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# CONTINUOUS EXPOSURE OF RODENTS TO $10^8$ PULSES OF ELECTROMAGNETIC RADIATION

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Research was conducted according to the principles enunciated in the "Guide for Laboratcry Animal Facilities and Care," prepared by the National Academy of Sciences - National Research Council.

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## FOREWORD
(Nontechnical summary)

It has been reported that electromagnetic pulses (EMP) produced by a nuclear explosion could damage electronic test equipment. To test the extent of such effects, a number of simulators of such electromagnetic environments have been constructed with consequent exposures of workers to these fields. The present study was designed to determine if such exposures presented a potential hazard and to develop safety standards.

The AFRRI EMP simulator which provided five pulses per second for $10^8$ pulses and a peak electric field strength of 447 kV/m with a 5-nsec rise time and 550-nsec 1/e fall time was utilized in the present experiment. This represented a condition in excess of that normally encountered by humans who operate EMP facilities.

At the time of writing this report, the rodents were 1 year of age and had approached approximately one-half of their life-span. For the last 38 weeks of this time they were exposed to $10^8$ electromagnetic pulses. No apparent acute injuries were demonstrated based on blood cell production and concentration, blood chemistry, chromosomal aberration, histology, leukemia and mammary tumor determinations.

It appears that one could safely predict that humans exposed under similar conditions would show no acute injurious biological effects. It is difficult to predict at the present time whether exposure to EMP could increase the incidence of malignancies in personnel working in an electromagnetic environment. This must await further studies during the second half of life of the experimental rodents. However, the negative results obtained from the leukemia-prone mice, the absence of damage to bone

marrow cell chromosomes and of abnormalities in the progeny of EMP exposed pregnant rats make the possibility for an increased incidence of malignancies less likely.

## ABSTRACT

The present experiment tests the hypothesis that rapid rises and falls of electric and magnetic fields would adversely affect vital ionic and electrochemical processes at the molecular level in biological systems. Rodents were exposed to $10^8$ pulses from the AFRRI electromagnetic pulse (EMP) simulator which provides five pulses per second with a peak electric field intensity of 447 kV/m, a 5-nsec rise time and 550-nsec 1/e fall time.

When results obtained from EMP exposed animals were compared with those from controls no changes were observed in the number and production of rat bone marrow cells, the incidence in chromosomal aberrations in mitotic bone marrow cells, the concentration of circulating neutrophils, lymphocytes and erythrocytes. Reticulocytes appear to have been elevated and platelets decreased; however, both counts remained within acceptable levels.

No incidence of mammary tumors was observed in the female Sprague-Dawley rats. In leukemia-prone AKR/J male mice, leukemia did not occur earlier in EMP exposed animals, nor was the fraction of leukemic mice greater in this group when compared with the nonirradiated control mice.

The present data do not indicate an acute biological hazard to rodents from EMP exposures. The possibility for the development of late effects and malignancies will only be determined during the second half of the rodents life-span. The negative results of the present study appear to make such occurrences less likely.

# I. INTRODUCTION

It has been known that the energy contained in electromagnetic pulses (EMP) produced by nuclear explosions could damage electronic test equipment.[2] To test these effects, a number of simulators of such electromagnetic environments have been constructed. This necessitated the exposure of personnel during routine operation of these EMP simulators.[1,6] These exposures presented a potential hazard to the workers in the field and suggested the proposal of safety standards.[3] However, the absence of sufficient biological data questioned the validity of these standards.[11]

Theoretical considerations of the events caused by the coupling of biological systems with electromagnetic fields suggest that no hazard exists from current flow and thermal heating for a body insulated from the ground.[2] However, at the molecular level in biological systems there exist numerous vital ionic and electrochemical processes which could be seriously altered by rapid rises and falls of electric and magnetic fields. If such effects of EMP simulators exist they could acutely affect biological systems with high cellular turnover such as the hematopoietic and the reproductive systems and possibly introduce somatic changes which could result in fatal disease later in life. In addition, a transient derangement of the neurotransmitting apparatus cannot be excluded.[7]

At present, there exist few reports dealing with the effects of EMP on biological systems. Some of these reports indicated a possible biological effect,[5,8-10] while others detected no changes in enzyme or mammalian system.[6,7,13]

The present experiment was designed to measure the effects of exposing rodents to an EMP simulator. The biological tests dealt with mammalian systems of continuous

high cellular turnover and with leukemia-prone mice. Exposures to approximately $10^8$ electromagnetic pulses during 38 weeks did not induce leukemia at an earlier time in AKR/J male mice nor did it demonstrate any acute biological hazard.

