Los Alamos National Laboratory

UNIVERSITY OF CALIFORNIA

Environmental Restoration

Environmental Restoration Project
MS M992
Los Alamos, New Mexico 87545
505-667-0808/FAX 505-665-4747

Date: April 4, 1996
Refer to: EM/ER:96-188

Mr. Ted Taylor
Los Alamos Area Office
US Department of Energy, MS A316
Los Alamos, NM 87544

SUBJECT: SUBMITTAL OF THE INTERIM ACTION REPORT FOR TECHNICAL AREA (TA) 10, BAYO CANYON SHRAPNEL

Dear Ted:

Enclosed is a copy of the Los Alamos National Laboratory's Interim Action Report for TA-10, Bayo Canyon Shrapnel. The report documents the shrapnel removal activities in Bayo Canyon, and the risk assessment conducted on the results from those activities. This document is due to your office on April 5, 1996.

Please contact Garry Allen at (505) 667-6080 or Bonnie Koch at (505) 665-7202, if you have any questions.

Sincerely,

Jorg Jansen, Program Manager
Environmental Restoration Project

JJ/bp

Enclosures: Interim Action Report for TA-10, Bayo Canyon Shrapnel

TL

Cy (w/enc.):
B. Driscoll, EPA
B. Garcia, NMED-HRMB
D. Griswold, ERD, AL, MS A906
J. Harry, EM/ER, MS M992
[redacted]
R. Kern, NMED-HRMB
G. Allen, CST-18, MS E525
B. Koch, LAAO, MS A316
N. Naraine, EM-453, DOE-HQ
T. Taylor, LAAO, MS A316
N. Weber, Bureau Chief, NMED-AIP, MS J993
J. White, ESH-19, MS K490
S. Yanicak, NMED-AIP, MS J993
RPF, MS M707

Cy (w/o enc.):
T. Baca, EM, MS J591
T. Glatzmaier, DDEES/ER, MS M992
D. McInroy, EM/ER, MS M992
G. Rael, ERD, AL, MS A906
W. Spurgeon, EM-453, DOE-HQ
J. Vozella, LAAO, MS A316
EM/ER File, MS M992

What? RIO

RECEIVED
APR 17 1996

Interim Action Report for

TA-10, Bayo Canyon Shrapnel

Field Unit 1

Environmental Restoration Project

April 1996

A Department of Energy
Environmental Cleanup Program

Los Alamos
NATIONAL LABORATORY

LA-UR-96-1088

EXECUTIVE SUMMARY

This report describes the interim action conducted at the TA-10 Bayo Canyon site.

Radioactively contaminated shrapnel fragments were found during geomorphic mapping activities at the former TA-10 firing site in September 1993. Because there was the potential for human health risks to recreational users of the canyon, a voluntary corrective action (VCA) was initially planned. The VCA plan called for shrapnel pieces in the upper 4 ft of soil to be located using geophysical techniques and removed by hand. During the first few days of the survey it was discovered that there were thousands of pieces of shrapnel per acre in the vicinity of the former firing pads. Removal of all the shrapnel by hand was then recognized to be an impractical solution.

The VCA plan was then shifted to an interim action with three main objectives.

1) Immediate reduction of potential public risk by removing all surface shrapnel from those areas of Bayo Canyon open to the public.

2) Performing a systematic shrapnel density distribution study to support future remedy selection tradeoffs should further shrapnel removal be necessary.

3) Obtaining data concerning radioactive contamination distribution on shrapnel pieces sufficient to support a risk assessment.

A customized version of the Laboratory Integration and Prioritization System (LIPS) was used to evaluate the relative strengths and weaknesses of a number of alternatives for remediating the Bayo Canyon site. The results of the LIPS model show that the preferred option would be removal of surface shrapnel over the entire site using a method that would cause little or no disturbance to the existing canyon environment. However, to determine whether this action was warranted, a risk assessment was conducted to determine whether shrapnel remaining at the site presented a human health risk.

The risk assessment was performed based on the data collected during the shrapnel distribution study and the surface shrapnel removal activity. The risk modeling shows that the increased cancer risk from the shrapnel is less than the Environmental Protection Agency (EPA)

acceptable risk range from 1 in 10 000 to 1 in 10 000 000. The potential acute effects are also negligible. Therefore, the human health consequences of the remaining Bayo Canyon shrapnel were determined to be minimal.

Because all objectives of this interim action were achieved and the resulting risk evaluation showed that there was minimal risk to the public, no further action is recommended for the remaining shrapnel in Bayo Canyon.

CONTENTS

EXECUTIVE SUMMARY ..... **i**

1.0 INTRODUCTION **1**

1.1 Operational History 1

1.2 Geology 3

1.2.1 Natural and Anthropogenic Distribution of Shrapnel 3

1.3 Hydrology 4

2.0 VOLUNTARY CORRECTIVE ACTION **5**

3.0 INTERIM ACTION APPROACH **5**

3.1 Objective 1: Shrapnel Removal 6

3.2 Objective 2: Evaluation of Remedial Alternatives 7

3.2.1 Shrapnel Distribution Study 7

3.2.2 Laboratory Integration and Prioritization System Model 7

3.3 Objective 3: Gathering of Data to Support a Risk Assessment 8

3.3.1 Results of Shrapnel Removal 8

3.3.2 Results of the Shrapnel Distribution Study 11

4.0 HUMAN HEALTH RISK EVALUATION **12**

4.1 Exposure Assessment 12

4.1.1 Potentially Exposed Populations 12

4.1.2 Exposure Pathways 13

4.1.3 Radiological Dose Assessment 14

4.1.3.1 Ingestion of Shrapnel 14

4.1.3.2 Skin Dose Rates 15

4.1.3.3 Skin Exposure Model 18

4.4 Health Effects Evaluation 24

4.4.1 Risk Model 24

4.4.2 Noncarcinogenic Health Effects 29

4.4.3 Carcinogenic Risk 32

4.5 Limitations of the Evaluation 33

4.6 Risk Summary 35

5.0 CONCLUSIONS AND RECOMMENDATIONS 36

6.0 REFERENCES 37

LIST OF TABLES

Table 3-1 Summary of Size Distribution of the Radioactive Shrapnel 9

Table 3-2 Summary of Analyses of the Radiological Composition of the Shrapnel 10

Table 4-1 Data Used to Determine Average Density of Shrapnel Pieces 16

Table 4-2 Shrapnel Density and Depleted Uranium Shrapnel Progeny Activity 17

Table 4-3 Derivation of Strontium-90/Yttrium-90 Shrapnel Activity 18

Table 4-4 Varskin Mod2® Input Assumptions for Depleted Uranium and Strontium-90/Yttrium-90 Skin Dose Rate Calculations 18

Table 4-5 Skin Dose Rate Conversion Factors for Several Scenarios of Imbedded Depleted Uranium and Strontium-90/Yttrium-90 Surface Contamination 20

Table 4-6 Summary of Distributional Assumptions for the Crystal Ball™ Dose Simulations 24

Table 4-7 Area Weighted Cancer Risk Factors 28

Table 4-8 Area Weighted Dose Conversion Factors for Pendant Scenario 28

Table 4-9 Area Weighted Dose Conversion Factors for Child Recreational Scenario 28

Table 4-10 Effects of Beta-Radiation to the Skin 29

Table 4-11 Results of Encounter Modeling Simulation 32

LIST OF FIGURES

Fig. 1-1. Location map of TA-10 with the shrapnel investigation search area indicated. 2

Fig. 3-1. Count data for radioactive shrapnel (log-transformed) for the surface shrapnel pickup in Bayo Canyon. 8

Fig. 4-1. The probability distribution for the number of radioactive pieces collected per year for the child recreational scenario. 21

Fig. 4-2. The probability distribution for the number of radioactive pieces collected per year for the pendant user scenario. 22

Fig. 4-3. The distribution of doses predicted by the Crystal Ball™ simulation model for the child recreational scenario. 30

Fig. 4-4. The distribution of doses predicted by the Crystal Ball™ simulation model for the pendant user scenario. 31

1.0 INTRODUCTION

This report presents the results of the interim action conducted to address the Bayo Canyon shrapnel at Technical Area (TA) 10 of Los Alamos National Laboratory (LANL) (Fig. 1-1). The Resource Conservation and Recovery Act (RCRA) Facility Investigations (RFI) at TA-10 are presented in the RFI Report for Solid Waste Management Units 10-001(a-d) and the RFI Report for Potential Release Sites (PRSs) 10-002(a-b), 10-003(a-o), 10-004(a-b), 10-005, and 10-007 (LANL 1995, 06-0130; LANL in preparation, 06-0131).

1.1 Operational History

TA-10 is the location of a former firing site where experiments using high explosives were conducted from 1943 to 1961 in conjunction with nuclear weapons research. TA-10 is located in the central portion of Bayo Canyon, between Kwage Mesa to the south and Otowi Mesa to the north (Fig. 1-1). The site consisted of firing pads, control buildings, battery buildings, a radiochemistry laboratory, subsurface disposal systems, and other associated structures.

TA-10 was constructed to test assemblies containing conventional high explosives and components fashioned from depleted or natural uranium. The assemblies contained a lanthanum-140 source of several hundred to several thousand Curies for blast diagnostics. The lanthanum-140 (half-life of 40.3 hours) was contaminated with a small amount of strontium-90 (half-life of 28.8 years). The explosives detonations at TA-10 resulted in dispersion of radioactive materials, including uranium, lanthanum-140, and strontium-90, in the forms of aerosols and shrapnel.

TA-10 was decontaminated and decommissioned beginning in 1960. During cleanup activities in 1963, 90 truckloads of debris, shrapnel, and high explosives material were removed from a radius of 760 m (2 493 ft) from the detonation control buildings at the firing sites. In 1963, a team of workers walked the canyon shoulder-to-shoulder and removed all visible surface shrapnel.

TA-10 was released to Los Alamos County in 1967 but remains under Department of Energy (DOE) administrative control. It is presently open to the public and is used for recreational activities.

