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SUMMARY OF THE NEVADA APPLIED ECOLOGY GROUP AND CORRELATIVE PROGRAMS

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UNITED STATES DEPARTMENT OF ENERGY
NEVADA FIELD OFFICE
LAS VEGAS, NEVADA

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PREFACE

The rationale underlying the formation of the Nevada Applied Ecology Group is stated by Paul B. Dunaway and Mary G. White in the Preface to NVO-142. They also enumerate the principal objectives of the Group's plutonium program. Selected portions of their Preface provide the background upon which this book is built. As editors of NVO-142 in 1974, they wrote

> One of the earliest concerns of Atomic Energy Commission and United States military organizations responsible for utilizing nuclear weapons was safety of the devices with respect to storage, handling, transport, and accidents. Accordingly, there were a number of tests conducted which were designed to test for safety of various devices or assemblages. "Safety" in this context meant "safety against fission reaction." Most of these so-called safety shots consisted of detonating a chemical explosive in close proximity to arrangements or assemblies of plutonium and/or uranium. Few of these tests resulted in an appreciable yield or fissioning. Many of the safety-shot areas also were used for exercises or tests in detecting alpha contamination, or for developing methods of cleanup of contamination. A few of these areas were utilized for studies of plutonium and uranium contamination in the living environment. The wisdom of conducting the safety tests was demonstrated by accidents near Palomares, Spain, Thule Air Force Base, Greenland, and elsewhere. More recently, there was a resurgence of interest in plutonium because of (1) increased knowledge about its toxicity; (2) its presence in several natural environments at the Nevada Test Site, Enewetak, Rocky Flats, etc; and (3) the portent of greatly increased quantities of plutonium to be produced in breeder reactors and to be handled in reprocessing plants.
>
> In 1969, before the advent of the National Environmental Policy Act, Robert E. Miller, Manager of the Nevada Operations Office, and other Atomic Energy Commission staff decided to investigate potential environmental problems on the Nevada Test Site. As part of the Office of Effects Evaluation, the Nevada Applied Ecology Group was established in July 1970, by Planning Directive NVO-76. The stated purpose of the Nevada Applied Ecology Group was to coordinate the ecological, radiation monitoring and other environmental programs necessary to support continued nuclear testing activities, and to provide the mechanism to effectively comply with requirements of the National Environmental Policy Act of 1969.
>
> Planning Directive NVO-76 provided a charter for the Nevada Applied Ecology Group which was relatively broad. A Steering Committee was established as the principal organization to oversee and review ongoing and proposed programs. Membership of the Steering Committee consisted of representatives of appropriate Headquarters divisions of the Atomic Energy Commission, Lawrence Radiation Laboratory, Los Alamos Scientific Laboratory, Sandia Laboratories, and the Nevada Operations Office . . . . The Steering Committee recommended studies of plutonium on Nevada Test Site and environs as a first priority problem for Nevada Applied Ecology Group.
>
> * * * *
>
> Responding to the September 1970 recommendation of the Steering Committee that plutonium on Nevada Test Site and surrounding lands was a first priority problem, a Plutonium Ad Hoc Committee, chaired by Wright Langham, Los Alamos

Scientific Laboratory, was established and first met in October 1970. This "ad hoc" committee . . . continued as a permanent committee and . . . served the Atomic Energy Commission elsewhere as a plutonium problems review committee . . . .

* * * *

The principal objectives of the Nevada Applied Ecology Group plutonium program were:

1. Delineate locations of contamination.
2. Determine concentrations in ecosystem components.
3. Quantify rates of movement among ecosystem components.
4. Evaluate radiological hazards of plutonium.
5. Identify areas which need to be cleaned up or treated.
6. Develop techniques for cleanup or treatment.

The Nevada Applied Ecology Group was established at the Nevada Operations Office under the administration of the Atomic Energy Commission. Federal reorganization abolished the Atomic Energy Commission and transferred agency functions to the Energy Research and Development Administration in January 1975. The Energy Research and Development Administration was abolished on October 1, 1977, and its functions were transferred to the newly organized Department of Energy. Conduct of Nevada Applied Ecology Group work was not materially affected by these reorganizations. To reduce possible confusion, all work performed during the existence of the Nevada Applied Ecology Group will be addressed as though the responsible federal agency was always the Department of Energy.

Other name changes are clarified on first use of the old name. Old and new names are also presented in the list of organization acronyms. To maintain proper historical perspective, all agency names are presented as they were commonly used during the existence of the Nevada Applied Ecology Group.

The Nevada Applied Ecology Group conducted studies of plutonium, uranium, americium, and other radionuclides in the environment on and near the Nevada Test Site from July 1970 to September 30, 1986. About 540 reports and papers were prepared during this 16-year effort. These were progress reports, papers presented at symposia, or papers published in peer-reviewed journals. The Nevada Applied Ecology Group compiled and published ten collections of progress and research reports. The last compilation consisted of reports presented at the Plutonium Information Conference in June 1983. Research reports for work conducted from June 1983 through September 1986 have not been compiled into one document. However, some of the concluding work has been published in peer reviewed journals since project termination. This book presents some historical background regarding the Department of Energy's Test Range Complex and summarizes research results of the Nevada Applied Ecology Group and correlative programs.

The Nevada Applied Ecology Group was funded as a separate program. Other correlative programs were funded and conducted with some overlap with operations of the Nevada Applied Ecology Group. The Animal Investigation Program was carried on from 1957 through 1981 by the U.S. Public Health Service/Environmental Protection Agency with funding support from the Atomic Energy Commission, Energy Research and Development Administration, and Department of Energy. The farm in Area 15 of the Nevada Test Site was operated by the Environmental Protection Agency from 1963 through 1981 under an interagency agreement with the Atomic Energy Commission. The Plutonium Inventory and Distribution Program was conducted approximately from 1970 through 1980. The Radionuclide Inventory and Distribution Program was conducted from 1981 through 1986.

The correlative programs managed by the Environmental Protection Agency had specific objectives closely related to objectives of the Nevada Applied Ecology Group but were not administered by managers of this Group. This distinction is of no particular significance in presenting the findings of the combined programs. This summary document presents results in a broad context; it is not limited to findings of the Nevada Applied Ecology Group.

This book is organized to present the findings of the Nevada Applied Ecology Group and correlative programs in accordance with the originally stated objectives of the Nevada Applied Ecology Group. This plan, in essence, traces plutonium from its injection into the environment to movement in the ecosystem to development of cleanup techniques. Information on other radionuclides was also obtained and will be presented briefly.

Chapter 1 presents a brief description of the ecological setting of the Test Range Complex. The results of investigations to meet Objective 1, as stated by Dunaway and White, are presented in Chapter 2 for the area surrounding the Test Range Complex and in Chapter 3 for on-site locations. Chapters 4 and 5 present the results of investigations concerned with concentrations and movement, respectively, of plutonium in the ecosystem of the Test Range Complex, and Chapter 6 summarizes the potential hazard from this plutonium. Development of techniques for cleanup and treatment is presented in Chapter 7, and the inventory of radionuclides other than plutonium is presented briefly in Chapter 8.

The bibliographies are presented in six parts. Part A: References, lists 13 referenced documents not included in the other five Parts. These bibliographies do not include documents referenced in passages of quoted text. Part B documents were compilations of 266 reports of Nevada Applied Ecology Group work which have each been separately identified for ease of reference.

Appendix A presents a cross-referenced compilation of scientific and common names of flora and fauna encountered at the sites studied by the Nevada Applied Ecology Group. Two versions of this book have been prepared, one without microfiche (NVO-357, Version 1) and one with microfiche (NVO-357, Version 2). References to the microfiche have been deleted from Version 1, except for this paragraph, which has been retained so readers of either version will know about the other version; the two versions are otherwise identical.

Editorial notes, shown as [Ed. Note: . . . .], appear at various places in the text. These notes are intended to (1) provide introductory information which could not be found in a suitable reference, (2) provide connecting text where the need seemed apparent, and (3) address questions or relationships, raised in the text, which were not answered in subsequent research reports. This book is intended to summarize past work and provide source references to individuals with a need or an interest in more details. No new work was conducted for this book and the only new results reported here are from an unpublished EPA report on plutonium in soil outside the Nevada Test Site.

A note regarding figure captions: Most of the figures are reproduced from published reports and the original captions have been retained. By editorial edict the captions used herein identify the source document rather than repeat the original caption. Both captions are, however, presented in the List of Illustrations.

Several people were instrumental in starting the Nevada Applied Ecology Group: Robert E. Miller was Manager of the Nevada Operations Office at the inception of the program and provided vigorous support to long-term environmental programs at the Nevada Test Site; Jared (Jerry) J. Davis envisioned a comprehensive applied ecology program at the Site and, with Frank D. Cluff, co-chaired the Steering Committee during the early years; Wright Langham was particularly effective in formulating the early activities of the program; Gordon C. Facer, Department of Energy, Headquarters, supported the program in many ways from its beginning until his retirement; Mahlon E. Gates continued the pattern set by Robert E. Miller, and supported the program throughout his tenure as Manager of the Nevada Operations Office. Many others could be recognized for their highly valued contributions, but Paul B. Dunaway and Mary G. White persevered for a decade in the management of this multidisciplinary program. They

conducted symposia for dissemination of information; they saw to the publication of voluminous reports of work by the Nevada Applied Ecology Group; they orchestrated the program as requirements changed over time; and they found monetary resources to keep the program alive during several years of very constrained budgets.

Present understanding of the fate of plutonium in the environment, and the possible consequences to man, is on a firmer foundation now than it was before the inception of the Nevada Applied Ecology Group. We owe a debt of gratitude to the above named dedicated and diligent "civil servants" who accept and acknowledge this term with pride and dignity.

We also owe a debt of gratitude to the many scientists and technicians who contributed to the Nevada Applied Ecology Group. A list of principal participants is included; however, this list admittedly does not include laboratory technicians, typists, clerks, and other individuals who would be involved in programs as extensive as the programs herein described. Thanks to all of you.

And especially to Cam Deckert who was involved in text entry for all ten of the Nevada Applied Ecology Group compilations during the 1970s and 1980s. Appropriately, Cam played a tireless and significant role in the preparation of this (possibly) final compilation.

The assistance of several reviewers is gratefully acknowledged. The reviewers were intentionally given a draft to review without also being told of the criteria under which the book was prepared. (In a nutshell: present the basic facts for all important topics in the minimum number of pages without analysis or editorializing.) Their return comments indicated problem areas to be addressed, but also indicated different perceptions regarding desired or anticipated format, content, and style. Most reviewer concerns were addressed, although perhaps not to the extent they envisioned.

Special thanks for their helpful review comments are due Ed Essington, Los Alamos National Laboratory; Dick Gilbert, Pacific Northwest Laboratories; Rich McArthur, Desert Research Institute; Tom O'Farrell, EG&G; and Lynn Anspaugh, Lawrence Livermore National Laboratory. After Dr. Anspaugh voiced his concerns about an early draft of this book, he was tasked to write an epilogue, which is included following Chapter VIII. This is not truly an epilogue, which would address events following termination of the NAEG, but more like a prologue presenting his perceptions of circumstances underlying formation of the NAEG.

Finally, Fred Au, Physical Scientist, and presently manager of the Basic Environmental Compliance and Monitoring Program, DOE Nevada Field Office, also participated in NAEG microorganism research during the 1970s. His review comments and his persistence in seeing this summary document through to completion are sincerely appreciated.

HERBERT N. (Bert) FRIESEN
RAYTHEON SERVICES NEVADA
June 1, 1992

ORGANIZATION ACRONYMS

AEC	Atomic Energy Commission. (See DOE.)
ARL	Air Resources Laboratory. (Now WSNSO.)
BCL	Battelle Columbus Laboratories.
DoD	Department of Defense.
DOE	Department of Energy. The AEC was established August 1, 1946 and abolished January 19, 1975. Many AEC functions were transferred to the newly created Energy Research and Development Administration (ERDA). ERDA was abolished October 1, 1977; ERDA's functions were transferred to the DOE.
DOE/HQ	Department of Energy Headquarters in Washington, D.C.
DOE/NV	Department of Energy Nevada Operations Office in Las Vegas, Nevada (now DOE Nevada Field Office).
DRI	Desert Research Institute. A research organization within the University of Nevada System.
EG&G	Edgerton, Germeschausen and Grier (now EG&G/EM, EG&G Energy Measurements, Inc.).
EMSL	Environmental Monitoring and Support Laboratory (now Environmental Monitoring Systems Laboratory). EPA laboratory in Las Vegas, Nevada. Also known in the past as SWRHL, NERC, and WERL.
EPA	U.S. Environmental Protection Agency.
ERDA	Energy Research and Development Administration (see DOE).
ICRP	International Commission on Radiological Protection.
LASL	Los Alamos Scientific Laboratory (now LANL, Los Alamos National Laboratory). U.S. Government laboratory in Los Alamos, New Mexico, operated by the University of California.
LFE	LFE Environmental.
LLL	Lawrence Livermore Laboratory (now LLNL, Lawrence Livermore National Laboratory). U.S. Government laboratory in Livermore, California, operated by the University of California.
MCL	McClellan Central Laboratory at McClellan Air Force Base.
NERC	National Environmental Research Center (now the EMSL).
NVO	Nevada Operations Office (see DOE/NV). Also known in the past as the Nevada Test Site Organization and the Office of Field Operations under the Albuquerque Operations Office.
ORAU	Oak Ridge Associated Universities.
ORNL	Oak Ridge National Laboratory.
PHS	U.S. Public Health Service, whose radiation monitoring functions were taken over by the EPA in December 1970.
PNL	Pacific Northwest Laboratories
REECo	Reynolds Electrical & Engineering Co., Inc., operating contractor for the DOE at the NTS and in Las Vegas, Nevada.
SWRHL	Southwest Radiological Health Laboratory (now the EMSL).
UCLA	University of California at Los Angeles.
UNLV	University of Nevada, Las Vegas.
WERL	Western Environmental Research Laboratory
WSNSO	Weather Service Nuclear Support Office located in Las Vegas.

NON-ORGANIZATION ACRONYMS

AIP Animal Investigation Program.
ARMS Aerial Radiological Monitoring System.
ASN Air Surveillance Network.
CIC Coordination and Information Center (an archive operated by REECo for the DOE of information on nuclear testing and radiological measurements).
CR Concentration Ratio. (The activity per gram of sample, either vegetation or animal tissue, divided by the activity per gram of soil; usually used in reference to uptake of plutonium or other radionuclides.)
EIS Environmental Impact Statement.
FIDLER Field Instrument for the Detection of Low Energy Radiation.
GIT Gastrointestinal tract.
GMX Gadgets, Mechanics, and Explosives.
GZ Ground Zero. The point on the ground surface at, below, or above the location of a nuclear detonation.
NAFR Nellis Air Force Range (formerly the Las Vegas Bombing and Gunnery Range.)
NTS Nevada Test Site. A 1,350-square-mile area in Nye County, Nevada, with the southeast corner located about 65 miles northwest of Las Vegas, Nevada.
PIDP Plutonium Inventory and Distribution Program.
Rad Radiation absorbed dose. A unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
Rem Roentgen equivalent man (or mammal).
RIDP Radionuclide Inventory and Distribution Program.
TNT Trinitrotoluene. A chemical high explosive.
TRC The Test Range Complex which includes the NTS, the Nellis Air Force Range (formerly the Las Vegas Bombing and Gunnery Range), and the TTR.
TTR Tonopah Test Range.

GLOSSARY

Atmospheric Test – A test of a nuclear device or weapon conducted above-ground in the open air. Surface tests are usually considered atmospheric because they were not designed to contain radiation.

Beta – Beta particle. Charged particle emitted from the nucleus of an atom as part of the decay process, with a mass and charge equal in magnitude to that of the electron.

Dose – A measure of the energy absorbed in tissue by the action of ionizing radiation on tissue. The unit of absorbed dose is the rad.

Dose Commitment – Dose calculated to be accrued in the future as a result of a present release of radioactivity.

Exposure – A measure of the ionization produced in air by x or gamma radiation. The special unit of exposure is the roentgen. (See roentgen.)

Fallout – The process or phenomenon of the fall back to the earth's surface of particles contaminated with radioactive material following an atmospheric or uncontained nuclear detonation. The term is also applied in a collective sense to the contaminated particulate matter itself.

Fission – The process whereby the nucleus of the particular heavy element splits into (generally) two nuclei of lighter elements, with the release of substantial amounts of energy.

Fusion – The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, combine to form the nucleus of the heavier element helium with the release of substantial amounts of energy. These are also called thermonuclear reactions because very high temperatures are used to bring about the fusion of the light nuclei.

Gamma (rays) – Electromagnetic waves of very short wavelengths produced during the disintegration of radioactive elements.

H + 12 hr – H is the time of detonation to the nearest minute, and " + 12 hr" means twelve hours after detonation.

Half-life – Time required for a radioactive substance to lose half of its activity by decay. Half-life values range from small fractions of a second to many millions of years but are constant for a specific radionuclide.

Ionization – The process by which a neutral atom or molecule acquires a positive or negative charge.

Ionizing Radiation – Electromagnetic radiation (gamma or x rays) or particulate radiation (alpha particles, beta particles, neutrons, etc.) capable of producing ions, i.e., electrically charged particles, directly or indirectly, in its passage through matter.

kt – A kiloton. The energy of a nuclear explosion that is equivalent to an explosion of one thousand tons of TNT.

Microcurie – One-millionth of a curie. A curie equals 37,000,000,000 nuclear transformations per second. One microcurie then equals 37,000 nuclear transformations per second.

Milliroentgen (mR) – One-thousandth of a roentgen. (See roentgen.)

Mt – A megaton. The energy of a nuclear explosion that is equivalent to an explosion of one million tons of TNT.

Nuclear Device – A device designed to produce a nuclear explosion for purposes of testing the design, for verifying nuclear theory, or for gathering information on device performance. Many devices were designed for diagnostic purposes and not as bombs or weapons.

Nuclear Weapon – A nuclear device designed to be used as a bomb or weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion, or both.

Nuclide – A general term applicable to all atomic forms of the elements; often used incorrectly as a synonym for isotope. Nuclides comprise all the isotopic forms of all the elements.

Off site - Generally refers to any location outside the Test Range Complex which is defined below.

On site - On the Test Range Complex which is defined below.

Radiation - The emission and propagation of energy through space or through a material medium in the form of waves and/or particles. Only alpha, beta, gamma, x-ray, and neutron emissions resulting from nuclear detonations and detonation products are intended herein.

Radioactive - Of or exhibiting radioactivity.

Radioactivity - The property of unstable nuclei of atoms of emitting particles or rays in the process of becoming stable.

Radionuclide - A radioactive nuclide. (See nuclide.)

Roentgen (R) - The special unit of exposure to ionizing radiation. It is that amount of gamma or x rays required to produce one electrostatic unit of charge of either sign per cubic centimeter of air at standard temperature and pressure.

Source Term - The inventory of radionuclides generated by a nuclear detonation.

Survey Meter - Any portable radiation-detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.

Test Range Complex - An area that includes the Nevada Test Site (NTS), the adjacent government-controlled Nellis Air Force Range (formerly the Las Vegas Bombing and Gunnery Range), and the Tonopah Test Range (TTR).

Yield - The total effective energy released in a nuclear explosion. It is usually expressed in terms of equivalent tonnage of TNT required to produce the same energy release in an explosion.

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CHAPTER I. BACKGROUND

A. THE ECOLOGICAL SETTING

(Condensed and abstracted from O'Farrell, NVO-167, CIC:# 14337[1])

The U.S. Department of Energy's NTS (Nevada Test Site) occupies 1350 mi^2 (square miles) (about 3500 km^2, square kilometers) of desert mountain and valley terrain situated in Nye County, Nevada. The main site entrance is at Mercury, Nevada, 65 miles northwest of Las Vegas. The 4120 mi^2 (10,670 km^2) NAFR (Nellis Air Force Range) borders the test site on the east, north, and west sides. A northwestern portion of the NAFR is occupied by the 624 mi^2 (1616 km^2) TTR (Tonopah Test Range). These federal reserves comprise the 6094 mi^2 (15,780 km^2) Test Range Complex) TRC illustrated in Fig. I-1. The NTS was selected in 1950 as the continental location for testing of nuclear devices and weapons. Nuclear testing was periodically conducted principally in the atmosphere from January 1951 through October 1958. Following a moratorium from November 31, 1958, through September 15, 1961, nuclear testing was resumed, principally underground through 1968, and wholly underground since then.

The NTS lies in an area that is geologically complex and has deposits of igneous, sedimentary, and metamorphic rocks. At least 17 Paleozoic formations and one of Tertiary age have been recognized. The former consist primarily of limestone, dolomite, quartzite, shale, and conglomerates. About 30 percent of the site outcrops are sedimentary in origin; the remainder are predominantly Tertiary volcanics. Quaternary deposits are mainly mixtures of detrital material derived from bedrock areas and a fill of caliche, siltstone, and conglomerates. These deposits spill downslope from mountains toward large basins, such as Frenchman Flat and Yucca Flat (Fig. I-2), forming extensive bajadas (coalescent alluvial fans merging with the valley floor) leading to a playa. Quaternary valley sediments generally vary in depth to about 1500 ft (460 m), but in Yucca Flat they extend to 3800 ft (1160 m). The playas consist almost entirely of impermeable fine silt and clay. These alluvium-filled basins occupy about 30 percent of the land area.

The lowest elevation on the NTS is 2688 ft (820 m) at the southwest corner where Fortymile Canyon exits the site (*Fig. I-2*). The highest elevation within the test site is 7679 ft (2340 m) on Rainier Mesa in the north-central region (*Fig. I-2*).

Frenchman and Yucca Flats are typically dry playas with standing water present only briefly following sporadic runoff from thunderstorm activity or snowmelt. Except for a few small springs, there is no permanent surface water on the NTS. The normally dry streambed of Fortymile Canyon can be transformed into a raging torrent under proper thunderstorm conditions. Such surface drainage may extend to the Amargosa River which is usually dry but which may flow, under thunderstorm conditions, to its terminus in Death Valley, California.[2]

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[1] CIC# is the accession number assigned to documents by the Coordination and Information Center. The CIC# is given only at the first reference to each NVO compilation; see Bibliographies Part B: Publications of the NAEG.

[2] Several times since the mid 1970s, these flows contributed to standing water covering a large area to a depth of four feet at Badwater, in Death Valley, California. (Telephone communication with local employee of Bureau of Land Management, May 1991.)

Figure 1. Location of the Nevada Test Site in relation to population centers of neighboring western states and the Nellis Air Force Bombing and Gunnery Range.

FIGURE I-1 NTS, TTR AND NAFR COMPOSE THE TEST RANGE COMPLEX. MODIFIED FROM O'FARRELL AND EMERY, NVO-167, 1976

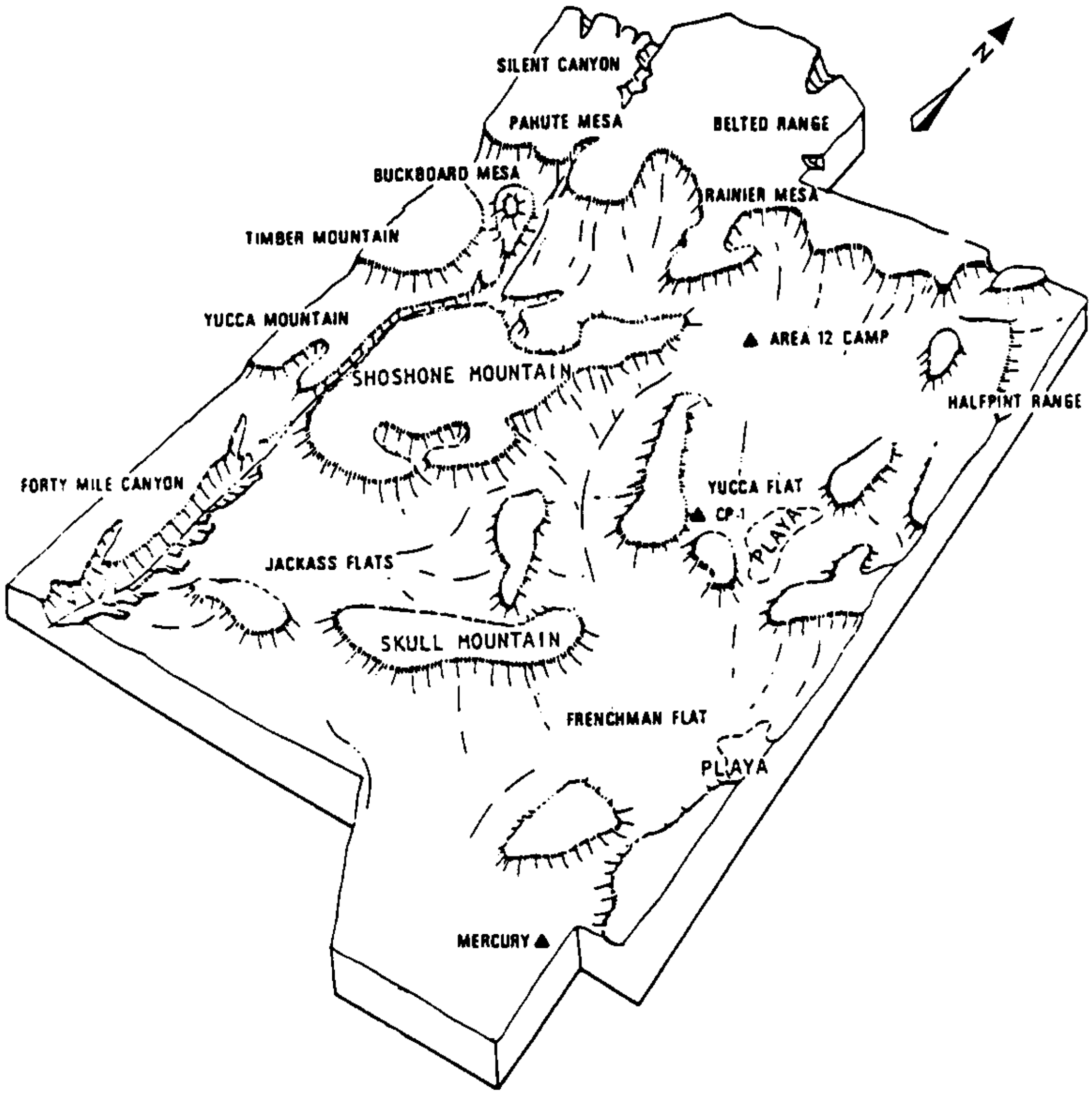

FIGURE II-7 TOPOGRAPHY

FIGURE I-2 FROM FINAL ENVIRONMENTAL IMPACT STATEMENT, NEVADA TEST SITE, ERDA-1551, 1977

The climate exhibits extremes in temperature, precipitation, and wind velocity, as well as great variability in these parameters from year to year and between sites within years. Temperatures at Yucca Flat range from −14 to 110°F (−26 to 43°C). Average annual precipitation ranges from 4 in (10 cm) at the playas to 12 in (30 cm) at the mesa tops. Average relative humidity at Yucca Flat ranges between 14 percent in the afternoons during June and July, and 68 percent in the early-morning hours of December days.

Average annual wind speed at Yucca Flat is about 7 mph (about 10 m s^{-1}). The prevailing wind direction from September through April is from the north, while from May through August winds are primarily from the south–southwest. Daily surface heating causes air motion upslope, while nightly cooling causes gravity flow downslope producing a daily cycle in wind speed and direction. This mountain–valley diurnal wind system is most intense during the summer and least active in winter and on cloudy days.

Most soils developed on alluvial deposits of mixed origins and characteristically have coarse texture, carbonate accumulation within a few feet of the surface, low organic matter content, and low carbon to nitrogen ratio. Soils are young in terms of profile development and show little evidence of leached upper horizons. Diversity in soil profiles reflects their mixed alluvial origins. Coarser fragments are found in soils developed nearer the base of mountains and hills, and finer textures are found toward the middle of valleys. If clay is present, it is usually found in B horizons in more level areas. Moisture retention characteristics of NTS soils are very poor and primarily reflect the low silt and clay content, as well as the relative lack of organic matter. Soil profile moisture reserves seldom exceed field moisture capacity except during periods of winter precipitation.

Accelerated soil–forming processes are evident under desert shrubs, which demonstrates their important role in desert ecosystems. Compared to non-vegetated areas, higher concentrations of organic carbon, organic nitrogen, and available phosphorus consistently occur in the upper horizons of soils under shrubs. Shrubs intercept the wind-borne, finely textured loess, which is added to the coarser alluvial material at the shrub bases. Salts also accumulate under shrubs, possibly because of recycling through leaf-fall and litter decomposition, as well as trapping of airborne materials. Under shrubs, there is often some decomposition of subsurface hardpans, and a better-developed A horizon. Also, soil pH tends to be lower, conductivity of saturation extracts is higher, nitrates and chlorides accumulate more, and exchangeable cations, such as potassium, are greater under shrubs. There also tends to be more soil mixing under shrubs because burrowing animals locate their homes in these softer soils; shrubs provide these animals with some protection from predators.

The NTS spans the transition between the Mohave and Great Basin deserts; consequently, the flora and fauna consist of species characteristic of both deserts. A total of 711 taxa of vascular plants have been collected in the major vegetation-type areas outlined in Fig. I–3. About 67 families are represented, with one-third of the species belonging to just three families: Sunflower Family (*Compositae*), Grass Family (*Gramineae*), and Buckwheat Family (*Polygonaceae*).

Distributions of the Mohave Desert, Great Basin Desert, and transitional vegetation associations are closely linked to temperature extremes, precipitation, and soil conditions. Shrub coverage within the Mohave Desert types averages about 16 percent, transitional types average about 29 percent, and Great Basin types average 24 percent, with ranges in the various types from 7 to 50 percent. Winter annual forbs and grasses are the dominant species of ground cover and contribute most to the annual biomass production. However, the majority of winter annual seedlings do not survive to maturity due to inadequate soil moisture.

At least 1028 taxa of invertebrates in the Phylum *Arthropoda* (joint-footed animals) have been identified: 80 percent of the known arthropods are insects. Ants, termites, and ground-dwelling beetles are probably the most important groups of insects in terms of distribution, abundance, and functional roles.

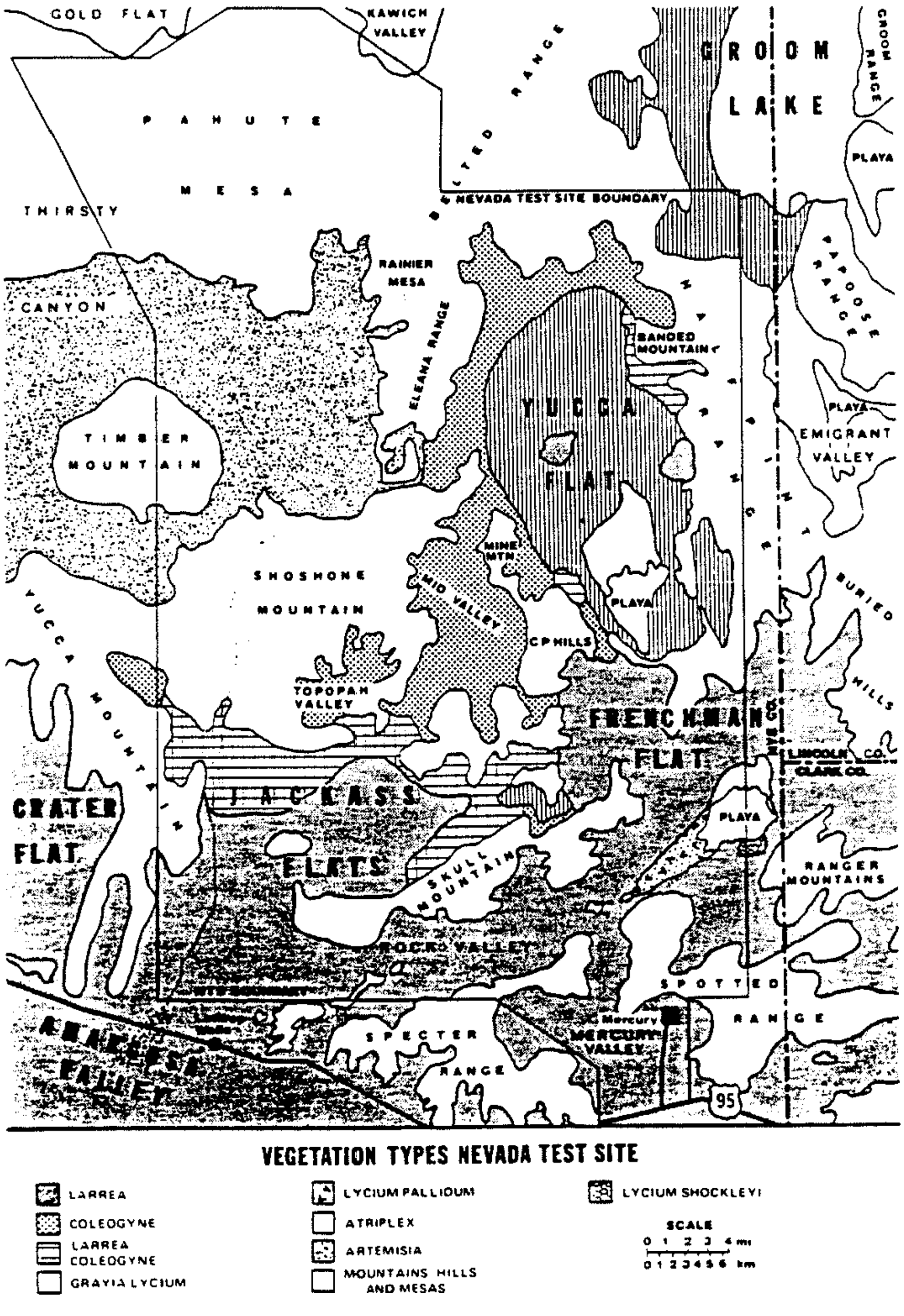

Figure 10. Major vegetation types of the Nevada Test Site (Redrawn from maps prepared by J. C. Beatley and printed with her permission).

FIGURE I-3 FROM O'FARRELL AND EMERY, NVO-167, 1976

Goldfish (*Carassius Auratus*[3]) and golden shiners (*Notemigonus crysoleucas*) have been introduced into ponds and springs on the NTS; no other fish species are known to occur here.

The reptilian fauna includes 1 species of tortoise, 14 species of lizards, and 17 species of snakes. The most abundant, widely distributed lizards include the side-blotched (*Uta stansburiana*), western whiptail (*Cnemidophorus tigris*), desert horned (*Phrynosoma platyrhinos*), and desert spiny (*Sceloporus maqister*). Reproduction among side-blotched lizards is correlated with winter rainfall and growth of winter annual plants. The western shovel-nosed snake (*Chionactis occipitalis*) is the most common snake on the NTS. At least four species of poisonous snakes are also found there. No known records exist of amphibians collected on the NTS.

Records exist for 190 bird species observed on the NTS. About 86 percent of the species are transients; only 27 species are permanent residents. In winter the NTS provides feeding grounds for thousands of small passerine birds (perching birds and songbirds), many of them remaining as winter residents. A surprising number of transient waterfowl and shore birds frequent this arid location. In addition to migratory waterfowl, the only game birds are Gambel's quail (*Lophortyx gambelii*), chukar (*Alectoris chukar*), and mourning dove (*Zenaida macroura*).

Observers have recorded a total of 42 species of terrestrial mammals and 4 species of bats at the NTS. Small mammals (rodents named in detail in Chapter III) account for half of the known mammalian species and are the most abundant and widespread group of mammals on the NTS.

Medium-sized mammals found on the NTS include the black-tailed jackrabbit (*Lepus californicus*), desert cottontail (*Sylvilagus audubonii*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), badger (*Taxidea taxus*), bobcat (*Lynx rufus*), and mountain lion (*Felix concolor*).

Larger mammals are also present on the NTS. A herd of mule deer (*Odocoileus hemionus*) may be found on the high mesas during the summer and at lower elevations in the winter. Wild horses (*Equus caballus*) and domestic cattle (*Bos taurus*) range over parts of the site. Pronghorn antelope (*Antilocapra americana*), desert bighorn sheep (*Ovis canadensis*), and wild burros (*Equus asinus*) are thought to be rare but occasional visitors

B. SITE HISTORY PRIOR TO ESTABLISHMENT OF THE NTS

(This text, with updated numbers, was abstracted from the Final Environmental Impact Statement, NTS. [Ref. 1][4] pp. 2-11 to 2-14.)

Use of the NTS area prior to 1951 mainly comprised mining, grazing, and hunting. Two inactive mining districts lie wholly or partially within the NTS, Oak Spring District occupied part of the test site's northeast corner and included at least two low-grade tungsten properties, the Climax and Crystal mines (Fig. I-4, Area 15), when the NTS was established. Prospecting and exploration started before 1905, and numerous small pits, shafts, and tunnels at higher elevations remain as evidence of sporadic activity which continued until 1951. Most of the prospects are at locations showing slight mineralization and low values in copper, lead, silver, gold, or mercury.

Significant production of ore did not occur in the Oak Spring mining district until 1956 when high tungsten prices permitted economic ore extraction. After ten years of co-use concurrent with atmospheric testing at the NTS, the mining claims were acquired by the government through routine condemnation procedures and the owners were reimbursed. The mine works have remained in disuse.

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[3] Scientific names are presented only on first appearance of each common name. Appendix A presents a cross reference between common and scientific names for flora and fauna mentioned in this document. A comprehensive list may be found in O'Farrell, NVO-167.

[4] Source documents shown by [Ref. #] are listed in Bibliographies Part A: References.

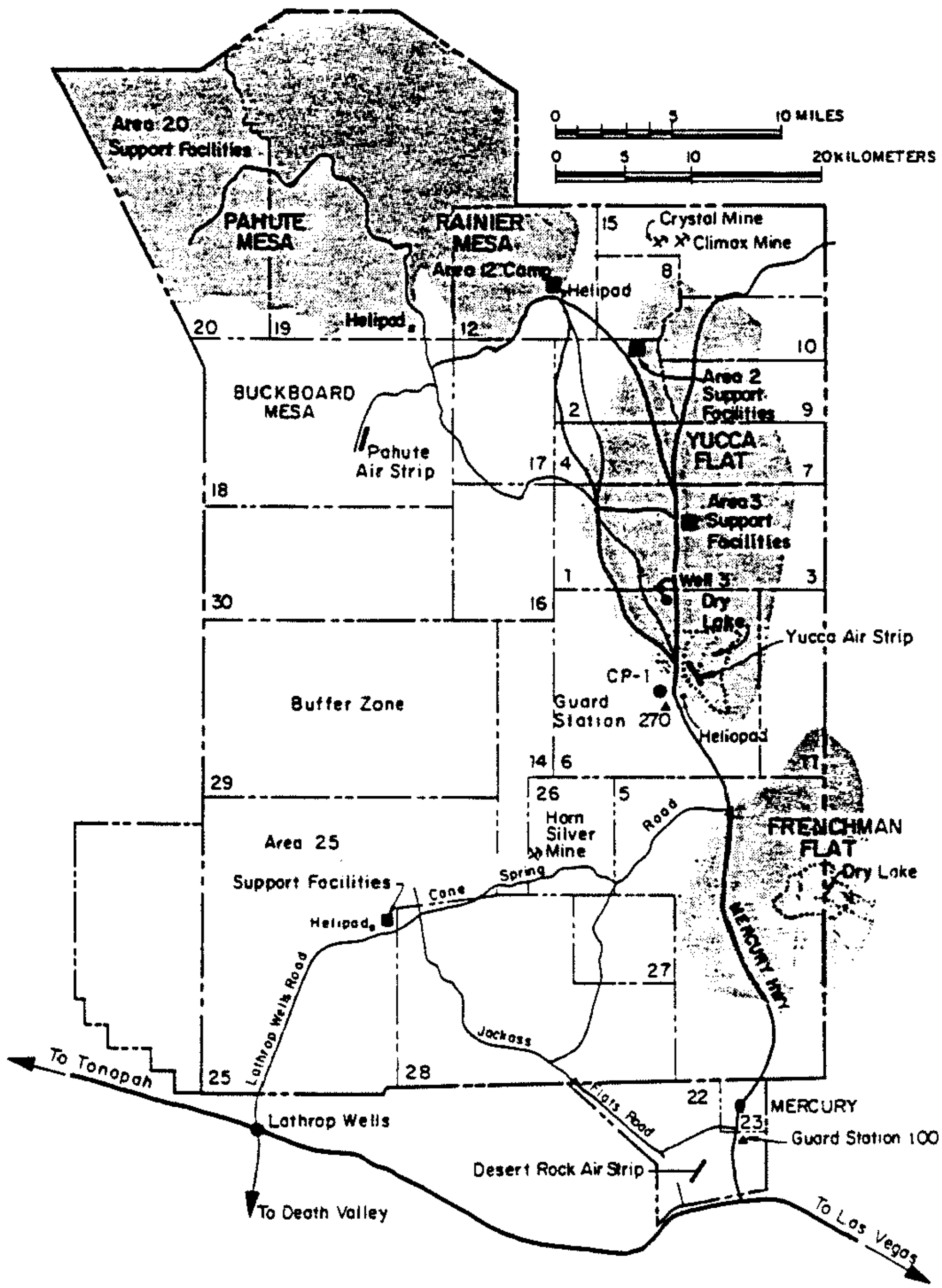

FIGURE II-3 NEVADA TEST SITE

FIGURE I-4 FROM FINAL ENVIRONMENTAL IMPACT STATEMENT, NEVADA TEST SITE, ERDA-1551, 1977

The Wahmonie District, located in south-central NTS, was prospected about 1905 for gold and silver ores. First production occurred in 1928 when a high-grade silver-gold ore was discovered at the Horn Silver Mine (*Fig. I-4*, Area 26). This resulted in minor shipments of ore and caused an influx of 1500 people into Wahmonie. However, after several shafts and extensive prospecting in the area revealed no additional ore finds, interest rapidly waned and the town was abandoned by the summer of 1929.

In addition to the designated mining districts, signs of sporadic prospecting are evident throughout the NTS. Extensive geologic investigations by the U.S. Geological Survey, using samples taken from exploratory drill holes, emplacement holes, and tunnels in the areas used for nuclear testing, have revealed no mineral deposits which would be economically recoverable considering national mineral requirements during the 1980s.

The area encompassing what is now the NTS was used for cattle grazing in the past, and water holes were developed and cabins and corrals built at several points on the site. Water and grazing rights of two ranches operating on NTS areas were acquired by the government in 1956 by negotiated purchase.

C. TESTING OF NUCLEAR DEVICES AND WEAPONS

In the years following World War II, nuclear weapons tests were conducted in the atmosphere or underwater. Before 1951, this work was done at remote island sites in the Pacific Ocean to minimize damage to property or to man. Testing at those distant sites required an extensive logistic effort and an inordinate amount of time. When weapons development was accelerated in 1949 and 1950 in response to national defense policy, it became increasingly clear that, if nuclear weapons could be tested safely within U.S. continental boundaries, weapons could be developed in less time and at considerably less expense, particularly for small nuclear weapons. At that time, a number of sites throughout the continental United States, including Alaska, were considered on the basis of low population density, safety, favorable year-round weather conditions, security, available labor sources, reasonable accessibility including transportation routes, and favorable geology. Of all the factors, public safety was considered the most important. After review of known information about fallout, thermal effects, and blast effects, it was decided that under careful controls, an area within what is now the Nellis Air Force Range could be used for relatively low-yield nuclear tests with full assurance of public safety.

The NTS was originally selected to meet criteria for atmospheric tests, but it has also been found suitable for underground tests up to one megaton and provides an established facility in a location relatively remote from population centers.

Construction of NTS facilities began in January 1951, and the first device was airdropped and detonated on January 27, 1951. Subsequently, various nuclear tests were conducted, mostly in the atmosphere through 1958. Some bombs and devices were airdropped during test series through 1955. Steel towers (one per device) 100 to 500 ft (30 to 152 m) high—one was 700 ft (213 m) high—were used for many tests through 1958. In 1957 and 1958, helium-filled balloons, tethered to precise heights and locations, provided a simpler, quicker, and less-expensive method for the aboveground testing of experimental devices. On October 31, 1958, the United States and the U.S.S.R. entered into voluntary test moratoria which lasted until the U.S.S.R. resumed testing on September 1, 1961. The U.S. resumed testing on September 15, 1961, with primarily underground tests at the NTS and atmospheric tests at Pacific sites.

From the establishment of the NTS in 1951 through December 1991, the U.S. conducted 720 announced nuclear tests at the NTS. All atmospheric tests and Plowshare program tests conducted at the NTS have been announced. (The Plowshare program investigated peaceful uses of nuclear explosives.) Some underground tests with low yields were not announced. Eighty-four of the 720 announced tests were atmospheric detonations conducted on the NTS before the signing of the Limited Test Ban Treaty in August 1963. All but three of the atmospheric tests were conducted prior to the 1958 moratorium. These exceptions are Small Boy, a low-yield test on a short tower; and Little Feller I and II, which were surface tests. Four storage-transportation tests were conducted (three on the TTR and one on the NAFR) and one safety test was conducted at Area 13. Of the nine cratering tests, seven sere conducted after the moratorium as part of the Plowshare program. Selected information is presented in Table I-1 for the tests discussed in this summary.