## II. METHODS

EMP exposure. The AFRRI EMP generator employed in this study has been previously described in detail.[2] Basically, it provided five pulses per second with a peak electric field intensity of 447 kV/m. The system specifications are as follows:

| | |
|---|---|
| transmission line: | parallel plates, 122 cm wide, 10 m long, 56 cm separation, 95 Ω impedance (with animal load and in shielded room) |
| power supply: | two ± 150 kV dc supplies |
| energy storage capacitors: | four 5-nF tubular capacitors, two series banks of two parallel capacitors; total capacitance in banks 5 nF |
| spark gaps: | triggered, pressurized switch |
| pulse shape: | double exponential |
| rise time: | 4-5 nsec (10-90 percent) |
| fall time: | 550 nsec (to 1/e of peak) |
| peak field strength: | 10-500 kV/m |
| pulse repetition rate: | up to 7 pps; single shot |
| energy per pulse: | 160 joules maximum |
| field power density: | 66.3 kW/cm$^2$ peak (at 500 kV/m) |
| system line impedance: | 95 Ω |
| spectral content: | double exponential. |

Biological parameters were periodically assayed in exposed and nonexposed animals at appropriate intervals during the nearly continuous EMP irradiation. Exposures were interrupted daily for only 1 hour for biological sampling and animal care. Food and water were supplied ad libitum to 700 male and 40 female Sprague-Dawley rats and to 100 male AKR/J mice.

Biological tests.

A. Bone marrow. A total number of 600 male Sprague-Dawley rats were utilized for the determination of bone marrow cellularity and possible chromosomal aberrations every 2 weeks after the onset of initial exposure to the EMP irradiation. One-half of these animals were placed into the EMP field, while the other half served as nonirradiated controls. The details of the procedures for the measurement of bone marrow cellularity were described previously.[11] For the study of possible chromosomal aberrations, bone marrow cells were arrested in metaphase with colchicine in vitro, fixed, prepared and placed on slides for histological studies in accordance with the methods described by Tjio and Whang.[14]

B. Blood. To determine the concentration of erythrocytes, leukocytes, neutrophils, lymphocytes, reticulocytes and platelets per $mm^3$ of blood, peripheral blood samples were obtained from 20 irradiated male rats and from an equal number of nonexposed controls as previously described.[11]

C. Histology. Histological studies as well as postmortem examinations were performed on the animals sacrificed for bone marrow assays.

D. Mammary tumors. Twenty female rats were continuously exposed and observed for possible development of mammary tumors and were compared with an equal number of nonexposed animals.

E. Leukemia. Approximately 33 weeks after the onset of EMP exposure, the 42 surviving AKR/J leukemia-prone male mice which had been subjected to $8.6 \times 10^7$ pulses and 24 surviving nonirradiated controls were sacrificed. Histopathological studies were conducted to test for the presence of leukemia.

Statistics. The t-test was used to determine the significance of differences between groups.

## III. RESULTS

Figure 1 represents the total number of nucleated bone marrow cells and the number of mitotic rubricytes and myelocytes in Sprague-Dawley rats exposed to $10^8$ electromagnetic pulses and in their nonexposed controls. In all instances EMP irradiation did not alter the bone marrow cell concentration. Furthermore, there were no changes in the rate of cellular production as represented by the number of mitotic cells.

It appears that the concentration of circulating reticulocytes is greater in most instances in the irradiated rats (Figure 2). At the same time the concentration of circulating red cells is the same in both groups throughout the 38 weeks of study (Figure 3). With the exception of some isolated instances during the early weeks of this study there were no differences in the peripheral concentration of leukocytes (Figure 4). A similar picture is presented by the circulating neutrophils (Figure 5). Although during the early weeks the number of circulating lymphocytes in the EMP

