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Environmental Impact Assessment Sandia Laboratories, New Mexico

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SANDIA LABORATORIES
ALBUQUERQUE, NEW MEXICO

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Abstract: This Omnibus Environmental Assessment describes the ongoing operations of the Sandia Laboratories, Albuquerque, (SLA) and evaluates the actual and possible impacts on the environment that continuation of these operations entails. Since the Laboratories predates the National Environmental Policy Act of 1969 (NEPA) by two decades, there previously has been no overall formal retrospective environmental assessment of the whole of its facilities and operational although each facility that post-dates NEPA has been assessed for its potential environmental impact. The SLA plant and facilities are owned by the U.S. Government, and are operated by Bell System through a contract between the Western Electric Company and the U.S. Atomic Energy Commission (now the U.S. Energy Reserach and Development Administration (ERAD) as a prime contractor (Sandia Corporation) of the ERDA. All laboratory ongoing activities are discussed, except that this asessment does not evaluate the consequence of possible terrorist activity against the laboratory facilities, nor does it concern itself with transportation hazards outside Kirtland AFB East. Precautionary measures are in effect to assure that all nuclear materials are secure. The internal accounting system shows the locations and quantities of all nuclear material at all times.

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~~Facility~~ Env. Project Name: Sandia Lab.

Scope of Project: ______

FY for Construction: ______

Type of Project: MILCON MC RDT&E DEM/VAL Other: ______

Environmental Documentation Relating to Project:

Type: Installation EIA

Title: Sandia Laboratories (Energy Res + Develop Ad. Dev) ml/Apple)

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Documentation: ______

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CHAPTER I

SUMMARY

This Omnibus Environmental Assessment describes the ongoing operations of the Sandia Laboratories, Albuquerque, (SLA) and evaluates the actual and possible impacts on the environment that continuation of these operations entails. Since the Laboratories predates the National Environmental Policy Act of 1969 (NEPA) by two decades, there previously has been no overall formal retrospective environmental assessment of the whole of its facilities and operations although each facility that post-dates NEPA has been assessed for its potential environmental impact.

The SLA plant and facilities are owned by the U. S. Government, and are operated by the Bell System through a contract between the Western Electric Company and the U. S. Atomic Energy Commission (now the U. S. Energy Research and Development Administration [ERDA]) as a prime contractor (Sandia Corporation) of the ERDA.

All laboratory ongoing activities are discussed, except that this assessment does not evaluate the consequences of possible terrorist activity against the laboratory facilities, nor does it concern itself with transportation hazards outside Kirtland AFB East. Precautionary measures are in effect to assure that all nuclear materials are secure. The internal accounting system shows the locations and quantities of all nuclear materials at all times.

Background

The Sandia Laboratories operates government-owned facilities in Albuquerque, New Mexico; Livermore, California; and Tonopah, Nevada. This assessment concerns itself only with the Albuquerque operations. Sandia's principal responsibility is engineering, research and development on nuclear ordnance. This primary mission has led to support capabilities in a number of scientific and advanced development areas, and the skills gained over the years have led to a number of other tasks in such fields as weapons protection (safeguards), fuel cycle protection (safeguards), nuclear waste management, electron-beam fusion and laser development, nuclear reactor safety and a range of nonnuclear energy programs.

The Sandia Laboratories is an outgrowth of the Los Alamos Scientific Laboratory, and dates back to 1946 as a distinguishable entity. Since 1949, the Laboratories has been operated by the Bell System through the Sandia Corporation.

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Benefits

The Sandia Laboratories is one of three nuclear weapons design laboratories of the United States, the one concerned with ordnance engineering in contrast to the nuclear design activities of the Los Alamos Scientific Laboratory and the Lawrence Livermore Laboratory. These activities are necessary to maintain an up-to-date stockpile of nuclear weapons. Sandia is also addressing other problems of national concern, especially those related to energy.

The existence of a capable staff with varied abilities has led to numerous technological spin-offs, for instance laminar-air-flow clean-rooms. It has resulted in many technical and scientific papers in the appropriate literature, and in Sandians holding many responsible positions in government advisory bodies.

Facilities

The SLA is located at the foot of the Manzano Mountains southeast of Albuquerque, New Mexico (see Figure 1). Sandia's facilities are in part on ERDA-owned land almost completely surrounded by Kirtland Air Force Base East, in part on land used by agreement with the Air Force, and in part on land withdrawn from the public domain for the exclusive use of the Air Force and ERDA (Figure 2).

SLA operations are conducted in five areas, called Technical Areas I, II, III, V and the Coyote Test Field (CTF). In that order they are progressively farther from the housing areas on the base* and in the city, with the more remote areas dedicated to the more hazardous activities. In addition, some field tests are carried on at a group of sites northeast and northwest of the town of Edgewood, New Mexico, 40 minutes by road east of the base, herein called the Edgewood Sites.

Area I is used to research and design activities, and for administrative and support functions. Supporting laboratories and shops are also in Area I.

Area II was originally established for the assembly of chemical high explosive devices, and is now used for various laboratory and testing operations of intermediate hazard.

Area III is devoted to the simulation of a variety of natural and induced environments, and includes such facilities as a rocket sled track, two centrifuges, and a radiant heat testing facility.

Area V is where SLA's experimental and engineering reactors and its more bulky particle accelerators are to be found. Two reactors are now operating: an Annular Core Pulse Reactor (ACPR) that can be used either in a steady-state or a pulse mode, and a Sandia Pulsed Reactor

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*Throughout this report, the phrase "the base" means Kirtland AFB East and especially that part of it used by SLA.

(SPR II) that operates in a pulsed mode. In 1975 another SPR will be put into operation. The Area V particle accelerators are electron beam generators usually used in the X-ray mode.

The Coyote Test Field (CTF) contains the more hazardous operations permitted on the base, each facility separated from the rest by approximate buffer zones. The facilities in the CTF are: explosively driven shock tubes, aerial cable sites where test configurations are pulled down for high-speed impact with the ground, a test site where large amounts of cased conventional explosives can be detonated, numerous small explosive sites, igloos for the storage of explosives, and a laser strain seismometer. Tests in the CTF use chemical explosives only.

The Edgewood Sites are used for tests that cannot be handled in SLA facilities because of requirements for a soft ground, low radio-frequency background, low seismic noise from traffic, and for a free air-space. Tests include airdrops of inert shapes, earth-penetrating gun shots, and evaluations of parachute configurations.

Future Construction

Future construction ranges from modifications of existing buildings to a new construction. For each construction project an assessment of potential environmental impact is submitted with the request for its funding.

The Environment

SLA is located on a high, arid mesa or tableland and in the foothills of the Manzano Mountains. It is located on and is essentially surrounded by the base, which in turn is adjoined on the north and northwest by the City of Albuquerque; on the east by the Cibola National Forest; on the south by the Isleta Indian Reservation; and on the west by unoccupied State lands, Kirtland AFB West, and the Albuquerque International Airport. The mesa is high mountain desert covered with grass, sage, cactus, and associated vegetation. This grades into juniper, pinyon, and ponderosa pine as one ascends into the mountains to the east. The fauna of the mesa consists of such animals as rabbits, coyotes, lizards, and a variety of birds. In the moister and more fertile mountains there are also deer, bear and a few bobcat. Hunting has not been permitted on the base for fifteen years, and the land has not been grazed since before World War II.

The Manzano Mountains to the east rise as high as 8000 feet MSL, 2500 feet above the mesa. The higher, eastern parts of the base are used only as buffer zones. The mountains have a gently sloping, stream-dissected eastern side, and a rough, canyon-cut western side. The mountains receive more rain and snow than the mesa, and tend to channel winds through Tijeras Canyon, giving rise to occasional periods of high winds in Area I.

Albuquerque's climate is mild and dry, but given to large diurnal and seasonal changes in temperature, from a record high of 105°F to a record low of -17°F. Clear, sunny days with light to moderate winds are the rule. Rainfall is about 9 inches a year on the mesa, increasing to about 20 inches a year in the mountains. The rain comes principally in late summer, as torrential thundershowers. Spring winds often produce dust storms.

The Albuquerque area is the metropolis of New Mexico, with over 300,000 people. Kirtland AFB East itself houses about 5000 people (military personnel and their dependents). Densely populated residential areas are to the north and west of the base.

Environmental Impact

Normal Operation

The impacts of the normal operation of the SLA consist of effects on the land, the use of resources and energy, the release of some effluents and effects on the community.

SLA was not the first user of the land. There are traces of old roads, houses, and even evidence of prehistoric occupation. Past over-grazing still shows in the biological structure of the grasslands. Today, where buildings have been built, especially in Area I, there is almost complete removal of the original vegetation. Roads have been built. There are borrow pits and waste disposal areas. There is much traffic among the various work sites.

Resources used are electricity, fuel oil, natural gas, motor fuel, water, construction materials, and the supplies needed for the ongoing work of the Laboratories.

Radioactive effluents for the years 1971, 1972, 1973, and 1974 have averaged 8.02 curies (Ci) consisting of argon-41 (97%) and hydrogen-3 (tritium) (3%). In the most recent calendar year report, the argon-41 discharge was 5.05 Ci and the tritium discharge was 0.09 Ci. The trend thus is slightly downward. A small amount of solid, low-level radioactive waste is buried in a landfill in Area III. Releases and procedures are well within applicable Federal, State, and local guidelines.

Chemical wastes are also small in quantity. About ten metric tons of airborne wastes are released each year, 60% of it being sulfur dioxide from the steam plant. The principal liquid waste is about 70 pounds (32 kg) of chromate per year from the photo labs. These releases are well within applicable Federal, State, and local guidelines. All solid chemical waste is buried in a landfill in Area III.

Sanitary wastes from Area I enter the base sewage system from whence they flow either to sewage stabilization lagoons or to the city sewage treatment plant. Remote areas are served by septic tank systems.

The demographic effects of the Laboratories are significant. Sandia is the third largest single employer in the area (with 5400 employees in Albuquerque) dispersing about $127 million into the local economy annually through payroll and local purchases. SLA employees with their families constitute about 7% of the local population, and contribute about 20% of the local United Community Fund. Sandia employees are active in the political, cultural, and religious life of the city.

Accident Analyses

Area I - Ammonia is used in Area I. If it should escape in quantity, most likely through a leak in the piping connected to the storage tank, or by an accident during filling, it might be necessary to temporarily evacuate people downwind. Because some base housing area is next to Area I, evacuation could extend there as well if the wind had a southerly component.

A large methane tank sits on the north edge of Area I. If it should spill, there is the possibility of a large fire, which would require evacuation of the SLA surrounding buildings and nearby base housing area.

Occasionally there is tritium in the Area I vault being held temporarily while in transit elsewhere This tritium is in sealed, Department of Transportation-approved containers, which are never opened in Area I. Nevertheless, if there was a release from one, it could produce radiation exposures in Area I greater than the Radiation Concentration Guidelines permit, and would require evacuation of Laboratories personnel. Calculations indicate that exposures would be reduced to below guideline levels before reaching adjacent housing areas.

An explosion of a boiler in the steam plant is considered quite unlikely. Nevertheless if one did occur, the effects would only be damage to adjacent boilers and to the building housing the boilers, with no effects outside Area I.

Area II - There was no significant accident found in analyzing Area II operations.

Area III -- Normal operation of the Rocket Sled Track gives off noise and dust. There might also be shrapnel from detonations of high explosives in test units or from impacts at the end of the track. Tests sometimes start brush fires which, if not controlled, could start a range fire. Test units leave the track, either by failure of the sled shoe or by plan. Other lesser incidents might also occur. Certain mitigating measures, however, are taken: ample buffer zones will contain shrapnel or an erratic test unit; fire-breaks have been cut; and a professional fire department stands by during tests on days of great dryness and wind.

Mockup of nuclear weapons containing fissile materials or high explosives are sometimes present in Area III (never both implosion assemblies and fissile materials in the same mockup in any SLA facility; likewise, no two mockups, one of which contains implosion assemblies and the other fissile materials, in the same facility). These mockups are deliberately exposed to environmental stress in Area III. If, in spite of precautions, a plutonium-bearing mockup were to be exposed to fire, the spread of plutonium would not be great: British tests in which plutonium was burned in an open gasoline fire indicate that at most .05% would be released in particles of respirable size, and 2.5 acres of land would be contaminated to levels that would require decontamination. The consequences of such an accident would therefore be limited to Area III.

If an explosives-bearing mockup were to detonate during test, the consequences would be local because of the small amount of explosives typically involved.

Explosives and radioactives occasionally need to be transported between various SLA operating sites. Care is taken in these movements to reduce to a practical minimum the possibility of these materials being involved in transportation accidents. If, nevertheless, explosives were to detonate in such an accident, the consequences would be a shock wave, possibly a crater, and both dirt and container fragments thrown as shrapnel. Possible environmental effects include smothering or disruption of vegetation and the starting of grass or brush fires. The consequences of an accident involving radioactives would be (if tritium) a rapidly dissipating radioactive cloud without ground deposition, or (if plutonium) local effects as described immediately above.

Area V - During the safety analysis of reactor operations, several possible accidents were identified that might release radioactivity outside the reactor buildings. For the SPR these were: fire in the reactor room, improper adjustment during initial reactivity checks, experiment movement changing reactivity, and melt-down of a fissile-material experiment. For the ACPR these were: vaporization of a fission foil, melt-down of a fissile-material experiment, and failure of "water-logged" fuel elements. The last is the worst; all others would be locally disruptive and perhaps damaging to the reactor, and might lead to exposure levels above Radiation Protection Guides in the reactor area and beyond the Area V fence, but would lead to well below guideline levels at the distance of the nearest housing areas even if the wind were blowing in that direction.

A water-logged fuel element is one with a leak in the cladding. The sharp increase in pressure during pulse operation could be too fast to be relieved through the leak, and several fuel elements might rupture. In such an event, the filters on the building would remain intact, but would release noble gases and some halogen fission products to the atmosphere. Such a release, though unlikely, would be of small consequence. Radiation exposure levels at all distances would be well below guideline levels. Effects on nearby flora and non-human fauna would be scarcely noticeable.

Coyote Test Field--During tests at the large explosive site or at the two aerial cable sites, brush fires are sometimes started. One of these might escape control and escalate into a forest fire. To prevent such a fire, fire-breaks have been cut around these sites, fire-fighting equipment is always with the test crew, and the fire department is brought to the scene before a test on days of great dryness and wind.

At these three sites there is also the possibility of an aircraft flying low over the shot area at shot time. The aircraft would then be exposed to the shock wave of the explosion and might be hit by a piece of shrapnel. Using conservative assumptions, the probability of serious damage to the aircraft was found to be less than 10^{-6} per test. Nevertheless, on every test a man is sent to a lookout tower on a nearby ridge to watch for aircraft and to defer the test if one should appear.

Occasionally a test is conducted at the Sol se Mete Canyon cable site in which a rocket is fired at a target in the air. Trajectories are toward the east away from habitations, and impacts are well within the uninhabited boundaries of the base. After such a test, a helicopter follows the rocket to bring fire-fighting equipment to the scene should any brush fire result.

The Edgewood Sites--During a gun firing, the igniter might fail to produce a full deflagration of the propellant, in which case burning pieces of propellant would spew forth, starting local fires. The thinness of the vegetation assures that such fires would not spread.

Cattle are not removed from the vicinity during tests. One might be hit by a reaction mass or other missile.

An aircraft involved in a test might crash. If so, the environmental consequences would be a local land scar and possibly a fuel fire. Again, the thinness of the vegetation assures that such a fire would not spread out of control.

Unavoidable Adverse Environmental Impacts

Environmental impacts that are unavoidable consequences of the operations of SLA are the use of the land; the use of some natural resources; the release of some chemical, sanitary, and radioactive effluents; the generation of noise, dust, and smoke; and the exposure of the surrounding populace and the native flora and fauna to potential accidents.

Alternatives

The alternatives to continuing the operation of the SLA are: plant shutdown or complete relocation and site decommissioning; partial transfer of functions elsewhere; reducing the number and size of those operations with the greatest potential for adverse environmental impact; and wider use of alternate technologies with reduced environmental impact.

Discontinuing weapons development would be against the national interest. Removing operations to another place would merely transfer environmental impacts elsewhere at great expense. Decommissioning would in principle be possible, but the fact that existing use of the land is shared with the Air Force means that this would not necessarily release the land for non-governmental use. Shutting down SLA or moving it elsewhere would also have a great adverse economic impact on the Albuquerque area.

Partial transfer of operations elsewhere includes moving more operations from Area I to the remote areas of the base. This would reduce the possible consequences to humans at the expense of an increase in possible consequences to the native flora and fauna. To move an operation from Albuquerque to a more remote area such as Nevada would reduce the efficiency of operation, and would result in a poorer product.

No useful suggestions have surfaced for changes that would reduce environmental impact by reducing the number or size of operations.

Some alternate ways of operating appear in the budget as construction items. These often reduce environmental impact. Two of the projects now planned will bring outdoor operations indoors. One will save water by changing from once-through cooling to closed-loop cooling.

Relationship Between Short-Term Use and Long-Term Productivity

In principle, SLA facilities could be razed and the land returned to grazing, or the laboratory could be shut down and the facilities put to other uses. In an arid area revegetation is slow, and some scars on the land would remain essentially forever. Conversion to other uses would be complicated by Air Force use of the surrounding land, and would make difficult its use for non-governmental purposes. Nevertheless, the present SLA operations do not preclude use of the land or facilities for other purposes.

Relationship to Land Use Plans

The only published plan for land use in this area is one commissioned (but not adopted as policy) by the City of Albuquerque in 1969. This plan accepts the existence of SLA. It proposes the extension of the Albuquerque International Airport on State lands to the west of the main part of the base and establishment of industrial areas around the airport. Development of such industrial areas south of the airstrip could conflict with SLA's use of a portion of those State lands as a buffer zone for Area III operations.

Otherwise continuing operation of SLA is not in conflict with any known plans of Federal, State, or local entities.

Commitment of Resources

Few commitments of resources at SLA are absolutely irreversible and irretrievable. The use of fuels, most construction materials, and supplies used in the operation and maintenance of the laboratory are irretrievable. The use of water is within the natural recharge capability of the aquifer. The human resources that have been invested in the past are also irretrievable.

The use of land is not absolutely irreversible, although return to its pristine state would be difficult and costly. The difficulties would be in large part due to the slowness of natural revegetation and the fact of shared use of land with the Air Force.

Cost-Benefit Analysis

The environmental costs of the operation of SLA are several. They are the use of resources (although a SLA anywhere else would use as many); the use of land, precluding its possible use for other purposes; the release of some chemical and radioactive effluents; and the potential exposure of the community and of the native flora and fauna to the hazards of accidents.

The principal benefit to the United States from the continued operation of SLA is its contribution to the national defense.' Other benefits are the existence of facilities and teams of scientific and engineering personnel available to turn their skills to other national needs, and the technological spin-offs that have come from past operations.

The economy of Albuquerque and New Mexico benefits through the employment of 5400 people and the expenditure of over a hundred million dollars annually in payroll and local purchases. As individuals, Sandians also contribute to the advancement of the State in many social-cultural ways.

The various alternatives studied have great dollar costs and few environmental benefits, except that some improved methods of carrying on operations may be slightly less environmentally damaging.

Conclusion

These costs and benefits imply that as long as the nation maintains nuclear weapons and has a need for technical centers which can address other emerging needs, the Sandia Laboratories, Albuquerque should continue to operate at its present site. The environmental costs inherent in both present and planned future work are small, can be mitigated, and are reasonable for the benefits gained.

CHAPTER II

BACKGROUND

Introduction

Objectives of the Operation

Sandia Laboratories Albuquerque (SLA) plant and facilities are owned by the U. S. Government, and have been operated by the Bell System (through a contract with Western Electric Company) as a prime contractor (Sandia Corporation) of the U. S. Atomic Energy Commission (now the Energy Research and Development Administration).

Sandia's principal responsibilities have been, and for at least the near future will continue to be, engineering research and development on nuclear ordnance: the arming, fuzing and firing systems used in U. S. nuclear bombs and warheads. Components developed by Sandia include power supplies, timing mechanisms, radars, switches, and other parts and circuitry which make up the intricate actuating, safety and control systems. Sandia also designs structures, aerodynamic shapes and parachutes for the weapons which would be dropped from aircraft. In team efforts with missile designers, Sandia assures warhead compatibility with delivery vehicles. Responsibilities extend to field and product engineering; stockpile monitoring, quality assurance and surveillance; and training for military forces. Safety, reliability and survivability of weapon systems have received primary emphasis.

As a consequence of these varied activities and charters, Sandia maintains support capabilities in a number of advanced development areas: analysis, simulation and measurement of nuclear weapon phenomenology requiring sophisticated field and laboratory testing, prototype manufacturing and computational facilities; earth penetration, satellite, and seismic instrumentation capabilities; materials and miniaturized device development; and work in related disciplines of mathematics, physics and chemistry.

Although for the foreseeable future, a major task at Sandia will remain that of developing nuclear weapons for the military services, considerable additional diversification in support of energy-related projects may be expected.

History

In 1943, the University of California agreed with the U. S. Army to direct the technical and scientific aspects of the nuclear weapons design and development work conducted at Los Alamos Laboratory, where the Army provided necessary construction, housekeeping, security and general administration. In July 1945, Oxnard Field near Albuquerque was transferred to the U. S. Engineers, Manhattan District, to be used as a development engineering and assembly site for the nuclear weapons components coming out of Los Alamos (Figure 1). Earlier in this same month, a "Fat Man" prototype bomb was successfully tested at Trinity Site, some 110 air miles south of Albuquerque. In September, after the Hiroshima and Nagasaki bombings in early August, construction of a guard building and storage facilities was authorized at "Sandia Base," east of Albuquerque.

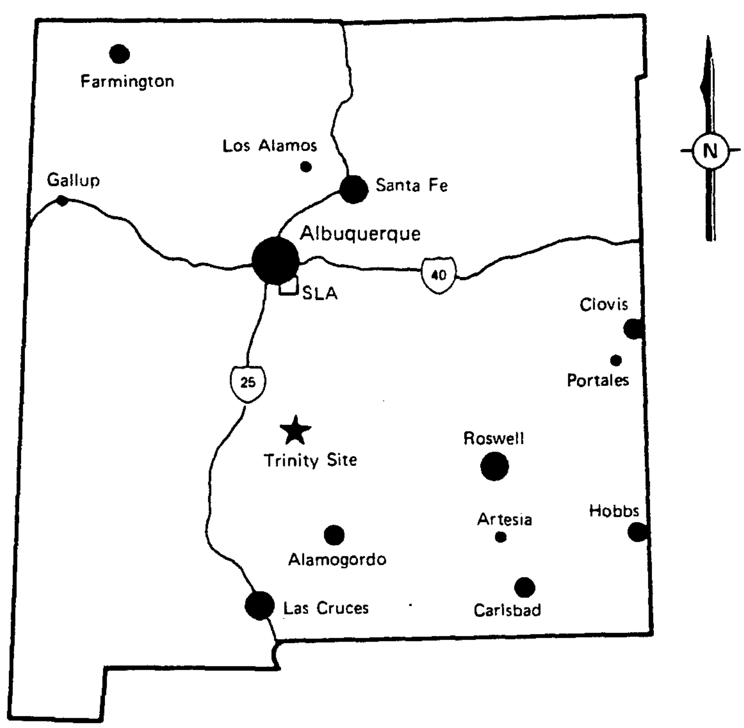

Figure 1. New Mexico Cities of Greater Than 10,000 Population

Personnel from the Z Division (for Jerrold Zacharias) at Los Alamos were transferred to Albuquerque, along with procurement specialists, to assemble a stockpile of atomic bombs (using components already on order) and to design new weapons in cooperation with other Los Alamos Divisions. While the formation of the AEC was being debated in Congress and finally formalized over several months, Z Division personnel continued their work on improving existing nuclear systems, conducting non-nuclear tests south of Albuquerque and participating in tests at the Bikini Atoll (July 1946). Sandia activities continued as a branch of Los Alamos Scientific Laboratory until the Regents Committee on AEC projects of the University of California expressed a wish on December 13, 1948 to divest the university of the Sandia engineering operations as inappropriate to an educational institution.

President Truman asked the Bell System to undertake management of Sandia activities, and on November 1, 1949, a new entity "Sandia Corporation" (a wholly owned subsidiary of Western Electric Company) assumed active direction of the Sandia Laboratories under a no-fee, cost-reimbursement five-year contract between the Western Electric Company and the U. S. Atomic Energy Commission. That contract has been renewed every fifth year since.

In 1956, a branch of Sandia Laboratories was established at Livermore, California, to support directly the weapon development efforts of the Lawrence Livermore Laboratory, also operated by the University of California.

In support of both laboratories, Sandia Corporation maintains and operates extensive range-test facilities at Tonopah, Nevada and Kauai, Hawaii.

The Facility (General)

At their nearest points, Sandia Laboratories, Albuquerque, facilities are one mile south of U. S. Highway 66, two and one-half miles south of U. S. Interstate 40 and about six and one-half miles east of downtown Albuquerque, New Mexico (Figure 2). The Laboratories is essentially surrounded by Kirtland Air Force Base (East), with co-use agreements on some portions of the Air Force's 24,500-acre property. An additional 22,500-acre area to the east of the KAFB has been withdrawn from public domain for the exclusive use of KAFB and ERDA. High explosive tests, explosive storage, and other hazardous operations are buffered and barricaded by the mountanous terrain toward the eastern edge of this withdrawal area. Areas to the west and south (by use agreements with the State of New Mexico and the Isleta Pueblo) serve as buffer zones for certain other test operations (Figure 2).

Sandia Laboratories has been divided into five areas, each with distinctive operations and requirements: Technical Areas I, II, III, and V, and Coyote Test Field (Figure 2). The Technical Areas I, II, V, and each test facility within Technical Area III are surrounded by security fencing, lighting, alarms and security guard patrols. Day and night remote TV monitoring is also used.

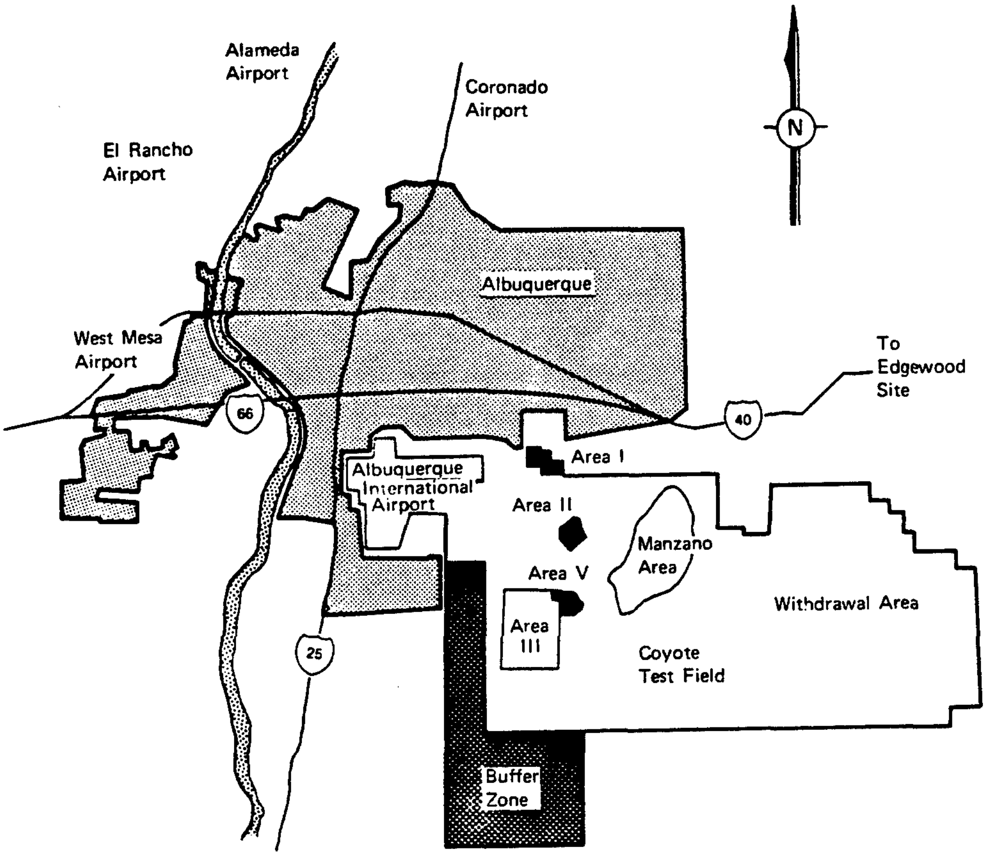

Figure 2. Albuquerque, Kirtland Air Force Base, Sandia Laboratories technical areas and buffer zones

Of the 49,835 acres of land set aside for these uses, ERDA owns 2,835 acres, and 47,000 acres are used jointly with the Military. Sandia's 285 buildings totalling 2,233,000 square feet are scattered or clustered throughout the area. Buildings and utilities are valued at $74 million, and facilities and equipment at $174 million, for a total plant investment of $248 million. A breakdown of buildings in each Area by number, type of construction and square footage is provided in Table I.

Throughout this background section, maps, accompanying tables and descriptions reveal, by area, the type and extent of land use, the number and type of buildings, and the nature of Laboratories' activities in research and engineering development and testing.

TABLE I

Present Construction by Type at SLA

(Sq. Ft. in Thousands)

Type*	Area I No.	Area I Sq. Ft.	Area II No.	Area II Sq. Ft.	Area III No.	Area III Sq. Ft.	Area V No.	Area V Sq. Ft.	Outlying No.	Outlying Sq. Ft.
1	32	1,389	7	9	20	63	6	47	90	190
2	15	66	10	33	12	39	3	15	7	21
3	31	186	6	10	16	19	3	9	10	38
4	10	65			5	3			2	1
5	**	28			***	2				
	88	1,734	23	52	53	126	12	71	109	250

**56 *trailers* ***5 *trailers*

*Type 1 - *50-year classification*
Masonry or reinforced concrete exterior walls, reinforced concrete and/or structural steel framing.

Type 2 - *40-year classification*
Masonry exterior walls, with wood or light steel framing.

Type 3 - *30-year classification*
Prefabricated metal buildings.

Type 4 - *10-year classification*
Temporary wood frame buildings.

Type 5 - *Mobile Offices.*

Benefits

National Defense -- The Sandia Laboratories is one of the three nuclear weapons laboratories of the former United States Atomic Energy Commission, the other two being the Los Alamos Scientific Laboratory, New Mexico, and the Lawrence Livermore Laboratory, California. As described earlier, Sandia's responsibility, in contrast to the nuclear design labs, is the ordnance engineering of U. S. nuclear weapons. The Senate, in giving its assent to the 1963 "Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water," specified that the U. S. shall maintain "modern nuclear laboratory facilities and programs in theoretical and exploratory nuclear technology which will attract, retain and insure the continued application of our human scientific resources to these programs on which continued progress in nuclear technology depends." (Com. For. Rel., U. S. Senate, 1963, p 274.) The Sandia Laboratories is an integral part of this posture.

Technological -- In the process of becoming expert on the many and varied facets of ordnance engineering, the staff of the Laboratories has had to become and remain expert in many of the scientific and engineering disciplines underlying their basic mission. The technological spinoffs that have resulted are demonstrated by many patents, by new developments in energy concepts and engineering, by technical and scientific papers written by the staff and appearing in the technical literature, and by the responsible positions Sandians hold and have held in government advisory bodies.

Area I

Area I is dedicated primarily to the design, research and development of weapons systems and weapon system components. Related studies of science and/or engineering are carried on. Support activities include administration, technical library, computing, systems evaluation, advanced planning, instrumentation, testing, military liaison, fabrication, receiving and shipping, and health and safety. Relatively new activities to Sandia Laboratories include design, research, development, testing and prototype construction of potential nonnuclear energy sources and installations. Current work in nuclear energy program activities, in weapons protection, fuel cycle protection, nuclear reactor safety, and fusion will be enlarged. Nonnuclear energy programs, including research and engineering in areas such as solar, fossil fuels, combustion, magma and advanced drilling are evolving rapidly.

Included in Area I are offices, laboratories, shops and other facilities (see Figure 3 for overview). The vault where radioactive materials, including fissile materials, are stored is also here. For the purposes of this document, Area I is defined to include nearby buildings outside the security fence such as Medical, Personnel, Van de Graaff Accelerator, Plant Engineering, and the Fuel Oil Storage Tanks. The latter are 1.4 miles from the east end of the east-west runway of the Albuquerque International Airport (used jointly by private, commercial and military aircraft).

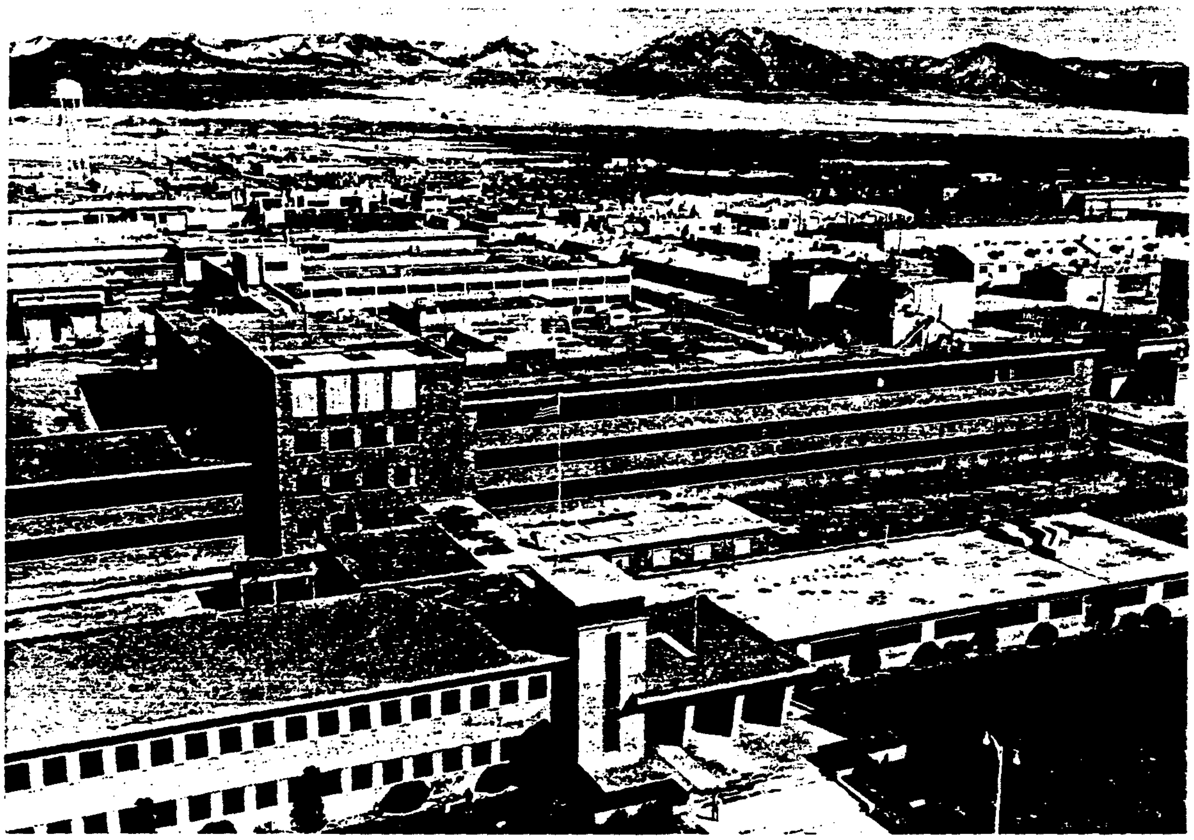

Figure 3. Technical Area I facilities

The administrative and technical offices, laboratories, shops and other facilities house about 5000 people. Significant features of the major facilities and identifiable potential hazards are detailed below:

Offices

Offices for administrative and clerical activities are located in nearly every building in Area I—some devoted exclusively to such functions. All the hazards associated with operations are internal to the buildings in which they are conducted.

Laboratories

A brief review of several kinds of laboratories maintained and operated in Area I is included here to illustrate that no environmental impacts are predicted as a result of operations carried out in them.

Chemical -- Although chemical laboratories located in many different buildings contain lab quantities of reagent grade chemicals, no bulk quantities are concentrated in Area I and it is not likely that catastrophic destruction of a building by explosion would produce detectable traces off site.

Explosives -- The maximum amount of explosive allowed in any one building in Area I is half a pound (200 grams). The maximum amount allowed to be tested or evaluated in the explosives laboratories is about an ounce (25 grams). Adherence to this rule in conjunction with review of every use assures that no missiles or excessive noise from explosives will emanate from Area I boundaries.

EMR Laboratory -- This laboratory was established to test or evaluate systems or subsystems exposed to radiation from electromagnetic sources such as electromagnetic pulses or to continuous wave radiation. When tests threaten to emit radiation that would affect communications systems nearby, review and authorization of those tests is sought by the Sandia Frequency Coordinator through ERDA from the Office of Telecommunications Policy, which controls federal agency transmissions.

High Pressure/Vacuum -- Several organizations throughout Area I use equipment which creates high pressure or vacuum. Only the possibility of excessive noise could exist outside Area I.

High Voltage -- High voltage is present in a variety of laboratories in Area I, sometimes as a basis for research in high voltage, occasionally for other applications, but always completely contained within the area.

Laser -- A number of lasers in Area I find application in research, some in conjunction with other kinds of laboratory equipment, some independent of other operations. All these are contained within buildings except a 5-milliwatt continuous wave helium neon laser that originates from the southeast tower of Bldg. 802. The beam from this source is focused on a recipient telescope situated on either of two buildings, approximately one mile east of the source. The beam operates 24 hours per day and is everywhere far above eye level between these buildings.

This laser beam poses no health hazard at the ground level of the target buildings and it is evaluated for safety each month since it leaves the confines of Technical Area I (though not the base boundary). The power of this equipment is less than one microwatt per square centimeter in the 8-foot diameter of the roof-top target.

Accelerators and X-Ray Equipment -- Research in solid-state physics and materials accounts for a number of uses of particle accelerators at Sandia Laboratories, Albuquerque. A list of large electron or positive ion accelerators in Area I includes:

2-MeV Van de Graaff (two)
300-KeV van de Graaff
Kaman Neutron Generator
2.5-MeV Positive Ion Cockroft-Walton

Other electron-beam, low-voltage-pulsed, and continuous X-ray machines are used of considerably less power.

X-ray machines are used in the Medical Department, in research projects and in various shops for nondestructive testing.

Shops

Of the several shops operated within Area I, some like paint and plating present no environmental hazard beyond the Area; one (the glass shop) is planned for relocation into a permanent fire-resistant building which will provide a fire wall between open flames and supplies of hydrogen and oxygen. Only two shops require detailed consideration to evaluate hazards to the environment beyond the confines of Area I:

Composites -- In the composites facility, a large quantity of methane gas is used as process gas in a pyrolytic carbon deposition process. Figure 4 shows the storage tank, which is about 500 feet from the nearest base housing (within the treed area) and about 150 feet from the nearest Sandia parking lot (close-up background). The composites function is scheduled for relocation to another building considerably further removed from these inhabited areas and the methane tank will be decommissioned. Potential hazards as a result of tank filling or explosion before the move is accomplished are discussed in the Accident Analysis section of Chapter III.

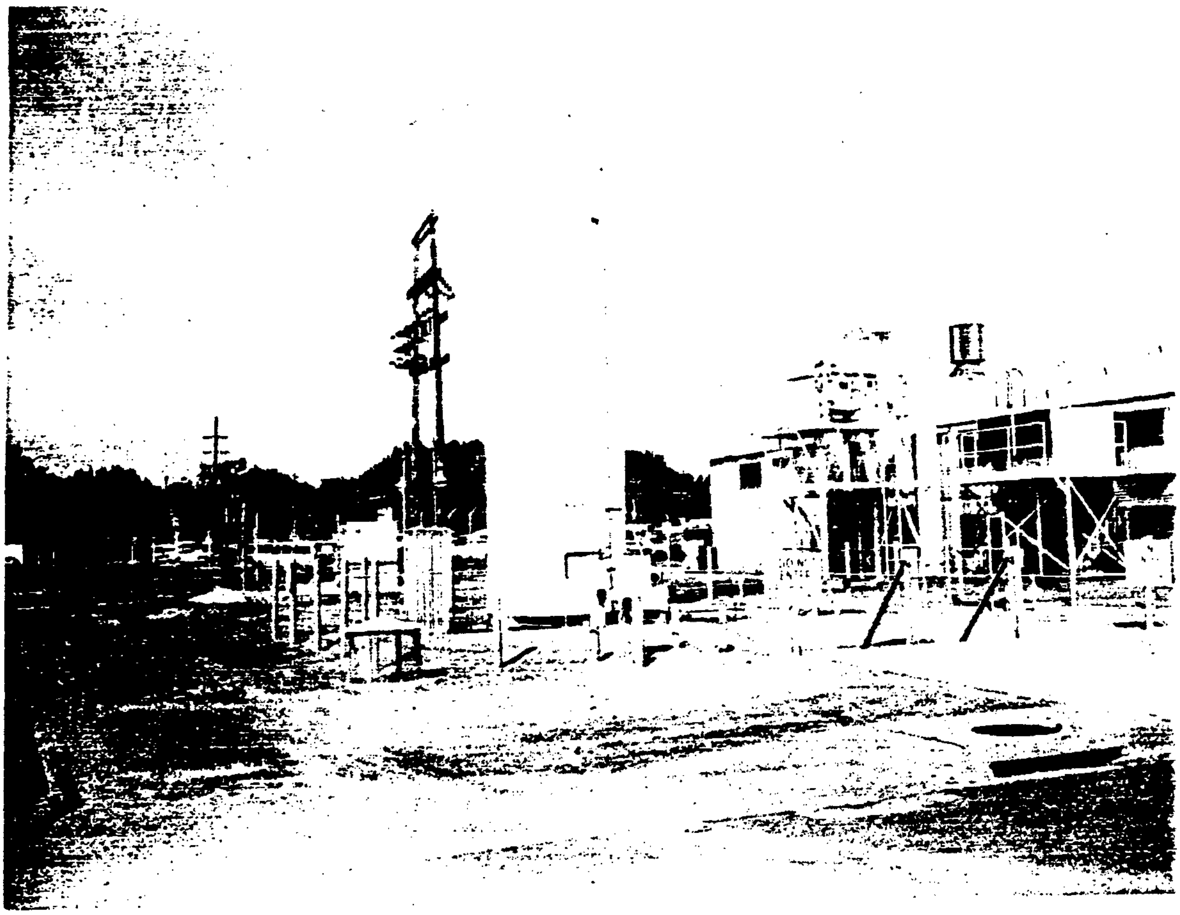

Figure 4. Methane gas facility

Physical Electronics -- For reducing-atmosphere furnaces, personnel in this laboratory use hydrogen derived from three sources:

A manifold takeoff from 50 DoT-approved cylinders
A takeoff from a tube-bank trailer (Figure 5)
Two storage tanks of liquid ammonia (280 cubic feet total maximum) (Figure 6).

Hazards from potential hydrogen explosions are handled by normal fire control operations. Potential hazards from accidental dispersal of the ammonia are discussed in the Accident Analysis section.

Other Facilities

Steam Plant -- Sandia Laboratories operates a six-boiler centralized steam plant on a 24-hour continuing schedule that serves all of Area I and the immediate surrounding facilities, including ERDA/Albuquerque Operations (ALO) headquarters and adjacent military facilities. Combined capacity is 490,000 pounds of steam/hour at a saturated steam pressure of 125 psig. The boilers are designed to burn natural gas as a primary fuel, and No. 2 fuel oil as a standby fuel. Automatic controls for flame safeguard and combustion are incorporated into the boiler systems, and safe operating procedures are in effect, including regular inspections and valve tests. Beyond the hazard of possible fuel oil spills, there is the remote possibility that a boiler might fail in an explosion mode. Boiler failure analysis can be found in the Accident Analysis section of Chapter III.

Oil Tank Farm -- For assurance of continuous power from the steam plant (the gas service contract is on an interruptible basis), Sandia maintains an oil tank farm 0.4 mile south of the steam plant (Figures 7 and 8). Six tanks in the farm (1 of one million gallons capacity; one of half a million, two of one quarter million, and two of 40,000 gallons) are connected into a piping system that feeds four 10,000-gallon, underground day use tanks located at the steam plant. These six tanks on the surface are surrounded by earthern-dike areas of sufficient size to contain the entire tank volume in case of rupture, plus a freeboard to contain fire-suffocating foam in case of fire. The tanks are designed in accordance with the American Petroleum Standard 650 and to Uniform Building Code requirements for Seismic Risk Zone-2 (Moderate Damage) earthquake acceleration. The location, installation, testing and protection of all tanks is in accordance with National Fire Protection Code No. 30, Chapter II (Storage Tanks) and Chapter VI (Bulk Storage Stations). Since the tanks are about 1.4 miles from the eastern end of a main runway at Albuquerque International Airport, we have estimated the probability of an aircraft impacting the million-gallon tank (discussed in the Accident Analysis section of Chapter III).

Vault -- Because of its involvement with a variety of valuable and radioactive materials, including fissile materials, Sandia maintains a vault. The content of this facility differs from day to day because of varied use and in-transit custodian service. Quantities may be very small, but they can also be as large as metric tons of depleted uranium, kilograms of plutonium, and classified

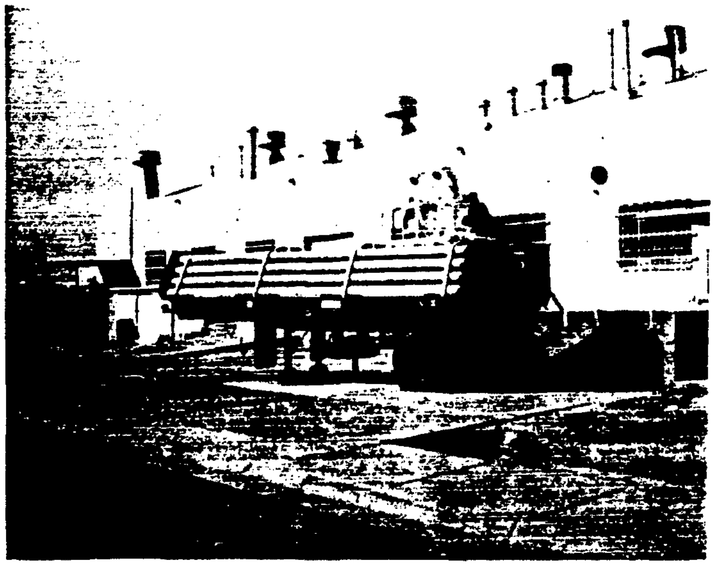

Figure 5. Hydrogen tube-bank trailer

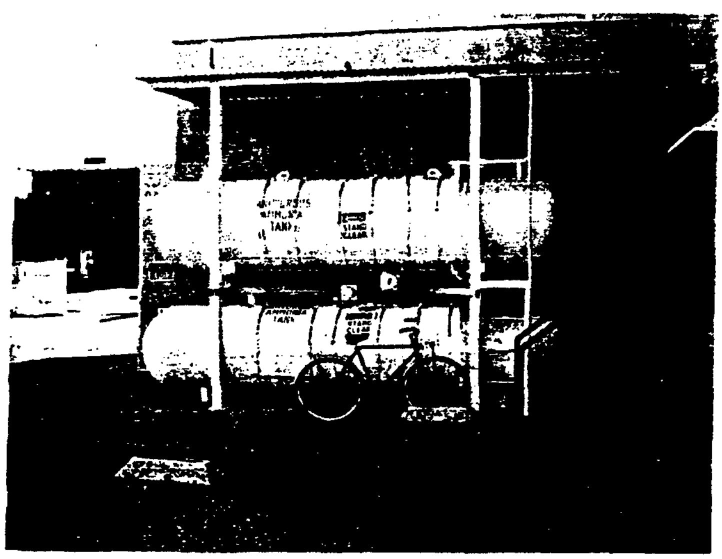

Figure 6. Liquid ammonia storage tanks

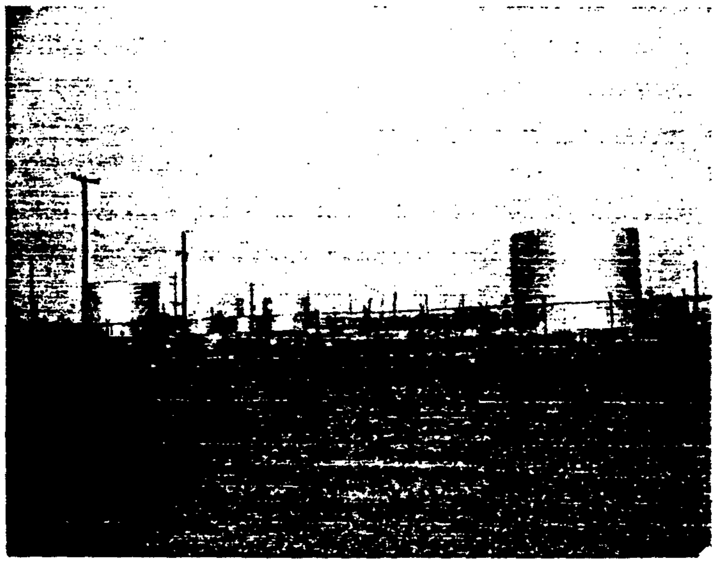

Figure 7. View of oil tank farm 1.4 miles from main runway at Albuquerque International Airport

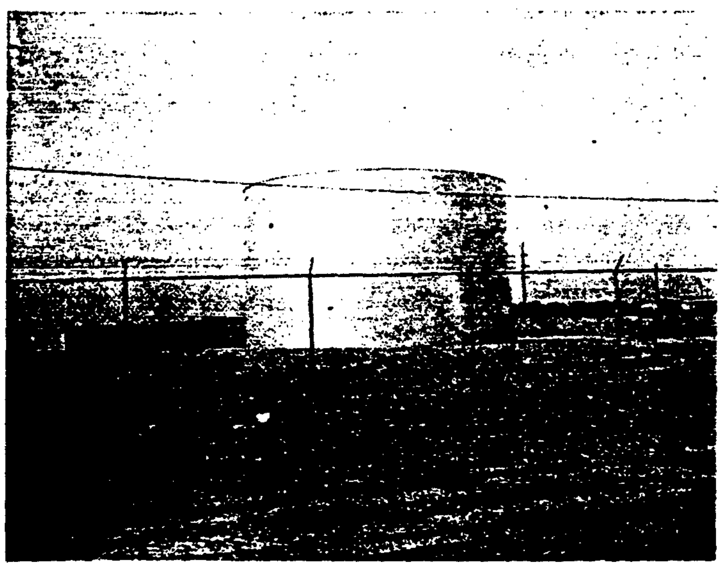

Figure 8. Million-gallon oil tank

quantities of tritium, as well as an occasional radioactive source. Plutonium-bearing mockups are stored in the vault as well as in operational buildings in Area III. (See Area III section below.) The vault has been accepted as being in substantial compliance with the AEC (now ERDA) Plutonium Storage Criteria of 1971, certain small variances such as not having multiple exits having been waived because of the small quantity of plutonium usually present. The vault building contains little combustible material (because it is a storage rather than an operational building) and no flammable liquids. No explosives or propellants are allowed in the building and smoking is not allowed. The vault is constructed of 12-inch reinforced concrete walls and ceiling. The building is equipped with an automatic sprinkler system and the vault itself has a CO_2 extinguisher system. Heat for the building is supplied by steam lines from the steam plant a quarter mile away.

A criticality evaluation is required before a fissile mass larger than 0.5 kg is placed on the storage shelves. When the vault was constructed, the AEC did not require a criticality monitoring system or an emergency procedure, but today ERDA does. Funding is being sought in the FY 1976 budget for installing a redundant fail-safe criticality monitoring and alarm system and establishing a procedure to conform to the basic intent of the current revision to ERDA-0530, Nuclear Criticality Safety Manual, Part II, B.3.C(7).

The environmental impact that release of radioactive materials stored in the vault might present is analyzed in the Accident Analysis section of Chapter III.

Gas Storage -- In addition to those gases previously mentioned, various other gases of a toxic, flammable or cryogenic nature are stored in small quantities throughout Area I. The central disbursement area for these gases is located outside the Area I perimeter fence. Compressed gas cylinders and lecture bottles are used as containers and those containing gases that have an affinity for each other, such as oxygen and hydrogen, oxygen and acetylene, are stored in an open atmosphere at least 10 feet apart, or separated by an approved fire wall when in storage.

