PANEL REPORT

INDEPENDENT TECHNICAL REVIEW

of Proposed Drilling Activities for Operable Unit 7-10 Staged Interim Action [Alternative Pit 9 Project]

October 1999

INDEPENDENT TECHNICAL REVIEW OF PROPOSED SONIC DRILLING ACTIVITIES FOR PIT 9 IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

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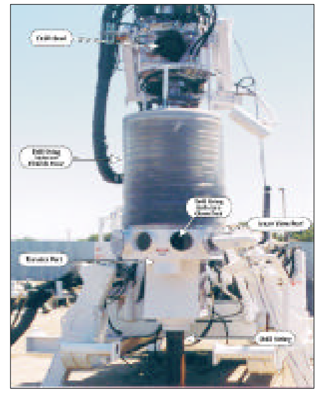
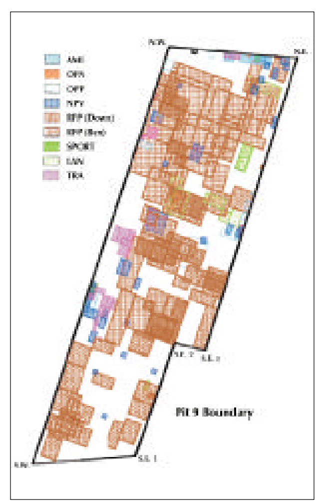


Sonic drill rig.

Dumping of wastes at SDA.



Map showing Pit 9 boundary.

Executive Summary

This report presents the results of an independent review by the Independent Technical Review Panel (ITRP or the Panel) of the proposed Operable Unit (OU) 7-10 Staged Interim Action, also known as the Alternative Pit 9 project. The Interim Action is a multi-staged approach jointly developed by the Department of Energy–Idaho Operations Office (DOE-ID), Environmental Protection Agency (EPA)–Region 10, and Idaho Department of Health and Welfare (IDHW) to meet the requirements of the Comprehensive Environmental Response, Compensatory and Liability Act (CERCLA) Record of Decision for Pit 9. It is intended to support exploration, characterization, and remediation of the waste buried in Pit 9, located at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering and Environmental Laboratory (INEEL). This review was undertaken in response to safety concerns raised by several employees of INEEL. Their concern was that the planned sonic drilling for exploration and characterization of the waste in Pit 9 had the potential to create an explosion or fire that was more likely than had been concluded in safety evaluations. At the request of DOE-ID on July 6, 1999, DOE Offices of Environmental Management (EM) and Environment, Safety and Health (EH) established the ITRP to evaluate the planned remediation approach for Pit 9.

The Panel commenced its review by developing a safety assessment approach having four basic elements:

- Identify safety concerns.
- Develop scenarios to address identified safety concerns.
- Collect evidence for evaluating the scenarios.
- Evaluate the scenarios using the "Risk Triplet," i.e., What can go wrong?, How likely is it?, What are the consequences?

The major safety concern is the potential for explosions or fires in the pit during drilling that would result in radiological releases to the aboveground environment. This safety concern led the Panel to select six reasonable bounding scenarios dealing with potential explosions or fires as a result of sonic drilling into buried materials. The most important scenarios dealt with the buried nitrates and organic materials which might become commingled, possibly forming an explosive mixture.

To provide a basis on which to develop and evaluate the scenarios, the Panel interviewed cognizant DOE and contractor staff and interviewed individuals who had expressed concerns with the proposed sonic drilling. The Panel also toured the Pit 9 area, sonic drill rig, and remote control station that had been used in the cold test pit drilling area. The Panel had at its disposal, extensive documentation of the history of Pit 9, numerous safety studies and submittals to state and national authorities, and extensive amounts of internal memoranda and drafts. Based on reviewing and evaluating this information, the Panel developed a series of tests that were conducted at Los Alamos National Laboratory, Brookhaven National Laboratory, and an experimental facility near College Station, Texas. These tests were designed to bound the types of nitrate and fuel mixtures that might possibly exist in Pit 9 and included a nitrate/organic mixture, nitrate/graphite mixture, and nitrate/wood mixture. The Panel and its consultants also made independent confirmatory calculations in reaching its conclusions on the risk and safety of sonic drilling in Pit 9. The Panel concludes that the maximum shock pressure from sonic drilling in the nitrate/oil mixutre in the Pit 9 waste disposal area should not exceed 1000 psi. The Panel also concludes that under normal drilling conditions, the soil-drill interface temperature will increase only a few tens of degrees centigrade in the expected Pit 9 soil and buried waste. More importantly, the Panel concludes that if the proposed conditions for determining refusal are strictly implemented, the soil-drill interface temperature can be maintained below 150°C under refusal conditions.

The underlying basis of the Panel's conclusions are:

- Reasonable knowledge of the waste characteristics, especially waste components that, on energetic stimulation, might explode or ignite. This is especially true with respect to the waste component classified as miscellaneous in the nitrate sludges.

- Explosion and fire tests on surrogate waste mixtures that reasonably bound the uncertainties in the waste composition of Pit 9.
- The absence of sufficient energetics from drilling activities to create a radiological source term for atmospheric releases.

In the language of DOE Standard 3009 for conducting safety analyses, the Panel has concluded that an explosion from sonic drilling into any nitrate/fuel mixture in Pit 9 is beyond extremely unlikely if the moisture content is greater than 5wt% and the soil-drill interface temperature is maintained below 150°C. If the moisture content is less than 5wt%, an explosion is extremely unlikely. While one surrogate mixture of nitrate/organic mixture did explode during the testing conducted near College Station, Texas, that explosion only occurred when a Pentolite booster was used and the mixture was dry. With respect to fires and other scenarios that were selected by the Panel to reasonably bound the possible waste forms to be found in Pit 9, the Panel concluded that no sonic drilling scenario results in the potential for radiological releases to the environment. A summary of the Panel's evaluation is presented in Table ES-1.

Although the Panel concluded that the risks of explosions or fires from the planned sonic drilling in Pit 9 were extremely unlikely, the Panel identified three recommendations that they believe should be implemented as preventive and mitigating measures. These recommendations are made to increase the margin of safety of the planned remediation activities.

Recommendations

1. Implement a cautious approach in which each step builds upon the knowledge and experience gained from prior actions.
2. Adopt formal drilling procedures that prevent soil-drill interface temperatures from exceeding 150°C.
3. Demonstrate that the moisture level in the overburden is in excess of 5wt% prior to probing below the overburden.

The Panel considers the other mitigation and design measures that are planned to be appropriate. These measures include, among others, a minimum 50-foot separation of the drill rig from the remote operation station, the use of the drill string enclosure during coring, and the use of properly calibrated radiation monitors when removing core samples.

Table ES-1. Evaluation of scenarios.

SCENARIO	DESCRIPTION	EVALUATION
1. Drilling into a mixture of nitrate salts and hydrocarbon oils.	Drums containing sodium and potassium nitrates and hydrocarbon oils and chlorinated solvents were disposed into Pit 9. The potential for the drill to encounter a mixture of nitrates and combustible organics does exist.	Explosion beyond extremely unlikely if H_2O > 5wt%. Explosion extremely unlikely if H_2O < 5wt%. Fire extremely unlikely.
2. Drilling into a mixture of nitrate salts and graphite.	Graphite (mainly in the form of chunks and large pieces) was also placed into drums and disposed into Pit 9. There is the potential for the sonic drill to encounter a mixture of nitrate salts and graphite.	Explosion beyond extremely unlikely. Fire extremely unlikely.
3. Drilling into a mixture of nitrate salts and cellulose (wood/paper).	Large quantities of wood and paperboard containers were disposed into Pit 9 permitting the possible encounter of nitrate salts and cellulose based materials.	Explosion beyond extremely unlikely if drill bit < 150°C. Fire extremely unlikely.
4. Drilling into an intact drum containing hydrogen.	Hydrogen can be produced through radiolytic decomposition of organic materials. There is the potential for the production of hydrogen and other gases.	
5. Drilling into potentially pyrophoric or reactive materials, e.g., zirconium and depleted uranium; containers of picric acid, and lithium batteries.	There is documentation and, in some cases, concerns that these materials were placed in Pit 9.	Explosion extremely unlikely. Fire extremely unlikely.
6. Drilling into pressurized cylinders containing a flammable gas.	While no documentation exists which supports the disposal of pressurized gas cylinders, this possibility was considered to be credible.	

Independent Technical Review of Proposed Drilling Activities for Pit 9

1.0 INTRODUCTION

This report presents the deliberations and results of an Independent Technical Review Panel of safety concerns related to the planned remediation of Pit 9, a waste disposal pit at the Idaho National Engineering and Environmental Laboratory (INEEL). Pit 9 is located in the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC) at INEEL. This independent review addresses specific safety issues related to the sonic probing and coring of Pit 9. The Panel consists of technical experts on explosive safety, environmental chemical processes, nuclear safety, and probabilistic risk assessment.

In July 1997, DOE-ID, EPA-Region 10, and the Idaho Department of Health and Welfare jointly developed a staged interim action to remediation of Pit 9 that consisted of three stages.[*] (Ref. 1)

Remediation Approach

- Stage I – Subsurface exploration in OU 7-10 to obtain material for bench scale treatability studies and allow for Pit 9 characterization
- Stage II – Limited retrieval/ excavation in select areas of OU 7-10 for conducting treatability studies and evaluating how effective the characterization of wastes and soils had been in Stage I
- Stage III – Full-scale remediation

In June 1998, DOE-ID issued the work plan (Ref. 2) for Stage I, which stipulates the methods that will be used to perform a subsurface exploration of the wastes in Pit 9. The Stage I work plan identified a 40' x 40' section of Pit 9 for sonic drilling. This section was selected because of the high likelihood of finding transuranic (TRU) radionuclides (primarily plutonium) contained in drummed sludge and organic wastes, which are the two major contaminants of concern. Important safety information would be obtained from the probe holes and subsequent logging, which would be used to identify a drill location for coring operation. [The Panel believes this is an important step in ensuring the safety of the drill location for the coring operation.]

All of the wastes in the 40' x 40' sonic drilling area are believed to be from the Rocky Flats Plant (a DOE facility located near Golden, Colorado) and to contain solid radioactive waste materials and radioactive sludge and salts. The dominant waste forms in the drilling area are Series 743-sludge containing organics and Series 745-sludge containing nitrates. Other waste types buried in this area include combustible materials, noncombustible materials, graphite material containing up to a few hundred grams of plutonium per drum, Series 741-sludge (which is the waste form containing free Americium 241 and depleted uranium), and "empty" waste drums that were previously filled with lathe coolant, and thus may have contained residues of carbon tetrachloride and oil (Table 1-1). This waste was shipped from Rocky Flats in separate 55-gallon waste drums, but was potentially mixed when it was dumped into the open pit by truck or spread with the tractor. Obtaining samples of these types of materials from Pit 9 for characterization and treatabililty studies is the objective of Phase II of Stage I of the project.

Of concern to those evaluating the safety of the proposed drilling efforts was the statement in the 1993 Record of Decision (Ref. 3) that the 745-sludge contained a mixture of 90% nitrates and 10% miscellaneous, with the implication that the miscellaneous wastes were 10% organic material. This mixture of nitrates and organics was seen as being a potential explosive mixture.

[*] In order to distinguish the 1997 multi-staged contingency approach from the previous Pit 9 agreement, the new agreement uses the term OU 7-10 instead of the Pit 9.

In July 1999, the DOE commissioned the Independent Technical Review Panel, which comprised of the following experts to address safety issues related to the planned sonic drilling.

Hugh Thompson, Chairman – Nuclear Safety

John Auxier, Ph.D., CHP – Radiological Safety

James Clarke, Ph.D. – Environmental Chemistry and Risk Assessment

Michael Coburn, Ph.D. – Energetic Material Chemistry and Explosive Safety

B. John Garrick, Ph.D., PE – Nuclear Safety and Risk Assessment

A screening process was used to ensure that each panel member has no conflicts of interest. Biographies of panel members are presented in Appendix A.

