To: Senator Reid, Senator Ensign,
Congressman Gibbons,
Congresswoman Berkley
Congressman Porter

From: Mrs. Sally Devlin
P.O. Box 9266
Pahrump, NV 89060
775-727-6853

Subject: Earth Currents Not addressed in Yucca Mountain Licensing

The potential danger from lightening at Yucca Mountain hasn't been addressed.

The danger from lightening is not only to people but it may cause fires but has the potential to destroy all communications equipment.

There are many types pf lightening. Most people are aware of the sheet and streak forms but the most dangerous are the ball and plasma types. The ball and plasma lightening give no warnings and can appear at any time emitting upwards of 60,000 volts and do tremendous damage.

Is this a deliberate oversight? Are contractors required to put this potential problem in their contracts? Will, it if damage occurs from lightening require and expensive "Change order"?

All my research comes from N.A.S.A. research reports at our CCSN in Pahrump. Thanks to you we have this facility for curious student like me!

This report will also be sent to the proper agencies. LIGHTENING IS A REAL RISK!!!!

I have 142 pages on this topic and would like to hear your opinions on this danger.....

Sincerely,

Mrs Sally Devlin

Mrs. Sally Devlin 10/1/04

To. N.W.T.R.B
9/31/04

Enclosure 4

CHARACTERIZATION OF CLOUD-TO-GROUND LIGHTNING FLASHES ON THE NEVADA TEST SITE

Darryl Randerson and James B. Sanders

ARL/SORD
Las Vegas, Nevada

from: N.T.S. Environmental Report 2003 (Oct 2004) DOE/NV11718-971

I. Introduction

Thunderstorm activity and the accompanying cloud-to-ground (CG) lightning are both primarily summertime phenomena in the vicinity of the Nevada Test Site (NTS) (Quiring 1977 and 1983). Consequently, in this study the focus was on warm-season lightning where the warm season is defined as June through September.

With the conclusion of the 2000 lightning season, the available CG lightning data base for the NTS covers eight warm seasons. In an initial analysis of the data base for 1993 through 1997, one of the authors (Randerson, 1999) concluded that " a 5-yr data base does not include enough realizations to form a robust or representative climatological data base for CG lightning over southern Nevada". With the addition of three more years, two of which where active thunderstorm seasons, a more complete climatology of CG lightning can now be assembled for the NTS.

A characteristic of desert thunderstorms is that many produce little precipitation. For example, in Las Vegas, Nevada (LAS), 85% of all warm-season precipitation events have set-hour rainfall depths of 0.10 in (2.5 mm) or less (Randerson, 1997). Although desert thunderstorms exhibit this tendency toward little or no precipitation production, they all generate lightning. Consequently, lightning may be a representative measure of desert thunderstorm activity.

Desert thunderstorms pose a serious threat to life and property. More study of these storms is needed to improve forecast and warning capabilities; especially in the desert southwest. Accordingly, this analysis was undertaken to describe the CG lightning distribution over the complex terrain setting of the NTS, to continue to expand the scientific understanding of desert thunderstorms, and to contribute to improved forecast procedures for these dangerous storms.

II. Safety Issues

Desert thunderstorms can produce intense CG lightning, locally heavy rain, hail, and strong outflow winds. Heavy rainfall can cause flash floods and the strong outflow winds can create dense blowing dust that can restrict visibility. CG lightning, flash floods, and strong winds are all serious threats not only to life and property but also to power distribution systems and to communication networks. Dense blowing dust is hazardous to aircraft and to surface vehicles. Moreover, CG lightning that strikes storage or processing vessels containing flammable or toxic materials can cause devastating accidents.

read 12/20/04

No breakdown of 4 types of CG
Reference: from above 500 (almost) report.
1st one I ever received – thanks, Michael Brown, NNSA

Mrs. Sally Devlin
P.O. Box 9266
Pahrump, NV 89060-9266
775-727-6857

Lightning is a random, capricious event. It is simply static electricity that has extremely large electrical potentials. Therefore, CG lightning flashes can generate temperatures up to 30,000°K and currents as large as 200,000 amps. Damage from a CG strike can result from the energy of the initial strike or from secondary effects such as fires or loss of power. In the United States, lightning causes the majority of the forest fires and over $2 billion in property loss. The National Lightning Safety Institute (NLSI) reports that lightning is also responsible for 100-200 deaths per year in the United States. Lightning is a serious safety hazard.

In compliance with the United States Department of Energy (DOE) policy to create and maintain a safe working environment, lightning safety and awareness are part of the Nevada Operations Office (NV) Integrated Safety Management Program. In addition, DOE Order 420.1, Facility Safety, provides guidance on the mitigation of natural phenomena hazards, including lightning at DOE facilities. In 1996, the DOE Office of Nuclear and Facility Safety issued DOE/EH-0530, "Lightning Safety" to alert DOE managers of the lightning hazard and to examine their lightning protection and safety programs. The DOE Explosives Safety Manual, DOE M 440.1-1 also provides guidance on lightning safety. According to the NLSI and to the DOE Occurrence Reporting & Processing System (ORPS) for October 1993 to July 1995, there were 298 reports indicating that lightning was the cause of monetary loss and/or work stoppages at DOE facilities. Nine of these occurred on the NTS.

Safety from natural hazards, such as CG lightning, requires advance notice, or forecast, of potential high risk weather conditions and the ability to communicate that information to people. Moreover, an essential element of lightning safety is early detection. For the NTS, CG lightning detection is accomplished with a modern lightning detection system. This system was first installed in 1986 and was upgraded in 1993. Since 1993, comprehensive cloud-to-ground (CG) lightning flash data have been collected and archived for that area of southern Nevada surrounding the NTS.

III. The Network and Warning System

The NTS CG lightning detection network was designed to provide high-detection capability on and within 170 km of the NTS. It has been used successfully to guard the safety of personnel working on and around the NTS, to locate lightning induced brush fires on the NTS, to identify potential points of electrical power disruption, and to support of aviation safety. This system is operated and maintained by the Air Resources Laboratory, Special Operations and Research Division (ARL/SORD) personnel.

The NTS CG lightning detection network has been described elsewhere (Randerson, 1999, and Randerson and Sanders, 1999) and will not be repeated here. Lightning detection technology has been documented by Krider et al. (1980) and the original NTS network of magnetic direction finders has been described in detail by Scott (1988). High resolution of CG flashes on the NTS was achieved by establishing short base lines for the direction finders (DFs). East-west baselines of 40 km and north-south baselines of nearly 75 km were established on the NTS With the requirement for high resolution flash capability on the NTS, the DF gains were reduced to be compatible with the baseline length of the NTS detectors.

