APPENDIX II

RADIONUCLIDE EXPOSURES TO PERSONS IN THE VICINITY OF THE NEVADA TEST SITE/YUCCA MOUNTAIN SITE

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For populations living near the Nevada Test Site (NTS), exposure to normal background radiation levels may be modified by NTS activities. Past NTS activities have introduced radioactivity into air, soil, and ground water. Atmospherically-released radioactivity has contributed to local and global exposure in the past and will continue to do so in the future. Radioactivity introduced on-site into soil and proximally to ground water has the potential to expose future persons living in the vicinity of the NTS. For purposes of this discussion, past NTS activities relevant to human exposure may be grouped into several discrete categories that are discussed below. In addition, risks and consequences from these activities are summarized.

Atmospheric Weapons Testing

Over 100 events on the Nevada Test Site have resulted in the release and deposition of radionuclides on the soil surface outside the test-site boundary (HIC90). Atmospheric weapons testing at NTS began in 1951 and continued into 1962. Atmospheric testing included weapons that were dropped by airplanes, those detonated from towers at heights ranging from 30 to 213 meters (m), tests conducted on land surfaces, and tests in which helium balloons lofted weapons 137 to 457 m above ground.

It is estimated that for near-surface detonations, about 12 percent of the fission products were distributed locally, with the remaining 10, 76, and 2 percent introduced into the troposphere, stratosphere, and very high altitudes, respectively (UNS82). In addition, the large number of neutrons released at the time of the detonation results in significant quantities of activation products in the bomb's structural components, as well as ambient surface materials.

The primary radionuclides deposited locally were americium, plutonium, cobalt, cesium, strontium, and europium. Based on the most recent estimates, about 20 Curies (Ci) remain in surface soils at or near the original testing area(s) (MCA91).

Safety Tests

Between 1954 and 1963, more than 30 tests were conducted to investigate safety issues regarding nuclear weapons in accident scenarios. The safety tests used mixtures of plutonium and uranium that were detonated using conventional explosives. These tests also assessed the disposal and transport of these isotopes in the environment, including plant and animal uptake. In the 3,500 acres originally contaminated, the inventory of radionuclides is estimated to be between 34 and 39 Ci.

The primary isotopes at test locations are plutonium, uranium, and americium, with lesser amounts of cesium, strontium, and europium. Currently, these long-lived radionuclides are contained in surficial soils and are relatively immobile. They are, however, potentially available to be transported off-site by wind erosion.

Nuclear Rocket and Related Tests

Between 1959 and 1973, the Nuclear Rocket Development Station area was used for a series of open air nuclear reactor, nuclear engine, and nuclear furnace tests, and for the High Energy Neutron Reactions Experiment. The total estimated inventory of soil contaminants that include strontium, cesium, cobalt, and europium has been estimated to be one Ci (MCA91).

Waste Disposal Activities

Since the early to mid-1960s, NTS Areas 3 and 5 were established for disposal of low-level waste from on-site and off-site DOE waste generators and include landfill cells (pits and trenches) and greater confinement disposal (GCD) boreholes. Approximately one-half of the buried waste represents atmospheric testing debris generated during cleanup activities of above-ground nuclear test areas, with the remaining half from other defense-related facilities.

Currently, NTS operates Areas 3 and 5 as a LLW repository and receives waste from on-site activities and off-site defense generators. Approximately 500,000 Ci of low-level waste are disposed in shallow pits and trenches. Approximately 9.3 million Ci of high-specific-activity waste containing primarily tritium have been disposed in GCDs. In addition, both areas also contain smaller inventories of mixed waste.

Underground Testing

In August of 1963, the United States and the former Soviet Union signed the Limited Test Ban Treaty (LTBT), which effectively banned weapons testing in the atmosphere. Approximately 800 underground nuclear tests have been conducted that include shallow borehole tests (< 60 m) and deep underground tests (about 600 m). Of the total inventory (estimated to be 300 million Ci), about 112 million Ci are considered a potential hydrological source term. About 90 percent (or 100 million Ci) of this radioactivity is represented by tritium.

Table II-1 provides a summary of residual radionuclide source terms at NTS for the aforementioned activities.

