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CIRCADIAN COUNTERMEASURES FOR SHIFTWORKERS DURING USMP-2
A Report to Mission Management

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Final Report

April, 1994

Prepared in response to P.O. #H1301-2D

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ABSTRACT

People who must work at night experience a number of physiological and psychological difficulties. These include sleepiness and fatigue at work, poor daytime sleep, gastrointestinal distress, impaired concentration and performance, disturbed mood, and increased health complaints and risk of disease. These difficulties arise because nocturnal work and daytime sleep take place at inappropriate phases of the body's circadian rhythms. Intense artificial light can shift the phase of human circadian rhythms, and can thus be used to promote adaptation to shifted work schedules.

The first attempts to investigate the efficacy of light treatment for MSFC POCC shiftworkers took place during USML-1 and ATLAS-2. The findings from these studies led to the development of a Circadian Countermeasures Program that was implemented during USMP-2. Light treatment and other circadian countermeasures were employed to promote adjustment to mission shiftwork in POCC cadre volunteers. Treatment protocols were designed and customized for each volunteer's work hours and personal preferences. Treatment protocols included some or all of the following: scheduled self-administration of intense light, scheduled avoidance or attenuation of sunlight at other times, and sleep schedules. Data from post-mission questionnaires indicated that volunteers found the program to be effective, convenient, and beneficial.

CIRCADIAN COUNTERMEASURES FOR SHIFTWORKERS DURING USMP-2

I. SCIENTIFIC BACKGROUND

A. Circadian Rhythms and Shiftwork

Circadian rhythms are periodic fluctuations in biological or psychological functions that are generated by clock-like processes in the brain. Without input from environmental cues, the rhythms would run with a periodicity close to, but not exactly, 24 hours. Therefore, the circadian "clock" must be appropriately "reset" each day in order to remain synchronized to the 24-hour cycles in nature. In mammals, this daily resetting is caused by exposure to sunlight at certain times of day [1]. Light exposure that occurs around the time of biological or "subjective dawn" advances rhythms; that is, it makes all events in the rhythm occur earlier in time. Light exposure around the time of subjective dusk delays rhythms, or makes the cycle of events occur later in time. Light exposure during the middle of the subjective day has little or no effect. A phase-response curve (PRC) that predicts how circadian rhythms respond to light at different times constitutes the conceptual basis for the phase-shifting protocols developed during this project.

The human circadian system is similar to that of other species, in that the innate period of its rhythms is different from 24 hours, and it must, therefore, be reset, or phase-shifted, each day [2]. Scientists have only recently recognized, however, the importance of light as a resetting stimulus for human rhythms, as opposed to interpersonal or societal time cues. Although humans may require greater light intensities or durations, compared to other species, preliminary data indicate that the properties of the human phase-response curve to light are similar to that of other animals, with phase advances occurring in response to light around the end of the night or subjective dawn, and phase delays in response to light exposure around subjective dusk or early night [3,4].

Unlike animals, humans are subject to a variety of circadian derangements that arise from modern technological society. For example, shiftworkers must override the control of the circadian system to sleep and work at biologically inappropriate times. Thus sleep and work are displaced relative to both internal circadian rhythms and environmental cycles. Even after some time on shifted work schedules, most workers' circadian rhythms do not fully adapt [5,6,7,8], presumably because environmental light cycles and other time cues keep them entrained to the natural 24-hour day. Although some individuals can tolerate shifted work and sleep schedules, most experience a constellation of symptoms that includes sleepiness and fatigue during work, poor daytime sleep, gastrointestinal distress, impairments in concentration, alertness, and performance, and disturbed mood [9,10,11]. These symptoms, and the chronic sleep deprivation that results from consecutive days of disturbed sleep, have important on-the-job repercussions such as decreased productivity, increased errors, high worker turnover, poor morale, and increased absenteeism.

Moreover, shiftworkers are at increased risk for both cardiovascular and gastrointestinal disorders. The impact of shiftwork on the health, economy, and safety of the public is enormous, as is documented in a recent report by the Congressional Office of Technology Assessment [12].

The first attempts to devise treatment strategies for shiftwork disturbances involved manipulation of sleep and work schedules to conform with circadian rhythm principles [13,14]. While such schedules may improve shiftworker well-being, complete adaptation is usually counteracted by workers' tendency to revert to normal sleep schedules on days off [15], and by exposure to sunlight and other time cues in society.

Recent research has demonstrated that intense artificial light can shift the phase of human circadian rhythms. As with natural light, the direction and magnitude of phase shifts induced by artificial light are a function of the time of exposure. This finding suggested that exposure to artificial light might help workers adjust to shifted work schedules. Laboratory studies have shown that a combination of scheduled exposure to intense light, scheduled avoidance of light at times that would counteract the desired phase-shift, and scheduled sleep, can effectively shift rhythms and improve well-being during simulated night shifts [15,16,17,18,19,20]. However, in some of these studies, subjects were completely or partially shielded from sunlight and other environmental time cues, and their sleep and light exposure were rigorously controlled and monitored. In addition, subjects were not true shiftworkers performing their usual jobs. It may be relatively easy to phase-shift circadian rhythms under such circumstances, as opposed to when real shiftworkers carry out their jobs, live at home, are exposed to sunlight, are not under close supervision, and have personal obligations that take precedence over light treatment.

The first attempt to use light treatment for real shiftworkers was an uncontrolled pilot study of night workers on a television news crew [21]. The subjects reported improved daytime sleep and nighttime alertness after light treatment was instituted. Since then, NASA has taken the lead in investigating the use of light treatment for its shiftworkers.

B. Shiftwork and Light Treatment at NASA

Manned spaceflight missions often require flight crews and ground personnel to follow shifted sleep and work schedules, both because of specific mission demands and the need for continuous operations. In addition to the circadian disruption and disturbed sleep that may result from nightwork, mission personnel may suffer from extreme fatigue due to long duty shifts for many consecutive days. Adaptation to shifted schedules may be even more difficult if work times vary over several hours from day to day. The recent advent of longer-duration missions may cause even greater fatigue for mission personnel.

Mission shiftwork schedules appear to have deleterious effects on flight crews. Decreased sleep duration and quality have been reported by both American and Soviet astronauts [22, 23], although poor sleep may result from many factors peculiar to spaceflight. Nevertheless, electroencephalographic studies of Gemini [24,25,26] and Skylab [27] astronauts who slept at night showed few significant reductions in sleep duration, quality, or latency, compared to preflight baseline recordings. These findings suggest that when astronauts maintain normal sleep schedules, weightlessness and other factors do not seriously compromise sleep. This conclusion is supported by the results of a simulated Spacelab mission utilizing a shifted sleep/work schedule similar to those used on actual missions, in which subjects exhibited circadian desynchronization, impaired amount and quality of sleep, and indications of increased stress [28,29]. More recently, retrospective reports from 58 Space Shuttle astronauts from 9 crews [30] revealed that although sleep duration was not different in dual-shift vs. single-shift crews, those on dual-shift missions used more sleep medications (50% vs. 19%). This suggests that some aspect of shiftwork resulted in poorer sleep. In order to reduce these problems, astronauts who must work on shifted schedules during Space Shuttle missions now use light treatment before launch to shift their circadian rhythms and pre-adapt them to mission work/sleep schedules [31,32]. Drs. K. Stewart and C. Eastman provided light treatment protocols for the flight crews of ten Shuttle missions between April 1991 and September 1993.

When Space Shuttle missions call for shifted work schedules, not only flight crews are affected. Ground support personnel at various NASA installations are also required to follow similar schedules, subjecting them to all the disturbances common to shiftworkers. For example, a survey of 28 past and present MSFC POCC cadre members indicated that 54% of responders felt their performance was degraded during mission-related shiftwork, 75% did not feel rested after sleeping, and 32% experienced illnesses they believe related to working third shift. In addition, 45% used sick leave, compensatory leave, or annual leave to recover after the mission. The average number of leave days used to recover was 2.5 (range= 0 to 7 days) across the entire sample. This finding suggests that the NASA workforce may lose a significant number of man-workdays each year because of the debilitating effects of shiftwork. The survey also showed that most cadre members are interested in undergoing light treatment to help ameliorate their shiftwork difficulties [33].