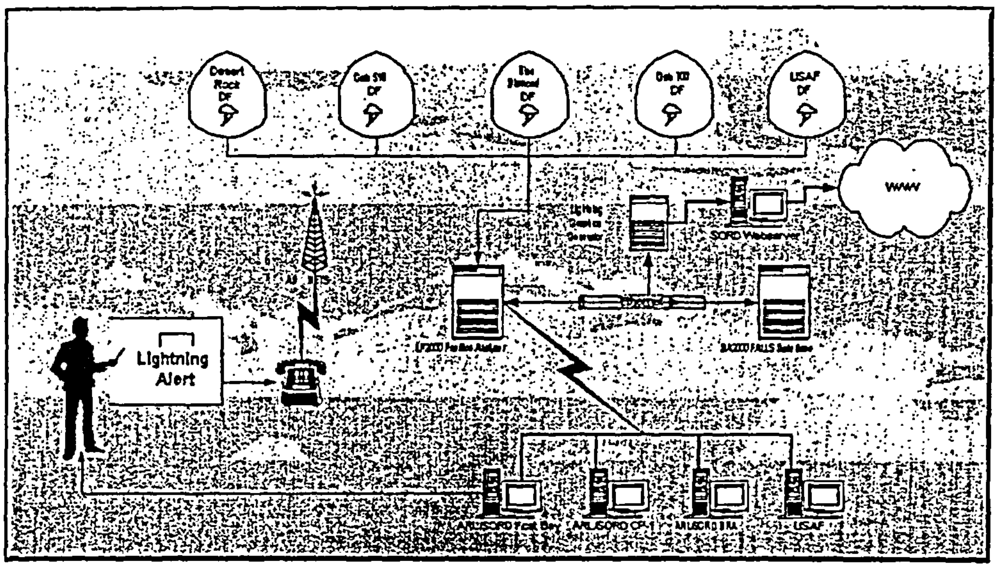

Figure 1. NTS Lightning data distribution and alert system.

As Fig. 1 demonstrates, CG lightning flashes detected by the DFs are multiplexed from the NTS to the Position Analyzer (PA) located in the ARL/SORD Weather Forecast Center in the National Nuclear Security Administration (NNSA), Nevada Support Facility (NSF) in Las Vegas, Nevada. The PA promptly processes the raw DF data and automatically computes and displays the locations of the CG flashes in the ARL/SORD, Weather Forecast Center, in the NSF building, and to our forecast center at Control Point 1 on the NTS. In addition, the data are also transmitted via a Data General processor and a D470 Emulator to numerous customers at the NTS, to local United States Air Force weather offices, and to the ARL/SORD Web Browsers (<www.sord.nv.doe.gov>).

The ARL/SORD lightning detection network operates continually. Every morning, at approximately 7 a.m. local time, the Duty Forecaster verifies the status of the network by transmitting a test flash. Moreover, SORD personnel have developed an automatic lightning status (ALS) check system that monitors the communications lines from the DFs to the PA. This system verifies that the DF self-test messages are active. If they are not, the LP2000 system generates an alarm message that, when displayed, provides an explanation of the potential communication problem. Corrective actions are taken promptly.

In agreement with project managers on the NTS, SORD weather forecasters are responsible for providing weather updates to senior management. Focus is on the potential for CG lightning; especially, if personnel are handling explosives or are working on towers and around electrical cables. If CG lightning is detected within 20 mi (32 km) of the boundary of the NTS, the SORD Weather Forecaster issues a Lightning Alert for the NTS. This area is defined by the heavy red line encircling the NTS in Fig.2. An example of one of these alerts is shown in Fig. 3. The Lightning Alert is announced by the SORD forecaster via an "all nets" radio broadcast on and around the NTS (see Fig. 1). In addition, the forecaster notifies other key facilities by telephone calls as well as through the SORD Meteorological Alert Distribution System (MADS). Once the alert has been issued, the Duty Forecaster tracks lightning activity, issuing updates as needed to protect personnel and sensitive experimental equipment. Through an Internet connection, CG lightning displays (see Fig. 1) are available to project managers so that they can monitor the lightning threat through consultation with the Duty Forecaster. When the threat of CG lightning has ceased, project managers are notified.

IV. Climatology and Topography

The NTS lies in the southwest corner of the Great Basin and on the northeastern edge of the Mojave Desert. Consequently the climate is arid with limited precipitation. Two fundamental physical factors drive precipitation events on the NTS; those resulting from cool-season, mid-tropospheric cyclones and those resulting from summertime convection. Thunderstorms and cloud-to-ground lightning over the NTS are infrequent from October through May (Quiring, 1977 and 1983). Summer is the thunderstorm season for the desert southwest which includes southern Nevada (Skrbac, 1999). At the Desert Rock (DRA) meteorological observatory on the NTS, an average of 10 thunderstorm days occur annually from June through September.

Figure 4, demonstrates that thunderstorm activity at DRA increases rapidly in early July. Mid-July tends to be quite active; however, the primary period of thunderstorm activity is centered on August 12. An obvious characteristic of the plot is the periodicities in thunderstorm activity. These fluctuations may be related to the northward flow of moist tropical air over the lower Colorado River valley and into Arizona, Nevada, and Utah. This seasonal event is referred to as the southwestern monsoon by many researchers and weather forecasters (Bryson and Lowery, 1955, Hales, 1972, Brenner, 1974, Carleton, 1985, Balling and Brazel, 1987, Douglas, et al., 1993, and others). Furthermore, McCollum et al. (1995) have shown that low-level moisture from the Gulf of California can increase the convective instability of the atmosphere over Arizona dramatically. This phenomenon can be associated with significant thunderstorm development, heavy precipitation, and flash flooding in Arizona, Nevada, Utah, and the Mojave Desert.

Topography, of course, can play a critical role in modulating thunderstorm activity and in augmenting precipitation near mountain ranges. On the mesoscale, mountain ranges can create thermally driven convergence zones that enhance thunderstorm development (Hill, 1993, Maddox et al. 1995, and Runk, 1996). Figure 2 shows that the topography of the NTS is complex and consists of mountains, plateaus, and dry lake beds. Elevations range from approximately 850 m above mean sea level (MSL)

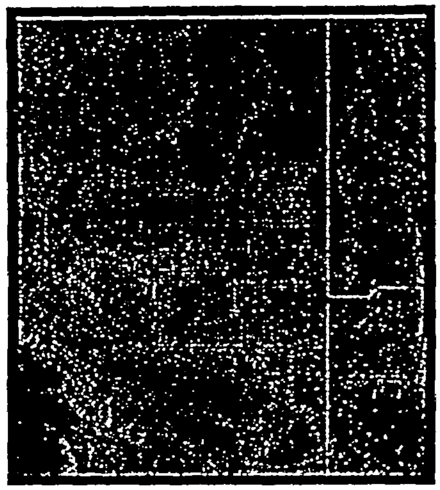

Figure 2. Topographical map of the NTS. The red "circle" surrounding the NTS represents the boundary of the NTS CG Lightning Alert area. The black "boxes" within the NTS boundary are the various operational areas. · Area numbers are in black.

AIR RESOURCES LABORATORY/SPECIAL OPERATIONS & RESEARCH DIVISION
2:00 PM PDT FRI JUN 22 2001

THE AIR RESOURCES LABORATORY HAS ISSUED A LIGHTNING ALERT EFFECTIVE UNTIL 8:00 PM FOR PEOPLE AT THE NEVADA TEST SITE.

THE NTS AUTOMATIC LIGHTNING DETECTION SYSTEM HAS DETECTED SEVERAL GROUND STRIKES JUST TO THE NORTH OF THE NTS AND TO THE SOUTHEAST OF THE NTS. THE THUNDERSTORMS PRODUCING THIS LIGHTNING ACTIVITY ARE MOVING SLOWLY NORTHWARD AND WILL POTENTIALLY IMPACT THE NTS THROUGHOUT THE AFTERNOON AND EVENING.