Safety tests have been performed since 1955 to determine the behavior of nuclear weapons in conventional explosive accidents during handling, storage, and transport operations. The major purpose of these tests was to ensure that if nuclear weapons were involved in an accident, they would not result in a nuclear explosion. Plutonium (Pu) or uranium (U), and mixtures of the two, were the major elements utilized in these safety tests. Before 1963, the tests were conducted at or near ground surface at locations within government-controlled land on the TRC, that is, lands of the NTS, the NAFR, and the TTR (Ref 1, p. 2-88).

Prior to 1963, safety tests were also conducted to determine the size and distribution of Pu particles which might result from fires and conventional explosive accidents involving nuclear weapons. Associated with some of these safety tests were experiments to determine biological uptake of Pu by various species of animals positioned downwind from locations at which Pu particles were dispersed. These biological experiments were intended to study the health physics aspects of dispersed Pu oxide. Another series of experiments, designed to examine rapid physical changes in various Pu configurations subjected to chemical explosives, led to dispersal of small quantities of Pu (*Ibid.*).

All nuclear tests since 1963, including those for determining safety, have been conducted underground in emplacements designed to contain the maximum conceivable yields, and to keep radioactive materials from reaching aboveground environments.

Early safety test areas are unique in that remaining radioactive contamination is primarily plutonium ($^{239+240}Pu$, ^{241}Pu)[5] and uranium (^{235}U, ^{238}U) with very little or no contribution from fission products. Small amounts of americium (^{241}Am) and other transuranic elements are also present. Fission products are present in some areas because some of the safety experiments were intended to establish benchmarks between non-nuclear explosive accidents and accidents in which some nuclear explosive energy was released. Some safety tests in the latter category did produce small amounts of fission. Fallout from atmospheric weapons tests conducted on other parts of the test site during the atmospheric testing days, and worldwide fallout, also contribute to the fission product inventory (*Ibid.* p. 289.).

The aboveground areas where safety experiments have been conducted in the past offer unique sites for studies of the behavior of Pu in the natural desert environment. Recognizing this, the Nevada Field Office has intentionally (*Ibid.* p. 2-91.) preserved these sites. Since 1970, interdisciplinary studies have been conducted of the behavior of Pu in the NTS environment. The interdisciplinary studies program was conducted by the NAEG (Nevada Applied Ecology Group), whose investigations and findings are reported in the remainder of this book.

Two types of craters exist on the NTS: subsidence craters produced by rubble chimney collapse following an underground explosion, and throw-out craters resulting from detonations designed to achieve a cratering effect. In the latter cratering detonations, the nuclear device was placed near enough to the surface such that the bubble of explosion gases broke through to the surface producing a crater surrounded by a rubble field of ejecta. The ejecta grades in size from very coarse boulders near the crater to very fine dust particles at considerable distances downwind; much of the smaller ejecta contains radioactivity, and some of the large boulders are

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[6]The site of PROJECT 57 is located outside of the NTS proper in what was then the Las Vegas Bombing and Gunnery Range and is now the Nellis Air Force Range (NAFR). The site is in a locale commonly called Area 13. The title "Area 13" was never formally or officially conferred and does not appear on NTS or NAFR maps. However, for ease of reference, agreement with historical usage, and to keep geographic bearings straight, the site will be called AREA 13 in the remainder of this book.

TABLE I-1. SITES OF NUCLEAR TESTS STUDIED BY THE NAEG

TEST NAME	DATE	LOCATION	TYPE	YIELD (kt)	OFFICIAL PURPOSE
			PLUTONIUM DISPERSAL		
PROJECT 56-1	11/01/55	Area 11	Surface	Zero	Safety Experiment
PROJECT 56-2	11/03/55	Area 11	Surface	Zero	Safety Experiment
PROJECT 56-3	11/05/55	Area 11	Surface	Zero	Safety Experiment
PROJECT 56-4	01/18/56	Area 11	Surface	Slight	Safety Experiment
PROJECT 57-1	04/24/57	Area 13	Surface	Zero	Safety Experiment
DOUBLE TRACKS	05/15/63	NAFR (TTR)	Surface	Zero	Storage/Transportation
CLEAN SLATE I	05/25/63	TTR	Surface	Zero	Storage/Transportation
CLEAN SLATE II	05/31/63	TTR	Surface	Zero	Storage/Transportation
CLEAN SLATE III	06/09/63	TTR	Surface	Zero	Storage/Transportation
			CRATERING EXPERIMENTS		
SEDAN	07/06/62	Area 10	Crater	104.	Plowshare
PALANQUIN	04/14/65	Area 20	Crater	4.3	Plowshare
CABRIOLET	01/26/68	Area 20	Crater	2.3	Plowshare
			WEAPONS EFFECTS		
LITTLE FELLER II	07/07/62	Area 18	Surface	Low	Weapons Effects
GALILEO	(Four; 1952-57)	Area 1	Atmos.	12–43	Weapons Related
T2	(Six; 1952-57)	Area 9	Atmos.	14–43	Weapons Related

(DOE/NV-209 [Rev. 12] May 1992.)[Ref. 2]

covered with radioactive materials. The NAEG studied cratering experiment sites, but did not study subsidence craters because these sites are not contaminated at the surface by radioactive residues.

D. HISTORICAL SUMMARY OF NAEG INVESTIGATIONS

(Condensed from Essington, NVO–272 (CIC# 67421), CIC# 83091; Gilbert, NVO–142 (CIC# 14333), CIC# 64843 and NVO–153 (CIC# 14334), CIC# 64880; Brady, NVO–153, CIC# 64876; and Tamura, NVO–171 (CIC# 14329), CIC# 64887.)

At the first NAEG planning workshop, held in December 1970, safety-shot sites were recommended for intensive study on the basis of research requirements and on the simplicity of their radiological and ecological characteristics. The scope of study at the various sites included efforts to establish the source term, that is, the amount and distribution of the major radionuclides present. The safety-shot tests dispersed the nuclear material over tens or hundreds of acres at relatively high concentrations, whereas nuclear explosions dispersed radioactivity over hundreds or thousands of square miles at relatively low concentrations. Following is a brief description of the testing conducted in the five safety-shot areas depicted on Fig. I–5.

The site of PROJECT 56 in Area 11, Plutonium Valley, was one of the first chosen for intensive study because the radiological conditions at this site were better known than the conditions at other sites. Contamination resulted from three safety tests in 1955 and one in 1956 at sites separated by a few hundred feet, but with considerable overlap of dispersed residue among the test sites. The quantities of Pu and U deposited there were typical of nuclear weapons and hence were large, with from 1 to 10 kilograms of nuclear material dispersed by each test. The site could be maintained in an undisturbed state for studies of the characteristics, distribution, and translocation of Pu under existing natural conditions. The site was thought to be ideal for study of resuspension and lateral and downward movement of Pu in soils by the action of surface waters. In fact, survey data indicated that Pu had been moved several miles down a wash that drains that area toward the playa in Yucca Flat.

Contamination at Area 13[6] was deposited by the PROJECT 57 test in 1957. Pu was used in the test, and readily measurable amounts were distributed over a few tens of acres. This site was chosen for intensive study to conduct inventory and distribution measurements and to evaluate Pu assimilation by grazing animals in a contaminated area with enough natural vegetation to support livestock grazing. Evaluation of the radionuclide inventory and distribution at Area 13 and at TTR (discussed below) was considered important because these sites are outside the controlled boundary of NTS proper (but still within the TRC) and the feasibility of site cleanup was being considered. In addition, experiments were to be conducted to determine how man's activities influence resuspension and to explore methods and effectiveness of treatment and cleanup activities.

The Area 5 GMX (Gadgets, Mechanics, and Explosives) site was incorporated as an intensive-study site; the site had previously been chosen for resuspension studies and represented an ecosystem different from those of PROJECTS 56 and 57. Between December 1954 and February 1956, 24 experiments were conducted at the GMX site, each utilizing relatively small quantities of Pu. These experiments were "equation-of-state" studies designed to make measurements of "instantaneous" changes in the physical properties of Pu materials subjected to conventional explosives detonations. These experiments were conducted on or near one place so that essentially the source can be considered one site measuring 3200 by 3600 ft (975 by 1100 m). An area with these dimensions would encompass 264 acres (107 ha), but only about 1/10 of this area bears significant levels of Pu contamination.

Four tests at the Roller Coaster sites on and near the TTR used moderately large amounts of Pu or Pu and U. Each test consisted of one event: DOUBLE TRACKS and CLEAN SLATES I, II, and III. The CLEAN SLATE sites form a triangle with the longest leg measuring about 20,000 ft (6100 m); the DOUBLE TRACKS site is about 18 mi (29,000 m) west of the CLEAN SLATE sites.

During 1972, NAEG study emphasis was placed on the safety-shot sites in the TTR. The range surrounding the sites was being used for commercial grazing and although only small fenced areas contained potentially significant contamination, the grazing animals as well as various wild animals in the region had access to forage bearing low levels of Pu contamination. (Planning at the time intended that characterization of the contaminated locations would provide important source term information for interpretation of concurrent controlled assimilation studies; these studies were not done.) These sites also represented different soil characteristics and different ecosystem attributes compared to the other intensive-study sites.

Studies on the ten discrete surface safety-shot areas were designed to provide data on movement of Pu and other radionuclides through living and nonliving components in varied sites in Mohave and Great Basin desert environments. These sites have been exposed to natural environments and weathering processes for various lengths of time since 1954.

These safety-shot areas were selected for the initial intensive study by the NAEG and became known as safety-shot-intensive study sites. As work progressed from safety-shot sites to other cratering and atmospheric test sites, the latter became known as nuclear-shot intensive-study sites.

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[6] In the remainder of this book, Pu will mean $^{239+240}$Pu because usual analytical methods cannot distinguish between these species, Am will mean ^{241}Am, and U will mean ^{238}U, unless clarity requires separate identification of radioactive species.

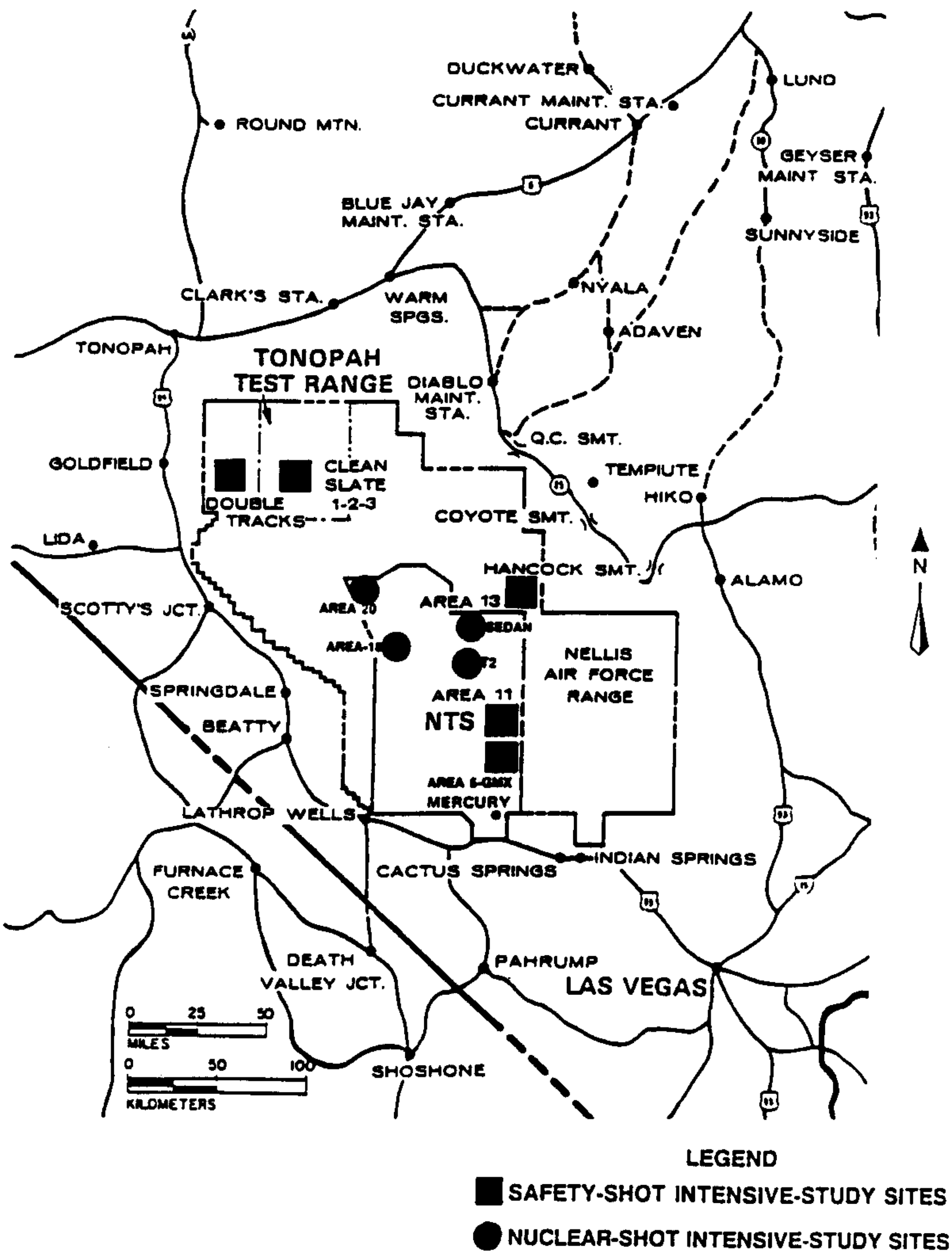


FIGURE I-5 INTENSIVE-STUDY SITES

FIGURE I-5 MODIFIED FROM FINAL ENVIRONMENT IMPACT STATEMENT, NEVADA TEST SITE, ERDA-1551, 1977

[Ed. Note: The AEC and DoD also conducted 27 safety tests in Areas 3 {fourteen}, 7 {one}, 8 {three}, 9 {three}, and 12 {six} in 1957 and 1958, resulting in some Pu contamination in those areas. Contamination from Pu and other radionuclides also persists in other areas on the NTS where atmospheric weapons tests and near-surface Plowshare tests were conducted.]

By 1976, source term information had been obtained relative to Pu, Am, and U distributions at the safety-shot sites; efforts were then directed to the more complex nuclear-shot sites. The presence of a larger number of long-lived radionuclides contained in surface deposits of fused materials, dispersed in various particulate configurations, and situated in a generally more rugged terrain, constituted a complexity not seen at the sites investigated earlier.

Based on initial suggestions of the Plutonium Ad Hoc Committee, four nuclear detonation locations in Area 18 were evaluated by the NAEG (DANNY BOY, LITTLE FELLER I, LITTLE FELLER II, and JOHNNIE BOY). Only LITTLE FELLER II was selected as an intensive-study site because it included almost all of the features that would impact radionuclide assimilation by animals grazing in Area 18.

Three Plowshare cratering detonations in Area 20 on Pahute Mesa were also evaluated (PALANQUIN, CABRIOLET, and SCHOONER). The PALANQUIN and CABRIOLET sites were chosen because they were conducive to an integrated study of radionuclide distribution, redistribution, and assimilation by grazing animals. These sites were close together and their main fallout paths overlapped.

The NAEG expanded nuclear-site studies in 1981 to include two areas in Yucca Flat. The first was the region surrounding the SEDAN crater in Area 10 in north-central Yucca Flat where throwout debris covers much of the north-central and northeast portions of the valley. The other intensive study site is located on the northwest side of Yucca Flat encompassing the T-2 series of tower-mounted detonations in Area 2. Three GZs (ground zeros) encompassing six tests were included in the study area: T-2 (HOW, BADGER, TURK, and WHITNEY), T-2a (SHASTA), and T-2b (DIABLO).

The Yucca Flat study areas were chosen because they represented source term characteristics differing substantially from the previously studied sites. The SEDAN test was detonated in desert alluvium as opposed to the hard-rock tests of PALANQUIN and CABRIOLET. Tests at the T-2 location were conducted on steel towers either 300 or 500 ft (91 or 152 m) tall as opposed to the ground-level test of LITTLE FELLER II. In addition to supplementing ecological studies at the Pahute Mesa sites, it was believed that evaluation of the radionuclide distribution in the Yucca Flat areas would help in assessing the potential radiation hazard to individuals working in these areas should the areas be needed for further nuclear testing.

E. PLUTONIUM INVENTORY AND DISTRIBUTION PROGRAM

Determination of the plutonium inventory and distribution in the surface soil at the NTS received early emphasis by the NAEG. The program relied on laboratory analyses of soil samples and field measurements with various hand-held radiation-detection instruments. These procedures were used throughout the 1970s.

NAEG studies could begin promptly because postshot monitoring and other radiological surveys had identified all contaminated areas of potential concern. Collection and analysis of environmental samples, and calculations of inventory, progressed through a series of iterations. Several different calculational methods were used to derive Pu to Am ratios, to map and integrate estimates of distribution, and to derive inventory estimates based on results from other investigations. This summary presents only the final results of the NAEG work elements along with background information requisite to an understanding of these results.

Written procedures were developed for collection of the many different types of environmental samples (see NVO-166 (CIC# 14339), 2 Volumes, V.1 CIC# 14338, V.2 CIC# 14339; see Bibliographies Part F for a compressed table of contents and CIC#s of individual entries). Sampling procedures varied according to sampling purpose. Environmental samples were collected by trained field crews whose members were often trained or accompanied by experienced investigators. Field crews were instructed to collect specific samples, or to make specific measurements, at locations designated by project element leaders who had specific objectives in mind. Project objectives were coordinated to obtain as much information as possible with the smallest feasible expenditure of limited manpower and financial resources. The following example will illustrate the point.

The Pu environmental studies program required statistical design and analysis relating to soil sampling. The primary objective was to design a field sampling plan that would result in a precise estimate of the Pu inventory in the upper 5 cm of soil in Areas 5 and 13 at a minimal cost. A secondary objective was to examine for these two areas whether gamma scans for Am and wet chemistry determinations of Pu were sufficiently well correlated so that Pu concentrations could be accurately predicted using the gamma scans. A third objective was to investigate whether the FIDLER (Field Instrument for Detection of Low-Energy Radiation), a portable field instrument calibrated to detect Am gamma rays, could be used in a double-sampling scheme for estimating Pu concentrations on the soil surface. Some data obtained for these objectives were also utilized to (1) estimate the proportion of the total Pu in the vertical profile (to a depth of 25 cm) that is in the upper 5 cm, (2) investigate whether the Pu to Am ratio may change with soil depth, (3) estimate the precision of replicate Pu and Am analyses on the same batch or sample of soil, and (4) look for laboratory bias in the Pu and Am analyses of samples sent to more than one laboratory. Different objectives usually call for different field sampling plans, and the design used to estimate inventory was not in all respects ideal for satisfying other objectives.

Investigations started with a simple plan and used the results as the foundation for later planning which required finer detail or involved greater complexity. In keeping with this philosophy, the first soil sampling effort was called the Overview Sampling Phase which was designed to provide enough preliminary data to (1) determine which of all the older atmospheric tests did, in fact, result in soil contamination, (2) determine generally the area and depth of deposited fallout contamination, and (3) determine the types and gross magnitudes of deposited radioactive contaminants.

Overview Sampling Phase results were used to determine the scope of later sampling phases. The Overview Sampling Phase verified the presence of radioactive contaminants at 73 of a possible 118 locations where atmospheric tests had been conducted. A tagged identifying stake was placed at each GZ location and the line of maximum radioactivity was staked at 100-ft (30-m) intervals out to 500 ft (152 m) and every 1000 ft (305 m) thereafter until a cutoff value of 0.2 mrad/h (2 μGy/h) was reached. Initial measurements were made with portable alpha and beta-gamma detection instruments whose detectors were held as close to the ground surface as practicable. A trench was dug with a backhoe at each stake and three soil samples were collected from the trench sidewall. Soil was taken in 2.5-cm increments at the surface and at depths of 15 and 30 cm.

The overview sampling illuminated the need to increase sampling depths to 120 cm at 30-cm increments to more fully assess the depth distribution. This increase was necessary because of the extensive mechanical disturbances that occurred over the years at many sampled sites. Particularly at multi-test sites, contaminated surface soil was bladed off (sometimes into a trench or pit) and clean soil backfilled to reduce exposure rates to personnel preparing the site for another test. For this reason, intensive sampling was based on a grid location system rather than a random sampling technique. Caution was required to avoid sampling backfilled material which appeared to be native soil, especially at locations close to GZs where the results could be misleading.

[Ed. Note: In the following chapters, no distinctions are made as to the phase or type of sampling performed because this information may be inferred from the apparent objectives and presented results. It could be confusing to include all the information required to keep track of the different sampling phases because many samples were used to meet several purposes and the results presented may include data from several different sources with dissimilar systems used for sample identification.]

Stratified random sampling was used at intensive-study sites to obtain an estimate of Pu inventory. The intent was to obtain estimates of inventory with smaller variance than could be obtained using simple random sampling. An important objective was to design strata selection so the variation in Pu concentrations from soil sample to soil sample within each stratum would be as small as possible and the variation between stratum means would be large. Strata were defined for all sites by intensive field surveys using the FIDLER for counting Am gamma rays from the soil surface (except Area 11, Site A, where the principal contaminant is ^{235}U which is not measured with a FIDLER). The amount of Am present in the soil is an approximating indicator of the amount of Pu present.

After strata were defined, surface soil samples (0-5 cm) were collected from at least ten randomly chosen locations within each stratum, without regard for surface characteristics (blow sand, desert pavement, sand and gravel, etc.). Profile samples were also collected at random desert pavement locations in each stratum to investigate the distribution of Pu with depth. Profiles consisted of 10 samples taken at 2.5 cm increments from the surface to 25 cm.

A common feature in the desert is the presence of a soil mound at the base of almost every shrub, and grasses appear to grow on or out of a mound of accumulated sands and silts. The mounds are formed as vegetation intercepts wind-borne particles and retards their further movement. Mounds at bases of grass clumps are quite small whereas quite large mounds may form under long-established shrub clusters; large mounds may be 10 to 20 ft (3 to 6 m) in diameter and several feet (about 1 m) high but are usually smaller.

In contrast to the mounds, adjacent areas are usually sparsely vegetated or bare soil. In many areas the surface consists of a thin veneer of gravel, referred to as "desert pavement," where fine particles have been removed by the erosive forces of wind and water. The surface of the remaining soil/gravel matrix usually has a thin, weak crust which retards further erosion. In places where this crust has been broken, erosion will proceed at an increased rate until the next rain contributes to the reforming of a new crust. However, water erosion will occur during the first few rains because several wetting and drying sequences are required for good crust formation. Desert pavement does not form in sandy areas; some minimum fraction of the soil matrix must be clay or alkali elements to bind the soil particles into a crust.

These coexisting areas show morphologic and topographic differences and measured levels of Pu activity in contaminated areas are higher in the mounds than in the contiguous desert pavements. Because the mounds serve as sites for biological activity, NAEG scientists studied the character and behavior of the Pu in these two related soil systems. Examined factors include Pu concentration as a function of depth, particle size, and particle density.

F. ANIMAL INVESTIGATION PROGRAM

Prior to 1955, investigations of animal injuries alleged to be related to the nuclear testing program were handled by various investigators on a fee or consultant basis. This arrangement was unsatisfactory as there was usually a significant delay between the alleged incident and the investigation. Furthermore, the investigators were handicapped by a lack of baseline data on the radiation exposure of the species being investigated. The off-site radiological safety report for Operation Teapot (1955) recommended that continuous services of a veterinarian with radiological training should be available to supervise a sound investigative program (Sanders, 1955, [Ref. 3]).

The Off-Site Rad-Safe Livestock Studies for the AEC's Office of Test Operations (now the Nevada Field Office) began in November 1955 under control of the U.S. Army. The Off-Site Animal Investigation Project was initiated in July 1957 and continued to be directed by Army veterinary officers until operation was transferred to the PHS (U.S. Public Health Service) on

June 1, 1964. The PHS facilities in Las Vegas were transferred to the EPA in December 1970. The PHS and the EPA conducted the renamed AIP (Animal Investigation Program) until the program was terminated in 1981 (EPA 600/6-84-020; CIC# 65154). With the inception of the NAEG in 1970, various aspects of the EPA's efforts on the NTS were reported as NAEG work. However, some aspects, while funded by AEC/ERDA/DOE, were not reported as part of the NAEG effort; the AIP fell in the latter category even though there was coordination of effort between the EPA and several other NAEG contractors. As stated in the first annual report,

> The primary aims of the Program were: (1) to enhance the Nevada Test Site — Offsite rancher relationships through an active investigation program in their interests, and (2) to provide further information as to the status of the offsite animals in their environment with special emphasis on the radioactivity from fallout. The other objectives of the AIP were: to provide authentic information regarding various claims, complaints, and inquiries arising among livestock raisers, wildlife management personnel, and other groups concerned with animal welfare; and to provide information as to levels of internal radioisotopes that accumulate in grazing animals that ingest fallout under range conditions. (Johnson, 1958; CIC# 2040.)

Through the years, these goals were modified to include the following objectives as stated in the 1981 annual report:

> 1. To conduct surveillance of domestic and wild animals on and around the NTS in order to assess the radionuclide burden present in their tissues and to detect pathological effects from the burdens.
> 2. To investigate alleged damage to domestic animals and wildlife resulting from the activities of the NVO of the USDOE.
> 3. To provide public information through education and veterinary advice to the offsite population.
> 4. To conduct special ad hoc investigations. (Smith, EPA 600/3-83-014, 1983; CIC# 41868.)

The AIP began in 1957 with the purchase of a herd of beef cattle which was allowed to graze on the NTS. This herd was maintained on the NTS until 1981. During the 25-year existence of the AIP, periodic sampling of cattle and other indigenous animals was conducted to measure tissue concentrations of radionuclides. In addition to the NTS cattle, other animals consistently sampled included deer on the NTS and bighorn sheep off the NTS.

Measurements of radionuclides in the bones and soft tissues of animals living on or off the NTS have been made since 1956. The groups of animals in the long-term studies and the periods for which data are available at EPA include:

NTS Beef Herd	1957-1981
Delamar Valley Beef Herd	1957-1968
Knoll Creek Beef Herd	1958-1968
NTS Mule Deer	1964-1981
Other Mule Deer	1956-1972
Desert Bighorn Sheep	1956-1981

[Ed. Note: EPA has continued to collect and analyze bioenvironmental samples since the AIP was terminated. Results appear in the EPA's annual report series titled "Off-Site Environmental Monitoring Report." Results available for years since 1981 are not discussed in this book.]

The program changed somewhat over the years, but, in general, a few animals from the beef herd were sacrificed for sampling each spring and fall. One deer was collected for analysis every three months beginning in 1966. Whenever possible, the program used deer which had been killed by vehicles; otherwise, they were collected by hunting. Selected samples from desert bighorn sheep were obtained through cooperation of licensed hunters and the Nevada Department of Wildlife. The number of samples varied from 7 to 34, depending on hunter success and cooperativeness.

G. NTS EXPERIMENTAL FARM

In a cooperative effort between the AEC and the PHS, an Experimental Farm was established in Area 15 of the NTS during the period 1963–64 to investigate the transport of radioiodine through the air-forage-cow-milk chain. The farm included an irrigated agricultural area, a dairy-cow herd, milking facilities, and facilities for surgical and necropsy procedures. Metabolism stalls were added later to allow individual collection of urine, feces, milk, and blood from dairy cows. As the research program progressed, additional radionuclides (listed in Chapter VI) were studied in a variety of animal products which could be ingestion sources of human exposure (Black, EPA 600/4-84-066, CIC# 65152).

[Ed. Note: The reference contains a chronological listing of the studies involving the Farm. A bibliography of reports issued appears in Smith, EPA 600/6-84-020; CIC# 65154.]

The radioiodine program was essentially complete by 1970 and was summarized in a 1976 report (Black, EPA-600/4-76-027 [Ref. 4]).

In addition to the objectives mentioned above, the Farm was used in cooperative studies with the LLNL, Oak Ridge Associated Universities, and other EPA laboratories. The Farm also served as a staging area for the AIP. The surgery and necropsy procedures could be performed at the Farm in a clean environment and space was available for maintenance of animals and, particularly, for the fistulated steers. It also served as the operation base for NAEG grazing studies conducted on actinide-contaminated ranges and for ad hoc AIP investigations (Black, EPA 600/4-84-066, CIC# 65152).

H. RADIONUCLIDE INVENTORY AND DISTRIBUTION PROGRAM (RIDP)

During the early 1970s, scientists at the LLNL developed the capability of taking *in situ* (in place, or in-the-field) measurements of ^{241}Am gamma rays with semi-portable detectors. Early work, including a demonstration study at the NTS, was reported (Anspaugh, CIC# 83153; Anspaugh, CIC# 13717). The equipment used was not as sensitive as desired; this was remedied (Kirby, CIC# 43954) and an improved system was tested at the NTS in 1976 and found to produce superior data in comparison to results from soil samples (Kirby, NVO–181 (CIC# 14359), CIC# 64969). This *in situ* system was used as a primary data-gathering method in the radiological cleanup of Enewetak Atoll from 1977 through 1979 [Ref. 5], and was fielded at the NTS for inventory and distribution work in 1978 (Kordas, CIC# 83166).

[Ed. Note: Because gamma-ray detectors alone cannot directly measure plutonium in soil, radioanalysis of soil samples is also required to determine the Pu to Am ratio; then the Pu may be estimated from the measured Am. The *in situ* gamma ray detector system also records the gamma rays from other radionuclides, so a relatively complete inventory of gamma-ray emitters at a location can be obtained from one measurement session.]

In 1980 the LLNL was asked to evaluate the ongoing inventory and distribution program being conducted by others. The results of this evaluation led to formation of the RIDP as outlined by the LLNL (*Ibid.*). The RIDP was conducted from 1981 through 1986; results are presented in Chapter VIII.

CHAPTER II. PLUTONIUM OUTSIDE THE NEVADA TEST SITE

A. HISTORICAL PERSPECTIVE

(Condensed from the Final Environmental Impact Statement for the NTS [Ref. 1], pp. 2–104 to 2–107.)

The EPA, through its EMSL, has performed radiological monitoring in the NTS off-site area since 1954 (as the U.S. Public Health Service from 1954 through 1970). From 1954 through 1958, all such monitoring was specifically related to each test series. Since 1958, several types of monitoring have been performed to determine the levels of radioactivity present. Samples of air, water, and milk are collected for gross beta analyses, and external gross-gamma exposures are measured at both fixed locations and for individual residents. Sample collection frequency has usually been a function of the type of testing program and anticipated off-site effects. Samples of other environmental media are collected during special studies to characterize the distribution and availability of radioactive materials in the total environment. Sampling and analysis of surface soil fall into the latter category. EPA acquired and analyzed hundreds of soil samples from the region surrounding the NTS both before the advent of the NAEG and as part of NAEG studies.

A general pattern of steadily decreasing levels of manmade radioactivity has been observed since the cessation of atmospheric testing (except for Pu). Since early 1971, with minor exceptions, the surveillance networks have measured only the expected ambient levels of radioactivity. The results from a widespread dosimetry network around the NTS indicate that annual gross-gamma exposures are below 110 mrem (1.1 mSv), while the typical average value for the southwestern states is 130 mrem (1.3 mSv). Annual gross-gamma exposures do reach 130 mrem in areas to the north-northwest and northeast of the NTS, but these levels of exposure are decreasing with time. These gross-gamma measurements do not consider alpha radioactivity from radionuclides such as $^{239+240}Pu$.

The long-lived Pu is present in small quantities off the NTS, both on the NAFR and on the public domain beyond the Range. The EPA has sampled both the vertical and areal distribution of Pu in soil in the areas believed to have been affected.

B. PLUTONIUM DISTRIBUTION IN NTS ENVIRONS

(Condensed and abstracted from NAEG reports as indicated.)

[Ed. Note: Under a 1954 memorandum of understanding between the AEC and the PHS, the EMSL-LV (formerly known by other acronyms such as SWRHL, NERC) serves as the off-NTS radiological safety organization. Within the mission of this memorandum, the EMSL has developed air and soil surveys to determine ambient Pu-in-air concentrations and the distribution of Pu in soil around the NTS.]

1. Air-Sampling Program

The PHS established a permanent network of air samplers around the NTS in 1958 to monitor ambient levels of beta and gamma radioactivity. Filters from this network have been stored since 1966. Filters taken from selected stations adjacent to NTS in EPA's routine ASN (Air Surveillance Network) were analyzed for Pu content for the period from 1966 to mid-1975. Laboratory procedures are capable of measuring 0.02 pCi (740 mBq) of Pu at the 95 percent confidence level. This sensitivity is adequate to determine worldwide contamination from nuclear testing in an air filter representing 500 m^3 of air (Church, NVO–142, CIC# 64860; Bliss, NVO–153, CIC# 64878).

To establish a background level of Pu in air and to determine whether worldwide fallout was distributed evenly throughout the western United States, statistical analysis of Pu-in-air results was performed on data from eight widely separated stations of the ASN. The locations were chosen to meet three criteria: (1) geographical representation, (2) potential influence from NTS, and (3) variety of altitude and climatological parameters. The locations selected were Aberdeen, South Dakota; Albuquerque, New Mexico; Austin, Texas; Barstow, California; Medford, Oregon; Provo, Utah; Spokane, Washington; and St. Joseph, Missouri. (Church, NVO-142)

Data from these locations were analyzed by various statistical techniques. Means were used to place the eight locations into three groups: (1) Provo and Barstow, (2) Spokane, St. Joseph, and Albuquerque, and (3) Austin, Aberdeen, and Medford. Analyses of the data to determine trends or correlations have not shown any significant relationships within the plotted data (Bliss, NVO-153, p. 240). Charts of the data representing the analyzed filters are available for the years 1966 through mid-1975 (Bliss, NVO-153, pp. 243-246 and Bliss, NVO-181, pp. 196-199, CIC# 64972).

For investigation of possible elevated levels of Pu in areas adjacent to the NTS, filters were selected from stations operating near the NTS which would most likely show either resuspension of localized Pu or wind-borne Pu carried directly from the NTS. The stations were chosen from 60-degree sectors upwind and downwind of on-site Pu sources for days when surface winds at Las Vegas and Yucca Lake averaged greater than 10 knots, and ground conditions were dry. The data from each station were grouped according to selection as upwind or downwind, and a one-way analysis of variance was performed on each. In 7 of the 10 stations selected, no significant difference in Pu concentration was found between upwind and downwind. A difference was noted in two cases, and a probable difference in one case. These differences are believed to be due to seasonal differences in atmospheric Pu levels. Comparison of downwind results from the 10 NTS stations and results from the 8 stations from other states indicates that only background concentrations were detected (Church, NVO-142, p. 317).

2. Soil-Sampling Program

Soil samples were collected from around the NTS to define depth of Pu penetration and the total amount deposited. Vertical profile sampling (42 profiles) has shown that for 86 percent of the locations sampled, 90 percent or more of the Pu resides within the top 3 cm (top inch) of soil. Analyses of soil data from all samples, replicate samples, and replicate analyses indicate that the distribution of results is best defined by a combination of overlapping lognormal curves: one containing 86 percent of the results with mean deposition of 3.5 nCi/m^2 (130 Bq/m^2), and one containing 14 percent of the results with a mean of 41 nCi/m^2 (1.5 kBq/m^2). This information suggests that some soil samples contained Pu particles which were significantly larger than the majority of Pu particles. Results from surface soil samples collected outside of federally controlled lands ranged from background to 96 nCi/m^2 (3.6 kBq/m^2) (Church, NVO-142, p. 318). The highest value from a profile sample, obtained by summing the individual layer values of the profile, is 132 nCi/m^2 (4.9 kBq/m^2) at a sampling location 15 km southeast of Diablo (north of the NTS; see Fig. II-1).

The EPA collected surface (0-5 cm) soil samples from 855 locations around the NTS for areal definition of Pu contamination. Sampling site locations are shown in *Fig II-1.*

[Ed. Note: This figure is presented to show the areal distribution of sites; readable figures appear in Bliss, NVO-153, p. 241, (CIC# 64878) and NVO-181, p. 190, (CIC# 64972). Samples from sites shown only by dots in these two reports have been analyzed but the results have not been published.]

Results from the 855 samples are shown in Fig. II-2 by segments of circles and sectors surrounding the NTS. The circles, labeled A, B, C, and D, represent increments of 50 mi (80 km) in radius from the approximate center of the NTS. The 30-degree sectors are numbered 1 through 12. The highest observed value, 180 nCi/m^2 (6.7 kBq/m^2), appears in segment A-11 at a location very close to the northwest corner of the NTS.

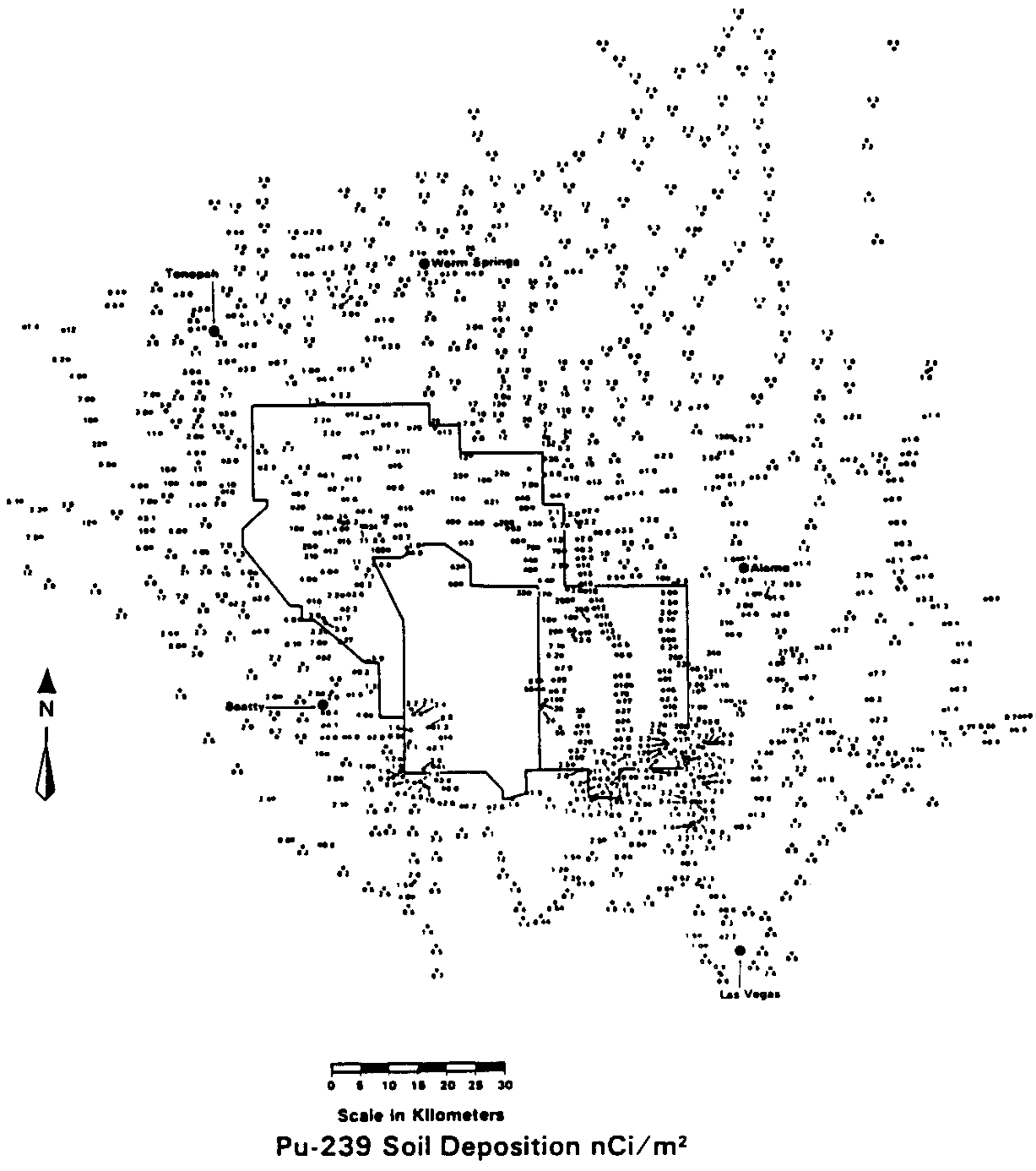


FIGURE II-1 Pu-239 IN SURFACE SOIL IN NTS ENVIRONS. FROM EPA/EMSL UNPUBLISHED REPORT. (SEE ALSO NVO-181, pp.190-194 FOR EARLIER REPORT)

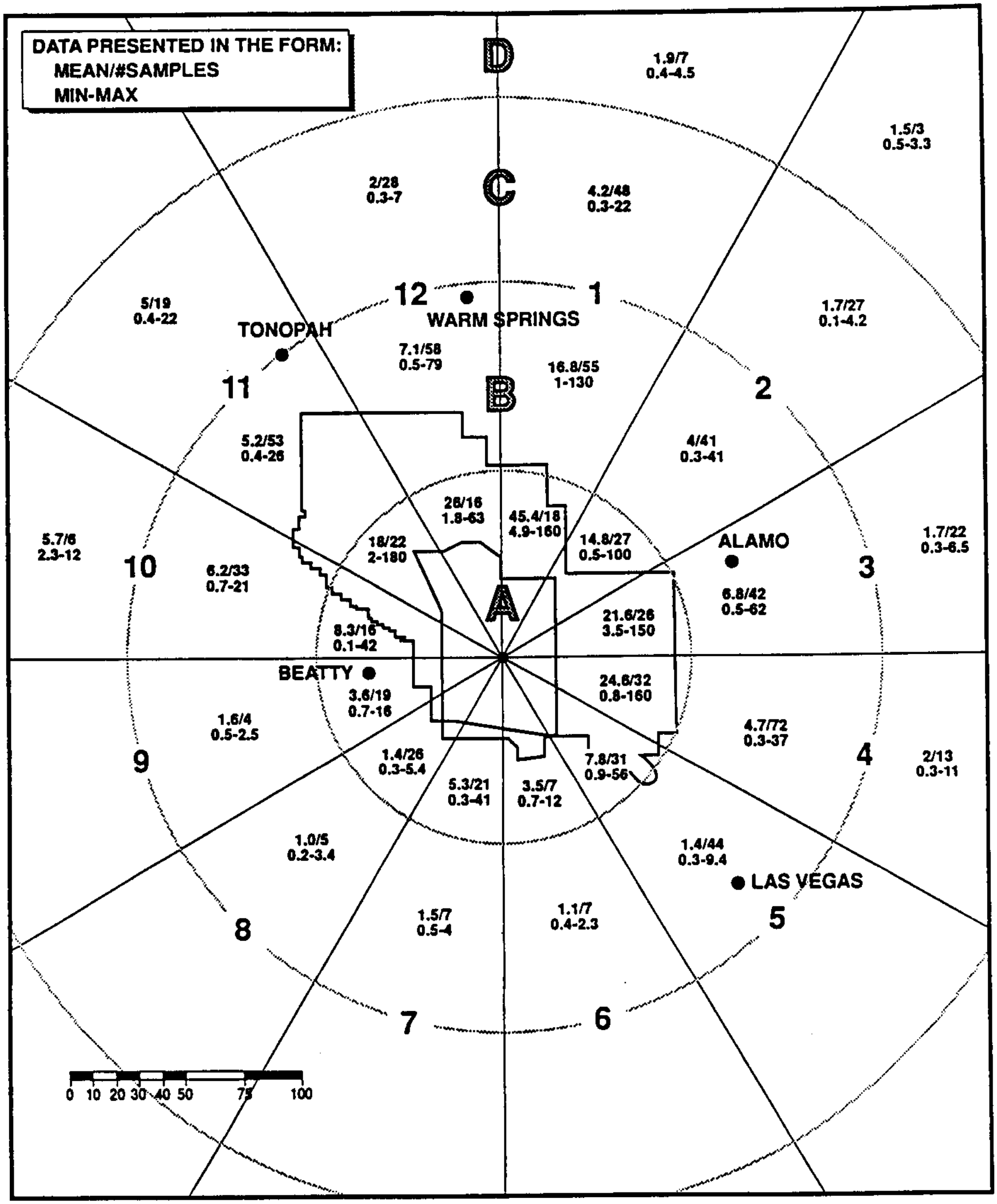


FIGURE II-2 MEAN, MINIMUM AND MAXIMUM Pu-239 SOIL DEPOSITION nCi/m^2 AS DETERMINED FROM SOIL SAMPLES COMPILED FROM EPA/EMSL UNPUBLISHED REPORT OCT. 1980

Data for Pu in surface soil are summarized below:

Circle	Distance (mi)	Number Samples	Mean Pu (nCi/m^2)
A	0 - 50	261	15.3
B	50 - 100	421	6.4
C	100 - 150	163	3.0
D	150 - 200	10	1.8

The data in *Fig. II-2* show that distribution of Pu in soil is not uniform in the area surrounding the NTS, and that the concentration decreases rapidly with distance. Concentrations approximating the contribution from global fallout are observed in sectors 5 through 9 beyond 50 mi (80 km) (circle B); in sectors 2, 3, 4, and 12 beyond 100 mi (circle C); and in sector 1 beyond 150 mi (circle D). Soil samples were not collected beyond 150 mi in sectors 10 and 11 where the mean concentrations were still about three times global fallout contribution at a distance of 100 to 150 mi.

Results from 63 surface soil samples collected in eastern Nevada and central Utah are presented in Fig. II-3 (Bliss, NVO-153, p. 242). Values of Pu in soil range from 0.54 to 41.0 nCi/m^2 (20 to 1,517 Bq/m^2) with the mean of these data being 2.72 nCi/m^2. Three unusually high values (41, 11, and 8.3 nCi/m^2) appear near Ely, Nevada. When these values are deleted from the calculation, the range is from 0.54 to 4.6, and the mean is 1.85 nCi/m^2.

