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MEDICAL SURVEILLANCE FOR FORMER DEPARTMENT OF ENERGY WORKERS AT THE NEVADA TEST SITE

PHASE I REPORT: NEEDS ASSESSMENT

Boston University School of Public Health
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This report was completed for Phase I of the pilot project "Medical Surveillance for Former Department of Energy Workers at the Nevada Test Site" under a cooperative agreement between Boston University and the US Department of Energy (DE-FCO3-96SF21261). The report was prepared by Dr. Lewis Pepper, Dr. Les Boden, Nicole Kozar, Jody Lally and Kerry Souza of Boston University and by Sandie Medina of the Southern Nevada Building and Construction Trades Council. Technical assistance and review was provided by Mr. John F. Campbell of Las Vegas, retired Nevada Test Site miner, and Mr. Rob Trenkle, vice-president of the Southern Nevada Building and Construction Trades Council and Business Manager for the Laborers' Union Local 872.

I. ABSTRACT

The overall objective of this project is to develop a medical surveillance and screening program for former workers at the DOE's Nevada Test Site (NTS) in order to prevent and minimize the health impact of diseases caused by site-related workplace exposures. The findings in this report respond to the intent of Section 3162 of the 1993 Defense Authorization Act which urges the DOE to "carry out a program for the identification and ongoing evaluation of current and former DOE employees who are subjected to significant health risks ... during such employment."

This Phase I Needs Assessment Report documents the nature and extent of health hazards encountered by these workers and the need for further follow-up, including medical surveillance. It presents the results of a year-long investigation at the NTS and documents the need for establishing a medical evaluation and notification program for the targeted former workers at the Nevada Test Site.

In order to evaluate the extent of need for a Former Worker Medical Surveillance activity, the US Department of Energy has requested that we provide information on the following items:

1. What is the size and scope of occupations of the target population?

There are approximately 15,000 individuals who worked during a 37 year interval in one of the identified high-risk construction trades. We are in the process of establishing the age distribution for this cohort in order to perform a more accurate assessment of the expected current size of this group. However, we have decided to use the figure of 15,000 former NTS workers throughout the document and assumptions regarding estimated disease burden, etc., will be based on the 15,000 number.

2. What is known about specific chemical, physical and radiological hazards at the NTS?

The health hazards to which the underground workers were exposed direct resulted from the mining and construction activities. We have targeted ionizing radiation, silica, diesel exhaust, noise, and other miscellaneous hazards. The hazards resulted from the different technologies used during the years and tunneling and excavation. Drill-and-blast techniques resulted in exposures to blasting agents and gases, noise and vibration, and silica dust. The dust hazards associated with drilling depended to some extent on the type of rock drilled through, use of wet or dry drilling method, and the effectiveness of ventilation provided. The introduction of the Alpine Miner continued to expose workers to noise while greatly increasing the dust level as wet methods and ventilation often provided only limited relief. Shotcreting and mucking activities further increased the dust and silica hazard to workers. Exposure to diesel exhaust emitted by locomotives and mucking equipment was also common, especially since electrical equipment did not become widely available until the 1980's. External and internal radiation exposures were also a concern, particularly during re-entry activities. Other hazards present in the underground environment included welding fumes, asbestos, lead, epoxy, solvents, and button-up and stemming compounds.

3. What are the health effects associated with the site-specific hazards?

The cohort of NTS workers was exposed to substances that affect several organ systems. These outcomes correspond to many of the health concerns voiced by the former workers. Cancers (respiratory, thyroid, leukemia, and bladder) are associated with the exposures of concern. Respiratory disease, malignant and non-malignant, is also a major health outcome of concern. We believe that silica related respiratory disease is vastly underdiagnosed, especially among a retired work force.

Silica, diesel emissions, asbestos, and radon all are associated with lung cancer. Although the targeted cohort was not equally exposed to each of these agents, the biological impact will reflect the combined effect of exposure to multiple respiratory carcinogens. The respiratory system is at risk for malignant and nonmalignant respiratory disease resulting from exposure to silica, diesel fumes, radon, and asbestos.

4. What is the estimated health burden to former workers from the NTS for these specific health effects?

Although the radiation dose data for the underground test workers are currently incomplete, a rough estimate of the numbers of cases of leukemia, lung cancer and thyroid cancer can be made from published information. For the purpose of generating a rough estimate of the number of cancer cases, we have assumed that the dose was effectively to the bone marrow, lung, and thyroid. Using the method described by Moeller (1997), this results in a total of 10 excess lung cancers, 6 leukemias and 9 thyroid cancers in the exposed population.

We have utilized a variety of data sources to estimate a reasonable silica dose for our cohort. Based on these assumptions, we have estimated that there will be approximately 150 to 2,200 excess cases of silicosis and 59 - 63 excess cases of lung cancer.

The available data make it difficult to interpret the lung cancer burden in the NTS cohort secondary to diesel fumes. Clearly, diesel fumes are but one respiratory tract carcinogen to which the former NTS worker cohort was exposed. The lack of adequate epidemiologic data demonstrating coherent and consistent risk estimates, along with the paucity of industrial hygiene information, make it impossible to estimate risk more precisely.

Almost 100% of the measurements for the underground trades exceeded the noise PEL. We have assumed that 25% of NTS workers exposed above the noise PEL will have material impairment of hearing. Further, we assume that this will be an excess impairment, that is over the baseline for this population. Therefore, we estimate that there will be approximately 3750 former NTS workers with NIHL. We also assume that this is an extremely conservative estimate since many of the noise measurements exceeded 95 dBA and our estimates only considered impairment occurring from 90 dBA.

In conclusion, the cohort of former NTS workers were exposed to a variety of hazards during the years 1956-1991 which place this group at increased risk of work-related disease.

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II. INTRODUCTION

A. Overview of Report

As one of six medical surveillance pilot programs funded under a cooperative agreement with the Department of Energy, the project at the Nevada Test Site (NTS) focuses on former NTS workers who dug, maintained and re-entered the tunnels and shafts used for underground nuclear testing. In Phase I of this project, we were charged with determining the size of the targeted former worker cohort, the nature and extent of health hazards encountered by these workers and the need for further follow-up, including medical surveillance.

This report presents the results of these investigations and documents the need for establishing a medical evaluation and notification program for the targeted former workers at the Nevada Test Site. In the report, we define the size of the target population and describe their occupations; we present what is known about specific chemical, physical and radiological hazards they were exposed to; and characterize the nature and extent of anticipated health outcomes, as well as describing the sources of data our evaluation is based on.

We begin with an overall review of the Nevada Test Site, our approach to developing risk estimates, and the organization of the project, including a description of the participating unions and the project advisory panel. Next, we describe the sources of information on which we base our estimates of the size of the cohort eligible for screening and the disease burden of this cohort. These data sources are both quantitative and qualitative. Some of them refer to experience specific to the Nevada Test Site, while other sources refer to other work with exposures that we believe to be very similar to those at the Test Site.

Next, we draw together the data we have accumulated from all these sources to develop an estimate of the eligible cohort. We follow this with evidence on exposure to the primary hazards identified at the NTS. This evidence paints a picture of substantial exposure to ionizing radiation, crystalline silica, diesel emissions, and noise. Qualitative information from current and former NTS employees also suggests that virtually all those who worked underground were exposed to all these hazards, and that some above-ground workers also were exposed. We also identify other hazards, about which we have found more limited information and for which we cannot develop credible exposure assessments or risk estimates.

Then, for the identified substances, we review the health-effects literature. The health effects we identify include silicosis, asbestosis, cancers at various sites, noise-induced hearing loss, and others. Finally, we bring together the data on cohort size, exposures, and health effects to create estimates of the health burden to former workers from the NTS. Table 23 presents these risk estimates. For some health outcomes, we believe that the former employees of the NTS have a substantial risk burden. For other health outcomes, our estimates are not large. For still others, available data do not allow us to determine the level of risk. The rest of this document describes how we arrived at these estimates.

B. Description of Nevada Test Site

The Nevada Test Site (NTS), located in Nye County in southern Nevada, sixty-five miles northwest of Las Vegas, was the primary location for testing of nuclear explosives in the continental U.S. from 1951 until the present moratorium began in 1992. The NTS encompasses 1350 sq. miles (860,000 acres), an area larger than the state of Rhode Island. The remote site is surrounded by thousands of additional acres of land withdrawn from the public domain for use as a protected wildlife range and for a military gunnery range, creating an unpopulated land area comprising some 5,470 square miles.

During the testing era, 100 atmospheric tests took place from January 1951 until July 1962. After that time the Limited Test Ban Treaty took effect, prohibiting testing underwater, in the air or in outer space, thus forcing nuclear testing underground. The first underground nuclear tests were conducted in 1957, and then resumed in 1961, continuing until 1992. During that period of time over 800 nuclear charges were detonated in drilled vertical holes and horizontal tunnels. (see Appendix 1). The majority of these tests were not merely to test the nuclear weapons per se, but consisted of complex technological events designed by the Los Alamos and Lawrence Livermore National Laboratories to measure the effects of intense radiation on a wide range of materials and equipment.

At the peak of underground testing in the mid-1980's as many as 15,000 workers were employed at the Site, about one-third of them construction workers. Since the nuclear testing moratorium took effect in 1992, the work force at the NTS has dwindled to 2,600 full-time employees, and many of the construction workers have moved on to the Yucca Mountain Project and other large projects in the Western United States. Under the direction of the Department of Energy (DOE), Test Site use has diversified into many other programs such as hazardous chemical spill testing, emergency response training, conventional weapons testing, and waste management and environmental technology studies. (See Appendix 2 for a description of agencies and laboratories at NTS.)

C. Rationale for Selecting Nevada Test Site

One of the principal activities at NTS, and the one most intimately connected with its former mission, was tunneling and excavation to conduct the underground tests. No major research or intervention program has yet attempted to follow up on the health concerns of the construction workers who built the Test Site's vast tunnel complexes, shafts, laboratories and other facilities. Our program focuses on the underground and excavation construction workers and re-entry crews for the following reasons:

1. Underground, excavation and re-entry work are "high-risk" occupations in terms of conventional occupational hazards, thus responding to the Congressional mandate contained in Section 3162 of the National Defense Authorization Act for Fiscal Year 1993 which directs the Secretary of Energy to develop medical evaluation programs for former DOE workers most at risk for work-related health conditions.
2. The underground environment is one that concentrates airborne radionuclides and other air contaminants and produces high exposures to workers.
3. Approximately half of the NTS work force was unionized and thus more accessible to the project through the unions with whom we are working.
4. There is a relatively stable cohort of such workers, many of whom have settled in the Las Vegas area and who keep in touch with each other, even after they have moved away.

Digging, maintaining and re-entering the tunnels and shafts used for nuclear testing at the Nevada Test Site was the daily work principally of six unions: Laborers Local 872, (Tunnel Workers), Operating Engineers Local 12, Electrical Workers Local 357, Plumbers and Pipefitters Local 525, Ironworkers Locals 416 and 433, and the Carpenters Local 1780, who together represented as many as 5000 Test Site workers at the peak of Test Site activity.

Reflecting tunneling practices world-wide, drill-and-blast techniques predominated through the 1970's, with consequent exposures to blasting agents and gases, noise and vibration, and silica dust. Exposure to diesel exhaust emitted by locomotives and mucking equipment was also common. Large quantities of lead (powdered, pelletized and bricks) were used for radiation shielding. Yet some of the greatest health concerns are related to the potential radiation exposures of re-entry crews -- groups of workers who crawled through confined spaces toward ground zero in the hours after a nuclear shot -- and tunnel crews engaged in "mining back," or driving tunnels through rubble back to ground zero. An average of 10 tests per year were conducted in vertical shafts and two per year in tunnels. Pockets of radioactive gas and steam and pressurized rocks were commonly encountered. Steel drill bits shattered under the force of hundreds of psi. Radiation meters "pegged." A tunnel worker described mining back in the 1960's:

"After they blast and get all the muck blasted, then I'd go in with the mucking machine...You could see the steam coming out of the sides and the awfullest smell, just burnt, just nothing you could ever describe. Burnt dirt, burnt sand is what it smelled like. Just real hot, maybe 153 degrees or hotter. They had Rad Safe in there because it was real hot with radiation too, and they'd change our film pads twice a day at noon and at the end of the shift. No one ever said what it would do to you." (Prescott, 1993)

We are focusing on the cohort of underground construction and re-entry workers likely to have experienced the most intense exposures, not only to radiation, but also to chemical and physical hazards including, but not limited to, respirable silica, diesel exhaust, lead, asbestos, epoxies, blasting agents and gases, shotcrete and concrete, noise, and radiation.

III. APPROACH

A. Framework

In carrying out activities to develop this needs assessment for a comprehensive medical evaluation program among former NTS workers, we employ a conceptual framework which is adapted from the literature on "community diagnosis". Community diagnosis is the "process of assessing and defining needs, opportunities and resources in initiating health action programs". (Haglund et al., 1990). For the purposes of this needs assessment, the "community" consists of the cohort of former Nevada Test Site workers who are potential participants in a medical evaluation program, as well as their families and social networks, their former and present employers and their unions, as well as the community of health care professionals in the Las Vegas area who may be involved in the various aspects of establishing and carrying out a surveillance and screening program. According to Haglund, et al., "community diagnosis," or "community needs assessment," models have evolved from three basic assessment traditions:

1. The medical science approach, which emphasizes the application of medical science and technology to a community, relying on the activities of medical "experts";
2. The health planning approach, which involves the assessment of long-term health-related resource needs, which focuses on improving the delivery of medical and preventative services to target populations and encourages coordination among current providers;
3. The community development approach, which views health in a broader social and economic context and emphasizes the importance of direct citizen participation in the community assessment process. The process of gathering information to assess community health needs facilitates developing partnerships among the organizations, groups and individuals concerned.

Common to each of these approaches are methods for defining and describing the target population, identifying health risks, developing a health outcomes profile and determining the scope of existing programs as well as the capacity within the community to carry out new programs. Yet each represents different approaches to defining the "needs" of a community. Elements of all three approaches have been employed in our efforts to define the scope of health issues and concerns at the Nevada Test Site

1. Medical Science

In Phase I, the objective of the medical science component has been to estimate the occupational disease burden in the population of NTS workers. These "informed estimates" will provide part of the basis for allocating resources for medical screening in Phase II. The process of estimating the disease burden has been conducted in a dynamic, iterative manner utilizing a wide array of information sources, including:

- historical hazard and exposure data from the NTS and from mining and tunneling activities with similar exposures;
- focus groups and interviews with current and former workers, and Test Site safety and health professionals;
- published epidemiologic studies of workers engaged in similar tasks.

2. Health Planning

During Phase I, the health planning component of the needs assessment has targeted resources within the community, both individuals and organizations, who can contribute to planning a medical surveillance program. The project has identified individuals and programs within the local and state health departments with responsibility for health promotion and disease prevention, surveillance, chronic disease, and physician education. We have met with representatives of these agencies, as well as with local physicians to inform them of the project objectives and to solicit their ideas and help in developing a network of physicians with interest and/or skills in occupational and preventive medicine. We have also inquired about the presence of occupational health resources among union members, DOE staff, and contractor health and safety officials.

Other objectives of this component have included conducting an inventory of the various databases available for identifying the targeted cohort and attempting to target medical surveillance to specific health conditions and groups of workers.

3. Community Development

In order to accomplish the project's objectives, potential stakeholders and interested parties need to be involved. We have already gained the interest, support and participation of the unions representing underground construction workers, and the community development component seeks to identify ways in which the medical surveillance program can be incorporated into existing union structures and traditions. Union assistance and input has been invaluable in developing this needs assessment. Former Test Site workers have contributed their extensive knowledge from their own work experience, as well as ideas and opinions as to how the project should proceed. The project Advisory Panel (described below) has involved other interested parties in the assessment and planning process. In addition to the unions and the cohort of retirees, these stakeholders include the NTS contractor, DOE Nevada Operations, and the local public health and medical communities.

B. Partnerships

The "Medical Surveillance for Former Department of Energy Workers at the Nevada Test Site" project is being carried out by Boston University School of Public Health (BUSPH), in collaboration with the University of California San Francisco (UCSF) and the Southern Nevada Building and Construction Trades Council (SNBCTC). The Department of Environmental Health at BUSPH has oversight of the project under the direction of the Principal Investigator, Dr. Lewis Pepper, and is involved in all aspects of work on the project. The UCSF Division of Occupational and Environmental Medicine will have principal responsibility for designing and conducting the medical screening program. The SNBCTC represents construction unions in the region and is the parent body for the six unions representing the targeted groups of former NTS workers who dug, maintained and re-entered the tunnels and shafts used for underground testing. The trades council has a full-time, dedicated staff member based in Las Vegas, Union Project Manager Sandie Medina, who works directly with the project and is involved in identifying, locating and notifying former workers for inclusion in the surveillance program.

The three parties in this effort have meetings periodically in Nevada or Boston and are in frequent telephone contact. The combined experience and expertise of these three organizations will help to ensure the achievement of the project objectives. This project team works closely with DOE Nevada operations Office (NVO), the site contractor, Bechtel Nevada (BN) and other interested local parties, and has convened an Advisory Panel to oversee the operation and effectiveness of the project.

Boston University School of Public Health: The Department of Environmental Health: The Department of Environmental Health in the Boston University School of Public Health specializes in environmental and occupational health research, with particular emphasis on evaluating health outcome data and assessing worker and community health concerns around hazardous waste sites. In the course of its work it has had frequent occasion to coordinate and collaborate with local, state and federal agencies, and it has demonstrated a special capacity to address the public health concerns of populations exposed to hazardous substances from waste sites.

Occupational Medicine Clinic: The UCSF Occupational Medicine Clinic (OMC) is staffed by clinic physicians and health care professionals from the University of California, San Francisco, Division of Occupational and Environmental Medicine and provides comprehensive occupational health services to employers, employees, and labor unions. Faculty and staff of the OMC have extensive experience in the development and implementation of medical surveillance programs, both on site as well as in the field.

Building and Trades Council: The Southern Nevada Building and Construction Trades Council, (SNBCTC), is a coordinating organization that works with its 25 affiliated local unions representing approximately 20,000 members. The jurisdiction of the Council includes the four southern Nevada counties for all building and construction work. The NTS is located within these geographic boundaries. The Council meets on a regular basis with NTS contractor Bechtel Nevada, and also works closely with local, state and federal agencies in an attempt to ensure the cooperation of all parties. A brief description follows of each of the six union locals from whose membership our cohort will be drawn:

1. Laborers' Local Union 872: Laborers' International Union of North America, Local Union 872, is an affiliate union of the International Union based in Washington, DC. The union

represents laborers and miners at the Nevada Test Site, performing work in the capacity of construction laborers, maintenance laborers, and underground miners. Work performed by miners covers the construction, alteration or renovation of all tunnels, shafts, excavation underground, re-entry's, and radioactive waste removal. Laborers working above ground maintain surfaces and drillhole events.