SOUTHERN NEVADA IS UNDER THE INFLUENCE OF A RIDGE OF HIGH PRESSURE ALOFT THAT IS HELPING STEER MOISTURE NORTHWARD INTO THE AREA. THIS MOISTURE IS HELPING TO CAUSE THE THUNDERSTORMS AND WILL CONTINUE TO PRODUCE THUNDERSTORM ACTIVITY UNTIL 8:00 PM TODAY.

PEOPLE IN THE VICINITY OF THESE STORMS SHOULD BE ALERT TO THE HAZARD OF LIGHTNING. KEEP CLEAR OF TALL ISOLATED STRUCTURES AND TREES. USE CAUTION AROUND POWER LINES AND OTHER ELECTRICAL SOURCES AND TELEPHONES.

PLEASE DIRECT ANY QUESTIONS OR REPORTS TO THE DUTY FORECASTER AT 5-1255.

Figure 3. Example of a Lightning Alert for the NTS area.

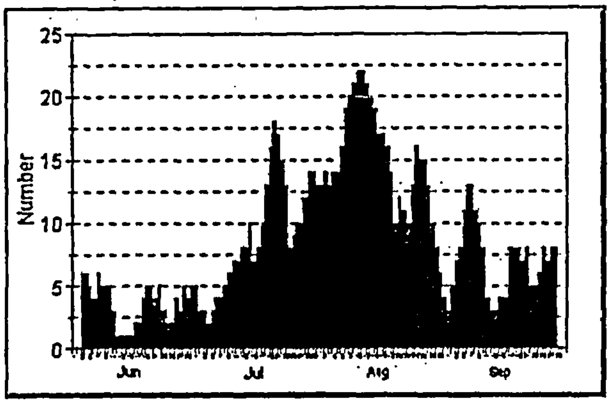

Figure 4. Five-day running total of thunderstorm days for Desert Rock, NV, for June through September, 1978 through 2000.

in the southwest corner of the NTS to nearly 2700 m MSL on Rainier Mesa in the northern part of the NTS. Terrain above 2000 m MSL extends from Shoshone Mountain (2200 m MSL) northward, forming the Belted Range and Kawich Range that extend northward from the NTS. Death Valley is located in California to the southwest of the NTS and a large flat basin, the Amargosa Desert, lies to the south and west of the NTS.

V. Analysis

Procedure: The area of analysis was focused on the NTS. Due to the size of the NTS (3500 km^2) and the need to resolve the details in the CG lightning pattern, CG flashes were resolved into 1.0 sq km areas. Individual CG lightning flashes were located and placed in 1.0 km by 1.0 km (or 1 km^2) bins or boxes overlaid on the analysis area. Approximately 3,500 bins covered the NTS. CG flash totals were calculated by summing the number of flashes detected inside each of these boxes. The resulting seasonal CG flash totals were plotted at the center of each 1.0 km^2 box to produce annual warm-season summaries of total flash counts. The plotted data were then analyzed by contouring the data field. Contour intervals were selected to represent flash counts of 4.0, 6.0, 8.0, 10.0, and 12.0 fl/km^2. To acquire the mean for the eight warm seasons, the flash totals simply need to be divided by 8.0 to yield fl/km^2/warm season.

General: Cloud-to-ground lightning data were summarized and analyzed for June through September for the 8-yr period 1993 through 2000. Results of the summary are tabulated in Table 1. Data listed in the table show that a total of 9,596 cloud-to-ground lightning flashes were detected on the NTS for the period of record. Of these flashes 9,346 lowered negative charge to the ground (negative flashes) and 250 lowered positive charge to the ground (positive flashes). The data listed in this table clearly illustrate the large inter-annual variability in CG lightning (thunderstorm) activity in a desert environment. Measured total warm-season CG lightning flashes on the NTS range from only 409 flashes in 1993 to 2,532 flashes in 1999. It has not gone unnoticed that the most active lightning season was the one following the 1998-1999 El Nino event.

Table 1 also shows that not only is there great inter-annual variability in negative flashes on the NTS, but also in positive flashes. The annual percentage of positive CG flashes on the NTS ranges from 1.0% in 1993 to 6.2% in 1997. An annual average of 6.2% is large for the summer months for the continental United States (Orville and Silver, 1997). However, the average warm-season positive flash percentage of the 8-yr sample is 2.6%. This average is similar to that reported by Fuquay (1982) for three summers in the northern Rocky Mountains and by Orville and Silver (1997) for southern Nevada.

Table 1. Warm season (June through September) cloud-to-ground lightning flash totals for the NTS for 1993 through 2000.

Year	Total Flashes	Positive Flashes	Percent Positive
1993	1039	10	1.0
1994	778	23	3.0
1995	409	9	2.2
1996	642	8	1.2
1997	900	56	6.2
1998	1913	58	3.0
1999	2532	54	2.1
2000	1383	32	2.3
Total	9596	250	2.6

Based on the total number of CG flashes detected on the 3,500 km^2 NTS during eight warm seasons, the mean annual (warm season) CG flash density for the analysis area is 0.34 flashes/sq km (fl/km^2). This number is smaller than the annual average of 2.0 fl/km^2, for the contiguous United States, that can be derived from the data presented by Orville (1994). However, Orville (1994), in an attempt to adjust for a 70% detection efficiency, multiplied flash density counts by 1.4. If the average NTS warm season flash density of 0.34 fl/km^2 is multiplied by 1.4, the average NTS flash density (0.48 fl/km^2) is very similar to that reported by Orville (1994) and by Orville and Silver (1997) for southern Nevada. In the data and charts presented in this report, no attempt was made to account for undetected

CG flashes; only flashes actually detected were counted.

Annual: Annual plots of the warm season GC flashes on the NTS are shown in Fig. 5 a and b. These plots clearly demonstrate the marked inter-annual variability of CG flashes on the NTS. Notice that 1998 and 1999 were very active thunderstorm seasons. The least active warm season was 1995 with a total of only 409 CG flashes on the NTS. The flash patterns in these plots appear to be rather random; however; there are indications of the influence of the mountainous terrain that extends north-south through the center of the NTS.

The spatial distribution of the positive CG flashes is shown in Fig. 6. This figure illustrates that the positive flash distribution on the NTS is rather uniformly distributed. A plot of all the CG flashes on the NTS for the eight warm seasons is displayed in Fig. 7, demonstrating that the only areas on the NTS not saturated by CG flashes are found in the southwestern and, perhaps, the extreme northeastern corners

Spatial: All the CG flashes detected on the NTS for the 1993 through 2000 warm seasons were summarized into 1.0 fl/km^2 areas. The results of this summary are shown in Fig. 8, the first high-resolution analysis of CG lightning on the NTS. Figure 8 is a contour analysis of total flash counts. For example, the area enclosed by the gray shading includes a total of 4 to 5 fl/km^2 for the eight warm seasons. The blue areas enclose those parts of the NTS where a total of 8 to 9 fl/km^2 were measured for the 8 warm seasons. In other words, the blue shading encloses areas with average warm-season flash densities of 1.0 fl/km^2 to 1.1 fl/km^2 or simply 1.0 fl/km^2/warm season as an approximation.

