 0.46	4
Valine	0.648 ± 0.04	0.61 — 0.69	4
Essential Fatty Acids (% of total diet)			
Linoleic	3.95 ± 0.41	3.59 — 4.54	4
Linolenic	0.295 ± 0.06	0.21 — 0.35	4
Vitamins			
Vitamin A (IU/kg)	6,106 ± 1,800	3,060 — 9,460	18
Vitamin D (IU/kg)	1,000[a]		
α-Tocopherol (ppm)	84.06 ± 15.25	62.2 — 105.0	5
Thiamine (ppm)	10.52 ± 2.07	7.30 — 15.0	18
Riboflavin (ppm)	5.9 ± 1.46	4.20 — 7.70	4
Niacin (ppm)	75.22 ± 2.55	72.8 — 78.8	4
Pantothenic acid (ppm)	25.02 ± 3.38	21.4 — 29.1	4
Pyridoxine (ppm)	10.65 ± 2.29	6.9 — 12.4	5
Folic acid (ppm)	1.70 ± 0.41	1.46 — 2.32	4
Biotin (ppm)	0.394 ± 0.21	0.277 — 0.704	4
Vitamin B_{12} (ppb)	108.6 ± 70.4	47.4 — 174.0	4
Choline (ppm)	3,000 ± 216	2,700 — 3,200	4
Minerals			
Calcium (%)	0.94 ± 0.06	0.84 — 1.02	17
Phosphorus (%)	0.58 ± 0.03	0.50 — 0.64	17
Potassium (%)	0.667 ± 0.03	0.629 — 0.691	4
Chloride (%)	0.352 ± 0.04	0.300 — 0.392	4
Sodium (%)	0.196 ± 0.02	0.160 — 0.212	4
Magnesium (%)	0.198 ± 0.01	0.185 — 0.213	4
Sulfur (%)	0.174 ± 0.02	0.153 — 0.205	4
Iron (ppm)	156.5 ± 16.1	135.0 — 172.0	4
Manganese (ppm)	52.20 ± 4.70	46.2 — 56.0	4
Zinc (ppm)	51.15 ± 5.24	45.0 — 57.5	4
Copper (ppm)	6.345 ± 0.92	5.38 — 7.59	4
Iodine (ppm)	0.546 ± 0.021	0.39 — 0.84	4
Chromium (ppm)	0.85 ± 0.77	0.33 — 2.0	4
Cobalt (ppm)	0.65 ± 0.90	0.20 — 2.0	4

[a] From formulation

TABLE G4
Contaminant Levels in NTP-2000 Rat and Mouse Ration[a]

	Mean ± Standard Deviation[b]	Range	Number of Samples
Contaminants			
Arsenic (ppm)	0.28 ± 0.09	0.1 — 0.4	16
Cadmium (ppm)	0.05 ± 0.01	0.04 — 0.07	16
Lead (ppm)	0.20 ± 0.10	0.06 — 0.4	16
Mercury (ppm)	<0.02		16
Selenium (ppm)	0.22 ± 0.11	0.10 — 0.50	16
Aflatoxins (ppm)	<5.00		16
Nitrate nitrogen (ppm)[c]	8.49 ± 4.59	2.30 — 17.7	16
Nitrite nitrogen (ppm)[c]	1.56 ± 1.27	0.30 — 4.00	16
BHA (ppm)[d]	1.30 ± 1.33	0.05 — 5.0	16
BHT (ppm)[d]	1.05 ± 1.18	0.0 — 5.00	16
Aerobic plate count (CFU/g)	193,429 ± 293,221	10 — 1,000,000	16
Coliform (MPN/g)	40 ± 104	0 — 420	16
Escherichia coli (MPN/g)	<10		16
Salmonella (MPN/g)	Negative		16
Total nitrosoamines (ppb)[e]	6.64 ± 2.63	3.20 — 11.20	16
N-Nitrosodimethylamine (ppb)[e]	4.58 ± 2.06	1.20 — 9.40	16
N-Nitrosopyrrolidine (ppb)[e]	2.06 ± 0.90	1.00 — 3.60	16
Pesticides (ppm)			
α-BHC	<0.01		16
β-BHC	<0.02		16
γ-BHC	<0.01		16
δ-BHC	<0.01		16
Heptachlor	<0.01		16
Aldrin	<0.01		16
Heptachlor epoxide	<0.01		16
DDE	<0.01		16
DDD	<0.01		16
DDT	<0.01		16
HCB	<0.01		16
Mirex	<0.01		16
Methoxychlor	<0.05		16
Dieldrin	<0.01		16
Endrin	<0.01		16
Telodrin	<0.01		16
Chlordane	<0.05		16
Toxaphene	<0.10		16
Estimated PCBs	<0.20		16
Ronnel	<0.01		16
Ethion	<0.02		16
Trithion	<0.05		16
Diazinon	<0.10		16
Methyl parathion	<0.02		16
Ethyl parathion	<0.02		16
Malathion	0.12 ± 0.14	0.02 — 0.60	16
Endosulfan I	<0.01		16
Endosulfan II	<0.01		16
Endosulfan sulfate	<0.03		16

