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SAFEGUARD LIGHTNING EVALUATION TASK GROUP: SUMMARY REPORT (U)

Compiled by
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SAFEGUARD LIGHTNING EVALUATION TASK GROUP: SUMMARY REPORT (U)

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Compiled by C. E. Jackson
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ABSTRACT (U)

This paper summarizes the accomplishments of the Safeguard Lightning Evaluation Task Group established to assess the Sprint and Spartan lightning vulnerability.

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Key Words: Sprint, Spartan

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This summary report is approved by the following agency members of the Safeguard Lightning Evaluation Task Group:

Sandia Laboratories, Albuquerque (SLA)	C. E. Jackson
Sandia Laboratories, Albuquerque (SLA)	G. O. Folkins
Picatinny Arsenal (PA)	Peteris Jansons
Martin-Marietta Corporation (MM-O)	J. M. Ashford
Missile Command (MICOM)	C. D. Ponds
Bell Telephone Laboratories (BTL)	R. P. Massey
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McDonnel Douglas Astronautics Corporation (MDAC)	Nigel Thomas
Sandia Laboratories, Livermore (SLL)	C. M. Furnberg

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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SAFEGUARD LIGHTNING EVALUATION TASK GROUP: SUMMARY REPORT

Introduction

The Safeguard Lightning Evaluation Task Group was established by the Sprint and Spartan electrical environment working groups to assess the lightning vulnerability of the warhead sections for the Sprint and Spartan systems. From September 1969 to April 1971, the task group conducted and documented seven meetings before completion of its major assignments led to termination of its formal activities with the March/April meeting. The purpose of this report is to summarize the accomplishments of the Task Group and to identify tasks which should be continued within the Sprint and Spartan programs.

The following charter, written by the group at the first meeting, was subsequently approved by the parent Sprint and Spartan electrical environment groups.

> The purpose of this Task Group is to assess the Sprint and Spartan subsystem vulnerability to a lightning environment. This Task Group reports to the Sprint and Spartan electrical environments working groups. The responsibilities [tasks] of the Task Group will be as follows:
>
> 1. Evaluate the specified lightning requirements and make appropriate recommendations.
>
> 2. Evaluate the effects of lightning on the nuclear safety of Sprint and Spartan during transportation, storage, and assembly in-cell (including maintenance) and inflight and make appropriate recommendations.
>
> 3. Determine whether a lightning stroke experienced by the missile in-cell or inflight is sufficiently probable to be of concern to overall system reliability.

The Group was chaired by C. E. Jackson, SLA. Membership Agencies and their representatives are as follows:

BTL -- R. P. Massey
MM-O -- J. M. Ashford
MDAC -- N. Thomas
PA -- Peteris Jansons
PA -- Roger Zimany
MICOM -- C. D. Ponds
SLA -- G. O. Folkins
SLL -- W. F. Gordon

Because lightning may induce voltage in circuits throughout the entire system, the group found it necessary at times to examine the entire system rather than to limit its activities to the WH section.

Status

The following discussion relates the work of the Safeguard Lightning Evaluation Task Group to the three tasks defined in the charter above. Although this document is organized by Charter Tasks, supporting details can be found throughout the minutes of the meetings.

Task 1 - Lightning Requirements Recommendations

Task 1 of the charter is complete. The lightning requirements specified in the STS's for Sprint and Spartan were studied by the Task Group, and changes to the requirements were recommended. These changes, summarized below, have been incorporated in the Spartan STS and are being incorporated in the Sprint STS:

1. Clarification of the lightning pulse definition
2. Provision for multiple-pulse lightning strokes
3. Typical cloud recharge time
4. Cloud-to-cloud stroke parameters.

The changes also defined lightning-induced EMP as a normal environment. Lightning EMP is less severe than nuclear EMP; hence, the design is not affected, but the lightning group thought that the environment specification should be complete. The specific changes for incorporation in the Sprint and Spartan STS's are listed in Table I.

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TABLE I

Lightning Statement

(Proposed for Abnormal Environments Section of STS's for Sprint and Spartan)

A. CLOUD-TO-GROUND DISCHARGES

1. Single Pulse Parameters

a. Peak current	2,000 to 200,000 amperes with 50 percent of the pulses having peak values greater than 20,000 amperes.
b. Time to peak	1 to 15 microseconds with 50 percent of the pulses having times greater than 2.5 microseconds.
c. Rate of current rise (10 to 90 percent peak current)	2 to 50 kiloamperes per microsecond with 50 percent of the pulses having rates greater than 8 kiloamperes per microsecond.
d. Time to half-value on decay side of peak	10 to 120 microseconds with 50 percent of the pulses having decay times greater than 35 microseconds.
e. Time for current decay to 1000 amperes	60 to 800 microseconds with 50 percent of the pulses having decay times greater than 200 microseconds.
f. Time for current decay to 100 amperes	0.1 to 20 milliseconds with 50 percent of the pulses having decay times greater than 0.4 millisecond.
g. Pulse duration (time for current to decay to a few amperes)	0.5 to 400 milliseconds with 50 percent of the pulses having durations greater than 2 milliseconds.