[Ed. Note: Analysis of soil samples collected during the early 1980s indicates that the Pu inventory in surface soil in the western states is generally less than or close to 2 nCi/m^2 (McArthur, DOE/NV/10384-23 Rev., 1989 [Ref. 6]). The three high values would be easier to explain had they been contiguous. But the highest value has normal values to each side, and the other two high values, while together, have normal values to each side of the pair. Funding for this work was terminated before these anomalies could be investigated.]

3. Special-Purpose Investigations

The EPA conducted several special-purpose investigations to evaluate Pu transport off site by surface water runoff. The situations studied include (1) Fortymile Canyon, (2) a drainage basin southeast of the NTS, and (3) a drainage basin north of the NTS.

In the first special study, two water and sediment collectors (Bliss, NVO-181, p. 189, CIC# 64972) were buried (with the top of the collector at grade) in the wash of Fortymile Canyon which provides surface drainage for a large portion of the western NTS. During several years following collector placement, rainfall was insufficient to produce surface runoff. However, there was sufficient runoff in the spring and summer of 1976 to provide water and sediment samples from both collectors (*Ibid.*, p. 195). [Ed. Note: These samples were not analyzed due to insufficient funding and have reportedly been discarded.] Then, in 1977, severe thunderstorm activity within the drainage basin produced excess runoff which excavated both collectors. The smaller part of one collector was located about a quarter-mile downstream from where it had been set in the wash. The second collector could not be found. The investigation was terminated without further results.

In a second special study, soil samples were collected from an array around the mouth of Fortymile Canyon. The array extended from within the NTS into the off-NTS area. The sampling array and Pu data are shown in Fig. II-4 (Bliss, NVO-159 (CIC# 14336), p. 84, CIC# 64956). "Results from these samples show no definitive patterns of radionuclide movement or concentration as a result of hydraulic transport." (Bliss, NVO-159, p. 86).

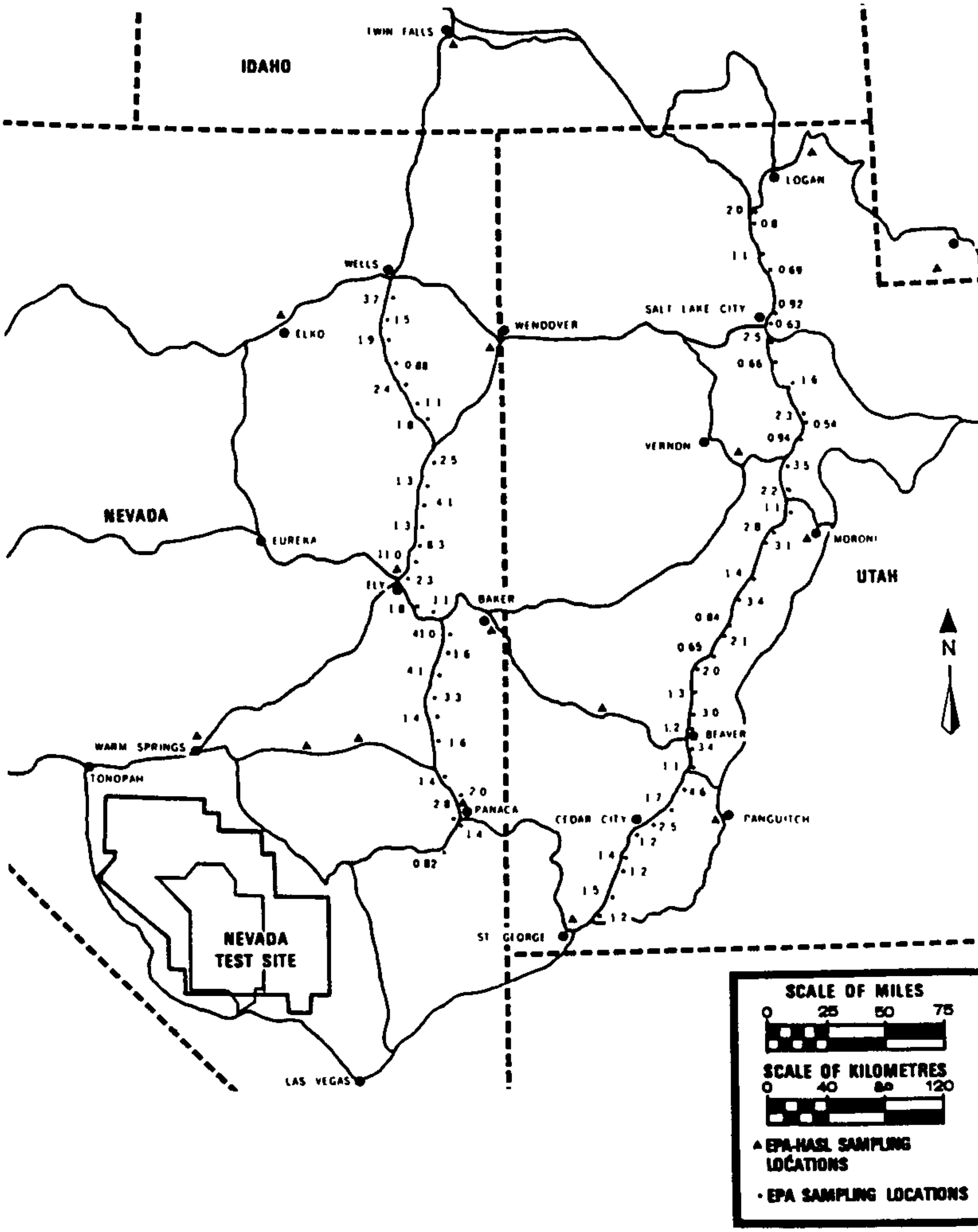


Figure 2. Plutonium–239–in–Soil (nCi/m^2)—Eastern Nevada and Utah

FIGURE II-3 FROM BLISS AND JAKUBOWSKI, NVO-153, 1975

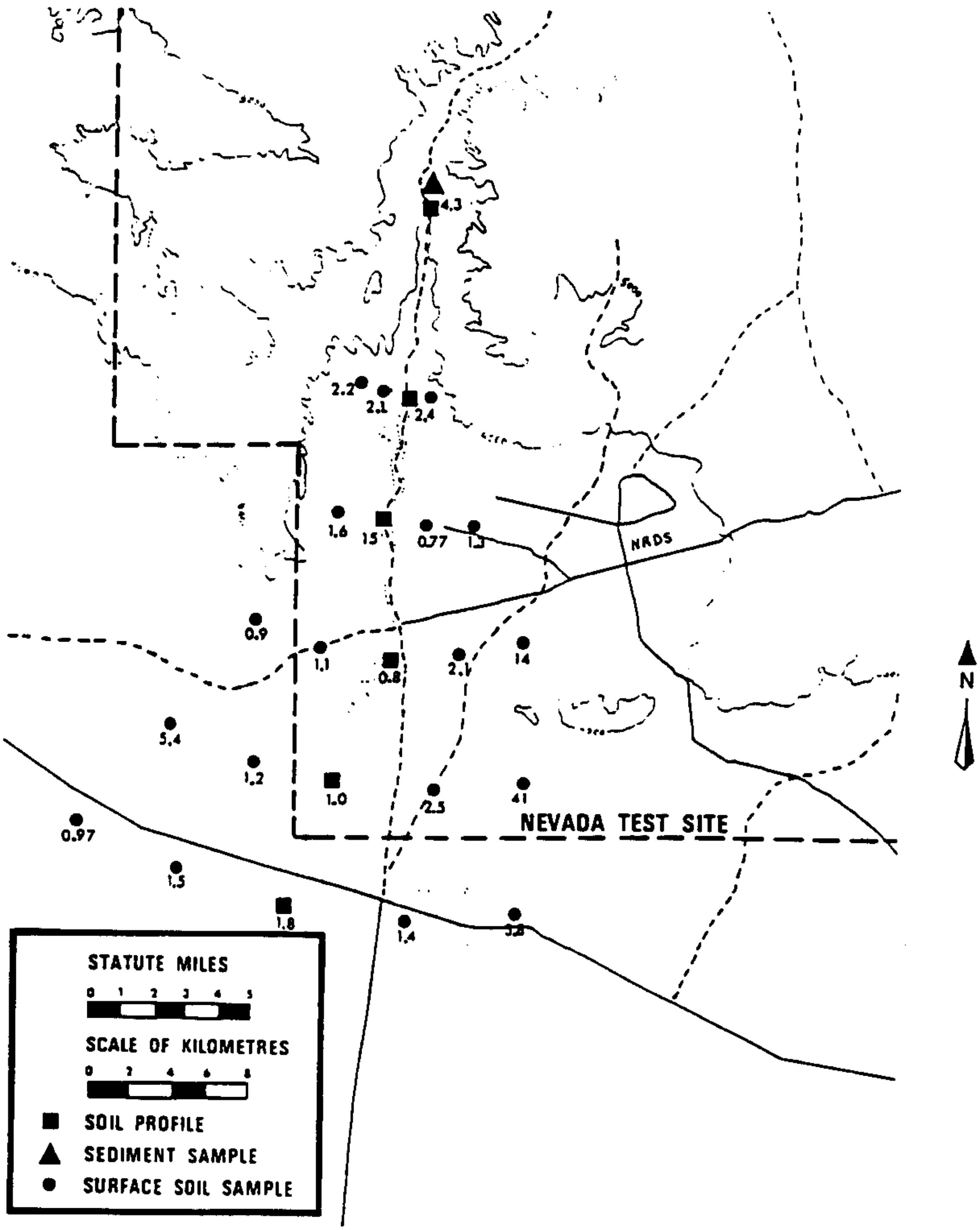


Figure 3. Plutonium - 239 in Soil Around the Nevada Test Site (nCi/m^2)
Fortymile Canyon

FIGURE II-4 FROM BLISS AND JAKUBOWSKI, NVO-159, 1976

In the third special study, a drainage basin located approximately 7 mi southeast of Frenchman Flat was sampled to define the movement of Pu with surface water drainage. The sample locations and results are shown in Fig. II–5. These results do not show movement or concentration of Pu within the basin (Bliss, NVO–159, p. 84).

In another basin study, soil samples were collected from Box Canyon, about 9 mi south of Currant, Nevada (about 85 mi north of the NTS). This canyon was selected as the best representation of geographical relief normal to air flow from the NTS where accumulations of wind-borne contaminants might occur as the result of impingement or turbulence and subsequent drainage. The results of these samples are mapped in Fig. II–6. One anomalously high value, 33 nCi/m^2, is shown, but its cause or significance remains unclear. Otherwise, the data indicate generally higher values above 5600 ft elevation (an arbitrary choice) and lower values below this elevation (Bliss, NVO–181, p. 202).

[Ed. Note: Budgetary considerations caused postponement then cancellation of work required to complete several studies being pursued by the EPA during the late 1970s and early 1980s. Final results are not available for the basin study, the Fortymile Canyon study, and the analysis of Pu in soils surrounding the NTS.]

The results of EPA's soil sampling and Pu analyses in the region surrounding the NTS during the mid-1970s can be compared with early proposed standards for Pu in soil. The highest measured Pu value from a surface (0 to 2.5 cm) soil sample collected outside the Test Range Complex was 132 nCi/m^2. The implied concentration is more than an order of magnitude below one proposed maximum for an occupied (inhabited) area [Ref. 7]. Additionally, the measured high sample was collected from unoccupied desert land.

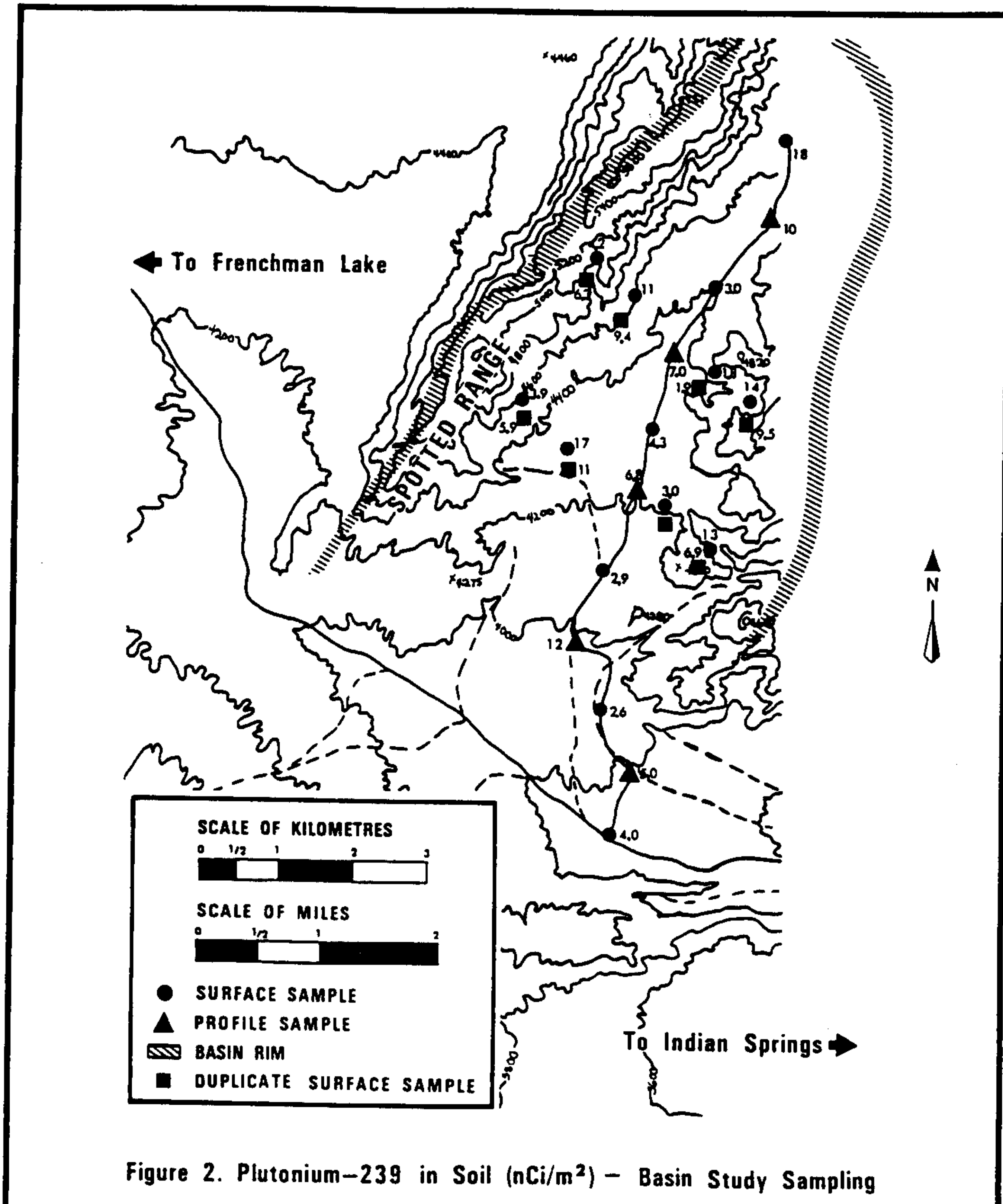


Figure 2. Plutonium–239 in Soil (nCi/m²) – Basin Study Sampling

FIGURE II-5 FROM BLISS AND JAKUBOWSKI, NVO-159, 1976

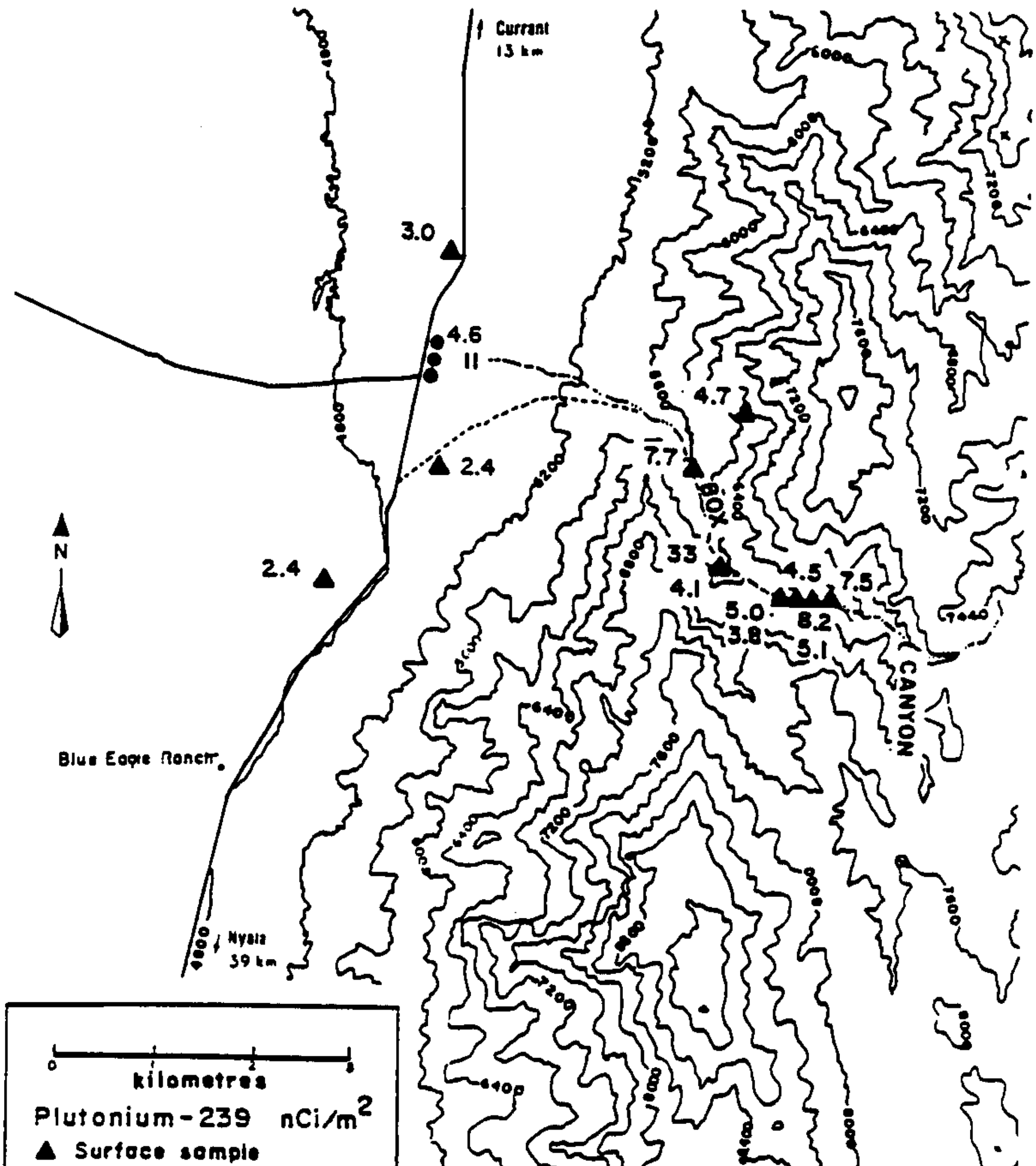


Figure 11. Plutonium-239 in Soil — Box Canyon

FIGURE II-6 FROM BLISS AND JAKUBOWSKI, NVO-181, 1977

CHAPTER III. PLUTONIUM INVENTORY AT STUDIED SITES ON THE TEST RANGE COMPLEX

A. INTRODUCTION

[Ed. Note: This chapter presents a descriptive background on studied sites as a prelude to presentation of analytical results and other considerations. Summarized specifics are presented here only for soil particle size and Pu activity distributions. Analytical results are discussed in Chapter IV.

Following a "worst first" plan, NAEG investigations progressed from safety-shot intensive-study sites to nuclear-shot intensive-study sites, then on to other areas where Pu was known to be in the environment. Five safety-shot sites were subjected to intensive study; these are discussed first. Attention is then directed to two nuclear-shot intensive-study sites followed by three other nuclear-shot sites which did not receive the same degree of study as the earlier sites of interest. The change in intensity of study will become apparent in this chapter by the lesser amount of information available to describe the sites last studied.

To the extent that information is available, the following items or topics will be presented for each area: location, elevation, topography, vegetation, animals, soil type, soil particle size, Pu in soil, the Pu to Am ratio, Pu inventory, and a figure illustrating the strata used for statistical analyses of Pu distribution. The location is mentioned with reference to *Fig. I–4*. Environmental factors such as elevation, topography, vegetation, vertebrates present, and selected soil characteristics are summarized in Table III–1 for the safety-shot intensive-study sites (and in Table III–9 for the other studied sites).

Considerations and conclusions which are not amenable to tabular presentation, and factors special to a site, are presented in the text. Tabulated items are, in general, not discussed here. Soil particle sizes, Pu activity in soil, the Pu to Am ratio, and Pu inventory are presented with some discussion in the remainder of this chapter.]

Extensive research has been directed toward gaining a better understanding of the deposition and effect of Pu on biota following aboveground nuclear explosions. Surveillance beginning in the 1950s has shown the persistence of Pu in soil, plants, and vertebrates in certain NTS areas. Pu contamination in these areas is an important environmental factor. The NAEG assigned a high priority to studies of soil-plant-animal relationships (Moor, NVO–142, CIC# 64851).

Mammals, reptiles, and birds were observed and tallied at most study sites (*Table III–1*). For census purposes, animals were livetrapped, tagged and released, and the frequency of repeat trappings of the same animals was used in the calculation of population density and inventory. Birds were tallied by species but not caught. Selected animals (reptiles and rodents) whose residence area had been defined during a six-month period were submitted to the laboratory for autopsy and radioanalysis of selected tissues (*Ibid.*). Similar procedures were used at all sites.

B. SAFETY-SHOT INTENSIVE-STUDY SITES

1. Area 11: PROJECT 56

Area 11 is on the eastern boundary of the NTS (*Figs. I–4 and I–5*); the Project site is near the south end of the area. Vegetation in the area is a heterogeneous mix which might be classed as transitional between Mohave and Great Basin Deserts.

Reptiles in the area include seven species of lizards and five species of snakes; all are common inhabitants at the lower elevations of the northern Mohave Desert. The snakes are known to be present but they were not studied (*Ibid.*).

TABLE III-1. SUMMARY OF ENVIRONMENTAL FACTORS AT SAFETY-SHOT INTENSIVE-STUDY SITES

	AREA 11 PROJECT 56 SITES A, B, C, D	NAFR (AREA 13) PROJECT 57	AREA 5 GMX	TTR CLEAN SLATE I, II, & III	NAFR (TTR) DOUBLE TRACKS
PHYSICAL:					
Elevation (ft)	3,400	4,500	3,160	5,400	5,000
Slope (%)	2 to 30	0 to 2	0 to 2	0 to 2	0 to 4
VEGETATION:					
Desert Class	Transitional	Great Basin	Mohave	Great Basin	Mohave
No. common species	6	7	4	10	9
Dominant species	Wolfberry	Saltbush	White bursage	Galleta grass	Spiny hopsage
	Joshua tree	Spiny hop-sage	Creosote bush	Rabbitbrush	Rabbit-thorn
	Creosote bush	Horsebrush	Saltbush	Saltbush	Saltbush
	Spiny hop-sage	Winterfat	Ind. ricegrass	Sagebrush	Sagebrush
Cover (%)	16.1 to 16.5	17.3 to 20.1	(sparse)	0.3 to 14.7	ave. 14.9
VERTEBRATES:					
No. mammal species	13	11	6	9	N.A.
Dominant mammals	Ant. squirrel	Ant. squirrel	Ant. squirrel	Ant. squirrel	Ant. squirrel
	GB kang. rat	GB kang. rat	GB kang. rat	GB kang. rat	GB kang. rat
	pocket mouse	pocket mouse	pocket mouse	pocket mouse	pocket mouse
	So. Grshpr mouse	M kangaroo rat	M kangaroo rat		
Density (#/ha)	3 to 27	2 to 30	1 to 5	N.A.	N.A.
No. reptile species	7	4	5	4	N.A.
Abundant lizards	desert whiptail	desert whiptail	desert whiptail	side-blotched	N.A.
	side-blotched	side-blotched	zebra-tailed	desert horned	
No. bird species	18	24	28	25	N.A.
SOILS:					
Surface type	Gravelly loam	G S loam	G S loam	G S loam	G S loam
Range in pH	8.0 to 8.8	7.8 to 8.4	8.0 to 8.8	7.0 to 8.8	8.2 to 9.0
Water permeability (inch/h)	0.80 to 2.50	0.80 to 2.5	2.5 to 10.00	0.80 to 2.5	5.0 to 10.0

N.A. = Not available; in soil type, G S = gravelly sandy. GB kang. rat = Great Basin kangaroo rat.

Birds may represent a temporarily important and dominant vertebrate group at the NTS during spring and fall migrations. Ten species of birds observed at the study site were considered permanent residents and the other eight were classified as being migrant or residents during the winter only or summer only. One species, the horned lark (*Eremophila alpestris*), was considered a common-to-abundant resident (*Ibid.*).

Four species of rodents were considered dominant (in terms of numbers observed), and nine other species were also present. The number of observable animals varied from year-to-year and within year; pocket mouse (*Perognathus*) numbers ranged from none to 67 observed during a one-year period (*Ibid.*).

Soil samples were collected for particle size analysis at two sites in Area 11 at distances of 31 ft (9.4 m) and 102 ft (31.2 m) from the GZ. Separate samples were taken from desert pavement and from a nearby mound at each site. Samples represented four depth increments of 2.5 cm each. (The following discussion refers to the samples 31 ft from the GZ.) In the desert pavement soil, 95 percent of the Pu activity was found to be in the surface increment, while in the mound, 60 percent of the activity was in the surface increment, 30 percent in the second increment, and 7 percent in the third increment. The mound soil contained about 2.9 times as much Pu activity as did the pavement soil (Tamura, NVO–171, CIC# 64887). (Pu analyses were performed in the laboratory in accordance with procedures specified in NVO–166.)

The coarse veneer of the desert pavement is reflected in the percentage of particles found in the fraction greater than 2 mm as shown in Table III–2. It may be inferred from the data that particles larger than 2 mm are not readily transported by wind from desert pavements to mounds. The data also show that desert vegetation is not effective in trapping small particles ($<20\ \mu m$) which are relatively depleted from the surface increment of desert pavement and from the top three increments in the mound. These fine particles are most readily carried away by wind and water. Similarities in particle size distribution in the bottom increment suggest that this increment in the mound actually included material from the surface of the native soil.

Pu activity in different particle sizes is shown in Table III–3. The activity appears to be more evenly distributed between size classes in the surface increment of both soils than in the next two lower increments. Below 5 cm, the Pu activity is predominantly associated with the smaller size classes. Data pertaining to the gravel-size fraction (>2 mm) were deleted prior to these calculations (a negligible effect) and the percentages have been recalculated to reflect this deletion.

The data show that small amounts of Pu have moved into deeper horizons in the desert pavement soils. The association of Pu with the finer particle sizes in the deeper horizons supports this hypothesis of downward movement. However, the mechanisms of movement have not been established (Tamura, NVO–171).

Selected size fractions of pavement and mound samples were subjected to density gradient segregation. The technique separates minerals with different densities by allowing them to accumulate at their respective mineral density positions in a linear density gradient solution. The activity measurements, obtained with a portable alpha survey meter, should be considered as approximate indications rather than definitive values.

Results show (Table III–4) that smaller particles are associated with lower density, and the Pu activity is associated with the lower density particles in the small (2-5 μm) size class. In the larger size classes (5-20 and 20-53 μm), activity is associated with particles of higher density; up to 90 percent of the activity is contained in about 18 percent of the weight in the fraction with density greater than 2.9 g/cm^3.

The four safety tests in Area 11 were conducted at locations close together (Fig. III–1). Results of radiological surveys were used to define strata in the four areas (Gilbert, NVO–153, pp. 355–358, CIC# 64880). Soil samples were collected from 456 random locations throughout the strata; 23 of these were profile locations where 10 increments of 2.5 cm each were collected.

TABLE III-2 PARTICLE SIZE DISTRIBUTION IN PAVEMENT AND MOUND SOILS FROM NTS, AREA 11 (results in % by weight).

Soil Depth (cm)	Sampling site	Size Range (um)			
		<2-20	20-250	250-2000	>2000
0 - 2.5	Pavement	3.6	45.2	33.3	17.9
	Mound	1.7	62.5	34.9	0.8
2.5 - 5.0	Pavement	20.1	45.4	32.2	2.3
	Mound	3.7	66.3	28.7	1.2
5.0 - 7.5	Pavement	23.2	42.3	31.4	3.1
	Mound	7.1	65.	26.3	1.6
7.5 - 10	Pavement	18.8	46.1	29.6	5.5
	Mound	14.4	53.4	29.5	3.7

(after Tamura, NVO-171, p. 7, CIC# 64887)

TABLE III-3. Pu INVENTORY DISTRIBUTION IN PAVEMENT AND MOUND SOIL PARTICLE SIZE CLASSES <2000 μm, NTS AREA 11

Soil Depth (cm)	Sampling Site	Size Range (um)			Total for Increment	
		<2-20 (%)	20-250 (%)	250-2000 (%)	Inventory (%)	Activity (dpm/g)
0-2.5	Pavement	17.4	68.6	10.4	96.4	10,824
	Mound	11.6	30.3	7.4	49.3	9,951
2.5-5.0	Pavement	0.5	1.	0.06	1.56	185
	Mound	7.8	29.4	2.7	39.9	8,045
5.0-7.5	Pavement	0.2	0.1	0.01	0.31	38
	Mound	3.3	5.9	0.7	9.9	2,001
7.5-10	Pavement	1.	0.4	0.05	1.45	168
	Mound	0.5	0.3	0.03	0.83	175

(After Tamura, NVO-171, pp. 8-9.)

TABLE III-4. DENSITY GRADIENT SEGREGATION OF SURFACE INCREMENT SILT FRACTIONS OF TWO SOILS FROM NTS AREA 11.

		Desert Pavement		Desert Mound	
Size Class (μm)	Density Range (g/cm³)	Weight Fraction (%)	Pu Activity (%)	Weight Fraction (%)	Pu Activity (%)
2 - 5	<2.5*	60	48	95	74
	2.5 - 2.9	33	17	--	--
	>2.9	2	36	1	26
5 - 20	<2.5	48	11	87	43
	2.5 - 2.9	41	9	--	--
	>2.9	4	78	3	57
20 - 53	<2.5	28	7	30	15
	2.5 - 2.9	43	2	45	6
	>2.9	18	90	19	80

(After Tamura, NVO-171, p. 11.)
* (There was not a clean cutoff at 2.5 g/cm3; reported values ranged from 2.48 to 2.56.)

Results of sample analyses were used to calculate the Pu to Am ratio for sites B, C, and D. Ratios ranged from 5.3 ± 0.98 (± one standard error) to 7.8 + 0.11. Site A was used for testing a U device so the Pu to Am ratio is not relevant there. (Site A data plots are shown in Gilbert, NVO-159, p. 132, CIC# 64959.)

2. **NAFR (Area 13): PROJECT 57**

Area 13 is a few miles north of the northeastern corner of the NTS proper (see *Fig. I-5*). The site of PROJECT 57 is in the bottom of a relatively wide alluvial valley bound on the east by the Groom Range and on the west by the Belted Range (Rhoads, NVO-142). The area is classed as potential agricultural cropland.

The vegetation is typical of Great Basin Desert with relatively few species of perennial shrubs. Most of the Pu-contaminated area is enclosed by a fence. A significant grass, indian ricegrass (*Oryzopsis hymenoides*), occurs with significant frequency only in the north end of the fenced area in a locale with a sandy soil quite unlike the alkaline clay soils of most of the fenced area (*Ibid.*).

Two insectivorous species of lizards (*Table III-1*) were most abundant among the four species noted at the times of observation (Moor, NVO-142). The patterns of bird species and species abundance paralleled observations at the Area 11 site. The common raven (*Corvus corax*) was an additional species frequently observed at the Area 13 site. Six species considered uncommon migrants were observed at Area 13 but not at Area 11 (Moor, NVO-142).

Dominant mammal species were similar to those observed at the PROJECT 56 site. Seven other species were also present in lesser abundance. Only one southern grasshopper mouse (*Onychomys torridus*) was observed at the Area 13 site. The estimated number of animals in the sampling area ranged from a high in May 1972 to a low in January 1973 (when there was two inches of snow on the ground). The Great Basin kangaroo rat (*Dipodomys microps*) was the most abundant and the number observed showed the least variation among species (*Ibid.*).

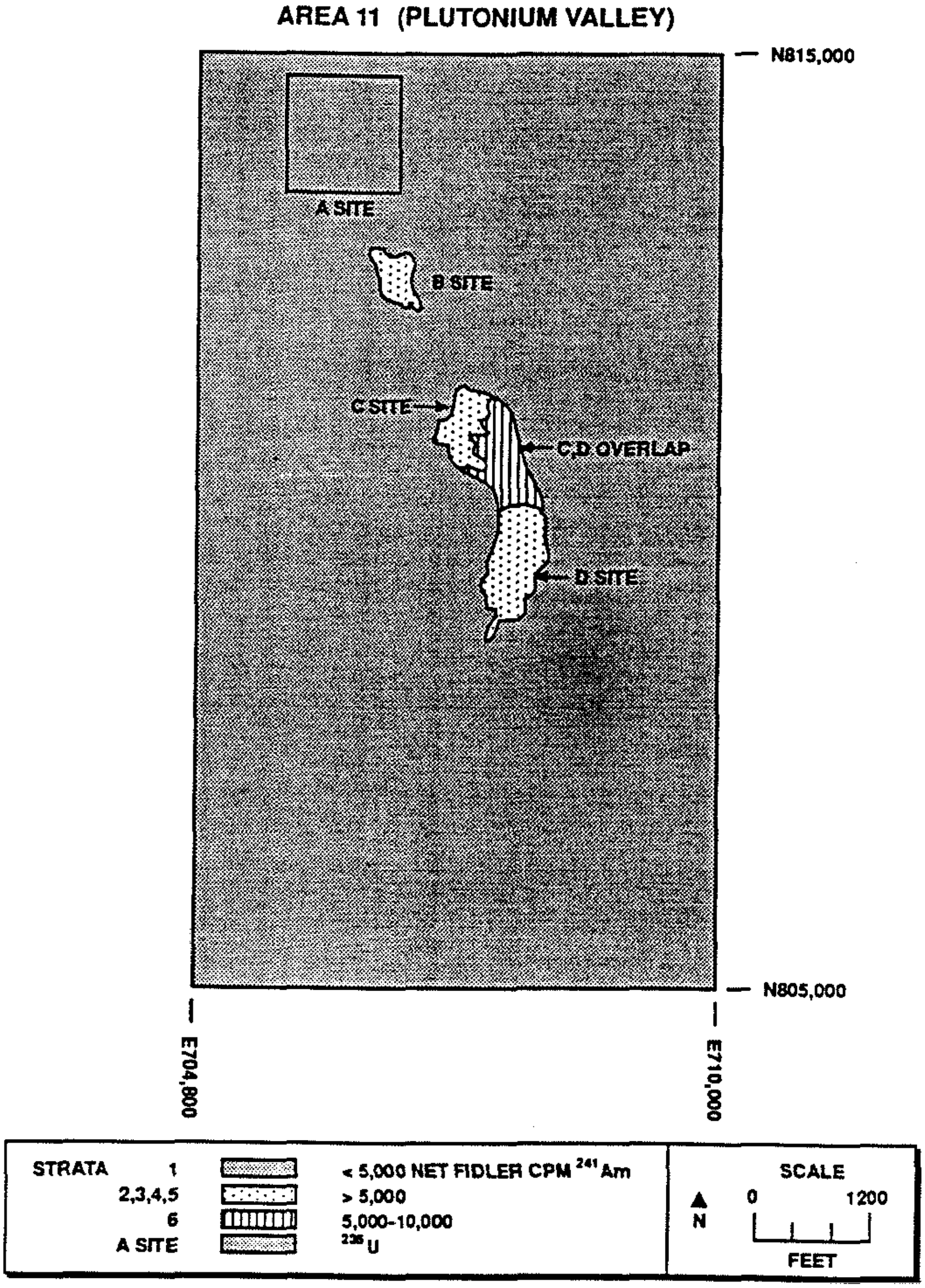


FIGURE 10

FIGURE III-1 MODIFIED FROM GILBERT et al., NVO-153, 1975

Particle size analysis was performed on one soil sample collected from an enclosed, covered plot in Area 13 where vegetation studies were in progress. The highest concentration of Pu activity was in the coarse silt fraction (20 to 53 μm) (Table III-5), followed by the medium silt fraction (5 to 20 μm). Although the combined amount of these size fractions is about 11 percent, they contribute 72 percent of the total activity (Tamura, NVO-142).

Density gradient separation of silts and clay revealed that Pu in the silts (2-53 μm) was associated with particles >2.8 g/cm^3 (heaviest fraction), whereas in the clay (<2 μm) Pu was in the 2.1 to 2.2 g/cm^3 fraction (Table III-6). This distribution suggests that Pu in the silts is probably present as an oxide, whereas in the clay it may be a polymeric form adsorbed on lighter clay minerals (Tamura, NVO-142.)

In a follow-up study, 12 soil samples were collected on a transect beginning near the PROJECT 57 GZ and extending out to about 6700 ft (about 2040 m). Pu activity in these samples decreased from a high of about 7000 dpm/g in the GZ sample to a low of about 18 dpm/g in the most distant sample. Particle size analysis showed that the soils are high in sands (53-2000 μm) and low in clays (<2 μm). The highest level of Pu occurred in the medium silt fraction (5-20 μm), but the highest contributor to total Pu was the coarse silt fraction (20-53 μm). These measurements differ because there was usually twice as much coarse silt as there was medium silt in the collected soil (Tamura, NVO-153, CIC# 64866).

In another follow-up study, a soil sample was collected from a mound located very near one of the earlier transect sites so that comparisons could be made of soil from vegetated and nonvegetated sites. One characteristic of desert mounds is that the portable field survey instrument records a higher activity level over a mound than over the surrounding bare soil. At the site selected for this study, the reading over the mound was 35,000 cpm, and over bare soil the it was 25,000 cpm. Collected soil samples represented the 0 to 5 cm depth. A noticeable feature was the uniform texture of the sandy mound in contrast to the more gravelly nature of the nonvegetated bare soil. Analysis showed the gravel content to be 19.5 percent by weight of total sample from the bare soil, and 2.7 percent by weight of total sample from the mound. After removing the gravel and making other measurements and adjustments, the Pu content was determined to be 66 percent in medium and coarse silt sizes in the bare soil sample, and 81 percent in these sizes in the mound sample. The analytic results corroborated the survey meter readings (Tamura, NVO-159, CIC# 64947).

Particle size segregation in the above analyses was performed without use of a dispersive treatment. To evaluate possible differences in particle size and Pu distributions, the samples from the mound and the bare soil were given 5 minutes of ultrasonic treatment. Results indicated a notable reduction in the sand fractions and a corresponding increase in the silt and clay fractions. The ultrasonic treatment also displaced the Pu from the sand fraction to the silt and clay fractions. The largest change involved the medium silt fraction wherein the Pu activity contribution increased from 22 up to 33 percent in the bare soil sample, and from 6 up to 15 percent in soil from the mound. (Tamura, NVO-159.)

The Area 13 ecological study area has an outer fence enclosing an area of approximately 1000 acres (405 hectares, ha) and an inner fence enclosing an area of about 250 acres (101 ha) of the more highly contaminated surface (Tamura, NVO-153). The configuration of the site and the strata used in sampling for Pu inventory are shown in Fig. III-2. Based on the 1972-73 analytical results of 154 surface (0-5 cm) soil samples, the Pu to Am ratio was found to be 9.4 + 0.14 (Gilbert, NVO-153).

[Ed. Note: The fences were erected years before these arbitrary strata were assigned, so there should be no expectation that the outer fence would encompass a given stratum.]

TABLE III-5. PARTICLE SIZE AND Pu ACTIVITY DISTRIBUTIONS IN THE TOP 3 cm OF SOIL, NAFR (AREA 13). (Particle size in % by weight, activity in % contribution.)

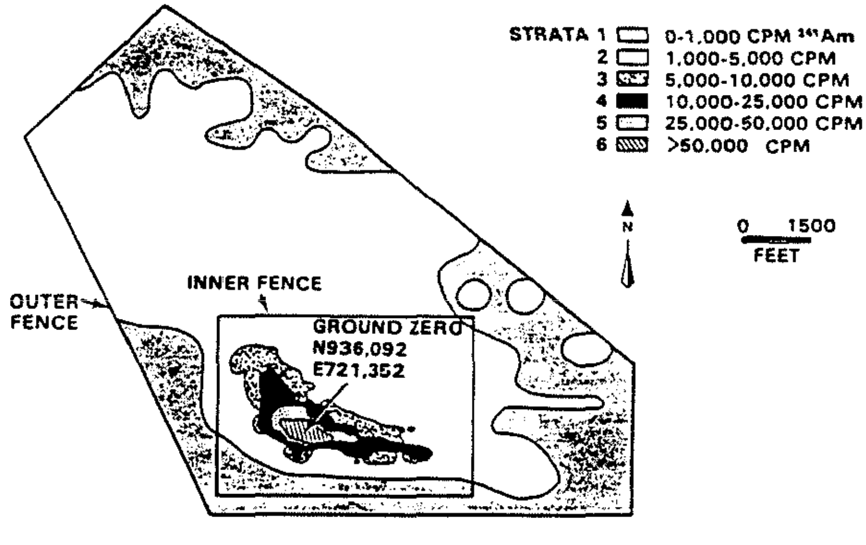
Distribution	Size Range (um)					
	<2-5	5-20	20-53	53-250	250-2000	>2000
Size	3.0	4.5	6.6	45.3	34.7	5.0
Activity	3.3	25.3	47.0	23.8	0.6	--

(Total soil activity = 2,629 dpm/g)
(After Tamura, NVO-142, p. 35, CIC# 64841.)

TABLE III-6. DENSITY SEPARATION AND Pu DISTRIBUTION IN SMALL-SIZE FRACTIONS OF SOIL FROM NAFR (AREA 13).

Size Class (μm)	Density Range (g/cm^3)	Weight Fraction (%)	Pu Activity (%)
<2	<1.8	1.0	0.4
	2.1-2.2	97.4	98.6
	2.2-2.7	1.3	0.8
	>2.8	0.3	0.2
5-20	<1.8	2.4	0.2
	2.3-2.5	32.2	5.3
	2.5-2.8	59.6	9.3
	>2.8	5.8	85.2

(After Tamura, NVO-142, p. 39.)



AREA 13 — SHOWING STRATA
USED IN SAMPLING FOR INVENTORY

FIGURE III-2 FROM DELFINER, NVO-192, 1978

3. Area 5: GMX

The Area 5 GMX site in Frenchman Flat (*Figs. I-4 and I-5*) encompasses an area of about 265 acres (107 ha) of which about 31 acres are considered in calculating Pu inventory estimates (Gilbert, NVO-181, CIC# 83142). The site was used for 24 safety experiments involving Pu and high explosives. These experiments did not involve nuclear detonations. The experiments started in late 1954 and ended in early 1956. Following the tests in 1956, the contaminated area was enclosed with a barbed-wire fence and has remained essentially undisturbed (Phelps, NVO-142, CIC# 64874).

The flora and fauna are characteristic of the lower Mohave Desert of southern Nevada. There is little biotic or topographic diversity. Five species of lizards and 28 species of birds were tallied; 17 bird species were considered permanent residents although sightings of some were uncommon. The horned lark was the only species considered a common-to-abundant resident. Fewer migrants were observed at this site than at other safety-shot sites. Several species were sighted at a well in the area. Six species of mammals were present; animal density was low compared to other studied sites. (Moor, NVO-142.)

The deep and coarse-textured soils in the GMX area are derived from recent alluvium washed down from the mountains to the north. These soils are well to excessively drained with slow runoff, and have a high to very high permeability. Moderate wind and water erosion are evident (Leavitt, NVO-192 (CIC# 14360, 14361), CIC# 83058).

Two samples of soil were collected from the GMX site for the purpose of characterizing the soil and the particles of Pu contained therein. One sample was taken from a bare area of weak desert pavement, the other from under a creosote bush about 10 ft from the first sample location. The mound of soil under the bush was strikingly different from the desert pavement by the absence of gravel particles (Tamura, NVO-142).

In both the desert pavement and mound soils, the highest Pu concentrations were in the very fine sand fractions (53-125 μm) shown in Table III-7. The silt and clay size fractions contained 36 percent of the total Pu in the pavement sample and 16 percent of the total Pu in the mound sample. The most significant difference between samples was the large fraction of gravel in the pavement soil and the relative absence of gravel in the mound soil; there was no Pu activity associated with the gravels (Tamura, NVO-142).

TABLE III-7. PARTICLE SIZE AND Pu ACTIVITY DISTRIBUTIONS IN TOP 3 cm OF PAVEMENT AND MOUND SOILS, NTS AREA 5. (Particle size in % by weight, activity in % contribution.)

Distri-bution	Sampling Site	Size Range (μm)					
		<2-20	20-53	53-125	125-250	250-2000	>2000
Size	Pavement	4.1	6.6	19.8	17.1	21.8	30.7
	Mound	2.1	6.3	25.2	35.2	29.9	1.3
Activity	Pavement	5.3	30.2	46.6	17.5	0.4	--
	Mound	4.4	11.5	38.7	36.2	9.3	--

(Total Pu activity, dpm/g: 2,571 in Pavement; 3,108 in Mound.)
(After Tamura, NVO-142, pp. 33-34, CIC# 64841.)