The light treatment protocols used by Space Shuttle flight crews have not been subjected to controlled experimental verification, and thus, their efficacy for shifting circadian rhythms and improving sleep, performance, and well-being has not been demonstrated. Previously, the only published, controlled data showing the efficacy of light treatment for shiftwork have been obtained from laboratory subjects during shiftwork simulations. Recently, Marshall Space Flight Center was the venue for the first controlled tests of light treatment for real shiftworkers [33], who lived at home and carried out their jobs while exposed to normal sunlight and societal time cues. The studies were conducted during Space Shuttle Mission STS-50, whose Spacelab payload was devoted to the first United States

Microgravity Laboratory (USML-1). Volunteer subjects from the evening and night shift MSFC POCC cadre were assigned to treatment or control groups. During the pre-launch week, subjects in the treatment groups were exposed to intense artificial light at times of day that phase-delay circadian rhythms. They self-administered light treatment at home using a novel light delivery system developed for this project at MSFC. Light treatment continued throughout the mission, to maintain shifts in circadian phase, and for several days afterward, to promote rapid readjustment to normal sleep and work schedules. No treatment was administered to subjects in the control groups.

All subjects kept detailed records of sleep and physical and emotional symptoms for approximately four weeks before launch, throughout the two-week mission, and for one week after. Among night-shift subjects, those who received light treatment fared better than control subjects, relative to pre-mission baseline, on all symptoms measured, especially mental fatigue, physical fatigue, and irritability. In addition, sleep duration and quality were better in the treatment group. Self-rated job performance was markedly higher in the treatment group than in controls, and after the mission, control subjects took more days off from work to recover from the effects of their shiftwork schedules.

Light treatment also had beneficial effects on the USML-1 evening-shift POCC subjects. During the mission, gastrointestinal distress, anxiety, sleepiness, insomnia, sadness, and fatigue were more severe in the control group than the treatment group, relative to baseline. Although sleep quality was not better in the treatment group, they were more alert at the beginning and end of their duty shifts than controls. The most impressive effect of light treatment for evening shiftworkers was after the mission ended, when the treatment group recovered much sooner and took fewer days off from work.

Subjects rated the treatment protocols as highly effective for promoting adjustment to their shifted work schedules, and indicated their interest in using light treatment for future missions. These studies demonstrated that light treatment is both feasible and useful for NASA personnel who must work on shifted schedules during Space Shuttle missions.

A similar light treatment study was conducted during ATLAS-2 [34]. Volunteers from the night shift and nighttime 12-hour replan teams self-administered light treatment at home. Light exposure was used to maintain shifts in circadian phase during the mission and to promote rapid readjustment to normal sleep and work schedules after the mission's end. At the end of the mission, subjects who underwent light treatment and untreated control subjects completed detailed questionnaires concerning their sleep, job performance, and recovery from shiftwork during ATLAS-2.

On all four measures of sleep quality and all four measures of self-rated job performance, subjects who received light treatment fared better than control subjects. In addition, control subjects took longer to recover from the deleterious effects of mission shiftwork and took more days off from work after the mission ended.

The results of this study replicated our previous data from USML-1, and confirmed the beneficial effects of light treatment for MSFC POCC NASA personnel who must work on shifted schedules during Space Shuttle missions, including both those on 13-hr duty shifts as well as 9-hr shifts.

II. CIRCADIAN COUNTERMEASURES FOR USMP-2 POCC SHIFTWORKERS

A. Introduction

The objective of the project was to design and implement countermeasures for minimizing physiological and psychological disturbances in USMP-2 POCC cadre shiftworkers. These countermeasures involved scheduled exposure to intense artificial light, scheduled avoidance or attenuation of sunlight, and/or schedules for sleep in darkness. The countermeasures were customized to be appropriate for each individual volunteer. In addition, questionnaire data were collected in order to evaluate the effectiveness of the countermeasures.

This project differed from the USML-1 and ATLAS-2 light treatment projects in several important respects:

1) In this project, light treatment was made available to more POCC cadre members, and treatment protocols were designed for a wider variety of work schedules, compared to previous missions.

In the previous projects, only night- or evening-shift workers were offered light treatment. In contrast, all USMP-2 POCC cadre members were eligible to participate in the project even if they were on the day shift. The major reason for this is that most of the daytime duty shifts during USMP-2 began very early in the morning, e.g., 6:00 A.M. This means that most workers on this shifts must arise between 4:00-4:30 A.M. in order to be on console on time. This is difficult for many people, and some dayshift workers experience the same difficulties as nightshift workers. Such workers may benefit from light treatment.

USML-1 investigated treatment protocols designed for night- and evening-shift workers on 9-hour duty shifts, and all protocols were designed to phase-delay circadian rhythms. ATLAS-2 included subjects working 13-hour duty shifts, and included some whose protocols induced circadian phase-advances. In both of these studies, volunteers worked on relatively fixed shifts. To date, there have been no studies of the efficacy or feasibility of light treatment for workers on rotating shifts. Some USMP-2 cadre members were assigned to rotating shifts, and this was the first time light treatment has been used by rotating shiftworkers.

2) Countermeasures were customized for each participant and did not necessarily include light treatment.

USML-1 treatment protocols all included light treatment and protocols were not individualized for different workers. ATLAS-2 treatment protocols were somewhat customized, but all included a light exposure component. In contrast, USMP-2 countermeasures were entirely individualized, and some workers were treated with protocols that did not include exposure to artificial light.

This decision was based on recent findings from two studies. The USML-1 study showed that although evening shift workers may benefit from pre-mission light treatment, the inconvenience of light treatment may not justify the benefits, except in individuals who are extremely intolerant of shiftwork. On the other hand, "recovery" light treatment after landing is extremely beneficial for helping evening shift workers readjust to normal work and sleep schedules.

In addition, a recent study by Eastman and Stewart [35] evaluated the separate contributions of light treatment and dark goggles (to attenuate exposure to sunlight at inappropriate circadian phases) to adjustment to simulated shift work. That study showed that although the combination of light and goggles is the optimal treatment for promoting adaptation to night shifts, some shiftworkers may still derive some benefit from goggles alone. This study that circadian countermeasures can help even those shiftworkers who cannot or will not undergo light treatment.

These findings were incorporated into the USMP-2 project. Dark goggles were offered to any volunteers who did not wish to use light, whose work schedules did not warrant the inconvenience of light treatment, or who had medical contraindications for light. Similarly, those who could not or would not use light or goggles were offered sleep schedules and heavy black plastic to cover their bedroom windows, which enables them to sleep in darkness and avoid exposure to undesired daylight. This was the first time that circadian countermeasures that do not involve exposure to artificial light were tested by real shiftworkers.

3) The emphasis of this project was on implementation rather than research.

The major goal of this project was to implement findings from previous studies. Data collection and analysis were secondary. Although volunteers were requested to complete questionnaires, participation in the project was not contingent on supplying data.

Because of the wide variety of work schedules and treatment protocols used in this mission, the data cannot be pooled for analysis. Instead, the data will be stored, and then pooled with and analyzed with any additional data that become available in the future.

B. Recruitment of Volunteers

Potential volunteers were introduced to the project through a series of presentations made to the USMP-2 POCC cadre. The goals of the project and the specific procedures were explained and volunteers were solicited. Individuals were eligible to participate even if they typically experienced no difficulty adjusting to night work.

Twenty members of the USMP-2 POCC cadre were invited to participate in the project. Ten people signed up for treatment. Two of them declined light treatment but only wanted plastic and goggles. Those who participated constituted most of those on night or rotating shifts.

Volunteers were not paid or otherwise compensated for participation. They were guaranteed that all personal information would be kept confidential. They received complete instructions, both orally and in writing, about the treatment procedures and possible side effects of light treatment, which can include mild and transient eyestrain and headache. All volunteers who underwent treatment provided written informed consent. All volunteers were healthy, as determined by a Health Information Questionnaire that was required for participation.

C. Treatment Protocols

Eight of the ten people who signed up for the project underwent light treatment. Of these, phase-delay schedules were prepared for five of the volunteers, whose duty shifts encompassed the nighttime and early morning hours. These protocols (see Appendix, Schedules A-E) were designed to induce large circadian phase delays until the "subjective day" coincided with night duty shifts, and the "subjective night" occurred during daytime sleep. Light exposure was scheduled during the first part of the "subjective night", starting several days before the first night shift. The time for light exposure shifted each day to keep pace with the shifting circadian system. During the mission, brief daily exposures were scheduled when appropriate, in order to maintain the light-induced phase shifts. At the end of the mission, exposure times changed in order to phase-shift rhythms back to their normal phase relative to sleep, work, and sunlight. Contingency protocols were prepared in case the launch was delayed.