2. Total Stroke Parameters

a. Number of pulses	1 to 34 with 50 percent of the strokes containing greater than 3 pulses.
b. Interval between the end of one pulse and the start of the next pulse	5 to 500 milliseconds with 50 percent of the strokes having intervals greater than 35 milliseconds.

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Table I (cont)

c. Total stroke duration	0.01 to 1.5 seconds with 50 percent of the strokes having durations greater than 0.2 second.
3. Cloud/Earth System Recycle Time After a Discharge	Typically 20 seconds
B. CLOUD-TO-CLOUD DISCHARGES	
1. Single Pulse Parameters	
a. Peak current	150 to 22,000 amperes with 50 percent of the pulses having peak values greater than 1,800 amperes.
b. Rate of current rise	70 to 5,000 amperes per microsecond with 50 percent of the pulses having rates greater than 700 amperes per microsecond.
c. Rate of current decay	30 to 7,000 amperes per microsecond with 50 percent of the pulses having rates greater than 100 amperes per microsecond.
2. Total Stroke Parameters	
(Unknown)	

NOTES:

1. For single-pulse considerations, all times are referenced to the start of the pulse.
2. All statistical descriptions apply only on a parameter basis. Statistically relating different parameters is not legitimate.
3. All values stated are based upon either observations or empirical estimates.

Lightning EMP Statement
(Proposed for Normal Environments Section of the STS's for Sprint and Spartan)

A. ELECTRICAL FIELD

1. Maximum Amplitude	20,000 volts per meter

Table I (cont)

2. Frequency spectrum example

Frequency in Hertz	Frequency spectrum in volts per meter per Hertz
10	5
100	10^{-1}
1K	6×10^{-3}
10K	6×10^{-4}
40K	6×10^{-5}

NOTES:

1. Spectrum based upon measurements at 10 km from stroke.
2. High-frequency components may exist due to initial lightning growth. These components are anticipated as being small.

B. MAGNETIC FIELD

1. Maximum Amplitude — 1.6 ampere-turns per meter.

Task 2 - Effect of Lightning on Nuclear Safety

Task 2 of the Charter is largely complete. Table II outlines Task 2. A more detailed discussion follows. Notice that Task 2, which deals exclusively with nuclear safety, is concerned with the warhead inputs which, if unintentionally supplied, could conceivably degrade warhead nuclear safety. These inputs are prearm, arm, fire, acceleration impulse (which arms the WH ESD's) and large lightning pulses which might spark through other warhead circuits or through the case directly to the warhead detonator system or X-unit.

TABLE II

Lightning Nuclear Safety

		Sprint	Spartan
General	Logistical Situation 1 - Transportation and storage	1. WH/WH section always in shipping container which is lightning hardened. 2. Buildings and vehicles usually provide cone of protection.	1. WH/WH section always in shipping container which is lightning hardened. 2. Buildings and vehicles usually provide cone of protection.
In Missile Complex Area	Logistic Situation 2 - Warhead building	1. Building is hardened against lightning.	1. Building is hardened against lightning.
	Logistic Situation 3 - Movement to cell and installation in cell	<u>Direct Stroke to WH/WH Section</u> 1. WH section kept in service van at all times. Service van provides cone of protection. 2. Procedures minimize operation when lightning threat in area. <u>Conducted Transients Through WH Cable*</u> 1. WH lightning arrestor protects against modest transients and DOD system attenuates raw lightning to modest level. <u>Lightning-Induced Normal Signals*</u> 1. AK must not provide normal signals as the result of lightning. Lightning must not produce inadvertent launch or WH ESD may arm.	<u>Direct Stroke to WH/WH Section</u> 1. WH section kept in UTL at all times, and UTL provides cone of protection. 2. Procedures minimize operation when lightning threat in area. <u>Conducted Transients Through WH Cable*</u> 1. WH lightning arrestor protects against modest transients and DOD system attenuates raw lightning to modest level. <u>Lightning-Induced Normal Signals*</u> 1. AK must not provide normal signals as the result of lightning. Lightning must not produce inadvertent launch or WH ESD may arm.
	Logisitc Situation 4 - In-cell storage and alert	<u>Direct Stroke to WH/WH Section</u> 1. WH protected from direct strokes by cell, cell cover, and missile. <u>Conducted Transients Through WH Cable*</u> 1. WH lightning arrestor protects against modest transients and DOD system attenuates raw lightning to modest level. <u>Lightning-Induced Normal Signals*</u> 1. AK must not provide normal signals as the result of lightning. Lightning must not produce inadvertent launch or WH ESD may arm.	<u>Direct Stroke to WH/WH Section</u> 1. WH protected from direct strokes by cell, cell cover, and missile. <u>Conducted Transients Through WH Cable*</u> 1. WH lightning arrestor protects against modest transients and DOD system attenuates raw lightning to modest level. <u>Lightning-Induced Normal Signals*</u> 1. AK must not provide normal signals as the result of lightning. Lightning must not produce inadvertent launch or WH ESD may arm.
Postlaunch	Logistic Situation 5 - Inflight	1. Unknown - limited effort has been expended to determine probability of being struck inflight.	1. Unknown - limited effort has been expended to determine probability of being struck inflight.