2. Operating Engineers Local 12: The International Union of Operating Engineers Local 12 received its charter from the American Federation of Labor (AFL) in 1939. Today, the membership of Local 12 stands at over 27,000 members. Operating Engineers usually come from families of engineers. They are of all ages, gender, and race, with the average age being in the mid to late forties. The Operating Engineers started performing work at the Nevada Test Site in 1951 under the Atomic Energy Commission (AEC). The duties of the Operating Engineers include the operation and maintenance of heavy duty equipment and large bore drill rigs, as well as the maintenance of the vehicle fleet, both light and heavy duty. The engineers also perform surveying, building and soil testing, as well as mining operations. Clearly, they face many hazards at the NTS.

3. Electrical Workers Local 357: The International Brotherhood of Electrical Workers Local 357 received its charter in 1931, when its members began servicing the Southern Nevada area. The union continued to service this area as its growth increased and have supplied contractors with wiremen and linemen to facilitate those contractors' needs in the area of nuclear testing and other endeavors from 1951 through present. Wiremen were employed at NTS to run power once it was transformed down to a usable voltage to supply all other electrical needs above and below ground. Linemen set power poles and transmission lines to bring in electrical power to satisfy distribution requirements above ground, as well as underground supply voltages.

4. Plumbers and Pipefitters Local 525: The United Association of Journeyman and Apprentices of the Plumbing and Pipefitting Industry of the United States and Canada was founded in 1889. Local 525 has supported the mission for underground testing at the Nevada Test Site, and presently has a limited number of members working for Bechtel Nevada. Union members were involved in all phases of underground nuclear testing, and before 1962, in atmospheric testing. The plumbers, pipefitters, and refrigeration mechanics supported the LOS (Line-of-Sight) pipe, closures, and all lifting fixtures to rig from. They put in supply and return for cooling systems and venting lines for tunnel air. During re-entry members would go back into the tunnels to cut and unbolt pipe and bring it out. On completion of the recovery of experiments, the tunnel would be completely refurbished by removing all chillers, air handlers, LOS pipe, and closures.

5. Carpenters Local 1780: The United Brotherhood of Carpenters and Joiners of America Local 1780 was chartered April 12, 1929. It has represented workers at the Nevada Test Site from its beginning to the present time, covering all construction above and below ground. This included constructing observation towers and also buildings to be exposed to nuclear explosions at varying distances from above ground events. Work underground included constructing containment plugs, alcoves, concrete forms, and blast walls. Carpenters also do all building and facility maintenance within out-trade jurisdiction, including locksmiths.

6. Ironworkers Local 433 (Structural) and Local 416 (Rodbusters): The International Association of Bridge, Structural, Ornamental, and Reinforcing Ironworkers was chartered 101

years ago. They have supported Test Site operations for over 50 years. The Structural Ironworks fabricated and assembled steel containment doors for gas seal and other plugs. They constructed metal containment trainways for tunnel re-entry. They also supported various crafts in tunnel construction both underground and outside. The Rodbusters assembled reinforced steel in the containment plugs and aided in placing reinforced rebar in the concrete structures underground that were used for nuclear experiments.

Union Project Manager: The Union Project Manager maintains weekly and often daily phone communication with the respective business managers of the six unions on the progress of the project in trying to identify the cohort of former underground construction and excavation workers, especially those among them at high risk. All six current business managers worked at the NTS and are very knowledgeable about construction and maintenance operations. Meetings have been held with all the unions, who have valuable resources, materials, records, and personnel to provide information regarding site and worker histories and relationships. The Union Project Manager has also met individually with the training coordinators of the respective unions and informed them about the project. She has established open lines of communication with the business agents, office staff, and executive board members. Attending as many union social functions as possible has enabled her to disseminate information about the project to a large number of union members and former workers.

Advisory Panel: The NTS Medical Surveillance Program has an advisory panel which performs broad oversight of the operation and effectiveness of the project. The panel advises the project team and includes representatives from participating labor organizations, Bechtel Nevada (NTS primary contractor), the Nevada State Health Division, the local medical society, NIOSH, and scientists with expertise in relevant disciplines including clinical occupational medicine, epidemiology, toxicology, industrial hygiene, and health and worker education.

The first meeting of the advisory panel took place in Las Vegas in March. (See Appendix 3 for a summary report of the first meeting of the advisory panel). During two days of discussion, panel members offered guidance to project staff, generated ideas, and responded to questions. Topics discussed include: health hazards; data systems; issues of privacy and informed consent; worker notification; workers' compensation; and medical resources.

IV. SOURCES OF INFORMATION/METHODOLOGY

In order to determine the size and scope of our target population and to pinpoint the specific hazards to which this group of workers was exposed, our general approach has been to utilize NTS sources where and when available. These include records, reports, memoranda and databases held by the present contractor (Bechtel Nevada), as well as verbal reports of former tunnel workers, managers and supervisors, scientists and health and safety officials who participated in the various underground operations (See Appendix 4 for a list of NTS contractors). Where we have been unable to obtain primary site data we have presented analogous data, e.g., reports from the same time periods in similar industries such as coal mining and construction.

A. Cohort Information

In beginning to construct the former NTS worker cohort we have relied on the following sources (which are described in detail in Section IV: "Cohort" below):

1. NTS Dosimetry Research Project (DRP) Database, which includes dosimetry and exposure records for the period 1945-1986;
2. Central Personnel Clearance Index (CPCI), in which DOE personnel clearance records are stored in a nationwide electronic database which was created in the early 1960's for all DOE personnel with clearances;
3. Former NTS miner John F. Campbell's list of underground workers which covers the period from 1955 to 1997;
4. Union membership and health and welfare rolls from member unions of the Southern Nevada Building and Construction Trades Council, who have been asked to aid us in assembling a roster of their members who have worked at the NTS.

B. Hazard Information

In order to assess the hazards to which underground workers were exposed we drew on the following sources of information:

1. NTS Records, Reports, and Databases

Preliminary library research and initial interviews with unions and DOE health and safety officials provided an overview of the types of relevant data sources for determining underground hazards and exposures which might be available at the Nevada Test Site from the contractor, Bechtel Nevada and the DOE Nevada Operations Office. (See Appendix 5 for Database Profile Summary). These included personal and area sampling data, incident and accident occurrence reports, safety and health progress reports, engineering and construction records and environmental documents.

Subsequent meetings took place with Bechtel Nevada personnel from the safety and health, medical, engineering, construction, environmental, information services, information coordination and public relations departments to get an idea of how they might be helpful to the project and of the availability and location of relevant records and other types of documentation. Project staff also met with DOE counterparts from similar departments, with Defense Special Weapons Agency personnel and with union trainers, business managers and retirees to further inform ourselves about the existence and whereabouts of materials needed for the Phase 1 assessment of hazards.

Difficulties arose thereafter in accessing the records we determined to be of interest, as the contractor, Bechtel Nevada (BN), was concerned about compensation for its time involved in locating and transferring the information. This was eventually resolved by an agreement whereby project staff would go through the DOE Nevada Safety and Health Division to request documents and other materials from the contractor. This process seriously delayed our progress in obtaining essential information for this report. Records that we were able to obtain were typically limited in scope and time period covered, often too recent to give us any information on earlier operations where the hazards may have been greater.

Although a steady stream of secondary sources on safety and health at specific facilities in the weapons complex has been produced since the era of the Atomic Energy Commission, we have been unable to obtain comprehensive industrial hygiene information from BN or DOE Nevada Operations Office (NVO). Annual reports, compendia, and progress reports on industrial hygiene activities were not produced until the early 90's.

In early June, a project staff member visited the NTS to collect industrial hygiene, health physics, and personnel data. Approximately 6 weeks prior to the visit, we were informed by an NVO IH that ten notebooks containing industrial data from the mid-60's through the early 80's had been located. As we had not previously located IH data from the site, this was our first opportunity to review real site data. Unfortunately, our hopes were dampened when we received another call from the ES&H Director at the NVO two days before the visit, informing us that the ten notebooks, which had been seen as recently as the end of April, had disappeared. Furthermore, a print-out of an IH database had also been lost. The visit was nonetheless productive, as a copy of the industrial hygiene print-out, covering the period of 1974 through 1984, was re-created for our use. Furthermore, documents describing measurements of silica, dust, noise, welding, oil mist, and diesel fumes were located. These data have been our only source of historical workplace monitoring records.

Our holdings of NTS data include:
1. Industrial hygiene memos, which describe operations, particular sampling events and information on silica, diesel, noise, welding, oil mist, lead, asbestos, shotcrete and epoxies;
2. An industrial hygiene database with measurements of diesel exhaust, silica, noise, ventilation, welding, and oil mist from 1974 - 1984;
3. Two comprehensive industrial hygiene reports from the 90's, covering many of the hazards present in the tunnel environment;
4. Tunnel inspection reports containing primarily oxygen, carbon monoxide, carbon dioxide, and ventilation measurements;
5. Area 12 shop files from the various crafts, e.g., carpenters, operating engineers, which include information on toxic materials, ventilation, illumination, noise, and routine monitoring;
6. A report on radiation effluents from 1961 to 1992, which describes every test which released radiation into the environment during that time period;
7. Microfilm reels containing reports on radiation, memoranda from supervisors, daily logs, personnel rosters and various measurements;
8. Tunnel records held at Pierce-Leahy (PL), (the "Flangas files") which are boxes of reports, daily tunnel logs and other miscellaneous documents related to underground testing; (see Appendix 6 for a summary of files obtained at PL and the "Flangas files.")
9. United States Geological Survey (USGS) documents covering geological surveys;
10. The NTS environmental impact statement;
11. Accident and injury reports (mostly related to safety);
12. Onsite radiation safety reports for several Test Site operations.

Information which we would have found useful, but were not able to obtain by the time of writing of this report include Material Safety Data Sheets on substances used in underground operations; radiation data including bioassays and whole body counts from the Dosimetry Research Project; industrial hygiene reports for the earlier time periods and sampling records which indicate how measurements were collected and for how long and what methods of analysis were used. (Appendix 7 details the status of requested documents).

2. Other NTS Sources of Information

As this is a project about workers, their work, and their health, we have spent a great deal of time in meeting, interviewing, and conducting focus groups and risk mapping exercises with former NTS workers. We have sought to enlarge our understanding of the hazard environment with their information and opinions. The quantitative world of numbers and measurements often provides a less informative picture of a workplace than can be found in the descriptions provided by the workers. We have utilized this information both to help fill in the gaps of missing data but also (and perhaps more importantly) to provide us with an understanding that can only be gained from a lifetime of work experience. A description of some of these qualitative data collection methods follows:

a. Focus Groups

Project team members have organized and facilitated focus groups of former workers, managers and supervisors and health and safety professionals in order to gather firsthand information from those who worked underground at the NTS about the construction of the tunnels, the phases of operations and the hazards encountered, as well as to get a better idea of the types of records that were kept and where these might be located. Participants were recruited by the Union Project Manager, who was able to locate and invite key informants for each of the following focus groups convened during the period, December 1996 - June 1997:

"Mining Men" Focus Group: This was a group of supervisors and managers, most of whom had worked underground at the Test Site for many years throughout the period of underground testing, and who were very familiar with the details of construction and operations in the tunnels and downhole shafts and boreholes and how they changed over time (See Appendix 8 for excerpts from the focus group transcript). In addition, we learned from them how these changes affected the conditions under which employees worked and their exposures to potential health hazards.

Former Industrial Hygiene Personnel Focus Group: Four individuals along with DOE industrial hygienists were present. Questions were raised concerning health hazards which were present at the NTS, the sampling which was conducted, and records which were kept.

Focus Group with Former Operation Nougat Workers: For this group we had attendees from the Plumbers and Pipefitters, the Operating Engineers, and the Laborers unions, who had worked in the tunnels during Operation Nougat which took place in the early 1960's and was one of the earliest tunneling operations. They were presented with the phases of construction for tunnel events as outlined in the report, "Industrial Hygiene Support of Underground Operations at the Nevada Test Site." All of the men agreed that the breakdown of the work into the particular phases was acceptable and agreeable to them. They then filled in a chart indicating the crew sizes and health hazards associated with each phase of work for each trade. We intend to conduct similar focus groups with workers from the 70's and 80's for the different tunnels.

b. Interviews with Former Workers

Both the Union Project Manager and other members of the project team have carried out individual interviews with former workers who reside in the Las Vegas area. These have been very helpful in providing background information on the history of operations at the Test Site and have given us a personal view of what it was like to work there. They also offer an important opportunity for members of the cohort who will eventually take part in the medical evaluation program to contribute their views, ideas and concerns related to the program.

The Union Project Manager schedules interviews with any former NTS workers who contact her by telephone, at retiree breakfasts or union meetings or social functions. She uses these interviews as an opportunity to inform former workers about the project and to answer questions they may have, as well as to collect demographic, health status and health concerns information. The interviews are mostly done in person at the Las Vegas project office and last approximately one hour. Former workers who reside elsewhere and are unable to travel to Las Vegas are interviewed over the phone. During the initial contact, usually by telephone, the "Medical Surveillance Project Intake Log" is completed which contains personal data as well as questions concerning union membership, years and locations of work at the Test Site, payroll code and other workers to contact. In a subsequent longer interview, information is obtained on workers health concerns related to work at the Test Site. (See Appendix 9 for sample "Intake Log" and "Worker Profile" forms). Learning about former workers' health concerns is an important part of developing a needs assessment for a medical evaluation program.

c. Retiree Breakfasts

The monthly retiree breakfasts are held on the first Wednesday of every month at a Las Vegas area restaurant. Participants include former workers from the NTS, most of whom worked in the Area 12 tunnels at one time or another. The Union Project Manager regularly attends these breakfasts. By attending the breakfasts, she has been able to publicize the project and communicate informally with attendees.

Other project staff members attended a breakfast with retirees from the Laborers and Operating Engineers, at which time the project was explained and a hazard mapping exercise was carried out (see below). At another breakfast attended by project staff members, retirees of the Plumbers and Pipefitters were informed about the project and then talked about their work experiences at the Test Site, the hazards they experienced and their related health concerns.

d. Risk Mapping

The project has used risk mapping as a participatory method of constructing retrospective assessments of workplace exposures. Risk mapping draws on the knowledge of former workers from on-the-job experience and has provided the project with vital information on the underground workplace in different time periods. A risk mapping exercise was undertaken at one of the breakfast with former workers (See Appendix 10, Risk Mapping Exercise). For this exercise retirees were divided into groups of five to seven people, based on era, trade and work location. Groups were then asked to draw a map of a typical work area and to indicate the location of hazards and the frequency of exposures from those hazards. These maps were then presented to the entire group of retirees and project staff members. The resulting maps of tunneling, downhole and re-entry work provided insight into the spatial and temporal distribution of health hazards in the different work environments, as well as providing an opportunity for former workers to participate in and contribute to the needs assessment.

e. Union Survey

In a preliminary survey, representatives of the Plumbers and Pipefitters, Operating Engineers, International Brotherhood of Electrical Workers, and the Laborers' International Union were interviewed by telephone to obtain information about the NTS operations conducted by their union membership; the size of the work force; the availability of job descriptions, health and injury records, and workers compensation data; worker length of employment; health and safety issues and radiation and chemical exposure sources; and location of former workers. This process provided useful background information for beginning the needs assessment and was a way of involving the unions in the project from the outset.

f. Advisory Panel Meeting

During the Advisory Panel meeting held in March, union and retiree representatives to the panel were able to share many of their experiences working underground at NTS and to further clarify to the project team and other panel members the construction methods, phases and equipment used and changes over time, as well as the wide range of hazards to which all workers were exposed in the underground work environment. At a buffet breakfast, retirees from the different unions joined panel members in an interactive exercise designed to draw on the former workers experiential knowledge of Nevada Test Site operations. In addition, several former workers gave presentations to the panel on tunnel construction, operations and hazards.

Additional sources of site-related information include site newsletters, newspaper articles from local papers, and books and articles specifically about the Test Site.

3. Other Relevant Literature, Databases, and Government Reports

To allow for a better assessment of the potential hazards to our cohort, where Test Site information was lacking, analogous reports and measurements were substituted from similar operations and hazards in other locations and related industries, e.g., industrial hygiene reports from the same era in similar trades such as mining, other construction or tunneling. This data come from two major sources, the MIDAS database and OSHA's database. The MIDAS database is a source of compliance data from 1976 through the present compiled by the Mine Safety and Health Administration for metal and nonmetal mines. (Because it is used for compliance purposes, inspectors may choose to do measurements where exposures appear to be the highest. For this reason, the data may be biased toward higher exposures. Also, if an overexposure is found during an initial survey, the database includes both the initial sample and the results of any re-sampling to determine compliance. The subsequent samples may be biased downward. On average, however, we expect the MIDAS data to be overestimates, but we cannot say by how much.)

IMIS records comprise OSHA's enforcement database and include inspection date, inspection type, employment size, contaminant sampled, the measured level of that contaminant, and other applicable items. This database cannot be considered to be representative of all workplaces since OSHA targets high-risk industries for inspection. IMIS also reports exposure as a function of its relationship to the current permissible exposure limit (PEL) and uses a severity measure rather than a measured level as an indicator of intensity.

Literature searches were also conducted to aid in defining possible health outcomes and expected risks associated with the various health hazards to which our cohort was exposed.

V. COHORT

In our initial proposal for this project, we estimated that the NTS work force peaked in the mid-1980's at approximately 15,000 workers. We also assumed that close to half of these workers were in the construction trades. In the union survey mentioned above, the union representatives we contacted believed that they had a total of approximately 5,000 members during this peak period and that the average length of employment for their members at the Test Site was approximately 10 years.

We have begun to construct a roster of potential medical surveillance project participants. Personnel records have been requested and received from Bechtel Nevada (BN), the current contractor at NTS. A similar request has been made of the DOE's Nevada Operations Office (NVO). Identifying individuals who worked at the NTS and when they worked there has been one of the most challenging tasks the project has encountered. We have enlisted the aid of members of the Advisory Panel who have assisted project staff in locating employment rosters, union membership rolls, pension lists and other databases.

To date, our initial work in constructing the former NTS worker cohort has benefited from information derived from the following sources:

A. Dosimetry Research Project (DRP) Database

The DRP was established by the U.S. DOE under the direction of the NVO in January 1978. The DRP was established to collect, organize, and tabulate dosimetry and exposure source documents; create and maintain a master dosimetry file; respond to exposure history requests; and publish an historical report on Radiation Safety in the Nuclear Testing Program. (See Appendix 11 for DRP Structure). The DRP is currently operated by BN.

Currently the DRP operates as the federal, DOE and contractor records center for radiation dosimetry. Dosimetry and exposure records are maintained for 1945-1986. During 1946-1987, all employees, contractors, vendors, and DOD personnel at the NTS were issued a monthly film badge regardless of their length of stay or potential exposure. In 1987, thermoluminescent dosimeters (TLD) replaced film badges and were issued quarterly.

There have been over 500,000 participants in the DRP. Source documents have been indexed and archived and a master file has been created. In early 1997, our project filed a data request for NTS employee personnel records with the DRP. During a June 1997 site visit, Martha DeMarre, the DRP director, provided us with many documents we had requested, along with a CD-ROM containing numerous payroll and personnel databases for 22,000+ current and former NTS workers. The 22,000 subjects include individuals in underground operations as well as administrative, secretarial, and construction personnel who did not work in the targeted areas. We are currently reconfiguring this database in order to use it as one of the central pieces of the project's database infrastructure (Appendix 12 contains a description of BUSPH Project Databases).

