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ANALYSIS OF BASELINE AND GEMINI FLIGHT GT-7 EEG DATA WITH SPECIFICATION OF ON-LINE COMPUTING REQUIREMENTS

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1. Introduction

re than 90 years ago, continuous oscillations in potential differences were first recorded across the scalp of man (Caton, 1875). These oscillations were called the electroencephalogram by Berger (1929), who observed the broad relationship between regularity of these waves and closing the eyes. These early findings led to enthusiastic endeavors to relate the EEG to finer aspects of consciousness. Disillusionment followed rapidly in an era where evaluation of the records rested on visual inspection. Their inherent complexity has challenged the investigator to seek evidence of their patterning through the use of increasingly sophisticated mathematical analyses (Grey Walter, 1950; Siebert et al., 1959; Burch, 1955; Adey and Walter, 1963; Walter and Adey, 1963, 1965; Adey, 1965). The power of spectral and other times series analyses (Blackman and Tukey, 1959), used in conjunction with the modern digital computer, has made it feasible to test notions of basic interrelations between EEG patterns and specified behavioral acts, including learned performances (Walter, Rhodes and Adey, 1965).

Nevertheless, widespread doubts have persisted that the EEG would ever be established as having a basis in the transaction and recall of information in cerebral systems, and that it, in fact, might be merely a noise therein. Moreover, the difficulties in its acquisition with older

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transducing techniques in inexperienced hands lent credence to the view that it would be impractical to rely on it as a physiological monitor in the aerospace environment. Developments in the past five years have essentially demolished these lingering shibboleths. Intracellular recording in a variety of anesthetized (Fujita, 1964) and unanesthetized (Creutzfeldt, Fuster, Lux and Nacimiento, 1965; Elul, 1965) preparations have indicated a series of precisely definable relationships in the genesis of the EEG as a wave process at the cellular level, so that it can no longer be considered as a random process unrelated to the cellular transaction of information. Use of electrodes free from contact potential and making only a sliding scalp contact, yet remaining artifact free, has eliminated the bogey of adhesive or penetrating scalp contacts (Kado, Adey and Zweizig, 1965), and together with microminiature circuitry, has laid a firm foundation for the direct monitoring of central nervous activity as a highly meaningful measure of behavioral state.

With seemingly endless individual variations in EEG patterns, we have established a common baseline in a population of astronaut candidates, not merely in broad shifts of consciousness, but in the performance of vigilance tasks, and in progressively finer discriminative visual performances that simulate closely the very conditions of critical judgment requirements in aerospace flight. Subsequent application of pattern recognition techniques to these initial spectral analyses have allowed computer recognition of inter- and intrasubject factors that delineate these states of consciousness with considerable precision, using minimal numbers of EEG channels, and a small number of variables within each channel (Walter, Rhodes and Adey, 1965).

On this basis, it becomes feasible to specify the requirements for on-line computer analysis of the EEG, with display techniques suited to the medical monitor, or with an in-flight computer, to the needs of a pilot warning system.

Applications of the basic analysis techniques to EEG data from an astronaut in states of sleep and wakefulness in Gemini flight GT-7 will be described.

2. Essential nature of the electroencephalogram: its cellular origins

Intracellular recording in unanesthetized cortical neurons in our laboratory (Elul, 1965; Adey and Elul, 1965) has revealed a large wave process, from 5 to 15 millivolts in amplitude, which appears to arise in the dendritic branches of the cell, rather than in the soma (Fig. 1). Spectral analysis of this wave process has indicated that its density distribution closely follows that of the EEG recorded grossly in the same domain of tissue. Despite this similarity of density contours, calculations of coherence (Walter, 1963) between the intracellular and gross EEG records have shown that there is virtually no linear relationship between the two processes, so that the population of neuronal generators appear to be independent and non-linearly related (Elul, 1965). The wave process recorded extracellularly arises from generators no larger than cellular dimensions (Elul, 1962), and has an amplitude less than one hundredth of the intracellular wave process. Elul has suggested that the occurrence of a rhythmic EEG as the integral of activity in such a population of independent and non-linearly related generators may be mathematically modeled in terms of the central limit theorem of Cramer (1955).

This cellular origin strongly suggests a vital relationship to the transaction of information in cerebral tissue, not only in the course of broad aspects of sleep and wakefulness, but also in fine processes of focused attention and discriminative judgment. This hypothesis is borne out in the normative library from 50 astronaut candidates described below.

3. Spectral methods of analysis; evaluation of finely shifting power distributions and components shared between channels

The EEG represents an essentially continuous spectrum of frequencies from under 1 cycle per second to well over 50 cycles per second. Functions relating intensity to frequency in any one lead are classified as autospectra, whereas crossspectra describe shared intensities across a band of frequencies (Walter, 1963). Both analog and digital spectral analyses have been applied to EEG records. Problems of designing physical filters with appropriately narrow skirt characteristics have led to the development of digital filters, in which the digital computer provides weighting factors by which the time function is multiplied. The sum of these products is taken as the output of the digital filter. The weighting function can be considered as having a narrow passband characteristic, as in an analog filter, or the application of a set of digital filters to a function of time can be viewed as a discrete version of a Fourier transform (Walter, 1963; Adey, 1965).

It is in our capacity to precisely specify the bandpass characteristics of the digital filter, particularly in the low frequency range between 0.5 and 10 cycles per second, that has established its superiority over analog methods. Since its phase shift is zero, it has become possible to measure for the first time the phase relations between EEG wave trains at each frequency across the spectrum, as well as shared amplitudes between them at each frequency. This has led us to the calculation of the coherence function, as a measure of statistical variability in linear interrelationships between brain regions. Its magnitude may be expressed:

$$\mathrm{coh}(f) = \mathrm{MAGS}\ (f)/\mathrm{ASX}(f)\ \mathrm{ASY}(f)$$

where MAGS(f) is the mean cross spectral magnitude at frequency f and ASX(f) is the autospectrum of X and ASY(f) the autospectrum of Y, at the respective frequencies. The coherence function is expressed between 0 and 1, and is a measure of the linear predictability of activity in any area, on the basis of knowing the activity in any other area, or series of other areas. As we shall see, it is a most valuable measure of changing brain organization in focused attention, emotional arousal, fatigue and sleep, even with minimal numbers of channels for comparison, as in the recent Gemini GT-7 flight.

4. Development of simple pattern recognition techniques based on discriminant analysis

Use of the spectral analysis methods described above has, in itself, allowed recognition of patterns in the EEG, simply from the ability to compress onto a single contour plot many minutes or several hours of raw records, while retaining all relevant details that might be quite transient and last but a few seconds (Walter and Adey, 1965; Adey, 1965).

Such plots are too complex for easy use by the flight monitor, however, and have prompted development of simple pattern recognition techniques with discriminant analysis (Walter, Rhodes and Adey, 1965). Using typical matrix methods, it has been possible to secure a computed classification of the variables that best specify states ranging from simple wakefulness, through the EEG correlates of vigilance task performance, to the detection of differences accompanying progressively briefer and more difficult visual discriminations. The method was applied to data from a series of subjects simultaneously, as well as to their records individually.

This method was applied to the outputs of the initial spectral analyses, and as the results below indicate, the method indicates the feasibility of a reliable recognition technique, and compatibility with on-line analysis. At this stage, particular value has rested in directing attention to the small numbers of data channels and variables on which reliable decision making might rest. Moreover, the method requires only short epochs of data, probably as little as 30 seconds.

5. Applications in baseline analysis; the normative EEG library

It has long been a matter of concern that definition of EEG patterns has rested, not only on the subjective opinion of the investigator, but also on wide individual variations in apparently normal subjects. We have, therefore, sought to establish by computer analysis the presence of common EEG factors in a significant population of astronaut candidates, both in relation to task performances and in assessment of sleep states.

In detailed studies to be reported elsewhere (Walter, Rhodes, Kado and Adey, 1966), a series of 200 astronaut candidates were tested in a series of perceptual and learning tasks, by means of a programming device, developed in our laboratory, and using a magnetic tape command system to ensure accurate timing in task presentation from one subject to the next (Fig. 2). Subject testing and EEG recording were performed by

Dr. P. Kellaway and Dr. R. Maulsby, at the Methodist Hospital, Houston. Physiological data was recorded on magnetic tape, together with the command signals, for subsequent computer analysis. This data constitutes a normative library, and includes not only 18 EEG channels from all scalp areas, but also the electrooculogram (EOG), electrocardiogram (EKG), galvanic skin responses (GSR) and respiration.

A series of 50 subjects were selected at random from the total of 200, and intensive spectral analyses performed. Each hour of subject data required 25 hours of main computation time, wherein multiplications were performed at approximately 500,00 per second, thus indicating the scope of the analysis. Moreover, this comprehensive analysis appears well justified, in that it has allowed selection of variables for a possible on-line system that would be far less demanding in computer requirements.

To synthesize the data, an averaging procedure was adopted on the spectral outputs, covering all 50 subjects in the various test situations, and in selected sleep epochs. These averages were made for each scalp region, and are presented as a series of bar graphs (Fig. 3), covering the spectrum from 0 to 25 cycles per second. First, an average was prepared of spectral densities at each scalp recording site for all test epochs, including sitting with eyes closed at rest, eyes closed during 1 per second flash stimuli, during an auditory vigilance task, during visual discriminations at 3 second intervals, and a similar series of more difficult discriminations at 1 second intervals (Fig. 3, top left).

The contours of these "lumped" spectra were then used as the mean for comparison with the spectra for the individual situations. The subsequent graphs in Fig. 3 thus show the variations about the mean established by the average over 12 situations in the top left figure. Spectral densities above the mean at any frequency have bars above the baseline, and vice versa. It will be seen that such a display clearly separates spectral density distributions for the 50 subjects in the five situations shown. In particular, the distributions for more difficult visual discriminations in one second (Fig. 3, lower right) exemplify trends that already characterize discriminations made in three seconds (Fig. 3, lower middle). It is also possible to compare an individual with the mean for the group, or with his own mean, using a two color display technique.

Similar averages were made for 30 subjects in various stages of sleep and drowsiness (Fig. 4 and 5). Here, the mean was established by an average over 7 stages of presleep, sleep and post sleep, and thus became the baseline for measurement of variance for individual sleep states. It will be noted that states of drowsiness, and light, medium and deep sleep can be readily distinguished from each other, but that separation of deep "slow wave" sleep from subarousal with "K-complexes" is less clear.

Discriminant analysis was applied to these spectral outputs in four subjects (Walter, Rhodes and Adey, 1965), covering five situations: eyes closed at rest, eyes open at rest, an auditory vigilance task, and the two visual discriminative tasks described above. A computer program attempted to assign each segment to the situation from which it came, using measurements derived from four EEG channels: left and right parieto-occipital (P3 - 01 and P4 - 02), vertex (FZ-CZ), and bioccipital (01-02). Each channel's activity was analyzed into four frequency bands, 1·5 to 3·5 cycles per second (delta band), 3·5 to 7·5 cycles per second (theta band), 7·5 to 12·5 cycles per second (alpha band) and 12·5 to 25 cycles per second (beta band). In each band, measurements were made of the strength of activity in each channel, mean frequency within the band (the dominant frequency when present), band width within the band (an expression of the regularity of the dominant frequency), and the coherence between pairs of channels.

This discriminant analysis program initially considers all the measurements for all the segments, and selects that parameter which best discriminates segments recorded in different situations. It then reexamines all measurements and chooses that parameter which will add most to the discriminating power of the first measurement. It calculates five linear functions of those two measurements whose values differ as much as possible among the situations. The program continues this iteration of selecting and calculating linear functions, until insufficient improvement is made by adding another parameter.