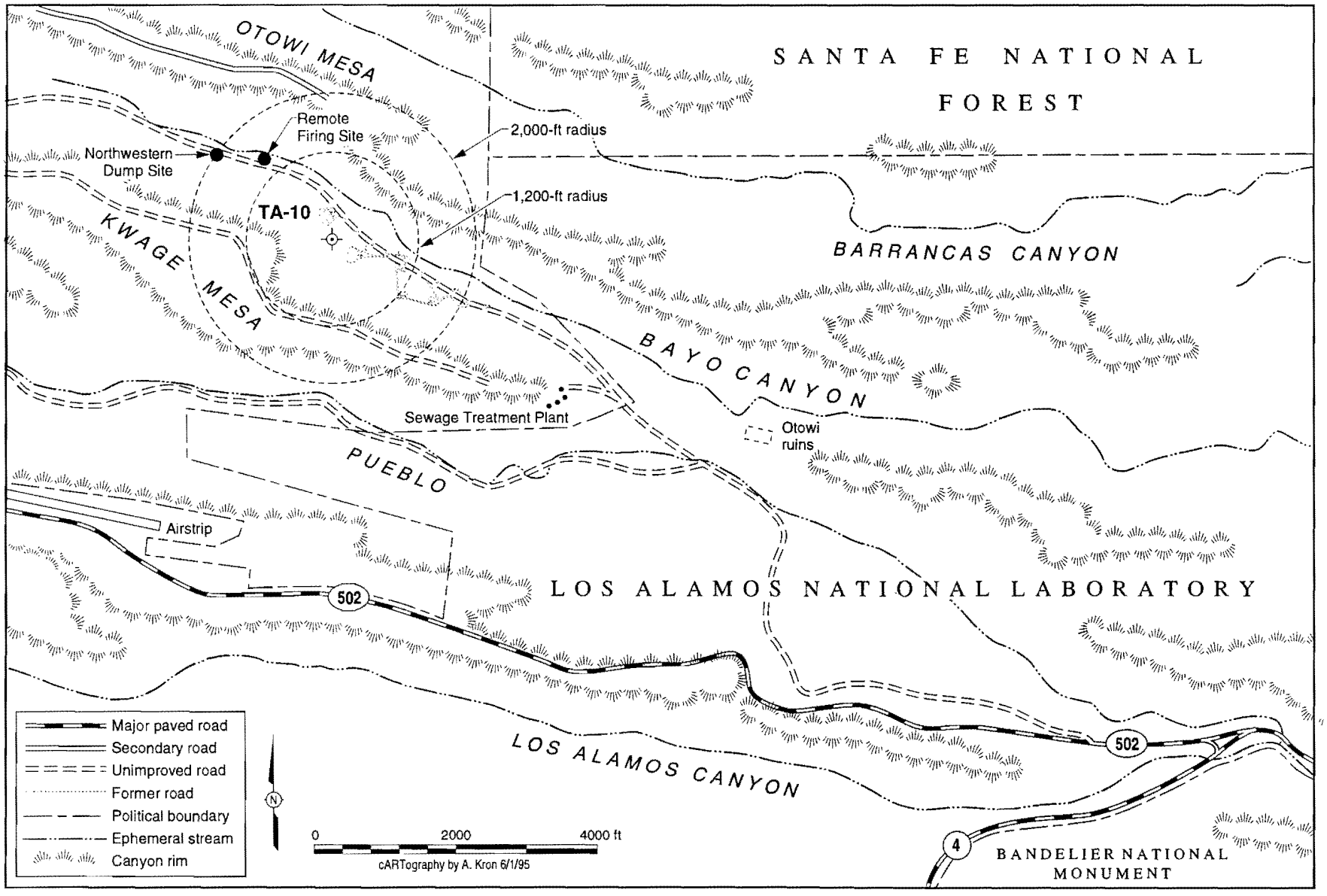


Fig. 1-1. Location map of TA-10 with the shrapnel investigation search area indicated.

1.2 Geology

TA-10 is located in the bottom of Bayo Canyon at an elevation of about 6 600 to 6 740 ft. Adjacent mesa tops range from about 7 000 ft to slightly over 7 100 ft. The upper portions of the canyon walls are vertical or near-vertical cliffs cut into the (upper) Tshirege Member of the Bandelier Tuff. From the base of the cliffs, steep slopes ranging from 10° to 30° lead downward to wide, gentle slopes, and then to a relatively flat canyon floor. The slopes and canyon floor are mainly cut into the (lower) Otowi Member of the Bandelier Tuff. The slopes are overlain by talus and colluvium derived from the cliffs above. Within the canyon, several meters (typically 4 to 6 m) of unconsolidated alluvium overlie the Bandelier Tuff and older volcanic rocks from the Jemez Mountains. The canyon floor consists of broad, low-angle side slopes covered with from less than 0.5 m to more than 2 m of colluvium, and a narrow, inner canyon consisting of the modern braided steam channel with low banks (0.5 m to 2 m high). Up to 6 to 8 m of Quaternary stream alluvium underlie the canyon floor.

Alluvial and colluvial sediments in the bottom of Bayo Canyon are subdivided into deposits associated with four distinct geomorphic surfaces of different ages (Drake and Inoue 1993, 06-0122). The youngest units, those within and adjacent to the stream channel, contain metal fragments; in places, these sediments are up to 1.1 m thick. The metal particles, which include lead disks, indicate that sediments were deposited concurrent with, or subsequent to, use of TA-10 as a firing site (Drake and Inoue 1993, 06-0122).

1.2.1 Natural and Anthropogenic Distribution of Shrapnel

The shrapnel present at former TA-10 resulted from surface detonations, and the original distribution of shrapnel was primarily on the ground surface. However, in the 51 years since activity at the site began and in the 32 years of inactivity, shrapnel has been redistributed by a combination of natural and anthropogenic processes.

Runoff resulting from rain and snow has tended to move shrapnel fragments downslope from their original locations. A geomorphic survey of a portion of Bayo Canyon showed that surface and geological processes in that area are very dynamic (Drake and Inoue 1993, 06-0122). At least two cycles of erosion and deposition have occurred since the firing sites at TA-10 became active, resulting in incorporation of shrapnel into alluvium, and burial to depths up to 1.1 m. Also, shrapnel has been carried downstream and off-site by intermittent streamflow events along the main drainage through the site.

In addition to natural processes, shrapnel has been redistributed (i.e., moved across the site or buried) by human activities at the firing sites. Redistribution occurred by clearing firing pads

for subsequent shots, regrading the area around firing sites with mechanical equipment, and deliberate burial of material for disposal. Redistribution also likely occurred during removal of firing pads, bunkers, and other structures during site decommissioning. In general, inadvertent lateral transport and burial of the shrapnel occurred as the surface was churned up by trucks and heavy equipment. Most of the shrapnel located during the most recent site work occurs at a depth of up to 15 cm below the surface, but some occurs at depths up to 1.1 m below the surface.

1.3 Hydrology

The elevation of the main aquifer is about 6 000 ft, approximately 600 ft below the level of Bayo Canyon at the site of the former TA-10. No perched or alluvial aquifers were known to be present in Bayo Canyon prior to RFI sampling, and none were encountered during subsurface sampling at the site of the TA-10 radiochemistry laboratory in 1994 (LANL 1992, 0783). More than 90 holes were augered to depths of approximately 50 ft. The holes encountered only damp alluvium and Bandelier Tuff. Two holes were deepened and cased to the contact between the Bandelier Tuff and the underlying Puyé Formation, a depth of approximately 70 ft below the center of Bayo Canyon. Because of uncertainty regarding whether a saturated zone might overlie the contact, one hole was completed as a groundwater monitoring well and the second was equipped with a suction lysimeter to measure formation pore water in unsaturated rock. To date, no saturated conditions have been observed. No other groundwater monitoring wells and no environmental surveillance stations are present in Bayo Canyon. Therefore, no connection between the surface water and the main aquifer within Bayo Canyon is known or suspected.

Surface water flow on the canyon slopes and floor occurs mainly as sheet flow during intense rains. Several shallow tributary channels collect water that flows over the cliffs and across the ground surface. The only sediment sampling station in Bayo Canyon is located at the intersection with Los Alamos Canyon about two miles to the east.

Bayo Canyon contains a floodplain and an ephemeral stream. The stream in Bayo Canyon carries water only during periods of intense thunderstorm activity, which occur on an irregular basis. Individual flooding events probably cause realignment of the main channel during each event.

2.0 VOLUNTARY CORRECTIVE ACTION

Radioactively contaminated shrapnel fragments were found during geomorphic mapping activities at the former TA-10 firing site in Bayo Canyon in September 1993. These pieces of shrapnel had activity levels of approximately 800 counts per minute (cpm) beta/gamma. Because these levels were above the background for the area (about 200 cpm beta/gamma), a follow-up investigation was initiated to corroborate the findings. During the follow-up investigation, one fragment was found that exhibited a dose reading of 8 mrem/hr, with an activity level of 350 000 cpm beta/gamma. Other pieces of shrapnel and debris were found with radioactive contamination that ranged from 800 to 12 000 cpm beta/gamma. Because of the perceived risk from radioactive shrapnel, an initial voluntary corrective action (VCA) plan was designed to locate shrapnel pieces in the upper 4 ft of soil using geophysical techniques and to remove all shrapnel pieces by hand from the former TA-10 firing site.

A geophysical survey was implemented to locate and remove ferrous and nonferrous anthropogenic metals in the upper 4 ft of the soil in Bayo Canyon. The 4-ft depth was determined based on the available geomorphic data which indicate that the maximum thickness of material that has been deposited in the last 40 years and, therefore, may contain man-made materials, is approximately 3.5 ft.

During the first few days of the survey thousands of pieces of shrapnel were discovered per acre in the vicinity of the former firing pads. Removal of all the shrapnel by hand was then recognized to be an impractical solution. The VCA plan was then shifted to an interim action plan.

3.0 INTERIM ACTION APPROACH

The interim action plan had three main objectives.

1) Immediate reduction of potential public risk by removing all surface shrapnel from those areas of Bayo Canyon open to the public.

2) Performing a systematic shrapnel density distribution study to support future remedy selection trade-offs should further shrapnel removal be necessary.

3) Obtaining data concerning radioactive contamination distribution on shrapnel pieces sufficient to support a risk assessment.

These three objectives are discussed in Subsections 3.1, 3.2, and 3.3, respectively.

3.1 Objective 1: Shrapnel Removal

The first objective was immediate reduction of potential public risk by removing all surface shrapnel from those areas of Bayo Canyon open to the public. These areas were outside of a fence that had been put in place previously during the Phase I RFI in Bayo Canyon. Shrapnel was removed from the upper 2 in. of soil/sediment on the canyon floor, side slopes, and adjacent mesa tops. Shrapnel removal began in September 1994 and was completed by January 1995. The approach used was to conduct a thorough geophysical/visual survey of the area surrounding the firing sites in an effort to locate and remove debris from outside the fenced areas. Because the majority of the debris is metallic, metal detectors were used in combination with visual observation to locate shrapnel pieces.

A grid system consisting of 100-ft by 100-ft grid sections was established in the areas open to the public. If any shrapnel fragments were identified within a grid section, then shrapnel was to be removed in all of the adjoining grid sections (those that contain a common side). The outward extension of the screening continued until no shrapnel fragments were found in at least two adjacent grid sections.