The DRP is structured with multiple components which are linked, by person, via a unique NTS number. The payroll database, which we are currently utilizing, is the core of the DRP architecture. It includes the following information for 1956 through 1985: first and last name, social security number (only for the first fifteen years), NTS number, cost-center (a six digit location and payroll code identification), job classification (only for the first fifteen years), and other fields. The payroll code, which is part of the cost-center data element, has a unique 3 digit sequence for each of the construction trades at the NTS. We are using this information to construct a list of project specific construction trades and individuals who worked in the underground high-risk environment.

The payroll codes for the NTS changed over time. However, we have been fortunate to have the assistance of the project's Nevada area coordinator, Sandie Medina (Union Project Manager), who worked at the NTS for 25 years, in creating a list of payroll codes for the years 1954 to 1991. She was able to do this by drawing on knowledge gained in creating payroll databases for REECO, the previous contractor at NTS. Based on Ms. Medina's payroll code revisions, we have created the a preliminary estimate of the total high-risk NTS work force organized by construction trade (See Table 1). (Each row in the table contains individuals with an NTS number who worked in the listed trade).

There are a total of 14,610 individuals, identified by a discrete NTS number, who worked during a 37 year interval in one of the listed trades. Although the total number of individuals working in at least one of the trades is 16,427, the 1,817 excess (above the 14,610 total) is explained by the number of NTS employees who worked in more than one trade during their NTS tenure.

We recognize that the current target cohort has aged and died at a relatively comparable rate to the standard U.S. and Nevada population. We are in the process of establishing the age distribution for this cohort in order to perform a more accurate assessment of the expected current size of this group. However, we have decided to use the figure of 15,000 former NTS workers throughout the document, since we do not currently have a more accurate estimate. Assumptions regarding estimated disease burden, etc., will be based on the 15,000 number. As part of initial Phase II activities, we will establish the cohort's age distribution and then update estimated cohort size and its mortality experience.

Table 1: NTS Workforce by Trade

Payroll Code	Trade/Union	Number
003	Carpenters	1139
004	Painters	212
005	Ironworkers	1083
006	Surface Operators/Op Eng	1402
007	Laborers	1529
008	Wiremen/IBEW	3169
009	Lineman/IBEW	312
010	Underground Operators/Op Eng	2642
011	Refrig Mech/Pipefitters	56
012	Sheet Metal Workers	247
013	Pipefitters	1391
014	Miners/Laborers Union	1940
015	Bullgang/Chucktender	459
018	Teamsters	846
TOTAL		16427

In the near future, we will be submitting a list to DRP Director Martha DeMarre of the former NTS workers, by NTS number, who fall into our list of high-risk trades. Upon receipt of this list, DRP staff will create a database containing individual and cumulative dosimetry records for each of the identified individuals. This data, which will be derived from the DRP's historical dosimetry database, will be used to construct a database with each potential participant's occupational history and radiation exposure.

B. The CPCI Database

During the June visit to NTS, project staff were informed of two security clearance databases which might be useful for the project's participant roster. All former NTS workers were issued security badges as part of their employment. DOE personnel clearance records are stored in an electronic database called the Central Personnel Clearance Index (CPCI). This nationwide database was created in the early 1960's for all DOE personnel with clearances. It is maintained by DOE headquarters. The fields in the database include: name, company, job code, date of birth, site (e.g., NTS), and social security number. The job codes are different from the ones which were used by REECO payroll.

In early June, we requested access to the CPCI database. According to our contact at DOE headquarters, old CPCI data have been moved to microfilm. The original clearance files are located at the sites and have a retention period of ten years. The freeze on destruction of all records related to the conduct of possible epidemiologic studies, which was instituted in 1990, probably ensures that there are paper records and a linked computer file for records from 1980 to the present. It is believed that the records from earlier periods exist in paper and computer format, especially if the designated destruction schedule was not followed. The file is generally located at the last place where the person had the clearance.

There is a computerized name index for the microfilm that points to a specific roll. The names are in alphabetical order and have to be searched individually. There may be several people with the same name, so additional data such as date of birth will be needed to find the correct person. The microfilm is located at the DOE offices in Germantown, MD. The people who control the database have indicated that they would be willing to aid the BUSPH project team. We hope to use this database to supplement and verify the information generated by the DRP database.

C. John Campbell's List

Mr. John F. Campbell, a former NTS miner and member of the project Advisory Panel, has spent the last several years documenting the experience of underground workers at the NTS. Mr. Campbell, a photographer and videographer, has worked to assemble a pictorial history of mining at the site. In addition, he has interviewed and filmed former miners and other underground workers and captured images of many miners suffering from possible mining related illnesses. In recognition of Mr. Campbell's interest and expertise, he has been asked to become a member of a U.S. DOE committee formed to overview the ethical issues involved in the former workers' pilot projects.

Mr. Campbell, along with the assistance of many former miner friends and Ms. Sandie Medina, has also assembled a list of underground workers. This database lists 1150 records. Under each is first name, last name, craft code, address, home phone, current employer and work phone if working, date retired if retired, nickname, date hired NTS, date left NTS, job title, places worked, and if deceased (date). The period of time covered for these records is from 1955 to 1997. The listing was compiled from old personnel rosters, personal Christmas card lists and address books, and former workers' knowledge and memories of people they knew. Not all the records are complete; many are just first names and nicknames. All of the names in this record are persons who worked at the NTS in one capacity or another, mostly as operators (operating engineers) or miners.

D. Union Membership and Health and Welfare Rolls

Member unions of the Southern Nevada Building and Construction Trades Council have been asked to aid us in assembling a roster of their members who have worked at the NTS. This effort is being aided by Mr. Rob Trenkle, a member of the project Advisory Panel, former NTS miner, and Business Manager of the Las Vegas area Laborers' Union. Laborers' (Local 872) has informed us that the International will be sending a letter approving the release of information on their members.

Carpenters (Local 1780) have given us four listings that include name, address, and phone numbers. The listings are of early retirees, carpenters aged 65 years or older that worked 30 years and are retired, carpenters retired and currently working that have been members of the union for 50 years or more, and lastly, current union members still employed at the NTS.

Plumbers and Pipefitters (Local 525) will be able to assemble a roster by using the benefit package provided by REECO through the files kept by the third party administrator. This will have to be approved by the United Association (International) and/or the Local 525 membership.

Ironworkers (Locals 416 and 433) will be giving us all their memberships names, address, and phone numbers once they receive the list from their regional office in California.

Operators (Local 12) will call and notify their respective union workers at the monthly membership meetings.

Electrical Workers (Local 357) will notify their respective members either through phone calls, correspondence, or at the monthly membership meetings.

As we noted earlier in the discussion of the rationale for selecting the NTS, we intend to focus on underground workers, who were likely to have experienced the most intense exposures to chemicals, radiation and physical hazards. Our approach is supported by the former NTS union members on our Advisory Panel. It is their opinion that all of the underground trades were exposed to a variety of hazards and that most exposures varied little by occupation. They believe that the group of underground and excavation workers should be considered as a relatively uniformly exposed population, rather than as a series of trades. To quote one former worker who attended the Panel meeting:

"The air travels from the portal to the heading, which is the farthest point in the tunnel, and everybody in that tunnel is exposed to that air because you've got jobs going everywhere in that tunnel, and that air is coming right past you with all the contamination all day long. If I'm running a motor and it's smoking, it's going past everybody as it goes in that tunnel - everybody's exposed. And this is the same way with radiation - there's a lot of places back there where they had radiation stored, that we went into and stirred it up - here it comes, back in that drift. And this is everyday, every minute that you worked there. Everybody in that tunnel is exposed to the stuff coming in there."

We are therefore focusing on the entire cohort of underground construction and re-entry workers. However, excavation workers who operated drilling and boring equipment are also included. Despite spending the majority of their time above ground, they were potentially exposed to similar hazards, since many also worked for periods of time in the underground environment.

We have made a preliminary estimate of the size and job breakdown of our target population. In addition, we have estimated how many individuals worked in these occupations and where they were located during the years 1956-1991. Approximately 15,000 workers worked in potentially at-risk occupations at the Nevada Test Site during this period.

We intend to develop more information about the cohort so that we can effectively target their screening. As the first step, we already have narrowed the size of the possible former worker cohort to workers in high-risk occupations at the Nevada Test Site. We also will learn about the number who have died and the number who moved out-of-state. Presently, we have not established the length and time of service at NTS for individuals in the cohort. Obviously, some of these workers may have worked only a short time at the Site, therefore having less of an opportunity for significant exposure. Typically, individuals in these occupations were at risk of exposure to all the primary health hazards described later in this needs assessment. Given common exposures, length of service is a useful measure of risk.

As we get a better picture of who is currently in the target cohort and how long they have worked at the site, we may consider possible individual and group factors to further limit our target group. The distribution of length of service may be such a useful factor. However, the benefits (more service for fewer people) and the limitations (eliminating people still facing substantial risks) in using length of service (or any other criteria) as a possible way to limit the cohort needs to be thoroughly discussed. At our first phase II Advisory Panel meeting, we will discuss and then jointly decide on how to most effectively and efficiently deliver a screening program to a commonly agreed upon high-risk workforce.

VI. SPECIFIC HAZARDS AND HEALTH OUTCOMES

One of the principal activities at the NTS, often leading to the most extensive worker exposures, was the tunneling and excavation necessary to conduct the underground nuclear tests. The construction workers who built the Test Site's vast tunnel complexes, shafts, laboratories and other facilities were members of the six trades comprising our cohort. Their daily work in the underground environment resulted in an average of two tunnel and ten vertical shaft tests per year from 1957 until 1992.

Underground tunneling operations can be divided into five consecutive phases which, although not entirely distinct, provide a means of simplifying and understanding the complex tasks involved in preparing a tunnel test (DOE, 1992). The health hazards, predominant trades, and crew sizes fluctuate as the underground work progresses through each phase from mining, construction, support, button-up, and finally, re-entry. The mining phase almost exclusively employs the Laborers (miners and bullgangers) and Operating Engineers in the excavation of drifts, removal of rock and debris, or muck, and the installation of tunnel supports. The union support multiplies during the construction phase as all of the trades are engaged in the construction of the test bed for the nuclear device, the Line-of-Sight (LOS) pipe which will direct and control the flow of radiation to the various experiments and detection equipment, the instrumentation alcoves where experimentation devices will be stored, and the stemming bulkheads used for containment of the radioactive debris following the shot. The support phase utilizes a similar number of construction workers and also a large number of laboratory and oversight personnel. For the trades, this phase consists primarily of maintenance and clean-up of the tunnels and also the transportation of the auxiliary personnel to and from the tunnel alcoves. The bulkhead and plugs necessary for containment of radioactivity are completed during the button-up phase with the Laborers and Operating Engineers again being the primary trades. The re-entry phase occurs after the nuclear device has been detonated and consists of mining back to the instrumentation alcoves for retrieval of experimentation equipment.

The several phases of construction employed different tasks and machinery which created the various health hazards to which the underground workers were exposed.

Drilling: Workers operate automatic (pneumatic) drilling machines such as jackleg drills or drill jumbos to bore holes in the face of the tunnel for subsequent blasting of the rock or for the installation of tunnel supports.

Blasting: After holes are drilled, they are loaded with dynamite and blasted to remove the rock. The drill and blast technique was used primarily in the 60's and 70's, and intermittently thereafter. During blasting, tunnelers are withdrawn from the face of the tunnel; the ventilation is also often reversed for a short period following the blast to exhaust the laden air (Bavley, 1950).

Alpine Mining: The Alpine Miner is road-heading equipment which grinds and removes the rock at the face of the tunnel. This piece of machinery essentially replaced the drill and blast method during the 1970's.

Mucking: Mucking involves the removal of crushed rock and debris. Mucking can be done by hand (with shovels) although by 1950, miners and tunnelers had access to mucking machines.

Shotcreting: Shotcreting follows excavation and bolting of a tunnel section and involves securing the tunnel by shooting a mixture of cement, sand, binding accelerator, and water under high pressure against the surface (Kessel, 1989). Shotcrete application methods included the use of pneumatic pressured delivery devices.

The health hazards to which the underground workers were exposed were often a direct result of these operations. Drill-and-blast techniques resulted in exposures to blasting agents and gases, noise and vibration, and silica dust. The dust hazards associated with drilling depended to some extent on the type of rock drilled through, use of wet or dry drilling method, and the effectiveness of ventilation provided. The introduction of the Alpine Miner continued to expose workers to noise while greatly increasing the dust level as wet methods and ventilation often provided only limited relief. Shotcreting and mucking activities further increased the dust and silica hazard to workers. Exposure to diesel exhaust emitted by locomotives and mucking equipment was also common, especially since electrical equipment did not become widely available until the 1980's. External and internal radiation exposures were also a concern, particularly during re-entry activities. Other hazards present in the underground environment included welding fumes, asbestos, lead, epoxy, solvents, and button-up and stemming compounds.

The underground environment concentrates the contaminants and is therefore likely to produce high exposures to workers. The special tunneling and construction activities at the NTS, which were necessary for containment of the nuclear test and re-use of the tunnel complex, created a work environment that exacerbated already significant job hazards. The "branch-rejoin" pattern of tunnel construction likely introduced "kinks," "crimps," and 90-degree bends into the extensible tubing or "vent line" which is the primary means of controlling air contaminants in the underground work environment. Such non-linear patterns in the vent line carry with them the potential to greatly reduce the efficiency of the tunnel ventilation system. Industrial hygiene reports from other tunneling operations attest to the ultimate importance of tunnel ventilation in reducing contaminant exposure to workers (Bavley, 1950, Burns, 1962, and Wong, 1988). Second, work in the Line-of-Sight and bypass tunnels took place amidst a shifting array of large objects -- instrument control panels, steel and concrete barriers and even satellites -- and, as the test date drew near, amidst literally hundreds of people, each with a scientific or technical role in the ultimate nuclear test. Obstruction of the return air flow by the large objects, and air flow of less than 200 cubic feet of air per minute per capita required under OSHA and MSHA standards, would have further degraded the efficiency of the ventilation system. Third, the convoluted pattern of tunnel design militated against the use of conveyor systems for removing spoils. Points of spoils transfer, always a major source of worker exposure, would have been more numerous than with a continuous conveyor, thus resulting in greater worker exposures.

The inherent complexity of the construction work environment has been approached analytically in industrial hygiene by task-based exposure assessment methodologies. We have not performed a formal task-based retrospective exposure analysis since the information needed even to attempt to conduct one is not available at this time and as far as we are aware, such a retrospective exercise is without precedent in the construction field. However, the unique enterprise of the Nevada Test Site has provided us with the opportunity to utilize other methods of exposure analysis. The following sections will detail worker exposures to radiation, silica, diesel, and noise, and the health outcomes associated with each. The final section on exposures briefly summarizes additional health hazards for which exposures and likely health outcomes are not as well documented in NTS sources or the literature.

A. Ionizing Radiation

1. Radiation Exposure

Radiation exposure has been a predominant concern of the former Nevada Test Site workers, having surfaced time and again in interviews and focus groups. A great deal of the concern stems from the nature of radioactivity, which cannot be seen or smelled, requiring workers to place their health and safety in the hands of radiation monitors and in the accuracy of their film and TLD badges. Distrust of these processes were widely prevalent as stories such as this one from a former Nevada Test Site miner were told during our interviews and focus groups:

"In 1988, I requested a copy of the total accumulated radiation from '58 to '80. About four months later, I got a letter showing that it hadn't accumulated any. During that period of time, I know of more than six times that I completely burned out, had gone home in the rad-safe coveralls. A couple of times, due to these burnouts -- One was on Antler in E Tunnel. My skin was scruffy. I had developed a rash."

Reasons for concern were not unjustified as workers were often sent into tunnels soon after an event to recover property and equipment or were put to work on drill rigs with the goal of obtaining core samples from a recently detonated downhole shot. Releases of radioactivity during or immediately following a test and also during post-event operations were also a common occurrence. Tunnel workers further faced naturally occurring radiation in the form of radon gases emanating from their surroundings along with the effluent of past tunnel events which leaked tritium and other radioactive substances into their work environment. (Appendix 13 contains a sample report of test event effluents).

a. Yearly Summary Reports

The annual summary reports for personnel exposure at the Nevada Test Site were gathered for the years covering 1961 to 1980. External radiation doses were recorded on the AEC-190 form entitled, "Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During the Year (see Appendix 14)," for the years of 1961 to 1976 (Atomic Energy Commission, 1961 - 1976). Internal doses accumulated during the reporting year were described in detail on a similar form in each summary report. Dose measurements were similarly reported in annual summary reports for the years of 1974 - 1978 and 1980 (AEC, 1972; ERDA, 1974; ERDA, 1975; DOE, 1976; DOE, 1977; DOE, 1978; DOE, 1982) (see Appendix 15). Table 2 describes the number of individuals who accumulated external radiation doses in each of the listed rem ranges for the years covering 1961 to 1980.

Table 2: Summary of Whole Body Radiation Exposures to External Penetrating Radiation Accumulated During 1961-1980

Time Span	0 - 1 Rem	1 - 2 Rem	2 - 3 Rem	3 - 4 Rem	4 - 5 Rem	5 - 6 Rem	6 - 7 Rem
1961 - 1980	112,550	865	420	170	107	10	1

The majority of the accumulated doses measured as three rem or higher occurred in the years of 1961 and 1962, although random exposures continued to be present at these levels until 1972. In 1961, a total of 83 individuals were counted on the external exposure form as having received exposures of 3 rem or higher. However, the attachment to the 1961 summary report lists 107 individuals who had exposures in that year exceeding either 3 rem per quarter or 5 rem per year. Further, a memo from 1961 describes the exposure to 108 individuals, mostly occurring in the last quarter of 1961, with the highest accumulated dose recorded at 8.045 rem (NTS, 1961, see Appendix 16 for memo). The summary report for 1961, however, did not list exposures above 7 rem. The discrepancy in numbers for that year are inexplicable, causing us to believe that the numbers in the summary reports may have underestimated the actual number of individuals receiving exposures above the quarterly and yearly limits of three and five rem, respectively.

We anticipate that the majority of the individuals who had exposures of 3 rem or greater belong to our cohort of workers. In evaluating the attachment to the 1961 summary report listing 107 individuals, 87 were determined to be miners, 16 were operating engineers, 2 were area supervisors, and 2 could not be identified. Further, the memo mentioned previously describes the accumulated doses of "108 miners and supporting personnel" exceeding the 3 rem per quarter limit. Another memo in that time period requests permission for thirty B Tunnel workers to exceed the three rem per quarter limit in order to maintain the busy test schedule and allow scheduled shots to be detonated on time (NTS, 1961A, see Appendix 17 for memo).

b. Release of Effluents

A total of 68 tests were conducted in the tunnel complexes of the Nevada Test Site over nearly four decades of operation. Thirty-six (53%) of these tests released radioactivity to the atmosphere in quantities ranging from 0.23 to 11,000,000 Curies during test events, drillback operations, and controlled releases (DOE, 1996). The radioactive releases were generally comprised of beta and gamma emitting isotopes with short half-lives. A third of the releases were measurable off-site, with the remainder being contained within the test site boundaries.

