NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA CONTRACT NO. NASW-4598
TASK ORDER NO. 27

ENVIRONMENTAL ASSESSMENT FOR LIDAR IN-SPACE TECHNOLOGY EXPERIMENT

LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

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ENVIRONMENTAL ASSESSMENT
LIDAR IN-SPACE TECHNOLOGY EXPERIMENT
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

DECEMBER 1993

Prepared By:

Ebasco Services Incorporated

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ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
CFR	Code of Federal Regulations
cm	Centimeter
EA	Environmental Assessment
EMP	Enhanced Multiplexer/Demultiplexer Pallet
ft	Feet, Foot
FWHM	Full Width Half Maximum
in	Inch
J/cm^2	Joules Per Centimeter Squared
km	Kilometer(s)
km/sec	Kilometers Per Second
LHB	Langley Handbook
lidar	Light Detection and Ranging
LITE	Lidar In-space Technology Experiment
LTM	Laser Transmitting Module
m	Meter
mJ	MilliJoule
mm	Millimeter
MPE	Maximum Permissible Exposure
mph	Miles Per Hour
mrad	Milliradian
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NHB	NASA Handbook
nm	Nanometer
n. mi.	Nautical Mile
NHZ	Nominal Hazard Zone
NOHD	Nominal Ocular Hazard Distance
nsec	Nanosecond
RE	Radiant Exposure
w/m^2	Watts Per Square Meter

A fold-out copy of this list appears at the back of the EA.

1.0 SUMMARY AND CONCLUSIONS

The proposed action involves testing a lidar (LIght Detection And Ranging) system in space for its potential use in a global atmospheric monitoring program. Lidar systems have been used for nearly three decades to study atmospheric conditions from the ground and from aircraft, and research results have indicated the potential advantages of using lidar systems to monitor atmospheric conditions from space.

The principal components of a lidar system are the laser transmitter module (LTM) and the telescope-receiver. The LTM shoots a pulsed laser beam into the atmosphere where much of the laser energy is absorbed by the atmosphere. Some of the energy is reflected back toward the telescope-receiver, while a small fraction passes through the atmosphere and reaches the Earth's surface. The reflected energy received at the telescope-receiver is used in assessing meteorological conditions (e.g., cloud conditions) and atmospheric aerosols (e.g., atmospheric contaminants), as well as in monitoring the ozone layer. By using pulsed laser energy to penetrate the atmosphere, a lidar system can operate continuously, making global measurements, and can provide a better understanding of the vertical distribution of atmospheric constituents than the passive spaceborne atmospheric monitoring systems currently in use.

The proposed Lidar In-space Technology Experiment (LITE) will entail flying a lidar system as an attached payload on the Space Shuttle. The first flight is scheduled for the fall of 1994. The first flight will be a nine-day mission to gain experience in operating a lidar system in a space environment, and to evaluate the sensitivity of the lidar instrument for performing scientific studies on clouds, aerosols, and the middle atmosphere. The current flight plan calls for ten data takes consisting of three 90-minute orbits (4.5 hours per data take). The planned orbit will cover the entire Earth between the 57° north latitude and the 57° south latitude, and will have a 269-kilometer (km) (145-nautical mile (n. mi.)) altitude, although the LITE instrument can operate at altitudes from 195 to 324 km (105 to 175 n. mi.).

The proposed action and the No-Action alternative were considered in this Environmental Assessment (EA). The No-Action alternative will not fulfill NASA's objective to advance the nation's atmospheric monitoring capabilities. Under the No-Action alternative, it will not be possible to develop the technology for a space-based lidar system, and it will be necessary to continue to rely on existing passive monitoring instruments which have limitations in providing an understanding of the vertical distribution of atmospheric constituents.

The only potential source of environmental impact from the proposed action is the portion of the laser energy which will pass through the atmosphere and reach the Earth's surface during laser shoots.

