NsG-237

EFFECTS OF LOW LEVEL, LOW FREQUENCY ELECTRIC FIELDS ON HUMAN REACTION TIME

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N68-16115
(ACCESSION NUMBER)
13
(PAGES)
CR-92700
(NASA CR OR TMX OR AD NUMBER)
(THRU)
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(CODE)
04
(CATEGORY)
FACILITY FORM 602

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Several investigators have reported effects of low level, natural and artificial electromagnetic fields on human behavior. Friedman and co-workers compared geomagnetic activity with psychiatric hospital admissions[1], and later reported effects of artificial low frequency (0.1, 0.2 Hz) magnetic fields on simple reaction time[2]. Reiter[3] reported effects of atmospheric electricity on human simple reaction time and Konig and co-workers[4] experimented with a similar apparatus and paradigm using low frequency (3, 10 Hz) artificial electric fields. Simple reaction time is a standard, uncomplicated measure of an organism's ability to organize a response to its environment and therefore appropriate for experimental studies with weak electromagnetic fields.

Although the reported effects are small, they should be demonstrable independently of any contamination by sensitivity of the experimental method to subject populations or changing methods of testing. It should be feasible to demonstrate a valid null hypothesis. Flaws in experimental methods may have occurred, as for instance in Friedman's use of the counter balance technique[2]. From a previous experiment involving 30 subjects, he selected 12 and inserted their reaction time data in the counter balance experiment and collected additional data to complete the balanced conditions. Without random selection or complete rejection of the earlier data, a bias can be introduced.

There is the possibility in both Konig's[4] and Friedman's[2] studies that the effects noted were not due to the different frequencies used but to the presence of the field. In the present study of human reaction times (RT) at different electromagnetic field frequencies, care was taken to assure that the RT effects observed actually arose from the different frequencies applied. In addition, procedures were adopted as controls for individual differences, as well as to assure experiment sensitivity. These procedures are detailed below.

The sample consisted of 29 undergraduate male and female students aged 17 to 23 at the University of California, Los Angeles. Subjects were selected at random and screened for physical and mental aberrations; those under medication or with any history of recurrent illness were rejected. All but two completed the experiment.

The experimental apparatus that shaped the electric field consisted of two parallel metallic plates (71 cm x 91 cm) placed 53 cm apart. The long axis of these plates was vertically oriented. A chair placed between the plates positioned the subject. The lower edges of the plates were 15 cm above the chair seat. Earphones and a microswitch handgrip were provided to the subject for audio signal presentation and response. An electronic counter with a 1.0 μsec accuracy measured the subject's response time (data were recorded at 0.1 msec resolution). A two-pole single throw toggle switch controlled the audio and counter start signals. The time relations between the audio signal and start signal was checked by placing a resistor in series with the earphones and observing the start signal and resistor voltages on a dual trace oscilloscope. RC networks between the switches and counter inputs assured clean, fast rise time start-stop pulses to the counter. Each switch (toggle and microswitch) connected one RC network to a separate DC voltage source, generating the voltage pulse. A 1000 Hz square wave generator was used as a signal source for the earphones. The audio signal strength was kept constant and at a comfortable level. A clock and table of random numbers kept the average interval between tones at 15 sec with a small variation in the time of tone delivery. The clock face was marked with six adjacent 0.01 min intervals over which the tone delivery was varied, the exact variation determined by a table of random digits. A low frequency generator (Hewlett Packard 202A) with 2% dial accuracy energized the plates with 2.0 V RMS sinusoidal potential. The experimenter, oscillator, audio source, and counter were located in one room, while the subject was isolated in an adjacent room of approximately 23 m^2 floor area, devoid of apparatus except for the field plates, earphones, microswitch and chair. The room was dimly lit, and conventional air conditioning equipment controlled the temperature. The room was not provided with electromagnetic screening from sources outside the room.

Subjects were informed that their reaction times were to be measured in the presence of a weak electric field with not more than 2.0 V applied to the plates. It was explained that uniform RT performance was highly desirable to reduce data variance, and each subject was instructed to remain alert, leave his thumb on the microswitch button and depress it as soon as he heard an audio tone. The first tone was a warning, indicating the start of the experimental session, after which tones would be applied at random without forewarning cues and with short intervals between each. The subject was told that after each trial, a minimum rest period of 11 sec would follow to prevent fatigue. Termination of the experiment would be signaled by the assistant entering the room.