Signs identifying these gases are prominently displayed and the gases are handled by special hand trucks and skids. Safe Operating Procedures are in effect for storage, handling, pressure relief and use of these gases. Through these controls, the volume, containment and toxicity can be considered moderately low, presenting no hazard to the environment.

Incinerator -- An incinerator for the disposal of classified combustible waste is located at the east end of Area I (Figure 9). Tests showed that it did not meet the state emission standards for particulates, so in 1973 an afterburner and two Venturi scrubbers were added to reduce its emissions. Also located in this area is a process furnace to recover silver from photonegatives.

Photo and Reproduction Facilities -- Two photography and four ozalid reproduction facilities are maintained throughout Area I; they present no environmental hazards.

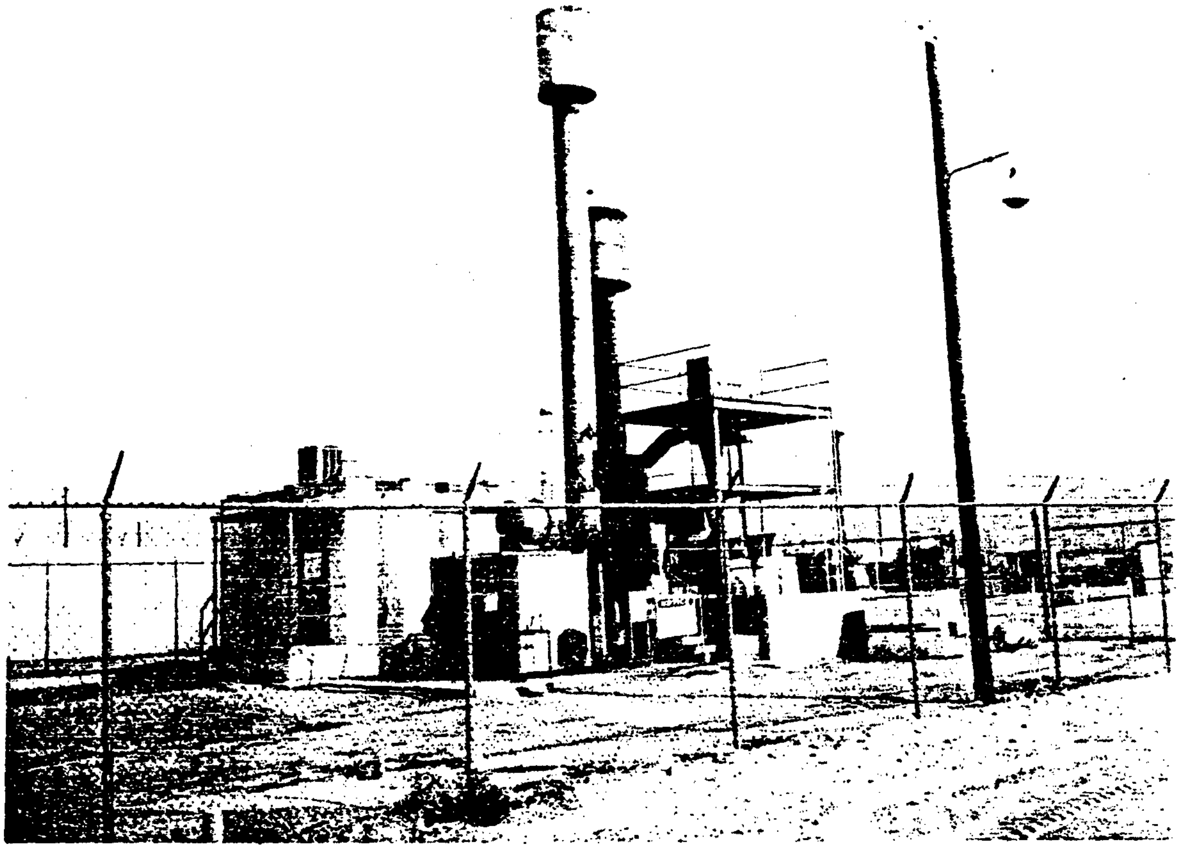

Figure 9. Incinerator with stack scrubbers

Area II

Activities in this area began some 25 years ago when it was used as a remote location for the assembly of high explosive devices. The facilities which were then constructed continue to be of service to Area I projects, particularly for hazardous testing needs. Although structures are less than optimum by today's standards, they do provide useful space and have always been used by Sandia Laboratories to take advantage of their special design characteristics (Figure 10). Five major kinds of activity are conducted in Area II; none presents any environmental hazard beyond the area.

Postmortems

Electromechanical devices, components, and subassemblies (which have been designed in Area I) undergo testing and are disassembled and evaluated in one of the Area II facilities. These postmortem operations are conducted to determine the effects of the test the devices were subjected to.

Material Studies

Research and Development studies on explosive delay timers are being performed with a variety of high-energy chemical explosives (RDX, PETN and HNAB) enclosed in aluminum or lead sheathing. Maximum quantities of these compounds do not exceed 0.5 ounce (15 grams) per test.

Oxidizers and metal fuels are blended to produce explosive chemical mixtures (e.g., titanium and potassium perchlorate). Maximum quantities used per sample range from one-third to 3.5 ounces (10 to 100 grams).

Nondestructive Tests (NDT)

Personnel make X-rays of small, explosive-containing components in a radiography laboratory.

Explosive Tests

Some of the facilities in Area II were originally designed to accommodate the destructive testing of various explosive weapon components or bulk quantities of explosives themselves. The maximum quantity of explosives was 10 pounds per "firing." Usually, however, the quantity now expended is less than 5 pounds and the missile distance produced by 5 pounds is only about 1000 feet. The orientation of the firing chambers also places their open sides toward buffer zones to the east which are visually checked before each firing and provide sufficient safety margin to prevent incidents.

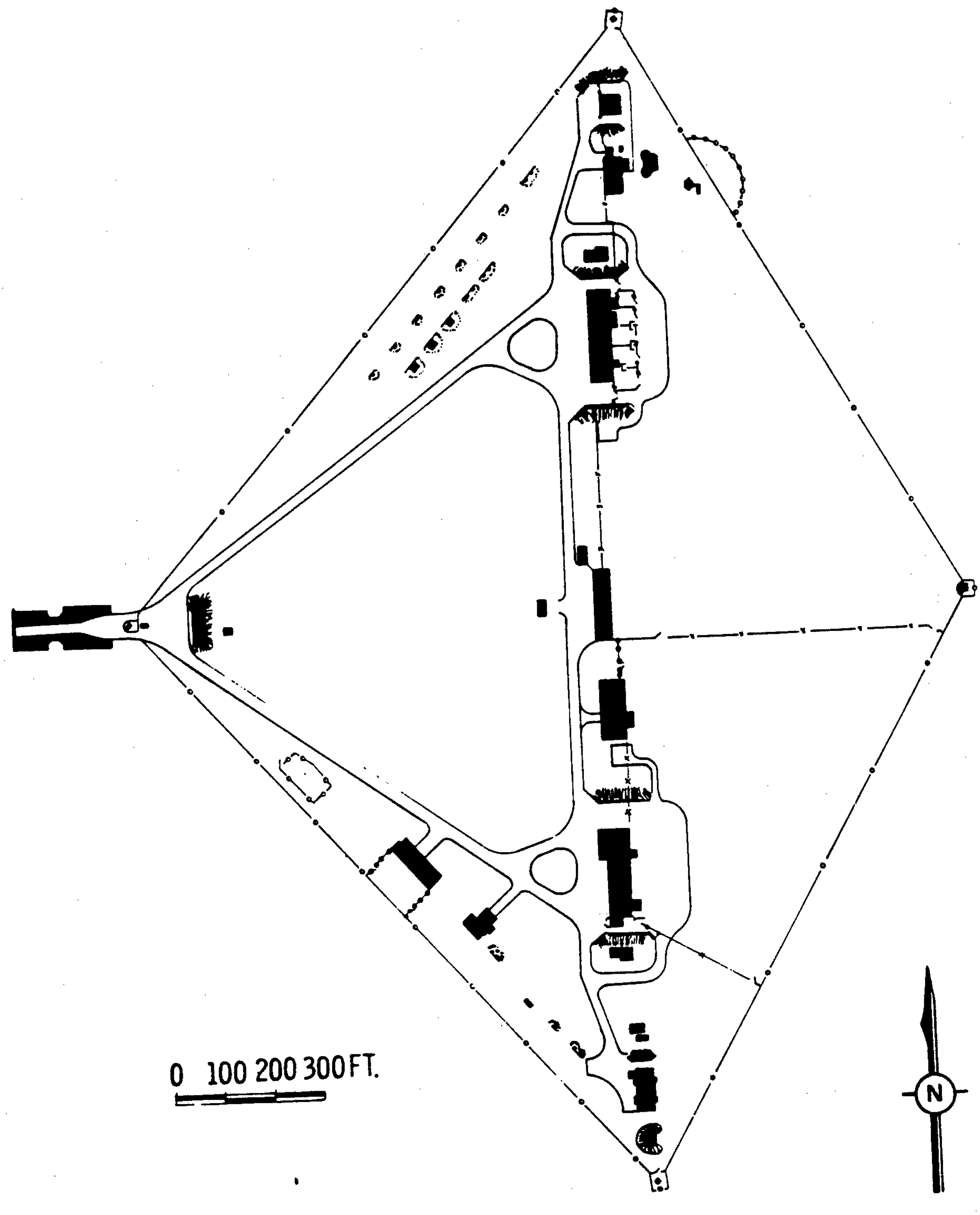

Figure 10. Technical Area II facilities

The structures in Area II include a number of explosive and storage magazines and igloos; laboratories for systems analysis; and facilities for environmental, component and explosives testing, explosive applications, and explosive and component assembly.

Pressure Tests

A laboratory designed for proof-pressure-testing of equipment is located in this semi-isolated area. Activities in this facility have the potential for releasing shock waves, noise and missile fragments to the atmosphere, but the hazard would not extend beyond Area II. The energy stored in these tanks would be no larger than that involved in explosive tests.

Area III

Area III comprises about 1900 acres located 5 miles south of the main technical and administrative area of Sandia Laboratories (Figure 11). It was established to permit the operation of test facilities which produce hazards during normal operations (such as the rocket sled track) and test facilities which subject weapons systems containing high explosives or fissile materials (such as ^{233}U, ^{235}U, and plutonium) to simulated natural and induced environmental conditions. Administrative controls prevent the simultaneous location in any one building of a weapon mockup containing fissile material and pound amounts of high explosives whether the high explosive is in the weapon mockup or not.

Table II summarizes the major facilities and minor structures within Area III, and, when relevant, those normal operational characteristics which could produce some effect on the environment. Potentially adverse effects of particular facilities are discussed below in more detail.

TABLE II

Facilities in Technical Area III

Test facilities: 20

Support structures: 33

Square feet available: 126,000

The following operations produce minor environmental effects which are not likely to present hazards beyond the boundaries of Area III:

Centrifuge: Pulsating low-level noise

Radiant Heat Testing: Occasional smoke and fumes from burning of small quantities of rubber, plastics, paint, etc.

Reentry Burn-up Simulation (Arc Tunnel): High noise level from steam ejectors, smoke and fumes from boiler combustion process, and nitric acid during test runs.

Water Tunnel: Release of high-pressure water and air.

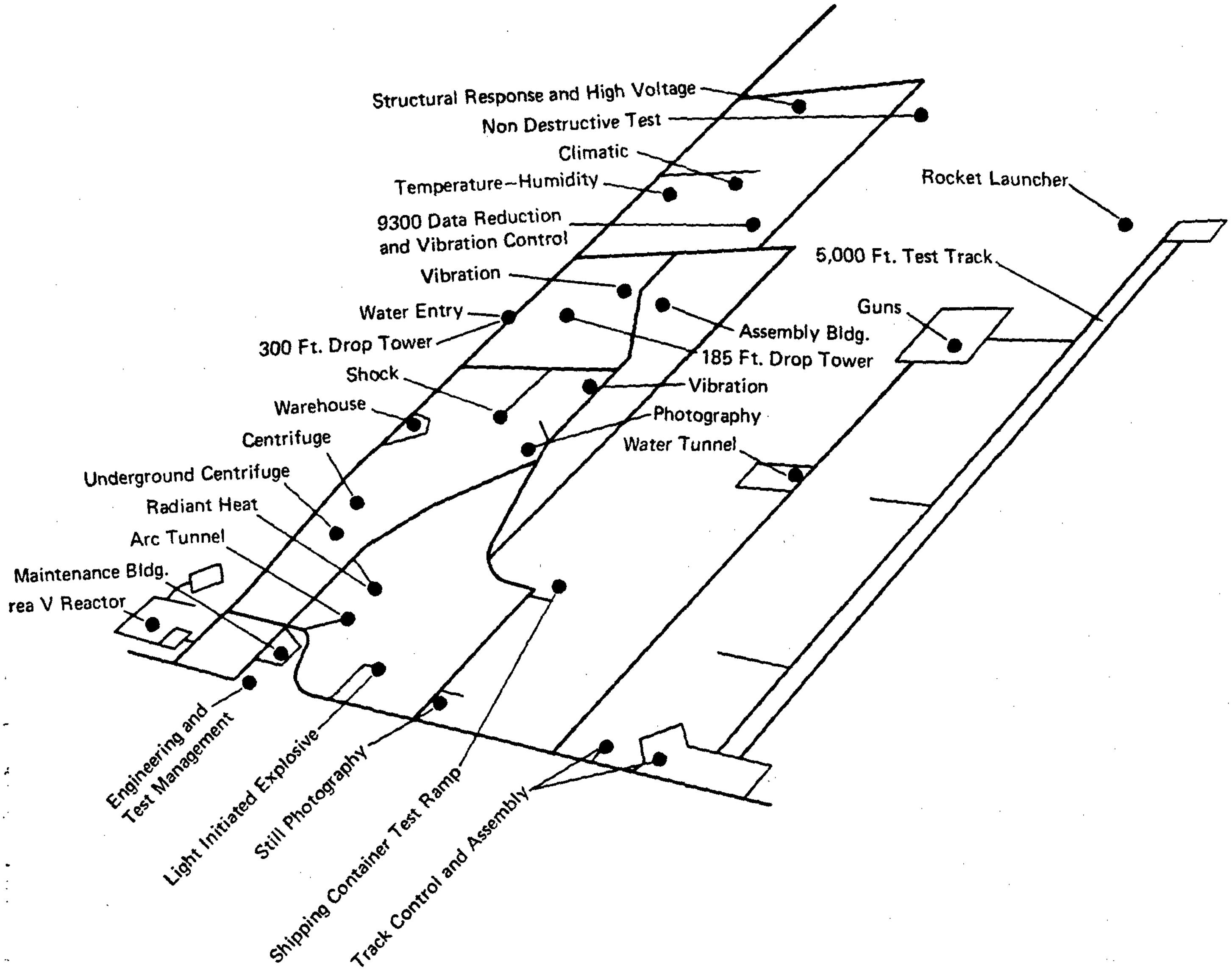

Figure 11. Technical Area III facilities

Rocket Sled Track

The potential hazards associated with the Test Track operation are shrapnel, overpressure, noise, missile hazard from a controlled or uncontrolled test unit, toxic discharges and fire. Buffer zones have been established on the west and south sides of Kirtland Air Force Base (East) (Figure 2), both for the protection of the general public and to prevent encroachment of enterprises that could jeopardize or reduce the effectiveness of environmental simulation activities in and adjacent to Area III, with particular reference to the test track. There is a joint-use agreement with the Isleta Indians for an area 3-1/2 miles EW by 3 miles NS adjacent to the south boundary of the Military Reservation. This easement, initiated November 1, 1968, is for 10 years. The second buffer area (1 mile EW by 4-1/2 miles NS) is located immediately adjacent to the west boundary of the Military Reservation. An easement for this area, issued by the State of New Mexico, extends to September 1978, and will be renewed at that time.

Continuation of these buffer zone agreements should insure that no environmental affects in the form of fragments would be produced outside of Area III and the buffer zones as a result of tests on the Test Track. The Joint Firing Area Coordinating Committee procedures (AFSWC Regulation 55-12, dated June 14, 1974) require notification of SLA's Coyote Test Field Division which in turn notifies the base Operations and Training Division in advance of any test that will involve "... missiles, excessive overpressures (1/4-pound per square inch (PSI) or greater) or other undesirable effects beyond an altitude of 300 feet above the terrain...". In addition, various requirements on visibility, communications during a test, atmospheric evaluations prior to a test, etc., are called out in the procedures. (See Appendix A for the complete agreement.)

The potentials for environmental impact or for hazards to persons outside the Area III boundaries, with respect to controlled and uncontrolled test units, toxic discharges and fire are discussed in the Accident Analysis section of Chapter III.

Area V

General

The Area V complex is located in the southern portion of Kirtland Air Force Base East, in the northeast corner of Area III (Figure 12). Twelve structures totalling 71,000 square feet house major facilities.

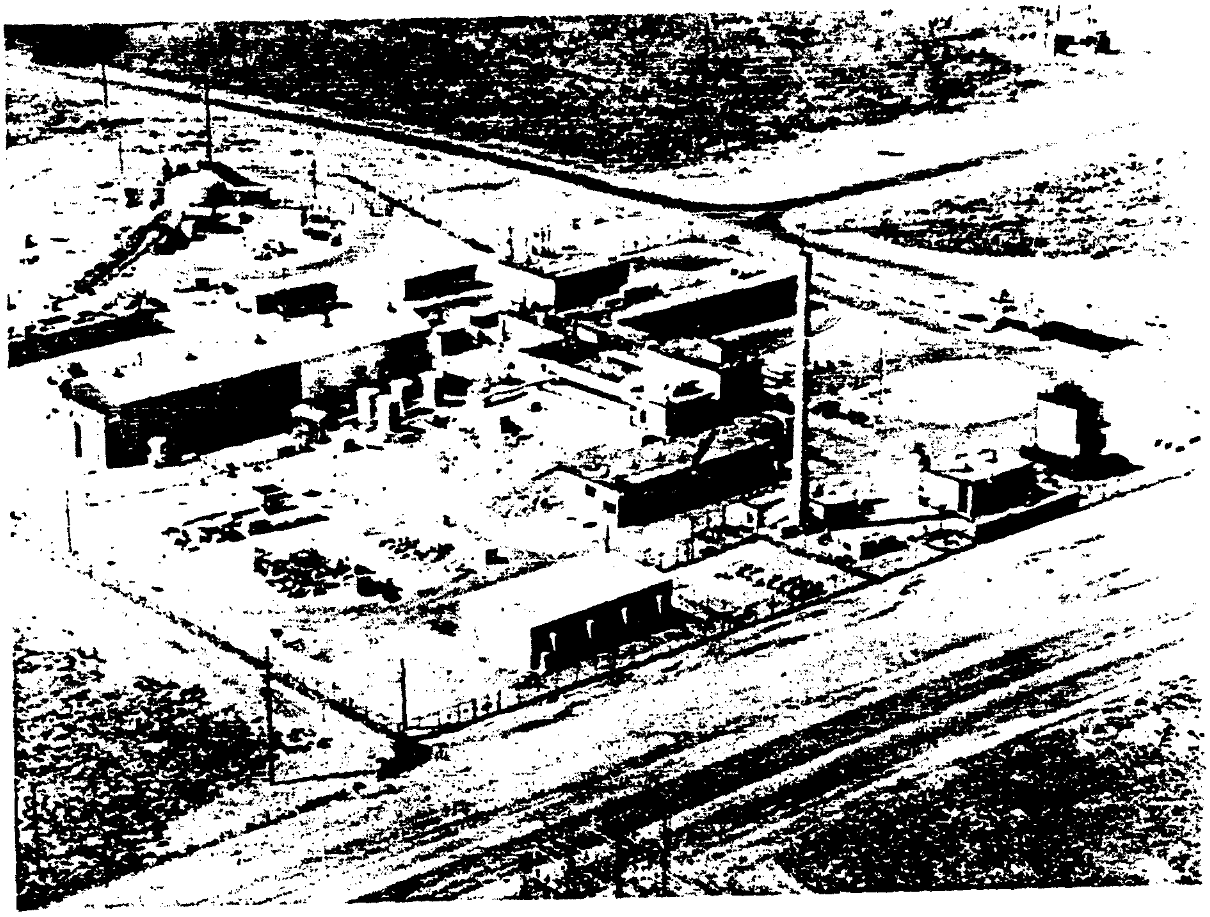

Figure 12. Technical Area V facilities

Activities within the area are associated with experimental and research programs conducted in two major fields: nuclear energy and high energy particle acceleration. Principal facilities include:

Reactors --

Annular Core Pulse Reactor (ACPR)
Sandia Pulsed Reactor II (SPR II)
Sandia Pulsed Reactor III (SPR III)

Electron Beam Generators --

Hermes II
Relativistic Electron Beam Accelerator (REBA)
Hydra
Febetron
Pelletron Electron Accelerator
Heavy Ion Accelerator
Marx Generators

These facilities are briefly described below; potential hazards are discussed in the Accident Analysis section of Chapter III. Safeguards for the protection of materials at SLA are discussed in Appendix G.

Reactors

Annular Core Pulse Reactor (ACPR) -- The ACPR is a TRIGA-type reactor using cylindrical uranium-zirconium hydride ($H\text{-}ZrH_{1.625}$) fuel-moderator elements arranged in a triangular lattice forming a hexagonal grid pattern. The ACPR is authorized for pulsing up to 1000°C and for steady-state operation at power levels up to 300 KW (thermal).

The core is situated in an open pool 10 feet in diameter and 28 feet deep and is supported 3 feet from the tank bottom by the core support shroud. Two 16-inch I. D. flanges are diametrically mounted in the core support structure to permit in-flow of coolant to the core bottom. The reactor core shroud encloses and isolates the core from the surrounding pool water forcing all convective coolant flow to enter the reactor core through the 16-inch I. D. flanges.

Normal core loading consists of 140-150 fuel-moderator elements, 6 fuel-followed control rods, and 3 transient rods. Each fuel-moderator body is 1.4 inches (3.5 cm) in diameter by 15 inches (38 cm) long and sealed in a 0.2 inch (0.5 cm) thick stainless steel cladding. Dimples fabricated into the cladding act as spacers to ensure a thermal insulation gap of about 0.016 inch (0.4 mm) between the fuel-moderator material and cladding. End reflectors and fittings added to the body extend the overall length of the fuel-moderator elements to about 29 inches (73 cm). Close packing of the fuel-moderator element in an equilateral-triangular array produces a spacing of 0.17 inch (4.4 mm) between elements and a corresponding flow cross-sectional area of 0.6 square inch per fuel-moderator element. Cross-sectional area of each fuel-moderator element is 1.7 square inches (11 cm^2).

In all modes of operation, core cooling is achieved by natural convective flow. There are no installed facilities for forced flow through the core. A bulk coolant system is installed which extracts coolant about 4 feet (1.2 meters) from the reactor tank top, passes the coolant through a cooled heat exchanger, and returns the coolant to the reactor tank through a set of diffusion nozzles adjusted to direct the stream over the top of the core. This system can reject approximately 300 kW (thermal).

Sandia Pulsed Reactor (SPR) Facility — The SPR consists of two reactors referred to as SPR II and SPR III. These are air- or forced-nitrogen colled, bare, unmoderated assemblies of solid uranium metal, enriched to 90 percent ^{235}U with 10 weight percent of molybdenum for phase stabilization. They are designed for and usually used in pulsed operation, although the SPR II can be used for steady-state operation up to 3 kW thermal for 15 hours, and SPR III up to 15 kW. They provide neutron fluences in an inner cavity of 6×10^{14} neutrons per cm^2, or peak neutron flux rates of 1.1×10^{19} neutrons per cm^2 per second with pulse widths at half power of 50 microseconds. Such pulse operation involves temperature rises of 300 to 450°C.

The 234-pound (106-kg) core of SPR II consists of six stacked fuel rings mechanically fastened into two groups of three rings each. The 569-pound (258-kg) core of SPR III consists of eighteen stacked fuel rings, fastened into two groups of nine rings each. In each case, the upper group is held stationary to the core support structure, and the lower group ("safety block") is mechanically fastened together with high-strength bolts. The lower "safety blocks" are attached to electromechanical drive mechanisms. Control devices include three control elements and one burst element in each reactor.

Control element drives are standard electromechanical assemblies, with power to the rack and pinion drive transferred through an electrical clutch (armature) which disengages upon a loss of power. The burst element is pneumatically driven to achieve the high rates of reactivity insertion required. The safety block, normally either fully inserted or withdrawn, is not used for fine control. Rather, the control elements are used to establish a critical configuration of the core.

The SPR II reactor can be shut down by any one of four independent instrumentation channels which initiate shutdown signals to the actuating devices for the control rods, burst rod, and safety block. The SPR III reactor can be shut down by signals to the actuating devices for the control elements and safety block. These channels are designed, constructed, and tested to assure compliance with IEEE-279, "Criteria for Protection Systems for Nuclear Power Generating Stations."

Two inherent reactor characteristics, in addition to the strong negative temperature coefficient, act to place the reactor in a subcritical configuration: (1) the mechanical shock forces induced by the burst (which cause the safety block to break away from the holding armature and free-fall to a full-out position) and (2) the thermal expansion of the fuel as a result of temperature rise (which also can cause the safety block to break away from the holding armature). During normal burst operations, a preprogrammed sequence of operations that does not require human intervention initiates a shutdown signal which results in the release of the safety blocks; however, the inherent electromechanical delay times in this action are such that the actual disassembly occurs after the pulse peak has been achieved.

The primary shutdown mechanism is the inherent negative temperature coefficient of reactivity. Following the reactivity insertion, the fuel heats up rapidly. Simultaneously, the negative temperature coefficient of reactivity reduces the reactivity of the system and terminates the pulse. The pulse size can be determined very accurately by preselecting the total reactivity of the assembled core.

Electron Beam Generators

The electron beam generators operated at Area V have the general characteristics of Marx-type generators coupled to target anodes with suitable transmission lines. These machines develop high voltage pulses which are converted into pulses of electrons emitted from the target material with relative high energy over a very short time. Radiation is normally characterized by beta emissions. Shielding in place around the machines has reduced the radiation levels outside the buildings as discussed further in Chapter III.

Hermes II — This generator can be operated either in the electron-beam mode or the flash X-ray mode. The output voltage is in the range of 6-12 MV. The machine was built by Sandia and consists of a Marx generator and Blumlein transmission line which serve as the pulse power supply for a cold-cathode electron accelerator tube. Within the tube, a titanium anode serves as a window to pass electrons into a drift chamber for electron-beam experiments. X-ray mode operation is achieved by replacing the titanium anode by a tantalum anode which serves as a bremsstrahlung converter. The X-ray mode has been used almost exclusively; however, some electron beam mapping was accomplished prior to X-ray output enhancement studies.

Relativistic Electron Beam Accelerator (REBA) — This generator can be operated in either the electron-beam or the flash X-ray mode. The output voltage is in the range of 1 to 4 MV. The machine was built by Sandia Laboratories and is of the Marx generator/Blumlein transmission line/cold-cathode electron-accelerator-tube type. The unusual feature of REBA is that two Blumlein transmission lines and electron tubes operate from a single Marx generator so as to gain more utility from the Marx generator (a major cost item in systems of this type). Within the electron tube a titanium anode serves as a window to pass electrons into a drift chamber for electron-beam experiments. X-ray mode operation is achieved by replacing the titanium anode with a tantalum anode which serves as a bremsstrahlung converter.

Hydra Electron Beam Generator -- Basically a Marx generator, the Hydra is submerged in an oil bath (standard type transformer oil). The Marx generator charges a coaxial pulse forming (PF) transmission line which is deionized-water-insulated to 3 MV in 0.9 microsecond. At peak voltage, a 3 MV SF_6 spark gap electrically connects the 4 ohm PF line to the impedance transforming transmission line. The pulse is transmitted through this line to the single radial insulator diode. An intense electron beam is formed by a cold cathode in each diode.

Febetron -- The Febetron 705 is a pulsed electron source (2 MeV) using a high-power Marx-surge pulser and high-vacuum electron tube to produce very intense, short-duration electron beams. The electron beam tubes employed in the 705 use a cold-cathode electron source to produce a high density electron beam which is accelerated through a thin window of low density material. Operation is in either electron mode or X-ray mode. Electron beam confinement is obtained with a magnetic field and regulated at the control console.

Pelletron Electron Accelerator -- This machine is a steady-state (D. C.) accelerator which provides monoenergetic electrons of well-defined energy, variable from 50 to 1100 keV. It has an electrostatic charging system in which the charges are transported to the high-voltage terminal by a chain having alternate links of nylon and stainless steel, rather than by a conventional broad insulator belt. The machine is the basic tool in a research program which provides electron and photon transport data. Typically, experiments are conducted to determine energy deposition profiles for electrons in various materials and bremsstrahlung dose to various metals. The objectives of this program are to provide (1) high-precision data for code verification and (2) specific data which are needed for experiments on the pulsed machines such as Hydra and REBA.

Heavy Ion Accelerator -- This accelerator, which uses an electronically regulated high voltage supply, provides a monoenergetic ion beam in the energy range from 10 to 100 keV. Ion sources of several different designs are available, so that ion beams of most of the elements can be obtained. The machine has been used in studies of atomic and molecular physics. Measurements have been made of cross sections for photon emission and charge transfer resulting from ion-molecule collisions. It is also used to calibrate the calorimeters used in the electron and photon transport program.

Marx Generators -- This category of electron beam generators consists of six pieces of equipment used primarily for experimental research and development. As such, the equipment is constantly being changed and does not remain in a fixed configuration. The main components are a Marx generator, an oil bath, coupling transmission lines, and a target electrode (gas, or diode). (A Marx generator is a machine which produces high voltage discharges by charging capacitors in parallel and discharging them in series.)

Coyote Test Field

Coyote Test Field is located in the southeast corner of Kirtland Air Force Base, and derives its name from Arroyo del Coyote which traverses the test field. The western part of the test field is on base property where the terrain is that of a high plain. The eastern part is located in mountanous terrain that has been withdrawn from the U. S. Forest Service.

The test field provides an area close to SLA for fielding large hazardous experiments, usually involving the detonation of large quantities of chemical explosives. Explosively driven blast, shock and impact simulations are conducted on weapon systems at facilities throughout the test field. Experiments to determine explosive yield and/or effects are conducted at specified firing sites. Rocket-powered flight simulations and air-to-ground weapon evaluations are performed on or from aerial cables spanning the mountain canyons.

The locations of the various Coyote Test Field (CTF) facilities are indicated on the map of Figure 13. Table III lists the CTF facilities and maximum amount of explosives that may be detonated at each site, maximum hazard radius, and frequency of use of that facility. The maximum hazard altitude permitted for missiles generated by a test at any of the facilities is 10,000 feet above the terrain east of 106^{o} 31' west longitude and 4000 feet above the terrain west of that line. This limitation was designed to protect aircraft approaching or leaving east of the Albuquerque International Airport.

Shock Tubes

Explosively driven shock tubes ranging in size from 4 inches to 19 feet in diameter and lengths of 20 to 300 feet are used to subject various test items to blast environments. Most of the shock tubes are located where indicated in Figure 14.

Explosives are loaded at the breech end of the tube and the test item is placed at the muzzle end. Ignition of the explosive generates a blast wave that travels down the tube and subjects the test item to the increased pressure, temperature and density associated with the blast wave. The test item is usually thrown from the shock tube and recovered in a sawdust impact area. The breech end of the shock tube is usually heavily tamped in order to direct most of the explosive energy down the tube and also to minimize the missile hazard. The shock tubes are also used with test gases other than air, including sulfur hexafluoride, carbon dioxide, and helium. Figure 15 shows the largest of the explosively driven shock tubes in CTF during a blast test. In this photograph, the shock front can be seen after it has emerged from the end of the tube.

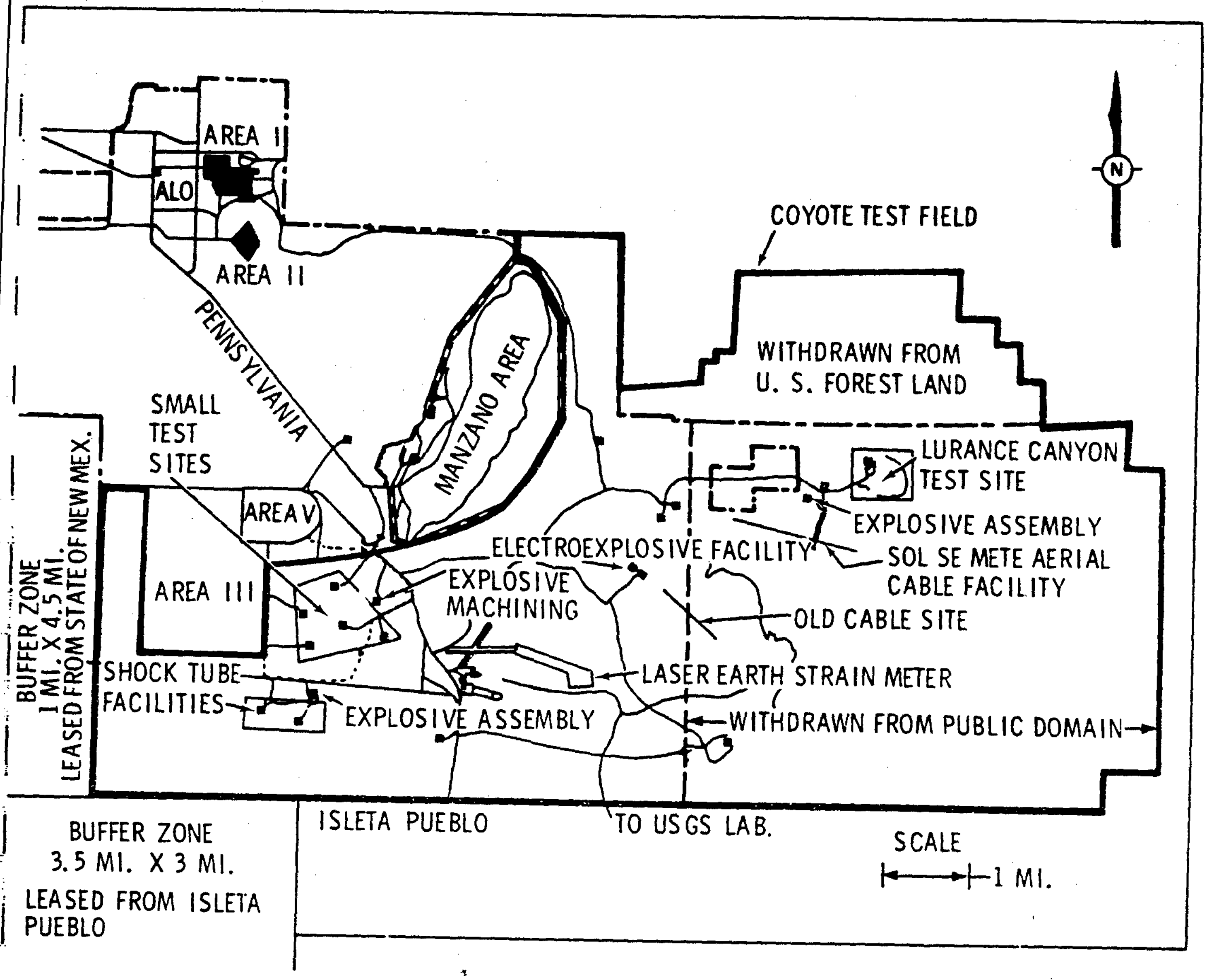

Figure 13. Coyote Test Field facilities

TABLE III

Data for Coyote Test Field Facilities

FACILITY	EXPLOSIVE LIMIT (W) (LB)	FRAGMENT HAZARD RADIUS (R)* (FT)	TESTS PER YEAR
SHOCK TUBES			
4-in. Dia.	0.32	410	60
2 x 200 Ft.	150	3,190	10
6 x 200 Ft.	381	4,350	5
6 x 50 Ft.	70.0	5,325	1
19 Ft. Dia.	381	4,350	7
AERIAL CABLES			
2700 Ft. Span	10,000	12,925	45
4800 Ft. Span	10,000	12,925	37
LURANCE CANYON TEST SITE	10,500	13,140	41
SMALL EXPLOSIVE SITES	50	2,210	100
ELECTROEXPLOSIVE	400	4,420	75
STORAGE IGLOOS	90,000**	26,890	--
EXPLOSIVE MACHINING	350	4,230	--
EXPLOSIVE ASSEMBLY	4,000	9,525	--

Missile hazard radius is greater than the overpressure hazard radius for most tests.

*According to $R = 600\ W^{1/3}$ (Explosive Ordnance Reconnaissance and Disposal, Department of the Army, FM9-40, March 1953)

**Larger amounts of explosives can be stored for SLA by the military on KAFB.

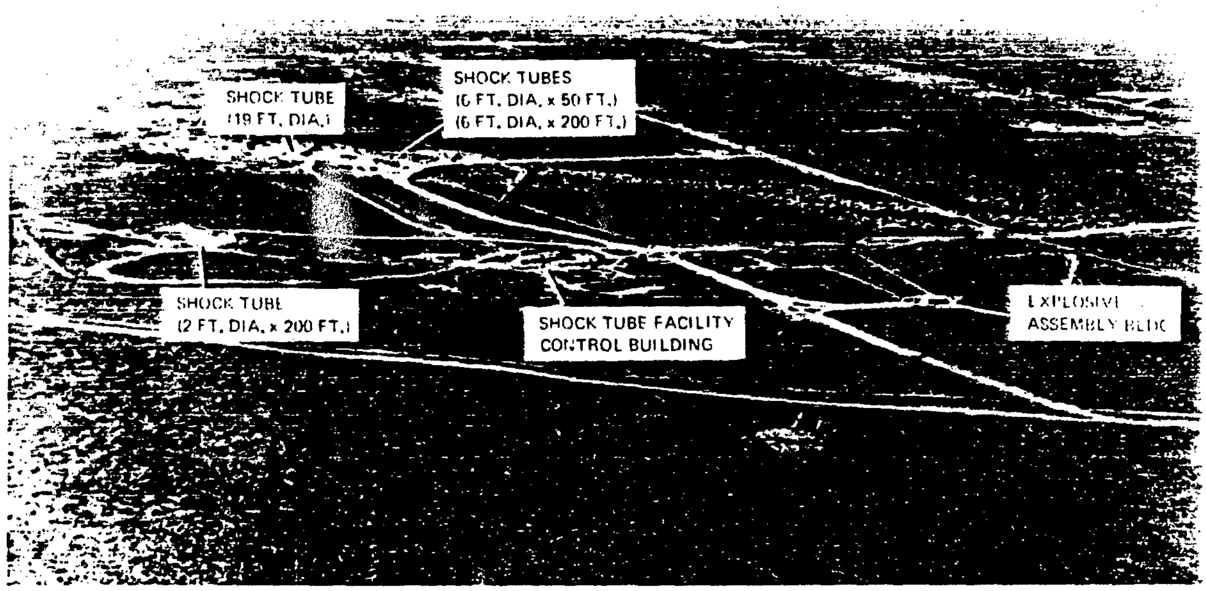

Figure 14. Explosively driven shock tube facilities

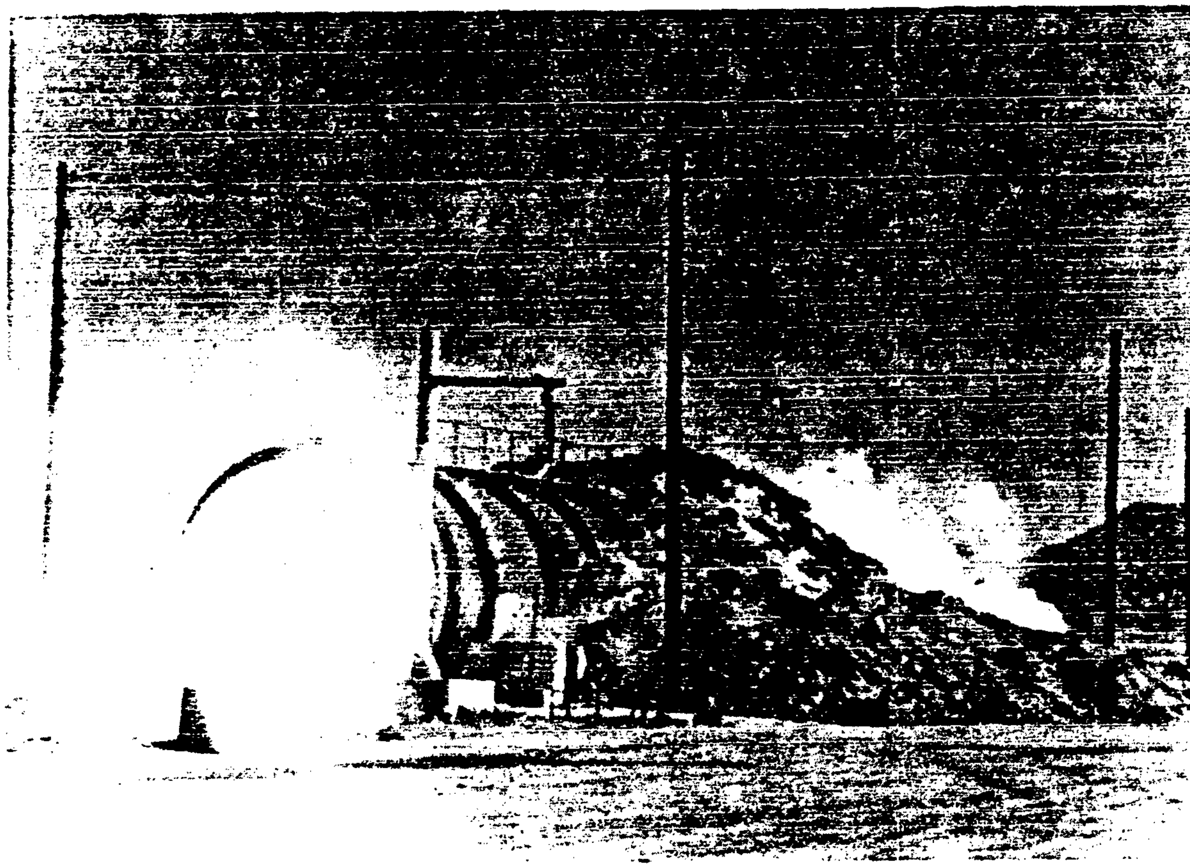

Figure 15. Largest shock tube (19-feet diameter)

Aerial Cable Facilities

The facility in Sol se Mete Canyon provides a means of duplicating many air-to-ground impacts under controlled, well-instrumented conditions. As shown in Figures 16 and 17 it consists of a cable, stretched between two mountains, which supports a launch platform from which test vehicles can be pulled down toward targets on the valley floor. Figure 17 illustrates the terrain around this facility. Pull-down force is generated by a rocket sled about 200 feet away from the target area. The pull-down force is transmitted to the test vehicle via wire rope towing lines as illustrated in Figure 16. The towing lines can be separated from the test vehicle at a suitable time or position above target, leaving the vehicle completely free of extraneous hardware when it strikes.

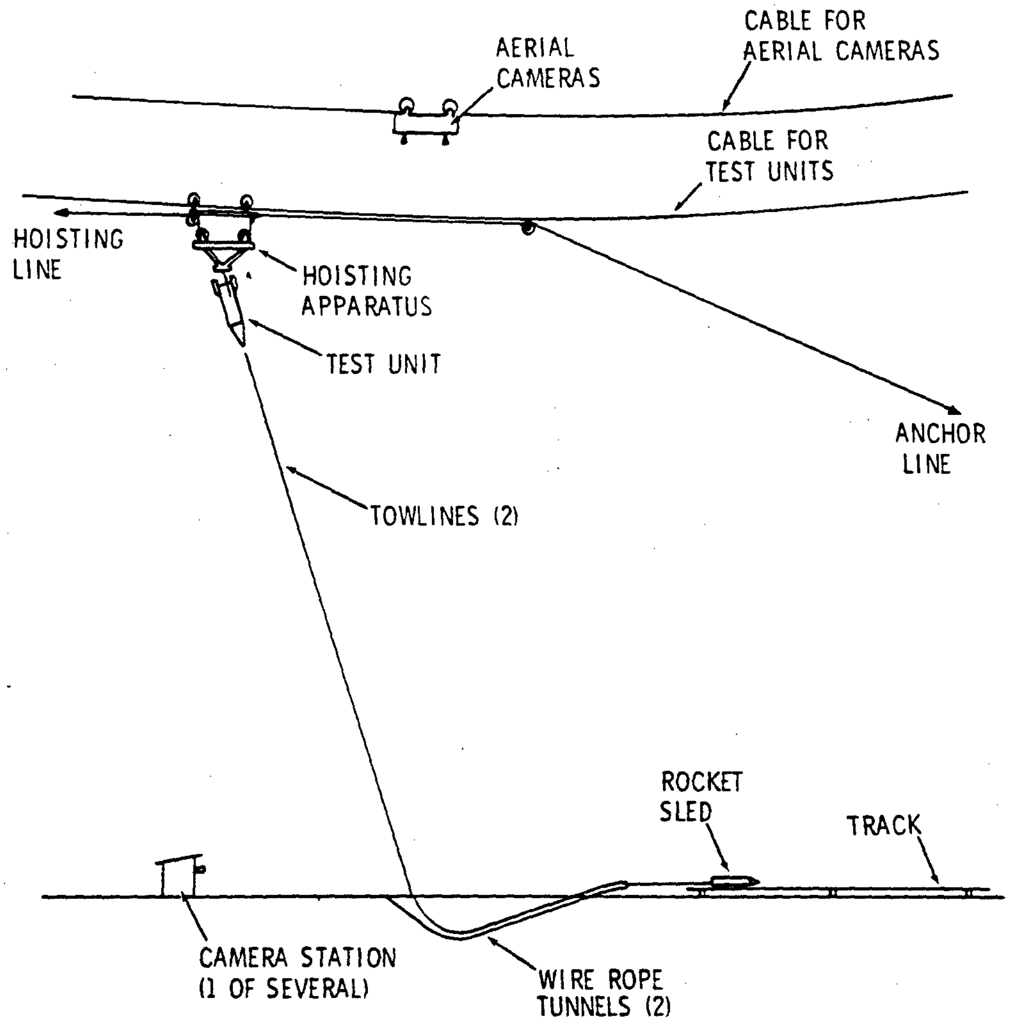

Figure 16. Typical aerial cable test arrangement, Sol se Mete Canyon

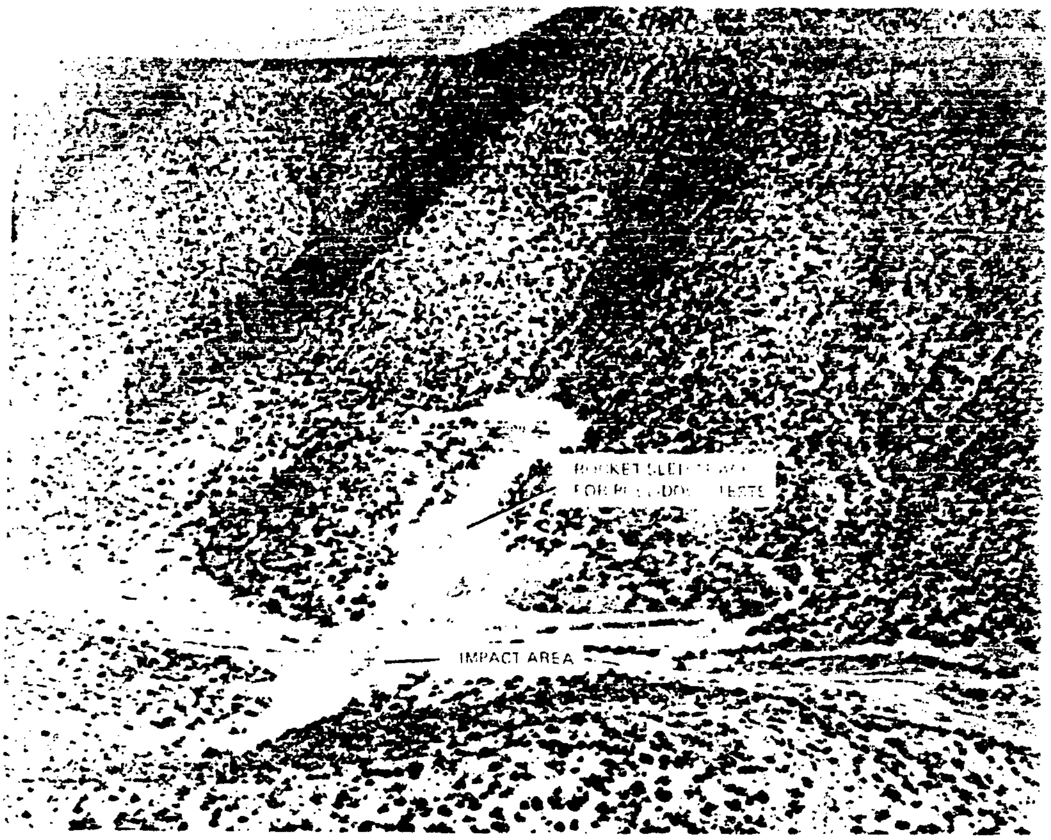

Figure 17. Terrain around Sol se Mete aerial cable pull-down facility

The height of the aerial cable can be varied from zero to a maximum of 600 feet and the launch platform can be moved along the cable, so that a great variety of flight trajectories can be programmed.

The Sol se Mete aerial cable test facility is in a remote area and tests involving up to 10,000 pounds of explosives can be conducted. Data recovery from the test vehicle is possible through a hardwire link trailed behind the vehicle during its flight or from onboard telemetry. Ground instrumentation typically consists of impact sensors, pressure transducers, and high-speed photometrics.

The Old Cable Site is shown in Figure 18; it is similar to Sol se Mete facility, except that the maximum drop height is 250 feet.

Lurance Canyon Test Site

Lurance Canyon Test Site, shown in Figure 19, is a remote facility for conducting experiments involving up to 10,500 pounds of explosives, with a 13,140-foot fragment hazard radius. A variety of tests is conducted here primarily because it is one of the few test sites on Kirtland Air Force Base East where large amounts of cased explosives can be detonated safely.

The facilities available at the Lurance Canyon Site are two underground trailer bunkers, a photographic bunker, and the necessary communications cabling (underground) to interconnect the facility.

Small Explosive Test Sites

A number of small explosive test sites are used to conduct a variety of tests which involve up to 50 pounds of explosives.

Electroexplosive Facility

This facility may be used to simulate, by magnetic means, radiation-induced impulses on structures. Explosive-powered generators can provide up to 6 megajoules of magnetic energy for this purpose. Either direct magnetic pressure or flyer-plate techniques may be employed.

Capacitor banks also available at this site are, first, a 648-kJ, 20-kV bank which is divided into three modules (usable in any combination) and second, a Maxwell 110-kJ, 40-kJ bank located in the basement. The latter is connected through parallel plates to the experiment area located in an upstairs room.