One volunteer whose duty shifts began early in the morning was provided with a light treatment protocol designed to phase-advance circadian rhythms (see Appendix, Schedule F). Light treatment was scheduled in the last part of the night. This individual's duty shifts began progressively earlier during the mission; consequently, the times for light treatment also advanced during the mission. At the end of the mission, light was scheduled in the evening in order to delay rhythms back to their normal phase, in time for the individual to return to normal work and sleep times.

Two individuals whose duty shifts encompassed primarily the late afternoon and evening hours were not treated with light prior to the beginning of mission shiftwork. Instead, they were given sleep schedules and instructions and schedules for avoiding exposure to sunlight during the morning hours. For these individuals, light treatment did not begin after the last duty shift (see Appendix, Schedules G and H). Light treatment was scheduled during the morning hours in order to phase-advance rhythms back to their normal phases.

The final two volunteers did not wish to undergo light treatment. They were simply provided with goggles and black plastic window coverings to help them avoid sunlight, and instructions for using them.

When the times for light treatment coincided with daylight, volunteers could go outdoors instead of using the light box. Volunteers were instructed to adhere to the treatment protocols even on off from work. Thorough instructions were provided, both in written form, and through a presentation to the POCC cadre.

D. Treatment Procedures and Apparatus

1. Light Exposure. Subjects self-administered light treatment at home using portable light boxes (Apollo Light Systems, Orem, UT). These wooden boxes are 24 in x 15 in x 5 in and weigh 15 lbs. Each is equipped with six cool-white fluorescent lamps behind a sheet of prismatic plastic. The boxes were modified by surrounding them with four trapezoidal-shaped pieces of a stiff, light-weight material (1/2" Gatorfoam) that formed a frame extending two feet beyond the light box. The smaller end of the frame was placed against the luminous aperture of the light box, and the user sat at the larger end, which formed an opening measuring 3 ft x 2 ft. The interior surfaces of the frame were non-specular white with a reflectance of approximately 86%. The exterior surfaces were painted black and black tape was used along all seams to hold the frame in place and prevent light leakages. The frame served to increase the illuminance of the device, to deliver both direct and indirect light to the user, and to ensure maximal exposure to the light source even with variations in gaze. Users are exposed to approximately 8800-10,670 lux. The enclosure served as a workstation which permitted subjects to read, work, or relax while undergoing light treatment. The light delivery system was developed for this project at MSFC by Benita Hayes [33,34].

2. Avoidance of Sunlight. During times of day when light exposure would counteract the desired phase-shifts, volunteers were instructed to avoid sunlight by remaining indoors in ordinary room light, which is not intense enough to shift circadian rhythms [19,20]. When they had to go outdoors in sunlight at times when light exposure was prohibited, they wore dark goggles to attenuate light intensity. They were provided with two different goggles, one with a transmittance of 1.0% and one with 0.35%, and were to wear the darker ones if they could see adequately. The frames and earpieces of the goggles (Cricket, UVEX Winter Optical, Inc., Smithfield, RI) are adjustable so that they may fit closely around the face and minimize light leaks around the eyes.

3. Sleep. For most individuals, eight hours were allotted for sleep each day throughout the mission, and sleep times were flexible whenever possible. Instructions were provided regarding naps.

Light exposure during sleep can disturb sleep and induce undesired circadian phase shifts. Because ordinary window blinds and so-called "blackout" shades admit some light, all bedroom windows were covered with heavy black plastic to prevent any daylight from entering the bedrooms. With the black plastic on all bedroom windows, bedrooms approached photographic darkroom standards even during daylight. In addition, volunteers were provided with earplugs to wear during daytime sleep.

E. Post-Mission Survey

At the completion of the study, volunteers were asked to complete a post-mission survey. They were requested to rate their sleep quality and job performance during USMP-2, their readjustment to normal sleep and work schedules after the mission, and other features of their shiftwork schedules. Volunteers who underwent light treatment also rated their perceptions of the light apparatus and treatment efficacy.

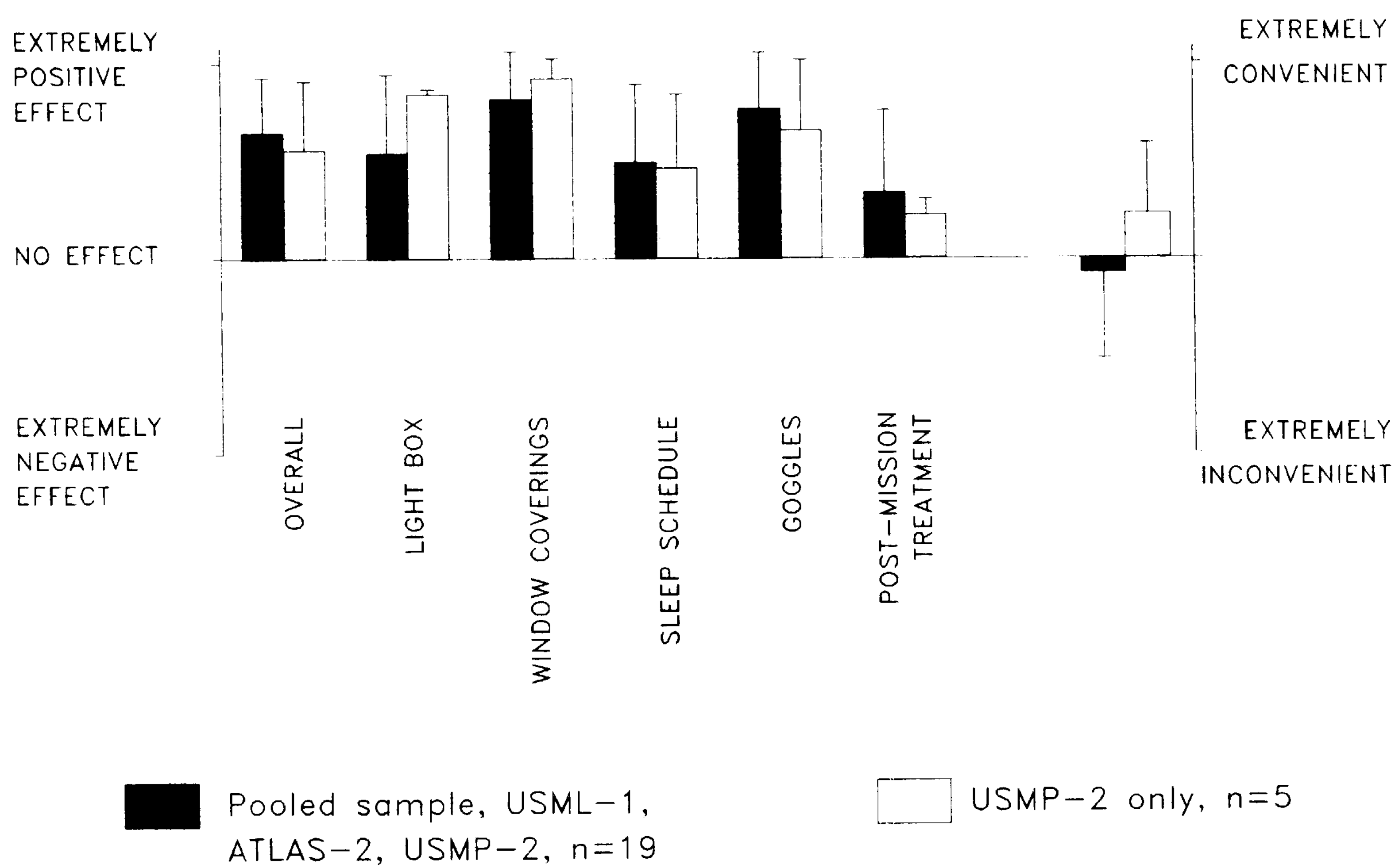
We recruited an additional five individuals to serve as controls. These workers had mission duty schedules similar to the treatment volunteers, but either were not interested in trying light treatment, or had personal obligations that made it impossible to follow a treatment protocol. During the pre-launch week, the mission, and the days following landing, control participants selected their own sleep times and underwent no treatment. They were free to employ any means they thought would help them cope with their shifted work schedules. Most of the control subjects used some method to help them sleep during the day and stay awake on console. These methods included covering their bedroom windows, shifting their sleep schedule before launch, earplugs during sleep, naps, alcohol, and over-the-counter sleep medications. The control participants completed the same post-mission survey as the volunteers who underwent treatment.