It has been shown that certain features of an experimental situation may cue the subjects as to what response may be desired[5]. Hence, in this study, data were collected by a research assistant unaware of the statistical hypothesis being tested, and not informed of the significance of the data nor allowed to reduce it for analysis until the whole experiment was completed. In addition, a partial double-blind technique was used, whereby the experimental conditions (e.g., the frequency of the electric field to be used and the time of presentation of audio tones) were established by a random process <u>after</u> the assistant isolated the subject. The moment of presentation of the audio tone was controlled by a clock and based on a table of random digits; the assistant was instructed to terminate the tone when the subject completed his or her response, as indicated by the counter used to measure RT.

To ensure that changes in reaction time were the result of the different frequencies being applied, the RTs were measured at different frequencies but with a constant field strength and sinusoidal electric field. Each subject was observed at two field frequencies. Only two frequencies were used to avoid further complexity in the situation. The normal scatter in RTs of different subjects was controlled by testing all subjects at two frequencies, but not necessarily at the same pair of frequencies. Use of the same frequency pair for all subjects was considered unreasonable, since there was not an <u>a priori</u> reason for the existence of unique frequencies best suited to each subject. A crude criterion for frequency selection was used based on each subject's RT: if his RT was fast, higher frequencies were used (12 and 6, for example); if his RT was slow, lower frequencies were used (6 and 2, for example). In subsequent data reduction, these two frequencies were classified HIGH and LOW. Alternative criteria were considered but discarded. Each subject attended two experimental sessions per day for 16 days, with 24 RT measurements at one frequency during the first session, and 24 at the second frequency during the second session. Collecting equal amounts of data on all 16 days controlled for day to day variations in each subject's RT, and any long term trend in RT performance that might be attributable to habituation (See Figure 2).

This 16-day period was divided into three parts. The first day was used to familiarize Ss with the apparatus and was not used as a formal test day. The sensitivity of the experimental method was tested for the next five days by collecting data with the fields off, unknown to the subjects. Data collection methods during this period were identical to later testing; all data were indexed by the randomization process later used to determine the order of frequency application (HEADS, TAILS). At the end of this 5-day period, two frequencies were selected for each subject in the 2 to 12 Hz range, and the experiment was run the remaining 10 days with the fields always present and at a constant strength. The amount of data collected with the field on was doubled to test repeatability of results. The order of these frequencies (HIGH or LOW first) was determined by a binary random event (coin toss). The order for a subject on a given day was randomized to eliminate any effect that might arise from always giving the HIGH first or the LOW first. Each session consisted of 24 RT measurements, with a 15-min interval between sessions. After the subject was seated, the plates were energized and there was a 5-min wait before the tones began. A warning tone signaled the subject that the experiment was to begin. The audio tones were presented at intervals of 15 ± 2 sec, the exact time of presentation being determined by a table of random digits. The interval was varied by ± 2 sec to provide the subject with an adequate rest period between tones and mask any unconscious bias of the research assistant. After 24 measurements which took 11 min, the subject left the room and 15 min later returned to repeat the experiment for 24 more measurements at the second frequency. The subject was never informed of the frequencies, or as to whether the plates were or were not energized. To reduce variability, it was made standard procedure to discard both sets of a subject's data if the difference in mean RT was greater than 50 msec. This precaution was taken because of the rare occurrence of extremely large changes in average RT performance between sessions (later observed to be as high as

100 msec average difference).

The data analyzed consisted of measurements on 29 students for the first 5 days of the experiment, and 27 students for days 6 through 15, as two dropped out for personal reasons. Since the first 3 RT measurements at each session were considered "warm-up" and discarded, this involved a total of 11,340 RT measurements, 5670 at the HIGH frequencies and 5670 at the LOW frequencies.