Potential Impacts on Surrounding Populations

Population impacts from NTS activities are most effectively discussed in terms of activities that have resulted in the introduction of radioactivity: (1) into the atmosphere; (2) into surficial soils; and (3) at subsurface depths, where radioactivity could in the future become available to the ground water regime.

While maximum human exposure from atmospheric releases essentially coincided with peak periods of past nuclear detonation, human exposure to radioactivity introduced below ground is primarily a concern of the future.

Past Impacts Associated with Atmospheric Releases

In 1979, the Department of Energy (DOE) launched a major effort, called the Off-site Radiation Exposure Review Project (ORERP). The principal objective of the ORERP was to collect, organize, and analyze all relevant documents and data pertaining to fallout and resultant exposure to off-site population groups in the vicinity of the NTS. Since that time, more than 200,000 documents have been amassed and exposure estimates for discrete fallout events have been derived from empirical measurements and computer-projection models (ANS90).

Table II-1. Summary of Remaining Radioactivity on the NTS

Source	Area Affected	Media	Major Known Isotopes	Depth Range	Remaining Inventory (Ci)
Atmospheric & Tower Tests	Aboveground Nuclear Weapon Proving Area	Surficial Soils & Test Structures	Americium Cesium Cobalt Europium Strontium	Above land surface	~ 20
Safety Tests	Aboveground Experimental Areas	Surficial Soils	Americium Cesium Cobalt Plutonium Strontium	At land surface	~ 35
Nuclear Rocket Development Station	Nuclear Rocket Motor, Reactor, and Furnace Testing Area	Surficial Soils	Cesium Strontium	Less than 10 ft	~1
Shallow Land Disposal	Waste Disposal Landfills	Soils & Alluvium	Dry-packaged low-level & mixed wastes	Less than 200 ft	~ 500,000[a]
Greater Confinement Disposal	Monitored Underground Waste Disposal Borehole	Soils & Alluvium	Tritium Americium	60 meters	~ 9.3 million[a] (~ 10,000 ft^2)
Shallow Borehole Tests	Underground Nuclear Testing Areas	Soils & Alluvium	Americium Cesium Cobalt Europium Plutonium Strontium	Less than 200 ft	~ 2,000 at land surface, unknown at depth
Deep Underground Tests	Underground Nuclear Testing Areas	Soils, Alluvium, & Consolidated Rock	Tritium, fission, and activation products	~ 600 meters	112 million[b]

[a] Inventory at time of disposal (not corrected for decay).

[b] The 112 million Ci represents that fraction of the total underground source term (estimated to be 300 million Ci) which is within 100 m of the water table. It is this fraction that is available to the ground water regime and is, therefore, referred to as the hydrological source term.

External exposure estimates were originally published in 1986 (ANS86) and updated in 1990 (ANS90). The total collective external exposure from 1951 through 1975 for all communities was estimated to be 86,000 person-R, with the greatest exposures occurring in Saint George, Utah; Ely, Nevada; and Las Vegas, Nevada. Summaries of the distribution of individual cumulative external exposures are provided in Tables II-2 and II-3, which identify three discrete time periods. By far, the largest collective and individual exposures occurred between 1951 and 1958. During the period from 1961 to the time of the Limited Test Ban Treaty, no individuals are known to have received cumulative external exposures greater than 0.5 R. The 480 individuals who received exposures between 0.1 and 0.5 R lived in small ranch communities just north and northeast of the NTS. From 1963 to 1975, cumulative external exposures were small, with only six individuals (at the Diablo Maintenance Station) receiving more than 0.1 R.

The contribution of dose resulting from inhalation and ingestion of radionuclides was not considered in earlier exposure estimates. Investigators from the Desert Research Institute (DRI), Colorado State University (CSU), and the Lawrence Livermore National Laboratory (LLNL) are now systematically reconstructing the internal dose to individuals for all locations and test events at the NTS. The computer code PATHWAY was developed to predict radionuclide ingestion by residents in the arid regions around the NTS following radioactive fallout deposition (WHC90). PATHWAY simulates the transport of approximately 21 fallout radionuclides through agricultural ecosystems to humans and accounts for agricultural conditions of the southwestern United States during the 1950s. Outputs can be generated that are specific to age, sex, and radionuclides. For the inhalation pathway, estimates will be based on empirical air sampling measurements, fallout data, and meteorologic records.