As described by a former industrial hygienist during a focus group, releases of radioactivity, especially at the time of an event, were quite common in the earlier years of testing:

"Prior to 1971, radiation exposure to drillers or operating engineers could go high at some times because of the venting gases from the shots, they got better and better at keeping from doing that over time. There was a good chance when we had a test in the sixties that it was going to leak, period, before you did anything to it."

The frequent release of radioactivity during scheduled test events contributed to the exposure of workers. Operations typically persisted in areas near the shot detonation, a practice which was eliminated after the Baneberry event in 1970 which showered residents of the Area 12 camp with radioactive fallout (AEC, 1971). Post event crews for downhole shots were sometimes exposed to radiation as they drilled back to ground zero, as described by a former scientist during a focus group:

"...we were drilling back into the hot spot very quickly, relatively quickly after the shot was fired. It was hot. There was a lot of gas created down in this cavity, and when you penetrated that, sometimes that gas had only one way to go, and that was out. So, in the early days of post shot drilling, the people that were working around this drill rig might -- not in all cases, but in a lot of cases -- were subjected to fairly high levels of radioactivity, radioactive gas finding its way out of the cavity to the surface."

Workers on re-entry crews for the tunnels were exposed to radiation, first during clean-up of tunnels contaminated during a test release and second during the mining back operation to recover equipment and instrumentation located near ground zero.

c. Radon Concentrations in the Tunnels

Radon measurements were collected and analyzed for several tunnels in 1984 and reported in the document, "Survey of Radon and Radon Daughter Concentrations in Selected Rainier Mesa Tunnels" (DOE, 1987, see Appendix 18). Table 3 below summarizes the radon levels for G and N Tunnels with and without the ventilation system in operation. For N Tunnel, the working levels fall well below the EPA standard of 0.33 working levels when the ventilation equipment is working. However, the levels immediately begin to rise to an equilibrium value of around 0.27 working levels once the system is shut down. The radon levels for G Tunnel were much higher on average which, according to the report, was the result of "a lower ventilation rate in conjunction with the more highly fractured nature of the 'welded tuff' rock formation."

Table 3: Radon Concentration in NTS Tunnels (1984)

Location	Ventil-ation?	N	Mean (WL)	Range (WL)	Percent over EPA Standard	Percent over Twice Standard
G Tunnel	Yes	11	0.43	0.32 - 0.82	73	9
N Tunnel	Yes/No	12	0.12	0.01 - 0.27	0	0
N Tunnel	Yes	4	0.04	0.01 - 0.09	0	0
N Tunnel	No	8	0.16	0.02 - 0.27	0	0

The lowering and/or elimination of ventilation was a common circumstance in the tunnels as the "button-up" phase approached. During these final steps prior to an event, access to the bypass and line-of-site tunnels were restricted at times to that of small crawl tubes which were not able to maintain the necessary ventilation level for safe working conditions (DOE, 1992). The decrease in ventilation rate is likely to have led to increased radon levels in these instances. Further, ventilation in the early years has been described as "poor" (pipefitters focus group) which is likely considering that several crews worked in different headings of a single tunnel at one time and often worked in less ventilated side drifts.

d. Tritium And Iodine Exposures

Tritium is a beta-emitting radioisotope which readily replaces one hydrogen molecule in water to create "tritiated water." Its twelve year half-life indicates that even the tritium created during the first tunnel event in 1957 could still be cause for concern as an occupational exposure to radiation. The report, "Simple Method for Isolating a Source of Tritiated Water Vapor," briefly mentions internal exposures to personnel due to tritiated water vapor (SNL, 1988). A graph in the report illustrates the internal doses received by several individuals over a number of years. The doses range from over 600 mrem down to a few mrem over the time period of 1977 until 1986, the highest exposures occurring in the earlier years. Information was not given regarding the method of determination for the internal doses.

Several isotopes of iodine are typically present in the fission products following a nuclear detonation. These isotopes have short half-lives ranging from eight days down to mere minutes and predominantly emit beta particles. Of the radioactive releases to the environment described earlier, a total of fifteen of the releases during tunnel events contained an isotope of radioactive iodine (DOE, 1996).

A report of the Atomic Energy Commission (AEC, 1975) contains descriptions of the following "operational accidents":

- Date: 6/6/63 NV-Reynolds Electrical & Engineering Co., Inc. 9 Exposed
  Fifteen employees exposed during re-entry and recovery operation in tunnel, nine receiving in excess of 30 rem per year to thyroid. (593, 371, 350, 265, 200, 133, 37, 36, & 34 rem).

- Date: 2/5/65 NV-Reynolds Electrical & Engineering Co., Inc. 2 Exposed
  Two employees, participating in a post-shot drilling operation, received estimated thyroid exposures of 31 and 27 rem, respectively, when gaseous radioiodine escaped from an abandonment valve opened in error.

The incident in 1965 involved one operating engineer receiving an exposure of 31 rem. This exceeded the limit to the thyroid, the target organ for iodine, which at the time of the exposure was set at 30 rem (the current standard is 40 rem, ICRP, 1991). The determination of exposure burdens, for the fifteen individuals exposed in 1963, was detailed in the paper, "Monitoring of Several Individuals Exposed to Mixed Fission Product Gases at NTS" (Eckert, 1964). The workers were exposed to fission gas products during re-entry operations for an event which occurred on the previous day. Of the nine individuals receiving exposures exceeding 30 rem, seven were miners and one an operating engineer. The average exposure burden was 236 rem, ranging from 34 to 593 rem. The majority of the employees wore no type of respiratory equipment, a few wore protection for time periods in the minutes range, and one wore protection for the entire exposure duration. The workers were exposed for time periods ranging from 0.5 to 4 hours.

A report recently released by the National Cancer Institute assesses the I-131 exposure to Americans due to the radioactive fallout from 90 atmospheric tests conducted at the Nevada Test

Site in the 1950s and 1960s (NCI, 1997). Doses to the thyroid were reconstructed for each county in the United States, with an average accumulated thyroid dose of 2 rads across the entire country. Nye county, where the test site is located, had doses ranging from 0.1 to 5.0 rads. According to the report, people living in the Western states to the north and east of the test site accumulated the highest doses. These were also the areas from which the test miners in the early years typically originated. See Appendix 19 for NCI report.

e. Baneberry Incident

The Baneberry event was a downhole shot detonated on December 18, 1970. Venting occurred 3.5 minutes following event time. The unusual release of radioactivity was reported as being a result of the high water content in the surrounding medium at ground zero (AEC, 1971; AEC, 1973). A radioactive cloud was formed from the release and traveled in the direction of the Area 12 camp, causing a massive evacuation effort to commence. In the end, approximately 900 personnel were surveyed for radioactive contamination on their person, clothing and personal effects. Decontamination activities were necessary for 86 of the workers with contamination levels ranging from 0 to 200 mR/hour (reference Onsite Report), 66 of whom were subsequently sent to Test Site base camp at Mercury for thyroid activity measurements. Eighteen individuals then went on to the whole body counter in Las Vegas for an additional measurement of the deposition of radioactivity in their bodies.

Prior to and during the Baneberry shot, workers in the forward areas, including Area 12, were not evacuated on event day outside of a small exclusion area. Therefore, personnel living or working in the vicinity of Area 12 were present in the area at the time of detonation and subsequent release of radioactivity. Workers in the Area 12 camp were subject to external exposure from the cloud passing overhead, contamination of their clothing and person, and internal exposure from airborne radionuclides. The highest doses, received by two security guards, were 1.0 R whole body, 2.4 rem to the lens of the eye, 4.6 rem to the skin, and 3.7 rem to the thyroid.

"Significant contamination levels" were found in the Area 12 camp, including inside the worker's change house, causing the camp to be closed down until clean-up could be accomplished. Decontamination of the Area 12 camp took place from January 22 to January 31, 1971, and required the cleaning of roads, buildings, and housing trailers, inside and out. Following the Baneberry event, personnel were evacuated from all of the forward areas on event day, eliminating the possibility of a repeat of this incident.

2. Radiation Outcomes

The human health effects of ionizing radiation have been the subject of extensive investigation for more than four decades. There are numerous authoritative reviews that have summarized the world literature (National Research Council, 1990; UNSCEAR, 1993) that will not be repeated here. The biological effects include acute effects such as erythema, nausea and vomiting from high dose exposures as well as chronic effects such as cancer and genetic effects. With low dose exposures, in the 0-25 rem range, only the chronic effects are likely to occur. Therefore, we will focus on these effects, and especially on cancer, as the health effect of concern in on-going surveillance of NTS workers.

Of the radiation exposures to NTS employees (described above), the most important types of ionizing radiation are external gamma, internal alpha, and beta radiation from a variety of sources and routes. The amount of exposure to underground test workers cannot be estimated with certainty, but from the descriptions of the work process and the radiation monitoring data available at present, it appears that there have been several NTS workers whose dose to either external penetrating radiation or inhaled alpha radiation exceeded exposure limits in effect during the years 1961 to 1980. This provides the rationale for recommending surveillance for specific cancers.

The combined evidence from epidemiologic studies of workers in the nuclear weapons complex in the U.S. and other countries is that these workers are at increased risk for leukemia and multiple myeloma, and other cancers depending on the specific exposure circumstances. For example, workers exposed to plutonium may also be at risk for brain cancer and workers and "downwinders" exposed to radioactive isotopes of iodine appear to be at increased risk for thyroid cancer. Furthermore, studies of underground miners demonstrate increased risk of lung cancer, even at relatively low radon exposure levels. (See Appendix 21 for a review of epidemiologic studies).

B. Silica

1. Silica Exposures

Underground mining and tunneling generate mineral dusts as a consequence of work activity. The tunnels at the NTS, as indicated above, were built into volcanic tuff containing crystalline silica. Each of the various phases of tunnel preparation, mining, construction, support, button-up, and re-entry, presented opportunities for silica exposure to the former Test Site worker. Clearly the tunneling phase, which involved the excavation of major headings, cross-cuts, formation of test alcoves, and invert preparation, generated the highest dust and silica exposure. Although tunnelers and the continuous miner operators faced the most intense exposures, the underground environment provided an essentially uniform dust exposure to all the workers. Focus group discussions, former worker interviews, and Advisory Panel input concur with our assessment that all those working in the mining/tunneling environment experienced similar levels of exposure.

In the relatively soft volcanic tuff which characterizes the geology of the tunnel area, the Alpine continuous miner, which was introduced in the early 1970's, generated significant noise and dust. Typical dust control measures, such as water mist, were not used and, instead, respirators were provided. A 1990 Technical Safety Appraisal of the NTS conducted by the US DOE Office of Environment, Safety, and Health cited a concern that "personal protection is used as the primary control for health hazards, when engineering controls or administrative controls are both feasible...." (DOE, 1990).

Choice of tunnel support method also added to the load of silica dust to which NTS workers were exposed. Volcanic tuff, which provides good tunneling substrate, requires a well developed support structure. In the earliest tunneling period at the NTS, tunnel supports were steel sets. Later, rock bolts, wire mesh, and shotcrete provided the basis for the tunnel's supporting infrastructure. In addition to silica and total dust exposure encountered in drilling, blasting, and mucking, shotcreting further increases the dust hazard of the tunneling workplace. Wong (1988), in describing the industrial hygiene aspect of tunneling work which took place between 1984 and 1986 for the mass rapid transit system in Singapore, listed shotcreting as another activity responsible for dust generation in the tunnels. Dust emission in shotcreting and pneumatic breaking was the most difficult to control. In one case, shotcreting in a working shaft resulted in dust levels of 4.1 to 22.6 mg/m3.

The use of grout compound also added to respirable silica contamination of the ambient air. The area around the Line-of-Sight (LOS), as well as the bypass drift, was filled with grout, leaving the LOS as the only clear pathway between the explosion and the test chamber. Different types of grouting compounds were used along the tunnel to permit the containment of the explosion, to moderate any potential geologic stress, and to effectively fill-in and plug any fractures which may form following the device's explosion. MJ-2 grout, which had been used during the 1980's, consisted of cement, silica flour and fume, 20/40 sand, and other substances. Chemical characterization of the grout revealed 61% silica dioxide. At this time we have yet to secure MSDS's for the grouting compounds and other adhesive/sealants compounds used in the tunneling and containment process for this period at the NTS.

a. Exposure Assessment

Few NTS datasets have been created or are available which can provide us with a portrait of the underground work environment. Even less information is available specifically for silica.

The mineral content of rock, while not as informative as ambient measures, tells us a great deal about the possible hazard from working in a substrate containing crystalline silica. Drilling through rock with a high percentage of crystalline silica is more likely to lead to higher air concentrations in a mining/tunneling work area. To characterize the potential silica exposure environment, we have attempted to locate "core sample" data which were analyzed by the U.S. Geologic Survey.

Freeman and Grossman (1995) evaluated silica exposure in workplaces using OSHA's Integrated Management Information System (IMIS). We used a similar approach to assess silica and noise exposure in two construction standard industrial classifications (SIC's). We requested information from OSHA and received records from the IMIS detailing levels of respirable crystalline silica and noise measured during OSHA inspections in SIC 1622 (tunnels, bridges, and elevated highways) and 1629 (other heavy construction).

We also have gone to the medical and industrial hygiene literature to supplement and enrich our understanding of the NTS. There has been a great deal of interest in silica, especially in mining, since it is the most abundant material in the earth's crust. It is also a substance whose health effects have been recognized since antiquity. We've sought out government reports (EPA, OSHA, Mine Safety and Health Administration (MSHA), and NIOSH), have used electronic data search systems, and have relied upon a vast array of texts.

b. Silica Content of the Rock

Bulk analyses of the silica content of rock on specific tunnel projects conducted for industrial hygiene purposes have been conducted by the United States Geologic Survey (USGS) on the downhole and tunnel areas at the Test Site. Core samples were obtained by the agency or laboratory responsible for running the test (Los Alamos National Laboratory, Lawrence Livermore National Laboratory or the Defense Nuclear Agency, now the Defense Special Weapons Agency). We have contacted numerous individuals and groups at LANL, LLNL, and the NTS and to date have come up with the results from a few core samples. The limited data that are in-hand indicate both non-crystalline and crystalline forms of silica in the volcanic tuff and granite rock of the Test Site. The finding of cristobalite in the rock of Yucca Mountain has recently spurred labor and management to focus on developing a respiratory protection plan for tunnel workers.

Table 4 list core sample results obtained from the USGS "Core Library" at the NTS.

Table 4: Core Samples, United States Geologic Survey, Nevada Test Site, 1959 - 1971

Year	Location	Mineral	Concentration (%) Weighted Average		
February 1959	U 12 e	Silica	70		
March 1959	U 12 b	Silica	66		
			Minimum	Maximum	Mean
April 1971	U 12 t	Cristobalite/crystalline silica	< 10 %	40 %	30 %

These samples were taken from three tunnels at the Area 12 complex as part of the selection and characterization process for the construction of new "drifts." Because of the special containment demands and the tremendous stresses placed on the surrounding rocks by the nuclear test, USGS geologists obtained and analyzed the minerologic characteristics of the area. These three samples, while not representative of the entire Area 12 tunneling complex, provide an indication of the high silica content of rock in at least three work areas. Discussions with USGS geologists confirm that the volcanic tuff at the NTS, especially in the Rainier Basin area, has a silica content in the same range as the above samples.

Guthrie, et al. (1995) reviewed the health risks and geologic data associated with the tunneling project at Yucca Mountain (YM), which adjoins the Nevada Test Site. The YM site characterization project, in which Guthrie is involved, is an on-going study of YM and its surroundings to assess the suitability of the area as the country's first high-level radioactive waste repository. The geology and mineral characteristics of the YM site have much in common with those of its neighbor, the NTS. Mineralogic analysis of YM core samples was performed using X-ray powder diffraction analysis. Three crystalline silica polymorphs, quartz, cristobalite, and tridymite, were noted to be abundant in the rocks at YM by Guthrie. Mineral composition of the rock for these three polymorphs ranged form 10 to 50 % depending upon the sample's depth from the surface.

c. Silica Content of Ambient (Work) Air

i. Site information

Table 5 summarizes the silica sampling done as part of the NTS industrial hygiene program. Total dust concentrations ranged from 2 to 543 mg/m3. The percent free silica in the reported samples ranged from 0 to 62 %.

Table 5: NTS Silica Dust Exposure

	NTS Silica dust exposure: Respirable Mean Samples (mg/m3)						
NTS Area U12E at mole points							
Period	N	Mean	Min, Max	Percent over 0.05 mg/m3	Percent over 0.1 mg/m3	Percent over 0.2 mg/m3	Mean percent crystalline silica
Jul-74	3	0.68	0.33,1.2	100	100	100	40.3
NTS Area U12G at Alpine Miner							
Aug-74	8	2.64	0.9,4.7	100	100	100	1.33

ii. Analogous work exposures/historical tunneling exposure To silica

Although we were unable to obtain much information from the NTS IH records, we considered standard tunneling and mining industry data as reasonable surrogates of the NTS experience. Several reports describe the major threats to health that were encountered by individuals employed in this tunneling workplace. Health hazards are described as deriving from several underground construction activities: drilling, blasting, mucking, and shotcreting.

d. OSHA and MSHA DATA

OSHA and the Mine Safety and Health Administration (MSHA), collected industrial hygiene samples at workplaces and mines throughout the U.S. Their programs' site monitoring was part of a larger enforcement and compliance function which these agencies performed. The type of information gathered is a non-representative sampling of U.S. workplaces and thus the information collected also can be expected to be not representative. In Tables 6 and 7, silica samples are reported as a ratio of the TLV. During the years 1979 through 1997, greater than half of the reported silica measurements for SIC's 1622 and 1629 exceeded the TLV.

Table 6: OSHA Silica Sampling, 5/1/79 through 5/31/97,
SIC 1622 (Bridge, Tunnel, and Elevated Highway)

Substance	Number of Samples	TLV	Severity < 1.0	1 - 2	>2
Silica (Quartz)	82	0.1 mg/m3	25 (31%)	14 (17%)	43 (52%)
Noise	18	90	2	5	11

Table 7: OSHA Silica Sampling, 5/1/79 through 5/31/97
SIC 1629 (Heavy Construction)

Substance	Number of Samples	TLV	Severity < 1.0	1 - 2	>2
Silica (Quartz)	84	0.1 mg/m3	43 (51%)	13 (16%)	28 (33%)
Noise	29	90	13	9	7

The MIDAS database was created in 1976 by MSHA and is currently managed and maintained by NIOSH. MIDAS, like the previous OSHA database, contains measurements obtained during inspections. Thus, it is also a non-representative sampling of the universe of SIC 1622 and 1629. We requested data from the MIDAS system from NIOSH for the years 1976 through 1991 for metal and non-metal mines. The MIDAS records in Table 8 are organized in 5 year intervals. The percent of the samples over the NIOSH REL (0.05 mg/m3 crystalline silica) ranged from 21 to almost 60%.