III. RESULTS

Post-mission surveys were collected from five volunteers who under went treatment: two from the evening shift, one from the night shift, one from the rotating shift (night/day) and one whose 13-hour shifts spanned the evening and night hours and also gradually advanced during the mission. Five control participants with similar duty schedules also completed the survey. Because the disparity in work and treatment schedules precludes pooling the data from these volunteers, data on sleep, on-the-job alertness and performance, physical and mental well-being, and recovery from shiftwork schedules were not analyzed at this time.

Subjective ratings of treatment efficacy were rated along 125-mm visual analog scales, collapsed across the various shift schedules and treatment groups, and pooled with data from USML-1 and ATLAS-2 treatment groups. Mean responses (± 1 standard deviation) to these questions are shown in Figure 1 (page 10).

SUBJECTIVE RATINGS OF TREATMENT EFFICACY
ALL SHIFTS (mean ± 1 s.d.)



In general, responses from the USMP-2 volunteers were similar to those of the pooled sample. Strong positive effects were attributed to each of the treatment components (light box, window coverings, sleep schedule, and goggles) as well as to the overall treatment program. Post-mission treatment was also rated as conferring a positive effect, although the magnitude of the effect was not as great as for pre-mission treatment. The treatment was not seen as particularly inconvenient, and the beneficial effects appear to outweigh the inconvenience. All the volunteers who returned the survey stated that they would like to undergo light treatment again on future missions. The Appendix contains verbatim transcripts of written feedback from subjects.

IV. DISCUSSION AND RECOMMENDATIONS

In contrast to the light treatment projects conducted during USML-1 and ATLAS-2, the USMP-2 project focussed more on program implementation than on research. Accordingly, analysis and conclusions concern program efficacy rather than treatment efficacy.

One important indicator of program efficacy is participation rate. The ten individuals who volunteered for treatment constitute the largest group we have treated at MSFC to date, and they represent the largest variety of duty schedules and treatment approaches as well. The high participation rate is a likely consequence of the difficulty of the USMP-2 duty schedules, the customized treatment approaches, and the fact that completing questionnaires was not required for participation. It is possible that more in-service training about shiftwork and circadian countermeasures could increase the participation rate in future missions. For example, when those who did not sign up for the project were asked to give their reasons, a commonly cited reason was that personal or family responsibilities would not leave enough time for light treatment. However, these individuals may not have been aware that treatment protocols can be customized to accommodate such conflicts. Similarly, many non-participants used self-selected techniques for coping with their shiftwork schedules. Some of these techniques, such as increased caffeine intake, alcohol, and over-the-counter sleep medications, may have deleterious effects on performance, sleep, and well-being, while others, such as napping, pre-mission sleep shifting, and dark window coverings are a part of the countermeasures program. Education could induce some workers to abstain from the undesirable coping methods and use others more systematically and effectively.

Subjective ratings of program efficacy were consistently high, both in USMP-2 volunteers and from the entire pooled sample from three missions. Both the overall treatment program, and each of the treatment components (light box, window coverings, sleep schedule, and goggles) were seen as conferring positive benefits. These findings are supported by the written comments we have collected from volunteers. Although post-mission treatment was also rated as effective, the ratings were lower than for pre-mission treatment. This is probably a result of the fact that compliance with post-mission treatment is generally not as good as with pre-mission treatment. Once a mission ends, workers face less incentive to maintain peak performance and alertness, and increased pressure to resume their normal occupational and personal responsibilities and make up for "lost time". Thus, post-mission treatment is not a high priority for many workers. Increased emphasis on convenience of treatment may improve compliance, and hence, efficacy, of post-mission treatment. In this regard, participants were asked to rate the convenience or inconvenience of treatment, and the data suggest that the inconvenience is not a significant problem. In fact, the USMP-2 volunteers did not find treatment to be inconvenient at all, in contrast to the pooled sample, which found treatment to be slightly inconvenient. This suggests that when participants are not required to complete questionnaires and surveys, they find the countermeasures program to be much more convenient. The data suggest that the benefits of the countermeasures program outweigh the inconvenience involved.

Finally, all but one of the nineteen volunteers who have been treated with light at MSFC indicated that they would sign up for treatment again on future missions, especially for an extended-duration mission or for nightshift duty. This finding, along with the high participation rate during USMP-2, the efficacy and convenience ratings, and the treatment data from USML-1 and ATLAS-2, lead to the impression that the circadian countermeasures program is successful.

The efficacy data described above were collapsed across different kinds of shift schedules, because this project was designed to address "program" efficacy more than "treatment" efficacy. However, several observations regarding treatment for specific shift schedules are pertinent, because treatment efficacy is largely a function of the duty schedule. For the first time during this mission, a worker on a rotating shift schedule was treated with light. The data from this individual, who worked at night during the first part of the mission, and by day during the last few days (see Appendix, Schedule D), showed that light treatment was extremely effective in helping her adjust to the night shifts and then quickly readjust to daytime work. It is tentatively suggested that light treatment may be feasible and useful for rotating shift schedules, _if_ there are several days off (at least three) between rotations when light treatment can be used to readjust circadian phase, and _if_ it is not a "rapid rotation" schedule (e.g., two nights, two days, one off, repeat). The ability to successfully treat rotating shiftworkers would greatly extend the range of workers and work schedules that can benefit from a countermeasures program.

Schedule E (see Appendix) is an example of a shift schedule that is so difficult that even light treatment is of limited benefit. This schedule combines three features that adversely affect alertness, performance, sleep, circadian rhythms, and well-being: 1) long (13-hour) duty shifts that promote fatigue; 2) duty shifts that span both evening and night hours, such that both sleep and work will take place at inappropriate circadian phases; and 3) gradual advances in work times during the mission, which are impossible for circadian rhythms to adjust to without light treatment. This means that even if pre-mission light treatment successfully shifts circadian phase to an appropriate phase for the first few duty shifts, by the second half of the mission circadian rhythms will again be "out of phase" with the work schedule. With such long duty shifts, there is no time during the mission itself when light treatment can be used to adjust circadian phase. As expected, this worker reported good performance and sleep during the first half of the mission, and poor performance and sleep during the second half. Every effort should be made to avoid using such work schedules. The IML-2 flight crews will work on a similar schedule; despite the fact that POCC duty schedules are often keyed to the flight crews, it is recommended that IML-2 POCC management reduce the number of POCC cadre members who will work on this type of schedule.

Two additional recommendations emerge from our experiences working with MSFC shiftworkers:

1. Healthy, appropriately phase-shifted meals should be provided to POCC cadre during Space Shuttle missions. Virtually all participants in our three studies indicated that they would like to have healthy meals available to them at the POCC during missions. Healthy nutrition is essential to proper cognitive and physical functioning and well-being, and POCC personnel have little free time during missions to prepare healthy meals at home. Furthermore, gastrointestinal disturbances are one of the most prominent symptoms of shiftwork. This can arise from eating the "wrong" meals at the wrong circadian times, or from eating too much unhealthy food. Healthy, balanced, "circadian time-shifted" meals would help promote optimal functioning during mission duty shifts.

2. MSFC work schedules should be redesigned in accordance with circadian principles. Although shiftwork is unavoidable during Space Shuttle missions, work schedules can be developed in accordance with circadian principles in order to minimize the detrimental effects of shiftwork and to maximize the efficacy and convenience of shiftwork countermeasures.

