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Noise and Vibration Investigations of the Sandia National Laboratories Sol se Mete Aerial Cable Facility

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**NOISE AND VIBRATION INVESTIGATIONS
OF THE SANDIA NATIONAL LABORATORIES
SOL se METE AERIAL CABLE FACILITY**

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Abstract

The noise and vibration effects and fragmentation hazards of the test and evaluation activities at the Sandia National Laboratories Sol se Mete Aerial Cable Facility are investigated. The predominant contributor to the existing noise environment is the operation of aircraft arriving at or departing from Albuquerque International Airport. This airport is jointly used by civilian aircraft and military aircraft operating from the adjacent Kirtland Air Force Base. Noise sources associated with the Aerial Cable Facility are examined in detail. Both the ongoing program and construction that would be required for the proposed additions to the facilities are investigated. Project-related noise sources include vehicles, tests involving detonation of high explosives, rocket motors, a 3-inch gun, and a 20-mm gun. Ground vibration, blast overpressure, and fragmentation from high explosives also are considered. Noise predictions are made by scaling noise values from handbooks and other reference sources to the appropriate distances. Ground vibration, overpressure, and fragmentation are predicted using standard scaling laws. Predicted noise levels for specific Aerial Cable Facility activities are used to estimate the equivalent sound level for the 8-hour work day and to determine when worker hearing protection is necessary. Hazard radii for tests involving high explosives also are given.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACF	Aerial Cable Facility
AGL	above ground level
ANSI	American National Standards Institute
ASEL	A-weighted sound exposure level
CFR	Code of Federal Regulations
CSEL	C-weighted sound exposure level
dB	decibel
dBA	decibel, A-weighted
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
fps	feet per second
ft	foot or feet
HE	high explosive
HVAR	High Velocity Aircraft Rocket
Hz	hertz (cycle per second)
ips	inches per second
KAFB	Kirtland Air Force Base
kg	kilogram
km	kilometer
kPa	kiloPascal
kW	kilowatt
L_A	A-weighted sound level
lb	pound
L_C	C-weighted sound level
L_{dn}	equivalent day-night weighted average sound pressure level
L_{eq}	equivalent sound level
$L_{eq}(8)$	equivalent sound level for an 8-hour work day
m	meter
mi	mile(s)
mm	millimeter
NOISEMAP	U.S. Air Force noise exposure computer simulation model for aircraft operations
OSHA	Occupational Safety and Health Administration
SEL	sound exposure level
SNL	Sandia National Laboratories
SPL	sound pressure level
TNT	trinitrotoluene (high explosive)
μ Pa	microPascal

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EXECUTIVE SUMMARY

This document is an assessment of the noise, vibration, and overpressure effects and fragmentation hazards of the operation of the Sandia National Laboratories (SNL) Sol se Mete Aerial Cable Facility (ACF). Baseline noise measurements have not been conducted near the ACF. The predominant source of background noise is civilian and military aircraft operating from Albuquerque International Airport. In the immediate vicinity of roads, vehicular traffic also makes a major contribution to the background noise in the area. Major noise sources associated with project operations and considered in this report include rocket motors, chemical explosions, 3-inch gun, 20-mm gun, vehicular traffic, and engines of electricity generators. In addition, construction equipment noise is considered. Construction would be required for the proposed minor expansion of some of the facilities and would temporarily increase the noise level in the immediate vicinity of the construction sites. Ground vibration, blast overpressure, and fragmentation hazards resulting from explosions also are considered.

Noise exposure of ACF personnel is expressed as the equivalent sound level for the 8-hour work day, and is computed by scaling to the proper distance and combining the appropriate noise values for continuously operating equipment such as vehicles and generators. Explosions and gun firings are impulsive events, and overpressures are predicted and expressed as decibel (dB) at the control building, at other nearby facilities, at Sol se Mete Spring which is frequented by wildlife, and at the nearest housing area to the facility. Potential effects of noise on wildlife are considered by comparing the explosion-produced noise levels with the noise level produced by a hunting rifle. The conclusion reached in the noise analysis is that continuously operating equipment would not produce a serious noise hazard except in the immediate vicinity of the electricity generators and heavy equipment where hearing protection devices should be used. Rocket motors, guns, and detonations of less than 54 kilograms (kg) (120 lb) of explosives would not produce noise levels above the threshold for individual protection at the control building, other nearby test areas, or Sol se Mete Spring. Rare tests involving explosive weights between 54 and 454 kg (120 and

1,000 lb) could produce impulsive noise levels above 140 dB that would require evacuation or other provision for individual hearing protection at the ACF control building and at certain nearby facilities not associated with ACF.

Other blast effects including overpressure, ground vibration, and fragmentation produce hazard radii that generally are smaller than the corresponding noise hazard radius, which is defined as the distance at which the predicted noise level drops to 140 dB. The largest non-noise hazard radius results from fragmentation of a 454-kg [1,000-pound (lb)] cased explosive device. There are no adequate protective measures against the fragmentation hazard except spatial separation and fragment-resistant physical barriers. No test event except for a cased detonation of an amount larger than 54 kg (120 lb) of explosives would require extraordinary safety measures beyond the intersection of the test site road with the Sol se Mete Canyon access road, although hearing protection may be needed for workers who would be outside a protective structure.

1.0 INTRODUCTION

Sandia National Laboratories (SNL) operates the Sol se Mete Aerial Cable Facility (ACF) at Kirtland Air Force Base (KAFB), New Mexico, for the Department of Energy (DOE). The ACF is located on the eastern portion of KAFB. It is situated within Cibola National Forest on land withdrawn under a 1967 agreement between the U.S. Air Force and the U.S. Forest Service. Subsequently, a portion of the land was placed under DOE control for use by the ACF under a supplemental agreement between DOE and KAFB. The ACF is located within an area known as the Coyote Test Field.

The ACF consists of a test area where a series of cables are suspended across Sol se Mete Canyon. The cable systems are used to suspend test articles for ground impact tests under controlled acceleration conditions. Gravitational acceleration is used to achieve test article impact velocities of up to 46 meters per second (m/s) [150 feet per second (fps)]. Impact velocities up to 244 m/s (800 fps) can be achieved through a rocket sled pull-down towing technique. The cable also is used as a tramway for moving trolleys that support targets used for testing a variety of passive and active electronic, optical tracking, and acquisition devices.

Presently, one heavy steel cable and one Kevlar cable are used in the South Test Arena, and two lighter steel cables are used in the North Arena. The two test arenas are located approximately 305 meters (m) [1,000 feet (ft)] apart on the canyon floor.

Figures 1 and 2 define the geographical location of the ACF. Figure 3 is an aerial photograph of the ACF, labeled to show significant structures.

Figure 1. Project Location near Albuquerque, NM

Figure 2. Kirtland Air Force Base and Sandia National Laboratories Test Areas

Figure 3. Aerial Photograph of SNL Aerial Cable Facility

The ACF fulfills multiple purposes in support of DOE research and development activities listed below. These purposes are discussed in greater detail in this section. ACF test activities include the following:

- Precision impact certification testing of nuclear material shipping containers in accordance with Title 10 Part 71 of the Code of Federal Regulations (10 CFR Part 71).
- Precision testing of full-scale, air-delivered weapons tests.
- Precision testing of airborne sensors and sensor-fuzed weapons systems released from a stable aerial platform located above ground targets.
- Precision testing of ground-based sensors and target-acquisition devices directed against simulated aircraft and aircraft targets traversing the ACF cableways.

1.1 SOUTH ARENA TEST SCENARIOS

The South Arena is the primary test area for impact tests and tests requiring trolley travel along the overhead cables. Presently, one heavy steel cable and one Kevlar cable are used in conjunction with the ACF Sled Track for nuclear material shipping container impact certification testing, and air-to-ground weapon testing. For purposes of impact tests, the South Arena also contains a unique “unyielding target” constructed beneath the ACF cableway with two million pounds of reinforced concrete below ground level and capped with steel armor plate at ground level.

The ACF South Arena is shown in Figure 4.

Figure 4. View of South Arena from West Anchor Site

1.1.1 Container Impact Testing

In accordance with Title 10 Part 71 of the Code of Federal Regulations (10 CFR Part 71) shipping containers used to transport nuclear materials must be designed to minimize the likelihood of releasing radioactive material in transportation accidents. The ACF is used to demonstrate compliance with impact-related container test provisions of this Federal regulation. The regulations require that the evaluation and certification of containers for transporting radioactive material will be completed by testing the containers under conditions to include impact, puncture, penetration, thermal exposure, water spray, and immersion.

The ACF is capable of testing large containers weighing up to 90,000 kg (100 tons). Large containers are lifted a few meters above the ground and dropped to achieve impact velocities up to a few meters per second. Smaller containers weighing up to 1,000 kg (1 ton) can be accelerated to impact velocities up to 250 m/s (800 fps). Current container impact resistance specifications are largely based upon work that has been performed at the ACF.

Over the past 7 years, 123 container impact test series have relied on the ACF testing facilities in the ACF South Arena (Hohnstreiter et al. 1991). Included in these test programs were tests of the Plutonium Air Transportable (PAT) container, the TRUPACT II container, the Big Rock Point container, the Helicopter Accident Resistant Container (HARC), and Three Mile Island Transportation Systems. The most recent container test programs have been for the certification of the Transportation Safety Container-Variant (TSC-V) and the H1501A HARC. Test articles used in the impact studies conducted in the South Arena are actual shipping containers with mock weapon components.

Since 1987, over 123 tests have been conducted using test articles designed to contain nuclear materials, and over 23 of these test units contained depleted uranium. There have been no recorded incidents of mock weapon components being fractured as a result of test activities, and all radioactive materials have been recovered following each test (Bickel, 1993). Therefore, impact tests of transportation containers have successfully confirmed the

capabilities of these containers to protect ordnance from damage. Because there are no data indicating any release of radioactive materials from these tests, there is very little likelihood of contamination of the test facility as a result of these tests.