Removal of the surface shrapnel was implemented using a technique to ensure that each grid section was surveyed in its entirety. Within each grid section, 10 parallel lanes of 10-ft by 100-ft were delineated using string. The survey was then conducted within each lane individually (i.e., when a lane was completed, the next lane within the grid section was investigated). If an anomaly was identified with the metal detector, an effort was made to locate the source of the anomaly by removing any humic material or forest litter on the surface. If a shrapnel fragment corresponding to an anomalous metal detector reading was not found within the first one to two inches, then no additional excavation was conducted. Often, shrapnel fragments were identified visually without the assistance of metal detectors. When a shrapnel fragment was found, the piece was evaluated for radioactive contamination using hand-held instruments. All shrapnel material was screened for beta/gamma activity on site using hand-held meters. Radiological monitoring was performed using a Ludlum™ Model 12 with a shielded Geiger-Müller™ (GM) probe Model 44-40 and/or a Ludlum™ 2221 with a shielded GM probe. Background activity was established by collecting several readings of the ground surface daily. Shrapnel materials that exhibited above-background activity were segregated as radioactively contaminated.

During this surface shrapnel removal operation, over 19 000 pieces of shrapnel were collected. Of these, a total of 458 pieces were found to emit radioactive activity levels that measured above instrument background levels. Twelve shrapnel pieces were sent to an off-site fixed analytical laboratory to determine the species of radioactive contamination (LANL 1995, 06-0134).

3.2 Objective 2: Evaluation of Remedial Alternatives

3.2.1 Shrapnel Distribution Study

Geophysical surveys were conducted within the fenced area to support future remedy solution tradeoffs should further shrapnel removal be necessary. These surveys were conducted at 74 subsurface locations surrounding the four firing pads to assess the areal depth distribution of shrapnel. To characterize the shrapnel distribution, a 2 400-ft by 24 000-ft cross (eleven acres) was established as the area to be surveyed. Shrapnel was removed from selected 10-ft by 10-ft squares within the survey area. Distribution with depth was recorded in 3-in. intervals. Depth distribution and shrapnel count data from these squares were used to estimate the distribution of shrapnel over the region.

An additional geophysical survey was conducted in the active channel (dry stream bed) that runs through Bayo Canyon. Shrapnel densities were recorded for 10-ft by 10-ft squares at 200-ft sample intervals over a distance of 8 600 ft.

Nonintrusive geophysical surveys were conducted to characterize the shrapnel distribution at two newly identified sites northwest of the four firing pads: the Northwestern Dump Site and the Remote Firing Site. Shrapnel was surveyed in alternate 10-ft by 10-ft squares within the survey area, but was not collected.

3.2.2 Laboratory Integration and Prioritization System Model

A customized version of the Laboratory Integration and Prioritization System (LIPS) was used to evaluate the relative strengths and weaknesses of a number of alternatives for remediating the Bayo Canyon site. A team of experts developed inputs to the LIPS model for ten specific remedial alternatives. These alternatives included permanent fencing scenarios, contaminant stabilization techniques, use of sedimentation ponds, central area grading, and various shrapnel removal techniques. The LIPS model also measured impacts of remedial alternatives on four primary criteria: health and safety, environmental protection, regulatory compliance, and public assessment.

The results of the LIPS model showed that the preferred alternative would be removal of surface shrapnel over the entire site using a method that would cause little or no disturbance to the existing canyon environment. However, to determine whether this action was warranted, a risk assessment was conducted to determine whether shrapnel remaining at the site presented a human health risk.

3.3 Objective 3: Gathering of Data to Support a Risk Assessment

3.3.1 Results of Shrapnel Removal

There were over 19 000 pieces of shrapnel collected during the surface shrapnel removal operation conducted in the fall and winter of 1994. A total of 458 pieces of shrapnel (2.4%) contained radionuclide levels that measured above background. Size was recorded for 168 of the 458 radioactive shrapnel pieces. The majority of these shrapnel pieces (87%) are less than 6 in. in length, and 47% are less than 2 in. in length (Table 3-1).

Statistical analysis of the results from the shrapnel removal activities are shown in Fig. 3-1. The distribution of the gross beta/gamma activity data, recorded in cpm, was approximately lognormal. The median activity for the radioactive shrapnel was 1 750 cpm. The normal quantile plot seems to indicate that the cpm data may be best modeled by a mixture distribution. Thus, the majority of the shrapnel is represented by a lognormal distribution (mean = 10 200 cpm; standard deviation = 42 700 cpm), while a second distribution represents another population containing only outliers with very high radioactivity. Depending on the specific use of the data, an empirical distribution of all radioactivity levels, including outliers, is another, simpler way to statistically model these data and is also used in assessing risk.

The normal quantile plot is approximately linear, which indicates that the natural log of the cpm data is approximately lognormally distributed. The histogram also approximates the bell-shaped curve indicative of a normal distribution of the log-transformed data. Two high values are identified as outliers from this distribution in the outlier plot. An empirical distribution was also evaluated in simulations using the Crystal Ball™ software, which is discussed in Subsection 4.1.3.3.

TABLE 3-1

SUMMARY OF SIZE DISTRIBUTION OF THE RADIOACTIVE SHRAPNEL

SIZE CLASS (length in inches)	NUMBER OF RADIOACTIVE PIECES
0 to 2	79
2 to 6	67
> 6	22
Length not recorded	290
Total radioactive pieces	498

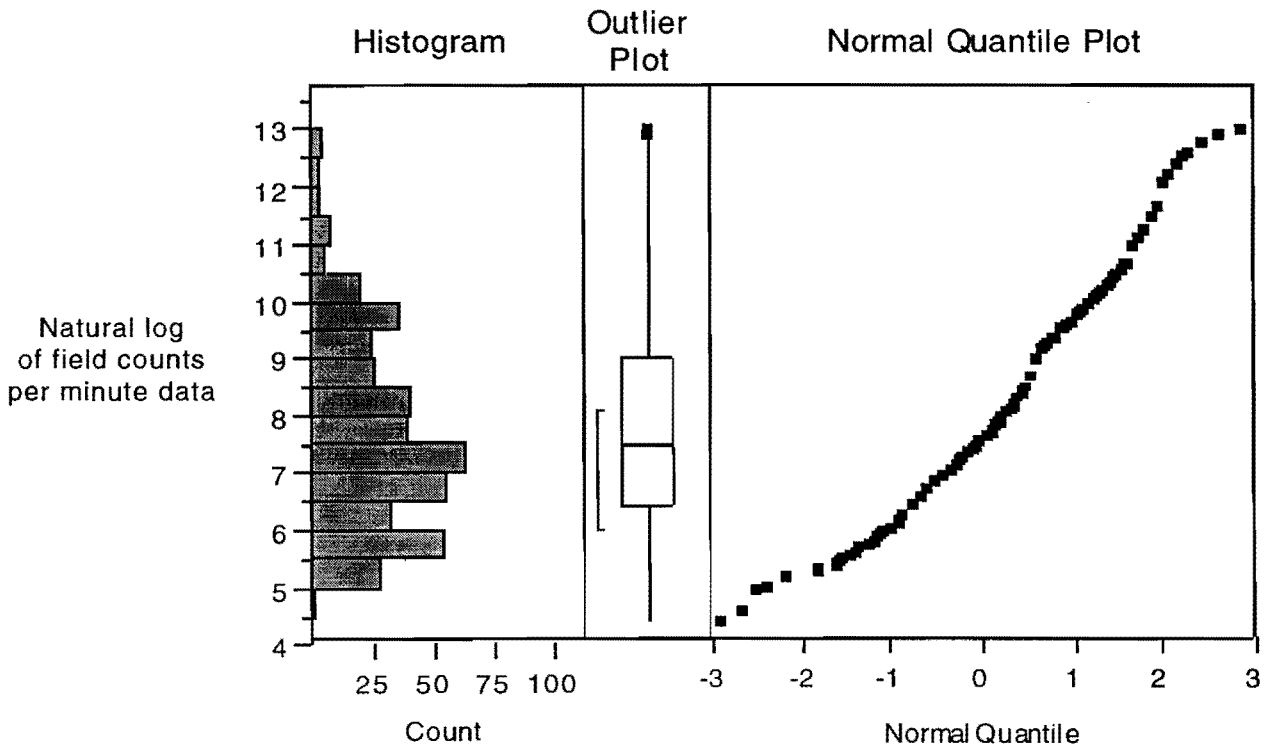


Fig. 3-1. Count data for radioactive shrapnel (log-transformed) for the surface shrapnel pickup in Bayo Canyon.

Laboratory analysis of 12 of the 458 radioactive shrapnel pieces indicated that the radioactivity is from either strontium-90 on the surface or discrete pieces of uranium metal embedded into the metal shrapnel fragments during the Bayo Canyon testing. The details of the radiological analyses are presented in a LANL internal memorandum (Fowler 1995, 06-0136). The radiological analyses of these shrapnel pieces were conducted by taking surface counts for gamma radiation using a calibrated high resolution high purity germanium (HPGe) detector, and for beta radiation using a GM counter (Eberline™ SRM-100) and an ionization chamber calibrated with 100 µCi of a strontium-90/yttrium-90 source. Because the pieces were not homogenized and were left intact, the shape of each piece affects the counting efficiency and, therefore, the amount of radiation measured. Therefore, these analyses should be considered screening-level measurements. Table 3-1 presents the size and number of radioactive shrapnel pieces.

Table 3-2 summarizes the analytical data for the 12 shrapnel pieces. The average mass fraction of uranium in these 12 pieces was 15%. The highest reported fraction was 71%. Five of these pieces did not have detectable uranium. It is important to note that the measurements suggested that strontium-90/yttrium-90 was present as surface contamination, whereas uranium was present as an embedded mass. This observation is consistent with current understanding of the test assemblies construction. Some parts of these test assemblies were manufactured from uranium, whereas strontium-90/yttrium-90 were present in the assembly associated with the lanthanum-140 tracer.

It also appears that the embedded contamination, which should have been soluble in nitric acid, was imbedded in the metal such that it could not be removed by the acid. Sample AAB8207, an elongated rectangular solid piece of light metal (most likely aluminum), weighed 21 g and had a strontium-90 activity of approximately 2.6 µCi and no detectable uranium activity. Analysis indicated that most of the activity was on the surface of the metal. However, the sample was placed in a dilute nitric acid solution to remove the strontium-90 from the surface of the metal, and the dilute nitric acid leach yielded less than 0.3 µCi of strontium-90. A second leach using more concentrated nitric acid yielded only 10 to 20% of the total activity, and the surface of the sample was heavily etched. While these results represent a single sample, they indicate that most of the surface contamination from strontium-90 may not be removable.

TABLE 3-2

SUMMARY OF ANALYSES OF THE RADIOLOGICAL COMPOSITION OF THE SHRAPNEL

SAMPLE ID	WEIGHT (g)	URANIUM MASS (g)	STRONTIUM-90 ACTIVITY (μCi)
AAB8193	44.03	ND[a]	0.2
AAB8198	22.8	2.52	<0.01
AAB8199	90.8	ND	0.02
AAB8200	24.3	9.45	0.13
AAB8201	284	0.5	<0.01
AAB8202	236	0.96	<0.01
AAB8203	18.2	ND	<0.01
AAB8204	380	ND	<0.01
AAB8205	0.8	0.09	<0.01
AAB8206	65	46.41	0.17
AAB8207	21.1	ND	2.6
AAB8208	473	195.98	0.5

[a] ND = Not detectable.