*The Safeguard Lightning Evaluation Task Group has recommended serious consideration of the use of lightning surge arrestors on all lines entering the LPEC/LPEV and cell. Incorporation of surge arrestors would improve the system in the areas indicated.

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Logistic Situation 1 on the chart (transportation and storage) considers the warheads with their external connectors covered by metal caps, the warhead sections with their electrical connectors covered by metal caps, and the warheads or warhead sections in their shipping containers.

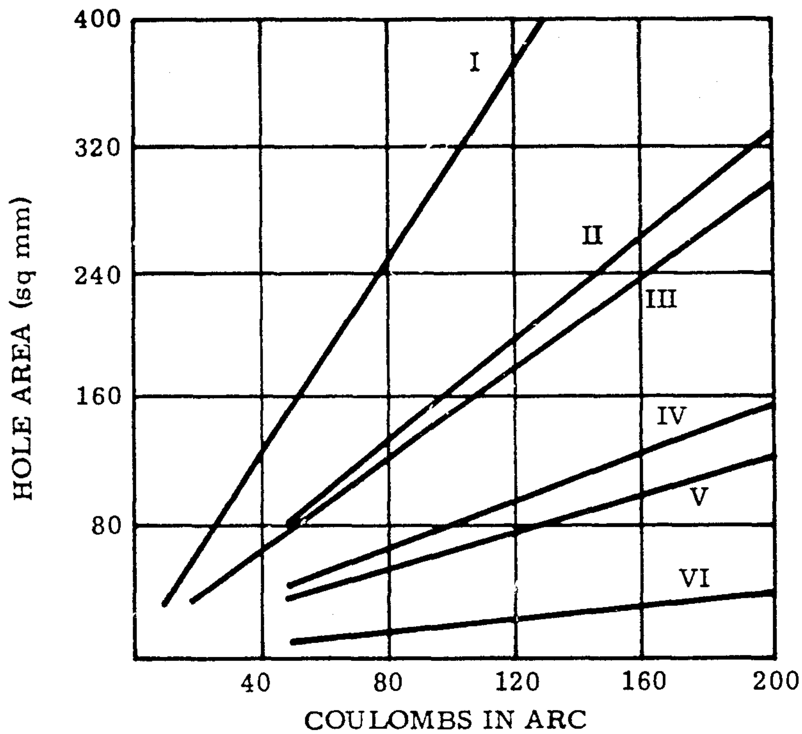
Each shipping container, for Sprint and Spartan, consists of two half-cylinders bolted together. The containers are constructed of carbon steel sheet with joining flanges of stainless steel. The stainless steel, which is used to prevent corrosion, assures good electrical conductivity between the two halves. The gasket used between the flanges is a combination environmental seal and EMR gasket. The containers are designed to attenuate EMR, 5 to 10 db at low frequencies and 50 to 100 db at high frequencies. In both the Sprint and Spartan containers, the warhead section is on rubber shock mounts with a one-point ground to the container. The carbon steel skin on the WH section containers is 0.105 inch thick for Spartan and 0.075 inch thick for Sprint.

Figure 1 shows the damage done by varying-size lightning strokes to various metallic skins. It should be noted that a typical lightning stroke transfers 25 coulombs of charge, while an extreme stroke transfers 200 coulombs.