Table 8:

Silica Exposure: Personal Samples, Respirable Fraction, MIDAS Database
Underground metal and nonmetal mining occupations, 1976-1991

Period	N	Mean*	Min, Max	Percent over NIOSH REL (0.05 mg/m3)	Percent over Twice the NIOSH REL	Mean percent crystalline silica
1976-1991	3369	.48	0,853	22.6	13.6	5.37
1976-1980	1656	.24	0,68	21.0	12.3	5.61

1981-1985	894	1.0	0,853	59.6	10.0	3.98
1986-1991	819	.39	0,193	31.1	20.0	6.39

e. Worker-based Information

In a series of interviews and focus groups conducted in Las Vegas in 1996-97, former workers described their experience with mining and dust. The following excerpts reveal the extent of dust and smoke from blasting and the Alpine Miner as experienced by former workers:

"I was mucking and had to hose down the drift, there was no ventilation at all, you couldn't see for the smoke, I was wearing one of those white respirators and I changed it about every thirty minutes." -- [former operating engineer talking about hauling muck from an Alpine mining operation to a drift with no ventilation].

"When they first got them Alpines, it was so bad you couldn't see, in fact I remember a crew walked off the job...it was so dusty you couldn't, I mean we had to muck behind it, the miners were running it, you couldn't see a car lamp, it was so dusty, so once a night crew, they just walked off the job they said they wouldn't do it no more...they was trying to use water to spray it down, but that just wouldn't do it, so then they finally put the vent line right over the head of the miner, and then that would suck the dust out, but that dust would be so far back in the drift, you couldn't see nothing, when they first brought them out, it was terrible." -- [former operating engineer talking about the dust created by the Alpine Miner before the use of ventilation at the heading].

"In '58, '59, '61, until they started the Line-of-Sight pipe, there was no stemming material like that, it was all sand bags, and very dusty. You stack them drifts, you have a thirteen by thirteen drift, you stack sand bags, tight, and then they come up with the blowing fan, and that was even dustier, and worse. And then in the sixties, I think '62, or very early '63 was when they had the first pipe shot, that used a stemming material, and it wasn't too dusty then." -- [former miner discussing containment in the tunnels over time].

The data sources utilized for this section on silica show respirable crystalline silica to be a significant hazard in the tunneling, downhole, and excavation work performed at the NTS. The mineralogical analysis frames our consideration of risk in this environment. With concentrations of crystalline silica ranging as high as 60% and averaging in the mid 20's, underground workers drilled, blasted, and manipulated rock high in silica content.

2. Silica Outcomes

a. Non-Malignant Health Outcomes

The health effects of occupational silica exposure probably have been known since humans began to mine and smelt precious ores, to make glass, and to cut stone, all of which produced high dust levels and, consequently, dust diseases in the lungs (Raffle et al., 1987). Workers in the so-called dusty industries had severe respiratory diseases that shortened their lives markedly (Raffle et al., 1987). In 1915, the British physician Edgar Collis demonstrated that the lung disease of many "dusty trades" workers was silicosis (or silicotuberculosis), and that it was caused by the inhalation of "free" or crystalline silica dust (Collis, 1919). The insensitivities of current diagnostic techniques (Hnizdo et al., 1993) still hamper efforts to determine the prevalence of silicosis in the United States. Recent occupational studies by Hnizdo and Sluis-Cremer (1993), Muir et al. (1989a, b), Ng and Chan (1994), Rice et al. (1986), and Steenland and Brown (1995a,b) provide important evidence of the exposure levels that can cause silicotic effects (See Appendix 22 for Mechanisms and Manifestations of Occupational Silica Health Effects).

Epidemiology of Chronic Silicosis

In a retrospective cohort study, Hnizdo and Sluis-Cremer (1993) investigated the risk of silicosis among 2,235 white South African gold miners. The miners had an annual radiological examination while employed, and most returned for occasional radiological examinations after leaving the mines. The onset of silicosis was defined as the year in which rounded opacities of ILO Category 1/1 or higher were first read.

Hnizdo and Sluiz-Cremer (1993) assigned exposure levels to 11 occupational categories based on measurements taken with a thermal precipitator in the late 1950's and in the early 1960's in 20 gold mines. Cumulative dust exposure in milligrams per cubic meter years was calculated for workers using data for mean mass respirable dust concentrations for various activities within mines, number of dusty shifts, and average number of hours spent underground. The respirable dust in South African gold mines was found to contain about 30% silica within the airborne dust. Net number of years working in dusty occupations in gold mines was calculated.

Figure 1(below) shows the estimated cumulative risk of silicosis in relation to the cumulative dust exposure. Of the 2,235 miners, 313 developed radiological evidence of silicosis (ILO Category ~ 1/1). The onset of silicosis occurred at an average age of 56 years, after 27 years of net service. For 135 of the 313 miners (43%), the onset occurred while the miners were still working in the mines, at an average age of 51 years (range: 39 to 61 years). The other 178 miners (57%) developed silicosis an average of 7.4 years (range: 0.1 to 25 years) after leaving the mines, at an average age of 59 years (range: 44 to 74 years). Thus, a large portion of the miners developed silicosis after 50 years of age and after their employment ended (our emphasis).

Kreiss and Zen investigated exposure response relations for silicosis in former miners (men over 40) in a community-based random sample study in a Colorado mining town. The authors determined that miners exposed to estimated average silica levels of 0.064 mg/m3 (ACGIH TLV = 0.1 mg/m3) over their working lifetime had a 32% prevalence of silicosis. Many of these men had normal X-rays upon leaving mining employment only to have the abnormality show-up in a later screening. Kreiss and Zen concluded that assessments of silicosis made at the time miners leave the industry may underestimate risk for occurrence.

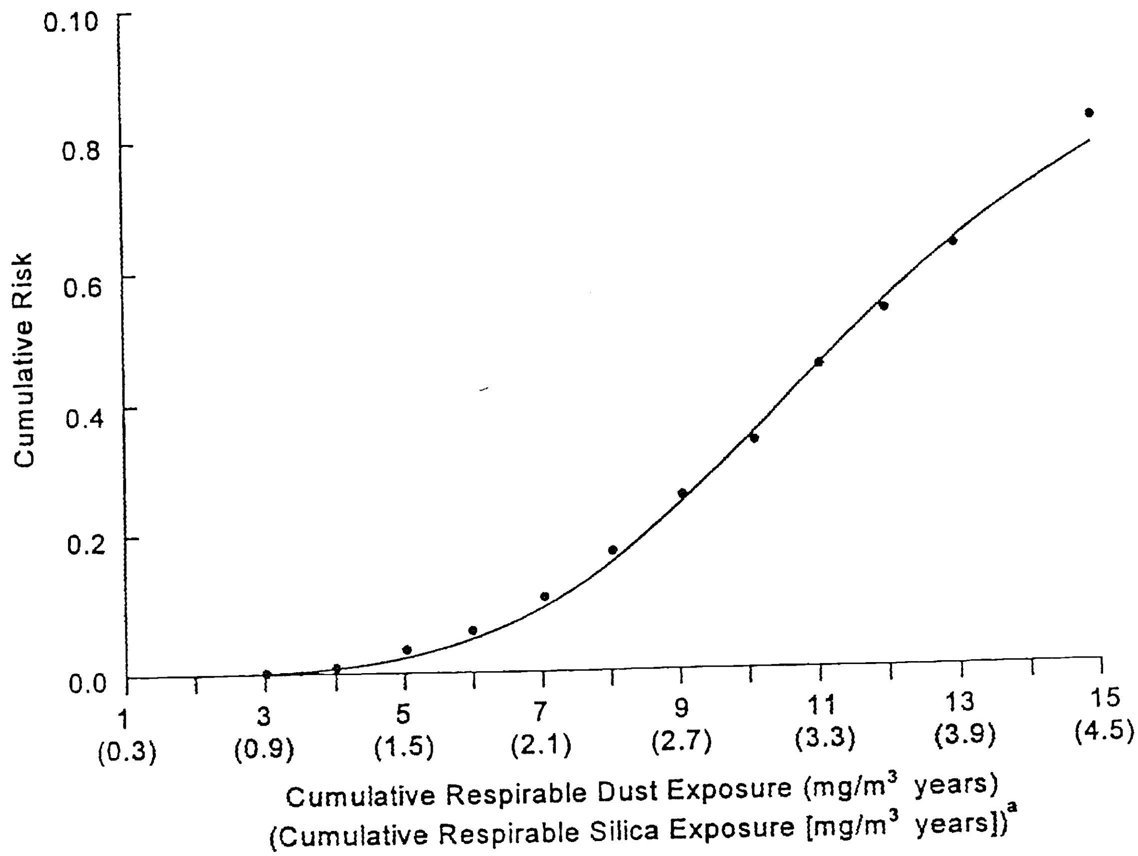

Fig 1: Cumulative risk of silicosis in white South African gold miners versus cumulative respirable dust and silica exposure. Miners were followed from 1968 or 1971 to 1991.

An epidemiological investigation to determine the relationship between silicosis in hardrock miners in Ontario and cumulative exposure to silica dust has been reported (Muir et al., 1989a, b; Verma et al., 1989; Muir, 1991). The cohort consisted of 2,109 miners first exposed between 1940 and 1959 who spent 80% or more of their total mining experience in one or more of the designated 21 mines. Each participant had a chest X-ray which was evaluated by a panel of B-readers. Of the 2,109 Ontario hardrock miners, only 32 were considered to have silicosis (ILO Category of 1/1). The onset of silicosis in these 32 occurred at an average age of 52 years, after an average of 26 years of net service, and while they were still working in the mines. A radiological survey of retired miners was not performed.

McDonald and Oakes (1983) analyzed a cohort of 1,321 South Dakota gold miners employed for at least 21 years prior to 1965, with follow-up through 1973. Average exposures were estimated based on observed dust counts from 1937 to 1973. The investigators identified 49 cases each of silicosis and tuberculosis from death certificates. They estimated the risk of dying from silicosis or tuberculosis (as the underlying cause of death) by category of average exposure. They found an increasing linear trend in risk of about 2.4% for each 0.1 mg/m3 of silica exposure. They did not calculate risk by cumulative exposure.

Steenland and Brown (1995b) estimated the risk of silicosis by cumulative exposure-years in an expanded cohort of South Dakota gold miners (n=3,330) who had worked at least one year underground between 1940 and 1965 (average 9 years), with follow-up through 1990. During 106,000 person years of observation, 1,551 of the 3,330 miners died. Average dust exposures for six job categories were estimated using existing measurements for each year from 1937 to 1975. The cohort was exposed to a median silica level of 0.05 mg/m3 (0.15 mg/m3 for those hired before 1930). Using death certificates and two cross-sectional radiographic surveys (636 cohort X-rays in 1960, 229 cohort X-rays in 1976), the authors determined 170 cases of silicosis. The estimated cumulative risk of silicosis in relation to the cumulative respirable silica exposure with and without adjusting for age and calendar time was determined to be less than 1 % for a cumulative respirable silica exposure under 0.5 mg/m3 years, increasing to 68 to 84% for the highest cumulative exposure category of more than 4 mg/m3 years. The authors estimated a lifetime risk of silicosis for someone exposed for 45 years at the Occupational Safety and Health Administration (OSHA) standard (0.09 mg/m3) to be 35 to 45%, after adjusting for competing causes of death.

Ng and Chan (1994) evaluated the risk of chest X-ray markings among 338 male Hong Kong granite workers employed a minimum of one year between 1967 and 1985 (Ng and Chan, 1994). Films were read independently by three physicians using International Labour Organization (1980) criteria. The authors estimated past cumulative silica exposures from quarry- and job-specific airborne dust (midget impinger) samples, with an overall average of 27% silica. Rounded or irregular opacities of profusion 1/1 or greater were defined as silicosis if they were so read by two of the three readers. The probability of radiological abnormalities increased for men 50 years and over, according to their cumulative dust exposure, and no smoking effect was shown. The authors suggest a threshold exposure of <1.0 mg/m3 years may be compatible with zero risk, because no cases of X-ray silicosis were detected. This is in general agreement with the results of Hnizdo and Sluis-Cremer (1993) and Muir et al. (1989b), which also suggested zero risk at cumulative silica exposures below 1 mg/m years. (For additional epidemiologic studies of chronic silicosis, see Appendix 23.)

Summaries of epidemiologic studies of chronic silicosis are included inTable 9.

Table 9: SUMMARY OF OCCUPATION STUDIES OF SILICOSIS RISK

Reference	Study Typea	Study Population	Health Effect	% Silica (Quartz)
Hnizdo and Sluis-Cremer (1993)	LRC	2,235 South African miners; started after 1938 and worked ≥ 10 years; followed to 1991	313 cases of silicosis (ILO Category ≥ 1/1)	30
Muir et al. (1989 a,b), Muir (1991), Verma et al. (1989)	LRC	2,109 Canadian miners; started 1940 to 1959; followed to 1982 or end of exposure	32 cases of silicosis (ILO Category ≥ 1/1)	6.0 to 8.4

Ng and Chan (1994)	XRC	338 Hong Kong granite workers' 132 past workers (1967 to 1985) and 206 current workers (1985); only most recent X rays examined	36 radiographical abnormalities, rounded opacities (ILO Category ≥ 1/1)	27
Rice et al. (1986)	CC	U.S. (North Carolina) dusty trades workers diagnosed with silicosis, 1935 to 1980.	216 cases of silicosis; 672 controls	1 to 50
Steenland and Brown (1995b)	LRC	3,330 South Dakota gold miners who worked at least 1 year underground between 1940 and 1965; followed to 1990.	170 cases of silicosis (ILO Category ≥ 1/1)	13

a CC = Case control, L = Longitudinal, RC = Retrospective cohort, X = Cross-sectional, Q = Quartz

(See Appendix 24 for review of Other non-malignant Silica Related Conditions).

b. Lung Cancer Outcomes

The International Agency for Research on Cancer (IARC) has recently classified crystalline silica as a Group 1 carcinogen (carcinogenic to humans). This upgrade in classification, from a Group 2 (probably carcinogenic to humans) is based on epidemiological studies that provided sufficient evidence for a increased risk of lung cancer that could not be explained by confounders such as cigarette smoking or radon exposure, or other factors. Epidemiological studies have been conducted with worker cohorts employed in a number of industries characterized by high exposure to crystalline silica dust. When exposure to other possible carcinogens and smoking were taken into account, the majority of these studies found increased risks of lung cancer in the worker populations. Studies of workers in such industries have provided convincing evidence for the causal role of exposure to crystalline silica dust in occupational lung cancer. The lung is the principal target site in exposed human populations because inhalation of dust containing crystalline silica is the primary route of exposure (Checkoway, 1993).

i. Silica exposure and excess lung cancer risk among tunnelers

Studies on above-ground workers exposed to silica dust give us a better indication of the unconfounded effects of silica in contributing to excess mortality from lung cancer. However, studies conducted among miners are more indicative of the range of carcinogens that one would expect to be present in an underground environment like the Nevada Test Site. While the work environment of tunneling has not been well documented in the literature with regard to silica exposure and health outcomes, studies that include populations of tunnelers among their cohorts have found high estimates of exposure and lung cancer risk for tunnel workers. Mastrangelo et al (1988) carried out a case-referent study in which the effect of silica exposure and silicosis were investigated among admitted lung cancer patients. Statistically significant excesses in risk for lung cancer were found only among silicotics (OR of 1.8, CI 1.1 to 2.8). Among those exposed in mines, tunnels, and quarries, the highest rates were found for tunnel workers. In general, workers involved in heavy construction such as that performed in tunnel work are exposed to significant amounts of respirable silica from various operations (IARC, 1997).

ii. Cohort studies of worker populations in underground workplaces

Though the relationship of silica exposure to lung cancer is not often studied among tunnelers, underground mines bear many of the same exposures. Studies of underground workplaces have the potential for confounding by concomitant exposures to other carcinogens such as radon, asbestos, and diesel exhaust. Many of these studies examine lung cancer risk among silicotics; others look at the relationship between silica exposure and lung cancer without specific regard to silicosis status. Table 10 presents the relative risk data generated by studies of mining cohorts.

Hnizdo and Sluis-Cremer examined the effects of exposure to gold mining dust with a high concentration of silica on the mortality from lung cancer among white South African gold miners who started mining exposure during 1936 to 1943. The cohort of 2209 white gold miners was followed up from 1968-71 to December 1986. One of the selection criteria was ten years of underground work in gold mines; miners worked 23.5 years on average. Occupations within the gold mines were classified on the basis of measured dust counts and exposure was estimated on the basis of job classification and shifts worked. The average level of respirable dust in the gold mine in 1968 was 0.3 mg/m3 of which approximately 30% was crystalline silica. The cumulative dust counts and the actual years of exposure were calculated for each decade - 1940's, 1950's, 1960's and to the start and end of the follow-up period (1968-71 to December 1986) in terms of respirable dust-particle years. The associations between death from lung cancer and degree of silicosis were examined by odds ratios. The study found a significant dose-response relationship between death from lung cancer and silica-dust particle years. The relative risk for lung cancer associated with the exposure to 1000 particle-years of silica dust was 1.023 with an expected RR of 3.18 among the highest exposure. The odds ratio for the association between lung cancer and silicosis of the hilar gland was 3.9 (CI 1.2 to 12.7). (See Appendix 25 for silica and lung cancer in non-mining workplaces).

C. Diesel

1. Diesel Exposure

a. Diesel Exposure at the Nevada Test Site

Although diesel-powered equipment was used throughout tunneling and mining workplaces, particulars of the construction at NTS further increased exposure to diesel exhaust. Convoluted tunnel patterns, necessary to contain atomic blasts, mitigated against the use of conveyer systems for removing spoils. Instead, diesel-powered mucking and haulage equipment was used, increasing the potential for significant exposure to harmful exhaust. From the diesel monitoring data available, one can infer that controls for diesel exhaust were less effective in the early years of tunnel construction. A former miner and tunnel walker commented on diesel exhaust in the tunnels:

"Your diesel smoke, you could put on them little dust masks, but I don't think they ever done you too much good, I've seen the guys wear 'em, and in an hour they'd be just black from the diesel smoke. You had your ventilation, but yet your ventilation never picked up all that stuff in your heading. You had, back behind, where your fresh air was coming in, which your ventilation fans are runnin', then it was good back there but right straight in the heading, you had a lot of diesel smoke and a lot of that, you get your vent lines up close to your heading, but there was a certain distance that a lot of times when we would blast, we would put a, join a, vent line up to get it up as close to that heading as you could. And, in the early days, you didn't have fans in the tunnels that was effective as they were in the later days."

A REECO Office Memorandum dated April 12, 1966 attests to the poor ventilation that sometimes allowed the accumulation of gases in the tunnels. Three men had passed out in a LOS drift; air samples revealed 100 ppm carbon monoxide. According to the memo "he stated that due to necessities the vent line was reduced to 3" inside diameter in this area. He also stated that the miners did in fact work beyond the end of the vent line."

Diesel exhaust is a highly complex mixture of gases, vapors, and particles (soot) consisting of a very large number of elements and compounds. The products of incomplete combustion include gases such as carbon monoxide, oxides of nitrogen, and sulfur dioxide, unburned fuel and lubricants, and unburned additives and contaminants. Measurement of diesel exposure is confounded by the fact that gases such as CO and nitrous gases may also be produced by blasting and welding. There is presently no known unique marker for diesel exhaust exposure. There is also no specific U.S. permissible exposure limit for diesel particulate matter at this time; many of the compounds found in diesel exhaust are also emitted from other combustion sources. However, occupational health standards are enforced for a number of the gaseous constituents of diesel exhaust including carbon monoxide (CO), carbon dioxide (CO2), sulfur dioxide (SO2), nitric oxide (NO), and formaldehyde (HCHO) (Watts, 1995).