3.3.2 Results of the Shrapnel Distribution Study

Considerable variation in shrapnel density was found. Near the firing pads shrapnel densities in excess of 2 000 000 pieces per acre were found. Shrapnel densities of 5 000 pieces per acre or greater cover approximately 75 acres. Sixty-five percent of the shrapnel occurs in the top 3 in. of soil and 68% of the shrapnel was found within the upper 6 in. of soil. Less than four percent of the shrapnel occurs at depths greater than one foot. Approximately 1% (0.87%) of the 8 513 shrapnel pieces collected had radioactive contamination levels of 200 cpm or higher (LANL 1995, 06-0133).

In the active channel, the survey was curtailed at 8 600 ft, with shrapnel densities consistently recorded at one to three pieces per 10-ft by 10-ft square for every 200-ft sample interval. Two radioactively contaminated pieces of shrapnel were recovered (LANL 1995, 06-0133).

At the Northwestern Dump Site shrapnel densities ranged from 0 to more than 2 000 pieces per acre. At the Remote Firing Site, shrapnel densities ranged from 0 to more than 5 000 pieces per acre. No shrapnel was removed from either of these areas.

4.0 HUMAN HEALTH RISK EVALUATION

Upon completion of the shrapnel removal activities and the shrapnel distribution study, a risk evaluation was conducted to determine whether there were human health risks associated with shrapnel remaining at the site. The data collected during the shrapnel removal activities and the shrapnel distribution study were used as a basis for estimating the amount of shrapnel remaining in the canyon and the associated risk to human health.

4.1 Exposure Assessment

This section describes the potential exposure pathways associated with the surface shrapnel and quantifies the exposure from these pathways.

4.1.1 Potentially Exposed Populations

This risk evaluation considers potential exposures to populations that currently use Bayo Canyon for recreational activities. Quantitative surveys of the numbers and types of users of Bayo Canyon have not been conducted. An order of magnitude estimate of daily use of the canyon is 10 to 100 people during mild weather. It is likely that frequent users of the canyon are residents of Los Alamos or White Rock. The Los Alamos townsite is the nearest population center to TA-10. The 1990 census data showed an estimated population of 11 437 people. The nearest residences to TA-10 are on North Mesa, approximately 3 800 ft to the west. Residences on Otowi Mesa are approximately 6 200 ft to the northwest. Children living on the mesa tops can easily access the canyon for play.

Bayo Canyon has not been developed for commercial, industrial, or residential use, but the public does have access to the canyon and the land is used for recreational purposes. Activities in the canyon include picnicking, trail riding, jogging, hiking, firearms practice, and possibly wood cutting and piñon nut gathering. Additionally, many pottery shards are present because numerous archaeological sites are located within Bayo Canyon. Although it is unlawful to remove the shards, their presence may increase the likelihood of someone picking up shrapnel, initially mistaking it for a shard. The canyon area of TA-10 is currently under a deed restriction preventing any excavation until the year 2142 because of strontium-90 burial pits located in the canyon floor.

Although many leisure activities are pursued in Bayo Canyon, it is likely that hiking is the primary activity that could lead to exposure to radioactive shrapnel. This is because it is necessary to pick up the shrapnel in order to receive a significant exposure, and hikers are

more likely to see pieces and pick them up than are joggers or horseback riders. Hikers of any age could use the area. It is assumed that children would be somewhat more likely to observe and pick up pieces of unusual material than adults. It is also possible that a very young child would put a piece in his or her mouth.

4.1.2 Exposure Pathways

This evaluation considers exposure pathways associated with recreational use of Bayo Canyon. Bayo Canyon does not have widespread contamination; rather, contaminated material is present in discrete pieces. In addition, the contaminated shrapnel does not pose an external radiation hazard from the ground. Therefore, the exposure scenarios leading to the greatest potential dose would involve finding pieces of shrapnel, picking them up, and carrying them home. Three scenarios are considered. The first scenario considers risk due to ingestion hazards. The second and third scenarios consider risk due to potential external exposure to the skin surface of a recreational user.

- The first scenario was evaluated to estimate the risk from placing a piece of shrapnel in the mouth, presumably by a young child. Ingestion hazards are likely minimal, because most of the pieces found do not have transferable radioactive activity. That is, activity that may be removed from the surface and subsequently absorbed through the gastrointestinal tract.

- The second scenario assumes a child regularly visits the canyon area and picks up pieces of shrapnel during these visits. The pieces are then assumed to be placed in a pocket and carried for 1 to 48 hours. The child is assumed to find and pick up one to 43 pieces of shrapnel during the year. This range is based on the assumption that 50% of 170 annual recreational visits are taken in Bayo Canyon, and a piece of shrapnel is collected during 1% to 50% of the visits.

- The third scenario assumes an adult finds an interesting piece of shrapnel and makes a pendant out of it. It is assumed that this pendant is worn next to the skin for 18 hours/day for a year. This is considered the reasonable maximum exposure scenario because it involves skin contact with the shrapnel for extended periods of time and because jewelry making is a common hobby/vocation among northern New Mexico residents.

Several other potential exposure pathways were considered but were determined to be insignificant or irrelevant to this evaluation. For example, this risk evaluation is of shrapnel and not soil or respirable-sized particulates; therefore, inhalation pathways are not considered complete. In addition, direct radiation hazards from passing through the area are not likely to be significant because most of the radiation emitted from the shrapnel is beta radiation that does not typically penetrate a long distance, and the shrapnel is partially buried. The emissions from uranium and strontium and their progeny, which are primarily alpha and beta, are not expected to penetrate the soil and air above the buried shrapnel, nor the air between shrapnel found on the ground surface and a recreational user.

4.1.3 Radiological Dose Assessment

4.1.3.1 Ingestion of Shrapnel

Only a small portion of the limited transferable radioactivity is likely to be water soluble (rather than indigestible solid fragments) and, therefore, subject to absorption through the gastrointestinal tract. Approximately 1% of the activity of the pieces that were evaluated could be rinsed off with water. Using this information, the following ingestion screening calculation was conducted:

$$R = A \times T \times SF$$

Where:

R = excess cancer risk,

A = maximum measured activity in pCi,

T = transferable fraction (assumed to be 1%), and

SF = Environmental Protection Agency (EPA) slope factor for cancer risk in lifetime excess cancer risk per pCi, 6.2×10^{-11} for uranium-238 plus progeny, 5.6×10^{-11} for strontium-90 plus progeny (Miller 1994, 1169).

The highest measured activity in the field was 480 000 cpm. Assuming a 50% counting efficiency, this equates to 4.4×10^5 pCi. Conservatively assuming that the transferable radioactive mass responsible for this activity was entirely ingested, the lifetime excess cancer risk is 3 in 10 000 000 if uranium was the source of the measured activity. Assuming the ingested piece has transferable strontium-90, and using the highest activity piece measured in the lab, 2.6×10^6 pCi, the lifetime excess cancer risk would be 1 in one million. Even under

the highly unlikely screening assumption that a person would put the highest activity pieces in his or her mouth, the potential cancer risks from ingestion of material are still within the acceptable risk range specified by the National Contingency Plan (1 in 10 000 to 1 in 1 000 000) (EPA 1990, 0559).

Assuming 4.6×10^{-7} Ci/g depleted uranium-238 plus progeny and 136.5 Ci/g strontium-90, the mass of uranium or strontium ingested under these conditions is estimated at 5 mg and 2×10^{-5} mg, respectively. These are well below the thresholds for noncarcinogenic effects for a single oral exposure to uranium oxide (the compound likely to be present due to oxidation-reduction reactions in the soil) or strontium (Syracuse Research Corporation 1990, 06-0137; EPA 1994, 1167).

4.1.3.2 Skin Dose Rates

Two recreational use scenarios were evaluated to determine the potential extent of exposure to shrapnel by way of contact through skin. These scenarios include a child picking up a piece of shrapnel and putting it in a pocket worn close to the skin for 1 to 48 hours and an adult finding a piece of shrapnel, making a necklace with it, and wearing that necklace next to the skin for 18 hours per day every day for a year.

The skin dose rate conversion factors for the recreational use scenarios were calculated for shrapnel fragments containing both depleted uranium and strontium-90/yttrium-90 contamination. The term skin dose rate refers to the dose rate to the basal skin layer at a depth of 10 mg/cm^2 averaged over a 1 cm^2 area of skin. Beta radiation is the primary radiation type of concern in skin dose scenarios. It was assumed that the radioactivity contaminating the surface of the fragment is from strontium-90 and its progeny, yttrium-90, both of which are beta radiation emitters. The radioactivity imbedded in the fragment is from depleted uranium. Of the three prevalent beta-emitting progeny of depleted uranium (protactinium-234 metastable, thorium-234, and thorium-231), only protactinium-234 metastable is considered in these scenarios due to its much greater beta energy.

The skin dose rate conversion factors were determined for several percentages of depleted uranium imbedded in the shrapnel, and for several count rates from surface contamination of strontium-90/yttrium-90. The following assumptions were made:

- strontium-90/yttrium-90 activity is calculated from beta/gamma screening results without regard for depleted uranium (or uranium progeny) contributions;

- strontium-90/yttrium-90 activity detected by screening instrumentation is uniformly distributed over the area of emanation;
- screening instrument detection efficiency is 50% for both strontium-90/ yttrium-90;
- density of the nonradioactive shrapnel component was calculated from material composition data compiled during field activities;
- depleted uranium composition by weight is 0.002% uranium-234, 0.3% uranium-235, and 99.7% uranium-238;
- depleted uranium is uniformly distributed within the shrapnel; and
- protactinium-234 metastable is in equilibrium with uranium-238.

The density of the nonradioactive portion of the shrapnel was estimated by calculating the weighted average density of the materials found in Bayo Canyon during removal of the surface shrapnel (average density = 7.8 g/cm^3). The data used to derive the average density are presented in Table 4-1.

TABLE 4-1

DATA USED TO DETERMINE AVERAGE DENSITY OF SHRAPNEL PIECES

MATERIAL	NUMBER OF PIECES	DENSITY (g/cc)
Aluminum	268	2.55
Brass	3 612	8.4
Copper	717	8.8
Iron	1 937	7.0
Lead	116	11.34
Nails	215	7.0
Steel	92	7.7
Wire	469	7.0
Average		**7.8**

The total density of the shrapnel pieces (the weighted average density of the nonradioactive portion and the density of percent depleted uranium) and the density calculations are listed in Table 4-2. The average concentration of depleted uranium in the shrapnel fragments that were examined was 15%, and the upper bounding limit for the concentration of depleted uranium in any shrapnel fragment was 100%. These two percentages are listed in Table 4-2.