The data were analyzed with the aim of showing the effect of variability in RT performance within all experimental sessions on the results of the experiment. One session consisted of 21 measurements as the first 3 measurements were considered "warm-up" and discarded. Since the fastest RTs were assumed to have the least variability, the 21 RT measurements in every set of data were ranked in order of increasing magnitude; that is, the shortest RT was assigned rank 1, the next longest RT in magnitude rank 2, and so on. All the data in each of the four treatment classifications (HIGH, LOW, HEADS, TAILS) were averaged by ranks, starting with rank 1 and going to ranks 3, 6, 14, and 21. In total, 5 ranks were averaged. As we progressed from rank 1 to rank 3, all the data in ranks 1, 2 and 3 were included; likewise, when rank 6 was averaged, all the data from ranks 1 through 6 were included, and so on. In this way the data were cumulative by ranks.

When the field was off, the data were collected and processed in the same way as when the field was on: HEADS was used to select the HIGH frequency, and TAILS the low frequency. This assured parallel data collection and processing, allowing comparisons between the two conditions. The differences between the averages of the HIGHs and LOWs, and between the HEADS and TAILS were computed and plotted by rank. The result was two cumulative difference curves indexed by rank. At rank 21, the average difference is independent of ranking because the average is cumulative and all data from the lower ranks are included. The average difference at rank 1 represents the "best" or shortest daily responses, but only 1/21 of all data collected; the averaged difference at rank 14 represents the 14 fastest responses but only 14/21 of all data, and so on. Figure 1 summarizes these results. The dashed line shows reaction time difference sampled with the field on, the solid line with the field off. Negative values of RT difference represent reaction times slower at the high frequency than at the low. The flat, uniform slope of the two curves indicates that the outcome of the experiment, for the number of replications, was independent of the daily variation in performance. The "field off" result shows that the experimental method was sensitive and the null hypothesis valid. An artificial bias may be introduced by randomization if the random events do not occur as expected. The incidence of HEADS for both samples of data was close: 0.41 with fields off, 0.47 with fields on, and within the one sigma variation of the expected value (0.5).

To aid in experiment evaluation, all daily RT data were combined for the 27 subjects who completed the testing period and cumulative RT averages made from day 1 to day 5 (field off) and from day 6 to day 15 (field on) (see Figure 2). The first 5 days showed the expected trend in speed up of average response as the subjects adapted to the RT task. The last 10 days showed a trend of increased latency of average response, apparently due to boredom. As Figure 2 illustrates, there is a marked increase in average RT latency between days 5 and 6, not consistent with the observed trends in the data. The daily variance is also included in Figure 2 for completeness.

The usual test for the difference of two means with correlated observations, the "t" test having in this case 5669 degrees of freedom[6], was used to test the hypothesis that the mean RTs (rank 21) at the two field frequency conditions differed significantly. The standard error for the difference of the two means was 0.6 msec. The type two error was less than 0.05 for accepting the hypothesis that the RT means differed significantly at the two frequencies. The electric field RT data were then divided into the first 5 and the second 5 experimental days across all subjects. The average RT differences at rank 21 were -1.2 and -1.9 msec respectively, in close agreement with the overall experimental value -1.6 msec and within the one sigma variation (0.6 msec).

The experimental results indicate that low level, low frequency electric fields can affect human reaction time performance. The experimental design used emphasized that the effects are frequency sensitive and not due merely to the presence of the field. The effects are quite subtle, however, and demand high sensitivity of method for reliable evaluation. To substantiate the results of this study, further experiments are being conducted using other behavioral responses as the experimental end points.