The four variables which best distinguish among the five situations are: left parieto-occipital alpha intensity, the mean frequency of theta-band activity in the vertex, the coherence in the theta band between left parieto-occipital and vertex, and coherence in the beta band between vertex and bioccipital leads. A detailed account of the respective contributions of each of these variables to the identification of each of these situations is given elsewhere (Walter, Rhodes and Adey, 1965).

The separate analysis of each subject's records in the same way yielded a higher proportion of correct classifications than in the group analysis. With his own best four measurements, between 62 and 69 per cent of a single subject's samples were correctly classified, as contrasted with 51 per cent for the subjects simultaneously. An even greater disparity appeared after 15 measurements were selected. Individually, 95, 93, 96 and

90 per cent were correct, while for the subjects together, only 65 per cent were (Fig. 6). It would appear that each subject may have a spatially and numerically characterized individual EEG "signature", as to which measurements are most effective in distinguishing different situations.

6. Requirements for on-line computation

On-line analysis of EEG records for classification of behavioral state would appear a desirable objective from the point of view of the medical monitor, or for pilot warning in anticipation of defective attention through drowsiness, fatigue or problems in environmental support.

The foregoing account has described analysis methods resting heavily on elaborate analysis with a large computing system (Fig. 7). Such a comprehensive analysis appears to have been justified in that it has allowed successful evaluation of EEG patterns within and between a population of astronaut candidates, and hopefully, has established a needed baseline for use in future flight studies. It has also indicated the feasibility of using a small special purpose computer that would deal with data from 3 or 4 EEG channels, and achieve a classification of state on the basis of calculations of a small number of variables for each channel, including spectral densities and band widths, dominant frequencies and coherence functions. Such requirements would appear well within the current state of the computer art. Such a system (developed theoretically by D.O.W.), would involve a flight computer calculating spectral characteristics and applying weighting factors to these calculations for classification of state (Fig. 8). Only a limited amount of data would thus be telemetered, to then take its place as a small part in a larger flight monitoring computer program.

7. Application of these analysis techniques to flight EEG data from Gemini GT-7; preliminary evaluation

Successful EEG recording from Astronaut Frank Borman for a period of 54 hours in the initial phase of Gemini Flight GT-7 has provided the first opportunity to evaluate these baseline techniques for flight monitoring. For the first 30 hours, two channels of data were recorded, and one channel thereafter. As will be indicated, even one channel has provided highly significant data on sleep and wakefulness. The flight data was available to us for only 2 weeks prior to this meeting, so that although all data has been analyzed, comprehensive displays for the whole period of 54 hours are not yet complete.

The prelaunch period and a substantial part of the first orbit have been analyzed on the basis of two consecutive 10 second samples approximately every minute, to afford a fine grained analysis (Fig. 9). The prelaunch period was characterized by increased amounts of theta rhythms (4 to 7 cycles per second) than occur normally in the resting state, and may be interpreted as relating to strongly focused attention and orienting responses in an undoubtedly novel situation. At one minute before lift-off, there was an increment in this activity and in the higher frequencies in the alpha and beta bands. The power density of the EEG was augmented by a factor of ten over many frequencies in the period immediately preceding and following launch, indicating a strong "arousal reaction" in the classic neurophysiological sense. Thereafter, there was a slow decline in these augmented densities, with recurrent epochs of higher powers in the higher frequency bands above 10 cycles per second in the first half hour of flight. Epochs with gross movement artifacts have been deleted from these computed analyses, and in general, the records are remarkably clean. A low frequency cut-off of 3 cycles per second was arbitrarily designated in the computation to minimize contamination of the analysis by movement artifacts.

There was only a slow decline in the amount of theta activity in the early hours of flight, and the findings indicate persistence of substantial amounts of theta activity in the major part of the waking records throughout the 54 hours of available data. A baseline data tape for Astronaut Borman, collected according to the techniques of the normative library by Kellaway and Maulsby, has recently been made available to us, and will be examined as described above. Meanwhile, visual inspection of the baseline data suggests that there is augmented theta activity in the flight record in the awake state by comparison with the baseline.

With the prime interest in this experiment centered on drowsiness and sleep, analyses of subsequent data were displayed in a fashion emphasizing these phases. During the waking state, two consecutive 15 second samples were analyzed every 10 minutes, whereas in the drowsy and sleep states, two consecutive 10 second sample were taken every 2 minutes. The graphic display thus emphasizes even brief drowsy episodes.

From the third to the seventh hour of flight (Fig. 10), the subject was awake with occasional drowsy episodes, which the EEG and computed analyses clearly reveal, in the absence of concomitant changes in respiration or heart rate. Often these epochs lasted only from 3 to 15 seconds, but were clearly manifested in the EEG records.

From the fifteenth to the twenty-first hour, there were long episodes of drowsiness and light sleep, with a brief episode of slow-wave sleep in the sixteenth hour (Fig. 11). By contrast with the waking states, coherence (right-hand figures in each row) between the two channels rose sharply with onset of drowsiness and actual sleep, corresponding to the increasing synchrony observed in the paper records. A period of wakefulness occurred at the beginning of the eighteenth hour, characterized by much theta activity, and was followed by drowsiness and light sleep in the twenty-first hour.

From the twenty-first to the twenty-third hour, there was a gradual progression toward full wakefulness, with decreasing drowsy episodes (Fig. 12). Compression of almost five hours of wakefulness into a single display is shown in the middle panel of Fig. 12, with only occasional drowsy episodes. Coherences remained low through this period, except during the drowsy episodes. More frequent drowsy episodes occurred during the twenty-ninth hour.

Finally, there was a long epoch of medium and deep sleep during the second "night" in space, characterized by long periods of uninterrupted slow waves. Even here, however, computer analysis shows elegantly the transitions in states over many hours (Fig. 13). At this stage, only one channel remained operative, due to inadvertent detachment of electrodes by the astronaut. Only autospectra for this channel could be calculated. It is apparent that even a single channel of data appropriately analyzed can be highly revealing of changing states. Moreover, the EEG clearly reveals changes in pattern during shifting states of sleep and wakefulness not detectable with EKG or respiration (Fig. 14).

Certain significant questions remain unanswered by this study. Firstly, on the basis of further analysis of baseline data, it should be possible to answer categorically the question of apparent preponderance of theta thythms in the waking state in the flight records. If this should prove to be the case, it would be interesting to seek its persistence over longer periods of flight, since it may represent an adapting phenomenon to the strange, and, indeed, hazardous environment of space. It is for this reason that lengthy recordings initiated, for example, after the fifth day of prolonged flights would be particularly useful, in revealing the extent of adaptation to the space environment. Such additional information would also be relevant to the evolution of sleep patterns in prolonged flight. It may be relevant that the data from two nights' sleep does not clearly indicate any paradoxical or REM (rapid eye movement) sleep, associated with the dream phase, and approximately 20 per cent of a normal night's sleep. It may be that the location of the electrodes in the anterior lead are too posterior to record the EOG potentials, although blink artifacts are clearly present. In any event, the characteristics of the EEG records from the locations used are not clearly indicative of dream sleep. Clarification of this point would be a simple matter if, in the future, electrodes were placed in inferior frontal positions. From the bioinstrumentation point of view, it would be desirable to consider non-adhesive, zero contact-potential electrodes, inserted into a "bathing cap" for simple wearing or removal by the subject (Kado, Zweizig and Adey, 1965). This would allow initiation of recording at any desired phase of the flight, and eliminate problems of preflight adhesive fixation.

8. Summary

Evidence has been presented, from analysis of EEG data from a population of 50 astronaut candidates, of common characteristics that clearly separate a gamut of conscious and sleeping states, including concomitants of vigilance and decision-making tasks. Extensive digital computing methods for spectral analysis were used, with display techniques that are suited to medical monitoring. Computer recognition of these states by discriminant analysis has indicated the feasibility of on-line computation by special purpose flight computer, using minimal numbers of data channels, and as few as 4 variables in each channel. The essential requirements are discussed for on-line computation and display. Application of these techniques to EEG data from Gemini Flight GT-7 are discussed. The analyses emphasize the value of the EEG in detection of both slow and rapid shifts in states of sleep and wakefulness beyond levels that can be detected by observations of EKG and/or respiration.

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Legends to Figures

Fig. 1. Examples of large intracellular waves and simultaneous EEG records from cortical surface in sleeping cat (A and B), and faster intracellular and surface records when awake (C). From Elul (1965).

Fig. 2. Block diagram of human behavioral test apparatus used in EEG data acquisition from 200 astronaut candidates. Apparatus was designed and constructed with NASA support in UCLA Space Biology Laboratory and data collected by Kellaway and Maulsby at Methodist Hospital, Houston.

Fig. 3. Spectral analyses from 50 astronaut candidates, pooled into averages for each scalp location (see text). Top left figure is average for all subjects over 12 situations. Bars cover spectrum from 1 to 25 cycles per second at intervals of 1 cycle per second. The average over 12 situations was used as the mean for measurements of variance at each frequency in the five situations shown for the population of 50 candidates.

Fig. 4. Spectral analyses for sleep records from 30 astronaut candidates, prepared as in Fig. 3. Averages over 7 stages of presleep, sleep and postsleep (A) were used as the mean for assessment of variance for records with eyes closed, awake (B), drowsy states (C), light sleep (D). Calibrations for 7 stage average are in microvolts squared per second per cycle, and for the individual states in standard deviations.

Fig. 5. Spectral analyses for sleep and arousal records from 30 astronaut candidates, prepared as in Figs. 3 and 4, with clear differentiation of variance in density distributions over the spectrum from 1 to 25 cycles per second in each state. Calibrations are as in Fig. 4.

Fig. 6. Step-wise discriminant analysis as applied to the spectral outputs of EEG records in five situations: eyes closed, resting (EC-R), eyes open resting (EO-R), during performance of auditory vigilance task with eyes closed (EC-T), performance of a visual discrimination task in 3 seconds (EO-T-3), and performance of a similar, more difficult task in 1 second (EO-T-1). The cross-hatched bars are for the simultaneous calculation of the most significant variables in 4 subjects, and the striped bars for each subject individually. This automated computer classification clearly performs best with data from individual subjects.

Fig. 7. The basic elements of the computer system used in the comprehensive analysis of normative library data from 50 astronaut candidates.

Fig. 8. Proposed system for on-line, inflight analysis of EEG parameters relating to behavioral state.

Fig. 9 Contour maps of EEG data from F. Borman in Gemini Flight GT-7, showing enhancement of autospectral densities in theta range in two EEG channels (CPEEG4 and CPEEG5) prelaunch, and great exaltation of many EEG frequencies immediately before and during lift-off. By comparison with later awake and sleeping records, coherences (CPEEG4/CPEEG5) were low at this time. Spectral densities above 10 cycles per second gradually declined in first 30 minutes of flight, but very little alpha activity appeared before 70 minutes (see text). Numerals on abscissae indicate minutes of record in that analysis frame. Calibrations in autospectral contours are in microvolts squared per second per cycle. Shaded contours are: 100-300 uV^2/sec/cycle, horizontal shading; 300-1000, vertical shading; over 1000, solid black. In the coherence plots, values above 0.7 (statistically significant level) are in black.

Fig. 10. Contour maps similar to those in Fig. 9 or two EEG channels with spectral density (CPEEG4 and CPEEG5) and coherence CPEEG4/CPEEG5) plots from the third to the seventh hour. There is a drifting from alertness to occasional drowsy episodes in this period. Calibrations as in Fig. 9.