NTS Health Studies

Numerous population groups exposed to fallout from NTS weapon tests have been studied for health effects. Those studied include civilian populations in the Utah - Nevada area and military participants in weapons testing. Most of these studies assessed the incidence of leukemia and thyroid disorders among the exposed populations.

Table II-2. Exposure Summary by Major Time Period of the Locations with Recorded External Gamma Exposures, the Mean Location Exposure, and the Population Weighted Exposure[1]

	Time period		
	1951 to 1958	**1961 to LTBT[2]**	**LTBT[2] to 1975**
Collective exposure (Person-R)	84,400	610	320
Number of locations with recorded exposure	260	74	72
Mean location exposure (R)	1.3	0.048	0.017
Population weighted exposure (R)	0.47	0.031	0.002

[1] Source: ANS90
[2] Limited Test Ban Treaty signed August 5, 1963

Table II-3. Distribution of Individual Cumulative External Gamma Exposure by Exposure Range During the Three Major Time Periods

Exposure Range (R)	Persons within Exposure Range		
	1951 to 1958	1961 to LTBT	LTBT to 1975
<0.01 to 0.1	61,000	180,000	180,000
0.01 to 0.5	80,000	480	6
0.5 to 1.0	19,000	0	0
1.0 to 5.0	20,000	0	0
5.0 to 10.0	520	0	0
10.0 to 15.0	45	0	0
Total	180,000	180,000	180,000

Source: ANS90

The results of key leukemia and thyroid studies involving NTS population groups are summarized below.

- A 1979 study reported an apparent tripling in the rate of leukemia mortality among Utah residents born between 1951 and 1958 in "high exposure counties" (LYO79). Some scientists view this finding with skepticism because of a possible misinterpretation of the dose distribution and the paradox that the rates of cancer at other anatomical sites were lower in "high exposure" areas than those in "low exposure" areas.

- Machado et al. (MAC87) reported similar findings of an excess of childhood leukemia deaths in three "high exposure" southwestern Utah counties among individuals younger than 15 years of age who were born before the tests ended. These authors suggested the possibility that the transient increase of radiation-induced childhood leukemias followed the peak fallout deposition between 1953 and 1957.

- Johnson (JOH87) identified radiation-induced cancers among Mormon families in southwestern Utah exposed to fallout between 1951 and 1962 and venting of underground nuclear detonations between 1962 and 1979. This study was found to suffer from methodological deficiencies related to the selection of study subjects, the methods of obtaining medical information and cancer diagnosis, and the interpretation of data (ICR91).

- Caldwell et al. (CAL83) reported an excess incidence of leukemia, but no overall excess of other cancers, among the 3,224 military personnel who participated in the 1952 Smokey nuclear test. Through 1977, nine cases of leukemia had occurred, compared with 3.5 cases expected. The recorded average external dose was 520 mrem. A similar study of 5,000 other individuals who had participated in 24 detonations found no leukemia excess (ROB83).

- Another population group studied since 1965 for thyroid disorders includes a cohort of about 2,600 public school students who as infants lived in proximity to the Nevada Test Site in Utah and Nevada. The prevalence of thyroid abnormalities in these children has been compared to that in a control group of 2,219 children selected from a county in Arizona that was presumed to have received little or no fallout from the Nevada Test Site. Thyroid doses occurred primarily as the result of ingesting milk contaminated with radioiodine. Cumulative thyroid doses among study subjects were estimated to range from 30 to 700 rad (MAY66). Incidence of thyroid neoplasms was first reported in 1974 and 1975 (RAL74, RAL75). Although the rate of thyroid neoplasms among the Utah/Nevada subjects of 5.6 per 1,000 was higher than that of Arizona control subjects (3.3 per 1,000), the difference was statistically insignificant. In a follow-up study conducted in 1985-1986, in which 3,122 of the original 4,819 subjects were reevaluated, the rate of thyroid neoplasms in the Utah/Nevada subjects of 24.6 per 1,000 was again slightly but insignificantly higher than the Arizona subjects (20.2 per 1,000) (RAL90). The authors previously concluded that living near the Nevada Test Site in the 1950s had not resulted in a statistically significant increase in thyroid neoplasms among exposed subjects when compared to control subjects of the same age and gender.