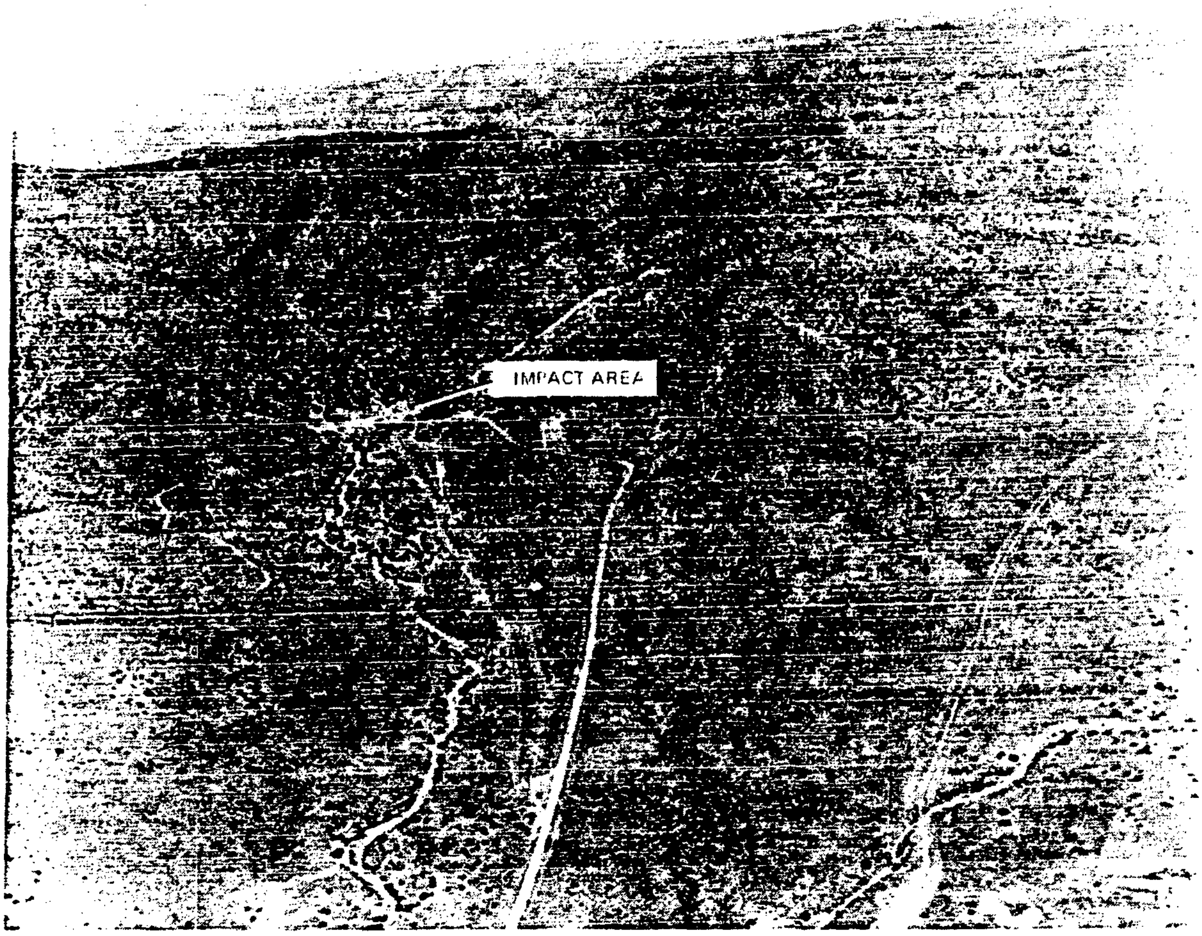

Figure 18. Old aerial cable site

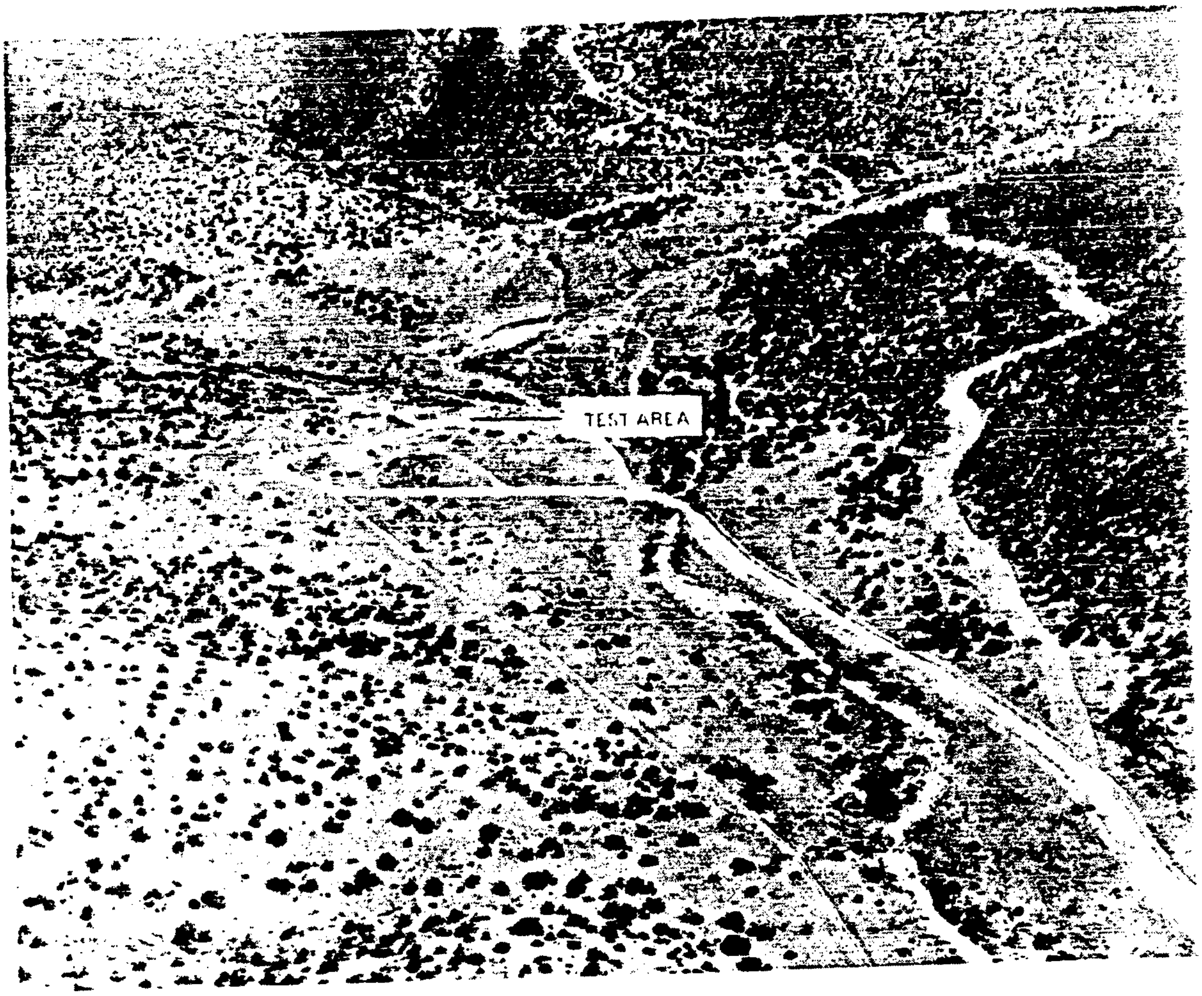

Figure 19. Lurance Canyon large-explosive test site

This facility has a maximum allowable explosive detonation limit of 200 pounds at 35 feet from the building or larger amounts at larger distances.

An 11.5 inch diameter recoilless propellant-driven gun is located 30 feet from this facility. A maximum of about 100 pounds of propellant can be fired in this gun to drive a 150-pound projectile out the muzzle end.

High Explosive Storage Igloos

A series of igloos is used to store high explosives and/or test units containing high explosives. The maximum amounts that can be stored at any of the locations in CTF or elsewhere are listed in Table III.

Two explosive assembly buildings are used to work explosives in test units in preparation for tests at all Coyote Test Field sites.

Laser Strain Seismometer

Sandia has constructed a long-span laser interferometry system to examine changes in the earth strain. The primary use of the instrument is detection and analysis of seismic waves from underground nuclear tests. The facility is located on the alluvial fan west of the Manzano Mountains and just north of the Pueblo border. Two vacuum pipes were installed to serve as interferometry arms; both are oriented along the great circle passing through the central part of the Nevada Test Site (N 72° W). The longer one has a span of about 5200 feet; the shorter is 500 feet long. Both pipes are above the ground (at heights varying between 1-5 feet) and are supported by adjustable stands at 20-foot intervals. The longer pipe is equipped with three spaced vacuum pump stations. A single pump is used on the short pipe. Measurements are taken at the east ends of the pipes where a common structure provides shelter for optical and electronic equipment. Individual structures were built at the other end of the pipes to protect equipment.

Edgewood Test Site

A set of activities at a place called the Edgewood Test Site (20 air miles east of SLA) may be considered part of SLA facilities and operations (Figure 20).

In 1968, SLA undertook a project for the Department of Defense for the design of remotely emplaceable counter-insurgency devices for use in the Viet Nam conflict. To test these a drop target was needed with a soft and/or marshy soil. Initial tests carried out in Texas, Florida, and near Bernardo, New Mexico proved expensive and operationally inconvenient, so a site was chosen east of the Sandia and Manzano Mountains, just northeast of Edgewood, New Mexico, to conduct tests that cannot be handled at the SLA facilities.

To hard rock areas

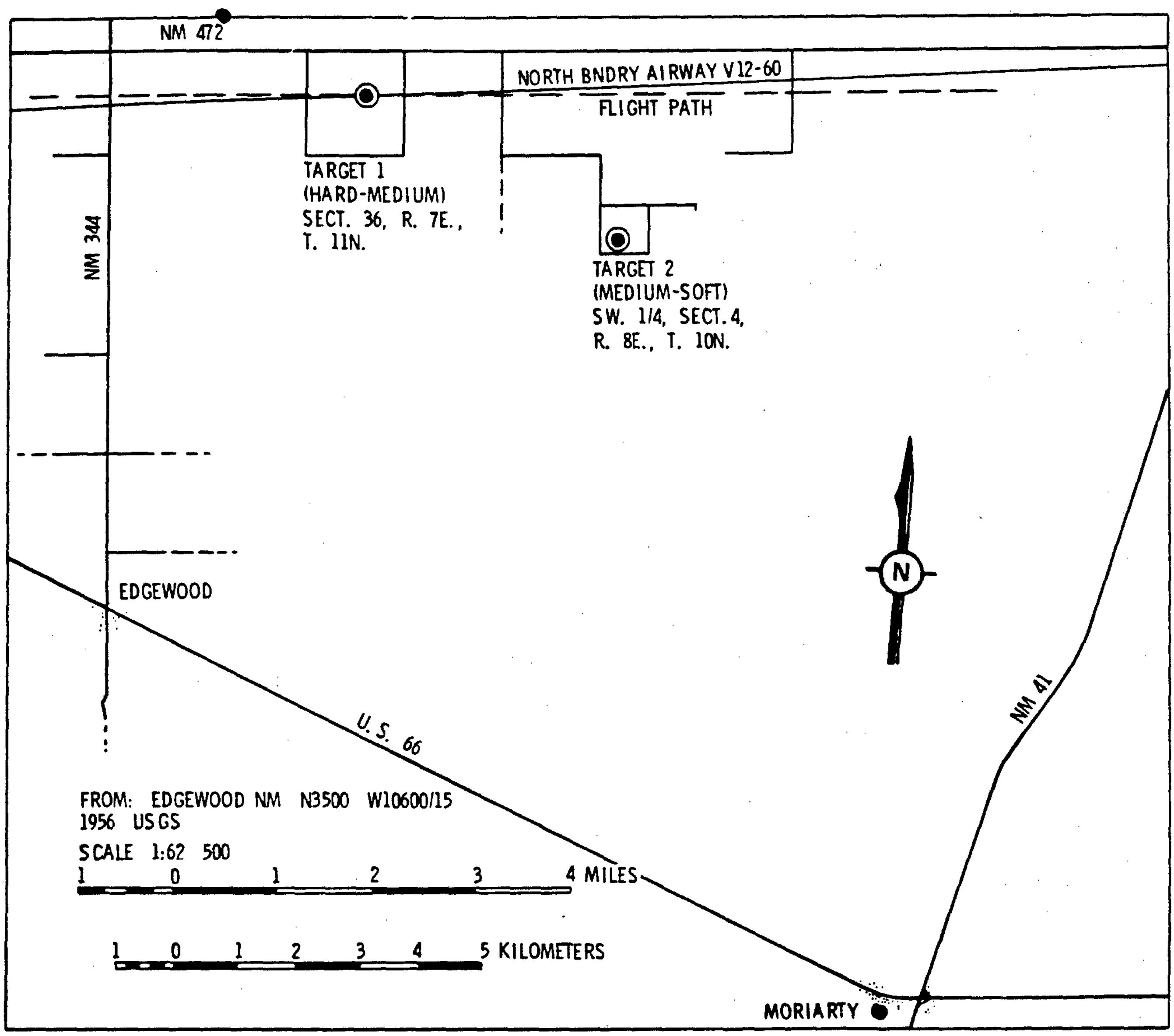

Figure 20. Edgewood test sites

The SLA leases, for nonexclusive use, four parcels of land from two ranchers: two sections of land (2 square miles) 6 miles northeast and north-northeast of Edgewood, and two smaller parcels 6 miles northwest of Edgewood. The two sections to the northeast offer as near-surface soil a fine, silty material with varying depths of overburden above caliche. The northwest parcels of land offer various kinds of surface rock, with zero to 40 feet of overburden. Cattle graze here on range grasses and small shrubs, even during SLA testing. All these sites are close to and in well-defined positions with respect to the Otto radio of the Albuquerque Air Traffic Control Center, so that they are easily locatable from the air. They lie near the major east-west airway into Albuquerque (V-12-60). Thus test-related aircraft are easily tracked and controlled by the FAA.

The only "permanent" facilities at the Edgewood sites are commercial electric power, telephones, two dragged strips for small aircraft, and a prepared soft target (a deeply plowed area of about an acre that can be thoroughly wetted). Typically, these sites are operated with mobile equipment brought from SLA as needed. The basic advantages of these sites are that they are only 40 minutes by car from SLA, that they can be operated part-time by crews not on travel status, and that they have a softer ground material (less gravel), medium limestone, a lower RF background, less seismic noise from traffic, and a freer air-space than can be found on Kirtland AFB itself.

Present tests include about 25 airdrops a year of inert shapes; 3-4 downward firings a year of a 12-inch gun (with a reaction mass of 500-1500 pounds thrown upwards several thousand feet); 4-12 downward firings a year of an 8-inch gun (without a reaction mass); and some drops which test parachute configurations. At one time in the past there were a number of mortar tests (as many as 200 in three weeks, firing as high as 7000 feet above the ground) but there are no more of these in prospect. No toxic or radioactive materials are used in these tests. In general, the rate of testing at the Edgewood sites is irregular and sporadic, and it is difficult to forecast what the future use of the sites will be, except that there is no indication of decrease.

Other tests at these sites do not involve free-flying objects; these include aircraft fly-overs to determine acoustic signatures, radar tests of terrain returns, radio-frequency and infrared tests of various sorts, and recently (related to the nation's energy problems) investigation of new drilling techniques.

The amount and proportion of the time the Edgewood sites are used is variable, depending on demands that others within SLA put on the test organization. Since the beginning of 1974, one or another of these sites has been used for well over half the working days.

FUTURE FACILITIES

Use of FY 1976 Funds

Area V

Modifications to a Basement -- This project will provide modifications to the air conditioning and exhaust system, additional shielding, and provision for improved remote handling facilities in existing hot cells. Construction will be noncombustible and will provide those measures needed to prevent the release of radioactive or toxic materials.

Because this project is entirely internal modifications to an existing building, construction will not result in additional environmental impact. In normal operation there will be no more effluents from operations than there are now; in case of accident effluents will be reduced because of better filtering.

Performance Improvement of the Annular Core Pulse Reactor -- This project will enhance the capability of the ACPR for reactor safety research by installation of a new core, control system, and forced flow cooling. Post accident conditions and containment assessments will be researched. Since this is a modification to an existing facility, there will be no environmental impact from construction or operation.

Coyote Test Field

Five Megawatt Solar Thermal Test Facility -- This facility consists of a field of approximately 262 mirrors which will reflect solar energy into a "Central Receiver" mounted on a tower.

The facility is being constructed on land which was sparsely covered with arid, high meas type grasses. The areas disturbed by construction will be paved, adequate drainage will be provided, and effluents will be discharged through a disposal system designed to comply with current State of New Mexico requirements. The impact upon the environment from this project will be minimal.

Use of FY 1977 Funds

Areas I and II

Nuclear Safeguards Security Laboratory -- This project consists of a high bay heavy laboratory building for the development and modification of "safe/secure" highway vehicles, transportation containers, and rail-cars. An office/light laboratory building will house approximately 275 people engaged in the Safeguards Security Programs.

Construction will be in an area already denuded of original vegetation. Liquid effluents will be discharged into the Kirtland Air Force Base sanitary sewer system. There will be very little impact upon the environment.

New Cafeteria -- Construction will be in an area denuded of vegetation, liquid effluents will be discharged into the Kirtland Air Force Base sewer system, and the present cafeteria will be closed. No significant environmental impact is expected.

Rock Mechanics Laboratory -- An existing building will be modified to permit the consolidation of rock mechanics activities in one facility. Since this is a modification to existing facilities, there will be no environmental impact from construction or operation.

Modification to Mezzanine -- Approximately 12,300 aquare feet of mezzanine will be modified to provide space for the consolidation of automated word processing activities in one central location. This is a modification of existing space so there will be no environmental impact from construction or operation.

New Warehouse -- A rigid-frame, prefabricated metal warehouse building is required for the storage of noncombustible material and equipment. The building will be constructed on land denuded of vegetation and effluents will be discharged into the Kirtland Air Force Base sewer system. No environmental impact is anticipated.

Electron Beam Fusion Facility -- This facility consists of a high bay accelerator building, an electron beam accelerator, and an office/light laboratory building. The facility is being constructed on land sparsely covered with arid, high mesa type grasses. The access road and parking areas will be paved and adequate storm drainage will be provided. The accelerator will be shielded to prevent radiation leakage and a collection basin and berms will collect insulating oil in the event of an accidental spill. Sanitary wastes will be discharged into the City of Albuquerque sewer system.

Area V

Diode Assembly Addition -- A high bay addition to the electron beam accelerator facility will be added for storage and assembly of diodes. Restroom facilities will also be added. The addition will be constructed on land denuded of vegetation and effluents will be discharged into a disposal system designed to comply with current State of New Mexico requirements. No environmental impact is expected.

Use of FY 1978 Funds

Area 1

Modifications to Building 868 -- Building 868 will be modified to provide for better utilization of space. All work will be inside and no change will be made in the occupancy of the building so no environmental impact is expected.

Surface Physics Research Laboratory -- This project will provide environmentally controlled space for consolidation of surface physics activities by modification of an existing building. Since these are modifications in an existing building, there will be no environmental impact from construction or operation.

Addition to EMR/EMP Facility -- An addition of approximately 2,000 square feet will be added to the electromatic radiation (EMR) and pulse (EMP) facility to alleviate overcrowding. This facility will not produce external radiation or other effluents. There is no vegetation in the construction area and no impact on the environment is anticipated.

Area V

Safeguards for Special Nuclear Material -- This project will upgrade physical security of SNM in Area V. Included are a new command and control center, a new SNM storage vault, fences and barricades, perimeter and space intrusion systems, and access control portals.

Part of the construction area is sparsely covered by arid, high mesa type grasses. Effluents from the command and control center will be discharged into the Area V disposal system which is designed to conform with current State of New Mexico standards. Any impact on the environment will be minimal.

Dangerous or Toxic Materials

Sandia Laboratories as a large ordnance research and development laboratory utilizes a wide variety of chemical compounds, radionuclides, carcinogens, and explosive materials. All these materials are used so that both occupational and environmental exposures conform to nationally accepted standards. Some specific items that are used or are present in sufficient amounts to warrant further discussion in the following portions of this Assessment are:

- Chemical:
  Beryllium, ammonia.
- Carcinogens:
  MOCA.
  Radioactive materials:
  Plutonium, tritium, uranium (depleted and ^{235}U), and reactor fission products.
- Explosive materials:
  Liquid and solid compounds.
- Flammable gases
  Methane, hydrogen, natural gas.

By way of background, some description of the above materials is given below:

Beryllium -- Beryllium is a toxic element presenting two potential hazards to health. If inhaled over an extended time, beryllium may lessen the efficiency of an individual's lungs and in severe cases can be fatal. If beryllium enters a break in the skin, a slowly healing ulcer may form until the beryllium is surgically removed.

Ammonia -- Ammonia in high concentrations is an irritating and corrosive compound that may damage the eyes, mucous membranes and skin, and on inhalation inhibit respiration. Upon removal from an ammonia atmosphere, an exposed individual usually recovers in a few days although in an extreme case eye damage may be permanent. Severe lung exposures, however, can be fatal.

Carcinogens -- Carcinogens, substances or agents capable of producing cancer, fall into three general categories: The first includes human carcinogens for which there are established threshold limit values (TLV); examples are asbestos and coal tar pitch volatiles. The second category consists of human carcinogens known to be so potent that no exposure or contact by any route is permitted; examples are benzidine and beta-naphthylamine. The third category includes industrial substances found to be of high potency in inducing tumors under experimental conditions in animals and hence of possible concern to humans; examples are 4,4'-methylene bis (2-chloroaniline), also known as MOCA, and beta-propiolactone.

Plutonium -- Plutonium is a radioactive, alpha-emitting element. Particles can enter the body through ingestion, inhalation or skin breaks. Once absorbed in the body, plutonium could cause ulcers at the site of entry and cancer to the bone, liver, or lung (although no case in humans is known). Potential health problems for the public are essentially those posed by the possible inhalation of particles in the oxide form.

Tritium -- Tritium, an isotope of hydrogen, emits a very low-energy beta particle with an average energy of 0.0057 MeV. It can be incorporated into any of the organic molecules found in the body of man, but ^3H (or T) is most commonly released as hydrogen gas or water. Tritiated water can be absorbed by the body by inhalation or ingestion, with a significant fraction absorbed through the skin from an atmosphere containing tritiated moisture. Tritium is not concentrated by biological mechanisms and the behavior of the water form in the environment is simply that of dilution by the various sources of water, either free or in the tissues of plants or animals. The maximum permissible body burden, for occupational exposure, is one millicurie (1,000 microcuries), and is based on a whole body radiation dose of 5 rems per year. The effects of tritium exposures are the same as for any other whole body radiation: at low levels, subclinical effects, being at most depression of white blood cell count; at intermediate levels, delayed production of various kinds of cancers, and possible genetic effects in later generations; and at high levels quickly administered, inflammation of the gastrointestinal tract with possible death from infection or internal hemorrhaging.

Uranium -- Uranium is a slightly radioactive element that is also chemically toxic to the kidneys and liver. It may be absorbed by inhalation, ingestion, or through skin breaks. The problem of lung cancer in uranium miners is due to exposure to radioactive decay products found in uranium ore and does not exist with refined uranium as used at Sandia. As used at Sandia, the level of exposure to uranium is very low and easily controlled.

Reactor Fission Products -- Reactor fission products are radioactive materials resulting from the operation of nuclear reactors. These materials may be gaseous, liquid, or solid and may enter the body through inhalation, ingestion, or skin breaks. Potential health problems from exposure to fission products run the gamut from short term effects such as blood damage and increased susceptibility to infection, to long term effects such as cancer induction, life shortening, and genetic mutations.

Explosive Materials -- Explosive materials, being chemical, may be toxic to the manufacturer or user but for the most part the concern of the public is with the shock wave resulting from detonaation. The air blast associated with the shock wave can injure body tissue and damage ear drums. Normally this air blast is similar to the sonic boom from aircraft as far as the public is concerned. At close ranges, missiles and dust are apparent. When explosives and radioactive materials must be transferred from storage igloos to sites of use, they are the responsibility of specially trained personnel who follow Safe Operating Procedures. These SOP's specify vehicle inspection, loading and marking; permitted speeds and hour of movement. There has never been a detonation of such transported explosives, but if one were to occur it might incur injury or death to persons nearby, a shock wave, a crater, dust and debris, and possibly scattering of burning brands of wood or pieces of explosive. Further details may be found in Chapter III.

Methane, hydrogen, and natural gas -- These are flammable gases typical of industrial operations. All burn freely in air, and can explode if in proper mixtures in confined spaces. They are not toxic per se, but to the extent that they are present displace oxygen needed in breathing. Additives in natural gas make it offensive to the smell; the other two are odorless.

Environmental Monitoring

Sandia Laboratories has maintained an environmental monitoring program (soil, water, and vegetation) since 1959, before the establishment of the Sandia Engineering Reactor Facility (SERF) (decommissioned in 1970) and the Sandia Pulsed Reactor Facility (SPR). The principal objectives of this surveillance program are (1) to determine population exposure levels above normal background radiation that can be traced to reactor operations, and (2) to check effectiveness of control measures on plant operations. Water, soil, and vegetation samples are collected once during the year. In the past, well water samples from Area III and Kirtland Air Force Base have been collected quarterly.

Former Sampling Plan

Until plans were revised in 1974, soil and vegetation samples were collected at 22 sites. (See Appendix B for details.) Deep well water samples (about 1000 feet) were collected from whichever of eight domestic supply water wells on Kirtland Air Force Base East were in use when the samples were taken. All of these samples were analyzed for gross beta activity. If high gross beta counts were noted, an analysis was performed for ^{90}Sr and/or ^{137}Cs. From October 1970 through the end of 1973, soil at four additional sites was sampled annually and analyzed for either gross alpha or total plutonium. These samples were only for background data since Sandia Laboratories, Albuquerque, generally handles plutonium only as sealed sources. Plutonium soil sample analyses are no longer performed, since it has been demonstrated that only background levels (minimum detectable levels) exist in the Sandia environs (Brewer 1973, 1974).

Sampling Site Plan

Since the original survey program was begun, the SERF has been dismantled. The fuel has been removed. Only the reactor vessel and some coolant piping remain, these not being removable because of the massive concrete structure around them. As a result, the fission product production in Area V has decreased and the need for the extensive environmental monitoring program described above has diminished.

Beginning in 1974, the program was reduced to that which follows:

1. Sampling frequency: Annual (after growing season - around October).

2. Types of samples
   a. Water: 1 sample at 4 KAFB wells
   b. Soil: none
   c. Vegetation: Green bunchgrass
      6 sites around Area V
      1 site at Lovelace ITRI
      3 sites for backgrounds: Isleta, Alameda, and Tijeras.
3. Type of analyses: gross beta activity
4. Standards for comparison
   a. Vegetation: 5-year average for 1968-1972
      Average = 130.9×10^{-6} μCi/g-ash
      Range = $(10 \text{ to } 263) \times 10^{-6}$ μCi/g-ash
      No. of samples = 110
   b. Water: 10^{-8} μCi/ml

Summary

Based upon the environmental sampling data contained in annual reports, the most recent of which is Holley (1975), SLA operations have not released any significant amount of radioactive containments to the environment from its inception through December 31, 1974: while there are no national standards on soil and vegetation radioactivity, the current levels are of the same order or, in some areas, below the background levels obtained before the startup of the reactor facilities. In the case of water, the 1974 measured beta activity in water from four base wells averaged 2.1×10^{-9} μCi/ml. This is comparable to off-base surface and tap water levels of 2.9×10^{-9} and 1.5×10^{-9} μCi/ml, respectively (1973 data, the most recent available). It is well below the Radiation Concentration Guide of 3×10^{-8} μCi/ml for unidentified beta activity in drinking water (ERDAM 0524).

The external radiation background in the Albuquerque area has been measured to be about 150 millirem per year per person (unpublished data, 1973). This is higher than the 100-130 millirem per year usually quoted for individuals in the U.S. (N.A.S. 1972, Klement et al 1972). The principal reason is the greater cosmic radiation associated with the altitude of about 5000 feet. Klement et al estimate the level even higher:

Source	N.M.	U.S.
Cosmic rays	105 mrem	45 mrem
External terrestrial radiation	70	60
Internal terrestrial radiation	25	25
Total	200 mrem	130 mrem

For those interested in long term genetic and somatic effects, the whole body integrated radiation dose from natural background to the Albuquerque Standard Metropolitan Statistical Area has been calculated to be around 50,000 man-rem/year, based on the background dose rate and the Midyear 1970 population for this area of 316,000.

Population doses from SLA gaseous radioactive effluents have been calculated using conservative meteorological diffusion parameters. In 1974, exposure rates from tritium were 7.1×10^{-3} mrem/year at 50 m, the distance from Area I to the nearest base housing; and from argon-41, 1.5×10^{-3} mrem/year at 3000 m, half the distance from Area V to the nearest base housing. Dose rates at greater distances were smaller.

Waste Generation and Disposal

Liquid Sanitary Waste

Liquid sanitary waste from Area I activities (except for Bldg. 887) is discharged at the Area I boundary into the KAFB sewer system. The KAFB system in turn connects either to a sewage lagoon or to the Albuquerque City Sewage Plant. Sanitary sewage from all other areas discharges into septic tank systems with no surface discharge, constructed according to USPHS standards.

Storm Water

Storm water from Area I is collected into a separate sewer system that discharges into the Tijeras Arroyo. Storm water from other areas follows natural drainage paths across the mesa and if not absorbed into the soil discharges eventually into Tijeras Arroyo.

Chemical Waste

Waste chemicals, including toxic materials, generally are not disposed of through the sanitary sewer system. Administrative exceptions are as follows:

Inorganic acids may be dumped into sink drains after dilution to 1 Normal.

Quantities of less than 100 ml of alcohol, acetone, and chlorinated hydrocarbons may be dumped into sink drains.

Small amounts of dichromate salts from the photo labs in Area I are discharged to the sewer. The annual discharge amounts to approximately 30 kg of chromium. At the time of the discharge the concentration of chromium in water is less than 50% of 0.01 mg/l as stated in Regulation #6, N.M. Water Quality Control Commission.

All other chemical waste is collected in suitable containers for burial in the Chemical Burial Site, a controlled and disposal area within Sandia Tech Area III (Figure 21). Materials are segregated according to chemical compatibility and buried in separate pits. The chemical disposal area is about two acres, and additional adjacent land is available if required for future expansion.

Radioactive Waste

Solid -- Sandia Laboratories, Albuquerque, radioactive waste is generated in technical and remote test areas as the result of nuclear weapons ordnance research and development. Except for an occasional encapsulated gamma source disposal, the volume bulk of waste generated is fission-produced or induced activity and uranium-contaminated solid material. Most of the radioactively contaminated waste consists of suspected rather than detected contamination. The kinds and quantities of solid radioactive wastes for the past three years, and estimates for the next year are (in cubic feet):

	CY 73	CY 74	CY 75	CY 76
Fission product/induced activity	971	2521	2000	2000
Uranium contaminated	267	807	400	400
Transuranic contaminated	0	0	0	0
Total	1238	3328	2400	2400

Liquid -- The small amounts of liquid radioactive waste produced are filtered through ion exchange resins, which in turn are disposed of as solid wastes.

Gaseous -- Small amounts (0.09 curie in CY 1974) of tritium are released from stacks in Tech Area I. Small amounts (5.05 curies in CY 1974) of argon-41 are released from reactor operations in Tech Area V.

Waste Handling Facilities

Radioactive Waste Disposal Area -- The Sandia Laboratories, Albuquerque, radioactive burial ground is located in Tech Area III approximately 4 miles south of the main Laboratories complex located on Kirtland Air Force Base (East), Albuquerque, New Mexico (Figure 21). This is the only active radioactive disposal site now in use. There is one inactive radioactive disposal area in Area II, closed in 1960. It covers 0.28 acre and contains about 5000 ft^3 of waste. The radionuclides buried in this dump include 0.23 g of ^{239}Pu and 4504 kg of ^{238}U.

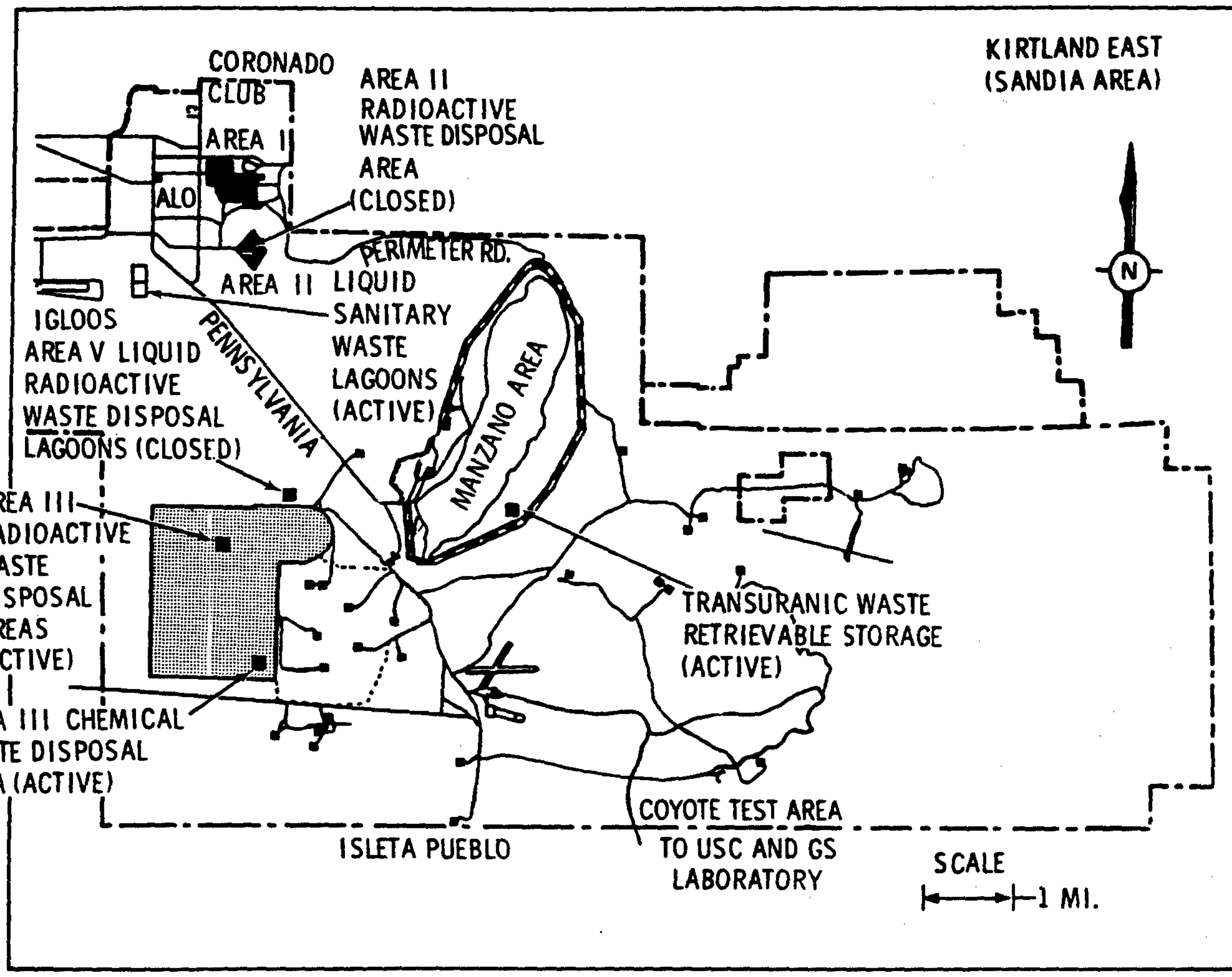

Figure 21. Waste disposal facilities

The radioactive waste disposal area consists of (1) a number of pits for radioactive waste with surface dose rates in excess of 2.5 mrem/hr and/or security-classified radioactive waste, both of which require a high level of access control, and (2) an open trench for other beta, gamma, and alpha wastes. The open trench receives waste that is properly bagged and marked as to quantity and type of material. As waste accumulates, it is covered as necessary with a 1-foot-thick layer of dirt overburden. The classified or high-level waste pits are covered with concrete caps, a dirt overburden of several feet, and marked with metal posts-in-concrete for permanent location information. Both disposal areas are fenced and together occupy 1.6 acres. Additional land is available for future expansion. Core drill-holes around the periphery of the disposal areas have shown no detectable radioactive contamination migration. Since the ground water table is approximately 500 feet below the surface, and the percolation rate is less than a foot per year, the potential for potable water contamination is extremely remote. Transuranic waste that meets the ERDA criterion of 10 nCi/g for 20-year retrievability (ERDAM 0511) is placed in sealed containers and stored in a concrete-lined tunnel.

Effluent Control -- Sandia Laboratories generates very little liquid radioactive waste. When the Sandia Engineering Reactor was still in operation (it was decommissioned in 1970), acids were periodically used to clean the filter resins for the primary coolant, and in the process the acids became contaminated. The spent acids were discharged into fenced lagoons immediately northwest of Area V. The radionuclides they contained, consisting of sodium-24 (15-hour half life) and manganese-56 (2.5 hour half life), have long ago decayed out. There is no residual problem.

Extremely low level tritiated waste in vacuum pump oil (of order millicuries per liter) is generated from the experimental use of tritiated targets in radiation producing accelerators. Also some waste solutions (of the order of millicuries per liter) are generated in analytical chemistry experiments. This liquid waste is adsorbed onto a solid medium, placed in sealed cans, and treated as solid radioactive waste (see above on Radioactive Waste Disposal Area). Liquid radioactive waste is not discharged to the sanitary sewer.

Gaseous radioactive material is discharged directly to the atmosphere at levels at the site boundary below ERDA standards, which are consistent with the NCRP radiation concentration guides.

Reactor operation related air-borne activity is filtered through high efficiency particulate air (HEPA) filters. The used filters when replaced are then handled as solid radioactive waste. Solid radioactive waste is administratively controlled by line management and health physics personnel procedures to preclude inadvertent diversion to the sanitary land-fill.

Explosive

Explosive waste is generaged in technical and remote test areas. There is no explosive waste-treatment facility maintained by SLA. All reject and defective explosives and explosive devices are picked up and destroyed by a military explosive ordnance demolition (EOD) team from KAFB.

All transportation to the test site and interim storage until use of the explosives is handled by a specially trained Sandia team to minimize the probability of an unplanned detonation.

Other Solid Waste

Domestic solid waste is delivered to a sanitary land-fill operated by the City of Albuquerque.

Emergency Response Capability

Sandia Laboratories Albuquerque has published and follows an Emergency, Disaster and Mobilization (EDM) Plan which describes the general principles governing operation of the Laboratories under conditions of national or local emergency. The objective is to provide the procedural guidance necessary to protect the lives, health, safety and property of the Laboratories and the public; to maintain continuity of management and executive direction; and to maintain or resume essential operations as may be required.

Local emergency plans include actions in the events of fire, explosion, aircraft crash, inclement weather, tornado and earthquake, bomb threats, civil disturbances and air pollution episodes. Especially important facilities such as the reactor area and the automated data processing center have especially detailed plans.

Fire

Kirtland Air Force Base maintains a fire department with stations at these three locations:

Station No.	Location
1	Kirtland Air Force Base, West
4	Kirtland Air Force Base, East
5	Manzano area

These stations provide fire fighting and rescue support to all areas of Sandia Laboratories operation. They are equipped to fight brush, forest, electrical, chemical and other types of fire. With the additional use of Sandia's emergency rescue trailers (#1 located in Area I and #2 located in Area V) they have a wide variety of rescue equipment for the release of entrapped personnel as needed.

The nominal response time of the KAFB East Fire Department from their Station #4 to Area III is 5.5 minutes. To the Coyote Test Field Building 9830, Lurance Canyon, the response time is 19 minutes. Response time from Station #5 at Manzano to Lurance Canyon is 12 minutes.

Station #1 at KAFB West is on alert to assist Stations 4 and 5 as required.

Medical

SLA employs three medical doctors (MD), four registered nurses (RN), one medical technologist (MT), and one X-ray technologist (RT). In case of emergencies, two ambulances are available, one in Area I (also serving Area II) and one in Area V (serving Areas III, V, and Coyote Test Field (CTF)). For radioactively contaminated casualties, a special wing of the medical facility located on the north side of Area I has facilities for personnel decontamination and first aid for up to three casualties.

Supplementing all the above in case there are more than three casualties at any one time are the base hospital facilities located approximately 1/2-mile from the SLA medical facilities.

Characterization of the Existing Environment

General Description

The Sandia Laboratories, Albuquerque, facilities are located on what is locally called the East Mesa and in the foothills of the Manzano Mountains. The general appearance is of a high, arid plateau which nestles against the mountains to the east and slopes gently down to the Rio Grande to the west. Sandia Laboratories is adjoined by the city of Albuquerque to the north; National Forest and the Manzano Mountains to the east; a military air base, a commercial airport and undeveloped state land to the west; and open Isleta Pueblo land to the south. The plateau or mesa region is high mountain desert, covered—lightly by eastern standards, lushly by local ones—with grass, sage, cactus, and associated vegetation, grading into juniper, pinyon, and ponderosa pine as one ascends into the mountains to the east. To the northeast lies Tijeras Canyon, which divides the Sandia Mountains to the north from the Manzano Mountains. As it runs west through the mountains, the canyon becomes an arroyo (a generally dry water course or wash) that cuts through the middle of Kirtland AFB East and constitutes the principal natural collector of drainage from the northern half of the base. The open mesa's fauna consists of reptiles such as snakes and lizards, mammals such as rabbits and coyotes, and a variety of birds. In the wetter and more fertile mountains are deer, a few bobcat, black bear and an occasional cougar. Hunting has not been permitted on the base for over 15 years. The land has not been grazed since before World War II.

The Manzano Mountains to the east peak at about 8000 feet, 2600 feet above the mesa on which most of Sandia's activities take place. The Forest Service withdrawal area includes much of the northern Manzanos, almost to a state highway (#14) east of them. Most of the higher area is used only as buffer zone. Both the Sandia and Manzano Mountains are characterized by a gently sloping, stream-dissected eastern face, and a precipitous, rough, canyoned western side facing Kirtland AFB and the city of Albuquerque. The mountains form a barrier to the prevailing winds. They receive more rain and snow than the mesa to their west, about 20 inches a year in some places as against 8 inches in Albuquerque, which accounts in part for their greater biological productivity. They channel surface winds into Tijeras Canyon, giving occasional periods of high winds in Area I of up to 60 knots.

The climate is mild and dry, but given to large diurnal and seasonal variations in temperature, from a record high of $105^{\circ}F$ to a record low of $-17^{\circ}F$ ($41^{\circ}C$ to $-27^{\circ}C$). (Since the official records are taken at the Albuquerque International Airport 3 miles to the west, they are not completely indicative of Sandia Laboratories' conditions.) Clear, sunny days with light to moderate winds are the rule, but there are exceptions: rain, principally in July through September, tends to come in torrents when it does come; and the winds of the dry spring months produce dust storms.

Demography

As indicated earlier, Sandia activities are carried out partly on land owned outright by ERDA, partly on military land on Kirtland AFB East for which there is a co-use agreement, and partly on land withdrawn from the Forest Service's Cibola National Forest. SLA activities share the co-use land with Air Force users and with two other tenants, the Defense Nuclear Agency and two laboratories of the Lovelace Foundation. Both Lovelace and the Air Force have facilities in the remote areas in the southern part of the base. In addition, there is a military housing area on Kirtland AFB East and extensive military office and recreational facilities.

The areas within the base used for SLA activities have been delineated previously. The base housing area is immediately to the north and west of Area I, at its closest point only 400 feet from the Area I fence. It houses about 5050 residents: men, women, and children, some in barracks for single men or women, some in detached or semidetached family houses resembling typical residential areas. Just to the west and northwest of Area I are Kirtland AFB office buildings; about a quarter mile west is a large Air Force hospital.

Between Areas I and II and the remote areas (III, V, and CTF) are such Air Force recreational facilities as a golf course, a skeet shooting range, and riding stables. There used to be a picnic area at the entrance to Coyote Canyon and an unimproved airstrip just north of Bldg. 9925 used by a base flying club. The latter two have been closed. Subsequent construction will keep the strip closed, but there is no assurance that the picnic area might again some day be reopened. Officially, the remote areas are closed except for authorized visitors and employees; nevertheless, such attractions tend to draw nonworkers into areas near where the activities of greater hazard are situated. The presence of the riding stable encourages people to ride out from it on many of the roads and trails in the southern part of the base.

All the facilities in the southern part of the base are locked, whether they be Air Force, Sandia, or Lovelace facilities. Although Kirtland AFB as a whole is nominally "closed," access is quite easy, and there can be no assurance other than by visual checks that there are no unwanted strangers in the vicinity of a test about to take place in a remote area. As indicated elsewhere in this report, this possibility has led to visual lookouts and helicopter sweeps before certain tests were conducted at the sites.

Nevertheless, distances within the southern part of Kirtland AFB East and the associated withdrawal areas are great. Table IV shows distances between representative SLA facilities, and between them and on- and off-base housing, and highways.

The city of Albuquerque abuts Kirtland AFB on the west and north, with the adjacent areas being principally residential. The 1970 census showed 243,751 people within the city limits and 315,774 in the metropolitan area. Santa Fe, the state capital which lies about 65 road miles north of Albuquerque, had a reported 1970 population of 41,167 people. These and other towns nearby, and their populations and distances from SLA are given in Table V.

Another zone of interest is the Albuquerque International Airport. The airport forms an integral unit with Kirtland AFB, sharing runways, and consists of private and commercial facilities at the west end of Kirtland AFB West, about 5.5 miles west of Kirtland AFB East. The main runway is oriented east-west; its axis crosses Kirtland AFB East just south of Area I; however, because of the proximity of the Manzano Mountains no more than 8 miles off the end of that runway, most approach or takeoff patterns involve turns to the north or south, so that flight paths cross over most of the SLA facilities. This has necessitated agreements for coordination with the Federal Aviation Administration, vested in a Joint Firing Area Coordinating Committee, described above and in Appendix A.

The eastern portion of the SLA area consists of lands withdrawn from the Cibola National Forest. Land beyond it, to an average farther distance of about 5 miles, is also part of that forest. A number of residences scattered along State Highway 1 are within the forest, and about 1 mile from the SLA area fence.

TABLE IV

Distance Between Various SLA Facilities and to Off-Base Points (in feet)

	Nearest Base Housing	Nearest City Housing	Area I	Area V	Nearest KAFB-E Boundary	Hiway I-40	Hiway NM-14
Area I fence	400	4,000		18,000	3,700	10,800	46,600
Area II	4,000	8,600	2,000	14,600	8,000	14,400	48,000
Area V reactors	20,000	22,600	18,000		10,000	28,000	48,000
Area III, sled terminus	20,400	21,000	22,800	8,000	3,800	35,000	55,000
centrifuge	21,400	23,300	19,200	1,800	9,000	29,600	49,000
CTF, Lurance Canyon Control Center	42,800	28,400	42,000	37,500	9,000	22,000	13,600
New cable site	42,300	29,400	41,000	34,000	12,800	27,000	20,000
Explosive Machining Facility	29,000	20,000	26,000	9,600	12,200	30,800	43,400

TABLE V

Distances to and Populations of Nearby Cities and Towns from SLA Area I

	Distance (miles)	Bearing	1974 Population
Albuquerque (down town)	6.5	NW	286,300
Belen	30	SSW	5,450
Bernalillo	19	N	2,016
Cochiti Pueblo	41	N	390
Estancia	33	SE	721
Grants	75	W	8,300
Isleta Pueblo	13	SW	1,080
Jemez Pueblo	41	NNW	1,197
Laguna Pueblo	48	W	2,960
Los Alamos	59	NNE	15,400
Los Lunas	20	SW	973
Moriarty	27	E	758
Sandia Pueblo	15	N	125
San Felipe Pueblo	27	N	1,187
Santa Ana Pueblo	28	NNW	370
Santa Fe	56	NE	44,800
San Ysidro	39	NNW	200
Santo Domingo Pueblo	36	NNE	1,662
Socorro	71	SSW	5,875
Zia Pueblo	35	NNW	380

Sources: Bahti, 1971.
Bureau of the Census, 1971.
University of New Mexico, Bureau of Business Research, 1976

To the south of Kirtland AFB East lies the Isleta Pueblo Indian Reservation. The Isleta Pueblo (1080 population) itself is on the Rio Grande, 7 miles to the wouthwest. Pueblo reservation lands south of Kirtland AFB East are used solely for grazing.

Albuquerque achieved its importance and growth because it is a crossroads of traffic. The old Spanish Camino Real (Royal Road) from Mexico City to northern New Mexico led up the Rio Grande, and has become in turn U. S. Highway 85 and now Interstate 25. East and west, Interstate 40 (Highway 66), the main route from Los Angeles to the east coast, is now more important. The latter passes quite close to Kirtland AFB East. It is constrained by topography to pass through Tijeras Canyon and at its closest approach is only 1.3 miles north of the base boundary and 2 miles north of Sandia's Area I. By contrast I-25 is 3.5 miles west of Area I, below the rim of the mesa and just above the edge of the flood plain of the Rio Grande. Each of the highways carries a great deal of traffic, especially I-40, which is one of five crossings of the Continental Divide in the Interstate Highway system.

To some extent air traffic has followed the routes originally dictated for surface traffic, and the Albuquerque International Airport, already mentioned, is a large and busy airport.

Ship and barge traffic are nonexistent, since the Rio Grande, though it looms large on maps and is indeed one of the principal rivers of the Southwest, is a shallow stream in its surface expression, and even during times of flow in the spring run-off from the mountains is hardly deep enough for use in water-transportation.

The principal industry of the Albuquerque area is government-related. The Sandia Laboratories is the third largest employer in Albuquerque with 5400 employees; the public school system employs 6050; and Kirtland AFB employs about 7000. Various other state and national government agencies also have offices or regional headquarters in Albuquerque. Beyond this emphasis and a growing light industry, which for the most part dates from World War II, the basic industries of New Mexico are agriculture, ranching, construction, timber, oil and gas, and service and tourist businesses. Agriculture is concentrated along the perennial streams of the area, especially the Rio Grande, with some dry farming on the mesas. Local crops include apples, corn, chiles, and truck garden crops. Pinto beans and peanuts are typical crops in the Estancia Valley east of the Sandia-Manzano Mountains. The great bulk of the land in New Mexico not in the mountains is devoted to grazing cattle and sheep on natural range grasses. In the immediate Albuquerque area, there is little grazing, and there is none at all on Kirtland AFB East. Timber is cut in the mountains of the northern part of the state, but not in the Sandia nor Manzano Mountains; apart from cutting Christmas trees and firewood, these are reserved by the Forest Service for recreational use. New Mexico oil and gas fields are in the northwestern and southeastern sections, far from the Albuquerque area. Tourists, on the other hand, are a major business in the Albuquerque area. A particular tourist attraction, in addition to the scenery, is a large number of Indian pueblos within 50 miles.

Geology

The SLA area is situated in the eastern portion of the Albuquerque-Belen Basin as shown in Figure 22. One of the largest of a series of north-trending basins in the Rio Grande trough (about 90 miles long and 30 miles wide), this basin is bounded by the Sandia and Manzano Mountains in the east, the Lucero uplift and Puerco plateau in the west and the Nacimiento uplift in the north. The southern boundary is defined by the Socorro channel. The basin is widest in the Albuquerque area and is constricted to the south and north. Large-scale faulting, deepening of the basin, and tilting of the mountain areas occurred in the late Miocene times. Since then, basin deposits have been laid down in a sequence of complex layers.

The basin is composed of poorly consolidated Cenozoic deposits eroded from the surrounding mountain areas following the faulting and structural changes that occurred in late Miocene times (Figure 23). Specifically, the upper part of the basin is a complex sequence of gravel, sand, silt, clay, and caliche deposits known as the Santa Fe formation. Underlying these deposits are sedimentary rocks of unknown total thickness, but gravity and aeromagnetic mapping indicate that these rocks extend down to about 10,000 feet (3000 m) below sea level, or about 15,000 feet (4600 m) below ground level. These sedimentary rocks rest on a bed of Precambrian rocks which underlie the entire basin and then lift up to form the western plateaus and eastern mountains. The Sandia Mountains are about 5000 feet (1500 m) above the basin, giving a total difference in elevation between the Precambrian rocks in the basin and the mountains of about 20,000 feet (6100 m). On the west side, Precambrian rocks lie at about sea level, with sedimentary rock overlying them to a height of about 5000 feet (1500 m) above sea level.

The mountain regions on or near Kirtland AFB East and the associated withdrawal areas have at various times been prospected for minerals of commercial value. No mineral claims remain outstanding in any part of this area; any that did exist have either been declared invalid and thus null and void, or were purchased back from their holders by the Forest Service.

At the time of the most recent withdrawal in 1966, a survey was made for mineral values there. The Forest Service's chief Mineral Examiner concluded that the land was "nonmineral in character within the meaning of the mining laws." He also said that the underlying Paleozoic sediments contained "no known structures for the accumulation of oil and gas."

Nevertheless, there remain some claims in Forest Service or Indian land beyond the boundaries of the withdrawal areas; for instance a Moon Ray Mine (fluorspar) just south of the boundary on Isleta Pueblo land remains intermittently active; in addition, the Albuquerque Gravel Products Company is planning to recover quartzite from an area just northwest of the 1966 withdrawal area.