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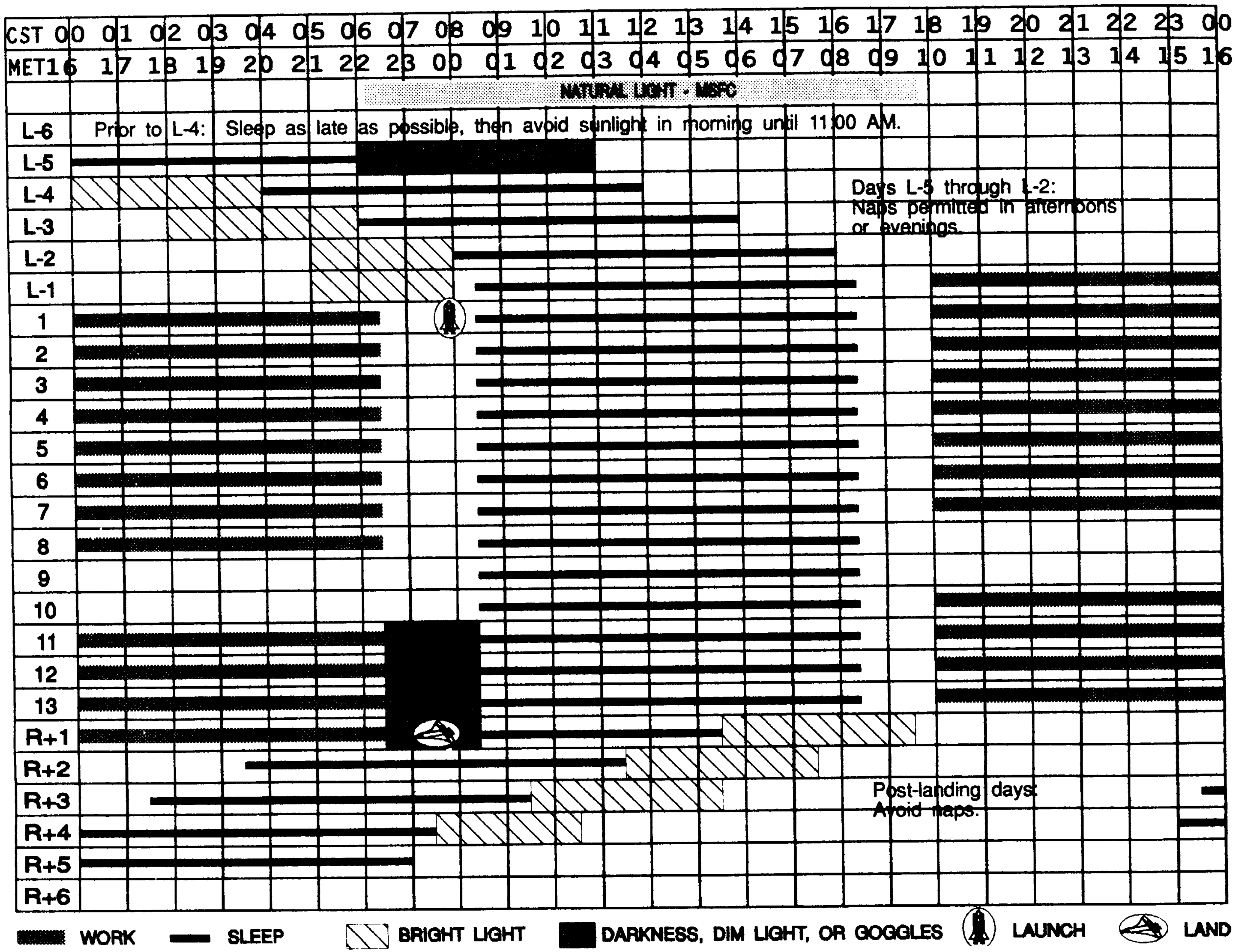
APPENDIX

Treatment Protocols

Subject Comments

USMP-2 SHIFTWORK TREATMENT PROTOCOL

SCHEDULE A



USMP-2 SHIFTWORK TREATMENT PROTOCOL

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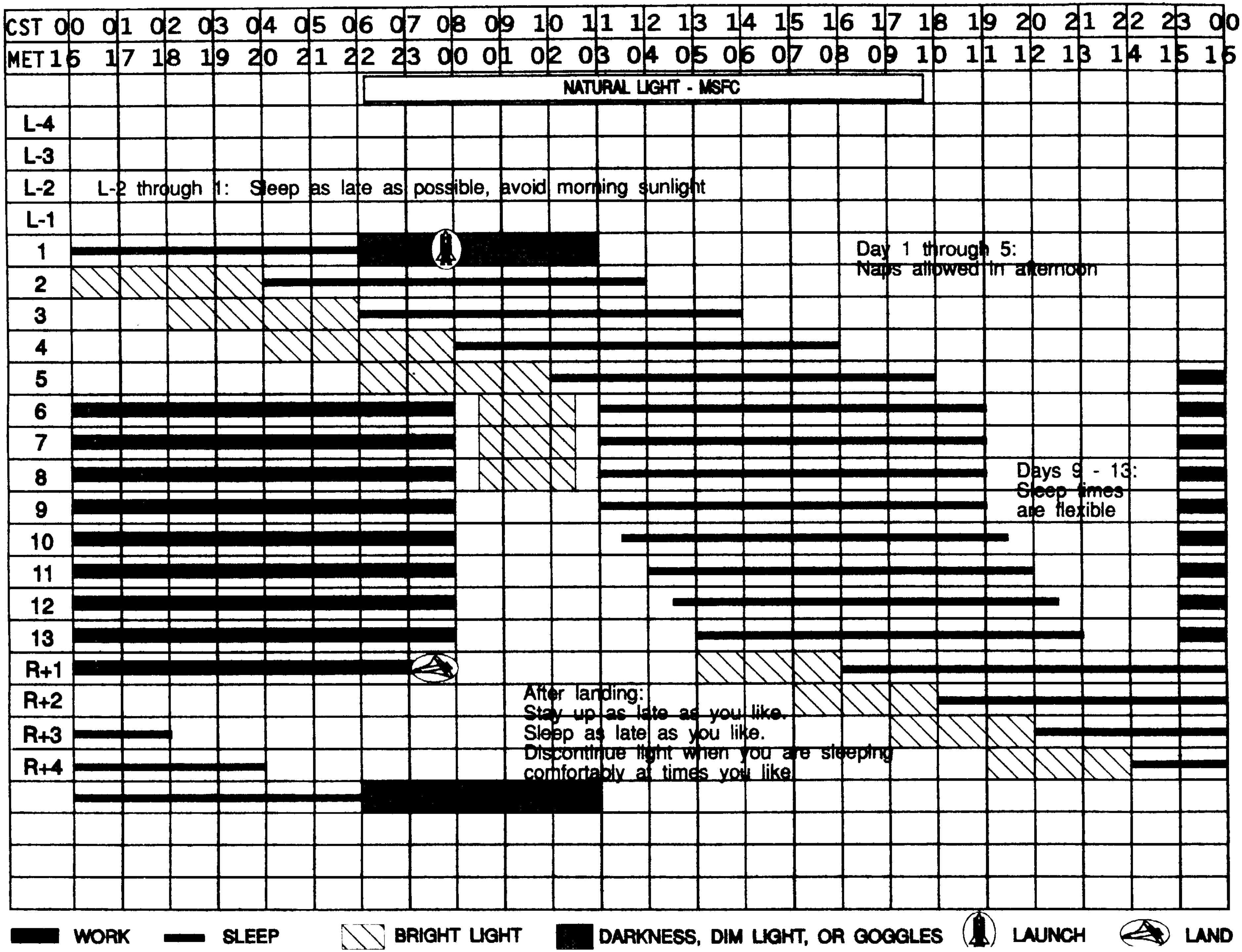