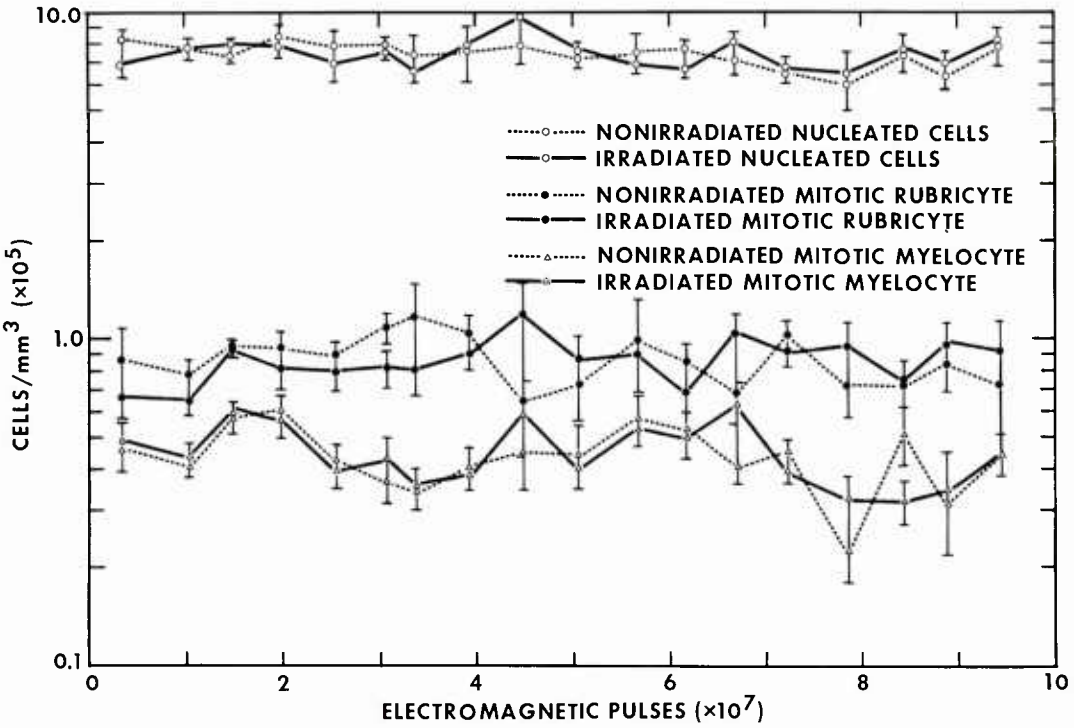


Figure 1. Nucleated cells from the bone marrow of rat femurs during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

exposed rats appeared to be greater as compared with that of the nonexposed animals, no such trend is noted beyond the 12th week of irradiation (Figure 6). It is of interest to note that the number of platelets appears to decrease in the irradiated animals when compared with that of the controls beyond the 6th week of EMP exposure (Figure 7).

Table I clearly indicates that exposure to EMP does not induce an earlier onset of spontaneous AK leukemia. There were no significant differences in the number of leukemic mice between the two groups, nor in their thymic or splenic weights.