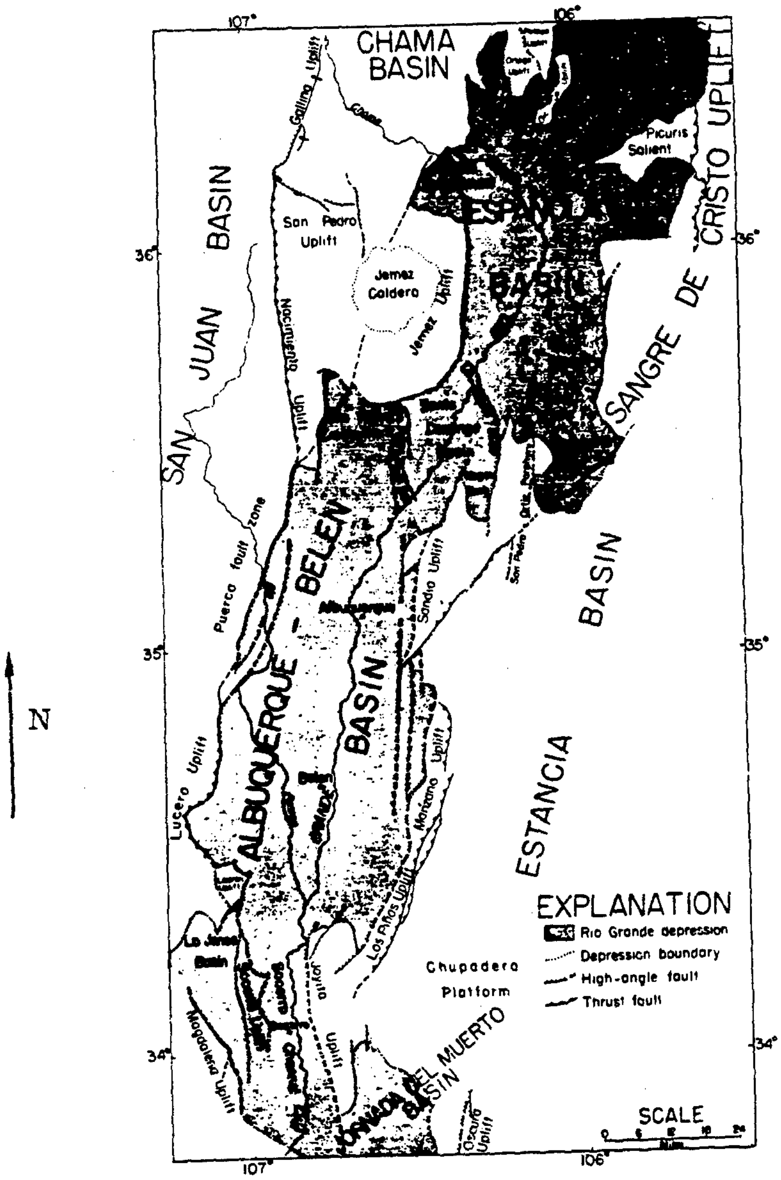

Figure 22. Tectonic map of Middle Rio Grande depression

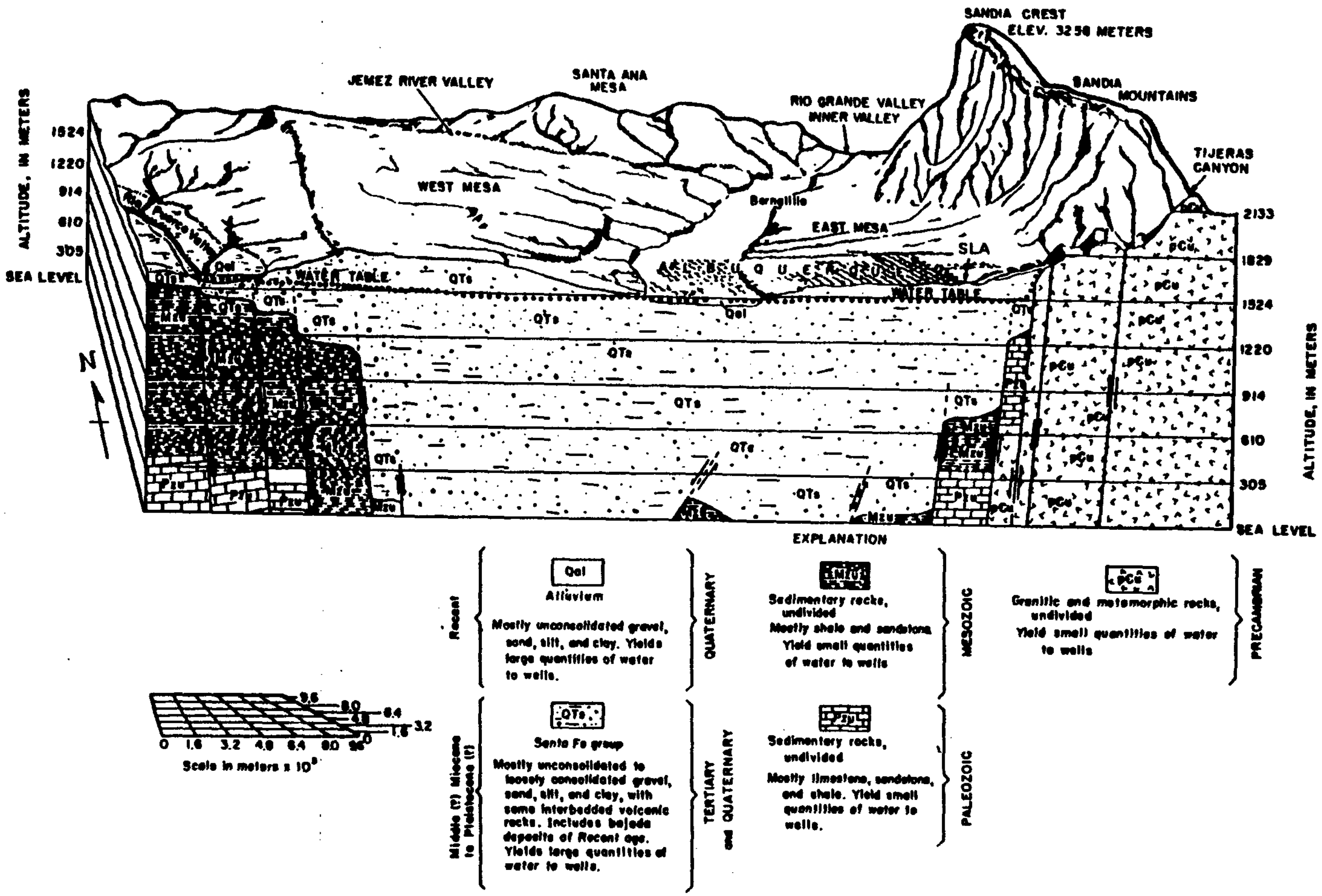

Figure 23. Block diagram of an area 85.5 square kilometers in E-W cross-section through KAFB, New Mexico, showing topography, generalized geology, and the water table in the alluvium and the Santa Fe formation

In general, however, the areas being used for SLA activities appear to harbor no minerals likely to be of value or in demand in the foreseeable future.

Hydrology

The Albuquerque area is drained by the Rio Grande, which flows generally southward, with an average flow of 730,000 acre-feet per year (9×10^8 m^3/yr). In recent years total annual pumpage in the Albuquerque area has been around 125,000 acre-feet (1.5×10^8 m^3) from about 300 large-discharge municipal, industrial, and irrigation wells and a considerably greater number of small-discharge wells. Pumpage from area water sources is expected to increase to over 220,000 acre-feet per year (2.7×10^8 m^3/yr) by the end of the century. At present about 20% of this water is derived from deep wells, and this fraction is expected to increase to 27% by the end of the century (Reeder et al, 1967).

Surface Drainage -- The East Mesa, on which the Sandia Laboratories operations are located, has a generally west-southwesterly ground surface slope ranging from about 250 feet per mile (47 m/km) near the mountains to 20 feet per mile (3.8 m/km) near the river. The distance from the foot of the mountains to the river varies from 3 miles in the northern to 9 miles in the southern part of the mesa.

The topography of Kirtland Base East is dominated by Tijeras Canyon, which cuts across it from east to west between Areas I and II on the one hand and Areas III and V and the Coyote Test Field on the other. In addition, numerous small drainages emerge from the mountains onto the Mesa. Important among these is Coyote Canyon, on or near which lie a number of the facilities of the Coyote Test Field. Tijeras Canyon and its tributaries, including Coyote Canyon, drain the north half of Kirtland AFB East. The southern half drains southward into arroyos on Isleta Pueblo land.

During heavy precipitation the higher interfluvial regions drain by sheet flow into small gullies and rivulets; this water is carried by natural or artificial flow paths into Tijeras Arroyo, whence it eventually reaches the river to the west. Flooding is only possible within these gullies and arroyos, and no facilities are built directly in their beds. The reactor sites of Area V, for instance, are situated on a slight ridge of high ground to the west of a small gully which shields them from sheet flow from the east. Area I, being a built-up area comparable to any other industrial area near a city, has its surface flow channeled by streets and gutters, and during periods of heavy rainfall sometimes has curb-to-curb flow, but this is only a temporary inconvenience.

Subsurface or Ground Water -- The major subsurface reservoir is the basin fill material of the Rio Grande (fan deposits and other alluvial material of Quaternary and Tertiary age) with a depth of nearly 5000 feet (1.6 km) throughout most of the basin (Figure 23). Subsurface water is not confined in a closed aquifer, but has a water table and is free to move with local hydraulic gradients to the extent that local permeability permits. The ground-water reservoir is bounded on the west by the Lucero uplift and on the east by the Sandia-Manzano Mountains.

The water table in the Albuquerque area is a somewhat irregular, gently sloping surface. On both sides of the river it slopes toward the river, with a slight downstream component as well, so that the overall gradient is about 10 feet per mile (2 m/km), although there are local perturbations such as those caused by deep wells. The characteristics of the reservoir have been studied by the Water Resources Division of the U. S. Geological Survey, in cooperation with the State Engineer of New Mexico. The transmissivity is estimated to be about 200,000 gpd/ft (gallons per day per foot of aquifer; 2480 m^2/day) and the storage coefficient is about 0.2. This corresponds to a ground water flow velocity of about 20 feet per year.

Recharge of the subsurface reservoir is principally from the Rio Grande. At the Rio Grande the water table is at the surface, and the river constitutes a hydrological barrier between ground water flows to the east and the west of it. The subsurface reservoir is also recharged to a lesser extent at the foot of the mountains where small canyons open onto the alluvial fan, and where the alluvium is coarsest. Percolation down through the unsaturated material above the water table elsewhere, however, is almost nonexistent, either from water flowing over the surface during rainstorms or from water ponded in natural or artificial depressions. Rainwater either flows into gullies, thence into Tijeras Canyon and to the river, evaporates, or is transpired by vegetation along intermittent water courses.

At present the water table under the East Mesa where the Sandia Laboratories operations are located is about 500 feet (150 m) deep. Because of withdrawal for city and industrial use, it is gradually lowering. USGS projections indicate that by the end of the century it will have dropped another 30 to 50 feet (10-15 m) (Reeder *et al*, 1967).

Seismology

The Albuquerque area is located in Seismic Risk Zone 2, which by definition is a region that can be expected to receive moderate damage from earthquakes (corresponding to Intensity VII of the Modified Mercalli Intensity Scale of 1931) (Figure 24 and Table VI). The record shows that for the most part it is a region of fairly high activity but of low magnitude and intensity, especially as compared with west coast earthquake history (Figure 25). There have been only ten earthquakes of intensity VII in New Mexico in the last century, and the largest earthquake on record was probably of body magnitude (m_b) 6.5, though it occurred before instrumental determinations were made.

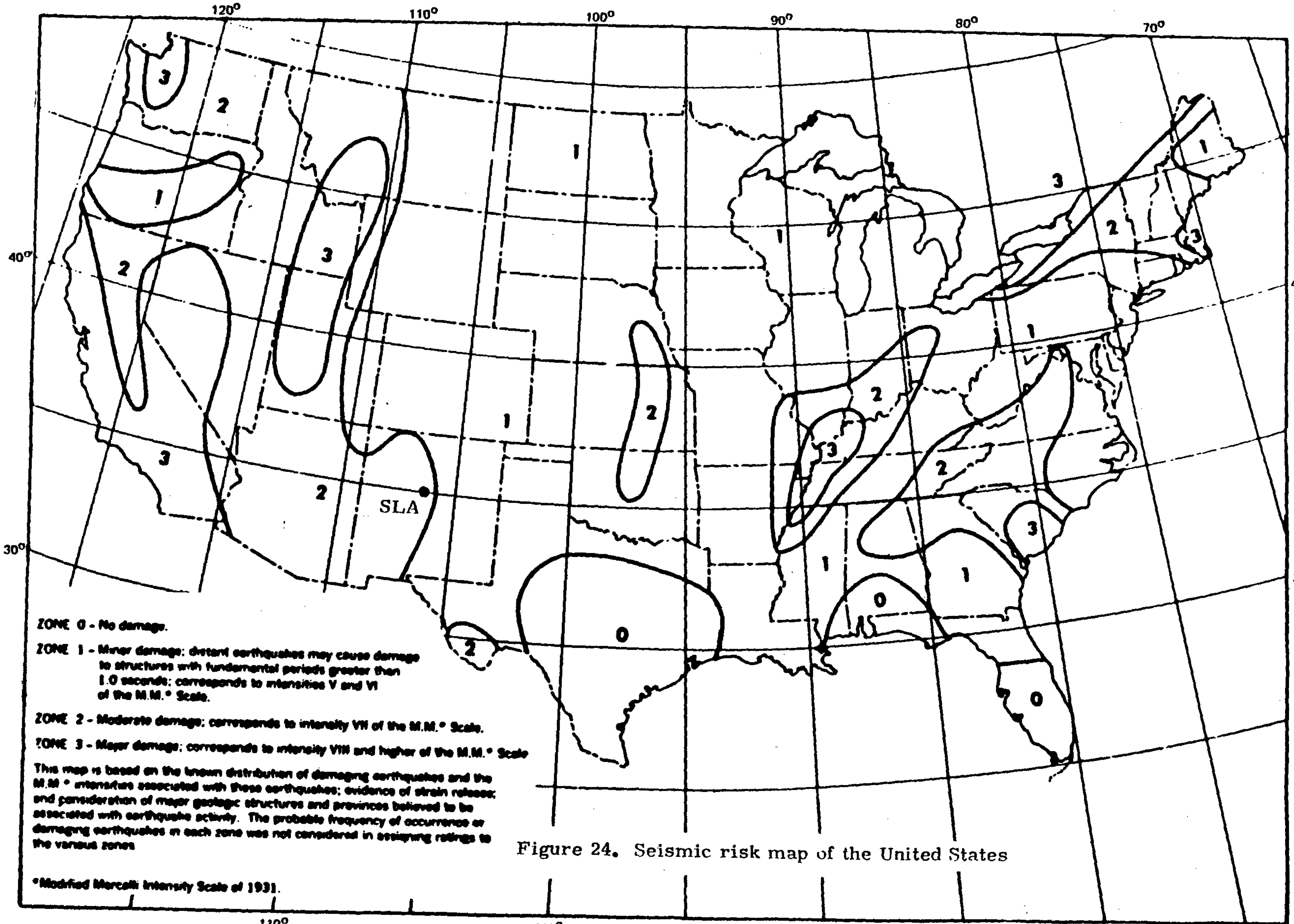

Figure 24. Seismic risk map of the United States

TABLE VI

Abridged Modified-Mercalli Intensity Scale* of 1931

I. Detected only by sensitive instruments.

II. Felt by a few persons at rest, especially on upper floors; delicate suspended objects may swing.

III. Felt noticeably indoors, but not always recognized as a quake; standing autos rock slightly, vibration like passing truck.

IV. Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably.

V. Felt by most people; some breakage of dishes, windows and plaster; disturbance of tall objects.

VI. Felt by all; many are frightened and run outdoors, falling plaster and chimneys; damage small.

VII. Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of autos.

VIII. Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed.

IX. Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken.

X. Most masonry and frame structures destroyed; ground cracked; rails bent; landslides.

XI. New structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent.

XII. Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air.

*This scale is a subjective measure of the effect of the ground shaking and is not an engineering measure of the ground acceleration.

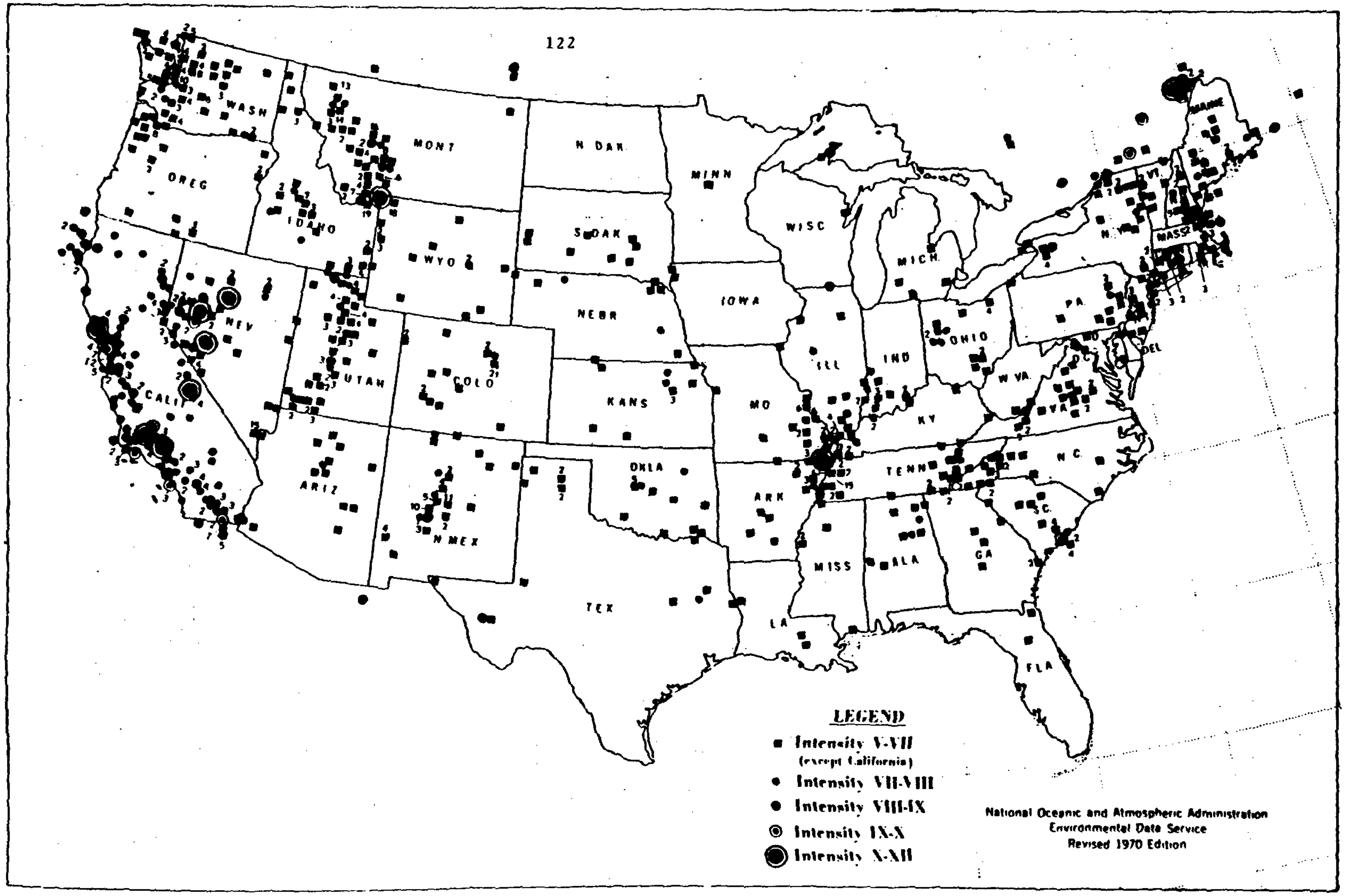

Figure 25. Earthquakes (intensity V and above) in the United States through 1970

The basin within which SLA activities are situated is bounded on the east and west by complex fault zones that generally underlie the surface but are exposed along the edges of the mountains. The series of faults at the face of the Sandia and Manzano Mountains has a vertical displacement of at least 20,000 feet (6100 m), which took place in Miocene times. There is no geological evidence that movement on those faults with accompanying strong earthquakes has occurred within geologically recent times. On the contrary, they appear to have been stable at least since the mid-Pleistocene. Present activity shows little correlation with existing fault scarps, but is aligned with the Rio Grande trough, with a particular concentration in the mountains west of Socorro, 75 miles to the south of Albuquerque.

Tables VII and VIII present accumulated available information on New Mexico earthquakes since the beginning of the record in 1868. The records are poor and incomplete. As Eppley says in his Earthquake History of the United States (1965), "Less is known about the earthquake history of this part of the United States (the western mountain region) than of any other. The list begins with 1852, a very recent date compared with those for the other regions, and for some time even after that date the accounts are very inadequate. Many of the earthquakes have occurred in slightly populated regions with many of their people little interested in helping to preserve earthquake records." The earlier records (surviving as mentions in newspapers, diaries, and letters) constitute an insufficient number of reports to enable identification of epicenters by mapping intensity contours.

The record does indeed show that earthquakes have occurred in the Rio Grande basin during all this time, and we must presume that they have occurred here ever since the basin stabilized in its present form in late Tertiary times.

The earthquakes which have most affected New Mexico in the past century are those of 1906, 1966, and 1971. In 1906 a series of shocks at Socorro occurred almost daily from July 2 until well into 1907. On July 12 some adobe walls were cracked and others thrown down. Waves were seen and there were fissures in the ground. A more severe shock on July 16 was felt at Raton, N. M., and at Douglas, Arizona, each over 200 miles distant; and a train was nearly derailed 10 miles west of Socorro. The November 15 shock was felt over a region of about 100,000 square miles. The history of the Socorro region shows frequent earthquakes of some intensity; it may rightly be considered the Earthquake Capital of New Mexico. (Eppley, 1965; Reid, 1911)

The January 1966 earthquake and its aftershocks were centered near Dulce, N. M., near the Colorado border. Nearly every house in Dulce was affected, and damage was estimated at $200,000. Porches were displaced from houses; walls and foundations cracked; water pipes were broken; fireplaces were cracked in half; a church roof partially collapsed; people in houses were knocked down. This shock (m_b 5.5) was the largest in New Mexico history since 1906. Between January 23-28, 119 after shocks were recorded at the Coast and Geodetic Survey's (CGS's) Albuquerque observatory, 140 miles (225 km) to the south. (Lander, 1966)

TABLE VII

Noninstrumentally Located Earthquakes in New Mexico, 1868-1959

Date	Place	Latitude	Longitude	Intensity	Source	Other Reference
1868 Apr 28	Socorro	34	107	V	a, d, e	
1869 Apr 18	Socorro	34	107	VII	a, b, d, e	
1879 unknown	Socorro	34	107		a, b, d	
1886 July 6	Socorro	34	107	V	a, d, e	
1893 Apr 8	Belen			VII	c	
July 12	N.M.	35	106.4	V-VI	a, b, c	
Sept 7	Los Lunas	34.7	106.6	VII	a	
1895 Oct 7	N.M.	34.5	106.7	V	a	
Oct 31	Socorro	34	107	VI	a	
1897 unknown	Socorro	34	107	VI	a, d, e	
1904 Jan 19-Sept 10	Socorro	34	107	V-VI	a, d, e	
1906 July 12	Socorro	34	107	VII	a, b, d	
July 16	Socorro	34	107	VIII	a, b, c, d	
Nov 15	Socorro	34	107	VII-VIII	a, b, c, d	
	(plus many smaller shocks - see source d)					
1913 July 18	Socorro				a	
Dec 5	Az-NM	34.1	106.8		a	
1918 May 23	Cerrillos	35.5	106.6	VII	a, b, c	BSSA 8, 92
1919 Jan 31	Socorro	34	107	IV-V	a	
Feb 1	Socorro	34	107	V	a	
1924 Aug 12	N.M.	36	104.5	V	a	
1930 Mar 23	Albuquerque			slight	c	BSSA 20, 38
Dec 3	Albuquerque	35	106	V-VI	a, c	
Dec 4	Albuquerque			slight	c	
1931 Jan 27	Albuquerque			III	c	
Feb 3	Albuquerque			V	c	
Feb	Albuquerque	35	106	VI-VII	a, b, c	
Apr 7	Socorro			slight		BSSA 21, 174
1934 Jan 7	Socorro	34	107	V	a	BSSA 24, 77
May 6 (7?)	Silver City	32.7	108.2	V	a	BSSA 24, 330
1935 Jan 17	Socorro	34.5	106.8	VI	a	BSSA 25, 186
Feb 20	Bernardo	34.8	106.8	V-VI	a, b, c	
Dec 12-20	Belen (an earthquake swarm)					
1936 Sept 9	Albuquerque			IV-V	c	BSSA 26, 394
Sept 11	Albuquerque			III	c	
1938 Apr 15	Albuquerque			slight	c	
Apr 16	Albuquerque			slight	c	
Sept 17	Az-NM border	33.2	108.6	VI	a, b	M_b = 5.5
Sept 19	AZ-NM border	33.2	108.6	V	a	
Sept 29	AZ-NM border	33.2	108.6	V	a	
Oct 31	Az-NM border	33.2	108.6	V-VI	a	
Nov 2	Silver City					BSSA 29, 413
1941 Aug 4	Socorro					BSSA 31, 350
1947 Nov 6	Sandia Mountains			VI	a, c	
1949 May 23	East Vaughn	34.6	105.2	VI	a	
1952 Aug 3	Cimarron	36.5	105.0	V	a	
Aug 17	Los Alamos	35.5	106.2	V	a	
1955 Aug 12	Santa Fe	30.2	104.6	V	a	BSSA 45, 342
1956 Apr 25	Sandia Mountains			slight	c	

Sources:
a. Eppley, 1965
b. Sanford, et al, 1972
c. Estes et al, n.d.—a
d. Reid, 1911
e. Bagg, 1904

TABLE VIII

Instrumentally Located Earthquakes in New Mexico Since 1960

Date	Time-GMT	Latitude	Longitude	Nearest Town	m_b	M_L	Intensity	Sources
1960 July 22	15:49:30	34.4	106.9	Bernardo		3.3		b, e, f
July 23	14:15:26	34.4	106.8	Bernardo		3.8	VI	b, e, f
1961 July 3	07:06:16.5	34.2	106.9	Socorro			VI	b, e, f
1962 Jan 3	23:29:54.2	35.2	103.8	Tucumcari		3.0		a
June 14	07:27:55.8	35.6	106.9	San Ysidro		2.8		a, b
1963 Feb 22	07:02:08.1	32.4	107.0	Las Cruces		2.9		a, b
	07:53:17.7	32.4	107.0	Las Cruces		2.8		a, b
June 6	08:05:32.6	36.7	104.4	Raton		3.7		a
Aug 19	00:08:23.4	32.45	107.1	Las Cruces		2.9		a, b
Dec 19	16:47:29.6	35.1	104.25	Santa Rosa		3.6		a
1965 Feb 3	11:33:10.5						IV	e
Apr 10	07:00:55	34.0	107.1	Magdalena		2.7	IV	b
July 28	03:52:06	33.9	106.8	San Antonio		3.0		b
	04:38:53	33.9	106.8	San Antonio		2.7		b
Dec 22	03:33:31.5	34.15	106.95	Socorro			IV	c, e
	04:04:53.0	34.15	106.95	Socorro			IV	c, e
1966 Jan 23	01:56:38.0	37.0	106.9	Dulce	5.5		VII	c, d, e
		(severe damage in Dulce, N.M. - see BSSA 56, 976)						
May 19	00:26:44	37.0	107.2	Dulce	4.6			c, d, e
1967 Jan 16	18:14:36	34.5	107.1	Bernardo		3.6		b
Sept 29	03:52:46	32.2	107.0	Las Cruces		3.6		b
1969 Jan 30	05:17:37.8	34.3	106.9	Bernardo	4.1		V	b, c, d, e
May 12	08:26:18.7	31.8	106.4	El Paso, Texas		3.4		b, d
	08:49:16.3	31.8	106.4	El Paso, Texas	4.3	3.3		b, d
July 4	14:43:34.0	36.1	106.1	San Juan Pueblo	4.4		IV	b, d, e
1970 Jan 12	11:21:15.4	36.1	103.2	Stead	3.5		VI	c, d, e
Nov 23	07:40:11.6	35.0	106.7	Albuquerque	4.5	3.8	VI	b, c, d, e
1971 Jan 4	07:39:06.7	35.0	106.7	Albuquerque	4.7		VII	c, d
		(worst damage in Albuquerque on record - see BSSA 61, 1475)						
Feb 18	11:28:13.7	36.2	105.7	Picuris Pueblo	3.7			d
Apr 28	11:36:52.7	35.8	106.6	Jemez Springs	3.0			d
Dec 6	05:18:13.7	36.1	106.3	Abiquiu	4.2	3.2		c, d
1973 Mar 17	07:43:05.5	36.1	106.2	Abiquiu	4.5			c, d
Sep 22	23:38:35.8	34.5	107.0	Bernardo		3.1		d
Nov 14	07:56:28.8	35.9	106.6	Jamez Springs				d
Dec 24	02:20:14.7	35.3	107.7	San Mateo	4.9	4.1		d
1974 Nov 28	03:35:20.5	32.3	104.1	Loving	3.9	3.7		d
1975 Jun 28	07:20:30.4	34.8	106.9	Los Lunas				d
Dec 3	20:12:22.8	32.8	108.7	Cliff		3.9	V	d
1976 Jan 5	06:23:32.9	35.8	108.3	Gallup	5.0	4.6	VI	d

Note: Mountain Standard Time is GMT less seven hours.

Sources:
- a. Sanford, 1965
- b. Sanford et al, 1972
- c. Various issues of the Bulletin of the Seismological Society of America (BSSA)
- d. Listings of the ESSA/CGS Preliminary Determination of Epicenters
- e. Various issues of the ESSA/CGS annual "U.S. Earthquakes"
- f. Eppley, 1965

Perhaps the worst shock of the century in the Albuquerque area was that of January 4, 1971, even though it was only of magnitude 4.7. Lander's summary (1971) has this to tell about it: "Felt principally at Albuquerque where minor damage occurred, consisting principally of cracked walls and plaster, window breakage, and damage from fallen items. One observer reported ground cracked.... City police reported street lights were out along Central from San Pedro to Louisiana N.E., but were unable to determine if the outage was due to the weather or the earthquake. Bernalillo County Jail: Wall cracked. The crack, about 4 feet long and parallel to the floor, came at the same instant that plaster fell to the floor. University of Albuquerque: Damage estimated at $30,000 to $40,000, much of it in the form of breakage and spillage in the chemistry laboratories in St. Francis Hall, the main classroom building. It was reported no structural damage was done to university buildings, but buildings would require extensive cleanup, plastering, painting, tiling, and replacement of supplies and office equipment.... West Mesa High School: A consulting engineer examined West Mesa High School, damaged in the earthquake, and pronounced it structurally sound. Principal damage was some fractures on the ends of six or seven 'double-T roof members', most of them in the gymnasium." The pattern of the reports suggests that the epicenter was to the west of the Rio Grande. The records indicate no appreciable or serious damage to SLA or ERDA buildings; cracks were observed in some of them, but there was nothing to show that they did not predate the earthquake, and apparently they were noticed only after the event when a search for possible damage was made.

As noted, the Albuquerque area has been classified as lying in Seismic Risk Zone 2, which is a zone subject to moderate seismic damage, and corresponds to intensity VII of the Modified Mercalli Scale, or an acceleration of about 0.1 g. The evidence given above indicates that moderate damage is a reasonable expectation, but of rare incidence. As Sanford et al say (1972:17), the largest shock to be expected in New Mexico in a 100-year period is of magnitude 6. In consequence, all buildings used by SLA and ERDA in Albuquerque are built to the specifications of that Seismic Risk Zone, as specified in the Uniform Building Code (I.C.B.O., 1970).

Meteorology and Climatology

The general climate of Albuquerque is briefly described in the National Weather Service's "Local Climatological Data for Albuquerque":

> "Arid Continental characterizes the climate of Albuquerque and vicinity. With an average annual rainfall of just over eight inches (20 cm) there is generally insufficient natural moisture to maintain the growth of any but the most hardy desert vegetation. In the mountains east of the city, precipitation is considerably heavier. At Tijeras Ranger Station, about 15 miles (24 km) east of Albuquerque, the average rainfall is more than 15 inches (38 cm). The average monthly precipitation at Albuquerque varies from about one-third inch during the winter months, November through March, to over an inch and a quarter during the summer months, July through September. With normally less than two inches of moisture, the winters are generally very dry.

A considerable portion of this meager winter precipitation falls in the form of snow, but the average monthly fall never exceeds two inches and there are normally only four days a year when as much as one inch of snow occurs. Snow rarely remains on the ground in the valley for more than 24 hours but in the nearby mountains, snow cover is normal from the middle of December until early spring.... The July-September period furnishes almost half of the annual moisture with most of the rain falling in the form of brief but at times rather heavy thundershowers. Prolonged rainy spells are practically unknown. These summer showers do not materially interfere with outdoor activities but do have a considerable moderating effect on summer daytime temperatures.

Temperatures in Albuquerque are those characteristic of high altitude, dry, continental climates. The average daily range of temperature is relatively high but extreme temperatures are rare as testified by the fact that there is normally less than one day a year when the temperature reaches 100° or drops to zero ($37^{\circ}C$ to $-18^{\circ}C$). Daytime temperatures during the winter average near 50° with only three days on which the temperature does not rise above the freezing mark. In the summer, daytime maxima average less than 90° ($32^{\circ}C$) except in July, and with the large daily range, the nights normally are comfortably cool. The air is normally dry with an average annual relative humidity of about 46 percent. "Muggy" days are unknown and the usual humidity during the warmer part of the day is about 30%, dropping down to less than 20% in June, the least humid month of the year.

Another feature of the climate is the large number of clear days and the high percentage of sunshine. Sunshine is recorded during more than three-fourths of the hours from sunrise to sunset and this high percentage carries through the winter months when clear sunny weather predominates.

Wind movement throughout the year averages less than nine miles per hour, but during the late winter and early spring months the average is somewhat higher and occasional windy and dusty days occur. These occasional dust storms are the most discomforting part of Albuquerque's climate. However, there are on the average only 46 days during the year when the maximum velocity reaches 32 miles per hour (14 m/s).... (Quoted in Palmer & Plagge, 1957.)

Climatological statistics for the latest year available (1973) are given in Table IX. There are the official statistics for Albuquerque, and are those recorded at the Albuquerque International Airport, 3.5 miles (5.6 km) west of Area I. In a region with pronounced orographic effects (effects due to mountains and other topographical features), these statistics are not entirely representative of precipitation and winds at the base.

TABLE IX

Normals, Means, and Extremes - Climatological Statistics, 1973

Month	Temperature: Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	14		14		(b)	(b)	34		34		34	
J	46.9	23.5	35.2	69	1971	-17	1971	924	0.30	1.17	1941	T	1970+	0.87	1962
F	52.8	27.4	40.0	75	1972	1	1964	700	0.39	1.42	1948	0.04	1959	0.48	1957
M	59.2	32.3	45.8	85	1971	9	1966	595	0.47	2.18	1973	T	1966+	1.11	1973
A	70.1	41.4	55.8	89	1965	22	1973	282	0.48	1.97	1942	T	1972+	1.08	1969
M	79.9	50.7	65.3	94	1969+	28	1967	58	0.53	3.07	1941	T	1945+	1.14	1969
J	89.5	59.7	74.6	102	1972+	42	1971	0	0.50	1.71	1967	T	1964+	1.64	1952
J	92.2	65.2	78.7	104	1971	54	1964	0	1.39	3.33	1968	0.14	1958	1.77	1961
A	89.7	63.4	76.6	99	1972+	52	1968	0	1.34	3.30	1967	T	1962	1.22	1967
S	83.4	56.7	70.1	94	1971	37	1971+	7	0.77	1.99	1940	T	1957	1.92	1955
O	71.7	44.7	58.2	87	1972+	25	1971+	218	0.79	3.08	1972	0.00	1952	1.80	1969
N	57.1	31.8	44.5	73	1973	12	1973	615	0.29	1.45	1940	0.00	1949	0.76	1940
D	47.5	24.9	36.2	68	1966	4	1968	893	0.52	1.85	1959	0.00	1956+	1.35	1958
YR	70.0	43.5	56.8	104	JUL. 1971	-17	JAN. 1971	4292	7.77	3.33	JUL. 1968	0.00	DEC. 1956+	1.92	SEP. 1955

Month	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 05 (Local time)	Hour 11	Hour 17	Hour 23	Wind &: Mean speed	Prevailing direction #	Fastest mile: Speed	Direction #	Year
(a)	34	34		34		13	13	13	13	34	15	34	34	
J	2.1	9.5	1973	5.1	1973	66	48	36	57	7.9	N	61	E	1949
F	1.8	8.2	1964	4.2	1946	62	43	32	51	8.8	N	68	NW	1944
M	2.1	13.9	1973	10.7	1973	54	32	24	41	10.0	SE	80	NW	1943
A	0.5	8.1	1973	6.6	1973	45	25	18	33	10.9	S	72	S	1948
M	T	T	1951	T	1951	44	23	16	31	10.5	S	72	W	1950
J	0.0	0.0		0.0		45	24	18	32	9.9	S	82	SE	1946
J	0.0	0.0		0.0		61	36	28	49	9.1	SE	68	E	1945
A	0.0	0.0		0.0		65	39	30	52	8.1	SE	61	SE	1951
S	T	T	1971+	T	1971+	58	40	30	52	8.5	SE	62	SE	1945+
O	T	0.3	1970	0.5	1970	58	37	29	47	8.3	SE	66	N	1959
N	1.2	9.3	1940	5.5	1946	64	43	35	54	7.7	N	57	NW	1948+
D	2.7	14.7	1959	14.2	1958	69	51	43	60	7.6	N	90	SE	1943
YR	10.4	14.7	DEC. 1959	14.2	DEC. 1958	58	37	28	47	8.9	SE	90	SE	DEC. 1943

Month	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max: 90° and above ‡	Max: 32° and below	Min: 32° and below	Min: 0° and below	Average daily solar radiation - langleys **
(a)	34	34	34	34	34	34	34	34	34	13	13	13	13	
J	73	4.8	13	8	10	3	1	*	1	0	3	29	1	
F	73	4.9	11	8	9	4	1	*	1	0	1	23	0	
M	74	4.9	12	10	9	4	1	1	1	0	*	18	0	
A	77	4.5	13	9	8	3	*	2	*	0	0	5	0	
M	80	4.1	15	10	6	4	0	4	0	3	0	*	0	
J	83	3.2	18	9	3	4	0	5	*	16	0	0	0	
J	76	4.5	12	14	5	9	0	11	*	23	0	0	0	
A	78	4.2	14	13	4	10	0	12	*	18	0	0	0	
S	81	3.3	18	7	5	5	0	5	*	3	0	0	0	
O	79	3.4	18	7	6	5	0	3	*	0	0	2	0	
N	77	3.9	16	7	7	3	1	1	1	0	*	15	0	
D	72	4.6	14	8	9	4	1	*	1	0	2	29	0	
YR	77	4.2	174	110	81	59	4	43	5	61	6	121	1	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Maximum monthly precipitation 8.15 in June 1852 (measured by Medical Officers of Army at Army Post near plaza).

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
\- Below zero temperatures are preceded by a minus sign.
‡ ≥ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

** The National Weather Service considers the accuracy of solar radiation data questionable; therefore, publication is suspended pending determination of corrected values.

In New Mexico, summer rains fall almost entirely during brief, but frequently intense, thunderstorms. The general southeasterly circulation from the Gulf of Mexico brings moisture for these storms into the state, and strong surface heating combined with orographic lifting as the air moves over higher terrain causes convective air currents and condensation. Winter precipitation is caused mainly by frontal activity associated with the general movement of Pacific Ocean storms across the country from west to east. As these storms move inland, much of the moisture in them is precipitated over the intervening mountain ranges, with the result that winter is the driest season in Albuquerque.

Thus the principal source of rainfall in the Albuquerque area is summer thunderstorms. Generally these develop during the afternoon over the Sandia and Manzano Mountains and drift to the northwest over the Rio Grande valley, so that SLA areas of the base receive more precipitation than does the official weather recording station at the airport to the west.

Winds on the base were studied extensively in 1957 during preparations for the Sandia Engineering Reactor Facility (SERF, decommissioned in 1970). Details are given in Appendix C. Prevailing winds were found to be from the east, except that winter winds at 100 feet elevation are from the north. Generally temperature decreases with altitude; but after sunset on cloudless or near cloudless days, rapid radiational cooling of the ground brings about strong temperature inversions, resulting in a very stable atmosphere so far as rise and diffusion of gaseous effluents and explosion products are concerned.

The night-time ground cooling also generates drainage winds out of the mountains. A dominant effect was found to be winds down Tijeras Canyon, which bisects the base. It acts as a barrier to surface flow between Areas III, V, and CTF on the one hand, and Areas I, II, and the city of Albuquerque on the other. Smoke tests run in early morning with south winds showed that clouds did not pass the canyon until the inversion had disappeared.

Standard diffusion parameters have been calculated for the atmospheric conditions represented by these smoke tests. The meteorological mixing parameters and diffusion coefficients for these and other stability conditions are given in Table X (from Estes et al, n.d.-a).

Tornadoes -- Tornadoes in the Albuquerque area are practically nonexistent. Within the whole state of New Mexico they occur with a mean annual frequency of 0.2 to 1.1, principally in the eastern half of the state. Only two tornadoes have occurred in the Albuquerque area itself in the last 20 years. One was at Edgewood, east of the mountains, and the other (on October 10, 1974) was at Canoncito 20 miles west of the city.

TABLE X

Meteorological Mixing Parameters and Diffusion Coefficients

Lapse Classification	Vertical Temperature Gradient with Respect to Ground Level (°F/100 ft)	n Value	$\bar{u}$ (m/sec)	C_x ($m^{n/2}$)	C_y ($m^{n/2}$)	C_z ($m^{n/2}$)
Strong Lapse	<-1.0	0.20	7.0	0.1	0.4	0.35
Weak Lapse	-1.0 to 0	0.25	5.0	0.1	0.4	0.20
Weak Inversion	0 to 2.5	0.33	3.0	0.1	0.4	0.08
Strong Inversion	>2.5	0.50	2.0	0.1	0.4	0.04

Biology

The biological features of the 75 square miles of Kirtland Air Force Base (East) were surveyed by members of the University of New Mexico staff in the summer and fall of 1974 to identify the species of flora and fauna whose patterns of distribution extend into this area and to classify the vegetational and animal associations occurring. A brief synopsis of that survey (conducted in the field, herbarium and literature) is provided here. Further details from the complete report (Martin and Wagner, 1974) are in Appendix D.

The biology of the area is affected by the topography, soils and climate. The elevation ranges between 5200 and 8000 feet. A series of small hills between the main portions of the base and Manzano Mountains to the east creates an area protected from the drying effect of the wind and results in a more moist habitat that supports vegetation like that on the eastern slope of the mountains. The soils of the area are "young" (at an early stage in the weathering process), highly calcareous and alkaline, underlain with caliche (hard pan) at the level of maximum moisture penetration (stunting root growth), of lean and sandy texture and of slight organic content. The climate, typical of the semidesert areas of the Southwest (low precipitation, wide extremes of temperature, frequent drying winds, heavy showers with erosive effects, and erratic seasonal distribution of precipitation) is reflected in many species of drought-resistant flora and fauna.

Vegetation -- The vegetation of the area surveyed (some 369 species) can be classified into two basic ecological associations, the Pinyon-Juniper Association and the Grassland Association. Other minor associations are found within the major associations.

The Pinyon-Juniper Association dominated by one-seed juniper is found at elevations over 5,800 feet. In the higher canyons, some Rocky Mountain juniper is also found, along with an occasional ponderosa pine (the area was once logged). The juniper is the most common species at the lower limit, with many scrub-oaks and an occasional Gambel oak also present. The understory of this Pinyon-Juniper Association is dominantly grasses except where the canopy of the pinyons and junipers becomes almost continuous, and there small shrubs and forbs (sub-shrubs other than grasses) become more important. In the densest shade one even finds a small fern; other ferns occur on rocky outcroppings.

Within the Pinyon-Juniper Association are two minor associations. The spring in Lurance Canyon was not examined, but Sol se Mete Spring has a small area of permanent water below it that supports semi-aquatic plants such as cattails and rushes. Arroyos down which flow seasonally intermittent streams support vegetation with higher moisture requirements, such as the narrowleaf hop-tree and tree-of-heaven (ailanthus) as well as shrubs. Many of these larger plants in or near arroyos physically support climbing species such as morning glory or grape.

The Grassland Association extends through the rest of the base below 5800 feet. Over 50 species of grasses are found, but only a few are relatively abundant: grama grass, muhly, dropseed, and galleta. Several shrubs are common: sand sage, winter fat, and four-wing saltbush. There are numerous forbs and some cacti in this area. Some of the cacti (dagger cholla, pincushion cactus, and strawberry cactus) are more abundant there than in more freely accessible lands where they are being drastically reduced by collectors and vandals. The unendangered cane cholla and prickly pear are also very common.

The vegetation of arroyos at lower elevations of the base is substantially different from the typical grassland vegetation, tending towards such shrubs as four-wing saltbush, Apache plume, and rabbitbrush. Because of the erosion near arroyos, pioneering species are common. Along roadsides and in waste areas may be found another characteristic minor association of such annuals as tumbleweed, aster and mustard. Within the Grassland Association there is a group of sulphur springs (Coyote Springs) at the outlet of Coyote Canyon onto the mesa, which creates a locally swampy area supporting aquatic vegetation and two species of trees. The vegetation of the area, although less disturbed than surrounding off-base areas, still shows evidence of past disturbances. The presence of abundant snakeweed and burro grass indicates heavy grazing of large portions of the Grassland Association before establishment of the base. Since succession proceeds slowly in semi-arid regions, this area will not reach maturity for at least another several decades.

Several features of the area give it special scientific interest: The protection from the drying effect of the wind afforded by the hills within the Manzano area provides the conditions on the west side of the mountains for the development of an extensive Pinyon-Juniper Association of the kind more usually found on the east side. There are plants found here that are not normally a part of the central New Mexico flora: dentate goldeneye, big-flowered bricklebush, and southern morning glory, all in Sol se Mete Canyon. These are either relict populations or constitute the northern limit of the distribution of these species; further study would be necessary to distinguish between these hypotheses. The area is also of interest for its undisturbed nature resulting from its having had limited access and no grazing for some decades.

Fauna -- In view of the lack of competition on the base from livestock, wild animals that feed on grasses and other range plants would be expected to have higher population densities than in the surrounding off-base heavily grazed areas. Evidence supporting this contention is the sighting of numerous rodent burrows during the field survey. The Pinyon-Juniper Association provides abundant browse for mule deer, which descend into this zone to winter, but are uncommon during the rest of the year. Pinyon nuts,' abundant once or twice every 5 years, provide food for mice, rats, squirrels and chipmunks. Birds are common. In the Grassland Association are larks, thrashers, hawks and falcons, several species of sparrows, quail and mourning doves. In the Pinyon-Juniper Association are found jays, titmice, bushtits, woodpeckers of several species, and warblers. Fauna species may be summarized as follows: 7 amphibians; 27 reptiles; 49 mammals, and 128 birds, as listed in Appendix D. These include no species on the Secretary of the Interior's list of Rare and Endangered Species.

Archaeology and History

The Southwest is well known as an area rich in archaeological remains, due principally to the arid climate and consequent long-time preservation of artifacts and sites used or disturbed by primitive man. Indeed, one of the oldest sites of remains of primitive man in the New World is the Sandia Caves, less than 20 miles north and east of the SLA area.

A recent survey of five sections of land in Tijeras Canyon just north of the base resulted in over 70 archaeological sites being found. There is every reason to believe that a similar survey of the base itself would result in the finding of as many if not more archaeological sites. Indeed, at various times in the use of this area, artifacts have turned up of Basket Maker up through Pueblo origin, as identified by knowledgeable amateur archaeologists on the SLA staff. Other artifacts may have been Apache; and paleo-occupation sites are suspected.

Before World War II, there was a small Spanish community in the Coyote Canyon and Manzano area, and a ranch on homesteaded land (Sections 17 and 18 of Township 9 N., Range 5 E.) All of these rights have been extinguished by negotiated purchase or land trade, and the military has removed most of the buildings associated with them. Old roadways, irrigation channels, and evidences of contour plowed land are still to be found in various parts of the base, particularly in Area III. However, no sites on Kirtland AFB East and the associated withdrawal areas are listed on the National Register of Historic Places.

There has never been a formal archaeological survey of KAFB East and the associated withdrawal area off the base for sites of archaeological or historical interest and value, as defined in the Antiquities Act of 1906 (34 Stat. 225; 16 USC 432-3). That act and its successor modifications (including Executive Order 11593 of May 13, 1971 (37 FR 24146), provide for identification, protection, and preservation of cultural values, both historic and prehistoric. Public Law 93-291 of May 24, 1974, (88 Stat 174) directs the Secretary of the Interior to survey government-owned lands for such archaeological and historical sites, and to make recommendations for their preservation, salvage, or other treatment, in order that the values in them not be lost.

CHAPTER III

ENVIRONMENTAL IMPACT

Land Use

Biological and other surveys of Kirtland AFB East have made it clear that the impact of man and his works on this land started long before the advent of what was to become the Sandia Laboratories. Evidences of this previous use still remain in the form of old wagon roads and trails that are still visible, remnants of an aborted irrigation project near the present Tech Area III, buildings and building foundations left from the small Spanish community that used to be in Coyote Canyon, and a biological structure of the grasslands that, after thirty years of no grazing, still shows signs of previous overgrazing.

The immediate areas of use by Sandia and other tenants on the base are, of course, much affected by that use. Roads have been built, or improved, or not allowed to revert to the wild. There are excavations, cleared lands, and the like. Heavily used areas, particularly Tech Area I, are almost completely removed from their original state, and any additional construction or changed use will not change this fact. New construction elsewhere usually entails excavation and land clearing, new access roads, as well as an increase in traffic in the immediate surroundings. Some but not all of the future projects described previously are of this sort (the exceptions are those calling for internal modifications of existing buildings).

However, the facilities used by Sandia exist, and their impact in terms of land use is history. In a period of decreasing budgets and shifts elsewhere of national priorities, and of a gradually decreasing workforce, the pace of new construction is much less than it was before 1960, when the Laboratories was growing rapidly. In principle the land use could be returned to something approaching its original state, but in practice this would be difficult because the arid climate means slow natural revegetation. And in any case, if SLA were to cease to exist, it is more likely that the buildings and facilities it has used would be turned to other uses. From this point of view, the historic and continuing impact of land use by the Sandia Laboratories and its predecessors is permanent.

Use of Resources and Energy

Electrical power is supplied by the Public Service Company of New Mexico through the 115 kilovolt Eubank Switching Station. The Laboratories are serviced by substations of approximately 54,000 kVA capacity and about 32 miles of 44 kVA distribution lines. Emergency standby generators are available for Tech Areas I and II for lights and some power.

Natural gas supplied by the Southern Union Gas Company (SUG) is the primary fuel for the steam plant. A discontinuance clause in the government's contract with SUG allows the supplier to interrupt gas service when the demand of other customers warrants. This provides a better rate for the natural gas (dump rate) but necessitates the conversion to fuel oil when the gas supply is curtailed during cold weather.

Fuel oil is obtained on a bid and contract basis. The amount used varies as the temperature fluctuates and as natural gas supply is interrupted by Southern Union Gas Company. The approximate storage capacity for the six SLA oil storage tanks is 2 million gallons. Figure 26 shows two years of consumption of electric power and of fuel for the steam plant (with gas use conversion of 5875 cu. ft. of gas equal to 1 barrel of oil).