2.3 PROJECT OBJECTIVE

The primary goals of LITE are to test the feasibility of space-based lidar technology, to provide real measurements and data from outside the Earth's atmosphere, and to provide a platform for the development of technology for future space-based lidar systems. LITE is primarily a technology experiment, and will address the issues related to developing an instrument for long-duration operation on a free flying spacecraft platform, including lidar system operation and lidar techniques in space. The evaluation of lidar system operation will address laser design and operation in space, thermal management, alignment and control, and system autonomy (Couch et al., 1991). The evaluation of lidar techniques will address verification of the signal-to-noise ratio of the reflected energy, resolution of altitude measurements, and measurement of atmospheric characteristics at different wavelengths and different altitudes. LITE also will collect data regarding clouds, aerosols in the lower atmosphere, stratospheric aerosols, and atmospheric density/temperature, for use in atmospheric modeling (Couch, 1991).

2.4 SCOPE OF THE ENVIRONMENTAL ASSESSMENT

This Environmental Assessment (EA) addresses the environmental issues related to operation of the LITE experiment. This EA was prepared in accordance with the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (NEPA) (40 CFR Parts 1500 - 1508) and NASA policy and regulations (14 CFR Part 1216.3).

interfacing the mechanical, thermal, power, and command and data handling accommodations available from the Shuttle to the instrument (Couch et al., 1991).

The current flight plan calls for ten data takes consisting of three 90-minute orbits (4.5 hours per data take). The planned orbit will cover the entire Earth between the 57° north latitude and the 57° south latitude, and will have a 269-km (145-n. mi.) altitude, although the LITE instrument can operate at altitudes from 195 to 324 km (105 to 175 n. mi.) (Couch et al., 1991). During the lidar data takes, the Shuttle cargo bay will be oriented toward the Earth. The laser will be fired down into the atmosphere, and the reflected light will be collected by the telescope-receiver. Much of the laser output energy will either be absorbed or reflected by the atmosphere, but, a small fraction will reach the Earth's surface. During periods between lidar data takes, the laser will be in standby and will not emit energy.

During data takes, a series of circular laser spots will occur on the Earth's surface along the ground track of the Shuttle (Figure 2). The diameter of these spots will depend upon the divergence of the laser beam at each wavelength: at the planned Shuttle altitude of 269-km (145 n. mi.), the diameter will be 483 meters (m) (1,585 feet (ft)) for the 1064-nm wavelength, 295 m (967.8 ft) for the 532-nm wavelength, and 265 m (869.4 ft) for the 355-nm wavelength. Each laser pulse, and consequently the laser spot, will last for 20 nanoseconds. At the planned orbiting altitude, the Shuttle will have a ground track velocity of 7.4 kilometers per second (km/sec) (16,553 miles per hour (mph)). Since the laser will operate at 10 pulses per second, this ground track velocity will result in the laser spots being spaced at approximately 740-meter (2,428-foot) intervals along the ground track. Consequently, the laser spots will not overlap, and it will not be possible for a person on the Earth's surface to be within two consecutive laser spots.

3.2 ALTERNATIVES

The alternatives considered in this EA are the proposed action described in the preceding section and the No-Action alternative. The No-Action alternative provides the benchmark against which the proposed action is evaluated. Under the No-Action alternative there will be no LITE, and consequently no lidar technology testing for space-based application. Atmospheric conditions will continue to be monitored by passive instruments orbiting the Earth. Ground- and aircraft-based lidar systems will continue to be used to observe lower atmospheric conditions.