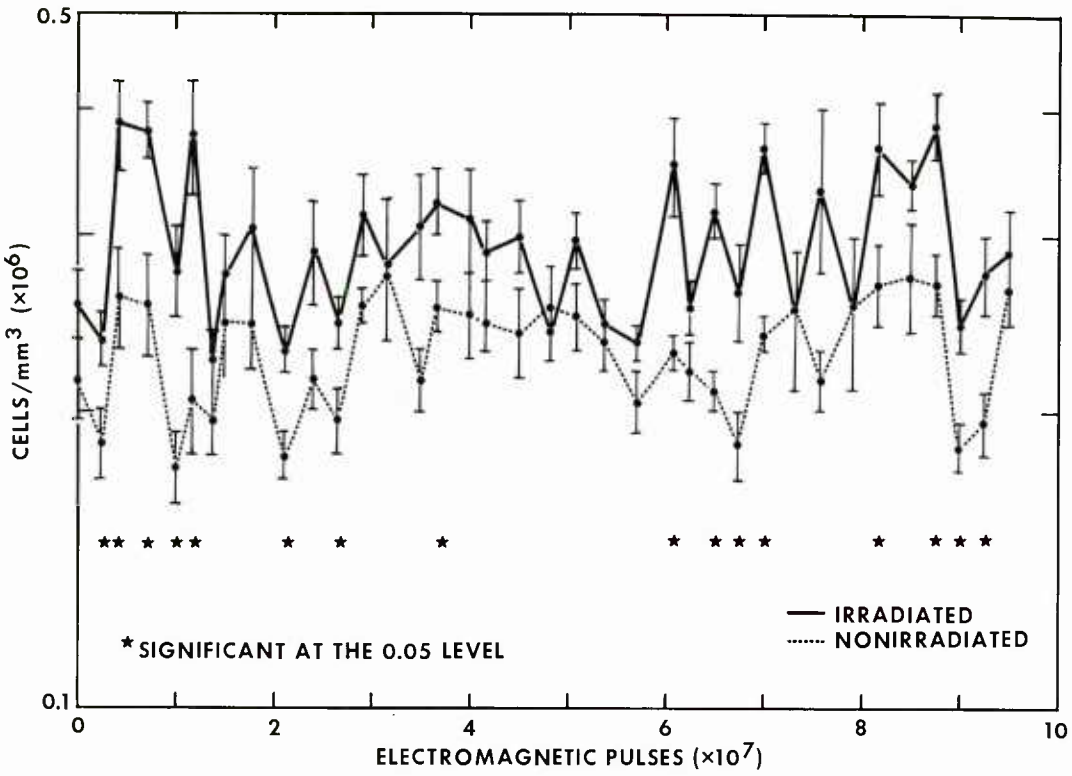


Figure 2. Reticulocytes in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

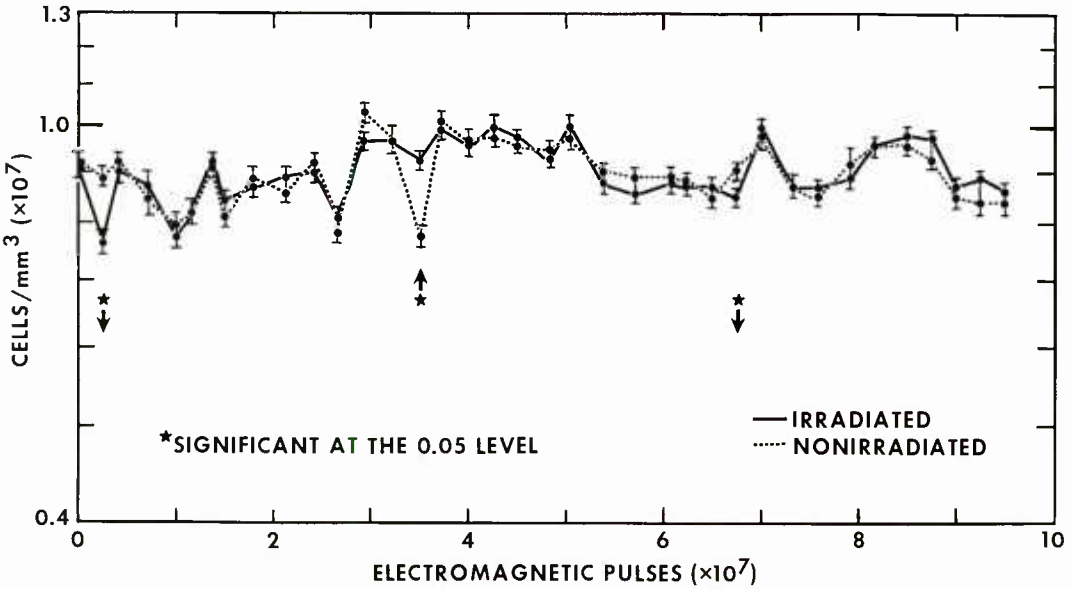


Figure 3. Red cells in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