[a] CFU=colony-forming units; MPN=most probable number; BHC=hexachlorocyclohexane or benzene hexachloride
[b] For values less than the limit of detection, the detection limit is given as the mean.
[c] Sources of contamination: alfalfa, grains, and fish meal
[d] Sources of contamination: soy oil and fish meal
[e] All values were corrected for percent recovery.

APPENDIX H
SENTINEL ANIMAL PROGRAM

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SENTINEL ANIMAL PROGRAM

METHODS

Rodents used in the Carcinogenesis Program of the National Toxicology Program are produced in optimally clean facilities to eliminate potential pathogens that may affect study results. The Sentinel Animal Program is part of the periodic monitoring of animal health that occurs during the toxicologic evaluation of chemical compounds. Under this program, the disease state of the rodents is monitored via serology on sera from extra (sentinel) animals in the study rooms. These animals and the study animals are subject to identical environmental conditions. The sentinel animals come from the same production source and weanling groups as the animals used for the studies of chemical compounds.

Serum samples were collected from randomly selected rats and mice during the 2-year studies. Blood from each animal was collected and allowed to clot, and the serum was separated. The samples were processed appropriately and sent to Microbiological Associates, Inc. (Bethesda, MD), for determination of antibody titers. The laboratory serology methods and viral agents for which testing was performed are tabulated below; the times at which blood was collected during the studies are also listed.

Method and Test	Time of Analysis
RATS	
ELISA	
Mycoplasma arthritidis	Study termination
Mycoplasma pulmonis	Study termination
PVM (pneumonia virus of mice)	1 week or 1 month; 7, 13, or 19 months; study termination
RCV/SDA (rat coronavirus/ sialodacryoadenitis virus)	1 week or 1 month; 7, 13, or 19 months; study termination
Sendai	1 week or 1 month; 7, 13, or 19 months; study termination
Immunofluorescence Assay	
PVM	13 months
RCV/SDA	13 months
Hemagglutination Inhibition	
H-1 (Toolan's H-1 virus)	1 week or 1 month; 7, 13, or 19 months; study termination
KRV (Kilham rat virus)	1 week or 1 month; 7, 13, or 19 months; study termination

MICE

ELISA

Ectromelia virus	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
EDIM (epizootic diarrhea of infant mice)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
GDVII (mouse encephalomyelitis virus)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
LCM (lymphocytic choriomeningitis virus)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
Mouse adenoma virus-FL	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
MHV (mouse hepatitis virus)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
M. arthritidis	Study termination
M. pulmonis	Study termination
PVM	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
Reovirus 3	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
Sendai	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination

Immunofluorescence Assay

GDVII	12 or 13 months; 18 or 19 months
LCM	12 or 13 months; 18 or 19 months; study termination
Mouse adenoma virus-FL	12 or 13 months
MCMV (mouse cytomegalovirus)	Study termination
MHV	Study termination
Parvovirus	Study termination
Polyoma virus	Study termination
Reovirus 3	6 or 7 months

Hemagglutination Inhibition

K (papovavirus)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
MVM (minute virus of mice)	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination
Polyoma virus	Study initiation or 3 weeks; 6 or 7 months; 12 or 13 months; 18 or 19 months; study termination

RESULTS

At the end of the studies, two rats and one mouse had positive titers for *M. arthritidis*, and one mouse had a positive titer for MHV. Further evaluation of samples positive for *M. arthritidis* by immunoblot and Western blot procedures indicated that the positive titers may have been due to cross reaction with antibodies of nonpathogenic *Mycoplasma* or other agents. Only sporadic samples were positive and there were no clinical findings or histopathologic findings of *M. arthritidis* infection in animals with positive titers. Further evaluation of the sample positive for MHV by Western blot analysis was negative for specific antibodies. Accordingly, *M. arthritidis*- and MHV-positive titers were considered to be false positives.