The conclusion from the above information is that lightning currents will not reach equipment inside the Sprint or Spartan conductive shipping container (although small holes less than 1/2 inch across might occur in the Sprint container as the result of an extreme lightning stroke). This system characteristic satisfies the lightning/nuclear safety requirement for Logistic Situation 1.

Logistic Situation 2 on the chart (warhead building) considers the Sprint and Spartan warheads and warhead sections assembled and during limited-life component replacement while inside the warhead building.

There is no requirement for disassembly of the Sprint or Spartan warheads anywhere in the missile complex except for replacement of limited-life components. Replacement of limited-life components on the Spartan warhead will normally be done in the cell with the cell cover in place. Replacement of limited-life Sprint warhead components will take place in the warhead building.



Relation between coulombs in the arc and the size of hole burned in metal sheets.

I. Stainless steel - 10 mil
II. Galvanized iron - 15 mil
III. Copper - 20 mil
IV. Stainless steel - 40 mil
V. Aluminum - 51 mil
VI. Aluminum - 100 mil

Figure 1. Lightning Damage to Sheet-Metal Skins

The Requirements Document for the Warhead (Section) Handling Building (11427520), dated August 8, 1969, established National Fire Prevention Association Specification No. 78 and National Bureau of Standards Handbook 46 as lightning design criteria. It is the conclusion of the lightning task group that, if the WH building specification is complied with, lightning cannot get to the material inside the warhead building. This system characteristic satisfies the lightning/nuclear safety requirement for Logistic Situation 2.

Logistic Situation 3 in Table II (Movement to Cell and Installation in Ceil) considers movement of any warhead material between the WH building and the cell.

All movement of Spartan WH's between the WH building and the cell is accomplished with the Universal Transporter Loader (UTL). Figure 2 shows the UTL erected over the Spartan cell. The UTL is an all-metal structure which provides a good cone of protection (superior to the 30° or 45° cone recommended for power or communication lines) under all situations including transportation of WH's within the missile complex and lowering the WH section into the cell. The UTL is earth grounded during all loading, unloading, and erecting operations.

All movement of Sprint WH's between the WH building and the cell is accomplished with the Sprint Service Van (SSV). Figure 3 shows the SSV in the transportation configuration. Figure 4 shows the SSV with the cover extended over the cell; this condition exists when the WH section is being installed in the cell. The SSV provides a good cone of protection (superior to the 30° to 45° cone recommended for power or communication lines) under all situations including transportation of WH's within the missile complex and lowering the WH section into the cell. The SSV and its extendable cover are earth grounded during all loading and unloading operations.

The lightning task group concludes from the above that, in Logistic Situation 3, the warhead sections always have good cones of protection provided by the UTL and SSV.

After the electrical cables have been connected, between the warhead section and the remainder of the DOD system, receipt of WH inputs from the DOD system, caused either directly or indirectly by lightning striking the launch area, could pose a problem. The conducted lightning transients problem is being approached in two ways: (1) lightning arrestor connectors capable of providing lightning nuclear safety from typical lightning strokes at the Sprint and Spartan WH's are being developed, and (2) the DOD is performing analyses intended to show that the DOD system will attenuate extreme lightning strokes to levels the