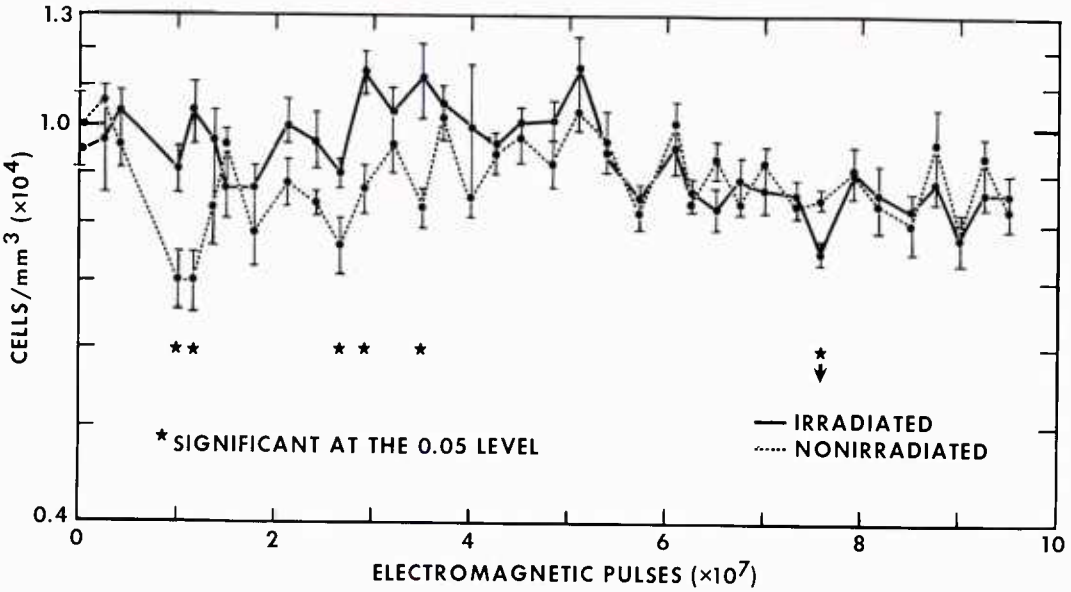


Figure 4. White cells in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

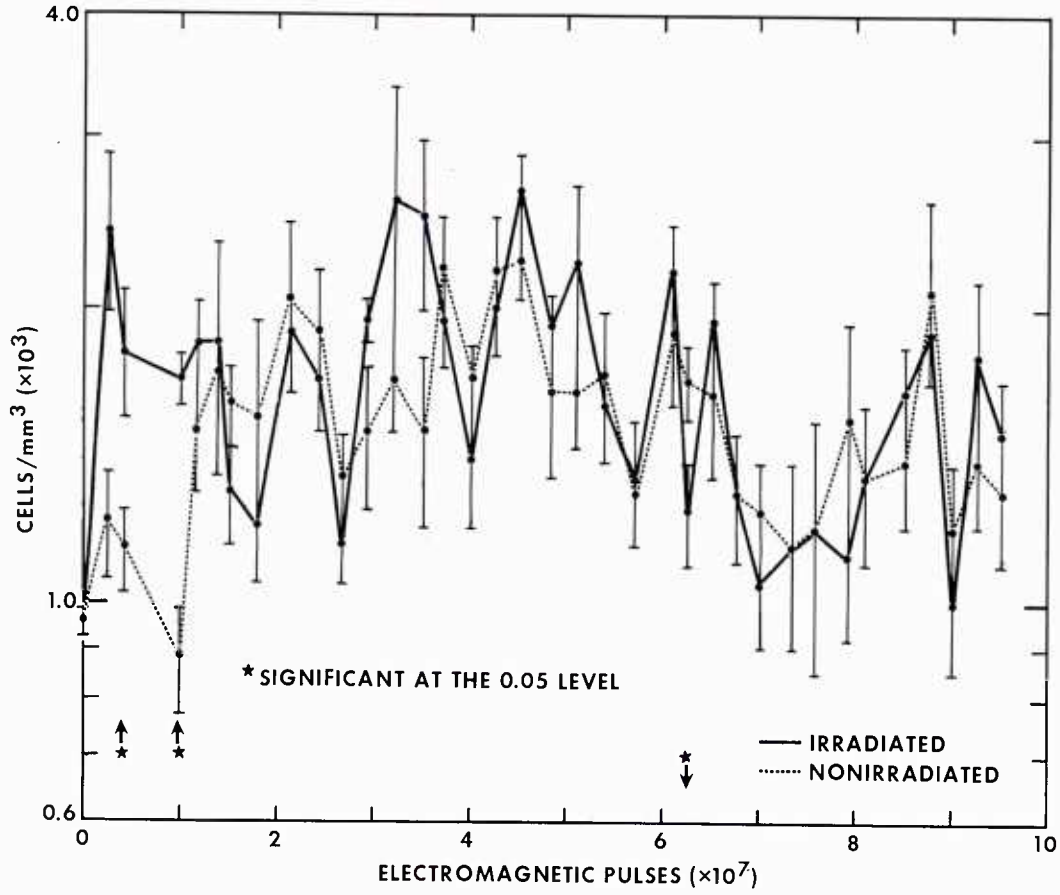


Figure 5. Segmented neutrophils in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