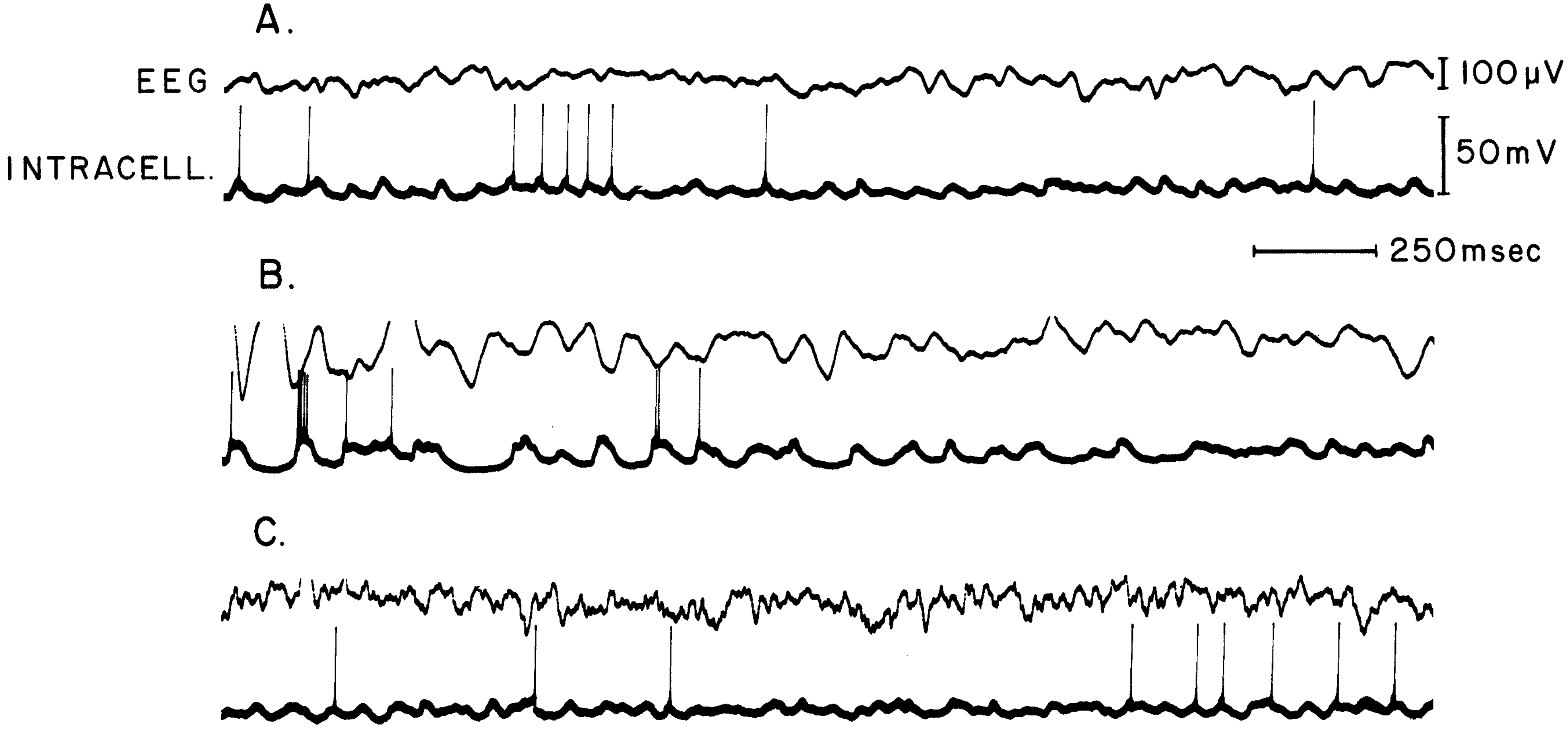
Fig. 11. Contour plots similar to those in Fig. 10, taken from the 15th to the 21st hour, showing a mixture of awake, drowsy and light to medium sleep states. Significant coherences extend to higher frequencies at this stage than in the awake records. Calibrations as in Fig. 9.

Fig. 12. Contour plots from the 21st to the 29th hour, as in Figs. 10 and 11, with long periods of wakefulness, but increasing drowsiness towards the end of the 28th hour. Calibrations as in Fig. 9.

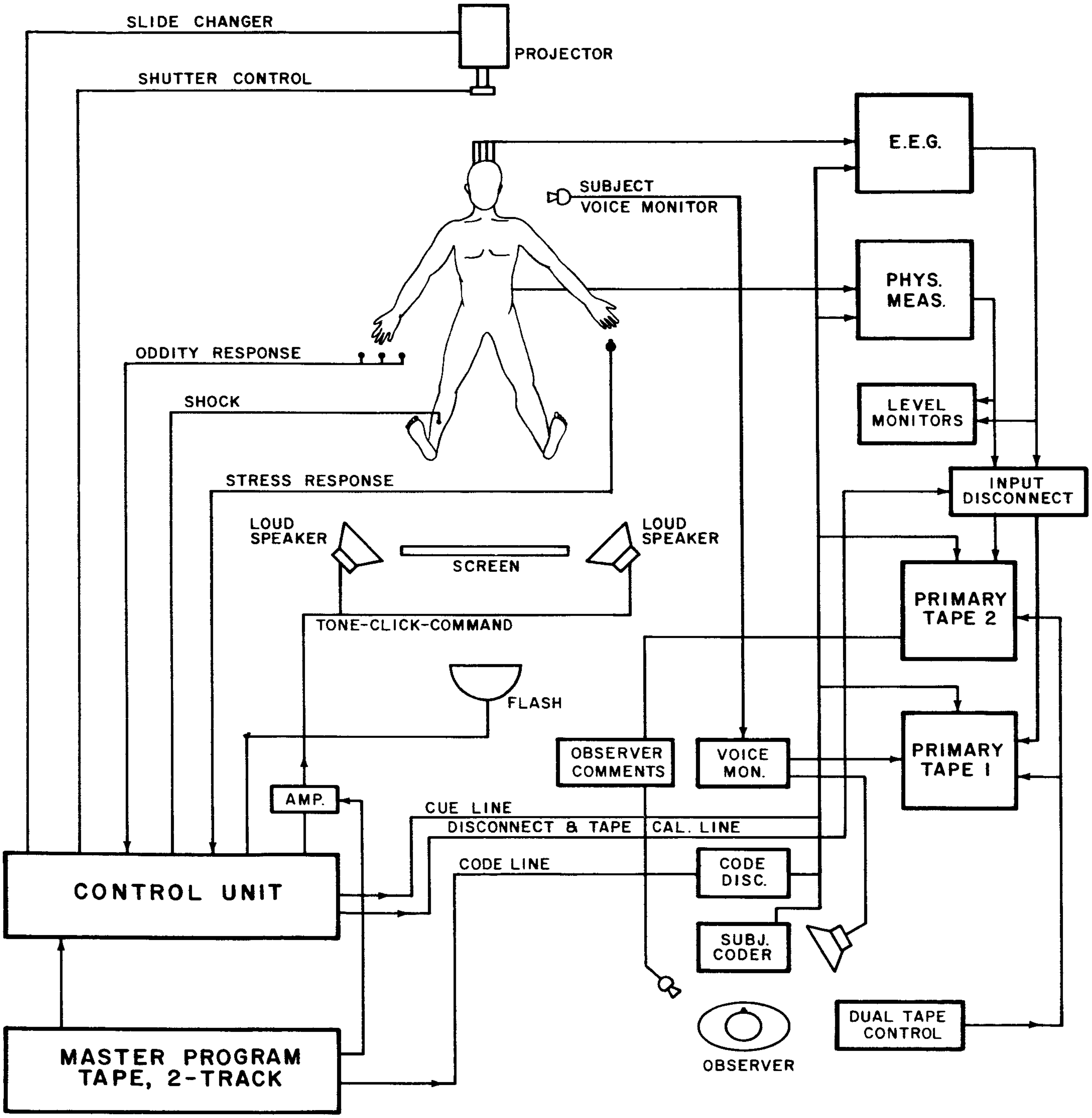
Fig. 13. With only one functional EEG channel remaining, a detailed and highly revealing analysis of sleep states during the second "night" in space is still possible, restricted to autospectral density measurements. Most of this sleep is characterized by big slow waves (Stages III and IV, deep sleep). Calibrations as in Fig. 9.

Fig. 14. Examples of EEG records (EEG.1.A and EEG.2.A), showing plastic and sensitive relationship to states of alertness, drowsiness and sleep, without concomitant changes in heart rate (EKG.A) or respiration (RESP.A), except in deep sleep. The EEG is particularly revealing in brief drowsy episodes (C), where changes in respiration and heart rate are minimal.

NEURONAL WAVES



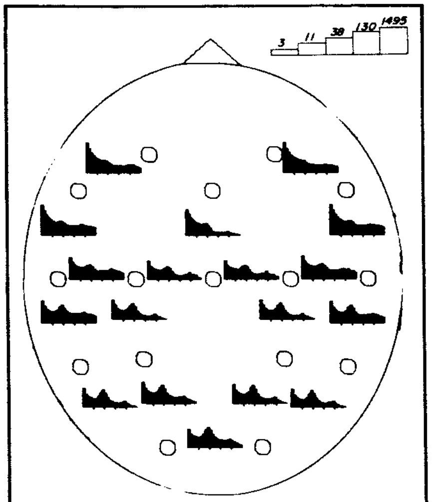
APPENDIX I A



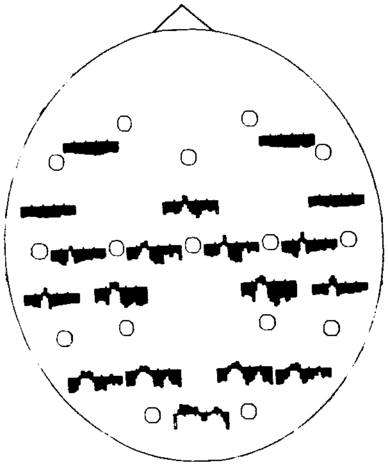
PSYCHO-PHYSIOLOGICAL TESTING AND
DATA ACQUISITION SYSTEM BLOCK DIAGRAM

RESPONSES OF ELECTROENCEPHALOGRAM TO DIFFERING SITUATIONS

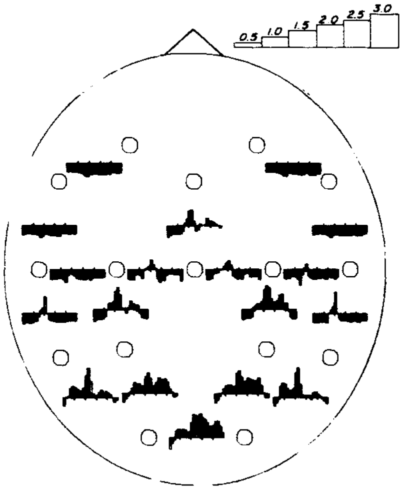
TOPO-SPECTROGRAPHIC VARIATIONS OF AVERAGES OVER FIFTY ASTRONAUT CANDIDATES



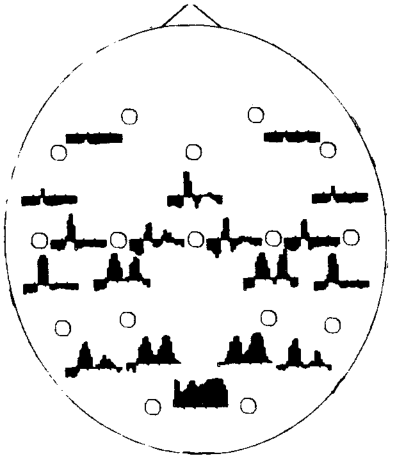
AVERAGE OVER
TWELVE SITUATIONS



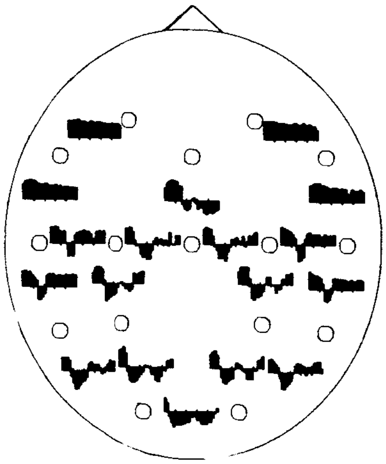
EYES CLOSED
INTERSTIMULUS RESTS



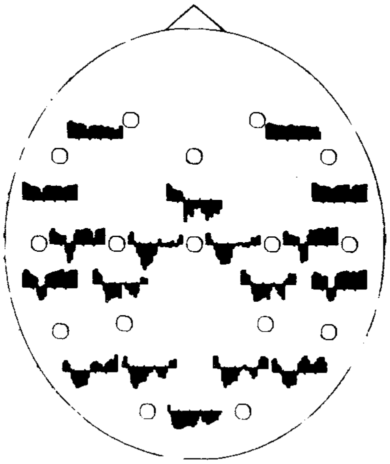
EYES CLOSED
FLASHES, ONE PER SEC.