TABLE 4-2

SHRAPNEL DENSITY AND DEPLETED URANIUM SHRAPNEL PROGENY ACTIVITY

PERCENT DEPLETED URANIUM	r_{mix} (g/cm^3)	ACTIVITY (Ci/cm^3) PROTACTINIUM-234m
15%	8.56	4.29×10^{-7}
100%[a]	19.1	6.38×10^{-6}

[a] Activity from 100% depleted uranium was also calculated as an upper bounding limit to the range.

$$r_{mix} = 1 / [(1 / r_U)(\%DU) + (1 / r_{nonrad})(1 - \%DU)]$$

where:

r_{mix} = Density of mixed (r_{mix}) shrapnel pieces, which includes the density of depleted uranium and weighted density of metal mixture (calculated to be 7.8 g/cm^3 from material composition data compiled during field activities);

r_U = Density of uranium (r_U) (19.1 g/cm^3);

r_{nonrad} = Weighted density of metal mixture (r_{nonrad}); and

%DU = Percent depleted uranium in metal mixture.

The strontium-90 and yttrium-90 activities in shrapnel were calculated using field count rate data. Several assumptions were made to establish a conversion factor for calculating the strontium-90 and yttrium-90 activities from field data (Table 4-3), and these results were used in the skin dose calculations. The Varskin Mod2® model was used to calculate the skin doses. The input assumptions are given in Table 4-4.

TABLE 4-3

DERIVATION OF STRONTIUM-90/YTTRIUM-90 SHRAPNEL ACTIVITY

ACTIVITY			
STRONTIUM-90[a] (dpm/cm^2)/cpm	YTTRIUM-90[a] (dpm/cm^2)/cpm	STRONTIUM-90 (Ci/cm^2)/cpm	YTTRIUM-90 (Ci/cm^2)/cpm
1.4×10^3	1.4×10^3	6.4×10^{-10}	6.4×10^{-10}

[a] Values derived assuming 50% instrument efficiency, 15.5 cm^2 detector area, and instrument response of 1 cpm.

TABLE 4-4

VARSKIN MOD2® INPUT ASSUMPTIONS FOR DEPLETED URANIUM AND STRONTIUM-90 / YTTRIUM-90 SKIN DOSE RATE CALCULATIONS

PARAMETER	DEPLETED URANIUM SCENARIOS	STRONTIUM-90/YTTRIUM-90 SCENARIOS
Source type	3-D disk	2-D disk
Diameter (cm)	3	3
Thickness (cm)	0.5	NA[a]
Skin depth (mg/cm^2)	10	10
Air gap (cm)	0	0
Thickness of cover material (mm)[b]	0.3	0.3
Density of cover material (g/cm^3)[b]	0.3	0.3

[a] Thickness is not applicable to the 2-D disk scenario.
[b] Shielding by cover material (pocket) was only used in the child scenario.

4.1.3.3 Skin Exposure Model

The skin dose assessment is based on an exposure model. The exposure model is based on simple assumptions about the exposure pathways, the fraction of shrapnel that is radioactive, and the range of dose rates emitted from the radioactive shrapnel. The exposure pathways help define conversion factors, and these factors are used to convert the field radioactivity measurements (cpm data) into a dose. The primary exposure pathway requires direct contact of the radioactive shrapnel to the skin or contact of the shrapnel in a pocket to skin.

The parameters for the exposure model are based on the recently completed surface shrapnel survey. The key assumption is that the inventory of shrapnel in Bayo Canyon has not been significantly impacted by the surface removal, and that future storms will expose currently buried shrapnel to the surface. It is assumed that the surface shrapnel removal provides

adequate estimates of the activity and composition of the shrapnel. The contributions of both depleted uranium and strontium-90/yttrium-90 to the skin dose are considered.

The dose model is based on the frequency of radioactive shrapnel in Bayo Canyon, and the dose emitted by the radioactive shrapnel to the skin. The model is:

$$D_{s,1cm^2} = ED_s \sum_{i=1}^{N(p)} (d_{s,1cm^2,Sr/Y} \cdot a_i + d_{s,1cm^2,DU})$$

where:

$D_{s,1\ cm^2}$ = The dose (D) received for each scenario ($_s$) to a 1 cm^2 patch of skin ($_{1\ cm^2}$) by collecting a piece of radioactive shrapnel and keeping it in direct skin (or pocket) contact for the time assumed for the generic recreational users of Bayo Canyon. The dose units are rad per year. The simulation model will estimate the distribution of possible doses to individual recreational users.

ED_s = Exposure duration for the scenario (ED_s), which is a uniform random variable for the child recreational scenario. The minimum of the uniform distribution is 1 hour and the maximum is 48 hours per piece of shrapnel. The exposure duration for the pendant scenario is set conservatively at the maximum reasonable value of 6 570 hours (18 hours per day times 365 days per year) per piece of shrapnel for the adult pendant wearer scenario.

$d_{s,1\ cm^2,Sr/Y}$ = The strontium-90/yttrium-90 dose conversion factor ($d_{Sr/Y}$), which converts the cpm data to rad/hr for each scenario (see Table 4-5).

a_i = The activity of (a) the radioactive shrapnel, which is a random variable ($_i$). This variable is based on the distribution of the measured cpm for shrapnel collected during the surface shrapnel pickup. Both the empirical cpm distribution and a lognormal distribution (mean = 10 200 cpm; standard deviation = 42 700 cpm) were evaluated in the simulations.

$d_{s,1\ cm^2,DU}$ = The depleted uranium dose conversion factor (d_{DU}), which differs for each scenario (see Table 4-5).

N(p) = The number (N) of radioactive shrapnel pieces collected during the year, which is a random variable (p) for each scenario (see Figs. 4-1 and 4-2 for the probability distributions used in the simulations).

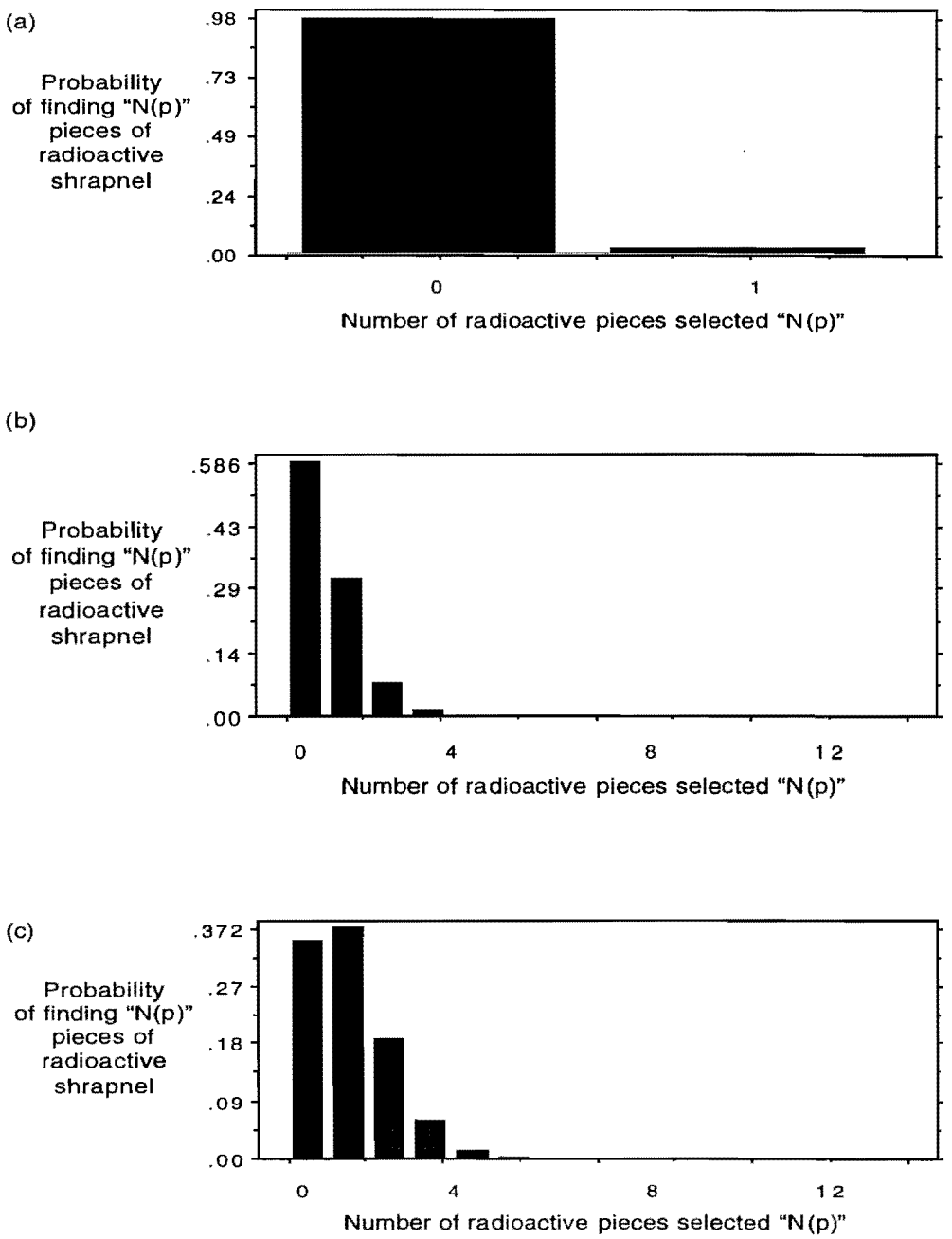
TABLE 4-5

SKIN DOSE RATE CONVERSION FACTORS[a] FOR SEVERAL SCENARIOS OF IMBEDDED DEPLETED URANIUM AND STRONTIUM-90/YTTRIUM-90 SURFACE CONTAMINATION

SCENARIO	DEPLETED URANIUM (rad/hr)[b]	STRONTIUM-90/ YTTRIUM-90 (rad/hr per cpm)
Pendant User	3.9×10^{-2} (4.3×10^{-2}) [15% depleted uranium]	6.9×10^{-7} (1.2×10^{-6})
Pendant User	2.59×10^{-1} [100% depleted uranium]	6.9×10^{-7} (1.2×10^{-6})
Child Recreational	3.5×10^{-2} (3.9×10^{-2}) [15% depleted uranium]	5.3×10^{-7} (7.1×10^{-7})

[a] Skin dose rate is to a 1 cm^2 patch of skin at a depth of 10 mg/cm^2. The dose rate in parentheses corresponds to the dose assuming a skin depth of 1.6 mg/cm^2 averaged over 1 mm^2 for comparison to noncarcinogenic endpoint data.

[b] Units are rad per hour, and assume that each piece of shrapnel is 15% depleted uranium imbedded in shrapnel (density of mixture is 8.56 g/cm^3). One hundred percent depleted uranium was calculated as an upper bounding limit for the pendant scenario.



(a) Distribution given 1 piece of shrapnel (average of uniform distribution) collected per year.

(b) Distribution given 22 pieces of shrapnel (average of uniform distribution) collected per year.

(c) Distribution given 43 pieces of shrapnel (maximum of uniform distribution) collected per year.