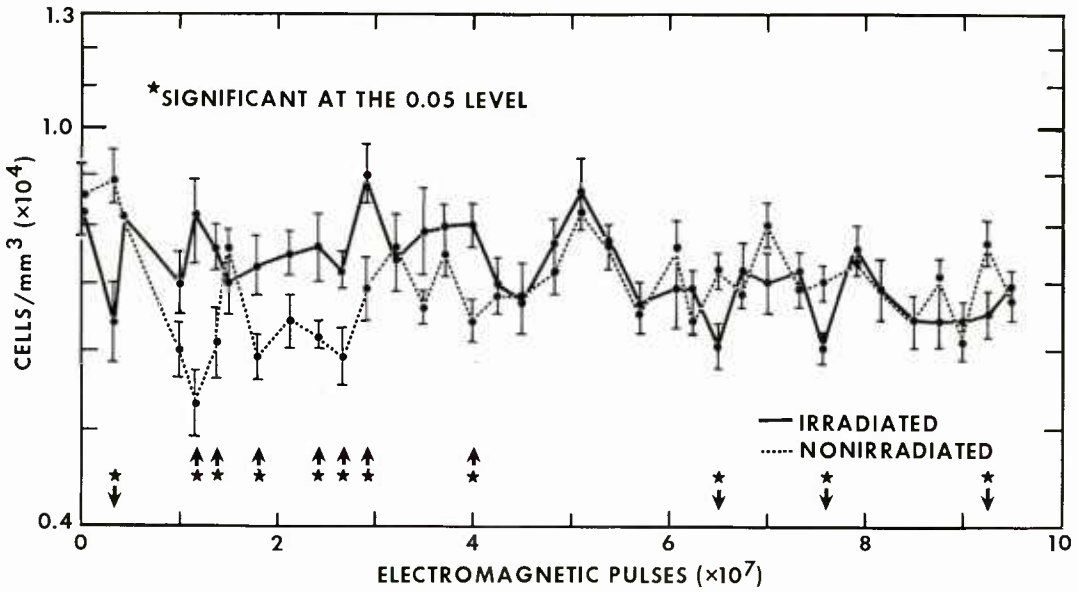


Figure 6. Lymphocytes in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

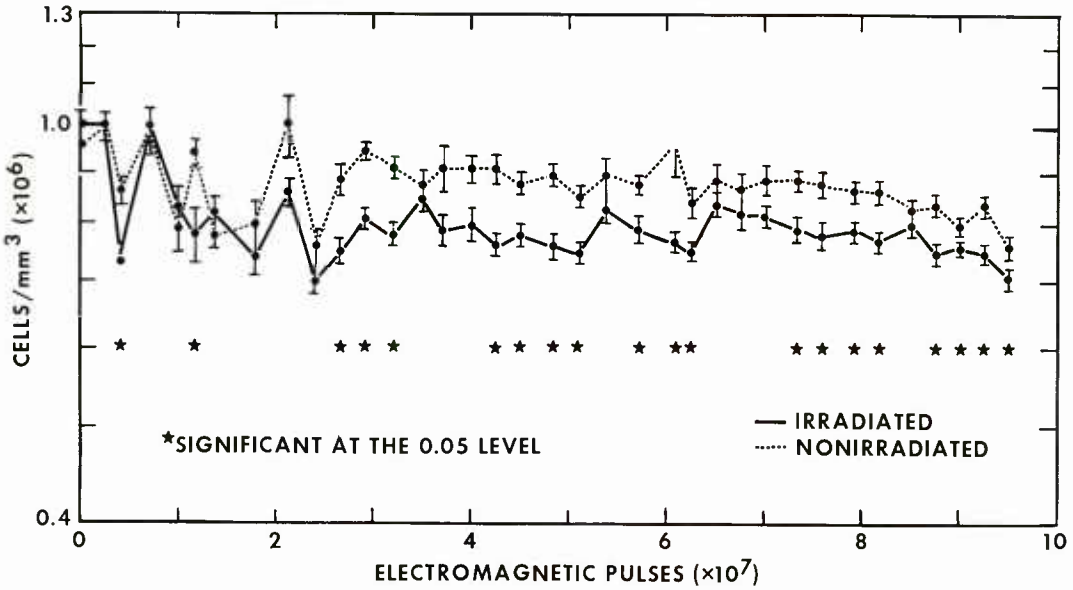


Figure 7. Platelets in peripheral blood from rats during 38 weeks of EMP exposure. Each point shows a mean value with the associated standard error.