Figure 8 shows that CG lightning occurs throughout the NTS; however, the extreme southwestern section (Area 25, see Fig. 2) has experienced the least number of flashes. The total flash count in this area are generally $\leq$ 4.0 fl/km^2 for the eight warm seasons, 1993 through 2000. Frenchman Flat, especially in the vicinity of the National Hazardous Materials Spill Facility has also experienced few ($\leq$4 fl/km^2) CG flashes during the 8-yr period. By contrast, widespread thunderstorm and CG lightning flash activity has occurred in the northwest quarter of the NTS. Total flash counts of 10 to 13 fl/km^2 have been detected along the northern border of the NTS for the period of record. In addition, another active area appears in the northeastern part of the NTS, in Areas 8 and 15. The largest total flash count on the NTS was measured approximately 5 km south of Mercury where 13 fl/km^2 occurred. Another active area of 12 fl/km^2 is located nearly 10 km southwest of Mercury. These two areas appear to be associated with thunderstorms that develop over the Spring Mountain Range and move northeastward onto the NTS. A curiosity with these two areas is that the time of maximum occurrence is between 2300 and 0300 PDT with the peak in activity at midnight.

Temporal: The NTS warm-season summary of the hourly variation in CG lightning is presented as a bar graph in Fig. 9. In this figure, time is plotted on the abscissa and flash count on the ordinate. Hourly summaries are for the hour beginning at the identified time and ending 60 min later. For example, the plot for 1100 PDT is for flashes that occurred between 11:00:00 and 11:59:59 PDT.

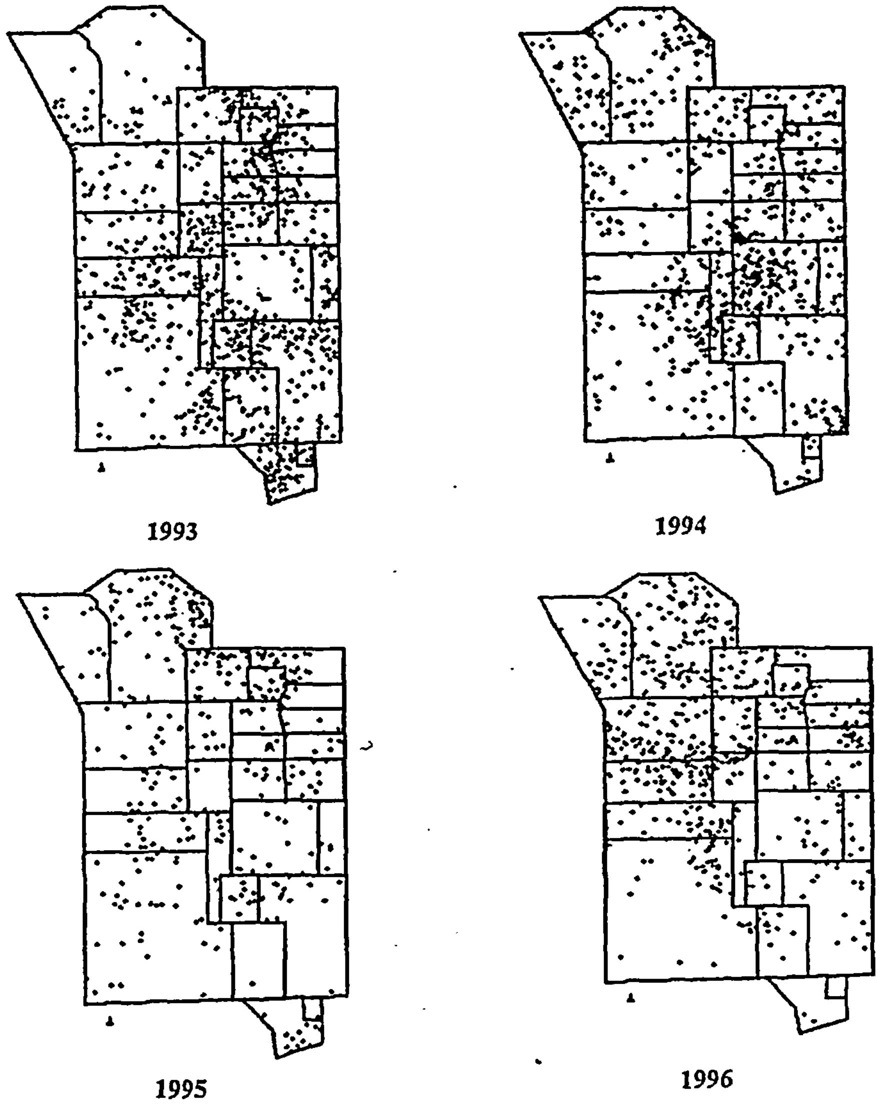

Figure 5a. NTS warm season, total CG flash distributions by year.

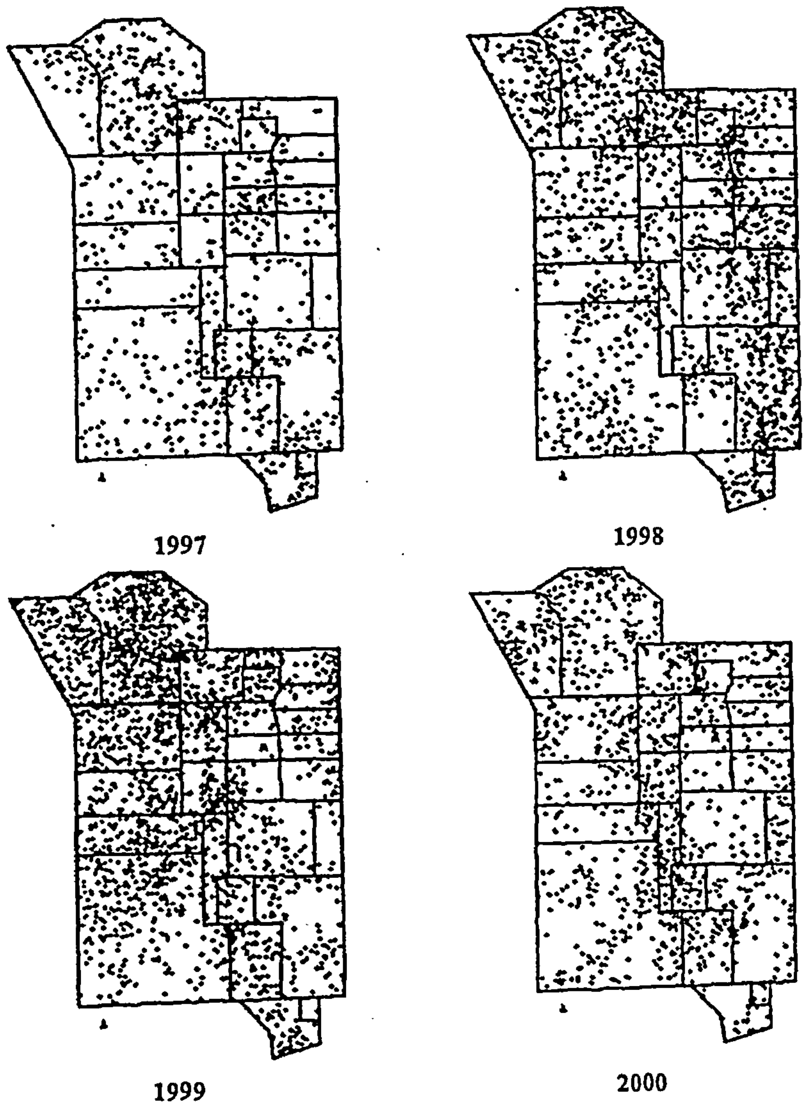

Figure 5b. NTS warm season, total CG flash distributions by year.