1.1.2 Air-to-Ground Weapons Testing

The ACF, by engineering simulation, can match the full range of sub-sonic aircraft speeds for delivering full-scale air-to-ground weapons. Weapons are suspended from the aerial cable and are either dropped free-fall or are "pulled down" by the rocket sled to simulate the appropriate delivery velocity of each weapon. Testing and evaluation using the ACF provide significant advantages over aircraft delivery methods during the early stages of weapons development, when accuracy of the weapon flight profile and impact characteristics are the critical parameters in evaluating weapon design. Additionally, release equipment and weapon separation characteristics can be tested at the ACF prior to entering that portion of the weapon test cycle involving compatibility with the delivery aircraft. At this stage in the weapon development cycle, use of the ACF provides for higher probability of acquiring valid test data using test procedures that are less expensive than attempting to test delivery methods using actual aircraft operations.

1.2 SPECIALIZED SUPPORT OPERATIONS

The South Arena also is used for highly specialized testing of the target and scoring system used to test U.S. Navy armaments. The target system, including the projectile missile sensors and scoring protocol, must be certified annually. The target is supported from the aerial cable, and up to 100 inert rounds of 20-mm (millimeter) cannon fire, 120 inert rounds of 3-inch naval gun fire, or other weapons are fired at the target. Sophisticated electronics inside the target are used to sense the miss-distance for the passing rounds. From known trajectories for the projectiles, the test allows calculation of the accuracy of target sensing and electronic equipment. Such tests are normally conducted once per year.

1.3 ACF SLED TRACK

Based on operational scenarios, up to 35 tests per year involve use of a rail-mounted sled accelerated by rocket motors to attain high velocities. The rocket sled is propelled by a combination of Zuni and High Velocity Aircraft Rocket (HVAR) rocket motors typically totaling about 60 kg [140 pounds (lb)] of propellant. The primary use of this sled track is to pull down test articles from the aerial cable at predetermined velocities that are greater than can be achieved by gravity acceleration. This capability has been used for more than 20 years in tests of mock nuclear ordnance and shipping containers for impact resistance and performance of weapon systems.

The pull-down testing sequence, as shown in Figure 5, is as follows: A wire rope towing system is used to attach the rocket sled to the test article that is suspended from the aerial cable. Towing lines run horizontally behind the sled for about 60 m (200 ft), where they turn vertically around high-speed wire rope pulleys. The towing lines continue vertically from 180 to 300 meters (600-1,000 ft), where they attach to the test article that is supported from the aerial cable. Zuni and HVAR motors are used to accelerate the sled and the pull-down apparatus. The test article is released from the cable as rockets are ignited, and the test article is pulled downward at the same rate the sled moves along the sled track. The test article is accelerated at up to 40 times the acceleration of gravity along its downward flight path reaching speeds up to 270 m/s [600 miles per hour (mph)] in less than 1 second, and the test article impacts precisely on target.

In 1992, as a maintenance replacement action, the original sled track was replaced by a new track with identical dimensions.

Figure 5. Rocket-Assisted Pull-Down Technique for a Side Impact

1.4 NORTH ARENA TEST SCENARIOS

The ACF North Arena was constructed in 1985. It comprises a separate steel cable system extending from the fixed East Anchor to the West Anchor, and extending down to a winch site that is separated from the winch sites used for the South Arena cable systems. The North Arena cable is steel, with a separate camera cable. One of the cable systems uses anchorages closer to the ground impact area.

This arena is used for engineering simulations involving test articles dropped from the cable onto a target array positioned underneath the cable. In previous tests, up to 16 separate test articles have been dropped against a simulated target array of up to 16 target tanks. In normal tests, the test article packages can range from sensor-only packages to test target acquisition capabilities, to packages using explosive charge devices to allow determination of impact circular error probable. The target array can be a variety of sensor packages or a variety of simulated or actual tactical vehicles.

Figure 6 is an annotated photograph depicting 16 target tanks.

1.5 DESCRIPTION OF TROLLEY OPERATION

A maximum of 50 trolley operations are performed per year at the ACF. Each unboosted trolley operation can consist of as many as 10 individual traversals of the cable. The ACF acts as a tramway for trolleys and/or targets that traverse the cable rolling on sheaves. The trolleys are able to achieve velocities on the order of 25 m/s (80 fps) if accelerated by gravity from the east end of the ACF. Higher velocities can be reached by rocket boosting the trolleys. Surplus Zuni and HVAR rocket motors are used to accelerate the trolley. Velocities up to 230 m/s (750 fps) are anticipated for an estimated ten yearly tests.

The trolley and target can weigh up to 3,175 kg (7,000 lb). Trolleys are braked by a combination of devices that could include drogue parachutes, restraining devices similar to

Figure 6. North Arena, SNL Aerial Cable Facility

those used on aircraft carriers, or similar devices capable of attaining a soft impact. Heavier trolleys traveling at higher velocities may require retro-rockets to reduce the trolley kinetic energy to a level at which other restraining and braking mechanisms are effective.

1.6 TEST FREQUENCY FOR ROCKETS AND EXPLOSIVES

The ACF is used for an average of 220 tests per year. Approximately 75 of these tests represent relatively environmentally benign activities such as testing operations involving passive electro-optical sensors or related activity. The remainder of these tests (approximately 145) involve detonation of high explosives or missile firings which inherently are environmentally intrusive. Tests in the latter category include the following:

Description	Assumed Maximum Annual Test Frequency
Rocket-boosted pull-down tests (typically, 5 rockets per test)	35
Rocket-assisted aerial target/trolley tests (typically, 5 rockets per test)	10
Detonation of up to 2 kg of high explosives	100
Detonation of 50 to 450 kg of high explosives	< 1
Weapons firing (20-millimeter or 3-inch guns) up to 120 rounds of 3-inch gun shots, or 100 rounds from 20-millimeter guns for each annual test	< 1

1.7 VEHICLE USAGE

During a typical year, ACF activity includes approximately 30,000 miles (mi) of vehicular movement, predominantly light vehicles used to transport SNL test personnel or test customers from the ACF offices in Technical Area III (TA-III) to the ACF. A small number of heavy construction support vehicles are used to transport test articles or used to prepare the ACF test areas for specialized testing. These vehicles include

- Light vehicles (up to 1-ton truck); estimated daily usage is 6 vehicle round-trips along paved and unpaved roads from TA-III to Building 9931 and from Building 9931 to the test arenas. Annual frequency is 1,440 trips.
- Contractor/test customers light vehicles. Daily usage is slightly more than one round-trip, and annual frequency is 240 trips.
- Heavy vehicles, including lowboys, cranes, and similar items, with an estimated annual frequency of 30 trips.

1.8 PERSONNEL

Approximately 15 SNL contractor employees are working at the facility on a regular basis. They report to the ACF project office in TA III some 13.1 kilometer (km) (8.2 mi) away and drive to Building 9831 and the ACF during working hours. As many as 20 people, including transient test observers, may work at the facility during peak testing activity.

1.9 UTILITIES

Commercial electric power is available only at the Control Building (9831) and at the Winch Site. Only Buildings 9831 and 9832 (Explosives Assembly Building) are heated using propane heaters. Instrumentation and test control equipment items are electrically powered by portable motor generators brought to the site on an as-needed basis. The Instrumentation Bunker (Bldg. 9834) uses a 60 kilowatt (kW) diesel-powered generator to provide electricity for heating, lighting, and instrumentation. The Explosives Assembly Building (Bldg. 9832) uses a 25 kW diesel-powered generator; however, a firm electrical power system is proposed to provide commercial power to this building.

2.0 DESCRIPTION OF THE PROPOSED ACTION

This report is a technical background document for the Sol se Mete ACF Environmental Assessment (EA). The proposed action consists of continuation of the use of the facilities previously described in conducting test operations discussed in Section 1.0 above, as well as the following projects:

- Placement of temporary instrumentation, command, and control trailers.
- Facility maintenance of roads, cables, fire breaks, and post-test site clean up of common construction materials.
- Proposed facility upgrades include the following:
 - Addition of restroom facilities next to Building 9831 that will incorporate a waste water capture tank;
 - Addition of two explosive storage bunkers comprising approximately 56 m² (600 square feet) installed next to Building 9832 within the fenced compound; and
 - Extension of commercial electrical power to Building 9832.
- An increase from an average of five tests per year of articles containing depleted uranium to an average of fifteen tests per year.

The proposed additions will accommodate modernization and improvement of the ACF to support continued operations and new Department of Defense (DOD) test programs. The new construction would occupy approximately 0.5 hectare (1.3 acres) of land, with new disturbance limited to less than 0.2 hectare (0.5 acres).

2.1 IMPACT IDENTIFICATION

The magnitude and potential impacts of noise and vibration resulting from ACF construction activities and operations are examined. In conducting this analysis, limits for noise exposure established by Operational Safety and Health Administration (OSHA) and SNL were considered, as well as Environmental Protection Agency (EPA) guidelines for noise exposure

compatible with land use. The effects of overpressure, debris, and vibration resulting from detonation of explosives are considered from the standpoint of protecting both personnel and property. Potential effects of noise on wildlife at Sol se Mete Spring are also evaluated.

This report contains an analysis of the existing noise environment at ACF. The predominant source of noise is overflight by civilian and military aircraft originating at Albuquerque International Airport. Other sources of noise include vehicle and equipment operations, particularly large winch motors and large diesel-powered electricity generators. These noise sources produce a background noise level against which the additive noise from ACF operations can be evaluated in terms of an overall baseline noise level. To this background noise is added the sound pressure levels generated by ACF test activities including explosive detonations.

As developed in this report, the prevailing or background noise level is influenced most strongly by aircraft noise. By convention, this noise level is evaluated in terms of day-night weighted average sound pressure level (L_{dn}). Under this convention, noise during the night time period from 10:00 p.m. to 7:00 a.m. is penalized by adding 10 dB to actual or estimated noise levels.