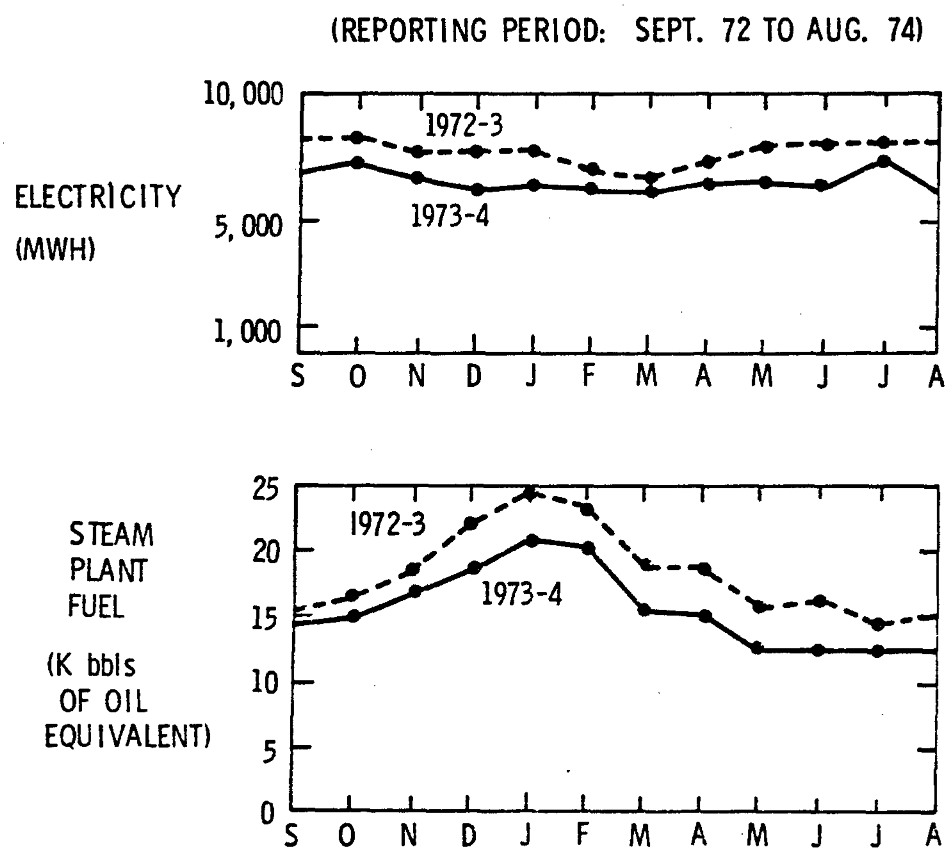

Figure 26. Energy use at SLA

Steam produced in the Sandia Laboratories steam plant provides heat and process steam for all Technical Area I and major military buildings of Kirtland Air Force Base East. The six boilers have a total rated capacity of 450,000 pounds per hour. The steam lines within Tech Area I are approximately 3-1/2 miles long with a parallel condensate return.

Water for Sandia Laboratories, Albuquerque, Technical Areas I and II is supplied by eight military water wells under operational jurisdiction of KAFB. The system is also tied into the Albuquerque water system for supplemental supply. A ten-inch water line between Tech Area II and III furnishes an additional supply of water from Sandia's own well in Area III. There is one 100,000 gallon elevated storage tank and one 50,000 gallon ground storage tank in Tech Area III and one 700,000 gallon ground storage tank under construction in Coyote Test Field east of Area III. Water is used for sanitary purposes at all major facilities. Several facilities (such as the Radiant Heat Facility) use water for cooling. At the Sled Track in Area III, water is used for the water-braking system. Waste water from all of these facilities is essentially unpolluted and is therefore dissipated onto the adjacent terrain where evaporation and percolation are sufficient to absorb all discharge in very little time.

Sandia Laboratories is dependent upon Kirtland Air Force Base East for water supply, sewage disposal, fire protection service and snow removal from primary streets leading through the base to Sandia's parking areas.

A base sewer system serves Area I, with effluent being divided between military lagoons and the city of Albuquerque sewage system. All sanitary and nontoxic liquid industrial wastes from facilities in and south of Area III are disposed of by means of a septic tank and subsurface drainfield system at each facility, constructed in accordance with U.S. Public Health Service Bulletin No. 526. No new or unusual treatment processes are involved. The effluent from septic tanks is disposed of through tile drain fields, by percolation and natural filtration. The nearest inhabited structures within the existing slope of the land are approximately 2,000 feet. The ground water level is in excess of 500 feet below ground level. The only water well in the area is about 1,000 feet from the nearest septic tank disposal field. Ground waters of the area are thus protected from pollution.

Construction Activities

Discussion of the environmental impact of construction activities at Sandia Laboratories is primarily concerned with how the land is affected by excavation, streets and parking lots, drainage control, and landscaping. Construction effects as related to the economic impact on the community, the commitment of utilities, and effluent emissions are addressed elsewhere in this report.

The land which has been and may be used was committed to government use over thirty years ago, and no new lands need be acquired in the foreseeable future.

Excavation for building construction is balanced, so far as is practical, with respect to cut and fill. Any left-over soil is taken to established land fill areas such as arroyos and other washed drainage ditches where it is used for erosion control. For additional fill material that may be needed, three borrow pits have been located in and near Area III, and surveyed and proved for gradation of materials required. Concrete target blocks which have been broken during drop testing from towers or during rocket sled tests are used for rip-rap stabilization of arroyos.

Roadways and parking lots associated with new construction projects are graded and paved to insure proper drainage and the direction of sheet water flow into the existing storm drainage system. Should money not be available for immediate paving, these areas are gravel plated as an interim measure to protect the surface and maintain proper drainage.

A standard practice of Southwestern landscaping is being implemented on existing buildings and new construction projects as time and money are available. Patterned ground cover of rocks and gravel along with native plants helps drain the surface during the infrequent rains and stabilize the fill dirt (thereby reducing blowing and tracking of dust into offices and laboratories). Conventional lawns, trees, and shrubs have been kept to a minimum because of high initial and maintenance costs.

Operational Effluents and Other Effects

Chemical

Although chemical effluents released to the environment vary from year to year, data from 1973 and 1974 (Brewer, 1974; Holley, 1975) may be considered typical. The SO_2 emissions meet the national standard of 40 CFR 76.5a that requires that the lowest sulfur fuel available be used. There are no emission standards to our knowledge for chlorine, hydrocarbon vapor, or oil mist. The chromium content in effluents as determined by material balance calculations is less than 50% of the 0.01 mg/l standard listed in Regulation No. 6 of the New Mexico Quality Control Commission.

Source	Effluent	Medium	Amount 1973	Amount 1974
Steam Plant	SO_2	Gaseous	6236 kg	1889 kg**
Development Labs	Hydrocarbon Vapor	Gaseous	1575 kg	1500 kg
Incinerators	Fly Ash	Gaseous	1850 kg	n.a.
Foundry	Chlorine	Gaseous	50 kg	50 kg
Wind Tunnel	Oil Mist	Gaseous	90 kg	n.a.
Photographic Development	Chromium	Liquid to the sewer	32 kg	35 kg
(All Sources)	-	Solid	none*	none*

*All solid chemical waste is buried in special disposal pits.

**Reduction was due to decrease in number of days fuel oil was needed.

Radioactive

Radioactive effluents released to the environment are very low. The 1974 data are typical for Sandia (Holley, 1975). During that year the following amounts were released to the environment (the concentrations are within ERDA and State standards):

Source	Effluent	Medium	Amount 1973	Amount 1974
Reactor Operations	Argon-41	Gaseous	6.85 Ci	5.05 Ci
Development Labs	Tritium	Gaseous	0.15 Ci	0.09 Ci
(All Sources)	-	Liquid	none*	none*
(All Sources)	-	Solid	none*	none*

*All solid and solidified liquid waste is buried as described in the section in Chapter II, titled "Waste Generation and Disposal."

External Radiation from Accelerators and Reactors

Of the numerous accelerators and reactors at SLA, none produces radiation measurable outside their buildings except the Hermes II electron beam accelerator and the SPR II reactor, both in Area V. The former produces a flux of 10 MeV gamma radiation directed to the east, and the latter produces a flux of mixed gammas and neutrons to the southeast out one of the experimental ports. The radiation fields from normal operation of these two machines have been determined by leaving TLD's (thermoluminescent detectors) for several months at numerous nearby places. The resultant contours of exposure rates within Area V proper, expressed in mrem/week, are shown in Figure 27. This figure indicates that radiation from Hermes II goes beyond the Area V fence to the east, and radiation from SPR II goes beyond the Area V fence to the southeast. The land for another half mile beyond the Area V fence is posted to exclude people. Thus only environmental effects on the flora and non-human fauna in this buffer zone are in question. Of the two "hotlines," the one from Hermes II is the more intense. Figure 28 shows the average weekly exposure along it.

The land in the buffer zone outside the Area V fence is nearly undisturbed grassland. It is exposed to radiation levels of as much as 1000 mrem/week or .14 rem/day. There are no standards for exposure of flora and other fauna, but several studies have shown that plants are not appreciably affected by much higher levels of radiation exposure (Fraley and Whicker (1971), Rhoads and Ragsdale (1971), Woodwell (1963)).

Some species of fauna found on Kirtland AFB East have been studied. Sacher and Staffeldt (1971) report that the mean lethal dose for the white-footed deer mouse, Peromyscus leucopus, is

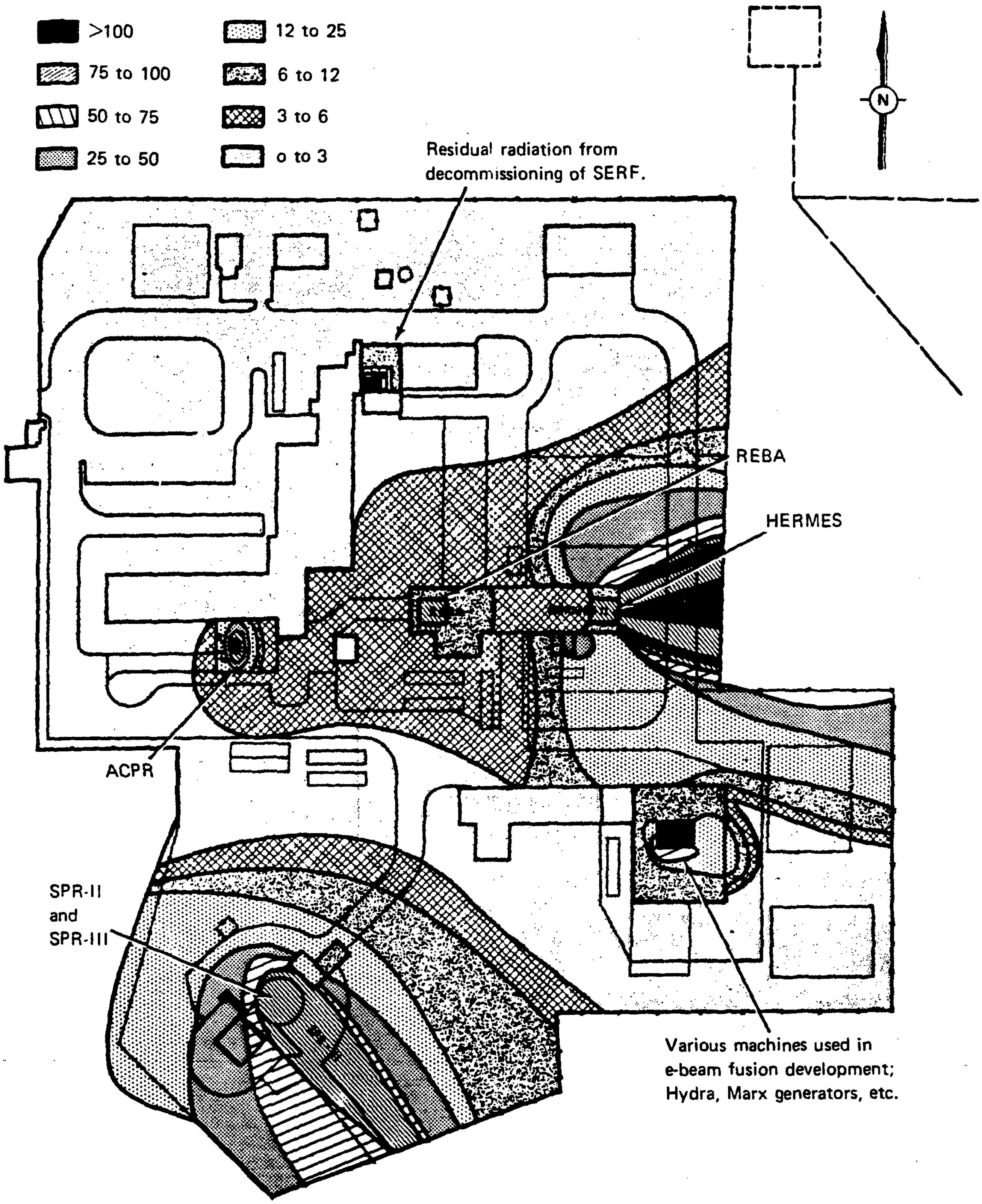

Figure 27. Radiation outside buildings in Area V (exposure levels in millirem/week)

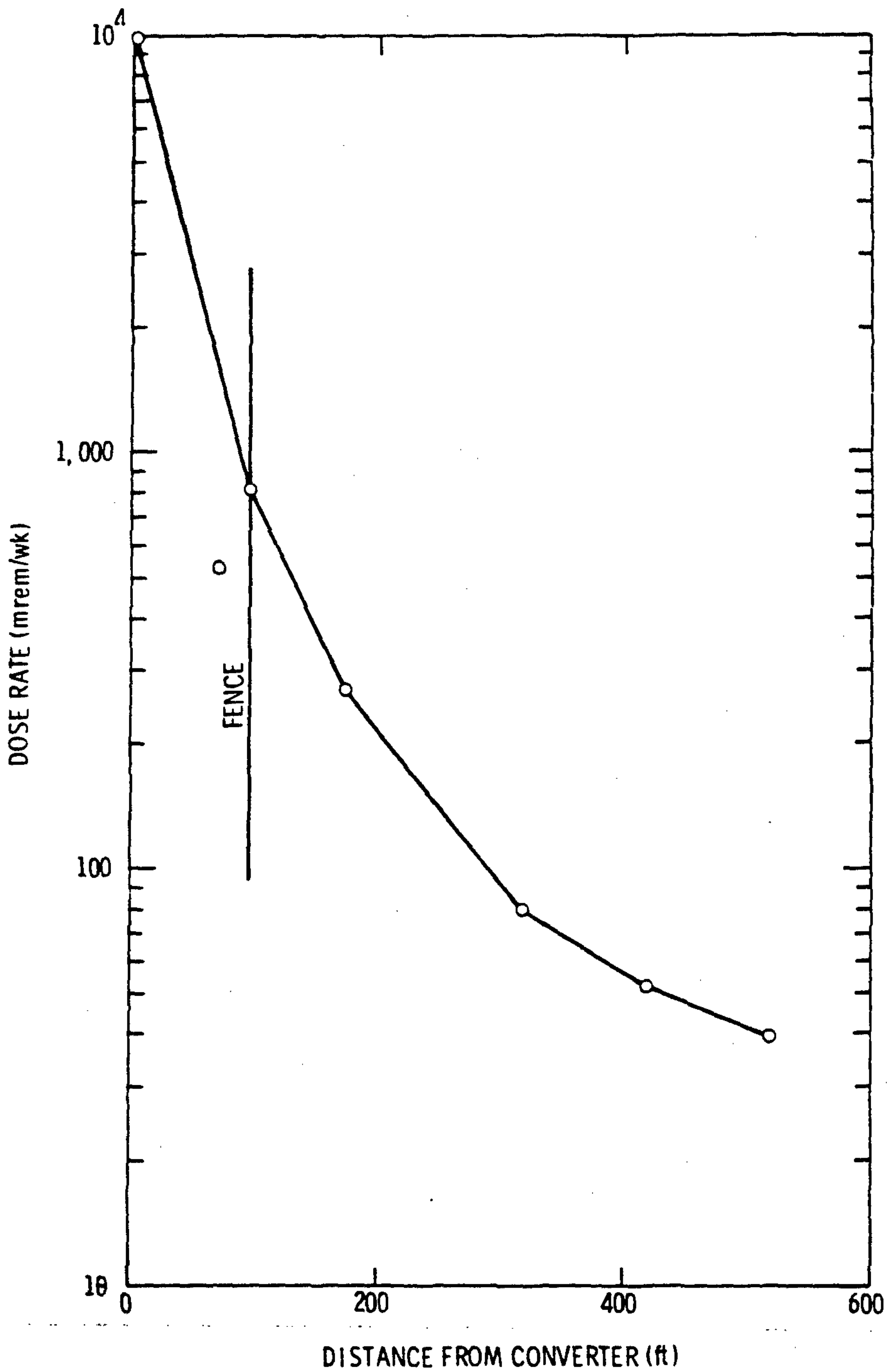

Figure 28. Radiation exposure rates in the direction of the Hermes II beam (to the east), into the buffer zone beyond the Area V fence, averaged over a typical week's operation of 20 pulses per week

1000 R for doses given in a short time (for man the comparable number is 400 R); exposed at levels of 24 R/day they survived a year or more. Other rodents are similarly resistant. Van Hook (1971) reports that grasshoppers (except in the egg stages of their life cycle) are at least twice as resistant as rodents to radiation.

Thus the radiation emanating from these two machines in Area V would not be expected to produce any effect on the grasslands it exposes, and it has not been observed to do so.

Operation of the Edgewood Test Site

Gun Firings -- The 12-inch gun is used at the Edgewood sites to test the penetration characteristics of various kinds and shapes of projectiles. This gun is truck-mounted, open at both ends, weighs 21,000 pounds, has a bore diameter of 12 inches, an external diameter of 19.2 inches, and a length of 35 feet. In its use a projectile is mounted on a sabot at the bottom, above that is a propellant charge, and above both of those is a reaction mass. The barrel must be erected before loading. Burning of the propellant forces the projectile downward to penetrate the earth and the reaction mass to fly upward.

The gun is normally fired 2 degrees off vertical so that the reaction mass will not come down on the gun. Calculations of its possible trajectory under the influence of a 50-knot following wind, with the maximum charge possible (1700 pounds of reaction mass ejected at 600 ft/s) indicate that the reaction mass would rise 5300 feet above ground level, and if the propellant were to be ignited while the gun was erected only 45 degrees above the horizontal, the reaction mass could travel 10,000 feet horizontally. At design weights (1100 pounds ejected at 500 ft/s) the horizontal distance decreases to 2750 feet if the wind is in the same direction as the lean of the barrel, or a lateral distance of 535 feet if the wind is perpendicular to the orientation of the barrel. (However, firing in a 50-knot wind is not permitted: the limit is 20 knots by reason of the static electricity hazard associated with propellants.) A safety distance of a mile has been established for this operation.

Gun firings produce three kinds of environmental impact. First, random cross-country tracks are made in putting the gun into position (a new place for each firing) and in stationing lookouts. Second, the reaction mass produces a scar on the land about 3 feet in diameter on landing. Third, the projectile fired downwards is recovered by digging with a back-hoe, leaving a scar on the order of 15 feet by 4 feet. All holes are refilled and grass seed has been furnished to the ranchers to control any possible erosion. Because they are not used in these tests, no toxic or radioactive materials are left in the ground.

Various safety precautions are taken during gun firings. The FAA is notified 24 hours in advance, and is kept in contact through an open radio link during each firing, to alert pilots in the area. Nearby dirt roads are barricaded, and observers are stationed at the corners of a 2-mile square to watch out for cross-country vehicles and aircraft. Clear visibility is required in all directions—10 miles with a 6000-foot ceiling—and surveillance radars are manned.

Airdrops -- Airdrops of inert shapes (no explosives, no radioactives) are made from light aircraft, often from low altitude. Calculations of the possible points of impact of the object dropped (its "footprint") vary greatly depending on the elevation and speed of the drop, the shape of the object, and whether or not it has a retarding parachute. In general the footprint is an ellipse with its major axis in the direction of the flight path, especially elongated for parachute-retarded drops because of the possibility of parachute failure.

The kinds of environmental impact of airdrops are two. First, there are random cross-country tracks made in putting into position the equipment and observers monitoring the drop. Second, the impact of the object on the ground produces a scar. Since, however, the same targets are used repeatedly for these drops, the scars tend to be localized. The ranchers are furnished with seed for replanting scarred areas.

Several guidelines developed for the Edgewood Test Site are followed by SLA's Test Operations Hazard Committee to determine if a test can be safely conducted at Edgewood and satisfy intangible items such as dust and noise, pollution and effects on neighboring ranches:

- Operations are limited to propeller-driven aircraft or helicopters and conducted under Visual Flight Rules.

- No operations are conducted in the controlled airspace above 18,000 feet mean sea level (12,000 feet above terrain), in excess of 250 knots indicated air speed, or involving acrobatic maneuvers.

- No operations shall involve classified hardware, or high explosives rockets or pyrotechnics which could cause range fires or off-range damage.

- Inert units without parachute retardation must have a 3-sigma impact "footprint" not greater than the target areas at ETS. If pre-test ballistic information is insufficient to establish such a footprint, then the minimum shall be a circular area with a radius one-half the release altitude above ground level.

- A unit retarded by parachute may be tested at ETS if chute failure, down time and drift parameters assure that the unit will impact within the cleared target area.

Demographic Impacts

New Mexico as a whole has experienced great impact from post-World War II government spending. It became the atomic capital of the country when the Los Alamos Scientific Laboratory was established in 1943. To benefit by nearness to Los Alamos, the armed services established nuclear weapons training, indoctrination, and study centers nearby in the Albuquerque area, at Kirtland, Manzano, and Sandia Bases (all since merged into one Kirtland AFB). Sandia Corporation (later Sandia Laboratories), an offshoot of Los Alamos, was set up in Albuquerque. Other new government facilities in New Mexico were Cannon AFB in Clovis, Walker AFB in Roswell (since closed), Holloman AFB near Alamogordo, White Sands Missile Range between Las Cruces and Alamogordo, and Fort Bliss (in New Mexico, although headquarters are in El Paso, Texas).

The long-term growth of New Mexico, Albuquerque and SLA are shown in Figure 29. New Mexico as a whole has grown at an average rate of 2.4% per year since the beginning of the century, with a pronounced slow-down to less than 1% per year in the last decade of record, 1960-1970. Albuquerque has grown much faster, at an average rate of 5.4% per year. This growth rate cannot, of course, be all attributed to Sandia and other government spending, inasmuch as part of it is the general demographic trend (throughout the U.S. and the world) of movement to the city. Nevertheless the government impact is to be seen in the accelerated growth of 1940-1960—also the period of great growth of Sandia—when Albuquerque experienced a growth rate of 9.1% per year, nearly doubling its population each decade. Since 1960, Albuquerque, like New Mexico as a whole, has slowed its growth, dropping to 1.9% per year. Not entirely by coincidence, in 1964 SLA also stopped growing, and has in fact become smaller; in 1964 it had 7100 employees and in 1974 5400 employees in the Albuquerque area, (and 1000 elsewhere) of which 1750 (or 32%) were recruited from the local population. The turnover in the latter, and hence the rate of new job openings becoming available is very small, about 60-100 per year, or 3-6%. At this size, Sandia Laboratories is the third largest single employer in Albuquerque. KAFB employs 7000; the Albuquerque Public Schools, 6050. Assuming an average family size of 4.3 persons per employee, Sandia thus accounts for 7.4% of the population of the Albuquerque area.*

The Sandia Albuquerque payroll is now about $93 million a year; purchases in New Mexico added another $34 million in calendar 1974 (Figures 30 and 31).

In other respects than economic, the Sandia impact on the community is considerable. As an example, consider employee and corporate support of local charities. Sandia has an Employee Contribution Plan (ECP), which in 1974 raised $413,845. Of this, 85.2% is allocated to the Albuquerque United Community Fund (UCF), which supports 34 agencies. Almost all the remainder goes to local chapters of national funds. So far as individuals are concerned, 85.5% of employees

*The Albuquerque area is taken as the Census Bureau's Albuquerque SMSA (Standard Metropolitan Statistical Area), coincident with Bernalillo County, and with a population of 315,774 in the 1970 census.

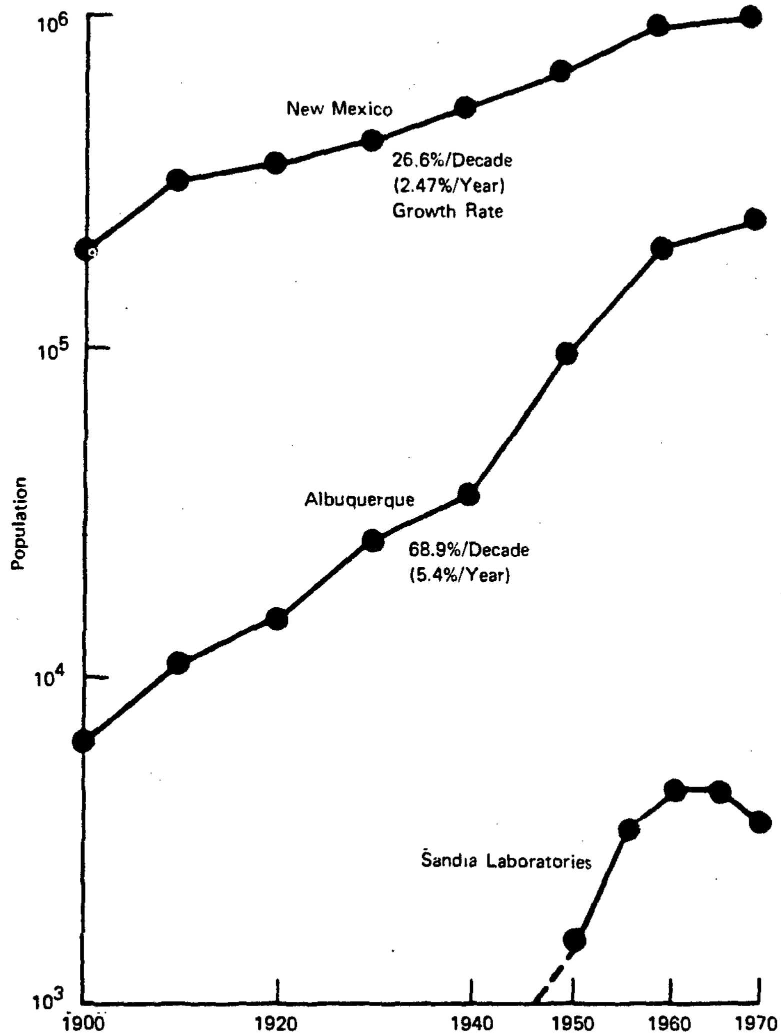

Figure 29. Population Growth in New Mexico, Albuquerque, and Sandia Laboratories, 1900-1970

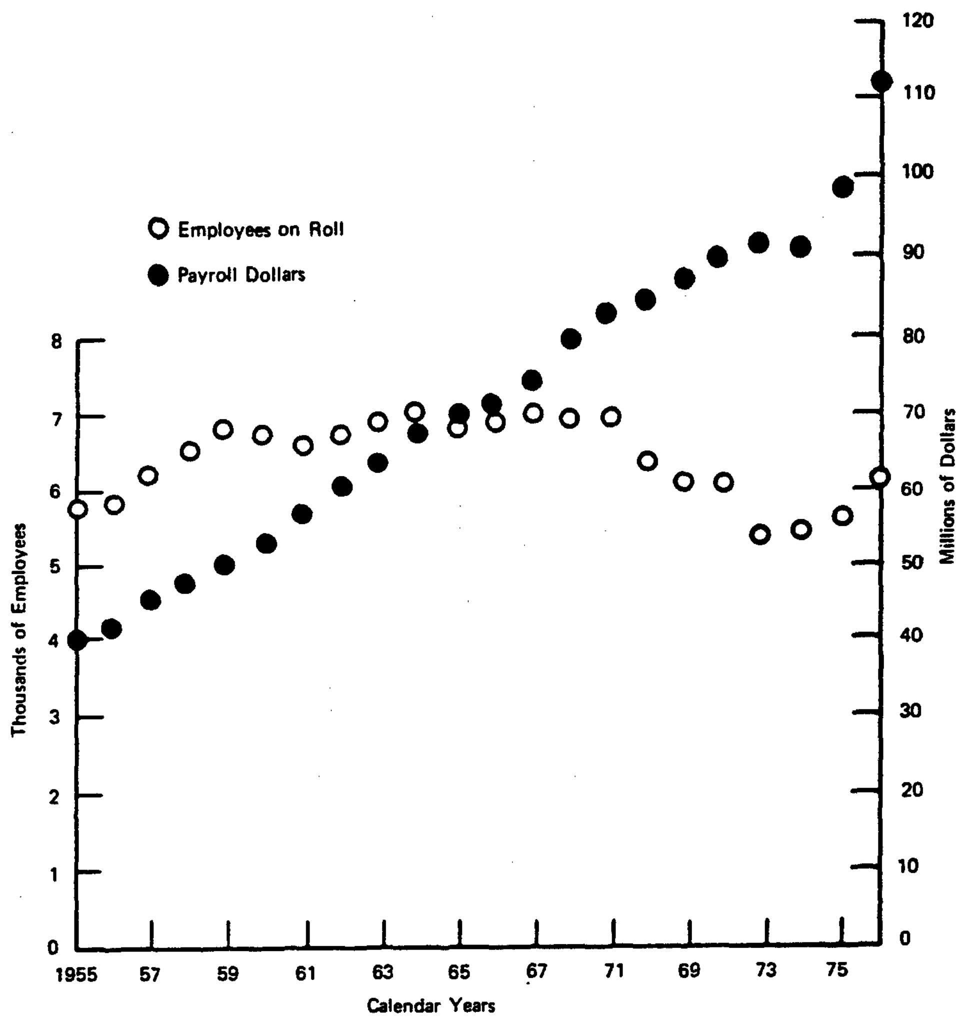

Figure 30. SLA employees on roll and gross annual payroll since 1955

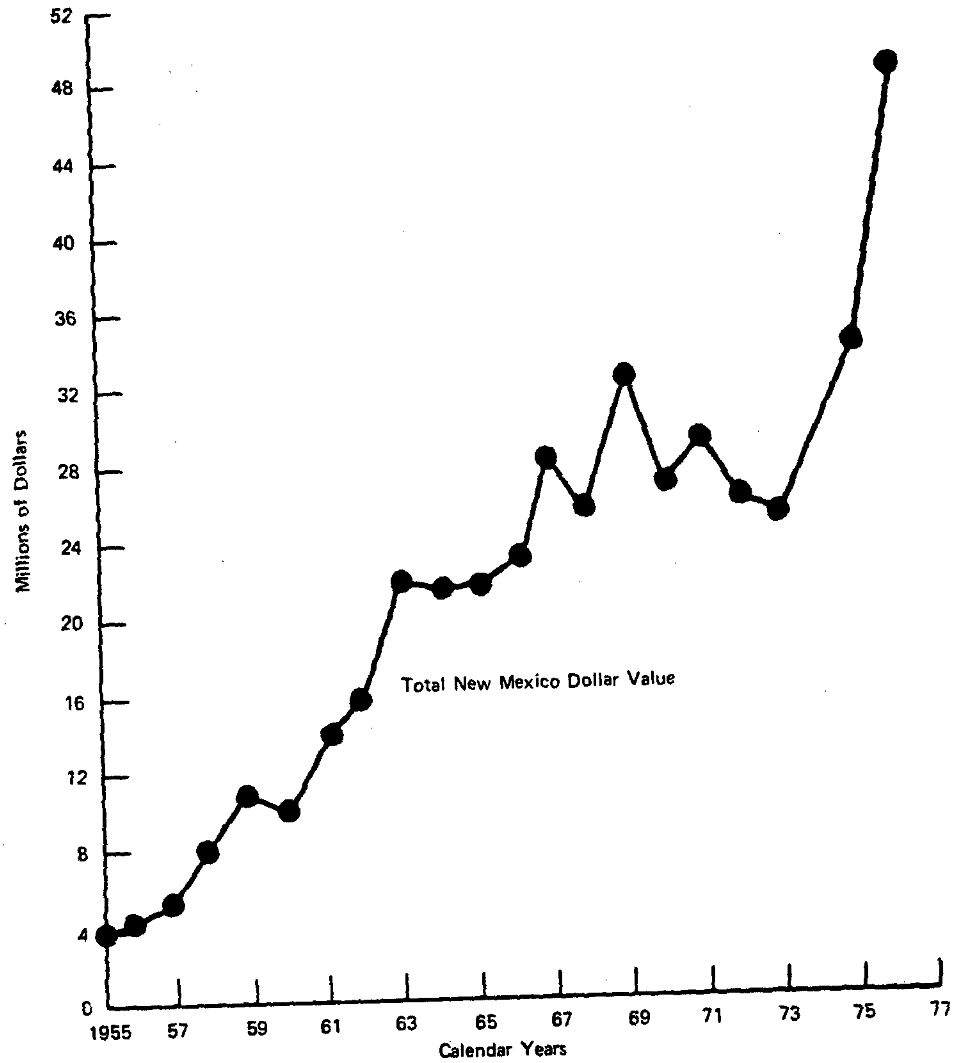

Figure 31. SLA purchasing activity in New Mexico since 1955, including construction

participated in the 1974 ECP, with an average annual contribution per participant of $87.33. The employee gifts to the UCF have amounted to about 20% of the UCF annual total budget for each of the past 15 years (Figure 32).

Sandia employees also serve as individuals in a wide variety of local political, cultural, and religious positions. For example, there are at present one Sandia serving in the New Mexico Legislature, two as County Commissioners (one for Bernalillo County and one for Valencia County), one as Mayor of Edgewood, and one as a member of the Albuquerque City Council. Only the last position has any stipend associated with it.

Sandia has a wide variety of educational programs designed to upgrade its staff, plus a few directed at the community and not necessarily at its own people. The Youth Opportunity Training Program had 52 participants in the summer of 1974. This program gives summer jobs to students who need financial assistance in continuing their education, and includes a limited number of high school students. The Student Development Assistance Program had ten in it during summer of 1974. It gives summer employment to students who are part way through an engineering or science major. It is being phased out in favor of a work/study program for the disadvantaged. The Work Education Experience Program employed 13 students the summer of 1974. It is a program for part-time work opportunities with local high schools. In conjunction with the Albuquerque Technical-Vocational Institute, there is a Cooperative Training Program for the Disadvantaged, just starting, aimed at producing salable skills to those who do not have them. Finally, a new venture with the Albuquerque Public Schools is a Science Program designed to interest 9th and 10th graders in science and engineering careers.

Closely allied to these educational ventures with strong flavors of concern for the hitherto disadvantaged, is Sandia participation in the National Alliance of Businessmen. Two men from Sandia are on full-time loan to that group, which specializes in training people for jobs, including those who cannot qualify for Sandia employment because of the requirements for a security clearance.

Finally, one might mention a miscellany of other services the Labs offer to the community, such as a Speakers' Bureau for organizations needing program help, a Science Exhibit Center, two annual Science Youth days, and films available for circulation to educational institutions.

Traffic

In 1973, 85% of the SLA employees came to work in single-passenger cars. There were two commuter buses. A very few employees walked or rode bicycles to work. As part of its response to the energy crisis that erupted that fall and winter, SLA made several changes to encourage employees to shift from cars to other modes of transportation, and thus to decrease their consumption of gasoline:

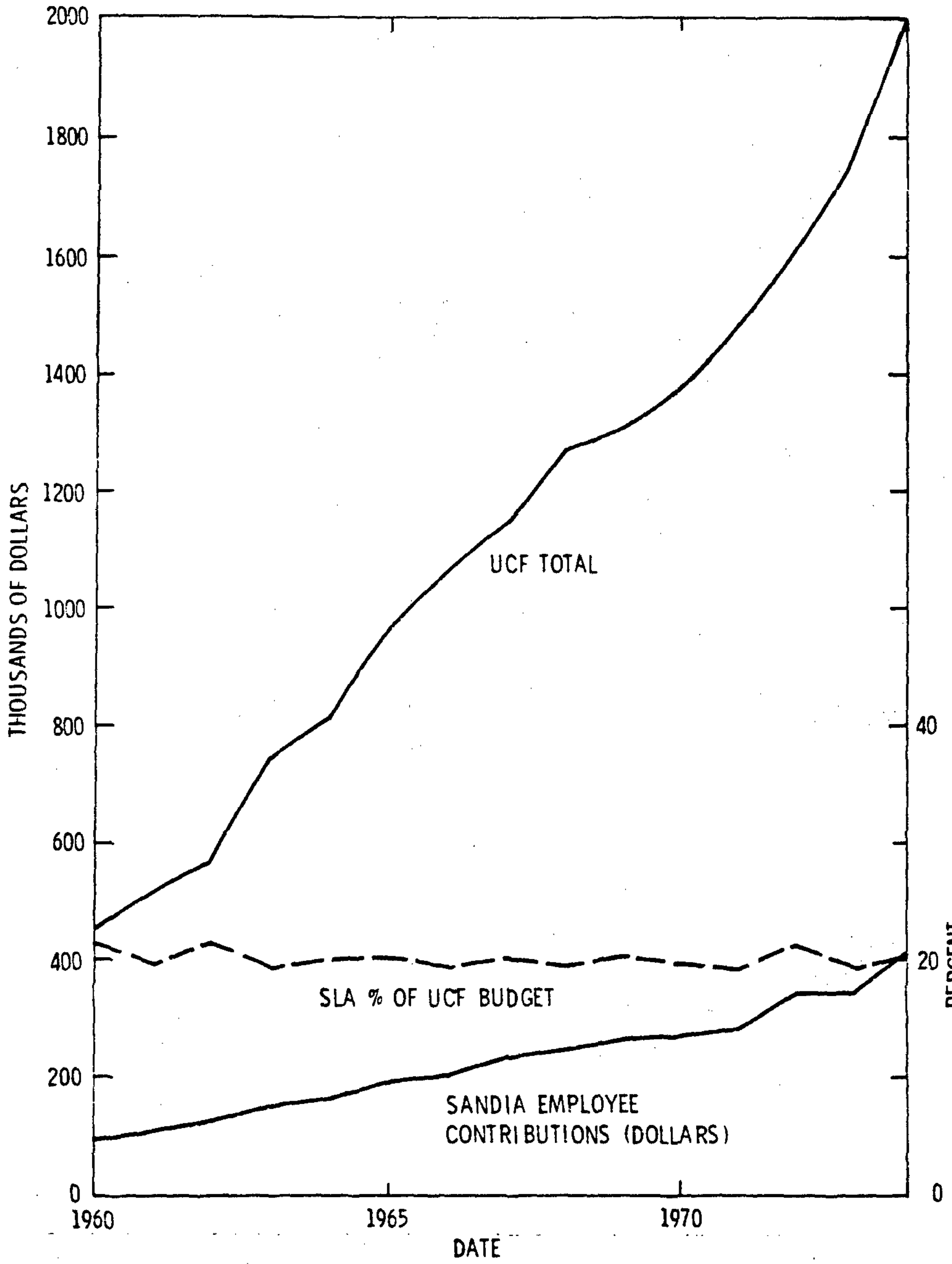

Figure 32. SLA contributions to Albuquerque United Community Fund

- The hours of work were changed to 8:00 a.m. to 4:30 p.m., with only a half hour for lunch, to discourage employees from driving off-base for lunch (an accompanying detrimental effect was the loss of business by nearby restaurants).

- An Employee Transportation Committee of five people was set up to find less energy-consumptive means of transportation.

- A computerized system borrowed from the Department of Transportation was used to match employees living in the same neighborhood into possible car pools.

- Car pools were given reserved parking spots convenient to the gates used by their passengers to enter the Tech Area.

- Numerous commuter buses were set up to make it more convenient for employees to take the bus to work than to drive their own cars.

- Three shuttle buses were established to take those arriving by bus to the remote areas (and hours of work in those remote areas were set at 8:15 a.m. to 4:15 p.m. to permit use of those shuttles).

As of June 6, 1974, there were 558 registered car pools serving 1373 employees. About 275 employees had taken to riding motorcycles or bicycles or walking to work on a regular basis. (In very good weather this number swells to 375; in very inclement weather it drops to nearly zero.) Five commuter buses following city routes and four serving rural areas transport about 330 employees. (If the city had more equipment available, four more routes could be set up immediately.) The remainder of the 5400 SLA employees continue to come to work in their own cars. In summary, about 4000 motor vehicles a day are used to transport employees to SLA. Since about 10% of these are on irregular or odd-shift schedules, about 3600 vehicles driven by SLA employees come into the base between 7 and 8 a.m., and leave between 4:30 and 5:30 p.m.

On the basis of a survey made in mid-1974 responded to by 60% of the employees, the average round-trip distance driven each day in each of these vehicles is 17 miles. Thus the existence of SLA entails about 68,000 vehicle-miles a day (1.36 million vehicle-miles a month) of automobile traffic in the Albuquerque area, and the accompanying discharge of pollutants into the atmosphere that this traffic produces.

Accident Analysis

Area I

Noxious Gases -- The physical electronics laboratory uses ammonia as a source of hydrogen for reducing-atmosphere furnaces. It is stored in two tanks on the north side of Area I (Figure 6). The supply tanks have between them a capacity of 280 ft^3 (2000 gallons). Small leaks have occasionally occurred in the piping to these tanks, and therefore a more serious leak must be considered possible.

It is not considered credible that the tanks themselves would ever fail; they are built to all industrial codes, having for instance a wall thickness of .32 inch in their cylindrical section. All the connections to the tanks enter their top sides, so that a leak would release the vapor in equilibrium with the liquid anhydrous ammonia in them. On a normal hot day in Albuquerque (100°F), the internal pressure of these vapors is 212 psi. If one assumes a pipe separation of 1/16 inch, half way around a one inch pipe, the area of the orifice would be .2 $inch^2$ (1.26 cm^2). Using the standard formula for flow through an orifice, (Marks, 1941, p. 354) and allowing for a coefficient of discharge of 60%, the initial release of ammonia would be at the rate of .56 lb/sec (250 g/sec). Then, using the Sutton diffusion equation, and assuming a weak lapse rate in the atmosphere (an inversion is inconsistent with a ground level temperature of 100°F) and therefore using the meteorological constants in the second line of Table X, Chapter II, we predict that the downwind concentrations would be:

$$TID = 404/d^{1.75} \ (g/m^3),$$

where d is the downwind distance in meters. Since the nearest base housing is 450 feet (137 m) from the ammonia tanks, the formula predicts ammonia concentrations there, if the wind is blowing in that direction, of 74 mg/m^3. This level is four times the Threshold Limit Value permitted for continuous exposure in the workroom environment (18 mg/m^3, ACGIH, 1974), and twice the noticeable concentration (38 mg/m^3, Henderson and Haggard, 1943), but well below the irritating or dangerous levels (300 and 1800 mg/m^3, ibid).

For persons closer to the source, the expected concentrations would be higher, and could be dangerous. For this reason, the laboratory and the building where the ammonia is used is equipped both with masks to let people escape the vicinity of such a leak, and with Scott air packs to let repair crews approach and fix it.

Methane Storage Tank -- The methane storage container is built to ASME specifications. It has double wall construction, with an inner wall of .500 inch thick nickel steel and an outer wall of .437 inch thick steel. The space between the tank and the casing is filled with MPS-165 Perlite. The Maximum Allowable Working Pressure (MAWP) is 250 psig at 100-320°F, but this tank has been hydrostatically tested to 420 psig. The burst disk is rated at 265 psig and the relief valve is set to 220 psig. The outer casing has a MAWP of 15 psig. The following codes were applied for the plumbing connected to the Methane Storage Tank:

Fittings	ASA B-16.11
Valves	ASA B-2.1
Piping	ASTM 120
Welding	ASA B-31.1, Sec. 6

Relief valves are ASME-rated and Materials-Board certified.

SLA Safe Operating Procedures are in effect for this tank and its controls and for the truck-to-tank fill. Emergency procedures relative to leaks, spills and fire control are also in effect.

A small leak of the type and size that would occur as the result of a failure at a pipe fitting, presents no significant hazard since the flow of methane could be stopped by a remotely operated solenoid valve at the base of the tank. Methane gas released by a small leak (as much as 20/30 gallons per minute) would be diluted with air to below the lower flammable limit within short distances of the break. A wind velocity of 10 mph would eliminate the hazard of a small leak.

Filling the tank from an over-the-road truck creates an opportunity for leaks and spills, so this work is confined to nonoperational hours. The tank is surrounded by bumpers to preclude vehicle impact. The worst credible accident that could occur would be a fire in the truck during tank filling that would eventually ignite collected gas vapor and start missiles flying. There also would be noise, the possible rupture of the truck or storage tank and the further release of flammable gas. The procedures in effect during the filling operation make this accident extremely unlikely. A foam truck stands by during filling. A fire and explosion of this sort would require preventive evacuation of nearby housing.

Tritium Release -- The largest quantity of tritium present is in the Area I Vault, where it is stored temporarily for ERDA while in courier transit elsewhere. The handling of this tritium is minimal; it arrives and goes out in sealed containers that are never opened. The vault is of reinforced monolithic concrete, with 12-inch walls and a 12-inch roof.

In the course of Sandia Laboratories' normal mission, tritium is used in two other places in Area I, in milligram quantities in one place and in tenths of gram quantities in the other.

The only possibly credible release of tritium from the Vault would be from one of the standard shipping containers. It is much more probable that an inadvertent release of tritium would take place in one of the buildings where it is being used, and in this case we must postulate a release of about a tenth of a gram of tritium (10^3 Ci).

All three facilities are equipped with tritium air monitors, with emergency sources of automatic diesel or battery power not dependent on the maintenance of electric utility power. If a release were to take place, it would be made known quickly by visual and audible indicators both at the site of the release and at the guard offices, which are manned all hours of the day and night. If the release were to occur at the Vault, such an alarm would also double the rate of flow of the ventilation system, to purge the building for the safety of the people working there and to permit recovery operations.

To estimate the possible consequences of such a leak, we shall assume it involves 0.1 grams (10^3 Ci) of tritium. The release would be in the form of tritium gas, a form which is very much less hazardous than tritiated water (HTO) and which converts into HTO at a rate of about one percent per hour. In order to have a conservative estimate (i.e., one that errs on the high side) we shall assume a strong temperature inversion that will hold the cloud together and maintain maximum concentrations downwind, using the meteorological parameters in the last line of Table X, Chapter II. Further we shall assume a wind from the south toward the base housing area that does not change its direction during the time needed for all the tritium to leak out of the building. With those assumptions the total integrated downwind concentration (TID) would be:

$$\mathrm{TID} = \frac{2Q}{\pi C_y C_z u d^{2-n}} = \frac{19,900}{d^{1.5}} \qquad (\mathrm{Ci\ s/m^3})$$

where d is the downwind distance measured in meters. Breathed at a rate of $2.8 \times 10^{-4}\ m^3/s$, the total quantity of tritium inhaled by a person in the path of the cloud would be:

$$\mathrm{QI} = \mathrm{B} \times \mathrm{TID} = 5.6/d^{1.5} \qquad (\mathrm{Ci})$$

The actual distance to the nearest base housing is 800 ft. (250 m). Substituting in the last equation, the quantity of tritium gas inhaled by a person in the open in the path of the cloud would be 1.4 mCi. With a wind speed as assumed of 2 m/s, the time to reach that housing would be 125 s, and since the conversion rate of tritium gas into HTO is 1% per hour, the quantity of HTO inhaled would be

$$1.4\ \mathrm{mCi}\ (0.01/\mathrm{hr})\left(\frac{125\ \mathrm{s}}{3600\ \mathrm{s/hr}}\right) = 0.5\ \mu\mathrm{Ci}$$

or, using the usual conversion factors, a one-time dose commitment of 0.1 mrem, very small compared to the allowable dose per year of 500 mrem to a member of the general population.

In addition, there is a dose to the skin (and only to the skin because of the low penetration power of beta radiation) from submersion in a tritium cloud. Without going into the details, it can be shown that the second formula above is equivalent to a submersion dose of

$$D_{sub} = 47/d^{1.5} \quad \text{(rem)}$$

or at 250 m, a dose of 12 mrem. This dose is about 1/250 of the 3 rem/yr permitted to the skin of a member of the general public.

The classified quantities of tritium sometimes present in the Area I Vault have been similarly analyzed, and also yield doses to the base public considerably less than the standard Radiation Protection Guides (ERDAM 0524).

Boiler Explosion

A boiler explosion could occur as a result of pressure vessel rupture or a fuel-air explosion in the firebox. Either of these types of conditions could conceivably cause the other. Such explosions would cause moderate damage to the adjacent boilers and the building housing the boilers, but no significant effects outside Technical Area I would occur.

The likelihood of a pressure vessel rupture is minimized by annual inspections conducted by boiler inspection experts from Factory Mutual Engineering Association. During these annual inspections the safety relief valves are checked for proper operation. Routine checks following safe operations procedures are also conducted.

Flame safeguard controls are installed on the boilers to reduce the possibility of a fuel-air explosion in the firebox.

Airplane Crash on the Oil Tank Farm -- The oil tank farm is about 1.4 miles away from the east end of the main runway of the Albuquerque International Airport and in line with it. An analysis has been made of the probability of an airplane crashing into the tank farm on takeoff or landing (Appendix E). The essence of the analysis is that national statistics indicate that a plane has a probability of 2×10^{-6} of crashing on takeoff or landing. If one further estimates where such an impact might be, the net probability of hitting the tank farm is reduced to between 1.5×10^{-9} and 1.3×10^{-8} per takeoff of landing.

Since the analysis of Appendix E was made, it was determined that an overestimate had been made of the amount of traffic at the airport; the proper figure is 420,000 takeoffs and landings per year (FAA, 1974). Combined with the probability above, this means that the annual probability of the oil tank farm being struck by an aircraft is between 6.3×10^{-4} and 5.5×10^{-3}, or in other words, that there would be an interval between such accidents of between 180 and 1600 years.

If there were to be an aircraft crash on the oil tank farm, the probable consequences would be death of the crew and passengers and a fire involving the contents of the particular tank struck. The berm around each tank is high enough to contain twice its entire contents. It is improbable that the crash would also break the berm, so the fire would not spread. The base fire department has the capability of extinguishing such a fire with foam, but this could not take place soon enough to prevent a large plume of smoke being formed, which with the prevailing winds would more often than not drift downwind over the residential areas of the city.

If the berm were to be broken, with or without a fire being started, roadside ditches and the natural slope of the land would cause the oil to flow to the southwest and into Tijeras Arroyo. How far and how fast the oil would flow would depend on how much fuel oil was in the broken tank, how big the break in the berm was, and how much oil would soak into the ground en route. Except at the edge of the arroyo, the slope is about 50 feet per mile (1%). An attempt would be made to throw up an improvised dam with a grader or dozer in the path of the flow, or diverting it from sensitive points. The nearest point of concern along the potential flow path is the Police Honor Farm three miles downslope; three miles beyond that Tijeras Canyon opens onto the Rio Grande Flood plain with its associated agriculture. It is not possible to say a priori how bad such an accident would be, except that it would be a serious matter both humanly and environmentally.

Transportation Hazards -- The very distances and numbers of peoples involved mean that there are traffic accidents of the ordinary sort associated with SLA operations. In recent years (1968-1974) there have been on the average 48 traffic accidents a year involving only property damage, 7.6 accidents a year with minor injury to persons, and 3.5 accidents a year with injuries severe enough to cause loss of time from work. There has never been a work-related traffic fatality to SLA persons on the base.

The dangerous materials SLA transports about the base are fuels, explosives, radioactives, and noxious gases. Fuels are transported according to Department of Transportation regulations designed to prevent accidents, insofar as this is possible; this hazard is not peculiar to SLA operations. Noxious gases are also transported according to DOT regulations; in a previous section the hazard of off-loading methane was discussed. Explosives and radioactives remain to be discussed at greater length.

Except in very small quantities, no explosives are allowed in Area I. Shipments received from commercial suppliers are taken directly to the igloos where they are stored, using routes through the base specified by base authorities. Transportation thereafter of quantities needed for day-to-day operations are moved from these igloos to sites of use by a specially designated and trained group within SLA, using Safe Operating Procedures (SOP's) consistent with base regulations and approved by SLA's safety organization. These SOP's specify vehicle inspection, loading, and marking; permitted speeds and hours of movement; and especially forbid the mixing of incompatible explosives (e.g., detonators and Class 7 explosives) and movement or other operations during times of high atmospheric potential gradient.

These SOP's reduce to a practical minimum the possibility of transportation accidents resulting in the detonation of explosives, something that has never happened in any SLA operation. Yet if such a detonation were to occur it would have a locally significant environmental impact.

The consequences of an accidental detonation might include injury or death of persons nearby; they would also include a shock wave, a crater, dust and soil debris, and possibly scattering of burning brands of wood or pieces of explosive. By way of example, a 100-pound detonation on soft ground would produce the following effects:

Effect	Up to Distance (feet)
Overpressure of 5 psi	70
Crater, diameter at original ground level	12
Dirt thrown	15
Dust cover of 0.2 inch thickness	440
Missiles or larger fragments thrown	2800

Although an overpressure of 5 psi may break a man's eardrums (Hirsch, 1968), rodents and other small mammals are presumably more resistant because of their smaller eardrums. A dirt cover may smother vegetation. Dirt clods or missiles formed from breakup of containers will produce disruption of the vegetation where they impact. Fire may be started by burning brands or pieces of still-burning explosive; how far these fires might spread would depend on the nature of the ground cover nearby.

The radioactive materials at SLA that must occasionally be moved include tritium, weapons mockups containing fissile materials, uranium, and a few radioactive sources. (For instance, sometime in 1975 the 258-kg charge of ^{235}U for the SPR-III will have to be moved to Area V. Also, delivery is expected in 1975 of a megacurie ^{60}Co source to be used in Area V for studies of biological sterilization.)