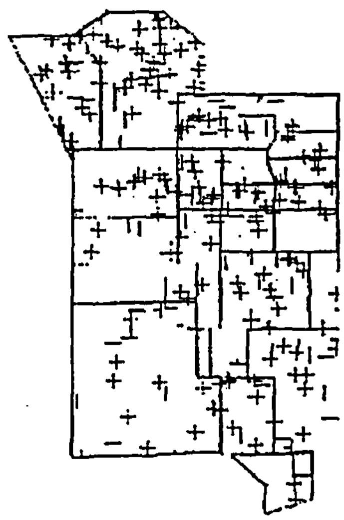

Figure 6. Distribution of warm-season positive CG flashes for 1993 through 2000 for the NTS.

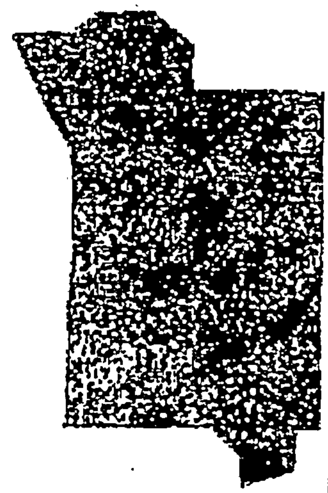

Figure 7. Locations of all NTS CG flashes for the 1993 through 2000 warm seasons.

Both negative and positive flashes are summarized. Positive flash totals are plotted as the black bar located on top of the solid gray bars which represent the total hourly negative flash count. Also, Pacific Daylight Time (PDT) is used in discussing lightning events since it is the local time used during the summer months and because of the close relationship between thunderstorm activity and solar heating of the ground.

Figure 9 clearly shows that CG lightning activity reaches maximum intensity during the hour beginning at 1400 PDT, two hours earlier than that detected for southern Nevada (Sanders and Randerson, 2000). This maximum is biased toward the northern half of the NTS where thunderstorm activity commences approximately one hour earlier than over the southern half of the NTS. This difference is terrain driven. Much of the terrain in the northern half of the NTS lies above 1700 m above mean sea level (MSL) while that over the southern half ranges from 800 m to 1500 m MSL.

Diurnally driven CG lightning activity begins after 1100 PDT on the NTS. However, it increases more rapidly over the northern NTS than over the southern NTS. For example, by 1200 PDT less than 100

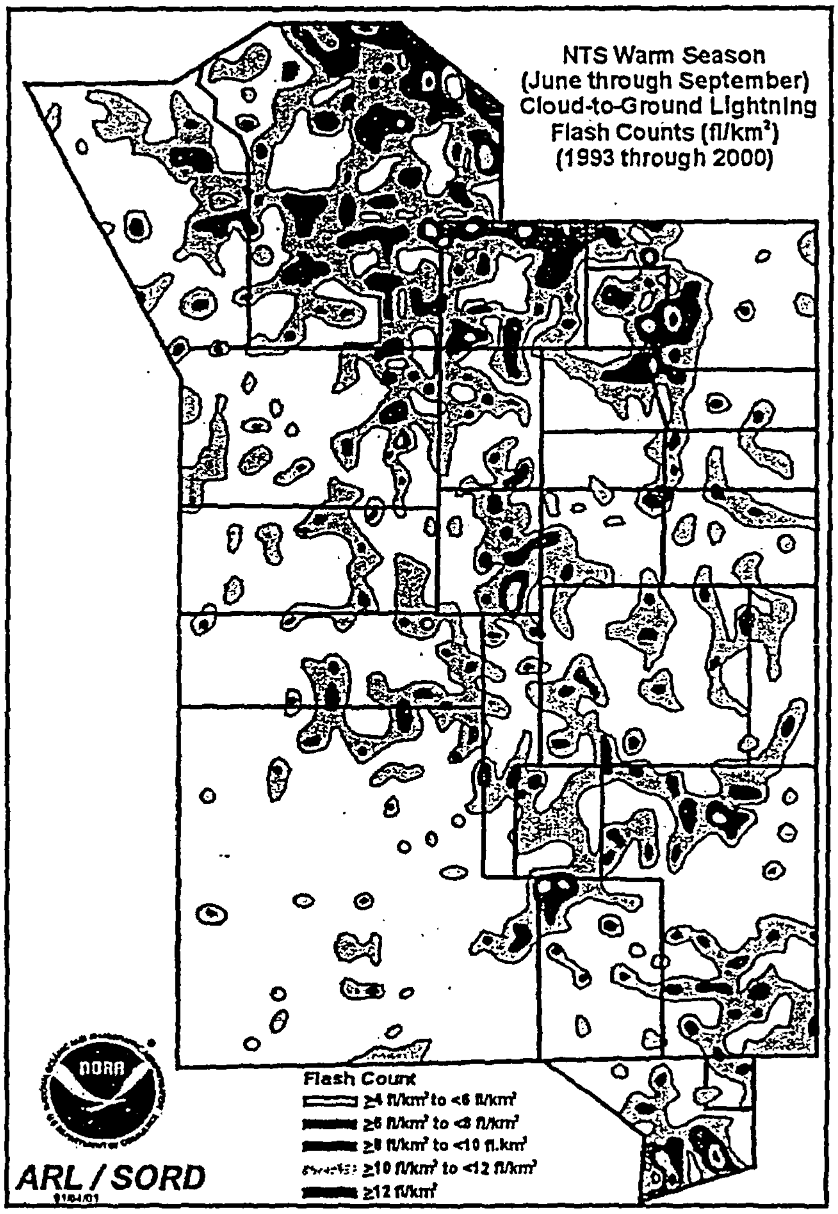

Figure 8. NTS warm season CG lightning flash totals for 1993 through 2000.

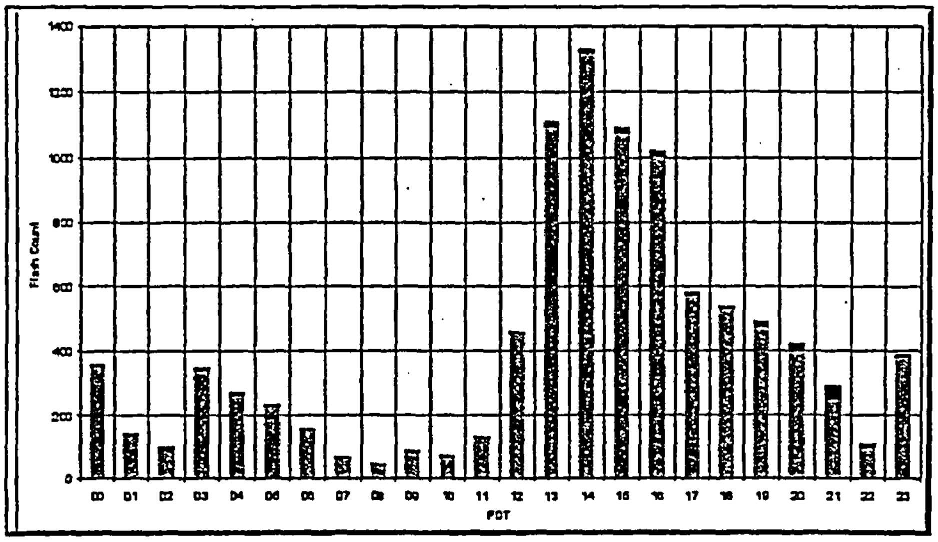

Figure 9. Diurnal distribution of CG flashes on the NTS for the warm seasons, 1993 through 2000. Time is in Pacific Daylight Time. Negative flashes are represented by the gray bars and the positive flashes by the black bars.