The configuration of the GMX site is portrayed in Fig. III-3 along with the strata used in sampling for inventory. Based on the 1972-73 analytical results from 89 soil samples, the Pu to Am ratio was estimated to be 10.3 ± 0.25. Stratum 1, the subregion of lowest counts, showed the widest variability in the calculated Pu to Am ratio (Gilbert, NVO-142, pp. 77-79, CIC# 64843).

4. Tonopah Test Range: CLEAN SLATES and DOUBLE TRACKS

The TTR is located near the northwest corner of the Nellis Air Force Range and is bordered by the latter on the west, south, and east (*Figs. I-1 and I-5*). Four safety experiments were conducted in this area during May and June 1963. These experiments were "Pu dispersal" and "storage/transportation" tests.

The region is typical Basin-and-Range Province with block fault mountain ranges paralleling the north-south trending closed valleys. Extending from the lower slopes of the mountains are numerous alluvial fans which converge to form a relatively flat valley floor with the usual playa in the lowest area (Rhoads, NVO-142).

The CLEAN SLATE tests were conducted in desert grassland communities at Cactus Flat. Dunes and a playa share the central part of the valley; the dunes appear to be fairly stable on the northeast (downwind) side of the playa. Dune area vegetation differs from vegetation in the rest of the valley. The vicinity of CLEAN SLATE I contains large numbers of blown-out areas

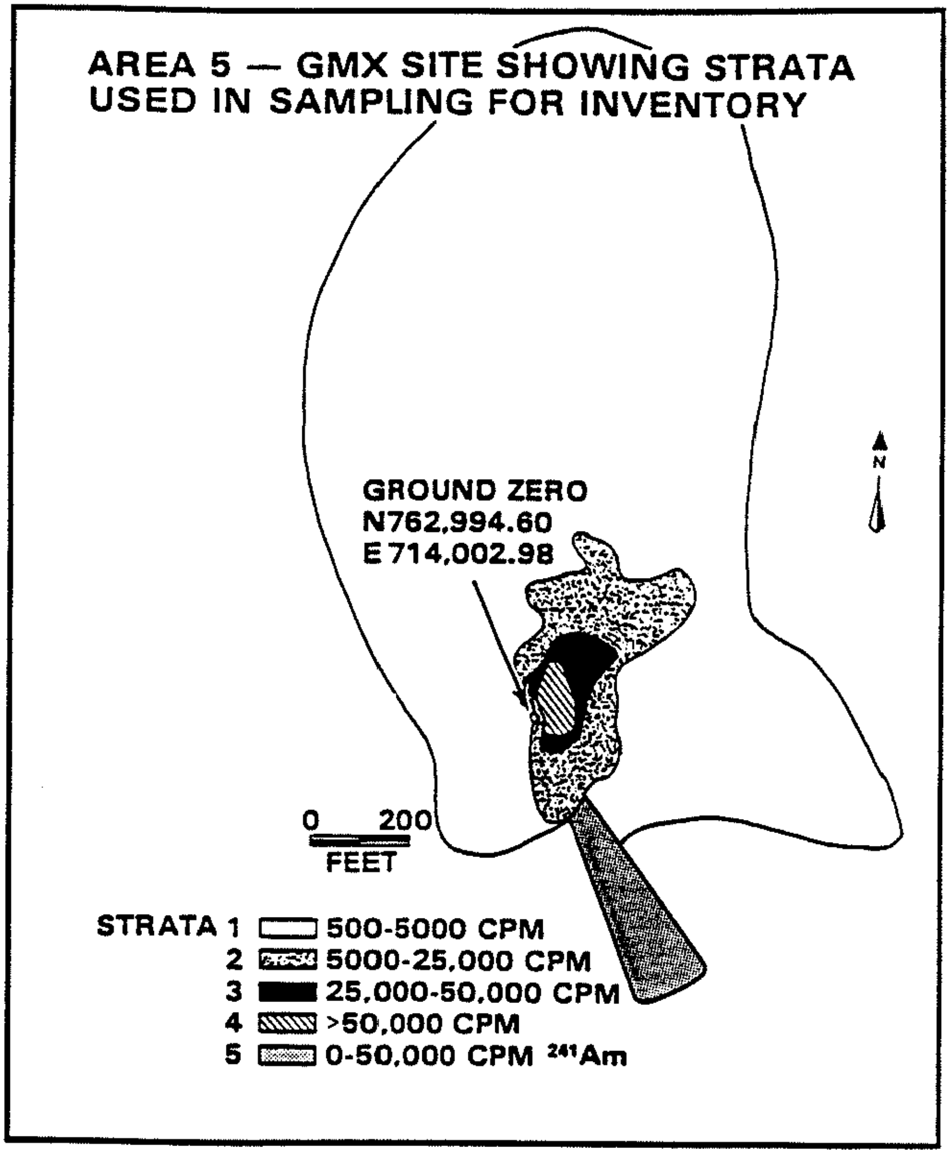


FIGURE III-3 FROM GILBERT et al., NVO-153, 1975

up to hundreds of square meters in extent. These are generally characterized by low ridges of relatively large shrubs in rows transverse to the usual wind direction. A large playa lies on the southwest boundary of the CLEAN SLATE I location. The CLEAN SLATE III site is also bordered on the west by a playa (*Ibid.*).

Vegetation at the CLEAN SLATE sites is dominated by galleta grass (*Hilaria jamesii*), an important forage grass. At each site, multiple plots of 100 m^2 were measured and the vegetation counted (*Ibid.*). Vegetation percent cover in the test plots varied from a low of 0.3 at CLEAN SLATE II to a high of 14.7 at CLEAN SLATE I. Vegetation is abundant inside the fenced enclosure but is extremely sparse outside because cattle graze in the valley surrounding the site (Bradley, NVO–153, CIC# 64872).

Four species of lizards and 25 species of birds were tallied at the TTR sites; the observer noted that the area appeared to be rich in raptors (birds of prey) (*Ibid.*). The estimates of mammal population were significantly lower than at other NAEG study sites (Moor, NVO–142).

Most of the soils surveyed in Cactus Flat would be considered of cropland quality if a suitable supply of water were available (Leavitt, NVO-192). However, at the DOUBLE TRACKS site the soils are coarse and unproductive.

The DOUBLE TRACKS test was in a typical Mohave Desert shrub community outside the TTR (*Fig. I-5*) in Stonewall Flat, the next valley west of Cactus Flat. Although outside the TTR, the site is within the NAFR and therefore within the TRC. Nine plots of 100 m^2 each were evaluated to derive an average 14.9 percent vegetation cover at the site of the DOUBLE TRACKS test (Rhoads, NVO-142).

The configurations of the four TTR sites are portrayed in Fig. III-4 (A-D), along with the strata used in sampling for inventory. A total of 570 soil samples was collected at these sites. Based on analytical results of 49 samples, the Pu to Am ratios were estimated to range from 28.7 at the DOUBLE TRACKS site to 37.0 at the site of CLEAN SLATE II. Good correlations between Pu and Am concentrations in the same sample were obtained from the data from DOUBLE TRACKS and CLEAN SLATE III, but the other two sites demonstrated higher variability. Data from the CLEAN SLATE sites contained one or two values which appear to be anomalous (Gilbert, NVO-142, pp. 72-3).

5. Summary of Pu Depth Distribution

Estimates were calculated of the Pu inventory in the top 5 cm of soil at each of the intensive-study sites. Profile samples taken in desert pavement soils were collected at each of the sites to determine the proportion of Pu activity in the top 5 cm because this increment contains most of the contaminant. Statistical parameters obtained are summarized in Table III-8. In all seven safety-shot areas, the results from at least one soil sample indicated that 90 percent or more (up to 99 percent) of the measured Pu was contained in the top 5 cm of soil. However, results were quite variable with samples from four locations indicating less than 50 percent of the Pu was contained in the top 5 cm of soil. One of five samples collected at the CLEAN SLATE II area contained as little as 13 percent of the Pu in the top 5 cm of soil; however, the mean of the five samples was 68 percent. This relationship suggests that some vertical mixing has occurred since the CLEAN SLATE II test and more soil sampling would be required to define the area of such possible disturbance.

TABLE III-8. STATISTICAL PARAMETERS REGARDING THE PERCENTAGE OF Pu ACTIVITY IN THE TOP 5 CM OF DESERT PAVEMENT SOILS AT SAFETY-SHOT INTENSIVE-STUDY SITES

Site	Number Samples	Pu activity in top 5 cm			Standard Error
		Minimum (%)	Maximum (%)	Mean (%)	
PROJECT 56 (Area 11)	8	65	99	84	0.045
PROJECT 57 NAFR (Area 13)	11	38	99	93	0.055
GMX (Area 5)	13	78	98	95	0.015
CLEAN SLATE I (TTR)	4	30	98	75	0.16
CLEAN SLATE II (TTR)	5	13	91	68	0.14
CLEAN SLATE III (TTR)	4	94	99	97	0.012
DOUBLE TRACKS (NAFR)	5	48	99	69	0.094

(after Gilbert, NVO-153, p. 387)

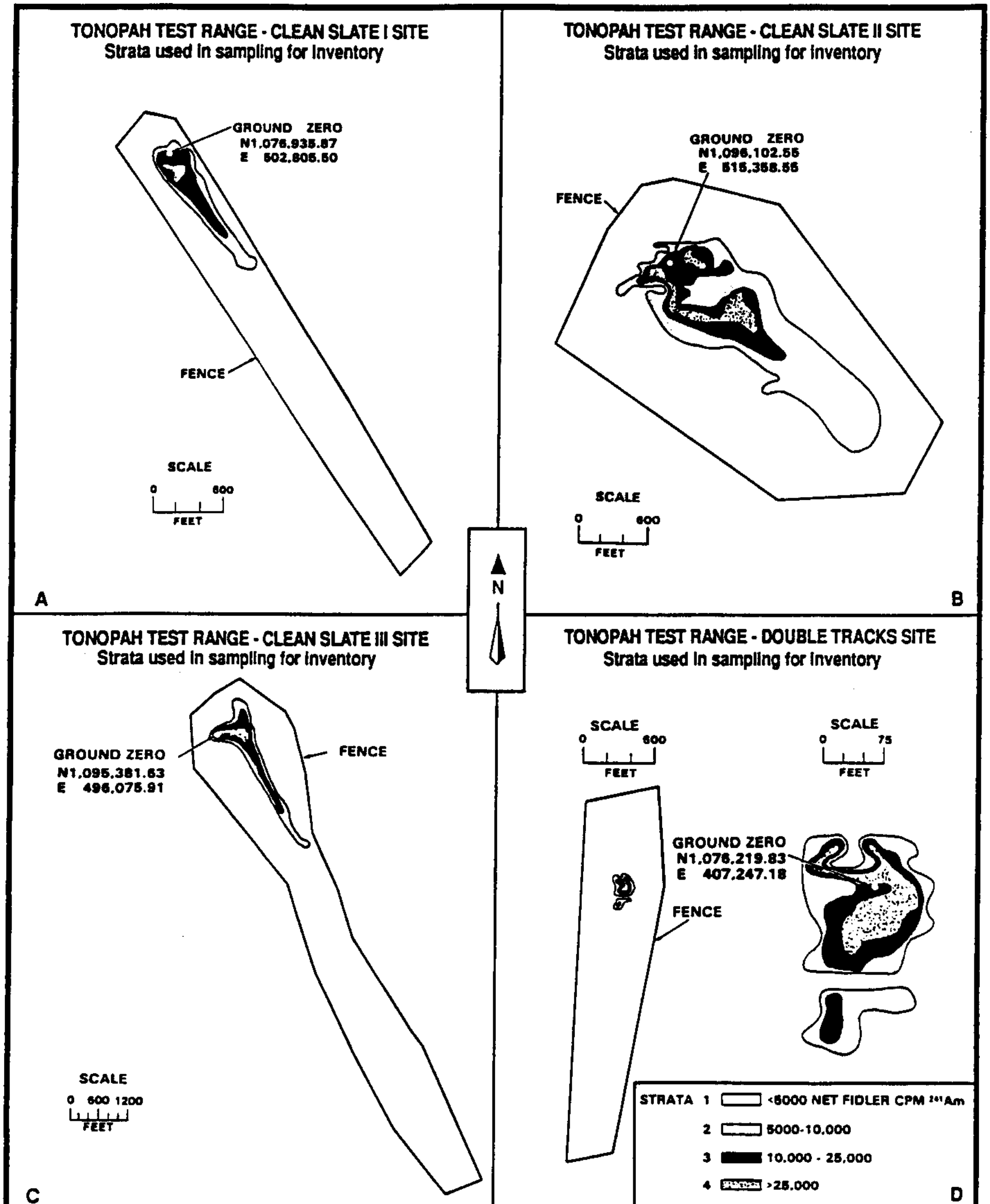


FIGURE III-4 MODIFIED FROM GILBERT et al., NVO-153, 1975 (INDICATED STRATA APPLY TO ALL FOUR SITES)

C. NUCLEAR-SHOT INTENSIVE-STUDY SITES

Environmental factors such as elevation, topography, vegetation, vertebrates, and selected soil characteristics are summarized in Table III-9 for the nuclear-shot intensive-study sites and for the other studied sites.

1. Area 18: LITTLE FELLER II (NS201)

Area 18 is in the northwestern part of the Nevada Test Site (*Fig. I-4*). The region of interest, called Buckboard Mesa, encompasses about 28,000 acres. Much of the surface area to the north consists of alluvial fans originating from the Pahute Mesa front. The soils in the washes are generally deep and coarse-textured, and those on the ridges and high alluvial fans are shallow and medium- to fine-textured (Leavitt, NVO-192).

The nature of the contamination at sites where nuclear explosions were achieved differs from safety-shot sites with no nuclear explosion; the former involved fission and high temperatures, thus, the soils in these areas are contaminated by radioactive fission products, Pu, and other actinides. In addition, surface soil particles have been modified by the high temperatures and neutron activation near the test site (Lee, NVO-224 (CIC# 41496), CIC# 64827).

The relative locations of tests LITTLE FELLER I (NS200), LITTLE FELLER II (NS201), and JOHNNIE BOY (NS202) are shown in Fig. III-5. (Note the airstrip in *Figs. I-4* and III-5 as a common point of reference.)

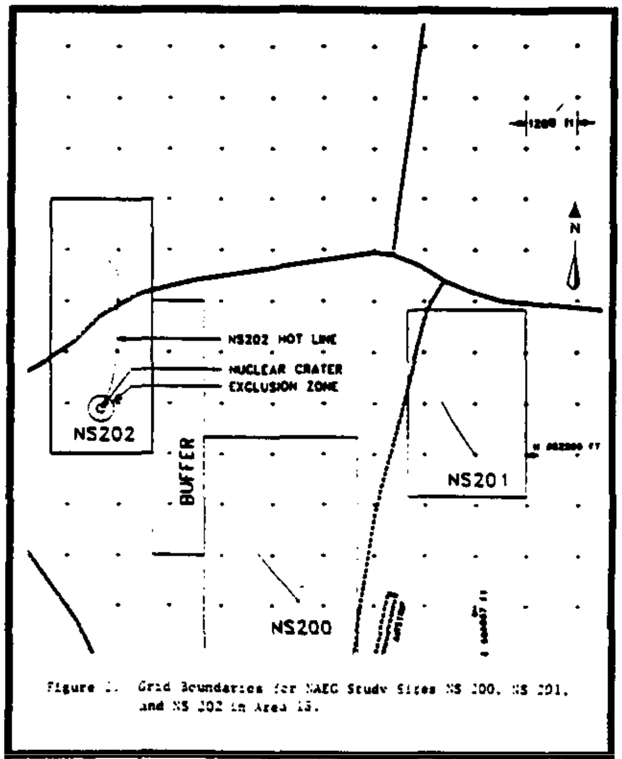


FIGURE III-5 FROM ESSINGTON, NVO-192, 1988

LITTLE FELLER II was a low-yield nuclear explosion conducted July 7, 1962, at ground surface in Area 18. Most of the flora and fauna at the site are typical for the southern Great Basin Desert. In addition to the typical vegetation, tumbleweed (*Salsola*; some people call this plant russian thistle[7]) was an abundant weed in areas that had been physically disturbed. A desert wash transects the study area.

Eight species of reptiles were observed in the study area during the periods of observation (Bradley, NVO-192).

Dominant mammals (based on numbers observed) were rodents; specimens of nine species were collected for autopsy and radioanalyses. Rodents were found to be more abundant in Area 18 than at sites studied earlier in the project. During the period June through August 1977, investigators observed rodents at an average of 78/ha in the Area 18 study site compared to the next highest 5/ha at the Area 11 site.

The soil sampling plan for particle studies called for profile collection at five locations in predetermined increments to a maximum depth of 50 cm. At several locations rock was encountered before the maximum depth was achieved. The rock zone contained no detectable Am. Other profiles were halted when three or four successive increments contained no detectable Am. Only one profile trench was dug to maximum depth and rock was encountered in the

[7] The plant is neither Russian nor thistle, but an Asian member of the pigweed family.

TABLE III-9. SUMMARY OF ENVIRONMENTAL FACTORS AT NUCLEAR-SHOT STUDY SITES

	AREA 18 LITTLE FELLER II	AREA 20 PALANQUIN	AREA 10 SEDAN	AREA 2 T2 Series
PHYSICAL:				
Elevation (ft)	4,800 to 6,200	ave. 6,500	ave. 4,300	ave. 4,440
Slope (%)	0 to 45	N.A.	N.A.	N.A.
VEGETATION:				
Desert Class	Great Basin	Great Basin	Transition	Mohave
No. common species	4	N.A.	N.A.	N.A.
Dominant species	Sagebrush Nev. joint-fir Saltbush	Sagebrush Nev. joint-fir Spiny hop-sage	Close-in buried by ejecta. Near normal at about 5,000 ft from crater.	Needlegrass Foxtail Galleta grass
Cover (%)	N.A.	N.A.	Sparse to normal	N.A.
VERTEBRATES:				
No. mammal species	9	13	12	N.A.
Dominant mammals	M kangaroo rat O kangaroo rat GB kangaroo rat pocket mouse	deer mouse GB pocket mouse	M kangaroo rat pocket mouse deer mouse	N.A.
Density (#/ha)	21 to 147	N.A.	N.A.	N.A.
No. reptile species	8	N.A.	N.A.	N.A.
Abundant lizards	side-blotched desert horned	N.A.	N.A.	N.A.
No. bird species	N.A.	N.A.	N.A.	N.A.
SOILS:				
Surface type	G S loam	N.A.	N.A.	N.A.
Range in pH	7.8 to 8.6	N.A.	N.A.	N.A.
Water permeability (inch/h)	0.80 to 5.0	N.A.	N.A.	N.A.

N.A. = Not available; in soil type, G S = gravelly sandy. GB kang. rat = Great Basin kangaroo rat.

bottom increment (30 to 50 cm). Data on particle size and Pu activity distributions are presented in Tables III-10 and III-11 for the top two increments. (Comparable data could not be obtained for other increments because rock was encountered or because Pu activity was below detection limits.) The study noted that Site 8 soil contained more silt-sized particles than did the other sample locations and this site contained the greatest level of Pu activity. The data show that the second increment of soil at Site 5 (very close to the GZ) contained a greater percentage of Pu in the fine particles but total Pu activity was relatively low. Soil particles larger than 2 mm in diameter contained minimal Pu activity.

Site configuration and transuranics (Pu + Am) concentration contours at the LITTLE FELLER II location are illustrated in Fig. III-6. This figure was based on 712 Ge(Li) scan data for Am, and Pu to Am ratio data from 110 locations where both Am and Pu values were available from the same soil sample. The Pu to Am ratio of 7.5 (Simpson, NVO-224, CIC# 64826) was used to estimate the transuranics inventory. Attempts to derive inventory estimates for the LITTLE FELLER II site are described along with discussion of the problems encountered and the rationale underlying the calculational method finally selected (Gilbert, NVO-272, CIC# 83099).

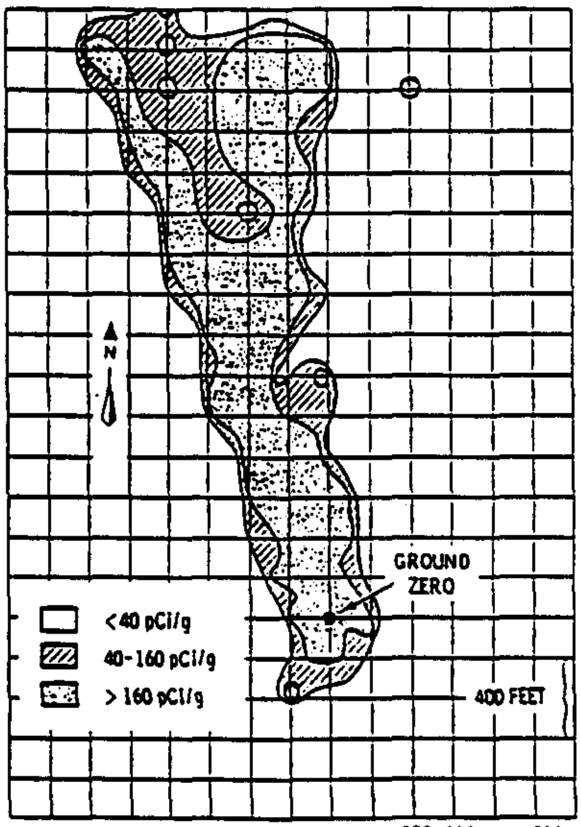


Figure 3. Concentration Contours of $^{239-240}Pu$ + ^{241}Am at Nuclear Site 201.

FIGURE III-6 FROM SIMPSON AND GILBERT, NVO-224, 1982

2. Area 20: PALANQUIN (NS219)

Area 20 is in the northwest corner of the NTS (*Fig. I-4*). The vegetation mosaic is characteristic of the Great Basin Desert and is dominated by sagebrush (*Artemisia*) associations with pinyon pine (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) being dominant at elevations above 6000 ft (1830 m).

TABLE III-10. PARTICLE SIZE DISTRIBUTION IN SOIL PROFILES, NTS AREA 18, LITTLE FELLER II (in % by weight)

Soil Depth (cm)	Site	Size Distribution Size Range (μm)			
		<5	5-250	250-2000	>2000
0 - 2.5	4	<2	42	36	21
	5	<2	34	40	26
	8	8	51	18	25
	10	<2	32	15	51
2.5 - 5.	4	<1	39	40	20
	5	3	41	32	26
	8	10	60	17	13
	10	5	49	19	26

(after Lee, NVO-272)

TABLE III-11. Pu DISTRIBUTION IN SOIL PROFILES, NTS AREA 18, LITTLE FELLER II (in % contribution to activity).

Soil Depth (cm)	Site	Pu Activity (dpm/g)	Pu Distribution Particle Size Range (μm)		
			<5 (%)	5-250 (%)	250-2000 (%)
0 - 2.5	4	17,000	1	15	84
	5	30,000	1	6	93
	8	77,700	1	3	96
	10	25,200	1	7	92
2.5 - 5.	4	19,600	1	19	80
	5	2,000	8	30	62
	8	31,700	1	8	91
	10	19,400	1	2	97

(after Lee, NVO-272)

The PALANQUIN device, 4.3 kt in yield, was detonated April 14, 1965, 85 m underground on Pahute Mesa. Ground surfaces consist primarily of lava outcroppings interspersed with shallow alluvial soils. In this southern portion of the Great Basin Desert, the primary vegetation associations are shrub-steppe consisting of perennial shrubs with an understory of sparse perennial forbs and grasses with some annuals. Following the PALANQUIN test, shrubs were killed or damaged by fallout radioactivity north of the GZ in an area of about 3 km^2 (Fig. III-7). Injury or death of shrubs released growth of perennial and annual grasses, and the area of complete shrub kill has been maintained as a grassland, subject to range fires (O'Farrell, NVO-272, CIC# 83093).

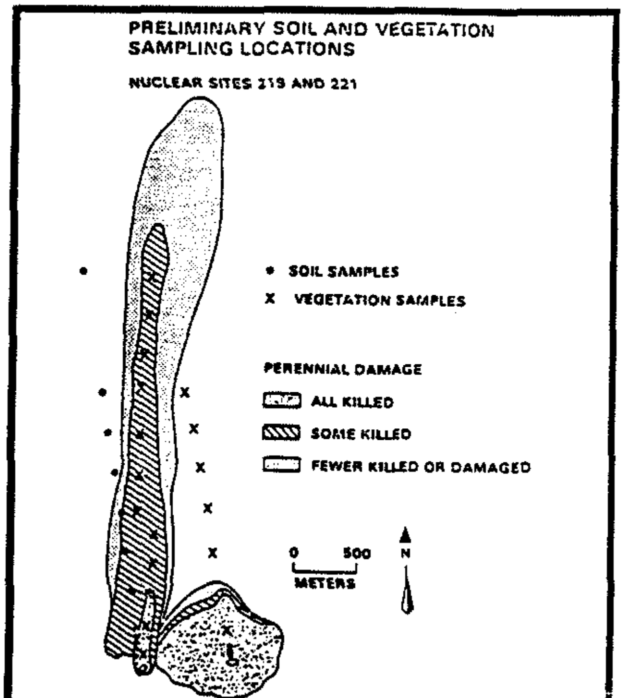


Figure 17. Preliminary Soil and Vegetation Sampling Locations Near NS's 219 and 221. Perennial Damage Zones Adapted From Rhoads et al. (1969) and Rhoads and Platt (1971).

FIGURE III-7 FROM GILBERT et al., NVO-181, 1977

[Ed. Note: Reports do not mention the presence of reptiles or birds at this site.]

Thirteen mammal species were trapped in the PALANQUIN area during the May to June 1980 study period. The deer mouse (*Peromyscus maniculatus*) and the Great Basin pocket mouse (*Perognathus parvus*) together accounted for 87 percent of all captures. The former outnumbered the latter by 3 to 1 on all plots and treatments. With minor exceptions noted in the report, species composition and relative abundance of small mammals were the same in both undisturbed shrub-steppe vegetation on Pahute Mesa and grassy habitats denuded by PALANQUIN fallout radiation (*Ibid.*).

[Ed. Note: Published data are not amenable to calculating animal density per hectare for comparison with other study areas.]

Five soil samples were collected along a transect north of the GZ. Three samples were taken at about 383 m (about 1250 ft) from the GZ, one at 722 m (about 2370 ft), and one at 3979 m (about 13,055 ft). Soil at the PALANQUIN site differs from soil at or near playa locations in that a greater fraction of the total sample is composed of particles (gravels) larger than 2 mm. The gravel content, particularly in the size fraction >4.76 mm, decreases in the soils located farther away from the detonation site. The unweathered rock fragments (>4.76 mm) in the surface soils near GZ are speculated to be fallout materials from the nuclear test. In this study, the gravel fraction was retained because it contributed a major portion of the surface soils (up to 51 percent) and contained radioactive particles which had be accounted for in studies of distribution and total inventory (Lee, NVO-224).

Analytic results for soil collected from the location nearest the GZ are presented in Table III-12.

TABLE III-12. **PARTICLE SIZE AND Pu ACTIVITY DISTRIBUTIONS IN TWO INCREMENTS OF NTS SOILS, AREA 20, PALANQUIN SITE.**

Soil Depth (cm)	Distribution	Size Range (μm)			
		<2-20 (%)	20-250 (%)	250-2000 (%)	>2000 (%)
0 - 2.5	Size	4	17	11	67
	Activity	<.01	4	14	81
2.5 - 5.0	Size	17	50	16	16
	Activity	<.01	12	49	38

(after Lee, NVO-224)

[Ed. Note: Results from other sampling locations are not included because they were not in a form suitable for generating comparable table entries. However, the results indicated that Pu activity decreased with distance from GZ and the activity was generally associated with larger rather than smaller particles.]

Additional laboratory work determined the physicochemical characteristics of the PALANQUIN site soils. Chemical composition of these soils was determined to be SiO_2 (60 percent), Al_2O_3 (20 percent), and about 5 percent each of the oxides of iron, potassium, and sodium. The density of these soils in their natural state is about 2.6 g/cm^3.

Following density separation, the study found that radioactivity was exclusively associated with particles of lower density (between 1.95 and 2.26 g/cm^3). Radioactive particles, examined under a microscope, were grayish-black and had a porous structure. X-ray diffraction analysis revealed that the radioactive particles were composed of x-ray-amorphous silicate glass, and the nonradioactive particles were composed of crystalline quartz and feldspars. Neutron activation analysis of radioactive particles revealed that the Pu was distributed through the matrix of particles rather than being incorporated as a separate domain in the particle. Scanning electron microscopy revealed that the radioactive particles had a sponge-like or volcanic-ash-like structure with varying sizes of voids and very thin, glassy walls between the voids. Compression tests showed the radioactive particles to be fragile, and the results suggest these particles will be susceptible to physical weathering and dispersion (Lee, NVO-224).

D. OTHER STUDY AREAS

EG&G completed an aerial radiological survey of Yucca Flat in 1978. The ARMS (Aerial Radiological Monitoring System) used 20 NaI(Tl) scintillation detectors mounted on a helicopter which crossed the area in lines 200 ft (60 m) apart at an altitude of 100 ft (30 m). The ARMS measures average radiation levels over a circle with a diameter of 5 to 10 times the aircraft altitude depending on the gamma-ray energies involved and the distribution with depth of the various radionuclides being detected. As a result, localized areas of high activity appear to be spread over a larger area with a lower activity than actually exists on the ground. For activity uniformly distributed over large areas, the agreement between ground measurements and the aerial survey measurements is generally quite good. Survey data were used to generate exposure-rate isopleths which delineate areas contaminated with radionuclides that emit gamma rays (Fritzsche, EGG-1183-1808, CIC# 83295; McArthur, NVO-272, CIC# 83085). The aerial-measurement data were used in planning the program of *in situ* measurements.

The RIDP (Radionuclide Inventory and Distribution Program) was developed to provide estimates of inventory and distribution of radioactivity on NTS as input necessary for evaluation of potential safety and health hazards posed by the presence of radionuclides in various environments at the NTS. The initial RIDP investigation was conducted in Area 1 at the GALILEO site. An *in situ* gamma-ray measurement system was used to acquire gamma ray counts at all the nodes of a square grid established in the area of interest. The instruments were carried in a vehicle which could be driven to each measurement point. Acquired data were analyzed later.

To confirm certain conversion factors used in subsequent computations, soil moisture and wet density were tested to a depth of 20 cm at 11 locations in the area of interest. Average soil moisture was found to be 8 percent and the corresponding wet density was 1.6 g/cm^3. The mean dry density was determined to be 1.5 g/cm^3, which value agrees with the density assumed in calculations of soil attenuation of gamma rays and in calculations required for detector calibration.

1. Area 1: GALILEO Site

The GALILEO site is located beside the major road junction in the northwest corner of Area 1 in Yucca Flat (Figs. *I–4* and III–8); four tests were conducted here in the 1950s. Test names, dates, tower heights, and yields are as follows:

EASY	05/07/52	300 ft	12 kt
SIMON	04/25/53	300 ft	43 kt
APPLE–2	05/05/55	500 ft	29 kt
GALILEO	09/02/57	500 ft	11 kt

Radiological residue in the GALILEO vicinity is composed of a mixture of fission products of different ages. The SIMON test, of relatively high yield on a relatively low tower, would have had a greater impact on the immediate environment than would the GALILEO test, which was of lower yield and on a higher tower. Posttest grading for reduction of personnel exposures, other site preparation between tests, and pre-test construction activities likely created a heterogeneous soil matrix which would be difficult to characterize. Particle size and depth distributions, and Pu to Am ratios, in the GZ vicinity would have little relevance to the situation found at greater distances from GZ. For this reason, measurements of radioactivity made within a radius of 500 ft (152 m) of the GZ were not used to evaluate other data.

In situ measurements were made in the GALILEO area from August through December 1981. The *in situ* data set contained 165 measurements made at 134 locations (27 locations were measured twice, one location was measured six times; these were intentional replicate counts).

2. Area 10: SEDAN

The SEDAN site is located in the northwest corner of Area 10 in Yucca Flat (*Fig. I–4*). The SEDAN experiment utilized a 104-kt thermonuclear device detonated 635 ft (193 m) below the gently sloped alluvial plain at the north end of Yucca Flat.

The site lies within the transition between Great Basin and Mohave Deserts. Prior to human disturbances, the major vegetation associations were dominated by spiny hop-sage/desert thorn (*Grayia spinosa/Lycium andersonii*) grading at higher elevations into black-brush (*Coleogyne ramosissima*), with some sparse stands of creosote bush (*Larrea tridentata*) to the east. During the 1950s, vegetation in the SEDAN area was reduced to a disclimax following destruction of shrubby vegetation by atmospheric nuclear tests preceding SEDAN. The disclimax consisted primarily of weedy species. Following the SEDAN test, deep throwout buried vegetation within 3000 ft (914 m) of GZ, while shrubs were destroyed or heavily damaged to a distance of about 6000 ft (1828 m) (O'Farrell, NVO–272).

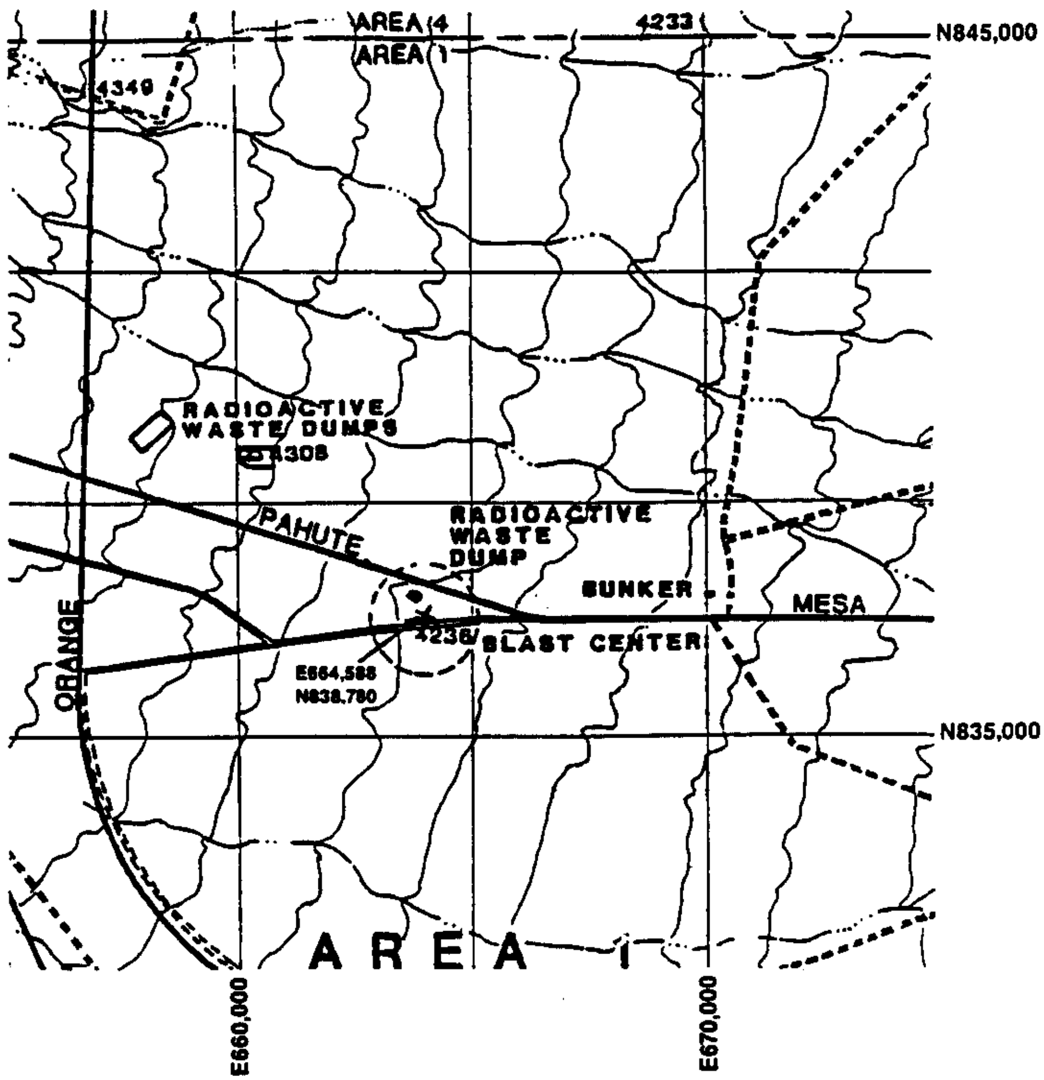


FIGURE III-8 GALILEO SITE IN AREA 1

NAEG study plots were located along two transects established near the SEDAN crater (Fig. III-9). Vegetative cover ranges from sparse near the crater to normal for the region at a distance of about 5000 ft (1524 m). Plant species reflect the natural succession in the region. Tumbleweed appeared first, followed by annual grasses, then forbs and perennial grasses, then woody shrubs. The succession order is likely influenced by the distance that the wind and animals will carry plant seeds from local sources.

Grasses are dominant within about 3000 ft (914 m) of the crater. Limited evidence suggests that native shrubs are becoming reestablished from the perimeter of the scarred boundary (where the ejecta is thin) in toward the crater lip (where the ejecta is 10s of ft thick). The new ground surface created by ejecta from the detonation is composed of previously buried alluvium that contains insufficient nutrient and organic matter to support plant growth. The material also consists of larger particles than existed in the original surface. Natural weathering has not progressed long enough for the surface to become amenable to growth of native plants other than grasses.

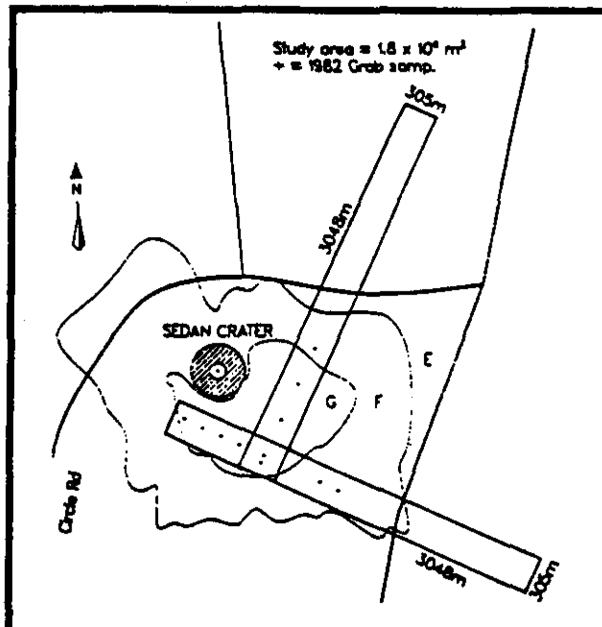


Figure 10.

Map of the SEDAN Area Showing the Location of the Transects Chosen for NAEG Studies. (Activity Contours Are Indicated and Coded According to the Aerial Radiation Survey after Fritzsche, 1982: Regions G, E, and F Are 30-100, 100-300, and 300-1000 μR/hr at 1 m above Ground Level, Respectively).

FIGURE III-9 FROM ESSINGTON, NVO-272, 1985

Mammals were live-trapped from August 1982 until May 1983. Trapped animals totalled 719 different mammals representing 12 species, with 87 percent of the captures being Merriam's kangaroo rat (*Dipodomys merriami*), the little pocket mouse (*Perognathus longimembris*), and the deer mouse. Although the latter two species were trapped on all plots, relative abundance was greatly reduced at sites within about 3000 ft (914 m) of the crater. The Great Basin kangaroo rat, southern grasshopper mouse, and white-tailed antelope squirrel (*Ammospermophilus leucurus*) were caught only on plots greater than 3000 ft from the crater, and were most frequently taken at sites with shrub cover. Three other species, the western harvest mouse (*Reithrodontomys megalotis*), the pinyon mouse (*Peromyscus truei*, and the Great Basin pocket mouse were the only species trapped exclusively in the sparsely vegetated alluvium within 3000 ft of the crater. No significant difference appeared in the number of individuals trapped on the sites beyond 3000 ft from the GZ regardless of the presence or absence of shrubs, although some species showed clear preferences for habitats containing shrubs (O'Farrell, NVO-272).

3. Area 2: T-2 Series

The T-2 sites are located along the western edge of Yucca Flat (Figs. *I-4* and III-10). Six tests were conducted here. Test names, dates, tower heights, and yields are as follows:

T-2	HOW	06/05/52	300 ft	14 kt
	BADGER	04/18/53	300 ft	23 kt
	TURK	03/07/55	500 ft	43 kt
	WHITNEY	09/23/57	500 ft	19 kt
T-2-a	SHASTA	08/18/57	500 ft	17 kt
T-2-b	DIABLO	07/15/57	500 ft	17 kt

Comments made regarding the radiological residue at the GALILEO site apply here as well.

Before 1952, the dominant vegetation consisted of mixed shrub associations that graded into pure stands of blackbrush. In the early 1980s, vegetation consisted of disclimaxes dominated by perennial grasses and various annuals. All of the disturbed sites had been subjected to ionizing and thermal radiation, and blast damage, and the areas around some of the GZs had also been mechanically disturbed by landclearing equipment after tests (O'Farrell, NVO-272).

E. PLUTONIUM INVENTORY AT STUDIED SITES

[Ed. Note: Table III-13 presents the estimated inventory of Pu at the sites studied by the NAEG during the period 1970–1986. Cited references discuss the derivation of these estimates and the qualifications that go with the data. The Pu concentrations used to derive these estimates considered the average concentration in each of up to six defined strata; highest and lowest strata differed significantly in Pu concentration. The average, then, does not represent any one area or stratum very well and would be no more than a general indicator of Pu contamination in surface soil. See the source documents for estimates of the area and Pu concentration in each stratum.]

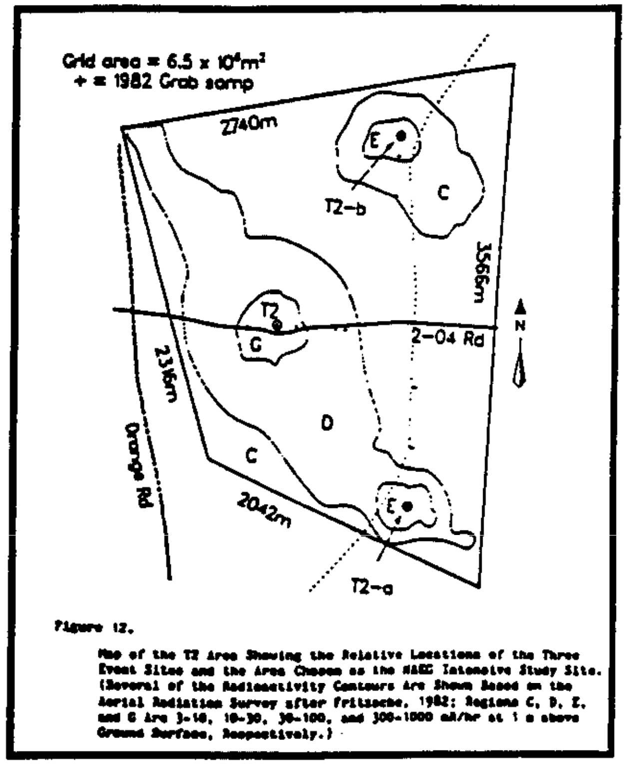


FIGURE III-10 FROM ESSINGTON, NVO-272, 1985

TABLE III-13. SUMMARY OF ESTIMATED INVENTORY OF Pu IN SURFACE SOIL (0-5 cm) AT STUDIED SITES

Site	Area Size (m^2)	Number Samples	Estimated Inventory (Ci)	Est. 95% C.I. on Inv.@ (Ci)
PROJECT 56 (Area 11)	4,830,900	205	36	28 - 44
PROJECT 57 NAFR (Area 13)	4,017,000	169	46	28 - 64
GMX (Area 5)	125,300	111	1.5	1.1 - 1.9
CLEAN SLATE I (TTR)	177,100	57	4.2	1.8 - 6.6
CLEAN SLATE II (TTR)	470,500	63	17	9.6 - 24
CLEAN SLATE III (TTR)	1,732,000	63	37	26 - 48
DOUBLE TRACKS (NAFR)	179,000	53	3.6	1.7 - 5.5
LITTLE FELLER II (Area 18)	375,000	712	32#	22 - 41
PALANQUIN* (Area 20)	3,895,000	148	13#	6 - 21
SEDAN (Area 10)	28,263,500		111.2	
T2-Series (Area 2)	30,100,000		16.7	

@ Estimated 95% confidence interval on inventory number.
* PALANQUIN and CABRIOLET areas combined.
# Inventory consists of Pu-239+240 plus Am-241.
(After Gilbert, NVO-181, p. 425, CIC# 83142; Gilbert, NVO-272, pp. 381-429, CIC# 83099; and McArthur, DOE/NV/10162-20, CIC# 83214.)

CHAPTER IV. CONCENTRATIONS OF PLUTONIUM IN THE ECOSYSTEM

A. FLORA

The significance of vegetation in Pu-contaminated areas rests primarily on its capacity to function as the carrier of Pu ingested by herbivores. Pu ingested by rodents may thus enter the food chain of carnivores, but this pathway is not of great concern as a route to man. Of more significance is the Pu ingested by larger herbivores which could be a food source for some people. Wild game (mule deer, bighorn sheep) are in turn minor as compared to cattle raised for commercial markets. Differences in Pu ingestion should be expected between animals grazing on semi-arid range and animals feeding on or from cultivated fields. Lower resuspension values should occur on irrigated or naturally moist (rainwatered) fields than in normally dry (possibly dusty) range lands.