It also is important to recognize that sound levels expressed in dB are logarithmic quantities. When adding two sounds, the levels in Bels (1 Bel = 10 dB) must be exponentiated before addition, and the logarithm taken after addition. Thus, one sound at 85 dB when added to a second sound of say 90 dB produces an effective sound pressure of 91 dB (not 175 dB). Figure 7 is a graphic representation of the sound levels produced by common events and their effects on people and structures.

In addition to the preceding factors, this assessment also evaluates risks to structures and the potential hazard radii resulting from detonation of cased and uncased explosives.

Regulatory Standards and Noise Thresholds

Noise Source (dBA)

Figure 7. Typical Sound Levels from Indoor and Outdoor Noise Sources and Their Effects on People and Structures

Data Source: Harris (1991), Miller (1980), Speakman (1978), Nordic Noise Group (1984) and TM 5-803-2 (1978)

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3.0 EXISTING NOISE ENVIRONMENT AT THE ACF

Aircraft are the major contributor to the existing noise environment at the Sol se Mete ACF. These include civilian and military aircraft operating from Albuquerque International Airport and military aircraft on training missions in the area.

3.1 ALBUQUERQUE INTERNATIONAL AND KIRTLAND AIR FORCE BASE OPERATIONS

Albuquerque International Airport runways are located approximately 15.3 to 16.9 km (9.5 to 10.5 mi) west-northwest of ACF. The ACF site is not located under any frequently used flight pattern. Most of the flights observed from the site pass to the north and west of the site. A conservative estimate of the closest approach of these aircraft to the site is 4.8 km (3 mi). Traffic patterns are such that most aircraft that pass near the ACF are on approach for landing. General aviation flights comprise about 1/3 of the total operations.

Albuquerque International Airport reports aircraft operations are listed in Table 1 for the 12-month period ending 30 June 1994.

Table 1. Number of Aircraft Flights at Albuquerque International Airport by Category for the Period from 1 July 1993 to 30 June 1994

Category of Aircraft	Actual	Operations/ Month	Fraction During Day
Commercial carrier	77,263	6,439	65 %
Air taxi	40,954	3,413	80 %
General aviation	70,688	5,891	75 %
Military	23,078	1,923	85 %

Data source: Federal Aviation Administration (FAA) (1994)

The fraction of operations during daylight hours in the table above excludes those operations after dark but before 10:00 PM. Therefore, using these fractions to compute the day-night average sound level (L_{dn}) will lead to an overestimate of the penalty accruing to night operations.

Noise levels at the ACF site due to aircraft operations from Albuquerque International Airport were computed based on 220 commercial carrier operations and 120 air taxi operations per day. These numbers are slightly higher than the averages reported in Table 1 to allow for some daily variation. General aviation operations are excluded because they normally use an approach more distant from the site, while military aircraft are treated separately in the following section. Assuming equal numbers of takeoffs and landing, and assuming that only flights on landing approach pass within 4.8 km (3 mi) of the site, there are an estimated 110 commercial aircraft and 50 air taxi aircraft passing within 4.8 km (3 mi) of the site per day. This is probably a conservative estimate because not all flights use this approach, but it tends to correct for the exclusion from this analysis of departure operations. The analysis also excludes 6,788 military aircraft operations in a category titled "Local Area Operations" whose flight patterns generally do not take them within 4.8 km (3 mi) of the ACF area.

Commercial carrier aircraft are modeled in this study by using the characteristics of a Boeing 727 aircraft, while air taxi operations are modeled with the characteristics of Beechcraft King Air aircraft. These aircraft are in current use at Albuquerque International Airport, but the choice of the Boeing 727 will lead to a conservative estimate of noise because this is an older-design aircraft and is among the noisiest commercial aircraft in use (Smith, 1989).

3.2 MILITARY FLIGHT OPERATIONS

More specific information is available for military flight operations near the ACF area. Observations of aircraft reported near the SNL North Thunder Range located about 8 km

(5 mi) west of ACF indicate that most of the flights observed are military aircraft (Mathews, 1991). Aircraft include helicopters approaching or leaving the 1550th training area 8 km (5 mi) to the southwest. According to Mathews, the helicopters are usually moving at an altitude of approximately 305 m (1,000 ft) above ground level (AGL). Most other military aircraft are traveling at altitudes higher than 610 m (2,000 ft). Because of the more mountainous terrain at the ACF compared with the North Thunder Range area, it appears likely that helicopters would pass no closer than 610 m (2,000 ft) from the ACF area.

For the purpose of modeling the risk of overflying aircraft being damaged by fragments generated by explosives, Mathews obtained a "conservative estimate" of 6.25 per day for the number of aircraft crossing any portion of a 625-m (2,050-ft) radius at the firing site. One in five of these aircraft are assumed to be flying below 610 m (2,000 ft) AGL. Mathews only considered aircraft flying within this hazard zone; however, for estimating noise exposure levels, the contributions of flights not passing directly over the hazard zone also are included.

Air traffic data for local tactical aircraft indicate numbers of operations as shown in Table 2.

Table 2. Local Tactical Aircraft Flight Activity

Category of aircraft	Operations/ month	Operations/ day	Fraction during day
Fighter (F-15)	383	13.0	95 %
Transport (C-130)	48	2.0	75 %
Helicopter (HH-53)	135	4.5	75 %

Data source: Kirtland AFB Operations (1991) and FAA (1994)

Data in the table have been rounded to the nearest 0.5 flights per day. A specific aircraft listed for each category is assumed to be a representative aircraft used for the purpose of estimating the noise produced by each. According to tabulated data used in the Air Force NOISEMAP model for predicting noise exposure resulting from aircraft operations (Moulton,

1990), the noise level from an F-15 tends to be greater than that for most other fighter aircraft given the same operating conditions. Data for the C-130 used in the model were based on actual measurements on a C-130E (Speakman, Powell, and Lee, 1978a). Other versions of the C-130 are modeled by NOISEMAP by adding or subtracting an offset of less than 1 dB at 1,000 ft range to the C-130E value. The noise level from an HH-53 helicopter in flight at 100 knots is near the median value for the types of helicopters listed in the NOISEMAP database, and differs from the noisiest helicopter listed by 5.2 dB at 305 m (1,000 ft) range.

The military aircraft flights are assumed to be equally distributed between aircraft taking off and landing. Helicopters are assumed to be in level flight at 185 km/hr (100 knots). One-third of the fighter and helicopter flights are assumed to pass within 610 m (2,000 ft) of ACF. Another one-third of the flights are assumed to pass within 1.6 km (1 mi) of the site at closest approach, while the remaining one-third of flights pass within 4.8 km (3 mi) of the site. For calculating the equivalent day-night weighted sound pressure level (L_{dn}), this leads to a set of hypothetical flights, listed in Table 3, for which noise conditions were analyzed by computer simulation.

Table 3. Military Aircraft Activity Assumed for Computing L_{dn}

Operating Aircraft	Closest Conditions	Closest Approach to ACF (m)	Flights/Day	Night
F-15	Takeoff	610	2.1	0.1
		1,610	2.1	0.1
		4,830	2.1	0.1
	Landing	610	2.1	0.1
		1,610	2.1	0.1
		4,830	2.1	0.1
	Takeoff	610	0.2	0.1
		1,610	0.2	0.1
		4,830	0.2	0.1
C-130	Landing	610	0.2	0.1
		1,610	0.2	0.1
		4,830	0.2	0.1
	Level Flight	610	1.1	0.4
		1,610	1.1	0.4
		4,830	1.1	0.4

The number of flights (6.5) passing within 610 m (2,000 ft) is consistent with the estimates of Mathews (1991) for the North Thunder Range. However, because ACF is located in a more distant area, this method of estimating aircraft induced noise at ACF is conservative and will result in overestimating the noise at the site.

3.3 COMPUTATION OF DAY-NIGHT AVERAGE SOUND LEVELS FROM EXISTING AIRCRAFT SOURCES

The A-weighted sound level (L_A) for a single flight of each type of aircraft was computed for each representative scenario as a function of time. The point of closest approach of each

aircraft to ACF was estimated. For the F-15 and C-130 aircraft, sound pressure level (SPL) spectra tabulated by Speakman, Powell and Lee (1978a, 1978b) were used. These SPL spectra were obtained from controlled aircraft flyovers at a distance of 305 m (1,000 ft). The SPL spectra at ranges other than 305 m (1,000 ft) were derived from the reference SPL spectra collected at 305 m (1,000 ft) according to the expression

$$I_B = I_{Ref} - 20 \log \left(\frac{r_B}{r_{Ref}} \right) - \phi$$

where

- I_B = intensity in dB at range of interest
- I_{Ref} = intensity in dB at referenced sound source
- r_B = distance from referenced source to range of interest
- r_{Ref} = distance from referenced datum
- ϕ = correction factor for absorption in air

From *American Institute of Physics Handbook* (1972), sound absorption in air is a function of the relative humidity, temperature, viscosity, and the frequency. Sound intensity quickly attenuates at higher frequencies. Above 2,000 hertz (Hz), the rate of attenuation increases so that higher frequency noises are reduced to minimal levels at distances greater than 500 meters (1,640 ft). Using this methodology, and assuming 20 percent relative humidity, viscosity of 0.004 m^{-1} , and 20°C , the attenuation for noise can be estimated. Using these data, it can be shown that the correction of sound intensity for air absorption is very small for relatively short distances.

For a distribution of frequencies, corrections for sound absorption can be estimated for various distances in air. Calculations assume 20 percent relative humidity and 20°C . It can be seen that the higher frequencies are attenuated more rapidly than the lower frequencies. Explosive detonations produce much low-frequency noise.

Absorption in Air
(dB of Attenuation)

Freq. (Hz)	-dB at 100 m	-dB at 500 m	-dB at 1,000 meters
125	0.046	0.23	0.46
250	0.10	0.5	1.0
500	0.24	1.2	2.4
1,000	0.6	3.0	6.0
2,000	1.74	8.7	17.4
4,000	6.3	31.5	63.0

The resulting SPL at each distance interval was then converted to an A-weighted sound level (L_A) by applying an A-scale filter network.