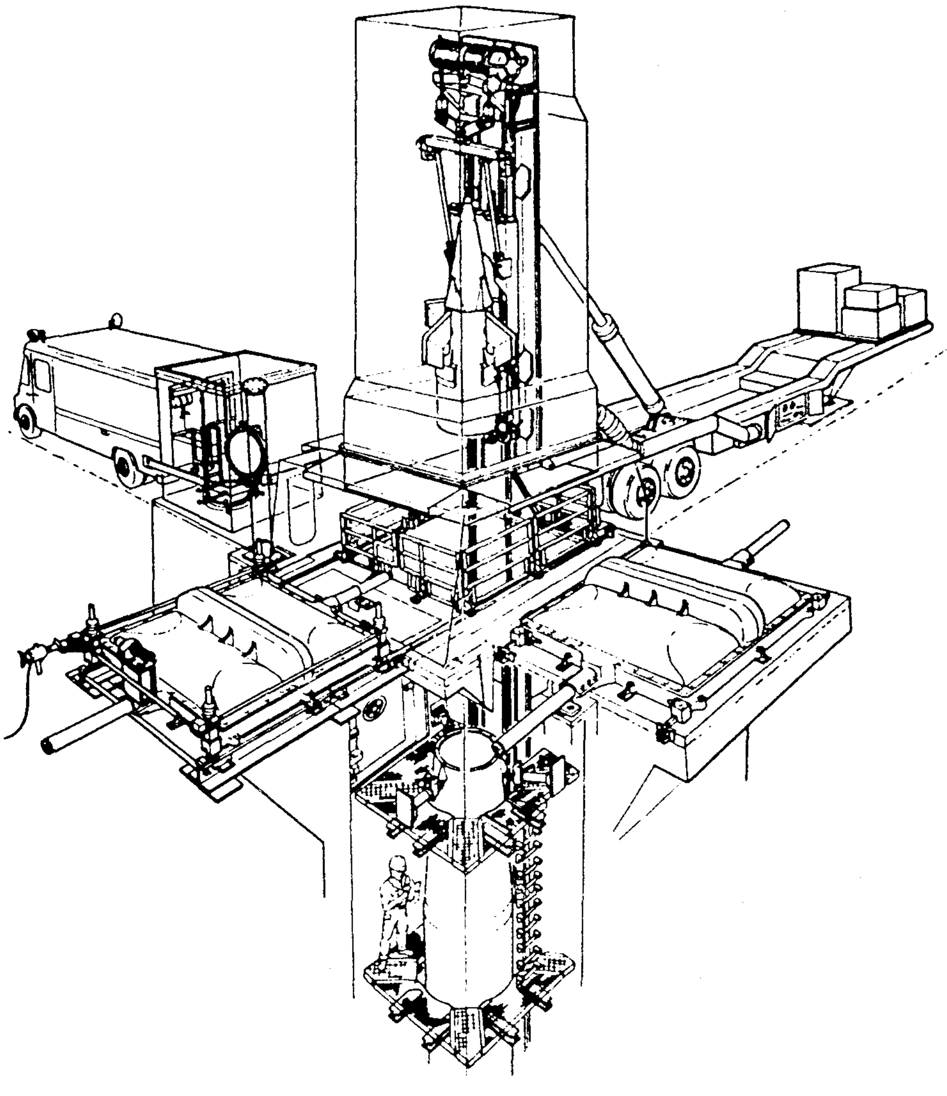


Figure 2. Launch Station Loading and Maintenance Operations (Spartan)

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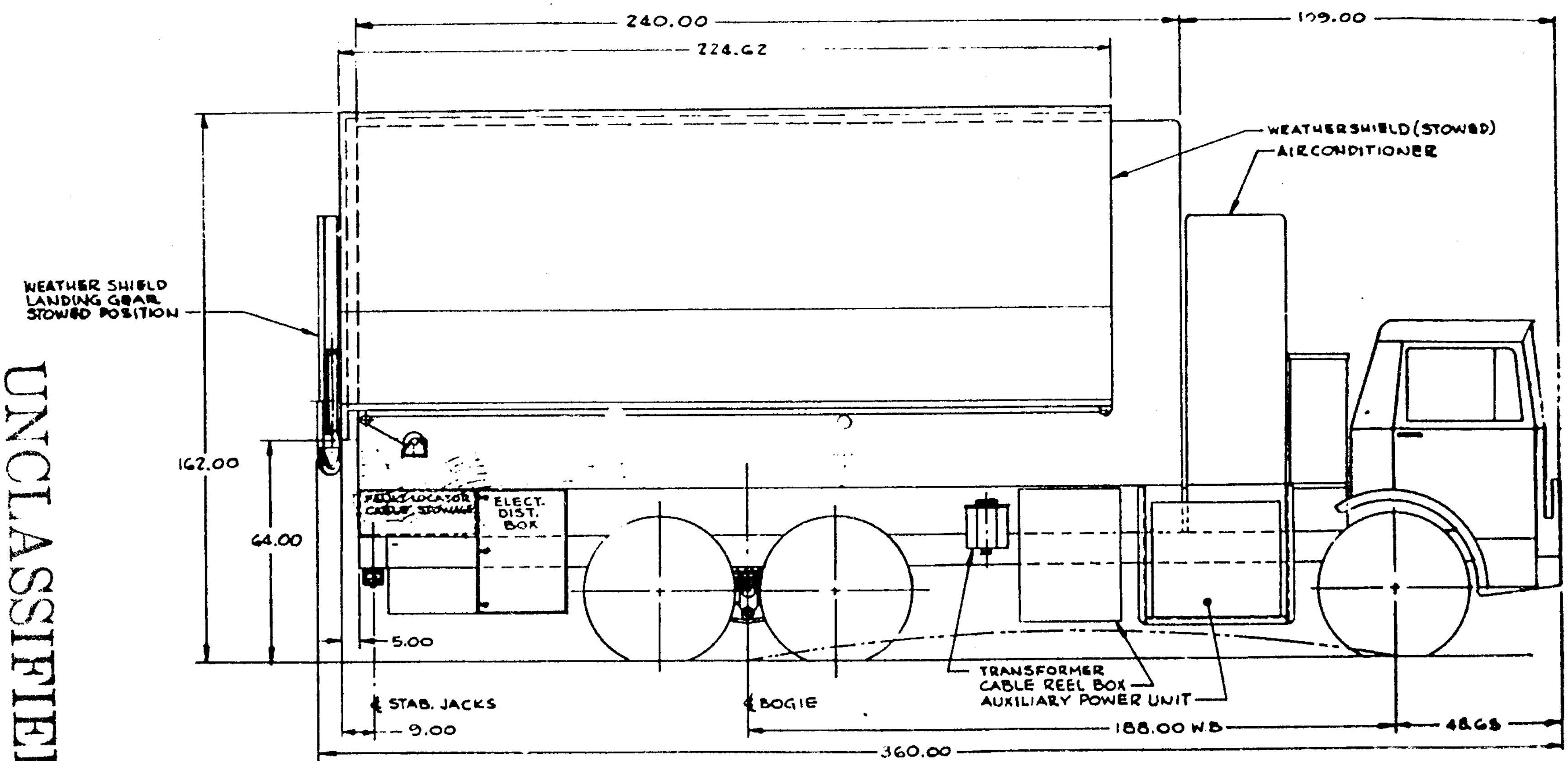