Table I. Incidence of Spontaneous Leukemia in AKR/J Male Mice

| | Group | |
|---|---|---|
| | Nonirradiated | Irradiated |
| Electromagnetic pulses (33 wk) | 0 | $8.6 \times 10^7$ |
| Surviving fraction | 24/50 | 42/50 |
| Leukemic fraction | 11/24 | 9/42 |
| Thymus weight (mg) | 165 ± 39 | 130 ± 27 |
| Spleen weight (mg) | 181 ± 73 | 115 ± 23 |
| WBC (cells/$mm^3$) | 9500 ± 1000 | 10,000 ± 900 |

At 1 year of age and after exposure to $10^8$ electromagnetic pulses no mammary tumors have been observed in the experimental female rats and in their nonirradiated controls.

As may be seen from Table II, no injuries to chromosomes were induced in the irradiated rats.

Table II. Chromosome Aberrations in Rats Exposed to $10^8$ Electromagnetic Pulses During 38 Weeks

| Group | Number of rats | Number of cells | Number of aberrations |
|---|---|---|---|
| Nonirradiated | 40 | 2,000 | 2 |
| Irradiated | 40 | 2,000 | 2 |

## IV. DISCUSSION

The results described in the present report were obtained from rodents which at 1 year of age have approached approximately half of their life-span. For the last 38 weeks of this time they were exposed to $10^8$ electromagnetic pulses. Analysis of the results clearly supports the contention previously expressed for rodents exposed to one-half the number of electromagnetic pulses,[11] that no acute biological injuries are detected.

Although the increases noted for the reticulocytes in irradiated rats appear to be statistically significant, they do not represent a biological hazard. As discussed previously,[11] since no concurrent increase in red cell production is seen, as determined by $^{59}Fe$ uptake and by the number of bone marrow mitotic cells observed and no increase in the peripheral red cell concentration is noted, this condition may indicate a slight delay in the conversion of reticulocytes into erythrocytes. Most likely it does not represent a functional disturbance.

Although the concentration of platelets is consistently lower in irradiated rats beyond the 6th week of exposure, it is still quite within acceptable normal levels and again represents no functional problem.

It was of concern in the present study to determine whether exposure of personnel to an EMP field could trigger the onset of leukemia, particularly in leukemia-prone individuals. Such possibilities are indicated in rodents exposed to ionizing radiation and subsequently subjected to experimental bleeding.[4] The AKR/J mice selected for the present study spontaneously develop leukemia between 6-12 months of age.[12] It was proposed that if EMP exposure were inducive to leukemia development,

it should be observable at an earlier time in the irradiated mice. However, the results do not demonstrate an earlier onset of the disease in EMP exposed mice. At the time of sacrifice, when the mice had been subjected to $8.6 \times 10^7$ electromagnetic pulses, no differences were observed between them and their nonirradiated controls. It is therefore doubtful if exposure to EMP induces an accelerated onset of leukemia in animals particularly prone to this disease.

It is difficult to predict from the present data whether exposure to EMP could increase the incidence of malignancies in personnel working in an electromagnetic field. This must await further studies during the second half of life of the experimental rodents. However, the negative results obtained from the leukemia-prone mice and the absence of excessive chromosome aberrations shown here as well as the normalcy of the neonatal progeny from EMP exposed pregnant rats reported previously[11] make the possibility for an increased incidence of malignancies less likely.

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13. ABSTRACT

The present experiment tests the hypothesis that rapid rises and falls of electric and magnetic fields would adversely affect vital ionic and electrochemical processes at the molecular level in biological systems. Rodents were exposed to $10^8$ pulses from the AFRRI electromagnetic pulse (EMP) simulator which provides five pulses per second with a peak electric field intensity of 447 kV/m, a 5-nsec rise time and 550-nsec 1/e fall time.

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