For aircraft other than the F-15 and C-130, SPL spectra were not available. Instead, A-weighted sound levels from the NOISEMAP database were propagated to the range indicated by considering only inverse-square propagation (6 dB reduction in L_A per doubling of distance). By ignoring atmospheric attenuation, the calculated values of L_A will be overestimated. The severity of the overestimation will be a function of the frequency content of the sound and the distance from the source. Figure 8, from TM 5-803-2 (1978), indicates that for mid-frequency sound the error should be less than 1 dB at 305 m (1,000 ft) and less than 2 dB at 610 (2,000 ft). The standard measure of sound exposure is the A-weighted Sound Exposure Level (SEL). It is defined as the time-integrated A-weighted sound level during an event referenced to a standard time of one second. It is approximated by computing the A-weighted level at intervals during a sound producing event. These are converted to an energy basis and summed to yield the total energy. Finally, the sum is converted back to A-weighted decibel (dBA). This method is prescribed by TM 5-803-2 (1978).

Each aircraft flyover was assumed to include the point of closest approach, and the duration of the flyover contributing to the time-weighted SEL consisted of the period from two minutes prior to the point of closest approach to two minutes after the point of closest

Figure 8. Typical Attenuation with Distance for a Point Source
Data Source: TM 5-803-2 (1978)

approach. The SEL for that flyover was then computed by integrating the A-weighted noise level over that period. The A-weighted noise level was computed at a sampling interval of one second, with aircraft distances from ACF computed based on the nominal aircraft speeds as shown in Table 4.

Table 4. Aircraft Speed Used in the Computation of SEL

Aircraft Type	Operating Condition	Speed (knots)
B-727	Takeoff	160
2-engine turboprop	Takeoff	160
F-15	Takeoff	300
F-15	Approach	170
C-130	Takeoff	170
C-130	Approach	140
HH-53	Cruise	100

Data Source: Moulton (1990)

The equivalent sound level for an 8-hour day [$L_{eq}(8)$] due to aircraft operations was computed by taking into account all aircraft sources listed above. The results yield $L_{eq}(8)=67.7$ dBA. The equivalent day-night weighted average sound pressure level, L_{dn} , was also computed applying a 10 dB penalty for night operations, yielding $L_{dn}=70.1$ dBA. Table 5 shows the contribution of each aircraft source to the calculation of $L_{eq}(8)$ and L_{dn} , as well as the total portion of $L_{eq}(8)$ and L_{dn} due to aircraft sources.

Table 5. Computation of $L_{eq}(8)$ and L_{dn} Due to Aircraft Operations

Noise Source (category)	SEL (dBA)	No. of Day Events	No. of Night Events	Contribution to $L_{eq}(8)$	Contribution to L_{dn}
Boeing 727	67.6	71.5	38.5	65.4	68.6
2-engine turboprop	49.6	48.0	12.0	45.6	46.3
F-15 takeoff, overhead	76.7	2.1	0.1	59.1	56.1
F-15 takeoff, 1 mile	64.8	2.1	0.1	47.2	44.2
F-15 takeoff, 3 miles	58.2	2.1	0.1	40.6	37.6
F-15 approach, overhead	57.4	2.1	0.1	39.8	36.8
F-15 approach, 1 miles	46.5	2.1	0.1	28.9	25.9
F-15 approach, 3 miles	39.9	2.1	0.1	22.3	19.3
C-130 takeoff, overhead	59.4	0.2	0.1	31.6	34.6
C-130 takeoff, 1 mile	48.6	0.2	0.1	20.8	23.8
C-130 takeoff, 3 miles	42.1	0.2	0.1	14.3	17.3
C-130 approach, overhead	57.1	0.2	0.1	29.3	32.3
C-130 approach, 1 mile	44.5	0.2	0.1	16.7	19.7
C-130 approach, 3 miles	37.4	0.2	0.1	9.6	12.6
HH-53, overhead	81.9	1.1	0.4	61.5	63.4
HH-53, 1 mile	71.8	1.1	0.4	51.4	53.3
HH-53, 3 miles	65.6	1.1	0.4	45.2	47.1
$L_{eq}(8)$ (all aircraft sources)	67.7				
L_{dn} (all aircraft sources)	70.1				

An alternate approach to computing $L_{eq}(8)$ and L_{dn} is presented in TM 5-803-2 (1978). Using this latter approach, L_{dn} is computed for an intermittent source as follows:

$$L_{dn} = L_{max} + 10 \cdot \log(N_d + 10 N_n) - 49.4$$

where

L_{max} = maximum sound exposure level occurring during a single event

N_d = number of individual events occurring during the daytime (0700-2200 hours)

N_n = number of individual events occurring during the nighttime (2200-0700 hours)

The 49.4 dB term is a correction factor to adjust for the units used in the computation. The peak SEL is assumed by this equation to have a duration of 1 second. The peak sound exposure level is assumed to occur at the point of closest approach of the aircraft to ACF. Using this alternate approach, the values of $L_{eq}(8)$ and L_{dn} are shown in Table 6.

Table 6. Computation of $L_{eq}(8)$ and L_{dn} Due to Aircraft Operations Using Alternate Method

Noise Source (category)	SEL (dBA)	No. of Day Events	No. of Night Events	Contribution to $L_{eq}(8)$	Contribution to L_{dn}
Boeing 727	91.0	71.5	38.5	62.0	68.2
2-engine turboprop	54.4	48.0	12.0	22.8	27.3
F-15 takeoff, overhead	91.5	2.1	0.1	45.5	47.0
F-15 takeoff, 1 mile	77.7	2.1	0.1	31.7	33.2
F-15 takeoff, 3 miles	65.0	2.1	0.1	19.0	20.5
F-15 approach, overhead	69.5	2.1	0.1	23.5	25.0
F-15 approach, 1 miles	56.5	2.1	0.1	10.5	12.0
F-15 approach, 3 miles	44.9	2.1	0.1	—	0.4
C-130 takeoff, overhead	71.5	0.2	0.1	16.9	22.9
C-130 takeoff, 1 mile	58.5	0.2	0.1	3.9	9.9
C-130 takeoff, 3 miles	47.1	0.2	0.1	—	—
C-130 approach, overhead	68.9	0.2	0.1	14.3	20.3
C-130 approach, 1 mile	54.3	0.2	0.1	—	5.7
C-130 approach, 3 miles	41.8	0.2	0.1	—	—
HH-53, overhead	93.2	1.1	0.4	45.6	50.9
HH-53, 1 mile	79.1	1.1	0.4	31.5	36.8
HH-53, 3 miles	69.2	1.1	0.4	21.6	26.9
$L_{eq}(8)$ (all aircraft sources)	62.2				
L_{dn} (all aircraft sources)	68.3				

3.4 SUMMARY OF EXISTING NOISE ENVIRONMENT

The principal existing sources of aircraft noise at ACF are due to commercial aircraft taking off from Albuquerque International Airport and local helicopter operations associated with the 1550th training area. Using conservative (pessimistic) assumptions yields an L_{dn} value of 70.1 dBA and an $L_{eq}(8)$ value of 67.7 dBA. Using the peak sound level value and the approach of TM 5-803-2 (1978) yields $L_{dn}=68.3$ dBA and $L_{eq}(8)=62.2$ dBA.

EPA recommendations call for outdoor equivalent sound levels less than 70 dBA for offices and administrative facilities before special noise insulation is required. At the ACF facilities, work day A-weighted sound levels are below the EPA recommendation. For outdoor work activities not requiring frequent speech communication, the acceptable noise environment range extends up to 80 dBA. For office and administration buildings, with appropriate noise level reduction requirements, military usage is permitted (but not encouraged) in higher noise exposure than recommended for civil offices (TM 5-803-2, 1978).

4.0 ENVIRONMENTAL CONSEQUENCES OF NOISE AND VIBRATION FROM ACF

4.1 NOISE LEVEL GUIDELINES

The present standard established for occupational noise exposure is based on a maximum 90 dBA average exposure for an 8-hour day with a 5 dBA doubling interval. The 5 dBA doubling interval means that with each 5 dBA increase in sound level, the permissible exposure time is halved, or conversely, that the permissible exposure time is doubled for each 5 dBA decrease in sound level. This value was established by OSHA based on a consideration of economic costs, technical feasibility, and health risks (Miller, 1985). Miller cites two lower noise standards that have been proposed that would result in decreased hearing loss among workers. The first proposed standard calls for a reduction of 5 dBA in permissible noise exposure levels. The second proposed standard calls for a reduction of 5 dBA in the 8-hour exposure limit and replacement of the 5 dBA doubling rate with a 3 dBA doubling rate to be consistent with the doubling rate of the total amount of acoustic energy.

A summary of the permissible noise exposure limits under 29 CFR Ch XVII and the two proposed standards is presented in Table 7.

Table 7. Permissible Noise Exposures Under 29 CFR Ch XVII, as amended (Standard) and Two Hypothetical Proposed Standards

Duration (hours per day)	Standard Sound Level (dBA) Slow Response	Hypothetical 85 dBA 5 dB doubling	Hypothetical 85 dBA 3 dB doubling
8	90	85	85
6	92	87	86.2
4	95	90	88
3	97	92	89.2
2	100	95	91
1.5	102	97	92.2
1	105	100	94
0.5	110	105	97
0.25	115	110	100

Occupational Noise Exposure, Sec. 1910.95 (29 CFR) states, “. . . [Human] exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure.”

The provisions of 29 CFR Ch XVII, as amended, state that when employees could be subjected to sound levels exceeding standard values listed in Table 7, feasible procedural controls should be utilized. If such controls cannot reduce sound levels to within the values of Table 7, personal protection equipment should be provided and used to reduce sound levels to within the values of the table.