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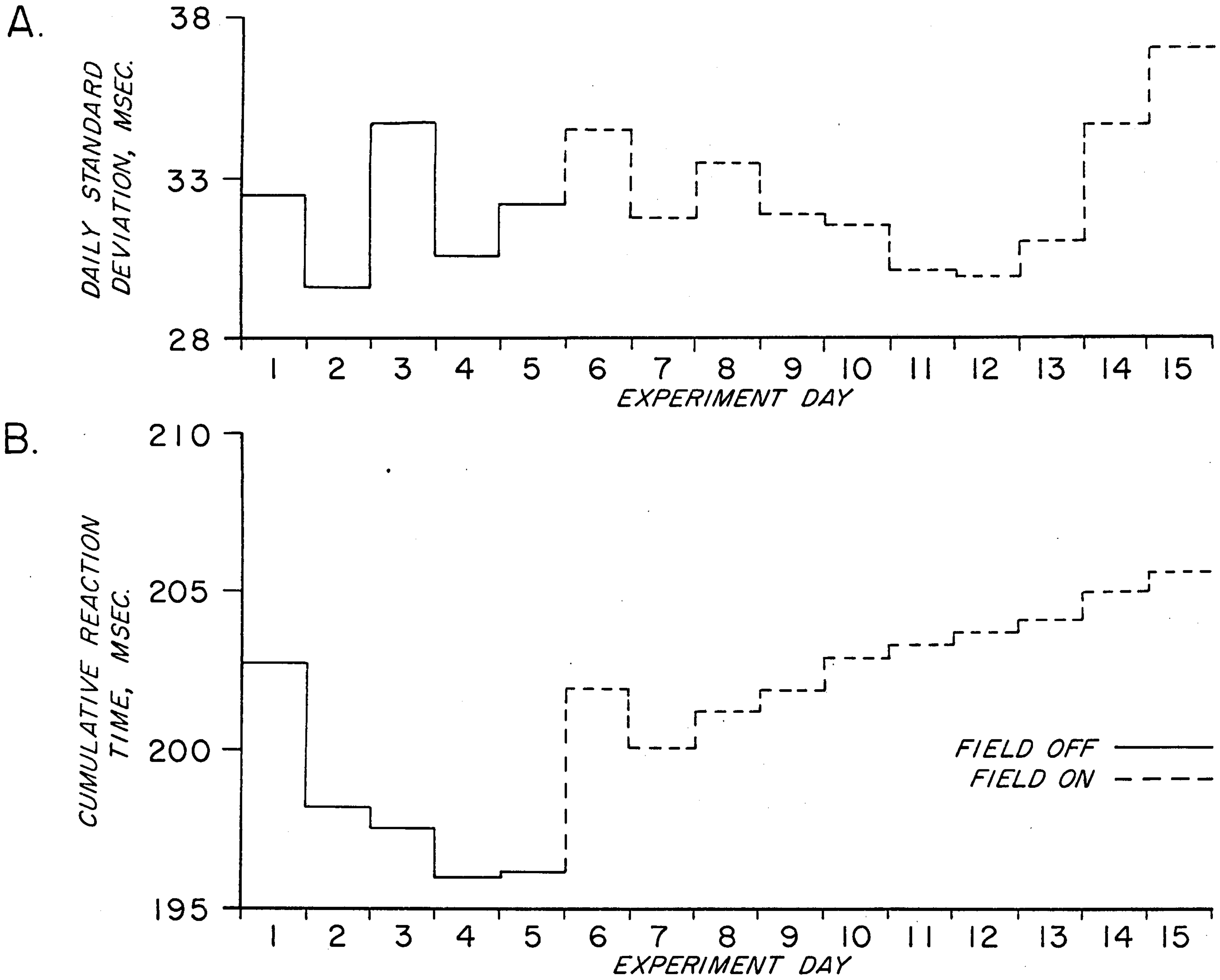
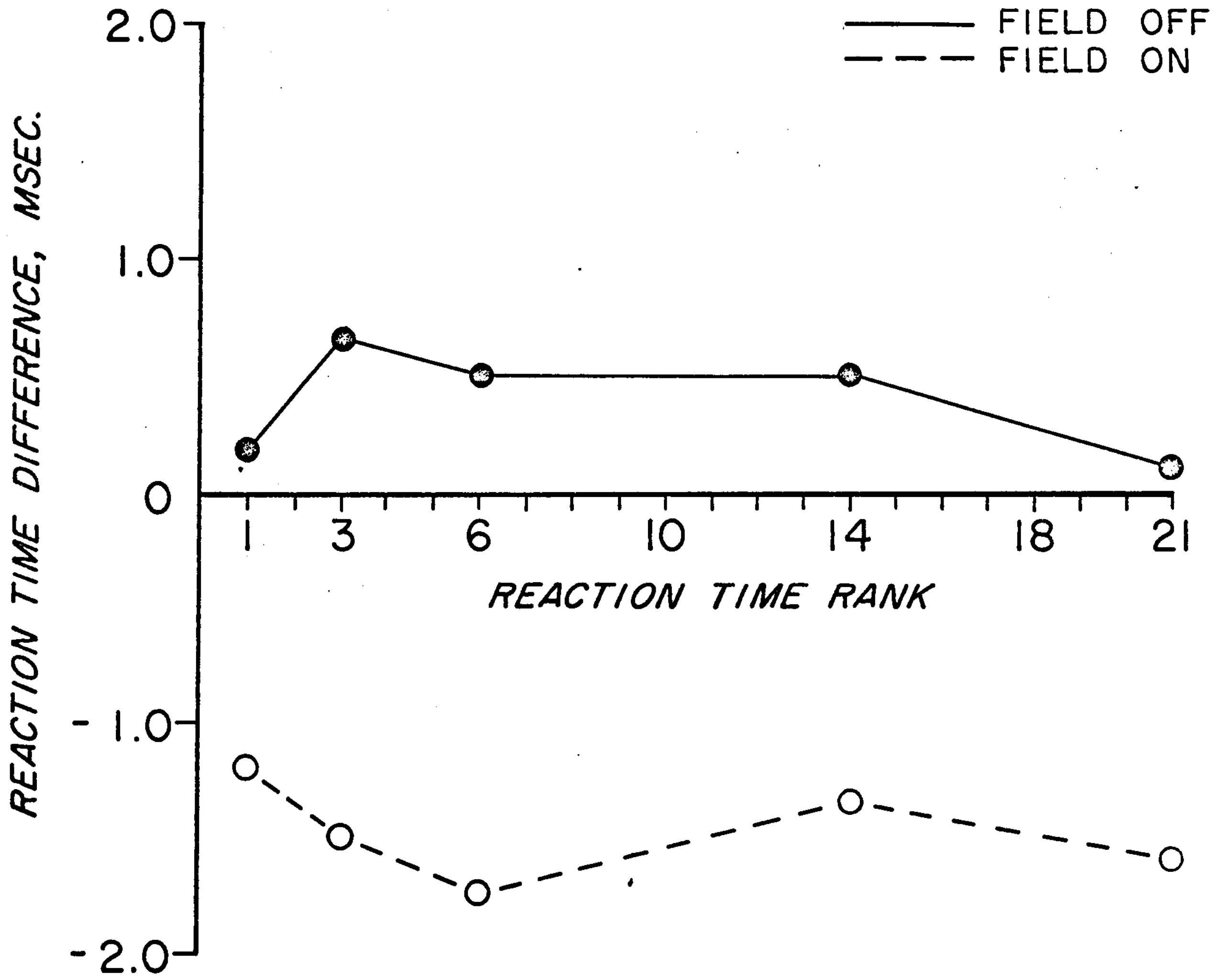
Figure Legends