It is now generally accepted that a fundamental limitation in all previous NTS studies was that individual radiation exposures were uncertain or lacking because individual residence histories for study subjects were unknown. In addition, reliable exposure rates for many locations were not available at the time of the study.

In response to DOE's previously cited Off-site Radiation Exposure Review Project that amassed exposure data on a county-by-county basis for all or part of seven western states, the National Cancer Institute (NCI) sponsored two major studies to determine whether there were any effects of fallout on the public near the NTS (WAC90).

The first NCI-sponsored study was intended to examine whether leukemia in the state of Utah was related to radiation fallout. Dose estimates for the Utah leukemia case-control study were recently reported by Simon et al. (SIM95). The primary objective of the dosimetry task was to estimate the total observed dose from all pathways to the active marrow by summing exposure from each event at each location where the individual resided. External exposure from radionuclides deposited on the ground presented by far the most significant dose contribution to the active marrow.

The second NCI-sponsored study was a reevaluation of the earlier thyroid study. This study reassessed exposures to the same cohort of subjects identified in the 1965-1970 study and reexamined subjects for thyroid neoplasia. Results of this study were reported by Kerber et al. (KER93) and more recently by Till et al. (TIL95). Their reassessment of the study cohort demonstrated a statistically significant dose-response relationship between exposure to radioiodines from open-air weapon tests at the NTS and the occurrence of thyroid neoplasms (carcinomas and benign neoplasms). It should be noted, however, that the association was not statistically significant for thyroid carcinomas alone.

In summary, the studies and information collected strongly indicate that most of the airborne radioactivity released during the detonation to which nearfield residents were exposed has been widely dispersed in the atmosphere, greatly diluted in the terrestrial biosphere, or decayed in the more than 30 years since the last atmospheric test. Therefore, future human exposures from past atmospheric tests can be assumed negligible.

Potential Future Exposures Associated with Current Soil Contaminants

The potential for significant future exposures to area residents of the NTS is limited to those soil contaminants that in time may migrate down through the unsaturated zone and encounter ground water that may subsequently be withdrawn for human use and consumption. Radionuclide inventories residing in surficial or shallow strata are unlikely to reach an aquifer. DOE considers only radionuclides from deep underground tests that were deposited beneath the water table or within 100 m of the top of the water table as a potential hydrological source term (DOE96).

As previously noted, the hydrological source term available to the ground water regime is estimated to be 112 million Ci, of which about 100 million Ci is represented by tritium. There is considerable uncertainty about the actual quantity of tritium that can enter the ground water regime. Uncertainties involve the extent to which radioactivity is securely trapped in the melt glass matrix formed in the detonation cavity and the nearfield impact of the detonation on ground permeability.

The shock wave and compressive forces from the tests can, on one hand, enhance permeability by creating fractures nearby; on the other hand, these forces may decrease permeability by closing pre-existing fractures.

Tritium, as water, is considered by far the most mobile radionuclide present in the subsurface environment surrounding the underground test cavity. With its half-life of about 12 years, the estimated 100 million Ci hydrologic source term of tritium represents the major radionuclide of concern for the next 200 years.

Risks Associated with Tritium Migration

Proposed changes in NTS operations, as well as DOE's policy of reviewing sitewide impacts under the National Environmental Policy Act (NEPA), have prompted the need for a new Environmental Impact Statement (EIS) for the NTS (DOE93a). The draft EIS (DOE96), issued in January 1996, assessed doses and risks from past activities and future operations under each of the following four alternatives:

- Alternative 1: No Action. The DOE would continue to support ongoing program operations, but no new initiatives would be pursued.
- Alternative 2: Discontinue Operations. Under this option, only services required to continue the protection of human health and safety would be performed, inclusive of environmental monitoring.
- Alternative 3: Expanded Use. Implementation of this alternative would involve expansion of many current activities and programs, including current remediation and waste management activities.
- Alternative 4: Alternate Use of Withdrawn Land. While defense programs would be discontinued, there would be increased activities for waste management, remediation, and nondefense research activities (e.g., solar energy).