SNL has established noise standards that are consistent with the stricter hypothetical standard (85 dBA, 3 dB doubling) listed in the table above (SNL, 1991, Section H, Noise and Hearing Protection). The SNL standard also mandates a maximum impulsive sound exposure of 115 dBA.

The SNL standard requires that all employees who routinely work in an environment where the noise level exceeds the 8-hour time-weighted average of 80 dBA be enrolled in the SNL audiometric surveillance program. Program participants have their hearing evaluated at least annually to determine if there has been any change in hearing.

SNL safety regulations for explosives test sites (SNL, 1991) limit overpressure levels for personnel exposure to uncased (no fragments) explosive detonation to 1.7 kiloPascal (kPa) (0.25 psi). It should be noted that this overpressure limit corresponds to a sound level of nearly 160 dB, which exceeds both OSHA standards for impulse noise (140 dBA) and SNL exposure limits for impulse noise (115 dBA). Therefore, workers subjected to overpressures that qualify as safe according to the 1.7 kPa level should nonetheless be provided with hearing protection devices.

4.2 SOURCES OF NOISE AND VIBRATION

During the construction of the new explosives storage buildings, the addition to Building 9831, and test fixtures, construction activities would serve as additional sources of noise and vibration. These sources may include construction equipment, trucks and related vehicles, generators, compressors, and winches.

Noise may be generated by ACF operations, including detonation of explosive charges, use of rocket boosters, and firing of 20-mm or 3-inch guns. During ACF operations, generators will be in use.

Additional vehicle usage in the vicinity of ACF would result from operations at the site. These vehicular noise sources would include light vehicles used to transport test support personnel to the site, trucks and related heavy vehicles transporting equipment and supplies to the site, and cranes or other heavy equipment associated with site operations.

4.3 NOISE LEVELS DURING CONSTRUCTION

Construction activities would result in generation of noise at ACF. The new explosives storage building would be constructed in the immediate vicinity of the existing Assembly Building, 9832. Most test fixtures would be constructed in the test arenas.

Typical noise levels from construction equipment at a distance of 15.2 m (50 ft) are listed in Table 8. These noise levels are referenced to a distance of 15.2 m to show the relative impact on personnel in the vicinity of the construction area. Equipment operators are assumed to be approximately 1 m from the noise source. Equipment operators would be exposed to higher noise levels, and personal protection equipment would be required.

Table 8. Typical Noise Level of Construction Equipment

Process	Equipment	Noise Level at 15.2 m (dBA)
Ground Clearing	Truck	91
	Bulldozer	87
	Scraper	88
Excavation	Rock Drill	98
	Backhoe	85
	Truck	91
Foundations	Truck	91
	Concrete Mixer	85
	Jackhammer	88
	Pneumatic Tools	85
Erection	Paver	89
	Derrick Crane	88
Finishing	Truck	91
	Paver	89
Miscellaneous	Generator	76
	Compressor	81
	Winch	88

Data Source: May (1978)

For construction activity in the test arenas or near Building 9832, an average A-weighted sound exposure level (ASEL) of 86 dBA results at a distance of 15.2 m from the equipment. At Building 9831 (ACF control), the L_{dn} is 48 dBA. This is well below the existing noise levels caused by aircraft. Although hearing protection should be provided for construction workers and heavy equipment operators, construction activities should not contribute to elevated noise levels beyond the immediate construction site. Construction modification to Building 9831 would result in a temporary ASEL as high as 98 dB on the outside of the building, but workers inside largely would be shielded. Attenuation by the building should reduce the level by at least 29 dBA to 69 dBA (AIHA, 1984).

4.4 NOISE LEVELS DURING OPERATIONS

During operation of ACF, noise would be generated from six sources: transportation vehicles and equipment, generators, booster rockets, rockets on cables, detonation of high explosive (HE) charges, and firing of ammunition from 20-mm or 3-inch guns. Each of these noise sources is considered and tabulated in the following sections.

For analysis purposes, impulse sounds for which the SPL may exceed 110 dB are considered separately, consistent with the procedure recommended in TM 5-803-2 (1978) and SNL Noise and Hearing Protection Standards. These latter standards establish a maximum noise level for impulsive sounds from normal industrial operations of 115 dBA. All sources of noise below 110 dB are aggregated with existing ambient levels for comparison to occupational health and safety and land use maximum noise standards.

4.4.1 Vehicle and Equipment Noise

During operations at ACF, it is estimated that site personnel would make 6 light vehicle round trips per day over paved and unpaved roads from Area III to the ACF Control Building (9831). An additional 240 light vehicle round trips per year would be made by contractor and test customers. During tests, approximately 10 round trips per day would be made by light vehicles from Building 9831 to the test arenas. These trips are all over unpaved roads. An estimated 30 round trips per year would be made by heavy trucks and equipment such as low boys and cranes. Infrequent trips from Building 9831 to the cable anchor sites would also be made. The routes used by vehicles are indicated on Figure 9. Vehicle speeds along the paved portions of the road are estimated at 72 km/hr (45 mph) for light and heavy vehicles. Along the unpaved portions of the road, vehicle speeds are estimated as 40 km/hr (25 mph) for light vehicles and 16 km/hr (10 mph) for heavy vehicles.

TM 5-803-2 (1978) provides a procedure for computing the peak hour L_{eq} for vehicular noise at a location of interest near a roadway. The vehicle type, speed, volume of vehicles, and

Figure 9. Roads Used by Vehicles in Association with the ACF Project

distance to the observer are included in the calculation. For a peak vehicle volume of 20 light vehicles per hour traveling 72 km/hr (45 mph), the procedure yields an equivalent level of 45 dB at 30 m (100 ft) from the roadway. For one heavy truck trip per hour at a speed of 16 km/hr (10 mph), $L_{eq}=57$ dB.

Adjustments to the calculated value are required to take into account the roadway surface and road grade. For rough road surfaces, TM 5-803-2 (1978) recommends adding 5 dB to the calculated values for all vehicle classes. For heavy trucks and equipment, the adjustment for road grade depends on average speed and percent grade as indicated in Table 9. A two-percent grade is assumed for the unpaved road between Building 9831 and the ACF test areas based on a 40-m (130-ft) change in elevation over a 2,000 m (6,500 ft) distance, resulting in a 5 dB increase due to roadway grade for the heavy trucks.

The resulting noise level from vehicles is $L_{eq}=67$ dB for heavy trucks and 50 dB for light vehicles. Traffic is assumed to take place during daylight working hours. According to TM 5-803-2 (1978), this implies a -3 dB correction when converting L_{eq} to L_{dn} . Applying this correction and summing the contributions from light and heavy vehicles yields $L_{dn}=64$ dB due to vehicle traffic. The value calculated for L_{dn} is based on conservative assumptions including increased noise level due to rough road surface and a two-percent grade.

Table 9. Noise Adjustment for Roadway Grade for Heavy Trucks and Transport Vehicles

Percent Grade	Adjustment in dB		
	Average Speed (mph)		
	≤ 15	20-35	≥ 40
1	4	3	2
2	5	4	3
3	6	5	4
4	7	6	5
5	8	7	6

Data Source: TM 5-803-2 (1978)

The noise level due to a roadway decreases with distance at the rate of 15 dB per tenfold increase in distance, as shown in Figure 10.

Figure 10. Reduction in Roadway Noise Level with Distance
Data Source: TM 5-803-2 (1978)

4.4.2 Generator Noise

During site operations at ACF, diesel-powered generators would be operating to provide power for test equipment. A 60 kW generator would be located in the vicinity of Building 9834 at the South Arena, and a 25 kW generator would be located at the Explosive Assembly Building. It is estimated that generators would be operational 5 hours per day for up to 240 days per year. Generators would be operating during the 8-hour working day.

The noise level at 15.2 m (50 ft) from a diesel powered generator is typically 76 dBA (Harris, 1991). Generator noise varies considerably from unit to unit and from time to time because of such considerations as the load factor, the condition of the exhaust muffler, and even the tightness of the access panel latches. Generators are treated as point sources of sound. Therefore, the noise level from generators can be calculated according to the following expression:

$$I = I_{ref} - 20 \log \left(\frac{r}{r_{ref}} \right) - \phi$$

which was described on page 26. Assuming 5 hours of generator operation per day, values of $L_{eq}(8)$ and L_{dn} were computed at a nominal distance of 15.2 m (50 ft) from the midpoint between the north and south test arenas. The values of $L_{eq}(8)$ and L_{dn} were then computed as a function of distance from the generator source, resulting in the curve shown in Figure 11.

Figure 11. Equivalent Sound Levels as a Function of Distance Due to Generators

Atmospheric absorption and inverse square law attenuation are included in this calculation. The distances at which $L_{eq}(8)$ and L_{dn} decrease to various levels are indicated in Table 10. For example, at 40 meters from the generator, the $L_{eq}(8)$ is 65 dB.

Table 10. Equivalent Sound Level and Day/Night Average Sound Level Due to Generators

A-weighted Level (dBA)	Radius (m) of Contour	
	$L_{eq}(8)$	L_{dn}
75	13.2	7.7
70	23.2	13.5
65	40.0	23.8

4.4.3 High Explosive Tests

It is estimated that up to 100 tests per year would require the detonation of 1.4 to 1.8 kg (3 to 4 lb) of high explosives. The maximum conceivable high explosive charge that would be detonated in any future test would be 454 kg (1,000 lb) of high explosives. Such a test is estimated to occur no more than once per year.

The distances of concern for this investigation are the distance to Building 9831 (ACF control) for occupational health and safety, the distance to other KAFB test sites, the distance to the nearest residential housing for residential land use compatibility, and the distance to Sol se Mete Spring for disruption of wildlife. These distances are shown in Table 11, as measured using a 1:100,000 scale map of the KAFB area.