The incorporation of Pu by vegetation may occur by two mechanisms. First, the contaminant may become trapped on vegetation surfaces through the processes of resuspension. [Ed. Note: Direct deposition of fallout particles is excluded from this discussion.] Second, the Pu disseminated in soil may be taken up through plant roots and translocated to the aboveground vegetation. Studies conducted during the period of atmospheric nuclear testing showed that superficial contamination of vegetation was the major source of radionuclides available to grazing animals. These studies also showed relatively low uptake of Pu through plant roots. The NAEG studies were designed to gather more information on how these two mechanisms of incorporation function in the vegetation-carrier transport of Pu from soil to animals living in contaminated areas (Romney, NVO–142, p. 92, CIC# 64844).

1. Foliar Contamination

A conservative estimate of the edible forage produced annually for livestock grazing in the fenced portion of the Area 13 site is approximately 1000 kg per hectare. This is about one-third of the average aboveground biomass harvested from eight test plots. One should anticipate that preferred edible species, i.e., winterfat (*Eurotia lanata*) and indian ricegrass, will be grazed first, after which cattle would consume less palatable species as the variety of forage is reduced (Romney, NVO–142).

A scaffold was erected over an 8 m^2 section of the Area 13 microplot study site in isopleth 4 (10,000-25,000 cpm Pu+Am). All vegetation was carefully removed so as to not disturb the soil surface (because of other studies). Individual shrubs were collected and radiochemical determination made of Pu and Am content. Vegetation was also collected in the other five strata. Pu and Am in samples of vegetation varied considerably within each isopleth. The range in concentration levels progressively decreased with distance away from ground zero. Comparisons of data among the different strata indicate that correlations between vegetation and soil Pu concentrations are not sufficiently near 1.0 to indicate a good linear relationship (*Ibid.*, p. 98.).

Results indicated uniform distribution of Pu and Am among individual plants of the same species at a given sampling site. However, there appeared to be considerable difference in the contamination levels between species. As a result, very poor correlations are indicated between soil and vegetation Pu concentrations in the different sampling strata within the fenced area (*Ibid.*, p. 103.).

[Ed. Note: Eight species of plants were collected from 17 plots in Area 13. Grazing animals prefer selected plant species and will not browse on some species available in desert ranges. NAEG studies did not always categorize vegetation in this manner, so the data are not amenable to analysis by important grazing plants separate from all vegetation. Where this distinction can be made, the data are presented accordingly.]

Winterfat, having very hairy leaf surfaces, contained higher concentrations of Pu than did four-winged saltbush (*Atriplex canescens*) or indian ricegrass as shown in Table IV-1. Because winterfat is one of the most preferred forage plants within the fenced area and would therefore be consumed first, Pu ingestion by cattle might initially be higher than would be predicted from estimates of concentration levels derived from composite vegetation samples. The Pu to Am ratio in Area 13 soils approaches 10. Ratio data presented in Table IV-1 led to the suggestion that there may be some preferential uptake of Am. Other studies dating back to 1967 have reported increased uptake of Am relative to Pu through plant roots (*Ibid.*, p. 98.).

TABLE IV-1. Pu AND Am IN AREA 13 MICROPLOT VEGETATION

Species	Number Samples	Pu Mean + S.D. (nCi/g ash)	Am Mean + S.D. (nCi/g ash)	Pu to Am Ratio
Winterfat	21	3.88 (1.42)	0.48 (0.18)	8.1
Indian ricegrass	7	1.75 (0.73)	0.20 (0.08)	8.7
Four-winged saltbush	9	1.22 (0.59)	0.14 (0.05)	8.7

(Romney, NVO-142, p. 97, CIC# 64844.)

The CR was found to be highly variable between activity strata in Area 13. The CR varied from <1 to as high as 5, as shown in Table IV-2, with no apparent pattern to the CRs or to the correlation coefficients.

Seven safety-shot sites received intensive study during the course of NAEG work. The Area 11 site was subdivided into four plots with some areas of overlap between plots. The seven sites were thus treated as ten sub-areas. Because the level of residual radiation differed between sites, five different schemes were used to define radiation activity strata for study purposes. Data from the ten sub-areas were grouped by strata, as well as could be done with the different strata definitions, to estimate an overall relationship between soil Pu and vegetation Pu. The data are summarized in Table IV-3. (The correlation coefficient for the raw data is $r = 0.79$, while for the mean values shown in Table IV-3, $r = 0.94$.)

A comparison of CRs between individual plant species and the mean of a large number of composite samples is revealing. Whereas 14 samples of winterfat had a mean CR of 5.1, the mean ratio for several hundred composite samples was found to be at most 0.07. Note also (*Table IV-3*) that the CR is highest for the low activity strata and lowest for the high activity strata (but the difference between CRs is small). In general, the low activity strata are some distance removed from the detonation site so the Pu particle size would be expected to be smaller, thus yielding a larger relative surface area from which Pu atoms could be absorbed by plant roots (a minor pathway), and a greater likelihood of resuspension and subsequent deposition on aboveground plant parts (such as the hairy surfaces of winterfat).

2. Root Uptake

Several species of plants were grown under glasshouse conditions in pot cultures using soil from some of the aged Pu fallout areas on the NTS and the TTR. Growth conditions were prepared in a manner to prevent transfer of contaminants from the soil to foliage surfaces. The experiments were designed with several objectives. In addition to testing uptake of Pu and Am

TABLE IV-2. Pu VEGETATION CONCENTRATION (nCi/g ash) vs Pu SOIL CONCENTRATION IN AREA 13.

STRATA (cpm#)	Number Samples	CR*	SE(R)**	r
<1K	24	2.0***	0.60	0.006
1-5K	19	1.4***	0.27	0.69
5-10K	10	5.0	1.3	0.63
10-25K	11	0.63	0.12	0.28
25-50K	10	2.1	0.96	0.14
>50K	18	3.0	0.73	0.70

Counts per minute, as determined by field survey with FIDLER.
* CR = (average Pu concentration in vegetation)/(average Pu concentration in soil). Samples from the same location.
** Standard error by the method of Snedecor and Cochran, 1967.
*** Reject H: "constant ratio for all values of soil Pu encountered" at alpha = 0.01 level.
(From Romney, NVO-142, p. 102, CIC# 64844.)

TABLE IV-3. MEAN CONCENTRATIONS OF Pu IN SOIL AND VEGETATION IN SAFETY-SHOT INTENSIVE STUDY SITES

ACTIVITY RANGE (cpm Am)	Pu SOIL		Pu VEGETATION		Pu RATIO
	No.	nCi/g	No.	nCi/g (dry)	VEG./SOIL
<5K	252	0.11	234	0.008	0.07
5- 25K	194	2.05	185	0.08	0.04
25-100K	190	9.09	169	0.45	0.05
100-500K	62	26.12	55	0.78	0.03
>500K	21	69.93	14	1.33	0.02

by roots from unmodified soil, the experiments evaluated the influence of adding soil amendments such as nitrogen, sulfur, and organic matter. Also, DTPA (diethylenetriaminepentaacetic acid), a chelating agent, was included in separate pots with the unmodified control soil and each of the above amendments (Romney, NVO–171, CIC# 64890).

The first series of experiments used soil from stratum 3 (5,000-10,000 cpm Am) of the Area 13 study site. Barley plants were grown first and harvested in the dough stage; plant tops were divided into straw and fruit-head sub-samples. Alfalfa was grown next in the same pots and soil as had been used for growing barley. Three successive cuttings of alfalfa forage were harvested in the quarter-bloom stage and the clippings were combined to form one set of pooled replicates for radiochemical analysis.

Results from this series of experiments showed the need for working with soil containing higher levels of contamination; both Pu and Am uptake were very erratic. The Pu CR for the unmodified control soil was 1.9×10^{-4} in barley straw and 4.1×10^{-4} in barley fruit heads. The experimental results are presented in Table IV-4. Two generalizations may be noted: acidification with sulfur tended to increase uptake of both Pu and Am, especially in association with DTPA; and addition of DTPA increased uptake of Am about an order of magnitude higher than uptake of Pu. The results for alfalfa followed the same pattern as for barley.

TABLE IV–4. Pu AND Am CONCENTRATION RATIOS FOR BARLEY AND ALFALFA PLANTS GROWN ON AREA 13 SOIL TREATED WITH AGRICULTURAL AMENDMENTS AND WITH OR WITHOUT DTPA

	Pu		Am	
	No DTPA	With DTPA	No DTPA	With DTPA
Barley straw				
Control	1.9×10^{-4}	2.3×10^{-4}	4.8×10^{-4}	1.3×10^{-3}
Nitrogen	1.8×10^{-5}	2.2×10^{-4}	1.6×10^{-4}	1.8×10^{-3}
Sulfur	2.8×10^{-5}	5.7×10^{-3}	5.8×10^{-4}	4.2×10^{-3}
Organic matter	2.4×10^{-5}	8.6×10^{-4}	6.0×10^{-5}	2.8×10^{-3}
Barley fruit heads				
Control	4.1×10^{-4}	5.9×10^{-6}	4.8×10^{-4}	7.0×10^{-5}
Nitrogen	3.8×10^{-6}	1.6×10^{-5}	ND	3.5×10^{-4}
Sulfur	2.1×10^{-4}	3.1×10^{-3}	5.2×10^{-4}	3.5×10^{-3}
Organic matter	5.0×10^{-6}	2.4×10^{-4}	1.4×10^{-4}	1.2×10^{-3}
Alfalfa				
Control	3.8×10^{-5}	5.9×10^{-5}	4.8×10^{-4}	9.2×10^{-4}
Nitrogen	6.4×10^{-5}	6.5×10^{-5}	5.8×10^{-4}	9.4×10^{-4}
Sulfur	7.2×10^{-5}	3.6×10^{-4}	1.1×10^{-3}	1.9×10^{-2}
Organic matter	1.3×10^{-4}	3.4×10^{-4}	4.9×10^{-4}	1.0×10^{-3}

ND = Not detected in some replicates.
(From Romney, NVO–171, pp.58-60, CIC# 64890.)

[Ed. Note: Extraction of Pu and Am from the soil by growing barley plants did not apparently reduce the availability of these radionuclides to the subsequently grown alfalfa.]

A second series of experiments was run using soil collected from eight NAEG study areas. For these experiments, the soil was collected from a site within each fallout area at which FIDLER readings of gamma activity ranged from 20,000 to 30,000 cpm. The design of each soil experiment consisted of three sets, with and without DTPA chelate, replicated three times. Soybean plants were grown on these soils, harvested, and pooled into one set of three replicates each. The results for soybean plants (Table IV-5) show Pu and Am CRs of the same magnitude as was found for barley and alfalfa. These results also show Am uptake being higher than Pu uptake and the influence of DTPA in enhancing absorption of both PU and Am. Notable in the soybean plants is the apparent discrimination by the plant in not concentrating Pu and Am in the seed pods which generally contained an order of magnitude less Pu or Am than did the leaf and stem samples (Romney, NVO-192, CIC# 83051).

TABLE IV-5. Pu AND Am CONCENTRATION RATIOS FOR SOYBEAN PLANTS GROWN ON SOILS CONTAINING AGED FALLOUT MATERIALS

	Pu		Am	
	No DTPA	With DTPA	No DTPA	With DTPA
Soybean leaf and stem				
Area 11 B	1.5×10^{-4}	1.6×10^{-3}	1.2×10^{-3}	5.2×10^{-2}
Area 11 C	1.8×10^{-4}	3.7×10^{-3}	2.7×10^{-3}	8.9×10^{-2}
Area 11 D	1.1×10^{-3}	6.6×10^{-3}	1.7×10^{-2}	3.7×10^{-1}
Area 13	1.1×10^{-4}	3.9×10^{-3}	3.3×10^{-3}	2.7×10^{-2}
CLEAN SLATE I	4.3×10^{-4}	7.1×10^{-4}	1.4×10^{-2}	2.1×10^{-2}
CLEAN SLATE II	7.6×10^{-4}	1.2×10^{-3}	2.5×10^{-3}	4.0×10^{-2}
CLEAN SLATE III	5.5×10^{-4}	7.8×10^{-4}	5.5×10^{-3}	8.6×10^{-3}
DOUBLE TRACKS	2.6×10^{-4}	4.2×10^{-4}	5.7×10^{-3}	6.7×10^{-3}
Soybean fruit pods				
Area 11 B	7.8×10^{-6}	2.6×10^{-5}	1.6×10^{-4}	1.2×10^{-3}
Area 11 C	1.1×10^{-5}	1.2×10^{-4}	1.9×10^{-4}	2.0×10^{-3}
Area 11 D	4.2×10^{-5}	2.2×10^{-4}	7.6×10^{-4}	2.3×10^{-2}
Area 13	2.4×10^{-6}	1.5×10^{-4}	8.1×10^{-5}	1.2×10^{-3}
CLEAN SLATE I	1.7×10^{-5}	2.2×10^{-5}	2.0×10^{-4}	1.0×10^{-3}
CLEAN SLATE II	1.4×10^{-5}	4.4×10^{-5}	1.3×10^{-4}	1.2×10^{-3}
CLEAN SLATE III	1.8×10^{-5}	2.7×10^{-5}	3.4×10^{-4}	5.8×10^{-4}
DOUBLE TRACKS	9.8×10^{-6}	1.3×10^{-5}	5.8×10^{-4}	8.6×10^{-4}

(From Romney, NVO-192, pp. 115-116, CIC# 83051.)

[Ed. Note: These results do not show any outstanding differences in CRs between soils from the different areas even though the soils differ considerably.]

The CRs determined for the plant species reported above are in close agreement with the CRs found in a variety of native plants and vegetable crops grown in the floodplain at Oak Ridge National Laboratory. The CRs at ORNL were found to lie in the range from 5×10^{-5} to 2×10^{-3} (Dahlman, NVO-178 (CIC# 14358), CIC# 64927).

The investigators were of the opinion that perhaps the most important finding from the above experiments pertains to the greater uptake of Am through plant roots as compared to uptake of Pu. In spite of the erratic data for barley, the Pu to Am ratios for plant tissues were generally much less than the average Pu to Am ratio of the soil in which the plants were grown. Data for alfalfa conclusively showed greater uptake of Am over Pu by a factor of at least 10 for the unamended soil. In those cases where the acidulation amendment had markedly enhanced Pu uptake, this effect was still around a factor of 5. Even higher factors indicating preferential uptake of Am are evident in the soybean data. The investigators believed that the differential uptake for Am probably contributed to the slightly lower Pu to Am ratios often encountered for vegetation samples collected in the aged fallout areas compared to Pu to Am ratios for the soils. The impact of this finding for Am uptake assumes greater importance when coupled with the fact that this radionuclide is an ingrowth product of the source material in the aged fallout areas. About 50 years still must elapse before Am will reach its peak due to ingrowth. The investigators were of the opinion that potential problems from Am would become equally important, if not of greater concern, as the aged Pu source material in these fallout areas (Romney, NVO-171, CIC# 64890).

[Ed. Note: Root uptake studies were continued for several years and involved several variations of the studies discussed above. Tests were conducted with wheat, bushbean, and carrot plants in pots in controlled greenhouse conditions.]

In another study, radish, lettuce, barley, and alfalfa plants were grown from seeds in previously undisturbed soil in Area 13. The plants were grown in small greenhouses erected over the soil to preclude aerial deposition of resuspended radionuclides on the growing plants. CRs in the various plant parts, with the exception of roots, ranged from lows in the radish cores of 7.6×10^{-3} for Pu and 3.2×10^{-3} for Am to highs in the lettuce leaves of 1.2×10^{-1} and 5.0×10^{-2} for Pu and Am, respectively. CRs for Pu and Am were found to be higher than most of those previously reported in the literature (Au, NVO-181, CIC# 64964).

During the radish/lettuce/barley study, two species of native plants grew as volunteers in the Area 13 study plots. The CRs for Pu were 0.9×10^{-2} in indian ricegrass and 1.0×10^{-2} in the four-winged saltbush; CRs for Am were two orders of magnitude lower. The investigator suggested that root uptake by native plants might be higher than had been assumed by other investigators who believed that most Pu and Am incorporated in native vegetation arrived via resuspension and aerial deposition (*Ibid.*).

[Ed. Note: The two native plants both grew in chelate-treated plots so the analytic results may not be representative of native plants growing in undisturbed environments.]

3. Pu Inventory Contained in Vegetation

Measurements were made of the vegetational biomass in contaminated areas to derive an estimate of the fraction of Pu inventory in aged fallout areas which would be contained in vegetation. Mean Pu contents of dry plant tissue were converted to nCi/m^2 using the biomass conversion factor of 290 g/m^2; this is the mean for the aged fallout areas which ranged from 210 to 580 g/m^2. The values for each activity strata were then multiplied by the appropriate area factor to obtain estimates of the inventory of Pu for vegetation in each strata. Comparisons of the soil and vegetation inventory estimates indicate that standing vegetation contributes a rather insignificant portion of the total amount of Pu present (from one to six ten-thousandths of that estimated for soil). It would appear, therefore, that the amounts of contaminant from vegetation transported through the food chains of grazing animals and men would be relatively small in comparison to the total amounts deposited on soil (Romney, NVO-153, CIC# 64867).

B. FAUNA

[Ed. Note: A program of planned animal collection and sampling became an integral part of the AIP. Animal populations sampled on a recurring basis included cattle from the NTS, Delamar Valley, and Knoll Creek beef herds, mule deer from the NTS and adjacent areas, and desert bighorn sheep from southern Nevada. The NTS beef herd was established in October 1957 through the purchase of 42 Hereford cattle from a local rancher. This herd was maintained on the ranges of the NTS until its disposal in November 1981. Twice a year, during this entire period, selected animals were removed, sacrificed, and sampled. Through a cooperative study with the University of Nevada, Reno, two other herds were sampled semiannually for an extended time. The Delamar Valley herd (located about 80 km east of the NTS) was sampled from the fall of 1957 through the fall of 1968. The Knoll Creek herd (located 480 km north of the Delamar Valley herd) was sampled from the spring of 1958 through the fall of 1968. NTS mule deer were sampled, generally on a quarterly basis, from 1964 through 1981. Mule deer from counties north and east of the NTS were sampled periodically from 1956 through 1972. Desert bighorn sheep were sampled annually from 1956 through 1981.

Animals sampled on a limited schedule or on a onetime basis included other NTS wildlife and feral horses, and cattle from herds located near Searchlight, Nevada, and in the vicinity of the TTR (Smith, EPA 600/6-84-020, CIC# 65154). The numbers and species of animals sampled each year are summarized in Table IV–6. (Analytical results are presented in the AIP annual reports listed in Appendix B, and are available on computer media from EPA/EMSL.)

Radioanalysis of sampled animal tissues sought information on the presence of many radionuclides, not just on the Pu reported in this book. However, because Pu was assigned the highest initial priority by the NAEG, it is the only radionuclide reported with consistency among the many types of samples collected and analyzed. Analysis for Pu was not of equal priority during the early days of the AIP; in fact, Pu was not reported in a routine manner by the AIP until 1970 after the inception of the NAEG. The AIP did, however, provide valuable baseline data beginning in 1957 for a wide variety of radionuclides found in animal tissues.

Radionuclides were sought in the tissues where they were expected to be found. For example, thyroids were analyzed for I-131 because the thyroid gland concentrates iodine; bone was analyzed for Sr-90 because strontium mimics calcium which is deposited in or on bone. The summary on page 59 is presented as an indication of the information available in the EPA's data base but is not intended to imply that every tissue listed was analyzed for every radionuclide listed.

Information of interest regarding uptake and retention of radionuclides by fauna in the vicinity of the NTS may be categorized many ways. Brief descriptions of the various categorizations are presented here to clarify the rationale underlying the emphasis given to the subject matter in following sections.]

Basic Scientific Research vs. Regulatory or Administrative Concern

Basic scientific research is necessary to gain an understanding of the movement of radionuclides in the environment. The study of native rodents (and other indigenous fauna) reveals the concentration ratios for radionuclides of interest in areas with different levels of contamination and provides an indication of the selectivity of various organs in concentrating Pu. Rodents and their predators are not part of the human food chain so the primary interest in studying these groups lies in evaluation of environmental and radiological health problems associated with Pu contamination. Other aspects studied include the presence and distribution of Pu on the NTS, the dynamics of Pu cycling on contaminated areas, and an evaluation of its effects on native biota.

Administrative concern centered on the possibility of Pu being transported away from the NTS to areas where administrative control might be lost. Such transport by rodents and their predators could not become significant because of the small number of animals leaving the NTS and the relatively minute concentrations of radionuclides this biotic fraction could transport.

TABLE IV-6. NUMBERS OF ANIMALS SAMPLED BY THE ANIMAL INVESTIGATION PROGRAM, BY YEAR, 1964 THROUGH 1981.

YEAR	CATTLE	MULE DEER*	BIGHORN SHEEP*	COYOTE*	RABBIT	OTHER ANIMALS#	EAGLE*	OTHER BIRDS
1964	11	6	5					
1965	12	20	14					
1966	14	14	14					
1967	11	4	17					
1968	12	6	23					
1969	12	5	16					
1970	13	6	14	1	1			2
1971	14	4	22	2		2	3	1
1972	14	4	17	1		2		
1973	19	4	20		1	1		1
1974	15	5	19	3	12	3		
1975	13	8	25	1	6			
1976	16	6	30	1	18	2		5
1977	14	8	20	2	11	2	2	
1978	12	6	13		19	1	3	2
1979	6	4	12	1	6	2	2	3
1980	6	4	14		4	1		
1981	14	4	17			1		1

* Animals were sampled following accidental or natural deaths as often as the opportunity arose, or with the cooperation of authorized game hunters.
# Other animals: 3 bobcats; 12 horses; 1 wild burro; 1 mountain lion.
(From AIP annual reports.)

Radionuclides and tissues for which results are available in the EPA data base.

RADIONUCLIDES	
H-3	Na-22
K-40	Mn-54
Co-60	Sr-89
Sr-90	Zr-95
Rh-102	Ru-103
Ru-106	Sb-124
Sb-125	I-131
Te-132	Cs-137
Ba-140	Ce-141
Ce-144	W-181
U-234	U-235
U-238	Pu-238
Pu-239	Am-241

TISSUES	
urine	mammary glands
testes	T-B lymph nodes
liver	abomasum tissue
bone	pelt
lung	kidney
muscle	thyroid
blood	thymus

OTHER

rumen contents
reticulum sediment
abomasum contents

However, cattle, mule deer, bighorn sheep, and possibly some of the larger bird species could carry significant body burdens of radionuclides, or ingesta containing radionuclides, off the NTS where these animals might be consumed by members of the general public. This possibility had to be investigated to determine the need for protective controls.

Uptake and Retention by Fauna On Site vs. Fauna Off Site

The important distinction between these two groups lies in the degree of contamination to which they could be exposed. Some on-site fauna have access to contaminated areas but off-site fauna do not (with the limited exceptions of Area 13 and the TTR sites, where the contaminated areas are fenced to keep range cattle out). Radionuclide uptake by cattle on the open range outside of the NTS is of scientific interest from the viewpoint of studying tissue burdens of animals ingesting limited concentrations of radionuclides. Animals such as mule deer which might spend a considerable amount of time on contaminated areas of the NTS, then migrate off site, could transport substantial contamination off site.

Radionuclide Burdens in Species Consumed by Man vs. Species Not in the Human Food Chain

To maintain the proper perspective on study results, it is necessary to understand the intended purpose of various studies. Study of radionuclide uptake, transfer to tissue, partitioning among organs, and tissue retention in rodents and their predators may help clarify radionuclide cycling in the environment, but these studies are not relevant to man's food chain. During the course of the Area 13 grazing study, several native animals were collected and their tissues analyzed. The Pu concentrations in bones, lungs, and livers ranged from 1 to 10 percent of the concentrations found in cattle restricted to the area. Analytic results for Pu are summarized in Table IV-7. The data indicate that body tissues of these animals retain only a small fraction of the Pu encountered in the environment as represented by the Pu concentrations found on the skin and in the stomach. (Results for ^{238}Pu and ^{241}Am also appear in the reference.)

Of the native fauna observed in the NTS environs, only a few species may be found in the human food chain. Regarding animals found on the NTS, only the mule deer could be consumed by humans under some conditions. [During a seven-year study period, two deer are known to have left the NTS herds. One tagged buck was shot by a hunter outside of the controlled area (Giles, EPA 600/4-85-030, CIC# 83283).] The NTS beef herd was not available for human consumption and very few cattle are known to have strayed from the surrounding open range into contaminated areas; such strays were herded back off the NTS.

TABLE IV-7. Pu CONCENTRATIONS IN SELECTED TISSUES OF AREA 13 WILDLIFE (pCi/kg)

	Fox*	Coyote	Rabbit
Skin	731 -1500	Lost	908
Stomach Contents	8 - 710	5150	241
Intestines & Contents	0.6 - 35	SNC	79.6
Muscle	1.4 - 190	36.1	Lost
Lung	0.2 - 8.7	SNC	0.1
Bone	<MDA - 1.3	2.6	2.3
Liver	0.2 - 0.6	0.24	1.3

*Range in values from three foxes. <MDA = Less than minimum detectable activity.
SNC = Sample Not Collected.
Lost = Laboratory problem prevented completion of analyses. Uncertainty terms have been omitted, and some numbers were rounded.
(From Smith, NVO-192, pp. 92-93, CIC# 83049.)

Radionuclide Burdens in Animals in Their Natural Environment vs. Animals in Special Study Situations

Free-ranging animals consuming vegetation of choice will browse or graze over large areas, thus the ingested matter is a composite representing the vegetation from a large area. In average (or better) range conditions, animals will browse from a few preferred species as they move through an area. As the preferred species become less available, the animals will move to a new area (in open range) or stay (if their movement is restricted) to eat less desirable species. Because the movement of mule deer, for example, is unrestricted, this species may best represent animals in their natural environment consuming vegetation of choice. Range cattle, on the other hand, have a more limited range and tend to overgraze areas near water sources. Thus, their radionuclide burdens will represent a long-term average intake but not necessarily from vegetation of preference.

Beef cattle placed in special study situations may not represent long-term freedom of choice in vegetative intake. Useful information regarding transfer of radionuclides from vegetation to animal tissue may still be obtained, but the sampled vegetation should not be considered representative of natural preference. In some feeding experiments, fistulated steers were tethered to a fixed location during the period of study; these results should not be considered comparable to the results from free-ranging animals. Beef cattle were placed in the Area 13 enclosure where they remained for several years; radionuclide burdens in these animals may be representative of natural range conditions. If the area inside the enclosure was either overgrazed or undergrazed relative to the surrounding open range, then the results are not strictly comparable to natural conditions. In the overgrazed condition the animals are consuming a larger portion of less desired species. In the undergrazed condition the animals are consuming an excess of preferred species compared to the mix available on the open range.

NAEG studies have produced an abundance of data regarding radionuclide uptake and retention by rodents (e.g., O'Farrell, NVO-272, CIC# 83093); rates of transfer to tissues for a variety of radionuclides administered to large animals orally (e.g., Patzer, NVO-224, CIC# 64835) or by hypodermic injection (e.g., Sutton, NVO-192, CIC# 83047); plant selection and consumption by fistulated steers and radioanalysis of ingested materials (e.g., Blincoe, NVO-224, CIC# 64834); and simulated bovine digestion systems (e.g., Barth, NVO-192, CIC# 83048).

[Ed. Note: Many of these were specialized studies conducted to comply with objectives stated in the NAEG Planning Directive (Miller, NVO-76, 1970, CIC# 165845). Data from three sources will be emphasized in following sections: results from the beef herd maintained in the Area 13 enclosure, results from the free-ranging beef herd located in Area 18, and results from the mule deer herd which ranges freely over the northern half of the NTS. These three sources provide the best measurement of the hazard to man through the food chain from radionuclide contamination in the uncontrolled environment and under near-natural conditions. Some data from desert bighorn sheep are also presented.]

1. Biological Retention in Bone

The study of biological retention faces the problem of measuring this factor under uncontrolled, natural environmental conditions: the investigator does not know the quantity of consumed material nor the average radionuclide concentrations ingested during the lifetime of free-ranging sampled animals. Radioanalysis will reveal the radionuclide quantity and concentration retained but cannot identify the proportion that is retained from the total ingested. Estimates of the proportion retained must be extrapolated from estimates of the quantity of food consumed and the results of vegetation analysis, where the vegetation is sampled manually, is retrieved from a fistulated animal, or is retrieved from the stomach of a sacrificed animal; all three of these methods were employed during the NAEG studies.

a. **Baseline Studies**

Beginning in 1971, studies were planned to assess the impact of an actual Pu release into the ecosystem. The studies called for beef cattle, goats, and fistulated steers to live and graze over an area of known Pu contamination (Area 13). Preparation for these studies included the collection of baseline data on Pu levels in tissues from beef animals that lived their entire lives in the Reno, Nevada, area exposed to radiation from only natural background and worldwide fallout. For comparison purposes, the AEC purchased beef cattle which had grazed the range surrounding the TTR safety-shot sites. (Some young stock from the TTR area was placed in the feedlot at the EPA farm for 111 days prior to slaughter.) Beef cattle were also purchased from a ranch near Searchlight, Nevada, where the cattle had grazed range similar to the TTR range. The Searchlight cattle were considered a control herd from an uncontaminated area. A young (six months) Holstein steer born and raised at the NTS farm in Area 15 was also considered a control. Table IV–8 summarizes Pu concentrations in various bone samples from these beef cattle. (See document reference at end of table; document also contains data for other radionuclides and other sampled tissues.)

b. **NAFR (Area 13) Cattle**

In April 1973, nine pregnant beef cows (three in each trimester of pregnancy) were procured from a herd near Kingman, Arizona. These animals and their descendants grazed within the fenced area at the Area 13 safety-shot site. One cow (and her offspring and a calf from another cow) grazed inside the inner enclosure. The remaining cows (and offspring) grazed between the inner and outer fences. Table IV–9 summarizes vital statistics for the cattle, and results of radioanalysis of bone samples. A complete synthesis of the study results has been published (Gilbert, HP 54:323, 1988, CIC# 83291).

The synthesis compared radioanalytic results from tissue samples from cattle restricted to the inner enclosure with similar data from cattle restricted to the outer enclosure. The study found that, for cattle grazing equal numbers of days in their respective enclosures, inner enclosure cattle had higher Pu concentrations in femur and vertebra than did outer enclosure cattle, and concentrations in these tissues tended to increase with duration time in the enclosure. Fig. IV–1 is a reproduction of Figure 3 in the synthesis paper (*Ibid.*).

The synthesis results indicated that the geometric-mean fraction of Pu transferred from GI to blood serum was 6.1×10^{-6} for adult cattle, 3.7×10^{-6} for cattle initially exposed *in utero*, and 4.9×10^{-6} for the two groups combined. However, once in the blood, transfer of Pu from blood to bone was estimated to range from 3.2×10^{-2} (adult femur) to 2.4×10^{-1} (*in utero* vertebra) (Gilbert, HP 54:323, 1988, pp. 330–332).

[Ed. Note: The fraction of Pu found in and on vegetation may be about 2×10^{-2} of the concentration in the soil. The fraction found in bone ash would be about 3×10^{-9} of the concentration in soil.]

c. **Desert Bighorn Sheep**

With cooperation from state and federal wildlife officials and participating hunters, tissue samples were collected from desert bighorn sheep each year during the annual hunt from 1956 through 1981. Samples were analyzed and reported for several radionuclides, but Pu was not added to the list until 1970. Table IV–10 presents Pu concentrations in the hocks (analogous to a human ankle; selected for ease of sampling) of sampled animals. During most years many results were below the MDA (Minimum Detectable Activity). Reported maximum values spanned the range from 0.6 to 25 pCi/kg. The apparent increase in median values from 1977 to 1980 may be an artifact of the method used for stating MDAs and uncertainty terms.

The EPA prepared two documents (Smith, EPA 600/3-81-027, CIC# 83209, and Smith, EPA 600/6-84-020, CIC# 65164) summarizing, among other projects, the historical record of radionuclides found in tissues of animals sampled during the life of the AIP. Fig. IV–2 is typical of analytic results, for the long-lived radionuclides of interest, from bones of the several species of sampled animals.

TABLE IV-8. **LOGNORMAL MEAN Pu CONCENTRATIONS IN BONE FROM SELECTED CATTLE SAMPLED DURING 1972 (pCi/kg tissue)**

Cattle Source	Number Cattle	Femur	Vertebra	Rib
Reno	6	0.12		
Searchlight	10	0.21		0.12
Dairy Cows (NTS)	2	0.28		
Control calf (NTS)	1	0.38	0.34	0.11
NTS, Area 18	5	0.41		
TTR, range	10	4.02		1.8
TTR, feedlot	5	4.6	5.8	5.4

(From Smith, NERC-LV-539-29, CIC# 4826.)

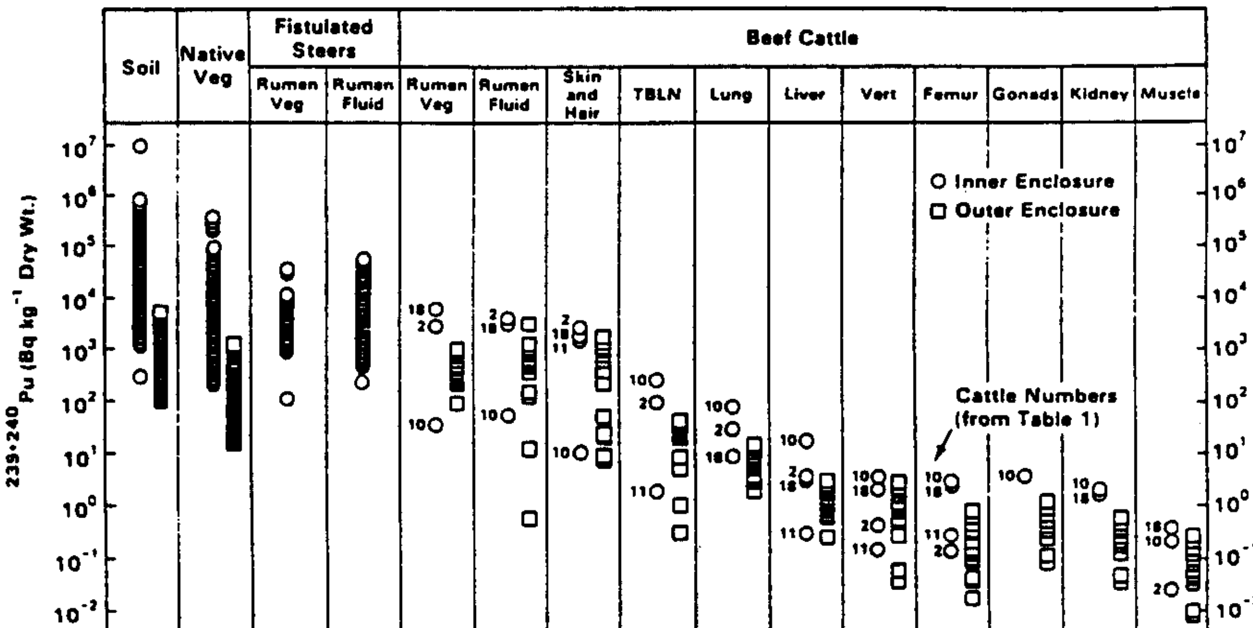
TABLE IV-9. **MEASURED Pu IN FEMURS AND VERTEBRA OF AREA 13 CATTLE (Each group ordered by number of days in enclosure.)**

Animal Number	Sacrifice Age (y)	Sacrifice Weight (kg)	Days in Enclosure In Utero	Days in Enclosure Total	Femur (pCi/kg)	Femur (aCi/g/d)#	Vertebra (aCi/g/d)#
Inside Inner Enclosure (mean Pu concentration in soil = 127 μCi/m^2)							
2, A*	10.	409	0	176	3.2	18.2	41.4
11/2, B	0.01	32	172	177	7.	39.5	19.8
18/10, B	0.62	184	283	509	68.9	135.4	111.4
10/7, B+	2.8	285	0	1001	82.9	82.8	67.4
Within Outer Enclosure (mean Pu concentration in soil = 4.5 μCi/m^2)							
8, A	10.	328	0	176	0.35	2	8
3, A	11.	432	0	176	1.	5.7	3.7
1, A	12.	252	0	431	1.4	3.2	13.8
4, A	11.	300	0	431	3.	6.9	13.2
6, A	12.	325	0	431	0.5	1.2	10.6
5, A	9.	298	0	636	1.9	3.	8.1
9, A	10.	382	0	1064	2.2	2.1	10.4
19/14, B	0.62	173	283	509	5.4	10.6	43
15/4, B	1.5	311	61	637	2.9	4.5	15.7
13/5, B	1.5	250	93	637	8.3	13.	18.6
14/6, B	2.4	405	158	1001	16.7	16.7	35.1
16/9, B	2.5	409	116	1064	12.	11.3	23.4
20/1, B	2.25	302	193	1064	14.	13.2	13.2

*A = Entered enclosure as an adult; B = Born in the enclosure; B+ = Born 6 days before entry into the enclosure.
Attocuries per gram of tissue per day in the enclosure.
Format "11/2" indicates animal 11 is offspring of animal 2. Data for animals 7, 12/8, and 17/3 were not collected or not used for reasons specified in the source reference.

(Soil Pu concentration data from Gilbert, NVO-181, p. 425, CIC# 83142.)

(Adapted from Smith, NVO-181, p. 300, CIC# 64978; and Gilbert, HP 54:323, 1988, CIC# 83291.)



	Soil	Native Veg	Fistulated Steers Rumen Veg	Fistulated Steers Rumen Fluid	Beef Cattle Rumen Veg	Beef Cattle Rumen Fluid	Skin and Hair	TBLN	Lung	Liver	Vert	Femur	Gonads	Kidney	Muscle
n	84 50	84 50	54	58	3 12	3 13	4 13	3 12	3 13	4 13	4 13	4 13	1 9	2 10	3 12
GM O	13,000	1800	3200	4000	760	790	390	27	26	3.8	1.2	1.0	5.0	2.0	0.19
GM □	1400	230			330	220	150	7.4	4.2	1.0	0.63	0.16	0.41	0.14	0.048
GSD O	5.6	4.7	2.7	3.5	16	12	13	13	3.2	4.4	4.4	5.1	...	1.5	5.2
GSD □	2.6	2.5			2.0	9.7	7.5	6.6	1.9	1.9	3.1	3.4	2.6	2.3	3.1

Fig. 3. Plutonium concentrations for soil, vegetation, rumen vegetation and fluid, and cattle tissues. n = number of samples, GM = geometric mean (Bq kg^{-1} dry wt.), GSD = geometric standard deviation (dimensionless). GM = exp(ybar) and GSD = exp(s), where ybar and s are the arithmetic mean and standard deviation, respectively, of the natural logarithms of the data. The GMs and GSDs describe the median concentrations and variability, respectively, for the particular cattle present in the enclosure, and hence depend on the grazing durations, age, and other factors peculiar to those cattle. Cattle tissues are given in this figure on a dry weight basis to facilitate comparisons with soil. Plutonium transfers in Table 3 were computed using the Bq kg^{-1} wet-weight data in Table I.

FIGURE IV-1 FROM GILBERT et al., HEALTH PHYSICS, 1988

TABLE IV-10. Pu IN HOCKS OF DESERT BIGHORN SHEEP, 1972-81

Year	Animals Sampled	Range (pCi/kg)	Median (pCi/kg)
1972	11	<0.42 - 3.8	0.73
1973	15	<0.13 - 3.4	<0.51
1974	7	<0.61 - 8.5	0.9
1975	18	<0.23 - 0.6	<0.53
1976	14	<0.2 - 25.	<0.71
1977*	20	<1.9 - 6.2	<2.7
1978	13	<0.8 - 13.	<2.4
1979	12	<0.8 - <10.	<2.9
1980*	13	<0.2 - 3.6	<1.4
1981	18	<0.2 - 4.3	<0.23

*EPA changed the format for reporting minimum detectable activity and expression of counting error.
(From Smith, AIP annual reports.)

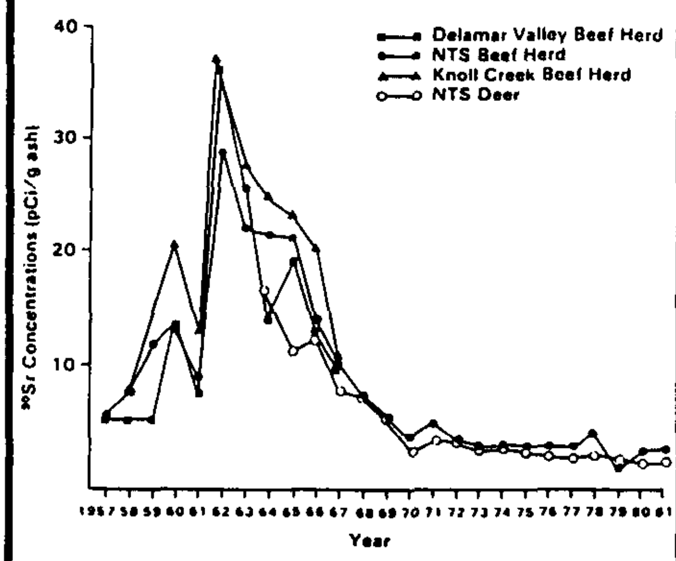


Figure 4. Average ^{90}Sr concentration in bone from Nevada cattle and Nevada Test Site deer.

FIGURE IV-2 FROM SMITH AND BLACK, EPA-600/6-84-020, 1984

[Ed. Note: Pu analyses were not performed during the period 1957–70 when the values of other radionuclides rose, peaked, and fell as illustrated in *Fig. IV–2*.]

2. Biological Retention in Muscle

a. Small Vertebrates

Results of radioanalyses of small vertebrates is reported in the "muscle" category because separate analyses of bone were not done. Rodents were typically sectioned into pelts, GIT (gastrointestinal tract), and remainder of carcass with separate radioanalyses of these components. Reptiles were sectioned in a similar manner except that results are reported for skin rather than pelt. During the later years of the NAEG, separate results were also reported for a collection of body organs which were removed from the carcass.

The first sampling of rodents under the auspices of the NAEG involved nine Great Basin kangaroo rats trapped in Area 13. Concentrations of Pu and Am were determined on the components mentioned above. The mean Pu values (in pCi/g ash) were 1050 for pelts, 720 for GIT, and 3 for the carcass (Moor, NVO-142, p. 207, CIC# 64851). Though representing a small sample and having high variability, the data suggest that a very small fraction of the Pu available in the environment is transferred into the carcass. Values for Am in the pelt and GIT were an order of magnitude lower than for Pu, and Am was not detectable in the carcass.

Small vertebrates were captured for radioanalysis in other intensive study sites; results are summarized in Table IV-11. With but few exceptions the Pu concentration in the carcass was generally less than two percent of the concentration found in the GIT at the time of capture. Considering that these results represent about 350 animals caught at different locations and different times of the year, and the relatively short life spans of these species, the contents of GITs should fairly represent the average ingestion patterns for these animals.

b. Large Vertebrates

As part of the AIP, the EPA annually sampled generally 12 beef cattle from the herd in Area 18. Published data, shown in Table IV-12, indicate the Pu retention percentage normally falls in the range from <0.01 to 0.04.

[Ed. Note: Data for Pu in muscle for 1978 appear to be unusually high; the anomalous data are not discussed in the report. Also, this retention calculation is at best an indicator of retention because the Pu in muscle is derived from earlier ingestion of forage and not derived from forage found in the rumen at the time of sacrifice. Dose estimation models take biological half-time into consideration.

Source documents also contain Pu concentration data for sampled lungs, tracheobronchial lymph nodes, livers, gonads, and some years for reticulum sediments. Similar data are available for mule deer, various other animals, and desert bighorn sheep. Analyses for gamma-emitting nuclides were also performed and the results appear in the AIP annual reports.]

C. SUMMARY REMARKS

During the 25-year existence of the AIP, various herds of cattle and other indigenous animals were sampled periodically to measure tissue concentrations of radionuclides. The cattle herds sampled included one on the NTS, one at Knoll Creek in northeastern Nevada and one in the Delamar Valley in eastern Nevada. Other animals consistently sampled included deer on the NTS and deer and bighorn sheep off the NTS. Other animals sampled when the opportunity arose included feral horses, coyotes, foxes, rabbits, and several species of birds (Smith, EPA 600/6-84-020, CIC# 65154).

The EPA calculated dose commitments from hypothetical longterm, continuous consumption of animal products. In summary, the calculations suggested that the dose commitment from ^{137}Cs for the 25-year period was 68 mrem (1.6 percent of the permissible guide set by the Federal Radiation Council (FRC)). The dose commitment from ^{90}Sr produced by activities at the NTS was considered to be negligible for the local off-site population. The 50-year hypothetical

TABLE IV-11. MEAN CONCENTRATIONS OF Pu-239 IN COMPONENTS OF SMALL VERTEBRATES CAPTURED AT VARIOUS SITES ON THE NTS.