The Panel was provided with a review plan (Ref. 4) and charter. The Pit 9 Review Project Plan provided the following background:

"The first step in remediating the waste contained in Pit 9... is to insert probe tubes into the buried waste using a sonic drilling technique. Because of the landfill disposal methods used during the 1960s when this waste was placed in the pit, potassium or sodium nitrates were dumped into the same area as organic materials. This situation raised concerns with respect to having potentially explosive and/or flammable mixtures of nitrates and organics which could present health and safety risks during the drilling operation. These issues were analyzed by the contractor, and the contractor's conclusions were presented to Department of Energy (DOE) Idaho Operations Office (ID) with recommendations to proceed with the remediation strategy. DOE/ID, in turn, requested the Office of Environment, Safety and Health (EH) to review the contractor's basis documents and to provide DOE/ID its conclusions. The Office of Nuclear and Facility Safety (EH-34) concluded that a fire involving a few barrels of waste was a credible event, and that an explosion (large breach of the earthen cover and large airborne release of radioactive material) was extremely unlikely.

In April 1999, an anonymous employee submitted a technical concern to DOE/ID alleging that an explosion was more likely than what was concluded in previous evaluations. DOE/ID commissioned an expert consultant to review the employee's information. The consultant concluded that the concern had merit. Consequently, the technical issue is being reevaluated, taking into account the information provided by the concerned employee."

The Charter (also in Appendix A) directed the Panel to evaluate the concerns related to the planned remediation approach and to derive technical conclusions on the following:

"(1) Review INEEL plans for investigating Pit 9, considering an Employee Concern regarding the risk of explosion.

Table 1-1. Expected waste contents in Stage I / II 40' x 40' area*. (Ref. 5)

RFO DOW Shipping Record	Combustible	Non-Combustible	Sludge 741	Sludge 742	Sludge 743	Sludge 744	Sludge 745	Graphite	Empty
68-83B	9	-	-	6	51	-	10	-	54
68-84B	12	-	-	10	43	2	10	-	54
68-93B	16	5	-	8	28	-	19	-	53
68-94B	20	4	-	-	52	-	-	-	53
69-95B	23	1	-	-	50	-	2	-	54
68-96B	13	12	-	1	49	-	1	-	54
68-97B	16	6	-	2	52	-	-	-	54
68-98B	22	-	-	-	54	-	-	-	54
68-115B	68	-	3	-	-	-	-	7	57
68-120B	61	-	-	-	-	-	-	15	57
Subtotals	**260**	**28**	**3**	**27**	**379**	**2**	**42**	**22**	**544**
Total Drums = 1,307									

** 40' to 80' and 0' to 40' east of the Pit 9 SW monument.*

(2) Review relevant technical information and render an independent technical opinion with respect to the likelihood and consequences of fires, explosions or other safety consequences (including nuclear safety) that could result from sonic drilling in Pit 9 (i.e., apply best engineering judgment).

(3) Identify design features, both engineered and administrative that are normally provided to prevent or mitigate accidents for similar evolutions and hazards (i.e. radioactive and hazardous and to maintain the design safety margin)."

The approach taken by the Panel to address these safety concerns was to adopt the principles of risk-informed safety evaluation. The steps were to:

1. Identify the safety issues of concern.
2. Develop a set of scenarios whose end states address these issues, e.g., explosions, fires, and radiological releases.
3. Collect evidence for evaluating the scenarios.
4. Evaluate the scenarios against the definition of risk, recently adopted by the Nuclear Regulatory Commission in their white paper on Risk-Informed and Performance-Based Regulation (Ref. 6).

In particular, risk is defined as the answer to three basic questions, often referred to as the risk triplet.

The Risk Triplet

- What can go wrong?
- How likely is it?
- What are the consequences?

The Panel did not attempt to quantify the risk scenarios. However, the Panel structured the set of scenarios to reasonably bound the safety concerns. The safety issues of concern center around accidents that could be initiated by the sonic probing and coring operations associated with the subsurface exploration program. In particular, the primary safety issue addressed by the Panel is the risk of radiological releases as a result of explosion or fire that could be initiated by the sonic probing and coring operations. The scenarios represent the answer to the question, "What can go wrong?" and, the end states of the scenarios answer the question, "What are the consequences?"

Although the results of the Panel's review are more qualitative than quantitative, the spirit of quantitative risk assessment is followed. Specifically, the Panel adopted the language of DOE Standard 3009 (Ref. 7) to express its conclusions.

In assigning likelihoods for those cases where the safety results were not supported with actual test data, the Panel adopted the practice of assigning a risk no lower than "extremely unlikely." Ultimately, some risk conclusions were based on scientific and engineering judgment.

A key element of the Panel's approach was the consideration and collection of evidence to develop and assess the scenarios. In this regard, the Panel received presentations and documentation from DOE, DOE contract personnel, involved experts, and outside consultants. A structured process was implemented for documenting questions raised by the Panel as well as the responses prepared for the Panel's consideration. The most significant evidence for evaluating the bounding scenarios was test data requested by the Panel. Important test data were obtained from the Los Alamos National Laboratory, Brookhaven National Laboratory, and from large-scale tests performed by the Sudhakar Company, Inc. at an experimental facility near College Station, Texas.

The order of presentation in the Panel's report mirrors the four-step approach to risk-informed safety evaluations. Section 2 presents detailed descriptions of the site, waste treatment operations, and the sonic drilling project. The safety concerns are discussed in this section and Section 3. The development of scenarios and their evaluation are covered in Sections 4, 6, 7, and 8. The information, i.e., the evidence supporting the safety evaluation, is contained in Sections 1, 5, 6, 7, and 8. Section 9 presents the Panel's conclusions and recommendations. This section also discusses risks associated with the remediation activities of Stages II and III.

2.0 DESCRIPTION OF THE SITE AND PLANNED SONIC DRILLING

2.1 SITE DESCRIPTION

Pit 9 – Pit 9 was operated as a waste disposal pit from November 1967 to June 1969. It is located in the Subsurface Disposal Area of the RWMC, a disposal site established in the early 1950's at INEEL. The RWMC encompasses 144 acres or 0.58 km^2 and consists of two main disposal areas: the Transuranic Storage Area (TSA) and Subsurface Disposal Area (SDA). The TSA is an interim storage area where TRU waste is stored in containers on asphalt pads. The SDA is an 88-acre site where radioactive waste materials have been buried in underground pits, trenches, and soil vault rows, and placed on one aboveground pad. Pit 9 is located in the northeast corner of the SDA (Figure 2-1) and is 379 feet long and 127 feet wide (about one acre). The depth of the pit from ground surface to the bedrock is about 17.5 feet, with approximate layers of 3.5 feet of soil on top of the bedrock, 8 to 11 feet of waste on top of the soil, and 3 to 6 feet of clean soil overburden on the waste.

The waste in Pit 9 is primarily TRU waste that was generated at Rocky Flats and shipped to INEEL. Additional low-level radioactive and other miscellaneous wastes are from generators located at INEEL. The waste shipped from Rocky Flats consisted of drums of sludge (contaminated with a mixture of TRU elements and organic solvents), drums of assorted solid waste, and cardboard boxes containing empty contaminated drums. The boxes were generally disposed of at the north end of the pit, and the drums were generally dumped in the south end, although intermixing of containers in the pit may have occurred as a result of pit flooding in 1969. Also, because of the landfill disposal methods used during the 1960s, potassium or sodium nitrates were dumped into the same area as organic materials.

Figure 2-1. Site map showing Pit 9 in the NE corner of the SDA.

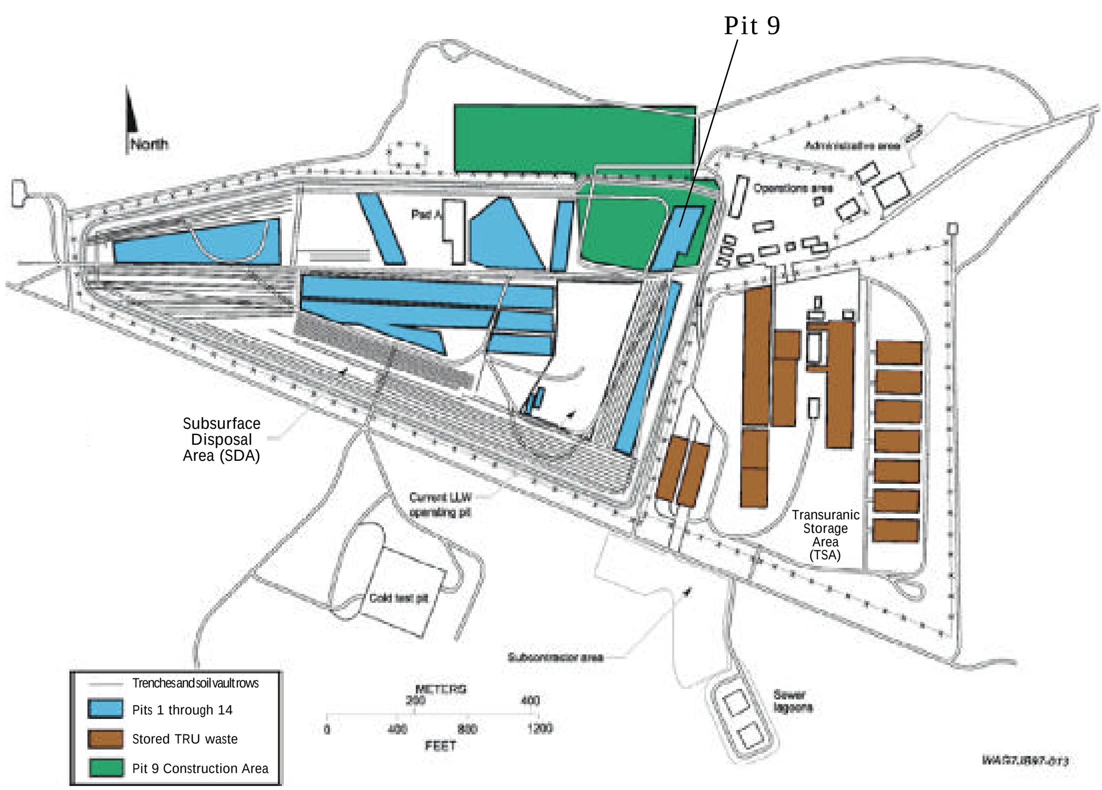


Table 2-2 summarizes the radiological inventory for all of Pit 9 (Ref. 8). The activity levels have been corrected for decay to reflect 1998 levels. Besides the radioactive isotopes of uranium, thorium, plutonium, and americium, the waste contains activated Co-60, and the mixed fission products Cs-137, Ba-137, Sr-90, and Y-90. It should be noted that Am-241 inventory increases with time because Pu-241 decays to Am-241 with a half-life of 14.4 years, while Am-241 itself decays with a half-life of 432 years.

The organics in Pit 9 include oil, carbon tetrachloride, trichloroethylene, alcohols, organic acids, Freon 113, tetrachloroethylene, trichloroethane, and trace amounts of polychlorinated biphenyls. Among the inorganics are various hydrated metal oxides, such as iron, magnesium, aluminum, silicon, plutonium, and americium. Other inorganic materials in the waste include containerized mercury, lithium batteries, portland cement, beryllium, magnesia cement, and calcium silicate. The Record of Decision estimated that sodium and potassium nitrates comprise 12% of the drums, an estimated 180 tons of alkali nitrate salts. Miscellaneous wastes include materials such as rags, paper, and gloves, and atypical wastes include a 6-foot steel vault and a large carbon steel reactor vessel weighing approximately 220,462 pounds and sized into 12 sections with a total container volume of 8,600 feet^3. Also, approximately 880 pounds of asbestos may be in the pit. The condition of other layers of waste containment, such as plastic bags and liners in the drums and boxes, is unknown. Earlier retrieval efforts did observe some leaking containers indicating free liquid in drums.