Figure 3. Curbside View - SSV in Travel Mode (Sprint)

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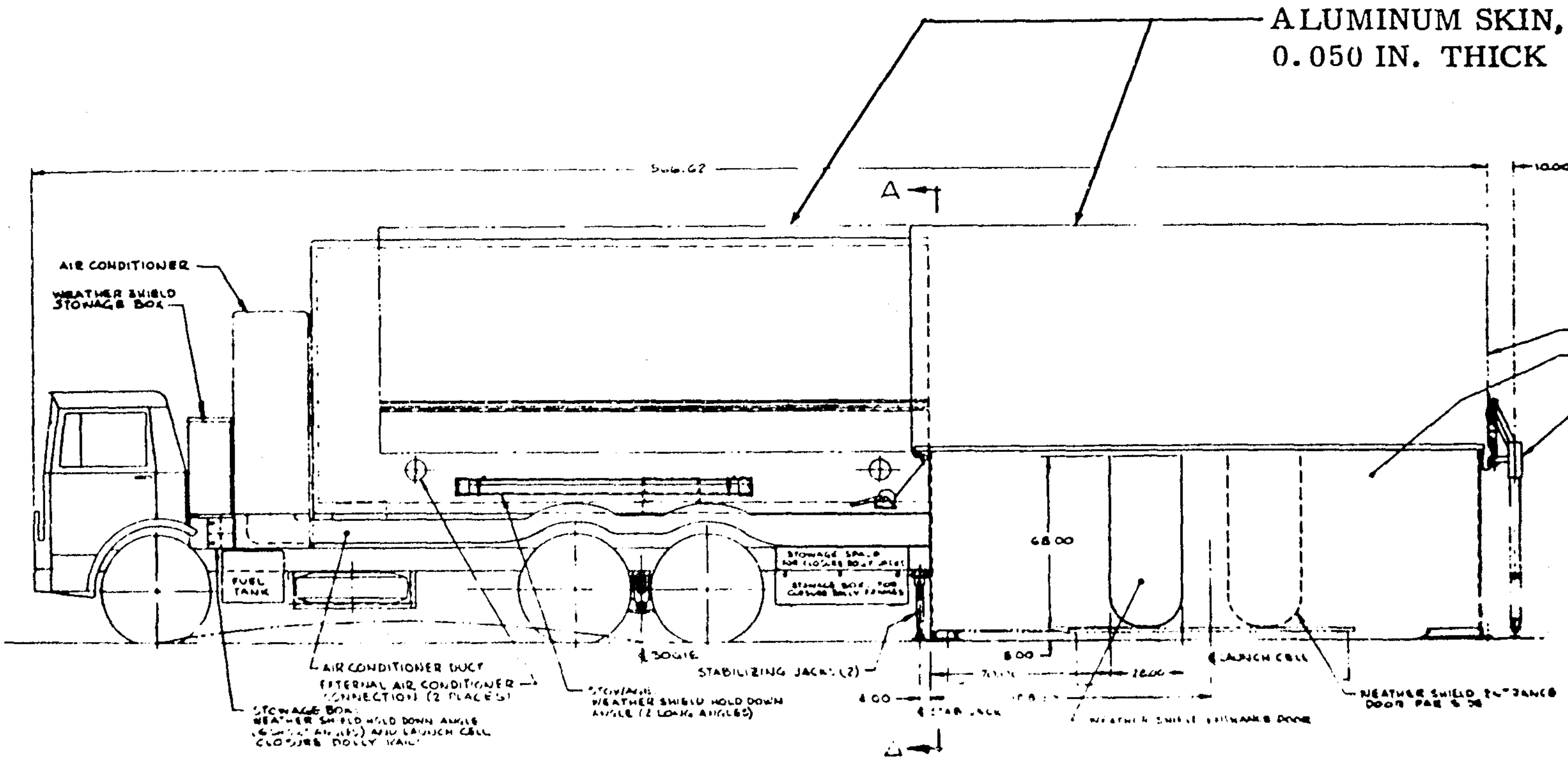