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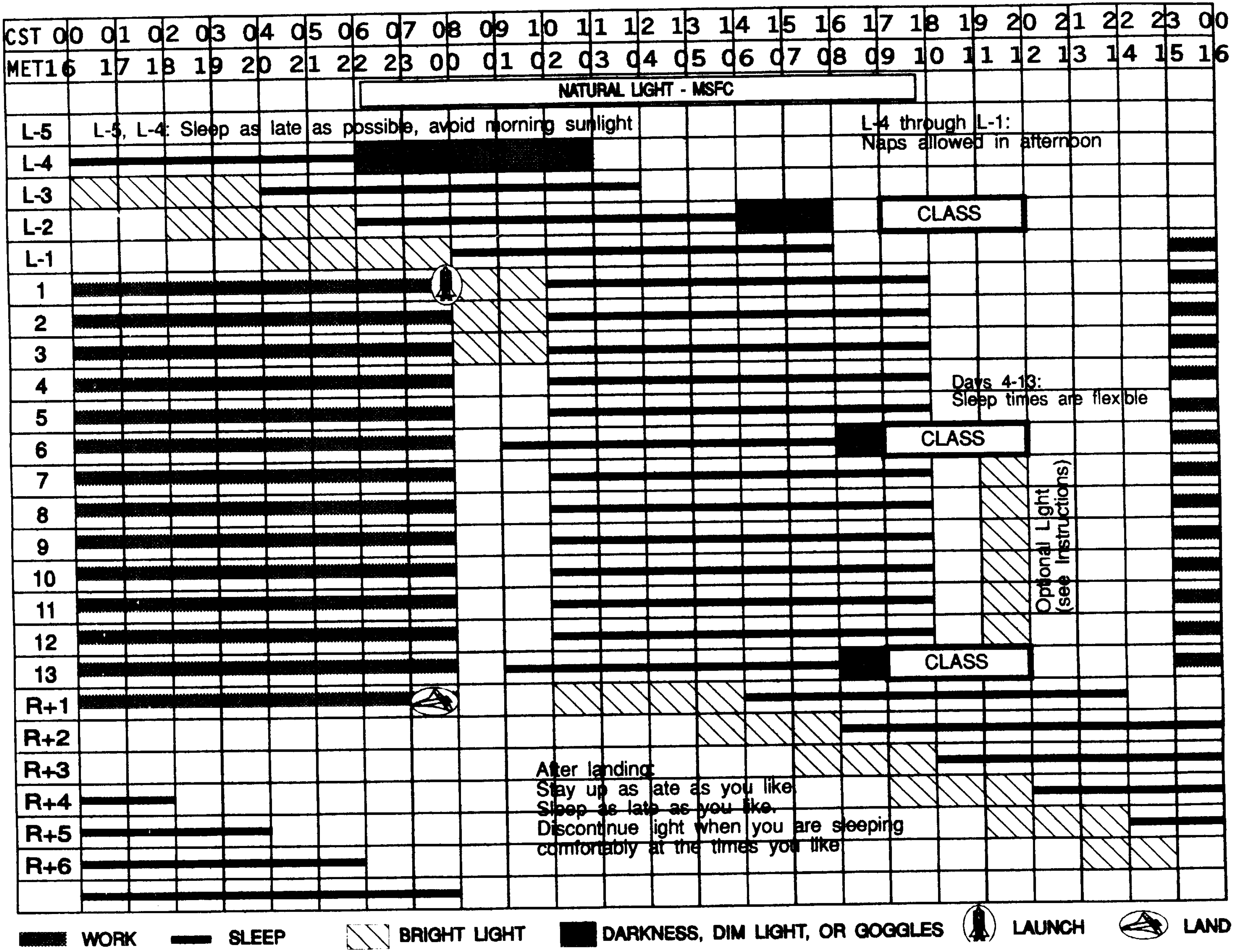

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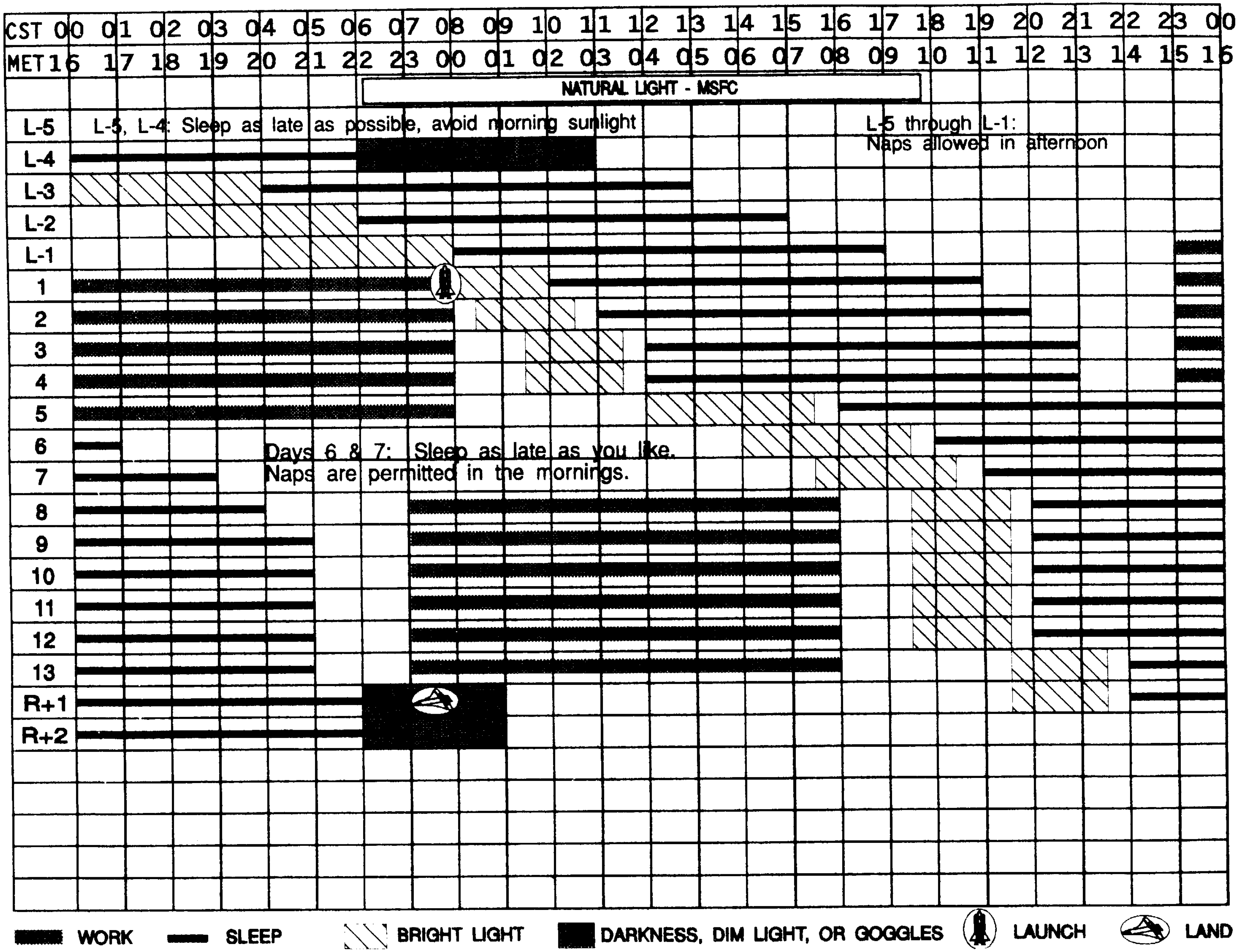