Materials are shipped into SLA by common carrier following DOT regulations. (If classified or Special Nuclear Materials are involved, they are ERDA couriered. Where needed, requirements for labelling and for separation of explosives and radioactive materials are waived under a National Security Exemption. All other DOT regulations are followed.) Radioactive shipments are received at the Area I Vault, and distributed from there to the prospective user. Movements on the base are in the care of the SLA Health Physics organization, who must adhere to the ERDA regulations of Manual Chapter 0529 (Safety Standards for the Packaging of Fissile and other Radioactive Material). These regulations prescribe standards for packaging, labelling, permitted external radiation, and criticality safety.

These ERDA regulations reduce to a practical minimum the possibility of a significant release of radioactivity in the course of handling or transportation, and in fact there has never been such a release by SLA on base since SLA was established. Still, the potential impact of such a release must be discussed.

Release of tritium is discussed in a previous section, and that discussion is equally pertinent here. There would be no permanent deposition of tritium on the ground, and the potential exposure of persons during cloud passage would be below guideline levels beyond a distance of about a hundred yards downwind. The exposure of the native fauna would in general be greater than man's. Since small mammals have a higher metabolic rate than large ones, one would expect their ratios of breathing rate to body weight to be higher than man's and hence one would expect them to receive greater exposures. Using Brody's (1945) estimate of the dependence of basal metabolism on weight, ($M/W = 3.8\ W^{-0.27}$, where M/W is the metabolic rate in cc $O_2 (g\ hr)^{-1}$ and W is the weight in grams), a 4-g rodent would be expected to have a basal metabolism 14 fold greater than a 70-kg man. Since with the native fauna one is concerned with populations rather than individuals, this greater exposure is acceptable.

Accidents to plutonium-containing mockups are discussed in a later section in context of Area III environmental testing, which includes subjection of such mockups to impact shocks and excessive temperatures, but not to fire. The greatest concern in a transportation accident is the possibility of a gasoline fire combined with a broken shipping container. As indicated below, even then very little plutonium would be released as respirable particles, and there would be no significant hazard to humans beyond 200 yards downwind from cloud passage. There would be residual surface contamination of perhaps 2.5 acres to levels over Healy's (1974) suggested soil deposition limit of 8 $\mu Ci/m^2$. The accident hypothesized might happen anywhere in Area I or between there and Area III, the material's probable destination. Wherever it might be, decontamination would likely be called for, and the resulting removal of vegetation would constitute a locally significant environmental impact.

Area II

There was no serious accident found in analyzing Area II operations.

Area III

In order to ensure personnel safety, hazard zones are established around each potentially hazardous test. These hazard zones are cleared of personnel and the access points into the hazard zones are posted with signs warning of the hazard. In most instances the hazard zones are within the boundaries of Area III.

Track Testing -- Test vehicles are propelled southward on the track, by solid propellant rocket motors, at speeds up to 6000 ft/sec (approximately 4,000 miles/hr). These vehicles are stopped in one of three ways: (1) by water brake (from speeds up to 3,000 ft/sec); (2) by impingement onto a target; or (3) by parachute deployment after a short free flight. Various test requirements determine the deceleration procedure.

The potential hazards associated with the test track operation are shrapnel, noise, overpressure, fire, toxic discharges, and missile hazard of a controlled or uncontrolled test unit.

Shrapnel can result from detonation of HE in test units or possibly from explosion of the propulsion rockets or from fragmentation of targets or impacting test vehicle parts. The worst-case range of fragments is 4,000 to 5,000 feet in any direction from the origin. Only minor environmental effects on plant life are envisioned. Such effects would be confined to the localized uprooting of grass or small shrubs at the point of impact of the larger pieces of shrapnel.

Overpressure results from detonation of HE or from sonic booms. The shrapnel hazard radius exceeds the distance of excessive overpressure.

Noise is caused by sonic booms from sleds traveling at supersonic velocities. Beyond the limits of excessive overpressure (4,000 to 5,000 feet) noise becomes only a nuisance to public areas. At the west boundary of Area III pressures caused by sonic booms have been measured up to 0.25 pound per square inch, which is considered a level which will not damage human hearing. Calculations indicate that overpressures would be approximately 0.05 psi at the west boundary of the west buffer area. Since persons in residential areas begin to complain at pressures above 0.007 psi, there might be occasional complaints if a residential area were ever established adjacent to the west boundary. However, since this is presently state-owned land, the possibility of its becoming a residential area does not appear to very realistic within the next decade.

Fire is a consideration since every test has the potential of starting a grass fire south of the track terminus. The source is primarily from burning rocket liners which continue to smolder for some time after rocket burnout. When the sled stops on the track there is usually no problem, but in impact or off-the-ramp tests, burned out rockets are scattered and fires may be started. Protective measures include bladed firebreaks, patrol of the areas after each test, and Fire Department standby for all tests which are expected to present serious problems.

Toxic Discharges sometimes result from facility operations. Whenever toxic materials are involved, tests are coordinated with and monitored (including documentation) by Environmental Health personnel to assure protection of both operating personnel and the general public. Test restrictions are prescribed, wind speed and direction are established, protective clothing is issued, buffer areas are cleared and other precautions are taken as necessary to assure quick detection and corrective action of any irregularity. Noxious gases are released in the rocket exhaust, along with quantities of carbon dioxide, water vapor, hydrogen, aluminum oxide and nitrogen. Hydrogen sulfide is not a significant factor because the quantity is small. Only two gases are considered toxic under usual operating conditions—carbon monoxide (CO) and hydrogen chloride. Maximum concentration occurs in line with the track, but no one is there. Concentrations of these two gases at 10,000 feet from the end of the track compared to the Threshold Limit Values (TLV) set by the American Conference of Governmental Industrial Hygienists (ACGIH, 1974) are:

Gas	Acute Exposure TLV	Sled Track Concentration
CO	0.083 g/m^3	0.023 g/m^3 maximum
HCℓ	0.007 g/m^3	0.022 g/m^3 for 12 minutes

In any case, because the cloud is transient, the excess concentration of HCℓ is not a hazard or polluting condition.

Controlled Free-Flight Test Units are launched off the end of the track. These tests are run to obtain flight environment information, and often to recover the high-speed test vehicle by parachute. Control of travel distance in the direction of flight is maintained by use of drag devices which actuate upon launching, backed up by self-destruct systems (for high-speed vehicles). Lateral control, where the flight unit drifts beyond predetermined limits, is obtained by integrating accelerometers with self-destruct systems. These combinations of control methods and devices are considered sufficient to assure that the maximum travel would not exceed five miles and the dispersion cone would not exceed 30 degrees. Both the distance and dispersion cone are within the established buffer zone to the south.

An Uncontrolled Test Unit could result from structural failure of a sled or brake shoes or separation of propulsion rockets. For structural failure at maximum vehicle speed of 10,000 ft/sec, the travel distance would approximate that from an explosion—10,000 feet downstream from the point of failure. Experience over a period of several years shows that the dispersion cone will not exceed that of field artillery pieces, a central angle of 30 degrees. Calculations show that a powered rocket coming loose from a vehicle has a maximum potential travel distance of about three miles, but because of poor aerodynamic qualities would almost certainly be limited to half this distance. Of the 22 different solid-propellant rockets that might be used on the track, the Gila IV rocket, with an average thrust of 35,800 pounds and a burning time of 1.4 seconds, will attain the highest terminal velocity (7358 ft/sec). If this rocket were not stopped but were deflected upward at the end of the thrust phase, it would become an airborne missile. The Gila IV rocket could attain a terminal velocity of 7358 ft/sec and if deflected at the optimum angle, it would have a maximum range of 1.2 miles, well within present buffer zones. The maximum altitude associated with this trajectory would be 1469 feet above local terrain, well within the 4,000-foot ceiling permitted by the Joint Firing Area Coordinating committee regulations. Since it is not possible to predict an uncontrolled event, prior notification of air space disturbances above 300 feet cannot be given.

Environmental Testing of Assemblies Containing High Explosives -- Assemblies containing various quantities of high explosives are subjected to a variety of mechanical and thermal tests at the facilities in Area III. Precautions are taken to insure that all electrical circuits which could initiate detonation are interrupted. However, the possibility exists that the high explosive may detonate as a result of the mechanical or thermal testing. The maximum possibility for effects outside Area III from shrapnel and overpressure would be for the detonation to occur at an outside test facility such as the 35-foot centrifuge or test ramp. Only minor environmental effects on plant life are envisioned. Such effects would be confined to the localized uprooting of grass or small shrubs at the point of impact of the larger pieces of shrapnel.

Assemblies containing as much as 50 pounds of high explosive have been tested at both the centrifuge and test ramp. Using the missile range calculated from the formula $d = 600W^{1/3}$, where d is the range in feet and W is the weight of the high explosive in pounds, the maximum shrapnel range is 2210 feet from the point of origin of the detonation. The range for damaging overpressure from a high-explosive detonation is nominally about one-half the range for shrapnel.

Thus both shrapnel and damaging overpressure effects are confined to Laboratory-controlled areas with the exception of air space where both shrapnel and overpressure in excess of 1/4 psi would extend above the 300-foot level. Scheduled disturbances in the air space above the 300-foot level require prior notification so that aircraft may be warned.

Plutonium-Bearing Mockups

The existence of plutonium-bearing mockups of nuclear weapons in various buildings in Area III raises questions about the possible spread of plutonium as the result of an accident or fire. These mockups are present in Area III several times a year for exposure to environmental testing (temperature cycling, mechanical shock, and vibration) and for X-ray examination.

In such a mockup the plutonium is buried inside a metal case and within a plastic simulant of what in a real weapon would be high explosive. This simulant is not flammable, but can burn slowly like a hard wood such as oak. During the testing, the whole may be further enclosed within a sturdy metal shipping container.

The temperature test building in Area III represents a worst probable accident condition. It is a metal building 76 x 162 feet in size, surrounded by a chain link fence, alarmed against instrusion, and routinely checked by roving guards. It contains up to five gallons each of flammable materials, principally refrigeration oil, hydraulic oil, vacuum pump oil, solvents, as well as paper and wooden boxes. Factory Mutual inspectors surveyed SLA facilities in 1972, and advised the AEC of the fire risk to the contents of this building and of the value of these controls; as a result, it was decided that the cost of a sprinkler system was not warranted. No explosives or propellants are permitted within the building. There is an automatic fire alarm system with a connection to the base fire department, with a nominal response time of 5-1/2 minutes after the alarm has been set off. Heat for the building is supplied by an oil heater in a utility room, separated from the test area by a block wall with a doorway in it. Normally, this doorway is sealed with a large steel plate bolted in place.

The possibility of a fire in the building is real; indeed there have been two minor fires there since 1961. However, the shipping containers and casing surrounding the plutonium components of the mockups provide a sufficient time-delay barrier to penetration by fire to allow responsive action by the fire department. Hence the risk of spreading this plutonium by fire is small.

If, nevertheless, the plutonium components of these mockups were to be exposed directly to a fire, the results of the 1959 Vixen trials (in which plutonium was burned in a gasoline-fired chimney) indicate that very little of the plutonium would be released downwind as respirable particles. In these tests, 200-gram rods of plutonium were suspended in a 4-foot square chimney, 11 feet high. One such rod was heated by a gasoline fire to 805°C for 30 minutes, and the other by heat slowly increasing to 600°C in an hour. The releases of plutonium oxide were measured by weight loss, integration of downwind air concentrations (Jordan, 1963).

A full material balance was not attempted, but it appears that much of the material released fell to the ground within the first few hundred yards, and little remained airborne.

Higher releases were obtained from the lower temperature oxidation. In reporting the results of the trials, Stewart concluded that (1961, p. 27-28):

- "The larger value of 0.05% is clearly a satisfactory safe value to use in estimation of the airborne hazard downwind from a fire involving plutonium.
- "Therefore, no significant inhalation hazard would be produced at 200 yards and beyond downwind as the result of burning several kilograms of metal."

These distances are well within the confines of Area III, so that such a plutonium-spreading fire constitutes a remotely possible occupational hazard to those working there, but no hazard offsite.

In addition to the hazard represented by the passing cloud of airborne plutonium, there would be a residual deposition of plutonium on the ground. Based on the kilogram levels of plutonium characteristic of such mockups, the Vixen ground deposition results indicate that perhaps 10,000 m^2 (2.5 acres) of land would be contaminated with levels above the recently suggested soil deposition limit of 8 $\mu Ci/m^2$ (Healy, 1974), and actions would be taken, e.g., restriction of access or removal of topsoil.

As indicated, plutonium-bearing mockups are subjected to temperature cycling. Typically these cycles are within the range of -65° to +165°F (-54° to +74°C), conditions much less extreme than those just supposed, and hence less hazardous.

These mockups are also subjected to mechanical stress during their environmental testing. Given an accident in this process, a credible consequence is a mockup broken loose of its constraints, and possibly ruptured or split open. If the plutonium therein were to have its protective nickel coating broken, it could ignite, since the oxidation of plutonium is an exothermic reaction. Normally, however, ignition follows only when the metal has been raised to a temperature of 200-500°C, depending on its area-to-weight ratio, and even then its oxidation is a slow process that has been likened to burning charcoal (Hilliard, 1963), and would be a straightforward business to extinguish.

Area V

The reactor area, Area V contains two reactors (with a third being installed) and a number of electron beam accelerators. Reactors are subject to extensive safety reviews, the results of which are reported in safety analysis reports (SAR's). The SAR's forthcoming are: for the ACPR, Estes, Morris, Rivard, and Conant (n.d.-c); for the SPR III, Estes, Bonzon, Philbin, and Reuscher (n.d.-b); and for the SPR II, Estes, Bonzon, and Philbin (n.d.-a).

The following discussion is a synopsis of information on possible reactor accidents given at greater length in the two SAR's. Accidents to accelerators are of a quite different type; they consist of such events as explosion of transformers or capacitor banks and at Sandia do not involve radioactivity. Since the effects of the latter would be contained within the accelerator buildings, they will not be discussed further.

Reactor accidents (disturbances, malfunctions, and failure of equipment or operators) can be grouped into three classes of events:

Class 1: Those essentially trivial events which lead to no radioactive release beyond those experienced in routine operations, do not breach a barrier to fission-product release, do not lead to significant radiation exposures outside the reactor building, and do not propagate to a more serious accident;

Class 2: Those events that do lead to small or moderate radioactive release, may breach barriers, and may result in off-base exposures in excess of the limits permitted in normal operations, but do not require interruption of public or private domain, and do not propagate into a more serious event; and

Class 3: Those improbable events postulated for evaluating the design and performance and acceptability of the site, which will require the operation of the engineered safety features, and may require interruption or restriction of public or private domain, but will not exceed the emergency radiation guideline doses specified in 10CFR100 (Reactor Siting Criteria).

Sandia Pulsed Reactor (SPR) Facility Class 1 Events -- These lead to no environmental impact, and hence are listed here only by title:

- Loss of electric utility power
- Shutdown of cooling gas during power run
- Uncontrolled insertion of one control rod
- Explosion of fully contained explosives experiment
- Fission foil vaporization
- Experiment movement at power
- Inadvertent criticality on startup
- Blocked ventilation system (blower shutdown)
- Missile penetration of reactor building (including airplane crash)
- Fire not in the reactor building
- External forces: storms, floods, tornadoes, earthquakes
- Detonation of uncontained explosives
- Inadvertent criticality during loading or maintenance

(Airplane crashes fall into this class because there is little chance of an airplane crashing in the area [$P \leq 3 \times 10^{-4}$ per year], less of its impacting the reactor building, and even then the worst consequence would be release of room air contamination. The SPR is not a continuously operating reactor.)

SPR Class 2 Events -- These events are by definition those that lead to some release of radioactivity but not at levels high enough to require interruption or restriction of normal public or private activity.

Fire in the Reactor Building

In spite of minimization of burnable materials within the reactor building, a fire there must be considered possible. Three general sources of fires can be qualitatively identified: combustion of the reactor fuel itself, an experiment involving flammable materials, or a fire not specifically related to the reactor, such as one caused by electrical shorts. The normal response required on detecting the presence of a fire in the building is to shut down the reactor, close the shield door, and shut down the ventilator system. These actions, as experience elsewhere has shown, minimize the dispersal of radioactivity. Shutting down the ventilation system does not, per se, extinguish the fire, since there is enough air in the reactor building to sustain quite a bit of oxidation, and indeed enough to seriously degrade the filter system, but this shutdown does retain the radioactive materials inside.

External exposure to radioactivity is not strongly dependent on the amount of fission products on the HEPA and charcoal filters since this is very low; the greater danger is the fission products released from melted or oxidized fuel, and from release of the heavy-metal (uranium; the reactor fuel material contains no plutonium) itself.

Spread of uranium can be estimated by analogy with plutonium. The primary experiments were the British Vixen trials of 1959, in which both plutonium and uranium were burned in a gasoline fire, and the amounts dispersed determined by weight loss, integration of deposition contours, and integration of air concentrations 500 yards downwind (Stewart 1961; Jordan, 1963; see page 123 for a further description of these trials). The uranium results were inconclusive, especially the results of air samplers; weight loss indicated 3 to 5% dispersal, most of it appearing as close-in ground deposition; little was picked up by downwind air samplers. The experimenter, Stewart, interpreted his results to mean that "0.05% is clearly a satisfactory safe value to use in estimation of the airborne hazard downwind from a fire involving plutonium." Presumably some similar percentage also applies to uranium.

At other laboratories there have been at least two incidents with fast burst reactors releasing uranium after partial meltdown, one of them involving fire. The results were that even with substantial melt (1/3) of the fuel, little uranium was released, certainly no more than Stewart's 0.05%.

On the basis of these considerations, the effect of a fire in the reactor building would be at most, (1) a breach of the filter system, (2) a release to the environment of 18 grams* (0.038 mCi) of uranium in respirable particle sizes, and (3) a release to the environment of all the fission products. Calculations give the dose commitments** summarized in Table XI.

*106 kg x (1/3) x 0.05%.

**Dose commitment as used here means the lifetime dose that would be received by an individual from assimilation of a radionuclide in a critical organ.

TABLE XI

U-235 and Fission-Product Dose Commitments

^{235}Uranium dose commitment, 18 grams released

Distance (meters)	Bone (mrem)	Lung (mrem)	Kidney (mrem)
200 (north fence)	4.7	5.2	1.2
1000	.42	.46	.11
3000	.08	.09	.02
6000	.03	.03	.007
10000	.013	.015	.003

Fission-product dose commitment, 6 x 10^{16} fissions total release

Distance (meters)	External Whole Body (mrem)	Thyroid (mrem)	GI Tract (mrem)
200 (north fence)	16200	1000	700
1000	250	140	86
3000	18	30	20
6000	2	10	7
10000	.5	5	3

Although these fission-product dose commitments exceed normal operational exposures, they do not warrant interruption or restriction of public use of areas more distant than a few hundred meters, and certainly not in the military housing areas of the base (20,000 ft. or 6000 m away), or off the base.

Residual surface contamination would be above background levels only transiently. Uranium levels would be unmeasurable, and fission product levels would be down to 35 mrem/hr within an hour.

Burst-Rod Insertion During Period Measurement

Normal burst operation is proceded by a routine check of the burst-rod worth,* to allow the operator to account for the influence of the experiment on the system reactivity and to adjust the final reactor configuration accordingly. Although this standard check is performed by competent and well-trained people and has been performed successfully in thousands of operations, there remains a possibility of operator error with a resulting super-critical burst. The specific cause of such an accident would be the operator's failure to withdraw a control rod prior to the measurement. The maximum possible result of such an error is a burst equivalent to the total worth of the burst rod, since failure to withdraw a control rod leaves the system at exactly delayed critical before insertion of the burst rod.

The probability of achieving a maximum size burst is an interplay between decreasing numbers of neutrons present and increasing reactivity as the burst rod is inserted-the neutron source that dominates the problem being delayed fission neutrons from the preceding operation at the one-watt level necessary to establish the reactor at delayed critical. The new result is that a full-size burst is least probable, and calculations put this probability at 3×10^{-5}.

The consequence of an unplanned super-prompt critical burst is a fission yield of 3.1×10^{18} fissions. Such a burst would be expected to lead to substantial fuel melt and partial vaporization. Essentially complete fuel destruction would occur, and detailed calculations which take into account the nonuniformity of the heating indicate that two-thirds of the fuel would exceed the vaporization temperature.

The consequences of such an event would be to release into the room an abnormally large amount of fission products, some of which might escape through defects in the filter system (such as a leaking gasket) that were too small to be detected by routine testing, or that had developed since the previous routine tests. The results would be a fission product cloud passing down wind. The probability of a complete filter failure is very low, but as a worst case we assume it happens. The down wind cloud passage dose is calculated using the FISSP-CLOUD** codes, and assuming an instantaneous point source and strong inversion conditions. This yields the results tabulated in Table XII.

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*The worth of a burst-rod, or of any other portion of a pulsed reactor, is the contribution of the rod to the system's reactivity. It is normally measured in "dollars and cents," where one dollar of reactivity is equivalent to the difference between prompt and delayed criticality.

**Bonzon and Rivard, 1970.

TABLE XII

Downwind Dose in rem from 3.1×10^{18} Fissions

	With Filters		Without Filters	
Distance (meters)	Whole body (rem)	Thyroid (rem)	Whole body (rem)	Thyroid (rem)
200*	7.0×10^{-2}	5.0×10^{-3}	700	50
1000	1.4×10^{-3}	7.6×10^{-4}	14	7.6
3000	8.8×10^{-5}	1.5×10^{-4}	0.88	1.5
6000	1.0×10^{-5}	5.0×10^{-5}	0.098	0.5
10000	10^{-8}	2.5×10^{-5}	0.025	0.25

*Distance to the Area V fence.

Residual surface contamination would be on the order of 1800 rem/hr at the fence line an hour after the incident, and 10 mrem/hr at 9000 feet. The fence line level would fall to 10 mrem/hr in three days.

In summary, the worst possible consequence of an operator's failure to withdraw a control rod before measurement would be nearly complete destruction of the reactor core and subsequent release of an abnormal amount of fission products to the reactor room and to the external environment. If the filter systems were to fail, it would be a very serious event locally, but doses at the base housing and at the nearest general population sites 6 km downwind would be at most 100 millirem to the whole body and 500 millirem to the thyroid.

Experiment Movement During the Wait Period

In good operating practice all equipment near the reactor is structurally stable and does not require additional guy wires or unattached props. The possibility of movement can never be entirely removed, however.

The effect of such movement is that the reactivity of the reactor-experiment configuration is changed; the control rod setting is no longer correct. Unlimited changes are not possible; although high-worth experiments are routinely performed, they are of high worth because of their close proximity to the reactor, and the amount of additional movement is limited and hence also the additional reactivity that can be added.

Depending on the magnitude of the worth change, experiment movement could result in a power transient or a larger than anticipated super-prompt critical burst during or after the programmed burst-rod insertion. The maximum possible consequences are very much like that just discussed. Downwind doses, under the most severely conservative assumptions, would be about 0.1 rem to the whole body and 0.5 rem to the thyroid at the nearest uncontrolled population.

Control-Rod Misadjustment Before Burst-Rod Insertion

This is another possibility of getting a larger than anticipated prompt critical burst. One possible source of this error is a miscalculation of the desired control-rod position and the subsequent rod insertion to the wrong position. A second involves an incorrect position insertion based on a correct adjustment calculation. Finally, the error could be due to a faulty position indicator. The first two possibilities are guarded against in that the operator and the supervisor independently calculate the desired rod adjustment position and the position to which the rod is set. Nevertheless, these possibilities cannot be said to be impossible, even though they have never occurred.

Misadjustment may result in a larger than anticipated burst (the burst may also be smaller than anticipated, but that is obviously of no concern). The maximum possible consequence is that discussed in the two topics immediately preceding. There could be nearly complete destruction of the reactor core, and subsequent release of an abnormal amount of fission products to the reactor room and to the environment. Downwind doses, under the most severely conservative assumptions, could be 0.1 rem to the whole body and 0.5 rem to the thyroid, at the distance of the nearest uncontrolled populations.

Melt-Down of a Fissile-Materials Experiment

Fissile materials, particularly uranium and plutonium, are commonly irradiated at the SPR facility. Typical of the historical experiments involving fissionable material are the so-called shock rod experiments of Reuscher (1971). These experiments involve the rapid heating of rods to excite the fundamental modes of oscillation of the rod. The tests are generally carried to material failure, which is usually due to high-stress cracking at elevated temperature. The purpose of these experiments is to study the basic static and dynamic properties of the fissionable material.

Because of the hazards involved, fissile-material experiments require special reviews and approvals. An effort is generally made in this design to reduce reactor parameter perturbations by decoupling the reactor from the experiment, as by the use of boron carbide (B_4C) to absorb neutrons that would otherwise return to the reactor fuel.

Experiments with the highest neutron fluxes take place in the "glory hole," where physical constraints limit the amount of fissile material subject to the highest levels of flux to about 1500 grams. For a worst-case analysis, Estes et al (n. d. -a) assumed the complete melt of 1500 grams of plutnoium without containment and in the glory hole center.* Their calculations indicated that there would be a high enough energy density present to melt but not vaporize the plutonium. The plutonium would be raised to a temperature well above its ignition point, and this would be the primary mechanism of its spread. (Automatic scram systems would shut down the reactor, but not before partial core meltdown would have taken place.) Because it could be expected that the filters would remain intact, Estes et al assumed that there would be a release in respirable particle size ranges of 0.001% of the fission products and plutonium (i.e., 15 milligrams of plutonium).

The calculated fission product doses were in the millirem range, typical numbers being 0.3 millirem whole body gamma and 2 millirem thyroid dose at a distance of 6 km, the distance of the nearest base housing. Residual plutonium surface contamination would be unmeasurable beyond the Area V fence.

Plutonium's principal mode of entry into the body in circumstances such as these is by inhalation and deposition in the lungs. There that part which is not removed from the lungs to the GI tract within hours by cilial action on the surfaces of the bronchial epithelium irradiates the lung directly, and some of it is translocated through the blood stream to the bone and liver. Using conservative assumptions (1 m/s wind and a strong inversion), the amount of plutonium inhaled at various distances, and the resultant dose commitments to the lung and bone are given in Table XIII.

TABLE XIII

Plutonium Breathed and Dose Commitments to the Lung and Skeleton

Distance (meters)	Breathed (nCi)	Lung Dose (millirem)	Bone Dose (millirem)
200 (north fence)	3.3	600	18000
1000	0.30	53.0	1640
3000	0.057	10.0	320
6000	0.0020	3.6	110
10000	0.0009	1.7	52

*Subsequent calculations for SPR III used 7000 g, known to be conservatively high, but corresponding to a greater diameter glory hole. There is no possibility of such a large amount of plutonium ever being used.

The lung and bone dose commitments indicated are long-term commitments, since the biological half-life of insoluble plutonium in the lung is 500 days, and in the skeleton is many years (TGLD, 1966). The amount of plutonium and the dose commitment they entail are far below the standard radiation protection guides of 16 nCi lung burden or 40 nCi body burden, and 500 mr/yr organ exposure.

SPR Class 3 Events -- No events of this level of severity can be postulated for the SPR II facility.

Annular Core Pulsed Reactor (ACPR) Facility Class 1 Events -- These lead to no environmental impact, and hence are listed here only by title:

Break in primary coolant return pipe or in cleanup return pipe

Uncontrolled withdrawal of control-rod bank

Withdrawal of experiment while at power

Leak in 16-inch pipe closure

Minor coolant loop accidents

Detonation of explosive being radiographed

Aircraft or missiles striking reactor building

Fire in the reactor area

Earthquake causing fall of bridge crane

Detonation of fully contained explosives experiment

Maximum pulse

Loss of coolant

Fuel-handling incident

Loss of electric utility power

ACPR Class 2 Events -- Those leading to some release of radioactivity.

Vaporization of Fission Foil

Small foils of a few grams or less of fissile materials are used to measure neutron flux and to determine the performance of the ACPR. Standard procedures allow the use of these fission foils up to fluences of 1.5×10^{15} n/cm^2, if they are contained in a standard boron carbide ball. Calculations indicate that when the foils are in these balls, this flux level will not melt or vaporize them. If on the other hand, in violation of standard procedures, such a foil were to be exposed bare and not in a boron carbide ball, it would be vaporized.

With the bare foil in the central experiment space of the ACPR, most of the vaporized material would plate out on the cold surfaces within the experiment space. What did not would be exhausted from there through the purge system, which contains a HEPA filter, and thence into the main exhaust system. The exhaust monitor would alarm, and the exhaust system would automatically switch to its emergency setting, adding additional HEPA filters to the exhaust stream.

HEPA filters have a minimum particle-removal efficiency of 99.9% for 0.3-μm particles when operating at rated airflow capacity. The fissile materials themselves and most of the fission products would thus be confined to the reactor room and the filters, but noble gas fission products and some of the halogens would pass through (since there are no charcoal filters in the system) to be released from the reactor building to the local environment.

The calculations indicate that as much as 5700 cal/g might be deposited in a PuO_2 foil (3600 cal/g in a UO_2 foil). This energy density corresponds to a fraction of 3×10^{-7} of the material fissioned. From a 3-g foil, this leads to these quantities of some of the noble gas and halogen radioisotopes:

Isotope	Half-Life	Quantity	Decays To
^{85}Kr	10.6 year	0.55 μCi	^{85}Rb, stable
^{133}Xe	5.7 day	19 mCi	^{133}Cs, stable
^{131}I	8.1 day	6 mCi	^{131}Xe, stable
^{134}I	50 minutes	3.6 Ci	^{134}Xe, stable

(The quantity listed as produced assumes that the whole mass chain is produced at its lowest nonstable point. In the 134 fission product chain, there are two such points, ^{134}I and ^{134}Cs, separated by the stable isotope ^{134}Xe. For the present argument, production of ^{134}Cs is ignored.)

Continuing with ^{134}I, and assuming the usual Sutton diffusion formula:

$$TID = \frac{2Q}{\pi C_y C_z u d^{2-n}} e^{-at}$$

where the exponential term allows for decay during cloud movement. Setting $C_y = 0.4$, $C_z = 0.06$, $u = 1$ m/s, and $n = 1/2$, and multiplying by a breathing rate of 2.8×10^{-4} m^3/s, the resultant quantity inhaled is:

$$QI = \frac{26,600}{d^{1.5}} e^{-0.00023d} \; (\mu Ci) ,$$

where d is the downwind distance in meters. There is no charcoal filter on the ACPR building, so no credit for filters can be taken. The maximum permissible body burden (MPBB) for ^{134}I is 0.2 μCi (ICRP, 1960). This level is reached at 1900 m (6200 ft), well short of the base housing at 6000 m. At the fence line 110 m north of the ACPR building, the level would be 22 μCi, 100 times the MPBB. (Similar calculations for ^{131}I indicate 0.04 μCi inhaled at the fence line as compared to a MPBB of 0.7 μCi.) Assuming a deposition velocity of 1 cm/s, the ground deposition of ^{134}I at the fence line would be 14 $\mu Ci/m^2$.

In this estimate several conservative assumptions were made: no ^{134}Cs, a strong inversion, a light wind blowing to the north. Thus this possible incident would present no hazard off-base, though it would occasion concern for reactor personnel and would require decontamination of the reactor building.

Meltdown of a Fissile-Material Experiment

Experiments involving irradiation testing of prototype fast reactor fuel samples were analyzed as representative of fissile-material experimentation in the ACPR. A standard proviso for approval of such experiments is double encapsulation of plutonium-bearing experiments. Such containment canisters are hydrostatically tested to twice the vapor pressure that could result from a possible over-test.

A malfunction in the experiment (an incorrect calculation, for example), or a larger-than-planned reactor pulse (due to operator error, for example), coupled with a failure of the containment canisters constitutes an unintended combination of multiple independent failures that is not considered credible. Certainly the additional failure of a doubly contained plutonium experiment is in this category. Thus only the simple failure of the single containment of an uranium experiment is credible.

In such an event, the comments of the previous section about condensation and filtration products apply here as well. Noble gas fission products and some halogens would be released from the reactor building to the local environment. The quantity would be considerably less than in the previous event because one is not postulating vaporization of the fissile material. Thus the release would be less of concern than there. The reactor facility itself would sustain no physical damage, and the decontamination problem would be confined to the area inside the building.

ACPR Class 3 Events -- Design-basis accidents with possible release of significant amounts of radioactivity.

Failure of Waterlogged Fuel Elements

"Waterlogging" is an action that develops after a pinhole forms in the cladding of a fuel element. A small quantity of water may migrate through the hole into the element, particularly during cooling from operational temperature when there are falling gas pressures within the fuel element to draw water into the element. In pulse operation, if the heating increases so fast that the steam buildup exceeds the venting capacity of the hole and the resulting pressure exceeds the strength of the cladding, the cladding may rupture explosively. Such failures have happened elsewhere, in experiments investigating the effect at the National Reactor Testing Station (Stephan, 1969, 1970) and in an incident at PULSTAR at the Western New York Nuclear Research Center (Anon, 1972). The documents describing these incidents do not discuss their environmental consequences, if any, and it is doubtful that any such analysis is available.

Despite a long history of fuel-element integrity at the ACPR, it cannot categorically be said that waterlogging is impossible. Moreover, the possibility of simultaneous failure of several elements cannot be denied, especially since simultaneous failure is possible from nonsimultaneous perforations. For example, perforations might occur over a span of time during which the reactor is operated in the steady-state mode only, during which period explosive ruptures would not occur. A single pulse following this period of steady-operation would then produce simultaneous fuel ruptures.

Because no other potential single accident results in greater release of radioactive material from the fuel, simultaneous failure of four waterlogged fuel elements was established as the design-basis accident. (It must be appreciated, however, that since the failure of a single fuel element is demonstrably improbable, the failure of several becomes an exceedingly unlikely occurrence. Moreover, the presence of such a waterlogged element would be signaled by a rise in the radioactivity of the water in the reactor tank, and noted by the operator, who would investigate the cause of the increase in activity.)

For the analysis it was assumed that the pulse that ruptured four elements was preceded by eight hours of operation at 2MW, and that the fuel elements were approaching the end of their useful life. This combination maximizes the quantity of fission products present. The rupturing pulse was assumed not to be affected by the rupture itself; this assumption is conservative inasmuch as the rupture would decrease the reactivity of the reactor.

It does not take much water to rupture a fuel element. Four percent of the free volume of a cubic inch filled with water raised to its triple point would rupture the cladding. With more water present, rupture would be more certain, and would occur early in the pulse. A variation in bursting pressure may be expected in actual practice; assuming a factor of two here, the actual amount of energy released explosively in a single element could be as high as equivalent to an underwater explosion of 2.4 x 10^{-6} pounds of TNT. At the lattice distance of 41.7 mm, adjacent fuel rods would experience pressure waves of about 1600 psi with a very short time constant (1.3 μs). The magnitude is so small and the duration so short that it is not likely that other fuel elements would be damaged at all. (The shock wave situation is actually quite complicated because of wave reflections at the surfaces of the core structures.)

The rupture of fuel elements would in addition expose the fuel contained in them to the surrounding water. The high temperature of the fuel material ensures that the heat would be transferred to the water by film boiling, a process in which there is a sheath of steam around each piece of fuel material, and a process which is inefficient in transferring heat compared to normal turbulent boiling. The net result is that, although all the heat would in fact be transferred to the water, it would take several seconds, and this additional energy would not further contribute to the explosion so far as shock waves are concerned.

The fission products in the four fuel elements would contain about 205 kCi of halogens, 236 kCi of noble gases, and 797 kCi of other (solid) radioisotopes. In accordance with NRC Regulatory Guide 1.25, 1% of the halogens and all of the noble gases were assumed to escape from the pool. Thus 238 kCi of noble gases and radioiodine would mix with the atmosphere of the reactor room. Although in practice the iodine would deposit on the walls and other surfaces of the reactor room and would be adsorbed onto particulate matter, making it susceptible to capture by the room filters, all of it as well as the noble gases was assumed to be released to the atmosphere and transported downwind as a radioactive cloud. Dose calculations made with the RSAC code (Coates and Nelson, 1968; Anon, 1977) gave these downwind dose commitments:

Organ	TA-V Boundary 100 Meters (rem)	Exclusion Radius 3 kilometers (rem)	General Population 6 kilometers (rem)
External Gamma	0.66	0.08	0.014
Lung	1.13	0.71	0.56
Thyroid	17.1	0.49	0.20
G. I. Tract	0.04	0.0014	0.0006
Bone	0.13	0.0085	0.0028
Whole Body	0.04	0.0013	0.0006

There would be some surface deposition of radioiodines, decaying with the eight-day half life of ^{131}I, and no deposition of noble gases.

In conclusion, if this design-basis accident were to occur, which is unlikely, a release of radioactivity would ensue. The consequences are well within the reactor siting criteria (10 CFR 100). Effects on the Flora and nonhuman fauna would be scarcely noticeable.

The response in case of emergencies in TA-V is for all people in the area to assemble in the Emergency Assembly Building, which is located on the fence line to the north. This building is equipped with a full-time HEPA charcoal filter system on the incoming air and environmental controls to assure that the building remains at a positive pressure with respect to the outside. It has been designed to permit occupancy by 200 people for two hours. Actual exercises indicate that every one in the area can be accounted for within 25 minutes. Evacuation from the area could take place within an additional 5 minutes.

Coyote Test Field

Forest Fire -- Although only brush fires have started to date, this does establish the potential for starting a forest fire at the Lurance Canyon Test Site and the two aerial cable test sites in the Coyote Test Field (see Figure 33). Tests with cased explosives conducted at any of these three sites produce burning or hot missile fragments that are usually distributed symmetrically about the impact or detonation point. Rocket motors used at the cable sites for pulling down test units are secured to a sled on a railroad track that is long enough that the rocket motors are burned out before they impact on a large built-up earth embankment at the end. On 10 of 450 tests, the hot rocket motors have bounced off the embankment and have started small brush fires.

Brush fires can spread to a forest fire if the right conditions exist. These conditions include testing periods of low relative humidity (mostly in the summer), high winds, and lack of a fire fighting crew standing by.

Tests have been conducted in Coyote Test Field since 1950, but accurate records concerning the exact locations of these tests are available for only the last five and one-half years. During that time, 675 tests have been conducted at the three test sites in the Coyote Test Field, for an average of 123 tests per year. Therefore, assuming that the tests have the same probability per test of starting a fire, an upper confidence limit for this probability at the 90% confidence level is 0.0034.

Preventive measures against the uncontrolled spread of brush fires are taken at all Coyote Test Field tests. These include construction of permanent fire breaks around the test sites, fire department stand-by at tests in which the test director feels that environmental conditions for that day warrant it (dry season, low relative humidity, and windy weather), and availability of test support crews with fire fighting equipment at all tests. (The nearest fire department is in the Manzano area, a nominal 12 minutes from any of the test sites in the Coyote Test Field.)

Although the potential for starting a forest fire exists, past statistical data show that the probability is low, and the preventive measures taken for fighting fires make it unlikely that the brush fires will spread out of control.

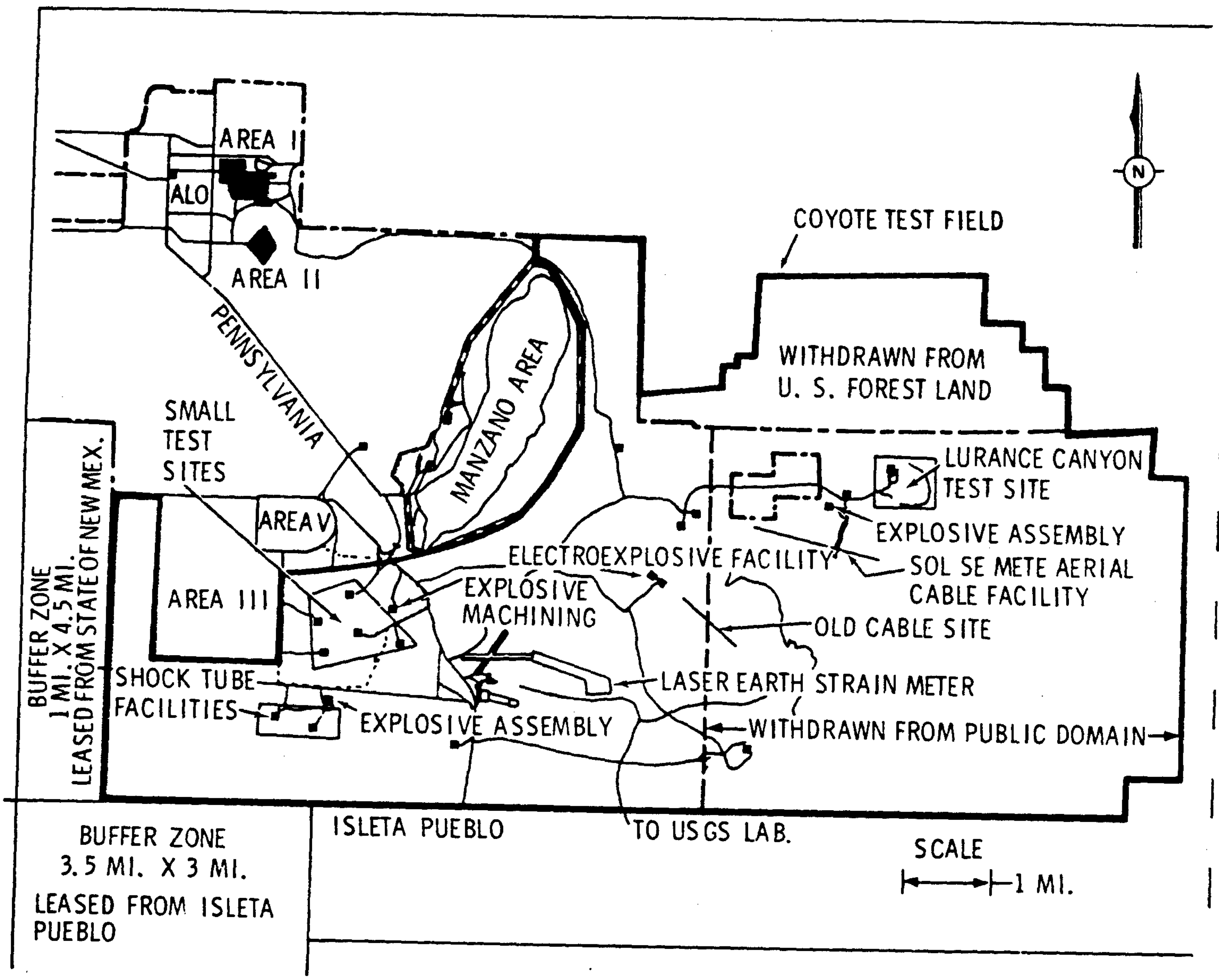

Figure 33. Coyote Test Field facilities

Shrapnel Hitting Low Flying Aircraft -- Table XIV indicates that tests are conducted at the Lurance Canyon Test Site and the two Aerial Cable Sites on the basis of a shrapnel hazard radius of about 13,000 feet. The peaks of the mountains nearby are only on the order of a thousand feet above the detonation points in the canyons, and therefore there is concern over shrapnel fragments thrown above the level of the peaks and into the path of aircraft flying over the site.

TABLE XIV

Data for Coyote Test Field Facilities

FACILITY	EXPLOSIVE LIMIT (W) (LB)	FRAGMENT HAZARD RADIUS (R) (FT)*	TESTS PER YEAR
SHOCK TUBES			
4-in. Dia.	0.32	410	60
2 x 200 Ft.	150	3,190	10
6 x 200 Ft.	381	4,350	5
6 x 50 Ft.	70.0	5,325	1
19 Ft. Dia.	381	4,350	7
AERIAL CABLES			
2700 Ft. Span	10,000	12,925	45
4800 Ft. Span	10,000	12,925	37
LURANCE CANYON TEST SITE	10,500	13,140	41
SMALL EXPLOSIVE SITES	50	2,210	100
ELECTROEXPLOSIVE	400	4,420	75
STORAGE IGLOOS	90,000**	26,890	--
EXPLOSIVE MACHINING	350	4,230	--
EXPLOSIVE ASSEMBLY	4,000	9,525	--

Missile hazard radius is greater than the overpressure hazard radius for most tests.

*According to $R = 600\ W^{1/3}$ (Explosive Ordnance Reconnaissance and Disposal, Department of the Army, FM9-40, March 1953)

**Larger amounts of explosives can be stored for SLA by the military on KAFB.

Tests carried on at other test sites in the Coyote Test Field do not usually involve cased explosives and therefore present only the hazard of debris rising from the surface on which they are detonated and the hazard of the shock waves they generate. Vortman (1967) reports maximum debris distances from surface bursts of $70W^{0.4}$, with the recommendation that where this relationship is to be used for safety considerations the distance be multiplied by a factor of 2. The maximum debris radius for a 10,000 pound surface burst therefore would be 5700 feet. As for overpressure, an accepted safe level is 1/4 psi. This occurs at a distance of 3400 feet from a 10,500 pound surface burst. Thus an uncased explosion is a hazard only to people near the test, and the principal hazard is debris. These possibly hazardous areas lie well within the boundaries of the base. The only potential effect outside the base would be refraction and subsequent convergence of shock waves from a thermal and/or wind refracting layer in the atmosphere, should such a condition exist during a test. Overpressures from such refractions are quite low, but in the past have resulted in complaints of broken windows and other annoyances off base. Weather advice is available from the Sandia meteorology group and is used when appropriate.

The potential accident of greatest concern when using cased explosives is that of a piece of shrapnel hitting an aircraft passing over the test area. In Appendix F the probability of this happening is analyzed. The essence of the analysis is the estimation of several probabilities: of an aircraft being in or flying into this airspace at the time, of the aircraft not being seen from the lookout tower, and of the path of a piece of shrapnel actually intersecting the path of the aircraft. The analysis is made for Lurance Canyon, since the problem is less severe at the two cable sites.

The conclusion of the analysis is that the probability per test of an aircraft being hit with a piece of shrapnel is 7.8×10^{-8}, or, since in recent years there has been an average of 41 tests per year conducted at this site, the probability per year of this accident is 2.9×10^{-6}.

Shock Wave Effects on Low Flying Aircraft -- Ordinary aircraft are considered endangered by a passing shock wave if the shock overpressure exceeds 0.5 psi. This overpressure or greater is experienced everywhere within a hemisphere of radius 1650 feet from a 10,500 pound surface burst. Although this distance is smaller than the distances to which pieces of shrapnel are thrown, the probability of damage to an aircraft within the airspace is larger, because in this smaller hemisphere excessive overpressures are everywhere, whereas in the larger volume in which there might be pieces of shrapnel there are only a few (Appendix E estimates 780), which may or may not intersect the path of an aircraft.

Appendix E also analyzes the overpressure problem. The conclusion of the analysis is that the probability per test of an aircraft being injured by the shock wave from an explosion in Lurance Canyon is 8.2×10^{-7}, or, since in recent years there has been an average of 41 tests per year conducted at this site, the probability per year of this accident is 3.4×10^{-5}.

It should be noted that, in fact, both risks to aircraft are smaller than estimated since aircraft tend not only to avoid the mountains, but also to avoid flying low over them.

Rockets Getting Away -- An average 82 tests have been conducted annually at the two Aerial Cable Sites, with solid propellant rockets (Red-eye, HVAR, or DB-1) launched toward a test unit suspended on the cable. These rockets have burn times of up to 5 seconds and ranges of up to 4 miles. These rockets are launched to the east at angles relative to the horizontal of less than 20 degrees. The rockets impact either on the mountains or just over them. They have always impacted at least 2.5 miles from the boundary of the withdrawal area. A helicopter with fire fighting equipment follows the rocket to impact. Also the test support crew stands by on the top of the nearby ridge to be able to go to and fight any fire. The support crew also serves as the aircraft lookout before the test.

Toxic and Radioactive Materials -- Radioactive materials are rarely used in explosive tests at CTF. Uranium with the ^{235}U removed is the only one that has ever been involved. Being dense, it settles to the ground quickly, and after the cloud has settled the hazard is considered ended. Air samples taken where such tests have been carried out have not detected any resuspended uranium. Sample volumes are about 10 m^3, and the analytical detection limit for uranium is 1 nanogram per sample, making the effective detection limit about 0.1 ng/m^3, equivalent for depleted uranium to 4.4×10^{-17} $\mu Ci/ml$. This is well below the Radiation Concentration Guides for insoluble airborne ^{234}U and ^{238}U of 4×10^{-12} and 5×10^{-12} $\mu Ci/ml$, respectively.

Edgewood Test Site

Gun Firings -- It is only remotely possible that the gun barrel will burst during a firing since the barrel is 3.6 inches thick, and the maximum propellant charge is only 50 pounds.

More likely (and this has actually happened), the igniter may fail to start a full deflagration of the propellant. In this case the propellant would still be burning when the reaction mass left the top of the barrel and would spew out like fireworks, scattering burning and unburnt pieces of propellant for several hundred feet in all directions. There is a possibility that small brush fires might be started, but a range fire is not possible because grazing has made the vegetation cover too scant. The unburnt pieces of propellant must be picked up or burnt in place with a weed burner. A water tank and other extinguishers are kept on site.

Cattle are not removed from the vicinity during gun firings or airdrops. It is always possible that one may be hit by a reaction mass or other missile, although this has not yet happened after more than 3,000 operations to date.

Propellants are transported from SLA to Edgewood as needed; none are stored there. Transportation is along public highways, and must adhere to Department of Transportation regulations, which are designed to prevent accidents or to mitigate their consequences.

Airdrops -- All aircraft operations bear some possibility, however remote, of leading to an aircraft crash. The probability of this happening in connection with the operation of the Edgewood site has not been assessed. It is very low, because of the close cooperative relationships with the FAA; because the sites are flat, unobstructed and uninhabited; and because operations take place only on days of excellent visibility in addition to surveillance radar and ground observers. If, nevertheless, a crash were to occur, the consequences would be probable death of the crew, a land scar and scattered debris, death and injury involving cattle, and possibly a fuel fire—which would not spread because the grazed vegetation is so sparse. Sabotage could not produce any worse accident than the maximum credible accident resulting from natural causes.

Emergency Response Plans and Resources

Plans for the emergency response to any of these hypothetical accidents, and resources available to mitigate their consequences, are discussed in the Emergency Response Capability section of Chapter II.

CHAPTER IV

UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

Environmental impacts described in Chapter III that are unavoidable consequences of the operations of Sandia Laboratories, Albuquerque are:

Land use

Use of resources and energy

Impact of normal releases of radioactive and chemical effluents, dust, smoke, noise, and debris

Exposure to the hazard of accidents.

Land Use

Land use by SLA together with the Air Force and other tenants of Kirtland AFB East involves the commitment of almost 50,000 acres of land to government use. Such a commitment curtails for an indefinite period other potential uses, including its original use for grazing. Only a small part of this total is actually not in a condition approaching its natural state, since much of the total exists solely to isolate potentially hazardous activities. Buildings used by SLA occupy about 50 acres. Except for the closely built-up areas of Areas I, II, III, and V, the principal continuing disturbance of the land is from traffic among the various sites.

Use of Resources and Energy

Electrical power is used at SLA at the rate of about 82 GWhr per year. Fossil fuels (natural gas and fuel oil) are used at about the rate of 190,000 barrels (equivalent) per year (a breakdown between the two is not available). Since water and other services are supplied by base authorities for a fixed fee, no record of water consumption is made. Inasmuch as electric utility power in the Albuquerque area is generated by plants burning natural gas from the San Juan basin in northwestern New Mexico, all of the electricity consumed represents irrecoverable use of a nonrenewable resource.

Operational Effluents

During normal operation SLA emits practically no radioactive effluents; the annual total is about 7 Curies, principally argon-41 from reactor operation. A small quantity of solids is, or is suspected to be, radioactively contaminated; this solid waste is buried in a small controlled disposal area in Area III.

The principal effluents from SLA are chemical and sanitary wastes. Airborne wastes total about 10 metric tons per year. The biggest single contributor is the steam plant, which emits about 6 metric tons of sulfur dioxide per year. The steam plant's emissions are in compliance with Federal and State standards. Sanitary wastes are well within the treatment capacity of the city's treatment plants to which they are discharged.

Dust, Smoke, Noise, and Debris

Various SLA activities occasionally result in the generation of dust, smoke, noise, or missile debris (by which is meant soil or other material thrown from explosions or rocket exhausts, such as fragments from the break-up of experimental fixtures). These activities are principally those carried on in the remote areas of the base, such as the sled track in Area III or chemical explosives detonated in the CTF. Because of the remoteness of these operations, the dust and smoke clouds from them dissipate to the point of not being detectable by the time they cross the boundaries of the base. Noise is an occasional short-lived nuisance. Missile debris from explosions, rocket exhausts, or impacts remain on base or within buffer zones adjacent to the base. Since these activities are in the remote areas of the base, they are generally surrounded by nearly undisturbed vegetation. Heavy dust disturbs local areas by smothering vegetation, and debris fragments by causing impact scars. Another occasional disturbance is the initiation of small brush fires.