The proposed NTS EIS alternatives, however, are not expected to change the current inventory or configuration of subsurface contamination. Thus, an assessment of future radiological impacts to off-site residents is considered identical for each of the proposed alternatives. The migration of tritium from discrete underground NTS test areas to locations outside the current site boundary and accessible to members of the public are of primary concern and have been evaluated in the draft EIS.

Table II-4 provides summary data regarding doses and risks to hypothetical individuals. Individuals are assumed to ingest contaminated well water for a period of 70 years from the nearest accessible location. The 70-year lifetime exposure scenario coincides with the time of peak concentrations of tritium in ground water for each of the three underground test sites:

- Yucca Flat. Tritium concentrations migrating from Yucca Flat to Mercury, Nevada are not expected to reach the minimum detectable level of one pCi/L. Lifetime doses and risks are, therefore, negligible.

- Project Shoal Area. At the closest accessible location (the eastern boundary of the Project Shoal Area), tritium is expected to reach a maximum concentration of about 280 pCi/L in about 206 years, yielding a lifetime dose of 1.6 mrem. At the nearest existing public well, maximum concentrations are not expected to occur for 278 years, resulting in doses and risks that are nearly four orders of magnitude lower.

- Central Nevada Test Area. At the nearest existing public well, the time of maximum tritium concentration is not expected for more than 400 years at concentrations that are small fractions of one pCi/L. Associated doses and risks at this location are essentially non-existent. Near the southern boundary, tritium concentrations as high as 1.2×10^8 pCi/L had been predicted for 1983 (or 15 years after testing), yielding a lifetime dose of about 8,000 mrem, or an average annual dose of 114 mrem. In 1996, these concentrations would be reduced by more than a factor of two due to natural decay. However, there has been no confirmation of these concentrations by ground water sampling and assessment at this location.

Radiological Surveillance Around the Nevada Test Site

Since 1970, the EPA's Characterization Research Division (formerly named the Environmental Monitoring Systems Laboratory - Las Vegas or EMSL-LV) has assumed responsibility for the Off-site Radiological Safety Program (ORSP) at NTS and other U.S. nuclear test sites. Among ORSP's primary objectives are to systematically measure and document levels and trends of environmental radiation and radioactive contaminants in the vicinity of the test sites.

Off-site levels of radiation and radioactivity are assessed by gamma-ray measurements using highly-sensitive pressurized ion chambers (PICs) and thermoluminescent dosimeters (TLDs); by sampling air, water, soil, milk, meats, food crops, and indigenous flora and fauna; and by in-vivo/-vitro bioassays of off-site population groups. Results of these measurements are collated and made available to the public in an annual report (DOE93b). Provided below is a brief description of the major elements of the ORSP and summary data for 1993, the most recent year of published data.

Table II-4. Doses and Health Risks to Exposed Individuals[a] from Subsurface Radioactivity

Test Location	Receptor Location	Arrival Time[b] of Peak Conc. (yr)	Peak Tritium Concentration (pCi/L)	Lifetime Dose (mrem)	Risk of Fatal Cancer
Yucca Flat	Mercury, NV	100	< 1	3.0×10^{-5}	1.5×10^{-11}
Project Shoal Area[c]	Eastern boundary[d]	206	280	$1.6 \times 10^{+0}$	8.0×10^{-7}
Project Shoal Area[c]	Nearest public well	278	<1	2.0×10^{-4}	1.0×10^{-10}
Central Nevada Test Area[e]	Central Nevada Test Area boundary[d]	15	1.8×10^{8}	$8.0 \times 10^{+3}$	4.0×10^{-3}
Central Nevada Test Area[e]	Nearest public well	410	<< 1	1.8×10^{-17}	9.0×10^{-24}

[a] The maximally exposed individual is a hypothetical person who is assumed to obtain drinking water from a well at the receptor location for a lifetime of 70 years, centered around the time of peak tritium concentration in the well water.
[b] Time period from the underground test date to the arrival of the peak tritium concentration in well water at the receptor's location.
[c] Results based on analysis performed by Chapman et al. 1995 (CHA95).
[d] No public well currently exists at these locations.
[e] Results based on analysis performed by Pohlmann et al. 1995 (POH95).