Figure 4. Roadside View - SSV in Deployed Mode (Sprint)

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WH lightning arrestor connector can handle. Peak current lightning of 20,000 amperes is considered typical; 200,000 amperes is considered extreme.

Figure 5 shows the results of an analysis performed to determine whether a direct lightning strike to the system conduits could result in significant current being coupled into the wires in the conduit. The conclusion was that, while typical lightning does not appear to be a problem, extreme lightning could produce high enough voltage between conduit and wires to cause arcing through typical insulation and thereby a path for high currents into the conductors.

	Soil Resistivity (meter-ohms)		
	20	150	450 (Grand Forks Worst Case)
Typical Pulse $I = 30$ ka $t_{1/2} = 40\ \mu sec$	85 V	234 V	400 V
Extreme Pulse $I = 200$ ka $t_{1/2} = 100\ \mu sec$	985 V	2,700 V	4,670 V

Notes: Using an extreme figure of 10,000 meter-ohms for soil resistivity (corresponding to dry sand, gravel, or pure rock), typical lightning gives 1900 volts and extreme lightning gives 22,000 volts. It should be pointed out that this analysis assumes an infinite length of conduit and uniform soil resistivity.

Values for ρ measured at Grand Forks:

Average over immediate launch area = 20 meter-ohms

Upper bound over entire area surrounding MSR = 150 meter-ohms

Upper bound over entire area surrounding PAR = 450 meter-ohms

Figure 5. Peak Wire-to-Conduit Potentials

Figure 6 shows the results of an analysis performed to determine whether extreme lightning currents in the LPEV/LPEC and cell structures could produce magnetic fields in the cell of sufficient magnitude to cause dangerous currents to flow in electrical loops in the cell. The conclusion was that dangerous currents could not be produced in this manner.

The problem of ESD arming as a result of acceleration impulse is being worked by MM-0 (Sprint) and MDAC (Spartan) studies to provide assurance against lightning-induced peacetime inadvertent launch. In August 1970, MM-0 initiated a 2-year safety study which will include the question of lightning-induced inadvertent Sprint launch. In 1970, MDAC initiated a 1-year study (part of its ground EMP program) which will address the question of lightning-induced inadvertent Spartan launch.

The WH lightning arrestor connector is not, of course, designed to discriminate against normal signals. Therefore, an evaluation is being conducted by PA to determine whether lightning can cause the AK to generate normal signals and send them to the WH.

	B_{center} (TESLAS)	$\dot{B}_{center}$ (TESLAS/sec)	$\dot{B}_{avg}$ (TESLAS/sec)	EMF in Loop of 1 m^2 Area (millivolts)
Sprint LPEC	4×10^{-7}	1×10^{-5}	2×10^{-4}	0.2
Spartan LPEV	9×10^{-7}	5×10^{-5}	7×10^{-4}	0.7

Figure 6. Results of Magnetic-Field Penetration Calculations

In order to provide greater assurance that the DOD system will adequately attenuate extreme lightning pulses, that lightning-induced inadvertent launch will not occur, and that the AK will not generate normal signals as a result of lightning, the Lightning Evaluation Task Group made the following recommendation:

> "In the interest of Peacetime Nuclear Safety, the Safeguard Lightning Evaluation Task Group recommends that installation of lightning surge arrestors on every line entering the LPEC/LPEV be seriously considered. The objective of the surge arrestors is to limit voltages within the cell and LPEC/LPEV to levels which will not arc through electrical insulation, open switch contacts, etc. With only part of the lines protected as in the present design, the possibility exists that arcing may occur from unprotected lines to protected lines inside the cell or LPEV/LPEC and thus bypass the surge arrestors. The optimum location for the surge arrestors appears to be the point where the circuits enter the LPEC/LPEV. This recommendation applies to both Sprint and Spartan."