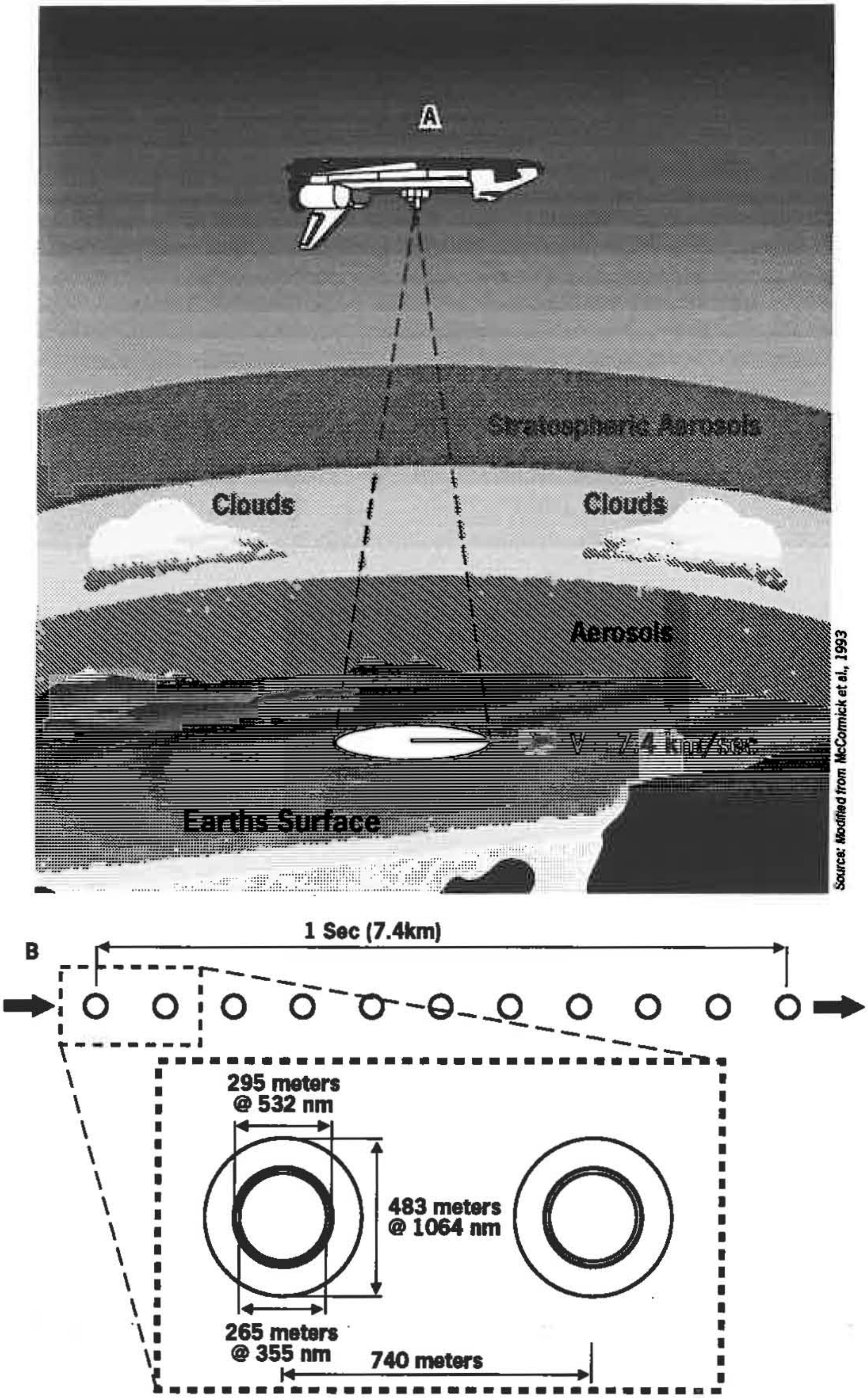

Figure 2. (A) LITE Space Shuttle Configuration, and (B) Laser Spot Diameters at 355-nm, 532-nm, and 1064-nm Wavelengths at a Space Shuttle Altitude of 145n. mi.

4.0 ENVIRONMENTAL IMPACTS

4.1 PROPOSED ACTION

4.1.1 Potential Source of Impact

The proposed action evaluated in this EA is the normal operation of the LITE payload from within the Space Shuttle cargo bay. The environmental impacts of the Space Shuttle have been addressed in existing NASA NEPA documentation for the Space Shuttle program (NASA, 1978).

All electrical operating power for the LITE payload will be received from the Shuttle fuel cells, and all heat generated by the operation of the payload will be controlled by the Shuttle cargo bay Active Thermal Control System. The Orbiter Attitude Control System will provide the pointing control of the laser beam; the LITE payload will not have any built-in attitude controls or propulsion systems. The payload will remain in the Shuttle cargo bay at all times during the on-orbit operations, and will not produce any effluent which could escape the cargo bay during mission operations. All data acquired during the flight will be either recorded on-board or downlinked through standard Shuttle communications facilities. The only feature of the LITE payload which will emerge from the cargo bay will be the laser beam. As described earlier, a portion of the optical energy from the LITE lasers will pass through the atmosphere and reach the surface of the Earth. Consequently, the environmental evaluation presented in this EA focuses on the potential impacts of the LITE lasers.