TYPE (SITE)	No.	Skin (Pelt) (pCi/g ash)	GIT (pCi/g ash)	Carcass (pCi/g ash)	Retention Ratio Carc./GIT
Mixed lizards					
Area 11	8*	7410	8690	160	0.018
Area 11-C	9	7410	7790	170	0.022
CLEAN SLATE II	4	45	103	26	0.25
Mixed rodents					
Area 11	9&	2480	939	27	0.028
Area 11-C	53	7800	1750	80	0.045
Area 5	16	96	29	0.3	0.01
Area 18	47	800	130	0.6	0.005
Great Basin Kangaroo Rat					
Area 11	6#	140	80	1	0.012
Area 11-C	23	1930	742	4	0.005
CLEAN SLATE II	4	363	825	2	0.002
CLEAN SLATE II	6@	300	510	7	0.013
CLEAN SLATE II	15	236	6976	11	0.002
DOUBLE TRACKS	7	146	274	1.3	0.005
NAFR (Area 13)	9+	1050	650	47	0.072
NAFR (Area 13)	13	772	498	4	0.008
Great Basin Pocket Mouse					
Area 20	**		5	0.05	0.01
Little Pocket Mouse (From three activity strata; see note below.)					
Area 5 (1)	10	110	53	0.6	0.011
Area 11 (2)	19	1400	220	36	0.164
Area 11 (3)	12	23000	7800	430	0.055
Great Basin Kangaroo Rat (From three activity strata; see note below.)					
Area 5 (1)	23	85	42	0.5	0.012
Area 11 (2)	27	930	440	4.1	0.009
Area 11 (3)	8	6300	3100	21	0.007

NOTE: Concentrations of Pu in soil, pCi/g dry wt., by strata were: (1) = 60 to 730; (2) = 830 to 2,200; (3) = 2,500 to 120,000.)

* Nine skin, 8 GIT and carcass. & Nine pelt, 10 GIT, 7 carcass.
# Three pelt, 6 GIT and carcass. @ Six pelt and carcass, 7 GIT.
+ Nine pelt and GIT, 10 carcass. ** Pu detected in 1 of 2 GIT and in 5 of 19 carcass.

(Summarized from NVO reports -142, -153, -159, -171, -181, and 272.)

TABLE IV-12. MEDIAN Pu CONCENTRATION IN RUMEN CONTENTS AND MUSCLE OF AREA 18 BEEF CATTLE, 1972-79

YEAR	SAMPLES ANALYZED	Pu RUMEN CONTENTS (pCi/kg)	Pu in MUSCLE (pci/kg)	RETENTION (%)
1972	13	6.1	<0.09	<0.01
1973	12	18.	<0.07	<0.04
1974	12	20.	<0.19	<0.01
1975	14	7.7	0.17	0.02
1976	12	3.3	<0.06	<0.02
1977*	12	7.1	<0.35	<0.05
1978	5	2.5	<1.15	<0.46
1979	3	2.2	0.1	0.04

*The EPA changed the format for reporting minimum detectable activity and expression of counting error.
(From Smith, AIP annual reports.)

dose commitment from ^{3}H based on the daily consumption of 0.5 kg of meat from the NTS beef herd was 0.15 mrem (1.5 uSv). The total hypothetical dose from ^{131}I to a 2-g human thyroid at the NTS (under the conditions stated in the reference) was 3160 mrem (31.6 mSv) in 21 years, which is less than one-third of the FRC guideline. Calculations indicated that an individual living in the same area as the cattle and ingesting the same diet would realize an increase in skeletal burden of Pu by 7 pCi in 10 years. This highly improbable scenario would result in a 2.2 mrem exposure in 10 years, roughly 1.3 percent of the ICRP guideline (*Ibid.*).

The beef herd was maintained at the NTS for 25 years. No unusual health problems were encountered during this period. Routine necropsy and histopathological examination revealed no consistent pathology that could be attributed to ionizing radiation. Ocular squamous cell carcinomas ("cancer eye") were a consistent finding; however, this condition is prevalent in Hereford cattle exposed to high levels of sunlight. The reported studies suggest that since 1957 no significant amounts of biologically available radionuclides have been contributed to near off-site areas by the nuclear testing activities at the NTS (*Ibid.*).

CHAPTER V. MOVEMENT OF PLUTONIUM IN THE ECOSYSTEM

A. RESUSPENSION BY WIND

The NAEG Resuspension Element was formed to (1) study the movement of Pu at the NTS by wind-driven forces, (2) assess the potential biological hazards associated with airborne Pu particles, and (3) provide input to the Nevada Field Office (Nevada Operations Office at the time of the study) regarding cleanup of areas bearing Pu contamination. The LLNL (Lawrence Livermore National Laboratory; Lawrence Livermore Laboratory at the time of the study) thus had the opportunity to study fundamental processes involved in the resuspension of Pu particles from a soil surface, and to develop a time and spatially dependent mathematical model describing average concentration of airborne Pu as a function of the source and driving forces. The ARL (Air Resources Laboratory, now the Weather Service Nuclear Support Office), National Oceanic and Atmospheric Administration, assisted LLNL by establishing an elaborate meteorological data-gathering system for measuring micrometeorological parameters during air-sampling periods at the NTS (Phelps, NVO-142, CIC# 64853).

The Area 5 GMX site was selected for the first NAEG Pu resuspension experiment. The experiment design and a description of special air-sampling equipment are presented by Phelps (NVO-142, p. 221). The ARL measured wind, air temperature, moisture, and other meteorological parameters as described by Kennedy (NVO-142, p. 235, CIC# 64854). Goluba (NVO-142, p. 241, CIC# 64855) describes the ultrahigh-volume air sampler constructed for this experiment. Saltation and creep samplers are described by Reichman (NVO-142, p. 247, CIC# 64856). The workings of an optical particle analyzer are presented by Koval (NVO-142, p. 255, CIC# 64857). Results from this experiment and analysis of collected data are reported by Anspaugh (NVO-142, p. 265, CIC# 64859).

A short-range goal of the total NAEG program was to determine if resuspension created an occupational hazard at the fence boundaries of the GMX area. During the period February 1971 to July 1972, REECo (Reynolds Electrical & Engineering Co,. Inc.) collected 503 air filter samples at the study site and 200 control samples in Mercury; these samples were all analyzed for Pu. At GMX, samples were taken on the fence perimeter at one station northeast and one station southwest of ground zero. Following data accumulation and analyses, the researchers concluded that the Pu deposited at the GMX site represented a significant resuspension source. However, the average air concentration of resuspended Pu was only a small fraction of the (then) accepted maximum permissible concentration for occupational exposure (Anspaugh, NVO-142, p. 266).

The prediction of vertical flux of dust is a central problem in assessing resuspension of Pu and other hazardous particles. Investigations by LLNL at the GMX site indicated the flux is much more sensitive to wind speed than previously thought, and that parameterization of the flux could be accomplished to reduce the number of variables required by modelling equations. The final objective of this work was to reduce the required parameters so that vertical dust flux could be estimated given the wind speed and a soil erodibility index (Shinn, NVO-153, p. 213, CIC# 64875).

[Ed. Note: See Chapter VI for further discussion.]

B. MOVEMENT BY SOIL MICROORGANISMS

Microbial studies conducted by EPA were designed to determine the ability of microorganisms to absorb Pu, to quantify the uptake, and to determine the microbial population of NTS soils. Also investigated were the possible consequences of the increase in microbial biomass in relation to increased Pu availability to plants, and of Pu migration in soil. Microorganisms in Pu-contaminated soils may play important roles as solubilizers and translocators of deposited Pu. Solubilization processes probably result in an increased transfer of Pu from soil and plants to livestock since solubilized Pu is more readily absorbed by plants and animals, whereas translocation processes will contribute to Pu migration within the soil profile. Plant studies were conducted in small greenhouses to study the relationship of soil microbial activity to the uptake of transuranics by vegetable and field crops. Some problems with non-uniform soils arose due to the presence of relatively large "hot" particles. Studies were designed which would allow the quantification of the contribution of soil microbial activities to the mobility of Pu in terrestrial environments (Howard, NVO-274 (CIC# 83106), p. 72).

Investigators studied the influences of different chemical forms and concentrations of Pu at two pH levels of the culture medium on uptake and transport of Pu to the spores of *Aspergillus niger* (no common name). Results indicated that Pu, when added to the culture medium as dioxide microspheres, nitrate, or citrate complex, was transported to the spores, and that an almost linear relationship existed between transport and concentration. Raising the pH of the culture medium from 2.5 to 5.5 generally increased transport of Pu to spores for all three chemical forms. At low Pu concentrations in the culture media, and for both pH 2.5 and 5.5, transport of Pu to spores was approximately three times as high from the nitrate or citrate form as from the dioxide microspheres (Au, NVO-253, CIC# 64873).

A later study determined the soil microbial population for soil depth segments from 0-3 cm, 3-6 cm, and 6-9 cm in a previously uncultivated high-desert area. Plots were covered by miniature greenhouses and planted with vegetables. After harvesting the vegetables, the microbial population was reassessed. The fungal population nearly doubled during the growing season, and the bacterial population increased by a factor of approximately 12.

The fungal and bacterial live weights per hectare of the investigated desert soil were calculated and compared with those of agricultural soils. Whereas one hectare of fertile agricultural soil, to a depth of 17 cm, may contain up to 5000 kg of soil microorganisms, the dry desert soil of Area 13 contains only about 77 kg of soil microorganisms. Following growth and harvest of selected vegetables (radishes and lettuce), reevaluation indicated that up to 219 kg of soil microorganisms could be present. Even with doubled growth of fungi and a twelvefold increase in bacterial population, irrigated desert soil contained only about 4 percent of the microbial biomass of moderately fertile soil. However, because some Pu is assimilated by soil microorganisms, and this Pu becomes available to other organisms on the death of the microbial cells, soluble Pu becomes biologically available to larger life forms (Au, NVO-159, p. 76, CIC# 64955). (Other possible mechanisms for movement of Pu are also discussed.)

Upon death of the microbial cells, any cellular Pu not assimilated by another organism would become available for movement by water, possibly in a chemical form which would facilitate this movement. The activities of mobile predators such as nematodes and protozoa further complicate the picture. These predators and other animals feed on soil microorganisms and thus spread any Pu incorporated in their food. Arthropods that feed on microorganisms further move ingested Pu both vertically and horizontally. A detailed review and discussion of the microbial investigations is reported (Au, NVO-171, p. 219, CIC# 64900).

A special experiment was designed to determine the degree of transfer of Pu from one generation of microorganism to the next generation. The results showed that Pu incorporated into microbial tissue is available to successive generations. This indicates that the fraction of soil-deposited Pu which is bioavailable would increase with time (up to some limit) due to microbial action. These findings suggest several implications. First, the mobility of Pu in soil will increase with time because microbial cells containing Pu can be moved by water, and can be the food source for larger life forms (as mentioned earlier). Second, the increased bioavailability will increase plant uptake with time, and plant assimilation of Pu as a pathway to man will become more important. Last, the direct contamination by Pu of animals and man will be affected because a larger percentage of the Pu ingested and inhaled with soil and dust particles will be soluble with passage of time. Consequently, a larger percentage can be assimilated (Au, NVO-192, p. 103, CIC# 83050).

The relationship of microbial processes to the fate of transuranic elements in soil is quite complex. A review of these complexities considers the influence of soil physiochemical and microbial processes on the long-term solubility, form, and plant availability of Pu and other transuranic elements important in the nuclear fuel cycle. The toxicity of Pu to microorganisms depends on its solubility in soil. However, soil microorganisms are generally resistant to Pu, with toxicity apparently due to radiation rather than chemical effects. Highly resistant bacteria, fungi, and actinomycetes have been isolated from soil, and these organisms can transport Pu into the cell and alter its form in the cell and in solution (Wildung, NVO-178, p. 127, CIC# 64919).

A very detailed inventory of soil microorganisms was compiled from soil samples collected at different depths and different vegetated environments at the intensive-study site in Area 13. In addition to the other details presented, the study results show (Table V-1) significant numbers of microorganisms present in soil sampled to a depth of 25 cm (Au, NVO-224, pp. 201-224, CIC# 64831).

TABLE V-1. AVERAGE MICROBIAL POPULATIONS OF SOILS COLLECTED AT 21 LOCATIONS ON THE NAFR (AREA 13).

	DEPTH INCREMENT (cm)				
	0-2.5	2.5-5	5-7.5	7.5-15	15-25
Bacteria (millions)	1.2	2.3	2.	0.6	0.5
Fungi (thousands)	1.2	2.7	3.	0.9	0.8

(From Au, NVO-224, pp. 216-242.)

C. RELOCATION OF VEGETATION

[Ed. Note: Very few reasonable situations could lead to movement of Pu within or off the TRC via relocation of vegetation. The possible situations are briefly discussed in this section.]

Estimates of the standing (perennial) biomass encompassed by the intensive-study sites ranged from 2000 to 6000 kg/ha. [Ed. Note: No estimate was found of the contribution that annuals would make to these totals.] The estimated inventory of Pu contained in or on the standing biomass is presented in Table V-2.

TABLE V-2. SUMMARY OF ESTIMATED INVENTORY OF Pu FOR VEGETATION IN AGED FALLOUT AREAS

SITE	NUMBER SAMPLES	AREA (m^2)	INVENTORY (mCi)(+S.E.)		AREA MEAN (nCi/m^2)
GMX (Area 5)	113	125,300	0.47	(0.073)	3.7
PROJECT 56 (Area 11)	184	4,840,900	12.8	(1.9)	2.6
PROJECT 57 (NAFR)	141	4,017,000	28.2	(3.8)	7.0
DOUBLE TRACKS (NAFR)	48	179,000	0.39	(0.12)	2.2
CLEAN SLATE I (TTR)	53	177,100	0.54	(0.27)	3.0
CLEAN SLATE II (TTR)	63	470,500	2.6	(0.38)	5.5
CLEAN SLATE III (TTR)	41	1,732,000	5.7	(1.4)	3.3
TOTALS	643	11,541,800	50.7		

(After Romney, NVO-171, p. 35, CIC# 64889.)

Mean Pu concentrations in sampled vegetation ranged from 0.33 nCi/m^2 in Area 11, Site A, Stratum 2; to 550 nCi/m^2, Area 11, Site D, Stratum 5. The grand mean for all samples at all sites is 4.4 nCi/m^2. In terms of the Pu concentration on a dry weight basis, values ranged from 0.00064 to 1.3 nCi/g (Romney, NVO–171).

Some annual plant species could be moved after death by wind away from their growth location. A plant such as tumbleweed, were it to comprise 10 percent of the biomass in the worst-case concentration scenario, would consist of perhaps 600 kg/ha (dry weight) containing perhaps 1.3 nCi/g. Under these conditions, perhaps 800 nCi of Pu per year could be transported away from the growth location for deposition elsewhere. However, this worst-case scenario is not realistic. Tumbleweed germinates and grows in freshly disturbed areas, and seldom persists for more than a few years (because of new crust formation on the disturbed soil). Annual production of tumbleweed in any area is not likely to reach 10 percent of biomass, and after-death movement of tumbleweed by wind is generally limited to short distances. Also, areas of the NTS contaminated with significant levels of Pu are fenced; these fences act as departure barriers for wind-blown tumbleweed.

Contaminated vegetation could be moved by harvest and subsequent transport. This mechanism is not relevant to the NTS because no crops are produced there. Some tests were conducted in areas that have been identified as having agricultural potential; however, these lands will not likely become cropland because they are within government-controlled areas set aside for uses incompatible with crop production.

D. RELOCATION BY ANIMALS

[Ed. Note: Pu can be moved through the ecosystem by vertebrates. The NAEG investigated two general situations and the results were presented, albeit in a different context, in Chapter IV. Rodents, lizards, and larger free-ranging mammals carry some average body burden of radionuclides. Voluntary exit, man-induced relocation within the NTS, or removal from the NTS represent relocation by animals. This aspect of Pu movement in the ecosystem was not addressed directly by NAEG studies. However, tissue samples collected for radioanalyses were handled as contaminated materials and were preserved or disposed of in accord with procedures addressing this situation.]

E. BIOLOGICAL TRANSFER

Discussion here will be limited to transfer from adults to offspring. Data are available with regard to (1) calves born within the enclosure at the Area 13 intensive-study site, (2) calves born at the EPA farm in Area 15 or in the beef herd in Area 18, (3) eggs produced by chickens fed known concentrations of radioactive materials, and (4) milk produced by cows and goats fed or injected with radioactive materials. These four topics will be discussed in order.

(1) Data for this topic is limited to two 8-month fetuses from sacrificed cows and one calf sacrificed five days after birth (animal 11/2 in *Table IV–9*). The Pu concentration in the femur of animal 11/2 was found to be 7 pCi/kg of bone. [Ed. Note: For comparison, the Pu concentration in the femur of the adult cow (animal 2) placed in the same enclosure was 3.2 pCi/kg of bone.] Positive Pu concentrations were found in several tissues sampled from the fetuses. However, the researchers concluded that

> While some transfer of Pu to the fetus did occur for these cattle, the data were inadequate to permit an accurate correction to the estimated transfers (Gilbert, CIC# 83291).

(2) [Ed. Note: AIP data are available for two fetuses (CIC# 14392, CIC# 6163) and several calves but a few days old (CIC# 14389, CIC# 83284, CIC# 67387). Most of the analytical results are below detection limits; positive values vary over a broad range. In general, Pu-238 and Pu-239 results varied from close to but below the values for the dam to only a small fraction of

the value for the dam. Collected tissue samples were samples of opportunity rather than the results of a controlled experiment; the investigators did not draw conclusions from the data.]

(3) Studies of transport of actinides through the chicken to the egg involved oral administration of ^{238}Pu citrate, particulate ^{238}Pu, and ^{241}Am. Egg yolks, whites, and shells were analyzed for nuclide content; radioactivity was observed in only the yolk. Plutonium citrate reached a peak of 0.0155 percent of the administered dose nine days after initial ingestion (Mullen, NVO-142, CIC# 64852). Additional research reported the Pu and Am concentrations in other chicken tissues and noted that the highest concentration per organ, 0.003 percent of dose, occurred in the liver of hens sacrificed 10 days after final administration of ^{241}Am (Mullen, CIC# 39423; Mullen, CIC# 53671).

(4) The EPA conducted numerous studies of radionuclide biotransport at the NTS farm during the 1970s. Most of these studies used ^{238}Pu, ^{241}Am, or ^{243}Cm for evaluation of retention and excretion; however, one study used ^{239}Pu for comparison to ^{238}Pu. Studies were reported in the NVO compilations. Stanley reported on the absorption, distribution, and excretion of plutonium in dairy cattle (NVO-142, CIC# 64850; NVO-153, CIC# 64869). Sutton reported on bovine milk uptake of ^{238}Pu (NVO-171, CIC# 64898); goat milk uptake of ^{243}Cm (NVO-171, CIC# 64897); plutonium retention in dairy calves following ingestion of labeled milk (NVO-181, CIC# 64975); and metabolism of ^{241}Am in dairy animals (NVO-192, CIC# 83047). These and other studies were summarized by Sutton (EMSL-LV-0539-35, CIC# 14404) in 71 detailed data tables. In general, transport of orally administered ^{238}Pu, ^{242}Am, and ^{243}Cm to milk was of the same magnitude (0.0002 percent); transport of intravenously injected doses was four orders of magnitude higher. [Ed. Note: The difference between orally and intravenously dosed transport is an indication of the effectiveness of the gastrointestinal barrier against particulate radionuclides of the size administered .]

Mullen, reporting on the transfer of ^{234}Np to goat milk, found the highest concentration in the milk of the orally dosed goats reached 0.005 percent of the dose per liter at 17 hours after ingestion. For an intravenously dosed goat the peak concentration in milk was 0.07 percent of the dose per liter at 5 hours after dosing (Mullen, NVO-181, CIC# 64977).

[Ed. Note: The reader is directed to this source for an explanation of the hypothesized relationships between neptunium and plutonium reactions in biotic media.]

CHAPTER VI. EVALUATION OF THE PLUTONIUM HAZARD ON THE TEST RANGE COMPLEX

A. DISPERSION BY NATURAL FORCES

Scientists from the LLNL have investigated Pu-aerosol resuspension at weapons test sites since 1968. Before 1970, the group studied resuspension at sites of nuclear cratering experiments. From 1971 to 1975, they conducted a major field study at the GMX site in Area 5 (Anspaugh, NVO–142, CIC# 64858; Anspaugh, HP 29:571-82, CIC# 83130) where many small nonnuclear explosions spread Pu over a limited area. From 1976 to 1980, they investigated Pu-aerosol characteristics at Bikini and Enewetak Atolls in the Pacific [Ref. 8]. Studies at NTS were resumed in 1980 with an investigation of Pu resuspension at the LITTLE FELLER II site in Area 18 (Shinn, NVO–272, CIC# 83092). This was followed by supporting the cleanup and treatment trials at the nonnuclear PROJECT 56 test site in Area 11 [Ref. 9].

In a study beginning in 1981, LLNL scientists monitored Pu-aerosols at the air inflow (southwest) and outflow (northeast) ends of Frenchman Flat in Area 5. In 1982, exploratory resuspension studies were carried out in Area 2 and in Area 10 near the SEDAN crater. From 1982 to 1986, the group carried out a year-long Pu-aerosol monitoring and resuspension study at the PALANQUIN test site in Area 20.

Resuspension studies of Pu-aerosol at the GMX, PROJECT 56, LITTLE FELLER II, and PALANQUIN sites are compared with similar studies in South Carolina, California, and the Pacific atolls. The scientists investigated the Pu-aerosol flux caused by wind erosion, the Pu-aerosol size distributions, and trends in Pu-aerosol concentration as affected by season and by disturbance (raking, grassfire). They used meteorological flux-gradient techniques supplemented by a portable, floorless wind-tunnel to control stress on the soil surface. They observed differences between sites due to the type of contaminating event and the peculiarities of the soil. Comparisons of resuspension rates, resuspension factors, enhancement factors, and median aerodynamic diameters are presented in Table VI–1. Seasonal trends in specific activity and in Pu concentration are reported to be out of phase in one case. Handraking and a grassfire caused great differences in specific activity as well as in dust concentrations [Refs. 10 and 11]. The resuspension factors, Pu flux, resuspension rates, and resuspension half times are shown in Table VI–2.

At the nonnuclear sites, GMX and PROJECT 56, micrometer-size Pu oxide particles were attached strongly to soil particles, and the ratio of specific activity in the aerosol to that in the soil (enhancement factor) was close to unity. On the other hand, the nuclear sites, LITTLE FELLER II and PALANQUIN, had much of the Pu contamination enclosed in tiny, amorphous glass beads which, although contributing to a soil concentration like that of the nonnuclear tests, produced orders-of-magnitude lower enhancement factors and lower Pu-aerosol concentrations. The PROJECT 56 site is the most erodible of the four sites and produced the highest dust concentration. Particle-size distributions were comparable in all four sites, producing about the same deep-lung respirable fraction (Shinn, UCRL-90746).

The important conclusion from comparing these site results is that the largest Pu source term for off-site transport occurred from the highly erodible PROJECT 56 site, a result not necessarily predicted by the soil-borne Pu, the aerosol-resuspension factor, or the wind characteristics. The nonnuclear safety-shot sites appear to be of larger environmental concern than nuclear sites, and may have to be examined on a case-by-case basis because these sites differed so greatly in their resuspension rates (*Ibid.*).

B. ACTIVITY IN VEGETATION

Radioactivity in vegetation has been measured directly as reported in Chapter IV. Another useful method for evaluating the Pu hazard is to examine the radioactivity in the rumen contents of ruminants grazing in areas contaminated with radionuclides of interest. Such examinations

TABLE VI-1. THE Pu AEROSOL CHARACTERISTICS AT FOUR LOCATIONS ON THE NTS, EACH WITH LOW-DENSITY SHRUB COVER

Location	Pu surface soil (pCi/g)	Pu aerosol (pCi/m^3)	Enhancement factor	Mass loading (μg/m^3)	AMAD* (μm)	Respirable# (%)
GMX	8,370	0.12	0.87	17	5.7	10
PROJECT 56	620	0.026	1.04	41	5.5	10
LITTLE FELLER II	675	0.0002	0.02	22	2.7	13
PALANQUIN	17,980	0.0002	0.002	7	2.5	14

* AMAD = Activity Median Aerodynamic Diameter.
# Respirable = Percent of particles retainable in the pulmonary region.

(After Shinn, UCRL-90746)

TABLE VI-2. Pu AEROSOL EMISSIONS AT FOUR LOCATIONS OF THE NTS, EACH WITH LOW-DENSITY SHRUB COVER

Location	Resuspension factor (m^{-1})	Pu flux (pCi/m^{2}s)	Resuspension rate (s^{-1})	Resuspension half time (y)
GMX	2.0×10^{-10}	5.1×10^{-4}	7.9×10^{-13}	2.7×10^{4}
PROJECT 56	6.1×10^{-10}	1.7×10^{-3}	3.8×10^{-11}	5.6×10^{2}
LITTLE FELLER II	4.3×10^{-12}	1.6×10^{-4}	6.0×10^{-13}	3.6×10^{4}
PALANQUIN	1.8×10^{-13}	8.9×10^{-6}	6.7×10^{-15}	3.3×10^{6}

(After Shinn, UCRL-90746)

were conducted for the years 1972–81 for mule deer from various locations on the NTS and for the years 1972–79 for beef cattle grazing in Area 18 of the NTS. The results of these examinations, for only Pu, are shown in Table VI–3.

TABLE VI-3. MEAN PU IN RUMEN CONTENTS OF SAMPLED BEEF CATTLE AND MULE DEER FORAGING ON THE NTS

	Beef Cattle		Mule Deer	
Year	Number Animals Sampled	Pu (pCi/g ash)	Number Animals Sampled	Pu (pCi/g ash)
1972	11	0.32	4	0.12
1973	10	0.85	3	0.13
1974	11	0.68	4	0.25
1975	13	0.86	7	0.20
1976	12	0.13	6	0.42
1977	12	0.34	8	0.12
1978	4	0.09**	5	0.03
1979	3	0.13	4	0.06
1980	-	-	4	0.08
1981	-	-	4	0.19
Means		0.43		0.16

** When the anomalously high value of 21 pCi/g ash from one additional animal is included, the mean for 5 sampled animals becomes 4.28 pCi/g.

(Abstracted from annual AIP reports.)

The EPA also measured radionuclide content of reticulum sediments in beef cattle during some years of the AIP. A comparison of Pu in rumen contents with Pu in reticulum sediments can be made for 45 animals sampled from 1973–79. Residual vegetation was removed by oxidation of the reticulum sediments by heating at 450°C for 3 hours. Pu in rumen contents ranged from 0.013 to 6.2 pCi/g ash. Pu in reticulum sediments ranged from 0.021 to 3.2 pCi/g ash. The ratio of the means for all animals was 0.99, and the r^2 from regression analysis was 0.009 (indicating absence of correlation). The ratio of Pu in reticulum sediment to Pu in rumen for individual animals ranged from 0.006 to 31.6.

Pu in the rumen contents of beef cattle and mule deer may be considered from several aspects. First, this parameter represents an average concentration of Pu on (resuspended) and in (root uptake) consumed vegetation. Second, this parameter may be thought of as the source term of interest to subsequent steps in the food chain analysis; Pu in the rumen is available for fractional transfer through the gut wall to blood. These parameters are used in modeling Pu concentrations in edible tissue (Kercher, NVO–272) as discussed later in this chapter.

C. ACTIVITY IN FREE-RANGING ANIMALS

[Editorial Note: One way to evaluate the hazard to man from Pu in the environment is to formulate a set of circumstances wherein man would ingest contaminated animal products. The results of such ingestion can be modeled and an estimate of internal exposure via ingestion can be calculated. This exercise has been completed by the EPA using the results of the AIP.]

During the life of the AIP, many animal tissues were sampled for radioanalysis and several radionuclides were targeted for evaluation. Long-term studies of ^{137}Cs, ^{90}Sr, ^{3}H, ^{131}I, and ^{239}Pu in animal tissues have been reported by EPA and are summarized by Smith for the period 1957–1981 (EPA 600/6-84-020, CIC# 65154). Details of annual sampling and analyses appear in annual reports. (Annual reports for the period 1969–1981 are identified in Bibliographies, Part C.) While other radionuclides were evaluated, data for only Pu will be presented here.
The EPA'S modeling results are stated as follows:

> Although meat from animals living on the NTS is not available for consumption by the general public, the dose to a standard man based on postulated consumption of the meat can be calculated. The dose estimates are not presented as an implication of potential doses, but rather to place the reported radionuclide concentrations in perspective. The dose estimates are based on the techniques and parameters of the International Commission on Radiological Protection [ICRP Reports 2 and 10], the maximum observed concentrations of the radionuclides in edible tissues of the cattle and deer sampled, and the postulated consumption of 500 grams (about 1 pound) of the meat each day for a year. (Smith, NERC-LV-539-35, 1976, CIC# 16234.)
>
> The ICRP [Report No. 2, 1959] and the DOE [Manual Chapter 0524, 1977] present different dose criteria for various parts of the body, based on estimates of relative radiosensitivity. The National Council on Radiation Protection and Measurements (NCRP) recognizes this philosophy, but recommends simplifying the guides for the general population, and uses the minimum guide (0.5 rem per year to the whole body for an individual in an uncontrolled area) for all body organs. The NCRP emphasizes that this is a simplifying administrative decision, rather than a reduction of the guides based on new technical information. (Smith, EPA 600/3-83-014, 1981, CIC# 41868.)

The EPA's postulated maximum doses to bone are shown in Table VI–4. The 50-year Pu dose to bone of 1.5 mrem, shown as the mean of the 10 annual maximums, is about an order of magnitude higher than the 50-year dose to bone from all radionuclides and all sources modeled by Kercher (NVO–272, p. 500, CIC# 83101). [Ed. Note: Kercher's model is the more detailed and may be considered the more realistic.] The largest 50-year dose, postulated by EPA from the anomalously high 1975 mule deer liver, was 0.4 percent of the simplified guide of 500 mrem per year to any body organ.

D. DOSE ESTIMATION MODELS

The first NAEG report on dose estimation models describes the procedure in the following general terms:

> The usual method of evaluating the radiological hazard associated with the presence of a given radionuclide in a given area is to calculate the potential radiation dose, due to that radionuclide, to people and other organisms that live in or are assumed to live in the contaminated area. To calculate potential internal radiation doses, it is necessary to determine the rates and routes by which the radionuclide may be transported (via soil, air, water, food, etc.) to man, how the radionuclide is then distributed in the body, the rates at which it is eliminated from different organs, and various other metabolic and radiometric parameters such as those given in the reports of ICRP-II (1959). To calculate potential radionuclide ingestion and inhalation rates, one must be able to characterize the behavior of the radionuclide of reference in the environment or ecosystem of reference.

TABLE VI-4. PEAK Pu CONCENTRATIONS IN LIVER AND MUSCLE FROM NTS BEEF CATTLE AND MULE DEER, AND HYPOTHETICAL 50-YEAR DOSE TO BONE FROM DAILY CONSUMPTION OF 500 GRAMS OF THE UNDERLINED TISSUE FOR ONE YEAR

	Beef Cattle			Mule Deer			
	No. Samp.	Pu in Liver (pCi/kg)	Pu in Muscle (pCi/kg)	No. Samp.	Pu in Liver (pCi/kg)	Pu in Muscle (pCi/kg)	50-Year Dose (mrem)
1972	12	<u>5.0</u>	0.38	4	<0.4	0.1	1.6
1973	12	<u>1.0</u>	<0.17	4	<0.047	0.094	0.3
1974	12	<u>3.1</u>	0.66	5	0.34	0.024	1.0
1975	13	3.1	1.3	8	<u>14</u>.	2.3	4.5
1976	12	<u>2.3</u>	0.41	6	0.4	0.56	0.7
1977	12	4.1	<u>7.3</u>	8	0.97	1.3	2.3
1978	12	<u>6.9</u>	1.0	6	1.8	2.9	2.2
1979	6	0.69	<0.099	4	<u>4.6</u>	4.6	1.5
1980	6	<u>0.64</u>	0.12**	4	0.13**	0.053**	0.2
1981	14	<u>2.3</u>	0.48	4	1.1	0.082**	0.7
Mean		2.9	1.2		2.4	1.2	1.5

** Counting error exceeded reported activity.
Liver and muscle samples not necessarily from the same animal.

(Abstracted from annual AIP reports.)

A preliminary model of potential Pu transport to man was introduced during the planning stage of the NAEG Pu Study in an effort to ensure the inclusion of laboratory and field studies which would provide the data and parameter estimates needed for later implementation of a Pu transport and dose estimation model which would: (1) simulate the behavior of Pu in desert ecosystems such as those found at NTS; (2) provide estimates of Pu ingestion and inhalation rates by Standard Man, assumed to live in a Pu-contaminated area; and (3) provide estimates of potential radiation doses, as a function of exposure time, to different organs (Martin, NVO-142, CIC# 64863.)

Martin presents an explanation of model assumptions, definition of model parameters, dose estimates for a person living in the contaminated area, and discussion of information needed to improve parameter estimates. Definitive values for many important parameters were not available in the early 1970s; these parameters were updated in later years as various studies were completed.

It is important to understand the "worst-case" scenario for the hypothetical man for whom these estimates pertain. The case presented here can be briefly summarized as follows:

Hypothetical man (Standard Man) enters a plutonium-contaminated area at NTS when he is 20 yr old and remains there until he is 90 yr old. The boundaries of the area in which he lives, and the initial concentrations of ^{239}Pu in soil and other ecosystem compartments, are variables to be determined by the model. During his 70-yr sojourn in this specified area, hypothetical man breathes contaminated air continuously. The concentration of plutonium in the air inhaled is a constant fraction of the average plutonium concentration in the top 2 cm of soil. He accidentally swallows a certain amount of soil each day, and he consumes specified estimated quantities of 1-yr-old vegetation as well as milk, muscle, and liver from 3-yr-old cows. The cows feed on an as yet unspecified mixture of annual and perennial plants and, in the process of grazing, accidentally swallow large quantities of soil. The concentration of plutonium in the food items consumed by hypothetical man are also expressed as constant fractions of the average plutonium concentration in the top 2 cm of soil. (Martin, NVO-142, p. 355.)

Modified and improved versions of this model were developed and reported (Martin, NVO-178, CIC# 64946). The improvements were the adoption of an improved inhalation model for man and simplifications in the vegetation-concentration portions of the model. Using the ingestion submodel for grazing cattle, Martin (NVO-192, CIC# 83070) analyzed the results of field studies at the NTS, found good agreement between model and experiment, and concluded that the experiments were internally consistent and well designed. Martin (NVO-178) also made detailed comparisons between NAEG model versions which had the ICRP II lung model (ICRP, 1959), the ICRP Task Group on Lung Dynamics (ICRP, 1972) lung model, and a lung model proposed by Stuart *et al.* (1968, 1971. See Martin, NVO-178 for these references.). Martin [Ref. 12] concluded that the model on the ICRP Task Group on Lung Dynamics was the model of choice. Martin (NVO-192) considered the effects of variations in model parameters on model results and examined the variations among predicted results for the three translocation classes that can be assigned to Pu; i.e., daily, weekly, or yearly (ICRP, 1972). The effect of particle size on equilibrium lung burden and the rate at which Pu reaches the blood were also considered. Bone burden as a function of blood-to-bone transfer rates and turnover time in bone was examined also. However, Martin (NVO-192) did not provide a comprehensive sensitivity analysis of the effect of variation of all model parameters on the cumulative dose to all target organs (Kercher, NVO-272, CIC# 83101).

The 1985 NAEG model divides the system into these compartments: (1) soil, (2) desert vegetation, (3) cultivated vegetables, (4) alfalfa, (5) beef cattle, (6) milk cows, (7) air, and (8) man as illustrated in Fig. VI-1. The beef cattle, milk cow, and man submodels describe radionuclide movement between internal organs. The transfers between the compartments are linear functions of the amount of radionuclide in the donor compartment. Thus, the model is described as a set of linear, ordinary, donor-controlled differential equations. The ecosystem portion of the model is not treated as fully dynamic. That is, the air, vegetation, and milk-cow compartment equations are solved at steady-state. The beef cattle equations are solved at a fixed end point; i.e., time-of-slaughter. Thus, the ecosystem portion of the model is static. The man model (ICRP, 1972), on the other hand, is fully dynamic; i.e., the compartment burdens and dose rates change over time (Kercher, NVO-272).

Kercher (*Ibid.*) examines the sensitivity of the NAEG model, analyzes the contribution of each pathway to the dose of each organ, and discusses the uncertainty in the model's predicted results (shown in Fig. VI-2) based on simultaneous propagation of all model parameters.

Sensitivity analysis results suggest that air is the critical pathway for the organs receiving the highest dose. Soil concentration and the factors controlling air concentration are the most important parameters. The only organ whose dose is sensitive to parameters in the ingestion pathway is the GI tract. The air pathway accounts for 100 percent of the dose to lung, upper respiratory tract, and thoracic lymph nodes; and 95 percent of the dose to liver, bone, kidney, and total body. The GI tract receives 99 percent of its dose via ingestion. Leafy vegetable ingestion accounts for 70 percent of the dose from the ingestion pathway regardless of organ; peeled vegetables 20 percent; accidental soil ingestion 5 percent; ingestion of beef liver 4 percent; beef muscle 1 percent. Only a few model parameters control the dose for any one organ. The number of important parameters is usually less than 10 (Kercher, NVO-272).

Uncertainty analysis indicates that choosing a uniform distribution for the input parameters produces a lognormal distribution of the dose. The ratio of the square root of the variance to the mean is three times greater for the doses than it is for the individual parameters. As found by

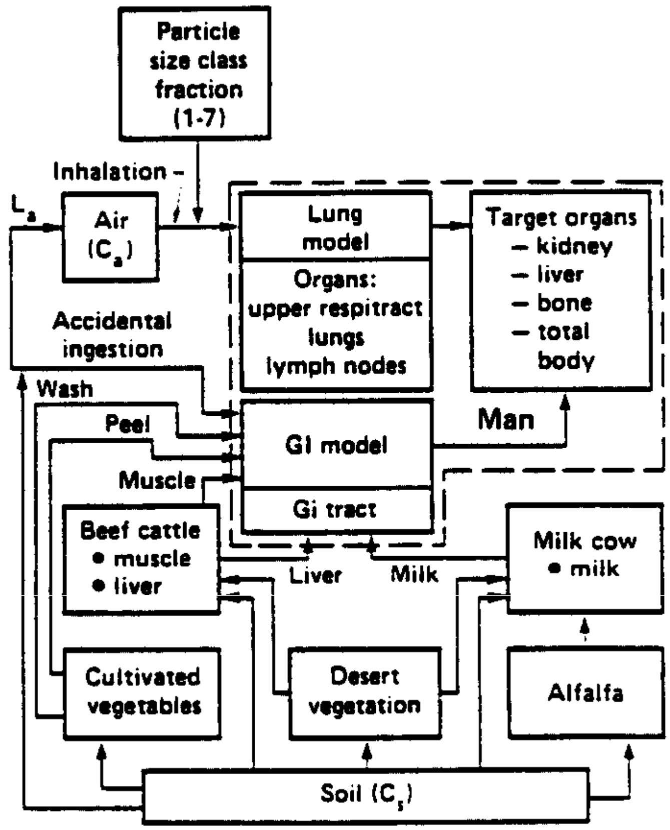


Figure 1. Schematic Diagram Showing Compartments of Major Submodels of the NAEG Model. Transfer of Pu Between Compartments Are Shown by Solid Arrows. The Man Submodel Is Surrounded by A Dashed Line.

FIGURE VI-1 FROM KERCHER AND ANSPAUGH, NVO-272, 1985

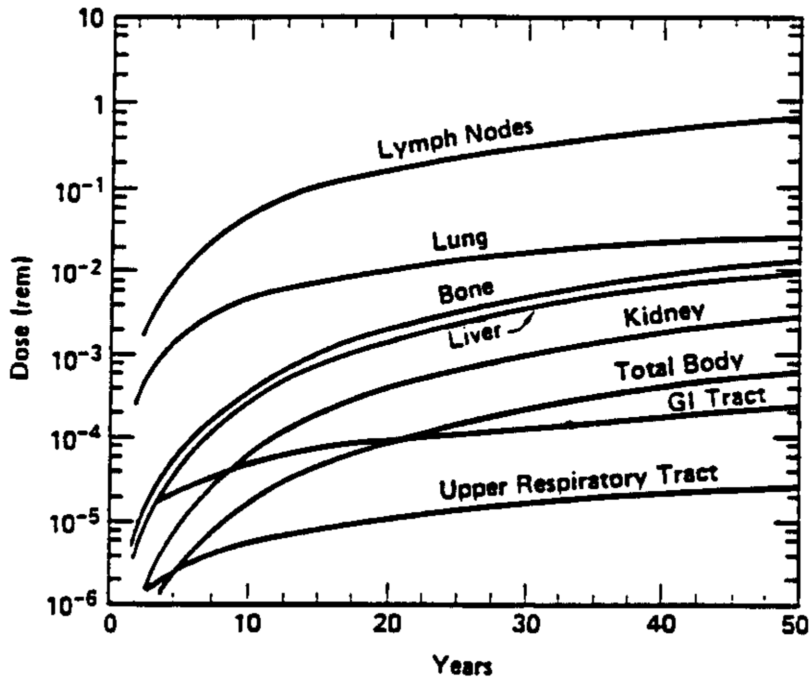


Figure 6. Cumulative Dose To All Organs Calculated in The NAEG Model. Simulation Is for a 50-year Exposure To Environmental Values in Tables 1 through 7.

FIGURE VI-2 FROM KERCHER AND ANSPAUGH, NVO-272, 1985 the sensitivity analysis, the uncertainty analysis suggests that only a few parameters control the dose for each organ. All organs have similar distributions and variance to mean ratios except for lymph nodes (Kercher, NVO-272).

E. REMEDIAL ACTION GUIDELINES

In their earlier analysis, Martin and Bloom [Ref. 13] calculated an acceptable Pu soil concentration. Using the lung as the critical organ which would have a permissible dose rate of 1.5 rem/yr, they calculated that the corresponding soil contamination level would be 2817 pCi Pu/g of soil (Kercher, NVO-272). The areas of NTS and TTR listed in Table VI-5 contain concentrations of Pu in excess of 2817 pCi/g. The total area exceeding this value is shown to be 156,200 m^2.

TABLE VI-5. AREAS OF INTENSIVE-STUDY SAFETY-SHOT SITES EXCEEDING 2800 pCi Pu-239 PER GRAM OF SOIL

Site	Strata	Pu Concentr. (pCi/g)	Area (m^2)	Portion of Inventory In Stratum (%)	Portion of Inventory In Area (%)
NAFR (Area 13)	6	14,245	24,000	43	43
Area 5 (GMX)	3	4,555	800	15	
	4	8,596	1,000	36	51
DOUBLE TRACKS	2	6,422	1,600	16	
	3	3,440	800	4	
	4	50,459	600	47	67
CLEAN SLATE II	3	5,721	26,200	41	
	4	5,605	11,000	17	58
CLEAN SLATE III	3	4,688	40,000	23	
	4	8,196	16,000	16	39
Area 11-B	3	5,323	6,000	21	
	4	33,224	3,300	75	96
Area 11-C	4	31,977	3,500	62	
	5	138,568	300	24	86
Area 11-D	3	4,385	13,300	17	
	4	19,802	4,900	29	
	5	53,018	2,900	46	92
TOTAL AREA			156,200		

(Adapted from GILBERT, NVO-181, p. 425, CIC# 83142.)

In 1977, the EPA proposed 0.2 $\mu Ci/m^2$ (in the top 1 cm) as screening guidance on transuranium elements in the general environment [Ref. 12]. With this proposed screening level as a firm upper limit, the total area to be given remedial action at intensive-study sites would be greater than 11,500,000 m^2; how much greater cannot be estimated because NAEG investigations did not extend far enough out from ground zeros to define the boundaries of areas with Pu concentrations as low as 0.2 $\mu Ci/m^2$.

[Ed. Note: The Pu hazard on the TRC must be evaluated with regard for potential health impacts on people, but the cost of remedial action cannot be ignored; the difference in cleanup cost between 156,000 m^2 and 11,500,000 m^2 must be factored into the cost/benefit analysis. The specification of "acceptable" cleanup criteria would have a significant impact on the area to receive cleanup treatment.]

CHAPTER VII. REMEDIAL ACTION ALTERNATIVES AND TECHNIQUES

A. INTRODUCTION

Identification of areas which need to be cleaned up or treated (NAEG Objective 5) is inextricably tied to the evaluation of radiological hazards of Pu on the NTS (Objective 4) and to applicable cleanup criteria. Arguments have been tendered to support the concept of applying different criteria to lands subjected to different uses similar to the idea that standards for one-time human exposure differ from the standards for chronic exposure. Land earmarked for residential use should meet more stringent criteria than would apply to land earmarked for agricultural use; unused, uninhabited, controlled-access lands should be allowed even less stringent criteria. Early NAEG investigations led to the following appraisal and definition of the magnitude of the cleanup task at the NTS:

> . . . [I]t is a common practice to establish standards, even though adequate data are not available. A number of standards for plutonium have been proposed. One of the most recent proposed soil standards is that of Healy and Smith (1973). If their proposed standard of 0.4 $\mu Ci/m^2$ is accepted, then it is clear from the tables [Gilbert, NVO-153, p. 339] that all of the areas within the boundaries of all the intensive-study sites would have to be cleaned up. The total area would be about 4.4 mi^2 or 11.4 km^2. Assuming removal of soil down to a depth of 10 cm, the resultant amount of soil to be removed would be about 6.0 x 10^6 yd^3. ([For comparison, the] Sedan crater volume: 6.5 x 10^6 yd^3.) Assuming a density of 1.6 g/cc for soil, there would be approximately 8.7 x 10^6 tons of soil to be removed. These estimates are probably minimal because: (1) there are obviously areas beyond the boundaries of the study sites which exceed 0.4 $\mu Ci/m^2$; (2) soil standards for ^{241}Am and uranium radioisotopes are not considered, although cleanup of plutonium presumably would also largely satisfy soil standards for ^{241}Am and uranium; and (3) some areas would need cleanup to a greater depth than 10 cm, particularly where mechanical disturbance has occurred.
>
> If the more permissive Healy and Smith (1973) standard of 8 $\mu Ci/m^2$ is accepted, the situation for the intensive-study sites would not be materially improved . . ., although the amount of soil to be removed beyond the boundaries would presumably be much less. (Dunaway, NVO-153, p. 500, CIC# 64886.)