Table 2-2. Total activities for radiological inventories in Pit 9. (Ref. 8)

Radionuclide	Ci	30-year Decay Activity 1998 (Ci)
Pu-238	5.0E+01	3.9E+01
Pu-239	1.7E+03	1.7E+03
Pu-240	3.9E+02	3.9E+02
Pu-241	1.1E+04	2.6E+03
Pu-242	2.0E-02	2.0E-02
Total Pu	1.3E+04	4.7 E+03
Am-241	3.2E+03	3.3E+03
U-235	3.5E-02	3.5E-02
U-238	1.5E+00	1.5E+00
U-234	7.0E-01	7.0E-01
H-3	1.9E-01	3.5E-02
Ra-226	2.1E-02	2.1E-02
C-14	1.9E-03	1.9E-03
Fe-55	4.6E+02	2.1E-01
Ni-59	3.3E-03	3.3E-03
Co-60	8.8E+02	1.7E+01
Ni-63	1.5E+02	1.2E+02
Sr-90	3.7E+01	1.8+01
Tc-99	5.0E-04	5.0E-04
I-129	6.2E-07	6.2E-07
Cs-137	3.0E+01	1.5E+01

Figure 2-3. Site map showing 40' x 40' area of sonic drilling operations at Pit 9.

Sonic Drilling Area – The region of Pit 9 of immediate concern is the 40' x 40' area where sonic drilling is planned (Figure 2-3). This location was chosen to assure the existence of Rocky Flats transuranic waste material and contaminated soils. Surface geophysical and radiation measurements were used in locating the 40' x 40' drilling area. As an indication of the inventory of wastes in the drilling area, the following quote is taken from a preliminary safety assessment (Ref. 8) performed by the Management and Operating Contractor of INEEL:

> *"From Thomas (1999a), there are 1,307 55-gallon drums in the Stage II 40 x 40 ft area. The dominant waste form is 379 drums of 743 sludge containing organics such as Texaco Regal oil, carbon tetrachloride, and trichloroethylene. The next significant waste type is 260 drums of combustible materials. Others are 42 drums of evaporator salts (nitrates), 28 drums of noncombustible materials, 22 drums of graphite material (believed to be crushed mold material containing high concentrations of Pu), and 3 drums of 741 sludge, which is the waste form containing free Am-241 and depleted uranium. There are also 544 empty drums. It is believed that these drums were formerly filled with carbon tetrachloride at the Rocky Flats Plant, then drained and boxed in individual cartons for shipment to the RWMC."*

Table 2-4. Estimate of plutonium and Am-241 in waste contents of the 40' x 40' Stage II area based on average quantity per drum loading. (Table 3-5 of PSA (Ref 8))

Waste Type	Number of Drums	Equivalent Waste Code	Waste Code Average g/drum Pu	Waste Code Average g/drum Am-241	Total Quantity (g) Pu	Total Quantity (g) Am-241
Combustibles	260	330	0.5	0	130	0
Non-Combustibles	28	480	3.6	0	100.8	0
741 Sludge	3	001	4.3	1.8	12.9	5.4
742 Sludge	27	002	0.2	0	5.4	0
743 Sludge	379	003	0.3	0	113.7	0
744 Sludge	2	004	1.0	0	2.0	0
745 Sludge	42	005	0.09	0.1	3.8	4.2
Graphite	22	300	9.9	0	217.8	0
Empty	544	950	0.03	0	16.3	0
Totals					602.7	9.6

Table 2-5. Plutonium and Am-241 converted to curies (uncorrected and corrected for 30 year decay) for 40' x 40' Stage II area. (Table 3-6 of PSA (Ref. 8))

Isotope	Weapons Grade Fraction[a]	Total Grams[b]	Ci/g[c]	Activity (Ci) Uncorrected	Activity (Ci) Corrected[d]
Pu-238	0.00012	0.0723	1.7E+01	1.23	0.97
Pu-239	0.93826	565.489	6.2E-02	35.06	34.97
Pu-240	0.0582	35.077	2.3E-01	8.07	8.04
Pu-241	0.0034	2.049	1.0E+02	204.9	48.35+5.06 Am-241[e]
Pu-242	0.00024	0.1446	3.9E-03	0.0056	Insignificant
Am-241	–	9.6	3.4E-03	32.64	31.1
Totals				281.9	128.5

a. Weapons grade fraction for Pu isotopes referenced from Detamore (1989).

b. Fraction applied to 602.7 g in Table 2.4. Am-241 amount from Table 2-4

c. Weight to activity conversion values from Table A-i in Appendix A. 10 CFR 71.

d. Decay correction for 30 years.

e. Represents Am-241 ingrowth from decay of Pu-241.

f. Estimate of waste volume based on 1,307 55-gallon drums less 544 empties is 763 drums with waste. Assume each drum is 80% full, giving a total volume 33.572 gal ($127.1 m^3$).

g. Average activity concentration = $\frac{\text{Corrected Curies}}{\text{Waste volume}} = \frac{128\ Ci}{127.1\ m^3} = 1.01\ Ci/m^3$

Tables 2-4 and 2-5 show the estimated radiological inventories for the current DOE Stage II 40' x 40' area. (Although this is the best estimate for the 40' x 40' area, the Panel elected to use the highest reported undecayed maximum concentrations of 1,000 grams of plutonium as a bounding condition for radiological dose calculations.)

2.2 WASTE TREATMENT OPERATIONS AT ROCKY FLATS*

Over 70% of the wastes by volume in Pit 9 originated at the Rocky Flats Plant, and essentially all of the waste in the designated drilling area is believed to be from Rocky Flats (Ref. 9). Solid radioactive wastes were generated in various manufacturing and plutonium recovery glovebox operations. The wastes consisted of a wide variety of materials including gloves, paper, plastics, rags, and other combustible wastes; various tools and other light metal or steel wastes; heavy metal wastes such as tantalum molds and funnels; graphite mold materials; and glass and other items used in day-to-day glovebox operations. The

Figure 2-6. Summary waste flow diagram for Rocky Flats. (Ref. 9)

Table 2-7. Waste stream products from Rocky Flats. (Ref. 8)

Waste Contents	
Combustibles	Paper and rags – dry
Non-Combustibles	Unleached light non-stainless steel
741 Sludge	First stage sludge
742 Sludge	Second stage sludge
743 Sludge	Organic setups
744 Sludge	Special setups such as alcohols and organic acids
745 Sludge	Evaporation salts-nitrates
Graphite	Graphite molds
Empty Drums	Low specific activity – metal, glass, etc.

various solid wastes were placed into 55-gallon drums for shipment to INEEL. Since some of the drums containing the graphite molds were also considered to contain some graphite fines, evaluation of graphite fines with nitrate is considered important.

Radioactive liquid wastes at Rocky Flats consisted of aqueous liquid waste from various plutonium recovery, analytical laboratory, and research and development operations; and organic wastes primarily from machining operations in the manufacturing process. The liquid wastes were transferred to a special processing building, Building 774 at Rocky Flats, via pipeline or individual containers. The liquid waste treatment process in Building 774 was divided into four process groups: first and second stages, evaporation processes, and solar evaporation ponds. Figure 2-6 presents a simplified block diagram of the processes. Note the various 700 series code names given to the waste stream products. An abbreviated description of the 700 series wastes are shown in Table 2-7.

The waste stream products considered most important to the safety of the drilling operations are the 743 organic sludge and 745 nitrate sludge. The 743-sludge is the product of processing organic liquid wastes (which were comprised of a variety of oils and solvents used in

* This section is primarily based on input from a former employee at Rocky Flats in waste treatment operations (Appendix F).

manufacturing operations at Rocky Flats) with an absorbent powder (calcium silicate) to transform the wastes to a putty-like solid suitable for shipment. The 743-sludge constitutes 29% of all the drums in the drilling region, with approximately 36 gallons of hydrocarbon oils and chlorinated solvents in each drum.

The 745 nitrate sludge resulted from the evaporation of the high nitrate waste in the asphalt-lined evaporation ponds at Rocky Flats. The evaporation process for these wastes consisted of two feed-storage tanks, a vertical long-tube natural circulation evaporator, a double drum dryer, a dust scrubber system, and a steam condensate collection system. The total system was used to evaporate water from the liquid waste, leaving a dry solid (10 to 15% water) that was packaged for disposal. The waste was pumped by pipeline from the ponds to the evaporator feed storage tanks. From these tanks, concentrated salt water was continuously circulated through the heat exchanger, along with the waste feed stream. A portion of the concentrate was continuously removed from the evaporator and gravity fed through a pipeline to the steam-heated double-drum dryer, where the remaining water was evaporated, leaving a film of dry solids baked on the rotating drum surfaces. Knife blades continuously scraped the solids from the dryer drums into catch containers (55-gallon drums). The resulting 745-sludge consisted of approximately 60% sodium nitrate, 30% potassium nitrate, and 10% miscellaneous. Based on recent test results, the miscellaneous waste is now believed to be inorganic sulfates, phosphates, chlorides, and water. It also contains approximately 1% organic carbon (Ref. 10).

The other wastes included the series 741, 742, and 744 sludges. Series 741 and 742 sludges were wet sludges consisting of water (approximately 50 to 70%) and precipitates of hydrated oxide of iron, magnesium, aluminum, silica, plutonium, depleted uranium and Americium 241. Each drum was layered with Portland cement to absorb any free liquid. Some of the drums of 742-sludge are believed to have contained other items such as containers of liquid chemical waste and other wastes such as small amounts of mercury and lithium batteries.

The series 744-sludge consists of alcohols, organic acids, and EDTA mixed with Portland and magnesia cements.

Also, during the time period of shipments to Pit 9, a large number of 55-gallon drums containing stored waste organic liquids were processed at Rocky Flats. Many of these drums contained residues of solidified organic sludge that adhered to the drum and were not fed to the liquid waste treatment process. This was a source of “empty” drums that were shipped to Pit 9.

The waste drums and boxes were transferred from the liquid waste treatment facility, and solid wastes from various other Rocky Flats facilities, to a storage building for loading either in trailer or container units for rail shipment to INEEL. A manifest sheet was generated for each shipment showing the number and weight of the drums and a general description of contents. Detailed item descriptions of the waste were not included on the manifest. The nature of the descriptions was combustible, non-combustible, graphite, empty drum, or 74-series sludge drums. The waste was delivered to Pit 9, where trucks backed up to the edge of the pit and drums rolled into the pit (Figure 2-8). The dumping location was determined

Figure 2-8. Typical dumping of wastes at the SDA.

by either pacing off the distance from survey monuments or by estimating the distances from the monuments. A caterpillar tractor pushed overburden over the drums while spreading out the waste containers. This procedure probably compromised the integrity of the drums, but was not an issue at that time since the wastes were not planned for retrieval and the drums would eventually fail. This type of landfill operation was typical of the 1960s.

2.3 PLANNED SONIC DRILLING PROJECT

The current project activities of Stage I of the Alternative Pit 9 remediation project (Ref. 2) are:

Phase I

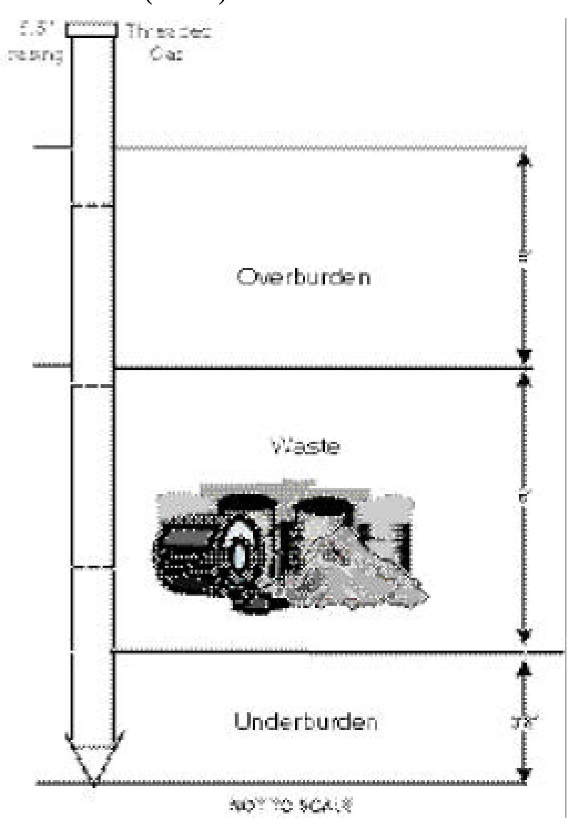
- Surface geophysical mapping and records review
- Subsurface exploration and down hole logging

Phase II

- Core sampling and sample characterization
- Treatability studies

The planned probing and coring project is part of the subsurface exploration activity. The methods chosen to perform a subsurface exploration include using a sonic drill rig to install cased probeholes into the soil and waste for downhole radiation logging efforts. Based on the results of the downhole logging, and using the sonic drill rig, cores will be drilled into the waste to retrieve core barrel samples for contaminant analysis and treatability studies. In particular, the subsurface exploration program should obtain data to bench-scale waste treatability investigations; perform char-

Figure 2-9. Cased probehole conceptual design. (Ref. 2)



acterization studies; and, in general, identify envi-

with remediation of Pit 9.