4.1.2 Biological Effects

With respect to flora, the LITE lasers will have no injurious effects since the solar energy reaching vegetation far exceeds the energy from the laser. The typical value of the solar radiation is 1,388 watts per square meter (w/m^2), and may be as high as 1,410 w/m^2 in January when the Earth reaches its point of closest approach to the sun. The total power of the LITE LTM laser energy at the lowest Shuttle altitude of 195 km (105 n. mi.) is 1.09E-03 w/m^2. Consequently, the solar energy exceeds the laser energy by a factor of at least one million (Appendix A).

With respect to animals and human beings, the potential for effect will be from skin exposure and eye exposure to the laser energy. The following presents the results of an analysis of the risk of injury to persons exposed to the laser beam during normal operation of the LITE LTM (Couch and Climolino, 1992). This analysis was subject to an independent critical review by the Laser Branch of the U.S. Army Environmental Hygiene Agency which did not identify any technical errors (Appendix B).

The maximum Radiant Exposure (RE) to which a person on the ground (i.e., a person in a laser spot) would be exposed during normal operation of the LITE LTM was calculated and compared to the Maximum Permissible Exposure (MPE) values for direct, intrabeam viewing as defined in ANSI Standard Z136.1-1986 "American National Standard for the Safe Use of Lasers". Under the ANSI standard, MPE values are calculated to be at least one or two orders of magnitude lower than exposures known to cause injury, which incorporates an additional margin of safety into the MPE values.

Table 2

REs and MPEs for Skin and Eye Exposure
at the Three Laser Energy Wavelengths

Wavelength (nm)	Maximum RE (J/cm^2)[1]	MPE for Skin Exposure (J/cm^2)	MPE for Eye Exposure (J/cm^2)
1064	3.83E-10 to 1.55E-10	1.0E-01	5.0E-06
532	9.13E-10 3.70E-10	2.0E-03	5.0E-07
355	2.33E-10 9.43E-11	6.6E-03	6.6E-03

[1] For Shuttle altitude of 195 to 324 km (105 to 165 n. mi.)

nm = nanometer
J/cm^2 = Joules per square centimeter

Table 2 presents the REs and the MPEs for skin and eye exposure during normal operation of the LITE LTM. As shown in this table, the highest calculated REs for skin exposure at the three operating wavelengths are at least six orders of magnitude lower than their respective MPEs. This calculation indicates that there is no reasonable risk of injury to skin from the LITE LTM at any normal Shuttle operating altitude. Similarly, the highest calculated REs for eye exposure at the three operating wavelengths are at least two orders of magnitude lower than their respective MPEs. The maximum simultaneous exposure from both the 1064-nm and the 532-nm wavelengths (i.e., the sum of the maximum REs for the two wavelengths), both of which act on the retina (the 355-nm wavelength acts on the cornea) was calculated to be at least two orders of magnitude lower than the MPE. Using binoculars or telescopes to view the Shuttle will increase the eye exposure to persons within a laser spot. As shown in Table 3, the highest

Table 3

REs and MPEs for Eye Exposure Through 50-mm Binoculars at the Three Laser Energy Wavelengths

Wavelength (nm)	Maximum RE (J/cm^2)[1]	MPE for Eye Exposure (J/cm^2)
1064	1.95E-08 to 7.91E-09	5.0E-06
532	4.66E-08 to 1.89E-08	5.0E-07
355	1.19E-08 to 4.82E-09	6.6E-03

[1] For Shuttle altitude of 195 to 324 km (105 to 165 n. mi.)

nm = nanometer
J/cm^2 = Joules per square centimeter

calculated REs for exposure through binoculars will be lower than the MPEs. The maximum cumulative simultaneous exposure to both the 1064-nm and the 532-nm wavelengths was calculated to be lower than the MPE. These calculations indicate that there is no reasonable risk of eye injury from the LITE LTM at any normal Orbiter operating altitude.

Table 4 presents the maximum telescope diameter which a person within a laser spot could use to view the Shuttle without exceeding the MPE. As indicated by this table, a 164-mm (6.5-in) diameter telescope will collect sufficient energy at the 532-nm wavelength from the laser to expose the eyes of an observer to a level of radiation equal to the MPE. However, because the MPE is chosen to be one to two orders of magnitude lower than the level of any known hazard, there is still a considerable safety factor in the MPE.