Among the limited diesel exhaust data available from NTS are measurements of carbon monoxide, nitric oxide, and nitrous oxide which are included in the Industrial Hygiene database (NTS, 1984). This report includes results of monitoring data from April, 1974 through June, 1984. Very little data was recorded for the latter four years of this period. Most data was collected in Area 12. Table 11 presents levels of carbon monoxide and nitric oxide that were measured at mucking locations, at the drilling face, and during re-entry between October, 1974 and December, 1974. Overall, average levels of gaseous contaminants are distorted by the elevated levels present at re-entry. Activity-specific levels are more representative.

Of 39 (non-re-entry) samples taken in 1975, the mean CO level was 7.35 ppm (range, 0 - 40), mean NO levels were 0.385 (n=13, range, 0 - 2) and NO + NO2 mean levels were 3.86 (n=35, range, 0 - 10).

Table 11:

Indicators of diesel exposure: NTS Area U-12N, 10/74 to 12/74					
Activity: Mucking					
Contaminant	N	Mean	Min, Max	Percent over TLV	Percent over Twice the TLV
Carbon Monoxide	9	48.9	10, 130	22.2	11.1
Nitric Oxide	6	7.7	0,30	16.7	0
Activity: Drilling					
Carbon Monoxide	7	54.28	0,80	57.14	0
Nitric Oxide	4	5	2,10	0	0
Activity: Re-entry *(10/74 to 11/74)					
Carbon monoxide	7	4500	3000, 7500	100	100

Note: TLVs are 1986-87 ACGIH TLVs for CO (50ppm) and for NO (25ppm)
*nitric oxide not monitored during re-entry

In the 1980's, electric tunneling equipment became more widely available, however diesel equipment continued to be used. A Progress Report for the Period July 1, 1989 through June 30, 1991 (DOE, 1992) indicates that diesel haulage units were operated about 30 % of the time (or roughly 20 minutes per hour). Load haul dumps (LHDs), which were used to remove muck, were operated an estimated 15 % of the time (10 minutes per hour). Among the diesel emissions produced by such locomotives and LHDs (CO, CO2, NO2, formaldehyde, and particulates) the Progress Report lists nitrogen dioxide (NO2) as the most harmful of the gases discharged by diesel equipment. This document reported typical CO levels of 0-10 ppm, and NO2 levels of 0.2 to 25 ppm, the higher values found after blasting.

Personal monitoring for diesel emission gases was conducted by the Health Protection Department Industrial Hygiene Field Operation Section (Barrow-Adams, 1994). From 1992 through 1993, monitoring occurred during the construction of nuclear test beds at two underground locations, P Tunnel and U-1A Shaft. The gases sampled were: carbon monoxide, nitrogen dioxide, hydrogen sulfide, sulfur dioxide, and formaldehyde. All results were well below TLVs. For example, the average carbon monoxide exposure for 72 personal samples was 1.02 (maximum value 3.24 ppm, TLV 50 ppm). Diesel activity at P Tunnel was considered low during this time. Diesel activity at U-1A Shaft was average - two muckers were operating for approximately half of the shift. Low exposure to diesel gases during this latter period of tunnel construction can be largely attributed to good ventilation and air velocity that was well above the requirement.

b. Monitoring for PAHs (Polycyclic Aromatic Hydrocarbons)

PAHs are mutagenic components of diesel soot. Monitoring for PAHs in the underground environment was conducted as early as 1978 as evidenced by a memo included in the REECO industrial hygiene printout (1974-84). Diesel exhaust air samples were collected over a period of three weeks in February/March of 1978. Industrial hygienists concluded that the level found "does not pose a health risk at this time." (Regulatory standards have not been developed for PAHs). Primary quantitative data has not been found for this or any other data collections during this period. The 1989-90 Progress Report stated that no PAHs were detected in any of the personal samples measured during this time period, except for trace amounts of anthracenes found in two samples (1 and 1.1 ug respectively). Personal monitoring of underground workers was done in P and N Tunnels during this latter period.

c. Diesel Exposure in Tunneling: oOher Sources

Mechanization of tunnel construction has resulted in contamination of the working environment by exhaust gases and particulate matter. The use of diesel equipment underground may be regulated by ventilation requirements (fresh-air flow), exhaust scrubbers, and gaseous exposure limits. Historical carbon monoxide limits were actually based upon limiting harmful quantities of oxides of nitrogen and aldehydes that are generated in a rough proportion to carbon monoxide. Low levels of carbon monoxide are assumed to be an indication that all harmful components of diesel exhaust are being adequately ventilated. Burns et al's 1962 report on the health hazards of heavy construction measured diesel exhaust indicators in nine tunnel construction projects in California. The results of their testing for carbon monoxide and oxides of nitrogen are presented in Table 12. Though carbon monoxide was usually found to be below the standard, the tunnel workers' greatest complaints were directed against the irritating effect of diesel exhaust gases. The industrial hygiene team received many complaints of eye irritation, of soot accumulations in nose and throat, and bronchial irritation and cough (Burns, 1962)

Table 12:

Indicators of Diesel Exposure: Tunnel construction projects, California, 1958 to 1961	
Contaminant: Carbon Monoxide (TLV 50 ppm)	
Tunnel#:	Min, Max
1	0,5
2	0,40
3	0,20
4	0,10
5	0,5
6	0,38
7	6,24
8	4,83
9	18,32
Contaminant: Oxides of Nitrogen	
Tunnel #:	Min, Max
1	1,4
2	2,12
3	3,12
4	0,1
5	0,1
6	3,6
7	1,8
8	0,1
9	0,1

Wong et al (1988) reported on the industrial hygiene aspects of tunnel construction for the mass rapid transit system in Singapore. Major sources of carbon monoxide emission were welding fumes and diesel engines. Mean level of CO in the free air tunnels was 1.71 ppm (N=191)

Table 13 summarizes diesel exposure (CO, NO, and NO2) measurements taken in metal and non-metal mining workplaces from 1976 to 1991. Data was obtained from the MIDAS database, maintained and managed by NIOSH, that contains measurements obtained during inspections. The MIDAS data are summarized in 5 year intervals. The percent of the samples over the ACGIH TLV ranged from 1.0 to 13.5%.

Table 13:

Indicators of Diesel Exposure: Area Samples, MIDAS Database Underground metal and nonmetal mining occupations, 1976-1991					
Contaminant	N	Mean*	Min, Max	Percent over TLV	Percent over Twice the TLV
Carbon monoxide (111)	63,362	20.4	0,9900	2.1	1.3
1976-1980	19,509	41.4	0,9900	3.7	2.4

1981-1985	24,940	11.4	0,9900	1.5	0.9
1986-1991	18,913	10.4	0,9900	1.1	0.5
Nitric Oxide (301)	1,401	4.4	0,200	1.1	0.6
1976-1980	126	5.5	0,200	2.4	2.4
1981-1985	268	3.4	0,101	1.1	0.4
1986-1991	1,007	4.5	0,57	1.0	0.4
Nitrogen Dioxide (493)	23,494	7.6	0,7500	8.0	1.7
1976-1980	6,360	22.5	0,7500	13.5	3.5
1981-1985	7,261	3.5	0,5000	6.5	1.1
1986-1991	9,453	0.9	0,1000	5.4	1.0

Note: TLVs are 1986-87 ACGIH TLVs based on an 8-hour time-weighted average daily exposure. They are: for carbon monoxide: 50 ppm; for nitric oxide 25 ppm; for nitrogen dioxide 3 ppm.

2. Diesel Outcomes

a. Non-Malignant Respiratory Disease [NMRD]

Diesel particulate matter is composed of an insoluble carbon core with a surface coating of relatively soluble organic constituents. Studies of diesel particle composition have shown that the insoluble carbon core makes up about 80% of the particle mass and that the organic phase can be resolved into a more slowly dissolving component and a more quickly dissolving component. The non-cancer toxicity of diesel emissions is considered to be due to the insoluble carbon core because the long-term effects seen with whole diesel are not found or are found to a much lesser extent in laboratory animals exposed to similar dilutions of diesel exhaust filtered to remove most of the particles.

Rodents exposed to high concentrations of chemically inert particles (Morrow, 1992), have revealed macrophage accumulation, epithelial histopathology, and reduced clearance, strongly suggesting that the toxicity of diesel particles results from the carbon core rather than the associated organics. However, the organic component of diesel particles consists of a large number of PAHs and heterocyclic compounds and their derivatives. A large number of specific compounds have been identified. These components of diesel particles may also be responsible for the pulmonary toxicity of diesel particles.

It has been difficult to separate the carbon core from the adsorbed organics in order to compare their toxicity. A study performed at the Lovelace Inhalation Toxicology Research Institute exposed rats to either diesel exhaust or to carbon black, an inert analog of the carbon core of diesel particles. The study, which is primarily concerned with the role of particle-associated organics in the carcinogenicity of diesel exhaust, also examined non-neoplastic effects. A preliminary report suggested that the chronic non-cancer effects of diesel exhaust exposure were caused by the persistence of the insoluble carbon core of the particles, rather than by the extractable organic layer (Nikula et al., 1991).

Epidemiologic studies do not provide strong or consistent evidence for non-malignant respiratory disease associated with diesel exposure (See Appendix 26 for Acute and Chronic Effects of Diesel Exposure). It is conceivable that the modest effects demonstrated in several of the cross-sectional studies may be suggestive of moderate effects. However, the weak and inconsistent pattern demonstrated make it difficult to confirm an association.

b. Lung Cancer and Diesel Exhaust

Evidence for an association between diesel exhaust and lung cancer has been developing over the past 40 years. Early studies by Kotin, et al (1955) of diesel exhaust extracts demonstrated their carcinogenicity in experimental animals. Epidemiologists also began to study health effects in diesel exposed individuals in the 1950's, starting with a study by Raffle (1957) which reported a relative risk of 1.42 for lung cancer in London transport workers. Subsequent studies by Kaplan (1959), Waxweiler, et al. (1973), and Menck and Henderson (1976) suffered from lack of control for possible differences in cigarette smoking in exposed and unexposed study subjects. Furthermore, many of the early studies relied upon surrogate information such as job title or interview data to estimate exposure. The difficulties introduced by the lack of information on smoking and exposure levels in interpreting the epidemiologic data have been noted by many reviewers, including Steenland (1986) and Cohen and Higgins (1995).

Later studies of diesel exhaust and lung cancer, such as the one by Garshick, et al. (1988), Steenland, et al. (1990) and Emmelin, et al. (1993) have gathered information on smoking and estimated exposure to levels of particles. These studies have consistently shown elevated risks of lung cancer in various occupational groups such as railroad workers, truckers and mechanics, and dockworkers. The increased risks range from modest (RR=1.27 for long-haul truckers in Steenland, et al. (1990)) to quite large (RR=6.8 for dockworkers with high exposure in Emmelin, et al. (1993)).

Some studies of diesel exhaust exposed workers have focused on miners, because of the exhaust exposure from underground equipment and generators. For example, a study by Ahlman, et al. (1991) reported an increased risk of lung cancer in Finnish sulfide ore miners who were exposed to diesel exhaust as well as radon and silica. The studies of miners are fewer in number than other occupational groups, and they may be exposed to dust containing silica or other minerals, as well as radon. Nevertheless, there is no reason to ignore the potential additive effect of these exposures with diesel exhaust exposure in increasing the risk of lung cancer.

Evidence for the association between diesel exhaust exposure and lung cancer has been reviewed by the International Agency for Research on Cancer (1989) and the U.S. Environmental Protection Agency (1994), and the weight of evidence from animal studies and epidemiologic studies is that diesel exhaust is probably carcinogenic to humans. The precise carcinogenic agent, whether it is benzo(a)pyrene, dinitropyrene or some other component, is still under investigation. The strongest epidemiologic evidence is for an increased risk of lung cancer in exposed persons, although there are studies suggesting an increased risk of bladder cancer and several other cancers, as well. These latter findings are more tenuous, however, because there are fewer epidemiologic studies focusing on these outcomes.

D. Noise

1. Noise Exposure

Noise has been a major issue for the tunnels at the Nevada Test Site since underground mining began in the late 1950's. The problem has persisted over four decades of mining, continuing to be an issue in the early 90's (DOE, 1992). Although the use and enforcement of hearing protection has likely increased over time, most of the same types of equipment continue to be in operation. Attesting to the long- reaching effects of noise exposure in the underground environment, a former NTS pipefitter made this observation, "I don't know a miner that can even hear." An actual entry in the Industrial Hygiene database (NTS, 1984) "Comments" section for noise measurements of 93 to 100 dBA shed further light on the exposures to underground workers and their substandard hearing ability. "Variable noise from air operated core drill, 2 F-S personnel and 2 drillers - not an ear plug among them and they were all half deaf anyway." Noise in such an underground work environment affects far more workers than just those operating the equipment or working in the immediate vicinity of a noisy operation. The small, confined space of the tunnel concentrates the hazard while also increasing its effective distance, causing workers in unrelated activities further down the tunnel to also be exposed to excessive sound levels. Moreover, mining requires the use of several large pieces of machinery working in combination in the same general area, which serves to further increase the noise level.

Noise measurements for the tunnels at the Nevada Test Site were recorded in an industrial hygiene database covering 1974 to 1984 (NTS, 1984), the report "Industrial Hygiene Support of Underground Operations at the Nevada Test Site," spanning 1989 to 1991 (DOE, 1992), and in a technical report entitled "A Method to Determine the Homogeneity of Noise Exposure Groups and Criteria for Enrollment into a Hearing Conservation Program," with data from 1993 (Zontek, 1993). The noise levels recorded in these sources are reported here. Although other sources of noise measurement data were alluded to in meetings and focus groups, none could be obtained.

a. California Tunneling Paper

Since noise exposure levels from the early 60's at the Nevada Test Site were not obtainable, the results of a comparable study are presented as an indication of the likely occupational noise hazard in the tunnels (Burns et al., 1962). This study reports on the measurements of various contaminants, including noise, taken over a period of three years from 1958 until 1961 at nine California tunnels. The tunneling process, which involved drill and blast techniques with drill jumbos and muckers, was extremely similar to that employed at the Test Site during this particular era (Mining Focus Group, 1996). The instantaneous noise measurements collected using General Radio Company's Sound Level Meter are summarized in the table below.

Table 14: California Tunneling Noise Dosimetry

Noise Source	Approximate Time over an 8 hour shift (min)	Range of Noise Levels (dBA)
Drilling	100 - 160	110 - 129
Mucking	240 - 300	96 - 120
Riding to and from heading	15 - 30	92 - 116
Track laying, loading holes, etc.	50 - 120	85 - 121

The paper, which details exposures to a number of contaminants, states, "Probably the most evident occupational health problem noted was noise intensity, particularly in tunnel construction." The excessive noise levels become even more evident when taken in consideration with the amount of time a worker is typically exposed to such levels over the course of a work day. For example, the OSHA PEL would permit a worker to be exposed to the lower limit of the drilling noise level (110 dBA) for only one half of an hour in an eight hour work shift. However, this job would be performed during tunneling for at least three times that amount of time. Noise measurements from the Burns paper are included in Appendix 27.

b. Industrial Hygiene Database

According to former Test Site industrial hygienists, nearly all measurements taken at the Nevada Test Site in the time period of 1974 to 1980 were entered into the industrial hygiene database (IH Focus Group, 1997). A summary is presented in Table 15 (below) of the noise measurements in the database stratified by the tunnel location (NTS, 1984). Little information was recorded in the database for each measurement. It is believed that the noise measurements in this database were instantaneous area samples collected using a sound level meter. Unfortunately, the amount of time that a worker would be exposed to recorded levels of noise could not be ascertained from the data. Noise levels were most often attributed to the drill jumbo, the jackleg drill, and to concrete operations, although the highest measurements were due to a variety of equipment. Through conversations with a former miner, it was determined that these tasks on a typical work day would have been performed for time periods ranging from several hours for a jackleg drill to practically an entire shift for the jackhammer/spader. The mucker and Alpine Miner would have been operated for approximately half of a work shift.

Table 15: NTS Tunnel Noise Dosimetry

Tunnel Location	N	Mean (dBA)	Range (dBA)	Percent Over ACGIH TLV	Percent Over OSHA PEL
15	6	101.0	85 - 115	100	67
E	29	101.0	85 - 120	100	97
G	8	92.0	78 - 103	75	63
N	31	101.7	87 - 120	100	94
T	7	107.9	97 - 117	100	100

Even though these measurements are not averaged over an eight hour work day, as the OSHA standard requires, they still point toward the existence of high noise levels in the underground environment. At a sound level of 115 dBA, for which ten of the measurements were at or above, workers would reach the 90 dBA OSHA limit in only fifteen minutes. In one hour, workers in 20 more of the areas measuring 105 dBA or above would reach the OSHA PEL. In total, only two of the eighty-one noise readings were below 85 dBA which, under OSHA regulations, requires an active hearing conservation program.

c. Industrial Hygiene Report

The report, "Industrial Hygiene Support of Underground Operations at the Nevada Test Site," reports on the various measurements taken for underground contaminants during the period of July 1, 1989 to June 30, 1991 (DOE, 1992). Noise comprises a very small portion of the overall report, which essentially concludes that noise is a very hazardous condition present in the tunnel complex. The following is an excerpt from the report.

"Noise surveys done during various underground operations have shown that the majority of underground activities produce hazardous noise levels. These activities include mining operations, shotcreting, rockbolting, jackleg drilling, operating locomotives, and running ventilation fans and compressors."

"Hazardous noise levels" were described as those at or 85 dBA. One table comparing the use of mufflers on jackleg drill equipment was presented in the paper and described the noise levels associated with jackleg drills as ranging from 109 to 125 dBA (see Appendix 28). No other noise measurements were discussed, leading to the conclusion that mining activities, even in the 90's, continue to expose workers to noise levels exceeding those recommended by the OSHA and ACGIH standards of 90 and 85 dBA, respectively. The report also stated that workers were "required to wear ear plugs, ear muffs, or a combination of both." Therefore, although the levels of noise have not decreased over the years, the enforcement of the hearing protection requirement has most likely become a more pressing issue.

d. Technical Report on Noise

A technical paper, "A Method to Determine the Homogeneity of Noise Exposure Groups and Criteria for Enrollment into a Hearing Conservation Program," authored by Tracy L. Zontek, describes the findings of a noise study conducted at the Nevada Test Site (Zontek, 1993). Reported in the paper were a total of 154 personal noise measurements, collected using the Bruel & Kjaer Noise Dosimeter Meter Type 4436, during the summer of 1993 (see Appendix 29 for a sample page of noise exposure measurements). The workers included in the study were miners, operating engineers, and tunnel supervisors, primarily from P Tunnel with a few from N Tunnel. Three samples were collected per worker, each over an entire work shift in the tunnel, typically six to eight hours. Table 16 was created from the raw data provided in the appendix to the report.

The types of work resulting in the highest noise exposures were Alpine mining, drilling, fibercreting, grouting, operating a motor, shotcreting, and swamping, all of which had 100% of the workers in that category exceeding the OSHA PEL of 90 dBA. In total, a third of the 155 samples exceeded the OSHA PEL. Although hearing protection would reduce the majority of the exposures to within acceptable limits, the usage of such devices was not reported on in this paper.