flashes have been measured over the southern NTS while slightly more than 350 flashes have been detected over the northern NTS. Furthermore, the diurnal pattern over the northern NTS shows a strong connection to the solar cycle, with CG flash activity reaching a maximum between 1400 and 1459 PDT and dissipating rapidly after 1659 PDT. However, over the southern NTS flash activity accelerates after 1200 PDT, reaches a peak between 1500 and 1559 PDT, dissipates rapidly after 1659 PDT, but remains somewhat elevated until after 2200 PDT when two secondary CG maximum of nearly 375 flashes appear between 2300 PDT and midnight and another for the hour beginning at 0300 PDT (see Fig. 9). Some of the nighttime activity over the southern NTS may be associated with the maintenance of strong convective instability long after sunset over the desert and in the vicinity of the Spring Mountain Range located southeast of the NTS. This mountain range contains several peaks above 3000 m MSL. In addition, outflow from late evening desert thunderstorms may help initiate additional thunderstorm development until late at night in the desert if adequate moisture is available. A similar observation was reported by the author (Randerson, 1997) in the analysis of set-hour precipitation data for Las Vegas, Nevada, by Watson et al. (1994) in Arizona, and by Fosdick and Watson (1995).

The small maximum at 0300 PDT is a curiosity. Examination of the data base revealed that most of the total flash count for this hour was due to three significant thunderstorm events. All three events occurred in September; on the 3rd, 1997, on the 19th, 1999, and the 8th, 2000. These three events accounted for nearly 90% of the CG flashes detected on the NTS between 0300 and 0359 PDT.

Daily CG Flash Densities: Daily flash totals (fl/km^2), or daily flash densities, on the NTS ranged from 1.0 fl/km^2 to 7.0 fl/km^2. These events were usually associated with a single thunderstorm. The peak daily flash densities by warm season are listed in Table 2. This table shows that very active thunderstorms, with intense CG lightning, can occur during any warm season month and any place on the NTS.

Table 2. Maximum daily warm-season flash densities (fl/km^2).

YEAR	PEAK FLASH DENSITY (fl/km^2)	DATE	LOCATION
1993	4.0	8/28/93	Areas 25 and 27
1994	5.0	8/13/94	Area 5, extreme SE
1995	6.0	6/30/95	Area 19
1996	3.0	7/11/96	Areas 16 and 18
1997	4.0	8/7-8/97	Areas 5 and 19
1998	4.0	Several days Aug/Sept	Several locations
1999	7.0	7/13/99	Area 15
2000	4.0	Several days in Aug	Several locations

CG Flash Rates: Single storm CG flash rates were quite variable. Some of the more active flash rates were associated with vigorous moist convection that produced intense thunderstorms. In some cases (e.g. August 13, 1998) a vigorous thunderstorm generated many CG flashes in a short time span (35 fl in 28 min). If normalized to a one-hour standard, this flash rate is equivalent to 75 fl/hr. A survey of the 8-warm season data base indicated that there were many thunderstorms with normalized flash rates of 30 to 45 fl/hr. The more active thunderstorms tend to generate flash rates of 50 to 75 fl/hr. These flash rates are smaller than 100 to 300 fl/hr reported by Randerson and Sanders (2000) for individual thunderstorms over southern Nevada. One mesoscale convective system contained a flash rate of 540 fl/hr in southeastern Nevada in 1998.

Precipitation and CG Lightning: Any relationship between warm-season precipitation and CG lightning is complex and difficult to establish; especially, in a desert environment with mountainous terrain. First, precipitation produced by desert thunderstorms tends to be light. For example, the author (Randerson, 1997) showed that 99% of all total, set-hour rainfall depths for warm-season precipitation events in Las Vegas, Nevada, are ≤ 6.4 mm (0.25 in.). However, the precipitation produced by some thunderstorms can be intense and focused into a small area, producing isohyetal gradients as large as 7-8 mm/km (Randerson, 1976 and 1997). The CG lightning footprint from these thunderstorms can be much larger than that produced by the precipitation or resulting isohyetal analysis for a single storm event. Terrain can also play a critical role, modulating thunderstorm development and influencing the CG lightning pattern, thereby complicating any linkage between CG lightning and the precipitation footprint. Furthermore, precipitation events without lightning can occur during the warm season in the desert.

To identify any potential relationship between CG lightning and precipitation on the NTS, every day (976 days) of the 8-yr, warm-season, CG lightning and NTS precipitation data bases were systematically reviewed. Daily NTS precipitation data were extracted from the ARL/SORD climatological data base for June through September, 1993 through 2000. Daily CG lightning data for the same period were drawn from the ARL/SORD lightning data base. These two data bases were fused together and analyzed, year-by-year. In this study, "daily" is defined to correspond with the solar cycle; namely, from local midnight to local midnight. Clock-hour time is in Pacific Daylight Time (PDT). An NTS CG lightning day is defined as one in which at least one CG flash was detected on the NTS between 0000 PDT and 2359 PDT. An NTS precipitation day is one in which a measurable amount of precipitation (≥0.01 in.) was measured in one of the 17 NTS precipitation climatological stations equipped with recording tipping bucket rain gauges. Analysis of the NTS data bases revealed four possible combinations of events, as follow:

- days with no measurable precipitation and no detected CG lightning
- days with measurable precipitation and no CG lightning
- days with CG lightning and with precipitation detected on the NTS
- days with measurable precipitation and with CG lightning detected on the NTS

This analysis showed that on 13.5% of the days, CG lightning was detected on the NTS and on 86.5% of the days there was no CG lightning on the NTS. Of these days, 11% were associated with both precipitation and CG lightning and 2.5% with CG lightning and no measurable precipitation. There were several widespread, heavy precipitation days in the data base which contained no CG lightning (e.g. June 5, 1993, June 13, 1997, September 25, 1997, and August 29, 2000) and many days with light precipitation and numerous CG flashes.

It was not possible to connect daily flash densities (or rates) with measured daily precipitation totals in a meaningful way. A typical example of what the data bases revealed can be seen by reviewing the daily CG lightning and precipitation totals for July 13, 1999. On this day a flash density of 7 fl/km^2 occurred in the northeastern part of the NTS along with flash densities of 1 to 3 fl/km^2 in the southwestern quarter of the NTS. Precipitation totals from 17 climatological rain gauges ranged from 1.0 mm (0.04 in) at Mercury to 27.4 mm (1.08 in) in Area 18. Flash densities of only 1 fl/km^2 were detected near the rain gauges containing the greater precipitation depths. Consequently, there appeared to be little or no direct linkage between CG lightning and precipitation.