USMP-2 SHIFTWORK TREATMENT PROTOCOL

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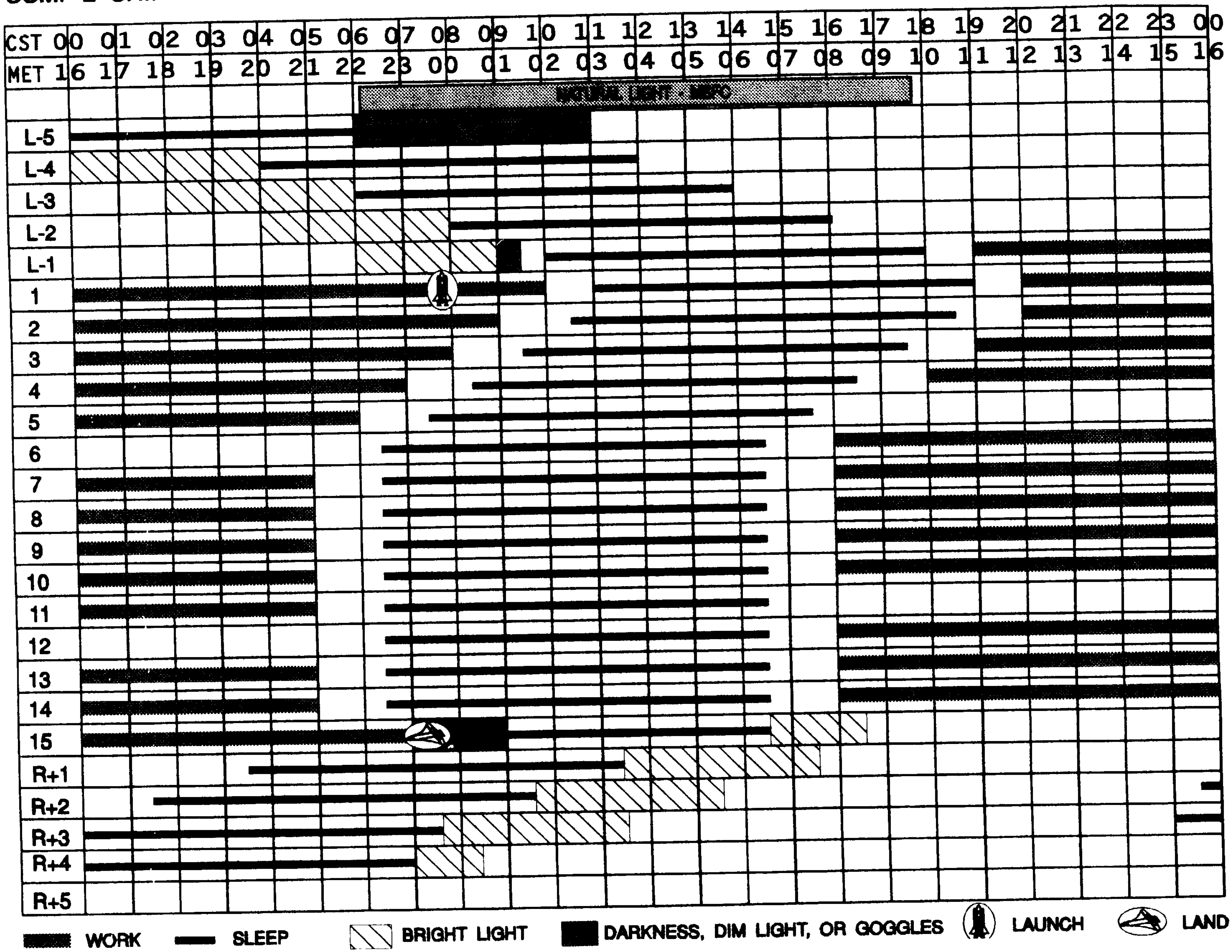

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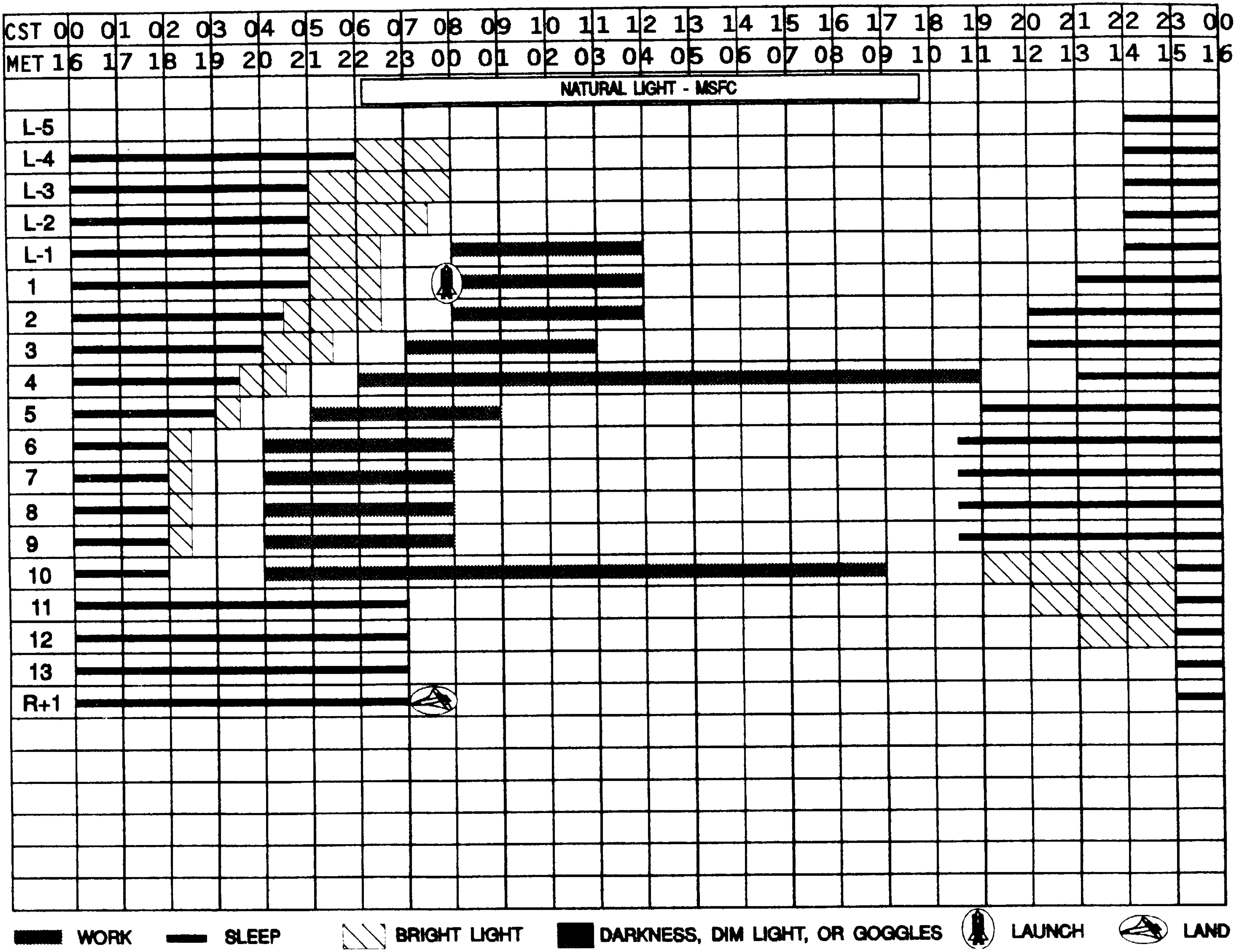