EYES CLOSED
VIGILANCE TEST
TONES & BUTTON PRESSING



EYES OPEN
VISUAL DISCRIMINATION
3 SEC. EXPOSURE

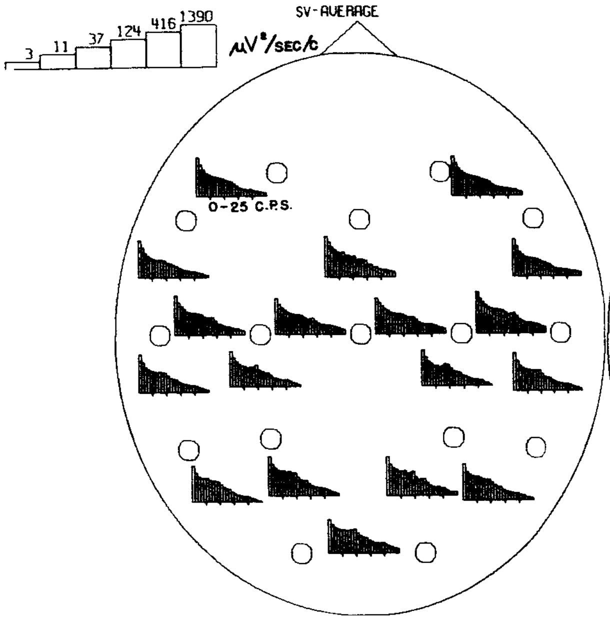


EYES OPEN
VISUAL DISCRIMINATION
1 SEC. EXPOSURE

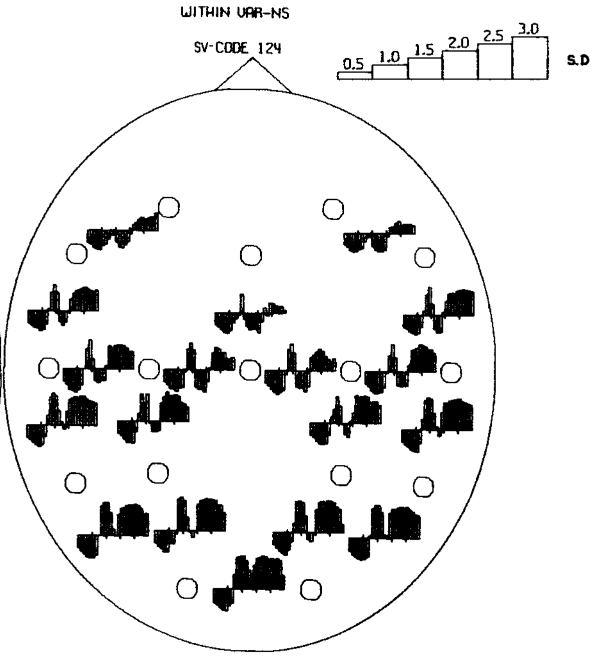
ELECTROENCEPHALOGRAPHIC CHARACTERISTICS OF SLEEP

TOPOSPECTROGRAPHIC VARIATIONS OF AVERAGES OVER 30 ASTRONAUT CANDIDATES

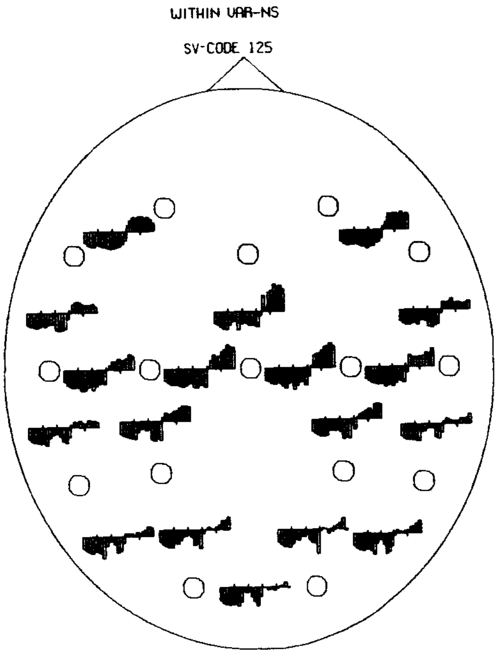
A. AVERAGES OVER 7 STAGES OF PRESLEEP, SLEEP & POSTSLEEP



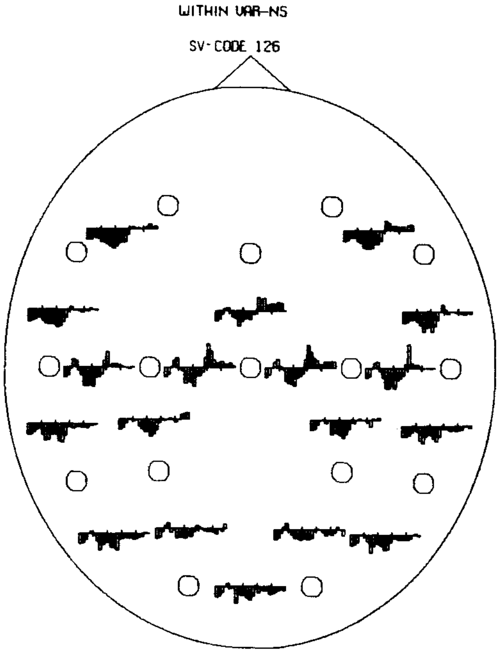
B. SLEEP 0 — EYES CLOSED, AWAKE



C. SLEEP I. "DRIFTING" OR DROWSY



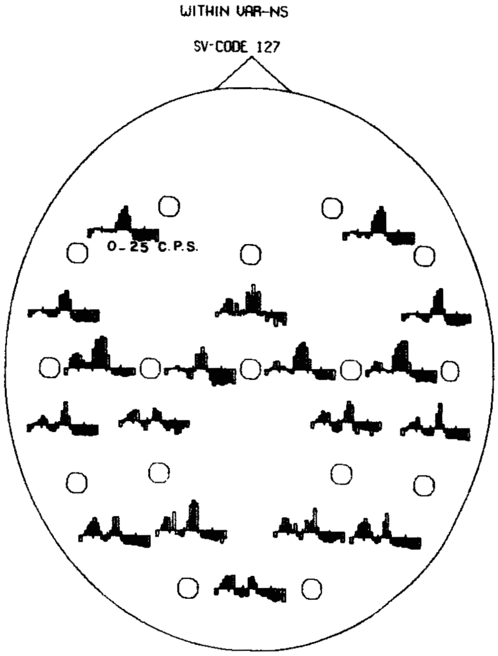
D. SLEEP II. LIGHT SLEEP—"PARIETAL HUMPS"



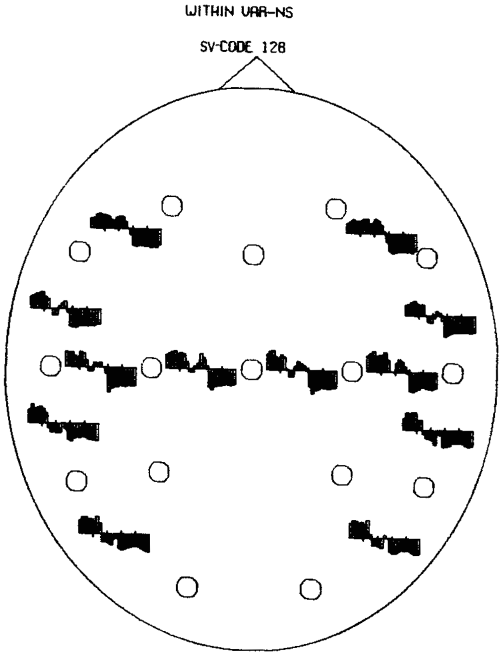
ELECTROENCEPHALOGRAPHIC CHARACTERISTICS OF SLEEP

TOPOSPECTROGRAPHIC VARIATIONS OF AVERAGES OVER 30 ASTRONAUT CANDIDATES

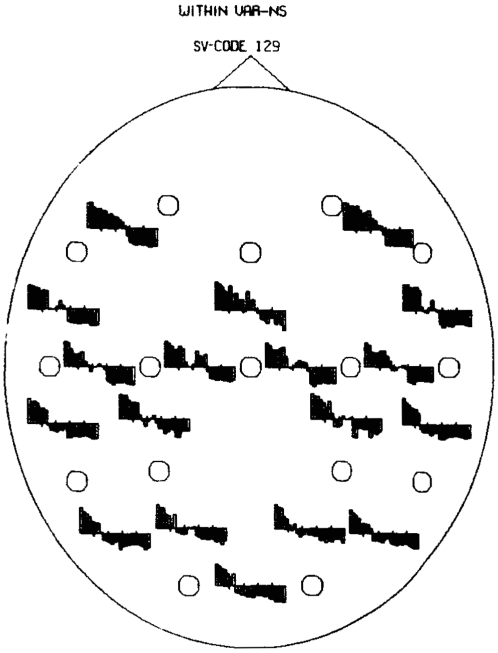
E. MEDIUM SLEEP — 14/SEC SPINDLES IN VERTEX