Table 11. Distance Between South Arena and Various Sites of Interest

Location	Distance (km)
Building 9831	1.1
Optical Range (Nearest Kirtland facility)	4.2
Building 9925	6.0
Nearest City Housing	8.9
Sol se Mete Spring (straight-line)	1.7
Sol se Mete Spring (indirect)	2.0

Shielding by mountains prevents sound from propagating directly from the canyon floor at the South Arena to Sol se Mete Spring. Sound generated at the aerial cables 210 m (700 ft) above the canyon floor possibly can take a more direct route, propagating a distance of 1700 m (5,580 ft) to Sol se Mete Spring. The blast overpressure at a distance R from a high explosive charge air blast is given by the following expression (ANSI S2.20-1983):

$$\Delta P = 105.93 W_A^{0.3667} R^{-1.1} \left(\frac{P}{P_0} \right)^{0.633}$$

where

- ΔP = overpressure (kPa)
- W_A = apparent air blast yield (kg HE)
- R = distance from blast (m)
- P/P_0 = ratio of air pressure to ambient sea level pressure

The blast overpressure is converted to a SPL with respect to 20 μ Pa according to

$$SPL = 10 \log \left(\frac{P}{P_0} \right)^2$$

where

$$P_0 = 20 \mu\text{Pa}.$$

The SPL spectrum from a blast typically contains a large low frequency component, as Figure 12 indicates. The curves in the figure do not include atmospheric attenuation. Overpressures of 130 and 110 dB could result from the detonation of 45.4 kg (100 lb) of high explosives at distances of 5.7 and 46.2 m (18.7 and 152 ft) respectively. Because of the low frequency content, absorption of blast noise in air is as low as 1 dB per km of propagation. From the equations for blast overpressure as a function of distance and SPL, estimates may be made of the impulse noise at various distances from the blast site (assumed to be the South Arena) to sites of interest as shown in Table 12.

As Table 12 indicates, the SPLs generated by blasting would exceed 115 dB at ACF control (Building 9831) for all contemplated explosive tests. Noise exposure standards established by SNL mandate hearing protection to limit worker exposure to impulse sounds greater than 115 dBA. Therefore, whenever explosive events are scheduled for ACF, workers in the vicinity of Building 9831 (ACF control) should be protected from noise levels generated by ACF test conditions. The building itself, due to its concrete and steel construction, would be expected to attenuate the sound by a minimum of 29 dB (AIHA, 1984).

Table 12. Noise Levels at Several Sites Due to Detonation of High Explosive Charges at the ACF South Arena

Explosive Yield kg HE (lb HE)	Sound Pressure Level (dB)			
	Bldg. 9831	Bldg. 9825	Sol se Mete Spring	Nearest Housing
1.4 (3)	126	111	122	107
1.8 (4)	127	112	123	108
22.7 (50)	135	120	131	116
54.4 (120)	137	123	133	119
454.0 (1,000)	144	130	140	126

Figure 12. Typical Spectra for 10- to 100-lb TNT Blast
Data Source: TM 5-803-2 (1978)

Explosive events involving yields greater than 4.5 kg (10 lb) high explosive (HE) equivalent can generate noise levels exceeding 115 dBA at sites in the vicinity of Building 9825. If such larger explosive events are planned, workers in the vicinity of these more remote sites should also be notified in advance and appropriate individual hearing protection provided.

Noise levels at the nearest residential housing would not exceed the present OSHA standard of 140 dBA for impulsive noise exposure during any contemplated blasting events. In addition to the four main areas of concern, impulse noise exposure also was calculated at more remote SNL test sites to determine whether the OSHA exposure limit for impulse sounds of 140 dB would be exceeded during any of the explosive events. Figure 13 displays the locations of several sites that might be affected by ACF explosive test events. Five representative sites were identified and the straight line distance from the ACF South Arena to each site was computed (Table 13).

Table 13. Distance from ACF South Arena to Nearby Test Sites

Site	Distance from ACF South Arena (km)
SNL Burn Site	1.75
DOE Firing Range	1.75
Building 9849	2.20
Building 9825	2.75
Building 9990	3.19

The resulting C-weighted sound exposure levels (dB) for each site were then computed for explosive yields between 1.4 and 454 kg (3 and 1,000 lb) HE. The results of these calculations are summarized in Table 14.

Table 14. C-weighted Sound Exposure Level at Remote Test Sites Resulting from Explosive Events at the ACF South Arena

Location	Sound Exposure Level (dB) resulting from Explosive Yield [kg (lb) HE]				
	1.4 (3)	1.8 (4)	22.7 (50)	54.4 (120)	454 (1,000)
SNL Burn Site	123	124	132	135	142
DOE Firing Range	123	124	132	132	142
Building 9849	121	133	130	130	139
Building 9825	119	119	128	128	137
Building 9990	117	118	126	126	136

The OSHA exposure limit for an ASEL due to impulse sounds is 140 dBA. Table 14 displays C-weighted sound exposure level (CSEL), which takes into account greater contributions from the low frequency sound components. C-weighting is believed to be more appropriate for blast noises because of the large amount of low-frequency sound produced. Because high-frequency sound is attenuated by atmospheric absorption much more strongly than low-frequency sound, the ASEL value for these events will be moderately lower than the CSEL. Therefore, a comparison between these values and the OSHA standard will lead to somewhat conservative limits on noise levels.

OSHA exposure limit for impulse sound would be exceeded at the DOE firing range and the SNL Burn Site only during the 454-kg (1,000-lb) HE event. Standard operating procedures ensure that essential personnel present at these facilities are provided with hearing protection devices during such events. Non-essential personnel are evacuated. These tests are usually held at times when workers are not present at the Burn Site and DOE Firing Range. Near Sol se Mete Spring, the impulse noise level from a 54.4-kg (120-lb) explosive would be expected to be somewhat less than 133 dBA. It would be perceived by sensitive wildlife species at the Spring to be a distant noise. This would be a once-yearly event. At that noise level, the effect would be somewhat larger than that produced by a hunting rifle at 10 m (33 ft) (127 dBA) but lower than the sound produced by a hunting rifle at 3 m (10 ft)

(137 dBA) (Nordic, 1984). The hunting rifle also would produce collateral effects of human presence and gunpowder odor. The distant noise event from ACF explosives detonation thus would have less effect than a rifle shot. Accordingly, this once-yearly explosive event would have minimal effect on sensitive wildlife species. If it is necessary to test explosive weights in the range of 54.4 to 454 kg (120 to 1,000 lb), scheduling during the winter season when migratory wildlife species are absent, and many other species are dormant would minimize effects.

As a general rule, explosive charges smaller than 54.4 kg (120 lb) TNT equivalent would result in CSEL of 140 dB or less at all points more than 1 km (0.62 mi) from the detonation point. Figure 14 shows the 140 B contours for the 54.4 and 454 kg (120 lb and 1,000 lb) TNT explosive events.

Figure 14. 140 dB Contours for 120 lb and 1,000 lb TNT Explosive Events

4.4.4 Rocket Boosters

Rocket motors would be used at the ACF on the sled track on the canyon floor and on the cable approximately 200 m (656 ft) above the canyon floor. Booster rockets would be either of two types: Zuni or High Velocity Aircraft Rockets (HVAR). Both of these are expendable 5-in diameter solid fuel motors. Although burn times are approximately 1 second, the duration is not so short that the sound should be treated as impulsive.

Sound levels produced by the rocket motors used at the ACF were predicted using a methodology originated by NASA. This methodology is described in detail in Appendix K of the Kauai Test Facility (KTF) Environmental Assessment (DOE, 1991). The computation requires the thrust, effective diameter, and exhaust gas velocity of the motor. The thrust and diameter were taken from the specification sheets, and the exhaust velocity was estimated from the nozzle expansion ratio by assuming that the speed at the nozzle throat is equal to the speed of sound. The methodology is not very sensitive to this parameter. A sensitivity analysis indicates that the largest likely error in estimating the velocity would affect the predicted sound level by only about 1 dB. The thrust of Zuni and HVAR motors are 29,000 and 24,000 Newtons (6,530 and 5,400 lb) respectively, and the estimated exhaust velocity is 760 m/s (2,500 ft/s) for both motors. In addition to these parameters, the computation requires a value for the acoustic efficiency and the maximum directivity. These values were taken to be 0.5 percent and 7 dB respectively.

The methodology consists of the following steps:

1. Calculate the overall acoustic power (total in all spectral bands) from the thrust, exhaust velocity, and acoustic efficiency.
2. Determine the octave band power level in each band from 63 Hz to 8 kHz.
3. Compute the attenuation by the atmosphere using nominal attenuation coefficients, and compute the reduction in level due to inverse square law propagation.
4. Apply A-weighting.
5. Integrate overall spectral bands to obtain the final A-weighted far-field sound level.

As noted in the KTF EA, this methodology tends to predict sound levels somewhat higher (typically 2-5 dB) than measured results; hence, they are a conservative estimate of the exposure level.

When a cluster of motors is fired simultaneously, the cluster should be treated properly as a single motor whose area is the square root of the number of motors times the area of a single motor. The result obtained by adding directly on an energy basis the effects of multiple motors would overstate the actual sound level. For a cluster of five motors, for example, the overestimate would be approximately 3 dB.

This methodology was used to predict the sound level at 15.2 m (50 ft) from Zuni or HVAR motors, and the results are summarized in Table 15.

Table 15. Sound Levels Generated by Rocket Motors

Rocket	Sound Level (dB) at 15.2 m from a Specified Number of Motors			
	1 motor	5 motors	10 motors	25 motors
Zuni	141	144	146	148
HVAR	140	143	145	147

The cable-mounted rocket boosters would be high enough above the surrounding terrain so that sound possibly could propagate directly to the vicinity of Sol se Mete Spring. Therefore, calculations for the sound level at the Spring used a propagation distance of 1,700 m (5,580 ft) for sound from the rocket boosters on the cable, and 2,000 m (6,560 ft) for sound from rocket boosters on the sled track. An average attenuation of 1 dB per km was used for air absorption. This value is appropriate for a noise spectrum with predominantly low frequency components.