4.1.3 Effects on Aircraft, Communications, and Space Systems

The Phase I Flight Safety Review found that normal operation of the LITE LTM will not be hazardous to persons in aircraft. The Nominal Hazard Zone (NHZ) (the distance from the LITE payload within which the radiation level during normal operation exceeds the applicable MPE) was calculated to be 11 km (6 n. mi.) from the Shuttle, which is well above the Earth's surface. The review also found that normal operation of the LITE LTM will not interfere with microwave, very-high-frequency, or ultra-high-frequency communication.

Table 4.
Maximum Telescope Diameter for Safe Viewing

Wavelength (nm)	Telescope Diameter [1] (mm)
1064	800
532	164
355	37,300

[1] Telescope diameter which would result in a RE equal to the MPE at a Shuttle altitude of 195 km (105 n. mi).

The LITE LTM was coordinated with the U.S. Space Command for review by the Laser Clearinghouse. The Clearinghouse responded that the LITE LTM lasers will not exceed the damage threshold, and will pose no threat to space systems (Appendix C).

4.2 NO-ACTION ALTERNATIVE

The No-Action alternative would entail no lidar testing from space and, consequently, would result in no laser energy reaching the Earth's surface from operation of the LITE LTM. This alternative would, however, curtail the development of a space-based lidar system for atmospheric monitoring. Without a demonstration of technological success in building, orbiting, and operating a lidar system in space, it would not be possible to establish a free flying spacecraft system for continuous global observation of atmospheric conditions by lidar systems. Space-based lidar observation systems are anticipated to be used to improve global climatic models and enable more-reliable weather prediction. Monitoring of atmospheric constituents by space-based lidar systems also is anticipated to greatly improve global monitoring of atmospheric pollutants and the condition of the ozone layer. Without advancement to space-based lidar systems, weather prediction and atmospheric monitoring would continue to rely upon existing monitoring technologies, which are capable of providing an imperfect understanding of global atmospheric conditions.

5.0 REFERENCES

Couch, R.H. and M.C. Cimolino, Ph.D., 1992. Revised Ground Observer Eye Safety Analysis for the Lidar In-space Technology Experiment (LITE). NASA Langley Research Center, Hampton, Virginia. LITE-02-1-03-01, Rev. A.

Couch, R. H., C.W. Rowland, K.S. Ellis, M.P. Blythe, C.P. Reagan, M.R. Koch, C.W. Antill, W.L. Kitchen, J.W. Cox, J.F. DeLorme, S.K. Crockett, R.W. Remus, J.C.Cases, and W.H. Hunt. 1991. "Lidar In-space Technology Experiment (LITE): NASA's first in-space lidar system for atmospheric research". Optical Engineering. Vol. 30, No. 1. January 1991.

McCormick, M.P., D.M. Winker, E.V. Browell, J.A. Coakley, C.S. Gardner, R.M. Hoff, G.S. Kent, S.H. Melfi, R.T. Menzies, C.M.R. Platt, D.A. Randall, and J.A. Reagan, 1993. "Scientific investigations planned for the lidar in-space technology experiment (LITE)". Bulletin of the American Meteorological Society. Vol. 74, No. 2, February 1993.

NASA, April 1978. Final Environmental Impact Statement, Space Shuttle Program

6.0 AGENCIES RECEIVING A COPY OF THE ENVIRONMENTAL ASSESSMENT

Department of Commerce, National Oceanic and Atmospheric Administration

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Environmental Protection Agency

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National Aeronautics and Space Administration

Randy Baggett
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Mail Stop SZG
Washington, D.C. 20546

APPENDIX A

COMPARISON OF LITE LASER POWER DENSITY TO SOLAR POWER DENSITY

National Aeronautics and
Space Administration
Langley Research Center
Hampton, VA 23681-0001

NASA

Reply to Attn of: 356

September 8, 1993

To: Ms. Dottie Keough, Ebasco Technical Services

From: 356/LITE Instrument Manager

Subject: Comparison of LITE laser power density to solar power density

In my draft of the Environmental Assessment I made the statement that the earth receives more energy from the sun than it will from the LITE laser. I present for your consideration the following justification:

1. First we must define the "solar constant." The solar constant is defined as the rate of reception of solar energy per unit area at the earths surface when the earth is at its mean distance from the sun, the radiation strikes the surface orthogonally, and the atmospheric absorption is accounted for. Since the solar constant is a rate of arrival of energy per unit area, it has the dimensions of watts per square meter. The nominal value of the solar constant is 1388 watts per square meter, but this value may climb as high as 1410 watts per square meter when the earth reaches its point of closest approach to sun, usually in January.