Fig. 1. Cumulative reaction time differences across all subjects in order of increased latency of daily response. Solid curve shows the result of 6,048 measurements from 29 subjects ($\overline{RT}$ Tail - $\overline{RT}$ Head) in no electric field. Dashed curve shows the results of 11,340 measurements from 27 subjects with random application of two field frequencies ($\overline{RT}$ Low - $\overline{RT}$ High).

Fig. 2. A. Daily standard deviation of reaction time performance in all subjects.

B. Cumulative daily reaction time performance across 27 subjects from day 1 to 5 and from day 6 to 15. Each experimental day 1134 measurements were taken.


A.
38
33
28
DAILY STANDARD DEVIATION, MSEC.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EXPERIMENT DAY
B.
210
205
200
195
CUMULATIVE REACTION TIME, MSEC.
FIELD OFF
FIELD ON
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EXPERIMENT DAY


FIELD OFF
FIELD ON
REACTION TIME DIFFERENCE, MSEC.
2.0
1.0
0
- 1.0
- 2.0
1
3
6
10
14
18
21
REACTION TIME RANK

Acknowledgements

This study was supported by the Air Force Office of Scientific Research, under Contract No. AF 49(638)-1387 and the National Aeronautical Space Administration, under Grant No. NsG 237-62, and the Advanced Research Project Agency of the Department of Defense monitored by U. S. Army Medical Research and Development Command under Contract No. OADA 17-67-C-7124.

The interest and advice of Dr. John D. French, Dr. W. Ross Adey, and Mr. Raymond T. Kado are gratefully acknowledged.