The Safeguard Lightning Evaluation Task Group concludes that when the above activities are implemented with satisfactory results the nuclear safety requirements of Logistic Situation 3 will be met.

Logistic Situation 4 (In-Cell Storage and Alert) includes all conditions from the time the WH section is installed in the cell until the decision is made to remove or launch the missile. In this situation, the cell, cell cover, and missile protect the WH/WH section from direct lightning strokes. Protection from conducted transients and from normal signals activated by lightning is provided in the same manner as in Logistic Situation 3.

Logistic Situation 5 (Inflight) covers the period from launch until the missile is beyond the altitude at which lightning occurs. The Lightning Evaluation Task Group acquired some qualitative information relative to probability of being struck in flight but concluded that quantitative statements could not be made without additional information such as data from a site survey of atmospheric conditions coupled with the small-rocket flight-test program.

Task 3 - Effect of Lightning on Reliability

Task 3 of the charter is complete with regard to the preflight situation. An analysis based on empirical telephone-line and power-line information concludes that the probability of a given Sprint missile complex being struck by lightning is about 0.5 per year. This analysis uses an average figure for lightning strokes per year per square mile. The missile complex area used in the analysis was adjusted to account for the fact that there are structures above ground and that there are conductive conduits and tunnels below ground in high-resistance soil. Although no Spartan missile complex was actually analyzed, it is believed that the complexes are similar enough to yield essentially the same results. On the basis of this analysis, the task group concludes that the probability of a lightning stroke experienced by the missile in-cell is too low to be of concern to overall system reliability. The Lightning Evaluation Task Group has been unable to assess the probability of the missile being struck in flight.

Future Work

Prelaunch

Evaluation of Logistic Situations 3 and 4 of Task 2 is incomplete in the following areas:

1. Lightning-induced inadvertent launch has not been completely evaluated for Sprint or Spartan.

2. Lightning transient attenuation in the DOD system has not been completely evaluated.

3. Probability of lightning causing the AK to produce normal WH signals has not been completely assessed.

4. The recommendation to consider incorporation of surge arrestors in all lines into the LPEV/LPEC has not been evaluated by the parent groups.

Completion of these activities should result in certification of the system in the prelaunch situation.

Inflight

Evaluation of the inflight situation has not progressed very far. To realistically work, the inflight safety or reliability problem requires, as a first step, the determination of probability of being struck by lightning in flight. The task group believes that such a determination would involve (1) site surveys of atmospheric conditions at each proposed Safeguard site, and (2) a small-rocket flight program designed to relate measurable atmospheric conditions to probability of inflight missile strike. The Lightning Evaluation Task Group recommends that SAFSCOM consider conducting such a program. Until the outcome of SAFSCOM's evaluation of the recommendation, SLA is attempting to develop a crude estimate of the percentage of time that a potential lightning threat exists at various geographic locations.

Final Action Items

The following action items were established during the seventh and final meeting of the Safeguard Lightning Evaluation Task Group. These action items are being performed by the assigned agencies; it is recommended that the Sprint and Spartan electrical environment groups consider the results of these actions.

No.	Item	Agency
1	Provide new information (as it becomes available) concerning criteria for missile abort because of a lightning threat. Also provide information on lightning rods, ground lines, and other lightning-protection devices at Cape Kennedy.	MICOM
2	Report results of safing-device tests for Sprint and Spartan relative to the probability of the AK supplying normal signals to the warhead as a result of lightning striking the systems.	PA
3	Provide information as it becomes available on Sprint relative to preventing lightning-induced inadvertent launch.	MMC
4	Provide information as it becomes available on Spartan relative to preventing lightning-induced inadvertent launch.	MDAC
5	Perform analyses and tests for Sprint and Spartan to determine magnitude of transients leaving the AK (to the warhead) which may be caused by threat-level lightning applied to the AK input.	PA
6	Write "straw man" closeout summary of the accomplishments and status of the Safeguard Lightning Evaluation Task Group.	SLA
7	Attempt to develop a crude estimate of the percentage of time that a potential lightning threat exists at various geographic locations.	SLA

Concluding Statement

The Lightning Evaluation Task Group's recommendation to disband is the result of the following:

1. Most of the tasks defined in the charter are complete.

2. The tasks associated with the prelaunch situation which have not been completed have been defined and are being performed. Hence, the progress of these tasks can be easily monitored by the electrical environment groups of Sprint and Spartan.

3. The task group has outlined an approach to the postlaunch lightning problem. This approach should be carefully considered by SAFSCOM.

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