2. The LITE laser beam has the following worst case characteristics as it illuminates the ground from its lowest operating altitude of 105 nautical miles:

Wavelength	Energy	Beam Area	Energy per pulse per sq. m.
1064 nm	0.45 J	96,300 sq. m.	3.83×10^{-6} J/ sq. m.
532 nm	0.6 J	36,000 sq. m.	1.03×10^{-4} J/ sq. m.
355 nm	0.17 J	24,100 sq. m.	2.31×10^{-6} J/sq. m.

3. The laser operates at ten pulses per second. The total energy delivered by the laser per second per square meter, or the total power per square meter, is simply ten times the sum of the energy per pulse per square meter at the three wavelengths. The value is, therefore, 1.09×10^{-3} watts per square meter.

4. The ratio of worst case values is, therefore, $1.410 \times 10^{+3} / 1.09 \times 10^{-3} = 1.29 \times 10^{+6}$. The solar radiation exceeds the laser radiation by a factor of over one million. At higher Shuttle operating altitudes, the solar radiation exceeds the laser radiation by even larger factors, approaching three million at 175 nautical miles.

Richard H. Couch

Richard H. Couch
(804) 864-1738

APPENDIX B

U.S. ARMY ENVIRONMENTAL HYGIENE AGENCY REVIEW LETTER

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
ATTENTION OF

May 25, 1993

Laser Branch

Mr. Richard H. Couch
Space Administration
Langley Research Center
Hampton, Virginia 23665-5225

Dear Mr. Couch:

The enclosed document, Revised Ground Observer Eye Safety Analysis for the Lidar In-space Technology Experiment was reviewed by James Franks of the Laser Branch. No technical errors were noted.

For additional information, please contact James Franks at 401-671-3932.

1 Encl
as

DAVID H. SLINEY
Chief, Laser Branch

* Note - this review refers to Couch and Cimolino, 1992.

APPENDIX C

U.S. SPACE COMMAND CLEARINGHOUSE REVIEW LETTER

UNITED STATES SPACE COMMAND

PETERSON AIR FORCE BASE, COLORADO 80914-5003

November 5, 1992

REPLY TO ATTN OF: J3SOO

SUBJECT: SPADOC Laser Clearinghouse (LCH) Waiver Response

TO: Dick Theis
NASA JSC
Mail Code: DM42

1. The below described laser combinations have been evaluated per your request. These lasers do not exceed the damage threshold and pose no threat to space systems. Therefore, you will not need clearance prior to conducting space directed laser operations.

Wavelength (nm)	Power (mJ)	Divergence (mRad)
1064	450	.9
532	600	.55
355	355	.45

PW: 20 nanoseconds
PRF: 10 Hz

2. This waiver is valid until superseded by another waiver response letter.

3. In the event of a change to the threshold, we will re-consider this laser for waiver status and notify you of any change. Likewise, should any of your laser parameters change, please notify us. Significant parameters are operating wavelength, beam divergence, and output power.

4. Should you have any questions, please feel free to contact me at DSN 268-3623 or commercial 719-575-3623.

James E. Thilenius

James E. Thilenius, LT USN
Orbital Safety Officer

UNITED STATES SPACE COMMAND - SPACE CONTROL OPERATIONS DIVISION FACSIMILE TRANSMISSION FAX#: (719)554-2131/DSN 692-2131	
SUBJECT	LASER CLEARINGHOUSE
FROM	JIM THILENIUS, LT USN - ORBITAL SAFETY OFFICER
TO	DICK THEIS, NASA JSC, MAIL CODE:DM42
DATE/TIME	November 27, 1992 8:00pm
NUMBER OF PAGES: 1	

AND ABBREVIATIONS

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