A later study presented rough estimates of the amount of soil removal necessary to decontaminate the land surface at selected sites to meet an upper limit criterion of 160 pCi Pu per gram of soil. Including ^{238}Pu and ^{241}Am in the criterion did not make a significant difference to the estimates because these radionuclides are not present in significant amounts. Results of these rough estimates are presented in Table VII-1.

Wallace and Romney reviewed proposed standards for Pu in soil, along with other important environmental factors that must be considered in any remedial treatment, and summaries were presented of land area decontamination experiences. Situations summarized include incidents involving planned and accidental release of Pu in the environment, problems involving fallout from nuclear tests, and materials from industrial processing which relate to the Pu cleanup problem. Also discussed were revegetation and land recovery experiences under arid conditions, and decontamination and land restoration procedures which may be useful in Nevada. Eight procedures are presented (Wallace, NVO-153, p. 251, CIC# 64879); six of the eight are summarized below. The procedures not summarized are combinations of summarized procedures. In every case, combining two or more procedures increases the total cost without contributing additional benefits.

TABLE VII-1. ESTIMATES OF LAND SURFACE AREA, SOIL VOLUME, AND SOIL WEIGHT REQUIRING DECONTAMINATION UNDER SPECIFIED ASSUMPTIONS FOR SELECTED INTENSIVE-STUDY SITES

SITE	AREA ($m^2 \times 10^5$)	VOLUME ($m^3 \times 10^4$)	WEIGHT ($kg \times 10^7$)
PROJECT 57	10.7	16.	18.
CLEAN SLATE I	1.77	2.7	2.4
CLEAN SLATE II	2.36	3.6	3.3
CLEAN SLATE III	17.3	26.	24.
DOUBLE TRACKS	0.62	0.92	1.
TOTALS	32.8	49.2	48.7
Acres	810		
Cubic yards		643,137	
Tons			537,000

Assumptions:
1. Decontaminate areas with $^{239+240}Pu$ >160 pCi/g of soil; this corresponds to about 9 uCi/m^2
2. Soil removal to an average depth of 15 cm.
3. Average soil density varied by site between 0.91 and 1.1 g/cm^3.

[Ed. Note: These densities differ from the usual 1.5 to 1.6 g/cm^3 used in other studies of NTS soils.)

(After Kinnison, NVO-224, p. 89, CIC# 64824.)

B. ISOLATION

Isolation with permanent fences would bar people and livestock from contaminated areas, would be less costly than removal and burial of contaminated soil, would not require revegetation, and would postpone additional treatment until a suitable technology is developed. The disadvantages of this procedure are that contaminating material would still be subject to some erosion and distribution by wind and water, increasing the size of the contaminated area requiring eventual cleanup, and the areas would not be available to the public or to large mammals. Isolation differs from "do nothing" in the sense that isolation is intended as a temporary measure to be taken until an economically and environmentally acceptable technology has been developed for Pu removal, whereas "do nothing" is intended as a long-term measure. Both alternatives require construction and maintenance of suitable fencing.

C. SELECTIVE SURFACE REMOVAL

Soil to a depth of 10 cm could be removed, but leaving at least 100 plants per acre (about 250 plants/ha). The advantages of this procedure are that long times will not be required for revegetation, that remaining plants will contribute to natural reseeding, protection and feed are assured for maintenance of native animal populations, costs of revegetation are largely avoided, erosional losses would be reduced, and the area is reasonably environmentally and aesthetically acceptable. The disadvantages are seen to be that selective soil removal is more costly than complete removal, cleanup may not be 100 percent effective, dust problems could arise during the removal process, there would be some loss of biomass, and some erosion by water could be accelerated.

[Ed. Note: The above general statement does not describe any particular method to be used for selective removal of contaminated surface soil. The following paragraphs describe one experimental method used to test this procedure.]

A Cleanup and Treatment (CAT) test was conducted during the summer of 1981 at the PROJECT 56 site in Area 11. A large truck-mounted vacuum unit was used for primary soil collection. The test was designed to (1) evaluate the viability of a vacuum method for land area decontamination, (2) evaluate the cost-effectiveness of the vacuuming method as compared with conventional earthmoving methods, (3) evaluate radiological safety aspects for the equipment operators, and (4) investigate environmental and operational impacts of devegetation with retention of root crowns and systems.

At the end of the test, the investigators concluded that (1) decontamination of land areas by the vacuum method is feasible with state-of-the-art equipment (the old equipment actually used had many mechanical problems), (2) for surface contamination, the vacuuming method presents an advantage over conventional earthmoving techniques because of the reduced volume of collected material possible with selective collection, (3) radiological safety could be maintained for equipment operators, and (4) selective removal of surface soil would likely minimize removal of organic matter and other nutrients (Orcutt, DOE/NV/00410-70 [Ref. 9]).

In a coordinated study, field surveys were conducted before and after the CAT trial to determine relative abundance of vertebrates. Investigators estimated by extrapolation from plots surveyed before treatment that up to 300 rodent burrows/ha existed in the area to be treated. No lizards were observed on the test plots. Resurveys conducted one and two years after treatment found no rodent burrows, but two lizards were seen on the edge of the treated area. The investigators concluded that removal of shrubs and 2 to 5 cm of surface soil had an immediate, dramatic, negative effect on indigenous small mammals. The closing discussion states:

> Although human health standards might demand decontamination of certain areas on NTS, the decision on whether to proceed should be made with the knowledge that serious, probably long-term, ecological effects would result . . . . If immediate human health risks are not involved, the seriousness of the ecological costs should be one reason to consider leaving the stabilized contaminants in place and continuing to restrict access. (O'Farrell, NVO–272, p. 317, CIC# 83095.)

D. COARSE-CUT SURFACE REMOVAL

This procedure consists of mechanically removing some defined surface layer, transporting the removed material to an acceptable site, and depositing the material for long-term storage. The area would be denuded of vegetation, and the new surface would be less fertile than was the original surface. This procedure may be less costly than leaving growing shrubs in place, cleanup may be closer to 100 percent complete, and the operation can be done rapidly. The disadvantages are that revegetation would be more difficult, that the excised area might be dusty until soil stabilization is achieved, that soil amendments may be required to restore fertility, and that native animals would be lost until they are replaced by migration from surrounding areas.

E. IN-PLACE SURFACE TREATMENT

Several treatments are available to decrease resuspension of Pu. The report mentions metallic iron, krilium, and light road oil. The advantage is that contaminated soil would not have to be relocated and stored. Disadvantages are that the Pu remains in the environment, the procedure could be costly and might not last an adequate period, and rainfall runoff may be increased.

A more drastic version of this option is to use asphalt or road oil to cover contaminated areas (but leaving an untreated space around major plants). The stated advantages are that plants could remain, there would be no windblown material, and this plan may be less expensive than other methods. Stated disadvantages are that the land is almost useless while covered, the covering would not be permanent, water might not penetrate to the root zone, the plan is not conducive to animal life, the Pu remains in the environment, and asphalt is expensive.

Several soil stabilizer products are also commercially available. These products decrease resuspension and erosion by binding soil into larger-than-normal particles.

F. MECHANICAL MIXING AND STABILIZATION

Deep plowing is usually considered the principal means of mechanical mixing. Plows capable of turning the soil to a depth of 3 ft (1 m) are available. This procedure is a dilution method that reduces the average concentration of a contaminant in a host material by mixing the original relatively small volume into a larger volume of host material. Deep plowing may not be an efficient method of mechanical mixing because the contaminated layer may remain relatively intact but reside at a deeper level; the contaminant will not be uniformly distributed throughout the plowed zone.

The principal advantage of mechanical mixing is that the contaminant (Pu in the present case) is diluted, thus decreasing availability to plants and animals. Disadvantages are that radionuclides are still available in the environment, manual revegetation is required, stabilization is required to reduce erosion, and the procedure is not useful for extremely high levels of contamination or in rocky areas.

G. DO NOTHING

This alternative would establish exclusion areas where Pu contamination is sufficient to justify restriction of human and animal access. This alternative has been described along with advantages and possible problems. The conditions around NTS were summarized as follows:

> In several areas within NTS, there are relatively large amounts of Pu contaminating the soils. This condition has existed for up to 20 years, during which time the Pu, thought to be primarily in the oxide form, has migrated to a few centimeters depth in the soils on NTS proper and to greater depths in other test areas. Within soils Pu appears to be associated with the silt fraction, with a low solubility. It has been moved by wind and weather in a redistribution pattern which now shows most of the Pu associated with the soils adjacent to, and under, shrubs and shrub clumps. The amounts of Pu moved by winds have been reduced sharply during the time since the tests. Wind movement and redistribution appear to result from saltation of larger soil particles which may not be carried to an altitude more than a meter above the surface, and which, when they strike the surface, dislodge smaller Pu particulates by an avalanching effect; and these smaller Pu particles may be more readily airborne. With distance, however, Pu-air concentrations decrease very rapidly. Plants growing in the Pu-contaminated areas have Pu contaminating their surfaces and likely have small amounts within their tissues from uptake from their roots and possibly from surface absorption through aboveground tissue. Cattle, restricted in their food to grazing these areas, have Pu in their tissues within a few 10s of times background values except in liver, where the concentration reached 260 times background. (Rhoads, NVO–159, p. 173, CIC# 64963.)

Rhoads then recommends the "Do Nothing" alternative and provides a defense of the proposal to do nothing other than exclude as much physical activity in Pu-contaminated areas as is possible.

H. REVEGETATION OF DISTURBED AREAS

Under the assumption that remedial actions might be taken in some contaminated areas, the problems of revegetation were investigated. The sites of principal interest are the PROJECT 57 site and the four TTR sites. These locations are of added interest because they are not within the NTS proper although they are within the TRC (government-controlled areas).

Investigators have observed the process of natural revegetation at two disturbed sites on the NTS. One site was disturbed (by blading off all vegetation) in 1979; new growth occurred in some cases from the crowns of plants with intact root systems. Grazing jackrabbits were a major deterrent to growth of new shrubs. The other site was the SEDAN crater throw-out area where old-growth shrubs were buried by infertile subsurface material. After 20 years, much of the new land surface was not yet suitable for reestablishment of natural vegetation. Some annual plants began to appear shortly after the disturbance, but they did not display vigorous growth and spread slowly over the disturbed area. Shrubs native to the area are only very slowly spreading from the perimeter in toward the crater (Hunter, NVO-272, p. 79, CIC# 83087).

According to the investigators, the limiting factors for reestablishment of vegetation on disturbed areas in any desert will be (1) low soil moisture, (2) unfavorable soil structure resulting from very low soil organic matter, (3) harsh chemical soil environment related to salinization and high $CaCO_3$, (4) the invasion of disturbed areas by unwanted annual plant species such as tumbleweed, and (5) animal activity which destroys many new seedlings. These five factors result not only in difficulty of plant reestablishment, but also in soil instability ending in wind and water erosion (Wallace, NVO-171, p. 67, CIC# 64891).

These problem factors have been addressed in attempts to shorten the time required for revegetation. Soil moisture may be increased for specific plants by developing small depressions or microcatchment basins around newly set plants (Wallace, NVO-171, p. 73). Soil amendments including organic material may be added to the planting hole when new plants are set out, and organic material and chemical amendments may be spread over the revegetated area (Wallace, NVO-181, p. 17, CIC# 64965). Barriers may be set out to prevent seedling destruction by native animals such as rabbits (Wallace, NVO-181, p. 25).

A weeding program may be required to destroy unwanted species before they can produce seed. This program could be required for several years and would incur a considerable annual cost.

[Ed. Note: Tumbleweed is considered an undesired plant yet serves an important function as the plant to germinate first in a disturbed area. Tumbleweed can grow to a substantial size, even in poor soil with little moisture, and is an important factor in the process of mound development. Wind-borne material, including seeds of grasses and other native plants, and fine soil particles, collects under the tumbleweed. The fine soil holds moisture, the tumbleweed provides some shade to retard evaporation, and the environment for seed germination is enhanced. After the tumbleweed dies and blows away, the deposited seeds have a better chance of survival than they would have had without the tumbleweed. After a few years of wetting and drying, the disturbed soil surface will have formed a new crust and additional tumbleweed will not germinate. The tumbleweed has, therefore, served a useful purpose in the natural order of plant succession. As a separate consideration, Smith has reported that tumbleweed constituted over 30 percent of the total diet at times during the summer months for beef animals grazing in Area 18 (Smith, SWRHL-110r, CIC# 53672). Tumbleweed contributed 86 percent of the diet for one fistulated steer in August 1969 (Smith, SWRHL-102r, CIC# 14754).]

Other factors to be considered in revegetating denuded desert lands include meteorological conditions at planting time, plant spacing, species hardiness and growth characteristics, the natural order of plant succession in an area, and terrain manipulation (other than forming catchment basins) (Wallace, NVO-181, p. 17, CIC# 64965).

I. SUMMARY OF CLEANUP TREATMENTS AND COSTS

A summary of cleanup treatments and costs at the NTS and other sites has been prepared (Talmage, ORNL-6317, CIC# 65165). The paper describes the original source of contamination, postevent actions contributing to soil disturbance, remediation experiments, and the radiological condition at ten sites on the TRC and four other locations. The paper continues with cost estimates for a variety of cleanup procedures. Of special note is the list of 76 references and 18 additional publications containing cost data. The document also contains an appendix titled "Component Cost Data for Landfill and Surface Impoundment Operations" taken from a 1982 U.S. EPA report (EPA-600/2-035).

CHAPTER VIII. CONSIDERATION OF OTHER RADIONUCLIDES

A. INTRODUCTION

The NAEG placed initial emphasis on studies of Pu in the environment of the NTS. These studies early found that results of gamma spectrometry for Am in soil could be used to derive estimates of Pu present. Collected soil samples were subjected to gamma spectrometry for determination of Am, and to chemical separation, electrodeposition, and alpha counting for determination of the Pu species. Because the former analysis can be done with relative ease and low cost in the field while the latter analysis requires costly and time-consuming laboratory work, many estimates of Pu in soil were based on gamma spectrometry for Am and the average Pu to Am ratio in an area. As the work of the NAEG matured and branched out to analyses of radionuclides in the environment in addition to Pu, use of gamma spectrometry became the principal means of determining inventory and distribution.

The objective and procedures were stated by McArthur:

> The testing of nuclear explosives at the Nevada Test Site (NTS) has caused widespread contamination of the surface soil. Atmospheric and surface tests in the 1950s produced most of the contamination, although the Plowshare experiments of the 1960s and several containment failures of underground tests have also contributed. While many of the original contaminants have decayed away, several long-lived radionuclides remain at levels high enough to be a source of concern. The areas which present an immediate safety hazard are generally well-known and well-controlled. Other areas, however, may be sufficiently contaminated to represent long-term health hazards. In addition, the entire Test Site is a source of resuspendible radioactivity.
>
> The Radionuclide Inventory and Distribution Program (RIDP) was developed to provide information necessary to evaluate such problems. Its objective is to determine both the distribution and the total inventory of the radionuclides in the NTS surface soil. The project incorporates data from three sources:
>
> 1. Field measurements of external exposure rate and radionuclide activities by *in situ* spectrometry. These measurements provide the primary data base for the inventory calculations and distribution maps.
> 2. Aerial surveys of external exposure rate. The results of these surveys are used as the basis for sampling plans for the field measurements. In some areas, it may be possible to use the field data to calibrate the aerial survey data and then use the aerial data directly. In most of Yucca Flat, however, the occurrence of several shots in the same area makes such calibration impossible.
> 3. Soil samples. Calibration of the *in situ* measurement system requires parameters such as soil density, soil attenuation, and the depth distribution of the various radionuclides in the soil. In addition, radiochemical analysis of soil samples provides information about radionuclides which do not emit gamma rays and therefore cannot be measured by *in situ* spectrometry. Soil sampling is thus a necessary aspect of the program, although we consider it the most difficult and least precise of the methods used (McArthur, DOE/NV/10162-14, CIC# 83293).

Fig. VIII-1 illustrates the coverage of aerial surveys of the NTS. Results are reported in the EG&G publications listed below. Portions of the NTS surveyed by the RIDP are shown in Fig. VIII-2. Reports of *in situ* gamma spectrometry results (the RIDP) were published by DRI as listed below.

Author	Report Number	CIC#	Areas covered
Fritzsche	EGG-1183-1752	12787	13
Jobst	EGG-1183-1737	12788	TTR (4 sites)
Fritzsche	EGG-1183-1808	83295	1-4, 6-10, 12, 15, 17
Clark	EGG-10282-1004	83296	11
Feimster	EGG-10282-1093	83297	18, 20
Jobst	EGG-10282-1113	83298	12, 15, 17, 19
Bluitt	EGG-10282-1118	83299	16, 30
McArthur	DOE/NV/10162-14	83293	Galileo (Area 1)
McArthur	DOE/NV/10162-20	83214	2, 4
McArthur	DOE/NV/10384-15	83212	3, 7, 8, 9, 10
McArthur	DOE/NV/10384-22	83294	18, 20
McArthur	DOE/NV/10384-26	91223	Portions of 16 areas as shown in Fig. VIII-2

[Ed. Note: Radionuclide inventory estimates summarized in following sections have been abstracted from the RIDP reports but have been revised to agree with a summary report (R. D. McArthur, 1991; *Radionuclides in Surface Soil at the NTS*, DOE/NV/10845-02), published by DRI.]

B. CESIUM-137 AND STRONTIUM-90

Measurements of ^{137}Cs were made in the field with a high-purity germanium detector suspended above the ground. The power supply, detector, and electronic components were vehicle-mounted. At each designated measurement point, the detector was raised to a fixed height, the electronics were activated, and the counting period begun. During each measurement period, pulses from gamma rays reaching the detector were fed into a pulse-height analyzer and sorted to produce an energy spectrum. After the measurement period, the spectrum was stored on magnetic tape which was sent to LLNL where the computer package GAMANAL was used to analyze the spectrum and convert the raw counts-per-minute data to estimated activities for each radionuclide. Full details of this procedure are provided by McArthur in the RIDP reports identified earlier.

Soil samples were collected from selected *in situ* measurement points. At each location, samples were taken in four increments to a total sampling depth of 15 cm. In the laboratory, each sample was oven-dried, homogenized with a ball mill, and sieved through a 10-mesh screen before analysis. Concentrations of gamma-emitting radionuclides in the fine fraction were determined by gamma-ray spectroscopy at LLNL and the REECo Analytical Laboratory. The fine fraction of the top increment from several locations was then analyzed for Pu and strontium.

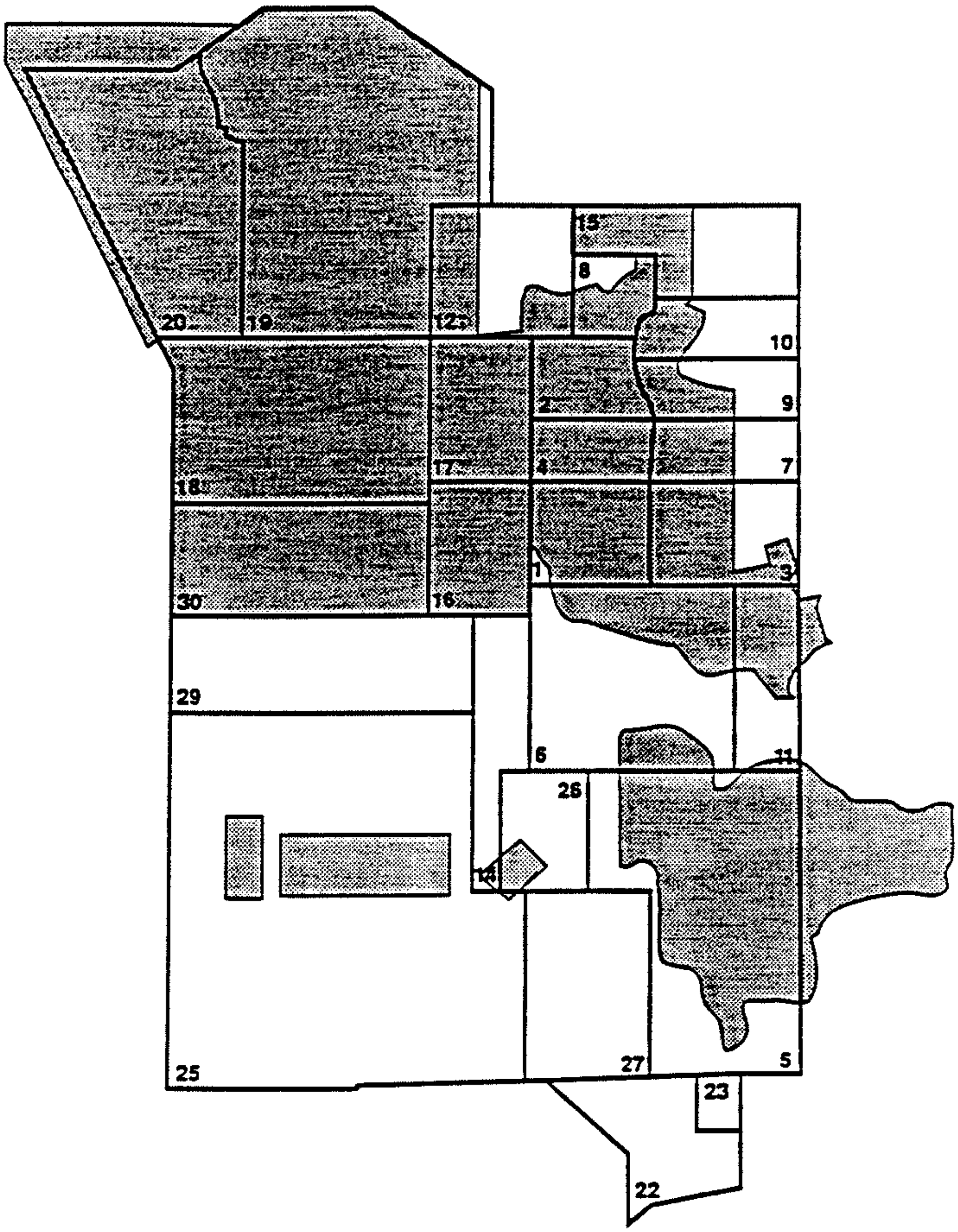


FIGURE 2. PORTIONS OF THE NTS COVERED BY EG&G AERIAL SURVEYS, 1975-1984.

FIGURE VIII-1 FROM McARTHUR AND MEAD, DOE/NV/10384-26, 1989

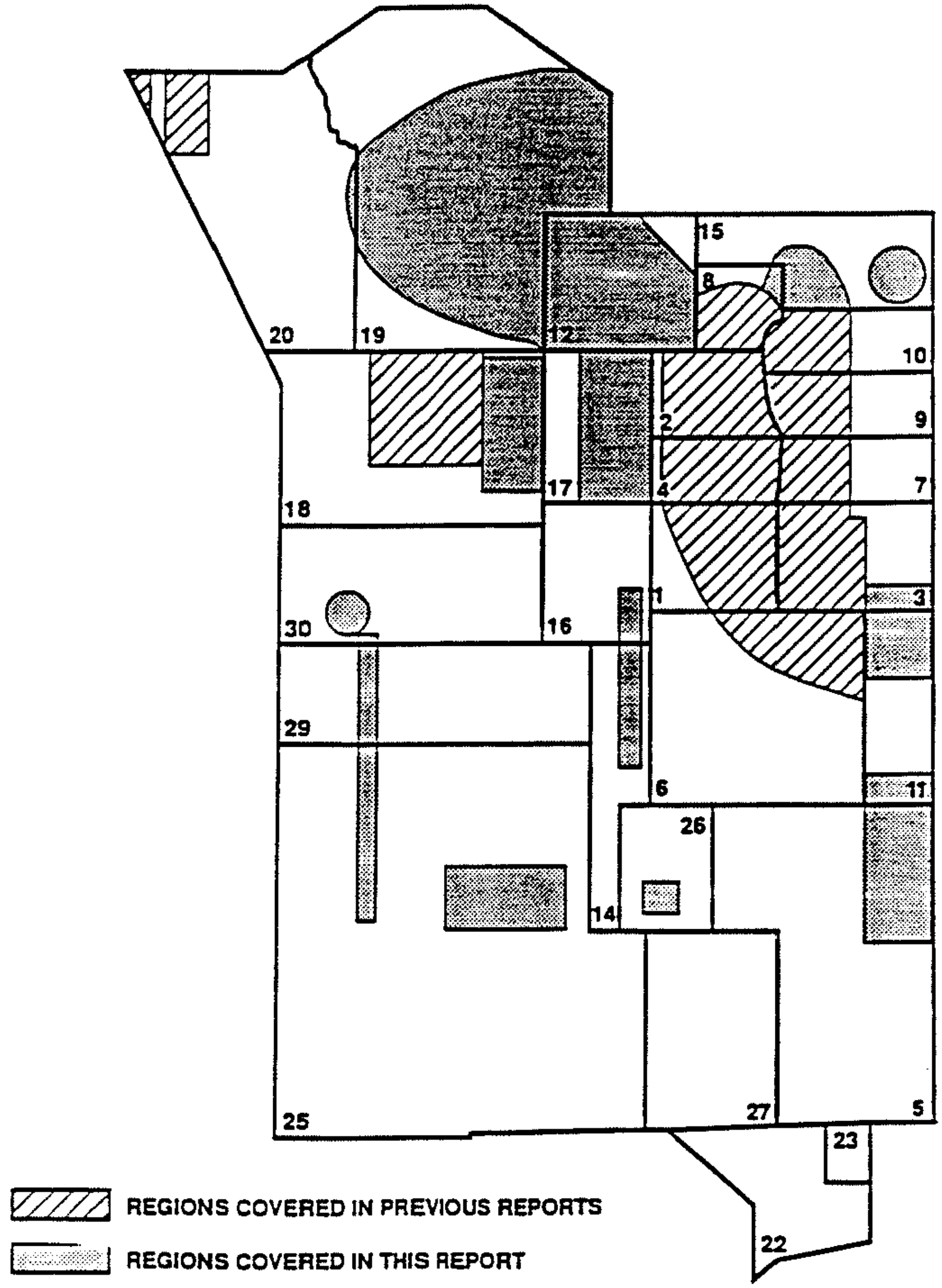


FIGURE 1. PORTIONS OF THE NTS SURVEYED BY THE RIDP, 1981-1986.

FIGURE VIII-2 FROM McARTHUR AND MEAD, DOE/NV/10384-26, 1989

Soil samples were analyzed for ^{90}Sr by beta counting following chemical separation. The Sr to Cs ratio in an area was then used to infer Sr at each location where Cs measurements were made. The Sr to Cs ratio was determined and applied separately for each area because the ratio varied over the range 0.5 to 5.0. The ratio was typically about 2.0.

Inventories of Cs and Sr at studied locations are summarized in Table VIII-1 along with Sr to Cs ratios. The reports by McArthur, listed above, provide results of soil analyses and present distribution maps of estimated radionuclide concentrations.

C. OTHER LONG-LIVED RADIONUCLIDES

Gamma spectra collected by the *in situ* system were analyzed for long-lived gamma-emitting radionuclides in addition to ^{137}Cs. The additional radionuclides, and their half-lives, reported by McArthur include: ^{60}Co - 5.26 yr; ^{152}Eu - 13 yr; ^{154}Eu - 16 yr; ^{155}Eu - 1.8 yr; ^{241}Am - 458 yr. These radionuclides were not all present at all measurement sites. (For Areas 8 and 10 only, inventory estimates are also presented for ^{102m}Rh, ^{238}Pu, ^{174}Lu, ^{125}Sb, ^{101}Rh, and ^{134}Cs.) Some of the data presented in the reports is qualified; the reader is directed to copies of the reports for qualification details. (Some estimates were based on "upper limit values" for radionuclides whose peaks are searched for but not found by the GAMANAL spectral analysis program. Some estimates are presented along with estimates of uncertainty.)

Ratios between the reported radionuclides do not follow any obvious patterns. For example, see in Table VIII-2 the estimates for ^{154}Eu and ^{152}Eu for the GALILEO and WHITNEY sites, and the estimates for ^{60}Co and ^{241}Am for the SMOKY and SEDAN sites. In the first example, the ratio $^{152}Eu/^{154}Eu$ is 9.7 for the SHASTA site and 27.7 for the WHITNEY site. In the second example, the ratio $^{241}Am/^{60}Co$ is 7.4 for the SMOKY site and 0.75 for the SEDAN site. These illustrations point out the need for separate analyses for each site, as was accomplished by the RIDP.

[Ed. Note: The tests differed from each other with respect to tower materials, tower height, device components, device efficiency, composition of other materials in the immediate vicinity, and possibly other factors. SMOKY was a fission device detonated atop a 700-ft steel tower; SEDAN was a thermonuclear device detonated 635 ft below ground surface. Differences in detonation environment alone do not explain the high inventory of ^{60}Co, an activation product resulting from neutron bombardment of iron, at the SEDAN site; a second and more careful appraisal is often necessary to understand unexpected relationships revealed by collected information.]

TABLE VIII-1. ESTIMATED INVENTORIES OF ^{90}Sr AND ^{137}Cs ON THE NTS

Location	Site#	Area (ft^2 x 10^6)	Inventory Sr-90 (Ci)	Inventory Cs-137 (Ci)	Ratio Sr/Cs
Area 1	GALILEO $	122.8	--	4.8*	1.5
Area 2	SHASTA	136.8	27.0	10.4	2.6
	WHITNEY $	75.6	11.2	4.0	2.7
	DIABLO	111.6	18.0	9.0	2.0
Area 3	HORNET	272.2	30.1	9.1	3.3
Area 4	KEPLER	273.9	14.3	11.0	1.3
Area 5	Frenchman Lake	62.4	1.1	0.43	2.6
	GMX $	10.4	0.015	0.026	0.56
	RWMS	4.8	0.005	0.008	0.63
	Kay Blockhouse $	4.0	0.008	0.009	0.86
Area 7	QUAY	443.5	15.1	6.7	2.2
Area 8	BANEBERRY $	159.5	6.6	26.4	0.25
	SMOKY $	30.5	9.5	4.2	2.5
Area 9	WILSON	327.1	16.5	8.8	1.9
Area 10	SEDAN	304.2	79.9	97.7	0.82
Area 11	Plutonium Valley $	94.	0.21	0.37	0.58
	PIN STRIPE $	15.7	0.18	0.19	0.88
Area 18	LITTLE FELLER I $	15.8	0.49	0.27	1.8
	LITTLE FELLER II $	9.4	0.58	0.29	2.0
	JOHNNIE BOY	111.0	10.9	2.1	5.2
	DANNY BOY $	24.6	1.4	2.3	0.63
Area 20	SCHOONER $	46.4	1.5	1.5	.95
	CABRIOLET $	125.9	4.5	4.9	1.0
Area 25@	RMSF	0.0024	0.02	0.024	0.83
	Test Cell C	0.0025	0.078	0.093	0.83
	Test Cell A	0.0025	0.074	0.088	0.83
	R-MAD Waste Dump	0.0025	0.034	0.041	0.83
Area 26@	Test Bunker	0.0025	0.013	0.016	0.81
Area 30	BUGGY $	7.68	1.6	1.7	0.97
Area 12	Tunnel portals	4.5	38.	39.	0.97
Area 15	Fallout plumes	120.	12.	8.8	1.4
Area 17	Fallout plumes	313.	14.	9.2	1.5
Area 18	Fallout plumes	625.	9.4	6.2	1.5

\# The same site was usually used for several tests; one test name was selected to identify the site.
* 4.8 Ci by the method of polygons of influence; 6.1 Ci by kriging.
RMSF = Radioactive Materials Storage Facility
R-MAD = Reactor Maintenance and Disassembly (building)
RWMS = Radioactive Waste Management Site
@ Radioactive contamination in Areas 25 and 26 resulted from tests of nuclear rocket and ramjet engines which did not involve explosions.
$ Revised by later report (McArthur, DOE/NV/10845-02, 1991); changes minor, but confounded by use of a different decay-correction date.

TABLE VIII-2. ESTIMATED INVENTORIES OF SELECTED RADIONUCLIDES ON THE NTS

		Inventory				
Location	Site#	Co-60 (Ci)	Eu-152 (Ci)	Eu-154 (Ci)	Eu-155 (Ci)	Am-241 (Ci)
Area 1	GALILEO	2.8*	21.3*	2.2*	0.6*	1.0*
Area 2@	SHASTA $	0.7	0.9	1.2	0.6	0.7
	WHITNEY $	1.6	19.4	0.7	0.1	0.4
	DIABLO $	0.4	0.4	--	0.1	1.0
Area 3	HORNET $	1.9	24.4	1.1	0.6	4.7
Area 4@	KEPLER $	3.9	13.0	0.9	0.2	5.8
Area 5	Frenchman Lake $	1.0	12.1	0.8	--	0.4
	GMX $	--	0.2	--	--	0.2
Area 7	QUAY $	2.2	42.9	2.4	0.4	1.9
Area 8	BANEBERRY $	8.9	--	--	--	0.9
	SMOKY $	2.1	6.0	0.4	0.7	15.6
Area 9	WILSON $	1.5	31.0	2.9	0.4	3.6
Area 10	SEDAN $	24.9	3.0	4.2	6.0	18.8
Area 11	Plutonium Valley	--	--	--	--	3.3
Area 18	LITTLE FELLER I $	0.3	--	--	0.1	6.0
	LITTLE FELLER II $	--	0.1	--	0.1	4.7
	JOHNNIE BOY $	0.8	0.8	0.4	0.4	1.0
	DANNY BOY	0.2	0.5	0.1	0.3	6.6
Area 20	SCHOONER	9.7	14.0	17.0	5.2	9.4
	CABRIOLET $	8.5	2.6	1.0	0.4	14.0
Area 25	Test Cell C	0.04	0.2	--	--	--
	Test Cell A	0.1	0.3	--	--	--
Area 30	BUGGY	1.4	0.9	0.4	0.2	3.2
Area 15	Fallout plumes	0.3	--	--	--	2.5
Area 17	Fallout plumes	1.4	--	--	--	1.8

-- = Data insufficient for calculating an inventory estimate. The following sites, present in Table VIII-1, have been omitted from this table either because subject radionuclides were absent or because collected data were insufficient for calculating an inventory estimate: Area 5 RWMS, Kay Blockhouse, PIN STRIPE, Area 25 RMSF, R-MAD Waste Dump, Area 26 Test Bunker, Area 12 Tunnel portals, Area 18 Fallout plumes.

\# The same site was usually used for several tests; one test name was selected to identify the site.

* By the method of Polygons of Influence and using all data.

@ Sum of background and above-background regions.

$ Revised by later report (McArthur, DOE/NV/10845-02, 1991). [Ed. Note: Nearly half of the numbers in this revised table differ from numbers published in earlier reports. Most of the changes were minor and affected Eu species.]

Radioactive contamination in Areas 25 and 26 resulted from tests of nuclear rocket and ramjet engines which did not involve explosions.

AN HISTORICAL PERSPECTIVE OF THE NEVADA APPLIED ECOLOGY GROUP*

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INTRODUCTION

Actually, I don't think of this as an epilogue at all, but rather as my own personal view of the NAEG—how and why it got started and what the significant accomplishments were. Also, as with anything else, the history of the NAEG is really a story of people, which the author of this book has almost totally neglected. In its earlier versions, the book did not even provide information on *who* was involved—as though the only things that mattered were the organizations and the US Department of Energy, Nevada Field Office (DOE-Nevada).

In a few pages I can't do justice to the many people who have been involved in the NAEG and to the many significant accomplishments. Here, I provide my own view of the key individual contributions and the most significant accomplishments.

THE BEGINNING OF THE NAEG

The NAEG didn't just happen overnight. It was born out of strife and with the wrenching realization that a new age of environmental awareness was dawning that wasn't going to go away. By happenstance, I was much involved in that strife, and I had a ringside seat to watch many external events that changed forever the way that the old Atomic Energy Commission (AEC) conducted its business. That strife and these changes ultimately led to the formation of the NAEG.

My story begins in 1968, when my colleague, Paul Phelps, and I were very much involved in environmental studies related to Project Schooner, the last Plowshare cratering experiment conducted by the United States. We had a major effort to study resuspension (Anspaugh et al. 1969, 1970) of the debris from that experiment, and we had automatic stations that would run a sequence of air samplers when the radiation emanating from the debris was detected (Holladay et al. 1970). When the event took place in December 1968, the amount of debris injected into the air was much greater than planned—radioactive materials were reported in Finland with the use of large-volume air samplers (Asikainen and Blomqvist 1970). In spite of this, plans continued for the Plowshare cratering program with two more experiments planned for the next few years. These had names of Projects Sturtevant and Yawl, and planning for these two projects was well advanced.[1]

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* Work performed under the auspices of the US Department of Energy at Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

[1] These projects and the Plowshare cratering program were eventually canceled and with it the dream of using nuclear explosives to dig a new "Panama Canal." (It was only a few years before that work on a nuclear reactor powered airplane engine had been stopped. This program was a technical success, but one has to marvel now that anyone ever thought that the concept would be acceptable to the public. However, this was two years before the first 'Earth Day' and all the environmental awareness that followed it.)

There was yet another element of strife that, in my opinion, fostered the environment that led to the implementation of the NAEG. This was the radioecological study of Dr. Robert C. Pendleton and colleagues at the University of Utah. These studies had been funded by the US Public Health Service and had been ongoing for several years; however, the funding had been canceled before Project Schooner took place.[2] Pendleton's group had previously drawn attention to the presence of radioiodine in milk in northern Utah following the Sedan,[3] Little Feller II, Johnnie Boy, Small Boy, and Little Feller I events in 1962; this had prompted the Utah State Department of Health to recommend that milk producers transfer cows from contaminated pasture to other feed or to divert highly contaminated milk to uses that would allow decay prior to consumption (Pendleton et al. 1963). The Lawrence Livermore National Laboratory (LLNL) had produced a special nuclear device for Project Schooner—one which was engineered to have a small ratio of fission-to-fusion. The device, however, contained a lot of tungsten, and the activation products, ^{181}W, ^{185}W, ^{187}W, and ^{188}W, were produced in copious amounts. When Project Schooner released its greater than anticipated amount of debris, the dominant radionuclides were short-lived ^{185}W and ^{187}W. When Pendleton made his measurements, he had no idea that the debris would be dominated by W radionuclides. Thus, he assumed that the major activity was radioiodine, as it had been in the past, and it was a few days before he deduced that the activity was due to radiotungsten. In the meantime, he had warned the public not to drink milk, because of concern for radioiodine and the dose to the thyroid of infants.

This produced a controversy,[4] and Roger Batzel at LLNL proposed that the University of Utah and LLNL Environmental Sciences Division personnel work together on future monitoring and radioecological activities. Thus, in 1969 we fielded the LLNL automated sampling stations (Holladay et al. 1970) in Utah at Pendleton's study sites, and we were prepared to inform him immediately, if any significant releases again took place at the NTS.[5] When we undertook our joint work with Pendleton's group, his organization needed a new source of funds to undertake their part of the study. Again, through the influence of Batzel and others, the DOE-Nevada agreed to fund these studies. Ernest Campbell and Frank Cluff of DOE-Nevada were instrumental in getting this activity in place. I think this episode was also a strong influence that led DOE-Nevada to realize that they needed to understand food-chain transport and ecological processes. One indication was that DOE-Nevada hired a radioecologist, Jared Davis, to work in their Office of Effects Evaluation.

During the summer of 1969, Phelps and I traveled extensively in Central Nevada to measure the residual radioactive debris deposited by the Schooner event and to collect 'background' samples for the scheduled Sturtevant cratering event. At that time the longer lived activation product, ^{181}W, was still an easily measured indicator of the Schooner device. During the course of our studies, we collected many soil samples, which we measured for ^{181}W. In a few months, aliquots of these saved samples would also be used for another purpose, which had even more impact on the formation of the NAEG, but we will come to that story below.

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[2] The cancellation of Pendleton's funds was itself controversial. Pendleton often expressed the opinion that he was being punished by an AEC official for his public statements. Others said that his funds were canceled because Pendleton had not published his work adequately.

[3] Sedan was the largest (104 kt) cratering experiment carried out at the Nevada Test Site.

[4] One element was the simple question of why Pendleton had not been warned to look for radiotungstens, rather than radioiodines.

[5] Fortunately, this system was in place and fully operational when event Baneberry unexpectedly vented on 18 December 1970 and released 6.7 x 10^6 Ci (Hicks 1981). As a result of the close cooperation between the Utah and LLNL groups, it was determined quickly that this venting would not have major impact in Utah (Pendleton et al. 1971; Koranda et al. 1971).

Two other very significant events occurred in 1969. The general mood of preserving the environment had culminated in the passage of the National Environmental Policy Act (NEPA), and it became clear that the continued testing of nuclear-weapons-related devices at NTS would require the writing of an Environmental Impact Statement (EIS). Eventually such an EIS would be prepared, and one of the primary contributors to that document was Dr. Harry Otway of the Los Alamos National Laboratory (LANL). (More about Otway later.)

The second significant event was the major fire in Building 776 at the Rocky Flats Plant near Boulder, Colorado, on May 11, 1969. This Plant, which may be thought of as a massive machine shop for plutonium and uranium, had had a previous fire in 1957. The 1969 fire was in one of the buildings where plutonium was processed and resulted in multimillion dollar damage (Hammond 1971; Schneider (1992) asserts that this fire resulted in $45 million in damage and burned up hundreds of pounds of Pu). Extensive Pu contamination was found on the roof of Building 776 after the fire, and there was some local ground contamination. On-site air samplers indicated an increase in total long-lived alpha activity of about an order of magnitude, but even this level was well below the protective guide level. Off-site air samplers showed no increase in alpha activity. No unusually high liquid effluent discharges were noted, and vegetation samples showed no anomalies compared to results from the routine environmental sampling program in prior years (Hammond 1971).

However, there existed a Colorado Committee for Environmental Information with Peter Metzger as Chairman, and following the fire they formed a Rocky Flats Subcommittee to consider the implications to public health and safety of the Plant fires and operations. This Subcommittee was chaired by Dr. Edward Martell, who worked at the neighboring National Center for Atmospheric Research (NCAR). This group refused to believe that the massive fire at Rocky Flats had not released significant amounts of Pu. At a meeting at Rocky Flats, the subcommittee members argued that the air-sampling network was not adequate to detect a channelized release, that vegetation was not a good sampling media, and that a land survey for localized hot spots should be conducted. Personnel at the Rocky Flats Plant agreed to conduct a limited soil-sampling program and, during August 1969, 50 soil samples were collected. However, the Rocky Flats personnel postponed analyzing the soil samples or even developing an analytical method for them (Hammond 1971).

In the meantime Martell and his colleague, Stewart Poet, collected soil samples from 27 locations (including one control location) outside the Plant and analyzed them in their laboratory in NCAR. Their results were so provocative that the Subcommittee prepared a report when the results from only 15 locations were available (Martell et al. 1970), and this report was sent by letter to Glenn Seaborg, then Chairman of the AEC. The reported results varied from 0.03 dpm g^{-1} (at the control location) and from 0.01 to 13.5 dpm g^{-1} for locations within a few miles of the Plant. This was clear indication that Pu from Rocky Flats had, in fact, contaminated the area outside the Plant; Martell et al. (1970) estimated "that curies to tens of curies...have been deposited in offsite areas." The title of the Martell et al. report did contain the word "fire," and it was frequently assumed that the fire was the source of the Pu.

Chairman Seaborg reacted quickly and asked the then Health and Safety Laboratory (HASL)[6] to undertake an immediate investigation. By August Krey and Hardy (1970) published their report, which confirmed that Pu from the Plant had contaminated offsite areas, and they estimated the amount released to have been between 2.6 and 5.8 Ci. They further concluded that the source of the offsite Pu was not the dramatic 1969 fire, but the boring leakage from rusting

[6] Now known as the Environmental Measurements Laboratory (EML).

barrels of Pu-contaminated machining oil. Thus, it was established that routine monitoring programs then in place at many locations might not be effective in detecting chronic low-level releases of radionuclides, and reliance on air-sampling networks would no longer be acceptable (Hardy and Krey 1971).

Phelps and I were aware of this situation as it developed. As we had a large number of just collected soil samples from offsite locations near the NTS, we decided to submit 35 of them for analysis in April 1970; we also sent along 14 samples from Utah. When we got the results on June 16, 1970, we were rather surprised to find that two of the soil samples close to NTS had appreciable quantities of $^{239+240}$Pu in them. One sample of surface soil from Queen City Summit was particularly high. (1.7 dpm g^{-1}, as compared to an average for Nevada of 0.02 dpm g^{-1} [Anspaugh and Phelps 1970].) We made these results known in August to management at LLNL and at DOE, both in Washington and in Las Vegas. This created a great deal of interest, especially in Nevada as the local authorities had no suspicion that $^{239+240}$Pu might be readily detectable in such amounts off of the NTS.