The casing used in the probing phase will be a

maximum of 5.5-inch outer diameter. The probe will penetrate the overburden, waste, and

None of the probeholes is expected to exceed 25 feet. Some 18 probeholes on approximately 6-feet

waste to the top of the basalt or until refusal, as illustrated in Figure 2-9. The probeholes will be

a nearly vertical hole to accommodate the instrumentation required to perform the desired mea-

believe that the in-situ logging methods will likely detect TRU contaminated waste with sufficient

confirm the acceptability of the location for the Stage II retrieval. Numerous logging methods are

- Passive gamma-ray spectrometry to assist in

- Prompt gamma surveys to identify chlori-

- Passive neutron surveys to identify fission-

- Active neutron surveys for enhanced detec-

When the logging is completed, the probeholes will be capped or backfilled.

six coreholes (or more as required to meet programmatic requirements) will be sited at differ-

assaying, and analyzing sections of the core. Among the desired properties of the corehole lo-

1. Maximum concentrations of TRU radionu-

   waste

2.
3. Contact handled waste (less than 200 mrem/

4. Absence of large metal objects

   The opportunity to obtain cores that contain at least 10 nCi/g TRU radionuclides, some

   waste forms

Sonic coring was chosen partly to minimize soil compaction and disturbance and to prevent contaminated soil and waste from being brought to the surface. Sonic coring methods have been used for previous investigations at the Idaho site. Figure 2-10 illustrates the material to be penetrated, average depths involved, sample intervals, and drilling dimensions.

Approximately two liters of soil are required to conduct the chemical treatment tests and as much as 7 feet^3 are required to conduct the physical separation treatability study. Collection of soil that can be contact handled (less than 200 mrem/hour on contact) is a requirement for Stage I. Soil that is retrieved that exceeds this 200 mrem/hour will be returned to the corehole and the corehole backfilled with granular bentonite.

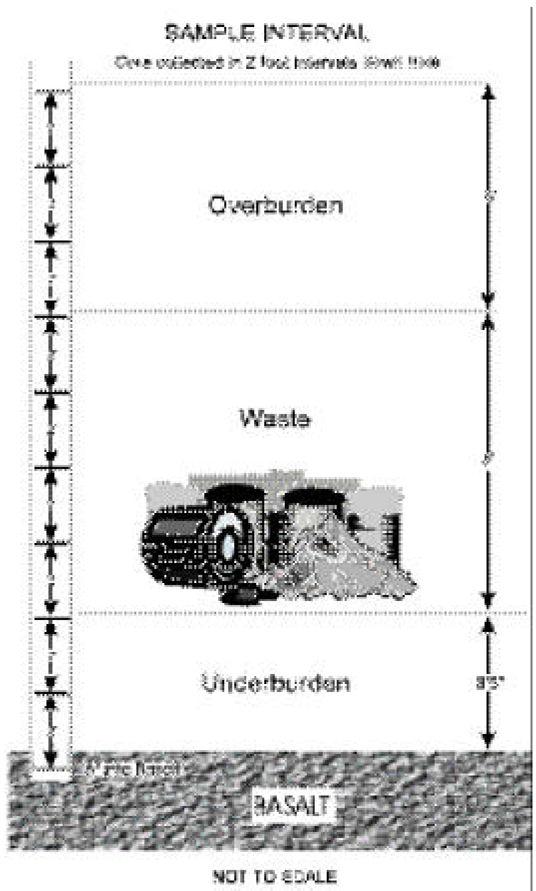
3.0 SAFETY CONCERNS

Extensive safety studies have been performed by DOE and its contractors on the proposed stages of the Alternative Pit 9 remediation project. These studies have addressed the hazards and accidents associated with such issues as radiation, criticality, toxic chemicals, fires, explosions, and natural phenomena. The Panel has reviewed many of these studies and finds that the methods employed and the depth of the analyses are consistent with good practices in safety analysis. Since most of the studies appear reasonable in scope and conclusions, the Panel has focused on those safety concerns considered unusual or unprecedented. The safety concern most prominent in this regard relates to the subsurface exploration program of Pit 9; and in particular, the safety of its sonic probing and coring operation.

The specific safety issue is the likelihood that the oscillating forces and radial flow caused by the drilling tip during resonant sonic drilling would create sufficient shock waves or elevated temperatures to initiate either an explosion or fire in the drilling media, and thus, create pathways for significant radiological releases.

The specific safety issue is the likelihood that the resonant sonic drilling would create an explosion or fire and thus create pathways for significant radiological releases.

Figure 2-10. Corehole conceptual design. (Ref. 2)



The resonant sonic drilling method, which includes both probing and coring, is relatively new in the field of environmental contamination assessment (Ref. 11). Resonant sonic drilling is a hydraulically-driven system. A sonic drill head generates a series of high frequency, sinusoidal wave vibrations into a steel drill pipe to create the cutting action at the bit face. Sonic drilling eliminates cuttings from the drilling process; produces continuous and relatively undisturbed cores; penetrates most materials at high speed; and requires no air, mud, water, or other circulating medium for penetration. These advantages have the potential to reduce "secondary" contaminated waste generation and lower worker exposures. Some of the disadvantages are higher cost, limitations on hole-depth (which is not a concern in the Pit 9 application), and sonic shock waves that may result in elevated temperatures under refusal conditions. The latter issue is the primary concern of sonic drilling in Pit 9 because of the possibility of igniting combustible materials in the pit, or worse, initiating an explosion in mixtures of nitrates, organic liquids, or graphite.

An important question in assessing the safety of the probing and coring operations is therefore understanding how much of the power delivered to the drill bit is transformed into heat. This transformation of energy into heat determines the temperature at the soil-drill interface and, therefore, the potential for igniting nitrate, organic, and graphite mixtures. The waste media of concern are nitrates, graphite, and petroleum products.

To evaluate the issue of heat generation from sonic drilling, the Panel made conservative calculations of the heat transferred to the soil during normal drilling. The Panel also had a drilling expert evaluate the available test data and pro-

transfer during drilling operations (Appendix G). Based on these analyses and calculations, the

the drill bit during anticipated drilling conditions will be on the order of a few tens of degrees Cen-

terface temperature can be maintained below 150°C providing there is strict adherence to "re-

The sonic drill rig to be used on Pit 9 is a Hawker Siddley Super Drill, 150 (Series 2) and is

trolled rig. The major components of the drill rig system are drill head, drill stinger, power pack,

force output is 30,000 pounds at 120 Hz. This rig

respond to safety issues. An example of a safety

enclosure around the drill string. The drill

protection against events involving the release of

ticulate contamination during the drilling and

tions. A procedural example is the decision to

approximately 50 feet from the drill string. This

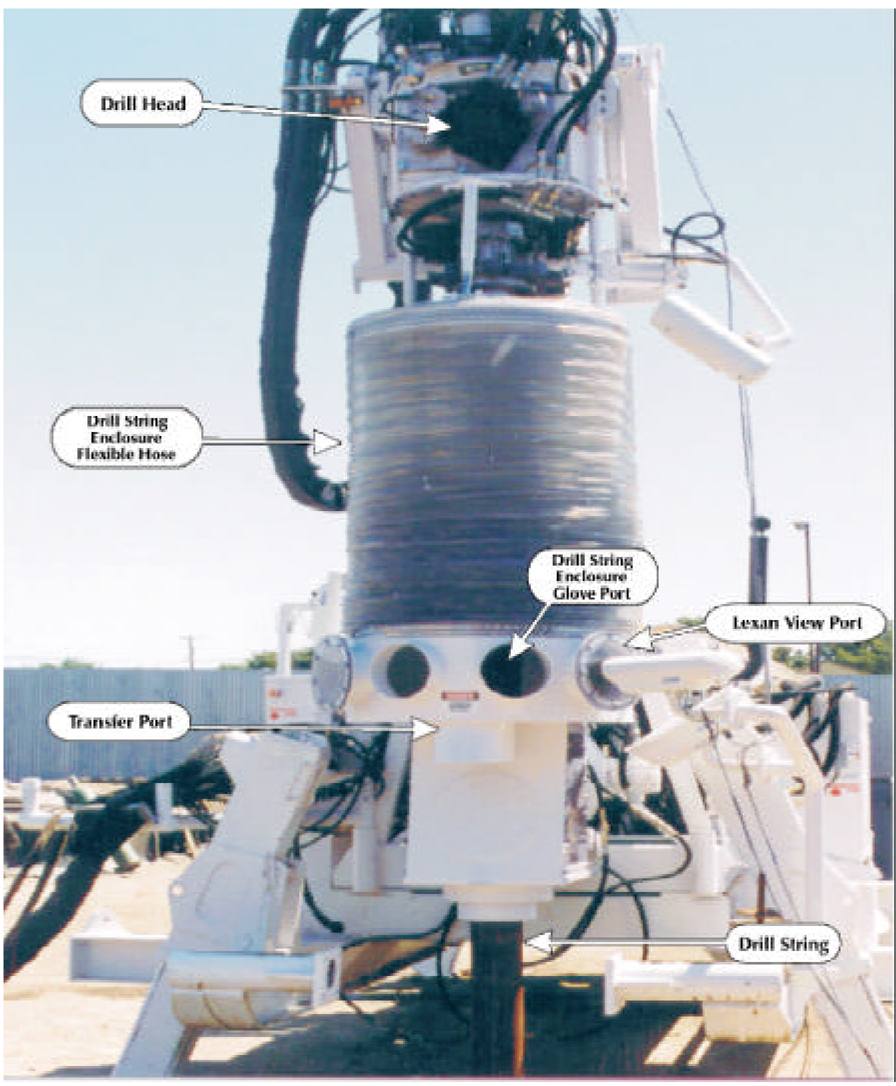
tion against more contamination spreading

explosions. Other procedural examples include

drill bit at refusal and limits on sonic frequency.

prototype drill string enclosure are shown in Fig-

Figure 3-1.



4.0 SCENARIO DEVELOPMENT

The Panel developed six scenarios to evaluate the risk of explosion or fire initiated by the resonant sonic drill. Much of the scenario development was driven by postulating conditions that would allow a reasonable bounding of the energy transformation that takes place during the coring operations. There are some concerns that the Panel initially evaluated and determined as not credible. In these instances, no scenario was developed for further evaluation of the concern. Among those concerns determined not credible are: (1) 745-sludge may contain 10% organics, (2) nitrates from 745-sludge may mix with alcohols, organic acids, and EDTA in the 744-sludge, and (3) nitrates from 745-sludge may mix with other organics such as butyl alcohol, xylenes, and acetone.

Six Scenarios for Evaluation

- Drilling into a mixture of nitrate salts and hydrocarbon oils
- Drilling into a mixture of nitrate salts and graphite
- Drilling into a mixture of nitrate salts and cellulose (wood/paper)
- Drilling into an intact drum containing hydrogen
- Drilling into potentially pyrophoric or reactive materials, e.g., zirconium and depleted uranium; containers of picric acid, and lithium batteries
- Drilling into pressurized cylinders containing a flammable gas

Given the time which has elapsed since Pit 9 was closed (approximately 30 years), most, if not all, of the drums will have lost their integrity (Refs. 12 and 13). Consequently, the possibility exists that the contents of drums in close proximity may have become mixed to some degree. Of specific concern is sonic drilling into mixtures of 745-sludge (sodium nitrate/potassium nitrate:2/1) and organic fuels (cutting oils from 743-sludge, graphite fines, wood from wooden crates, alcohols, organic acids, and EDTA) since certain mixtures of nitrates and organic fuels are commonly used as blasting explosives, such as ammonium nitrate/fuel oil (ANFO).