Fig. 4-1. The probability distribution for the number of radioactive pieces collected per year for the child recreational scenario.

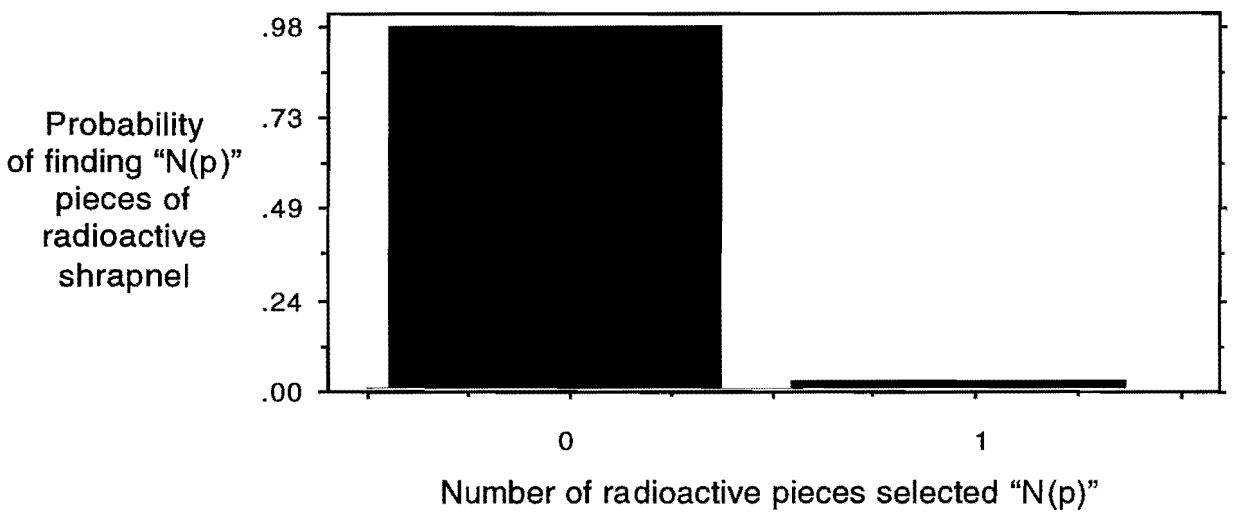


Fig. 4-2. The probability distribution for the number of radioactive pieces collected per year for the pendant user scenario.

In Fig. 4-1, the distribution is based on a binomial probability function, where the probability of encountering a piece of radioactive shrapnel is constant at 2.4%. The number of pieces of shrapnel collected per year is a uniform random variable between 1 and 43 pieces. The three parts of Fig. 4-1, parts a, b, and c, show the range in possible numbers of radioactive shrapnel collected.

In Fig. 4-2, the distribution is based on a binomial probability function (1 piece of shrapnel made into a pendant with a 2.4% chance that the piece of shrapnel is radioactive). The pendant scenario is presented as a reasonable maximum exposure scenario, and, thus, it was not appropriate to let the number of pieces of shrapnel made into a pendant be a random variable. Also note that the probability of finding a piece of radioactive shrapnel is identical to the minimum probability distribution for the recreational scenario (see Fig. 4-1, part a).

The dose model was run using Crystal Ball™ software. Crystal Ball™ operates as an add-on for Microsoft Excel™. The operation of Crystal Ball™ is controlled by the equations in an Excel™ spread sheet. As noted above, some of the input variables are defined as random variables in this spread sheet. If a spread sheet value is defined as a random variable, then Crystal Ball™ randomly selects a value for each trial. The value selected in each trial depends on the distributional assumption for each model parameter, and these assumptions are summarized in Table 4-6. A trial in these simulations represents the type of radioactive shrapnel encountered by a recreational user of Bayo Canyon in one year. To estimate the statistical properties of these doses, Crystal Ball™ simulated 25 000 trials for each scenario.

The predicted dose distributions for each scenario are presented in Subsection 4.4.3 for the empirical cpm data distribution simulations. The results are summarized by the percentiles (50%, 90%, 99%, and 99.9%) of the estimated dose distributions. For example, the 90th percentile is the dose where 90% of the doses are less than this value. Thus, the odds of receiving a dose that high (or higher) are one to ten (or lower). The odds of the dose will be considered in conjunction with the health effect (acute or chronic) in determining the human health hazard.

The median (50th percentile) dose estimates for the lognormal and empirical cpm distributions were similar, but the empirical cpm distribution estimated a higher dose for the upper percentiles of the dose distribution. The empirical cpm distribution represents a worst-case and, therefore, was used instead of the lognormal cpm distribution.

TABLE 4-6

SUMMARY OF DISTRIBUTIONAL ASSUMPTIONS FOR THE CRYSTAL BALL™ DOSE SIMULATIONS

MODEL PARAMETER	DISTRIBUTIONAL ASSUMPTION
Strontium conversion factors	Constants (see Table 4-4)
Depleted uranium conversion factors, which assume each piece of shrapnel is 15% depleted uranium	Constants (see Table 4-4)
Field activity as measured in counts per minute, which is assumed to be proportional to strontium activity	(a) Lognormal (mean = 10 200 cpm, standard deviation = 42 700 cpm) (b) Empirical distribution (see Fig. 3-1)
Number of pieces of radioactive shrapnel collected in one year	Binomial distribution, which is based on the probability that a piece of shrapnel is radioactive and the number of pieces of shrapnel collected per year for each scenario (see Figs. 4-1 and 4-2)
Number of pieces of shrapnel collected in one year	One piece for the pendant scenario. A uniform random variable between 1 and 43 pieces per year for the recreational scenario, which is based on taking 50% of the 170 annual recreational visits in Bayo Canyon and collecting a piece of shrapnel in 1% to 50% of the visits.

4.4 Health Effects Evaluation

This section characterizes potential health effects associated with skin dose rates estimated for the various exposure assumptions discussed in Subsection 4.1.3.2. The results of the dose models can be evaluated for noncarcinogenic health effects as well as cancer risks. Skin doses occur as a result of beta radiation emitters (strontium-90/yttrium-90, and beta-emitting uranium progeny) being in contact with the skin or near the skin in a pocket. Potential health effects associated with the ingestion of shrapnel are presented in Subsection 4.1.3.1.

4.4.1 Risk Model

The risk model is based on the dose received from the primary radionuclides present in the radioactive shrapnel, and the risk slope factors for either increased incidence of skin cancer or increased mortality. The increased incidence of skin cancer risk model is:

$$R_{c,s} = r_{c,Sr90} \cdot D_{s,t,Sr90} + r_{c,Y90} \cdot D_{s,t,Y90} + r_{c,DU} \cdot D_{s,t,DU}$$

$$D_{s,t,Sr90} = ED_s \sum_{i=1}^{N(p)} d_{t,Sr90} \cdot a_i$$

$$D_{s,t,Y90} = ED_s \sum_{i=1}^{N(p)} d_{t,Y90} \cdot a_i$$

$$D_{s,t,DU} = ED_s \sum_{i=1}^{N(p)} d_{t,DU}$$

where:

$R_{c,s}$ = The estimated incremental cancer risk (R_c) for each scenario ($_s$). The simulations will estimate the distribution of cancer risk to individual recreational users of Bayo Canyon.

$D_{s,t,m}$ = The dose (D) received to the total area of skin ($_t$) by collecting a piece of radioactive shrapnel from the mth ($_m$) radionuclide and keeping it in direct skin (or pocket) contact for the two exposure scenarios ($_s$). The dose units are rad per year.

$r_{c,m}$ = The carcinogenic risk factor for the mth ($r_{c,m}$) radionuclide (see Table 4-7), which converts rad per year into a probability of increased skin cancer incidence.

ED_s = Exposure duration for the scenario (ED_s), which is a uniform random variable for the child recreational scenario. The minimum of the uniform distribution is 1 hour and the maximum is 48 hours per piece of shrapnel. The exposure duration for the pendant scenario is set conservatively at the maximum reasonable value of 6 570 hours (18 hours per day times 365 days per year) per piece of shrapnel for the adult pendant wearer scenario.

$d_{t,m}$ = The dose conversion factor for the mth radionuclide, which converts the cpm data to rad per hour for each scenario (see Tables 4-8 and 4-9).

a_i = The activity of the radioactive shrapnel, which is a random variable. This variable is based on the distribution of the measured cpm for shrapnel collected during the surface shrapnel pickup. The empirical cpm distribution and a lognormal distribution (mean = 10 200; standard deviation = 42 700) were evaluated in the simulations.

N(p) = The number of radioactive shrapnel pieces collected during the year, which is a random variable for each scenario (see Figs. 4-1 and 4-2 for the probability distributions used in the simulations).

The increased mortality due to skin cancer risk model is:

$$R_{m,s} = r_{m,Sr90} \cdot D_{s,t,Sr90} + r_{m,Y90} \cdot D_{s,t,Y90} + r_{m,DU} \cdot D_{s,t,DU}$$

$$D_{s,t,Sr90} = ED_s \sum_{i=1}^{N(p)} d_{t,Sr90} \cdot a_i$$

$$D_{s,t,Y90} = ED_s \sum_{i=1}^{N(p)} d_{t,Y90} \cdot a_i$$

$$D_{s,t,DU} = ED_s \sum_{i=1}^{N(p)} d_{t,DU}$$

where:

$R_{m,s}$ = The estimated incremental mortality risk. The simulations will estimate the distribution of mortality risk to individual recreational users of Bayo Canyon.

$D_{s,t,m}$ = The dose received to the total area of skin by collecting a piece of radioactive shrapnel from the mth radionuclide, and keeping it in direct skin (or pocket) contact for the time assumed for the two exposure scenarios. The dose units are rad per year.

$r_{m,m}$ = The mortality risk factor for the mth radionuclide (see Table 4-7), which converts rad per year into a probability of mortality from skin cancer. Factors include area, weighted based on the area of irradiation from the source (18.5 cm^2, 8.5 cm^2, and 19 cm^2 for protactinium-234 metastable, strontium-90, and yttrium-90, respectively).

ED_s = Exposure duration for the scenario, which is a uniform random variable for the child recreational scenario. The minimum of the uniform distribution is 1 hour and the maximum is 48 hours per piece of shrapnel. The exposure duration for the pendant scenario is set conservatively at the maximum reasonable value of 6 570 hours (18 hours per day times 365 days per year) per piece of shrapnel for the adult pendant wearer scenario.

$d_{t,m}$ = The dose conversion factor for the mth radionuclide, which converts the cpm data to rad/hr for each scenario (see Tables 4-8 and 4-9). Factors include area, weighted based on the area of irradiation from the source (18.5 cm^2, 8.5 cm^2, and 19 cm^2 for protactinium-234 metastable, strontium-90, and yttrium-90, respectively).

a_i = The activity of the radioactive shrapnel, which is a random variable. This variable is based on the distribution of the measured cpm for shrapnel collected during the surface shrapnel pickup. The empirical cpm distribution and a lognormal distribution (mean = 10 200; standard deviation = 42 700) were evaluated in the simulations.