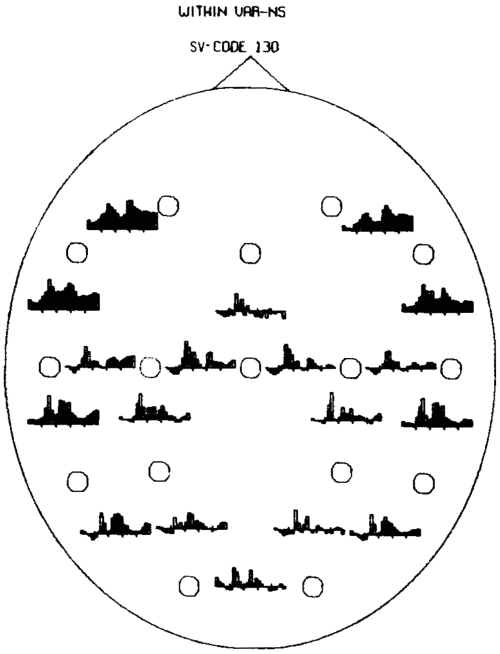
F. DEEP SLEEP — HIGH VOLTAGE SLOW WAVES



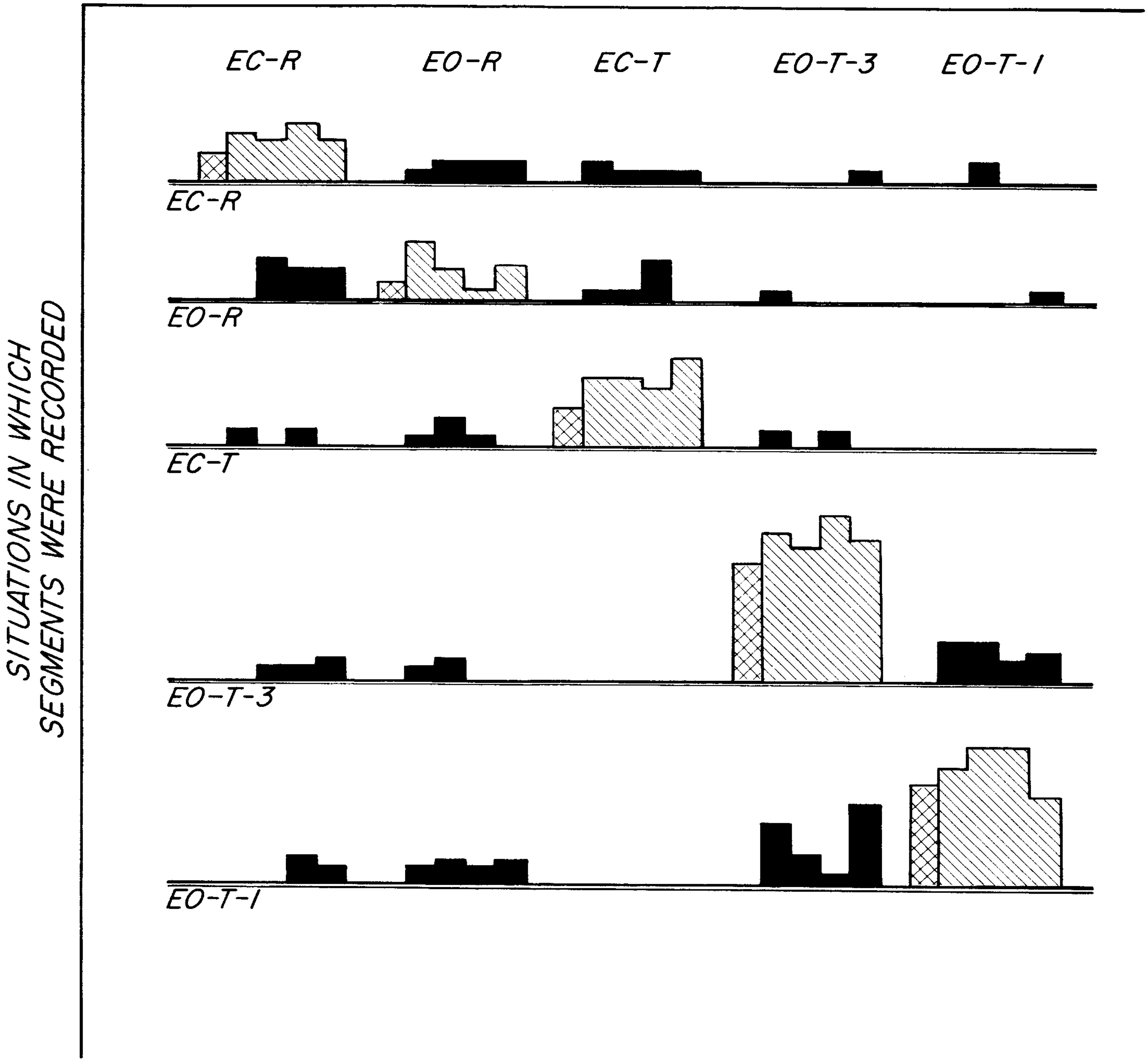
G. SUB-AROUSAL — "K-COMPLEX" TO AUDITORY STIMULI



H. AROUSAL TO AUDITORY STIMULI

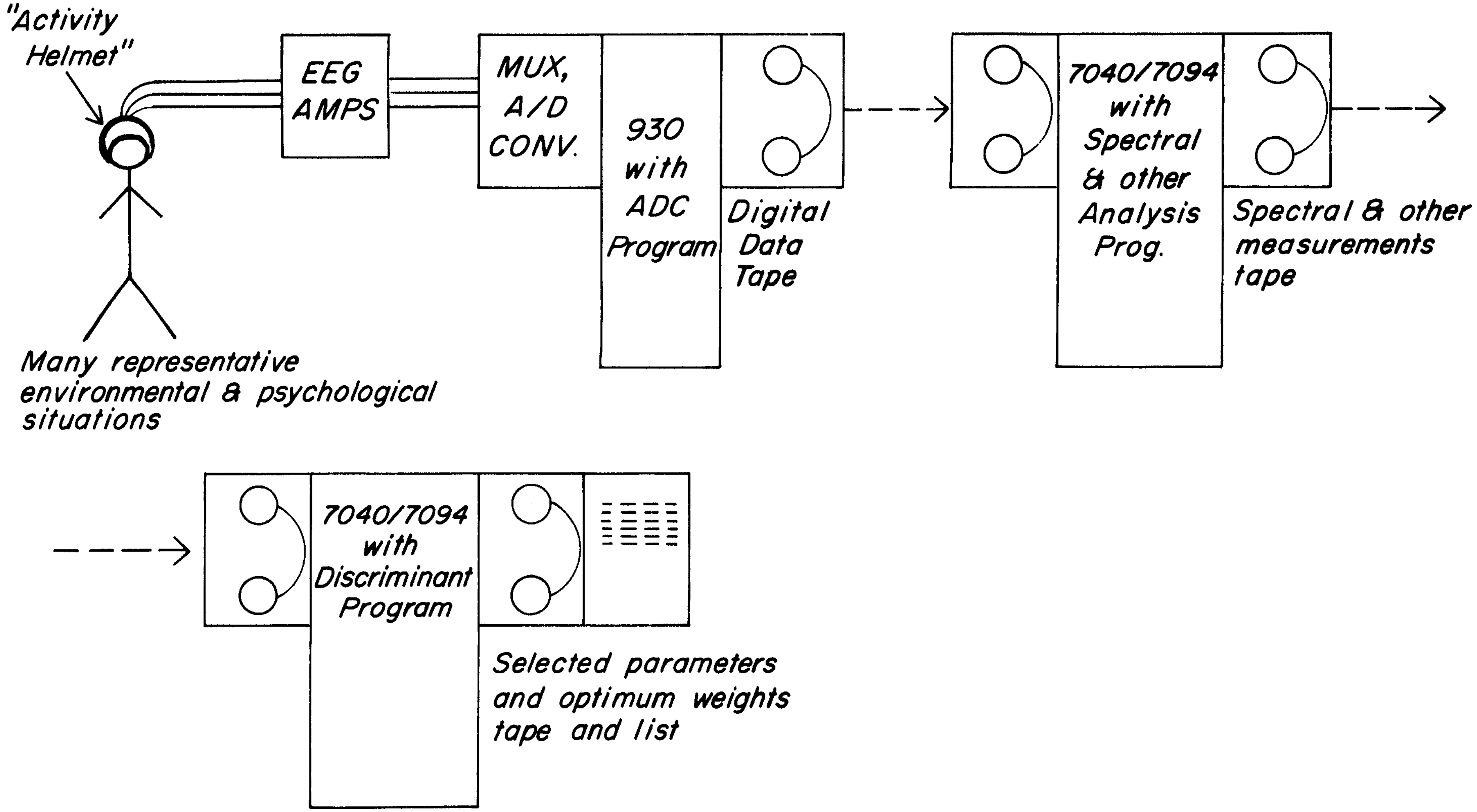


AUTOMATIC CLASSIFICATION BY BEST
4 MEASUREMENTS



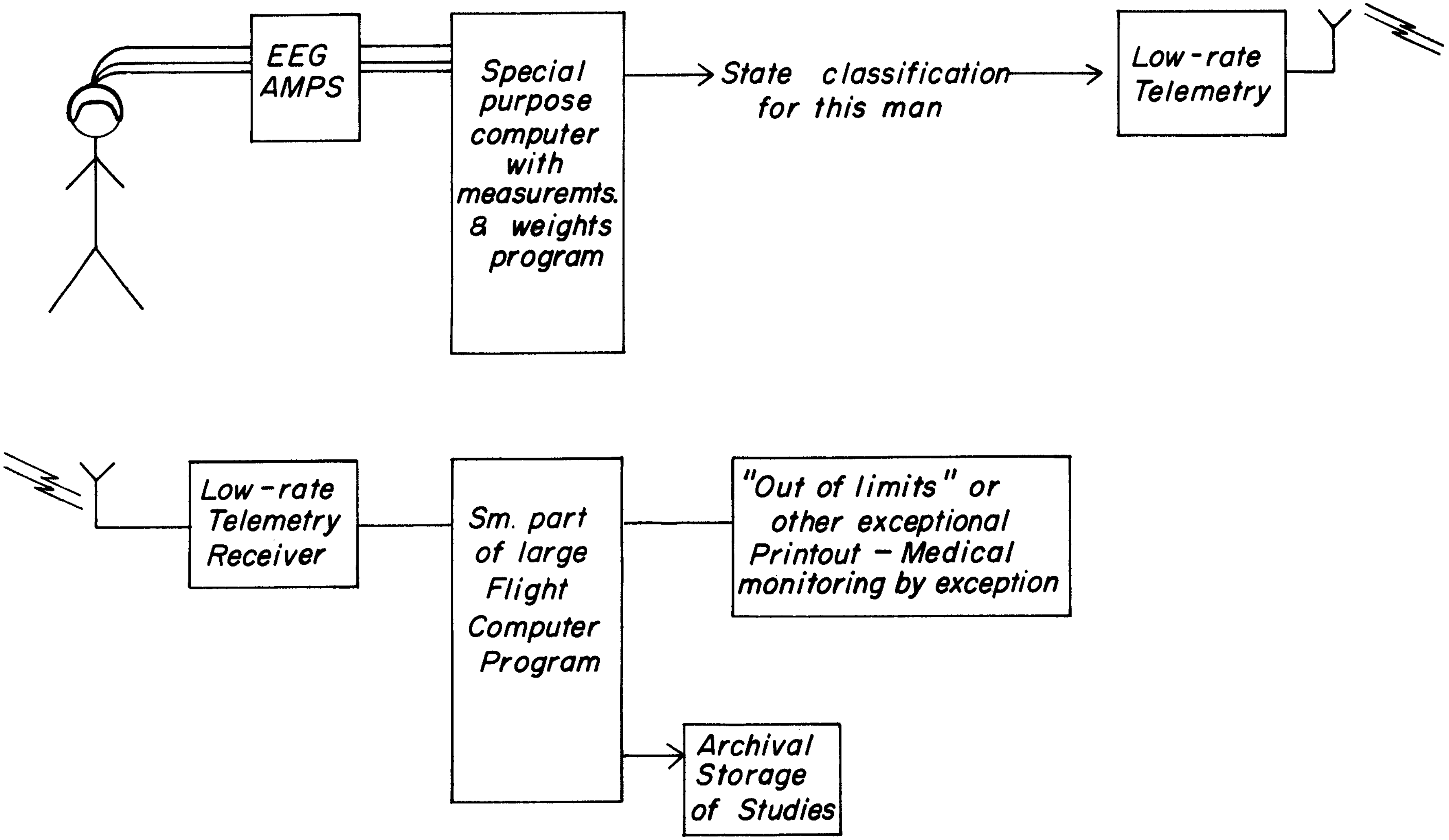
COMPUTER-ASSISTED ASTRONAUT MONITORING METHOD