The Panel evaluated the possible nitrate/organic mixtures and, for the reasons described, concluded that some needed no further evaluation. First, the possibility that 745-sludge contained 10% organic material, as implied in the Record of Decision, initially received significant Panel review and evaluation. The Panel evaluated several sources of information concerning the composition of the 745-nitrate sludges, including information provided by DOE on the waste buried in Pit 9, consultation with an expert on the Rocky Flats waste processing operations (Appendix F) and testing of actual 745-sludge by Brookhaven National Laboratory (Appendix D). Based upon its evaluations, the Panel determined that the description in the Record of Decision of the “10% miscellaneous” component is in error. Rather than containing 10% of combustible organics, that component of the 745-sludge was found to consist largely of other salts including chlorides, sulfates, phosphates, water, and only 1% total organic carbon. This finding supports the determination that the sonic drill cannot encounter a single drum containing both nitrate salts and combustible organics sufficient to be concerned about an explosion.

Second, for the concern that nitrates from 745-sludge may mix with organics in the 744-sludge, the alcohols, organic acids, and EDTA were mixed with Portland and magnesia cements, then covered with more Portland cement to form the 744-sludge (Ref. 14). In such a matrix, the organic acids would be tightly bound to the alkaline cement and the water-soluble alcohols would be solvated in the matrix like water. This would preclude their migration into nitrate sludge to form an explosive mixture.

Third, although other organic compounds, such as butyl alcohol, xylenes, and acetone, are reported to be in Pit 9, the quantities are in parts per million and are of no concern because that level of concentration is insufficient to form a detonable mixture with the nitrate sludge (Refs. 15 and 16).

The Panel identified three scenarios involving possible nitrate/organic mixtures. These scenarios are: oils from the 743-sludge (Scenario 1), graphite fines or particles in the drums with graphite molds (Scenario 2), and cellulosic materials, such as wood and paperboard (Scenario 3).

The mechanism for the oils to mix with nitrates is for a drum of 743-sludge to be stacked on top of a drum of 745-sludge, and both drums breached such that the oil percolates through the nitrates to form a potentially detonable mixture. For the other two scenarios, the nitrates would have to dissolve in water and the resulting solution coat the graphite particles or soak into the wood. The water would then have to evaporate for either the graphite particles or wood to form a shock or friction sensitive mixture. The latter two possibilities are much less likely than the nitrate/oil scenario because of the sequential requirements for intimate mixing of a sufficient amount of oxidizer to form a potentially explosive mixture. In addition, the expected moisture content of the pit will not allow the subsequent mixtures to become dry enough to form shock or friction sensitive mixtures (Ref. 17). The average moisture content measured in the SDA varies from 17-28vol% for the waste burial depth (Ref. 18). Moreover, virtually no chlorinated organic-free oil exists in any of the organic sludge. Organic chloride solvents are all fire suppressants and thus the pure oil/nitrate mixture is clearly a bounding scenario.

Nitrate salts are classified as oxidizing agents and, as such, they can support the combustion of other materials. The nitrate salts for scenarios 1, 2, and 3 are of particular concern in the subsurface environment of Pit 9 because they can liberate oxygen to an otherwise anaerobic environment. Introduction of the sonic drill into a potentially explosive or combustible material or mixture could then provide the needed energy of activation.

Scenario 4 is drilling into an intact drum containing hydrogen. Since many waste drums contained radioactive material and organics, and there has been a history of hydrogen gas in waste drums, this scenario was included. The Panel also addressed concerns about drilling into potentially pyrophoric material such as zirconium, and potentially reactive materials such as picric acid and lithium batteries. The waste burial records reflect that this material was either buried or may have been buried in Pit 9, thus drilling into this material was selected as scenario 5. Finally, individuals stated they observed disposal of gas cylinders during the period that Pit 9 was operating. The Panel concluded that drilling into a pressurized cylinder containing flammable gas was a reasonable bounding scenario and thus included it as scenario 6.

The six scenarios are summarized in Table 4-1. The key distinction between the scenarios involves the presence of the nitrate salts. The hydrocarbon oils, cellulosic materials, and graphite have a much greater ability to act as fuels in nitrate enhanced reactions, and the Panel considered scenarios 1 through 3 to be clearly more important than the other scenarios.

Table 4-1. Description of scenarios.

SCENARIO	DESCRIPTION
1. Drilling into a mixture of nitrate salts and hydrocarbon oils.	Drums containing sodium and potassium nitrates and hydrocarbon oils and chlorinated solvents were disposed into Pit 9. The potential for the drill to encounter a mixture of nitrates and combustible organics does exist.
2. Drilling into a mixture of nitrate salts and graphite.	Graphite (mainly in the form of chunks and large pieces) was also placed into drums and disposed into Pit 9. There is the potential for the sonic drill to encounter a mixture of nitrate salts and graphite.
3. Drilling into a mixture of nitrate salts and cellulose (wood/paper).	Large quantities of wood and paperboard containers were disposed into Pit 9 permitting the possible encounter of nitrate salts and cellulosic-based materials.
4. Drilling into an intact drum containing hydrogen.	Hydrogen can be produced through radiolytic decomposition of organic materials. There is the potential for the production of hydrogen and other gases.
5. Drilling into potentially pyrophoric or reactive materials, e.g., zirconium and depleted uranium; containers of picric acid, and lithium batteries.	There is documentation and, in some cases, concerns that these materials were placed in Pit 9.
6. Drilling into pressurized cylinders containing a flammable gas.	While no documentation exists which supports the disposal of pressurized gas cylinders, this possibility was considered to be credible.

For a sufficiently energetic reaction to occur, the following conditions must be satisfied:

- The presence of oxygen, or other oxidizers, such as the nitrate salts, and the potentially reactive material in near stoichiometric proportions and amounts sufficient to release enough energy to provide the transport of radionuclides to the surface.
- Good mixing of reactants. The state of the reactants has a large impact on the feasibility of attaining good mixing conditions, especially when the materials are all in the solid state, e.g., nitrate salts and graphite chunks, or nitrate salts and wooden boxes.
- Sufficient absence of moisture. The sensitivity of potentially explosive mixtures can vary dramatically depending on moisture content.
- Sufficient energy of activation provided by the sonic drill in the form of heat or shock.

These conditions were used as a basis for evaluation of the scenarios.

5.0 SUPPORTING EVIDENCE FOR EVALUATING SCENARIOS

In order to obtain the information needed to evaluate the scenarios, the Panel initially met with DOE-ID and supporting contractor personnel involved in planning and evaluating the Alternative Pit 9 Stage I and Stage II interim action. This meeting was held at the Idaho site, and included a tour of Pit 9 and the sonic drill rig at the RWMC. The Panel received formal presentations that included the background of the burials at Pit 9, overall approach for Pit 9 characterization and remediation, and planned sonic drilling approach. The Panel also had presentations from some of the individuals who had concerns about the proposed sonic drilling. A list of presentations is included in the References section of this report.

The Panel reviewed detailed documentation that included such material as the history of previous burial retrieval efforts, the sonic drill rig design and operating procedures, and the results of the Record of Decision for the Pit 9 interim action. Calculations were done on soil heating from sonic drilling and on radiation dose from potentially ejected contaminants. Additional important documents reviewed by the Panel include the Stage I Plan, Phase II Safety Assessment, and Health and Safety Plan for the OU 7-10 Staged Interim Action Project Stage I Subsurface Investigation (Refs. 2, 15, 19).

Three expert consultants assisted the Panel in evaluating the safety issues and concerns. These consultants included a drilling expert, a process engineer with detailed knowledge of the Rocky Flats Plant operations, and an explosives safety expert. The sonic drilling experts provided information on the magnitude of the heat rate produced at the drill bit-soil interface. The process engineer was an individual with detailed knowledge of the waste stream operations at Rocky Flats and clarified the waste material processes so that questions related to the content of the buried sludges could be evaluated. The explosive expert participated in interviews and briefings concerning the possibility of explosions, reviewed available information, and helped design explosion initiation and cook-off tests. This expert also explored the concern of explosive nitrates with members of the Department of Defense Explosive Safety Board. Reports prepared for the Panel are included in the Appendices.

Most importantly, after reviewing the available information and scientific data, the Panel concluded that conducting tests on surrogate waste material or actual sludge material was the most effective way to address significant unknowns associated with the planned activities at Pit 9. The Panel identified a series of tests––small-scale tests at the Los Alamos National Laboratory (Appendix C) and Brookhaven National Laboratory (Appendix D), and larger-scale explosion initiation tests by Sudhakar Company, Inc. (Appendix E) at a private explosive testing range near College Station, Texas. Explosive experts from Los Alamos National Laboratory provided theoretical interpretation of explosion initiation, and calculations of explosive performance. The results of the small- and larger-scale tests are key inputs for evaluating the nitrate scenarios.

6.0 EVALUATION OF EXPLOSION SCENARIOS

6.1 EXPERIMENTAL AND HISTORICAL EXPLOSION DATA

The Los Alamos tests included differential scanning calorimetry (DSC) analyses and sensitivity tests on surrogate mixtures. DSC measures the evolution of heat (exotherm) and the absorption of heat (endotherm) as the temperature is programmed from 25°C to 400°C. In DSC analyses, the observation of an exotherm would indicate that a large quantity of the material may decompose violently and possibly transition into a deflagration or an explosion. (See Appendix D for details on the theory of DSC). The sensitivity tests measured the sensitivity of the surrogate mixtures to explosion from impact and friction.

The Los Alamos tests were conducted on the following mixtures: (1) a surrogate 745-sludge, (2) a CO_2-balanced[1] nitrate/Regal R&O 32 oil mixture (13wt% oil), (3) a nitrate/Regal oil mixture (9wt% oil) that was 30% nitrate-rich, (4) a CO_2-balanced mixture of nitrates with graphite powder, and (5) an oven-dried sample of sawdust soaked in a saturated solution of nitrates. These specific mixtures were chosen because they were considered to be the most sensitive to initiation.

[1] A CO_2-balanced mixture of oxidizer and fuel is one in which sufficient oxidizer is present to convert all of the carbon in the fuel to carbon dioxide and all of the hydrogen in the fuel to water. This mixture yields the maximum explosive force.

The results of the Los Alamos DSC, impact sensitivity, and friction sensitivity tests (Appendix C) are summarized in Table 6-1, along with available literature values for ANFO and black powder (Ref. 20, 21). The DSC tests showed no exothermic decomposition below 400°C for the nitrate/oil mixtures and nitrate/graphite mixture. The nitrate/sawdust mixture showed exothermic decomposition above 300°C. None of the mixtures exhibited any sensitivity to impact or friction. The fact that none of the mixtures gave any positive event to the sensitivity testing, even at the limitations of the testing equipment, indicated that if the mixtures were explosive at all, the stimulus required to initiate them would be extreme.

Brookhaven National Laboratory also performed DSC analyses, but on a sample of the actual 745-sludge and on mixtures of the sludge with the Regal R&O 32 oil, graphite, and sawdust in the same proportions as in the Los Alamos study. No exothermic reactions were observed in the sludge itself, sludge/oil mixtures, or sludge/graphite mixtures below 400°C. The sludge/sawdust mixture showed an exotherm beginning at 300°C. The study is included as Appendix D. The Brookhaven results on the actual 745-sludge are in good agreement with the Los Alamos results on the surrogate sludge. Thus, the Panel concluded it is beyond extremely unlikely for these mixtures to be initiated by impact, friction, or transient temperatures below 300°C.

Table 6-1. Los Alamos test results.