Our results also came at the time the DOE-Nevada was preparing the first EIS for the NTS. What would they do with our preliminary results at this stage of the process? Phelps and I discovered that later during one of our subsequent visits to DOE-Nevada, when we were told not to release our data to the public. We were then faced with the moral dilemma of dealing with this implied threat, although we never doubted that our Laboratory would fully support us. At that time, Phelps and I were also performing measurements near Rulison, Colorado, at the site of another Plowshare experiment—this one designed to stimulate the production of natural gas (Anspaugh et al. 1971a,b). The problem in this case was the contamination of the gas with tritium. For this event the LANL had used a pure fission device to eliminate any spillage of tritium, but the production of tritium by ternary fission still resulted in some contamination. When we arrived at Grand Junction, Colorado, on November 4, 1970, on our way to Rulison to perform another series of measurements, we were astonished to find big red headlines in the *Denver Post* indicating that Pu had been found off site of the NTS![7] The story stated that Dr. Harry Otway, head of the team preparing the EIS for the NTS, reported to a meeting of the Colorado Committee for Environmental Information (the same Committee that found Pu outside of Rocky Flats) that Pu contamination had been found on "...2 of 35 areas tested in the Nevada desert." These were obviously our results, although our names were never mentioned.

Fortunately for us our moral dilemma was resolved by this revelation, and we were never again subjected to threats. These events, particularly the bad situation at Rocky Flats, did make DOE officials aware that the public was very concerned about Pu.[8] Also, the fact that a public interest group, rather than the Plant itself, had found Pu offsite at Rocky Flats had caused a serious problem.[9] The Manager of the DOE-Nevada then was Mr. Robert E. Miller. He wisely decided to create the Nevada Applied Ecology Group on July 29, 1970 (Miller 1970). The stated purpose was to coordinate the ecological, radiation-monitoring, and other environmental programs necessary to support continued testing and to comply with NEPA. A central feature of the NAEG was the creation of the Applied Ecology Steering Committee to oversee these activities. The Committee was to be co-chaired by J.J. Davis of the Office of Effects Evaluation and Frank Cluff of the Office of the Assistant Manager for Operations, both of DOE-Nevada. Other

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[7] The headline (with surrounding smaller words) was "Outside Nev. Test Site, 'N-Fallout No Danger,' AEC Finds Plutonium in Samples" (Anonymous 1970e).

[8] Virtually every AEC site that had ever worked with Pu undertook an extensive Pu in soil sampling and analysis program at this time (e.g., Corley et al. 1971; Gudiksen et al. 1972).

[9] This was a public relations disaster, and perhaps one of the prime examples of the concept that credibility may not be a renewable resource.

members of the Committee were to include representatives from the Division of Biology and Medicine (DBM), HQ; Division of Operational Safety (DOS), HQ; Division of Military Application (DMA), HQ; Division of Peaceful Nuclear Explosives (DPNE), HQ; LLNL; LANL; Sandia Laboratories (SNL); and DOE-Nevada. The initial problem areas suggested for consideration by the Steering Committee were these (Miller 1970):

1. Radioecology of Plutonium on the NTS.

2. Recommend Future Scope and Objectives for the Bioenvironmental Programs Conducted by PHS/SWRHL[10] and BMI.[11]

3. Establish an Applied Ecology/Radiobiology Information Center.

4. General Radioecological Survey of the NTS and Environs.

5. Long-Term Monitoring of Offsite Test Locations.

THE EARLY DAYS OF THE NAEG

The initial meeting of the Steering Committee was held on September 10, 1970, with the following Committee members in attendance (Anonymous 1970a).

J.J. Davis, DOE-Nevada, Co-Chairman
F.D. Cluff, DOE-Nevada, Co-Chairman
Captain G.C. Facer, DMA
R.D. Maxwell, DOS
J.S. Kirby-Smith, DBM
F.J. Clark, Jr., DPNE
P.L. Phelps, LLNL
H. Otway, LANL
M.L. Merritt, SNL

At its first meeting, Elwood Douthett, Director of the Office of Effects Evaluation, invited the Committee to review his Office's bioenvironmental programs to help ensure that they meet the needs of weapons testing and the Plowshare program. Dr. Douthett specifically asked that the Committee tackle two immediate problems (these are taken verbatim from Anonymous 1970a):

"1. Plutonium on the test site.

Programs are underway, but Davis and Douthett think they are insufficient.

"2. What should be the future role of the SWRHL Radiation Effects Program?

The Committee was invited to evaluate capabilities and to recommend program objectives for the future. A specific question that needs to be answered is 'What should be the job of the Public Health Farm in the future?'"

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[10] Public Health Service/Southwestern Radiological Health Laboratory, Las Vegas, Nevada.
[11] Battelle Memorial Institute, Columbus, Ohio.

The Committee was then briefed on the responsibilities of the Office of Effects Evaluation under NEPA and Executive Order 11514, which required agencies to comply with the requirements of the Act. This was followed with the presentation of the functional plan of the NAEG and by a brief outline of current programs at the NTS and at the other sites of interest.[12] One interesting comment made was that, "There is no routine program for sampling and analyzing for plutonium around the NTS." (Quote from Anonymous 1970a)

The Steering Committee was very powerful, as its members represented organizations that controlled activities at the NTS, and the Committee could easily have killed any concept of expanded ecological research at NTS. There was the pressure to comply with NEPA, however, and the Committee agreed to find the resources to undertake whatever work was necessary to understand the ecological situation at the NTS. At its first meeting, the Steering Committee recommended that studies of Pu on the NTS and environs be the first priority problem for the NAEG and that an Ad Hoc Working Committee be established with Dr. Wright Langham of LANL as Chairman, and names of potential members were suggested for consideration.

The latter Committee soon became known as the Ad Hoc Plutonium Committee, and it first met on October 13–14, 1970. This Committee consisted of

W. Langham, LANL, Chairman
C.R. Richmond, DBM/HQ
W.J. Bair, Battelle Pacific Northwest Laboratories (PNL)
O. Raabe, Lovelace Foundation
J.L. Olson, LLNL
E.M. Romney, UCLA
J.W. Healy, LANL
R.C. Thompson, PNL
J.N. Stannard, University of Rochester

At its initial meeting, the Committee was briefed on "...the state of knowledge of the occurrence, distribution and significance of Pu in the environment resulting from nuclear testing activities at NTS, and safety tests conducted on the Tonopah Test Range and the Nellis Air Force Bombing and Gunnery Range" (Anonymous 1970b). Phelps and I participated in this meeting and presented the results of our analyses of soil samples from offsite. The recommendations of the Committee included that the AEC should not rush into an extensive decontamination program, the Pu-contaminated areas on the NTS should be much better delineated and defined, the Pu levels in soil of offsite areas should be defined, the methods of sampling and analyzing soil for Pu must be standardized and intercalibrated, a research program should be developed and initiated to detect and evaluate any health hazards or radioecological problems associated with Pu-contaminated areas on the NTS, and the physical and chemical characteristics of Pu in the environment should be defined. The recommendation on the research program also included more specific recommendations that cattle be allowed to graze in one of the Pu-contaminated areas in order to study biological uptake and that the effects of man's activity relative to resuspending Pu from the contaminated sites should be determined.

The second meeting of the Steering Committee was held on October 28–29, 1970, with the following Committee members in attendance (Anonymous 1970c).

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[12] Amchitka, Bikini, Central Nevada, Utah, and others.

J.J. Davis, DOE-Nevada, Chairman
G.C. Facer, DMA/HQ
J.S. Kirby-Smith, DBM/HQ
R.D. Maxwell, DOS/HQ
L.S. Germain, LLNL
P.L. Phelps, LLNL
H.J. Otway, LANL
M.L. Merritt, SNL

Dr. Langham also attended this meeting to report on the first meeting of the Ad Hoc Pu Committee and to present their recommendations. Essentially all of the recommendations, including the undertaking of an applied research program, were approved by the Steering Committee. In addition, the Steering Committee asked that the NAEG "...establish a group to identify, evaluate and recommend programs or other actions needed to meet future potential radiobiological, ecological and health hazard problems that may arise relative to the NTS or testing activities elsewhere." And they suggested that an evaluation be made of the accuracy of predictions of movement of radionuclides in ground water away from nuclear test sites (Anonymous 1970c).

This was clearly the needed green light to form the applied research program that is the major theme of this book. In order to define this research program, Workshops were held at DOE-Nevada; the first was held on December 11, 1970 (Anonymous 1970d). Thirty-six individuals from twelve different organizations attended this Workshop "...to plan and develop an interdisciplinary applied research program which will define and evaluate the radiological health aspects of Pu contamination in natural environmental areas on the NTS and the surrounding area." The attendees discussed background information, and William Martin,[13] BMI, led a discussion on a "...systems approach experimental plan..." Three sites were selected for initial study; these were Plutonium Valley in Area 11, the Project 57 Site in Area 13, and Area 18, although the extent of Pu contamination in the latter area was unknown.

The group also agreed on these priority research areas (Anonymous 1970d):

"A. Determine distribution and characteristics of Pu in soils of study sites.

"B. Determine extent and conditions under which Pu is resuspended.

"C. Determine what biological experiments are needed to define the radiological health significance of Pu associated with NTS and provide information needed to develop required predictive capability.

"These experiments should be designed, their sequence planned and they should be initiated soon.

"A lower priority part of the program should be the development of studies to provide definite information in response to the question: 'What are the effects of the Pu on the plants and animals that live in the contaminated areas? Have you looked, and where is your proof?'"

[13] Dr. Martin had previously been at UCLA and he had performed ecological studies on the fate of fallout in Penoyer Valley, just a few miles NNE of the NTS (Martin 1963).

Several Working Groups were formed with the initial task of evaluating the problem under its purview and then recommending what work was needed for the future. These Working Groups and their Chairmen were

Soils Pu, E. Fowler, LANL
Resuspension, L. Anspaugh, LLNL
Biological Studies, R. Stanley, EPA/SWRHL
Pu Field Ecology, R. Mullen, EG&G
Pu Studies Program Development, J. Davis, DOE-Nevada

As I was Chairman of the Pu Resuspension Working Group, I will describe its work by way of example.[14] The members of this Working Group were

L.R. Anspaugh, LLNL, Chairman
V.E. Andrews, Environmental Protection Agency (EPA)
H.G. Booth, National Weather Service
D.N. Brady, REECo
F.D. Cluff, DOE-Nevada
J.W. Healy, LANL
N.C. Kennedy, National Weather Service
D.N. McNelis, EPA
P.L. Phelps, LLNL
O.G. Raabe, Lovelace Foundation

The first meeting of the Pu Resuspension Working Group was held in Las Vegas on January 15, 1971, and a second was held on January 28-29, 1971. The first meeting was highlighted by a presentation by Jack Healy, who had done some of the pioneering work on resuspension at the Hanford Site in the 1950s (Healy and Fuquay 1958), and who was probably the only person on the Working Group who really understood the meteorological aspects of the problem. We also came very quickly to the conclusion that there were really three separate issues under discussion. These were (1) Whether or not there currently is a Pu-resuspension hazard at NTS, (2) How such a hazard (or nonhazard) might be altered by mechanical disturbances of altered use conditions, and (3) Whether or not NTS is a suitable location for scientific experiments on the resuspension phenomenon itself, and if so, how such an experiment should be conducted (Anspaugh et al. 1971c).

REECo already had some measurements underway to examine the first issue, and the Working Group made several recommendations on how to improve these studies in order to provide more useful and defensible data. In relationship to the third question, the Working Group concluded that there were virtually no experimental data available that would be useful in predicting under various meteorological conditions, even within several orders of magnitude, the resuspended air activity arising from a source of ground-deposited activity, particularly an aged source. The Working Group therefore recommended strongly, if preliminary studies indicate feasibility, that such experiments be conducted at the NTS to provide data necessary to develop and/or verify predictive models (Anspaugh et al. 1971c).

It is an interesting sidelight that Wright Langham, the Chairman of the Pu Ad Hoc Committee, had been one of the first to measure resuspension at NTS during Project 56, the series of safety experiments that had taken place in Area 11 and gave rise to that location being

[14] The work of the other Working Groups is described in Anonymous (1971a).

known as Plutonium Valley. At that time (1956), the interest was in the resuspension of Pu only over relatively short time periods following its deposition. Langham had invented the term "resuspension factor," which is the measured concentration of Pu in air divided by the deposition density of Pu on the ground. Langham stated at one of the Pu Ad Hoc Committee meetings that the concept was "esthetically nauseating," as it was purely empirical and contained no fundamental understanding of the process. However, the concept had proved useful (and is still useful). From his and P.S. Harris' measurements in 1956, Langham had derived the following equation to describe the value of the resuspension factor S_f with time (Langham 1971).

$$S_f = 7 \times 10^{-6} \exp(-0.693t / 35 \text{ days}) \text{ m}^{-1}$$

As a result of the early measurements of resuspension made under the auspices of the NAEG at the NTS, it became obvious that this equation could not be valid over long time periods, such as several years. For example, at 15 years post deposition the use of this equation would yield a calculated resuspension factor of about 10^{-53} m^{-1}, whereas the measured values were about 10^{-9} m^{-1} (Anspaugh 1974).

The second Workshop to plan the applied research program was held on January 21–22, 1971; it was attended by 21 people from ten organizations. This was pretty much the final act of a lengthy process to define the new applied research program. Attendees agreed upon the following program (Anonymous 1971b):

1. Delineation and Characterization of the Pu Contamination. This was the first work to be done, and rather detailed plans were made relating to aerial and instrumental surveys, grid systems, aerial photographs, soil and vegetation characterization, determination of sampling and analytical variability of contaminated soils, and development of sampling and analytical plans to be used in assessment of Pu distribution. This recommendation led to the recruitment of several additional people to the project; these included L. Eberhardt and R. Gilbert of PNL, who provided much guidance to the group in terms of statistically sound sampling and analysis plans.

2. Determine the Health Hazards of the Pu Contamination of the NTS and its Environs. Plans here included biological studies, specifically metabolic studies on the transfer of Pu via milk and the distribution of Pu within tissues of test animals. In vitro studies were also planned with an artificial rumen. A study was also outlined wherein pregnant beef cattle would be grazed on one of the contaminated areas. Under this rubric, resuspension studies were also planned, including detailed studies on the mechanisms of resuspension.

3. Radioecology Studies. Studies planned included determining the uptake of Pu by vegetation, the study of native animals at the contaminated sites, and studies of the chemical form, valence state, and solubility of the Pu found.

4. Predictions. It was noted that the entire program had "...been developed in order to provide a set of effects predictions which will hopefully be more realistic than those based on the present limited information." Model development was therefore always an essential part of the NAEG.

The third meeting of the NAEG Steering Committee was held on February 17–18, 1971. J.J. Davis outlined the considerable work that had been done in planning for the new research program, and Wright Langham reported that in general the Pu Ad Hoc Committee supported the Pu research program (Anonymous 1971c). It was agreed that initially the program would include five projects: Pu in Soils, Pu Resuspension, Metabolism of Pu by Domestic Animals, Radio-ecology of Pu, and Systems Analyses of Environmental Pu. The Steering Committee endorsed Otway's recommendation that the priorities of the activities should be as follows (Anonymous 1971c).

"a. Determine the distribution of Pu in offsite areas.

"b. Determine to what extent and under what conditions Pu may be moving from the Test Site to offsite areas. This requires onsite resuspension studies in addition to an adequate offsite air monitoring program.

"c. Determine the distribution of Pu on the Test Site.

"d. Conduct scientific experiments to improve understanding of fate of Pu in the natural environment and its significance.

(1) Animal Studies:

Field

Laboratory

(2) Ecological Studies"

With this endorsement, the Nevada Applied Ecology Group very quickly became an operational organization. Eventually, the NAEG took the form of "elements," with this structure apparent from the first major publication (Dunaway and White 1974):

Plutonium Inventory and Distribution, Headed by B.W. Church, DOE-Nevada
Soils, Headed by E. Fowler, LANL
Statistics, Headed by L.L. Eberhardt, PNL
Vegetation, Headed by E.M. Romney, UCLA
Resuspension, Headed by L.R. Anspaugh, LLNL
Small Mammals, Headed by W.G. Bradley, University of Nevada, Las Vegas
Modeling, Headed by W.E. Martin, Battelle Columbus Laboratory (BCL)
Large Animals, Headed by R.E. Stanley, EPA

The EPA was a fairly new organization at that time and had absorbed the US Public Health Service, which for years had had the responsibility for offsite safety and monitoring for the NTS. The EPA was very serious about Pu on and near the NTS and did all kinds of additional studies with their own money and with their own agenda. These studies were always fully reported to the Pu Ad Hoc Committee, although the Committee had little control over the studies. Two very important activities that were carried out by the EPA were the survey of Pu in soil offsite (Bliss and Jakubowski 1975) and the major experiment with cattle grazing vegetation at the Pu-contaminated area at the site of Project 57 (Smith 1979). As it turned out, Phelps' and my early measurement of Pu in soil at Queen City Summit was almost the highest value measured offsite, so fears that much higher values might possibly be found were allayed.

Wright Langham, the Chairman of the Pu Ad Hoc Committee, was a remarkable man, blessed with great intelligence and wisdom. He was also a true gentleman with a great sense of humor. I particularly remember that he did not like to start meetings as early as 8:00 a.m., whereas the people at DOE-Nevada would try to start them even as early as 7:30 a.m. This came to a head when the Nevadans insisted on starting a meeting at 8:00 a.m., due to the full agenda. Langham solved the problem by simply not showing up until 9:00 a.m., aided and abetted by his fellow scientists from LANL. Certainly, no one would have dared starting the meeting without him. At that time Langham had the reputation of being Mr. Plutonium (in an environmental sense); it was to him that the US government had turned in 1966 and 1968, when planes carrying Pu-bearing nuclear weapons had crashed near Palomares, Spain, and near Thule Air Force Base, Greenland [much of this story is told in Langham (1969)].

Langham's influence on and guidance to the NAEG came to an abrupt and tragic end when he was killed in 1972 in an airplane accident. By this time, Jared Davis had already departed for a major position with the US Nuclear Regulatory Commission in Washington, and he had been replaced by Paul Dunaway from Oak Ridge National Laboratory (ORNL). We also lost the wisdom of Robert E. Miller, who retired from his position as Manager of DOE-Nevada. He was replaced by General Mahlon Gates, who took great interest in the NAEG and provided strong support for it. However, with these major changes, the early days of the NAEG were clearly over.

TIME GOES ON

With the loss of Langham, the Pu Ad Hoc Committee was chaired for a time by Chester Richmond, who had left DBM/HQ and was now at LANL. However, there were conflicts, and the Committee ceased to be active. Over the next several years, Dunaway assumed broader management responsibilities at DOE-Nevada. M.G. White, who had previously worked for EPA, Las Vegas, was hired as the Scientific Director of the NAEG.

The work of the NAEG during these years was reported in detail in a series of DOE-Nevada publications (Dunaway and White 1974; White and Dunaway 1975, 1976, 1977; White et al. 1977a,b; Howard et al. 1985; Howard and Fuller 1987). During this period of time, significant progress had been made in a number of areas. The NAEG had defined the areas of Pu contamination on the NTS and on the Nellis Bombing and Gunnery Range. NAEG studies determined that the Pu "in" vegetation did not come through root uptake, but was being redeposited from resuspended airborne activity. Grazing experiments sponsored by the NAEG had confirmed that the uptake of environmentally aged sources of Pu was still satisfactorily described by the gut absorption factor for plutonium oxide. The studies on resuspension had led to the development of empirical models to describe the process in desert environments and had been used successfully to describe resuspension in other environments (Anspaugh 1974). Of more significance Martin and Bloom (1980) had developed the NAEG model for estimating Pu transport and dose to man in the NTS environment; their model included the pathways of resuspended airborne activity and ingestion of food crops, milk, and meat grown in the same environment. This model embodied the empirical relationships that had been determined by the NAEG studies.

The work being done by our group at LLNL had been greatly accelerated by the addition of Joe Shinn to our staff. Our work was rather unique in the sense that our funding source was not primarily from the DOE-Nevada. Before the NAEG began, we had submitted a proposal to the Division of Biology and Medicine (which later became the DOE Office of Health and Environmental Research [OHER]) and this proposal was funded. However, our field support from REECo, the collaborative efforts of the Weather Service, and the radiochemical analyses of the samples were all funded by the NAEG. Our most meaningful results had been published (Anspaugh et al. 1975, 1976).

We had also become interested in the technique of field-gamma spectrometry for the measurement of radionuclides in the field; this technique had been developed by Beck (Beck et al. 1964) at the Environmental Measurements Laboratory. We had adapted and demonstrated this technique at the NTS (Anspaugh et al. 1973) and had published our analytical methods (Anspaugh 1976).

After the former Atomic Energy Commission (AEC) was transformed into the Energy Research and Development Administration (ERDA) in 1975, much more attention was suddenly focused on sources of commercial energy other than nuclear. Our Division at LLNL took on a major responsibility for the study of the environmental effects of exploiting geothermal energy, with Phelps and I sharing major responsibility for this study. As this study grew and had increased demands for funds, the ERDA/OHER provided us with the money, but they also canceled many other longstanding research activities. Thus, our successful resuspension studies at the NTS fell victim to this process, and funding from OHER was halved in 1976 and withdrawn in 1977. Thus, my own work and involvement with the NAEG came to a temporary halt.

A NEW BEGINNING

By 1979 I was back working with DOE-Nevada on a separate project, the Off-Site Radiation Exposure Review Project, which had the goal of reconstructing the dose to people living downwind of the NTS during the 1950s and 1960s. At this time of the NAEG, the mission had been broadened to include the non-transuranic elements present at the NTS. One of the prime missions was to determine the inventory and distribution of *all* radionuclides present in the surface soil of the NTS. This expanded work was to use the technique of field-gamma spectrometry supported by airborne measurements and the collection and analysis of selected soil samples. This work had not progressed very well, and Dunaway and others asked me to undertake an evaluation of this work based on my past experience with field spectrometry at the NTS. This evaluation was done and published with the active involvement of Joe Kordas, an engineer at LLNL (Anspaugh and Kordas 1980).

Eventually, we were asked to take over direction of this project, and an operational plan was prepared (Kordas and Anspaugh 1982). Thus was born a new project, the Radionuclide Inventory and Distribution Project (RIDP). "The basic objective of the RIDP is to inventory the significant radionuclides of NTS origin in NTS surface soil. This includes estimating both the distribution of each radionuclide and also its concentration integrated over the surface of the NTS. ...An important secondary goal is to provide the above data and complete the project in five years. The accuracy required for the measurements has not been specified by end-use criteria. Our overall goal is to provide a final inventory that is known with 95% confidence within at least a factor of two." Quotes are from Kordas and Anspaugh (1982). This was a tremendous and unprecedented undertaking considering the enormous size of the NTS (3460 km^2).

Unfortunately, as with any long-running project, several of the Principal Investigators of the NAEG died before their work could be completed. Among these was W.E. Martin, who had led the development of the NAEG model. Paul Dunaway asked me to take over the model-development work in about 1982. Jim Kercher took on the task of recoding this model to run on the computer system at LLNL. This was successfully accomplished, and an analysis of this model was published by us (Kercher and Anspaugh 1987). The next major task of the modeling group then became the updating of the model to include all of the other significant radionuclides and to incorporate the external gamma-exposure pathway.

THE END OF THE NAEG

By 1983 the NAEG had pretty well finished its major work, many management changes had occurred, and Dunaway left DOE-Nevada about this time. Bruce Church, who had inherited the responsibility for the NAEG, asked me to take over as the Scientific Director. Eventually, this became a request to direct an orderly termination of the NAEG. One of the problems with the NAEG was that, although many, many reports had been published, there were only a few publications in the open literature, and not enough had been done to synthesize the studies that had been done.

One of my first steps was to stop some of the field studies that had limited usefulness to our overall goal and to stop the analysis of many samples that had been collected for the purpose of estimating statistical variance. A primary, positive goal was to set up a mechanism to synthesize and publish the results that had already been achieved. Dick Gilbert, PNL, took on the major responsibility for this synthesis activity.

The latter goal was eventually accomplished with the publication of two major papers (Gilbert et al. 1988a,b). These papers had multiple authors and covered multiple subject areas. I think they are remarkable in the sense that they completely describe the behavior of Pu in an arid ecosystem that includes soil, vegetation, air, small mammals, and beef cattle. I know of no other comparable papers.

The complete inventory of radionuclides in surface soil at the NTS was eventually accomplished as well. This was a cooperative project involving EG&G, LLNL, and the Desert Research Institute (DRI). The data have been published in five individual reports, primarily authored by Rich McArthur of the DRI (McArthur and Kordas 1983, 1985; McArthur and Mead 1987, 1988, 1989) and in one summary report (McArthur 1990). As noted before, given the size of the NTS, this is truly a remarkable accomplishment as well.

In 1986 support for the NAEG formally ended, although work continued after that as necessary to get the key publications finished and published. At Church's request, E.M. Romney, R.O. Gilbert, and I did prepare a proposal for a follow-on program, which has become known as the Basic Environmental Compliance and Monitoring Program (BECAMP). Under this latter program, we did finish a major modification of Martin and Bloom's NAEG model. This "BECAMP model" now includes the external gamma-exposure pathway and the additional radionuclides, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{238}Pu, and ^{241}Am (Ng et al. 1988).

THE MAJOR ACCOMPLISHMENTS OF THE NAEG

When the NAEG began, there was relatively little known about Pu on the NTS and its environs. The problems at the Rocky Flats Plant had rocked the AEC community and called into serious question whether the traditional methods of environmental surveillance were adequate. For the first time, Congress and the President had also made it clear that they were not only serious about environmental regulation, but they intended that the AEC and other federal agencies comply, too. What was the most significant accomplishment of the NAEG? Simply put, it preserved the credibility of the DOE–Nevada management on the issue of Pu in the environment.

Other significant accomplishments of the NAEG were these:

- Defined the areas of Pu contamination.
- Provided detailed data on the attachment of Pu-bearing particles to host soil. This information has been very useful in understanding the resuspension process. This important work was done under the direction of Tami Tamura, ORNL, whom I haven't mentioned before.
- Provided definitive data on Pu transfer from soil to vegetation. The transfer is via air and is not through roots.
- Provided comprehensive data on the resuspension of Pu. This was a joint project of LLNL and the Weather Service.
- Provided a general model of resuspension, which has been widely used by others. The model includes both the time-dependent resuspension-factor approach and the time-independent mass-loading approach.
- Confirmed that the rate of movement of Pu off the NTS is extremely slow.
- Determined that the biological availability of Pu to small mammals is very low.
- Performed a comprehensive study of the availability of Pu to cattle under natural conditions. *In utero* animals were included in the study. Results indicated that the aged Pu still behaves like Pu oxide with very low biological availability.
- Developed a comprehensive model of Pu dose prediction. It is based on realistic soil-to-air movement, realistic soil-to-air-to-vegetation movement, and real data on the accumulation of Pu in cattle.
- Performed a successful cleanup trial. An important goal was minimal destruction of the desert environment. This was a cooperative effort of many individuals and has been published (Shinn et al. 1989).
- Completed an inventory and distribution of all significant radionuclides in surface soil on the NTS.
- Expanded the Pu predictive model to include all significant radionuclides and the external gamma-exposure pathway.

Thus, in terms of the objectives and priorities set out for it in 1971, the NAEG accomplished its mission. Along the way, the results of the studies also contributed substantially to scientific knowledge.

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REFERENCE NUMBER	CIC NUMBER	REFERENCE NUMBER	CIC NUMBER
1	91562	32	17808
2	91562	33	14977
3	91562	34	41496
4	91562	35	67421
5	91563	36	83101
6	91562	37	91568
7	91562	38	83166
8	91562	39	12875
9	13736	40	19651
10	5811	41	91569
11	83114	42	20377
12	13340	43	91570
13	41848	44	91571
14	91562	45	83293
15	51412	46	83214
16	64859	47	83212
17	83130	48	83294
18	83119	49	91223
19	51955	50	91572
20	91564	51	165845
21	*	52	91573
22	1707	53	91574
23	64878	54	41848
24	91566	55	91575
25	14333	56	91576
26	83291	57	4916
27	83292	58	14334
28	12857	59	14336
29	91567	60	14358
30	8428	61	14329
31	59112	62	14359

*Not available in the CIC as of October 1, 1992.

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Part D identifies publications of the Nevada Applied Ecology Information Center at Oak Ridge National Laboratory (ORNL). Part E lists additional selected bibliographies and compilations published by the Atomic Energy Commission, the University of California at Los Angeles, Oak Ridge National Laboratory, and the Comparative Animal Research Laboratory at Oak Ridge Associated Universities. These documents are all available through the Coordination and Information Center.

Part F is a compressed table of contents from NVO-166, the NAEG Procedures Handbook. This one NVO compilation contains a significant number of papers duplicated from earlier NVO compilations. The table of contents is presented here to provide cross-referencing to the earlier reports and to account for the duplicated documents being absent from the NVO-166 references.

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Reynolds Electrical & Engineering Co., Inc.
P.O. Box 98521
Las Vegas, Nevada 89193-8521

NVO #

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5285 Port Royal Road
Springfield, VA 22161

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NAEG PROCEDURES HANDBOOK FOR ENVIRONMENTAL TRANSURANICS OCTOBER 1976

VOLUME 2

IV. RESUSPENSION PROCEDURES AND TECHNIQUES

V. STATISTICAL ANALYSIS AND DATA PROCESSING

VI. OTHER NAEG METHODOLOGY

APPENDIX A. CROSS REFERENCE OF SCIENTIFIC AND COMMON NAMES OF FLORA AND FAUNA ENCOUNTERED AT THE NAEG INTENSIVE-STUDY SITES ON THE TEST RANGE COMPLEX

MICROBIOTA (No common names.)

BACTERIA

- Achromobacter
- Bacillus
- Pseudomonas
- Streptomyces

FUNGI

- Aspergillus
  - Candidus, Fumigatus, Niger, Carbonarius, Japonicus, Phoenecis
- Cephalidiaceae
  - Syncephalastrum
- Chaetomiaceae
  - Chaetomium
- Dematiaceae
  - Alternaria, Curvularia, Hormiscium, Papularia, Stachybotrys
- Gymnoascaceae
  - Gymnoascus
- Moniliaceae
  - Geotrichum, Fusarium
- Mucoraceae
  - Circinella, Mucor, Rhizopus
- Penicillium
  - Botrytis, Cephalosporium, Hemicola, Mortierella, Mycelia sterilia, Scopulariopsis, Septonema, Spicaria, Stysanus, Thamnidium

(Source: Au & Leavitt, NVO-224, pp. 201-206.)

FLORA

(NOTE: Match the letter in parentheses in the Scientific Names to the letter in the Common Names. Match the number in parentheses in the Common Names to the number in the Scientific Names. The letters and numbers start over within each group of flora and fauna. Plants with no common name listed in the source references are indicated by "Not in source ref". Source references are listed at the end of the flora section.)

GRASSES

	SCIENTIFIC NAMES		COMMON NAMES
1	Agropyron trichophorum (L)	A	Basin Wild Rye (4)
2	Bromus tectorum (C)	B	Buckwheat (5)
3	Bromus rubens (G)	C	Cheat Grass (2)
4	Elymus cinereus (A)	D	Desert Needlegrass (12)
5	Eriogonum maculatum (B)	E	Desert Squirreltail Grass (10)
6	Erioneuron pulchellum (J)	F	Fluffgrass (13)
7	Hilaria jamesii (H)	G	Foxtail Chess (3)
8	Oryzopsis hymenoides (I)	H	Galleta Grass (7)
9	Sitanion jubatum (K)	I	Indian Ricegrass (8)
10	Sitanion hystrix (E)	J	Not in source ref. (6, 11)
11	Sporobolus contractus (J)	K	Squirreltail Grass (9)
12	Stipa speciosa (D)	L	Wheat-grass (1)
13	Tridens pulchellus (F)		

APPENDIX A. CROSS REFERENCE OF SCIENTIFIC AND COMMON NAMES... (Cont'd)

FLORA (Continued)

ANNUALS AND HERBACEOUS PERENNIALS

SCIENTIFIC NAMES

1 Ambrosia acanthicarpa (S)
2 Amsinckia tessellata (C)
3 Astragalus lentiginosus (H)
4 Baileya pleniradiata (D)
5 Chaenactis stevioides (F)
6 Chaetadelphia wheeleri (K)
7 Chenopodium incanum (K)
8 Coldenia nuttallii (L)
9 Cryptantha circumscissa (Y)
10 Cryptantha micrantha (Q)
11 Cryptantha recurvata (B)
12 Cymopterus ripleyi (K)
13 Descurainia pinnata (AB)
14 Eriastrum eremicum (K)
15 Eriogonum deflexum (T)
16 Eriogonum maculatum (K)
17 Eriogonum nidularium (Z)
18 Eriophyllum pringlei (O)
19 Erodium cicutarium (V)
20 Gilia campanulata (K)
21 Gilia cana ssp. triceps (K)
22 Gilia leptomeria (W)
23 Glyptopleura marginata (K)
24 Halogeton glomeratus (K)
25 Ipomopis depressa (K)
26 Ipomopis polycladon (K)
27 Iva nevadensis (J)
28 Langloisia schottii (K)
29 Lipidium fremontii (E)
30 Lipidium lasiocarpum (N)
31 Lupinus flavoculatus (I)
32 Machaeranthera leucanthemifoli (K)
33 Malacothrix sonchoides (AA)
34 Mentzelia albicaulis (U)
35 Mirabilis pudica (K)
36 Nama aretioides (K)
37 Nama demissum (R)
38 Oenothera avita (K)
39 Oenothera claviformis ssp.integrior (K)
40 Oxytheca perfoliata (P)
41 Psathyrotes annua (G)
42 Salsola iberica (X)
43 Salsola kali (X)
44 Salsola paulsenii (X)
45 Stephanomeria exigua (A)
46 Stephanomeria parryi (M)

COMMON NAMES

A Annual Mitra (45)
B Arched-calyxed Forget-me-not (11)
C Checker Fiddleneck (2)
D Desert Marigold (4)
E Desert Alyssum (29)
F Esteve Pincushion (5)
G Fan-leaf (41)
H Loco Weed (3)
I Lupine (31)
J Nevada Poverty Weed (27)
K Not in source ref.(6,7,12,14,16,20,21,23,24,25,26,28,32,35,36,38,39)
L Nuttall Coldenia (8)
M Parry Rock-pink (46)
N Peppergrass (30)
O Pringle Eriophyllum (18)
P Punctured Bract (40)
Q Purple-rooted Forget-me-not (10)
R Purple Mat (37)
S Sand-bur (1)
T Skeleton Weed (15)
U Small-flowered Blazing Star (34)
V Storksbill (19)
W Tooth-leaved Gilia (22)
X Tumbleweed (42, 43, 44)
Y Western Forget-me-not (9)
Z Whisk Broom (17)
AA Yellow-saucers (33)
AB Yellow Tansy Mustard (13)

APPENDIX A. CROSS REFERENCE OF SCIENTIFIC AND COMMON NAMES... (Cont'd)

FLORA (Continued)

SHRUBS

SCIENTIFIC NAMES

1 Acamptopappus shockleyi (S)
2 Ambrosia dumosa (Y)
3 Amelanchier alnifolia (V)
4 Artemisia arbuscula ssp. nova (E)
5 Artemisia spinescens (F)
6 Artemisia tridentata (C)
7 Atriplex canescens (L)
8 Atriplex confertifolia (W)
9 Ceratoides lanata (Z)
10 Chrysothamnus greenei (S)
11 Chrysothamnus nauseosus (U)
12 Chrysothamnus viscidiflorus (O)
13 Coleogyne ramosissima (D)
14 Cowania mexicana (G)
15 Dalea fremonti (N)
16 Ephedra nevadensis (R)
17 Eurotia lanata (Z)
18 Franseria dumosa (Y)
19 Grayia spinosa (X)
20 Hymenoclea salsola (S)
21 Kochia americana vestitia (M)
22 Krameria parvifolia (S)
23 Larrea divaricata (I)
24 Larrea tridentata (I)
25 Lycium andersonii (AA)
26 Lycium pallidum (T)
27 Mendora spinescens(S)
28 Opuntia erinacea (Q)
29 Purshia glandulosa (J)
30 Purshia tridentata (A)
31 Sphaeralcea ssp. (K)
32 Symphoricarpos longiflorus (P)
33 Tetradymia axillaris (H)
34 Tetradymia glabrata (B)

COMMON NAMES

A (Antelope) Bitterbrush (30)
B (Awn) Horsebrush (34)
C Big Sagebrush (6)
D Blackbrush (13)
E Black Sagebrush (4)
F Bud Sagebrush (5)
G Cliffrose (14)
H Cottonthorn (33)
I Creosote Bush (23, 24)
J Desert Bitterbrush (29)
K Desert Mallow (31)
L Four-winged Saltbush (7)
M Green Molly (21)
N Indigo-bush (15)
O Little Rabbitbrush (12)
P Longflower Snowberry (32)
Q Mohave Prickly-pear (28)
R Nevada Joint-fir (16)
S Not in source ref. (1,10,20,22,27)
T Rabbit-thorn (26)
U Rubber Rabbitbrush (11)
V Service Berry (3)
W Shadscale (8)
X Spiny Hop-Sage (19)
Y White Bursage (2, 18)
Z Winterfat (9, 17)
AA Wolfberry (Desert-Thorn) (25)

TREES

1 Juniperus osteosperma (C)
2 Pinus monophylla (D)
3 Quercus gambeli (A)
4 Yucca brevifolia (B)

A Gambel Oak (3)
B Joshua Tree Yucca (4)
C Juniper (1)
D Pinyon Pine (2)

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JAEGER, E. C., 1969. Desert Wild Flowers, Stanford University Press.
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FAUNA
BIRDS

	SCIENTIFIC NAMES		COMMON NAMES
1	Accipiter cooperii (J)	A	American Coot (24)
2	Actitis macularia (AM)	B	Black-billed Magpie (32)
3	Agelaius phoeniceus (AE)	C	Black-headed Cowbird (29)
4	Amphispiza belli (AH)	D	Black-tailed Gnatcatcher (34)
5	Amphispiza bilineata (E)	E	Black-throated Sparrow (5)
6	Anas carolinensis (P)	F	Blue-gray Gnatcatcher (33)
7	Anas strepera (N)	G	Brewer's Blackbird (21)
8	Aquila chrysaetos (O)	H	Brewer's Sparrow (36)
9	Asio flammeus (AI)	I	Common Raven (19)
10	Buteo jamaicensis (AD)	J	Cooper's Hawk (1)
11	Buteo lagopus (AF)	K	Crissal Thrasher (41)
12	Calomospiza melanocorys (U)	L	Domestic Chicken (25)
13	Carpodacus mexicanus (R)	M	Fox Sparrow (31)
14	Cathartes aura (AN)	N	Gadwall (7)
15	Chondestes grammacus (V)	O	Golden Eagle (8)
16	Chordeiles acutipennis (W)	P	Green-winged Teal (6)
17	Circus cyaneus (Z)	Q	Horned lark (20)
18	Contopus sordidulus (AS)	R	House Finch (13)
19	Corvus corax (I)	S	House Sparrow (30)
20	Eremophilia alpestris (Q)	T	Hummingbird (43)
21	Euphagus cyanocephalus (G)	U	Lark Bunting (12)
22	Falco mexicanus (AC)	V	Lark Sparrow (15)
23	Falco sparverius (AL)	W	Lesser Nighthawk (16)
24	Fulica americana (A)	X	Loggerhead Shrike (26)
25	Gallus domesticus (L)	Y	Long-billed Marsh Wren (40)
26	Lanius ludovicianus (X)	Z	Marsh Hawk (17)
27	Melospiza melodia (AK)	AA	Mockingbird (28)
28	Mimus polyglottos (AA)	AB	Mourning Dove (47)
29	Molothrus ater (C)	AC	Prairie Falcon (22)
30	Passer domesticus (S)	AD	Red-tailed Hawk (10)
31	Passerella iliaca (M)	AE	Red-winged Blackbird (3)
32	Pica pica (B)	AF	Rough-legged Hawk (11)
33	Polioptila caerulea (F)	AG	Rough-winged Swallow (38)
34	Polioptila melanura (D)	AH	Sage Sparrow (4)
35	Pooecetes gramineus (AO)	AI	Short-eared Owl (9)
36	Spizella breweri (H)	AJ	Solitary Vireo (45)
37	Steganopus tricolor (AU)	AK	Song Sparrow (27)
38	Stelgidopteryx ruficollis (AG)	AL	Sparrow Hawk (23)
39	Sturnella neglecta (AR)	AM	Spotted Sandpiper (2)
40	Telmatodytes palustris (Y)	AN	Turkey Vulture (14)
41	Toxostoma dorsale (K)	AO	Vesper Sparrow (35)
42	Tyrannus verticalis (AQ)	AP	Warbling Vireo (44)
43	(Unknown) (T)	AQ	Western Kingbird (42)
44	Vireo gilvus (AP)	AR	Western Meadowlark (39)
45	Vireo solitarius (AJ)	AS	Western Wood Peewee (18)
46	Xanthocephalus xanthocephalus(AV)	AT	White-crowned Sparrow (48)
47	Zenaida macroura (AB)	AU	Wilson's Phalarope (37)
48	Zonotrichia leucophrys (AT)	AV	Yellow-headed Blackbird (46)

APPENDIX A. CROSS REFERENCE OF SCIENTIFIC AND COMMON NAMES... (Cont'd)

FAUNA (Continued)

REPTILES

	SCIENTIFIC NAMES		COMMON NAMES
1	Callisaurus draconoides (P)	A	Banded Gecko (4)
2	Chionactis occipitalis (O)	B	Coachwhip Snake (or Red Racer) (9)
3	Cnemidophorus tigris (F)	C	Collared Lizard (7)
4	Coleonyx variegatus (A)	D	Desert Horned Lizard (11)
5	Crotalus cerastes (K)	E	Desert Spiny Lizard (15)
6	Crotalus mitchelli (L)	F	Desert Whiptail Lizard (3)
7	Crotaphytus collaris (C)	G	Gopher Snake (13)
8	Crotaphytus wislizenii (H)	H	Leopard Lizard (8)
9	Masticophis flagellum (B)	I	Bullsnake (or Gopher snake) (12)
10	Masticophis taeniatus (M)	J	Side-blotched Lizard (16)
11	Phrynosoma platyrhinos (D)	K	Sidewinder Rattlesnake (5)
12	Pituophis catenifer (I)	L	Speckled Rattlesnake (6)
13	Pituophis melanoleucus (G)	M	Striped Whipsnake (10)
14	Salvadora hexalepis (N)	N	Western Patch-nosed Snake (14)
15	Sceloporus magister (E)	O	Western Shovel-nosed snake (2)
16	Uta stansburiana (J)	P	Zebra-tailed Lizard (1)

MAMMALS

1	Ammospermophilus leucurus (AE)	A	Badger (30)
2	Antilocapra americana (AA)	B	Black-tailed Jackrabbit (11)
3	Bos taurus (M)	C	Burro (8)
4	Canis latrans (G)	D	Cactus Mouse (24)
5	Dipodomys merriami (V)	E	California Myotis Bat (14)
6	Dipodomys microps (O)	F	Canyon Mouse (23)
7	Dipodomys ordii (Y)	G	Coyote (4)
8	Equus asinus (C)	H	Deer Mouse (25)
9	Equus caballus (N)	I	Desert Bighorn Sheep (19)
10	Felix concolor (W)	J	Desert Cottontail Rabbit (29)
11	Lepus californicus (B)	K	Desert Shrew (16)
12	Microdipodomys megacephalus (AD)	L	Desert Wood Rat (15)
13	Microdipodops pallidus (R)	M	Domestic Cow (3)
14	Myotis californicus (E)	N	Feral Horse (9)
15	Neotoma lepida (L)	O	Great Basin Kangaroo Rat (6)
16	Notiosorex crawfordii (K)	P	Great Basin Pocket Gopher (32)
17	Odocoileus hemionus (X)	Q	Great Basin Pocket Mouse (22)
18	Onychomys torridus (AB)	R	Kangaroo Mouse (13)
19	Ovis canadensis nelsonii (I)	S	Kit Fox (34)
20	Perognathus formosus (U)	T	Little Pocket Mouse (21)
21	Perognathus longimembris (T)	U	Long-tailed Pocket Mouse (20)
22	Perognathus parvus (Q)	V	Merriam's Kangaroo Rat (5)
23	Peromyscus crinitus (F)	W	Mountain Lion (10)
24	Peromyscus eremicus (D)	X	Mule Deer (17)
25	Peromyscus maniculatus (H)	Y	Ord Kangaroo Rat (7)
26	Peromyscus truei (Z)	Z	Pinyon Mouse (26)
27	Pipistrellus hesperus (AG)	AA	Pronghorn antelope (2)
28	Reithrodontomys megalotis (AF)	AB	Southern Grasshopper Mouse (18)
29	Sylvilagus audubonii (J)	AC	Southern Pocket Gopher (31)
30	Taxidea taxus (A)	AD	(Not in source ref.) (12, 33)
31	Thomomys umbrinus (AC)	AE	White-tailed Antelope Squirrel (1)
32	Thomomys bottae (P)	AF	Western Harvest Mouse (28)
33	Urocyon cinereoargenteus (AD)	AG	Western Pipistrelle Bat (27)
34	Vulpes macrotis (S)		