I. Comprehensive Data Collection Phase



COMPUTER-ASSISTED ASTRONAUT MONITORING METHOD

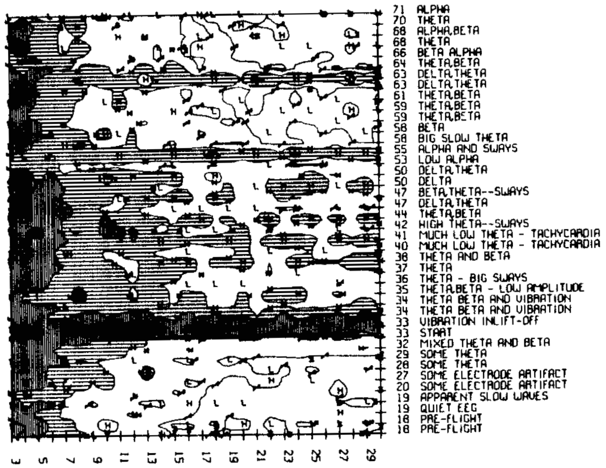
II. Application Phase



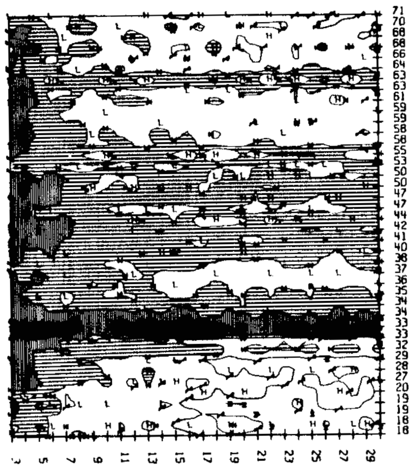
GEMINI GT-7

A. PRELAUNCH-ORBITAL INJECTION

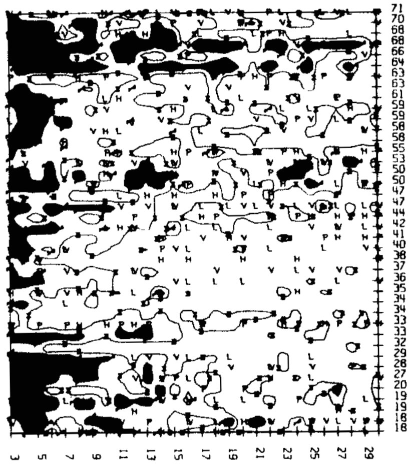
CPEEG4



CPEEG5

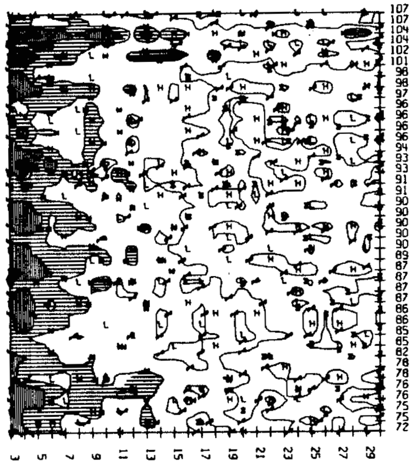


CPEEG4/CPEEG5

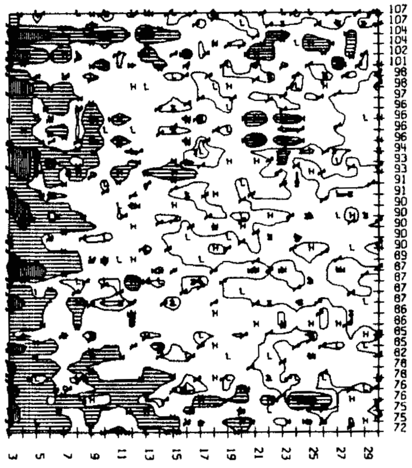


B. CONTINUATION OF FIRST ORBIT

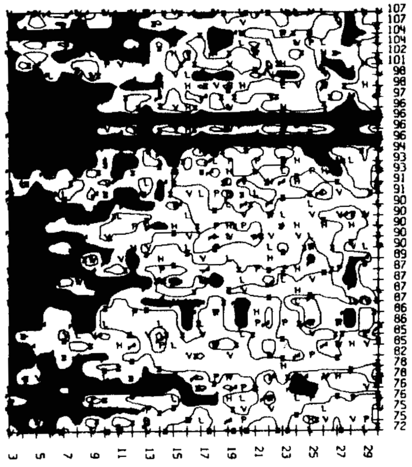
CPEEG4



CPEEG5



CPEEG4/CPEEG5



LEVELS

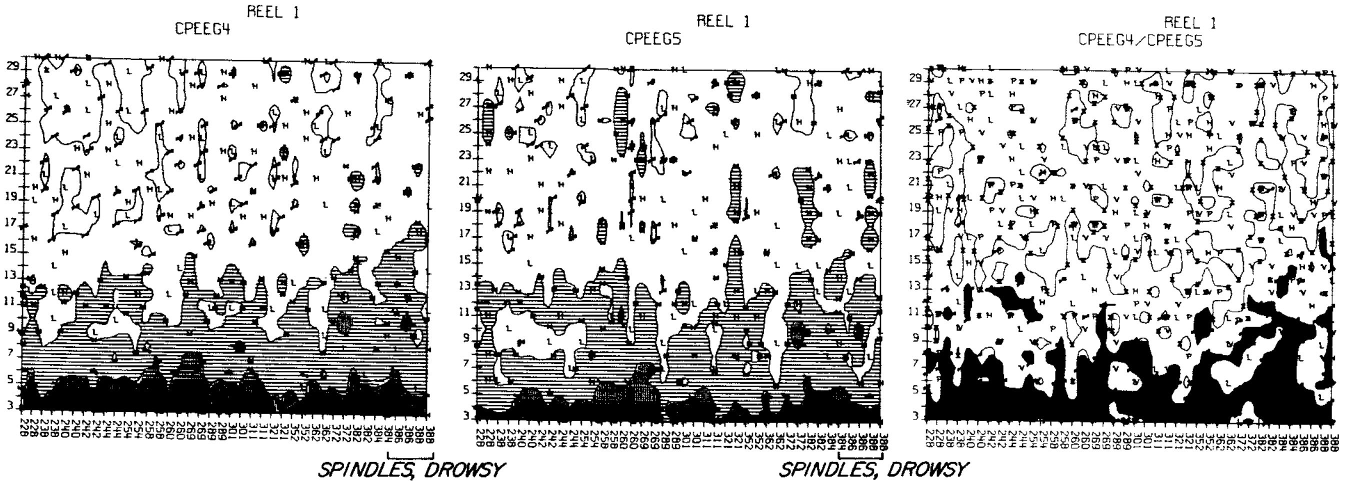
= 10
= 30
= 100 ▤
= 300 ▩
= 1000 ■
= 3000

LEVELS

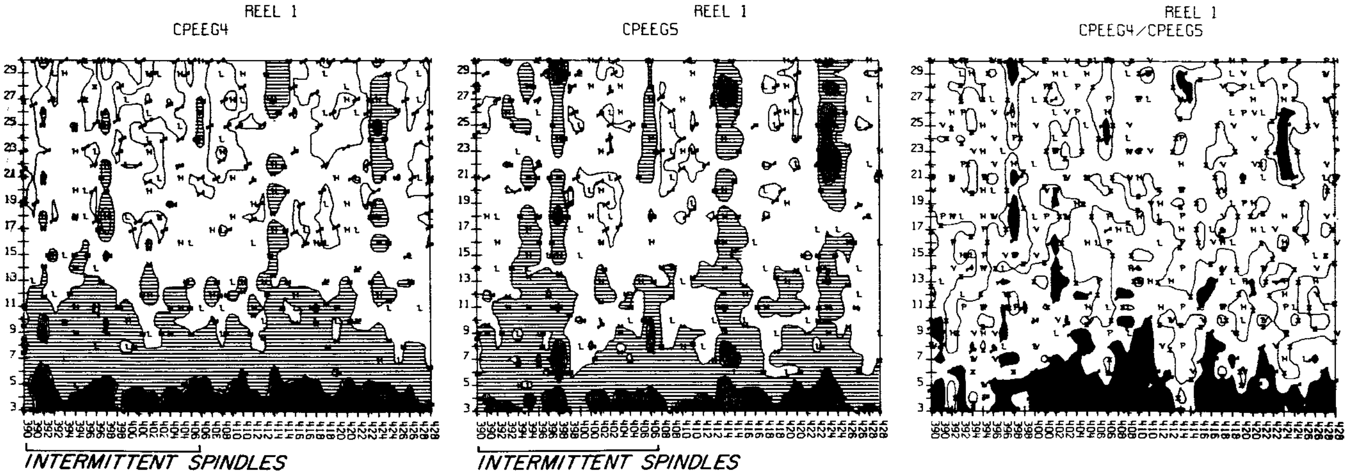
= 0.40
= 0.7 ■

GEMINI GT-7

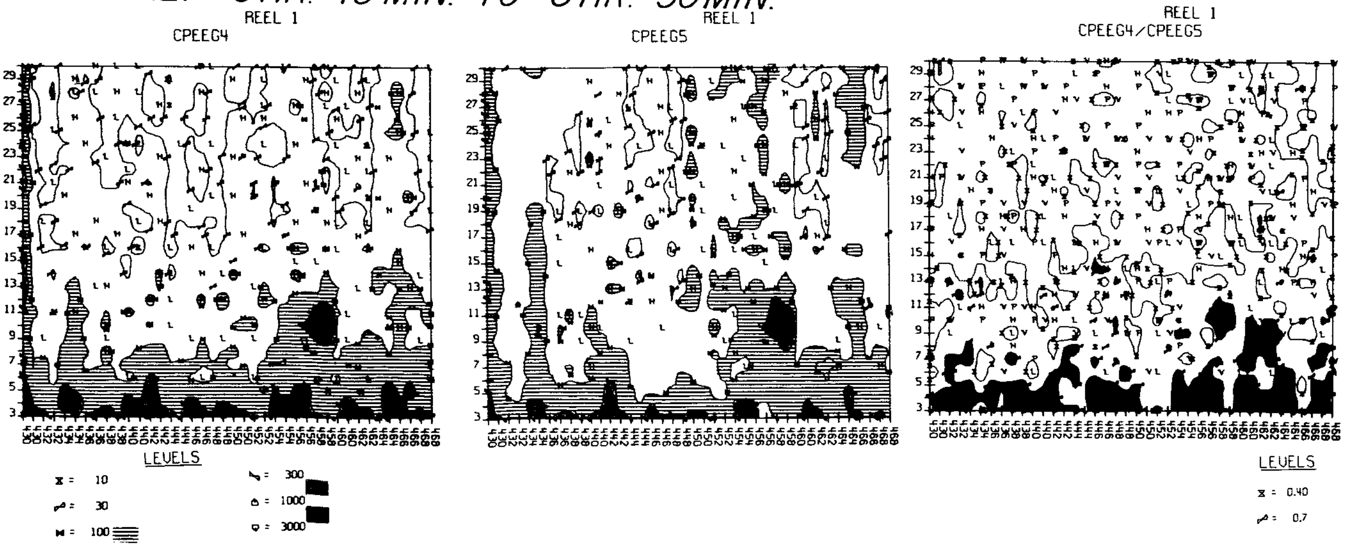
C. ALERT, BECOMING DROWSY. 3 HR. 4 MIN. TO 5 HR. 34 MIN.