Noise levels at the ACF control building and at Sol se Mete Spring due to the use of rocket boosters are listed in Table 16. Because the two motor types produce very similar sound levels, the slightly higher value for the Zuni motor was used as the basis for the table.

Table 16. Sound Levels at Receptor Locations

Location	Noise Level (dBA)							
	Single Motor on Sled	Single Motor on Cable	Five Motors on Sled	Five Motors on Cable	Ten Motors on Sled	Ten Motors on Cable	Twenty- five Motors on Sled	Twenty-five Motors on Cable
Source (15.2 m)	141	141	144	144	146	146	148	148
Nearby Area (100 m)	125	125	128	128	130	130	132	132
Building 9831 (1.3 km)	101	101	104	104	106	106	108	108
Sol se Mete Spring	97	98	100	101	102	103	104	105

Because the duration of the motor burn is approximately one second, these values are within the OSHA-established permissible limits for workplace exposure at the control building which is the closest point at which workers would be allowed during a live firing. The OSHA limits are presented in Table 17. The sound levels at Sol se Mete Spring would be a few dBA lower and probably do not pose a credible threat of hearing damage to wildlife.

Table 17. Permissible Noise Exposure as a Function of Exposure Duration

Duration (Hours per day)	Permissible Exposure Level (dBA) Slow Response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

Data Source: Occupational Noise Exposure, 29 CFR 1910.95

OSHA regulations require additional measures such as regular hearing testing when the time weighted sound exposure in the workplace reaches 85 dBA for the eight-hour workday.

Because of the very short duration of the sound from the rocket motors, the contribution to the time-weighted exposure from this source would be negligible; hence, it is extremely unlikely to trigger such additional requirements.

4.4.5 Noise from 3-Inch Guns

It is anticipated that one test per year at ACF would involve firing 120 rounds from a 3-inch gun. These rounds would be fired over a 5-day period during normal business hours. Therefore, the firing rate of this gun is assumed to average 3 rounds per hour, 8 hours per day.

According to the ASHRAE Handbook (1985), the sound pressure level from artillery at 3 m (10 ft) is estimated at 130 dB. Use of this value to represent the noise from a 3-inch gun is conservative because the 3-inch gun is among the smaller artillery pieces. Sound from artillery fire contains a large low-frequency content, similar to blast noise. Therefore, atmospheric absorption was calculated assuming the 250 Hz value, or 1 dB per km. Based on 130 dB at 3 m (10 ft), the sound pressure level at ACF Control due to the 3-inch gun is calculated as 76 dB and the SPL at Sol se Mete Spring is estimated to be 72 dB.

4.4.6 Noise from 20-mm Gun

One test per year would involve firing 100 rounds from a 20-mm Vulcan gun. The Vulcan can sustain firing rates as high as 3,000 rounds per minute. Therefore, the firing duration could be as short as two seconds. The firing of individual rounds would be impulsive sounds, but firing such that the repetition rate would exceed 1 per second would be considered a continuous sound.

A very conservative estimate is that the sound pressure level produced by firing a single 20-mm round would be the same as that used for the 3-inch gun discussed above. Treating the source as continuous, the maximum duration of the exposure would be two seconds, and

the ASELs at pertinent locations are summarized in Table 18. The levels at the control building and at Sol se Mete Spring are well below OSHA levels for workplace exposure.

Table 18. A-weighted Sound Exposure Levels (ASEL) at Various Locations Resulting from Firing 100 Rounds from a 20-mm Vulcan Gun.

Location	ASEL (dBA)
15.2 m (50 ft) from gun	116
100 m from gun	100
1,000 m from gun	79
Building 9831 (1,300 m from gun)	76
Sol se Mete Spring (2,000 m from gun)	72

4.5 SUMMARY OF NOISE DURING CONSTRUCTION AND OPERATION OF ACF

During construction at ACF, noise levels 15.2 m (50 ft) from construction equipment are expected to average 86 dBA. These levels are within OSHA standards of 90 dBA for $L_{eq}(8)$, but they marginally exceed SNL exposure limits of 85 dBA. Operators of heavy equipment and workers present at the site should take measures to protect their hearing. Construction noise would be minimal at Building 9831 except during construction of the modifications to that building. The building itself should provide adequate protection for people inside.

Vehicular noise is primarily due to heavy trucks. The noise level from vehicles contributes 67 dBA to $L_{eq}(8)$ and 64 dBA to L_{dn} at a distance 30 m (100 ft) from the roadway, well below the 85 dBA limit.

Generator noise during ACF operations would contribute less than 65 dBA to $L_{eq}(8)$ at distances more than 40 m (131 ft) from the generator. Generators would be located near the test arenas and at the Explosives Assembly Building. Because the Explosives Assembly Building (9832) is located approximately 100 m (328 ft) from the ACF Control Building (9831), generators would not contribute hazardous or annoying levels of sound at Building 9831.

Detonation of explosive charges during ACF operations can result in high impulsive noise levels. Limiting explosive charges to 54.4 kg (120 lb) or less would result in noise levels lower than the 140 dB OSHA limit at Building 9831, nearby test sites, and wildlife habitat near Sol se Mete Spring. Noise from booster rockets will contribute noise levels well below the OSHA limit for equivalent level [$L_{eq}(8)$]. Noise from firing single rounds from 3-inch guns and 20-mm guns will not exceed the impulse sound limits at distances more than 100 m (328 ft) from the guns. Likewise, high repetition rate firing of the 20-mm gun will not exceed the limit for a continuous source at distances greater than 100 m (328 ft) from the gun.

The $L_{eq}(8)$ and the L_{dn} were computed for the vicinity of the test arenas and Building 9831. At the test arenas, $L_{eq}(8)$ and L_{dn} did not include the contributions from explosive blasts, rocket boosters, or similar sources because personnel would be evacuated during such tests. However, noise from generators and vehicles should be added to the ambient noise level due to aircraft. The resulting value for L_{dn} is 69.4 dBA, while the value for $L_{eq}(8)$ is 69.8 dBA. At Building 9831, the value for $L_{eq}(8)$ is 69.1 dBA, while the value for L_{dn} is estimated to be 69.2 dBA. Events for which hearing protection is mandated because sound levels exceed SNL or OSHA limits for impulsive sound are not included in these calculations.

4.6 OVERPRESSURE, GROUND VIBRATION, AND FRAGMENTATION HAZARDS FROM EXPLOSIVES

A surface or subsurface explosion would generate air overpressure measured in kPa or pounds per square inch (psi), airborne rubble, and ground particle velocity measured in inches per second. Sound pressure measured in decibels relative to a base of 20 μ Pa (threshold of human hearing), can be directly correlated with air overpressure. Each of the three effects is evaluated in terms of the size of the explosive charge, burial depth, and distance from critical facilities, and Ground Hazard Areas. The noise levels which might result from use of explosives were evaluated in Section 4.4.3.

4.6.1 Overpressure Effects

Air overpressure resulting from high explosive blasts can be hazardous to personnel and cause property damage. Nicholls, Johnson, and Duvall (1971) note that overpressure due to air blast exceeding 5.2 kPa (0.75 psi) can cause breakage of properly mounted panes of glass, while improperly mounted and prestressed glass may crack at overpressures as low as 0.7 kPa (0.1 psi). Nicholls, Johnson, and Duvall (1971) recommend a safe air blast pressure level of 3.4 kPa (0.5 psi) to provide a margin of safety. They also note that air blast is not considered to be a major factor in causing damage to structures at these overpressures.

For the following discussion, air overpressure for high explosive blasts is calculated as follows (TM 5-855-1, 1986):

$$P = K \left(\frac{D}{W^{1/3}} \right)^{\beta}$$

where

- P = peak overpressure
- K = intercept at $D/W^{1/3} = 1.0$
- D = horizontal distance
- W = maximum charge weight
- $D/W^{1/3}$ = scaled distance for air blast considerations
- β = slope

The constants K and β in the above equation are determined empirically based on site characteristics.

The SNL *Environment, Safety, and Health Manual* (SNL, 1991) limits overpressure levels for personnel exposure to uncased (no fragments) explosive detonation to 1.7 kPa (0.25 psi). It should be noted that this overpressure limit corresponds to a sound level of nearly 160 dB, which exceeds both OSHA standards for impulse noise (140 dBA) and SNL exposure limits for impulse noise (115 dBA). Therefore, workers subjected to overpressures that qualify as

safe according to the 1.7 kPa (0.25 psi) level should nonetheless be provided with hearing protection devices.

SNL regulations note that windows of buildings and automobiles have been known to break when subjected to overpressures of 0.7 kPa (0.1 psi). This is a very conservative limit by comparison to the recommendations of Nicholls, Johnson, and Duvall (1971). For near surface bursts, SNL regulations call for safety radii for overpressure effects calculated according to the expression

$$R_{1.7} = 72 W^{1/3}$$

$$R_{0.7} = 156.6 W^{1/3}$$

where

- $R_{1.7}$ = safety radius (m) for personnel based on 1.7 kPa overpressure
- $R_{0.7}$ = safety radius (m) for glass breakage based on 0.7 kPa overpressure
- W = yield of explosive (kilogram TNT equivalent)

Table 19 lists safety radii for personnel and glass breakage for various explosive yields contemplated in the tests.

Table 19. Radii for Safe Blast Overpressure to Personnel and Glass

Explosive Yield [kg (lb) TNT]	Safety Radii [m (ft)]	
	Personnel (1.7 kPa)	Glass (0.7 kPa)
1.4 (3)	80. (262)	174. (571)
1.8 (4)	88. (289)	191. (627)
22.7 (50)	204. (669)	444. (1,457)
45.4 (100)	273. (896)	594. (1,949)
454.0 (1,000)	554. (1,818)	1,204. (3,950)

ACF control (Building 9831) is at the edge of the safety radius for glass breakage during the 454 kg (1,000 lb) HE event. Therefore, vehicles should be removed beyond the perimeter of this zone to reduce the likelihood of glass breakage.