Table 16: NTS Noise Measurements for Hearing Conservation Program, 1993

Job Description	N	Mean (dBA)	Range (dBA)	Percent Over ACGIH TLV	Percent Over OSHA PEL
Alpine Mining	19	91.4	85 - 97	100	100
Concrete Work	6	90.0	84 - 98	83	33
Drilling	3	90.2	87 - 95	100	100
Fibercreting	4	92.0	88 - 95	100	100
Grouting	5	90.7	87 - 100	100	100
Operating Motor	10	91.3	88 - 94	100	100
Mucking	28	86.3	77 - 94	68	18
Shotcreting	4	91.1	87 - 95	100	100
Swamping	10	91.7	88 - 99	100	100
Working in Yard	19	78.6	68 - 88	5	0

ALL SAMPLES	155	87.3	68 - 102	71	34

2. Noise Outcomes

a. Noise -Induced Hearing Loss

Noise Induced Hearing Loss (NIHL) starts with a temporary threshold shift (TTS) from a high exposure to noise and causes a temporary loss of hearing which is recoverable within hours or days after removal from the noise source (Levy et al., 1995). Repeated exposures to excessive noise can eventually lead to a permanent threshold shift (PTS), whereby the ear is incapable of recovering from the loss in hearing ability. This irreversible loss in sensorineural hearing ability may occur slowly over a prolonged period with the gradual reduction in hearing threshold remaining unnoticed for very long time.

Noise-Induced Hearing Loss is a very well-documented and generally accepted result of exposure to industrial noise sources, although the exact risk at specific levels is still being studied and argued. "Occupational hearing loss is a pervasive problem in the United States despite increasing efforts, particularly over the last 25 years, to regulate noise and to administer hearing conservation programs" (Merry et al., 1995). Boettcher, et. al. (1995) refer to age and occupational noise exposure as the two leading causes of sensorineural hearing loss. And, "Exposure to noise is an important extraneous noxious factor causing hearing loss, which has increased after the industrial revolution and the migrations from the country to the cities." (Rosenhall et al., 1995) Because NIHL is a widely accepted outcome of excessive noise exposure, this section will be only a brief summary of the research in the scientific literature.

b. Dose-Response Relationship

In 1996, MSHA published a proposed rule in the federal register titled, "Health Standards for Occupational Noise Exposure in Coal, Metal, and Nonmetal Mines," (30 CFR Parts 56, 57, 62, 70 and 71). A summary of the studies, recommendations, and conclusions discussed in the standard will be present here.

A clear definition of hearing loss is necessary to aid in the consistent diagnosis and reporting of cases, most importantly for assessing the risk of NIHL to the worker population through comparative studies. MSHA has chosen as its definition of material impairment of hearing, "a permanent, measurable loss of hearing which, unchecked, will limit the ability to understand speech, as it is spoken in everyday social (noisy) conditions." Further, MSHA has adopted the OSHA/NIOSH criteria, relating the results of audiogram measurements to a measurable hearing loss, as a means of determining risk estimates for miners. The criterion describes material impairment as a 25 dB loss in hearing ability averaged over the measurements at the frequencies of 1000, 2000, and 3000 Hz.

NIOSH has revised its criteria for defining material impairment (NIOSH, 1996) by including the 4000 Hz audiometric frequency in estimating excess risk of NIHL. NIOSH cited as its reason the importance of this frequency in the recognition and understanding of speech in noisy background environments. Excess risk values were calculated using the revised criteria for a forty year lifetime exposure to average daily doses of 80, 85, and 90 dBA. The excess risks were 1%, 8%, and 25%, respectively.

OSHA, in its preamble to the Hearing Conservation Amendment, presents similar risk estimates using the older OSHA/NIOSH criterion. Excess risks for noise exposures over a working lifetime of 80, 85, and 90 dBA were 3%, 15%, and 29%, respectively.

Numerous studies are cited in the MSHA proposal which provide additional estimates of the excess risk of developing NIHL. The results of these studies are summarized in the following table 17.

Table 17: NIHL in Mining

Source	Excessive Risk for NIHL (%)		
	80 dBA	85 dBA	90 dBA
Melnick (1982)	2	6	18
Melnick (1982)	2	6	13
Melnick, et al. (1980)	0.2	3	9.4
Baughn (1973)	0	10	19
Martin et al. (1975)		4	22

The conclusions of each study, including those from NIOSH and OSHA, fluctuate based on the definition of hearing loss applied, as methods other than the OSHA/NIOSH criterion tend to be more stringent in classifying cases of NIHL. Deviations may also be the result of different screening methods used for the control and exposure groups, which attempt, for example, to control for hearing loss due to aging. However, even with the slight variations in the numerical values of excess risk, the conclusion that exposure above 85 dBA increases the risk of developing NIHL can be drawn. Further, noise levels exceeding 90 dBA significantly increase the excess risk above that for the 85 dBA range. As MSHA concludes in its proposal, "The studies of risk reviewed in this section consistently indicate that the risk of developing a material impairment ... becomes significant over a working lifetime when workplace exposure exceeds average sound levels of 85 dBA."

A study of excess risk of NIHL to coal miners was published by NIOSH in 1976 (MSHA, 1996). The results reported an excess risk of 37% to coal miners under the OSHA/NIOSH criterion. Specifically, 70% of the workers at the age of 60 exhibited the signs of hearing loss, whereas only a third of the control population had developed a hearing impairment.

Audiometric data collected by MSHA were examined by NIOSH (Franks, 1996) to review the risks to the mining community. The study, using the 1996 NIOSH criteria, found that by age 35, the average miner exhibits mild hearing loss while 20% have developed a moderate hearing impairment. Further, 90% of the coal miners experienced hearing loss by the age of 50, as compared to only 10% expected in the general population.

E. Miscellaneous Hazards

In addition to the major hazards discussed previously, it is important to note the many other contaminants which were present in the tunnels. These include lead, asbestos, shotcrete, blasting gases, welding fumes, solvents, epoxies and stemming materials. These hazards may have been present in the tunnel environment to a lesser extent, resulted in exposures that were not easily defined, or affected fewer of the cohort of workers as compared to the major hazards already discussed. However, they were still of great importance to the former workers who frequently mentioned such topics during interview, focus groups, and breakfast meetings. As they are sources of health concern for these workers, it is important that these hazards be included in this report, even if only to acknowledge their presence. This brief summary is intended to describe the hazards, explain how they were used at the Test Site, and discuss the ways in which workers were exposed to each substance.

1. Lead

Large quantities of lead, in the form of shot, bricks, and sheets, were used for radiation shielding at the Test Site. Current requirements (DOE, 1992) stipulate that workers must wear coveralls and gloves when handling lead sheets or brick. An air-purifying respirator must also be worn during a lead pour involving the dumping of 25 pound canvas bags of lead shot into enclosed spaces. The 1992 industrial hygiene report stated, "Personal and area air sampling has indicated that exposure levels during these various operations can exceed the ACGIH TLV-TWA and the OSHA PEL of 50 micrograms per cubic meter in the immediate vicinity of the [lead pour] operation." The precautions taken in the 1990's, however, were not necessarily present in the early years. A former operating engineer discusses using a mucker to transport the various forms of lead.

"Lead, we used to handle lead without any coveralls on, or gloves or anything, and there at the end, they'd make you mask up, suit up, gloves, everything."

A miner, during a separate interview, adds to the discussion.

"When you dump lead shot, there's dust and stuff in that, and I've seen dumpin' tons of lead shot in some of that stuff and that dust flows up and the guys never used anything. But today, you gotta suit a man up with masks, coveralls, gloves, and everything else."

Pipefitters were also exposed to the lead fume created during the cutting of bricks using oxyacetylene torches. According to one pipefitter, in the early years they did not have access to the appropriate equipment for melting the lead, nor did they have any type of respiratory equipment while performing their jobs (Pipefitter Breakfast Meeting, 1997).

2. Asbestos

Asbestos was extensively used during mining and tunnel construction. Exposure to asbestos has been recounted by pipefitters who described cutting and using asbestos sheets for insulation and shielding while welding. The wiremen and pipefitters also used it for insulation during the installation of the miles of wires and the LOS. Although the Occupational Health Program has had an asbestos screening and surveillance program in place for almost twenty years, there is very little available industrial hygiene information. Asbestos is regulated by OSHA as a known human carcinogen. It causes lung cancer, asbestosis, mesothelioma, and has been associated with gastrointestinal cancer. It, along with silica, radon, and diesel fumes can contribute to the development of lung cancer in this cohort.

3. Shotcrete

Shotcrete is used for structural support of the tunnel back and ribs (top and sides) in the Test Site tunnels. The shotcrete is applied using compressed air which pulls the dry shotcrete through the line to the nozzle where it is combined with water before being sprayed onto the tunnel surfaces over wire mesh to a 4 to 5 inch thickness. Shotcrete was made of Portland cement and currently it may contain some "fast-bake/setting" components. Both wet and dry shotcrete were used, with the wet mix preferred at NTS "despite the safety problem.... associated with its use" (British Tunneling Society, 1989). Dust and noise from this application is considerable. Exposures to the shotcrete dust occur when transferring the dry material to the shotcrete pot which connects to the compressed air. Dust is also created during the application of the shotcrete in the small areas of a tunnel.

An industrial hygiene report at the Nevada Test Site (DOE, 1994), recorded respirable dust exposures to a nozzleman and his helper in excess of the OSHA PEL of 5 mg/m3. Respirable silica exposures were also measured. The average respirable silica exposure to the workers involved in shotcreting was 0.10 +/- 0.11 mg/m3, equaling the ACGIH TLV of 0.10 mg/m3.

Kessel, et al. (1989) in a study in the Federal Republic of Germany, measured changes in lung function in workers constructing tunnels utilizing shotcrete techniques. Thirty underground workers working with shotcrete under compressed air were administered pulmonary function tests before and after a full shift. Breathing zone samples were collected and analyzed for total dust. Total dust concentrations over one shift ranged from 3.2 to 62.1mg/m3. Post shift spirometry revealed decreased forced vital capacity (FVC) by 3 %, decreased forced expiratory volume in 1 second (FEV1) by 4 %, and reduced peak expiratory flow by 6 %. These changes were correlated with total dust concentration and were more pronounced in nonsmokers than smokers (Kessel, 1989).

4. Blasting Gases

From the early 1960's until the late 1970's drill-and-blast techniques were practiced at the NTS, as they were throughout the industry. Depending upon the ground conditions encountered or size of the cavity to be mined, drill-and-blast techniques continue to be used on occasion at the Test Site. This technique can result in worker exposures to blasting agents and gases as workers may re-enter the blasting area before the resultant smoke has been adequately ventilated. Such a situation is described below by a former operating engineer.

"We used to walk back in that, it was so smoky and gassy, that's when we was running the air muckers and that, I would muck a car or two, and then stand off the mucker and throw up, and then you go back, it was terrible....you get a headache like you couldn't believe from the powder...it was terrible when we used to drill and shoot, you know we would go right back in it, it'd be so smoky, we didn't wear masks then either."

According to this former worker, drilling and blasting events could occur five or six times over one work shift, leaving little time for the air to clear before another round was detonated. Workers in nearby drifts would continue their jobs as the drilling and blasting occurred. One pipefitter discussed the affect the close proximity to the blasting area had on him.

"Not so much in the later years, but earlier years, you'd be in one drift and they'd be dynamiting in the other drift and you'd have that gun powder smell in there, and instant headache, to me it was an instant headache."

5. Welding

Welding activities are extensive during the construction, support, and button-up phases. The Line-of-Sight pipe, brought into the tunnel in sections, must be welded together within the confined spaces of the tunnel. Bulkheads must also be installed, leading to reductions in ventilation as obstructions to the vent line are introduced. Although the typical welding emissions of CO, CO2, and NO2 were of concern, also of importance were the fumes created during the cutting of lead brick and other unconventional materials. During a breakfast meeting, a pipefitter described the fumes created when welding stemming materials.

"Another problem they had was the welding, what they would do is go in and pour these hard mounts, and then when you're welding on it with a little hydrogen and you hit this grout - whatever they want to call it - the fumes come off it were green, and you would sit there and breath that stuff, I mean you would almost choke, and you'd have to leave the area and come back and try to clean it up."

As the work progresses through the support and button-up phases, the number of personnel in the area increases while the amount of ventilation is progressively reduced. Through these stages, the pipefitters continue to weld the bulkhead and containment plugs as their work space steadily decreases.

6. Solvents

Chemicals maintained a constant presence at the Nevada Test Site over the decades as a means of cleaning or degreasing parts and materials and also as an additive to painting compounds. Although protective equipment such as gloves are now required when working with solvents, this does not appear to be the case in the earlier years. A pipefitter describes his past and present experience with a particular solvent.

"You also had carbon tetrachloride]... and the exposure to this was actually dip your hands in there and clean the parts, today you can't even have it on the job."

Further, a union survey mentions parts being cleaned with gasoline and hands being placed in grease buckets over the years (IUOE, 1996). Solvents present in paints also posed a hazard to workers while working in the confined spaces of a tunnel.

7. Epoxy

Epoxy resins were primarily used as a sealant for rockbolt anchors and cable boxes, although other applications occasionally surfaced. The types of epoxy compounds often changed for monetary reasons or as the technology improved. Common ingredients in the more recently used epoxies are trimethyl hexamethylene diamine, isophorone diamine, diphenylmethane diisocyanates, and methylene bisphenol isocyanate.

For sealing the rockbolt anchor, the epoxy resin and the hardener were placed in an "air pot" and pumped, using compressed air, around the rockbolt in the drill hole. Later, the epoxy was inserted in the hole first, using a form of epoxy which was described as looking like "a sausage dog on a stick" (IOUE, 1996). A hardener was added which automatically mixed with the resin as the rockbolt was twisted into the hole. Other forms of epoxy looked like "squares of butter" which would soften and could be molded to fit into the drill hole after some working with the hands. Further, cartridges of epoxy were broken and squeezed onto pieces of plywood or cardboard for mixing and then placed in the hole.

Epoxy resins were also used as a gas blocking compound in cable boxes to prevent releases of radioactive gas following an event. The epoxy and the hardener were mixed, sometimes using a hand drill, and then poured into the cable box. Respirators were often worn by the wiremen performing these tasks.

8. Stemming Materials

During the button-up phase, the containment plugs and bulkheads are filled with stemming materials to block the release of radioactivity following the test event. Stemming materials were constantly evolving mixtures of various substances, often including different types of grout. Additives such as bentonite and magnatite were mentioned during the industrial hygiene focus group. As most of the information on stemming materials is highly classified, documents describing mixtures and ingredients are not available. According to former industrial hygienists from the site, the stemming materials were a high source of silica exposure since it was necessary that the materials be at a certain moisture content, resulting in very dry substances.

In the 1960's, before the introduction of the Line-of-Sight pipe, dry sand was the only form of stemming material. Various types of sand were blown into a tunnel just prior to a nuclear detonation, causing a great dust hazard to the workers.

In the later years, grouts, along with some sand, were primarily used for containment. The types of materials often changed as stemming progressed through the containment plugs and bulkheads, even for a single event. Grouts were pre-mixed for larger jobs and pumped into the tunnel using a high pressure line or hauled into the tunnel using special moran cars. For smaller jobs, the mixing of the dry grout with water was done inside the tunnel, at the stemming location, using large tubs and paddles. Stemming operations often took three to six weeks of around the clock work and included frequent tests for voids and leaks and also the integrity of the mixture.

VII. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. Overview

During Phase I, we have attempted to estimate the occupational disease burden in the targeted population of NTS workers. These estimates will provide part of the basis for allocating resources for medical screening in Phase II. The process of estimating the disease burden has been conducted in a dynamic, iterative manner utilizing a wide array of information sources, including:

- historical hazard and exposure data from the NTS;
- published epidemiologic studies of workers engaged in similar tasks; and
- focus groups and interviews with current and former workers, and Test Site safety and health professionals.

Our goal has not been to arrive at precise point estimates for the incidence and prevalence of specific diseases in our targeted populations. Rather, the medical science component of the needs assessment has attempted to "bound the set of not clearly incorrect answers" (Ashford, 1986) to the question: "What is the potential disease burden in the population of NTS workers?"

B. Exposures

We have identified an initial target population for the medical surveillance program and have characterized the most serious work hazards for this group. Although job titles, tasks, and exposures differ for each individual, it is our opinion that this high-risk work group has been exposed to a similar array of hazards at similar dose levels. Except for a few special circumstances (e.g., Baneberry, Nougat, etc.) and a few limited hazards (lead), their exposures have been comparable. The largest part of our target group worked in the underground environment where exposures were distributed relatively uniformly among the workforce. Although some occupations (like miner or operator) probably had higher exposures to silica and noise, exposures of others to these and other substances were substantial, according to current and former workers. Those who didn't primarily work underground nevertheless spent a significant amount of their time either in the immediate vicinity of the tunnels.

As we have discussed above, the former NTS undergorund workforce was exposed to numerous hazards at levels that present an excessive disease risk for this group. We have described exposures to silica, diesel, ionizing radiation, noise, as well as to asbestos, lead, shotcrete, grouting compounds, epoxies, solvents, blasting gases and welding fumes. It is our opinion, which is consistent with the information we obtained in the risk-mapping exercises, the focus groups, and from the Advisory Panel, that the target workforce was exposed to these substances in sufficient quantity and for an adequate time period to consider them the major occupational exposure hazards. Still we plan to design the medical screening and surveillance program so that we will become aware of any other important hazards. We may need to modify our initial hazard assessment.

The following table 18 lists the significant hazards identified at the NTS for the targeted former worker cohort. Information for these hazards has been obtained from a variety of sources, the adequacy of which has been summarized in the table. As is the case at most DOE sites, the extent and quality of the health physics data is vastly superior to the industrial hygiene information. Noise, silica, and diesel exposure data from the NTS is poor to fair. In our opinion, silica, diesel, ionizing radiation, and noise constitute the primary hazards of concern for our target population.

Table 18: Sources of Exposure Information: Quality

Hazard	NTS Information	Epidemiologic Data	Qualitative Data (focus groups, risk mapping, interviews)	MIDAS/OSHA
Silica	+	+++	+++	+++
Noise	++	+++	+++	+++
Diesel Fumes	+	++	+++	+++
Ionizing Radiation	+	+++		
•Routine	+	+++		
•Accidents	+		+++	
•Radon	+			
•Tritiated Water	+		+++	
Other Hazards				
•Grout			+++	
•Shotcrete			+++	
•Blasting Gases		+	+++	
•Asbestos		+++		
•Lead		+++	+++	

Quality of Information + = poor
++ = fair

+++ = good________________________________

C. Disease Outcomes

The cohort of NTS workers was exposed to substances that affect several organ systems. In the following table 19, we have summarized information presented in the disease outcome sections of this report. These outcomes correspond to many of the health concerns voiced by the former workers. Cancers (respiratory, thyroid, leukemia, and bladder) are associated with the exposures of concern. Respiratory disease, malignant and non-malignant, is also a major health outcome of concern. We believe that silica related respiratory disease is vastly underdiagnosed, especially among a retired work force.