D. AWAKE, DROWSY. 5 HR. 35 MIN. TO 6 HR. 12 MIN.

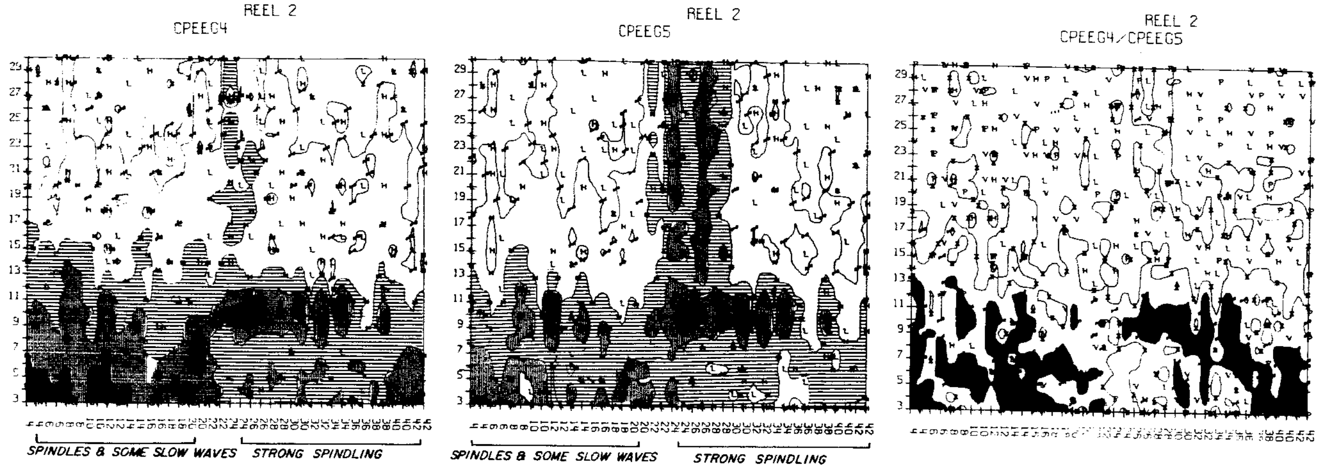


E. AWAKE. 6 HR. 13 MIN. TO 6 HR. 50 MIN.

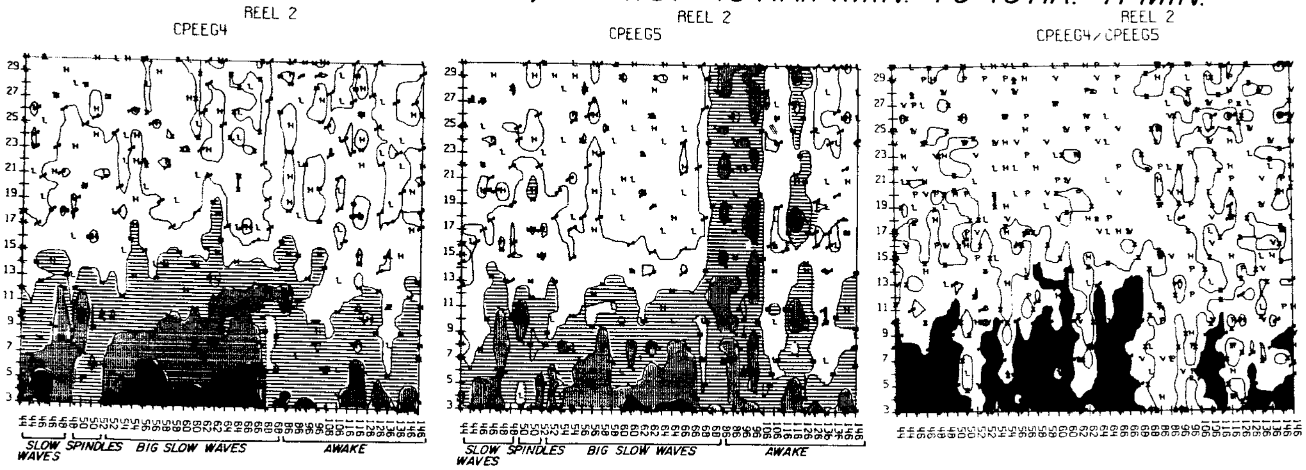


GEMINI GT-7

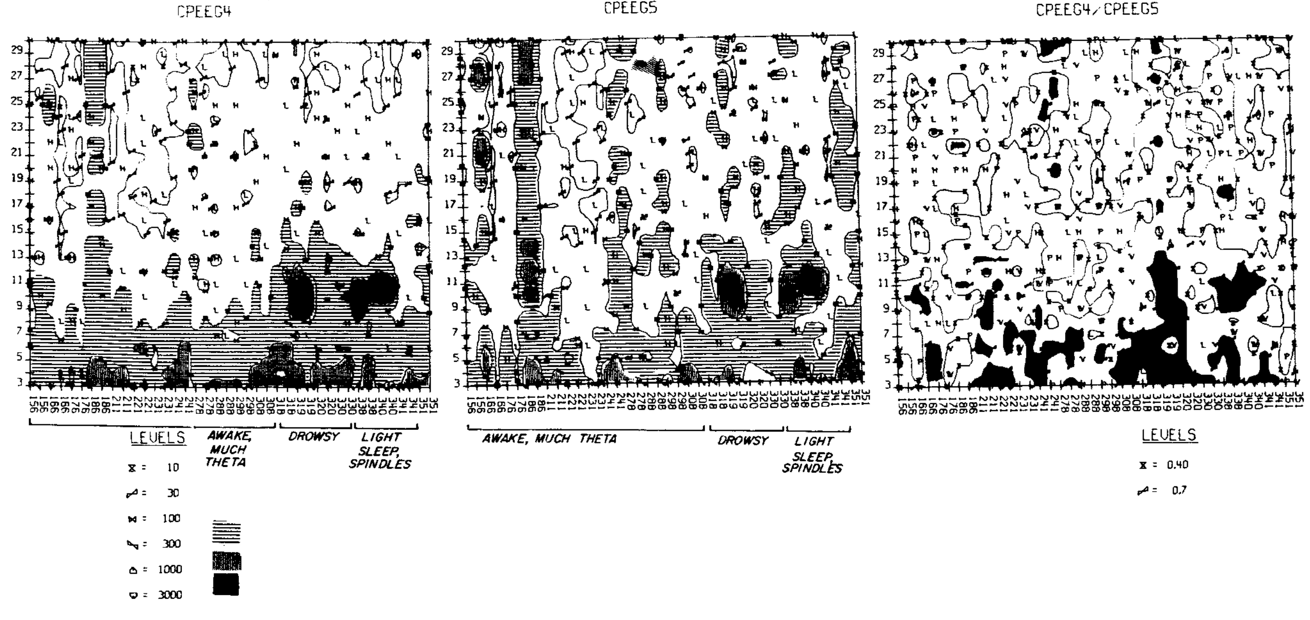
LIGHT SLEEP - 14HR. 36MIN. TO 15HR. 12MIN.



MIXED DEEP & LIGHT SLEEP, DROWSY - 15HR. 14MIN. TO 16HR. 47MIN.



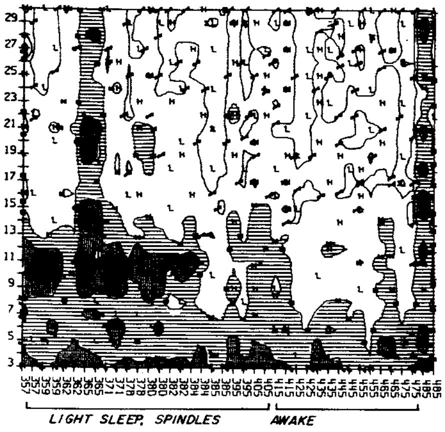
AWAKE, BECOMING DROWSY - 16HR. 56MIN. TO 20HR. 2MIN.



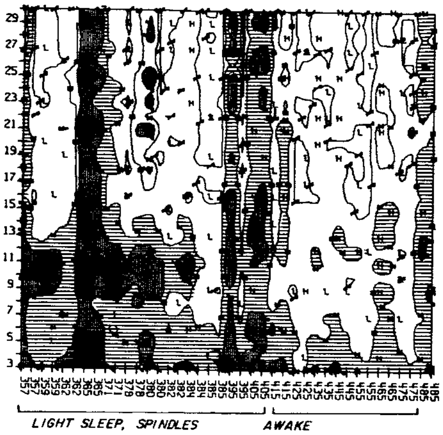
GEMINI GT-7

LIGHT SLEEP, DROWSY & AWAKE-20HR. 18MIN. TO 22HR. 8 MIN.

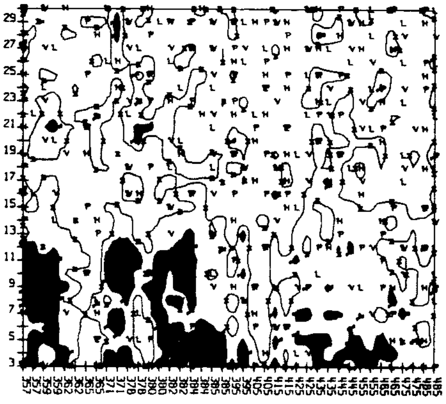
REEL 2
CPEEG4



REEL 2
CPEEG5

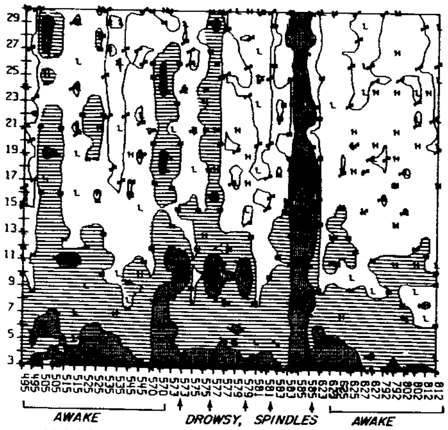


REEL 2
CPEEG4/CPEEG5

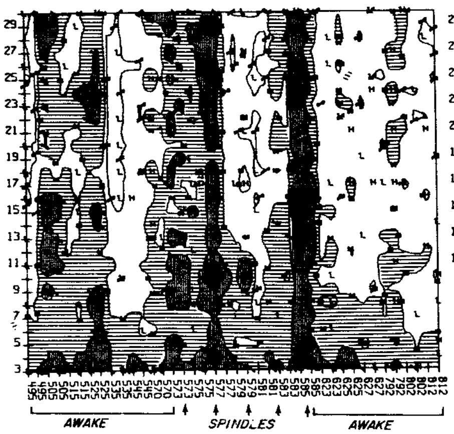


AWAKE-OCCASIONAL DROWSY EPISODES-22HR. 18MIN. TO 27HR. 16MIN.