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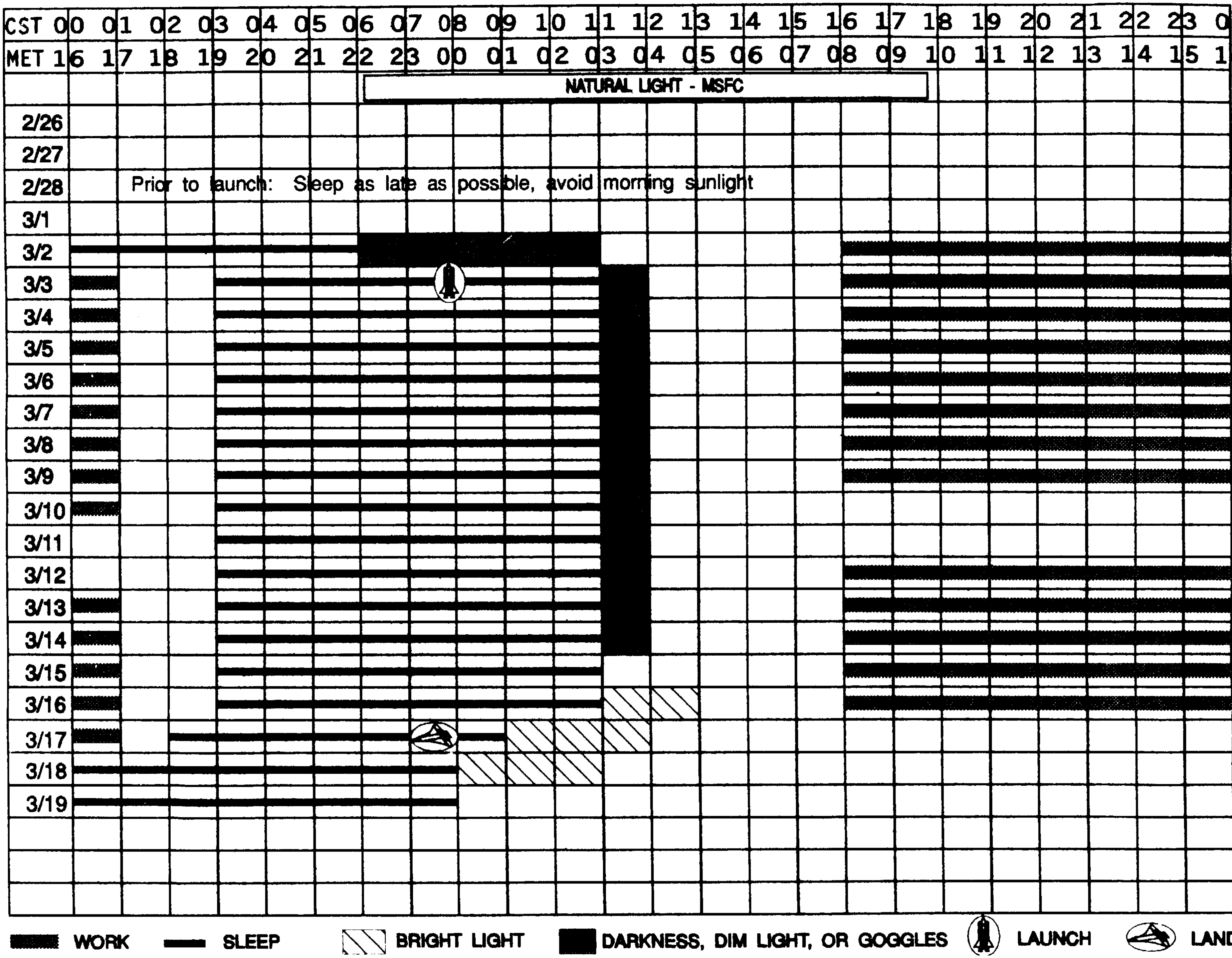
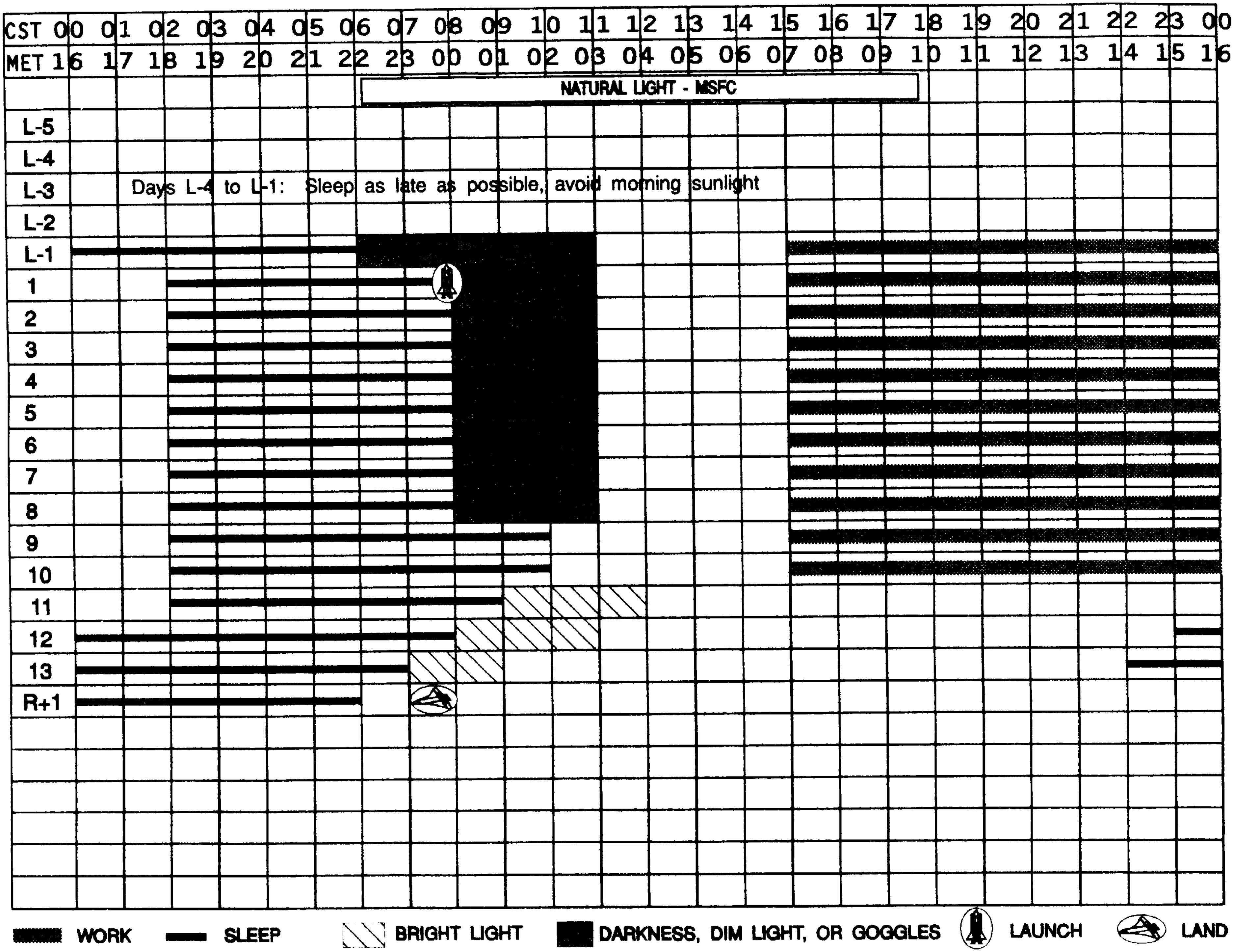


USMP-2 SHIFTWORK TREATMENT PROTOCOL

SCHEDULE H



SUBJECT COMMENTS

The final question on the post-mission survey was "Please feel free to add any observations, comments, or recommendations concerning your shift schedule, light treatment, or about the circadian rhythm study." Here we present verbatim transcripts of subjects' comments in response to the question. These comments are from both treatment and control participants.

Treatment participants:

1. During my light treatment times I took breaks and watched TV, washed dishes, even painted my kitchen with the light box in the room. The room was extremely bright. My body was completely shifted to the night shift. I felt more alert during the night shift than during dayshift and I think it's because I made more effort to sleep per schedule than on day shift. The light therapy during my days off in the middle helped me shift to day shift very effectively. Thanks for all your help and concern.

2. The treatment was very beneficial in shifting pre-flight. Post-flight I was so backed up with work and social events that I could not use the lights, ie. it was tough shifting back.

3. I wasn't able to use the light box once we got into the mission. The 12-hour shifts wore me out, and would have regardless of whether I had any light treatment during the flight (which would have been a moot point, considering I came home around dawn every day).

4. For IML-2, I will be working 3rd shift for a portion of the mission. Although I am interested in trying the light box, I think it will be difficult to come up with activities that can be done while using it.

Control participants:

1. The MSCI team works a 12+ hour shift. This makes the night shift more difficult because it leaves very little time to relax before going to bed. In order to leave enough time to get adequate sleep, it is necessary to go to bed immediately after eating. The feelings of boredom or fatigue are probably due to the nature of the work rather than the shift, because on the 2nd shift, the MSCI team seldom has many tasks requiring concentration or physical activity. Any nervousness or restlessness experienced during the mission is probably related to the long hours spent at the console.

2. Taking a two-hour nap before my shift kept me alert and awake during the entire shift.

3. I don't have anything against it [light treatment], except for invasion of my private life--and time. The best thing I

could do on future missions is find some place to sleep where family distractions will allow me to get 6 hours or so!

4. I was the relief shift. Therefore I did not stay on any shift for more than two days. Given those circumstances it is useless for me to try to shift my sleep schedule. By in large, I had no problems except for midnights.

5. The two days off during the mission helped tremendously. These should be required of cadre members working long hours for EDO missions.

Going to 8-9 hour shifts instead of 12-13 hour shifts would be the biggest help. It seems as though the off time (11-12 hours) is plenty each day, but when you start adding up driving time, sleep, eating and food preparation, personal hygiene, getting ready for work, etc., it's very hard to get all this accomplished to feel rested and not continually rushed each day.

Since no healthy food is available at the POCC I prepared my food and brought it almost every day. Although I was eating fairly healthy, food prep. time was <u>another</u> thing to do in the too short time between shifts. Good, health (and hot) food availability at the POCC would be a big help.

There was a distinct difference in the way I felt mentally and physically the lat four or so days of the mission (as seen in answers to questions.)