Exposure to the Hazard of Accidents

The very existence of SLA exposes the surrounding populace and natural environment to the hazard of accidents. Although the probability of these happening is small, their consequences would be significant.

Emergency services available, to be used as any particular incident should require, are the base fire department, SLA health physicists, SLA ambulance and medical doctors, the base and city hospitals, the SLA guard service, base military police, and a hot-line telephone notification and alerting system.

In Area I the concern over accidents is principally because military housing is right next to the technical area, so that the consequences of otherwise minor accidents could be serious. Three such were identified. Ammonia is stored for laboratory use about 400 feet from the nearest housing; a leak would be quite noticeable but not dangerous, though it might trigger spontaneous evacuation. Methane is also stored about 400 feet from the housing; a fire during filling of the storage tank would require evacuation of the nearest housing as a precautionary measure. Tritium is sometimes used in the area; a release would require evacuation of downwind portions of Area I.

There was no serious accident found in analyzing Area II operations.

In the more remote areas the possible hazard from accidents is more to the nonhuman environment. Thus in Area III, missiles from the sled track may get away, producing impact scars where they land. Plutonium-bearing mockups are deliberately subjected to environmental stresses, but the possibility of a fire in such a mockup is so small that it may be considered negligible. Nevertheless, if a fire were to occur, there would be an area of significant residual contamination needing isolation or decontamination with its accompanying denudation of land; this area would be about 2.5 acres in size.

In Area V, reactor accidents that would release radioactivity are always remotely possible. The most probable effluents would be radioisotopes of the rare gases or iodine in an organic form which are not removed by the existing filter system. The quantity that might be released from the existing facility is insignificant. If in the future there is a possibility of releases approaching the recommended minimum values, adsorbers could be added to the system to remove organic iodides. These materials would have only a transient effect during cloud pasaage there would be no residual ground contamination. Certain types of much less credible accidents could release fission products, producing both significant downwind exposures of people and other fauna, and residual surface contamination.

In CTF, the hazards identified were of a forest fire from a brush fire escaping control, or damage to a low-flying aircraft by pieces of shrapnel or by the shock wave from an explosion.

Explosives or radioactives being transported between sites could be involved in accidents. In the former case, the worst consequence would be an explosion, which would only differ from other explosions in its environmental impacts by being unplanned, at a place unprepared for it, and affecting the people in the vehicle involved. In the latter case, the effects would be like the effects of release of tritium or plutonium already mentioned, except that it could be almost anywhere that laboratory or field operations might require.

Finally, operations at the Edgewood sites have their own unique possibilities. A cow might be hit by a reaction mass from a gun firing or by some other missile. An aircraft involved in the operations might crash.

CHAPTER V

ALTERNATIVES

Alternatives applying to ongoing operations are plant shutdown or complete relocation and site decommissioning, partial transfer of functions elsewhere, reducing the number and size of those operations having the greatest potential for adverse environmental impact, and wider use of alternate technologies with reduced environmental impact.

Plant Shutdown or Complete Relocation and Site Decommissioning

Discontinuing the research, development, and engineering program being carried on at the Sandia Laboratories, Albuquerque, by dropping them entirely would detract from the nation's ability to maintain a strong posture of national defense and to have strong laboratories available to delve into other pressing national needs, such as energy. Removing these activities to another place would merely transfer the existing environmental costs to other locations where they might well be more significant, and such a move would be tremendously costly both in dollars and wasted manpower.

In either case it would be possible to decommission the existing facilities, and turn them to other uses. The fact that these facilities are enclaves within or situated on an Air Force base means that it would be not too likely that they would be converted to non-governmental use as long as the surrounding lands are still needed for Air Force activities. The environmental gains of complete shutdown are few, and would also mean a great economic loss to the community. It would be better stewardship of the nation's resources to put the facilities and staff to new uses, such as working on other national needs. The successor uses of the facilities would in all likelihood have environmental impacts as great, though possibly different in detail, as those of the present operation. Costs would also be involved in conversion to successor uses, whatever they might be, since many of the present facilities are of a very specialized nature.

Partial Transfer of Functions Elsewhere

The more hazardous of the SLA operations are carried on elsewhere. This is a principal reason for existence of Sandia's Tonopah Test Range in Nevada (for which a separate Omnibus Environmental Assessment is being prepared). The suggestion embodied in this alternative is that more functions might be moved, either from Area I to the more remote areas of the base, or from the base to the Tonopah Test Range, or to other places such as the Nevada Test Site.

Moving more facilities to the remote areas on base could be done; the analysis of Chapter III suggests the possible moving of the Area I Vault to Area III. In that case one would have to build a new, presumably better, building in a permanently guarded area. The net environmental gain of such a possible move would be relocation of a possible source of contamination farther from the residential areas of the base and of the city. It would not appreciably decrease the probability of a tritium release, already very low, but it would decrease the number of humans at risk at the expense of increasing the risk to the natural flora and fauna.

The other possibility for relocation of some SLA facilities would be to a less populated area, such as to the Tonopah Test Range or to the Nevada Test Site. Environmentally the result would be a reduction of risk to human, and no net change to the risk to the natural flora and fauna, merely a change in the place where the risk would be incurred. Relocating and staffing these operations in a new location would, by the geographic separation, reduce them to a satellite status. Work performance would lose the benefit of close contact with support and scientific personnel that Albuquerque-based facilities enjoy, and which is essential for smooth programmatic progress.

Reduction of the Number or Size of Operations

The level of effort in any research, development, or engineering program is regulated by the needs of that program, and no useful suggestions have surfaced for changes that would reduce environmental impact by reducing laboratory of field tests.

Alternate Ways of Doing Things

Engineering requires doing a job with the tools, materials, and methods at hand. Often there are several possible solutions to a problem; in the ordnance field the selection among these has usually been made on the bases of reliability, weight, ease of quality control, and similar considerations. On the other hand, sometimes it is because a new technology has been developed that a task can be undertaken at all. A forward-looking engineering organization must keep abreast of new technologies, to see which ones will be applicable to mission and product. Advance is often opportunistic.

Two of SLA's lesser efforts are in the fields of solar energy and wind power. Neither technology is that advanced that it could make an appreciable impact on the nation's energy problem, or even SLA's; still, these technologies must be investigated if they are ever to help. Part of SLA's plan in its investigations is to harness the energy from experimental and demonstration facilities and use it for local needs. The impact this will make on SLA's use of energy originally derived from fossil fuels will be very small, but it will be a start.

Alternate ways of doing things that are better either from the point of view of cost, or safety, or process efficiency, or environmental impact, will often show up in the budget as items of future construction or modification of existing facilities. Occasionally, as in the construction of fire breaks in the Coyote Test Field, they may be paid for out of operating funds, but usually not. In the section on Future Facilities in Chapter II these may be noted:

> Small arms addition, Area III. At present testing with small caliber arms is conducted in the open. Putting it in a structure eliminates the possibility of shots going astray and making scars on the landscape.
>
> Explosives assembly building, CTF. This building is justified for increased safety, security, and operational convenience. It reduces the explosives transportation risk by moving the assembly of experimental configurations much closer to their points of use, and thereby reduces the risk of environmental impact of an accidental explosion.
>
> Scientific glass facility upgrade, Area I, FY 75. This relocation will decrease fire hazard and the accompanying risk of air pollution.
>
> Radiant heat facility upgrade, Area III, FY 76A. Change from a once-through use of cooling water to a closed loop system will save an estimated 30,000 gallons of water a year.

Each of these modifications and new constructions will make a small contribution to increased safety and reduced environmental impact, and it is a truism that sometimes small steps start long journeys. No suggestion for change in emphasis or technology has been forthcoming that would have a large effect in reducing SLA's impact on the environment.

CHAPTER VI

RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

Prior to World War II, the major part of what is now Kirtland AFB East was used for grazing. The area that is now Area I was the northern part of Oxnard Field, and there was a small Spanish community practicing subsistence farming where Coyote Canyon opens out upon the grasslands. One possible long-term productive use of this semi-arid land would be for grazing.

If it were thought desirable, much of the land used by SLA, both on ERDA-owned land, and on land used by agreement with the Air Force, could be stripped of its present buildings and allowed to revert to the wild. Revegetation, however, would be very slow without supplemental water so that denuded areas would remain scarred for many decades.

The fact that SLA exists as enclaves within, and sharing land with the Air Force, means that the future use of the land involves judgments and decisions about their activities as well. In practical terms, the 30-year government use of this land precludes its ever being returned to its pristine state, and the shared use of the land would make it difficult to consider for use for non-governmental purposes.

Nevertheless, the present SLA operations do not preclude its future use either for grazing or for other governmental or non-governmental use.

CHAPTER VII

RELATION OF PRESENT ACTION TO LAND USE PLANS, POLICIES AND CONTROLS

Operations of Sandia Laboratories, Albuquerque, are not in conflict with any known plans of any other Federal, State or local entities, nor are they expected to be. Operations have been continuous for nearly 30 years and it is expected that they will continue at about the present scale for the immediate future. Joint use of the base with the Air Force is expected to continue on the same basis as at present, by coordinating activities in accordance with a Memorandum of Understanding between ERDA/ALO and the Air Force Special Weapons Center.

The only published plan for land use in this area is one commissioned (but not accepted as official policy) by the City of Albuquerque in 1969 from Landrum and Brown, consulting engineers. This plan accepts the existence of SLA. It proposes extension of the Albuquerque International Airport on State lands west of the main portion of the base and establishment of industrial areas around the airport. Development of such industrial areas south of the airstrip could conflict with SLA's use of a portion of those lands as a buffer zone for Area III operations.

CHAPTER VIII

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Few commitments of resources at the Sandia Laboratories are absolutely irreversible and irretrievable. Fuels for energy production, most construction materials, and other consumables used in the operation and maintenance of the facilities are irretrievable. In a less tangible but equally real way, the human resources invested in the past in the Laboratories and its many programs are also irretrievable.

The use of fuels has been discussed in Chapters III and IV. Electric power is consumed at SLA at the rate of about 80 GWhr/year. Fossil fuels (natural gas and fuel oil) are used at about the rate of 190,000 barrels (equivalent) per year. Since electrical power in the Albuquerque area is generated in steam plants burning natural gas, the use of electricity represents a further expenditure of fossil fuel. Starting in the fall of 1973, there has been a special effort on the conservation of energy used in the Laboratories; this resulted in a 14% reduction in the use of these resources in the year following August 1973.

The use of water at SLA is not completely irretrievable, since it is returned to nature and the quantity used is smaller than the recharge capability of the Rio Grande basin. It is, however, consumptive use in that the water must be reprocessed before it can be used again for industrial or household use. The actual amount used is not known, for water and other services are obtained at a flat rate from the base water system (a system independent of the city) and records of consumption are not kept. Of this unknown amount, something over half is returned through sewers to the City of Albuquerque sewage treatment plant and returned to the Rio Grande.

The use of land by SLA is not absolutely irreversible, although it would be difficult to return this land to anything approaching its pristine condition because of the slowness of revegetation and the cost of such an action. Moreover, there are other tenants and users of the land. Within that perspective, most of the present land use would have to be considered practically irreversible. In the unused portions of the base no irreversible or irretrievable changes are known to have occurred in overall ecological patterns as a result of the existence of SLA.

CHAPTER IX

ENVIRONMENTAL TRADE-OFF ANALYSIS

A basic principle established by the National Environmental Policy Act of 1969 is that all costs and benefits of a proposed action should be considered, even if some of them are only qualitative in nature and not measurable in economic terms. This analysis is therefore somewhat philosophical in nature.

The costs of the operation of the Sandia Laboratories, Albuquerque are several.

The use of land by SLA precludes its present use for possible other uses. At present about 50,000 acres of land are dedicated to Air Force and ERDA use. Much of this is relatively undisturbed buffer area, but the 50 acres occupied by buildings and associated clearings and roads is completely removed from its natural state. In principle, this land could be returned at least in part to its previous use for grazing or to private or industrial use, but the expense of the reversion and the fact that the land is used jointly with the Air Force makes that option difficult.

SLA uses these resources: electricity, about 82 GWhr per year; fossil fuels, the equivalent of about 190,000 barrels per year; water, the quantity not known because the base authorities do not meter use; and materials used in construction and operation.

The normal operation of SLA yields some effluents. About 6 Ci per year of radioactive gases, mostly argon-41, are emitted from reactor operations. Chemical effluents consist of two metric tons per year of sulfur dioxide from the steam plant, 1.5 metric tons per year of gaseous hydrocarbons from development laboratories, some chlorine from the foundry, and some chromates in waste liquids from photographic processing. Sanitary wastes are handled without trouble by the City of Albuquerque sewage plant. All these effluents are within applicable Federal and State guidelines and standards.

Various SLA activities result in the occasional generation of dust, smoke, noise or debris fragments (by which is meant soil or material from the break-up of experimental fixtures subjected to explosive or rocket test). These activities are for the most part carried out in the more remote areas of the base. Another occasional distrubance is the initiation of small brush fires, running in recent years to a frequency of one or two a year, and so far all soon controlled by test crews doubling as fire-fighting crews.

The final cost is that the existence of SLA brings with it the hazard of various kinds of accidents, some of them common to all industrial and research and development organizations, some of them peculiar to SLA. These have been discussed in detail in Chapter III of this assessment, but several of them bear repeating. Within Area I, ammonia and methane are stored and used near the base housing. If these were to leak in substantial amounts, either through a failure of their normal storage tanks and piping, or through an accident while a tank is being filled, evacuation of some of the technical area and adjacent housing would be required. Tritium is also occasionally stored in Area I in substantial quantities; if it were to leak from its containers, evacuation of downwind portions of the technical area would be required. Accidents at the Area V reactors could release radioactivity; most likely this would be radionuclides of the noble gases and iodine, exposure to which is only possible during cloud passage. Finally, if a brush fire were to get out of control during the early summer period of great dryness of vegetation, the resultant range or forest fire could be very serious indeed.

The principal benefit to the United States from the operation of the Sandia Laboratories, Albuquerque is the contribution made to the national defense by the laboratories in its function as the ordnance engineering laboratory for nuclear weapons. This work is carried on in response to long-stated national policy and must be carried on somewhere. The arguable point is not whether, but where and how.

The Sandia Laboratories constitutes a reservoir of talent available to turn its skills to other pressing national problems, such as the investigation of new energy sources. There have also been technological spin-offs in many of the scientific and engineering disciplines underlying Sandia's basic mission.

As a side effect, the economy of Albuquerque and New Mexico benefits from the employment of about 5400 people and the annual expenditure of about $127 million of Federal funds for payroll and for goods and services. As individuals, members of the staff also contribute substantially to the community: culturally, in leadership, and in support of worthy projects.

The various alternatives of Chapter V have been analyzed from the cost-benefit point of view, but in most cases their economic costs would be high and their environmental benefits small. Exceptions are reflected in the program for new construction and modifications of present facilities.

These costs and these benefits lead to the conclusion that as long as the nation maintains nuclear weapons, and because it is a viable technical center available for other national needs, the Sandia Laboratories, Albuquerque should continue to operate at its present site. The environmental costs inherent in the work are small and reasonable for the benefits gained.

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APPENDIX A

DEPARTMENT OF THE AIR FORCE
Headquarters Air Force Special Weapons Center (AFSC)
Kirtland Air Force Base, New Mexico 87115

AFSWC Regulation 55-12

14 June 1974

Operations

JOINT FIRING AREA COORDINATING COMMITTEE

This regulation establishes procedures for use and control of the Kirtland Air Force Base (KAFB) controlled firing area. It also establishes the Joint Firing Area Coordinating Committee and membership therein.

---

1. Terms Explained:

a. *Controlled Firing.* Any test or exercise conducted on KAFB firing area which involves the use of explosives or any piece of equipment which creates or is capable of creating a hazard to personnel, equipment, structures, or aircraft flying the vicinity of the area.

*b. *Controlled Firing Area.* The area contained within the boundaries of grid coordinates 16B, 16Z, 74Z, 74B, and 74E (excluding Manzano Base), as shown on the KAFB Disaster Preparedness On-Base Crash Grid Map. Copies of this map may be obtained by contacting the Operations and Training Division (61-2456/3104).

c. *Joint Firing Area Coordinating Committee.* Representatives of the Air Force Special Weapons Center (AFSWC) units and tenants using or controlling the firing area.

2. Membership in the Coordinating Committee. Representatives of the following organizations will function as indicated:

a. *Chairman:* Chief, Operations and Training Division (OT).

b. *Member:* Air Force Weapons Laboratory (AFWL) (SUH).

*c. *Member:* Sandia Laboratories, Department 9540.

d. *Member:* Civil Engineering Research Facility (CERF).

e. *Member:* Albuquerque Seismological Center (ASC).

f. *Member:* Lovelace Foundation Field Laboratories.

g. *Member:* EG&G, Incorporated.

h. *Member:* KAFB Safety Officer (AFSWC/SE).

i. *Member:* Explosive Ordnance Disposal (EOD).

Supersedes AFSWC Regulation 55-12, 13 March 1972.
OPR: OT
DISTRIBUTION: (See Page 5)

***3. Responsibilities:**

a. *The chairman will call meetings of the committee as needed.*

b. *The committee will:*

(1) Determine the types of explosives and other firings that require prior notification and coordination.

(2) Establish the parameters for explosives and other firings that require prior notification and coordination.

(3) Determine agencies to be notified of firing area activities and method of notification.

4. Participaring Agencies will:

a. *Insure that appropriate notifications are made* and that all safety/security measures are complied with.

*b. *Designate primary and alternate project officers* to assure compliance with this regulation.

5. Restrictions. All participating agencies will adhere to the following restrictions.

a. *All tests will be controlled events.*

b. *Maximum altitude limits for overpressures* or other hazards to air traffic are:

(1) West of 106 31 "00" west longitude - 10,000 feet mean sea level (MSL) (4,000 feet above terrain).

(2) East of 106 31 "00" west longitude - 16,000 feet MSL (10,000 feet above terrain).

*c. *Meteorological visibility shall be sufficient to insure visual surveillance* of the entire firing area for 5 miles in all directions.

d. *Ceiling shall be at least 1,000 feet* above the maximum ordinate of fire.

e. *No projectile shall be permitted to enter any cloud formation.*

f. *Radar surveillance will be required* if visibility is marginal. Radar must be sufficient to detect aircraft within 5 miles of each test and must be established at least 15 minutes prior to and continued through the test.

g. *Communications will be established between spotters* (visual and radar) and the project officer.

h. *All firings or test activities will be halted* when aircraft, personnel, vehicles, etc., approach or enter the hazard area.

i. Firing activities governed by this regulation will normally be conducted Monday through Friday between 0800 and 1800 local time.

6. Notification Procedures:

*** a.** ***Participating Agencies.*** **When an event or test will result in missiles, excessive overpressures (¼ pounds per square inch (PSI) or greater) or other undesirable effects beyond an altitude of 300 feet above the terrain, the agency conducting the test will, at least 24 hours in advance of the test, notify Coyote Test Field Division (264-7049) who will in turn notify Operations and Training Division (61-2456/3104) furnishing the following information (24 hours prior notification is essential to insure proper dissemination to other base agencies. Tests with less than 24 hours notification are not authorized):**

(1) Agency conducting the test.

(2) Date and time of event.

*(3) Location of event (by use of KAFB Grid Map – example: Coordinates 22-00).

(4) Type of test (high explosive (HE) detonation, laser, etc.),

(5) Visual disturbance (flash, smoke, dust, and/or cloud).

(6) Blast pressure – hazard radius in feet.

(7) Missile hazard radius in feet.

(8) Name of person reporting the above information.

(9) Name of person receiving the above information and time/date of notification.

b. Special Notification. When a test will cause disturbance or undue concern on the populace, special notification should be made to Coyote Test Field Division (264-3178) the day of the test unless previously reported under paragraph 6a above.

c. Test Information. Operations and Training Division will, in turn, transmit the test information to:

*(1) Base Operations (61-2743/3583).

*(2) Field Command Defense Nuclear Agency (264-4527).

(3) 3098th Aviation Depot Squadron (ADS) (264-6528).

*(4) AFWL (61-2508).

*(5) AFSWC Safety Office (61-2003).

(6) Civil Engineering Research Facility (CERF) (264-4644).

(7) Albuquerque Seismological Center (ASC) (264-4637).

d. *Base Operations will notify:*

(1) Kirtland Operations Center (264-4676).

(2) KAFB Fire Station #1.

(3) Air Traffic Control Tower (ATC).

✓(4) 58th Weather Reconnaissance Squadron (WRS).

✓(5) Naval Weapons Evaluation Facility (NWEF).

✓(6) 4900th Test Group.

✓(7) New Mexico Air National Guard (NMANG).

✓(8) Aero Club.

✓(9) Airport Manager.

(10) Information Service Officer.

✓ Tests with disturbance above 500 feet only.

7. Meteorological Data. To avoid potential property damage to atmospheric refraction and convergence of sound waves from the detonation of high explosive charges or other devices, certain meteorological data must be obtained and evaluated. The services of Sandia Laboratories Meteorological Group, Department 7251 are available to range users during normal duty hours. Guidance with respect to "GO" or "NO-GO" conditions for firing of explosive charges up to 500 pounds is routinely available to range users and may be obtained by telephone (264-2834/3045/5365). 7411

FOR THE COMMANDER

OFFICIAL

THEO[illegible]JENSON, Lt Colonel, USAF
Chief, Central Base Administration

Summary of Revised, Deleted, or Added Material

This revision requires use of KAFB Crash Grid Map (paragraph 1b), eliminates detailed breakdown of type tests, consolidates requirements of participating agencies (paragraph 4), emphasizes 24-hour notification procedures (paragraph 7), and eliminates use of AFSWC Form 48, "Notification Procedures."

DISTRIBUTION: X

HQ AFSC/DOO....................................1
4900th ABGp/DAPE...........................4
FCCOM..1
AFWL/SUH......................................1
SLA (Dept 9540)
Albuq., NM, 87115..........................1
CERF..1
ASC..1
Lovelace Foundation Field Laboratories
5200 Gibson Blvd. SE
Albuq., NM, 87108..........................1
EG&G
9733 Coors Blvd. NW
Albuq., NM, 87114..........................1
AFSWC/SE......................................1
4900th ABGp/OTS.............................1
3098th ADS/CC.................................1
AFSWC/XOOW..................................1
4900th ABGp/DEY.............................6
ATC Control Tower
Federal Aviation Administration
Albuq. ATC Tower
P.O. Box 9085 Albuq., NM, 87119.....1
58/DA..1
NWEF/XO.......................................1
4925th FMS/LGMFME.........................1
AFSWC/FT......................................1
NMANG..1
KAFB Aero Club...............................1
Airport Manager
Albuq. International Airport
P.O. Box 9022 Albuq., NM, 87119.....1
AFSWC/OI.......................................1
AFSWC/LG......................................1
AFSWC/XOO....................................1
AFSWC/FTO.....................................1
USAF Hosp KAFB/SG........................1
4900th ABGp/DE...............................1
4900th ABGp/SP...............................1
4900th ABGp/OT...............................1
Coyote Test Field
Organization 9322
Bldg. 9925
Kirtland AFB, NM, 87115................1

APPENDIX B

ENVIRONMENTAL MONITORING PLAN
Sandia Laboratories, Albuquerque
1959-1973

Until plans were revised in 1974, soil and water samples were collected annually at the 22 sites shown in Figure 34. Deep well samples were collected from whichever of eight potable water wells on Kirtland AFB East were then in use. All of these samples were analyzed for gross beta activity. If high gross beta counts were noted, an analysis was performed for ^{90}Sr and/or ^{137}Cs. From October 1970 through the end of 1973, four additional soil sites (each shown on Figure 34 by the symbol P) were sampled annually, and the soil was analyzed either for gross alpha or total plutonium. These samples were only for background data, since Sandia Laboratories Albuquerque generally handles plutonium only as sealed sources.

Offsite sampling locations

Abbreviations: S = soil sample
V = vegetation sample
W = water sample

1. Old Area III gate - east of Area III perimeter fence. S, V.
2. Manzano Base main gate. S, V, W (tap).
3. Pennsylvania Ave. and Tijeras Arroyo at southwest side of bridge, between bridge and bypass road. S, V.
4. Arroyo (aqueduct) north of Area III. S, V.
5. New McCormick gate. Samples were taken near the Southwest corner of the Area III perimeter fence. S, V.
6. Isleta Reservation gate. S, V.
7. Coyote Test Field, Coyote Springs picnic area. S, V.
8. Area east of building 880, Area I. S, V.
9. Albuquerque prison farm. S, V.
10. West mesa, corner of Coors and Rio Bravo Boulevards, S, V.
11. Isleta Pueblo at irrigation control gates on east side of River south of bridge. S, V, W.
12. Tijeras Canyon. S, V.
13. Manzano High School. S, V, W (tap).
14. Los Altos Park. S, V, W (tap and lagoon).
15. State fairgrounds, vicinity of administration building. S, V, W (tap).
16. Bataan Park. S, V, W (tap).
17. Riverside Park. S, V, W (tap).
18. Sedillo Hill, near Comer's Cafe and Service Stations. S, V, W (tap).
19. Corrales bridge, east side of bridge north of highway. S, V, W (river water or irrigation ditch water depending on flow).

20. Oak Flats picnic area on south State Highway 14. (S, V, W (surface or tap water, depending on local conditions).
27. Coyote Test Field headquarters, near building 9925. S, V, W (tap).
33. Road junction, Manzano Base road at turnoff to Areas III and V. S, V.

Kirtland AFB Well Water Samples

22. Area III well.
23. Base well No. 2 (Kirtland runway northwest of igloo area turnoff).
24. Base well No. 3 (between old Sandia housing area and Van Buren Junior High School).
25. Base well No. 7 (junction of ordnance road and Kirtland runway).
26. Base well No. 8 (just south of railhead security area).
28. Base well No. 1 (southwest of building 370).
29. Base well No. 4 (southeast of rifle range and west of railhead).
30. Base well No. 5 (15th and A streets)
31. Base well No. 6 (southsoutheast of Sandia salvage yard).
36. Base well No. 11 or 12 (wells not in use).

Plutonium soil sampling sites

1. South, near an old burn pit by Coyote Canyon.
2. North, north of Coronado Airport, 3 miles east of Interstate 25.
3. West, lookout point at Nine Mile Hill on Highway 66.
4. East, on Sedillo Hill on Highway 66.

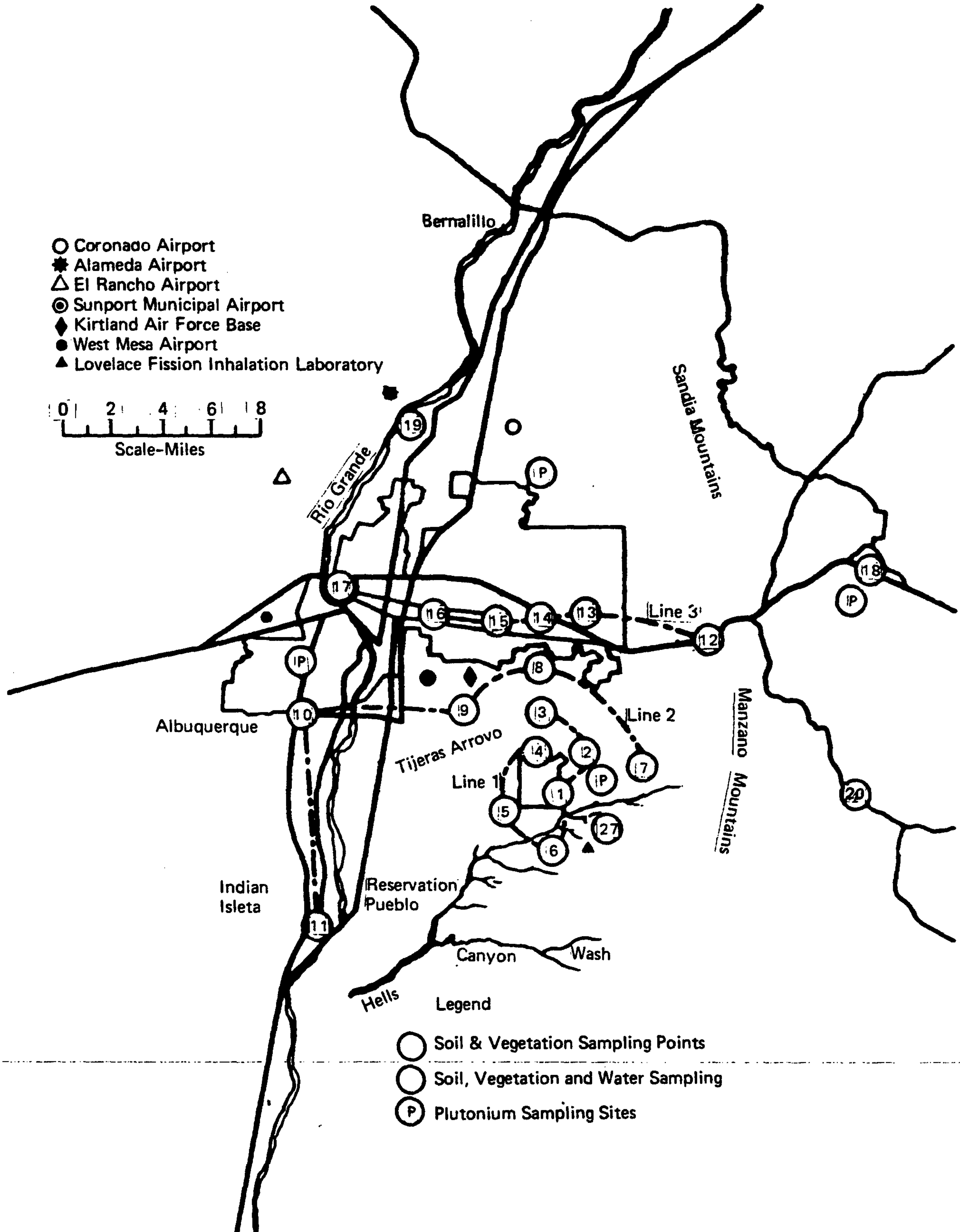


Figure 34. Environmental survey locations

APPENDIX C

WIND STUDIES ON KIRTLAND AFB EAST

Winds are particularly subject to orographic effects. Rather than the official airport statistics for information about winds on Kirtland AFB East, a decade of wind measurements made in the actual areas concerned (Olson et al, 1970) will be cited. A network of seven meteorological towers surrounding SLA-operated nuclear reactors was established in July 1960 to monitor weather conditions important to the safety of the surrounding community; an eighth station was added in May 1965. Of these eight stations, Station 1 was in Area III, and Station 4 was on the eastern edge of Area I. (Among the other six stations was one in Tijeras Canyon, but data from it are not representative of the mountainous areas of Coyote Test Field, because Tijeras Canyon is a major pass through the mountains, channeling winds through them, while Coyote Canyon and the canyons branching from it are not passes). Each tower had meteorological sensors at 12 and 100 feet (3.6 and 30 m) elevations above the ground.

Figures 35 and 36 summarize the wind data taken from Stations 1 and 4, for the coolest and warmest months of the year, January and July. Figure 35 summarizes all data taken during the decade of observations. It is to be seen that prevailing surface winds are from the east, except that winter winds at 100 feet are from the north. Figure 36 summarizes data taken during inversion conditions (an atmospheric condition in which temperature increases rather than decreases with height above the ground). Generally speaking, the large number of clear days and the dry nature of the climate assure that a dry adiabatic lapse rate (the decrease of temperature with altitude) is established soon after sunrise almost every day. After sunset on cloudless or near cloudless days, rapid radiational cooling of the ground often brings about strong temperature inversions. Shallow 7° to 10°F (4° to 6° C) inversions are not uncommon. Atmospheric inversions mean a very stable atmosphere as far as the rise and diffusion of gaseous effluents or explosive products are concerned. Inversion winds are seen to differ from all winds by generally being lighter with more uniform direction.

The night-time ground cooling also generates mountain-valley or drainage winds (catabatic winds). These flow out of all the Sandia and Manzano mountains, and are strongest at the mouths of the larger canyons. A dominant effect on Kirtland AFB East, inasmuch as Tijeras Canyon bisects the base, is the night-time and early-morning winds blowing down that canyon to where it opens out into the Rio Grande valley south of Albuquerque.

Tijeras Canyon constitutes something of a barrier to surface flow between Areas III, V, and the CTF on the one hand, and Areas I, II. and the city of Albuquerque on the other. In 1957, at the time of studies preceding the first Sandia reactor (the SERF, since decommissioned), a pair of smoke tests was conducted at Area III to measure local air trajectories. Since the concern was with diffusion into the heavily populated city, tests were conducted with southeast winds combined with a strong inversion condition (considered the worst case relative to a possible reactor incident). The results showed that the flow of the smoke was predominantly downslope and northerly towards Tijeras Canyon. Drainage flow in the canyon effectively blocked the northerly drift beyond the canyon and redirected the flow into a westerly, down-canyon direction in one case, and into both directions along the canyon in the other. This condition held as long as the temperature inversion held. Once the inversion dissipated, the smoke moved out of the canyon farther north in a well-diffused cloud in the direction of the prevailing wind; however, once adiabatic lapse conditions were established, the smoke cloud was seen to dissipate rapidly. (Palmer and Plagge, 1957).

Standard diffusion parameters have been calculated for the atmospheric conditions represented by these smoke tests. The meteorological mixing parameters and diffusion coefficients for these and other stability conditions are given in Table 10 in Chapter II.

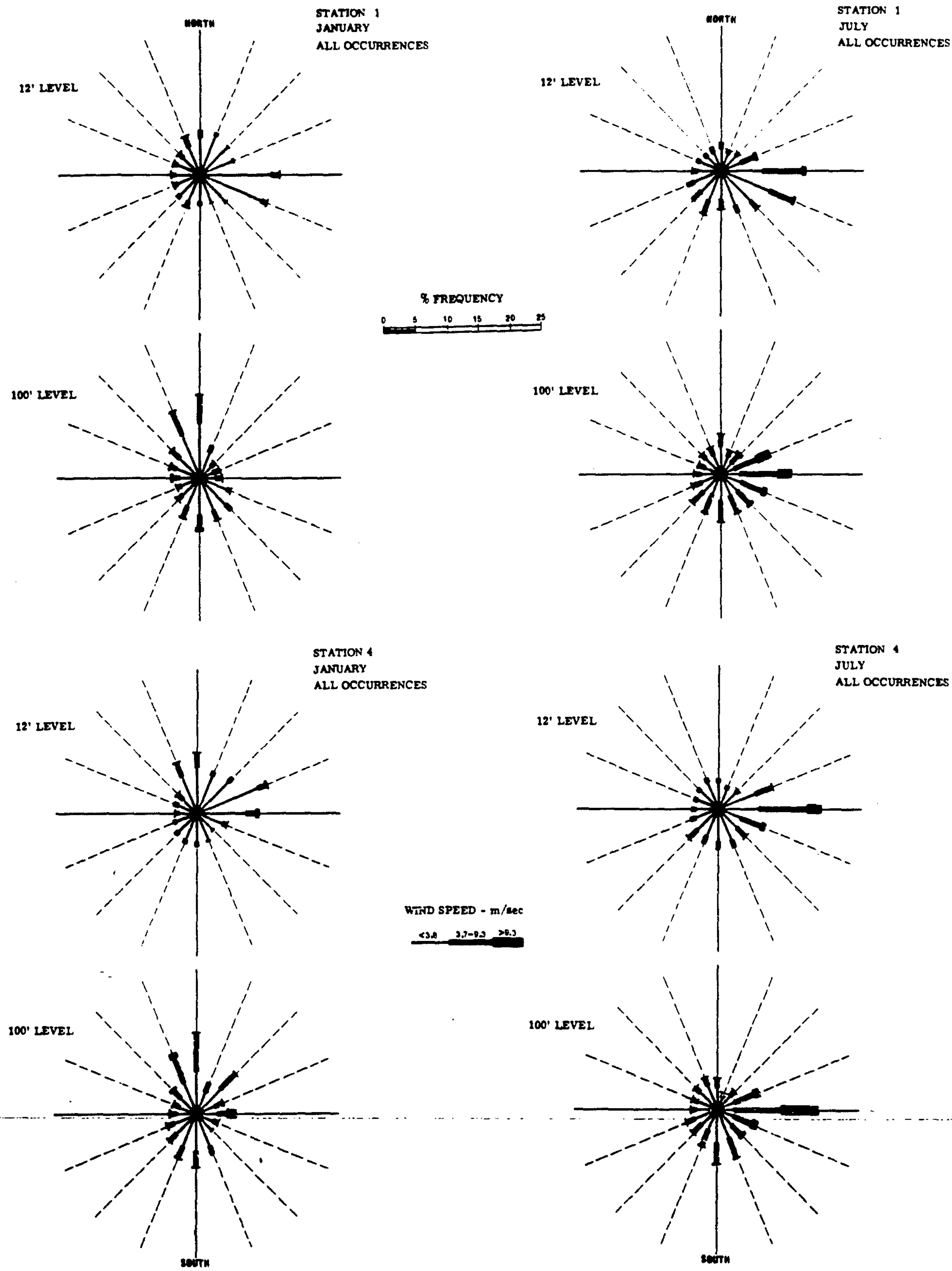


Figure 35. Wind roses summarizing ten years of all data taken at Stations 1 and 4, during January and July

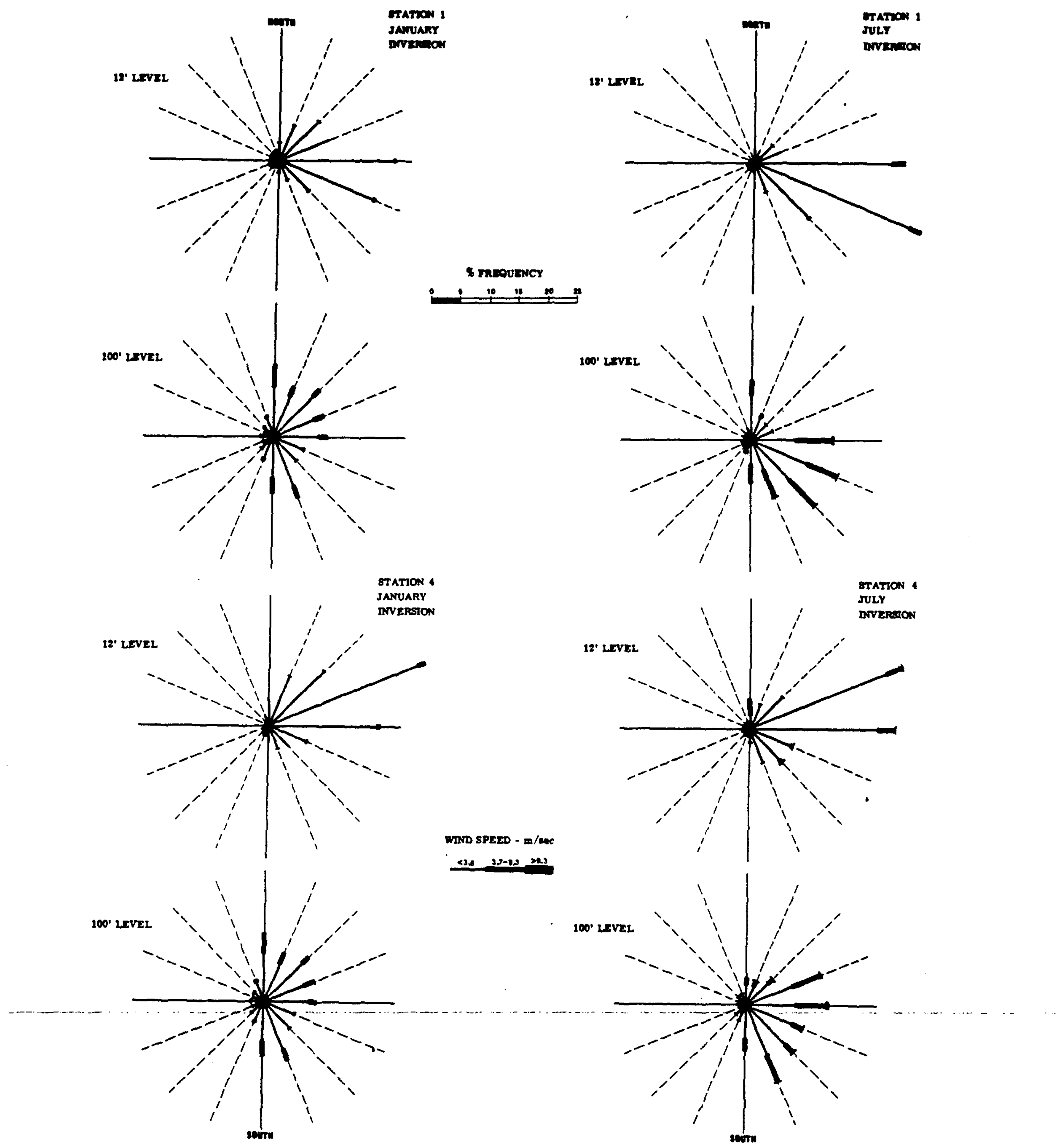


Figure 36. Wind roses summarizing ten years of data on inversion conditions at Stations 1 and 4, during January and July

APPENDIX D

CHECKLIST OF FAUNA AND FLORA ON ON KIRTLAND AFB EAST

In this checklist the most widely accepted phylogenetic sequences were used to arrange each part of the list. Only flora were confirmed by field observations: the 60 percent so confirmed on Kirtland AFB East are marked with an asterisk. (From Martin and Wagner, 1974)

FAUNA

Amphibians

1. Tiger Salamander (Ambystoma tigrinum)
2. Western Spadefoot (Scaphiopus hammondi)
3. Central Plains Spadefoot (Scaphiopus bombifrons)
4. Great Plains Toad (Bufo cognatus)
5. Red-spotted Toad (Bufo punctatus)
6. Green toad (Bufo debilis)
7. Canyon Tree Frog (Hyla arenicolor)

Reptiles

1. Western Box Turtle (Terrapene ornata)
2. Lesser Earless Lizard (Holbrookia maculata)
3. Collared Lizard (Crotaphytus collaris)
4. Eastern Fence Lizard (Sceloporus undulatus)
5. Side-blotched Lizard (Uta stansburiana)
6. Short-horned Lizard (Phrynosoma douglassi)
7. Texas Horned Lizard (Phrynosoma cornutum)
8. Great Plains Skink (Eumeces obsoletus)
9. Many-lined Skink (Eumeces multivirgatus)
10. Little Striped Whiptail (Cnemidophorus inornatus)
11. Chihuahua Whiptail (Cnemidophorus exsanguis)
12. Checkered Whiptail (Cnemidophorus tesselatus)
13. Western Hog-nosed Snake (Heterodon nasicus)
14. Striped Whipsnake (Masticophis taeniatus)
15. Coachwhip (Masticophis flagellum)
16. Mountain Patch-nosed Snake (Salvadora grahamiae)
17. Bullsnake (Pituophis melanoleucus)
18. Sonoran King Snake (Lampropeltis getulus splendida)
19. Painted Desert Glossy Snake (Arizona elegans philipi)
20. Texas Long-nosed Snake (Rhinocheilus lecontei tessellatus)
21. Black-necked Garter Snake (Thamnophis cyrtopsis)
22. Western Terrestrial Garter Snake (Thamnophis elegans)
23. Plains Black-headed Snake (Tantilla nigriceps)
24. Texas Night Snake (Hypsiglena torquata texana)
25. Western Diamondback Rattlesnake (Crotalus atrox)
26. Prairie Rattlesnake (Crotalus viridis)

MAMMALS

Chiroptera

1. Little Brown Myotis (Myotis lucifugus)
2. Fringed Myotis (Myotis thysanodes)
3. Long-legged Myotis (Myotis volans)
4. Small-footed Myotis (Myotis leibii)
5. Silver-haired Bat (Lasionycteris noctivagans)
6. Big Brown Bat (Eptesicus fuscus)
7. Hoary Bat (Lasiurus cinereus)
8. Townsend's Big-eared Bat (Plecotus townsendii)
9. Pallid Bat (Antrozous pallidus)
10. Brazilian Free-tailed Bat or Mexican Free-tailed Bat (Tadarida brasiliensis)

Lagomorpha

11. Desert Cottontail (Sylvilagus auduboni)
12. Black-tailed Jack Rabbit (Lepus californicus)

Rodentia

13. Colorado Chipmunk (Eutamias quadriuittatus)
14. Texas Antelope Squirrel (Ammospermophilus interpres)
15. Spotted Ground Squirrel(Spermophilus spilosoma)
16. Rock Squirrel (Spermophilus variegatus)
17. Gunnison's Prairie Dog (Cynomys gunnisoni)
18. Botta's Pocket Gopher (Thomomys bottae)
19. Silky Pocket Mouse (Perognathus flavus)
20. Hispid Pocket Mouse (Perognathus hispidus)
21. Rock Pocket Mouse (Perognathus intermedius)
22. Ord's Kangaroo Rat (Dipodomys ordii)
23. Banner-tailed Kangaroo Rat (Dipodomys spectabilis)
24. Merriam's Kangaroo Rat (Dipodomys merriami)
25. Western Harvest Mouse (Reithrodontomys megalotis)
26. Deer Mouse (Peromyscus maniculatus)
27. White-footed Mouse (Peromyscus leucopus)
28. Brush Mouse (Peromyscus boylii)
29. Pinyon Mouse (Peromyscus truei)
30. Rock Mouse (Peromyscus difficilis)
31. Northern Grasshopper Mouse (Onychomys leucogaster)
32. Southern Plains Wood-rat (Neotoma micropus)
33. White-throated Wood-rat (Neotoma albigula)
34. Mexican Vole (Microtus mexicanus)
35. House Mouse (Mus musculus)
36. Porcupine (Erethizon dorsatum)

Carnivora

37. Coyote (Canis latrans)
38. Kit Fox (Vulpes macrotis)
39. Gray Fox (Arocyon cinereoargenteus)
40. Ringtail (Bassariscus astutus)

Carnivora (continued)

41. Raccoon (Procyon lotor)
42. Long-tailed Weasel (Mustela frenata)
43. Badger (Taxidea taxus)
44. Western Spotted Skunk (Spilogale gracilis)
45. Striped Skunk (Mephitis mephitis)
46. Mountain Lion (Felis concolor)
47. Bobcat (Lynx rufus)

Artiodactyla

48. Mule deer (Odocoileus hemionus)

BIRDS

Falconiformes

1. Turkey Vulture (Cathartes aura)
2. Goshawk (Accipiter gentilis)
3. Sharp-shinned Hawk (Accipiter striatus)
4. Cooper's Hawk (Accipiter cooperii)
5. Red-tailed Hawk (Buteo jamaicensis)
6. Swainson's Hawk (Buteo swainsoni)
7. Ferruginous Hawk (Buteo regalis)
8. Rough-legged Hawk (Buteo lagopus)
9. Golden Eagle (Aquila chrysaetos)
10. Marsh Hawk (Circus cyaneus)
11. Prairie Falcon (Falco mexicanus)
12. Merlin (Falco columbarius)
13. American Kestrel (Falco sparverius)

Galliformes

14. Scaled Quail (Callipepla squamata)

Columbiformes

15. Band-tailed Pigeon (Columba fasciata)
16. Mourning Dove (Zenaida macroura)

Cuculiformes

17. Roadrunner (Geococcyx californianus)

Strigiformes

18. Barn Owl (Tyto alba)
19. Screech Owl (Otus asio)
20. Great Horned Owl (Bubo virginianus)
21. Pygmy Owl (Glaucidium gnoma)
22. Burrowing Owl (Speotyto cunicularia)
23. Long-eared Owl (Asio otus)

Caprimulgiformes

24. Common Nighthawk (Chordeiles minor)
25. Poor-will (Phalaenoptilus nuttallii)

Apodiformes

26. White-throated Swift (Aeronautes saxatalis)
27. Black-chinned Hummingbird (Archilochus alexandri)
28. Broad-tailed Hummingbird (Selasphorus platycercus)
29. Rufous Hummingbird (Selasphorus rufus)
30. Calliope Hummingbird (Stellula calliope)

Piciformes

31. Common Flicker (Colaptes auratus)
32. Lewis' Woodpecker (Asyndesmus lewisi)
33. Yellow-bellied Sapsucker (Sphyrápicus varius)
34. Williamson's Sapsucker (Sphyrapicus thyroideus)
35. Hairy Woodpecker (Dendrocopos villosus)
36. Downy Woodpecker (Dendrocopos pubescens)
37. Ladder-backed Woodpecker (Dendrocopos scalaris)

Passeriformes

38. Western Kingbird (Tyrannus verticalis)
39. Cassin's Kingbird (Tyrannus vociferans)
40. Ash-throated Flycatcher (Myiarchus cinerascens)
41. Say's Phoebe (Sayornis saya)
42. Western Flycatcher (Empidonax difficilis)
43. Western Wood Pewee (Contopus sordidulus)
44. Horned Lark (Eremophila alpestris)
45. Violet-green Swallow (Tachycineta thalassina)
46. Barn Swallow (Hirundo rustica)
47. Rough-winged Swallow (Stelgidopteryx ruficollis)
48. Cliff Swallow (Petrochelidon pyrrhonota)
49. Steller's Jay (Cyanocitta stelleri)
50. Scrub Jay (Aphelocoma coerulescens)
51. Common Raven (Corvus corax)
52. Common Crow (Corvus brachyrhyncos)
53. Pinyon Jay (Gymnorhinus cyanocephalus)
54. Clark's Nutcracker (Nucifraga columbiana)
55. Mountain Chickadee (Parus gambeli)
56. Plain Titmouse (Parus inornatus)
57. Common Bushtit (Psaltriparus minimus)
58. White-breasted Nuthatch (Sitta carolinensis)
59. Red-breasted Nuthatch (Sitta canadensis)
60. Pygmy Nuthatch (Sitta pygmaea)
61. Brown Creeper (Certhia familiaris)
62. House Wren (Troglodytes aedon)
63. Bewick's Wren (Thyromanes bewickii)
64. Canyon Wren (Catherpes mexicanus)
65. Rock Wren (Salpinctes obsoletus)
66. Mockingbird (Mimus polyglottos)
67. Crissal Thrasher (Toxostoma dorsale)
68. Sage Thrasher (Oreoscoptes montanus)
69. American Robin (Turdus migratorius)
70. Hermit Thrush (Catharus guttatus)
71. Western Bluebird (Sialia mexicana)
72. Mountain Bluebird (Sialia currucoides)
73. Townsend's Solitaire (Myadestes townsendi)
74. Blue-gray Gnatcatcher (Polioptila caerulea)
75. Ruby-crowned Kinglet (Regulus calendula)
76. Cedar Waxwing (Bombycilla cedrorum)
77. Bohemian Waxwing (Bombycilla garrulus)

Passeriformes (continued)

78. Loggerhead Shrike (Lanius ludovicianus)
79. Northern Shrike (Lanius excubitor)
80. Starling (Sturnus vulgaris)
81. Solitary Vireo (Vireo solitarus)
82. Warbling Vireo (Vireo gilvus)
83. Orange-crowned Warbler (Vermivora celata)
84. Virginia's Warbler (Vermivora virginiae)
85. Yellow-Warbler (Dendroica petechia)
86. Yellow-rumped (Audubon's) Warbler (Dendroica coronata)
87. Black-throated Gray Warbler (Dendroica nigrescens)
88. Townsend's Warbler (Dendroica townsendi)
89. MacGillivray's Warbler (Oporornis tolmiei)
90. Yellow-breasted Chat (Icteria virens)
91. Wilson's Warbler (Wilsonia pusilla)
92. House Sparrow (Passer domesticus)
93. Western Meadowlark (Sturnella neglecta)
94. Scott's Oriole (Icterus parisorum)
95. Northern (Bullock's) Oriole (Icterus galbula)
96. Brown-headed Cowbird (Molothrus ater)
97. Western Tanager (Piranga ludoviciana)
98. Hepatic Tanager (Piranga flava)
99. Black-headed Grosbeak (Pheucticus melanocephalus)
100. Blue Grosbeak (Guiraca caerulea)
101. Indigo Bunting (Passerina cyanea)
102. Lazuli Bunting (Passerina amoena)
103. Evening Grosbeak (Hesperiphona vespertina)
104. Cassin's Finch (Carpodacus cassinii)
105. House Finch (Carpodacus mexicanus)
106. Lesser Goldfinch (Spinus psaltria)
107. Red Crossbill (Loxia curvirostra)
108. Green-tailed Towhee (Chlorura chlorura)
109. Rufous-sided Towhee (Pipilo erythropthalmus)
110. Brown Towhee (Pipilo fuscus)
111. Lark Bunting (Calamospiza melanocorys)
112. Savannah Sparrow (Passerculus sandwichensis)
113. Vesper Sparrow (Pooecetes gramineus)
114. Lark Sparrow (Chondestes grammacus)
115. Rufous-crowned Sparrow (Aimophila ruficeps)
116. Black-throated Sparrow (Amphispiza bilineata)
117. Sage Sparrow (Amphispiza belli)
118. Gray-headed Junco (Junco caniceps)
119. Dark-eyed (Oregon) Junco (Junco hyemalis)
120. Chipping Sparrow (Spizella passerina)
121. Brewer's Sparrow (Spizella breweri)
122. Black-chinned Sparrow (Spizella atrogularis)
123. White-crowned Sparrow (Zonotrichia leucophrys)
124. White-throated Sparrow (Zonotrichia albicollis)
125. Fox Sparrow (Passerella iliaca)
126. Lincoln's Sparrow (Melospiza lincolnii)
127. Song Sparrow (Melospiza melodia)
128. Chestnut-collared Longspur (Calcarius ornatus)