Distance Between Successive CG Flashes

In April 2001, the ARL/SORD lightning detection system was upgraded with new IMPACT Sensors and a new position analyzer, LP2000, both manufactured by Global Atmospherics, Inc. This new system contained software (LTraX) that could be used to measure distances between CG flashes when displayed on the GAI LP2000.

A preliminary analysis was completed of the distances between successive CG flashes on the NTS using the CG flash data for 2001 warm season. This process was laborious because the goal was to identify and locate the CG lightning footprint accompanying a single thunderstorm. Moreover, the terrain within the boundaries of the NTS is complex (see Fig. 2) and CG lightning can occur during any hour of the day (see Fig. 9). Consequently, every effort was made to identify thunderstorms over different terrain environments, to collect CG lightning data at different times of the day, and to include weak, moderate, and heavy thunderstorm activity. A total of 16 individual thunderstorms were analyzed. These storms generated 271 CG flashes and they occurred on the NTS between 0900 LDT and 0200 LDT (next day). Some were located over the high terrain in the northern part of the NTS and others were located over the dry lake beds and the lower elevations in the southwest quarter of the NTS. This sample, although small, was representative of the NTS environment.

Successive CG flashes associated with each thunderstorm were categorized according to the distance between flashes. The grouping was into 1.0 mi (1.6 km) bins ranging from separation distances of ≤1.0 mi to ≥10.1 mi (≤1.6 mi to ≥16.3 km). Separation distance between successive flashes ranged from 0.1 to 11.9 mi (0.16 to 19.2 km). The distribution of the separation distances is shown graphically in Fig. 10. In this figure, notice that the greatest frequency of occurrence (23.9%) is in the 1.1 to 2.0 mi (1.8 to 3.2 km) category. Furthermore, 77% of the successive CG flashes had separation distances of ≤5.0 mi (8 km). Less than 2% had separation distances of more than 10 mi (1.6 km), and the confidence that these flashes were associated with the identified thunderstorm is low. The average separation distance for the entire data base is 3.4 mi (5.5 km), slightly larger than that reported by Krider (1988) for small thunderstorms in Florida. Recently, Lopez and Holle (1999) noted that successive separation distances were greater for large, more organized thunderstorms.

Based on the analyzed data, it is suggested that a lightning warning radius of 10 mi (16 km) can be identified for facilities and for personnel working on the NTS. This recommendation is slightly more conservative than that proposed during the "International Workshop on Lightning and Human Beings" (www.uic.edu/labs/lightninginjury/faq4.htm) by the American Meteorological Society (Holle', et. al., 1999), and by NOAA (www.lightningsafety.noaa.gov/factsheet.htm).

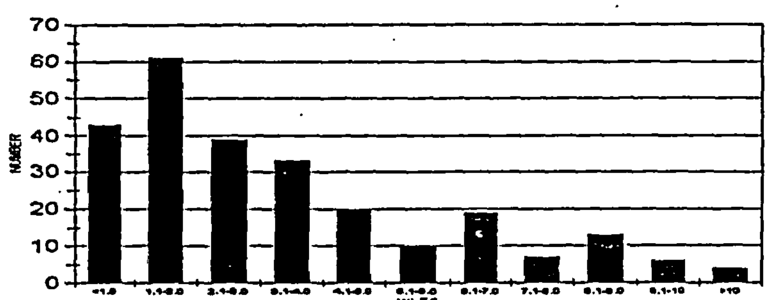

Figure 10. Distance between successive warm-season CG flashes on the NTS.

VI. Site-Specific Climatology

A thunderstorm moving at approximately 50 km/hr (30 mph) will travel a distance of 8 km (5 mi) in 10 min. Storm development and the erratic behavior of CG lightning could reduce CG-flash arrival time to less than 10 min. In most cases, lightning-sensitive work activities can be terminated within 10 min to implement safety precautions. To add to the margin of safety to protect people, valuable equipment, and facilities, this time is doubled to 20 min. Now, assume a **radius of safety**, r_s, of at least 16 km (10 mi) beyond the central work area. By counting all the CG flashes contained within r_s for the eight warm seasons, the total CG flash count, X_{10}, can be determined. Define a CG flash **safety incursion**, $A_{0.5}$, as a CG flash that strikes within 0.5 mi (0.8 km) of the central work area. Then the **probability**, P, of a CG flash, or **safety incursion**, at a work area can be expressed as,

$$P = A_{0.5} / X_{10}.$$

This expression can be solved by determining $A_{0.5}$ and X_{10} from the lightning data base. This calculation was completed for the following critical facilities and locations on the NTS:

U1a Complex	Big Explosives Experimental Facility (BEEF)
Mercury	Hazardous Materials Spill Center (HSC)
Area 16	Device Assembly Facility (DAF)
	Yucca Mountain Project (YMP)

Plots of X_{10} are shown in Figures 11 through 18 for each location and values of P, $A_{0.5}$, and X_{10} are listed in Table 3. The maximum flash amperage detected within a 10 mi (16 km) radius of each site (Figs. 11 through 18) is also listed in Table 3. For the summarized sites, the maximum flash-current detected is -167,000 amps which is also the maximum flash-current detected on the NTS. The maximum positive-flash current detected on the NTS is 152,000 amps. Other data listed in Table 3

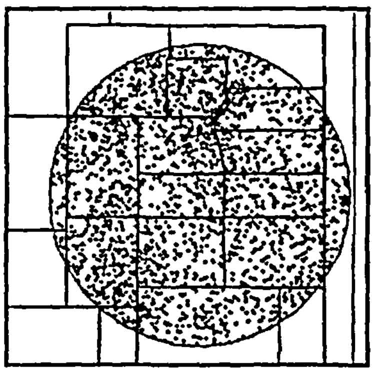

Figure. 11. Warm-season CG flashes within 10 mi of the BEEF facility, 1993-2000.

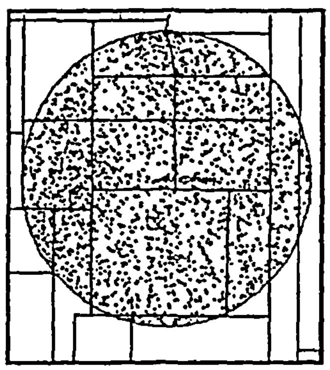

Figure. 12. Warm-season CG flashes within 10 mi of the U1a Complex, 1993-2000.

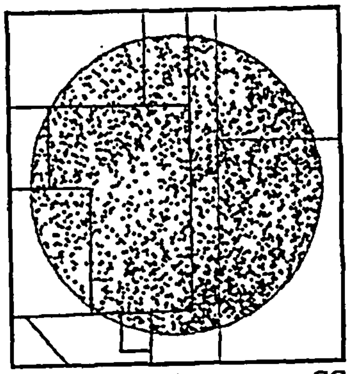

Figure. 13. Warm season CG flashes within 10 mi of the HSC, 1993-2000.

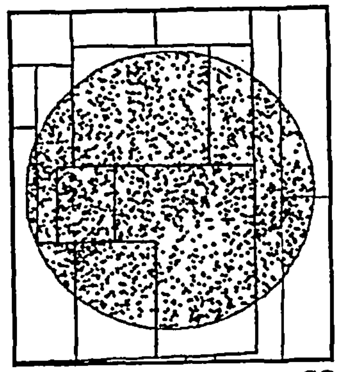

Figure. 14. Warm-season CG flashes within 10 mi of the DAF; 1993-2000.