N(p) = The number of radioactive shrapnel pieces collected during the year, which is a random variable for each scenario (see Figs. 4-1 and 4-2 for the probability distributions used in the simulations).

TABLE 4-7

AREA WEIGHTED CANCER RISK FACTORS

SCENARIO	STRONTIUM-90	YTTRIUM-90	DEPLETED URANIUM
Child - cancer incidence	3.6×10^{-8}	1.3×10^{-7}	1.2×10^{-7}
Child - cancer mortality	5.1×10^{-11}	1.9×10^{-10}	1.7×10^{-10}
Adult - cancer incidence	3.0×10^{-8}	6.6×10^{-8}	6.2×10^{-8}
Adult - cancer mortality	4.2×10^{-11}	9.5×10^{-11}	8.9×10^{-11}

TABLE 4-8

AREA WEIGHTED DOSE CONVERSION FACTORS FOR PENDANT SCENARIO

	STRONTIUM-90	YTTRIUM-90	DEPLETED URANIUM
Total skin area (cm^2)	8.5	19	18
Dose rate	3×10^{-7} [a]	2×10^{-7} [a]	1.5×10^{-2} [b]

[a] Units are rad per hour per counts per minute.
[b] Units are rad per hour, and assume that each piece of shrapnel is 15% depleted uranium.

TABLE 4-9

AREA WEIGHTED DOSE CONVERSION FACTORS FOR CHILD RECREATIONAL SCENARIO

	STRONTIUM-90	YTTRIUM-90	DEPLETED URANIUM
Total skin area (cm^2)	10	38	35
Dose rate	1.6×10^{-7} [a]	8.2×10^{-8} [a]	7.9×10^{-3} [b]

[a] Units are rad per hour per counts per minute.
[b] Units are rad per hour, and assume that each piece of shrapnel is 15% depleted uranium.

4.4.2 Noncarcinogenic Health Effects

Based on animal studies and limited human data, the effects of beta radiation to the skin include the sequelae shown in Table 4-10 (NCRP 1989, 06-0138; Hopewell 1986, 06-0139):

TABLE 4-10

EFFECTS OF BETA RADIATION TO THE SKIN

DOSE (rad)	EFFECT (species, if no human data)
0 to 2 000	No effect (monkey)
2 000 to 4 000	Mild erythema
4 000 to 15 000	Erythema
15 000 to 80 000	Superficial ulceration/acute necrosis
80 000 to 2 200 000	Ulceration (swine)

To compare these effects to a point estimate of dose, the highest Varskin Mod2® modeled skin dose rate from uranium is 0.04 rad/hr, whereas the highest from strontium-90/yttrium-90 is 0.58 rad/hr. These results are based on the Varskin Mod2® model using 1.6 mg/cm^2 skin depth and dose averaged over 1 mm^2 to compare with the above studies. Assuming these in combination (0.62 rad/hr) on the skin for 18 hours per day, a dose of 4 000 rad per year would be incurred. This could result in mild erythema or reddening of the skin, although the effects described above were for doses administered over time periods much less than a year. Spreading the dose over a year could allow for greater cell recovery and therefore mitigate progression to these effects. Based on the probabilistic encounter model for the pendant shrapnel scenario, the probability of a dose this high is less than 1 in 1 000 (Table 4-8). All other doses modeled in the encounter model, including the child recreational scenario, result in doses substantially below the threshold of these effects. The results of the probabilistic encounter modeling are presented graphically in Figs. 4-3 and 4-4.

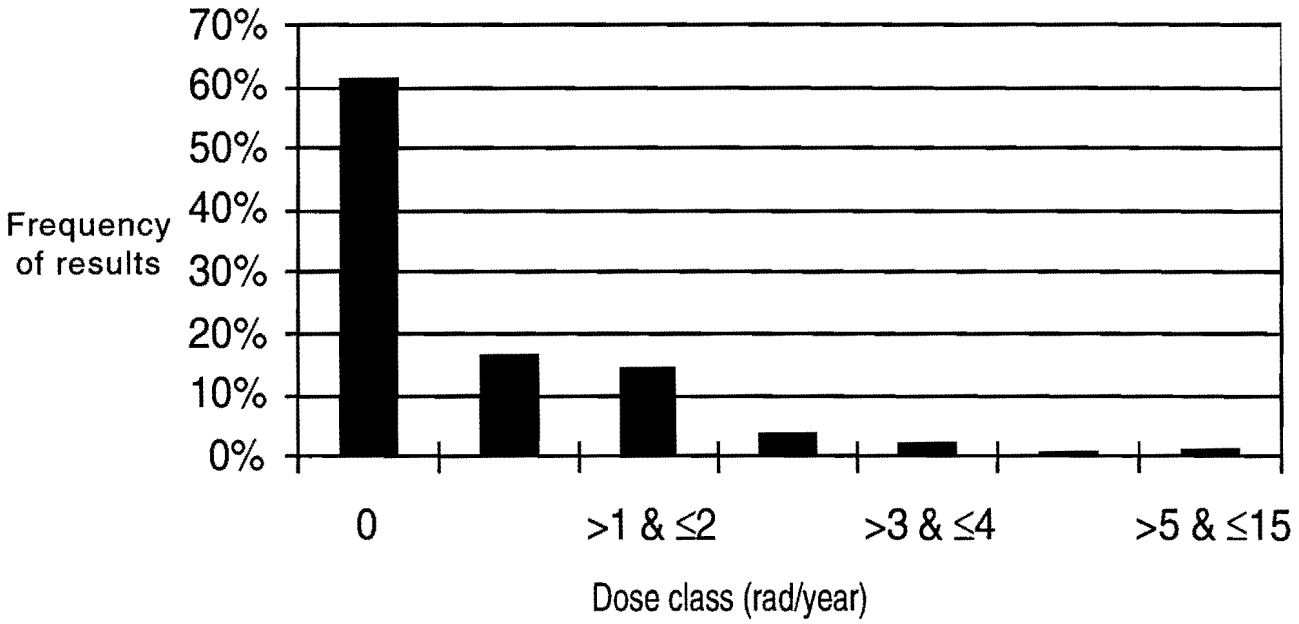


Fig. 4-3. The distribution of doses predicted by the Crystal Ball™ simulation model for the child recreational scenario.

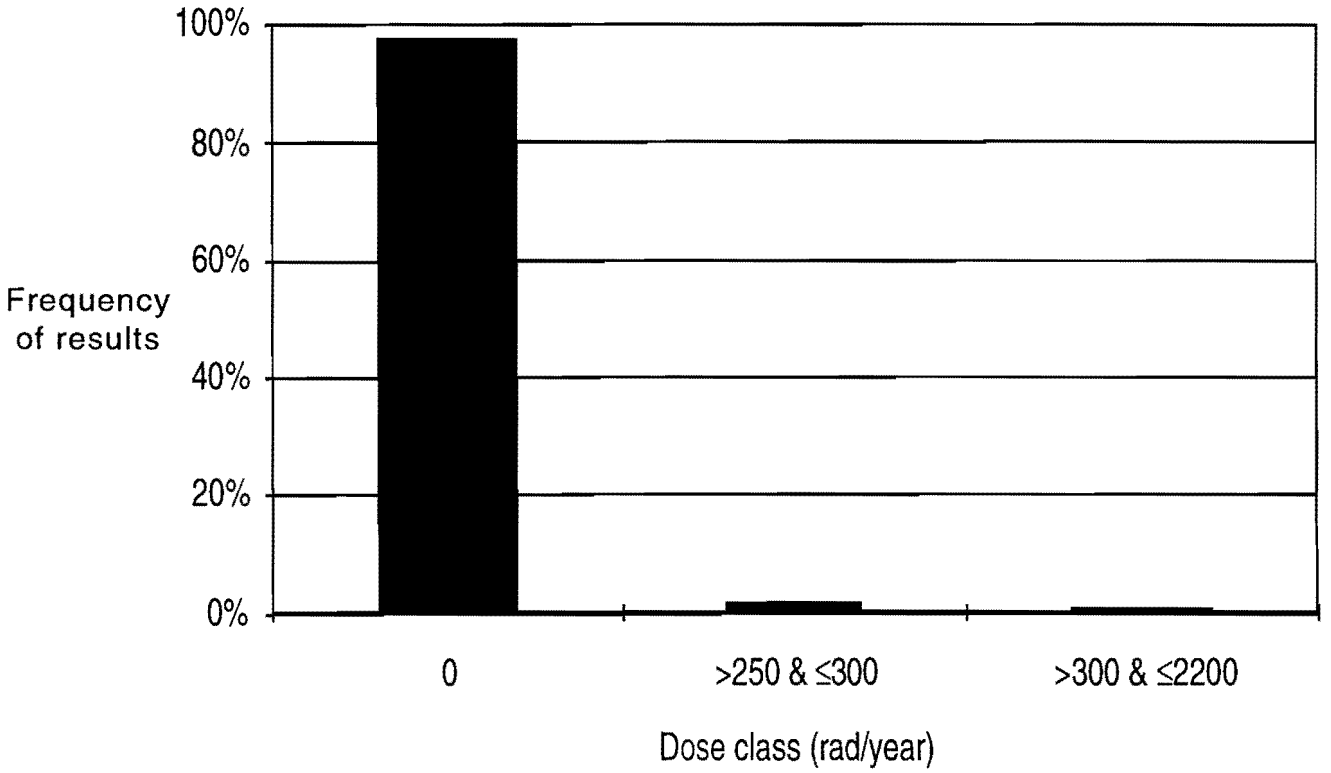


Fig. 4-4. The distribution of doses predicted by the Crystal Ball™ simulation model for the pendant user scenario.

4.4.3 Carcinogenic Risk

There is an increased risk of skin cancer associated with beta radiation to the skin. This risk is increased on skin areas also exposed to ultraviolet (UV) radiation. For these scenarios, the exposure location on the skin is assumed not to be exposed to UV radiation (i.e., where pocket and lapel are located). The increased skin cancer risk associated with beta-emitters on small areas (2 mm^2) of non-UV irradiated skin is estimated to be 7 x 10-11 per rad (NCRP 1989, 06-0138). The risk of skin cancer mortality is estimated to be 1 x 10^{-13} per rad. These factors were scaled proportionally to the area of skin that was irradiated by the piece of shrapnel. These risk factors are presented in Table 4-9. The resulting skin cancer risks are shown in Table 4-11 for the two scenarios and their encounter probabilities. As shown in the encounter model, exposure levels above 1 in 100 000 (1 x 10-5) cancer risk are highly improbable. There is a 1 in 1 000 chance that a skin cancer incidence risk of 1 x 10^{-5} would be exceeded for the shrapnel pendant wearer. The excess skin cancer incidence risk for the 99th percentile encounter dose for the child recreational scenario is 1 x 10^{-7}.