Composition	DSC Onset of Melting (°C)	DSC Onset of Decomposition (°C)	Type 12 Impact Sensitivity (cm), 50% point (2.5 kg Weight)	Friction Sensitivity 50% Load (kg)
Nitrates (NaNO3/KNO3:2/1)	217	None	N/A	N/A
Nitrates/Oil:91:9	217	None	>320*	>36.0***
Nitrates/Oil: 87/13	216	None	>320*	>36.0***
Nitrates/Graphite: 71/29	218	None	>320*	>36.0***
Nitrates/Sawdust: 62.5/37.5	216 & 335	306	>320*	>36.0***
Standard	N/A	N/A	24.8 (HMX)	8.4 (PETN)
ANFO	160	160	>320**	>36.0***
Black Powder	126	275	49–66****	No Reaction

* Thirteen consecutive “no goes” at 320 cm., the maximum height of the test.

** One explosion out of 10 drops at 320 cm. [Reference: Craig, B. G., Johnson, J. N., Mader, C.L., and Lederman, G. F., “Characterization of Two Commercial Explosives,” *Los Alamos Technical Report LA-7140* (1978).]. Ref. 23

*** Thirteen consecutive “no goes” at 36.0 kg.

**** Obtained with a 2.0 kg weight: 49 cm for KNO_3 black powder, 66 cm for $NaNO_3$ black powder [Reference: Fedoroff, B. T. and Sheffield, O. E., “Encyclopedia of Explosives and Related Items,” *Picatinny Arsonal Technical Report 2700*, Volume 2 (1962).]. Ref. 23B

Based upon the results of the Los Alamos small-scale safety tests, the Panel designed some large-scale explosion initiation tests to bound the explosiveness of the potential mixtures in Pit 9. Sudhakar Company performed the large-scale explosion initiation tests on surrogate nitrate/oil mixtures and surrogate nitrate/graphite mixtures (Appendix E). A cook-off test, which is subjecting a potential explosive to a fire, was also performed on a surrogate nitrate/oil mixture to see if a thermal explosion or deflagration would occur.

Three series of explosive testing were performed. A typical setup for the explosion initiation test is shown in Figure 6-2. The first series of tests was performed to establish a baseline using ammonium nitrate, a known industry standard (tests 1 and 2), and table salt (a known

Figure 6-2. Series of pictures showing preparation of test explosions.

Figure 6-3. Crater following initiation of test 5.

Figure 6-4. Setup for cook-off test.

Figure 6-5. White smoke from nitrate burning in cook-off test.

Unburned nitrate residue after cook-off test.

non-explosive salt) and regal oil (test 3). The second series of tests was performed using a nitrate/oil surrogate, with both a dry mixture and a mixture with 10wt% moisture content (tests 4, 5, 6, and 7). The third series of tests involved surrogate nitrate/oil samples with 5wt% moisture content (tests 8 and 10) and surrogate nitrate/graphite samples (tests 9 and 11).

In the second series of Sudhakar tests, 3-kilogram charges of the dry sodium nitrate/potassium nitrate/Regal 32 oil:60/30/10 were subjected to initiation with a blasting cap alone (test 4) and with a one-third pound Pentolite (PETN/TNT:50/50) booster initiated with a blasting cap (test 5). The blasting cap failed to initiate the charge, but the Pentolite booster initiated the mixture to give a crater about two-thirds the size of that obtained with an equivalent charge of ammonium nitrate/fuel oil (ANFO) (Figure 6-3). Next, an identical mixture containing 10wt% water was subjected to initiation with a Pentolite booster (test 6). This moisture content was selected since the moisture data for the SDA area averaged 17–28vol% (approximately 8-14wt%) (Ref. 18). In this test, the mixture did not contribute to the explosion, even with the use of the Pentolite booster.

Also, as part of the second series of tests, a 3-kg charge of the sodium nitrate/potassium nitrate/Regal 32 oil:60/30/10 mixture was subjected to a cook-off test or diesel fuel fire (test 7). The setup for the cook-off test is shown in Figure 6-4. The mixture did not explode or deflagrate. Over about a 20-minute period the burn produced a dark smoke indicating that the oil in the mixture was burning, then the container fell and spilled its contents into the fire. At this point the nitrates began burning to produce a white smoke as shown in Figure 6-5. After about 45 minutes, the fire had diminished to the smoldering stage and was extinguished. There was some unburned nitrate residue remaining as shown in Figure 6-6.

Since no contribution occurred with the 10wt% moisture content, the Panel decided to conduct a third series of tests using 5wt% moisture content (tests 8 and 10) and dry graphite (tests 9 and 11) to further bound the potential to have an explosive mixture in Pit 9. Pentolite boosters initiated with blasting caps were used on the two samples with 5wt% moisture. In both tests, there was no contribution to the explosion. It is important to note that although the Brookhaven National Laboratory analysis shows the moisture content of the 745-sludge to be less than 5wt% (1.8wt%) (Ref. 10), buried drums must be breached in order for a potential explosive mixture to be formed. Once the drums are breached, the nitrates will be hydrated with time to at least the extent of moisture in Pit 9, which is expected to be greater than 5wt%. Since the salts are hygroscopic and water soluble, they will hold the moisture more tenaciously than the surrounding soil.

Table 6-7. Pit 9 detonation test summary.

Test Number*	Sample Composition	System Initiation	Observed Results
1	Ammonium nitrate	Blasting cap and Pentolite booster	Partial energetic reaction (minor cratering)
2	Ammonium nitrate 94% and diesel fuel 6%	Blasting cap and Pentolite booster	Energetic reaction. This is an industry standard for earth blasting
3	Table salt 90% and Regal oil 10%	Blasting cap and Pentolite booster	No energetic reaction
4	Surrogate nitrate/ oil mix	Blasting cap	No energetic reaction
5	Surrogate nitrate/ oil mix	Blasting cap and Pentolite booster	Energetic reaction at about 2/3 the cratering of test 2
6	Surrogate nitrate/oil mix with 10wt% moisture	Blasting cap and Pentolite booster	No energetic reaction
7	Surrogate nitrate/ oil mix	Wood, diesel fuel and smokeless powder	No energetic reaction Oil burned when nitrates decomposed
8	Surrogate nitrate/oil mix with 5wt% moisture	Blasting cap and Pentolite booster	No energetic reaction
9	Surrogate nitrate/ graphite mix	Blasting cap	No energetic reaction
10	Surrogate nitrate/oil mix with 5wt% moisture	Blasting cap and Pentolite booster	No energetic reaction
11	Surrogate nitrate/ graphite mix	Blasting cap and Pentolite booster	No energetic reaction Some burning of the graphite

* This is the sequence in which the tests were performed.

Finally, as part of the third series of tests, CO_2-balanced mixtures of the nitrates with graphite (sodium nitrate/potassium nitrate/graphite:47.3/23.7/29) could not be initiated by either the blasting cap or the Pentolite booster (tests 9 and 11).

Detonation tests with nitrate/cellulosic mixtures were not performed because a situation in which nitrate soaked crates could be compressed to give a critical diameter to support a detonation could not be identified. However, since the nitrate/cellulosic mixtures could burn in a fire, this was evaluated as part of the fire scenarios. A summary of test results is given in Table 6-7.

6.2 ASSESSMENT OF EXPLOSION INITIATION TESTS

The dry nitrate/oil mixture could not be initiated with a Number 8 blasting cap, but it was initiated with a one-third pound Pentolite booster to give a crater approximately two-thirds the size of that created by an equivalent charge of ANFO. The latter observation is in reasonable agreement with Cheetah code calculations (Ref. 22) that predict a detonation pressure for the surrogate nitrate/oil mixture to be about one-half that of ANFO (Ref. 23). Although the detonation pressure of both the blasting cap and the Pentolite booster are comparable, insensitive non-ideal explosives like ANFO (Ref. 24) and the tested nitrate/oil mixture require a sustained initiation pressure, which is proportional to the weight of explosive in the initiator. For example, in the minimum-priming test for characterizing explosives, the weight of the booster is systematically reduced until the charge fails to propagate (Ref. 25).

Up to a limit, the weight of the booster is more important than its detonation pressure for initiation of insensitive non-ideal explosives, such as ANFO and the nitrate/oil mixture tested. These poorly performing explosives have detonation pressures of 20 to 50 kbar and will boost themselves only if the explosive material is present in very large amounts (several pounds or more). The lateral loading from a detonating column of a non-ideal explosive is about half its axial detonation pressure (Ref. 26). For a detonation to spread from a finite source, the explosive must be able to respond to about half its own detonation pressure within the duration of the shock loading pulse from the source (seldom more than a few microseconds). A realistic estimate of the minimum shock initiation pressure of mixtures of the 745-sludge nitrates with fuels is about 10 kbar (150,000 psi) and a conservative estimate is 5 kbar (75,000 psi) (Ref. 27). The drill pipe will never reach a point of resonance drilling within the depth of Pit 9 and will achieve a maximum force of 35,000 pounds at 120 Hz (Ref. 28). A subsequent value of 30,000 pounds was provided for the maximum dynamic force output achievable by the sonic drill to be used in Pit 9 (Ref. 29). The area of the 5.5-inch diameter conical probe face is 37 $inches^2$ and that of the beveled coring bit is 31.9 $inches^2$. Thus, a maximum shock pressure of about 810 psi (30,000 pounds/37 $inches^2$) could be generated by the sonic drill in the nitrate/oil mixture during 5.5-inch diameter probe emplacement. For coring, a maximum shock pressure of 940 psi (30,000 pounds/31.9 $inches^2$) could be achieved in the nitrate/oil mixture. The Panel concludes that the maximum shock pressure from sonic drilling in the nitrate/oil mixture in the Pit 9 waste will not exceed 1,000 psi. While higher pressures may be experienced during probing operations when the blunted probe tip hits bedrock, even that pressure is several times smaller than the conservative initiation pressure and would occur several feet below the potential nitrate/oil mixtures. Thus, a safety margin of about two orders of magnitude exists between the maximum pressure achievable by the sonic drill and the pressure necessary for detonation of the dry nitrate/oil mixture.

The results of the nitrate/graphite tests demonstrate conclusively that such mixtures do not have initiation characteristics comparable to those of black powder.

6.3 ASSESSMENT OF SCENARIOS

Scenario 1 – The nitrate/oil mixtures were found to be insensitive to impact, friction, and transient temperatures below 400°C in the Los Alamos tests and the actual 745-sludge/oil mixtures failed to exhibit an exothermic reaction below 400°C in the Brookhaven DSC tests. Although the dry surrogate nitrate/oil mixture can be initiated with a one-third pound Pentolite booster, a safety margin of about two orders of magnitude exists between the maximum pressure achievable by the sonic drill and the pressure necessary for detonation of the dry nitrate/oil mixture. It is reasonable to assume that if the drums are breached such that mixtures of nitrates and fuels can form, then the moisture level of the nitrates will reach at least the moisture level of the surrounding soil. Since the nitrates are water soluble and hygroscopic, they will not desiccate as rapidly as the surrounding soil. The surrogate nitrate/oil mixtures containing 5wt% water are not detonable. The surrogate nitrates are very similar to the actual 745-sludge according to a comparison of the Los Alamos and Brookhaven DSC tests. Thus, an explosion resulting from sonic drilling into any dry nitrate/oil mixture in Pit 9 is extremely unlikely, but beyond extremely unlikely if the moisture content is greater than 5wt%.

Scenario 2 – The CO_2-balanced mixtures of the nitrates with graphite (sodium nitrate/potassium nitrate/graphite:47.3/23.7/29) could not be initiated with the Pentolite booster and are not sensitive to impact, friction, or transient temperatures below 400°C. Therefore, an explosion resulting from sonic drilling into such a mixture in Pit 9 is beyond extremely unlikely.

Scenario 3 – Mixtures of nitrates with sawdust are not sensitive to impact, friction, or transient temperatures below 300°C and a situation in which nitrate soaked wooden crates could be compressed to give a critical diameter to support a detonation could not be identified. Thus, an explosion resulting from sonic drilling into a nitrate/cellulosic mixture in Pit 9 is beyond extremely unlikely if the temperature of the soil-drill interface is maintained below 150°C. The Panel recommends that the soil-drill interface temperature be maintained below 150°C for two reasons. First, this provides an additional margin of safety from the observed 306°C exothermic decomposition reaction temperature and is below the ignition temperature of cellulosic material. Second, this also helps reduce the potential that the drill bit temperature will be a source of energy that could evaporate the moisture content in any nitrate/oil mixture.