Table 19: Disease Outcomes of Concern at NTS

Disease	Exposure	Strength of Association
Silicosis	Silica, crystalline	+++
Lung Cancer	Silica Asbestos Ionizing Radiation, Radon Diesel	+++ (IARC) +++ (OSHA) +++ (EPA, others) + (NIOSH, suspect)
Bladder Cancer	Diesel	+
Thyroid Cancer	Ionizing radiation	+++
Leukemia	Ionizing radiation	+++
Auto-Immune	Silica	++
Tuberculosis	Silica	+++
Hearing Loss	Noise	+++
Asbestosis	Asbestos	+++
Chronic Obst Lung Disease	Silica Diesel	++ ++
Reactive Airways/Asthma	Grout	?

Silica, diesel emissions, asbestos, and radon all are associated with lung cancer. Although the targeted cohort was not equally exposed to each of these agents, the biological impact will reflect the combined effect of exposure to multiple respiratory carcinogens. The respiratory system is at risk for malignant and nonmalignant respiratory disease resulting from exposure to silica, diesel fumes, radon, and asbestos. The studies of these health effects, many of which are of miners and underground workers, convincingly support the argument that workers exposed to these hazards are at increased risk of disease. As mentioned previously, it is neither our intent nor are we capable with limited available information, to develop precise estimates of disease burden in this cohort. However, as indicated in the following table, some data for a number of the NTS hazards allow us to begin to define the potential disease burden in this population of NTS workers.

D. Disease Burden

The overall assumptions which apply to the four major NTS hazards (silica, ionizing radiation, noise, and diesel emissions) are as follows: We assume the cohort of exposed individuals to comprise about 15,000 former workers. We assume that the average length of service is somewhere around ten years.

1. Ionizing Radiation

As previously discussed, the combined evidence from epidemiologic studies of workers in the nuclear weapons complex in the U.S. and other countries is that these workers are at increased risk for leukemia and multiple myeloma, and other cancers depending on the specific exposure circumstances. Furthermore, studies of underground miners demonstrate increased risk of lung cancer, even at relatively low radon exposure levels.

Estimated Cases of Selected Cancers

Based on information available at the present about historical exposures to NTS underground test workers, it appears that the cumulative external radiation doses were quite modest. For example, from the table in Section V (A), external doses during the period 1961-1980 were quite low. Only 11 NTS personnel had cumulative doses greater than 5 rem during this period, and an additional 277 had cumulative doses in the 3-5 rem range. Similarly, only 11 eleven individuals were reported to have worked in tunnels with radon concentrations greater than .30 WL in a summary of Rainier Mesa tunnels. As a result, the number of expected excess cases of cancer is quite low in these workers.

Although the radiation dose data for the underground test workers are currently incomplete, a rough estimate of the numbers of cases of leukemia, lung cancer and thyroid cancer can be made from published information. By taking the cumulative monitoring data from the table in Section V (A), and multiplying the mid-point of the range for those with 3 rem or higher by the number of people with accumulated doses in each range, we get a total of 1,139 person-rem collective dose. For the purpose of generating a rough estimate of the number of cancer cases, we assume that this dose was effectively to the bone marrow, lung, and thyroid. Using the method described by Moeller (1997), this results in a total of 10 excess lung cancers, 6 leukemias and 9 thyroid cancers in the exposed population.

It is not possible with existing data to estimate the internal alpha radiation dose from radon in the underground test workers. Likewise, we cannot estimate the internal dose from exposures to workers from the Baneberry event in those workers who lived downwind from atmospheric tests during the 1950's. These exposures would increase the accumulated dose for these workers during a time period that is still relevant for surveillance of cancer.

2. Silica

The following are the range of assumptions about silica exposures of the target cohort. We have three sources of information about silica exposures, as described above in Section V (B). First, we have limited information about exposures from a small number of industrial hygiene samples taken at the Test Site during the 1970's. These samples show very high levels of respirable silica. In addition, they typically show lower than expected silica percentages. The net result is very high levels of respirable silica, all of which are above 0.3 mg/m3. Still, we do not feel confident of the accuracy of these measurements, nor do we know the sampling strategy used.

The other two sources of data are inspection measurements from the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA).

These measurements were taken for compliance purposes and are therefore probably upwardly biased indicators of actual exposures. According to the OSHA data, 69 % of bridge, tunnel, and highway workers had silica exposures over 0.1 mg/m3 and 52 % had exposures over 0.2 mg/m3. These data include tunnel workers, whose work may be similar to the NTS cohort. However, it may also cover workers doing sandblasting on bridges and performing other noncomparable work.

The MSHA (MIDAS) data for silica exposures in underground metal and nonmetal mining provides information on work that is relatively similar to that of the NTS cohort. In the MIDAS data, 23 % of measurements were over 0.05 mg/m3, 14 % were over 0.1 mg/m3, and 8 % were over 0.2 mg/m3, with a mean exposure of about 0.5 mg/m3. From these data, we believe that a reasonable range of annual exposures to crystalline silica would put 20 to 70 % over 0.05 mg/m3, 10 to 50 % over 0.1 mg/m3 and 5 to 35 % over 0.2 mg/m3. Using these, data, we make some extrapolations, understanding that we cannot have much confidence in these extrapolations, but that this does not absolve us from responsibility. At the low end, we assume only half the exposure above 0.05 mg/m3 that was found in the MIDAS data, that is 5 % exposed between 0.05 and 0.1 mg/m3, 3 % between 0.1 and 0.2, and 4 % above 0.2. Our high estimate is twice the MIDAS percentages - which still is lower than either the OSHA or (limited) NTS measurements. This is 9 % between 0.05 and 0.1 mg/m3, 12 % between 0.1 and 0.2, and 16 % above 0.2.

a. Silicosis

The underdiagnosis of silicosis, as described in our review of the literature, stems from at least three sources. First, there is obvious physician under-reporting, as evidenced in population-based disease surveillance systems (Rosenman 1996). Second, as highlighted by Kreiss and Zhen (1996), many silicosis studies only evaluate exposed workers during their working life, thus missing the onset of a large number of cases occurring 10 to 20 years after last exposure. Finally, underreporting also results from the utilization of excessively stringent radiographic criteria.

For silicosis, we have used exposure-response relationships from two sources, each of which has adequate follow-up to prevent substantial underdiagnosis of silicosis. The first, by Kreiss and Zhen (1996), which defines silicosis by radiologic profusion of small opacities of 1/0 or greater, suggests prevalence rates of about 10 % for those with exposures of 0.5 to 1 mg/m3-years of silica, or 30 % for those with exposures of 1-2 mg/m3-years, and 65 % for those with exposures of 2 mg/m3-years or more (based on a cumulative silica exposure model). [We use the coefficients of models 3 and 6 in Table V to generate the estimates, assuming 10 years since last exposure.]

Using a definition based on the 1/1 profusion criterion, the same study suggests a prevalence of about 5 % for those with exposures of 0.5 to 1 mg/m3-years of silica, of 20 % for those with exposures of 1-2 mg/m3-years, and 50 % for those with exposures of 2 mg/m3-years or more (based on a cumulative silica exposure model). The study of Hnizdo and Sluis-Cremer suggests prevalence rates of silicosis (also using the 1/1 profusion criterion) close to zero for those with exposures of 0.5 to 1 mg/m3-years of silica, of 5 % for those with exposures of 1-2 mg/m3-years, and around 20 % for those with exposures of 2 mg/m3-years or more (based on a cumulative silica exposure model).

Given these data, we can put together a range of reasonable informed guesses (which we will call estimates) about the prevalence of silicosis in the screened population. Note that an average exposure of 0.1 mg/m3 for 10 years is a cumulative exposure of 1 mg/m3-year.

For the low estimates of prevalence of silicosis of profusion >=1/0, we use our low exposure numbers; for the high estimates, we use our high exposure numbers. In both cases, we use the risk model of Kreiss and Zhen. For the low estimates of the prevalence of silicosis of profusion >=1/1, we use our low exposure numbers and the Hnizdo and Sluis-Cremer study; for high estimates, we use our high exposure numbers and the risk model of Kreiss and Zhen. These low and high estimates of silicosis are displayed in Table 20.

Table 20: Range of Estimates of Silicosis Burden in Target Population of 15,000 NTS Workers		
Grade of Silicosis	Low Estimate	High Estimate
Profusion >=1/0	600	2,200
Profusion>=1/1	150	1650

b. Lung Cancer

For lung cancer, we have used exposure-response relationships from Checkoway, et al. (1997). The authors, as described above in Section V (B) conducted an historical cohort study of 2,342 male workers exposed to crystalline silica, primarily cristobalite, in a diatomaceous earth mining and calcining facility. The rate ratio for lung cancer deaths reached 2.15 (95% CI 1.08-4.28) in the highest exposure category. These associations were unlikely to have been confounded by smoking or asbestos exposure.

The authors constructed a cumulative exposure index for respirable crystalline silica. Their exposure categories in mg/m3 *years were <0.5 , 0.5 - <1.1, 1.1 - <2.1, 2.1 - <5.0, and >=5.0. The rate ratios are included in table 21 below .

Table 21: Lung Cancer Mortality by Cumulative Respirable Silica Exposure, 15 lag years

Cumulative Exposure (mg/m3 *years)	Deaths	RR	95% C.I.
<0.5	17	1.00	
0.5 - <1.1	14	0.96	0.47 - 1.98
1.1 - <2.1	7	0.77	0.35 - 1.72
2.1 - <5.0	15	1.26	0.62 - 2.57
>=5.0	24	2.15	1.08 - 4.28

We have used data from the SEER (USDHHS, 1994) database in order to estimate the potential silica related lung cancer incidence in this cohort. The 1990-1991 U.S. average annual age-adjusted lung and bronchus cancer mortality rate for white males age 55 and older is 340 per 100,000. .

We will use the U.S. male, > 55 years-old, lung cancer mortality rate, to calculate the estimated lung cancer mortality for the next twenty years in our population. The rate is age-adjusted to the 1970 U.S. standard population. Although we are not able at this time to age-adjust our cohort, we have assumed the following:

1. We assume that approximately 90% of lung cancers occur after age 55.
2. The age distribution of the NTS cohort of 15,000 is similar to the age distribution of the U.S. cancer mortality rates, e.g., 90% are over age 55.
3. Our estimate is not age-adjusted.
4. The estimated silica-related lung cancer burden will be calculated using the U.S. lung cancer mortality death rate as the population baseline.

5. Estimated lung cancer incidence rates, which are similar to mortality rates, will be considered rather than mortality.
6. Lung cancer incidence will be estimated for the cohort using similar assumptions about the exposure distribution as noted for silicosis, i.e., that is 1 - 5% of the cohort was exposed to >=5 mg/m3 * years.

The estimates for the cumulative exposure values between 0.5 and 5.0 were too unstable to be confident about their values. Therefore, we only used the highest exposure category to estimate potential lung cancer burden over a twenty year period. There are 59 estimated excess lung cancers over a twenty year period for this cohort or approximately three per year (table 22). Our assumptions regarding excess lung cancer in this group neglects the concomitant exposure to other respiratory carcinogens (and risk from) including radon, diesel fumes, and asbestos.

We have also used the SEER estimate of the lifetime risk of dying from lung cancer to estimate potential excess lung cancer (SEER 1994). Lifetime cumulative mortality rates for lung and bronchus cancers was estimated as 7.7%. We assume a RR of 1.0 for Checkoway's low exposure groups. The lifetime lung cancer mortality experience will be 14,250 x 0.072 or 1029 lung cancer deaths for the low-exposure groups. For the high exposure (>= 5.0 mg/m3 years exposure), we infer that baseline lifetime lung cancer mortality experience would be 750 x 0.077, or 54 lung cancer deaths. If the high exposure RR is considered, then lifetime lung cancer mortality experience would be 750 x 0.0722 x 2.15, or 117 lung cancer deaths. The highest silica exposed group would experience almost 63 excess deaths from lung cancer.

Table 22: Expected 20 Year Lung Cancer Mortality/Incidence by Cumulative Respirable Silica Exposure (15 lag years) for NTS Cohort

Cumulative Exposure (mg/m3 * years)	Number former workers	Deaths expected unexposed * 20	Potential Expected Deaths1 exposed * 20	RR
< 0.5 - < 5.0	14250	970	970	
>=5.0	750	51	110	2.15
Total	15000	1021	1080 (59 excess deaths)	

1. We will use the following formula: % cohort exposed over 5 mg/m3/100,000 * years x 2.15

3. Diesel

As discussed above in Section V (C), diesel fumes probably are carcinogenic to humans. The evidence for the association between diesel exhaust exposure and lung cancer has been reviewed by the International Agency for Research on Cancer (1989) and the U.S. Environmental Protection Agency (1994), and the weight of evidence from animal studies and epidemiologic studies supports its status as a probable carcinogen. Unfortunately, the available data make it difficult to interpret the lung cancer burden in the NTS cohort secondary to diesel fumes. MIDAS data, along with NTS data, indicate that a significant percentage of carbon monoxide measurements exceeded the TLV indicating diesel overexposure. Clearly, diesel fumes are but one respiratory tract carcinogen to which the former NTS worker cohort was exposed. The lack of adequate epidemiologic data demonstrating coherent and consistent risk estimates, along with the paucity of industrial hygiene information, make it impossible to estimate risk more precisely.

4. Noise

Noise measurements collected both at the Nevada Test Site and in tunnels in California reveal noise exposures to underground workers which typically exceed the levels prescribed by the occupational standards. For example, nearly every measurement reported in the industrial hygiene database exceeded the 85 dBA noise level, as did all of the results reported for the California tunnels, and 71% of the 155 samples given in the Zontek technical paper. A large portion of these measurements also exceeded the 90 dBA level, which according to the latest NIOSH criteria document, leads to an excess risk in developing NIHL of 25%. Estimates of excess risk in the 95 to 100 dBA range were not reported in any of the studies, although some of the exposures to the test site workers in the noisiest of operations would be expected to fall into this category. The very intense noise levels which may be experienced by underground workers when operating equipment in the 115 to 120 dBA range would be expected to further increase the risk of developing NIHL, as is the reason for the establishment of a ceiling limit of 115 dBA by both NIOSH and the ACGIH. Overall, this cohort of underground workers have typically been exposed to levels of noise exceeding the OSHA standard (90 dBA), and even more often the NIOSH and ACGIH standard (85 dBA), over a working lifetime which frequently spans the four decades of nuclear testing at the Nevada Test Site.

The Zontek paper (1993), which measured noise over a work shift, reported almost 100% of the measurements for the underground trades exceeded the PEL. We have assumed that 25% of NTS workers exposed above the PEL will have material impairment of hearing. Further, we assume that this will be an excess impairment, that is over the baseline for this population. Therefore, we estimate that there will be approximately 3750 former NTS workers with NIHL. We also assume that this is an extremely conservative estimate since many of the noise measurements exceeded 95 dBA and our estimates only considered impairment occurring from 90 dBA.

Table 23: Exposure Associated Morbidity and Mortality in NTS Former Worker Cohort

Disease	Exposure	Excess Disease(N) Disease Burden
Silicosis	Silica, crystalline	150 - 2200, Kreiss 1996 and Hnizdo 1991
Lung Cancer	Silica Asbestos Ionizing Radiation, Radon Diesel	59 - 63, Checkoway 1997 and SEER 1994 ? 10, Moeller 1997 ?
Bladder Cancer	Diesel	?
Thyroid Cancer	Ionizing radiation	9, Moeller 1997
Leukemia	Ionizing radiation	6, Moeller 1997
Auto-Immune	Silica	?
Tuberculosis	Silica	?
Noise Induced Hearing Loss	Noise	3750, NIOSH 1996
Asbestosis	Asbestos	?
Chronic Obst Lung Disease	Silica Diesel	?
Reactive Airways/Asthma	Grout	?

E. Conclusion

Over the past five decades at least 600,000 workers have been employed in the nuclear weapons industry under the Department of Energy (DOE) and its predecessor agencies. Many of these workers have been exposed to ionizing radiation, lead, asbestos, excessive noise, and other chemical and physical hazards. As one of six DOE "Former Worker" grantees, we have focused on the former worker cohort at the NTS who worked underground. We selected this group for the following reasons: 1) Underground, excavation and re-entry work are "high risk" occupations with a workforce which is at significant risk for work-related health conditions; and 2) The underground environment is one that concentrates airborne radionuclides and other air contaminants and produces high exposures to workers;

In Phase I of this project, we were charged with determining the size of the targeted former worker cohort, the nature and extent of health hazards encountered by these workers and the need for further follow-up, including medical surveillance. This report has presented the results of these investigations and has amply documented the need for establishing a medical evaluation and notification program for the targeted former workers at the Nevada Test Site. We have defined the size of the target population and have described their occupations. The 15,000 workers we have identified through the use of the DRP database worked in high exposure excavation and tunneling occupations. As we enter Phase II, we will further develop and refine the membership in this cohort by establishing vital status, determining length of service and considering other factors suggested by consortia members and our Advisory Panel.

We were also charged with determining the type and extent of hazards present in the NTS work environment. Although there were many hazardous substances to which these former workers were exposed, we have chosen to focus on a few high exposure and high risk substances; ionizing radiation, silica, diesel emissions, and noise. We have utilized a variety of methods and data sources to estimate the exposure characteristics of this environment including primary NTS data, analogous occupational data, MSHA/OSHA databases, and focus groups, interviews and risk mapping exercises with former workers. Where the quality and availability of primary data was inadequate, we utilized other sources. The information we have assembled very clearly points to a work environment in which there was extensive and often excessive exposure to the hazards of primary concern, as well as to other hazards.

Finally, we have characterized the nature and extent of anticipated health outcomes for this group of workers who during the years 1956 - 1991 participated in the preparations for and post-test assessment of more than 800 underground nuclear explosions . Their work included the doubly dangerous and dirty work of construction in the underground environment along with digging, maintaining and re-entering the tunnels and shafts following a nuclear test. We have characterized risk recognizing that our estimates are likely to be imprecise, due to the paucity of site exposure information and the absence of clear and validated risk measures for many of the outcomes of concern.

The outcomes of concern developed out of our extensive review of the medical and scientific literature and also from our knowledge of the NTS workers concerns. Risk is not only a semi-quantitative phenomenon, but in this case, it is also based on health concerns of former workers. Individual's perceptions and concerns around a health risk are often equally as important as scientific data in a lay person's assessment of risk (Hance, 1988). The Union Project Manager, through individual interviews and informal contacts with former workers, actively solicited health concern information from members of the former worker cohort. We were extremely fortunate to have someone like Ms. Medina on our team. Her knowledge of the site, its workers and their work-related health concerns, provided us with important information as we developed the list of health outcomes. Project staff have also heard about health concerns in the various focus groups and other gatherings of retired workers. The principal concerns of all the underground workers at the Nevada Test Site relate to the wide variety of substances to which they were exposed. Their concern arises in part from the fact that they knew little about the potentially hazardous short- and long-term health effects. Many of the former workers have seen colleagues die from a variety of cancers and lung diseases which they attribute to the long years spent at NTS. Their major health concerns are lung, bladder, thyroid, and prostate cancer, heart disease, asbestosis, silicosis, lead poisoning, hearing and sight impairment and back disorders.

In conclusion, the cohort of former NTS workers were exposed to a variety of hazards during the years 1956-1991 which place this group at increased risk of work-related disease.

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