FLORA

Fern Family

1. Zigzag cliffbrake (Pellaea fendleri)
2. Cliffbrake (Pellaea longimucronata)
*3. Eaton's lip fern (Cheilanthes eatonii)
*4. (Woodsia mexicana)

Pine Family

*5. Colorado pinyon (Pinus edulis)
*6. Ponderosa pine (Pinus ponderosa)

Cypress Family

*7. One-seed juniper (Juniperus monosperma)
*8. Rocky Mountain juniper (Juniperus scopulorum)

Joint-fir Family

*9. Mormon tea (Ephedra torreyana)
10. Rough joint fir (Ephedra nevadensis)
11. Green joint-fir (Ephedra viridis)

Cattail Family

*12. Cat-tail (Typha latifolia)

Rush Family

*13. Wire rush (Juncus balticus)
*14. Torrey rush (Juncus torreyi)
*15. (Juncus saximontanus)

Sedge Family

16. Fendler flat sedge (Cyperus fendlerianus)
17. Yellow nut grass (Cyperus esculentus)
18. Mountain spikesedge (Eleochàris montana)
*19. Three-square (Scirpus americanus)

Grass Family

*20. Galleta (Hilaria jamesii)
*21. Foxtail barley (Hordeum jubatum)
*22. Western wheatgrass (Agropyron smithii)
23. False quackgrass (Agropyron pseudorepens)
24. Slender wheatgrass (Agropyron trachycaulum)
*25. Burro grass (Scleropogon brevifolies)
*26. Spike pappus grass (Enneapogon desvauxii)
*27. Canada wild rye (Elymus canadensis)
*28. Squirreltail (Sitanion hystrix)
*29. False buffalo grass (Munroa squarrosa)

*30. Windmill grass (Chloris verticillata)
*31. Feathery finger grass (Chloris virgata)
*32. Side-oats grama (Bouteloua curtipendula)
*33. Six-weeks grama (Bouteloua barbata)
*34. Black grama (Bouteloua eriopoda)
*35. Blue grama (Bouteloua gracilis)
*36. Needle grama (Bouteloua aristidoides)
37. Hairy grama (Bouteloua hirsuta)
*38. Crabgrass (Digitaria sanguinalis)
*39. Bermuda grass (Cynodon dactylon)
40. Tumble grass (Schedonnardus paniculatus)
*41. Rabbitfoot grass (Polypogon monspeliensis)
*42. Reverchon three-awn (Aristida glauca)
*43. Six-weeks three-awn (Aristida adscensionis)
44. Poverty three-awn (Aristida divaricata)
45. Arizona three-awn (Aristida arizonica)
46. Purple three-awn (Aristida purpurea)
47. Wright's three-awn (Aristida wrightii)
*48. Fendler three-awn (Aristida fendleriana)
*49. Red three-awn (Aristida longiseta)
*50. Little seed ricegrass (Oryzopsis micrantha)
*51 Indian ricegrass (Oryzopsis hymenoides)
*52. Sandbur (Cenchrus echinatus)
53. New Mexican porcupine grass (Stipa neomexicana)
*54. Scribner needlegrass (Stipa scribneri)
55. Needle-and-thread (Stipa comata)
56. Timothy (Phleum pratense)
57. Marsh muhly (Muhlenbergia sinuosa)
58. Mat muhly (Muhlenbergia richardsonis)
*59. Sand muhly (Muhlenbergia arenicola)
60. Sandhill muhly (Muhlenbergia pungens)
*61. New Mexican muhly (Muhlenbergia pauciflora)
62. Ear muhly (Muhlenbergia arenacea)
*63. Bush muhly (Muhlenbergia porteri)
64. Ring muhly (Muhlenbergia torreyi)
*65. Mesa muhly (Muhlenbergia monticola)
*66. Mountain muhly (Muhlenbergia montana)
*67. Spike Muhly (Muhlenbergia wrightii)
*68. Scratch-grass (Muhlenbergia asperifolia)
*69. Spike dropseed (Sporobolus contractus)
*70. Mesa dropseed (Sporobolus flexuosus)
*71. Sand dropseed (Sporobolus cryptandrus)
*72. Alkali sacaton (Sporobolus airoides)
*73. Fluff grass (Tridens pulchellus)
*74. Hairy tridens (Tridens pilosus)
*75. Desert saltgrass (Distichlis stricta)
76. Mexican lovegrass (Eragrostis mexicana)
*77. India lovegrass (Eragrostis pilosa)
*78. Stink grass (Eragrostis cilianensis)
79. Foothills brome (Bromus polyanthus)
80. Nodding brome (Bromus anomalus)
*81. Japanese chess (Bromus japonicus)
*82. Downy chess (Bromus tectorum)
*83. Kentucky bluegrass (Poa pratensis)

84. Arizona fescue (Festuca arizonica)
85. Six-weeks fescue (Festuca octoflora)
*86. Plains bristle grass (Setaria macrostachya)
*87. Green bristle grass (Setaria viridis)
*88. Bur bristlegrass (Setaria verticillata)
*89. Witchgrass (Panicum capillare)
90. Vine mesquite (Panicum obtusum)
*91. Johnson grass (Sorghum halepense)
92. Little bluestem (Andropogon scoparius)
93. Cane beardgrass (Andropogon barbinodis)
*94. Barnyard grass (Enchinochloa crusgalli)

Agave Family

*95. Banana yucca (Yucca baccata)
*96. Soapweed yucca (Yucca glauca)
*97. Bear grass (Nolina microcarpa)

Lily Family

98. Onion (Allium macropetalum)
99. Nodding onion (Allium cernuum)
100. Asparagus (Asparagus officinalis)

Lizard's-tail Family

*101. Yerba mansa (Anemopsis californica)

Willow Family

*102. Fremont cottonwood (Populus fremontii)

Beech Family

*103. Gambel oak (Quercus gambelii)
*104. Gray oak (Quercus grisea)
*105. Shrub live oak (Quercus turbinella)

Elm Family

*106. Siberian elm or Chinese elm (Ulmus pumila)
107. Netlead hackberry (Celtis reticulata)

Mistletoe Family

*108. Juniper mistletoe (Phoradendron juniperinum)
109. Dwarf mistletoe (Arceuthobium camylopodum)

Buckwheat Family

110. Antelope-sage (Eriogonum jamesii)
*111. Wright's wild buckwheat (Eriogonum wrightii)
112. Wild buckwheat (Eriogonum abertianum)
*113. Sorrel wildbuckwheat (Eriogonum polycladon)
*114. Canaigre (Rumex hymenosepalus)
115. Dock (Rumex mexicanus)

116. Corn-bind (Polygonum convolvulus)
*117. Knotweed (Polygonum aviculare)

Goosefoot Family

*118. Winter-fat (Eurotia lanata)
*119. Four-wing salt bush (Atriplex canescens)
*120. Russian thistle (Salsola kali)
*121. Summer cypress (Kochia scoparia)
*122. Lamb's quarters (Chenopodium album)
*123. Fremont goosefoot (Chenopodium fremontii)
*124. (Chenopodium incanum)
125. Jerusalem oak (Chenopodium botrys)

Amaranth Family

*126. Prostrate pigweed (Amaranthus graecizans)
127. Green amaranth (Amaranthus retroflexus)
128. Pigweed (Amaranthus hybridus)
*129. Pigweed (Amaranthus powellii)
130. (Acanthochiton wrightii)
*131. (Tidestromia lanuginosa)

Four-O'Clock Family

*132. Four-o'clock (Mirabilis multiflora)
*133. Four-o'clock (Mirabilis oxybaphoides)
*134. (Oxybaphus linearis)

Carpetweed Family

135. Carpet weed (Mollugo verticillata)

Purslane Family

*136. Common purslane (Portulaca oleracea)

Pink Family

*137. Chickweed (Stellaria longifolia)

Barberry Family

*138. Creeping mahonia (Berberis repens)
139. Red Barberry (Berberis haematocarpa)

Fumitory Family

140. Golden corydalis (Corydalis aurea)

Mustard Family

*141. Peppergrass (Lepidium montanum)
142. Peppergrass (Lepidium medium)
143. Shepherd's purse (Capsella bursa-pastoris)
144. Spectacle pod (Dithyrea wislizeni)
145. Wild candytuft (Thlaspi alpestre)

146. Whitlow grass (Draba cuneifolia)
*147. Bladderpod (Lesquerella fendleri)
*148. Tansy mustard (Descurainia sophia)
149. Tansy mustard (Descurainia obtusa)
*150. Water cress (Rorippa nasturtium-aquaticum)
*151. Western wallflower (Erysimum capitatum)
*152. (Sisymbrium irio)
*153. Tumble mustard (Sisymbrium altissimum)

Caper Family

154. Rocky Mountain bee plant (Cleome serrulata)
*155. Clammy weed (Polanisia trachysperma)

Saxifrage Family

*156. Cliff fendlerbush (Fendlera rupicola)
*157. Mock orange (Philadelphus microphyllus)
158. Waxcurrant (Ribes cereum)

Rose Family

*159. Wood's rose (Rosa woodsii)
160. Western black chokecherry (Prunus virginiana)
*161. Alder-leaf mountain mahogany (Cercocarpus montanus)
*162. Apache plume (Fallugia paradoxa)

Pea Family

*163. Rush pea (Hoffmanseggia jamesii)
164. False mesquite (Calliandra humilis)
165. White prairie clover (Petalostemum candidum)
166. Lemon scurf pea (Psoralea lanceolata)
167. Slender scurf pea (Psoralea tenuiflora)
168. Broom indigo bush (Dalea scoparia)
169. Dwarf indigo bush (Dalea nana)
170. Pea bush (Dalea leporina)
171. (Dalea formosa)
*172. Alfalfa (Medicago sativa)
*173. Black medic (Medicago lupulina)
*174. Yellow sweet clover (Melilotus officinalis)
*175. White sweet clover (Melilotus albus)
176. Deer vetch (Lotus wrightii)
177. Lambert locoweed (Oxytropis lambertii)
178. Locoweed (Astragalus amphioxys)
179. Locoweed (Astragalus allochrous)
180. Blue locoweed (Astragalus lentiginosus)
181. Nuttall milkvetch (Astragalus nuttallianus)
182. Ground plum (Astragalus crassicarpus)
183. (Astragalus mollissimus)
184. (Astragalus missouriensis)
185. (Astragalus emoryanus)
186. (Astragalus flexuosus)
187. (Astragalus humistratus)
*188. New Mexico locust (Robinia neomexicana)

Geranium Family

*189. Heronbill (Erodium cicutarius)
*190. Cranesbill (Geranium caespitosum)

Woodsorrel Family

191. Yellow woodsorrel (Oxalis stricta)

Flax Family

*192. Western blue flax (Linum lewisii)

Caltrop Family

*193. Goathead (Tribulus terrestris)
194. Caltrop (Kallstroemia californica)
195. (Kallstroemia parviflora)
*196. Caltrop (Kallstroemia hirsutissima)

Rue Family

*197. Narrow leaf hop tree (Ptelea angustifolia)

Simarouba Family

*198. Tree-of-Heaven (Ailanthus altissima)

Milkwort Family

199. White milkwort (Polygala alba)

Spurge Family

*200. Doveweed (Croton texensis)
*201. Spurge (Euphorbia fendleri)
202. Spurge (Euphorbia dentata)
203. Spurge (Euphorbia stictospora)
204. Spurge (Euphorbia revoluta)
205. Spurge (Euphorbia serpyllifolia)
*206. Spurge (Euphorbia exstipulata)
*207. Spurge (Euphorbia lurida)
*208. Nose burn (Tragia stylaris)

Cashew Family

*209. Skunk bush (Rhus trilobata)

Grape Family

*210. Canyon grape (Vitis arizonica)
*211. Virginia creeper (Parthenocissus inserta)

Mallow Family

212. Common mallow (Malva neglecta)
*213. Globe mallow (Sphaeralcea grossulariaefolia)

214. Silvery globe mallow (Sphaeralcea leptophylla)
*215. Red globe mallow (Sphaeralcea coccinea)
216. Globe mallow (Sphaeralcea angustifolia)
*217. Globe mallow (Sphaeralcea incana)
218. Globe mallow (Sphaeralcea fendleri)
*219. Globe mallow (Sphaeralcea subhastata)

Tamarisk Family

*220. Salt cedar (Tamarix pentandra)

Loasa Family

*221. Stickleaf (Mentzelia pumila)

Cactus Family

*222. Cholla (Opuntia imbricata)
223. Plains prickly pear (Opuntia macrorhiza)
224. Starvation prickly pear (Opuntia polyacantha)
225. Hairy prickly pear (Opuntia polyacantha)
226. (Opuntia polyacantha rufispina)
227. (Opuntia phaeacantha)
*228. Engelmann prickly pear (Opuntia phaeacantha disenta)
*229. Dagger cholla (Opuntia clavata)
*230. Pincushion cactus (Coryphantha vivipara)
231. Pincushion cactus (Mammillaria gummifera)
232. Pincushion cactus (Mammillaria wrightii)
233. (Pediocactus papyracanthus)
234. Fendler's Hedgehog (Echinocereus fendleri)
235. Strawberry cactus or Varied hedgehog (Echinocereus viridiflorus)
*236. Claret cup (Echinocereus triglochidiatus)
*237. White spined claret cup (Echinocereus triglochidiatus melanacanth
238. Woven-spine pineapple cactus (Echinomastus intertextus)
239. (Echinomastus intertextus)

Oleaster Family

*240. Russian olive (Elaeagnus angustifolia)

Evening-primrose Family

241. Scarlet gaura (Gaura coccinea)
242. Evening primrose (Oenothera albicaulis)
243. Evening primrose (Oenothera coronopifolia)
244. (Oenothera runcinata)

Carrot Family

245. Chimaya (Cymopterus fendleri)
*246. (Aletes acaulis)

Primrose Family

*247. Rock jasmine (Androsace septentrionalis)

Olive Family

248. New Mexico olive (Forestiera neomexicana)
249. Rough menodora (Menodora scabra)

Milkweed Family

*250. Antelope horns (Asclepias asperula)
*251. Poison milkweed (Asclepias subverticillata)
*252. Broad-leaf milkweed (Asclepias latifolia)
253. Green milkweed (Asclepias viridiflora)

Morning-glory Family

254. Dodder (Cuscuta megalocarpa)
255. (Evolvulus pilosus)
256. Field bindweed (Convolvulus arvensis)
257. Hedge bindweed (Convolvulus sepium)
*258. Morning glory (Ipomoea hirsutula)
*259. Morning glory (Ipomoea costellata)

Phlox Family

260. Gilia (Gilia longiflora)
261. Skyrocket (Gilia aggregata)
262. (Gilia rigidula)

Water leaf Family

263. (Nama hispidum)
264. Scorpionweed (Phacelia corrugata)
265. Scorpionweed (Phacelia crenulata)

Borage Family

*266. Stickweed (Lappula redowskii)
267. Plains hidden-flower (Cryptantha crassisepala)
268. (Cryptantha jamesii)
269. Puccoon (Lithospermum incisum)

Vervain Family

*270. Vervain (Verbena bracteata)
271. Vervain (Verbena ambrosifolia)
*272. Vervain (Verbena wrightii)
*273. Vervain (Verbena macdougalii)
*274. Vervain (Verbena bipinnatifida)

Mint Family

*275. Rocky Mountain sage (Salvia reflexa)
*276. False pennyroyal (Hedeoma drummondii)
*277. Horehound (Marrubium vulgare)

Nightshade Family

278. Indian apple (Datura meteloides)
279. Jimsonweed (Datura stramonium)
280. Ground cherry (Physalis virginiana)
*281. (Physalis hederaefolia)
*282. (Physalis hederaefolia cordifolia)
283. (Chamaesaracha conioides)
284. (Chamaesaracha coronopus)
*285. Horse nettle (Solanum elaeagnifolium)

Figwort Family

286. False snapdragon (Maurandya antirrhiniflora)
287. Cow tobacco (Penstemon ambiguus)
*288. Scarlet beardtongue (Penstemon barbatus)
*289. Beardtongue (Penstemon jamesii)
*290. Paintbrush (Castilleja integra)
*291. Clubflower (Cordylanthus wrightii)
*292. Monkey flower (Mimulus glabratus)

Unicorn-plant Family

293. (Proboscidea parviflora)

Plaintain Family

294. Wooly Indian wheat (Plantago purshii)
*295. Buckhorn plantain (Plantago lanceolata)
*296. Rippleseed plantain (Plantago major)

Gourd Family

*297. Buffalo gourd (Cucurbita foetidissima)

Aster Family

*298. Goat's beard (Tragopogon dubius)
*299. Skeletonweed (Stephanomeria pauciflora)
*300. Prickly lettuce (Latuca serriola)
*301. Sow thistle (Sonchus asper)
302. Desert dandelion (Malacothrix fendleri)
*303. Dandelion (Taraxacum officinale)
*304. Cocklebur (Xanthium strumarium)
305. Western ragweed (Ambrosia psilostachya)
306. Common ragweed (Ambrosia artemisiifolia)
307. Burdock (Arctium minus)
*308. Sand sagebrush (Artemisia filifolia)
*309. Bigelow sagebrush (Artemisia bigelovii)
310. Louisiana wormwood (Artemisia ludoviciana)
*311. Wormwood (Artemisia ludoviciana albula)
*312. Mexican sagebrush (Artemisia ludoviciana mexicana)
313. Estafiata (Artemisia frigida)
*314. False terragon (Artemisia dracunculoides)

*315. Hopi tea (Thelesperma megapotanicum)
*316. Santa Fe thistle (Cirsium ochrocentrum)
*317. New Mexican thistle (Cirsium neomexicanum)
318. Dogweed (Dyssodia acerosa)
*319. White ragweed (Hymenopappus filifolius)
*320. Yellow ragweed (Bahia dissecta)
*321. Bricklebush (Brickellia grandiflora)
*322. California bricklebush (Brickellia californica)
*323. Bricklebush (Brickellia brachyphylla)
*324. Thoroughwort (Eupatorium herbaceum)
*325. Threadleaf groundsel (Senecio longilobus)
*326. (Senecio multicapitatus)
327. (Baccharis wrightii)
*328. Gum weed (Grindelia aphanactis)
*329. Rabbitbrush (Chrysothamnus nauseosus-Bigelovii)
*330. Rabbitbrush (Chrysothamnus nauseosus-latisquamens)
*331. Rayless goldenrod (Haplopappus heterophyllus)
*332. False boneset (Kuhnia chlorolepis)
333. Goldenweed (Haplopappus gracilis)
*334. (Haplopappus spinulosus)
*335. (Haplopappus spinulosus-australis)
*336. Horseweed (Conyza canadensis)
337. Spreading fleabane (Erigeron divergens)
*338. Aster (Aster hirtifolius)
*339. Purple aster (Aster coerulescens)
*340. Aster (Aster commutatus)
341. Roughgolden aster (Chrysopsis hispida)
*342. Hairy golden aster (Chrysopsis villosa)
343. Gray-leaved golden aster (Chrysopsis foliosa)
344. Western goldenrod (Solidago occidentalis)
345. Canada goldenrod (Solidago canadensis)
*346. Dwarf goldenrod (Solidago decumbens)
*347. Rocky Mountain zinnia (Zinnia grandiflora)
*348. Plains blackfoot (Melampodium leucanthum)
*349. Desert marigold (Baileya multiradiata)
*350. Crownbeard (Verbesina encelioides)
*351. Goldeneye (Viguiera dentata)
352. Prairie coneflower (Ratibida tagetes)
*353. Annual sunflower (Helianthus annuus)
*354. Prairie sunflower (Helianthus petiolaris)
355. (Townsendia exscapa)
*356. (Townsendia formosa)
*357. Snakeweed (Gutierrezia sarothrae)
358. Snakeweed (Gutierrezia microcephala)
*359. Paper daisy (Psilostrophe tagetina)
360. Colorado rubberweed (Hymenoxys richardsonii)
*361. Bitterweed (Hymenoxys argentea)
*362. Blanketflower (Gaillardia pinnatifida)
*363. Bur weed (Franseria acanthicarpa)
*364. Mariola (Parthenium incanum)
365. Dwarf desert-holly (Perezia nana)
366. Engelmann daisy (Engelmannia pinnatifida)
*367. (Flaveria campestris)
*368. (Sanvitalia abertii)
*369. (Berlandiera lyrata)

APPENDIX E

ESTIMATED PROBABILITY OF AIRCRAFT IMPACTING OIL TANK, EAST OF ALBUQUERQUE AIRPORT EAST-WEST RUNWAY

Sandia Laboratories

Albuquerque, New Mexico
Livermore, California

date: September 9, 1974

to: J. H. Kesinger - 9542

from: R. K. Clarke - 1543

Ref: 1. National Transportation Safety Board, "Annual Review U. S. Air Carrier Accidents Calendar Year 1968."

2. R. K. Clarke, J. T. Foley, W. F. Hartman, and D. W. Larson, "Severities of Transportation Accidents, Volume II," SLA-74-0001 (to be published).

3. Department of Transportation, FAA, "Enroute IFR Air Traffic Survey Peak Day Fiscal Year 1971," March 1972.

ABSTRACT

Statistical data has been combined with crash location probability models to estimate the probability of an aircraft impacting the million gallon oil tank east of the Albuquerque airport east-west runway. The probability of hitting the tank, given a takeoff or landing, is estimated to be in the range of 1.5×10^{-9} to 1.3×10^{-8}, with the result that the tank would be expected to be struck once every 150 to 1300 years.

Statistics

Data from References 1 and 2 indicate that, for both military and civil aircraft, the probability of crashing close to the runway (e.g., undershoot, takeoff, go-around accidents) is about 2×10^{-6} per takeoff or landing. Albuquerque International Airport, including air carrier, general and military traffic, has about 500,000 takeoffs and landings yearly (Reference 3) so that one accident of this type would be expected per year at Albuquerque.

Location Models

(1.4 miles)

The tank is 75' in diameter and located 7392' directly east of the east end of the east-west runway. No statistical information was available on distances from runways for actual crashes, so recourse was made to probability density function models for crash location in both longitudinal (parallel to the runway) and lateral directions.

The longitudinal probability density function, pdf_y, was based on the assumption that the pilot would be making a definite effort to reach the runway (undershoots are the majority of the accidents of interest) and would therefore be more likely to crash at the runway than at the tank. The resulting linear distribution is shown in Figure 1, with the value at the runway equal to some multiple of the value at the back of the tank; multiples of 3, 5, 10 and 20 were considered. The probability of a crash at the tank longitudinal location, p_y, is given by the integral of this distribution over the last 225' (75' tank diameter plus one typical aircraft length - 150' for a Boeing 707-320).

$$p_y = \int_{7242}^{7467} pdf_y dy \qquad (1)$$

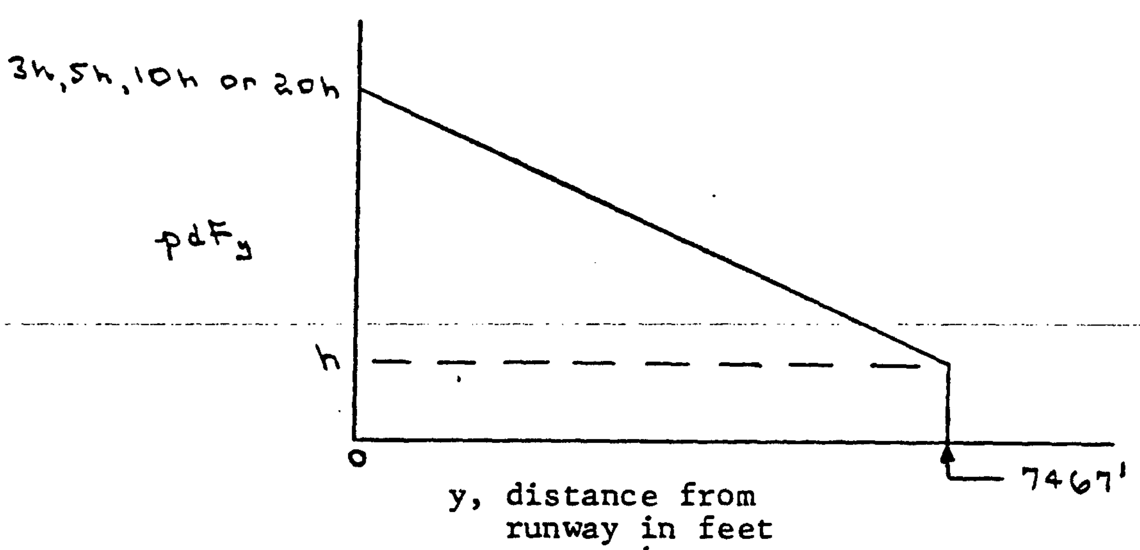
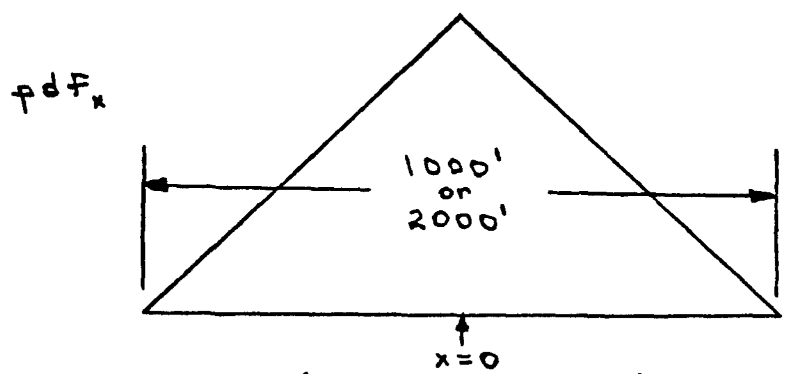


Figure 1. Assumed longitudinal probability density function for aircraft crash location

The lateral probability density function for the aircraft centerline, pdf_x, was based on the assumption that the pilot would be more likely to crash even with the runway centerline than off-center. The resulting triangular distribution is shown in Figure 2. Total widths of 1000 and 2000' were considered. The probability of a crash at the tank lateral location, p_x, is given by the integral of this distribution over the center 225' (75' tank diameter plus 2 half wing spans 75' for a Boeing 707-320).

$$p_x = \int_{-112.5}^{112.5} pdf_x dx \qquad (2)$$



x, distance from runway centerline in feet

Figure 2. Assumed lateral probability density function for aircraft centerline crash location

The probability of hitting the tank, given a close to the runway crash, p, is given by

$$p = p_y p_x \qquad (3)$$

The most conservative calculation, using the 3h to h longitudinal and 1000' width vertical distribution, yielded a p value of

.0067. The least conservative conditions, 20h to h longitudinal and 2000' width lateral, gave p = .00077. Combining these results with the probability of a close to the runway crash, given a takeoff or landing, and the Albuquerque traffic figures gives the results:

Probability of hitting the tank, given a takeoff or landing

$$\cong 1.5\times10^{-9} \text{ to } 1.3\times10^{-8}$$

Expected number of years between tank strikes

$$\cong 150 \text{ to } 1300$$

It will be noted that no account has been taken of the actual number of takeoffs and landings from the east end of the runway (since this is the preferred runway, winds are generally from the west, and most of the accidents of interest occur on landing, this deletion is not too critical). A thorough study of landing patterns for various aircraft types, the fractions of these types using Albuquerque Airport, and the actual accident rate at Albuquerque (which is lower than nationwide) could result in a better model and perhaps produce better than order of magnitude results. Actual statistics on locations of crashes relative to runways would be optimum for approaching the calculation, but these statistics do not exist.

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APPENDIX F

HAZARDS TO AIRCRAFT OVER EXPLOSIVE TEST SITES

This appendix assesses the probability of aircraft being damaged by flying into a piece of shrapnel thrown up from a cased explosion or by experiencing the shock wave from an explosion. To solve the shrapnel problem, one must look into the ballistics of shrapnel, estimate the probability of an aircraft being in the volume of space where pieces of shrapnel might be while they are still in flight, estimate the probability of the lookouts not seeing such an aircraft in time to delay the explosion, and estimate the probability of the aircraft actually flying into one of the pieces of shrapnel. To solve the shock wave problem, one must also estimate the radius of the hemisphere within which damaging overpressures may occur.

A worst-case explosion would be 10,500 lb. TNT equivalent of slurry explosives in a case 3/8-inch (1 cm) thick. (Such a case would actually be cylindrical in shape, but the estimation of probabilities is easier and little different if the case is assumed to be spherical.) The radius of the spherical case would be 35 inches and its volume 105 cubic feet; the case would weigh about 1600 lb. Thus from a case weighing about a sixth as much as the explosive, fragments might attain velocities as high as 8000 ft/sec (2400 m/s) (Gurney formula, 1943).*

Next, we need an estimate of the number of fragments the explosive case will break into as a result of the explosion. Experience indicates that such a fragment might be as big as a foot in size, which is to say it might have a volume of 0.031 ft^3. We assume that the smallest fragment that can seriously damage an aircraft is about an inch in size (1 in^3 or 0.00058 ft^3 in volume.) Then, knowing that there will be more small than large fragments, we approximate this by a particle diameter distribution varying as r^{-n}, where n is between 2 and 3. (Such a distribution approximates the more usual log-normal distribution, and is easier to handle analytically. The form and the exponent are suggested by studies of particle sizes in radioactive fallout (Russell, 1966), but the answers derived by using them are only weakly dependent on the exact value of the exponent.) Then the mean fragment volume will be 0.0043 ft^3, and there will be about 780 fragments in the size range of concern.

Next, we must discuss the ballistics in air of case fragments. The problem has been extensively studied by Bishop (1958), and for the most part this discussion follows his analysis. Bishop's primary assumptions were a constant drag coefficient and an air density that does not vary with altitude. He also

* The usual formula for horizontal missile radius is $600W^{1/3}$; it is clear that this present analysis is inconsistent with that formula, for it predicts initial velocities that do not depend on charge weight, but only the ratio of case and charge weights. Apparently the usual formula is an empirical one based on small-charge experience.

took into account tumbling particles. The drag coefficient of an irregular-shaped particle does vary with its speed relative to the air, especially near Mach 1, but generally by no more than a factor of two. Air density varies with altitude, but very little for the altitude range of interest here. Tumbling particles he found to travel up to 50% farther than non-tumbling particles.

The deceleration of a fragment going vertically upwards is:

$$dv/dt = -g - kv^2,$$

where $k = \frac{1}{2}(\rho_a/\rho_m)(C_d/\theta)$ and involves the air drag parameters of drag coefficient (C_d), thickness of fragment (θ), and the densities of the fragment (ρ_m) and of the air (ρ_a). The solution of this differential equation is the substitution of the velocity-time relationship:

$$v = \frac{v_o - \sqrt{g/k}\,\tan(\sqrt{gk}\ t)}{1 + \sqrt{k/g}\ v_o\ \tan(\sqrt{gk}\ t)}$$

into the height-velocity relationship:

$$s = \frac{1}{2k}\ln\left(\frac{1 + kv_o^2/g}{1 + k\,v^2/g}\right),$$

where v_o is the initial velocity upwards. Similarly for a fragment falling, its acceleration downwards is:

$$dv/dt = -g + kv^2,$$

whose solution is:

$$s = s_o - \frac{1}{2k}\ln\left(\frac{(1 + e^{2\sqrt{kg}\ t})^2}{4\ e^{2\sqrt{kg}\ t}}\right)$$

where s_o is the altitude from which the fall starts, and t is measured from the start of fall.

In Figure 37 we present results calculated for both a one-inch and a one-centimeter thick particle, with an initial upwards velocity of 3000 m/s, a drag coefficient of 1, a metal density of 7.8 (steel), and an air density of .9 g/l. It appears that an inch-thick piece of shrapnel may reach a height of 1650 m (5400 ft) above its starting point and be in flight for about 40 seconds. A centimeter-thick piece of shrapnel may reach a height of 740 m (2400 ft) above its starting point and be in flight for about 27 seconds.

The horizontal analysis is a good deal more complicated; suffice it to say that a horizontal range of 4000 ft is possible, and that the initial part of the trajectory (until a fragment loses the bulk of its kinetic energy) is in almost a straight line from the explosion.

The Lurance Canyon Test Site is 58,000 feet (11 miles) from the middle of the Albuquerque International Airport and is near

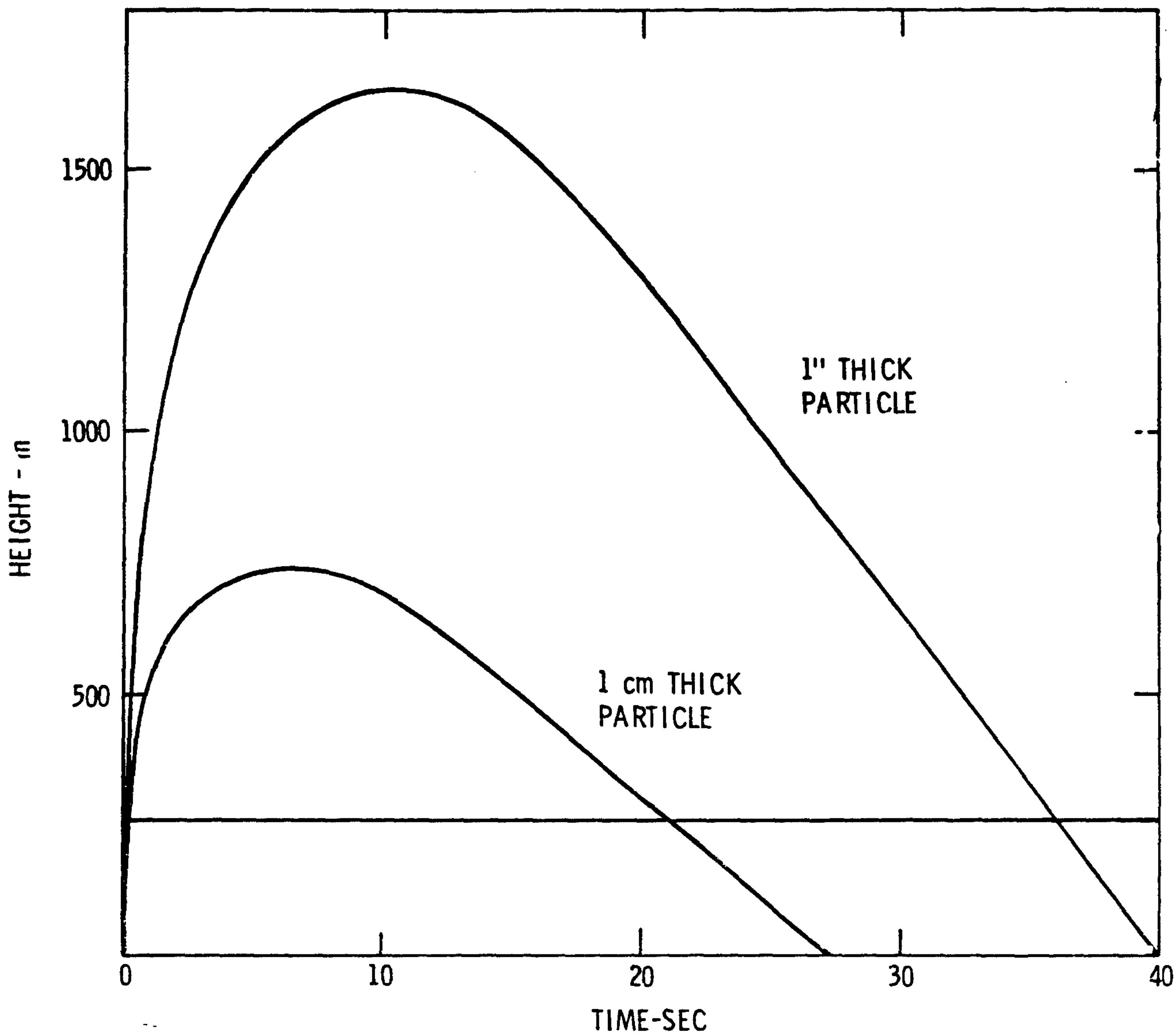

Figure 37. Height versus time calculations of shrapnel generated by cased explosion

frequently used landing and take-off patterns. There are on the average 574 departures a day at this airport, which is equivalent to about 420,000 take-offs and landings per year (FAA, 1974). The test site is at the bottom of a canyon with mountains around it on all sides but the west. Some of the peaks about are as much as 1200 feet higher than the test site, but more typically they are 850 feet higher and 2100 feet away.

Fragments from a cased explosion will fly in all directions, including into the ground. Since their trajectories must be at angles of greater than $\tan^{-1}(850/2100) = 22^{o}$ above the horizon to clear the adjacent mountains, the probability that a fragment escapes impacting the ground or the mountain is:

$$P_1 = (1 - \cos \theta)/2 = 0.31$$

where θ is the vertical angle, 68^{o}.

To estimate the probability that an aircraft will be in the area where pieces of shrapnel might be, while they are still in flight, we first estimate the area density of airplanes:

$$\rho_a = n/2 \ vR,$$

where n is the number of planes taking off and landing at the airport per unit time (574 per day = 0.0133 per second, if all the traffic is in daylight hours); v is the aircraft velocity; and R is the distance from the airport. This assumes that all directions of approach (or leaving) the airport are equally likely, whereas experience indicates that planes coming from or leaving to the east prefer to turn short of the mountains.

Continuing, we are concerned with there possibly being a plane in a position to move into the danger zone while the case fragments are in flight, or for a time (T) of about 20 seconds (from Figure 37 this is the time a centimeter-thick particle will be above the level of the surrounding mountains). These will be planes in an area A = v D T, where D is the width of the danger zone, 8000 ft. Thus the probability of an aircraft coming into the danger zone is, apart from other considerations:

$$P_2 = \rho_a A = (n \ D \ T)/(2 \ \pi \ R) = 0.0058 \text{ per test}$$

The probability that an aircraft will not be detected by the lookouts in a tower on an adjacent ridge will be assumed to be one in a hundred:

$$P_3 = 0.01$$

Finally we need the probability that, even if an aircraft should get by the lookout and fly into the missile hazard zone, the paths of a piece of shrapnel and of the aircraft would intersect. Generally speaking, the pieces of shrapnel are near the tops of their trajectories and moving much more slowly than the aircraft, so they will be treated as stationary, and the aircraft moving. The number of fragments has been determined to be about 780. The number density of fragments is:

$$\rho_f = N/V_{total}$$

and the volume swept out by an aircraft traversing the hazard zone will be:

$$V = A_{ac}\bar{d},$$

where $\bar{d}$ is the average distance traveled by an aircraft in the danger zone while the pieces of shrapnel are still in the danger zone. A detailed estimate, not repeated here, indicates that since an aircraft does not necessarily cross the danger zone at its point of greatest width and since it does not necessarily get all the way across the danger zone during the time pieces of shrapnel are in flight, the average distance travelled, $\bar{d}$, is about equal to the radius, r, of the danger zone, 4000 feet. Finally the volume of the danger zone is $\pi r^2 H$. The total probability is found to be:

$$P_4 = N\ A_{ac} r/\pi r^2 H = 0.0040,$$

where the vulnerable area A_{ac} has been taken to be 100 ft^2, and the height of the danger zone (H) 2400-850 = 1550 feet.

Two other factors act to reduce further the probability of damage to an over-flying aircraft, but are not evaluated here for lack of the necessary inputs. First, an aircraft has to be flying low, not more than 1500 feet over the terrain, and not all will fly that low. Second, the pieces of shrapnel do not all have the same velocity initially. A maximum velocity was used herein; if a velocity distribution with this as a maximum were used, one would find a lower density of pieces of shrapnel in the upper parts of the danger zone.

Finally, the joint probability per test of an aircraft being hit with a piece of shrapnel is the product of the foregoing probabilities, or:

$$P = P_1 P_2 P_3 P_4 = 7.2 \times 10^{-8} \text{ per test,}$$

or, since there have in recent years been an average of 41 tests a year conducted at this site, the probability (P) of a shrapnel-caused accident per year is

$$P = 2.9 \times 10^{-6}.$$

Turning now to the possible effects of the shockwave from an explosion on a low over-flying aircraft, we note first that ordinary aircraft are considered endangered by a passing shock wave if the shock overpressure exceeds 0.5 psi. Pressures this large or larger are felt everywhere within a hemisphere of radius 1650 feet from a 10,500 lb. surface burst. Although this distance is smaller than the range of pieces of shrapnel used above, there is no possibility of an aircraft not flying into the shock wave if it is close enough. An aircraft cannot, so to speak, fly between the pieces of shrapnel. Thus $P_1 = P_4 = 1$.

The portion of the 1650-foot radius hemisphere above the 850-foot level of the surrounding hills has a radius of 1400 feet. The danger period is also smaller, and will be taken as the time necessary for the shock wave to travel from the level of the tops of the hills to the 0.5-psi radius, a distance of 800 feet taking a time of 0.8 second. Then, using the previous formula,

$$P_2 = (.0133 \times 2800 \times .8)/(6.28 \times 58000) = 8.2 \times 10^{-5}.$$

As before,

$$P_3 = 0.01$$

Thus the joint probability per test of overpressure damage to a low over-flying aircraft is:

$$P = P_2 P_3 = 8.2 \times 10^{-7} \text{ per test}$$

or since there are 41 such tests a year,

$$P = 3.4 \times 10^{-5} \text{ per year.}$$

The unevaluated factor of aircraft altitude is obviously even more telling with respect to overpressure damage than for shrapnel damage.

APPENDIX G

SAFEGUARDS

Significant amounts of special nuclear materials (SNM) are located continuously at one location at Sandia Laboratories, Albuquerque. SNM is occasionally situated at several other locations on a temporary basis while being tested, or processed for shipment. In accordance with established ERDA guidelines SLA has established a Safeguards Security System.

This System provides for threat assessment studies, vulnerability studies, testing of the system, implementation of the system, and continuing review of the system in action.

A. SLA SAFEGUARDS PROGRAM

The objectives of the SLA Safeguards Program are:

1. To physically protect special nuclear material against theft, diversion sabotage, and vandalism.
2. To deter attempted attacks.
3. To apprehend attackers before they can successfully carry out their mission.
4. To minimize the consequences of an attack.

To achieve this, SLA has designed a system composed of three basic subsystems: physical protection, material control, and material accountability.

1. Physical protection comprises all measures related to access controls, physical barriers, alarm and assessment systems, and response by armed protective forces.
2. Material control procedures are those measures in effect where special nuclear materials are being handled, which provide constant and ready surveillance of the materials themselves.
3. Accountability systems are comprised of those systems which involve bookkeeping data on the location by physical verification of special nuclear materials inventories.

Physical protection procedures and measures provide for:

1. Early notification of an attack/intrusion.
2. Immediate assessment/evaluation of the situation.
3. Special barriers which cause attacker/intruder delays in carrying out the mission.
4. Adequate protective forces to respond to the attack <u>before</u> attacker/intruder has accomplished the mission.

Additionally, ERDA-approved security procedures have been established for the protection of significant quantities of SNM when it is being used, transported, processed, tested, or stored at SLA. The locations covered by these procedures are:

Location	Date
Building 868 Vault (Periodic)	2-25-77
Building 6590 KIVA (Continuous)	8-2-76
TAs III & V Test Areas (Periodic)	9-2-76
Manzano Base (Continuous)	KAFB Security Procedure dated 5-5-76

B. PHYSICAL PROTECTION

The physical protection system is designed within the following concepts:

1. To physically and administratively restrict access to SNM to only those persons who have an appropriate clearance and who have an operational need for such access.
2. To detect and assess as soon as possible, any attempt at unauthorized access.
3. To maintain an adequate, well-trained, and equipped Plant Protection Force for prompt response.
4. To coordinate response tactics with Federal, state, and local law enforcement agencies.

Such systems utilize physical barriers, electronic detection and alarm systems, personnel access control procedures, an armed security force, and trained operating personnel.

1. Physical Barriers

The SLA Building where SNM is located continuously and those buildings where SNM is periodically located, are situated within established security areas that are fenced, lighted, posted, and patrolled in accordance with established ERDA regulations.

All persons entering these sites must have an appropriate security badge. Visitors, vendors, and other nonresident personnel must be properly identified, escorted, and logged in before being issued a temporary badge.

2. Internal Security Areas

Material Access Areas have been established at each location where significant quantities of SNM are located either continuously or periodically. The access controls to these areas are in accordance with ERDA requirements as put forth in ERDAM 2405. These include:

a. Intrusion Alarm Systems.
b. CCTV.
c. 2-Man Rule.
d. Continuing Development Program by the SLA Nuclear Security Systems Directorate for DSS Headquarters.

Protection of these areas during non-occupational hours is provided by armed security inspections as required in the above cited MC.

3. Personnel Access Controls

Only authorized persons who are specially badged by the SLA Badge Office may enter SLA. Temporary visitors to SLA, on an uncleared basis, are issued badges, after appropriate identification at the Badge Office in Building 801, or at Escort Headquarters, south of Gate 10.

Access to a Material Access Area, requires a special access authorization or continuous escort approved by an authorized operational supervisor.

4. On-site Transfers

Physical transfers of special nuclear material outside secure facilities are made by operating personnel under the escort of armed guards.

C. MATERIAL CONTROL

1. Material Control System

Special nuclear materials (SNM) are located in specific areas throughout the plant site. Each area is assigned an account number under which all transactions are recorded. The areas are under the management of operating supervisors, custodians, or other individuals responsible for the safety, the use, and the internal control of SNM. These individuals verify and report each transfer to or from their areas. Multiple copy material transfer forms are filled out and signed by a responsible individual before each transfer. Material control personnel check the correctness of the data and record the transaction, while other copies accompany the material. Receipts of material are signed for by the receiver, who immediately verifies the material. Thus, the material control personnel check all transfers and material movements through the facility.

All special nuclear material measurements are reported for proper review and encoding. The accountability of the special nuclear material removed from a vault during a definite time period may be verified by examining the records.

2. System Monitoring

Special Nuclear Materials are under continual accountability review. Transactions are reviewed to ensure the validity and propriety of material movement and disposition. The accounting system and its methods of operation are directed by ERDA and are outlined in appropriate directives. Holders of special nuclear materials operate according to established written procedures which are prepared from ERDA directives or recommendations and serve as references for guidance in the proper handling of special nuclear material. Periodic reviews of the areas are made to ensure that operations are consistent with established directives and procedures.

D. MATERIALS ACCOUNTABILITY

Information on all ERDA controlled special nuclear materials is maintained in the Nuclear Materials Management and Safeguards System (NMMSS). The NMMSS is an ERDA centralized automatic data processing system which provides periodic reports for management purposes to all ERDA organizations in connection with nuclear materials inventory and financial management programs, nuclear material contract administration activities, and safeguards activities.

SLA maintains its own computerized nuclear materials accountability system. Outputs from the SLA computer are used as input to the NMMSS, which in turn provides reports to SLA.

1. Accountability System

The nuclear materials accountability system consists of a double entry accounting function utilizing computer storage capabilities for maintaining permanent records of all material activities and account balances.

The computer is programmed to review all incoming data for the purpose of ensuring validity of information and accuracy of item and/or material identification. Input information incongruent with programmed data is automatically rejected by the system and entered on a visual record with an explanation of its inacceptability.

Valid discrepancies such as encoding errors are corrected by members of the Accountability Department and reentered into the computer.

Invalid discrepancies such as incorrect item identifications, inaccurate material description codes, attempts to activate material movement between unauthorized areas, etc., are immediately investigated and corrected.

Upon shipment, the identities of the items shipped and all relevant information are removed from the storage banks and transferred to the historical files.

2. <u>Material Balance Accounts</u>

Material Balance Accounts are a required part of the accountability system. Each individual material balance account, while independent in itself, is part of the overall control system. The aggregate of all material in the separate accounts always equals, in weight, the total amount reflected by the overall control account.

Differences within single operating accounts resulting from inventories, or measurement of externally received material, etc., are activities requiring adjustment of the overall plant control account. Failure to post external activity to either the control account or to the individual material balance account automatically causes an imbalance which will draw attention to the error.

On a periodic basis special nuclear materials are accurately inventoried to check the actual amount of material on hand against the amount which is shown by accounting procedures to be on hand. The differences between these two quantities is known as "Book - Physical Inventory Difference" (BPID). Problems arise in this area because of the difficulty in accomplishing an accurate physical inventory. The conditions of material resulting from processing, errors in measurement, and many other circumstances cause problems that are manifested in apparent material losses or gains. These BPID figures generally do not represent stolen or diverted special nuclear materials. Rather, small but continuous losses within the materials processing system cause a portion of these materials to go unaccounted for.

3. <u>Quality Control Measurement Data</u>

The SAM-2 (assay meter) used for non-destructive assay is tested for accuracy against "standards" of established value prepared especially for use with each method.

In addition, scales and balances are checked regularly during periods of use by operating personnel and certified semiannually by the Physical Standards Division.

4. Inventories

Special nuclear materials are physically inventoried as directed by ERDA. All data, including identification number and weight, are recorded.

A statistically determined number of items that can be weighed are chosen randomly for reweighing. The results must compare favorably with the results of previous weighings within the error limits of the instruments used, and discrepancies are investigated immediately.

In addition, visual checks or area reviews are conducted.

5. Reporting

All reports are prepared and submitted by Nuclear Materials Management Division members. These reports reflect the composition of ending inventories, account adjustments, and material activity between ERDA facilities and licensees.

Summary reports of special nuclear material activity and inventories are routinely forwarded to ERDA and to SLA management after the physical inventories are completed and the accounts closed.

6. Appraisals

Yearly the SLA special nuclear materials control and management systems are subject to appraisal by a survey team from the Albuquerque Operations Office of ERDA. These appraisals consist of audits of the material accounting system and the corresponding operating manuals and a review of the materials management program including the forecasting and control procedures.

E. SAFEGUARDS ORGANIZATION AND MANAGEMENT

1. Safeguards System Review

Periodic reviews are made of all areas and methods relative to physical protection, the adequacy of SNM storage vaults, and the evaluation of monitoring systems. Audits include the regular observance of physical inventories to ensure the effectiveness of, and compliance with, current accountability procedures and the accuracy of inventory. Investigations are made of any circumstance bearing on the safeguards and security of either SLA or SNM.

2. Security Force

SLA maintains its own Protection Force. The Protection Force is equipped with good communications systems, suitable weapons, and vehicles. Backup manpower is available from the KAFB Security Police. Additional weaponry is stored at alternate locations.

Emergency power is available to all guard posts to maintain normal operations and communications in the event of normal power failure, or loss, regardless of reason.

Recurring training includes pre-shift meetings and annual meetings on various topics, using films, slide presentations, and lectures.

Weapons training and qualification are in accordance with all ERDA regulations. Weapon qualification is part of the initial training program, and no guard is granted the authority by ERDA to carry a specific weapon until all qualification requirements are completed. All guards receive additional training on other types of combat weapons and are trained in riot and mob control.

3. Emergency Plans

Emergency plans have been devised for possible riots, demonstrations, sabotage, terrorist attacks, strikes, Civil Defense, and disaster. These plans specify notifications of plant and off-site personnel, including management and other agencies, and provide guidance for necessary actions as the emergency situation may dictate.

Tests of security communications systems, both on site and off site, are conducted to ensure a proper response capability in the event of an emergency situation. Periodic exercises of the guard force are conducted under simulated emergency conditions to test their response performance.

Continuous liaison is maintained by the Security Department with Federal, State, and local law enforcement agencies. Such liaison includes on- and off-site meetings for capability and mutual support comparisons, and tours of the facility to acquaint the various agencies with the security and safeguards programs.