Scenario 4 – Although mixtures of hydrogen and oxygen can be explosive if the proper concentrations and an ignition source exist, it is extremely unlikely that sufficient amounts of these gases are present in Pit 9 to eject material. Thus, an explosion sufficient to release radionuclides into the atmosphere is extremely unlikely.

Scenario 5 – Sonic drilling into pyrophoric materials or lithium batteries cannot lead to an explosion because oxidation of these materials cannot form gaseous products. Drilling into a bottle of picric acid may cause an explosion, but the amounts presumed present (~1 pound) cannot lead to cratering of Pit 9. Thus, an explosion sufficient to release radionuclides into the atmosphere from this scenario is extremely unlikely.

Scenario 6 – In the event that the sonic drill encountered a pressurized gas cylinder containing a fuel such as hydrogen or acetylene, the initiation of an explosion would require the presence of oxygen or the formation of oxygen from the decomposition of nitrate salts, which will not occur in the expected anaerobic subsurface environment of Pit 9. The Panel concludes that an explosion to release radionuclides into the atmosphere is extremely unlikely.

The Panel has concluded that an explosion from sonic drilling into any nitrate/fuel mixture in Pit 9 is beyond extremely unlikely if the moisture content is greater than 5wt% and the soil-drill interface temperature is maintained below 150°C. If the moisture content is less than 5wt%, an explosion is extremely unlikely. Therefore, the project should demonstrate overburden moisture levels in excess of 5wt% prior to probing below the overburden layer. For the other scenarios, the Panel concludes that an explosion sufficient to release radionuclides into the atmosphere is extremely unlikely.

7.0 EVALUATION OF FIRE SCENARIOS

The Panel addressed the potential for subsurface fires initiated by the resonant sonic drill during the probe installation and sample core collection tasks of Stage I, Phase I and II. Of special importance is the ability of the nitrate salts to liberate oxygen and thereby support the combustion of fuels (such as the cutting oils) in the case of a potential subsurface fire. With respect to the Stage I activities where subsurface conditions can be anticipated to be predominantly largely anaerobic,* the Panel categorized the six scenarios in Table 4-1 into two groups—those that involve nitrates (Scenarios 1, 2, and 3) and those where nitrate salts are not present (Scenarios 4, 5, and 6).

* Anaerobic means processes that take place in the absence of molecular oxygen.

7.1 ASSESSMENT OF SCENARIOS

The first group of scenarios involves the sonic drill encountering a mixture of nitrate salts and hydrocarbon oils, graphite, or cellulosic-based material (wooden and paperboard containers). The nitrates have been explicitly incorporated into these scenarios because (1) the organics are much better fuels than the other solid or liquid materials known or suspected to be in the area targeted for investigation, and (2) the sonic drill is more likely to encounter such "mixtures" given their known quantities placed in the targeted investigation area.

Scenario 1 – Of the three scenarios involving nitrates and different potential fuels, Scenario 1 (drilling into a mixture of nitrate salts and hydrocarbon oils) addresses the most likely situation where the reactants (nitrates and oils) could be sufficiently mixed that an energetic event is possible. This is because the quantities of both the nitrates and oils disposed are substantial, and the fact that the oils are liquids and therefore mobile. The Panel evaluated the DSC test results on nitrate/oil mixtures, which were conducted at Los Alamos and Brookhaven. Neither test showed exotherms below 400°C. Moreover, in the Sudhakar study, a cook-off test (test 7) was performed using surrogate nitrates and Regal 32 oil. The materials were observed to react separately, with the nitrates only reacting when the mixture encountered the flame. This demonstrates that the oils would combust first and underscores the need for sufficient oxygen to support combustion of the oils until the nitrates can decompose to provide additional oxygen. The subsurface environment of Pit 9 is expected to be largely anaerobic and the decomposition temperature of the nitrates exceeds 400°C. Consequently, the Panel concludes that the risk of a subsurface fire for this scenario is extremely unlikely.

Scenario 2 – This scenario involves drilling into a mixture of nitrate salts and graphite. The Panel evaluated the Los Alamos DSC test results on nitrate/graphite fines. No exotherms were observed below the 400°C limit of the test. Additionally, the Panel evaluated the analysis that DOE-ID and its contractor conducted on the combustion scenarios involving graphite organic materials and nitrates during subsurface drilling in Pit 9 (Ref. 30). Based on an event tree probabilistic evaluation, which included the impacts of temperature, moisture content and other factors, the Beitel analysis in Reference 30 concluded that the probability of a graphite fire was beyond extremely unlikely. The Panel reviewed the assumptions and analysis and agrees with the conclusion. However, since the Panel did not conduct independent testing for evaluating this scenario, the risk of fire for this scenario is concluded to be extremely unlikely.

Scenario 3 – Drilling into a mixture of nitrate salts and cellulose is an appropriate scenario for evaluation for Pit 9 as a whole, although these materials are not expected to be encountered in the Stage I characterization. While cellulosic material would normally be considered to be an excellent fuel, three important factors affect the likelihood of a potential fire initiated by the sonic drill:

- Sufficient mixing
- Ignition source
- Sufficient oxygen

The nitrate salts would need to mix with the cellulosic material either as a aqueous solution or through the action of the drill bit. Additionally, the drill bit would need to supply the ignition energy equivalent to a temperature of approximately 215°C or greater (Ref. 31) and oxygen would need to be present either in the soil as soil gas or produced through the decomposition of the nitrate salts.

Given the 30 years since Pit 9 was closed, together with the occurrence of two flooding events while the pit was still open, the wooden and paperboard containers are expected to be well deteriorated with a low potential to react. Observations reported during early drum retrieval efforts in the late '70s support this expectation (Ref. 32). Notwithstanding the expected condition of the containers, the Panel concludes that the drill bit temperature will be well below that needed to cause nitrate decomposition. Consequently, oxygen will not be present to support combustion. The Panel concludes that the risk of fire with this scenario, during Stage I characterization, is extremely unlikely.

The second group of scenarios involved the sonic drill encountering a number of completely different types of material than the first group. A key factor in these scenarios is the physical characteristics of the potential material to be encountered during the sonic drilling, the extremely small amount of the material that could be buried, or the need for the drums to have maintained their integrity after being crushed during burial and buried for over 30 years. Also, since nitrate salts are not present, another source of oxygen must be present for the initiation and propagation of a potential fire.

Scenario 4 – This scenario involves drilling into an intact drum containing hydrogen gas resulting from the radiolytic decomposition of organics/plastics. With respect to the potential for a hydrogen burn, two cases are theoretically possible:

- The sonic drill encounters an intact drum containing hydrogen together with sufficient oxygen to form a combustible mixture.
- The sonic drill encounters an intact drum containing hydrogen and insufficient oxygen for combustion. The hydrogen is ignited in the surface or near surface where sufficient oxygen is present and an ignition source initiates the reaction.

The Panel reviewed the probabilistic determination (Ref. 33) performed by DOE-ID and its contractor, of the likelihood of a hydrogen fire. Important factors in the analysis included the number of drums where radiolytic decomposition was likely to produce sufficient hydrogen gas, probability that the drum was still pressurized after 30 years in a subsurface environment, and probability that sufficient oxygen was in the drum (for the underground reaction case). Beitel's analysis, for the potential underground reaction, resulted in a determination that this event is extremely unlikely and the Panel concurs with this conclusion.

Scenario 5 – This scenario considered drilling into potentially pyrophoric or reactive materials such as zirconium, depleted uranium, containers of picric acid, or lithium batteries. There is no documentation supporting the disposal of zirconium in the 40' x 40' investigation area. There is documentation, however, which supports the disposal of two loads of zirconium in Pit 9 from the Idaho Chemical Processing Plant. The total amount of zirconium disposed in Pit 9 is estimated to range from 33,000 to 43,000 pounds (Ref. 34). To pose a pyrophoric hazard, the zirconium must be very finely divided, on the order of a few microns. The material in Pit 9 has been described as fairly large pieces, with the smallest dimension being on the order of fractions of an inch. In this state, the zirconium would not be anticipated to be reactive. Furthermore, any combustion reaction which could occur, would be very localized and of limited duration in a largely anaerobic subsurface environment.

With respect to depleted uranium, the Rocky Flats wastes that contained uranium were incinerated prior to disposal, thereby converting most, if not all, of the uranium to the stable oxide form (Ref. 35). Any remaining uranium would have oxidized during the 30-year period of burial. Consequently, there is no possibility of encountering unoxidized uranium.

While there is no documentation to support the presence of picric acid in Pit 9, the Panel evaluated this possiblity based on briefings received during its investigations. Any event initiated by an encounter of the sonic drill with picric acid would be very localized because of the small amounts that could have been buried and thus extremely unlikely to result in a subsurface fire with sufficient energy to transport radionuclides to the surface.

Former Rocky Flats personnel indicated the possible presence of a limited number of batteries in the Series 742 drums. An encounter of the sonic drill with lithium batteries disposed in Pit 9 about 30 years ago would not be expected to result in a fire, because of the small amount of potentially reactive material in the batteries. Neverthless, if a fire did occur, it would be localized and incapable of being sustained in a largely subsurface anaerobic environment. The Panel concludes that the possibility of a fire sufficient to transport radiological materials to the surface resulting from an encounter of the sonic drill with lithium batteries is extremely unlikely.

Scenario 6 – This scenario involved drilling into a pressurized cylinder containing a flammable gas. In the event that the sonic drill did encounter a pressurized gas cylinder containing a fuel such as hydrogen or acetylene, the initiation and propagation of a combustion reaction would still require the presence of oxygen or the formation of oxygen from the decomposition of nitrate salts. The Panel concludes that a subsurface fire of significant consequence resulting from this scenario is extremely unlikely.

Conclusion – The Panel evaluated the six scenarios with respect to the potential for a fire initiated by the sonic drill. In every case, the Panel concludes that the risk for such an event is, at most, extremely unlikely. Also, any fire that did result would require oxygen (either from in-situ soil gas or from the decomposition of nitrates) to be sustained and would thus be very localized and limited in duration. Consequently, the risk of an event sufficiently energetic to transport radionuclides to the surface is believed to be extremely unlikely. Nevertheless, the Panel believes that there are mitigation measures, which should be considered that would increase the margin of safety and defense in depth for Stage I. These mitigation measures are addressed in Section 9.

8.0 EVALUATION OF OTHER SAFETY ISSUES

8.1 RADIOLOGICAL RISK TO WORKERS AND THE PUBLIC

Consideration is given to the issue of radiation dose to workers and the public as a result of an accident occurring during the drilling operation. Preliminary safety assessments (Ref. 19) were performed for DOE that included exposure assessments specific to the core drilling operations. These assessments and the Panel's independent evaluation of explosion and fire scenarios involving nitrate sludges and other waste material were considered in the assessment of radiological risks.

In general, an evaluation by the Panel of the set of reasonable bounding scenarios for accidents did not result in consequences that would eject material or create a pathway for radiological releases to the atmosphere. That is, no health threatening source term could be defined for atmospheric releases of radiation as a result of drilling initiated accidents. Of course, operational accidents not initiated by fires or explosions may result in contamination events at the drill rig. These events are considered manageable through planned operating procedures.

With respect to the radionuclides that must be considered, they are primarily transuranics (TRU). Pit 9 also contains uranium isotopes, activation products, and mixed fission products. Five radionuclides account for some 99.9% of the TRU waste. They are Pu-238, Pu-239, Pu-240, Pu-241, and Am-241. The uranium isotopes are U-234, U-235, and U-238; the activation products are mostly Cobalt-60; and the mixed fission products are Ba-137, Cs-137, Sr-90, and Y-90.