External Ambient Gamma Monitoring at the NTS

External ambient radiation levels are measured independently by a network of 27 pressurized ion chambers and 127 thermoluminescent dosimeters located in various communities surrounding the NTS (Figure II-1). Ambient dose and dose rates measured by these devices represent the combined sources of cosmic and terrestrial radiation. Ambient air dose levels ranged from 66 mR/yr at Pahrump, Nevada, to 166 mR/yr at Austin, Nevada, with an average absorbed tissue dose value of 97 mrem/yr. Observed variations in ambient dose rates reflect differences in altitude, soil composition, and meteorological factors. This average of 97 mrem/yr is considerably higher than the combined national average value of cosmic and terrestrial radiation level of 56 mrem.

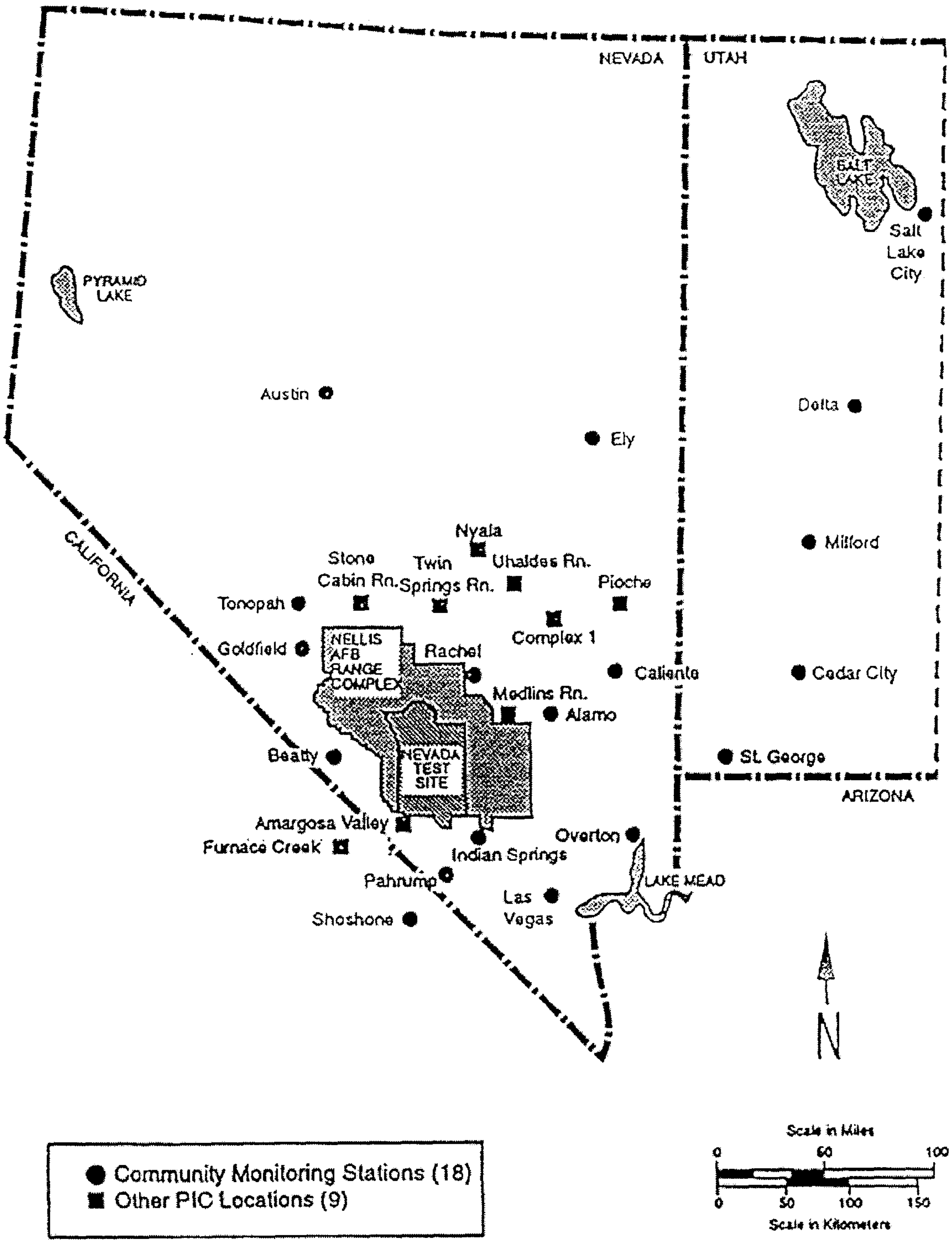

Figure II-1. Pressurized Ion Chamber Network Station Locations - 1993

Atmospheric Monitoring

A network of 30 continuously-operating stations monitor airborne particulate radionuclides and radioiodines. An additional 14 sampling stations sample for atmospheric tritium and noble gases. Data indicate that airborne radioactivity from diffusion, evaporation of effluents, or resuspension of radionuclides from past releases are currently below detection limits at off-site locations.

Using the CAP88-PC model and NTS radionuclide emission data, an effective dose equivalent of 0.004 mrem/yr was calculated for the off-site maximally exposed individual.

Monitoring of Local Food Products

A large variety of local foods that included milk, meat, vegetables, fruits, and wild game were obtained from specified locations to distances of up to 200 miles. Food products were analyzed for various radionuclides including H-3, Sr-89/90, and Pu-238/-239/-240. The Sr-90 levels in samples of animal bone remained very low, as did Pu-239/-240 in both bone and liver samples of domestic and game animals. Although a few milk samples contained measurable levels of Sr-90 and several fruit and produce samples contained measurable levels of Pu-239/-240 and Sr-90, their potential contribution to human internal exposures was considered insignificant.

Population Monitoring by Bioassay

Since 1970, the ORSP has been assessing representative members of the off-site populations for potential internal exposure from fallout. The off-site internal dosimetry program is designed to measure radionuclide body burdens among persons who were subjected to fallout during the early years of weapons testing, as well as to provide a monitoring system for present-day NTS activities and environmental conditions.