TABLE 4-11

RESULTS OF ENCOUNTER MODELING SIMULATION

SCENARIO	POTENTIAL EFFECT	50th PERCENTILE[a] (MEDIAN)	90th PERCENTILE	99th PERCENTILE	99.9th PERCENTILE
Child, Recreational[b]	Dose (rad)	0	1.7	5.1	11
	Incremental skin cancer incidence risk	0	5 x 10^{-8}	1 x 10^{-7}	3 x 10^{-7}
	Incremental mortality risk	0	7 x 10^{-11}	2 x 10^{-10}	4 x 10^{-10}
Shrapnel Pendant User[c]	Dose (rad) 15% depleted uranium	0	0	270	630
	Incremental skin cancer incidence risk (15% depleted uranium)	0	0	7 x 10^{-6}	2 x 10^{-5}
	Incremental mortality risk (15% depleted uranium)	0	0	9 x 10^{-9}	3 x 10^{-8}
	Dose (rad) 100% depleted uranium	0	0	1715	2 075
Odds that user will get a dose or risk of this value or greater		1:1	1:10	1:100	1:1 000

[a] The percentiles show the frequency of annual skin doses (rad/yr) and incremental risk for each scenario.
[b] 61.4% of simulations had no dose or risk to child recreational user.
[c] 97.7% of simulations had no dose or risk to shrapnel pendant user.

4.5 Limitations of the Evaluation

Many conservative assumptions were made to estimate potential exposure, doses, and risks. The scenarios were intended to reflect a reasonable maximum exposure. Nearly all of the terms and assumptions used in this risk evaluation have some inherent uncertainty. These uncertainties, and their potential effects on the risk estimate, include the following.

- Characterization of shrapnel activity levels included measurements on over 19 000 pieces. Although it is possible that pieces still in the canyon have higher activity than those evaluated, it is unlikely unless an entire area that was not evaluated has higher activity. Only twelve pieces were evaluated for their specific composition. The relative fraction of uranium to strontium could vary significantly from that estimated by these pieces. The overall effect of these uncertainties would widen the distribution of expected risk. Although no pieces were found to contain 100% depleted uranium, if such a piece existed, the resultant doses could be up to 7 times the doses used in the simulations in this report.

- The exposure assumptions include the assumption that shrapnel is certain to be encountered and certain to be picked up. Best estimates were used for the number of pieces of shrapnel a child might pick up and the duration of time a child would retain the shrapnel in a pocket. The distributions for these parameters likely present a reasonable range of potential exposures but the shape of the distribution (i.e., the frequency of occurrence of various values within the range) could be considerably different from that estimated. This is not expected to significantly affect the results.

- The ingestion screening assumptions included the assumption that 1% of the activity was transferable because it could be removed by water. However, this measurement was only made on a few pieces. The range of the transferable fraction could vary significantly from this. The component of this fraction that can be digested and absorbed through the gastrointestinal tract is likely less than that estimated by these calculations.

- Several assumptions were made for the skin dose model (Varskin Mod2®). These include source geometry and composition (15% and 100% depleted uranium), distance between the source and skin, and cover material. These were conservatively selected to maximize dose, resulting in an overestimate of risk.

- There are several methods that are valid for estimating dose from the scenarios examined in this report. A method not addressed in this report was to use the field screening data as a measure of the combined strontium/yttrium/depleted uranium activity. The strontium/yttrium decay chain has similar beta energies to the depleted uranium decay chain. It would therefore be valid to calculate the dose from the field screening data and not attempt to distinguish between strontium/yttrium and depleted uranium activities. A major limitation of this method is the limited sample size (3 samples with strontium/yttrium activity, depleted uranium activities, and field screening results). Also, the efficiency of the field data is unknown and would have to be estimated, introducing additional error to the estimate. It was determined that the limited analytical data were more accurately reflected by the current method described in the text.

- The health effects comparison was based on comparison to small (2 to 20 mm^2) beta-emitting particles for noncarcinogenic effects. A larger piece would result in a greater affected area, but is not assumed to result in significantly different effects.

- Skin cancer risks are based on whole body estimates scaled down to the smaller exposure areas estimated for each nuclide. Skin cancer risks are stochastic in nature, and as such, are related to the area affected. The area of irradiation is larger than the source area, and depends on both the energy of the beta particles emitted (radionuclide dependent) and the shape of the piece. While this analysis assumed a 3 cm diameter disc source (yielding an irradiated area of 18 cm^2, 8.5 cm^2, and 19 cm^2 for irradiation by protactinium-234 metastable, strontium-90, and yttrium-90, respectively), a wide array of sizes/shapes is possible for the shrapnel present at the site. The overall effect of this uncertainty could result in either overestimating or underestimating risk.

- The actual carcinogenic potential of this particular source and exposure route has not been determined experimentally or in epidemiological studies. Risk factors have been extrapolated from other types of radiation that may vary in their carcinogenic potential by comparison to strontium-90, yttrium-90, and depleted uranium.

The net effect of these uncertainties is likely to be an overestimate of risk for the pendant wearer scenario, whereas the distribution for the child scenario is likely to represent a range of doses that may be encountered by recreational users of Bayo Canyon.

4.6 Risk Summary

The results of this risk evaluation indicate that the probability of adverse health effects resulting from recreational users of Bayo Canyon picking up pieces of radioactive shrapnel is very low. Of the three scenarios evaluated, the only scenario that resulted in adverse effects was the one in which a shrapnel piece with the highest activity measured to date is made into a pendant and worn next to the skin for 18 hours per day for a year. Under these circumstances, mild reddening of the skin could occur. If the scenario occurs, the chance of receiving a dose this high is estimated at less than 1 in 1 000. This scenario could also result in an increased risk of skin cancer. It was estimated that there was a 1 in 1 000 chance of finding a shrapnel piece that would result in incurring a skin cancer risk of 1 in 100 000 (2×10^{-5}), which is within the range of risks generally considered acceptable by regulatory agencies (EPA 1990, 0559).

Recreational users picking up pieces of shrapnel and carrying them around would also have a potentially increased risk of skin cancer. These risks are estimated to be 1 in 10 000 000 (1×10^{-7}) for the 99th percentile dose, which is below the range of risks generally considered significant by regulatory agencies. Putting pieces of shrapnel in the mouth was also not associated with significant risk of adverse health effects.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The objectives of the interim action were achieved by:

1) Removal of all surface shrapnel from those areas of Bayo Canyon open to the public,

2) Thorough review of the remedial alternatives for any shrapnel remaining at the site, including a shrapnel distribution study and LIPS modeling, and

3) Performance of a risk assessment on data collected during the shrapnel removal activity and the shrapnel distribution study.

The risk modeling shows that the increased cancer risk from the shrapnel is less than the EPA acceptable risk range of 1 in 10 000 to 1 in 10 000 000 (EPA 1990, 0559). The potential acute effects resulting from the recreational scenarios are also negligible. The human health consequences of the remaining Bayo Canyon shrapnel are judged to be minimal. Therefore, no further action is recommended for the remaining shrapnel in Bayo Canyon.

REFERENCES

Drake, P. and Inoue, C., 1993. "Geomorphic Characterization of Operable Unit 1079, Formerly Technical Area 10, Los Alamos National Laboratory, New Mexico," informal report prepared by Glorieta Geoscience, Inc. for Los Alamos National Laboratory, Los Alamos, New Mexico. **(Drake and Inoue 1993, 06-0122)**

EPA (US Environmental Protection Agency), March 8, 1990. "National Oil and Hazardous Substances Pollution Contingency Plan," Final Rule, 40 CFR Part 300, *Federal Register*, Vol. 55, No. 46, p. 8666. **(EPA 1990, 0559)**

EPA (US Environmental Protection Agency), 1994. "Integrated Risk Information System (IRIS)," Office of Science and Technology, National Technical Information Service, Springfield, Virginia. **(EPA 1994, 1167)**

Fowler, Malcolm M., May 30, 1995. "Counting of Samples from Bayo Canyon," Los Alamos National Laboratory memorandum to Dave Finnegan (CST-7) from Malcolm M. Fowler (CST-11), Los Alamos, New Mexico. **(Fowler 1995, 06-0136)**

Hopewell, J.W., 1986. "Mechanisms of the Action of Radiation on Skin and Underlying Tissues," *British Journal of Radiology*, Supplement 19, p.39. **(Hopewell 1986, 06-0139)**

LANL (Los Alamos National Laboratory), May 1992. "RFI Work Plan for Operable Unit 1079," Los Alamos National Laboratory Report LA-UR-92-850, Los Alamos, New Mexico. **(LANL 1992, 0783)**

LANL (Los Alamos National Laboratory), April 12, 1994. "Interim Measure Work Plan, LANL Operable Unit 1079, Bayo Canyon–TA-10, Shrapnel Removal from Bayo Canyon Firing Sites," Los Alamos, New Mexico. **(LANL 1994, 06-0132)**

LANL (Los Alamos National Laboratory), May 1995. "Shrapnel Investigation at FU-1, TA-10, Bayo Canyon Firing Site," prepared by Geophex, Ltd., Geophex Job Number 437, Los Alamos, New Mexico. **(LANL 1995, 06-0133)**

LANL (Los Alamos National Laboratory), September 9, 1995. "RFI Report for PRSs 10-001(a-d), Field Unit 1," Los Alamos National Laboratory Report LA-UR-95-3643, Los Alamos, New Mexico. **(LANL 1995, 06-0130)**

LANL (Los Alamos National Laboratory), in preparation. "RFI Report for PRSs 10-002(a-b), 10-003(a-o), 10-004(a-b), 10-005, and 10-007, Field Unit 1," Los Alamos National Laboratory Report, Los Alamos, New Mexico. **(LANL in preparation, 06-0131)**

LANL (Los Alamos National Laboratory), April 5, 1995. "Shrapnel Removal Field Summary Report for Field Unit 1, Technical Area 10, Bayo Canyon," prepared by ERM Program Management Company and Golder Federal Services, Inc., ERM Project File G9454.7b, Los Alamos, New Mexico. **(LANL 1995, 06-0134)**

Miller, I. C., March 1994. "Health Effects Assessment Summary Tables Annual Update, FY-1994," 9200.6-303(94-1), EPA 540-R-94-020, prepared by Oak Ridge National Laboratory for the Environmental Protection Agency, Oak Ridge, Tennessee. **(Miller 1994, 1169)**

NCRP (National Council on Radiation Protection and Measurements), December 31, 1989. "Limit for Exposure to 'Hot Particles' on the Skin," NCRP Report No. 106, Bethesda, Maryland. **(NCRP 1989, 06-0138)**

Syracuse Research Corporation, December 1990. "Toxicological Profile for Uranium," prepared under Contract No. 205-88-0608 to Clement International Corporation, Agency for Toxic Substances and Disease Registry, US Public Health Service, Washington, DC. **(Syracuse Research Corporation 1990, 06-0137).**