The analysis performed for DOE calculated the radiological risk to workers (at 100 meters) and the public (at 6,000 meters). The assumptions of the calculations are conservative. The results indicate that fires and explosions can not create a radiological source term that can result in health threatening doses to either the workers or the public. In fact, the DOE assessment of highest consequence involved neither a fire nor an explosion. Rather, it was a drilling operation accident where a 300 pound weight associated with the core sampling apparatus was assumed to suddenly fall on a core sample during the operation of removing the core barrel from the drill string enclosure. While it is not clear what the exact mechanism would be, it is further assumed that part of the sample is suddenly released to the atmosphere through the drill string enclosure and that the sample is from a drum having the highest postulated concentration of Am-241. The worker dose at 100 meters for this DOE assessment was calculated to be 3.8 rem with a frequency of between 1E-04 and 1E-06. The individual dose to the nearest public boundary (6,000 meters) was calculated to be 4.1E-03 rem, also with a frequency of between 1E-04 and 1E-06. Considering both the consequence and the frequency, together with the extremely conservative assumptions in the analysis, the Panel believes this to be important analytical evidence on the radiological safety to workers and the public.

Independent of the DOE analysis, the Panel developed direct evidence on the likelihood that a drilling initiated fire or explosion could result in the release of radioactive materials to the atmosphere. The combination of the Panel's tests and scenario evaluation, the analyses performed for DOE, and consultation with outside experts led the Panel to the conclusion that it was extremely unlikely that the drilling operation could initiate an event that would result in releasing radiation to the atmosphere. The evidence indicates that the risk of exposing either workers or the public to harmful levels of radiation is extremely unlikely.

8.2 CRITICALITY SAFETY DURING SONIC PROBING AND CORING

The criticality issue addressed by the Panel is whether the probing and coring operations can result in the redistribution and concentration of fissile material into a critical mass (i.e., a self-sustaining nuclear chain reaction) in the Pit 9 waste. The fissile material of concern is Pu-239, which exists in very low concentrations in some waste forms in Pit 9.

The scenario in question is drilling into a waste form containing Pu-239 and through redistribution, concentration and mixing of the fissile material as a result of the drilling operation, a critical mass of Pu-239 is created. The conditions necessary to achieve a critical mass of fissile material are:

- There must be a sufficient mass of fissile material.
- The fissile material must be of a certain concentration.
- The fissile material must have a specific geometry.
- There must be a neutron moderating material.

There is a threshold value for each of these parameters to achieve a minimum critical mass. In particular, if any of the parameters do not meet the threshold value, a critical mass cannot occur. Consider the parameter having to do with geometry. The American National Standard ANSI/ANS-8.1-1998 (Ref. 36) indicates that a 6-inch diameter cylinder is a single-parameter limit for criticality. That is, a drill core of 6 inches, or less, constitutes a safe geometry for assuring a subcritical mass. What this means is that a drill core of 6 inches or less would be subcritical for an aqueous solution of plutonium nitrate in a water reflector. In fact, it is not likely that any of the conditions for criticality could be met as a result of drilling in the Pit 9 waste.

The Panel reviewed the criticality analysis performed by the DOE and its contractor, and agrees with the finding that criticality is not a safety concern during the probing and coring operations of the Pit 9 subsurface exploration program.

8.3 ENGINEERED AND ADMINISTRATIVE FEATURES FOR REMEDIATION

The Panel's Charter required that the Panel identify design features, both engineered and administrative, that are normally provided to protect or mitigate accidents for similar evolutions or hazards. The Panel reviewed the hazard and accident analysis for Stage II activities as well as defense-in-depth features. The result of that review is included in Section 9.3.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The underlying basis of the Panel's conclusions are:

- Reasonable knowledge of the waste characteristics, especially waste components that, on energetic stimulation, might explode or ignite. This is especially true with respect to the waste component classified as "miscellaneous" in the description of the nitrate sludges.
- Explosion and fire tests on surrogate waste mixtures that reasonably bound the uncertainties in the waste composition of Pit 9.
- The absence of sufficient energetics from drilling accidents to create a radiological source term for atmospheric releases.

9.1 RISK OF EXPLOSION OR FIRE BY THE SONIC DRILL DURING STAGE I CHARACTERIZATION

The Panel has evaluated several sources of information concerning the composition of the Series 745 nitrate sludges, including consultation with an expert on the Rocky Flats waste processing and testing of actual 745-sludge by Brookhaven National Laboratory. The Panel has determined that the description in the Record of Decision of the "10% miscellaneous" component is in error. Rather than containing 10% of combustible organics, that component of the waste was found to consist largely of other salts, including chlorides, sulfates, phosphates, water, and only 1% total organic carbon. This finding supports the determination that the sonic drill cannot encounter a single drum containing both nitrate salts and combustible organics.

The Panel developed six scenarios which were used as a basis for evaluating the potential risk of explosion or fire. The results of the evaluations of these scenarios are summarized in Table 9-1. The Panel concludes that the risk of explosion is either extremely unlikely or beyond extremely unlikely depending upon the moisture content of the buried wastes and the temperature of the drill bit, and the risk of fire is extremely unlikely.

Consistent with DOE's approach for evaluating the safety of its activities, DOE and its contractors have identified several measures which are responsive to the safety concerns associated with the proposed Stage I sonic drilling activities (Ref. 37). These measures include:

- Remote operation of the drill rig from a 50-foot distance
- Use of a drill string enclosure during sample core collection
- Radiation monitoring
- Capping or backfilling of boreholes to prevent aeration of the subsurface and chimney effects in the event of a localized subsurface fire

The Panel concurs with the merits of these measures and recommends the following additional preventive and mitigating measures:

- Implementation of a cautious approach in which each step builds upon the knowledge and experience gained from prior actions. Adoption of a slow, careful approach is not only prudent but warranted. For example, the importance of moisture content and the absence of data within the characterization area itself underscore the need for measurements using the first probehole casing before installing the subsequent probeholes. Additional measurements of moisture content at other probehole locations will generate a valuable database for Stages II and III waste retrieval and characterization.
- Adoption of formal drilling procedures that prevent the soil-drill interface temperatures from exceeding 150°C. If temperatures at the

Table 9-1. Evaluation of scenarios.

SCENARIO	DESCRIPTION	EVALUATION
1. Drilling into a mixture of nitrate salts and hydrocarbon oils.	Drums containing sodium and potassium nitrates and hydrocarbon oils and chlorinated solvents were disposed into Pit 9. The potential for the drill to encounter a mixture of nitrates and combustible organics does exist.	Explosion beyond extremely unlikely if $H_2O > 5$wt%. Explosion extremely unlikely if $H_2O < 5$wt%. Fire extremely unlikely.
2. Drilling into a mixture of nitrate salts and graphite.	Graphite (mainly in the form of chunks and large pieces) was also placed into drums and disposed into Pit 9. There is the potential for the sonic drill to encounter a mixture of nitrate salts and graphite.	Explosion beyond extremely unlikely. Fire extremely unlikely.
3. Drilling into a mixture of nitrate salts and cellulose (wood/paper).	Large quantities of wood and paperboard containers were disposed into Pit 9 permitting the possible encounter of nitrate salts and cellulose based materials	Explosion beyond extremely unlikely if drill bit < 150°C. Fire extremely unlikely.
4. Drilling into an intact drum containing hydrogen.	Hydrogen can be produced through radiolytic decomposition of organic materials. There is the potential for the production of hydrogen and other gases.	Explosion extremely unlikely. Fire extremely unlikely.
5. Drilling into potentially pyrophoric or reactive materials, e.g., zirconium and depleted uranium; containers of picric acid, and lithium batteries.	There is documentation and, in some cases concerns, that these materials were placed in Pit 9.	Explosion extremely unlikely. Fire extremely unlikely.
6. Drilling into pressurized cylinders containing a flammable gas.	While no documentation exists which supports the disposal of pressurized gas cylinders, this possibility was considered to be credible.	Explosion extremely unlikely. Fire extremely unlikely.

soil-drill interface are kept below 150°C, concerns about the initiation of explosions or fires are minimized. The temperature of the drill bit is directly related to the drilling resistance if refusal conditions are approached. The measures identified in the response to the Panel's request for a detailed description of determining refusal should be implemented (Ref. 8). These include the use of a second qualified operator to enforce any time period that is established for determining refusal and to ensure that the 100 Hz frequency is not exceeded.

- Demonstration that the moisture level in the overburden is in excess of 5wt% prior to probing below the overburden. If moisture needs to be added to the overburden soils, this would enhance the ability of these soils to act as a filter for any smoke resulting from a localized subsurface fire. A "gentle" irrigation approach would not create conditions that would raise concerns with respect to potential radionuclide migration to the vadose zone beneath the disposal area. Also, this approach would not compromise the ability of the coring to collect discrete, unmixed samples, as could supplying water from the drill bit through an injection mechanism.

Recommendations:

- Implement a cautious approach in which each step builds upon the knowledge and experience gained from prior actions.
- Adopt formal drilling procedures that prevent soil-drill interface temperatures from exceeding 150°C.
- Demonstrate that the moisture level in the overburden is in excess of 5wt% prior to probing below the overburden.

The Panel believes that the above measures will provide an additional margin of safety, without unduly compromising project resources and schedule for the Stage I activities.

Figure 9-2. Defense in depth features for Stage II operations (Ref. 8).

Hazard	First Level	Second Level	Third Level
Radiological	Primary confinement structures (i.e., RAE, ITM Transfer Tunnel, MHC, SHC Glovebox). Ventilation system. HEPA filters. New waste containers. Radiological control program.	Workplace radiation monitors, effluent monitoring, procedures, training.	Secondary confinement (EEF), emergency response/evacuation.
Criticality	Dig face monitor, MHC fissile material monitor. Criticality safety program.	Procedures, training.	Secondary confinement (EEF), emergency response/evacuation.
Chemical	Primary confinement structures (i.e., RAE, ITM Transfer Tunnel, MHC, SHC Glovebox). Ventilation system. HEPA filters. Activated charcoal filters. New waste containers. Hazardous material protection program.	Workplace VOC monitors, effluent monitoring, procedures, training.	Secondary confinement (EEF), emergency response/evacuation.
Fire	Primary confinement structures (i.e., RAE, ITM Tunnel, MHC, SHC Glovebox). New waste containers. Fire protection program.	Fire protection system, alarms, procedures, training.	Secondary confinement (EEF), emergency response/evacuation.
Explosion	Facility design.	Fire protection system, alarms, procedures, training.	Secondary confinement (EEF), emergency response/evacuation.
Natural Phenomena	Construction of primary confinement structures (i.e., RAE, ITM Transfer Tunnel, MHC, SHC Glovebox, CO_2 tank). Construction of mitigating systems. New waste containers. Emergency response/planning program.	Monitoring meteorology and seismic conditions, procedures, training.	Secondary confinement (EEF), emergency response/evacuation.

9.2 RADIOLOGICAL CONSEQUENCES AND CRITICALITY

After careful evaluation of the evidence, the Panel has found no credible scenario by which harmful levels of radiation could reach the aboveground environment due to sonic drill probing. The Panel concludes that the safety procedures and equipment design are such as to maintain acceptable levels of radiation in the core drilling and sample collection. There is no credible scenario for a criticality event.

9.3 RISKS ASSOCIATED WITH STAGES II AND III REMEDIATION ACTIVITIES

The Charter requested that the Panel also identify engineered and administrative features planned for remediation of the entire Pit 9. The Stage II and Stage III activities, beyond those evaluated for Stage I, are expected to be similar. Stage III activities are not available for review since those activities will not be developed until the results of Stage I and Stage II are available. The Panel reviewed the hazard and accident analysis contained in Section 3 of the Draft Preliminary Safety Analysis for Stage II (Ref. 8). The Panel concluded that the process and procedures DOE-ID and its contractor used were comprehensive and appropriate. The hazards analysis section considered issues beyond fire and explosion, and the defense-in-depth features are listed in Table 9-2. The Panel endorses the approach and process being utilized by DOE and and its contractors and believes that this approach, properly implemented for Stage III activities, will be adequate to maintain the desired safety margins.

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ERRATA

1. Section 2.1, page 6, Table 2-5: change Am-241 from 3.4E-03 to 3.4E+00.
2. Section 9.1, page 25: change Ref. 8 to Ref. 37.
3. Section 9.1, page 25, top paragraph: add the phrase "or a technically knowledgeable safety observer" after "second qualified operator."