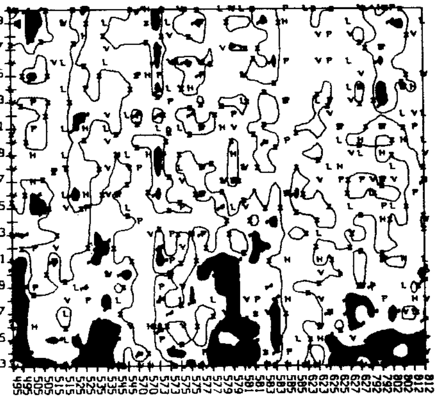
REEL 2
CPEEG4



REEL 2
CPEEG5

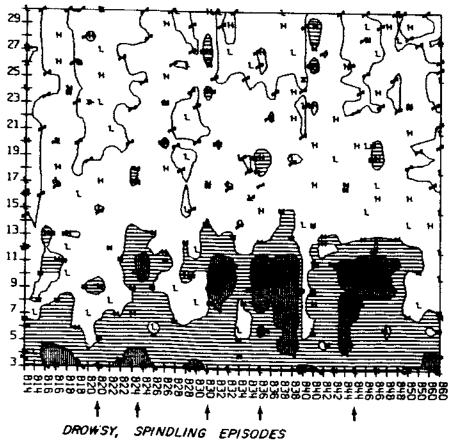


REEL 2
CPEEG4/CPEEG5

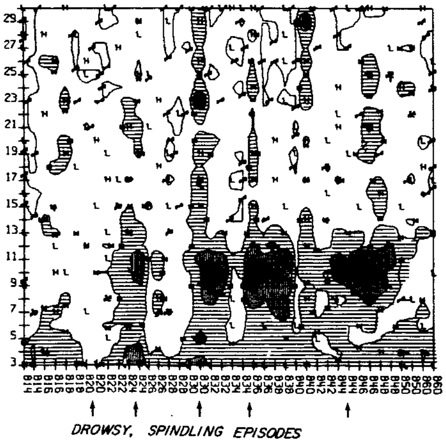


AWAKE, MORE FREQUENT DROWSY EPISODES-27HR. 18MIN. TO 28HR. 0MIN.

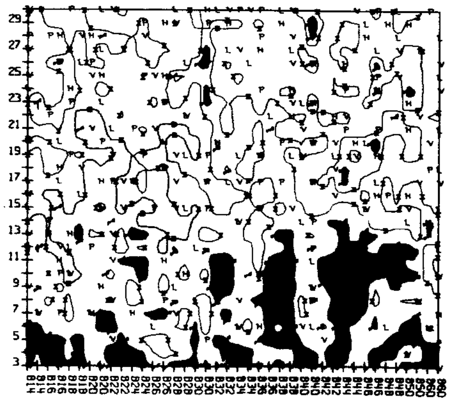
REEL 2
CPEEG4



REEL 2
CPEEG5

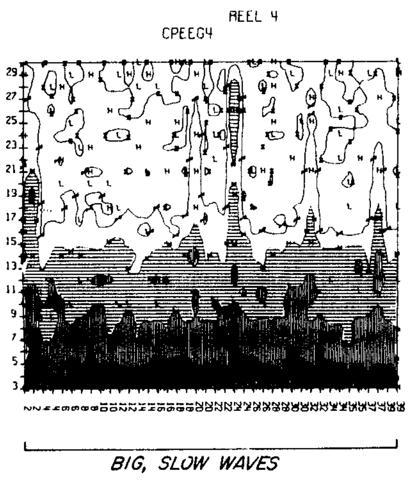


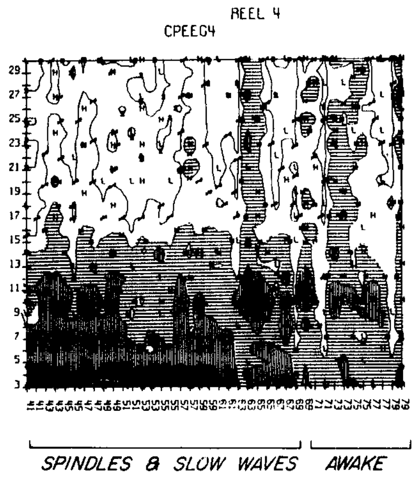
REEL 2
CPEEG4/CPEEG5

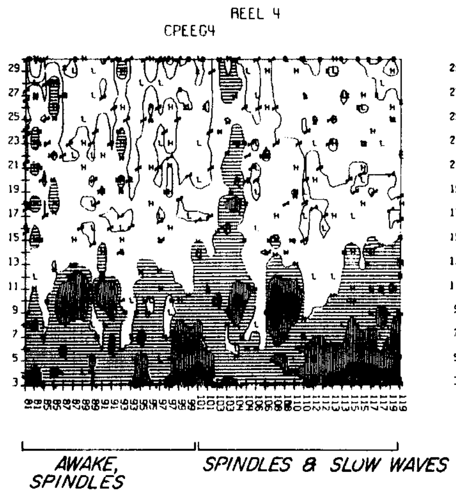


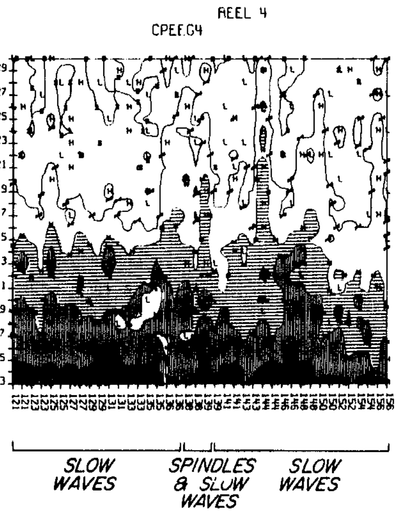
GEMINI GT-7

DEEP SLEEP - 36 HR. 7 MIN. TO 38 HR. 31 MIN.

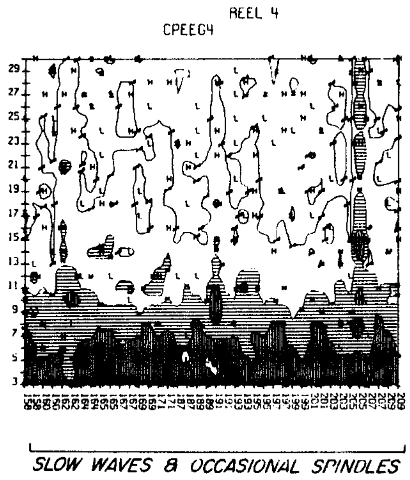


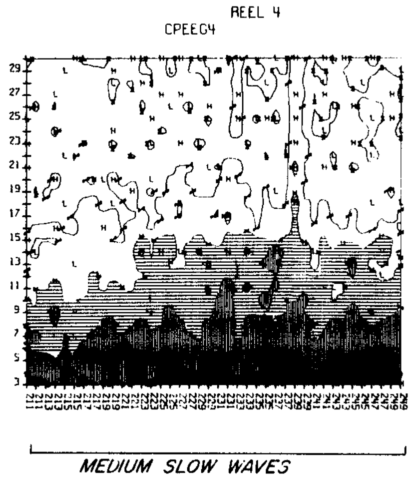


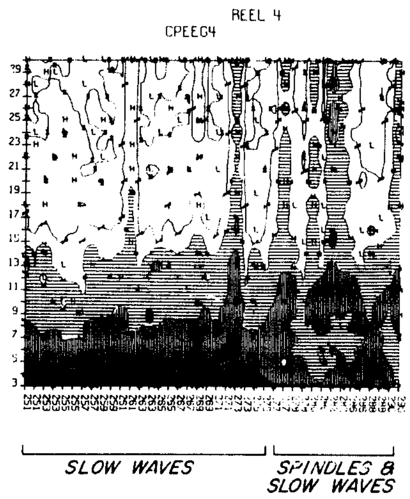




MEDIUM & DEEP SLEEP 38 HR. 33 MIN. TO 40 HR. 37 MIN.

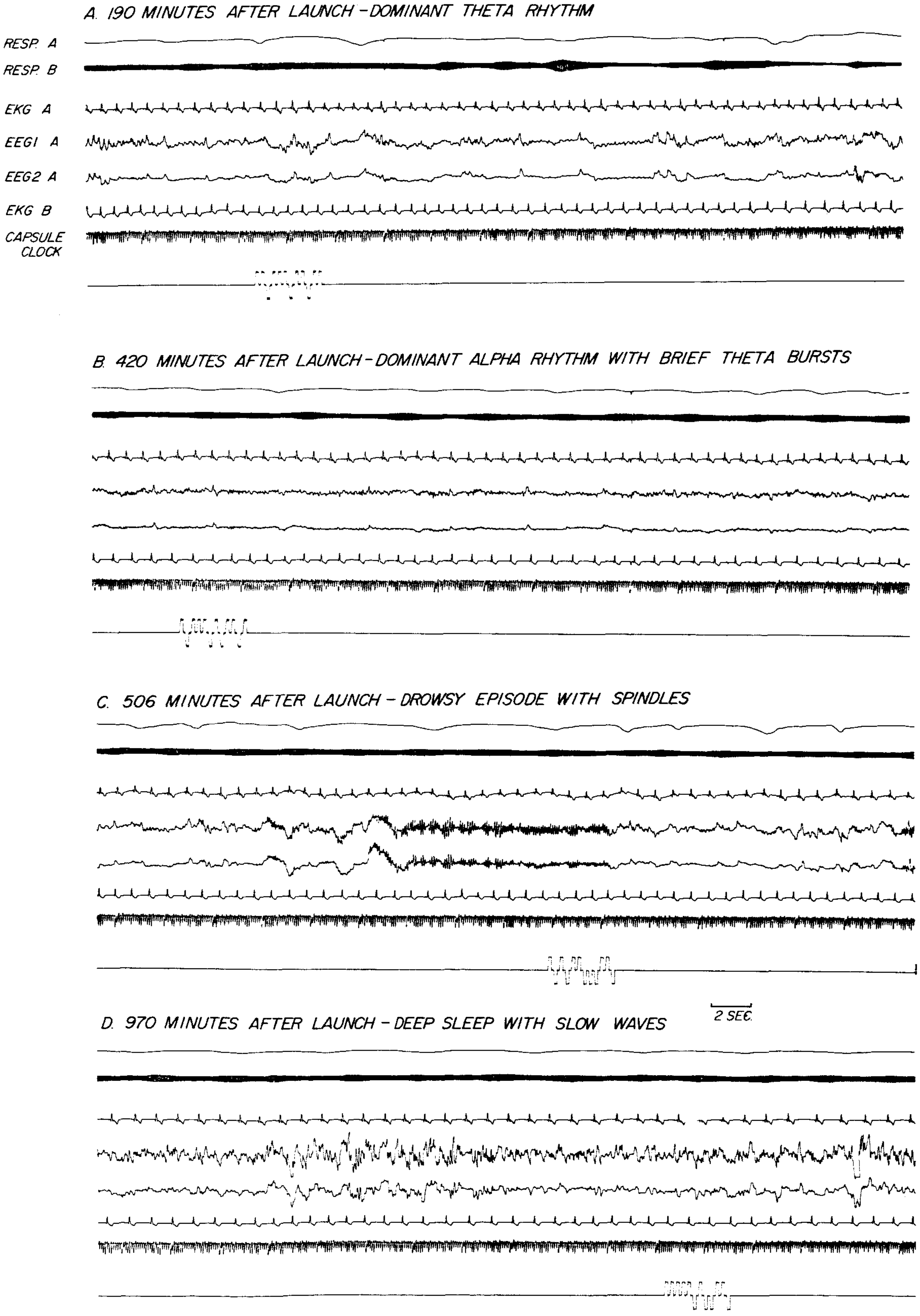






EEG IN SPACE FLIGHT - GEMINI GT-7

ASTRONAUTS A and B



A. 190 MINUTES AFTER LAUNCH - DOMINANT THETA RHYTHM

B. 420 MINUTES AFTER LAUNCH - DOMINANT ALPHA RHYTHM WITH BRIEF THETA BURSTS

C. 506 MINUTES AFTER LAUNCH - DROWSY EPISODE WITH SPINDLES

D. 970 MINUTES AFTER LAUNCH - DEEP SLEEP WITH SLOW WAVES