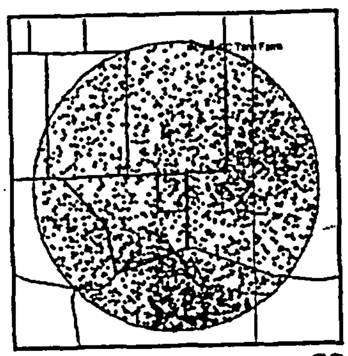

Figure. 15. Warm-season CG flashes within 10 mi of Mercury, 1993-2000.

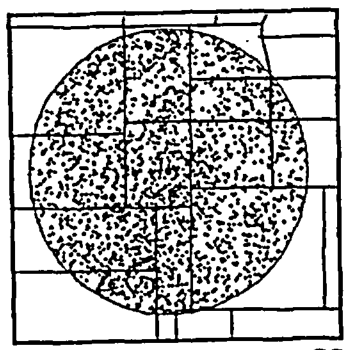

Figure 16. Warm-season CG flashes within 10 mi of Area 16, 1993-2000.

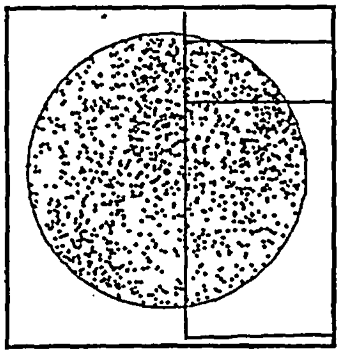

Figure. 17. Warm-season CG flashes within 10 mi of YMP, 1993-2000.

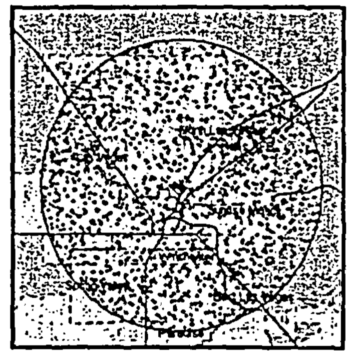

Figure. 18. Warm-season CG flashes within 10 mi of the NSF, 1993-2000.

Table 3. Site-specific, warm-season (1993-2000) CG lightning information for the NTS and Nevada Support Facility (NSF).

SITE	T_{10}	FD	POS	%+	$A_{0.5}$	maxKA	P[%]
BEEF	2255	0.35	81	3.6	6	-141	0.27
U1a	2165	0.33	73	3.4	4	-167	0.18
HSC	2453	0.38	51	2.1	6	+106	0.24
DAF	2161	0.33	55	2.5	6	-136	0.28
MER	2711	0.42	47	1.7	8	-97	0.30
A16	2356	0.36	79	3.4	7	-167	0.30
YMP	1313	0.20	34	2.6	0	+122	≤0.01
NSF	1729	0.27	28	1.6	2	-97	0.12

T_{10} = total number of CG flashes within a 10 mi (16 km) radius of a site.
FD = flash density in number of flashes/km^2/warm season.
POS = total number of positive flashes within a 10 mi (16 km) radius of a site.
%+ = percent positive flashes within a 10 mi (16 km) radius of a site.
$A_{0.5}$ = total number of CG flashes within a ½ mi (0.8 km) radius of a site.
maxKA = maximum flash amperage detected within a 10 mi (16 km) radius of a site.
P[%] = probability of a CG flash within a ½ mi (0.8 km) radius of a site.

also show that the maximum site flash density, 0.42 fl/km²/warm season, is at Mercury. The reason is related to thunderstorms that develop over the Spring Mountain Range and move northeastward over the southern part of the NTS. Larger flash densities, approaching 0.5 fl/km²/warm season, occur within comparable areas in the northern part of the NTS where terrain elevations exceed 6000 ft (1830 m) above MSL.

VII. Conclusions

This study focused on characterizing warm-season CG lightning on the NTS. Both spatial and temporal analyses of the eight-year CG lightning data base were completed. CG flash data was reviewed for each day in the 976-day data base. The following conclusions were reached :

1. CG lightning occurs on 13.5% of the warm season days. Of these days, 115 were associated with both measurable precipitation and CG lightning and 2.5% with CG lightning and no precipitation (dry thunderstorms).

2. There was no CG lightning on the NTS on 86.5% of the days in the eight-year warm season data base.

3. There is great inter-annual variability in total flash counts, ranging from 409 flashes in 1995 to 2,532 flashes in 1999.

4. For the eight warm seasons, a total of 9,596 CG lightning flashes were detected on the NTS. For the 3,500 sq km NTS, this total yields an average, NTS warm-season flash density, of 0.35 fl/km².

5. Of the total CG flashes, 2.6% deposited positive charge to the ground.

6. Total flash counts on the NTS ranged from less than 1.0 fl/km² (in Area 25) to 13 fl/km² in Area 22. These counts can be converted to average seasonal flash densities by dividing by 8.

7. The most active parts of the NTS are over the high terrain oriented north-south through the center of the NTS, over Pahute and Rainier Mesas (Areas 12, 19, and 20), and Area 22. The maximum in Area 22 appears to be related to thunderstorm activity that develops over the northern end of the Spring Mountains and moves northeastward on to the NTS.

8. Climatologically, CG lightning activity begins to develop rapidly after 1100 PDT, reaching a peak between 1400 and 1459 PDT over the mesas and between 1500 and 1559 PDT over the southern half of the NTS.

9. Although CG lightning has occurred during every hour of the day, minimum CG lightning occurs between 0600 and 1100 PDT, with 0800 to 0859 PDT representing the

hour of least CG activity.

10. Positive CG lightning has been detected during every hour except for 0200 to 0259 PDT. Most positive flashes occur between 1300 and 2300 PDT with 2100 to 2159 PDT being the most active hour.

11. Maximum daily warm season flash densities ranged from 3.0 to 7.0 fl/km^2.

12. The most active thunderstorms generated CG flash rates of 50 to 75 fl/hr.

13. Peak flash current detected was -167,000 amps.

14. Average spacing between successive CG flashes was 3.4 mi, and 77% of these flashes were ≤5.0 mi apart. Maximum separation detected was 11.9 mi.

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Florida had the most deaths (345) and injuries (1178) from lightning,and Pennsylvania had the most damage reports (1441). A rate of one fatality per 86000 cloud-to-ground flashes is estimated from recent lightning detection network information. After population was taken into account, Wyoming and New Mexico had the highest death, injury, and casualty rates. The U.S. rate is 0.42 lightning deaths per million people per year from 1959 to 1994. Highest population-weighted damage rates were on the plains, but the pattern was variable from decade to decade. July had more lightning entries of all types than any other month; damage reports

were spread more evenly through the year. Casualties and damages in the northern half of the United States had narrower distributions centered on summer than did the southern half. Two-thirds of the casualties were

between noon and 6 P.M.; damage reports were relatively frequent at night in the plains and Midwest. Most lightning incidents involved one person, and males were five times as likely as females to be killed or injured.

Storm Data excludes most small losses but includes more expensive and widely known lightning-related losses.

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