The safety radii for blast overpressure computed in Table 17 for personnel applies only to individuals with adequate hearing protection, as the safety radii required to reduce sound exposure level to the OSHA limits are considerably larger, as detailed in Section 3.0.

4.6.2 Ground Vibration

Nicholls, Johnson, and Duvall (1971) state that there will be no damage to facilities if the ground particle velocity is limited to 5 centimeters per second (cm/s) [2 inches per second (ips)].

Ground particle velocities and their constants are stated in three components of motion: vertical, radial, and transverse. Nicholls, Johnson, and Duvall (1971) state

“The relative magnitudes of the components of ground motion depend primarily on the interactions of the several types of elastic waves generated by the blast and the geometry of the media. Empirically, the largest component of ground motion usually is the radial. However, there have been measurements of the vertical components equaling or even exceeding the radial. In all cases, the transverse component is the smallest, probably due to minor amounts of shear-wave energy generated by the blast. The damage threshold criterion recommends that no single component of ground motion should exceed a particle velocity 2.0 ips. Because vector summation is not required, the actual ground vibration at the structure could be higher. Greatest ground particle velocity corresponds to all three components of motion being equal in magnitude at one instant in time (in phase). This unlikely situation would result in each of the single components being lower than the actual value by a factor of $3^{1/2}$ (or 1.73). The use of single components of ground motion is a good approximation due to the maximum values of the two biggest components (radial and vertical) usually being out of phase.”

The commonly accepted equation for the calculation of ground particle velocity is (Nicholls, Johnson, and Duvall, 1971):

$$V = H \left(\frac{D}{W^{1/2}} \right)^b$$

where

- V = ground particle velocity, in inches per second (ips)
- H = a site-specific constant, which is a function of the particular subsurface material. This constant is defined as the intercept of the curve of the plot of velocity versus quantity-distance for the specific site.
- D = the distance in feet from the blast
- W = the pounds of explosive
- $\frac{D}{W^{1/2}}$ = scaled distance for air blast considerations
- b = the slope of the velocity versus the distance line on a log-log scale for the specific site.

The values of the constants H and b are both specific to the site. Where site-specific constants are not available, Nicholls, Johnson, and Duvall (1971) recommend using a conservative scaling distance of 50 ft/lb^{1/2} to maintain ground particle velocity below 5 cm/s (2 ips). For 1.8 kg (4 lb) of HE, this implies a safety radius for ground particle velocity of 30 m (98 ft). For the likely maximum test involving 54.4 kg (120 lb) of HE, the vibration hazard radius would be 167 m (550 ft). For the maximum anticipated yield of 454 kg (1,000 lb) HE, the vibration hazard radius is 482 m (1,580 ft). Building 9834 is within 130 m (426 ft) of the test site, but its construction would withstand vibration effects of 454-kg (1,000-lb) detonation.

It is important to emphasize that most of the observational data on human response stem from continuous, sinusoidal vibrations. While all studies indicate that human reaction is a function of the frequency of vibration, little is known of the response to transient vibrations of the type that result from blasting activities. Bollinger (1971) suggests that the steady-state threshold might be doubled if the single impacts are frequent, and quadrupled if they are infrequent. It is obvious, however, that humans and wildlife are disturbed long before structural damage reasonably can be expected to occur.

4.6.3 Shrapnel and Debris Hazard

Hazards from shrapnel and debris may result from explosive blasts at ACF. Cased explosives provide a fragment hazard radius that can be computed according to

$$R = 600 W^{1/3}$$

where

R = radius (ft)

W = explosive yield (lb TNT)

(Department of the Army, 1953; SNL, 1977).

Maximum debris distances from surface bursts of uncased explosives may be computed from

$$R = 70 W^{0.4}$$

(Vortman, 1967; SNL, 1977).

It is recommended that the maximum debris radius from the equation above be multiplied by a factor of two to obtain a safety radius. Using these scaling laws and converting distances to meters, the hazard radii for cased and uncased explosives are as shown in Table 20.

Table 20. Hazard Radii for Cased and Uncased Explosives

Explosive Yield [kg (lb) TNT]	Hazard Radius [m (ft)]	
	Cased	Uncased
1.4 (3)	264. (866)	66. (217)
1.8 (4)	290. (951)	74. (243)
22.7 (50)	674. (2,211)	204. (669)
54.4 (120)	902. (2,959)	290. (951)
454.0 (1,000)	1,829. (6,001)	676. (2,218)

4.6.4 Summary of Overpressure, Ground Vibration, and Fragmentation Hazards

Conservative estimates of the hazard radii for personnel exposure to overpressure for various weights of high explosives are

- 1.8 kg (4 lb) — 88 m (289 ft)
- 54.4 kg (120 lb) — 273 m (896 ft)
- 454 kg (1,000 lb) — 554 m (1,818 ft)

Safety radii for damage to glass from overpressure from various weights of high explosives, assuming a surface blast which causes the greatest overpressure, are

- 1.4 kg (3 lb) — 174 m (571 ft)
- 454 kg (1,000 lb) — 1,204 m (3,950 ft)

The hazard radius for damage to buildings due to ground particle velocity is 482 m (1,580 ft) for a yield of 454 kg (1,000 lb) HE, based on a conservative scaled distance of 50 ft/lb^{1/2}.

Hazard radii for shrapnel resulting from various weights of cased explosives are

- 1.8 kg (4 lb) — 290 m (951 ft)
- 54.4 kg (120 lb) — 902 m (2,959 ft)
- 454 kg (1,000 lb) — 1,829 m (6,001 ft)

Hazard radii for shrapnel resulting from various weights of uncased explosives are

- 54.4 kg (120 lb) — 290 m (951 ft)
- 454 kg (1,000 lb) — 676 m (2,218 ft)

5.0 SUMMARY OF ENVIRONMENTAL EFFECTS

Noise exposure of ACF personnel is expressed as the equivalent sound pressure level for the 8-hour work day, and is computed by scaling to the proper distance and combining the appropriate noise values for continuously operating equipment such as vehicles and generators. Explosions, rocket motor firings, and gun firings are impulsive events, and overpressures are predicted and expressed as dB at the ACF Control Building, at other nearby facilities, at Sol se Mete Spring which is frequented by wildlife, and at the nearest housing area to the facility. During rare, very large explosive tests, there is a need to ensure hearing protection of workers or to evacuate certain nearby facilities not associated with ACF. Potential effects of noise on wildlife are considered by comparing the explosion-produced noise levels with the noise level produced by a hunting rifle. The conclusion reached is that continuously operating equipment would not produce a serious noise hazard except in the immediate vicinity of the electricity generators and heavy equipment where hearing protection devices should be used. Rocket motors, guns, and detonations of less than 54 kg (120 lb) of explosives would not produce noise levels above the threshold for protection at the control building, other nearby test areas, or Sol se Mete Spring. Rare tests involving explosive weights between 54 and 454 kg (120 and 1,000 lb) could produce impulsive noise levels above 140 dB that would require evacuation or other provision for hearing protection at the ACF control building and at certain nearby facilities not associated with ACF.

Other blast effects including overpressure, ground vibration, and fragmentation produce hazard radii that are generally smaller than the corresponding noise hazard radius, where the noise hazard radius is defined as the distance at which the predicted noise level drops to 140 dB. The largest non-noise hazard radius would apply to fragmentation from a 454-kg (1,000-lb) cased explosive device. There are no adequate protective measures against the fragmentation hazard except spatial separation and fragment-resistant physical barriers. No test event except for a cased detonation of greater than 54 kg (120 lb) of explosives would require extraordinary safety measures beyond the intersection of the test site road with the Sol se Mete Canyon access road, although hearing protection may be needed for workers who would be outside a protective structure.

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GLOSSARY OF TERMS

A-weighted level (L_A)—acoustic signal level weighted using A-weighted network designed to approximate the frequency response characteristics of a young human ear.

A-weighted sound exposure level (ASEL)—integration of A-weighted level over the duration of an event referenced to one second.

C-weighted level (L_C)—acoustic signal level weighted using a C-weighted network. C-weighting results in greater contributions from low frequency components than A-level weighting, and therefore may be more appropriate for those events, such as explosive detonation, that are richer in low frequency sounds.

C-weighted sound exposure level (CSEL)—integration of C-weighted level over the duration of an event referenced to one second.

decibel (dB)—a unit for describing the ratio of two powers or intensities, or the ratio of a power to a reference power. The range of acoustic energy density for the human ear between the threshold of hearing and the sensation of pain is as large as 10^{14} . Using a logarithmic scale to compare different values of energy with a reference value (threshold of hearing) reduces the average human hearing range to a manageable scale of 140 units.

Equivalent day-night average level (L_{dn})—a measure of the annoyance level of sound over an entire day, obtained by energy averaging A-weighted sound levels over a 24-hour period, with a 10 dB penalty applied to night operations.

Equivalent sound level (L_{eq})—a measure of the average sound level over a period of time, obtained by averaging, on an energy basis, all noise sources. The equivalent sound level is the continuous sound level that would be equivalent, on an energy basis, with the fluctuating sound level.

Equivalent sound level for an 8-hour working day [$L_{eq}(8)$]
—the equivalent sound level averaged over an 8-hour working day, used to determine sound exposure for a worker.

Sound pressure level (SPL)—for an acoustic signal, the level of sound pressure above atmospheric pressure, expressed on a logarithmic scale standardized to $20 \mu\text{Pa}$. SPL is calculated according to

$$SPL = 10 \log \left(\frac{P}{P_0} \right)^2$$

where P is the sound pressure of acoustic signal above atmospheric pressure and P_0 is $20 \mu\text{Pa}$.

Sound pressure level spectrum (SPL spectrum)—frequency distribution of sound pressure level, generally expressed in terms of 9 octave bands with geometric mean frequency of the bands ranging from 31 Hz to 16,000 Hz.

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