In 1993, this program included 158 individuals representing 54 families. Evaluation of participants includes a biannual whole-body count, lung count, and urinalysis. At 18-month intervals, participants also receive a comprehensive medical examination.

No transuranics were detected in any lung counts. In general, body burdens of participants were representative of any normal population when matched for age and sex distribution.

Ground Water and Long-Term Hydrological Monitoring

Since 1972, a Long-Term Hydrological Monitoring Program (LTHMP) has been implemented at the NTS. Routine monitoring is conducted at specified on-site wells and at wells, springs, and surface waters in the off-site area around the NTS.

Because tritium is a product of nuclear testing that was found in significant quantities in underground test cavities and is highly mobile, it is expected to be the first radionuclide to migrate. Therefore, tritium serves as a warning indicator of other potential radionuclide migration and was the primary radionuclide analyzed in the LTHMP. Off-site sampling locations include 23 wells, seven springs, and two surface water sites, which are sampled on a monthly basis.

In 1993 and over the past decade, detectable levels of tritium have been found in a limited number of samples obtained from surface water. In all cases, the tritium activities fall within the range of environmental levels and are thought to be the result of rainfall containing scavenged atmospheric tritium.

Summary of ORSP Results and Off-site Dose Estimates Pertaining to NTS Activities

For 1993, EPA's comprehensive off-site environmental surveillance program around NTS measured no levels of radiation that would contribute significant exposure to any member of the public.

Potential exposure from all pathways to members of the public due to NTS activities are estimated annually by two separate methods. The first calculates annual dose by means of computer effluent modeling (CAP88-PC), meteorologic, and demographic data. The second approach uses measurement data from the ORSP with conservative assumptions and standard dose conversion factors.

Based on computer modeling, the committed effective dose equivalent to the maximally exposed off-site resident for 1993 was estimated to be 0.004 mrem. Environmental sampling data estimate a comparable dose of 0.05 mrem/yr from NTS and non-NTS fallout. For the 80-km (50-mile) radius population of 21,750 individuals, a collective population dose of

1.2 x 10^{-2} person-rem was estimated for 1993. These doses are considered negligible when compared to the average ambient external gamma dose rate of 97 mrem/yr contributed by natural cosmic and terrestrial radiation alone.

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